The Impacts of Agriculture and Plantation Forestry in a Selection of Upper Catchments of the Strzelecki Ranges, Victoria

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Declaration

I certify that except where due acknowledgment has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged.

Daniel Mainville, MIEAust, P.Eng.

Monday 3 September 2007
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The landscape of the Strzelecki Ranges comprises of a mosaic of land uses featuring agriculture and forestry. The Strzeleckis form the headwaters to major waterways such as the Morwell River flowing north and east to the Gippsland Lakes, and the Tarwin River flowing south to Bass Strait. The intensive nature of these land uses gives rise to significant threats to the catchment’s environmental health. To protect and enhance the values of the Strzeleckis and those of the greater catchment, sediment and pollutant sources need to be identified and appropriate land management measures implemented. A comprehensive catchment management strategy in the Strzeleckis will ensure improved environmental health both inland and in the coastal and estuarine areas receiving their flows. The strategy, developed using sustainability science concepts, incorporates the careful management of landscape values, proper land management approaches, and government policy and legislative change to ensure that agriculture, forestry and other land uses become sustainable in this sensitive environment.

As demonstrated in this work, the adoption of a simple yet effective approach to monitor water quality and environmental change, based on a comparative study methodology, can empower land managers to take an interest in their environment and promote sustainable land use. Using the readily measurable water quality indicators of turbidity, flow, electrical conductivity and temperature, the research investigated the impacts of major land uses in the Strzeleckis. These water quality indicators were demonstrated to be good indicators of land use impacts in the catchments. When considered in concert with contemporary knowledge, the results highlight specific elements of land uses which would benefit from improved practices ultimately leading to more sustainable land management.

From a water quality perspective, analysis revealed that agricultural practices consistently generated higher levels of turbidity, higher average water temperatures and higher electrical conductivity values. The mean turbidity value for the agricultural catchment exceeded that for the plantation area by a factor of two and the forest area by a factor of three. It also exceeded the recommended maximum default target value for upland rivers by more than a factor of two. This reveals that agricultural practices in this catchment are significant contributors to overall poorer water quality and environmental amenity. The sediment budget also uncovered a trend of decreasing water quality with increasing intensity in land management.
However, from a total sediment load perspective, the forest area contributed the highest total sediment load due to higher volumes of stream flow. This suggests that the natural processes in the Strzeleckis may remain the principal mechanisms for sediment movement within the catchment.

Literature suggests that forestry, in particular timber harvesting, increases the risk to local water quality. However, the conservative timber harvesting practices employed in this project did not yield the predicted theoretical impacts. This is a significant finding as it can inform the development of sustainable timber harvesting practices in the Strzeleckis.

Extensive bioturbation found in the riparian zone of the plantation area was also a significant finding. The extent of bioturbation was not evident in the forest area, suggesting that it may be the most significant contributor to the degradation of water quality in the plantation catchment.

Literature cites that recreational use of poorly designed and maintained roads and tracks increases the risk of long-term impacts to water quality. Agricultural and forestry practices can be adapted to reduce their impacts on the landscape, but the nature of recreational use of the areas is much more difficult to manage and control. Properly closed and rehabilitated tracks may continue to be sediment sources or pathways for sediment delivery if heavily trafficked by recreational users.

The project has developed insights into the major environmental processes active in the upper catchments of the Morwell River. Understanding of the contributions to total sediment loads from natural erosional processes and bioturbation, findings related to impacts on water quality from agricultural practices, and encountering negligible impacts from conservative timber harvesting practices demonstrate that catchment management approaches need to be tailored to achieve sustainability in land uses across the landscape. Key recommendations include the re-establishment and protection of riparian zones in agricultural catchments, the careful assessment and setting of stream buffer zone widths for timber harvesting operations, and the need for further work to map the extent of natural processes such as bioturbation and stream bank erosion.
Increasing recreational use of the area poses a significant threat to the local water quality and overall catchment health. To mitigate these issues, government policy and legislation will need to focus on the preservation and enhancement of the Crown land riparian zones. Recommended changes to current administrative land management arrangements for these sensitive areas include a move from licensing the riparian zones for agricultural practices such as grazing to conservation. These will empower land managers such as the Department of Sustainability and Environment or the Catchment Management Authorities to undertake restorative works resulting in improvements to water quality and overall catchment health.
1 CONTEXT

1.1 Objective

The majority of published work evident in contemporary literature is focussed on specific areas of land use or erosion processes. A project linking a broad range of land uses and management practices with water quality in the Strzelecki Ranges (Strzeleckis) is not evident. Given the mixture of land uses and special environmental values associated with this part of Victoria, the research generates valuable knowledge of the impacts of land uses on the environmental quality of the Strzeleckis from a sustainability science point-of-view. Sustainability science is in its infancy; Lowe (2005) states that a serious investment is required in sustainability science with analytical work to be done at the complete system level taking into account the uncertainty and subjectivity of current knowledge.

Using water quality indicators, the research provides an insight into the relative impacts of agricultural and plantation forestry practices compared with a natural area. This approach builds on existing work conducted across catchments in South East Australia. Extensive work has been published on the impacts of forestry on water quality, quantity and catchment hydrology. Other studies have focussed on the impacts of agricultural practices in various catchments. The impacts of roads and tracks have also been studied in various catchments worldwide. Generally, research has been performed on a number of catchments investigating various aspects of water quality and yield, land use impacts, and natural processes. The following points describe the general areas of research to date:

- general forest management with respect to water yield;
- impacts of land uses;
- forestry;
- general catchment hydrology; and
- water quality runoff.

The research utilises key elements from the above recognised works to develop and test a simple methodology to monitor and evaluate the relative contribution of each land use to the environmental health across the Morwell River catchment. This approach utilises quality assurance and quality control measures (National Environment Protection Council 1999) ensuring that the weekly field data is relevant and meaningful.
Water quality indicators of turbidity, flow, electrical conductivity and water temperature have been used to determine the impact of major land uses on water quality in the upper reaches of the Strzelecki Ranges. This information will help with the identification and management of pollutant sources.

The primary objective of the research is to produce recommendations from this study that will improve the understanding of the major environmental processes in the Strzeleckis enabling the West Gippsland Catchment Management Authority, Grand Ridge Plantations, land managers, and other stakeholders to better target catchment management measures to improve the general condition and environmental health of the Strzeleckis and the Gippsland Lakes. These recommendations also provide informed input and direction for the practical implementation of key government objectives and policies pertaining to sustainable land management.

1.2 Introduction
The management of water quality is the most complex issue in the management of waterway health. This is primarily because of the nature of pollutant sources and the implications these have for management strategies. Pollutant sources can be categorised into point sources such as effluent discharges from wastewater treatment plants and diffuse sources such as erosion from farmland, forestry operations, roads and stream channels (Department of Natural Resources and Environment 2002).

The control of point sources is theoretically straightforward through monitoring and regulation. However, diffuse sources are much more difficult to manage as it involves every land use and activity in a catchment. Whilst the impact from any one land use in a catchment may be small, the cumulative impacts across wider catchments may be significant. This means that the management of water quality can only be undertaken with an integrated catchment management approach involving all land uses and land managers ensuring that they are aware of their impacts and are committed to the reduction of these impacts (Department of Natural Resources and Environment 2002).

To achieve effective integrated catchment management, approaches based on the principles of sustainability science will be required to enable research across catchments which is not only meaningful, comparable and reproducible but also applicable in local and regional contexts.
“Sustainability science differs fundamentally from most science as we now know it. The traditional scientific method is based on sequential phases of inquiry: conceptualising the problem, collecting data, developing theories, then applying the results. But this approach has run into difficulties as we study complex systems with long time lags between actions and their consequences. The traditional sequential steps must become parallel functions of social learning, incorporating action, adaptive management and experimental policy. Sustainability science will have to employ new methods, such as semi-quantitative modelling of qualitative data, or inverse approaches that work backwards from undesirable consequences to identify better ways to progress. Researchers will have to work with land users to produce new understandings that combine scientific excellence with social relevance.” Lowe (2005)

It is important to note that limitations in the techniques for direct measurement of surface erosion makes it difficult to determine the effects of changes in forest land use and management on erosion-induced damage (Anderson 1975). O'Shaughnessy and Bren (1998) have suggested that for larger catchments, the assessment of change due to changes in vegetation type and cover is rendered impossible because of the cumulative effects of many small changes acting at different rates and with differing characteristics unless the changes are widespread and significant. A paired-catchment study showed that even 18 years after the vegetative cover was changed from native eucalypt forest to radiata pine plantations, the effects of land use change on the catchment’s hydrology were not great (O'Shaughnessy and Bren 1998).

The current emphasis on the health of the Gippsland Lakes combined with the trend towards more sustainable land management practices makes forestry and agriculture in the Strzeleckis important components of the total picture. The erodible soils, high rainfall, and intensive land use of the Strzeleckis pose interesting challenges to land managers. The following questions guided the research investigations to better understand the natural processes, impacts of land uses, and their linkages to environmental health.

- What is the baseline water quality in the catchment?
- What are the impacts on water quality from forestry and agriculture?
- What are the relative magnitudes of these impacts?
- Which management practices are leading to the degradation of the water quality?
- Which measures or approaches can be modified or implemented to prevent and mitigate the impacts on water quality?
• How can we predict events of high sediment movement?
• What is the sediment storage capacity of the catchment?
• How can we improve the general environmental quality leading to sustainable land use practices?

1.3 Resources
A research steering committee was convened with membership from the funding organisations. The committee included Ms. Judy Alexander, former Stewardship Forester from Grand Ridge Plantations, Mr. Graeme Jackson, former Natural Resources Manager from the West Gippsland Catchment Management Authority, and Ms. Jenny Jelbart, former Environment Manager from Gippsland Water. The committee provided advice and support on current catchment management practices considering a range of issues and interests from forestry, catchment management policy, and water supply.

This level of cooperation is a clear example of what *Our Environment Our Future* (Department of Sustainability and Environment 2006) is trying to achieve by promoting strong partnerships and understanding between all levels of government, the community, major users, water authorities, catchment management authorities and private stakeholders.

The RMIT University Research Supervisory Committee membership included:
• Senior Supervisor: Associate Professor John Brumley, School of Civil, Environmental and Chemical Engineering;
• Supervisor: Professor Allan Bremner, the Faculty of Applied Science;
• Doctor Isobel Heathcote, Dean of Graduate Studies, University of Guelph, Canada.

1.4 Thesis Structure
The thesis is structured to provide a comprehensive understanding of the dynamics of current and historical land use change within the Strzelecki Ranges and to provide the detail required to apply the research methodology and obtain results and findings.

Chapter 2 describes the major processes and characteristics of the Strzelecki Ranges. The description begins with a broad overview of the issues arising in the Lakes followed by a more focused analysis of the Latrobe River, the Morwell River, and the Strzelecki Ranges.
Chapter 3 summarises the predominant erosional processes in temperate catchments similar to the ones found in the Strzeleckis. Typical impacts on water quality and environmental health are described with links to how land use changes affect erosion mechanisms and rates.

Chapter 4 outlines the research methodology adopted to deliver the desired outcomes. The description includes a detailed explanation on how the research sites were selected and subsequently monitored.

Chapter 5 discusses the data analysis and observations collected during the field research period. The data analysis is presented in a meaningful way to facilitate understanding of the processes of land use change and impacts on the landscape of the Strzeleckis.

Chapter 6 summarises the research project presenting a comprehensive discussion of the research approach, key findings and recommendations for further research. Resource management and environmental protection advice is highlighted and presented as recommendations to guide land managers towards the sustainable management of the landscape of the Strzeleckis.

The appendices provide additional detail on the history of settlement in the Strzeleckis, detailed structural descriptions of the relevant ecological vegetation classes, and publications stemming from the research.
2 BACKGROUND

2.1 Introduction

The sustainable use and development of catchments is dependent on the ability to accurately identify pollutant sources and develop appropriate management actions to minimise and mitigate their impacts. The definition of these sources and the assessment of land management practices requires accurate estimates of suspended sediment loads and nutrient levels (Grayson, Finlayson et al. 1996). Suspended sediment load in streams is strongly dependent on supply factors and is rarely transport limited (Gippel 1989). Ankcorn & Landers (2002) suggest that the analysis of water quality within a stream, over a period of time, may be helpful in isolating possible water quality trends in the catchment; thereby, identifying how land use and development may impact the catchment.

The study was conducted in the Strzelecki Ranges at the headwaters of the Morwell River. The Morwell River is a tributary to the Latrobe River which forms part of the catchment of the Gippsland Lakes. The location of the study area is highlighted in Figure 2-1. Historic land uses in the Strzelecki Ranges have contributed to extensive landslips and erosion delivering significant quantities of sediment to the local waterways. The history of settlement of the Strzelecki Ranges is provided in Appendix A.

More recently, a shift from agricultural pastures to plantation forestry appears to local land managers to have stabilised some of the sub-catchments; however, timber harvesting operations, agricultural practices, recreational use and the associated road and track networks continue to pose significant risk to water quality and environmental health. Improvements in land management practices in the Strzelecki Ranges will contribute to improved water quality in the Morwell River resulting in overall benefit to the Latrobe River and the Gippsland Lakes.

2.2 Study Areas

Three sites were selected to represent major land uses in the Strzeleckis. The three sub-catchments were:

- a plantation area populated with Mountain Ash (*Eucalyptus regnans*) to be harvested at the onset of the fieldwork; the area is locally known as Compartment 9 (C9);
- an agricultural area with cleared paddocks and homesteads; Prosper Valley Road runs through the area; hence, it was named Prosper Valley (PV); and
• a forest area populated with established Mountain Ash (*Eucalyptus regnans*) accessed by Grey Gum Track; hence, the site was labelled Grey Gum (GG).

For clarity, the area are referred to as C9 (plantation area), PV (agricultural area), and GG (forest area).

The sites were selected from the same land system, the Livingston Block 007 as described by Alexander (2001) and by Aldrick et al.(1992). The Livingston Block is located on the northerly aspect of the Strzeleckis at the headwaters of the Morwell River. It is bordered by Grand Ridge Road to the south, and the township of Boolarra to the north. The area can be accessed in two ways, heading south from the Latrobe Valley along the Morwell River Road or heading north from the Grand Ridge Road along Olsens Road. The exact location of the sites is shown in Figure 2-2.

The straight-line distances between each site are as follows:
• C9 (plantation catchment) to PV (agricultural catchment) – 8,600 metres;
• GG (forest catchment) to PV (agricultural catchment) – 11,900 metres;
• GG (forest catchment) to C9 (logged catchment) – 4,400 metres.

The following sub-sections outline the historical and current land use context for each catchment. Included are aerial photographs provided by Grand Ridge Plantations (GRP) illustrating the change in land uses and vegetation cover from the 1930’s to the present. Key features are highlighted in the photograph.
2.2.1 Forest Catchment - GG

The forest catchment is located on the north face of the Strzeleckis. With a north-westerly aspect, it drains a catchment area of approximately 65 hectares. Grey Gum Track is constructed on a ridge on the southern boundary of the catchment linking the Morwell River Road at the base of the catchment to the Midland Highway at the top of the catchment.

The forest catchment was selected as a control area because it represented the best compromise with regards to proximity to the other sites with safe and easy access. Grand Ridge Plantations (GRP) undertook not to harvest the area for the duration of the study.

Aerial photography in 1941 confirms that small sections of the catchment had been cleared; however, not as extensively as other parts of the Strzeleckis such as C9 and PV. Mapping indicates that the catchment was reafforested with Mountain Ash in 1972 and 1973. Figures 2-3 and 2-4 provide a comparison the catchment from 1941 to present. The areas of remnant vegetation in the riparian zone are clearly identified as the lighter areas surrounded by the darker canopy of the hardwood plantation.

The forest catchment features:

- steep slopes;
- continuously flowing stream supporting a variety of flora and fauna;
- established Mountain Ash plantation reafforested in 1972 and 1973 with remnants of Wet Forest (EVC 30) riparian vegetation;
- natural surface track running up the southern ridge of the catchment, Grey Gum Track, total length of 1850 metres;
- fire track running along the north ridge, total length of 2650 metres; and
- popular area for recreation including 4WD vehicles, trail bikes, horseback ridding, etc.
Figure 2-3 GG Historical Land Use (Map 1441 Foster Run 3, 12/04/1941)

Figure 2-4 GG Current Catchment Condition (QAS 3229c Run 29, 08/03/1999)
2.2.2 Plantation Catchment – C9

The plantation catchment is located on the northerly slopes of the Strzeleckis with a northeast aspect. The stream flows in an easterly direction as a tributary to the Morwell River. It drains a catchment area of approximately 70 Hectares. Olsens Road is the upper boundary of the catchment; however, this road drains in a north-westerly direction away from C9.

The C9 catchment features:

- a combination of forested and cleared steep slopes;
- established hardwood plantation forest;
- remnants of Central Highlands Cool Temperate Rainforest (EVC 31-01, a threatened ecological community) in the riparian zones;
- approximately 3550 metres of tracks; and
- a continuously flowing stream supporting a variety of flora and fauna with extensive evidence of bioturbation along the soak area.

Historical aerial photography taken in 1937 reveals that the area was extensively cleared except for the steep slopes and deep gullies of the drainage lines. As seen in Figure 2-5, the steep terrain of this area would have rendered any intensive land use very difficult except along the spurs and ridgelines of the catchment. Recent aerial photography, Figure 2-6, reveals widespread revegetation of the catchment.

The area was designated as a hardwood plantation by the Victorian Forest Commission and reafforested between 1964 and 1966 with Mountain Ash. Remnant native riparian vegetation and the stream can be clearly seen as the lighter coloured ‘depressions’ surrounded by the darker coloured canopy of the Mountain Ash forest.

The main stream channel is approximately 600 mm wide and less than 300 mm deep. It is flanked by a cool, moist and dark environment sheltered by tree ferns and other riparian vegetation. The stream channel is highly porous with numerous obstructions and small dams caused by organic debris. At the head of the catchment, the stream disappears at numerous points. Bioturbation is prevalent along the stream channel and drainage lines.
Figure 2-5 C9 Historical Aerial Photo (Map 3558, Mirboo North Run 13E, 27/11/1937)

Figure 2-6 C9 Pre-Harvesting (QAS 3229c Run 28, 08/03/1999)
2.2.3 Agricultural Catchment – PV

Prosper Valley Road closely follows the stream through a well established agricultural area. Prosper Valley Road runs in a southeast direction from Morwell River Road to Roys Road and Townsends Road at the top of the catchment. The land use in the catchment is typical of the cattle grazing areas found in the Strzeleckis. The stream flows in a north-westerly direction, draining a catchment area of approximately 160 Hectares.

The area was cleared between the late 1800’s and the early 1900’s to establish agricultural grazing lands. A comparison of Figures 2-7 and 2-8 reveals that land use patterns in this catchment have not changed significantly over the period between 1937 and 1999. In the bottom-right quadrant of the photograph, a Pine (*Pinus radiata*) plantation was established in 1989; however, this plantation lies outside the catchment area.

Riparian vegetation has been re-established on the northern end of the stream (on the bottom-left of the photograph), just above where it crosses Morwell River Road and reaches the Morwell River (as seen meandering on the bottom of the photo). However, the riparian zone and stream reach remains accessible to livestock.

The process of selecting an appropriate agricultural site was the most difficult one. The constraints limiting the number of appropriate sites included:

- need for cleared slopes;
- requirement for a continuously flowing stream;
- need for a sheltered monitoring location protected from damage by cattle;
- need for a catchment of adequate size to ensure consistent grazing by cattle;
- safe and convenient access; and
- consent from the landowner to access and construct the field monitoring site.
Figure 2-7 PV Historical Land Use (Map 3555, Mirboo North Run 9E, 1937)

Figure 2-8 PV Current Land Use (QAS 3227c Run 19, 22-23/02/1999)
The agricultural catchment features:

- fully cleared steep slopes;
- main gravel road approximately 3900 metres long running alongside the stream crossing it in 2 locations;
- numerous natural surface tracks for cattle movement across paddocks;
- 8 homesteads with farm buildings and ancillaries, all of which have gravel driveway access with one of the driveways running directly through the streambed;
- continuous cattle grazing with unrestricted access to most of the catchment area including drainage lines and streams;
- visible damage to the stream bank caused by cattle;
- no defined stream boundary with protected riparian vegetation or buffer strips; and
- unprotected continuously flowing stream intercepted by a total of seven dams.

2.3 Regional Context

Erosion processes, and sediment transport involve multifaceted interactions between climate variability, catchment runoff, stream flow dynamics, fluvial morphology, and small scale soil mechanics (Green, Beavis et al. 1999). Nutrients, pesticides, herbicides, fertilisers and / or pathogens are frequently transported along with suspended sediment. When combined with natural processes, anthropogenic activities tend to either open up areas to enhanced erosion or magnify pre-existing problems leading to gross soil loss and the degradation of local and regional water quality. Because of the potential magnitude of off-site impacts, the control of non-point source pollution from various land uses throughout catchments has become an important worldwide issue. The understanding of these processes is key to developing the knowledge required to properly manage land uses and to develop sustainable land management practices.

The protection of water resources in Australia’s catchments can only be achieved through the effective management of both sediment sources and sediment delivery pathways (Croke, Wallbrink et al. 1999). Most of the anthropogenic activities affecting coastal and marine environments are land-based. These environments are systematically linked through extensive drainage networks. A highly visible indicator of the impacts of catchment uses on coastal environments is the occurrence of periodic and severe cyanobacteria and algal blooms (henceforth referred to as algal blooms) such as the ones which occur in the Gippsland Lakes. These blooms have been attributed to high nutrient loads delivered by the major tributaries.
(Colman, Gwyther et al. 1991). Much of the nutrient pollution in these waterways has been linked to agriculture (Line, White et al. 2002).

2.3.1 Strzelecki Ranges

Rice (1988) portrays the Strzelecki Ranges as consisting of steep rounded hills which are strongly dissected to form symmetrical V-shaped valleys. They are prone to landslips and erosion. Historically, these conditions have been aggravated by large scale clearing of vegetation, inappropriate land management, and development.

Prior to European settlement, the Strzeleckis were densely vegetated by wet forest and cool temperate rainforest vegetation similar to remnants still found at Tarra and Bulga National Parks. In the time period from 1870 to 1900, farmers settling the Strzeleckis largely destroyed the stands of high quality Mountain Ash (Eucalyptus regnans) forests. Many farms were being abandoned in the 1930’s; dairying and grazing had become uneconomic in the steeper, eastern part of the ranges because of weeds, pest animals, isolation from transport and markets, increasing labour costs, and lower returns.

From the 1940’s onwards, many abandoned and marginal farms were reclaimed by the State for the establishment of forest plantations (Aldrick, Hook et al. 1988). By 1986, there were 438 hectares of softwood and 2,364 hectares of eucalypts established in the area. In addition to the reforested land, approximately 9,000 hectares of Crown Land have been dedicated as Reserved Forest. Most of this was farm land that had been abandoned by the owners and reverted to the Crown (Noble 1986). The majority of the plantation areas are now under long term leasehold and freehold to Hancock Victorian Plantations (HVP) and managed by their subsidiary in Gippsland; Grand Ridge Plantations (GRP). HVP has become the first major forest manager in Australia to be granted certification by the Forest Stewardship Council in recognition of high standards of operation and continuous improvement in forest management and environmental performance (Gippsland Integrated Natural Resources Forum 2006).

Ciesiolka et al.(1988) point out that it is naïve to assume that past land uses have not created a legacy on the natural environment. For example, by clearing the native vegetation for grazing pastures and the establishment of homes and communities, European settlement dramatically changed the landscape of the area. Clearing exposed erodible soils combined with high rainfall regimes, accelerated the erosion processes causing major landslips and reactivated slope movements on pre-existing landslides (Brumley 1993).
Present land uses in the Strzeleckis are a mixture of agriculture, forest plantations, reserved forest habitats and small communities. Each of these land uses has the potential to impact water quality and ecological health by exposing areas to soil erosion and landslips. There has been growing community support for the protection of areas of the Strzelecki Ranges as state or national parks and reserves.

The Natural Resources Report Card has assessed the Strzelecki Ranges with a Condition Rating of ‘C’ and a 3-star Stewardship Rating. The report highlights that large scale clearing has left approximately 26% of vegetation cover, with less than 2% of the bioregion in formal reserves (Gippsland Integrated Natural Resources Forum 2006).

Some of the areas that escaped fire, farming, and logging provide an excellent example of remnant native vegetation communities; however, only 13% of the Strzeleckis are under native vegetation (Rice 1988). In general, the western Strzeleckis remain as farmland, unlike most of the eastern Strzeleckis where farms were abandoned early last century.

2.3.1.1 Flora of the Strzeleckis
The wet sclerophyll forest is dominated by Mountain Ash (*Eucalyptus regnans*). Mountain Ash is the largest hardwood tree in the world; it can grow to heights of over 90 metres and lives up to 400 years. The Mountain Ash forests generally occur at elevations between 300 and 1000 metres in rainfall zones between 1000 and 1750 millimetres per year. It tends to grow in pure, even-aged stands. As shown in Figure 2-9, stands create a damp, temperate microclimate in the understorey that can support numerous plant communities including rainforest (Nicholson 1978).
Mountain Ash stands thrive on warmth and sunlight and are sensitive to fire and wind. They are fire dependent for regeneration. Fire kills older trees, allowing seedlings to grow. The trees grow very fast to take advantage of reduced competition and quickly outgrow other species. Mountain Ash reaches half of its mature height in 30 years. It does not bear seed until it is 15-20 years old. Seed storage on the tree is limited to 2 years and seeds in the soil are short lived (Aldrick, Hook et al. 1988).

The dominant Ecological Vegetation Classes (EVC) in the Strzeleckis and in the study area include EVC 30 Wet Forest and EVC 31 Central Highlands Cool Temperate Rainforest. Detailed descriptions of the EVC classes by VicRFASC (1999) are provided in Appendix B.

In the small naturally vegetated areas of the Strzeleckis, notably the Tarra and Bulga National Parks and some surrounding land, Mountain Ash is still dominant. It can occur with Messmate (*Eucalyptus obliqua*), Manna Gum (*Eucalyptus viminalis*), Blue Gum (*Eucalyptus globulus*), and Mountain Grey Gum (*Eucalyptus cypellocarpa*), with an understorey including Wattles, Myrtle, and Sassafras. The remainder of the areas generally carry closed, scrubby
vegetation dominated by Blackwood, and Silver and Black Wattles (*Acacia mearnsii*) (Rice 1988).

### 2.3.2 Morwell River

The Morwell River originates in the Strzelecki Ranges. It covers an area of 63,425 hectares and includes the tributaries of the East and West Branches of the Morwell River, Middle Creek, Billy’s Creek, Eel Hole Creek and Wilderness Creek and their respective tributaries (Latrobe City Council 2007). The catchment rises at an elevation of 686 metres flowing northerly into the Latrobe River adjacent to the Yallourn Power Station, at an elevation of 40 metres (Condina 1990). Due to coal mining activities, the lower reach of the Morwell River has been diverted on 4 occasions with the current configuration partially running through a piped section at the Hazelwood Power Station. The fifth diversion is currently being constructed as part of the Hazelwood Power West Field Extension; this diversion will take the river from the piped section back into an open channel.

The suspended sediment yield from the catchment of the Morwell River is low compared to other tributaries. In this regard, forest regeneration in the steep, fragile sedimentary Strzeleckis has undoubtedly been of benefit (Condina 1990). Studies have shown that the Morwell River contributes a suspended sediment load ranging between 4780 and 7800 tonnes/year or less than 8% of the Latrobe River’s total suspended sediment load. The maximum flow rate has been measured at approximately 5400 ML/day (Chessman and Marwood 1988).

However, in a relatively stable large tributary such as the Morwell River, channel erosion in the lower reaches would not be expected to be a major source of sediment. The Morwell River acts as a prime conduit for the transport of suspended sediment loads derived from the smaller streams and gullies and from more diffuse sources within the catchment.

Vegetation of the upper reaches of the Morwell River catchment is typical of that found in the Strzeleckis. Willows dominate the riparian zones of Morwell River well into the forested areas, reflecting origins of the plantings at the time the Strzeleckis were cleared (Condina 1990). Along the river, understorey is virtually non-existent and ground cover is mostly grass. In recent times, there have been efforts by local Landcare groups, the West Gippsland Catchment Management Authority, and individual landowners to remove the willows in some areas and replace them with native riparian vegetation.
The Morwell River is the subject of a Neighbourhood Environment Improvement Plan (NEIP) developed by Latrobe City Council, the West Gippsland Catchment Management Authority, Department of Sustainability and Environment and the local community. Key concerns for the Morwell River identified as part of the preparation of the NEIP include (Latrobe City Council 2007):

- Waterway health resulting from the impacts of forestry, farming, mining and urban development.
- Protection of biodiversity including the wide range of significant flora and fauna including the areas of vegetation of national significance.
- Weed management such as the removal of willows and exotic vegetation from the riparian zone.
- Protection of landscapes and cultural heritage.
- Land use impacts to ensure that impacts are minimised.
- Dumped rubbish being a significant issue for all public land.
- Effluent management from industry farming and residential areas.
- Vandalism of assets and the natural environment resulting from the lack of formal management arrangements.
- Recreational opportunities to improve community pride and tourism.

The prime objectives of the NEIP are aimed to improve the water quality of the river and its tributaries through the management of runoff to reduce suspended solids and to continue to monitor the impacts of logging in the upper catchments to ensure compliance with the Code of Forest Practices (Latrobe City Council 2007).

2.3.3 Latrobe River

The historical land uses in the catchment of the Gippsland Lakes particularly that of the Latrobe River has been a very interesting one, creating many land management challenges and environmental impacts. Outside of any urban area, no other large river system in Victoria has been as modified by humans as the Latrobe River and its tributaries (Eskrine, Retherfurd et al. 1990). However, Grayson et al.(1996) observed that the Latrobe River catchment is typical of many developed catchments around Australia.

The Latrobe River Basin extends from the Strzelecki Ranges in the south to the Great Dividing Range in the north, and from Warragul in the west to Lake Wellington, Lake
Victoria and the Gippsland Coast in the east. The total area of the basin is 467,600 ha or approximately 2% of the State’s surface area (Grayson, Finlayson et al. 1996). The Latrobe Valley and the Gippsland Plains contain the basin's agricultural land and urban centres.

The principal tributaries of the Latrobe River are the Toorongo, Tanjil and Tyers Rivers from the northern highlands, the Moe River from the west, and the Morwell River from the Strzelecki Ranges in the south. The major storages in the Basin include Blue Rock Lake, Yallourn Storage, Hazelwood Pondage and Moondarra Reservoir. The mean annual flow from the catchment is approximately $1.0 \times 10^6$ ML representing 4.4% of the total runoff generated in the State (Australian Natural Resources Audit 2002; West Gippsland Catchment Management Authority 2004).

Figure 2-10 provides a regional context for the research project outlining the location of the Gippsland Lakes, the catchment of the Latrobe River, and the location of the study area in the Strzeleckis.

![Figure 2-10 Latrobe River Catchment](Department of Sustainability and Environment 2006)

Being the highest contributor of flow to the Gippsland Lakes, the Latrobe River provides approximately 30% of the total flow followed by the Mitchell River at 27.6% and the Macalister with 16% of the flow (Eskrine, Rutherfurd et al. 1990; Grayson, Gippel et al.)
Of the total flow recorded at Rosedale, 60% of Latrobe River’s flow is from the rivers rising in the north, 30% by the Moe Drain, Morwell River, Narracan and Traralgon Creeks, and the remainder from minor ungauged tributaries. Significant increases in turbidity and suspended solids are apparent below the inputs of several tributaries, in particular the Moe Drain, Morwell River, and Traralgon Creek (Condina 1990).

The major land uses in the catchment of the Latrobe River can be categorised as follows (Aldrick, Hook et al. 1988; Condina 1990):

- **urban and industrial areas** - relatively small areas concentrated along the Princes Highway with the major population centres being Warragul, Moe, Morwell, Traralgon, and Sale;
- **timber production areas** - primarily hardwood eucalypt forests with extensive softwood plantations particularly along the northern face of the Strzeleckis; and
- **grazing of cattle and sheep** - the most widespread form of agriculture, in the higher rainfall areas dairying is generally the most important enterprise followed by large numbers of beef cattle.

The catchment area supports a population of approximately 150,000 with significant concentrations of rural residential areas scattered throughout the catchment (Grayson, Finlayson et al. 1996; Department of Sustainability and Environment 2006).

In the annual *Natural Resources Report Card*, the Latrobe River has been given a Condition Rating of ‘C’ and a 3-star Stewardship Rating. It has been identified as a stressed river system with an index of stream condition of moderate to poor for 65% of its length (Gippsland Integrated Natural Resources Forum 2006). The Latrobe River suffers from a changed flow regime as well as significant channel modification. Implementing the right combination of river channel restoration and enhanced flow regimes is important to meet the River’s long-term water needs (Department of Sustainability and Environment 2006).

As shown in Table 2-1, agriculture and timber production are the main land uses in the Latrobe River Basin, making use of approximately 80% of the total area; however, a significant feature of land use is the mining of brown coal for the thermal power stations at Loy Yang, Hazelwood and Yallourn.

The average annual surface water use in the catchment is approximately 194,100 ML. This can be broken down to:
75% urban and industrial;
24% irrigation;
1% rural, domestic.

<table>
<thead>
<tr>
<th>Land Use Description</th>
<th>Total Extent ('000 ha)</th>
<th>Total Extent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature conservation</td>
<td>3446.7</td>
<td>15.2</td>
</tr>
<tr>
<td>Other protected areas including indigenous uses</td>
<td>108.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Mining</td>
<td>896.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Livestock grazing</td>
<td>6629.3</td>
<td>29.2</td>
</tr>
<tr>
<td>Forestry</td>
<td>3849.5</td>
<td>16.9</td>
</tr>
<tr>
<td>Dryland agriculture</td>
<td>6616.9</td>
<td>29.1</td>
</tr>
<tr>
<td>Irrigated agriculture</td>
<td>619</td>
<td>2.7</td>
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<tr>
<td>Built environment</td>
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<td>2</td>
</tr>
<tr>
<td>Water bodies not elsewhere classified</td>
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</tr>
<tr>
<td>No Data</td>
<td>28.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Power generation is the largest user of surface and groundwater resources, accounting for up to 73% of the total urban/industrial surface water use. However, the greatest impact of water use by the power generation industry is the dewatering of aquifers for mine stability resulting in regional decline of artesian pressure. They also directly affect the lower reaches of the Morwell River through major diversions and associated works.

On average, the components contributing to the suspended sediment load in the Latrobe River are estimated to be (Condina 1990; Eskrine, Rutherford et al. 1990):

- 20% from erosion of the lower Latrobe River;
- 23% from erosion of the northern Mt. Baw Baw catchments;
- 57% from erosion of the western and southern Strzelecki catchments, of that
  - approximately 8% from Traralgon Creek and Tyers River, and
  - approximately 49% from the other lower tributaries.
The Latrobe River sediment budget, Table 2-2 below, highlights that stream bank erosion contributes up to 93% of the total sediment supply to the Latrobe River.

Table 2-2 Latrobe River Sediment Budget (Australian Natural Resources Audit 2002)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Unit</th>
<th>Basin value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment supply</td>
<td>t/yr</td>
<td>123369</td>
</tr>
<tr>
<td>Sediment supply</td>
<td>t/ha/y</td>
<td>0.24</td>
</tr>
<tr>
<td>Hill slope erosion</td>
<td>%</td>
<td>5.93</td>
</tr>
<tr>
<td>Stream bank erosion</td>
<td>%</td>
<td>92.44</td>
</tr>
<tr>
<td>Gully erosion</td>
<td>%</td>
<td>1.63</td>
</tr>
<tr>
<td>Length with riverbed deposition</td>
<td>Proportion</td>
<td>0.08</td>
</tr>
<tr>
<td>European to Pre-European sediment</td>
<td>Ratio</td>
<td>5</td>
</tr>
<tr>
<td>Sediment export to coast</td>
<td>t/y</td>
<td>31953</td>
</tr>
<tr>
<td>Contribution of sediment to coast</td>
<td>t/ha/y</td>
<td>0.06</td>
</tr>
<tr>
<td>Sediment delivery</td>
<td>Ratio</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Condina (1990) explains that the suspended sediment supply to the Latrobe River is primarily linked to past de-snagging and meander cut-off programs and is exacerbated by:

- lack of riparian vegetation;
- seepage affecting weakened banks causing landslips and stream bank collapse;
- localised deepening of the river bed;
- poorly located levee banks; and
- lack of control over stock access.

Concentrations of total suspended solids, electrical conductivity, total phosphorus, and total nitrogen remain relatively constant during the low flow periods encountered in summer (Grayson, Gippel et al. 1997).

Cecil (1982) reports that the Latrobe River is essentially “stable” in as much as the cross-section of the channel remains almost unaltered, but with an energetic meander migration.
The strategic catchment management issues related to the Latrobe River Basin include (Rice 1988):

- land instability and erosion with problems areas including landslips in the Strzeleckis;
- runoff that lowers water quality; the source of such runoff generated by forestry, agriculture, construction and mining; and
- in-stream ecosystem degradation caused by waste discharges, dams, changes to flow regimes, river management works, and removal of riparian vegetation.

2.3.4 The Gippsland Lakes

The Gippsland Lakes are a system of shallow, coastal lagoons approximately 69 km in length and 10 km wide at the widest point. They are connected to the ocean by a narrow, permanent man-made opening at Lakes Entrance. They are separated from the ocean by sand dunes. The seaward side of these sand dunes forms part of the Ninety-Mile Beach. The Lakes represent a unique aquatic ecosystem and their beneficial uses range from sustaining significant ecosystems to recreation and tourism to commercial fishing.

The Gippsland Lakes possess major heritage, cultural, environmental, and landscape values. The Lakes have been recognised at a range of levels from local to international significance. On the cultural and heritage front, the Gippsland Lakes fall within the boundaries of the area occupied by the Tatungalung clan of the Gunai/Kurnai people. Evidence of their occupation occurs at numerous midden sites containing shellfish remains, charcoal and burnt pebbles (Parks Victoria 2003).

Parts of the Gippsland Lakes system, including Lake Reeve, are listed under the Ramsar Convention on Wetlands of International Importance, especially as waterfowl habitat. The Lakes attract the largest concentration of migratory waders in East Gippsland (Parks Victoria 2003).

The total catchment area of the Gippsland Lakes is roughly 2 million hectares, approximately 9% of the area of the State of Victoria. The seven major rivers flowing into the Lakes are the Tambo, Nicholson, Mitchell, Avon, Macalister, Thomson, and the Latrobe Rivers (Rice 1988; Eskrine, Rutherfurd et al. 1990; Webster, Parslow et al. 2001). All the rivers originate in areas consisting of extensive native and regrowth vegetation. Stream flows are strongly seasonal with winter and spring flows contributing up to 70% of annual runoff and summer thunderstorms producing significant flood peaks (Eskrine, Rutherfurd et al. 1990). It is
estimated that 364,000 tonnes of suspended sediment is discharged to the Lakes by the rivers; 56% of which remains in the Lakes. Eskrine, Rutherfurd & Tilleard (1990) explain that the sediments deposited in the past 100 years have a higher content of reworked materials released by erosion triggered by land use change.

Of the four main rivers flowing into Lake Wellington, the Latrobe River delivers the highest suspended sediment load at approximately 100,000 tonnes per year followed by the Avon River at 50,000 tonnes per year (Chessman and Marwood 1988; Condina 1990; Webster, Parslow et al. 2001). Grayson et al. (1996) have suggested that during peak events the Latrobe River can contribute as much as 87% of the total suspended sediment load, 75% of the phosphorus and the majority of the nitrogen input to the Gippsland Lakes. Most rivers exhibit a pattern where suspended solids concentration is low during periods of low flow and increases during high flows; however, Condina (1990) suggests that the Latrobe River is unusual in that it carries high suspended solids concentration even at low flow conditions. The average annual suspended solids input to Lake Wellington from the Latrobe River is at least 5 to 6 times higher at present than the period prior to European settlement (Condina 1990).

European settlement began in the region in the 1840’s and has resulted in considerable modification to the Lakes’ catchments including the clearing of lowland and foothill forests, draining of wetlands, and diversion of water from the rivers for urban, agricultural, and industrial use. Catchment modifications, together with the creation of the permanently open entrance in 1889 have substantially changed the Lakes’ ecosystem (Webster, Parslow et al. 2001). Major water quality concerns include recurring blooms of the blue-green cyanobacterium (Nodularia) and extended periods of bottom water hypoxia (the reduction in oxygen concentration in the water column due to bacterial consumption of phytoplankton detritus). The Gippsland Lakes algal bloom of the summer of 1987/88 caused significant economic loss to the Gippsland region.

Water resources have been extensively developed to support irrigation, urban supplies, electricity generation, and industry. Table 2-3 highlights the land uses and associated surface areas in the catchment of the Gippsland Lakes. The rivers most affected by development are the Latrobe and Macalister Rivers, both of which have approximately 20% of their annual discharge diverted (Eskrine, Rutherfurd et al. 1990).
Forests comprise about 30% of the area of the State of Victoria and most are located at the headwaters of the State’s major rivers. The timber industry poses a large potential for impacts on the aquatic environment, second only to agriculture (Colman, Gwyther et al. 1991). However, since forest streams are perceived as being pristine and more highly valued than streams flowing through agricultural areas, the public is more likely to consider them as more sensitive and deserving a higher level of conservation. Colman, Gwyther et al. (1991) propose that since a far greater area of Victoria, approximately 60%, is utilized for agriculture, that the impacts of agricultural practices pose a much higher risk to water quality through the direct delivery of sediment and other pollutants to waterways.

The choice of specific management goals for waterways should reflect an informed community selection of options with a full awareness of environmental, social, and economic costs. Ideally, a system needs to be developed to understand and better manage water and soil resources while still gaining wealth and benefit from them. There is a need for local assessment of nutrient levels to minimise the incidence and severity of algal blooms in the Gippsland Lakes and of such variables as turbidity, temperature, total dissolved solids (salinity), and oxygen levels.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (ha)</th>
<th>Percent of Total Catchment Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Forest, State Park, National Park, Coastal Reserves and Lakes</td>
<td>1.3 million</td>
<td>61.5</td>
</tr>
<tr>
<td>Private Forests</td>
<td>180,000</td>
<td>8.7</td>
</tr>
<tr>
<td>Agriculture / grazing, irrigation, cropping and mixed farming</td>
<td>450,000</td>
<td>21.8</td>
</tr>
<tr>
<td></td>
<td>100,000</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>50,000</td>
<td>2.4</td>
</tr>
<tr>
<td>Urban Areas</td>
<td>5,000</td>
<td>0.2</td>
</tr>
<tr>
<td>Brown Coal Production</td>
<td>8,000</td>
<td>0.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2 million</td>
<td>100</td>
</tr>
</tbody>
</table>

### 2.4 Climate

Major factors influencing the climate of the region are the easterly movement of low and high-pressure systems and the development of low-pressure systems off the east coast of southern Australia.
Official figures show an average maximum temperature range from 23.6°C in January to 11.3°C in July, and the average minimum from 9.9°C to 2.1°C respectively (Bureau of Meteorology 2003). The highest reading recorded was 39.7°C and the lowest –6.1°C (Noble 1986). Cold prevents significant plant growth between May and October, but during the remainder of the year warmth and moisture are generally adequate to ensure continuous growth, with peak growth occurring during the summer months (Nicholson 1978).

The exposed areas of the Strzeleckis experience a rainfall regime which has a winter / spring maximum, with June generally being the wettest month and January the driest (Nicholson 1978; Rice 1988).

The effect of landform causes the well exposed regions of the Strzeleckis to receive substantially more precipitation than the areas that are rain-shadowed to the east (Rice 1988). Noble (1986) noted that the Strzeleckis exercise an important influence on the weather of central and east central Gippsland because the moisture-laden winds that blow from the southwest drop much of their rain on the slopes and ridges of the Ranges. Yearly rainfall totals are above 2,000 millimetres in the most exposed areas, while the mean annual rainfall ranges between 1,200 to 1,500 millimetres in the surrounding high country (Noble 1986; Rice 1988; Bureau of Meteorology 2003). The Strzeleckis are subject to major storms throughout the year contributing to occasional floods across the flood plain of the Latrobe River. Some areas of the Strzeleckis have recorded rainfall of 170 millimetres in a period of 24 hours. High rainfall volumes and intensities act on the geology and soils of the Strzeleckis greatly increasing the risk of erosion and landslides (Brumley 1993).

Table 2-4 provides a summary of Bureau of Meteorology (2003) climate data from the Morwell River Prison Site spanning from 1951 to 2002.

2.5 Soils and Geology

The Department of Primary Industries (2003) describe the Strzelecki Ranges as consisting of moderate to steep slopes, deeply dissected blocks of alternating beds of sandstone, siltstone and shales, and swampy alluvial fans in the lowlands. The geology is of Mesozoic non-marine deposits covered with a veneer of younger Cainozoic deposits including Newer Volcanics.
<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Monthly Precipitation (mm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>76.1</td>
<td>61.9</td>
<td>83.1</td>
<td>104.5</td>
<td>132.5</td>
<td>147.4</td>
<td>141.7</td>
<td>148.2</td>
<td>138.2</td>
<td>129.1</td>
<td>120.4</td>
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<td>1402.5</td>
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<td>Median</td>
<td>69.2</td>
<td>52.8</td>
<td>82.5</td>
<td>95.5</td>
<td>114.7</td>
<td>128</td>
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<td>125</td>
<td>112.1</td>
<td>99.4</td>
<td>1381</td>
</tr>
<tr>
<td>Lowest</td>
<td>8.4</td>
<td>4.8</td>
<td>13.1</td>
<td>17.2</td>
<td>48.6</td>
<td>30.3</td>
<td>34.7</td>
<td>37</td>
<td>46</td>
<td>41.8</td>
<td>31.6</td>
<td>20.2</td>
<td>869.7</td>
</tr>
<tr>
<td>Highest</td>
<td>165.6</td>
<td>231.9</td>
<td>331.5</td>
<td>244.4</td>
<td>350.3</td>
<td>559.1</td>
<td>247.2</td>
<td>273.4</td>
<td>366</td>
<td>249.4</td>
<td>241.1</td>
<td>228.2</td>
<td>2032.4</td>
</tr>
<tr>
<td><strong>Mean Minimum Air Temperature (°C)</strong></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.9</td>
<td>10.1</td>
<td>8.7</td>
<td>6.3</td>
<td>4.6</td>
<td>3</td>
<td>2.1</td>
<td>2.8</td>
<td>3.9</td>
<td>5.7</td>
<td>7.3</td>
<td>8.7</td>
<td>6</td>
</tr>
<tr>
<td>Median</td>
<td>9.9</td>
<td>9.6</td>
<td>8.8</td>
<td>6.3</td>
<td>4.8</td>
<td>3.1</td>
<td>2.2</td>
<td>2.9</td>
<td>4</td>
<td>5.7</td>
<td>7.3</td>
<td>8.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Lowest</td>
<td>6.9</td>
<td>7.7</td>
<td>5.5</td>
<td>4.5</td>
<td>1.4</td>
<td>-0.4</td>
<td>-0.7</td>
<td>1.3</td>
<td>0.7</td>
<td>3.9</td>
<td>5.1</td>
<td>5.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Highest</td>
<td>13</td>
<td>13.7</td>
<td>11.9</td>
<td>8.1</td>
<td>7</td>
<td>7</td>
<td>4.2</td>
<td>4.9</td>
<td>5.9</td>
<td>7.8</td>
<td>9.5</td>
<td>11.6</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Mean Maximum Air Temperature (°C)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>23.6</td>
<td>23.7</td>
<td>21.8</td>
<td>17.9</td>
<td>14.2</td>
<td>11.6</td>
<td>11.3</td>
<td>12.7</td>
<td>14.7</td>
<td>17.3</td>
<td>19.1</td>
<td>21.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Median</td>
<td>23.2</td>
<td>23.9</td>
<td>21.7</td>
<td>17.9</td>
<td>14.3</td>
<td>11.7</td>
<td>11.3</td>
<td>12.5</td>
<td>14.6</td>
<td>17.4</td>
<td>19.2</td>
<td>21</td>
<td>17.4</td>
</tr>
<tr>
<td>Lowest</td>
<td>20.4</td>
<td>20.4</td>
<td>19.4</td>
<td>15.3</td>
<td>12.6</td>
<td>9.5</td>
<td>9.3</td>
<td>10.8</td>
<td>12.8</td>
<td>15</td>
<td>15.9</td>
<td>18</td>
<td>16.6</td>
</tr>
<tr>
<td>Highest</td>
<td>26.8</td>
<td>28.3</td>
<td>24.9</td>
<td>20.6</td>
<td>15.3</td>
<td>13.5</td>
<td>12.8</td>
<td>14.7</td>
<td>16.5</td>
<td>19.9</td>
<td>21.9</td>
<td>24.5</td>
<td>18.1</td>
</tr>
</tbody>
</table>
The soils are mainly gradational textured acidic soils (Dermosols) together with friable red earths (Ferrosols). The side slopes of the valleys in the Strzeleckis are steeply convex, mantled by a deep Krasnozem type soil, which does not appear to generate any overland flow. The soils exhibit little horizon differentiation apart from a surface humus layer and organic staining of the top of the mineral soil (Australian Collaborative Land Evaluation Program 2007).

The study area is located in the Gunyah land system of the Balook Block, as described in Table 2-6. The soils are typical of the Lower Cretaceous sandstones, mudstones, siltstones, and conglomerates of the Strzelecki Group (Kls or Sz). A detailed overview of the Strzeleckis is provided below to highlight the complexity of the landform and how this complexity creates challenges for land managers.

The Strzelecki Ranges and surrounding foothills consist of early Cretaceous mudstone and sandstone found in three north-east to south-west trending blocks. The northern and central foothill areas of the Strzeleckis are commonly overlain by weathered volcanics with sub-volcanic Tertiary sediments (Childers Formation) occurring over large areas of the Central Narracan Block (Brumley 1993). The volcanics are deeply weathered usually to their full depth except in isolated areas such as in the valley of Narracan Creek where hard basalt outcrops form the Narracan Creek Falls.

The Childers Formation consists of up to 35 metres of non-marine sandy silty clays and clayey silts which are often gravely. The dominant clay mineral is kaolinite, sometimes with halloysite admixed. The Tertiary Older Volcanics are acid friable porous soils. They are usually deep soils with a dark red A1 horizon of friable clay with a strong crumbly structure. They are moderately plastic clays often rather compact in place, but highly structured, very permeable, and friable when moist. In wet environments the B-C horizons are somewhat mottled red, light grey, and yellow-grey clay grading into a thick C horizon of weathering rock which may be partially saturated with water. These soils are associated with well-drained sites on hilly uplands and plateaux. Under the pedological classification of soils, they are grouped with Krasnozems (Brumley 1978).

Strzelecki Group beds outcrop over two main elevated areas which trend northeast forming the South Gippsland Highlands. The locations of the outcrops are shown as the dark shaded areas in Figure 2-11. The first outcrop, called the Narracan Block, is centered on Korumburra.
with a southwest extremity in the Kilcunda area and northwest margin near Moe. The second, called the Balook Block, is centered on Balook, with its southwest extremity near Fish Creek and northeast margin near Carrajung. The outcrop area of the Strzelecki Group beds is about 390,000 hectares (Douglas, Abele et al. 1988).

Deposition and subsidence proceeded rapidly throughout the Early Cretaceous resulting in great thicknesses of sediment in the major basins, and rocks of this age outcrop over large subsequently uplifted areas such as the Strzelecki Group in the Gippsland Basin. The beds are principally felspathic sandstone, mudstone, and shale with conglomerate occasionally prominent at the base. Plant remains are the most common fossils and deposition was predominantly fluviatile (Abele, Gloe et al. 1988). Sargeant et al.(1995) describe the soils in the same area as being Strzelecki soils (Sz). The Strzelecki Group soils are described in Table 2-5.

Using the nomenclature for geotechnical soil classification system as recommended by AS 1726-1993 (Standards Association of Australia 1993), the soils formed on the mudstones and sandstones of the Lower Cretaceous Strzelecki Group can be described as consisting predominantly of silty clays (CH and CL) and clayey silts (MH) which are slightly sandy and commonly include angular fragments of highly weathered rock.
**Table 2-5 Description of Sz Soils (Sargeant, Imhof et al. 1995; Sargeant, Imhof et al. 1996)**

<table>
<thead>
<tr>
<th>STRZELECKI</th>
<th>Symbol: Sz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geology</strong></td>
<td>Cretaceous sediments (sandstones, siltstones, and mudstones).</td>
</tr>
<tr>
<td><strong>Landform</strong></td>
<td>Rolling Hills mostly with moderate slopes (10–32%) with some steeper slopes (32–56%). The area is regarded as a strongly dissected upland resulting from the series of uplifts dating from the Tertiary period and continuing spasmodically until the present day.</td>
</tr>
<tr>
<td><strong>Soils</strong></td>
<td>The texture of the soils is largely dependent on the nature of the sediments from which they were derived with mudstones forming more clayey soils than those derived from sandstones. Aspect and past erosional history also plays a part and often less clayey and shallower soils are found on the northerly to westerly slopes.</td>
</tr>
<tr>
<td><strong>Component 1</strong></td>
<td>Most of the soils on slopes have dark greyish brown clay loam surface soils which grade into yellow grey-brown clay loams or light clay at about 35 cm. At 60 cm pale greyish brown or paly brown light clay or medium clays are encountered which become yellow-brown mottled with light brownish grey with depth. Fragments of rock generally appear by about 80 cm and continue until about 1.2 m when rock becomes impenetrable.</td>
</tr>
<tr>
<td><strong>Component 2</strong></td>
<td>On the lower colluvial slopes and on the broad crests there is generally a sharper separation between the grey-brown clay loam or fine sandy clay loam surface soil and the mottled light brownish grey and yellow-brown light or medium subsoil, which occurs from about 50 cm. The bedrock occurs much deeper.</td>
</tr>
<tr>
<td><strong>Component 3</strong></td>
<td>On the narrow flats associated with the drainage lines, the soils are derived from locally derived alluvium and colluvium. The surface soils are grey-brown fine sandy clay loams to clay loams commonly grading into mottled grey-brown and yellow-brown light clays at depth.</td>
</tr>
<tr>
<td><strong>Occurrences</strong></td>
<td>This mapping unit occurs extensively throughout South Gippsland.</td>
</tr>
</tbody>
</table>

Clayey silty sands (SC and SM), silty sandy clays (CL), and clayey sandy silts (MH) also occur. The soils grade into friable hard soil or highly weathered rock, in which the original rock fabric is discernible. Lamellar, sub-horizontal bedding is present along which the material readily cleaves, often to show the impression of fossil plant fragments. Thin carbonaceous seams occasionally occur and joints are sometimes stained with limonite. The soils are moderately cohesive (Brumley 1978).

Depth of profile of the Sz soils varies frequently exceeding 2 metres in the wettest part of the Strzeleckis. At the base of the slopes, the soil is generally darker and has heavier subsoil containing iron-rich concretions, indicating periodic water logging. The soils have a high available water capacity and moderate permeability of profiles, as indicated by pore-size distribution. Like other gradational soils, they have a relatively high percentage of silt and a low percentage of coarse sand.
Following the same nomenclature, Noble (1976) describes soils in the Strzeleckis as being composed of yellowish friable porous earths which are highly structured, strongly acid loams, of good formation for root growth and absorption of rainfall. The parent rock lies within 1 to 2 metres of the surface, soils tending to be deeper where the rainfall is higher (Nicholson 1978). Table 2-6 presents each dominant land system in the Balook Block.

Table 2-6 Strzelecki Land Systems (Aldrick, Hook et al. 1992)

<table>
<thead>
<tr>
<th>Land System</th>
<th>Description</th>
</tr>
</thead>
</table>
| Gunyah land system (Gh)     | - Hills with ridge-and-ravine topography and moderately long, steep slopes on Cretaceous mudstones, siltstones, and sandstones in the South Victorian Uplands are mapped in the Gunyah land system.  
- Most occurrences are on the lower parts of the uplifted Balook Block. Landslides have been an important slope process, probably because of the soft porous nature of the sediments and the history of tectonic activity. This land system is similar to Jeeralang in most respects but has lower relief and elevation, and shorter slopes.  
- A somewhat cool, humid environment, a sedimentary rock that weathers easily and mostly steep slopes, have resulted in uniform and gradational soils with loam to light clay textures. The soils tend to have a medium to fine blocky structure and roots readily penetrate the subsoil horizons. |
| Jeeralang land system (Jg)  | - Jeeralang land system occurs on the Cretaceous mudstones and sandstones of the South Victorian Uplands.  
- The terrain is mountainous with pronounced ridge-and-ravine topography, long steep slopes, and shallow soils.  
- Most occurrences are on the elevated Balook Block. Landslides have been an important slope process, probably because of the soft porous nature of the sediments and the history of tectonic activity. This land is geologically and climatically similar to the Gunyah land system but has greater relief and elevation, and longer slopes.  
- A cool, humid environment, sedimentary rock that weathers relatively easily and steep slopes have resulted in moderately deep, uniform-textures, silty clay loams to clay loams with a medium to fine blocky structure. Roots are common in the subsoil. |
| Livingston land system (Ln) | - The Balook Block of the South Victorian Uplands was raised almost without tilting, between fault and monocline systems to the north and south. Some areas near the crest of the uplifted block have escaped deep dissection and remain as plateaux. These occur along the ridge of the Strzeleckis.  
- The slopes of the plateaux are gentle but as dissection is intense with shallow incision, the local terrain consists of steep-sided, low hills. The bedrock is composed of Cretaceous mudstones, siltstones and sandstones same as for the adjacent Gunyah and Jeeralang land systems.  
- A humid climate acting on predominantly, fine-textured sedimentary rock has produced deep, acidic, clayey soils. |

Due to continual mixing by slope processes and bioturbation, only low to moderate degrees of pedologic organization are characteristic of soils in this environment (Aldrick, Hook et al. 1988). In the A horizon, bioturbation and erosion are generally active enough to lead to a predominance of soils with uniform texture and little other differentiation. These processes
are variable, the steeper gradients and longer slopes have the potential to produce larger volumes of runoff, faster flow rates and hence increased risk for more soil loss. On the other hand, such losses are reduced where deep permeable soils and dense protective vegetation exist. In the Strzelecki Land Systems, cultivating, logging, burning, road building and other earth moving activities, and trafficking by stock dramatically increase the likelihood and severity of erosion.

As described by Aldrick, Hook et al. (1988), the high clay content of soils in the Livingston land system has increased the development of pedality and reduced the striping of sesquioxide coatings resulting in the lack of an A$_2$ horizon. The infiltration capacity and surface soil permeability are extremely high and as a result, overland flow is low under nearly all rainfall events. They are strongly leached, as evidenced by soil pH values ranging between 4.2 and 5.0.

Aldrick et al. (1988) observed that for the time period from May to November, precipitation is in excess of soil water storage capacity, reaching a maximum runoff potential of 90mm in June. The available water storage in the top 500mm of the brown earth soils in the Jeeralang land system (component 1) is about 60mm of water; whilst the Krasnozem soils can store about 110mm of water in the top 500mm of soil. The main reason for this difference in available water storage capacity is the much higher content of organic matter of the Krasnozem and the clay content of the soils.

The soils and weathering zone together are some 10-15 metres deep. With their heavy and normally regular rainfall, the Strzeleckis are a reliable source of water for the creeks and streams that flow out of their catchments. Since baseflow comprises nearly 70% of the annual stream flow, soil moisture storage is a very important component of the catchment’s hydrology (Finlayson and Wong 1982).

Towns that draw water from the north face of the Strzeleckis include Thorpdale, Boolarra, and Mirboo North. Water is also taken from the streams by landowners for stock and domestic use. The high rainfall makes it unnecessary to irrigate the area.

Inherent nutrient levels are affected by parent rock. Nutrient decline is significant on the permeable clayey soils; electrical conductivity and chloride levels in the soils reflect the high rainfall regime. In addition, surface accumulation of carbon and nitrogen is prevalent and
extends in the soil profile (Nicholson 1978). Fertility tends to be adequate for forestry on most of the deeper soils even though they are well leached. The availability of nutrients to support plantations is probably a result of the large volumes of soil accessible to the tree roots.

Agricultural productivity is considered only in terms of pastures since the long, steep slopes preclude cropping. Pasture productivity is limited by the fixation of nitrogen by legumes and this in turn, depends on the availability of phosphorus. The natural soil phosphorus content is low, and added phosphorus quickly becomes unavailable due to high soil acidity. Consequently pasture production tends to be low and can be increased only with considerable inputs of fertilizers and lime requiring capital investment and labour (Aldrick, Hook et al. 1988).

The most productive farming in the Highlands occurs on the friable red volcanic soils which are also the areas most prone to gully and tunnel erosion, stream erosion and landslides. Cultivation or other disturbances can lead to compaction, reduced infiltration and increased runoff resulting in sheet and gully erosion.

2.6 Landslides
Landslides are sudden movements of soil or rock masses down a slope. Landslides in the Strzeleckis have been occurring since before European settlement; however, land use changes have re-initiated old landslips and created new ones. Clearing of the forest, road construction, and farming activities have initiated second, third and even fourth generation landslides on the prehistoric landslides. They occur mainly on the steeper slopes (10° – 40°) in all three major geological units. They can extend over several square kilometres in some areas (Brumley 1993).

As shown in Figure 2-12, landslides leave characteristic concave hollows with crescent upper edges, whilst at their base the displaced material often exhibits an irregular surface (Aldrick, Hook et al. 1988). The slump-earth flow is the most common type of large landslide in the Strzeleckis with some translational landslides and numerous smaller landslips (Brumley 1978). The earth flows can be quite extensive reaching up to 1 kilometre in length (Brumley 1993).
The major variables within any site which contribute to increased landslide potential are decreasing soil cohesion, decreasing root strength, a decrease in shear strength, slope, and catchment geology (Campbell and Doeg 1984).

Rainforests are generally considered to be an effective buffer to climatic factors contributing to slope instability. Deforestation and road-related earthworks are considered the dominant anthropogenic factor contributing to landslips in the Strzeleckis. They are considered to have the following major disadvantages (Brumley 1978):

- immediate cessation of the stabilising or buffering effect of the forest from climatic variations – negatively affecting the behaviour of soils facing new stresses;
- immediate cessation of interception, retention, and evapotranspiration increasing the amount of water reaching the ground and infiltrating;
- quick loss of the superficial debris layer resulting in increased amount of water reaching the ground and infiltrating;
- rise in the groundwater table resulting in the possibility of saturation of the superficial soil layer and increase in weight; and
- long term loss of the mechanical binding of the root systems eventually resulting in the reduction of apparent cohesion, and shear strength of the soil mass.

Figure 2-12 Typical Landslide Process / Slump-Earth Flow (Varnes 1978)
Many factors are involved in contributing to slope movements in the Strzeleckis including:

- deeply developed weathered soil profiles;
- steep slopes;
- high rainfall;
- undercutting by streams and hydrogeological factors;
- clearing of forests and vegetation;
- cuttings into hillsides for roads;
- construction of unlined dams in unstable areas; and
- seismic activity.

The hills south of Boolarra have a history of landslips and sediment delivery to streams from the steeper grassed slopes especially during storm events; however, major effects were only observed where the landslips were directly connected to the drainage system (Condina 1990). Shallow landslips in the Strzeleckis generally followed clearing of the native vegetation on steep slopes, because clearing resulted in reduced transpiration and the gradual destruction of the deep root zone that stabilized the soils (Nicholson 1978; Aldrick, Hook et al. 1988). Noble (1986) has observed that as the forests re-establishes, the streams are running clearer because the roots of the forest trees bind the soils together in a region where extensive slips on the steep hillsides were once common.

Many of the most seriously affected areas occur where the Childers Formation underlies the Volcanics. The sandy Childers Formation acts a regional confined aquifer sandwiched between the relatively low permeability soils of the Volcanics and the Lower Cretaceous sediments (Brumley 1993).

The impacts of landslides include:

- loss of production;
- infrastructure damage (roads, fences, powerlines, buildings, dams);
- loss of access to land; and
- increased erosion and direct sediment and contaminant delivery to streams.

Up to 25% of the prime agricultural land in the northern portion of the Narracan block is affected by landslides requiring either remedial action or careful management to avoid initiation of new movements (Brumley 1993).
2.7 **Land Use Impacts**

Removal of native vegetation, particularly native old growth forests, can also result in major changes to the local and regional water balance contributing to erosion, increased salinity, and leaching of nutrients.

In the Strzelecki Ranges, potential evapotranspiration appears to be less than rainfall for 10 months of the year and there is virtually no period of water stress for plants except during periods of major drought. The excess of rainfall over potential evapotranspiration during the cooler months averages about 520mm (Nicholson 1978). Being perennial and having deeper root systems, trees transpire larger volumes of water than most crops or pastures. Consequently soils under forests will generally be drier, with a greater capacity for accepting and storing water. Deep percolation and runoff increase as soil becomes saturated, so that water loss by both processes tends to be greater under pasture (Aldrick, Hook et al. 1988). The resultant increase in overland flow often promotes erosion.

Condina (1990) explains that natural background levels of suspended sediment are always carried by streams. For example, low flow values of around 5 to 15 mg/l have been observed from relatively undisturbed areas in the Strzeleckis. He also states that in addition to the natural background loads, diffuse inputs occur from areas of the catchments that have been cleared or disturbed by forestry operations, agriculture, and industry. Unlike tributary channel erosion, diffuse land erosion is not closely related to flow-duration characteristics of the streams, but more to the status of vegetation cover and hence timing of storms during the year. A key factor is the direct connectivity between disturbed areas and drainage systems. Very high loads can be carried into the stream if the vegetation cover has been depleted at the time of a storm event. Examples of this could be at the time of a drought break, or following extensive timber harvesting operations and fire.

Harvesting affects the catchment’s water balance in two ways. The reduction in transpiring biomass increases infiltration leading to an increase in groundwater, which reduces the soil’s shear strength enhancing the probability of a landslip (Brumley 1993). Increased groundwater also increases stream baseflow reducing stream bank stability and enhancing erosion. The reduction in forest canopy also results in higher surface runoff leading to higher surface erosion rates; however this is quickly reversed when new vegetation re-establishes. Effective reafforestation and plantation management minimises the extent and magnitude of these effects.
The management of land uses at a catchment scale must account for these properties and processes. Land use planning must contend with these broad properties and processes, but these are manipulated in a variety of ways to provide maximum benefit for each land use. Multiple land use concepts aim to combine uses. Since each use is dependent on specific properties and processes, conflict at a catchment scale is inevitable and can only be resolved by compromising the maximum potential of the resources for one or more uses.

An alternative to multiple use concepts which tend to produce ‘moderate quality and yield over all the landscape’ is to divide the landscape into units, each of which is managed so as to obtain maximum productivity and quality for a specific use. The preference for this alternative will depend on the land type, processes, proposed uses, and local community acceptance (Aldrick, Hook et al. 1988).

The maintenance of diverse plant species, communities, gene pools, and landscapes is often the aim in establishing conservation areas. This is a realistic ambition only if it is recognised that, even in the absence of disturbance by man, the environment will change with time, so that management aimed at preserving specific values, may be just as unnatural as man-made disturbances (Aldrick, Hook et al. 1988).

### 2.7.1 Conflict

Conflict over land management strategies is inevitable even when there is agreement as to the type of land use which is most appropriate, for example, forestry, agriculture, or nature conservation. This is due to the variety of processes operating and the range of strategies that can be implemented to control them, each with its own significance for the landscape.

An understanding of the processes, their inter-relationships and their significance for the functioning of the ecosystem over time cannot resolve these conflicts. However, it can assist in making rational management decisions that consider the long-term implications as well as the short-term benefits that may be gained from a particular management strategy.

In 1975, the Victorian Forest Commission recommended the implementation of a multiple-use approach for the management of the forests leading to more sustainable management of the forest resources. Priorities were determined by equating the social and economic needs of the community with the ability of the forest to maintain timber supply. In the Strzeleckis, the
Forest Commission was concerned not only with the timber yields under progressive harvesting, but also with the needs of the people wanting to use the forests for recreation and enjoyment, and the intrinsic biodiversity values (Noble 1976).

Under the multiple-use approach, the production of wood was carefully planned to minimise environmental damage. In theory, this meant that riparian vegetation was to be maintained along the watercourses to provide wildlife corridors and to avoid soil disturbance associated with the timber harvesting activities. However, the lack of real information and guidelines on the appropriate sizing for riparian buffer zones combined with historical poor harvesting practices and the wide-scale clearing during settlement continued to contribute to large-scale erosion and landslips. These impacts combined with the perceived loss of native forest habitat raised concerns and led to conflict between forest managers, government, local residents, and conservation groups.

2.7.2 Land Management Initiatives

The Victorian State Government and Grand Ridge Plantations are working with conservation groups and the local community to implement an improved multiple-use approach for sustainable forest management of the Strzeleckis. One example of a good outcome is the ‘Cores and Links’ initiative presented in the Victorian State Government’s policy, Our Environment Our Future. The ‘Cores and Links’ will protect approximately 8000 hectares of high conservation areas to preserve and enhance areas of high biodiversity values; of this, a total area of 2,411 hectares is hardwood plantations and 5,660 hectares is native vegetation (Department of Sustainability and Environment 2006). The ‘Cores’ are rare stands of cool temperate rainforest, typically located in the valleys and riparian zones whilst the ‘Links’ are native vegetation corridors between the Gunyah Rainforest Reserve and the Tarra Bulga National Park (Department of Sustainability and Environment 2006). As part of Grand Ridge Plantation’s requirement to meet its wood supply contracts, approximately 1,500 hectares of the ‘Cores and Links’ will be once-off harvested then re-established as native bush. In order to achieve this, a harvesting plan will be developed incorporating the following buffers:

- Minimum 60m buffer for cool temperate rainforest;
- Minimum 60m buffer for warm temperate rainforest; and
- 100m buffer on the West Branch of the Morwell River.

Up to 12,000 hectares of the Strzeleckis remain in freehold title (Noble 1986). Much of this land is devoted to agricultural pastures. Overgrazing and cultivation result in compaction and
baring of soil leading to localised erosion. In addition, the clearing of riparian vegetation, uncontrolled and unmitigated stock access to streams and drainage lines, and unprotected stream crossings contribute to stream bank erosion processes resulting in high sediment yields and poor water quality.

A study of the Tarago Catchment conducted by O'Shaughnessy & Bren (1998) found that:

- land draining predominantly agricultural land had more frequent elevated levels of turbidity and nutrients;
- much of the pollution was associated with surface runoff processes, which in turn were associated with compacted areas such as cattle tracks; and
- an important mechanism for the transport of phosphorus was attachment to sediments.

Long-term solutions such as revegetation will play an important role in the longer-term stabilisation of the streams. Regardless of the past role played by stock in soil erosion; control of stock access in the future must be an integral part of the mitigation works (Condina 1990).

In summary, levels of nutrients and suspended solids in the Latrobe River remain a concern especially considering the fragile state of the Gippsland Lakes. These issues require an understanding of the dynamics of land uses and the fate and transport of pollutant in the catchment.

The sustained growth of plantation forestry combined with unregulated agricultural practices in the Strzeleckis continues to pose the risk of persistent and magnified environmental impacts.
3 POLICY AND PROCESSES

3.1 Background to the Study

Historically, Australian agriculture and forestry have been very successful, creating substantial wealth to support the nation’s economic development. However, commodities are now being produced with ever-declining terms of trade at a significant cost to the environment. This is evidenced by the extensive losses of species and changes in ecosystem processes resulting in the increasing degradation of land and water resources (Williams and Saunders 2003).

Water movement in a catchment plays a large role in the degree and magnitude of off-site effects, either by physically moving sediments, stimulating landslides, or by direct alterations in water volume, velocity, peak-to-mean discharge ratio, and direction of flow (Aldrick, Hook et al. 1988). Effective catchment management requires data which identifies major pollution sources and in-stream processes (Grayson, Gippel et al. 1993).

Soil erosion is a natural process occurring in most environments, but is more frequent and potentially more damaging in landscapes comprising steep slopes that experience high intensity rainfall events such as those which occur in the Strzelecki Ranges. When the protective vegetation cover is removed or degraded by clearing, tillage, grazing, or recreational use, the risks of erosion substantially increase. Soil erosion can reduce on-site productivity through the loss of fertile topsoil and associated water-holding capacity, and loss of nutrients resulting in the decline in soil structure and poor plant growth.

Soil erosion increases the potential of downstream impacts on creeks, rivers, reservoirs, lakes, and estuarine and marine environments. Moore et al.(2001) and Glysson & Gray (2002) report that, by volume, fluvial sediments are the largest water pollutant in the United States. They affect aquatic habitat, drinking water treatment processes, and recreational use of rivers, lakes, and estuaries.

Suspended sediments, a direct product of soil erosion, have a wide-ranging effect on the flora and fauna of receiving waterways. Most Australian animals dependent on stream habitat, including the platypus, are not directly affected by the physical presence of suspended solids and turbidity; however, they are indirectly affected when increased suspended sediment concentrations reduce the availability of food or the ability to catch it. The sudden and sustained increase in sediment concentrations caused, for example, by the failure of road
drainage infrastructure can greatly reduce populations of native fish. Deposited silt has also been shown to greatly affect habitat by smothering the substrate and filling pools and scour holes. These effects reduce shelter, fill egg deposition sites, and destroy rearing areas (O'Shaughnessy and Bren 1998). Macrophytic plants are also affected by sediment inputs due to smothering and the reduction of light intensity. Light penetration is of great ecological significance because of its impact on photosynthesis. Visual clarity impacts the behaviour of aquatic organisms that rely on sight to catch their prey, and also influences human perception of water (Holdren 2002).

Contaminated sediments can kill aquatic organisms or reduce their survival, vigour, and reproductive success. Contaminated sediments may also affect organisms indirectly through the food chain by bioaccumulation and biomagnification (Moore, Testa III et al. 2001).

The removal or destruction of riparian vegetation further enhances the risks and impacts of erosion by creating direct sediment and pollutant delivery pathways to the watercourses. The resultant destabilizing of the banks further accelerates the natural stream bank erosion processes.

Increased turbidity at a catchment outlet may, in fact, be related to increased channel erosion due to changed stream flow conditions after land use changes. The problem is particularly complex in mixed land use catchments where it is almost impossible to separate the sediment contributions of different land use practices from natural sources (Croke, Wallbrink et al. 1999). Gippel (1989) states that most streams transport the bulk of their suspended sediment load during relatively infrequent storm events. However, Grayson et al.(1997) emphasise that from the point of view of water quality and ecological health, the low flow period is generally the most critical time for the system.

The ecology of the Gippsland Lakes system is under stress; symptoms of which include large variations in lake-bed vegetation, algal blooms, and the perceptions of fishermen and recreational boaters that the Lakes are becoming shallower. The increase in suspended sediment and nutrient loads into the lakes has been documented and attributed to land use changes in the upper catchments (Erskine, Rutherfurd et al. 1990).
3.2 Government Policy and Legislative Context

Commonwealth and state policymakers are faced with the challenges of striking a meaningful and workable compromise with land managers; each one of whom should have a vested interest in maintaining the sustainability of high quality water resources to support a diverse range of catchment values and beneficial uses. In Australia, the water resources of greatest significance include drinking water supplies, catchments, rivers, lakes, aquifers, and estuarine and marine waters that possess economic, ecological and/or cultural values (ANZECC 2000).

An effective framework for the management of water quality needs to recognise the need for an integrated management approach for managing both point and diffuse sources of pollutants. The frameworks should be based on (Department of Natural Resources and Environment 2002):

- a state policy context which recognises regional catchment management arrangements as the predominant mechanism for the management of water quality;
- regional planning arrangements for water quality which:
  - are developed in the broader context of management of river health;
  - area catchment-based;
  - provide clear mechanisms for coordination; and
  - integrate the various aspects of water quality which impact on river health;
- the establishment of minimum acceptable standards for undertaking specific activities within the catchment, particularly to minimise the impact of various land uses and other diffuse sources on water quality; and
- an ongoing understanding of current and emerging water quality issues.

*Growing Victoria Together*, is a 10-year vision for Victoria to maintain and enhance liveability and employment, within a thriving economy, quality health and education, a healthy environment, caring communities and a vibrant democracy (Department of Premier and Cabinet 2001). The key aims of *Growing Victoria Together* are to promote sustainable development, build cohesive communities and protect the environment. Achieving these outcomes is essential to revitalise rural communities and regional centres, maintain sustainable economic growth, and to ensure that our natural biodiversity is preserved for future generations (Department of Sustainability and Environment 2007).

Building on *Growing Victoria Together, Our Environment Our Future - Sustainability Action Statement* provides the framework to make Victoria a sustainable State within one generation
by maintaining and restoring natural assets, using resources more efficiently, and reducing everyday environmental impacts (Department of Sustainability and Environment 2006). The Framework provides direction for government, business and the community on building environmental considerations into the everyday:

- outlining key environmental challenges facing Victoria;
- defining environmental sustainability and why it is important;
- identifying the strategic directions to become more environmentally sustainable;
- setting objectives to be achieved and interim targets for measuring progress; and
- outlining important steps for putting the framework into action.

*Our Forests, Our Future* presents a significant opportunity for the Government, in partnership with the community, to ensure the long-term future of our forests and regional communities. *Our Forests Our Future* committed to improve the management of the Victorian forest estate for multiple uses (Department of Natural Resources and Environment 2002). The major components of the initiative include:

- a 31% reduction in logging across the State;
- an $80 million assistance package, which includes funding for a Voluntary License Reduction Program and a Workers Assistance Package;
- new legislation to ensure resource security;
- independent auditing of forests; and
- establishment of VicForests, to separate commercial forestry objectives from the policy and regulatory functions of Government and ensure that the logging industry is managed efficiently.

Extraction of timber is guided by the *Code of Forest Practices for Timber Production* (the Code), (Department of Natural Resources and Environment 1996). The purpose of the Code is to ensure that commercial timber growing and harvesting operations carried out on both public and private lands are managed in such away that it:

- promotes an international competitive forest industry;
- is compatible with the conservation of the wide ranging environmental and biodiversity values associated with forests; and
- promotes the ecologically sustainable management of native forests proposed for continuous timber production.
Enforcement of the Code is the responsibility of local municipalities. The Code is not a clear legal document and is subject to interpretation; making it very difficult to consistently enforce prescriptions and prosecute breaches. The Victorian Environment Protection Authority also conducts routine audits of coupes to ensure compliance with the Code. Bushfire management and the impacts of firebreaks and access tracks also affect the application of the Code.

*Our Water Our Future* sets out the framework and measures to ensure the security of supply and quality of water resources in Victoria for the next 50 years. Part of the strategy is to achieve ‘sustainable water management’ with healthy rivers, aquifers, floodplains, estuaries, and catchments capable of delivering a wide range of water services (Department of Sustainability and Environment 2004). The strategy sets out to clearly define the role and responsibilities of catchment management authorities as caretakers of waterways and their role in the delivery of on-ground restoration works to improve river health.

Land use change can impact on the availability of surface water and groundwater by altering the amount of water intercepted and used by vegetation. Changes from pasture to plantations and indigenous revegetation resulted in net reductions in the volume water resources over the short-term (Department of Sustainability and Environment 2006). *Our Water Our Future* recognises the impact of timber harvesting on water availability in the water supply catchments and proposes measures to mitigate these impacts.

The *State Environment Protection Policy (Waters of Victoria)* (SEPP) (Environment Protection Authority Victoria 1988) states that: “The Central Gippsland region contains one of Victoria’s major river systems, The Latrobe River, the health of which has a major influence on the environment of the Gippsland Lakes. Good Water Quality and adequate flows within the waterways are essential to sustain the many uses of water resources in Central Gippsland and the Gippsland Lakes”.

The SEPP introduces the concept of *beneficial uses* which are protected under the policy. The beneficial uses include:

- maintenance of natural aquatic ecosystems and associated wildlife;
- potable water supply;
- water-based recreation, including swimming, boating, fishing and picnicking;
- agricultural water supply, including stock watering and irrigation;
- fishing and aquaculture, protecting both commercial and recreational fisheries;
• industrial water use, including boilers, cooling, paper manufacture and food processing; and
• aquifer recharge, ensuring that surface waters do not pollute groundwater.

The Commonwealth Department of the Environment and Heritage (2003) sets default target values for upland rivers, these values provide a guide for the measurement of water quality indicators across Australia. It sets turbidity value range for slightly to moderately disturbed ecosystems such as the Morwell River as 2 – 25 NTU.

Land tenure can also be a very important tool / opportunity in waterway management. Victoria has about 128,000 kilometres of water frontages of which 25,000 kilometres (or 20%) are frontage reserves (Department of Sustainability and Environment 2004). A Crown land water frontage is any strip of Crown land that runs alongside designated rivers and streams; however, may not continue for the whole length of the river or stream. Generally a Crown water frontage would be approximately 20-30 metres wide. However, the actual width of the water frontage may vary because of the distance between the water frontage and adjoining private land. Often the exact boundaries are unknown as the Crown land may not have been formally surveyed and / or the course of the river or stream may have altered over time.

Being long and narrow, Crown frontages occupy a relatively small area, approximately 1% of Crown land in the State (Gabriel-Jones 2006); however, water frontages contain key conservation, recreation, biodiversity and water quality values. The majority of the water frontage areas are reserved for various purposes. Reserved and unreserved frontages may be licensed to adjoining land owners usually for grazing, water supply or conservation. Licenses can be issued under the Land Act 1958 and the Crown Land (Reserves) Act 1978. The Land Act 1958 empowers the regulation of activities on the frontage but only for the licensed areas, whilst the Crown Land (Reserves) Act 1978 only provides regulations for the reserved land.

Generally, management of these Crown land water frontages is the responsibility of the Department of Sustainability and Environment (DSE), unless the Minister has issued a licence to another person or body. A licence over a Crown land water frontage provides permission to enter and use the land for the specified purpose; however, the public retains the right to enter and remain on the land for passive recreational purposes for example walking, fishing, or bird watching.
The Water Act 1989 empowers catchment management authorities to make by-laws in relation to waterways and their surrounds and empowers them close off access and prevent unauthorised works on land abutting or with 20 metres of a waterway (Gabriel-Jones 2006). Under the Victorian River Health Strategy (Department of Natural Resources and Environment 2002), the Government has committed to transfer the management of Crown frontages to the catchment management authorities. This provides an opportunity to consolidate the management of riparian land for conservation and the protection of water resources.

The rehabilitation and ongoing management and protection of riparian land can be undertaken in accordance with Victoria’s Native Vegetation Framework (Framework) and the Flora Fauna Guarantee Act 1988 (FFG Act). The Framework aims to achieve a reversal, across the entire landscape of the long-term decline in the extent and quality of native vegetation, leading to a net gain. The FFG Act regulates the taking of protected flora without authorisation (Department of Natural Resources and Environment 2002).

Formal recognition of the value of riparian vegetation under the Framework would encourage land managers to protect and enhance riparian zones. The Framework establishes the strategic direction for the protection, enhancement and revegetation of native vegetation across the State. It addresses native vegetation from a whole of catchment perspective but with a focus on private land where issues arising from past clearing and fragmentation of native vegetation exist. Under the Framework, land managers are required to mitigate against damage or destruction of native vegetation by providing protected offset sites which are managed to provide a "net gain" to the community. Land managers should lobby Government to recognise the value of riparian vegetation and the benefits of buffer zones for both forestry and agriculture. The establishment of native vegetation "banks" along riparian zones, above and beyond what is required by the Code of Forest Practices for Timber Production and other prescriptions, as net gain sites should be encouraged.

In order to achieve a net gain for native vegetation, it is critical that not only the vegetation is protected but also that biodiversity values be promoted. The establishment and maintenance of healthy riparian zones and buffers provide habitat connectivity and protect the soil and water resources.
Other relevant legislation and policy includes:

- *Catchment and Land Protection Act 1994*;
- *Environment Effects Act 1978*;
- *Environment Protection Act 1970*;
- *Planning and Environment Act 1987*;
- *Environment Protection and Biodiversity Conservation Act 1999*.

### 3.2.1 Role of Catchment Management Authorities

In Victoria, the concept of integrated catchment management underpins sustainable management of land and water resources and contributes to biodiversity management. The key goal of land and water management in Victoria is sustainable development, which requires the complex integration of ecological, economic and social objectives.

In embracing the concept of catchment management authorities, the Victorian Government has been able to fill a major institutional gap that commonly occurs in the management of waterways around the world; that is, whilst many groups are responsible for activities that impact on waterways, no one has had the overall responsibility for the resultant environmental condition of waterways (Department of Natural Resources and Environment 2002).

Catchment management authorities were established in 1997 by the Government of Victoria under the provisions of the *Water Act 1989* and the *Catchment and Land Protection Act 1994* (Department of Sustainability and Environment 2007). They were created to deliver integrated management of land and water resources. Authorities are accountable for the regulation of works on waterways and floodplains, rural drainage, waterway and floodplain management and the development and implementation of regional catchment strategies (West Gippsland Catchment Management Authority 2007).

Six principles govern the way catchment management is implemented throughout the State. They are:

1. **Sustainable Development** – whole-of-catchment approach to natural resource management to deliver social, economic and environmental outcomes for the community.
2. **Community Empowerment** - planning and implementation of natural resource management programs to maximise opportunities for community engagement.
3. **Integrated Management** - recognising the linkages between land and water.
iv. Targeted Investment - ensuring that resources are targeted to address priorities and deliver maximum on-ground benefits.

v. Accountability - decision making on natural resource management should be clearly accountable to Government and the community on a sustainability framework.

vi. Administrative Efficiency - To maximise on-ground results catchment management structures should facilitate more efficient procedures and practices.

Along with policy development related to the restoration and protection of waterways, catchment management authorities undertake on-ground works including the removal of weeds in waterways, stream bank stabilisation and protection, and the re-establishment of riparian native vegetation (West Gippsland Catchment Management Authority 2007).

In the land management area, catchment management authorities play a role in the development and implementation of actions plans that identify natural assets and outline management actions to reduce threats and impacts on these assets. The authorities have a particular focus on salinity management, nutrient management, soil health and pest plant and animal management (West Gippsland Catchment Management Authority 2007).

3.3 Erosion and Land Management Processes

Soil erosion can be defined as 'a combination of processes in which the materials of the earth's surface are loosened, dissolved, or worn away, and transported from one place to another by natural agents' (Academic Press Inc. 2003). The product of water-borne erosion is generally suspended sediment and increased bedload. The actual amount of erosion is dependent on the erosivity of the rainfall, the erodibility of the soil and the angle of the slope (Hazelhoff, van Hoof et al. 1981). At regional scales, elevation, relative relief, climate, lithology, and catchment area have all been identified as being key factors on long-term sediment yields (Foster and Lees 1999). However, Croke et al.(1997) observed that soil type is not a major factor in explaining the relative differences in runoff and sediment production rates of various catchments.

Generally, soils with faster infiltration rates, higher levels of organic matter, and good soil structure are more resistant to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Croke, Wallbrink et al. 1999).
Piehl and Stewart (2000) list four factors which determine the relative susceptibility of catchments to erosion problems as being:

- erodibility and availability of soils in source areas;
- area of catchment in the elevated zones where surface erosion is more prominent;
- limitation to the transport of sediments and likelihood of deposition due to the physical structure of watercourses; and
- existing water quality data identifying watersheds with sediment problems.

Steeper regions have proportionately larger sediment source areas because the steep gradients make it more likely that eroding soils will be delivered to streams. Anderson (1975) reports that sediment transport rates in high elevation catchments were three times more than those in low elevation catchments. He also calculated the relative contributions of stream bank erosion, landslides, and land surface erosion to be approximately:

- stream bank erosion – 55%
- landslides – 25%
- land surface erosion – 20%

Approximately one quarter (¼) of the soil lost through erosion in a catchment actually makes it to the ocean as sediment. The other three quarters (¾) is deposited on foot-slopes, in reservoirs, on river floodplains, and other low lying areas, or becomes part of the river's bedload which often results in channel shifts (Brown and Wolf 1984). Overbank sediment deposition can be considered to represent long-term sediment storage within a catchment with a residence time in the order of 1,000 to 10,000 years (Walling, Owens et al. 1999).

Lach & Wyzga (2002) reported that the annual rate of soil erosion in a forest is approximately three orders of magnitude lower than that of grazing lands and up to six orders of magnitude lower than fields used for cultivation.

The soil loss rate in the Strzeleckis at Leongatha Victoria has been reported to be 0.6 tonnes per hectare per year (Hua, Prosser et al. 2003). Rice (1988) estimates soil loss in the cleared areas of the Strzeleckis to be in the order of 0.3 mm of soil per year. Losses are attributed to point sources, stream bank erosion, and other erosion sources in the catchment including landslips.
3.3.1 Catchment Hydrology

By identifying the areas that produce runoff and by preventing contaminated runoff from reaching the streams, the only other avenue for increased sediment concentration in streams is the secondary influence of increased stream flow that accompanies the removal of vegetation (Grayson, Haydon et al. 1993).

In the Victorian upland environments, groundwater movement is a major factor in the hydrology and stream flow of the catchments. In this environment, the storm runoff process can be described as fast recharge of groundwater through infiltration, then fast discharge of groundwater into the streams (O'Shaughnessy and Bren 1998). These catchments are described as “infiltrating” because the groundwater recharge occurs during and after periods of heavy rainfall with no groundwater outflow observed on the slopes of the catchment (Bren and Turner 1979). For example, Melbourne Water catchments return about 50% of rainfall as stream flow during wetter periods, but in drier periods return from 0% to 10% of the rainfall as stream flow (O'Shaughnessy and Bren 1998). The effectiveness of the area in directly returning rainfall as stream flow greatly increases as the actual storm rainfall intensity increases (O'Shaughnessy and Bren 1998).

Dunne and Black (1970) observed that in upland catchments, the major portion of storm runoff produced as overland flow came from soak areas adjacent to streams with the remainder of the watershed acting as a ‘reservoir’ during storms.

At the beginning of a storm event, the storm runoff producing area is relatively small and is a function of the stream surface area and soil moisture near the stream. As the storm progresses, the area increases at a rate which is a function of the rainfall intensity and the depletion of soil moisture storage. Only a small portion of most catchment areas contributes runoff to the stream flow, this is referred to as the ‘contributing area concept’ or the ‘soak area’. Properties of these contributing areas vary from catchment to catchment according to topography, soil characteristics, and vegetation (Dickinson and Whiteley 1970). The soak area is usually composed of bedrock boulders, partly decomposed logs, vegetal detritus, and lenses of sediments deposited by the stream. Runoff generated within the soak area is dependent on antecedent moisture conditions in the catchment as determined by the history of rainfall and evaporation (Finlayson and Wong 1982). In small upland Australian streams, soak area materials are highly permeable and, in places, the stream disappears altogether from the surface.
For small Australian catchments, 70-80% of total runoff is generated through baseflow and the remainder 20-30% of storm flow generated largely as saturated overland flow from the saturated soak areas (Pilgrim, Cordery et al. 1982). This corresponds with the observations made by Bren and Turner (1979) who found that almost all of the storm runoff from a small forested catchment occurred as rapid subsurface flow or through flow. This is consistent with the catchments of the Strzelecki Ranges which comprise of deep, permeable soils. Given this condition, there is little surface runoff observed since the rainfall intensity is almost always less than the infiltration rate for all but the soak areas.

Runoff and sediment generation has been found to increase when forests are cleared and replaced with shallow-rooted vegetation such as pasture; however, the re-establishment of forest cover eventually reduces runoff (Pilgrim, Cordery et al. 1982; Nandakumar and Mein 1993). It is generally accepted that the increase in stream flow with the clearing of the forest vegetation results from a rise in the groundwater table rather than increased storm runoff (Pilgrim, Cordery et al. 1982).

According to Grayson, Haydon et al. (1993), stream flow increases, reaching a maximum 2 to 3 years following clearing of a eucalypt forest followed by a gradual decrease in flow over subsequent years. The maximum increase in runoff is proportional to the area of forest cleared, an average 33mm increase in annual flow results for each 10% of catchment area cleared. The subsequent decrease in flow is attributed to an increase in interception and transpiration rates, and a decrease in ground evaporation caused by the growth of new vegetation. Then stream flow drops to below pre-logging levels caused by the higher evapotranspiration rates of the emerging vegetation. In general, removal of forest vegetation increases stream runoff while afforestation decreases it (Campbell and Doeg 1984). However, at least 20% of a catchment has to be affected by a change in vegetative cover, in one year, for hydrological effects to be detectable (O'Shaughnessy, Fletcher et al. 1995).

O'Shaughnessy and Bren (1998) report that silvicultural thinning of 40 year old mountain ash stands increased stream flow by about 25% with the effect being detectable for about 15 years. However, a one time conversion of older mountain ash forest stands to well-stocked regrowth conditions caused a long-term reduction in stream flow reaching a maximum peak of 50% reduction about 30 years after the conversion, water yields then recover over the next 70 years.
3.3.2 Runoff
Public land is also the major source of water in Victoria, with more than 70% of runoff in Victoria’s water supply catchments originating from public land (Department of Sustainability and Environment 2006).

Surface runoff, and associated erosion, occurs when soil moisture deficits have been satisfied (Wass and Leeks 1999). Many catchments convert only approximately 20% to 30% of rainfall to runoff (Soste, Cooper et al. 1996).

Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Surface erosion by overland flow at forest sites is usually associated with intense rainstorms that follow baring of the soil by roads, fire, overgrazing, mass soil movement, or other causes (Anderson 1975). Although, soil erosion caused by longer and less-intense rain events may not produce as much instantaneous suspended sediment as that produced during larger storm events such as thunderstorms, the amount of soil loss can still be significant when considered over the period of the rain event.

Runoff and associated erosion reaches its highest point during the wetter months when the high precipitation, low evaporation, and minimum vegetative cover combine to produce saturated soils and excess water. Generally, an annual and seasonal variability is apparent in the sediment supply to streams (Wass and Leeks 1999).

The change in erosion mechanisms with increasing slope angles above 7° is reflected by the changes in runoff from unfocused flow on gentle or flat surfaces to channelled flow more likely to result in gully erosion (McHugh and Harrod 2002). Soil erosion potential also increases with increased slope length which permits the accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential. The increased runoff velocity causes a greater degree of scouring contributing to higher erosion rates.

3.3.3 Types of Erosion
The main erosion mechanisms in the Strzeleckis are stream bank erosion, gully erosion and tunnel erosion. Parts of the Strzelecki Ranges have been identified as being vulnerable to tunnel erosion (Department of Conservation and Environment 1992). Tunnels are often
initiated as a result of water concentration into rabbit warrens, old stump holes, and old tree root lines. However, this type of erosion is not a significant erosion mechanism in the study area.

Gully erosion is usually caused by the improper design of outlet structures. Concentrated runoff waters quickly erode the soil downstream from the outlet structure creating deeply incised drainage lines. Gully formation can be difficult to control if remedial measures are not properly designed and implemented. Control measures need to consider the cause of the increased flow of water across the landscape.

3.3.3.1 Stream Bank Erosion

Sedimentation from in-channel sources may be the greatest single human impact on Australian waterways (ANZECC 1992; Lawler, Grove et al. 1999). A catchment audit conducted by the Environmental Protection Authority Victoria found that stream bank erosion was a major source of sediment in certain parts of the Tyers River Catchment (Maloney 2001). Kuhnle et al.(1996) found that 64% of fine and up to 100% of coarse sediments could be attributed to stream bank and stream bed erosion.

Stream bank erosion can be defined as the weathering and eventual collapse of stream banks usually caused by under-cutting of banks by stream flow. It is often exacerbated by stock access, people, vehicles, and clearing of riparian vegetation. It is often enhanced or reduced by land use change in the catchment, for example clearing of forests which increases the frequency and volume of peak flows has been found to increase stream bank erosion rates (Aldrick, Hook et al. 1988). The primary mechanisms involved in stream bank erosion include subaerial bank weathering or weakening (preparational processes), fluvial entrainment mechanisms or fluvial erosion processes, and mass failure or bank collapse processes (Lawler, Grove et al. 1999; Couper and Maddock 2001).

Lawler et al.(1999) explain that in the upper reaches of the catchment, stream power is low because of relatively low discharge volumes. This limits the available energy for fluid entrainment of bank materials, combined with low bank heights greatly reduces the effectiveness of mass failure processes; therefore, subaerial weathering and to some extent fluvial entrainment processes dominate this region (Couper and Maddock 2001).
Lateral corrasion, a fluvial entrainment process, is the primary channel erosion mechanism in small upland streams such as the upper reaches of the Strzeleckis. It occurs at the toe of the bank up to the maximum high water level.

Lateral corrasion reflects the lack of balance between the shear stress exerted by stream flow and the stability of the bank material (Duijsings 1987; Couper and Maddock 2001). The rate of enlargement of the undercut resulting from lateral corrasion is dependent on the size of the undercut, texture of the subsoil, and the frequency and intensity of flow conditions. The highest rates of lateral corrasion have been observed at knickpoints in the longitudinal profile of the stream. These knickpoints corresponded to organic log dams and coarse sediment. Maximum rates of bank recession were always observed immediately downstream from the debris dams (Duijsings 1987).

As illustrated in Figure 3-1, stream bank erosion mechanisms can be broken down into lateral corrasion, mass movement or bank failure, subsoil fall, splash erosion, soil creep, and overland flow (Duijsings 1986; 1987).

![Figure 3-1 Catchment Erosion Mechanisms (Duijsings 1986)](image)
Mass movement or bank failure involves the failure of a whole bank, contributing a considerable supply of bank material to the channel bed; however, such erosion sites are limited in number. Only at the downstream end of the catchment or in large basins would bank geometries and materials become conducive to frequent bank collapse events. It is predominantly in these downstream areas that bank heights become sufficiently critical to allow for mass failure processes to contribute effectively to and even dominate, bank erosion (Lawler, Grove et al. 1999; Couper and Maddock 2001; Simon and Collison 2002).

Soil creep and splash erosion is primarily the product of bioturbation and frost heave in frost prone areas and can be a significant source of sediment. Splash erosion also occurs when the stream banks are free from litter cover.

Duijsings (1986; 1987) reported that for a small stream, stream bank erosion contributed 53% of the total sediment supply. This was broken down into lateral corrosion (43%) and subsoil fall (39%) being the main sediment producing processes with the remainder being supplied by bank failures (14%), splash erosion (3%), and soil creep (1%).

Green et al. (1999) found that much of the sediment deposited in the lower reaches of the Namoi River in New South Wales came from subsoil rather than topsoil. Subsoils are eroded from rills, gullies and stream banks. Bank erosion processes and rates appeared to be affected primarily by the mechanical properties of the bank material and seasonal wetness patterns, with the direct effects of stream flow being secondary.

Anderson (1975) explains that percolation and rising groundwater is important in humid forest environments. He observed that rising groundwater caused by increased baseflow enhanced the capacity of the stream flow to move the bedload by a factor of 1000. Fluidising of the stream bedload under normal stream velocities resulted in rapid sediment transport and increased stream turbidity.

Geomorphologically, bank erosion is a central component of meander formation, lateral channel migration and movement of sediment throughout the drainage basin and a long time-scale is required for these to be appreciated. When free channel development is allowed, a river adjusts to diminishing sediment loads by an increase in sinuosity and the reduction in gradients (Lach and Wyzga 2002).
3.3.4 Bioturbation

Finlayson & Wong (1982) report that since the peak in the quick flow is generated entirely within the *soak area*, mechanical erosion of the catchment by running water only occurs within that area. Other processes for transporting soil must therefore be responsible for the delivery of material to the soak area. These processes include bioturbation, rainsplash, tree throw, slope failure, and soil creep. The magnitude and importance of these processes are not known and very little research has been carried out in the Australian environment.

The rate of rainsplash detachment appears to be closely related to the forest ecology because of canopy effects on the erosivity of rainfall and the activity of burrowing fauna. The main effect of burrowing fauna was the removal of the protective layer of litter; thereby, creating bare surfaces susceptible to splash erosion (Duijssings 1987).

Bioturbation is the action of burrowing and foraging animals and tree throw in or near the stream channel. Bioturbation can significantly increase the rate of soil movement or the mixing of soil material (Aldrick, Hook et al. 1988). Duijsings (1987) reports that biological activity is the main cause of soil creep. Extensive freshwater crayfish burrows in the soak areas of many Australian streams is an example where bioturbation may be a major source of suspended sediment in these environments (Finlayson and Wong 1982).

Hazelhoff et al. (1981) studied the impacts of bioturbation by earthworms. They reported that earthworms are important catalysts in erosion by creating bare soil. They observed that litter removal by the earthworms began in spring reaching a maximum during rain events in summer.

Bioturbation is not only limited to the smaller fauna living in or near the soak area but also by larger animals such as lyre birds, wombats, wallabies and other animals which graze and forage in the catchment. For example, Evans (1998) found that deer in national parks in the United States initiated wide-scale erosion by creating tracks and expanses of bare soil on slopes.

3.4 Riparian Vegetation

The *Victorian River Health Strategy* (Department of Natural Resources and Environment 2002) defines riparian land as the area of land that adjoins, regularly influences, or is influenced by a waterway.
Riparian vegetation comprises indigenous and/or introduced vegetation alongside streams shaping its chemical, ecological and physical health. The availability of moisture in riparian zones creates highly productive ecosystems. Under pristine conditions, riparian vegetation and in-stream woody debris create significant in-channel roughness and with the binding effects of the roots, increase bank resistance to erosion (O'Shaughnessy and Bren 1998; Brooks and Brierley 2002; Liebault and Piegy 2002). Riparian zones have a variety of functions including supply of organic matter as a major food source, shading stream channels, minimising temperature fluctuations of stream water, increasing habitat diversity, trapping sediments and associated nutrients moving from the hillslope, and reducing the volume of overland flow moving to the channel (Herron and Hairsine 1998; Lovett and Price 1999; Department of Natural Resources and Environment 2002).

Riparian zones are also provide significant community benefit by providing recreation areas and are often sites of considerable Indigenous cultural heritage value due to their close association with water.

Many revegetation projects in Australia are targeting riparian zones to plant indigenous vegetation, with aims differing between community groups and water supply agencies, the latter being most often concerned with stream water quality. In deciding whether to use grass filter strips or natural riparian vegetation, land managers should consider their relative value and functional importance and how well each system fulfils its functions (Hairsine 1997).

Hairsine (1997) reports that grass filter strips performed similarly to near-natural riparian zones in their ability to trap sediments. The high hydraulic conductivity within vegetated areas also reduces overland flow and pollutant delivery to streams (Croke, Wallbrink et al. 1999; Foster and Lees 1999). Vegetative cover reduces soil erosion in the following ways:

- slows down runoff allowing for much of the rain to infiltrate;
- holds the soil in position and prevent it from being washed away;
- breaks the impact of raindrops before they hit the soil; reducing their erosion potential;
- slows down the flow of the water and their roots bind the soil; reducing the stream bank erosion processes.
Buffer strips (or filter strips) are areas of vegetation, usually grass, located between hillslopes and waterways to reduce the input of sediment and soil-attached pollutants from upslope activities.

Buffer and filter strips have been reported to be effective across many environments because they (O'Shaughnessy and Bren 1998; Croke, Wallbrink et al. 1999):

- reduce the flow of sediments and associated pollutants from key source areas such as roads and tracks;
- minimise the development of overland flow from the disturbed areas;
- slow down overland flow resulting in sediment deposition;
- reduce movement of soluble pollutants;
- provide for the infiltration of overland flow allowing sediment deposition;
- maintain channel stability; and
- provide near-stream vegetation for ecological and environmental health.

Filter strips trap between 80% and 90% of sediment and more than 70% of incoming nitrogen and phosphorus (Bren, Dyer et al. 1997; Hairsine 1997; Croke, Wallbrink et al. 1999). For example, a 6m forested buffer strip was found to trap 90% of incoming sediment for a wide range of overland flows (O'Shaughnessy and Bren 1998). The most important factors affecting the performance of vegetation buffer strips include (Hairsine 1997; O'Shaughnessy and Bren 1998):

- rate of upslope erosion;
- vegetation density and structure in the buffer zone;
- size of the buffer zone;
- water flow rate through the buffer zone;
- fineness of the sediment; and
- cumulative mass of sediment deposited compared with the capacity of the buffer to store the sediment.

The encroachment of riparian vegetation on active channels contributes to the narrowing of the channels during a period when the overall bedload supply decreases because of hillslope stabilisation due to land use changes (Liebault and Piegay 2002).
Buffer and filter strips must extend beyond the permanent or semi-permanent saturated zones (contributing areas / soak areas) for effective infiltration of runoff to occur. For the protection of biodiversity, Timewell et al.(2001) recommend that a buffer width equivalent to two tree heights (approximately 100 metres) is necessary to provide minimum protection. However, buffer widths of 250 metres around areas of Cool Temperate Rainforests (EVC 31) are recommended to protect the significant communities from spread of Myrtle Wilt, allow natural processes to operate, and permit the rainforest to expand.

The clearing of riparian vegetation also results in greater stream water temperature variations. Without the protection of overhead vegetation, streams tend to run warmer during summer. For example, the monthly mean maximum temperatures were elevated by 6°C and the annual maximum temperature increased by 12°C in streams without protective riparian vegetation. However, no detectable change in stream water temperature was found in areas where buffer strips were left intact (Campbell and Doeg 1984).

The major threats to riparian vegetation include clearing, erosion, unabated livestock access, recreational use resulting in the trampling of understorey, weed invasion, crossings for roads and powerlines, removal of timber for firewood, salinity, and water management (Department of Natural Resources and Environment 2002).

3.5 Forestry
The expansion of forestry on cleared agricultural land is becoming more attractive in higher rainfall zones. Commercial prospects for traditional grazing are poor, while market prospects for the expansion of plantation forestry appear to be improving. The opportunity to combine carbon sequestration incentives with reafforestation is attracting attention in Australia (Williams and Saunders 2003).

The Victorian Government has developed a biodiversity strategy which includes directions for the management of biodiversity in forest landscapes. These directions require continuous improvement of forest management processes, minimisation of disruptive impacts on biodiversity, and continuing to adjust management regimes to maintain the long-term ecological health of forests (Department of Natural Resources and Environment 1999).
In Victoria, Hancock Victorian Plantations (HVP) manage approximately 221,000 hectares of land, supplying about 2.3 million tonnes of softwood and over 100,000 tonnes of hardwood annually (Hancock Victorian Plantations 2001).

Forestry operations in the Strzeleckis primarily consist of clearing mature stands of trees (approximately 30 years old) for sawlogs and pulpwood followed by reafforestation of the plantation area. Pine plantations are a significant feature of the Strzeleckis in that almost half as much area is covered in pines as carries native vegetation (Rice 1988).

Harvesting of timber involves the physical removal of timber from the catchment. Usually involving skidding of felled trees to a central landing area where they are processed and loaded onto trucks for transport (Campbell and Doeg 1984). The main landscape elements representing the main sources of runoff and sediment in a logged catchment include (Croke, Wallbrink et al. 1999):

- unsealed roads;
- snig tracks;
- log landings; and
- general harvesting areas.

Increases in sediment yields during and following logging operations have been well documented and the reported increases can be considerable (Campbell and Doeg 1984). It has been widely reported that the primary sources of manageable runoff and sediment in production forests are disturbed and compacted areas such as snig tracks, log landings, and unsealed roads (Sheridan and Rosewell 2003). The ‘unavoidable’ impacts of logging on catchment water quality are small and can be minimised by understanding the processes that produce runoff, and by taking appropriate steps to minimise contamination of runoff and to prevent contaminated runoff from entering the waterways (Grayson, Haydon et al. 1993). The protection of soil properties is fundamental to sustainable forest management (Department of Natural Resources and Environment 1999).

Areas of intensive activity on or near the stream bank or within the stream channel, and mass movements of soil on the harvested slopes appear to contribute the greatest amount of sediment to streams (Campbell and Doeg 1984).
In poorly managed coupes, increases in suspended sediment yields in the order of 150% have been observed following the first major rainfall event. The increase in suspended sediment yield has been attributed to enhanced erosion of access roads and batters compounded by inadequate cross drainage (Campbell and Doeg 1984). Disturbance by heavy machinery on the general harvesting area is often restricted to small areas, unlike the broader disturbance caused by roads and tracks (Croke, Wallbrink et al. 1999).

For much of the timber production rotation, ground cover is continuous and undisturbed, and accelerated soil loss is not considered to be significant. There is a time window between harvesting of the mature crop and re-establishment of complete ground cover where the risk of soil and nutrient loss is significant (Constantini, Rose et al. 1991). During this period, the baring of soils combined with increased runoff creates serious management issues with regards to erosion. However, Croke et al.(1997) determined that general harvesting areas yielded relatively small volumes of sediment because high infiltration rates predominated with resultant patchy overland flow. If erosion sites are not directly connected to drainage lines most of the eroded material is redeposited within the harvested area or buffer strips (O'Shaughnessy and Bren 1998).

Grayson, Haydon et al. (1993) reported that if conducted in accordance with the prescriptions under the Code, the impact of logging operations on the east coast of Australia is only slightly detectable. The low impact could be attributed to the protection of runoff producing areas by the absence of stream crossings, the presence of deep permeable soils, and the temporary nature of the access roads. The suspension of logging operations during wet weather combined with the protection of runoff producing areas with buffer strips, and the management of runoff from roads, snig tracks and log landing areas eliminated intrusion of contaminated runoff into streams.

Croke et al.(1999) found that general harvesting areas retained the greatest amount of remobilised soil material. However, on an area-weighted basis, a buffer strip comprising 6% of the total area retained 5 times more sediment than the general harvesting area comprising 74% of the total area.

In the years following carefully planned and executed timber harvesting operations, sediment yields declined as vegetation stabilised the slopes and the physical disruption of the soil
surface was reduced (Bormann and Likens 1981; Campbell and Doeg 1984; Croke, Hairsine et al. 1997; Lach and Wyzga 2002).

O'Shaughnessy & Bren (1998) found that permanent flows into buffer strips require careful management to ensure that they are properly dispersed over a wide area because channelled flow could pass though a 40m forested buffer. Also, the development of rills in the wheel ruts of heavy logging machinery tracks concentrated the runoff, increasing flow velocities and sediment transport capacities even in vegetated areas. Prevention of these concentrated flow paths is essential. For example, severe disturbances of filter strips by successive bulldozer passes was reported to reduce sediment trapping efficiency by 60% (Croke, Wallbrink et al. 1999).

The Strzeleckis pose interesting challenges to plantation management. Under the requirements of the Code, Grand Ridge Plantations (GRP) is modernising its plantation management practices to prevent and mitigate the impacts of forestry. Alexander (2001) explained that GRP is continuously upgrading existing roads and tracks, improving drainage, and modifying timber harvesting approaches to prevent impacts on the local water quality. Some of these approaches include quick reafforestation of harvested areas, construction of water bars across snig tracks, implementation of sediment traps within drainage channels, and redirection of drainage discharge into vegetated areas.

### 3.5.1 Roads

Forestry roads and stream crossings have been found to be major sources of sediment in forested catchments (MacMillan 1987). O’Shaughnessy and Bren (1998) noted that when roads are excluded from catchment studies, the effects of forest harvesting on water quality is barely detectable.

A major cost of developing and managing forest resources is the construction of access roads and tracks. The total area of road in a catchment is a significant factor in determining the impact of forestry operations on aquatic values. Noble (1976) estimated that for every 250 hectares of plantation land to be harvested, 4 kilometres of secondary roads and 1.5 kilometres of access tracks area required.

The linear nature of roads and their tendency to run across topographic gradients yield an influence on watershed scale hydrologic processes that is much greater than one might expect.
from the small fraction of land area they occupy (Luce and Wemple 2001). Roads provide a very responsive overland flow system; with the main determinant of the volume of road runoff produced being the amount of rainfall. Roads have also been found to produce slightly more runoff than expected on the basis of depth of rainfall and area suggesting that roads also intercept down-slope subsurface flow (O'Shaughnessy and Bren 1998). For example, more than 80% of rain falling onto roads surfaces is converted to runoff (Croke, Wallbrink et al. 1999).

The likelihood and extent of any impact on water quality depends not only on the erosion or runoff mechanisms, but also on the degree of connectivity or linkages between sediment sources and the receiving water. Roads may be hydrologically connected to the stream either through culverts which drain directly into the stream channel or via culverts which drain into a system of gullies incised below culvert outlets (Tague and Band 2001).

Concentration of runoff from nearly impervious road surfaces flows into ditches effectively increasing the catchment’s drainage density, shifting the distribution of water and potentially increasing peak flows of streams and delivering higher sediment loads (Luce and Wemple 2001). The most damaging aspects of road drainage is poor drain spacing which results in gully development at the road-discharge outlets and provides maximum linkage between sediment sources and streams (Croke, Wallbrink et al. 1999).

Lateral concentration of water collected along lengths of roads and discharged at ditch relief or stream-crossing culverts also increases the risk of landslides, gullies, and destabilisation of existing stream channels. As a result of hydraulic rerouting, streams receive an increase in discharge and the channels enlarge through down-cutting and bank erosion (Madej 2001). Impacts are exacerbated when drainage structures are plugged by debris, diverting a stream to other places in the landscape such as other streams or previously un-channelled slopes (Luce and Wemple 2001; Madej 2001).

Factors that influence the availability and mobilisation of sediment include traffic volumes, sequence of rainfall events, and dominant sediment transport processes (Croke, Wallbrink et al. 1999). However, other equally important factors include the slope of the roads, adequacy of cross drains, the nature of stream crossings, and the frequency and quality of maintenance of roads and associated structures. For example, unsealed roads generate an order of magnitude more sediment than a recently disturbed snig track and a recently disturbed snig
track generates an order of magnitude more sediment than the adjacent general harvesting area in the same catchment for comparable rainfall intensities (Croke, Wallbrink et al. 1999; Maloney 2001). In North Western California, nearly 75% of erosion on 102 previously logged areas was from gullies and landslips; over 80% of which were associated with roads and tracks (Campbell and Doeg 1984).

For example, the conversion of approximately 0.6% of a catchment area into low-standard roads increased sediment yields by 24% (Anderson 1975). Grayson, Haydon et al.(1993) measured the rate of coarse sediment production from a typical Melbourne Water unsealed road to be in the order of 15-25 tonnes per hectare per year and suspended sediment production was in the order of 35-65 tonnes per hectare per year; suggesting that a road 4m wide and 100m long produced as much sediment as the total area of the control catchment (30.5 hectares).

Road usage and maintenance also play an important role in the generation of sediment in a catchment. Infrequently used or abandoned roads possess little available sediment and, in the absence of traffic, generate minimal amounts of sediment. Roads with higher intensity traffic have greater volumes of loose material available at the surface. This supply is replenished after each rainfall event by continuing vehicle traffic. Fine sediment eroded from road surfaces is derived from the breakdown of the surfacing material and from the forcing upward of fine-grained sediment from the road bed as traffic pushes surfacing gravels into the bed (Reid and Dunne 1984). Measured sediment concentrations in road runoff ranged between 5 to 8 times higher on well-used roads than abandoned ones (Croke, Wallbrink et al. 1999).

A properly gravelled road produces less sediment than an unsealed road. However, the gravel thickness must be in the order of 70-100mm to ensure road surface stability. Thinly gravelled roads (approximately 40-50mm) deteriorate quickly and produce large quantities of sediment (Haydon and Jayasuriya 1991; Grayson, Haydon et al. 1993).

Snig tracks are designed to provide efficient and easy access to the felled trees for skidding and collection of timber. Snig tracks were reported to be major sources of sediment in a logged catchment generating an average of seven times more surface flow per unit area and twenty times more sediment than the general harvested area. However, the sediment production rate of snig tracks decreased over a period of 5 years following the end of
harvesting as regrowth occurs and litter is deposited (Croke, Hairsine et al. 1997; O'Shaughnessy and Bren 1998; Croke, Wallbrink et al. 1999).

In environments where erodible and unstable soils are encountered, the use of geosynthetic materials should be promoted. When properly installed, these materials enhance the landscape’s ability to resist erosion and degradation. For example, the installation of Geoweb® cellular confinement systems (Arntec Limited 2001) at stream crossings and at vulnerable stream reaches enhances the channel’s ability to resist stream bank erosion. The application of Geogrids® on road surfaces improves the road surface strength and stability even during wet weather operations. Geotextiles and erosion control blankets are commonly used in a number of drainage, erosion control, and slope stability applications and are recognised as an effective means of minimising and mitigating landscape degradation when properly deployed.

3.6 Agriculture
European settlers have changed the hydrology of the Australian landscape to a remarkable degree in a relative short period of time. Large-scale clearing of native vegetation and its replacement with annual crops and pastures has substantially increased the amount of water beneath the root zone and entering the internal drainage and groundwater systems of landscapes (Williams and Saunders 2003).

Williams & Saunders (2003) list the main forms of land / landscape degradation as the following:

- loss and fragmentation of habitat, particularly on the more productive soils;
- decline of remnant vegetation, including riparian vegetation;
- decline in habitat trees;
- loss of native species;
- decline in native pastures and environmental value of rangelands;
- deteriorating soil quality caused by the depletion of nutrients, acidification, and structural and biological decline;
- dry land and irrigation salination of rivers and land;
- enhanced water and wind erosion;
- changes in riverine processes and loss of essential environmental flows;
- movement of nutrients, salts, and pollutants to river, wetlands and water bodies;
- contamination of groundwater with nutrients, salt, and pollutants; and
• contamination of land with residues of agricultural chemicals.

These effects are enduring, not easily reversed and are becoming increasingly expensive to manage. Evidence of environmental damage includes:
• reduced productivity of lands;
• declining water quality and biological diversity;
• increased risk to agricultural trade with increased contamination and failure to demonstrate sustainable practices; and
• increased health risks.

Dairying and beef production on the slopes of the Strzelecki Ranges are among the most intensively managed landscapes in Gippsland. Farms average 100 ha in area, each supporting approximately 125 head of cattle (Beilin 2001). Considering the extent of agriculture in the Strzeleckis, proper land management is essential for the preservation of water quality and environmental health.

Given that the majority of agricultural land in the Strzeleckis is devoted to grazing, pastures form an important component of the landscape. Conversion of forested areas to pasture can also generate important changes to the erosion processes in a catchment. Hairsine (1997) found that a catchment draining predominantly agricultural land consistently had more frequent and elevated levels of turbidity. The conversion of 14.8% of a steep catchment area from bush to grassland for grazing increased the sediment generation rate by a factor of 4.7 (Anderson 1975).

Grazing animals directly enhance the erosion rates by creating, maintaining, and expanding areas of bare soil, upon which the water acts. Indirectly, erosion processes are enhanced by facilitating rapid runoff of rainfall, which initially may only slightly erode the surface upon which it gathers, but when concentrated causes gully erosion (Evans 1998).

Animals prefer green vegetation and will concentrate on areas where green shoots survive the longest, especially along flood plains, valley floors, and drainage lines and riparian zones. Surfaces of these areas are constantly trampled killing the vegetation. These preferred locations provide approximately 60% of the vegetative production on only approximately 30% of the total available land (Evans 1998). It is in these areas where erosion is most prominent as evidenced by accelerated stream bank erosion, mass failure, and gullying.
Grazing animals also create sediment delivery paths to streams. In addition, bank retreat caused by unabated animal access to streams leads to shallower and wider channels that are more vulnerable to flood flows especially when the banks are moist such as the ones found in the Strzeleckis.

Bare soil is commonly exposed along tracks, watering points and along fence lines. Trafficking of livestock along the tracks not only leads to the decline in vegetation cover but also creates depressions in the soil surface. The exposed soil is then carried away by sheet and gully erosion. Evans (1998) explains that in Australia gullying along agricultural tracks is widespread.

Similar to roads and tracks used in forestry, farm tracks also considerably increase potential of high sediment loads to streams and water storages. Tracks intercept and channel water resulting in erosion and sediment supply (Department of Conservation and Natural Resources 1993). When in use, the tracks are a significant source of sediment, delivering up to 80% of the total suspended sediment load in an agricultural catchment (Lach and Wyzga 2002).

Current agricultural practices on a number of properties in the Strzeleckis clearly demonstrate the need for improved management approaches. Unabated cattle access to drainage line and streams creates erosion hazards by enhancing stream bank erosion processes. The lack of protected riparian vegetation also opens up pathways for enhanced sediment delivery into the local waterways.

The lack of a binding code of practice for agriculture and site specific management prescriptions makes the implementation of agricultural land management approaches very difficult and dependent on the goodwill of the individual land manager.

3.7 Recreational Use
Recreational use of trail bikes in Victoria’s State forests and other public land has long been a popular pastime. Trail bikes refer to two wheeled motorised off road bikes. With the increasing settlement of Melbourne’s outer eastern corridor, there is a growing trend in recreational use of public land. Extensive environmental damage has been observed in areas of high usage. Current levels of usage and numbers of riders using certain areas render the sport unsustainable, as admitted by many trail bike riders themselves (Department of Sustainability and Environment 2005).
*Our Environment Our Future* recognises that a large amount of damage is caused to the forest environment by unmanaged recreational use, the policy commits to increasing education, prevention, enforcement, and noise testing (Department of Sustainability and Environment 2006).

The key environmental issues associated with trail bikes relates to their ability to operate off-road into undisturbed areas and illegally create networks of single track. Whilst the thickness of the understorey can restrict the ease of creation of such tracks in some forest types; persistence and time have enabled trail bike riders to establish extensive networks of illegal track throughout public land. These tracks are usually created for the challenges of steep trails that climb natural contours, through wet areas and stream crossings. The unplanned and poorly established illegal tracks result in gully erosion, environmental degradation and delivery of sediment to local waterways. Illegal tracks also increase fragmentation of the forest, strip sensitive areas of vegetation, provide corridors for predator and weed establishment and affects local water quality (Department of Sustainability and Environment 2005).

Riding on and creating new single lane tracks is largely the biggest environmental issue associated with trail bike use on public land. These tracks are vulnerable to erosion. Stream crossings at non-designated spots have also been recognised as a risk. Off road impacts are equally an issue with four wheel drive activities, impacts amplified where the vehicles cross rivers and streams, often making passage impossible for trail bikes. Riders will then create new tracks around these bog holes, which over time are accessed by 4WD vehicles, exacerbating the problem (Department of Sustainability and Environment 2006).

### 3.8 Catchment Management - Mitigation

There has been considerable concern expressed about erosion and the degradation of water quality resulting from forestry operations and agriculture in the Strzeleckis (Rice 1988). Considering the sensitive environment of the Strzeleckis, the reliance of local communities for potable water, and its contributions to the flows into the Gippsland Lakes makes it essential that land managers develop an intimate understanding of the sensitive nature of the Strzeleckis. Land management approaches need to be tailored to minimize the risks of erosion to ensure reliable and sustainable water supply. However, Croke et al.(1999) found
that the best catchment management practices were most effective at a whole-of-catchment scale.

The United Nations Intergovernmental Panel on Forests (IPF) developed a number of recommendations to promote the best management, conservation and sustainable use of forests. These recommendations included the recognition of the need for further research on (Department of Natural Resources and Environment 1999):

- developing criteria and indicators for sustainable forest management;
- performing integrated site specific socio-economic and biophysical studies exploring the relationships between human development and forests;
- completing periodic forest assessments;
- assessing the value of forests and forest resources; and
- adopting the use of environmentally sound technologies for forest-based industries.

Sustainable forest management requires continuous improvement of forest and fire management practices; quality assurance and certification schemes may become a feature of sustainable forest management systems in the future (Department of Natural Resources and Environment 1999).

Croke et al.(1999) recommend a series of best management practices to control sediment sources and manage sediment delivery pathways during logging operations. These include:

- establishing riparian buffer-strips of variable widths;
- harvesting alternate coupes;
- siting and designing roads and road crossings to minimise sediment input;
- restricting logging activities in relation to coupe slope and soil type; and
- prompt closure and rehabilitation of roads and tracks and log handling areas.

Considering the surface area devoted to agriculture and forestry and the likelihood that the area of affected lands will increase in the foreseeable future, the protection and enhancement of the riparian zone essentially becomes the last line of defence in the protection of water quality and maintenance of environmental integrity.

There is no set rule defining the width of the riparian strip. Land management initiatives need to be directed at the catchment as a whole if riparian buffers of realistic widths are to be effective (Herron and Hairsine 1998; Lovett and Price 1999). As a general rule, for soils
exhibiting little overland flow, a minimum buffer width of 20 metres is recommended; however, for soils exhibiting overland flow, a minimum 30 metre buffer width is recommended (Murgatroyd and Ternan 1983; CSIRO Forestry and Forest Products 1997; O'Shaughnessy and Bren 1998). Knowledge of the local soil types and harvesting conditions are paramount in deciding buffer widths. Table 3-1 provides a summary of recommended buffer strip widths for various Australian conditions.

Removing the connectivity between the erosion site and the local waterways is an excellent means of reducing the suspended sediment load. The protection and enhancement of riparian vegetation is a significant way of minimising that connectivity; therefore, reducing the supply of sediment to waterway (Wass and Leeks 1999). Reduction of road to stream linkage can be achieved by planning a road network in areas where there is good potential to disperse road runoff on relatively gentle hillslopes (Croke and Mockler 2001). General harvesting areas can be considered as large buffer zones that can be used to reduce runoff volume and sediment loads. Whenever possible, it is recommended to disperse runoff water onto general harvesting areas (Croke, Wallbrink et al. 1999).

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<th>Table 3-1 Minimum Width (m) for Buffer Strips</th>
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<td><strong>Stream Class</strong></td>
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<td>Wetlands</td>
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<td>Department of Natural Resources and Environment (1996)</td>
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<td>Permanent Streams</td>
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<td>Drainage Lines</td>
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The recommended buffer widths are particularly important because a shift in policy could see a majority of Crown water frontage areas managed to protect the water resources.

During the initial stages of planning the harvesting operation, it is recommended that roads (Weitzman and Trimble Jr. 1955; Croke and Mockler 2001):

- be located on ridge tops - 89% of mitre drains draining ridge-top roads did not show any evidence of channel linkage – mitre drains are an extension of the table drain, it directs runoff and sediment onto the adjacent hillslope;
- include a larger number of drainage outlets to minimise gully erosion and channel initiation – drains must be kept rough, wide and dirty to slow runoff and induce sediment deposition;
- be kept away from streams;
- use appropriate culverts or temporary bridges for stream crossings;
- cross streams at right angles to prevent the stream from flowing down the road;
- be separated from streams by vegetated buffer strips; and
- be constructed away from the contributing area (soak area).

Effective maintenance and rehabilitation of the road and snig track network, following logging, is essential for catchment management and protection of water resources (Weitzman and Trimble Jr. 1955). To prevent erosion of roads and tracks and to safeguard roads for the next harvesting operation, the following steps are recommended:

- construct water bars across the roads to reduce runoff volume and divert flow into the natural scrub,
- out-slope and drain the road,
- for steep roads, scatter brush and artificially seed the road surface - the application of grass seed on rehabilitated road surfaces can reduce sediment production by more than 95% (Megahan and Kidd 1972).

Water bars provide two important advantages; they redirect overland flow into the general harvesting area and natural scrub and they provide an effective sediment trap for coarse sediment (Croke, Hairsine et al. 1997). They may also limit access to recreational vehicles.

Similarly, a proactive integrated approach based on national and international frameworks is required for a best-practice management of agricultural land. Beilin (2001) states that 50 years ago farmers were asked to do what could be conveniently done to save their soils and they did
just that and only that. She suggests that by attempting to make conservation easy, it has been trivialised. She explains that government sponsored voluntary compliance programs are not effective, because their voluntary character implies that conservation is optional. Facing extremely difficult conditions in sensitive and degraded landscapes land managers are unable to act effectively without the support from government. Beilin (2001) recommends that government support should enable farmers to balance the productive capability of the landscape encouraging them to invest in alternative and more sustainable land management regimes.

Lach & Wyzga (2002) report that apart from the positive effects of afforestation, sediment yields in some catchments also decreased due to the cessation of grazing, effectively terminating livestock related soil disturbance whilst enabling the re-establishment of an undergrowth canopy shielding the soil surface from rainsplash.

Riparian vegetation, control of stock access to streams, proper siting and construction of roads and tracks, and the use of wet weather operational prescriptions are required to reduce the environmental footprint of this essential land use. Community engagement, research, public policy, and education are critical in ensuring the sustainability of agriculture. Measures should include the following:

- herding of animals across vulnerable slopes to prevent grazing or sheltering in their preferred areas;
- removing or excluding animals from vulnerable or affected land, and effectively managing the re-establishment of beneficial vegetation on eroding soils and gullies; and
- active monitoring of paddocks to quickly identify problem areas and initiate proper measures to mitigate erosional processes.

The establishment and protecting of healthy riparian buffer zones to control erosion and protect water quality may reduce the amount of productive land; however, it may also introduce other benefits. The presence of riparian vegetation, even grass, can be important in removing nutrients, sediments and pathogens from agricultural sources (MacMillan 1987). Plantings to re-establish riparian zones require protection from grazing using suitable fencing. In areas where natural regeneration is deemed adequate, fencing alone may be sufficient to achieve restoration objectives. Ongoing management requirements of fenced areas can be satisfied by the means of controlled grazing or fuel reduction burns (Condina 1990). Grazing
and cropping must occur away from streams protected by healthy riparian zones of similar widths as recommended for the forest operations.

It is important to note that the seasonal distribution of rainfall erosivity can be as important as the annual average, because the risk of erosion increases considerably when soil exposure (e.g. through cropping, timber harvesting, road construction, recreational use, etc.) coincides with periods of high erosivity (Sheridan and Rosewell 2003).

Under the multiple use concept, there is a drive to bring recreational use of public land back to a level that is sustainable and equitable (Department of Sustainability and Environment 2005). Some motorcycle clubs and consultative committees are interested in working with DSE to develop a recreational code of practice including the mapping of soil types and erodibility, which may then lead to reduced impacts through education and further seasonal closures. Measures currently being implemented to mitigate damage caused by trail bike recreational use include the closure and prompt rehabilitation of illegal off-road tracks (Department of Sustainability and Environment 2006). The benefits of mitigation measures include:

- repair of environmental degraded areas and closure of illegal tracks;
- preventing vehicle access to sensitive areas; and
- improved information and education of trail bike riders resulting in riding behaviour more sympathetic to other forest users.

A recreational user code of practice could include the following prescriptions (Department of Sustainability and Environment 2006):

- riding only on formed roads and fire trails;
- riders should be licensed and bikes registered;
- no riding on walking tracks and timber snig tracks;
- wet weather prescriptions including not riding when tracks are wet; and
- no riding on or near environmentally sensitive areas such as wetlands, river and creek beds.

The recent shift towards putting a price on ecosystem services is providing land managers the opportunities to implement sustainable land management approaches. The Victorian Government has begun implementing a range of market-based systems such as BushTender, EcoTender, CarbonTender, and RiverTender to pay land managers to protect natural assets
through planting and enhancing vegetation and caring for waterways (Department of Sustainability and Environment 2006). *Our Environment Our Future* has also identified the protection of key reserves in the Strzeleckis ‘Cores and Links’ to safeguard sites of high biodiversity values.

### 3.9 Key Land Management Issues in the Study Area

The Department of Natural Resources and Environment (1999) identified a number of areas where additional research work is required to inform more sustainable management of forest resources. These include:

- determining the value of water from forested catchments;
- measuring stream buffer and filter strip dynamics;
- testing appropriate management approaches and prescriptions;
- establishing water quality, soil characteristics and nutrient status indicators;
- developing means of reducing sediment discharge from roads around water crossings; and
- minimising impacts on soil properties from timber harvesting operations.

A major priority for future research in Victoria should be on the development of appropriate indicators of sustainable forest management within the context of the national and international frameworks for criteria and indicators (Department of Natural Resources and Environment 1999).

Key issues related to current land use practices in the study area consist of:

- general forestry including roads, drainage, and harvesting practices,
- general agricultural management including grazing, stock accessing stream and drainage lines, roads and tracks, and the legacy of historical clearing of native vegetation,
- general high impact recreational use by four wheel drive vehicles and dirt bikes.

The land use issues are highly site specific and dependent on the various factors described in this chapter. The nature of the soils and geology combined with the higher rainfall regimes in the Strzeleckis increase the potential risk of large-scale erosion and landslips as experienced by land managers in the past. Careful consideration of future land management initiative is required to minimise potential risks and mitigate historical land use impacts.

To achieve sustainability, the soil/plant/animal interactions need to be studied in an integrated way and examined as part of the larger-scale ecological and hydrological processes that...
govern the landscape. Solutions must incorporate these interactions at a range of scales, including paddocks, hillslopes, catchments, whole of landscape features, and regional basins. The landscape designs need to integrate sustainable production and maintenance of biodiversity for the catchments and regions. Any revegetation program must have multiple objectives and be designed for restoring the ecosystem functions of hydrology, nutrient cycling, maintenance of habitat, and movement of biota (Williams and Saunders 2003).
4 METHODOLOGY

4.1 Introduction

Despite recent fundamental changes to the regulatory framework in Australia, there remains a lack of information on appropriate methodological or modelling frameworks within which to predict and control sediment and pollutant delivery to streams and oceans (Croke 2001). Emphasis on the erosion potential of forestry activities at the small plot or hill slope scale has resulted in a conceptual framework that largely ignores the delivery of sediment and pollutants to catchment-scale drainage systems. Croke (2001) reports that these approaches are not constructive and are of little benefit in pinpointing the source of the problem and in recommending appropriate remedial strategies to ensure the viability of water resources.

Effective water quality investigations should systematically collect physical, chemical and/or biological information, and analyse, interpret and report it according to a carefully pre-planned design following a basic structure incorporating the following elements (ANZECC 2000):

- clearly defined objectives;
- properly designed study, including type, scale, measurement parameters, sampling programs, and preferred sampling methods incorporating:
  - quality assurance and quality control procedures;
  - occupational health and safety concerns;
  - statistical analysis and interpretation of data; and
- clearly reported and disseminated information for various audiences.

Water quality criteria are made up of scientific and technical information used to provide an objective means for judging the values required to maintain a particular environmental quality. The criteria are described in terms of physical, chemical, radiological, microbial, and biological indicators. An indicator of ecological integrity is the degree to which an ecosystem has been altered from its natural state; however, defining the “natural state” can be problematic (ANZECC 1992).

In Australia, the main impediments in accurately monitoring and evaluating water quality indicators are the typically large spatial and temporal variations in values being monitored. It is difficult to account for the yearly variations in flows and changes in indicators from a short sampling program. The timeline chosen for the sampling program may not be typical of the types of flows and mechanisms usually associated with a given catchment since runoff and
other data can vary by orders of magnitude annually (Kuhnle, Bennett et al. 2000). Water quality investigations are expensive requiring extensive resources to conduct studies over large geographical areas spanning the longer timeframes required to develop accurate and meaningful datasets (ANZECC 2000).

The State Environment Protection Policy (Waters of Victoria) (Environment Protection Authority Victoria 1988) lists a number of indicators which can be used as a standard measure of the condition of water environments. These indicators include pH, dissolved oxygen, suspended solids, turbidity, colour, and others. Of these; flow, suspended sediment, turbidity, salinity, and temperature are most commonly measured because (Colman, Gwyther et al. 1991):

- they are normally present in water and can be readily monitored for a change in concentration, quantity or quality, some or all of which can be linked to a change in environmental values;
- they are not normally present but if detected in certain concentrations can be used to identify a change in or effect on an environmental value; or
- they are normally present but the absence of which reflect a change in an environmental value.

The monitoring of water quality parameters is a key element in understanding the impacts of various land uses. Increases in suspended solids concentration should be limited such that the optical guidelines are maintained and that the seasonal NTU (Nephelometric Turbidity Unit) values does not change by more than 10% (ANZECC 1992). The Commonwealth Department of Heritage and Environment (2003) publish a list of Default Water Quality Targets for a number of rivers in a variety of geographic areas. The default targets for aquatic ecosystem protection are based on slightly to moderately disturbed ecosystems. For ecosystems of high conservation value and essentially undisturbed, the target range should ensure that there is no detectable change from natural variation. The published targets for rivers of Southeast Victoria include:

- **Turbidity – Aquatic Ecosystem Protection:**
  - Default Target for Upland Rivers; 2 – 25 NTU (High values during high flows),
  - Default Target for Lowland Rivers; 6 – 50 NTU (Low values in undisturbed area; High values during high flows).

- **Salinity Surface & Groundwater – Aquatic Ecosystem Protection:**
  - Default Target for Upland Rivers; 30 – 350 µS/cm (Low values in Highlands),
• Default Target for Lowland Rivers; 125-2200 µS/cm.

The methods utilised in this research project are adapted from source documents, published paper as cited, and from the experience of the steering committee and supervisors.

4.2 Research Methodology

The fieldwork component of the project was focussed on monitoring water quality indicators for a period of time. Turbidity and flow were continuously monitored using a data logger equipped with a turbidity probe and pressure sensor. The continuous turbidity data was verified by weekly manual turbidity observations using a turbidity tube and flow was calibrated by means of a weir. Electrical conductivity and water temperature were also measured on a weekly basis as additional water quality indicators.

Through monitoring water quality at a series of outlets of sub-catchments, the contribution of these catchments to the river flow can be determined (Hairsine 1997). The upper reaches of the Morwell River are well suited to this type of study because land uses correspond closely with each sub-catchment and land uses correspond closely with soil type. Three sub-catchments representing the major land uses in the Strzeleckis were monitored. Two catchments were subject to the intensive management requirements of forestry and agriculture; the third being a relatively intact-forested catchment. Both the harvested and forested catchments were subject to extensive recreational use.

Lewis (1996) suggests that the most effective technique for identifying impacts of land use changes in catchments is the comparison of water quality indicators such as turbidity or sediment loads for comparable time periods within similar catchments.

The method relies on a “control” catchment used as a basis for comparison. Catchments experiencing some form of land use change are monitored and results compared with a control catchment in a similar geographic area and environment (Pilgrim, Cordery et al. 1982; Jayasuriya and O'Shaughnessy 1988; Fletcher 1995; Fransen, Phillips et al. 2001; Tague and Band 2001). For example Fletcher (1995) monitored electrical conductivity and turbidity, water yield, along with rainfall records to identify trends in water quality and yield caused by changes in land use practices.
Jayasuriya and O'Shaughnessy (1988) explain that while the paired catchment approach may be more expensive to conduct than other research methods, the data obtained from these studies provides a quick and reliable means of establishing, quantifying and comparing trends within catchments. However, Pilgrim et al. (1982) warn about the transfer of the data from one study in a geographic area to another because such a transfer is unlikely to be valid due to varying climactic, geologic, geomorphic, land use, and / or other characteristics.

Catchment size also plays an important role in catchment responses to suspended sediment loads. While general relationships have been developed between small and large catchments in a region; simple, closely defined, or accurate relations are not likely to be representative. The hydrological responses of small catchments are different from and more variable than those of large catchments (Pilgrim, Cordery et al. 1982). Wass and Leeks (1999) state that there exists a relationship between catchment scale and sediment load whereby suspended sediment loads increase with catchment area; however, at a rate that diminishes with increasing catchment area. This rate of increase and gradual decrease is highly site specific and not the focus of this research project.

Although this study was modelled on a paired catchment approach, it should more appropriately be considered as a comparative study. Paired catchment work normally integrates a rigorous monitoring regime over long study periods. The paired catchment work will monitor trends before a treatment is applied to a catchment, during the application of the treatment and for a period following the treatment; these observations are then compared with a similar catchment not subjected to the treatment. This work was aimed as using water quality indicators as measures of land use impacts on the environment. This combined with the remoteness of the study area, short timeframes (less than 3 years), scheduling of timber harvesting operations and the ongoing nature of agricultural practices prevented the application of the true paired catchment approach. However, the comparative approach will provide good quality insights into the major trends prevalent in the sub-catchments from short-term monitoring. This will achieve the aim to provide land managers with intuitive and user friendly tools to understand the current environment and develop better ways to progress. These steps satisfy Lowe (2005) steps towards sustainability science practice.

4.3 Experimental Design
Gippel (1994) suggests that since stream water turbidity reflects catchment conditions, a catchment-wide network of continuously monitoring instruments could be used in a
surveillance role to identify areas of landslips, stream bank disturbances, or inappropriate land use practices.

Catchment-wide monitoring of water quality parameters over a range of conditions requires the use of continuous data loggers equipped with appropriate equipment. Hasholt (1992) observed that major erosion most often occurs as a result of climatological events of a rather short duration which are difficult to forecast and furthermore, the areas with high erosion hazards are seldom situated near research facilities creating a reliance on the use of automatic monitoring stations; as is the case in the Strzeleckis. Given the low background concentrations of pollutants in runoff from the *Eucalyptus regnans* forests of Australia, Grayson et al. (1993) propose that any effects from catchment disturbance should be readily detectable.

A comparative study approach was adopted as the method to measure the relative impacts of each land use. The comparative study has been used to measure and compare water quality parameters across multiple catchments.

In general, the experimental approach adopted was based on the following steps:

- Sites were selected representing major land uses in the Strzeleckis.
- Remote monitoring stations were constructed at the outlet of each sub-catchment at a suitable stream reach. The sites were constructed using sandbags and weirs. This created small pools to ensure that the monitoring probes remained submerged. Weirs were used to gauge stream flow. Figure 4-1 illustrates a typical remote monitoring site.
- The monitoring equipment consisted of:
  - Greenspan TS100 Turbidity sensor;
  - 6508 B 2m Pressor Sensor Probe;
  - Micrologger Data Logger 2 by 4-20 mA inputs programmed with STARLOG Version 3. The logger was programmed to sample and record turbidity and stream level data at five-minute intervals; and
  - Vandal-proof enclosure.
- The sites were accessed on a weekly basis to download the data and perform regular maintenance including cleaning of probes, replacement of batteries and general site upkeep.
- Additional turbidity, water temperature and electrical conductivity observations were manually recorded during the maintenance runs.
4.3.1 Site Selection

Site selection was designed to reflect the major land uses in the Strzelecki. O'Shaughnessy (2000) recommended that the surface area of sub-catchments to be studied should range between 50 hectares to 200 hectares.

Catchment selection depended on their proximity to each other, planned harvesting program for the plantation, and in the agricultural catchment permission from the landowner to access the site and install the required equipment.

A number of sub-catchments were initially targeted based on aerial photography and geographic information systems (GIS) data. Three study areas or sub-catchments were selected. The areas represented an established hardwood forest plantation scheduled to be harvested, an agricultural pasture under standard grazing and an established forested area (reafforested approximately 30 years ago). As much as possible, each of the study areas possessed similar site conditions including surface area, climate, soil type, and relief. They were also located as close to each other as possible to mitigate climatic effects.
Each catchment was visually surveyed on foot to identify the main mechanisms for sediment generation and delivery to the waterways. Of particular importance was the soak area and any obvious sediment generation and direct delivery pathways.

4.3.2 Turbidity

The turbidity of stream water is a major concern for water management because it is considered un-aesthetic, it affects underwater light fields, in-stream ecology and signals catchment or channel erosion. Fine particles that cause turbidity can carry adsorbed nutrients and contaminants. Turbid waters also require more expensive treatment for water supply (Gippel 1994). Turbidity and associated suspended sediment loads may directly affect aquatic ecosystems by degrading benthic habitats, smothering benthic organisms, and exerting an oxygen demand. In small streams in New Zealand, where discharge of clays from alluvial gold mines caused a reduction in stream-bed light penetration of between 12% and 73%; benthic algal production was reduced almost proportionally to the light reduction (Australian and New Zealand Environment and Conservation Council 1992).

Turbidity is mainly caused by the entrainment of fine silt and clay-sized suspended mineral particles derived from soil erosion in the catchment or within stream channels. Examples of particles that affect turbidity include suspended solids such as silt, clay, algae, organic matter, organisms, colloidal material, and even large dissolved molecules such as tannins and lignins (Sadar 2002).

Turbidity, an optical property which is a function of materials suspended within the water column, is an excellent parameter in determining broad water quality changes over time, and providing an indication of overall condition of the catchment and its effects on water quality (Fletcher 1995). Particulate matter in a water sample will cause the incident light beam to be scattered in directions other than a straight line through the sample. These phenomena interfere with the direct transmission of light through the medium, which causes it to lack clarity. This lack of clarity, as perceived by the human eye, is referred to as turbidity (Gippel 1989; Ziegler 2002). Higher levels of scattered light reaching the detector result in higher turbidity values (Sadar 2002).

As a water quality indicator, turbidity is valuable in measuring water quality, particularly in the context of ecosystem viability (Riley 1998). The advantage of turbidity is the simplicity of measurement. Measurement of inherent optical properties requires sophisticated apparatus;
however, turbidity can be continuously measured in-situ using a simple device. This overcomes the problem of high frequency sampling in situations where water quality is temporarily variable, and reduces the requirement for the laboratory processing of large numbers of samples (Gippel 1989).

Although not measured in absolute terms, turbidity is measured relative to the turbidity of an artificial standard, usually formazine (Gippel 1989). Turbidity units are by no means standard and although NTUs are frequently quoted, these are not consistent across instruments. The type and magnitude of interference often depends on the turbidity level being measured. Primary interference when performing low-level turbidity measurements (<5 NTU) may include stray bubbles, ambient light, and contamination. For higher-level turbidity testing (>5 NTU), colour, particle absorption, and particle density generate greater effects.

In the measurement of turbidity, the most significant source of uncertainty has been shown to be instrument design, variations in the specific turbidity of river sediments and sensor location (Grayson, Finlayson et al. 1996; Wass and Leeks 1999; Sadar 2002). Research has demonstrated that measurements of the same water samples with different instruments yield different turbidity values (Gippel 1989; Grayson, Finlayson et al. 1996; Lewis 1996; Ziegler 2002). It is important to specify the equipment used in the measurements of turbidity and to recognise that the derived relationships are not universal (Grayson, Finlayson et al. 1996).

The main requirements for meaningful turbidity data collection include (Eads and Lewis 2002):

- real-time data filtering;
- properly mounted and housed sensor;
- selection of a sensor with appropriate lens cleaning capability;
- regular collection and inspection of the data; and
- regular maintenance of the equipment.

The key to a successful monitoring program is to determine the “natural” background levels through long-term, high frequency and high quality monitoring over a wide range of climatic situations and land use changes. The author acknowledges that to try to establish background level for the Morwell River was beyond the scope of this project as the study was restricted to three sub-catchments representing the major land uses on the headwaters of the Morwell River in Strzeleckis.
4.3.2.1 Turbidity Measurement

Optical instruments and gauges are the most widely used device for in-situ measurement of turbidity. They cover a wide range of concentrations, are sensitive to organic and inorganic particles and are relatively inexpensive (Gippel 1989). In-situ turbidity monitoring equipment has generally been found to provide reasonable reliability and is believed to be the best method currently available (Ciesiolka, Webb et al. 1988; Gippel 1989; Wass and Leeks 1999). For optimal performance when deployed in the field, instruments should ideally incorporate features such as (Gippel 1989):

- durability;
- low power consumption;
- minimal electronic drift;
- automatic temperature compensation;
- sensitivity of a wide range of turbidity;
- insensitivity to absorption effects;
- greater sensitivity to the dominant (mass percentage) fraction; and
- a means of overcoming the problem of lens fouling.

Sensors are sensitive to changes in temperature, fouling by debris and algae, variations in incident light, and vandalism (Wass and Leeks 1999). Gippel (1989) observed that inherent instrument inaccuracy is not a problem, usually ranging between ±2%. Gippel (1989) also observed a diurnal rhythm in turbidity measurements due to temperature fluctuations, but the amplitude did not exceed 0.6 NTU for a 4°C Celsius temperature range. This fluctuation is considered to be lower than the expected experimental error.

Other common problems with field deployment of turbidity probes include the growth of algae and deposition of fine particles on the lenses. Contamination of the optical surfaces imposes a severe limitation on the performance of continuous monitoring sensors (Gippel 1989). To ensure good quality turbidity observations, lenses may require regular maintenance and cleaning. Cleaning frequency is highly site specific depending on the biological activity of the stream environment. The problem of algal growth can be largely overcome by the use of an infrared light source, twin-beam light sources and self-cleaning models (Gippel 1989). A wiper can help prevent fouling from small contaminants such as fine organics and sediment, algae and macro-invertebrates; however, larger debris must be manually removed.
(Eads and Lewis 2002). Over time the wiper configuration may scratch the surface of the sensor reducing its accuracy and service life.

Considering that infrared turbidity meters draw little current and may require battery replacement only a few times per year, self-cleaning models add considerably to power requirements. To reduce the need for self-cleaning equipment and frequent maintenance runs, the optical surface of the Greenspan TS100 turbidity probe is coated with an anti-fouling polymer to help prevent algal growth on the lens (Greenspan Technology 1997). No matter what antifouling measures are adopted, Lewis (2002) stresses that it is virtually impossible to collect perfect turbidity data.

The following points provide a guide for deployment and operation of sensors:

- The sensors should be accessible over all flow regimes and the stream should flow continuously throughout the year. The flow rates should be sufficient to provide a degree of natural scouring reducing probe fouling (Rasmussen, Bennett et al. 2002).
- The site should allow for ease of access under various climatic conditions during the study period and ease of concealment to prevent damage or vandalism.
- The turbidity sensor should be located away from areas of excessive turbulence. Turbulence causes entrainment of air bubbles resulting in erroneous and erratic readings (Gippel 1994). The construction of a stilling well around the sensor is recommended.
- The sensor should be shielded from extraneous light. Light can induce a diurnal rhythm in the data (Gippel 1989). To overcome this, appropriate sensors can be utilised which are not affected by this.
- Cross-sectional variability in suspended sediment concentration can result from particle size gradation. Turbidity meters have relatively low response to sand, so the sensor should be located away from the coarse particles found near the bed during high flows (Gippel 1989); however, Gippel (1995) reports that for small Australian streams, channel cross-section variations are negligible. For example, even in the larger Latrobe River, the fine nature of suspended sediment results in uniform mixing throughout the cross-section of the channel with very little variations in observed turbidity (Grayson, Gippel et al. 1997).
- Greenspan Technology (1997) recommends that the sensor be angled facing downstream at a 45° angle to the stream flow. This will minimise the damage to the lens as a result of impact from travelling particulate matter. Care must also be taken when cleaning the optical surface as not to scratch the lens. The use of a soft cloth with a gentle rubbing action is recommended.
• Account for environmental transients greater than the mean signal which can contribute to background noise levels. These can be caused by large floating debris, aquatic life and other objects obscuring the optical path (Greenspan Technology 1997).

• Reflections from nearby surfaces such as the protective conduit or river beds can affect readings, a clearance of at least 450mm forward and 50mm to each side are recommended (Greenspan Technology 1997).

• Field installations should be limited to sites draining relatively small catchment areas. Rasmussen et al. (2002) explain that bank installations at sites with large catchment areas have failed during periods of extended periods of high flow because large floating debris damaged the equipment and high sediment flows buried the probes.

• Gippel (1994) also observed that gnawing of the cables by animals can also be a major problem, but can be overcome by sheathing and burying the cables.

The laboratory calibration of turbidity sensors is accomplished using a formazine solution (Gippel 1988). The full calibration procedure is described in the Greenspan TS100 Turbidity Sensor User Manual (Greenspan Technology 1997). Calibration with formazine, a suspected carcinogen, is an inconvenient and difficult operation in remote field sites (Gippel 1989). Once the instrument has been calibrated, calibration drift over periods exceeding 12 months was not a major problem (Finlayson 1985; Gippel 1989).

However, Wass and Leeks (1999) recommend that regular calibration checks be carried out. In this project, regular calibration checks were conducted using a simple turbidity tube.

Turbidity tubes are a low cost option for the measurement of turbidity and assessing water quality against water quality objectives (Irvine 2002). The turbidity tube operates in a similar way to a Secchi disk. The Secchi disk measures the depth of visibility in water. The depth of visibility depends on absorption due to dissolved substances and scattering by suspended particles. The disk acts as a contrast instrument, disappearing when there is no longer any contrast between the disk and its background.

Turbidity tubes are constructed with transparent acrylic pipe approximately 30 mm in diameter and 630 mm in length. The bottom of tube is sealed with a bright white plastic disk marked with 3 bold black lines. A logarithmic scale with equivalent turbidity is marked along the length of the tube. Turbidity is measured in good shaded light by looking down the tube.
while filling it with a sample of stream water until the black and white stripes at the bottom of the tube just vanish from sight. The turbidity value is then read off the logarithmic scale.

The turbidity tube offers several advantages in the context of simple and accurate water quality monitoring and reporting. It does not require regular calibration, it is cost effective, easy to use, and turbidity can be determined onsite without the need for extensive sampling and laboratory analysis (Irvine 2002).

4.3.3 Stream Flow Measurement
Measurement of flow rates in open channels is difficult because of non-uniform channel dimensions and variations in velocities across the channel. Weirs are one of the simplest and most accurate methods of measuring water flow in open channels. They allow water to flow through a structure of known dimensions, permitting flow rates to be easily measured as a function of depth of flow over the structure.

Stream flow was measured by means of a sharp-crested 90° V-Notch weir installed at each monitoring point. Flow over the weir was manually recorded during the maintenance runs and calibrated with the depth readings from the data logger. The weirs were installed as recommended by Smajstrla and Harrison (2001). For easy flow determination, a gauge board was installed upstream of the weir to manually verify depth and correlate it to stream flow.

4.3.4 Stream Temperature
Stream temperature can be an important indicator of catchment health. Temperature affects the biological, chemical, and physical features of a waterway. The amount of dissolved oxygen, the rate of photosynthesis, and organisms’ sensitivity to toxins are all influenced by water temperature (ANZECC 2000). Stream water temperature can also be an indicator of the degree of riparian vegetation cover over the length of the stream reach.

Manual stream temperature observations were also taken using the YSI Model 30 Handheld Salinity, Conductivity, and Temperature System.

4.3.5 Electrical Conductivity
Electrical Conductivity (EC) of water is a measure of its ability to carry an electric current. Because electric current is transported by ions in solution, conductivity increases as the concentration of ions increases. By measuring conductivity of a water sample, the amount of
ions or Total Dissolved Solids (TDS) in the sample can be determined. EC is expressed in microSiemens per centimetre (µS/cm) generally reported as a corrected value to a standard temperature of 25°C. Most field conductivity readings are not taken at 25°C; however, the YSI Model 30 probe, used to measure in-situ stream EC for this project, automatically performs the temperature correction, reporting an actual, non-corrected value and a temperature corrected value.

It is important to remember that EC provides an indication of the conductivity of water, but does not specify exactly its chemical characteristics since many ions contribute to the electrical conductivity. Variations in conductivity are related to a number of parameters such as soil type, geology, groundwater, land use, and vegetation cover (Fletcher 1995). Spatial variations of stream water EC is primarily related to geology; however, within individual geological formations variations such in EC have been attributed to land use change (Finlayson 1979).

Herricks and Milne (1998) suggest that EC is the most reliable indicator of changing water quality in a catchment. The use of EC as a general indicator of water quality in catchment studies is gaining popularity due to increases in salt affected land, associated with upland clearing (permanent vegetation removal) and subsequent rises in the water table (Fletcher 1995).

Investigations of spatial distribution of TDS within a river basin or of changes downstream on a single river, are best carried out during a dry period when streams are carrying only baseflow (Finlayson 1979). Depending on the nature of the catchment being studied, such an exercise can be designed to investigate spatial variation in erosion rates or to isolate sources of pollutants in streams stemming from various land uses. These spatial variation surveys can be done quite rapidly with a vehicle and a conductivity meter. In multiple land use catchments, the major interest in the exercise might be in locating sources of pollutants or evaluating the impacts of various land management approaches.

EC levels and TDS concentrations exhibit seasonal trends. This is because in summer, during low flow, groundwater contributes significantly to stream flow. At baseflow conditions, the dissolved solids concentration will be at its highest because water in the stream has been in storage in the catchment for sufficient time to reach chemical equilibrium with the soils and/or bedrock in the groundwater system (Tchobanoglous and Schroeder 1987). When the
flow is high, the groundwater contribution is lower with the majority of flow being contributed through runoff (Fletcher 1995). The baseflow water is also diluted by water which passes quickly through the catchment (quick flow) and the larger proportion of the quick flow the more dilute the stream water (Finlayson 1979).

Herricks and Milne (1998) observed that a storm event hydrograph typically displays a decreasing then increasing conductivity profile, indicative of the passage of low conductivity rainwater dominating the runoff. Spikes in conductivity were also often observed at the start of the storm events indicating first flush effects, or the effects of concentration time in a system where increased dissolved solids passed the sampling point.

Condina (1990) reported EC (and TDS) values in the upper reached of the Morwell River ranging between 80 and 160 µS/cm (50 to 100 mg/L). However, predicted natural EC values should range between 150 to 200 µS/cm because the upper reaches of the River are predominantly underlain by Cretaceous sediments. Grayson et al. (1997) observed that the increase in solute load through the agricultural areas of the Morwell River produced runoff with EC values still less than the estimated “natural load” from the catchments. Nicholson (1978) explains that the low electrical conductivity and chloride levels in the soils of the Strzeleckis are a result of the high rainfall regime.

During the fieldwork, EC readings were taken on a weekly basis during the monitoring runs. The measurements were made using a YSI Model 30 Handheld Salinity, Conductivity, and Temperature System. The YSI probe was submerged in the stream and readings were recorded once the displayed value stabilized. Two EC readings were recorded in addition to temperature. The readings were:

- **Conductivity** – A measurement of the EC without regard to temperature; and
- **Specific Conductance** – Also known as temperature compensated conductivity, automatically adjusted EC reading to a standard value at a stream temperature of 25°C.

Operation, cleaning and calibration of the instrument was conducted as prescribed by the Operations Manual (YSI Incorporated 1998).

**4.3.6 Catchment Inspections**

Each sub-catchment was inspected to identify possible sediment delivery pathways causing elevated levels of stream suspended sediments and to locate areas where erosion has been
occurring. Visual inspections were undertaken on each stream reach forming part of each sub-catchment. The agricultural catchment was visually inspected from the roadside. Inspections focussed on the following indicators:

- evidence of direct delivery of sediment from drainage structures;
- indicators of overbank sediment deposition;
- areas of significant bank erosion;
- obvious landslips and mass failure of banks;
- new erosion sites;
- tractor and cattle access tracks, stream crossings, catchment features (in-stream dams) and drainage structures;
- tree or vegetation fall; and
- bioturbation.

### 4.3.7 Soil Testing

Laboratory-based soil dispersion and slaking tests were conducted following the Emerson Class Number of a Soil, method (AS 1289.C8.1-1980) (Standards Association of Australia 1980). Representative soil samples were taken from the stream banks downstream of the monitoring sites.

Dispersion describes the tendency of the clay fraction of a soil to go into suspension in water forming a cloud around the soil particle (Standards Association of Australia 1980). A soil that disperses on wetting has a very unstable structure. It can form a surface crust or hard clods on drying. Dispersion may also block soil pores and voids below the surface. Dispersive soils also have a strong tendency to swell when wet, restricting the intake of water to the root zone following rainfall or irrigation resulting in poor water storage (NSW Agriculture 2000).

Most cultivated soils in Australia are prone to slaking. The results can be either favorable or detrimental, depending on the size of fragments produced. Slaking is involved in the process of self-mulching, which occurs in many cracking clays. Self-mulching produces a loose surface layer of granular aggregates. Sometimes a thin, fragile crust caps the layer, but the crust is not strong enough to affect seedling emergence. Crusting or hard setting soils slake into very small fragments that run together and then set hard on drying. This condition is evident in many red brown and transitional red brown earths (NSW Agriculture 2000).
Slaking is defined as the breaking up or fragmentation of soil aggregates from the soil crumb sample. Slaking occurs when most dry soils are immersed in water owing to the stresses induced both by the compression of air as the negative pore water pressure attracts water into the soil, and by swelling. Release of compressed air may cause particles to “fly off” the soil crumb (Standards Association of Australia 1980). Aggregate slaking has been found to be influenced by the initial water content of the soil and associated heat of wetting, organic matter concentration and clay mineralogy (The Department of Primary Industries 2001).

The combination of slaking and dispersion causes a reduction in the soil’s macroporosity resulting in lowered infiltration rates and hydraulic conductivities. Severe slaking or dispersion can lead to poor soil structure, soil aeration and water movement resulting in reduced root penetration. In addition to soil structural problems and land management issues, soil slaking and dispersion also play a major role in background turbidity levels of streams and rivers.

### 4.4 Routine Maintenance
Routine monitoring runs were performed on a weekly basis or based on the availability of a four wheel drive vehicle for site access. The following tasks were conducted during the monitoring runs:

- collect turbidity and level data from logger;
- replace data logger / turbidity sensor battery (as required);
- clean turbidity sensor lens;
- record manual stream flow measurement using the 90° V-notch weir;
- record manual temperature and electrical conductivity readings using YSI unit;
- conduct manual turbidity check using the turbidity tube;
- clear debris and accumulated coarse sediment from the vicinity of the probes; and
- verify the surrounding areas to monitor for any obvious changes to the catchment, new sediment sources or erosion sites.

### 4.5 Data Analysis
The first step in the data analysis included tabulating field data into a spreadsheet for immediate exploratory analysis. As recommended by ANZECC (2000), the data was given a preliminary examination to verify its completeness before more detailed analyses were undertaken.
The data sets were collated and checked for integrity. Periods of data loss and obvious outliers were discarded and, where required, the data was corrected to reflect the gradual fouling of the turbidity probes. Data analysis was performed using Microsoft EXCEL® and MINITAB® Release 14. As recommended by ANZECC (2000), the histogram was used as a check to determine whether the data collection was successful and to ensure that data collected across the catchments could be confidently compared and the daily arithmetic mean was calculated to generate the time-scale plots and calculate suspended sediment loads.

A simple histogram was applied to the raw data to:

- evaluate its robustness;
- identify outliers;
- determine which average or mean would be best suited as a basis for comparison; and
- establish whether the monitoring program was successful.

Given the high variability of most natural systems, it is not surprising that water quality data also exhibit a high degree of variation over both space and time. The high natural background variation tends to mask trends in water quality parameters and reduces the ability to extract a signal from the background noise. Smoothing works by placing a ‘window’ over a portion of data and computing a numerical quantity such as a mean and stepping the window across the data and repeating the process. Greater smoothing is achieved by increasing the span, i.e. the fraction of data to be captured in the moving window (ANZECC 2000). A smoothing approach was employed for this project; it consisted of calculating daily arithmetic means using the 5-minute interval turbidity and stream level observations.

It is acknowledged that the use of smoothed data for the analysis of trends in each sub-catchment may lead to the loss of event-based observations; however, this approach not only helps to tease out a signal from the noisy data as described by ANZECC (2000) but also helps to buffer against experimental errors caused by the fouling of probes. In this study the relatively small smoothing interval still allows for the effective tracking of trends. Outliers were discarded and not included in the analysis.

Indicators can be monitored over time by grouping them in intervals, for example by months or by season. Since the means are biased by extreme values (many of which are known to be data errors), the central tendencies of the grouped data can best be compared by looking at the median values and the 95% confidence intervals for the median values. The confidence
intervals for the true median have been calculated using nonlinear interpolation in MINITAB® Release 14. This method is a very good approximation for a wide variety of symmetric distributions including the normal distribution, the Cauchy distribution, and the uniform distribution, and examples of non-symmetric distributions studied show fairly reasonable results, consistently more accurate than linear interpolation (Hettmansperger and Sheather 1986; Marion 2004).

The data was visually checked for distributional assumption. Many naturally occurring phenomena exhibit normal-shaped distributions, and the Central Limit Theorem ensures that even when the distribution of individual observations is non-normal, aggregate quantities, such as the arithmetic mean, will tend to have a normal distribution (ANZECC 2000). For normal distributions the correct statistical measure of the average is the arithmetic mean (Holman, Barker et al. 2001). For example, river flows may be normally distributed at a single locality for a short period of time, but on the broader time they may decrease systematically with time in absence of rainfall, this is where time of sampling becomes a dominating influence; rainfall events also have a dramatic influence on flow, this is where arithmetic means will normalise a distribution. Water quality changes due to peak storm events will be reflected in the higher averaged daily information.

A simple descriptive tool is the time series plots and trendlines. ANZECC (2000) explain that the trendline is a very reasonable tool, but care must be exercised when attempting to extrapolate beyond the range of the observed series.

The manual temperature and EC observations were plotted over time to help visualise the water quality trends in the catchments and to assist with the analysis.

Following extensive discussions with various laboratories, water monitoring agencies, and experts in Australia, it seems that contemporary probe maintenance and data collection activities are conducted on a monthly basis and observations reported only as raw uncorrected values (Bannon 2000; Giddens 2001; Daniell 2003; Devlin 2003; Halliwell 2003; Waters 2003). Therefore, compared to industry practice, the rigorous probe maintenance and data collection protocols employed for this research project provided more rigorous data collection and reporting than current standards. The frequent monitoring runs combined with the manual turbidity checks greatly increased the confidence in the collected data.
4.5.1 Turbidity VS Suspended Sediment

Suspended sediment in stream flow is commonly measured because of its importance in water quality and because it is considered to be a useful index of total sediment discharge and future expected sediment deposition (Anderson 1975; Kuhnle, Bennett et al. 2000). Because of the increased emphasis on estimates of contaminant loads and the severe limitations on the accuracy of estimates from conventional methods, it is suggested that monitoring turbidity should become part of routine water quality monitoring (Grayson, Finlayson et al. 1996).

Turbidity is positively correlated with sediment concentration, so works that reduce sediment loads will also reduce the turbidity of water leaving sub-catchments. However, the link between high turbidity level in small upland catchments and downstream water quality in large complex river basins is tenuous (Armstrong and Mackenzie 2002). Annual suspended sediment yields may vary by as much as 590%, emphasizing the need for long-term records to determine the average suspended sediment yield accurately, taking into account climactic and land use variations (Wass and Leeks 1999).

The Australian and New Zealand Environment and Conservation Council (ANZECC) (1992) states that due to temporal variations, investigations of suspended sediment concentrations must be carried out with frequent sampling over a long study period, emphasizing that single “spot” values are uninformative. ANZECC (1992) also states that it should be recognised that suspended sediment measurement is a gross oversimplification because of the character of the suspended sediment (eg. particle size distribution, particle shape, fall velocity, optical character, specific surface area, organic content, etc…) is almost as important as the mass concentration with regards to environmental effects.

Gippel (1989) and Grayson et al.(1996) have suggested that turbidity is a good predictor of suspended sediment concentration if particle size, optical properties, and specific gravity remain constant. Wass and Leeks (1999) report that for the most part, the errors associated with deriving a suspended sediment record from turbidity records are free from bias, and good correlations may exist between the two parameters. General relationships derived from data collected for a range of flows throughout a catchment provide good predictive capability, sometimes up to 80% confidence level. However, this approach requires careful sampling, monitoring, and analysis because the relationship is highly sensitive to local site conditions and dependent on land use change, climate, and the source and nature of the suspended material (Anderson 1975; Grayson, Finlayson et al. 1996).
Experience from smaller scale studies has shown that monitoring turbidity along with flow at a high frequency, provides the best economic and accurate means of estimating suspended sediment fluxes in watercourses, provided that sediment and water properties either remain fairly stable or vary proportionately with suspended sediment concentration (Gippel 1989; Wass and Leeks 1999). This suggests that the composition of sediment in the stream water is highly variable (Gippel 1989).

Campbell & Doeg (1984) explain that turbidity observation taken from different streams cannot be used as a basis for comparison of the suspended solids concentration unless it can be established that the nature of the particles causing the turbidity remains unchanged. In addition, even turbidity readings from a single stream at different times may not give an indication of relative suspended solids concentrations if the suspended material in the water comes from different sources within the catchment with differing soil types at different times.

On the other hand, Riley (1998) states that while there exist statistically significant relationships between turbidity and suspended sediment concentration, for some uses the error in predicting the suspended sediment concentration using turbidity measurements is too high. He emphasizes that there appears to be no simple means for correcting the relationship based on the site characteristics of position in the landscape and catchment area. Errors in the estimate of sediment concentration can be in the order of 200% or more. Wass and Leeks (1999) report that a calibrated turbidity sensor consistently underestimated the suspended sediment load by between 2 and 12%. The errors inherent in the relationships suggest that it is not possible to accept turbidity as a firm surrogate for suspended sediment concentration without regular and long term calibration checks. Eads & Lewis (2002) explain that the turbidity versus suspended sediment concentration relationship should never be considered fixed except during individual well monitored episodes of sediment transport.

Even if a turbidity versus suspended sediment concentration calibration equation was derived for a turbidity probe at a specific location, a continuous program of water sampling would be required to ensure the reliability of each observation and to monitor the drift in the relationship (Riley 1998). Long term seasonal or annual loads are less variable than individual runoff-event loads, but long term monitoring over many years may be required to amass enough values to detect statistically significant changes. The monitoring period required for confidence may even exceed the longevity of the effects being studied (Lewis 1996).
The accuracy of a turbidity versus suspended sediment relationship would be limited by the following factors:

- infrequent nature of monitoring runs reducing the accuracy of the physical sampling procedure, over a wide range of flows and climatic conditions;
- highly dependent on site conditions and driven by climate and source of sediment;
- difficulty of access and dangerous nature of tending to the research area during storm or rain events;
- limited availability of vehicular access to tend to the monitoring sites, on average resulting to one day per week access; however on few occasions a vehicle was unavailable for a period in excess of 5 weeks;
- short time period of field monitoring and data collection; and
- assumption that sediment composition is uniform across the upper catchments.

A turbidity versus suspended sediment relationship was developed to estimate the suspended sediment loads and determine the relative contributions of each catchment on a per unit area basis. This was achieved using generic long-term data collected by International Power Hazelwood on a downstream reach of the Morwell River. Albeit, imperfect, it was assumed that the long-term data would provide a good general approximation of the turbidity versus suspended sediment relationship enabling meaningful comparisons across the catchment of the Morwell River.

### 4.5.2 Stream flow

Stream flow was calculated using a relationship derived by correlating the pressure level observations with the manual weekly flow level readings. The logged data was converted to a depth of flow above the weir. Then using equation 4.1, stream flow was calculated (Smajstrla and Harrison 2001). This relationship facilitated the conversion of pressure level information to actual stream flow rates.

$$ Q = 1.378 H^{2.5} \quad (4.1) $$

Where $Q$ is stream flow in cubic metres per second ($m^3/s$) and $H$ is the height of flow over the weir in metres (m). Equation 4.1 is valid only for sharp-crested 90° V-Notch weirs, such as the ones used in this study.
In the case where the experimental flow monitoring equipment failed. An approximation of flow over the study period was derived using the manually collected data. This provided a reasonable estimate of total flows over the duration of the study enabling the basis for suspended sediment load calculations.

4.6 Summary
Accounting for the remoteness of the study area, occupational health and safety considerations related to all weather access and the potential for equipment damage or failure it was important to develop a reproducible and simple approach for the study. The methods adopted in this study combine elements of widely accepted standards with simple yet innovative means of measuring trends in the natural environment.

The use of straightforward and generally reliable experimental designs and methodologies such as continuous logging of turbidity and flow, electrical conductivity, and temperature provided the tools to conduct simple comparative studies of land uses across catchments.
5 RESULTS AND DISCUSSIONS

5.1 Introduction
The fieldwork component of the project began with a preliminary equipment trial beginning in April 2001. All sites were operational, collecting data for a period of 18-months starting in July 2001. The field equipment was removed from site mid-December 2002.

The field monitoring equipment including the turbidity probe, level sensor and data logger operated reliably throughout the study period. With the exception of the short-circuiting of the flow measuring weirs by the action of burrowing freshwater crayfish and some minor tunnelling, the fieldwork was successful.

5.2 Forest Catchment
The results of the visual catchment inspection are presented below. Figure 5-1 reveals the typical stream channel with an approximate width of 1000 mm and less than 150 mm deep. Minor pools created by the accumulation of sediment behind fallen debris were also evident in the stream channel.

![Figure 5-1 GG Stream Channel](image-url)
The catchment survey did not reveal any direct sediment delivery pathways upstream from the monitoring point. In the upper reaches, the stream would disappear into the streambed for short lengths. Minor erosion sites were found in the upper section of the permanent stream generated by tree and vegetation fall along the stream bank. Figure 5-2 highlights extensive leaf litter and organic debris cover.

Downstream of the monitoring point, the stream flowed through a former sediment depositional area, Figure 5-3 showing that the deeply incised stream channel was approximately 1 metre deep with nearly vertical banks. These channel walls are prone to lateral corrosion and subsoil fall resulting in the gradual widening of the channel.

Sediment movement and damage to the stream channel embankment was only observed following intense rain events and localised flooding. However, downstream from the monitoring point, extensive erosion was occurring as a result of blocked culverts crossing the Morwell River showing evidence of overland flow at the crossing resulting from heavy rain events.
Apart from natural stream bank erosion processes, no anthropogenic-related erosion issues were identified in the immediate vicinity of the stream. However, recreational use of Grey Gum Track by 4WD vehicles and trail bikes is clearly creating erosion problems in the catchment. Figures 5-4 and 5-5 illustrate extensive damage to the tracks, formation of gullies, and potential direct sediment delivery pathways.

The track runs along the ridge separating GG catchment from the adjacent catchment. The wheel ruts act like channels concentrating flow down the track and delivering sediment directly into the Morwell River at the base of the catchment. The concentration of runoff within the wheel ruts is also creating accelerating erosion and gullying in some areas. If the tracks are not maintained, it is likely that further erosion will render them un-trafficable and cause extensive damage to the catchment area.

The monitoring site was located upstream of the area where the track meets the Morwell River. Hence, water quality of the catchment was not influenced by direct delivery of sediment from GG Track. In addition, a vegetation buffer ranging between 150 to 200 metres wide exists between Grey Gum Track and the stream.
Figure 5-4 Example of Damage to GG Track

Figure 5-5 Sediment Delivery to Morwell River from GG Track
GG was a stable catchment consistently generating high water quality. Data collected during this period could be used as a basis for further studies looking at the impacts of timber harvesting in this particular catchment.

5.3 **Plantation Catchment**

The plantation area was selected as an appropriate site based on the understanding that most of the available timber, as depicted by the darker areas in the photograph, was going to be harvested as prescribed by the Code of Forest Practices for Timber Production (the Code) (Department of Natural Resources and Environment 1996). This assumption was supported by the GRP harvest plan shown in Figure 5-6. The orange area scheduled to be harvested. The blue linear area depicting a permanent stream requiring a minimum buffer of 20 metres and the green linear areas located at the head of the catchment are the temporary streams requiring a 10 metre filter strip.

![Figure 5-6 C9 Harvest Plan (Alexander 2001)](image)

Buffer widths were set as recommended by the Code. Following initial site selection and harvest plan, the identification of Central Highlands Cool Temperate Rainforest (EVC 31-01) in the riparian zone led to a change in the proposed harvest area. EVC 31-01 is a threatened community of high regional significance (Timewell, Hill et al. 2001). Initial EVC mapping was based on aerial photography; however, ground truthing is performed prior to any
harvesting operation to enable land managers to update the EVC mapping to a finer resolution (Davies 2003).

This threatened EVC combined with the steep terrain and difficult access led to a revised smaller harvest area as seen in Figure 5-7. Of the initial 50 ha selected to be harvested; approximately 16.5 ha of the harvestable area was actually harvested. This resulted in an average stream buffer width of 50 metres, ranging from 20 to 80 metres throughout the post-harvested area. A 50 metre buffer width is 1.5 times the buffer width recommended by the Code. This larger buffer width would encourage the deposition of sediment from overland flow within the buffer zone before runoff reaches the stream.

Harvesting cleared approximately 24% of the catchment area exceeding the 20% threshold reported by O’Shaughnessy, Fletcher (1995) for changes in hydrology to be detectable. Therefore, based on Nandakumar & Mein (1993) approximation that an increase of 33 millimetres in annual stream flow results for every 10% of catchment area cleared, it was estimated that a resultant annual increase flow of $1.43 \times 10^2$ m$^3$ would result. This resultant increase in flow would be undetectable considering seasonal and climatic variations.

Revised harvest plans are a typical situation in the Strzeleckis where operations face a number of issues including:

- steep unstable slopes;
- high rainfall;
significant pockets of remnant vegetation; and
the legacy of former harvesting practices.

The revised area of timber to be harvested was only effected once the research site was constructed and monitoring was occurring. In light of the fact that no alternative sites were available and because of the limited timelines for the research project, it was decided to continue the monitoring and compare the results with the other catchments. It was understood that the findings may be compromised for a comparative study.

Harvesting of the area was accomplished using clear-fell harvesting methods. Harvest preparation works included upgrading the access tracks by reinforcing the surface with crushed rock and mechanical grading to minimise damage to the road surface and directing drainage into scrub away from the stream. Natural surface tracks tend to be very sensitive to erosion especially if trafficked during wet periods. As shown in Figure 5-8, wet tracks which have not been upgraded tend to form ruts which eventually become erosion channels. These channels increase the potential for direct delivery of concentrated suspended sediment to streams where a stream connection is provided through a culvert or stream crossing. The track was not utilised for harvesting operations and as a result was not upgraded, it remains as a fire management track which continues to be damaged by recreational use especially during wet weather.

Site investigations did not reveal direct sediment delivery pathways upstream of the monitoring site. Road and track drainage measures were consistent with the prescriptions of the Code with no apparent gullying or erosion at the outlets of drainage structures. The track table drains and the track seem to effectively collect runoff and disperse it into the adjacent vegetation away from the stream.

Following harvesting, stumps were left intact and debris was spread on the ground to minimise erosion. Debris and litter helps to reduce rainsplash erosion and weed growth while the new plantation re-establishes. The results of these measures are shown in Figures 5-9 and 5-10.
Figure 5-8 C9 Basic Access Track – Not Used for the Harvesting Operation

Figure 5-9 Example of Logged Catchment
Prior to the start of the harvesting operations, one minor landslip occurred at the head of the catchment. The small landslip was approximately 4 metres wide by 8 metres long; resulting from the concentrated drainage flow during a 1:50 year rain event in April 2001. The event caused localised flooding across the Strzeleckis and in the Latrobe River Basin. As seen in Figure 5-11 some soil erosion occurred, but remedial measures were quickly implemented to minimise further erosion and to stabilise the slip as it had the potential to undermine the main access road for the timber harvesting operations within C9. The measures included redirecting all drainage and runoff away from the affected area, placing debris and litter directly on the slip and revegetating the area. These measures halted the spread of the slip and resulted in successful rehabilitation.

The slip was located at the very top of the catchment in a heavily vegetated area feeding into a 400 metre long temporary stream. The distance between the slip and the main stream channel effectively mitigated the potential for direct delivery of sediment to the stream under moderate rain events and baseflow conditions. The buffer afforded by the dense vegetation and highly permeable soils combined with the very low frequency of overland flow in this drainage line further increased confidence that the slip did not create a significant impact on local water quality.
The catchment survey was performed by walking the total length of the soak area. Results of the survey are listed below including photographs of the major mechanisms observed in the catchment.

The main observation within the soak area was the scarcity of leaf litter and organic debris, and resultant high degree of exposed and disturbed soil. As seen in Figures 5-12, 5-13 and 5-14, there was clear evidence that the soil disturbance and lack of ground litter was due to extensive bioturbation by burrowing and foraging animals.

Soil disturbance extended through the majority of the soak area from the monitoring point up to the head of the drainage lines covering widths of up to 5 metres on each side of the stream.

The baring of soil not only creates a sediment source during rain events where rainsplash and increased stream velocities may entrain the soil particles but also during periods of high atmospheric moisture, as is common in the Strzeleckis, where water droplets resulting from condensation on vegetation may act in the same way as rainsplash dissolving soil particles and delivering sediment directly into the stream. These mechanisms may act in synergy with the effects of harvesting leading to a sustained increase in stream turbidity.
As described below, the extent of soil disturbance was not evident in the forest catchment. Although there were minor areas of soil disturbance and bioturbation in GG, the degree of disturbance was highly localised and insignificant compared to that found in C9.

Discussions with flora and fauna experts from the Department of Sustainability and Environment (Davies 2003; Hollis 2003) provided a few alternative reasons for this level of soil disturbance. These included:

- **Structural difference in EVC classes;** the Central Highlands Cool Temperate Rainforest (EVC 31-01) may provide a better habitat for burrowing and foraging animals and insects than the Wet Forest (EVC 30). However, this is an unlikely scenario given that the general vegetation structure of these EVCs are very similar and the close vicinity of the catchments to each other would suggest that similar fauna populations would exist.

- **Effects of drought;** drought may have forced animal populations to congregate along the wetter drainage lines within each catchment and that C9 may have a larger concentration of these animals. Considering that neighbouring land uses include grazing and agricultural
areas and that harvesting occurred on adjacent catchments, this may provide a reasonable explanation for the degree of bioturbation.

- **Structural changes to C9 and surrounding catchments**: timber harvesting in C9 and surrounding catchments may have forced some fauna to relocate and concentrate in the safer untouched areas of the riparian zone in C9. The lower numbers of available habitat areas around C9 as compared to GG may also provide clues for the higher levels of bioturbation. However, this does not explain the larger number of crayfish burrows along C9 as compared to GG. Alexander (2003) explained that freshwater crayfish need to be within 5 metres of soak area to survive and do not migrate away from the damp environment.

- **Natural differences**: there is also the possibility that historically, C9 has provided better or higher quality habitat for burrowing fauna populations than the forest area.

![Crayfish Burrows along Stream bank](image)

**Figure 5-13 Crayfish Burrows along Stream bank**
It is acknowledged that there could also be other explanations such as the degree of recreational use in each catchment or the presence of predators; however, more research would be needed before a conclusion could be drawn on the reasons for the difference in the degree of bioturbation and soil disturbance.

A number of fallen trees and tree ferns along the stream bank, mostly in the soak area, also created sites where localised erosion was occurring. Tree and vegetation fall is usually a natural process driven by the age of the vegetation and prevailing winds; however, higher wind energy as a result of the removal of surrounding vegetation may enhance these processes.

Stream bank erosion was apparent in certain areas of the stream. Minor stream bank erosion caused by lateral corrosion was observed examples of which are highlighted in Figures 5-15 and 5-16. These natural processes undermine the stream bank causing tree ferns and other riparian vegetation to fall into the stream.
Lateral Corrasion and Stream Bank Erosion

Undercutting Resulting in Subsoil Fall

Figure 5-15 Stream Bank Erosion

Figure 5-16 Stream Bank Erosion - Subsoil Fall
Erosion sites and potential sediment supply areas were generally related to natural processes. The extent of bioturbation would suggest that it is a major contributor to the turbidity of that stream. The continuous churning of soils and removal of protective litter layer could be compared to earthworks without strict erosion control measures resulting in a ready supply of sediment.

The dominant natural processes in this catchment provide an ideal opportunity for further research to quantify the contribution of bioturbation to turbidity and sediment movement in this catchment.

5.4 Agricultural Catchment

Since it was cleared, this catchment was surveyed from the road running along the major drainage line / creek. It was clear that at any one time cattle were grazing at least part of the catchment. For most of its length, the stream seems relatively stable with an average width of 1200 mm and depth of less than 150 mm. The channel has had approximately 100 years to adjust to agricultural land use. Figure 5-17 highlights the relatively wide and shallow stream channel with stable gentle embankments. There are still areas where minor stream bank erosion is occurring.

Unabated cattle access to the stream and drainage lines appears to be the major cause of sediment movement in the catchment and turbidity in the stream. Figure 5-18 illustrates the types of damage caused by cattle. This damage destabilises the stream channel accelerating stream bank erosion processes. Even at low flow conditions, this type of damage contributes to sustained stream turbidity and reduced water quality. This type of stream damage was evident throughout the catchment, especially in the damp zones downstream of the farm dams as seen in Figure 5-19.

The catchment surveys revealed a range of effects caused by agricultural practices and cattle including:

- intensive grazing of vegetation and baring of soils on the perimeter of drainage lines and streams (Figure 5-20);
- collapse of dam embankments and stream banks (Figures 5-20 and 5-21);
- landslips (Figure 5-21);
- ploughing of fields;
- cattle tracks (Figure 5-22); and
• improperly designed and/or constructed drainage structures along the road, driveways, and farm tracks, (Figure 5-23).

The survey revealed that current grazing and tracks in PV are the largest contributors to stream channel damage and lower water quality. Current agricultural practices are also increasing the risk of landslips and degradation of some localised areas.

Since most of the catchment is being used solely for pasture and not intensive cropping, the main concern for catchment health relates to livestock access to the streams and drainage lines. The establishment of healthy riparian zones with properly controlled livestock access to these areas is the key to improving water quality and ensuring sustainable agriculture in this area. Healthy riparian zones would also provide enhanced habitat connectivity across the local area. This would result in a net benefit for the Strzeleckis.
Figure 5-18 Example of Stream Damage caused by Cattle

Figure 5-19 Example of Stream Channel Damage Downstream from a Farm Dam
Figure 5-20 PV Typical Catchment Landscape

- Damage to Drainage Line and Embankment
- Cattle Tracks
- Initiation of a Landslip
- Cattle Access to Drainage Lines
- Failure of Embankment

Figure 5-21 Sediment Supply in PV Catchment
Figure 5-22 Cattle Tracks alongside the Stream

Figure 5-23 Driveway Access to a Home
5.5 **Continuous Data Analysis**

Differences in water quality found between the plantation, agriculture and forest catchments highlight the impacts on water quality resulting from increasing intensity land management.

Turbidity and flow monitoring occurred over a period of approximately 18 months with some data loss. Monitoring began in autumn / winter 2001 and ended in Summer 2002. This enabled the fieldwork to capture complete seasonal data over the following seasons:

- 1 winter season;
- 1 autumn season;
- 2 spring seasons; and
- 1 complete and 1 partial summer season.

5.5.1 **General Data Analysis**

The continuously logged data collected during the field work was interrupted in some instances reducing the accuracy of continuous data analysis. However, trends are still evident when data is grouped together monthly or seasonally. Since means analysis is biased by extreme values (many of which are known to be data errors), the central tendencies of the grouped raw data can best be compared by looking at median values. To support this, the 95% confidence intervals are also reported for the medians. Confidence intervals for the true medians have been calculated using nonlinear interpolation in MINITAB® Release 14 (Minitab Incorporated 2004). This method is a very good approximation for a wide variety of symmetric distributions including the normal distribution, the Cauchy distribution, and the uniform distribution, and examples of non-symmetric distributions studied also show reasonable results, generally much more accurate than linear interpolation (Hettmansperger and Sheather 1986; Marion 2004).

The raw turbidity data is summarised in a boxplot in Figure 5-24. Results for the raw turbidity data set is summarised in Table 5-1.

As an initial check, it can be seen that the median turbidity of the agricultural area is higher than the other catchments and the median values for both the plantation and forest areas are not significantly different. If considered in the context of the default target values for upland rivers (Department of the Environment and Heritage 2003), both the plantation and forest catchment values comply with the suggested range. The median turbidity value for the agricultural catchment exceeds the target range by approximately 2.5 times the upper limit.
Table 5-1 Total Median Turbidity Values and 95% Confidence Intervals

<table>
<thead>
<tr>
<th>Site</th>
<th>Lower</th>
<th>Median</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>C9</td>
<td>23.4</td>
<td>24.8</td>
<td>26.4</td>
</tr>
<tr>
<td>GG</td>
<td>23.5</td>
<td>24.9</td>
<td>26.8</td>
</tr>
<tr>
<td>PV</td>
<td>59.6</td>
<td>61.4</td>
<td>70.2</td>
</tr>
</tbody>
</table>

Monthly grouping of the raw data is shown in Figure 5-25. It reveals that the turbidity values of the agricultural catchment are consistently higher than the other catchments throughout the monitoring period. The variability in the turbidity observations renders the identification of seasonal trends very difficult. When considered in combination with the analysis of the corrected data presented in the following sections, a slight seasonal trend is apparent.
The forest catchment exhibited greater variability in the winter months from May to August, whilst during the other months the peak turbidity values tended to be lower and less variable. This suggests higher more variable stream flows during the wetter winter months.

The plantation area exhibited a different level of variability. Periods of higher variability were observed during the summer months from November to March coinciding with times of highest biological activity suggesting that bioturbation may be a major contributor to the suspended sediment load.

Figures 5-26 and 5-27 and Table 5-2 provide a summary of the flow analysis for each catchment; however, short-circuiting of the weirs resulted in erroneous flow information for the agricultural catchment.
This analysis is provided to demonstrate the variability of flow during the study period. The analysis of the raw flow data revealed slight seasonal trends whereby flow variability increased during the period from autumn to spring. This indicates that flow data resulting from storm events was successfully captured by the monitoring equipment. Due to extensive short circuiting and leakage, the continuously logged flow data for the agricultural catchment was discarded. The flow in the forest area was approximately 5 times higher than the flow in the plantation area. The higher volumes of flow, even combined with lower turbidity values, resulted in higher annual sediment loads being transported potentially posing a greater downstream water quality risk than the higher turbidity lower flow catchments.
In summary, preliminary analysis of the raw data revealed a general trend that the agricultural catchment generated higher turbidity values than the other catchments. Initial comparisons between the forest and plantation areas suggest that the effects of limited timber harvesting and bioturbation were negligible.

5.5.2 Turbidity / Suspended Sediment Relationship
Using the water quality data provided by International Power Hazelwood, a generic turbidity versus suspended sediment concentration relationship, Figure 3-28, was derived. This relationship was utilised to calculate a sediment load for each catchment.
5.5.3 Corrected Data Analysis
The data analysis is presented for each site. Data smoothing was achieved using daily arithmetic means for both turbidity and flow. Obvious outliers and large periods of data loss were discarded. Data correction included adjustments for instrument drift and fouling of the turbidity probe’s optical surface. As these mechanisms are quite site specific, the field work revealed that fouling was insignificant for both the agricultural and plantation catchments; however, the forest catchment suffered slightly from probe fouling. Instrument drift was not found to be significant for all in-situ instruments.

In Figures 5-29, 5-30 and 5-31, turbidity is plotted along the left y-axis in units of NTU and flow is plotted along the right y-axis in units of m$^3$/sec. The observed variability or saw tooth nature of the data is a function of the catchment’s response to the natural changeability of stream conditions. Turbidity measurements are dependent on a number of factors including rain events, fouling of the lenses, antecedent catchment condition, battery power, temperature, ambient light, and stream disturbances such as bioturbation, tree fall, and/or fauna crossing the stream.
Using the average daily flow, a daily discharge ($m^3$/day) was calculated. The daily average turbidity was converted to a suspended sediment concentration ($g/m^3$) using the generic relationship described above; then the daily discharge was multiplied with the concentration to calculate a daily load (g/day). The total discharge ($m^3$) and sediment load (kg) was determined for the duration of the study. To provide a meaningful comparison, the total discharge and sediment loads were divided by the catchment area to determine a unit area contribution to both stream flow and sediment loads. Finally an average sediment load ($g/m^3$) was determined based on the unit area adjusted data. This provided a standardised basis to the meaningful comparison across catchments.

5.5.3.1 Forest Catchment Analysis

Generally, the forest catchment was found to generate high quality water. Figure 5-29 presents turbidity and flow plotted with respect to time.

![Figure 5-29 Forest Catchment Combined Turbidity and Flow Analysis](image)

Features of the turbidity and flow analysis include:
• a seasonal stream flow pattern and resultant turbidity, flow is shown to increase in autumn / winter reaching a peak in July and November then exhibiting a decreasing trend from December to April; and
• generally, turbidity values rose with rising flow and dropped with decreasing flows.

Analysis of the corrected data during the monitoring period reveals that the forest catchment generated a mean turbidity value of 20 NTU and a median of 17 NTU with a mean flow of $2.0 \times 10^{-2} \text{ m}^3/\text{sec}$.

5.5.3.2 Plantation Catchment Analysis

Generally, water quality flowing from the plantation catchment was of good quality. Storm related flows delivered coarse sediment as evidenced by the accumulation of coarse gravel, pebbles, and debris in the stilling pond. Of the three monitoring points, flow monitoring was most reliable in this catchment because the weir was installed on a stream reach flanked by bedrock. This prevented the undermining and short-circuiting of flow. Figure 5-30 presents turbidity and flow plotted with respect to time.

![Plantation Catchment C9 Turbidity and Flow](image)

Figure 5-30 Plantation Catchment Daily Averaged Turbidity and Flow Analysis
Features of the plot include:

- a seasonal pattern apparent in the stream flow, whereby flow increases in the autumn to spring period reaching a peak in July and November and decreasing in the summer period reaching a low in March;
- turbidity behaviour is variable reaching two peaks in the study period during summer combined with lower flows and in winter coinciding with higher and more variable flows; and
- the higher, more variable turbidity values in the summer period may be the result of high levels of bioturbation due to increased biological activity both within and adjacent to the stream reaching a peak in the warmer summer months potentially contributing to increased turbidity readings with declining stream flow.

In summary, the plantation catchment generated a mean turbidity of 31 NTU and a median turbidity of 27 NTU with a mean flow of $3.38 \times 10^{-3}$ m$^3$/sec.

### 5.5.3.3 Agricultural Catchment Analysis

This catchment was observed to consistently deliver poorer water quality. Some of the data variability could potentially be attributed to local events such as livestock and vehicles accessing and crossing the stream. In addition, literature reports that in areas with cleared slopes and poor riparian vegetation, the catchment hydrology might be more responsive to high intensity rain events resulting in higher velocity stream flow flushes with the capacity to carry higher sediment loads.

Flow monitoring at the agricultural catchment was not successful due to extensive short-circuiting of the weir and consistent damage caused by livestock. To overcome the issues with the continuous flow monitoring, an averaged flow for the duration of the study was calculated using the manually observed flows. This approach ignores storm event-related flows; however, it must be considered the best estimation of flow for the study period enabling the calculation of sediment loads for the catchment. Figure 5-31 presents turbidity plotted with respect to time.
The apparent higher velocities of flow provided sufficient scouring of the turbidity probe to effectively prevent fouling.

Features and trends of the turbidity and flow versus time plot include:
- a period of more stable turbidity readings during the summer months could be a result of lower stream flow, livestock excluded from the immediate paddock, farm dams trapping a greater portion of sediment, and the lack of any significant rain events;
- turbidity values show greater peaks and higher variability during the winter period; and
- turbidity values are generally higher than those observed at other catchments.

In summary, the agricultural catchment generated a mean turbidity of 63 NTU and a median turbidity of 59 NTU with an averaged mean flow of $5.58 \times 10^{-3}$ m$^3$/sec.
5.5.3.4 Catchment Area Factors

In order to be able to draw meaningful comparisons, the sediment budgets were calculated for each catchment. The budget was generated utilising the data collected for the duration of the study period. Table 5-3 summarises the key features of this analysis.

<table>
<thead>
<tr>
<th></th>
<th>Forest Catchment</th>
<th>Plantation Catchment</th>
<th>Agricultural Catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge (m$^3$)</td>
<td>734,911</td>
<td>134,386</td>
<td>208,359</td>
</tr>
<tr>
<td>Sediment Load (kg)</td>
<td>13,418</td>
<td>3,784</td>
<td>11,852</td>
</tr>
<tr>
<td>Unit Area Discharge (m$^3$/ha)</td>
<td>11,306</td>
<td>1,920</td>
<td>1,302</td>
</tr>
<tr>
<td>Unit Area Sediment Generation (kg/ha)</td>
<td>206</td>
<td>54</td>
<td>74</td>
</tr>
<tr>
<td>Average Sediment Load (g/m$^3$)</td>
<td>18</td>
<td>28</td>
<td>57</td>
</tr>
</tbody>
</table>

In summary, it was determined that the forest catchment generated the highest discharge and accordingly the highest sediment load over the time period of the study. However, when considered on a per unit area basis, the agricultural catchment with a significantly lower flow generated an average sediment load approximately 3 times more than the forest catchment.

It is interesting to note that the findings clearly show that the forest catchment produced a unit area sediment generation rate of 206 kg/ha whilst the plantation catchment and agricultural catchments were 54 and 74 kg/ha respectively. In the absence of direct sediment delivery to the stream, this suggests that the higher flows in the forest catchment result in more effective channel erosion processes. The relative absence of bioturbation in this catchment further supports this.

The higher average sediment load associated with lower flow rates for the agricultural catchment would indicate that there are other processes in addition to natural channel erosion contributing to the suspended sediment load.
The natural processes combined with higher discharge rates combine resulting in the transport of larger loads of sediment potentially impacting further downstream; however, the higher flows may also provide better flushing of the system.

In summary, the data suggests that, on a per unit area basis, the impacts to the local water quality increase with increasing intensity in land use.

5.5.4 Manual Sampling

In addition to the continuous monitoring, manual sampling was also undertaken to test the accuracy of continuous turbidity monitoring. As described in Chapter 4, turbidity was measured manually using a turbidity tube.

Electrical Conductivity and stream temperature were also reported in the literature as providing good tools for the evaluation of land use impacts in each catchment. These additional indicators provide a quick and easy snapshot of catchment health while helping to build the knowledge base of land use impacts.

5.5.4.1 Manual Turbidity Analysis

The manual turbidity observations were tabulated and results presented in Figure 5-32.

The results support the analysis performed on the data collected by the monitoring stations. As seen in the chart, the mean manual turbidity values reported for both the plantation and agricultural catchments correlate closely with the values reported in previous sections. This suggests that the weekly snapshot may be adequate in describing the overall sediment supply processes in these catchments; however, losing some of the event based data which may result in a slightly underestimated sediment budget. Manual turbidity sampling in the plantation catchment also revealed a gradual increase in turbidity over the period between January and May 2002, further reinforcing the concept that bioturbation may be a major contributor to sediment in the stream.

Turbidity trends for each catchment generally seemed to correlate well with each other, increasing and decreasing during the same time periods. This would indicate that the catchments responded in equivalent ways to uniform climatic trends.
The mean turbidity value for the forest catchment is lower than the results calculated from the logged data. This suggests that the weekly snapshot may not have adequately captured event based changes in water quality. It also suggests that this catchment may be more sensitive to significant rain events, the higher stream flows resulting in increased channel erosion rates and sediment movement not captured during the routine monitoring runs. Although not observed above the monitoring point, track erosion aggravated by recreational use may have contributed to sediment loads during high rainfall events.

5.5.4.2 Electrical Conductivity Analysis
As described in Chapter 4, stream EC can be a good indicator of land use change in catchments within individual geological formations (Finlayson 1979). Figure 5-33 provides a summary of the electrical conductivity measurements taken during the fieldwork.

Electrical conductivity values of the plantation catchment were approximately 10% higher than the forest catchment. This small variation may be explained by significantly lower flows in the plantation catchment resulting in lower dissolution rates for solutes. However,
bioturbation and slight increases in through flow due to increased catchment infiltration as a result of harvesting may also have contributed higher concentrations of solutes in the stream water resulting in slightly increased EC readings.

![Electrical Conductivity Analysis](image)

**Figure 5-33 Electrical Conductivity Analysis**

EC values in the agricultural catchment were consistently higher than both the forest and plantation catchments. The higher values may be the result of nutrients, animal wastes, and fertilisers being washed into the stream. Solutes concentration increases may also be occurring due to evaporation of in-stream dam waters; however, this was not measured.

The apparent differences in catchment EC values suggest that the measurement of EC may provide a relatively quick and reliable indicator of land use impacts on water quality. However, further research is required to identify the solutes contributing to higher stream EC and their sources. This would enable land managers to be able to quickly measure and understand the implications of land use change.
5.5.4.3 Stream Temperature Analysis

Literature suggests that streams flowing from cleared catchment were more prone to diurnal temperature extremes and ran at higher temperatures during warmer months than streams protected by riparian vegetation.

As illustrated in Figure 5-34, the stream temperatures for both the forest and plantation catchments remained nearly identical throughout the study period whilst the agricultural catchment was approximately 3°C higher. This supports the concept that the lack of riparian vegetation along the agricultural catchment may contribute to higher stream temperatures.

![Temperature Analysis](image)

Figure 5-34 Temperature Analysis

Higher stream temperature may also be the result of heating of the water in the in-stream dams. Since temperature was not measured on a continual basis, diurnal variations were not detected. More research using continuous temperature monitoring of catchments would be required to confirm the effects of riparian vegetation and in-stream dams on water temperature.
5.5.5 Soil Dispersion Testing

Soil dispersion testing was conducted on two individual soil samples collected from areas adjacent to the steam channel of each sub-catchment. The tests were performed as described in Chapter 4. A summary of the observations is provided in Table 5-4.

Table 5-4 Soil Dispersion Test Results

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>SLAKING</th>
<th>DISPERSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C9-1</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>C9-2</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>PV-1</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>PV-2</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>GG-1</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>GG-2</td>
<td>Slight</td>
<td>None</td>
</tr>
</tbody>
</table>

Only slight swelling and minimal slaking of the soil crumbs occurred in each sample and no dispersion was evident. This finding is important as it rules out these mechanisms as a source of suspended sediment in the streams especially during baseflow conditions. Therefore, soil dispersion is not a major contributor to the suspended sediment load in each catchment.

5.6 Experimental Errors

The variability of natural environments poses challenges to monitoring, collection and analysis of data. This variability and the performance of monitoring equipment may introduce experimental errors in the data and have the potential to obscure the analysis, leading to erroneous conclusions. Literature reports that data quality issues can be associated with, for example, malfunctioning equipment, different brands or types of equipment, fouling and burial of probes, gnawing of cables, failure of batteries, and operator subjectivity.

Recognised experimental errors included:
- site access restrictions imposed for occupational health and safety reasons preventing manual sampling and monitoring of significant events;
• limited availability of vehicles for monitoring runs taking the time between maintenance periods beyond the planned 7 day period;
• failure of equipment leading to data loss;
• probe fouling and obstruction from debris;
• damage to the monitoring sites caused by cattle and wildlife;
• short-circuiting of flow through the burrowing action of fauna in the stream banks leading to underestimated flows;
• damage of the weir structure by cattle;
• other erosion processes in the catchments other than those being investigated such as recreational use; and
• failure to harvest the timber resource as previously planned.

The issues listed above create difficult challenges when pursuing fieldwork, especially in sensitive, remote locations such as the ones encountered in the Strzeleckis. From the onset of the project, site selection proved to be a difficult task in trying to locate catchments of equivalent sizes, located in the same geological unit, with similar weather patterns, containing flowing streams, and areas that would be of easy access under a number of climatic conditions. Selection of each catchment proved to be the best all round compromise satisfying most of the research requirements.

Fouling of the turbidity probe is influenced by a number of factors some of which are seasonal and highly dependent on antecedent site conditions. Considering that current standard industry practice is to access the sites on a monthly basis and report uncorrected data, the rigorous maintenance and quality assurance program adopted for this project provided good quality indicative results. In addition, the catchments were treated in the same manner improving confidence in the comparisons.

The sawtooth nature and high variability of the turbidity plot is partly a function of the fouling and cleaning process of the turbidity probe. The flushing action of a peak rain event or the manual cleaning of the lens would lead to a sharp drop in turbidity readings. The manual calibration checks confirmed that probe fouling was highly site specific.

The limited ability to collect storm-related sediment samples may have introduced a bias in favour of the fine fraction of the sediments derived from channel sources. Coarser particles were transported by the higher storm flows as evidenced by extensive accumulation of coarse
sediment in the stilling ponds at times burying the probes. Therefore, it can be assumed that the sediment loads for each catchment may be slightly underestimated; however, they still provide a good basis for comparison.

These issues highlight the difficulties associated with completing short-term detailed field-based research studies. The reliability of the field equipment and the need for regular site access make this type of study very demanding and time consuming. At times equipment limitations included probes being buried in sediment, fouled, no longer submerged, or no longer collecting data due to failed batteries. Errors arising from these factors are very difficult to quantify. It is essential that a strict quality control program is implemented. Quality control was achieved in this study by means of weekly manual calibration of field instruments. Quality assurance measures were applied to the raw data acceptance and rejection and to the selection of appropriate statistical methods (National Environment Protection Council 1999).

5.7 Summary
The methodology adopted for this project clearly demonstrated that it was a simple, effective and cost efficient approach for catchment management and water quality monitoring. The comparative approach in combination with sturdy and reliable water quality monitoring devices can provide land and waterway managers with the tools to implement simple and effective water quality monitoring programs ensuring that their efforts can be readily used and compared, establishing trends in water quality and determining which land uses impact the highest on local water quality.

Careful consideration needs to be given to determine which water quality indicators should be monitored. Electrical conductivity and stream water temperature may be the easiest indicators to monitor whilst the need for regular maintenance and accuracy checks makes turbidity monitoring more demanding and expensive. Proper site selection and equipment installation in combination with a good quality control program can overcome data quality assurance and quality control issues.

Soil dispersion testing confirmed that dispersion and slaking of the soils in the study area were not major mechanisms generating naturally high background turbidity values. Some rivers in Australia, including the Yarra River which flows through Melbourne, possess high natural background turbidity values due to the dispersive soils along their banks.
The project confirmed that both agricultural and forestry practices have the potential to generate impacts on local water quality. Turbidity, electrical conductivity, and even stream temperature combined to suggest that agriculture generated the highest impacts. The lack of reliable flow data prevented an estimation of sediment loads moving through the catchment.

Harvesting and forest management in the plantation area were performed under very controlled conditions due to the presence of EVC 31-01. This resulted in a smaller than planned harvested area with much larger stream buffers. Under these harvest conditions, negligible impacts were measured. This is informative to land managers as it helps define acceptable practices. The theoretically predicted changes in the catchment were not fully observed under these conservative harvest conditions.

The extent of bioturbation found in the plantation area was a surprise and represents a novel observation from this research. It provides an opportunity for further study on the impacts of biological activity along riparian zones and its effects on local water quality.
6 SUMMARY AND CONCLUSIONS

6.1 Introduction
A combination of on-ground physical works and the modification of traditional land management practices need to be considered when developing catchment management strategies promoting responsible land management. As demonstrated in this work, the adoption of simple yet effective methods to monitor water quality and environmental change empowers land managers to take an interest in their environment and promote sustainable land use.

Using water quality indicators, the research investigated the impacts of major land uses in the Strzeleckis, highlighting the changes in land management approaches which would benefit from improved practices ultimately leading to more sustainable land management. The comparative study methodology proved to be a robust method allowing the identification of trends across catchments.

Analysis revealed that from a water quality perspective, agricultural practices resulted in consistently higher levels of turbidity, higher average water temperatures and higher electrical conductivity. The mean turbidity value for the agricultural catchment (63 NTU) exceeded that for the plantation area (31 NTU) by a factor of two and the forest area (20 NTU) by a factor of three. It also exceeded the recommended maximum default target value for upland rivers (25 NTU) (Department of the Environment and Heritage 2003) by more than a factor of two. This reveals that agricultural practices in this catchment are significant contributors to poorer water quality and overall degradation in environmental amenity.

At 31 NTU, the mean turbidity values for the plantation area also slightly exceeded the maximum default target value for upland rivers. However, the forest area fell within the recommended maximum default target value for upland rivers.

The sediment budget also uncovered a trend of decreasing water quality with increasing intensity in land management.

6.2 Summary of the Research Methodology
A comparative study approach was adopted using water quality indicator to measure trends within catchments. The three catchments that were selected all lie within the same
geographical area with similar landform and soil types. The monitoring of the water quality indicators of turbidity, flow, electrical conductivity and stream temperature, enabled the identification of changes in stream characteristics due to land use.

The key research approach included:

- automated data loggers equipped with turbidity probes and level sensors;
- weekly manual water quality indicator observations;
- visual survey of each catchment to identify sediment generation and delivery mechanisms;
- simple statistics and trending were used to identify changes in water quality;
- water quality indicators were considered in the context of the default target values for upland rivers as published by the Commonwealth Department of the Environment and Heritage (2003).

The simple methodology has been demonstrated to be an effective tool to carry out comparative catchment studies. The methodology generated readily reproducible and comparable results, providing a good indication of catchment health and enabling targeted mitigation programs.

6.3 Research Questions

The research proposal identified key questions which would guide the research program to achieve its objective. The questions provided a basis for the design, implementation and completion of the study. The project would be undertaken by implementing a simple and effective methodology based on basic water quality indicators.

6.3.1 What is the baseline water quality in the catchment?

Each sub-catchment was monitored concurrently over a period of 18 months. The data collected during this phase of the project made it possible to establish an indicative baseline water quality for each sub-catchment. The results must be considered in the context of having been collected over a short period of time. Other catchment studies have spanned a much longer time period (i.e. 30+ years) resulting in findings, which would be considered more representative of the longer term mechanisms occurring in the catchments. Mechanisms affecting catchment dynamics may include a combination of climate and climate change, land management decisions, land use change, increases in the understanding of catchment dynamics, local / regional / state / national / global economics, plus a number of other natural and anthropogenic factors. However, snapshots in time can provide insights into dominant
longer-term catchment trends satisfying the basis of sustainability science. Lowe (2005) states that shorter-term studies can be used to assist in developing inverse approaches which work backwards from undesirable consequences to identify better ways to progress.

The water quality results for each sub-catchment are summarised in Table 6-1. They represent an indicative measure of the relative impacts caused by each land use.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Mean Turbidity (NTU)</th>
<th>EC (µs/cm)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manual</td>
<td>Logged</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>9</td>
<td>20</td>
<td>101</td>
</tr>
<tr>
<td>Plantation</td>
<td>28</td>
<td>31</td>
<td>112</td>
</tr>
<tr>
<td>Agriculture</td>
<td>52</td>
<td>63</td>
<td>168</td>
</tr>
</tbody>
</table>

The monitoring runs were restricted to good weather, the effects of climatic events were largely overlooked by the manual observations; however, compared to the logged data, generally the differences between turbidity values were not significant. The manual observations do provide an indicative representation of baseflow conditions encountered during the period of the study and indication of in-stream mechanisms which may be affecting water quality. This suggests that over the period of the study, probe fouling and high turbidity flows related to high-intensity, short-duration events did not contribute significantly to mean turbidity values over the duration of the study period.

Water quality at baseflow conditions in the forest area was consistently high. The turbidity was normally below 10 NTU with instances where the turbidity tube tests returned a near 0 reading. Sediment sources were observed as generally being in-stream.

The baseline water quality in the plantation area possessed higher turbidity values. However, the readings remained consistent with the default target values for upland rivers. The catchment survey revealed extensive bioturbation along the soak areas and within the stream channel. It was the most likely cause of consistently higher baseflow turbidity. This suggests that the stream’s riparian zone is providing habitat for a higher concentration of active
burrowing and foraging fauna. Hence, higher turbidity may not be a direct result of anthropogenic causes but a product of natural processes and / or indirect anthropogenic effects.

Baseflow water quality in the agricultural area was consistently poorer than that observed in the other catchments over the period of the study. Stream water turbidity values were generally more than twice the maximum default target value for upland streams. Livestock access to the stream combined with the absence of riparian vegetation for the majority of the stream reach are potential major contributors to poorer water quality even during low flow conditions. The higher stream water temperatures could be the result of heating due to in-stream dams and enhanced by the lack of riparian vegetation. The higher levels of light reaching the stream change the in-stream characteristics by promoting the growth of aquatic organisms and the in-stream dams directly in the stream channel also provides ideal conditions for enhanced growth of aquatic organisms.

The effect of farms dams could potentially be twofold; dams generate a benefit by trapping sediment as a result of reduced flow velocities during high flow events. However, during low flow conditions, water can be stored in the dams for extended periods of time. The accumulation of nutrients, sunlight, and warmth produce ideal conditions for algal blooms and promotes the growth of other aquatic plants and organisms. Increased algal growth results in lower oxygen levels and higher turbidity levels resulting in a net decrease in water quality.

The suspended sediment generated in agricultural catchments may also provide a pathway for the transport of pollutants and pathogens. The application of fertilisers, herbicides, pesticides, and other chemicals onto agricultural land and the sorption characteristics of some chemicals onto soil particles combine to increase the risk of impacts on the local waterways.

Although a slight difference in the electrical conductivities for each catchment has been observed, EC values for all catchments were within the recommended default target value range between 30 – 350 µs/cm. No clear conclusions can be drawn from these results.

These results suggest that more intense land use increases the potential for the degradation of water quality and overall environmental health.
6.3.2 What are the impacts on water quality from forestry and agriculture?

The results illustrate that both the forest and the plantation areas consistently generated better water quality than the agricultural area. The poorer water quality readings for the agricultural area suggest an elevated level of impact from this land use as compared with the other catchments.

The slightly higher temperatures observed in the agricultural catchment may be the result of an open stream lacking the protective canopy afforded by riparian vegetation and potentially the effects of water storage in the farm dams.

Results suggest that agriculture generated more direct impacts on the local waterway whilst forest harvesting contributed indirect impacts.

In the plantation area, natural processes of bioturbation and stream bank erosion were potentially the major sources of sediment. Bioturbation being a major source during baseflow conditions in the plantation area and lateral corrosion and stream bank erosion as dominant sediment sources during rain events. Literature suggests that natural effects can be magnified for a period of time where stream flow increases as a result of the timber harvesting. However, the predicted theoretical flow increase resulting from the harvesting operations was insignificant; suggesting that increased stream flow would not be a major mechanism.

In the agricultural catchment, road, tracks, stream crossings and livestock access to the waterway may be the main contributors of sediment resulting in enhanced stream bank degradation. Areas where livestock cross streams and frequent the banks display the highest level of impact and erosion.

Literature indicates that unsealed roads and tracks can also be major sources of sediment in a catchment. Inadequately designed and/or improperly sited drainage structures, especially at approaches to streams and stream crossings can deliver significant volumes of sediment laden runoff. As observed in the plantation, poorly functioning or blocked culverts can concentrate and divert large volumes of flow resulting in gullying creating pathways for the direct delivery of sediment to streams.

Farm tracks and livestock trafficking areas also exhibit symptoms of land degradation and erosion caused by the compaction of soils and concentration of surface flow. The alignment of
farms tracks originating on the crest of hills and moving downhill across contours creates direct sediment delivery pathways to the drainage lines and streams.

In the forest area, there is evidence that recreational use has caused substantial degradation of the road and track network. This damage concentrates runoff and provides pathways for the direct delivery of sediment laden runoff to the waterway.

In summary, agricultural practices are generating the highest direct impact on local water quality with forest harvesting potentially causing indirect impacts. However, recreational use of poorly designed and maintained roads and tracks increases the risk of long-term impacts to water quality. Agricultural and forestry practices can be adapted to reduce their impacts on the landscape, but the nature of recreational use of the areas is much more difficult to manage and control. Properly closed and rehabilitated tracks may continue to be sediment sources or pathways for sediment delivery if heavily trafficked by recreational users. Community education such as the Trail Bike Initiative (Department of Sustainability and Environment 2005) and ongoing maintenance of the tracks will continue to pose interesting challenges to land managers.

6.3.3 What are the relative magnitudes of these impacts?

Agricultural practices generated stream turbidity values over 2 times higher than the maximum target value for upland streams. Stream turbidity from the plantation area was marginally above the target turbidity value for upland streams whilst the forest catchment complied.

However, from a sediment load perspective, high flows and low turbidity values in the forest area combined to produce the highest total sediment load. The value exceeded the agricultural area sediment load by approximately 1,500 kg. The unit area sediment generation rate for the forest area was 206 kg/ha exceeding both the plantation and agricultural catchments at 54 and 74 kg/ha respectively. Finally, once corrected over the period of the study, the sediment generation rates for the forest, plantation and agricultural catchments were 18, 28 and 57 g/m$^3$ respectively.

Analysis of the logged and manual data in combination with the visual inspections indicates that agricultural practices in the Strzeleckis are generating the greatest impact on water quality.
6.3.4 Which management practices are leading to the degradation of the water quality?

Literature suggests that unsealed roads, tracks, and associated structures are major contributors to sediment loads in streams. They are main features of each sub-catchment studied. Improper trafficking of these roads and tracks in the absence of maintenance greatly increases the risk and impact of erosion and sediment generation. As observed in the forest area, continued use of the roads and tracks, especially during wet weather, leads to the formation of gullies eventually resulting in un-trafficable roads. Highly degraded roads and tracks may provide linkages between sediment sources and waterways. Rehabilitation of degraded tracks can become an expensive exercise.

In the agricultural catchment, the following features are believed to generate the highest impacts:
• livestock access to the stream and drainage lines;
• improper siting, design and maintenance of roads, tracks, and drainage structures; and
• in-stream dams.

The plantation area posed a greater challenge since it was not logged as initially planned. In addition, extensive bioturbation was identified as being the most likely source of suspended sediment. The higher turbidity values observed during the lower flow conditions during the warmer summer months supports this concept. However, further study is required to determine the extent to which bioturbation may be contributing to stream turbidity.

Literature suggests that timber harvesting results in increased stream flows for a short time period between the harvesting operations and the establishment of new vegetation. However, in this case, the resultant theoretical flow increase due to the limited harvesting was determined to be insignificant further supporting the concept that bioturbation was the major source of sediment in the plantation catchment.

The following points are general observations related to roads and tracks in each of the areas:
• in the forest area, no direct delivery of sediment was observed upstream from the monitoring point; however, there was evidence of sediment delivery downstream of the monitoring point due to the extensive erosion caused by recreational use of the area;
• **in the plantation area**, a small gully was initiated at the head of the catchment but it was not considered significant, as there was no direct link with the permanent stream and the area was promptly rehabilitated; and

• **in the agricultural area**, direct delivery of sediment to the stream was evident in the following areas:
  - downstream of some culverts and stream crossings;
  - in-stream livestock tracks and watering points.

Literature also suggests that wet weather operations on unsealed tracks are also major sources of suspended sediment in catchments. The extensive network of unsealed and poorly maintained roads and tracks in the upper reaches of the Morwell River are potential sources of sediment. Not only does large vehicular traffic result in impacts but also the destructive action of sustained traffic by recreational vehicles. The popularity of recreational activities in the Strzeleckis may continue to generate significant impacts on the local environment.

However, if considered over the time period since European settlement, the major initiator of erosion in the Strzeleckis has been large scale clearing which occurred between the late 1800’s to the early 1900’s. The destruction of the Mountain Ash forests combined with European agricultural practices initiated large scale erosion and landslips. If considered in this light, current practices are far less damaging to the local environment than the previous change in the landscape. However, continued interest in agriculture and plantation forestry in this sensitive environment requires careful management of natural assets and a tread lightly approach to reduce the environmental footprint of current and future land uses.

### 6.3.5 Which measures or approaches can be modified or implemented to prevent and mitigate the impacts on water quality?

In the agricultural catchment the following steps are recommended to improve water quality for aquatic ecosystem protection:

• restricting cattle access to the stream and by providing properly constructed, formal stream crossings;

• only grazing of stream reaches for weed control and fuel management during low flow / dry weather conditions;

• re-establishing healthy indigenous riparian vegetation;

• proper design and installation of road drainage structures;

• constructing and maintaining sediment control measures at major outlet structures;
• upgrading, surfacing, and/or sealing of main roads and access tracks;
• restricting use of secondary access tracks to dry weather;
• closure and effective rehabilitation of unused tracks;
• maintenance and reinforcing of downstream dam embankments; and
• developing and implementing a series of voluntary land management prescriptions similar to the ones found in the Code of Forest Practices, this could be achieved through a cooperative approach with the Department of Sustainability and Environment, Department of Primary Industries, Catchment Management Authorities, Landcare groups, community groups, and peak bodies such as the Victorian Farmers Federation. The Environment Protection Authority Victoria plays an auditor role in the implementation of the Code of Forest Practices; a similar role could also be beneficial with regards to the implementation of land management prescriptions for agriculture.

In forestry, strict adherence to the Code of Forest Practices would improve sustainability of forestry and protect the landscape of the Strzeleckis. Key features of the Code include:
• implement buffer strips of appropriate width centered on the local environment (buffer widths could be based on Ecological Vegetation Community (EVC) mapping prepared by the Department of Sustainability and Environment or similar measures);
• carefully planned design and proper siting of drainage structures including the use of sediment control features;
• strengthening and maintenance of roads and tracks;
• wet weather operation protocols; and
• proactive rehabilitation and replanting of harvested areas.

However, the implementation of larger buffer widths for significant streams and sensitive environments is also recommended. This would ensure connectivity between habitats providing better ecological health and increased resistance to disease, drought, fire, and other impacts. Generally, this will be achieved through the implementation of the Cores and Links policy. Both the forest and plantation catchments will be included in the protected areas.

Recreational use of forest roads and tracks has also been identified as a potential major contributor to deteriorating water quality in the catchments. It is important to control access to certain areas, upgrade or improve some tracks and close and rehabilitate redundant tracks; however, the most effective way to reduce the impacts of recreational use may be through engagement of user groups and educational programs. Community engagement and education
would raise awareness of the impacts associated with recreational use and encourage responsible use of the areas. Active mapping of the road networks, track rehabilitation, closure of areas, proper signage, and construction of formal stream crossings are all measures which would contribute to the general improvement of the catchment. There are a number of clubs and organisations which mandate responsible recreational trail use. Sponsorship of such groups to lead an educational campaign may assist in raising community awareness. Field personnel should be empowered to approach recreational users with educational material and information.

Legislative change and/or clarification of policy related to Catchment Management Authorities in *Our Water Our Future* (Department of Sustainability and Environment 2004) may prevent the duplication of land management activities. The use of licensing of Crown land and incentives to encourage adjoining land owner to rehabilitate and preserve riparian vegetation on water frontages may be the most significant measure government can take to improve stream water quality.

**6.3.6 How can we predict events of high sediment movement; hence high turbidity, to facilitate treatment of potable water without jeopardizing the water treatment plant?**

Land use change in the Strzeleckis is evolving towards lower impact agriculture, improved forest harvesting practices, and an increase in protected areas resulting from the *Cores and Links* Initiative. Over time, this will reduce the risk of landslides or wide-scale erosion as was observed when the Strzeleckis were initially cleared. In the future, effects are more likely to be localised.

To reduce the risk of high sediment movement in areas that have recently been cleared, it is recommended that best practice measures be adopted. This will minimise the risk of impact to the local environment.

**6.3.7 What is the sediment storage capacity of the catchment?**

Considering the geology and nature of soils in the Strzeleckis, the sediment storage capacity may be considered to be infinite; limited only by the amount of available soil. Sediment movement and deposition are driven by climate, stream flow, landscape change and land use change.
Definition of sediment storage is dependent on the trends of land use change and the amount of sediment rendered available or trapped in certain areas. Riparian zones combined with stable stream channels reduce the amount of sediment available for transport. The extent and quality of vegetation cover and the state of roads and tracks can also dramatically vary the amount of sediment available for transport. Therefore, the move towards more sustainable agriculture and forestry will result in a higher sediment storage capacity by removing sediment sources and sequestering sediment currently in the system.

6.3.8 What storm event can lead to massive movement of the stored sediment?

Historically, high sediment loads in the Strzeleckis have been the result of high intensity storm events, wide-scale land use change, and the failure of drainage and outlet structures.

Land use change and the drive for more sustainable agriculture and forestry will provide a level of stability enabling the local environment to resist higher intensity storm events and recover more quickly in areas that have been compromised.

As illustrated during the initial stages of the fieldwork, a 1:50 storm event caused a number of minor landslips and erosion resulting from concentrated flow and the failure of drainage structures. However, a comprehensive track and drainage structure improvement program and stabilisation of the catchment is gradually improving its resilience to storm-related sediment movement.

6.3.9 How can we improve the general environmental quality leading to sustainable land use?

Sustainable land use in the Strzeleckis can only be achieved through a considered and honest approach to the management of local resources, understanding the nature of the environment, and by respecting its limitations. It is clear that it takes knowledge and foresight to properly manage the landscape in an environment as sensitive. A proactive approach in implementing proper management procedures and the protection of sensitive areas will lead to improved environmental quality and sustainability.

In summary, changes to agricultural practices are key to maintaining and improving the health of the landscape. Important measures to be implemented include:

- restricting livestock access to the stream channels;
- use of bridges over streams rather than crossing within the stream channel;
• establishing healthy indigenous vegetation riparian zones where streams flow throughout the year and establishing filter strips in drainage lines;
• upgrading of access tracks;
• more appropriate siting of drainage structures;
• extensive use of sediment trapping measures;
• upgrading, resurfacing and/or sealing of roads or tracks to prevent the generation of sediment;
• restrict wet weather operations;
• rapid and effective rehabilitation of redundant tracks;
• effective rehabilitation of livestock tracks including fencing of degraded areas to allow for re-establishment of vegetation; and
• removal of redundant in-stream farm dams to encourage free stream flow.

The forest industry has taken significant steps to mitigate the effects caused by its activities. Improved practices and continued responsible stewardship of the land will ensure that the forest industry improves its sustainability in the Strzeleckis. Continued work and advances on the following points will ensure that forestry will continue to improve in the Strzeleckis:
• proper resurfacing and maintenance of haul roads and tracks;
• effective closure and rehabilitation of unused tracks;
• better drainage works including extensive use of sediment trapping measures;
• redirection of surface runoff away from steep coupses, streams and drainage lines;
• maintenance and protection of healthy riparian zones of appropriate width for the conditions being harvested;
• better control of wet weather operations;
• smaller coupses in steeper areas or during wet weather; and
• effective reafforestation of harvested areas with appropriate species.

The growing pressure of recreational use of the area will require proper management to reduce the impacts. As pristine environments become less accessible and as the population increases, the demand on these areas will grow. If the trend towards irresponsible recreational use of the area increases, this may heighten the potential for wide-scale erosion and degradation of water quality. Gullying and erosion of tracks not only reduces the amenity of the area but also restricts access to other vehicles in case of fire or other emergencies. Proper surfacing and maintenance of these tracks is required including a code of practice for
recreational use and wet weather trafficking. The promotion of “FRIENDS OF” groups or other similar community / peer organisations charged with the maintenance of the tracks may result in better maintained and safer tracks.

The land managers and local communities should be encouraged to take an active role in the management of their environment. The use of simple water quality indicators combined with the identification of small changes to the landscape can enable better targeted remedial actions. Indicators include:

- changes in stream turbidity, electrical conductivity and temperature;
- changes in the riparian vegetation health and quality;
- indications of soil erosion;
- changes in the stream channel characteristics; and
- a number of other environmental indicators (i.e., the presence or absence of certain flora and fauna).

### 6.4 Recommendations for Sustainability

Table 6-2 provides a list of recommendations for each land use to help mitigate the land use impacts and thereby improving the sustainability of the landscape.
### Table 6-2 Recommended Measures to Improve the Sustainability of Land Uses.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Element</th>
<th>Findings / Recommendation</th>
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</thead>
<tbody>
<tr>
<td>Research Methodology</td>
<td>Water Quality Monitoring</td>
<td>1. The comparative study approach was demonstrated to be an effective means of monitoring and comparing water quality indicators across catchments.</td>
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<td>2. To draw meaningful conclusions, proper quality control measures need to be implemented including:</td>
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<td>• keeping study areas as close to each other as possible;</td>
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<td>• ensuring that the catchments are within the same geological formations and / or land systems;</td>
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<td>• that the catchments experience the same climatic conditions; and</td>
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<td>• realise that the comparison is only valid for the region being studied.</td>
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<td>3. The simplicity of comparative studies makes them the ideal tool for community groups water quality monitoring projects. This enables them to track regional tends in water quality whilst ensuring that the data they collect can be considered at the local context with regards to local and regional conditions.</td>
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<td>4. Comparative studies enable land managers to identify areas of land use practice that generate the most significant impacts on the local environment and develop measures to mitigate these impacts.</td>
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<td>Issue</td>
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<td>Findings / Recommendation</td>
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</table>
| Research Methodology         | Water Quality Indicators - Turbidity Probe, Level Sensor & Turbidity Tube | 1. Turbidity, Electrical Conductivity, and Stream Temperature were demonstrated to be good indicators of changes in water quality as a result of varying land uses.  
2. Turbidity measurements based on turbidity probes and turbidity tubes demonstrated that turbidity could be easily and reliably measured. Turbidity provided a clear indication of land use impact and the resultant land degradation. Erosion and soil loss in the form of suspended sediment and turbidity is a clear indication land use impacts. The research found that stream turbidity consistently increased with increasing intensity in land management.  
3. Turbidity measurements based on turbidity probes and turbidity tubes demonstrated that turbidity could be easily and reliably measured. Regular maintenance is required to ensure data reliability and proper operation of the turbidity probes. Maintenance included downloading of data, replacement of batteries, cleaning of probes and calibration checks.  
   • Accuracy of the turbidity probes was dependent on proper calibration, installation and maintenance.  
   • The turbidity tube readings could be subject to operator bias.  
4. A level sensor was used to gauge stream flow with respect to the pressure head (i.e., height) of water above the pressure sensor.  
5. The level sensors performed consistently well; however, failure of the weirs prevented a meaningful relationship being developed between pressure head and flow. |
### Issue Element Findings / Recommendation

<table>
<thead>
<tr>
<th>Research Methodology</th>
<th>Water Quality Indicators - Electrical Conductivity &amp; Temperature</th>
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</table>

1. Electrical conductivity was easily measured using a hand-held conductivity meter. As indicated in the literature, stream EC varied slightly with land use. These slight variations may provide evidence of land use impact and / or land degradation. However, the application of pesticides, herbicides and fertilisers or even salt blocks may be contributors to slight increases in stream EC. This raises doubts in the accuracy of EC as a pure measure of measuring land use impacts on the local landscape. For example:

- A heavily grazed pasture not the subject of chemical applications may exhibit a lower EC than a pasture under light grazing but subject to extensive chemical application. The heavily grazed pasture would potentially result in more extensive land degradation not evidenced by EC;

- The stream EC of a plantation forest may slightly increase with the application of fertilisers and pesticides for a short period following the application.

2. Stream temperature observations were made using the same probe as for stream EC. Considering that stream EC is dependent on temperature, the device must also be able to measure temperature.

3. The measured difference in stream temperatures observed across the catchments was a direct indicator of the importance of riparian vegetation on streams. Higher temperatures change the ecology of the normally cold upland streams and impact on the in-stream biota. The use of stream temperature can provide a quick snapshot of the environmental conditions prevalent in the small tributaries of a catchment. However, slight changes in canopy cover of these small upland streams may also result in variations in water temperature. More research is required to quantify these differences.
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<th>Findings / Recommendation</th>
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<tbody>
<tr>
<td>Research Methodology</td>
<td>Monitoring Site &amp; Data Logger</td>
<td>1. The fixed horizontal bank installation and design of the monitoring sites enabled safe access to the monitoring equipment.</td>
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<td>2. The data logger / probe configuration utilised in this project proved to be a simple and effective means of measuring trends in water quality. Proper maintenance was the key to maintaining confidence in the data.</td>
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<td>3. It is recommended that future studies should consider using a data logger configuration incorporating the ability to continuously measure stream EC and temperature.</td>
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<td>4. The use of a vandal proof / concealed installation protected the monitoring equipment from people and from inquisitive cattle. At the agricultural catchment, cattle tried to reach the monitoring equipment and probes on a number of occasions.</td>
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<td>5. Placing the cables in conduit and burial of the conduit provided additional protection from cattle and from gnawing by local fauna.</td>
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<td>6. Proper installation and operation of the weir was difficult to achieve. The action of burrowing animals and cattle created short-circuiting pathways. These pathways were very difficult to identify and repair resulting in erroneous stream flow measurements. It is recommended that alternative stream flow measurements methods should be used in future studies.</td>
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</tbody>
</table>
Grazing was identified as a major contributor to the soil structure decline and to the degradation of the landscape. Recommended measures for the protection of the landscape and improving the sustainability of agriculture include:

a. Protect and re-establish healthy indigenous vegetation riparian zones and buffer strips.

b. Construct formal bridges over stream crossings for livestock to prevent and mitigate damage to stream banks.

c. Manage grazing away from areas showing signs of degradation. This can be accomplished by temporary fencing and active rehabilitation of erosion sites.

d. Discourage livestock from creating and trafficking informal tracks.

e. Limit agricultural traffic and the movement of livestock during wet weather to prevent initiation of erosion.

f. Formalise tracks were required by using appropriate surfacing materials and maintenance.

g. Use low impact tyres on farm equipment to reduce soil compaction and erosion.

h. Direct drainage away from drainage lines, gullies and streams towards paddocks and stable areas.

i. Where practical, reduce the number of livestock and improve pasture grasses to better resist stress and damage from grazing.

j. Where practical, utilise agro-forestry practices mixing grazing and forestry to maximise the use and value of the land.
### Agriculture

<table>
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<tr>
<th>Element</th>
<th>Findings / Recommendation</th>
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<tr>
<td>In-stream Dams</td>
<td>In-stream dams may have a twofold effect on water quality.</td>
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<tr>
<td></td>
<td>a. In-stream dams provide a certain buffer in stream by acting as sediment traps during</td>
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<td>periods of high flow. The reduction in stream flow velocity when the stream encounters</td>
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<td>the dams promotes the deposition of sediment in the dam.</td>
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<td>b. The lower resultant stream flow velocity will also reduce the action of stream bank</td>
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<td>erosion supporting a more stable channel.</td>
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<td></td>
<td>c. During the low flow conditions typically found during the hotter / drier months, farm</td>
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<td>dams trap stream resulting in warmer water whilst encouraging the growth of algae and</td>
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<td>other aquatic flora and fauna. These result in a more turbid stream with lower dissolved</td>
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<td>oxygen levels and in extreme cases, blue-green algal blooms.</td>
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</table>

In-stream dams need to be managed in a way to maximise their sediment trapping capacity whilst minimising temperature effects and the resultant changes in aquatic ecology. Measures include:

- a. Removal of redundant or disused in-stream dams.
- b. Relocation of the dams away from the stream channel.
- c. Establishing a healthy riparian zone, incorporating medium to large trees around the dams. The trees would provide some shade and bank stability.
- d. Active management of the dams to prevent the growth of algal blooms and other aquatic organisms.
- e. Protecting the dam and adjacent riparian zone from the livestock.
- f. Stabilising the embankments with geotextile or rip-rap to provide resistance to erosion and slumping.
The key to sustainable agriculture in the Strzeleckis is the protection of the soil and water resources. The development and implementation of a Code of Practices for Agriculture in the Victorian Uplands would assist land managers in making better decisions with regards to their day to day requirements.

a. Initial steps must include the protection of riparian zones and stream banks but also provide some strategic planning to build on the riparian zones in a way to incorporate agro-forestry into the landscape. Lower density plantations would not only potentially provide "better" more productive pastures but also provide shade for the streams and stabilise the landscape.

b. Farming trees in conjunction with grazing may also provide longer-term economic benefits through initiatives such as carbon sequestration and the concept of carbon credits in addition to the inherent value of high quality timber products.

c. Another means of promoting sustainable agriculture is to encourage producers to adopt environmental certification schemes or agricultural methods which generate lower impacts on the local environment such as organic agriculture.

d. The National Association for Sustainable Agriculture Australia Limited (2003) defines organic agriculture as a form of sustainable agriculture that is able to balance productivity with lower exposure to problems such as pest infestation and environmental degradation, while maintaining the quality of the land for future generations.
If timber harvesting operations are conducted in accordance with best practice they generate very little direct impact on the local soil and water regimes. However, it is important that any harvesting operation be planned in such a way to foresee any issues which may arise from the operation and resultant loss in vegetation.

The protection of the stream and water quality hinges on the implementation and protection of buffer zones and the prevention and mitigation of direct delivery of sediment to the watercourses.

Careful harvesting practices should include:

a. Clearly defined buffer zones.

b. Controlled timber harvesting in areas adjacent to the buffer zones including felling trees away from the zone and if the tree falls within the buffer it should be left in place.

c. Restricting machinery access away from the buffer zones.

d. Harvesting smaller areas, only returning to adjacent areas when the new plantation has re-established.

e. Employing selective harvesting techniques rather than clear-felling where appropriate.

f. Careful management of runoff, including redirecting runoff into the general harvesting area or to heavily vegetated and stable areas.

The forest industry should be encouraged to adopt environmental certification schemes and implement the above measures leading to more sustainable forestry.
### Forestry

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<th>Issue</th>
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<tbody>
<tr>
<td>Forestry</td>
<td>Roads and Tracks</td>
<td>Roads and tracks have been reported as being the major sediment sources in forested catchments. The following points outline measures leading to more sustainable forestry:</td>
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<tr>
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<td>a. Ensure that the roads are properly surfaced and maintained to mitigate impacts resulting from road use.</td>
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<td>b. Audit road drainage structure and replace, upgrade, or redirect drainage as required.</td>
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<td>c. Stream crossings should be properly designed and constructed to accommodate high flows and prevent the direct delivery of sediment to the streams.</td>
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<td>d. Restrict the use of heavy equipment on unsurfaced or sensitive roads, especially during wet weather.</td>
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<td>e. Use geosynthetic materials to reinforce roads and tracks in areas of heavy haulage during a variety of climatic conditions.</td>
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<td>f. Properly close and rehabilitate roads when no longer required. Rehabilitation may include:</td>
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<td></td>
<td>i. Ripping of the road surface,</td>
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<td>ii. Constructing cross bars at regular intervals,</td>
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<td>iii. Removal of culverts and redirecting runoff into stable vegetated areas,</td>
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<td>iv. Planting of trees or other vegetation,</td>
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<td>v. Preventing general traffic and recreational use of the area.</td>
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Recreational use creates an interesting dilemma whereby no specific land manager or land use can be made responsible. It is the responsibility of the recreational users to act in a responsible manner and approach their hobby in a "Tread Lightly" fashion. Public education is the key to minimising the impacts resulting from recreational use of the areas.

A few simple steps can be implemented to help raise awareness, these include: The following points outline measures leading to more sustainable forestry:

- a. Installation and maintenance of interpretive signage at key spots in the catchments.
- b. Community engagement programs including the promotion of user groups.
- c. Enforcement of legislative requirements, if applicable.

However, the most effective means of controlling and mitigating the damage caused by recreational use is the effective closure and rehabilitation of the redundant roads and tracks.

The application of a “special fee” or tax on four wheel drives, dirt bikes, and other all terrain vehicles could be used to fund track maintenance and landscape protection works in heavily trafficked areas. This would ensure that, at a minimum, monies could be made available to shires, companies, or community groups for the upkeep of tracks and protection of the local landscape.

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<td>Roads and Tracks</td>
<td>Recreational use creates an interesting dilemma whereby no specific land manager or land use can be made responsible. It is the responsibility of the recreational users to act in a responsible manner and approach their hobby in a &quot;Tread Lightly&quot; fashion. Public education is the key to minimising the impacts resulting from recreational use of the areas. A few simple steps can be implemented to help raise awareness, these include: The following points outline measures leading to more sustainable forestry: - a. Installation and maintenance of interpretive signage at key spots in the catchments. - b. Community engagement programs including the promotion of user groups. - c. Enforcement of legislative requirements, if applicable. However, the most effective means of controlling and mitigating the damage caused by recreational use is the effective closure and rehabilitation of the redundant roads and tracks. The application of a “special fee” or tax on four wheel drives, dirt bikes, and other all terrain vehicles could be used to fund track maintenance and landscape protection works in heavily trafficked areas. This would ensure that, at a minimum, monies could be made available to shires, companies, or community groups for the upkeep of tracks and protection of the local landscape.</td>
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<td>Issue</td>
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<tr>
<td>Policy / Legislation</td>
<td>Role of Land Managers and Catchment Management Authorities</td>
<td>Encourage the cooperation between Government Department and agencies, land managers and the community to promote the sustainable management of catchments and water resources.</td>
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|                              |                                                                         | *Code of Forest Practices for Timber Production* –  
  a. should be reviewed and updated regularly to reflect improvement in knowledge and incorporate best practice for the forest industry  
  b. should be made more prescriptive and include clearer measurable targets, providing local councils with clearer and more tangible measures for enforcement;  
  c. elements could be adapted to provide guidance to agricultural land managers and recreational use of forest roads and tracks.                                                                 |
|                              |                                                                         | *Victorian River Health Strategy* –  
  a. undertake the transfer of management of Crown frontages from DSE to the Catchment Management Authorities;  
  b. formalise water frontage boundaries through survey;  
  c. develop measures to rehabilitate riparian zones including weed management, control of stock access and bank stabilisation works;  
  d. promote the value of riparian zones through public education and community engagement.                                                                                                                                                           |
The forest catchment is scheduled to be harvested in the future. The data collected during this study presents an ideal opportunity for continued monitoring of pre-harvesting, during harvesting, and post-harvesting water quality. This would enable a better understanding of the effects of logging in the Strzeleckis; without the influence of bioturbation such as was encountered in the plantation area.

Detailed stream flow and turbidity monitoring including suspended sediment concentration sampling and analysis could be undertaken at the forest catchment and the agricultural catchment to generate a predictive model relating suspended sediment loads with stream flow.

Further research in the catchment of the Gippsland Lakes could incorporate the use of stream electrical conductivity and temperature monitoring as indicators of water quality. They are potentially a simple and cost-effective means of measuring water quality and catchment health. Further work is required bolster the confidence in these water quality indicators as a means to measuring land use impacts.

Timber Harvesting

Water Quality Indicators - Stream flow & Turbidity

Water Quality Indicators - Electrical Conductivity & Temperature

Bioturbation

Bioturbation has been identified as a potential major source of suspended sediment in the plantation area. Additional catchment surveys should be conducted to determine the extent and magnitude of bioturbation in the Strzeleckis. The impacts of bioturbation on water quality should be determined using additional comparative stream monitoring. Catchment surveys
should also include the identification of fauna responsible for bioturbation. This would enable land managers to identify sub-catchments which may be more susceptible to bioturbation.

| Recreational Use | The growing popularity and affordability of recreational vehicles is leading to increased usage of sensitive forested areas. The potential for large scale damage to the landscape increases with irresponsible recreational use. Further work is required to determine the extent and magnitude of damage caused by recreational use in the Strzeleckis; findings of which may help to plan remediation works. This type of research could be accomplished by means of visual inspections, user surveys, and stream water quality monitoring. |
6.5 Discussion

For the protection and enhancement of the local environment and water quality, land use practices must evolve and adapt to the environment. Improvements to the water quality in the Morwell River will contribute to current measures being undertaken to improve the water quality of the Latrobe River and hence the general condition of the Gippsland Lakes. However, the Morwell River is only a very small contributor to the flows into the Lakes. Lessons learnt in the catchment of the Morwell River could be adapted to generate a catchment wide strategy for the improvement water quality and amenity of the Lakes.

For sustainable grazing, it is essential that livestock access to watercourses be appropriately managed allowing for the re-establishment of healthy riparian zones populated with indigenous vegetation, stabilisation of the stream channels, and an overall improvement in water quality.

If, on the steeper slopes of the Strzeleckis, similar riparian zone widths as the ones for forestry were to be applied to agriculture, this would enable the riparian vegetation to re-establish and form a healthy ecosystem. This would not only help to stem the delivery of sediments but also trap nutrients. Along the larger rivers with formal Crown land frontages, Government, through catchment management authorities, could implement incentives, policy, regulation and/or legislation to achieve healthier catchment outcomes.

Protection and enhancement of stream riparian zones in the plantation areas is also of paramount importance. As discussed in previous chapters, the harvesting of large areas can initiate a number of issues including increased erosion and landslips, and an increase in stream flow (albeit for a relatively short time period). The protection and proper management of existing riparian zones and the implementation of larger buffer and filter zones would not only improve general water quality would also provide enhanced habitat and increased connectivity between areas.

Contemporary literature clearly recognises that roads and tracks are critical areas requiring attention in both agriculture and forestry. Issues surround the design, use and maintenance of the road network especially at approaches to streams and stream crossings. Proper siting and design practices must consider road drainage and the conveyance of surface flow away from streams, through filter strips and other sediment trapping mechanisms. Surface flow especially
that from road surfaces can be a major source of sediment to streams and it has been demonstrated that if the flow is channelled away from the waterway and dispersed into a vegetated area, the majority of the sediment is trapped.

Wet weather operation is also a crucial component to proper land management. Proper surfacing and maintenance of roads and tracks mitigate the risks of impacts on water quality; however, heavy traffic during wet weather causes road surface damage resulting in increased sediment generation. Therefore, upgrading the road network, and implementing wet weather operation guidelines for both agricultural and forestry traffic can help reduce the overall impact to the environment. In forestry, consideration of and adherence to the *Code of Forest Practices for Timber Production* is essential to ensure a sustainable forest industry.

### 6.6 Conclusions

The comparative study utilising water quality indicators was an effective means of evaluating the impacts of land uses in the catchments being studied. The data was readily compared across catchments. The weekly manual observations were the key to maintaining confidence in the logged data. Under low flow and warm conditions, the turbidity probes began fouling after approximately five days following cleaning. However, in the faster flowing streams no fouling of the turbidity probe’s lens was detected. Also, the lenses self-cleaned when a sudden flush of faster flowing water rushed by as would occur during a rain event of moderate to high intensity.

In addition to turbidity and suspended sediment concentration relationships, stream flow is a key element for estimating load or volume of pollutants. Determination of the loads of pollutants moving through the catchments enables the land manager to determine which areas in the catchment are the largest contributors of pollutants to the system. Stream flow is also key for the development of a per unit relationship for each land use. This relationship could also be used as a predictive tool to estimate pollutant loads over a range of climatic conditions. As illustrated in the study, stream flow can be relatively easily measured with the use of a sharp-crested 90° V-notch weir. Proper siting and installation, taking into account leakages and short-circuiting, ensures that accurate flow measurements are achieved. However, these relationships require continuous calibration and checks, especially if catchment conditions change over time.
Site selection proved to be the most difficult step in the process. Finding a stream to satisfy all of the site selection criteria presented a real challenge. Some of the site selection criteria included:

- reliable flow throughout the year;
- suitable stream reach near the outlet to of the catchment to construct a small dam and install a weir;
- safe area away from view to safeguard against vandalism and damage by people and animals (cattle are very inquisitive and destructive); and
- safe access for the monitoring runs.

One major impediment to stream flow measurement in the catchments was the action of burrowing crayfish. They were attracted to the deeper pools created by the installation of the weir and monitoring equipment. They burrowed in the banks both upstream and downstream from the weir causing short-circuiting and leaking around the weir. Their action also resulted in enhanced stream bank erosion downstream of the probes.

Soil dispersion testing confirmed that the soils in the study area are not subject to swelling or slaking, ruling out soil dispersion as a potential source of suspended sediment in local waterways. This finding was supported by the steady state / low flow turbidity encountered in the forest area. The turbidity was observed to be below detection limits (less than 10 NTU) for extended periods of time.

In summary, the literature review suggested that forestry; in particular timber harvesting increases the risk to local water quality. However, the conservative timber harvesting practices employed in this project did not yield the predicted theoretical impacts. This is a significant finding as it can inform the development of sustainable timber harvesting practices in the Strzeleckis.

The observed extensive bioturbation in the riparian zone of plantation area is also a significant finding. This represents a novel observation from the research. The extent of bioturbation was not evident in the forest area, suggesting that it may be the most significant contributor to the degradation of water quality in the plantation catchment.

From a water quality perspective, agriculture was found to be generating the greatest impact on the local waterway during all flow conditions. Establishing and maintaining healthy
riparian zones and preventing or controlling stock access to the streams would assist in the protection of the local water resource. However, from a total sediment load perspective, the forest area contributed the highest total sediment load due to higher volumes of stream flow. This suggests that the natural processes in the Strzeleckis may remain the principal mechanisms for sediment movement within the catchment. This significant outcome should be taken into account during the assessment and categorisation of waterways and catchment health. The natural movement of sediments in healthy waterways must be considered as an essential process in the overall catchment’s hydrological cycle.

Finally, this project has developed insights into the major environmental processes active in the upper catchments of the Morwell River. Understanding of the contributions to total sediment loads from natural erosional processes and bioturbation, findings related to impacts on water quality from agricultural practices, and encountering negligible impacts from conservative timber harvesting practices demonstrate that catchment management approaches need to be tailored to achieve sustainability in land uses across the landscape. Key recommendations include the re-establishment and protection or riparian zones in agricultural catchments, the careful assessment and setting of stream buffer zone widths for timber harvesting operations, and the need for further work to map the extent of natural processes such as bioturbation and stream bank erosion. Increasing recreational use of the area poses a significant threat to the local water quality and overall catchment health. To mitigate these issues, government policy and legislation will need to focus on the preservation and enhancement of the Crown land riparian zones. Changes to current management arrangements for these sensitive area including a move from licensing the riparian zones for agricultural practices such as grazing to conservation and empowering land managers such as the Department of Sustainability and Environment or the Catchment Management Authorities to undertake restorative works on these areas will result in improvements to water quality and overall catchment health.

A systematic approach in the preservation and improvement of riparian zones and land management will not only improve the health of the Morwell River, but also deliver overall benefits to the Gippsland Lakes.
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APPENDIX A - History of the Strzeleckis

The following historical account has been adapted from a variety of sources but the majority of the information was found in The Strzeleckis: A New Future for the Heartbreak Hills, Noble (1976; 1986).

The Strzelecki Ranges took their name from an explorer who came to Australia and spent four years exploring, travelling and examining the natural resources of the country. Paul Edmund de Strzelecki, as seen in Figure 1, was born in the Prussian-annexed part of Poland in 1797. He left Poland for England in about 1830, and then travelled through Britain, North and South America, the South Sea Islands, and New Zealand before arriving in Australia in 1839.

![Figure A-1: Paul Edmund de Strzelecki (Noble 1976)](image)

In January 1840, Count Strzelecki started south from Sydney accompanied by James Macarthur, intending to reach Port Phillip and go onto Tasmania. By February 15, he reached the summit of Mount Kosciusko, which he named after the Polish Patriot. From there he pushed south, crossing the Latrobe River and entering the dense forests that lay to the south and west. For 22 days, he and his party struggled through the brush, at times unable to cover
more than three kilometres in a day along the main ridge of the range, basically following the route of the Grand Ridge Road.

With the help of local aboriginal guides, they reached Westernport on May 12 practically exhausted with their clothes torn to shreds by the thick scrub. From there, Count Strzelecki went on to Melbourne and Tasmania and eventually left Australia in 1843. After leaving Australia, Strzelecki was awarded the Founder’s Medal of the Royal Geographic Society, was made a Companion of the Bath for his relief work in the Great Irish Famine, became a Fellow of the Royal Society and was awarded a K.C.M.G. He died in 1873.

Strzelecki was not the first to discover Gippsland. Angus McMillan discovered the area in 1839 in search of fresh pastures for the growing herds of the developing stations in southern New South Wales. McMillan founded numerous stations, became the first representative for South Gippsland in the Victorian Legislative Assembly and named many of Gippsland’s natural features including the Nicholson, Mitchell, Avon, and Macalister Rivers.

After McMillan and Strzelecki opened the way, it did not take long for settlement to develop along the river flats and grazing lands of Gippsland. The early settlers entered the western hills along the two main river valleys, working their way northward up the Tarwin River and southwards along the Morwell River.

The first settlement was established at Mirboo-on-Tarwin in 1876, and from there the land was quickly taken up. By 1887, every acre of the Strzelecki Ranges had been alienated from the Crown and claimed by private selectors.

The original forest of the Strzelecki Ranges was made up of a vast tangle of great trees. The big timber species consisted of Mountain Ash (*Eucalyptus regnans*), Blue Gum (*Eucalyptus globulus*), Candlebark (*Eucalyptus rubida*), Messmate (*Eucalyptus obliqua*), Swamp Gum (*Eucalyptus gunnii*), and large Blackwoods (*Acacia melanoxylon*) (Kim and Julie 2002). Many of which can still be found in remnant areas untouched by the settlers.

The selectors faced clearing 90 metre high trees with average diameters of two to three metres. Some trees had girths of 18 metres of more with buttresses running six metres up before merging into the trunk. At Bulga, a tree was measured at 29.5 metres circumference two metres from the ground. Near Boolarra, a tree had an inside diameter of eight metres. It
was used for a time as a church and hall, with space for 50 people, latter becoming a stable for five horses, as seen in Figure 2.

Beneath the trees grew a dense jungle of smaller species such as hazel, musk, wattle, and others combined with swordgrass and wiregrass as depicted in Figure 3. The mountain gullies were populated with tree ferns growing to heights of up to 12 metres. Supplejacks twined themselves around the trees, especially on the ridges and among the hazels. The swordgrass grew up to three metres high with leaves 25 millimetres wide. The understorey was so dense that the settlers feared to wander far from their campsites because of the danger of becoming lost. Some used compasses to keep direction in the scrub.

Settlers had to face not only the dense vegetation but also an abundance of leeches, scorpions, and snakes. Native animals included dingoes, wallabies, koalas, possums, bandicoots, bush rats, echidnas, platypuses, bats, and a wide range of bird life including lyrebirds, and numerous varieties of parrots. It was claimed that the scrub was too dense to allow kangaroos to flourish (Noble 1976; Kim and Julie 2002).
The damp, wet environment turned their leather goods mouldy, and matches had to be kept in a dry place or they became useless.

Original selectors were limited to 130 hectares but some held less. Clearing was achieved by partly cutting through trees working their way uphill, where at the top of the slope one large tree would be felled onto the others creating a domino effect on the other trees. This left a tangled, compacted mass of scrub, undergrowth and fallen timber. This was left to dry then set alight in the middle of summer. The success of the whole operation depended on getting a clean fall and a good burn. The results of this are shown can be seen in Figure 4.
As the forest was cleared, roads and tracks improved access and communications between the settlers. However, winter rains deteriorated the roads creating mud canals over which nothing could travel except horses and sledges. Accounts of the times include descriptions of horses becoming bogged in seemingly bottomless mud, as illustrated in Figure 5. Sledges passed along the winter roads pushing a wave of mud in front like the bow wave of a ship.

Settlement created a major change in the landscape. Ultimately, the settlers achieved their ambition and the forest was cleared, almost to the last tree; thus, completing one of the most rapid and dramatic changes experienced by any landscape in the world. Virtually all of the mountain ash forest was cleared during the 1880’s and 1890’s except for two very small areas at Bulga Park and Tarra Valley which are now protected as National Parks (Brumley 1993).
The combination of climate and bush fires, steep slopes, erosive soils, weeds and pest drove many settlers away. A State Development Committee report stated:

“It is a tragedy that so much effort was put into the destruction of these forests, only to find that the majority of it was unsuitable for the purpose for which it was cleared.”

The Forest Commission began purchasing property in the early 1930’s reaching a peak between 1944 and 1951. By 1976, the Forests Commission has purchased a total of 22,300 hectares of land, and approximately 9,000 hectares of land abandoned by the owners, which reverted back to the Crown, was designated as Reserved Forest.
APPENDIX B – Ecological Vegetation Classes

EVC 30 – Wet Forest
Wet Forest is predominantly a tall forest characterized by a layer of broad-leaf shrubs over a dense cover of tree-ferns and ground ferns. It occurs on relatively fertile soils such as deep organic loams and clay loams in the topographically protected high rainfall areas and headwaters of south flowing streams on the south side of the Great Dividing Range in the Avon Wilderness, around Mt Baldhead, Mt Elizabeth and on the southern fall of the Nuniong Plateau. It is also widespread in South and West Gippsland, particularly in the Strzelecki Ranges and at Wilson’s Promontory.

This EVC includes a very wide range of structural variation ranging from tall old-growth forest up to 60 meters in height through to regrowth forest and scrub which has the potential to support tall forest. It also includes treeless areas dominated by wet scrub and even “old fields” which were once cleared but are now dominated by native vegetation. These areas are typically dominated by broad-leaved shrubs such as Snow Daisy-bush (Olearia lirata), Hazel Pomaderris (Pomaderris aspera), and Three-nerved Cassinia (Cassinia trinerva). The native fireweed, Fireweed Groundsel (Senecio linearifolius) is often present.

Wet Forest is dominated by Mountain Ash (Eucalyptus regnans) but may also be locally dominated by Blackwood (Acacia melanoxylon) or Silver Wattle (Acacia dealbata). A range of other eucalypt species can be present but these tend to be on the periphery of extensive areas dominated by Mountain Ash (Eucalyptus regnans). These include Manna Gum (Eucalyptus viminalis) often occurring along major river flats and on associated slopes, Strzelecki Gum (Eucalyptus strzeleckii), Gippsland Blue Gum (Eucalyptus globulus ssp. pseudoglobulus), Messmate (Eucalyptus obliqua), and Mountain Grey Gum (Eucalyptus cypellocarpa) which occurs on the edges of Wet Forest stronghold areas immediately before Damp Forest (another EVC class) becomes more developed.

Tree-ferns are sometimes present, particularly Rough Tree-fern (Cyathea australis) on the slopes and Soft Tree-fern (Dicksonia Antarctica) along the creek lines as well as some of the “wet-ferns” such as Mother Shield-fern (Polystichum proliferum) and Hard Water-fern (Blechnum wattsii).
Common understorey species are the broad-leaved shrubs such as Snow Daisy-bush (*Olearia lirata*), Musk Daisy-bush (*O. argophylla*), Blanket Leaf (*Bedfordia arborescens*), Hazel Pomaderris (*Pomaderris aspera*, *Cassinia* spp.), Tree Lomatia (*Lomatia fraseri*) and Austral Mulberry (*Hedycarya angustifolia*). The prickly shrub, Prickly Currant-bush (*Coprosma quadrifida*) and the vines Mountain Clematis (*Clematis aristata*) and Wonga Vine (*Pandorea pandorana*) are also often present. Other shrubs sometimes include Sweet Pittosporum (*Pittosporum undulatum*), Tree Lomatia (*Lomatia fraseri*) and Victorian Christmas-bush (*Prostanthera lasianthos*).

At the drier end of this group the understorey becomes very low in stature (less than 2m) and broad-leaved species other than Snow Daisy-bush (*Olearia lirata*) are notably absent. This variant tends to occur on the most exposed, drier northerly aspects.

The Wet Forest develops extensively around the localized areas of Cool Temperate Rainforest. Thin remnants of riparian vegetation represented by this EVC contribute to biodiversity conservation. The beds and banks of streams, particularly smaller stream tributaries, are important areas for the Strzelecki Burrowing Crayfish and deep gullies may provide important refuge habitat for gliders and possums following logging activities (Timewell, Hill et al. 2001).

**EVC 31 – Central Highlands Cool Temperate Rainforest**

This EVC is further classified by floristic community to be EVC 31-01 Central Highlands Cool Temperate Rainforest.

The Central Highlands Cool Temperate Rainforest is only found in the highest rainfall areas of Wet Forest associated with the most topographically protected sites in the Strzeleckis and Wilson’s Promontory. There are also isolated occurrences in the foothills of the Great Dividing Range including the headwaters of Freestone Creek and Mount Useful Creek. It typically occupies protected south and south-easterly aspects and gullies of sheltered streams. On some southern slopes that have not seen fires for long periods of time, the community can extend upslope beyond its usual gully refuge, even to minor saddles.

The Central Highlands Cool Temperate Rainforest is characterized by a low diversity of trees, grasses, sedges, herbs and climbers and a high diversity of shrubs and ferns. The canopy is typically dominated by moss-covered Myrtle Beech (*Nothofagus cunninghamii*) and Southern
Sassafras (*Atherosperma moschatum*) but localized adjoining areas may also be dominated by Blackwood (*Acacia melanoxylon*). Scattered emergent Mountain Ash (*Eucalyptus regnans*) may also be present.

The fern-dominated understorey is typically open in structure and may include stands of old-growth Soft Tree-fern (*Dicksonia Antarctica*) with trunks covered with a diversity of delicate epiphytic filmy-ferns. These plants are only one cell thick and are extremely sensitive to drought stress. Species such as Austral Filmy Fern (*Hymenophyllum australe*), Narrow Filmy Fern (*H. flabellatum*) and Shiny Filmy Fern (*H. rarum*) are good indicator species for the group while Common Filmy Fern (*H. cupressiforme*) is also frequently present. The Rough Treefern (*Cyathea australis*) frequently occurs upslope from watercourses; the rare Slender Treefern (*Cyathea cunninghamii*) and Skirted Treefern (*Cyathea x marcescens*) are good indicator species for this group occurring closer to the gully floor and being more reliant on moisture.

A number of other epiphytic ferns are present on tree trunks such as Kangaroo Fern (*Microsorum pustulatum*), Weeping Spleenwort (*Asplenium flaccidum*), and Common Finger Fern (*Grammitis billardieri*), and the climber Fieldia (*Fieldia australis*) is also commonly found. Rare epiphytic primitive fern allies are sometimes present such as Long Fork-fern, (*Tmesipteris oblique*). Groundcover includes a number of “wet fern” species such as Mother Shield Fern (*Polystichum proliferum*) as well as Leathery Shield Fern (*Rumohra adiantiformis*) and a diversity of *Blechnum* species including Hard Water Fern (*B. wattsii*), Lance Water Fern (*B. chambersii*), Strap Water Fern (*B. pattersonii*) and Ray Water Fern (*B. fluviatile*).

Timewell et al.(2001) suggest that this endangered EVC possesses high regional conservation significance.
APPENDIX D: Paper Presented at the IEAust National Environment Conference 2003, Brisbane
APPENDIX E: Paper Presented at the International Conference on Sustainability Engineering and Science 2004, Auckland
A Comparative Study of Land Uses in the Strzelecki Ranges of Southeast Victoria, Australia

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EXECUTIVE SUMMARY

Prior to European settlement, the Strzelecki Ranges in South East Victoria, Australia were densely populated by temperate rainforest-type vegetation similar to remnant populations presently found in local reserves and parks. Since the early 1900’s, European settlement dramatically changed the landscape of the Strzeleckis by clearing the native vegetation for timber harvesting, agricultural pastures, and for the establishment of homesteads and communities. These activities have exposed highly erodible soils and created areas prone to significant landslips. Erosion and landslips not only lead to reduced productivity of the soils but also contribute to poor water quality in the catchment and diminished environmental health and ecological diversity.

This research project is focussing on the upper reaches of the Morwell River. The Morwell River is a tributary to the Latrobe River, which provides approximately 30% of the inflow and 39% of the suspended sediment load into the environmentally sensitive Gippsland Lakes. The Gippsland Lakes are a group of coastal lakes separated from the ocean by sand dunes. The lakes support commercial fisheries, water-based recreation, and tourism. They have also been recognised as having major conservation values including being listed as wetlands of international importance. The ecology of the lakes is under major environmental stress as evidenced by large variations in lake-bed vegetation and substantial algal blooms. Sediment and nutrient loads have been identified as major contributors to the degradation of the Gippsland Lakes ecosystem.

The Morwell River is also a water supply source for local communities. Water is drawn from the river and treated prior to being conveyed to the homes. Consistent water quality in the river is essential to ensure maximum treatment efficiency and potable water quality. Past events of high suspended sediment loads have caused the failure of some water treatment plants, jeopardizing the security of supply.

The project is comparing the relative impacts of each major land use in the upper reaches of the Morwell River. The major land uses include forestry, agriculture, and protected forests. The water quality indicators of turbidity, and electrical conductivity were used to measure the environmental impacts associated with land management practices.

Preliminary observations indicate that agricultural practices are contributing approximately two times the suspended sediment load and about 1.5 times the dissolved solids concentration than timber harvesting and plantation management. It has also been observed that the natural processes of stream bank erosion, landslips, and bioturbation...
are direct contributors to the sediment loads in the streams and rivers. With indications that bioturbation is a major source of suspended sediment in the logged catchment.

Although similar research has been performed in other catchments, a project linking the broad range of land uses and management practices with water quality in the Strzeleckis is not evident in literature. Given the mixture of land uses and special environmental values associated with this part of Australia, the findings of this work will provide valuable information on appropriate catchment management and land use planning measures leading to more sustainable land management practices. This will translate to better, more reliable water quality and environmental health, and contribute to improvements in the Gippsland Lakes system as a whole.

INTRODUCTION

Soil erosion is a natural process occurring in most environments but is more frequent and potentially more damaging in landscapes with high rainfall intensity, steep slopes and friable soils such as the ones found in the Strzelecki Ranges of Southeast Victoria. Where the protective vegetative cover is removed or degraded by timber harvesting, tillage, grazing, or recreational use; the risks of erosion can be substantially increased. The removal or destruction of riparian vegetation further increases the risks and impacts of erosion by creating pathways whereby direct delivery of sediments to the watercourses can occur and by accelerating streambank erosion processes.

Soil erosion also has the potential for downstream impacts on creeks, rivers, reservoirs, lakes, and estuarine and marine environments. The Australian Natural Resources Atlas (2002) states that high concentration of suspended sediments in rivers can:

- reduce stream capacity,
- inhibit respiration and feeding of stream biota,
- diminish light needed for plant photosynthesis,
- require treatment of water for human consumption,
- smother the stream bed,
- increase the nutrient loading, and
- increase the potential for flooding.

Some of these impacts have been observed in the Gippsland Lakes. The ecology of the lakes system is under stress as evidenced by large variations in lake-bed vegetation cover, more frequent toxic algal blooms, and the perception of fishermen and recreational boaters that the lakes are becoming shallower. The increase in suspended sediment and nutrient loads into the lakes has been documented and attributed to land use changes in the upper catchments (Eskrine et al., 1990). One of the major tributaries to the Gippsland Lakes is the Latrobe River.

The Latrobe River provides approximately 30% of the total discharge to the lakes and 39% of the suspended sediment load which is by far the largest contributor of suspended sediment to the lakes system (Eskrine et al., 1990). The next highest contributor is the Avon River contributing 13% of the suspended sediment load whilst providing approximately 7% of the inflow.

The Morwell River which originates in the Strzelecki Ranges flows into the Latrobe River. According to a lifetime resident of the area, the Morwell River has traditionally been a “dirty” river (i.e., carried high suspended sediment loads) especially during high flows associated with strong rain events. In order to understand and manage the impacts of the
land uses in the Strzelecki Ranges, it is important to understand the mechanisms both natural and anthropogenic by which suspended sediment is delivered to the streams feeding the Morwell River. It is also important to determine which land uses contribute the highest loads of suspended sediment.

The State Environment Protection Policy (Water of Victoria) (SEPP), Schedule F5 Protecting Water Quality in Central Gippsland states that “The Central Gippsland region contains one of Victoria’s major river systems – The Latrobe River - the health of which has a major influence on the environment of the Gippsland Lakes. Good Water Quality and adequate flows within the waterways are essential to sustain the many uses of water resources in Central Gippsland and the Gippsland Lakes”. The study area is shown in Figure 1.

**Historical Context**

Prior to European settlement, the Strzeleckis were densely vegetated by wet sclerophyll vegetation and cool temperate rainforests similar to the vegetation shown in Figure 2. Settlement meant a major change in the landscape.

During the period from the 1880’s to the late 1890’s, the settlers achieved their ambition and the forest was almost completely cleared; thus, completing one of the most rapid and dramatic changes experienced by any landscape in the world. Over 5000 km² of mountain ash (*Eucalyptus regnans*) forest was cleared (Brumley, 1993). An example of the clearing is illustrated in Figure 3.
By the 1930’s dairying and grazing had become uneconomic in the steeper, eastern part of the ranges because of weeds, pest animals, isolation from transport and markets, increasing labour costs, and lower returns. This led to many farms being abandoned and overgrown by weeds and scrub. From the 1940’s onwards, many abandoned and marginal farms were reclaimed by the State for the establishment of mountain ash and pine plantations (Aldrick et al., 1988). The majority of the plantation areas are now under the management of Hancock Victorian Plantations (HVP) through their subsidiary in Gippsland; Grand Ridge Plantations (GRP).

**Current Context**

Present land uses in the Strzeleckis include agriculture primarily beef production and dairying, forest plantations, protected forest habitats and small communities. In the steeper reaches of the Strzeleckis, forest plantations, agriculture and protected forests dominate the landscape. Each of these activities has the potential to impact the water quality and ecological health by exposing areas to soil erosion and landslips. Given their potential to create erosion and environmental degradation, these major land uses were targeted by this research project.
The Strzeleckis pose interesting challenges to plantation management. GRP manage timber harvesting and site preparation operations as per the requirements of the Code of Forest Practices (Department of Natural Resources and Environment, 1996). However, the Code of Forest Practices falls short of providing the necessary requirements to protect environmental values in the Strzelecki Ranges. Consequently, GRP have developed Best Management Practices that go beyond the requirements of the Code in an attempt to prevent and mitigate the impacts of forestry activities within these plantation areas. GRP are presently upgrading existing roads and tracks, improving drainage, and modifying timber harvesting approaches to prevent impacts on the local water quality. Alexander (2001) explained that some of these approaches include:

- quick rehabilitation of logged areas,
- leaving hardwood plantation permanent stream buffers intact and marking these prior to harvesting to ensure that permanent streams are fully protected,
- construction of cross banks across snig tracks,
- installation of sediment traps on road drainage structures, along with outlet protection, and
- redirection of water from drains on to undisturbed vegetation, unconsolidated soil or into logging slash.

Current agricultural practices on properties in the Strzeleckis clearly demonstrate the need for improved land management approaches. Examples of poor land management include unabated cattle access to drainage line and streams which create erosion hazards by accelerating the stream bank erosion processes. This combined with the lack of protected riparian vegetation opens up pathways for enhanced sediment delivery into the local waterways.

The current emphasis on the health of the Gippsland Lakes combined with the trend towards more sustainable land management practices makes forestry and agriculture in the Strzeleckis important components of the total catchment. The erodible soils, high rainfall, and intense management of the Strzeleckis pose an interesting challenge. Data and knowledge need to be gathered to better plan and manage these land uses. The following points detail the research questions that are being investigated to better
understand the land management processes and their linkages to environmental health. The research questions are:

- what is the baseline water quality in the catchment?
- what are the impacts on water quality from forestry, agriculture, and recreational use?
- what are the relative magnitudes of these impacts?
- which measures or approaches can be modified or implemented to prevent and mitigate the impacts on water quality?
- how can we improve the general environmental quality leading to sustainable land use practices?

Climate and Geology

The average maximum temperature in the Strzeleckis ranges from 23.3°C in January to 11.1°C in July, and the average minimum ranges from 9.6°C in February to 2.3°C in July. The highest recorded temperature reading was 39.7°C and the lowest –6.1°C (Noble, 1986).

Noble (1976) explains that the Strzeleckis exercise an important influence on the weather of central and east central Gippsland. The moisture-laden winds that blow from the southwest drop much of their rain on the slopes and ridges of ranges. The annual rainfall reaches a maximum of over 1,400 millimetres (Noble, 1976). Some areas have recorded rainfall of 170 millimetres in a period of 24 hours (Aldrick et al., 1988). Intense rainfalls are most likely from January to March, when vegetative growth is reduced making this period a particularly critical time for erosion (Aldrick et al., 1988).

With their heavy and normally regular rainfall, the Strzeleckis are a reliable source of water for the creeks and streams that flow out of their catchments. Towns that draw water from the northerly flowing streams of the Strzeleckis include Thorpdale, Boolarra, Mirboo North, Yinnar and parts of Churchill. In addition, some water is taken from the streams by landowners for stock and domestic use. The high rainfall makes it unnecessary to irrigate the area (Noble, 1986).

For the years of 1968-1969, a maximum stream flow of 57,110 megalitres, and a minimum annual stream flow of 13,570 megalitres was measured for the Morwell River at Boolarra (Aldrick et al., 1988).

Aldrick et. al. (1992) state that most of the soil is composed of yellowish friable porous earths which are highly structured, strongly acid loams providing a good formation for root growth and absorption of rainfall. They have identified major land systems in the upper reaches of the Morwell River catchment as the Gunyah, Jeeralang, and Livingston land systems. All of these systems belong to the Cretaceous sandstones, mudstones, siltstones, and conglomerates of the Strzelecki Group.

Only low to moderate degrees of pedologic organisation are characteristic of soils in this environment due to continual mixing of the soil by slope processes and bioturbation. These processes are variable, the steeper gradients and longer slopes tend to produce larger volumes of runoff, faster flow rates and the potential for more soil loss; however, such losses are reduced where there are deep permeable soils and dense protective vegetation. Bioturbation and erosion are generally severe enough to lead to a predominance of soils with uniform texture and little other differentiation. Most of the soils are strongly leached, as shown by pH values of 4.2 to 5.0 (Aldrick et al., 1988).

The low runoff compared to the relatively high rainfall can be explained by the fact that the Strzeleckis are basically unwarped, faulted and extremely eroded areas of Mesozoic
sandstones and mudstones, which in parts are capped by Older Basalt and minor amounts of Lower Tertiary formations. They are deeply dissected by valleys of comparatively recent formation, with steeply sloping sides and sharp ridges (Noble, 1986). The brown earth as found in the Jeeralang land system, available water storage in the top 500mm of soil is about 60mm; while the Krasnozemic soils can store about 110mm of water in the top 500mm of soil. The infiltration capacity and surface soil permeability are extremely high and as a result, overland flow is low under nearly all rainfall events (Aldrick et al., 1988).

Aldrick et. al. (1992) continue characterising the land systems by stating for all three land systems that cultivating, logging, burning, road building, and other earth moving activities, and stock trafficking, which are all common land uses in the Strzeleckis, create a moderate to high risk of erosion as shown in Figure 4.

![Figure 4 Historical erosion and landslips due to clearing on slopes (Noble, 1986)](image)

**METHODOLOGY**

For the first part of the research, three study areas were selected. These areas are highlighted in Figure 5. The areas represent a logged forest plantation, agricultural land, and undisturbed forest area. As much as possible, each of the study areas possessed similar site conditions including climate, soil type, and area size. A paired catchment approach as described by O'Shaughnessy et al. (1995) was adopted to compare the relative impacts of forestry and agriculture with respect to the undisturbed catchment.

To ensure that no other land use would affect the results in each of the study areas, the selected sub-catchment areas were located at the head of the Morwell River catchment. This would eliminate the likelihood of monitoring impacts generated by other land uses within the larger catchment areas.

The following points detail the experimental approach for this research project:

Sites were selected representing each major land uses in the Strzeleckis. Site selection was accomplished using topographic maps, a geographic information system-based
database (GIS), and aerial photographs. The sites were then inspected and deemed suitable or unsuitable based on the criteria listed below. In addition to the above criteria, the sites were judged on the following features:

a. safe and convenient access under the various climactic conditions to be expected during the study period,

b. continuous water flow even during the drier periods encountered during summer,

c. suitable location on the stream to construct a weir or small dam to ensure that the probes remained submerged even during low flow conditions,

d. ease of concealing the monitoring equipment to prevent damage or vandalism,

e. commitment from GRP that the harvested site would be harvested during the period of the study and that the undisturbed area not be logged nor intensively managed during the period of the study.

Monitoring stations were constructed at the base of each sub-catchment. The sites were constructed using sandbags and a 90° V-Notch Weir to gauge stream flow. The monitoring stations consisted of the following equipment:

f. Greenspan TS100 Turbidity sensor with a turbidity detection range from 0 to 250 NTU, the turbidity probes were selected and sighted in the stream as described by Gippel (1994).

g. 6508 B 2m Pressor Sensor Probe to measure water level for determination of stream flow.

h. Micrologger Data Logger 2 X 4-20 mA inputs for continuous monitoring of turbidity and water level. The data logger is programmed with STARLOG Version 3. The logger was programmed to sample and record turbidity and level data at five minute intervals.

The sites were accessed on a weekly basis, or when conditions permitted. The data was downloaded using a laptop computer and regular maintenance such as cleaning the lenses of the turbidity probes and replacing batteries was carried out.

During the maintenance runs, additional manual readings were taken to record turbidity, water temperature, and electrical conductivity (EC). The manual turbidity measurements were achieved using a “Turbidity Tube” commonly used by Waterwatch and the temperature and EC readings were taken using a YSI Model 30 Handheld Salinity, Conductivity, and Temperature meter.
RESULTS AND DISCUSSIONS

The research project is still in the field observation / data collection stage. The equipment will remain in place until the end of 2002 with detailed data analysis to be completed thereafter. However, some interesting trends have been observed. These trends are the subject of this paper and are discussed below.

The agricultural catchment is a typical cattle grazing area as found in the Strzeleckis. The features include:

- fully cleared steep slopes,
- gravel and natural surface road adjacent to the stream running to the top of the catchment,
- multiple houses, and hobby farms of which the driveway access to one of the homesteads runs directly through the streambed,
- cattle with unrestricted access to most of the catchment area including drainage lines and streams,
• numerous cattle stream crossing tracks exhibiting damage to the streambank and accelerated erosion,
• no defined stream boundary with protected riparian vegetation or buffer strips, and
• continuously flowing stream intercepted by a total of seven farm dams.

The logged catchment was selected under the understanding that the timber was going to be harvested carefully following the requirement of the Code of Forest Practices for Timber Production (Department of Natural Resources and Environment, 1996). Features of the logged catchment include:
• steep slopes,
• established hardwood plantation forest with Central Highlands Cool Temperate Rainforest (EVC 31-01, a threatened ecological community) scattered along the main stream on which GRP placed a larger than prescribed stream buffer zone,
• gravel and natural surface access road running the length of the catchment,
• snig tracks, and
• continuously flowing stream.

The undisturbed catchment was selected to be the control area for this paired catchment study. Features of this catchment include:
• steep slopes,
• established hardwood plantation forest with Wet Forest (EVC 30) riparian vegetation,
• healthy riparian vegetation,
• natural surface access track running the length of the catchment,
• frequent and popular use of the area for recreation including dirt bike riding and horse back riding, and
• continuously flowing stream.

Turbidity
The preliminary turbidity results are illustrated in Figure 6 and a basic statistical analysis in Table 1 was performed to provide a basis for comparison. General comments regarding the plot of Turbidity versus Time is that the peaks result from rain events. It is evident that the rain events affected each site at the same time and as expected increased the stream turbidities. However, it is the baseflow characteristics that are illustrating which mechanisms are important in the transport and delivery of suspended sediment to the streams.

<table>
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<tr>
<th>Turbidity (NTU)</th>
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<th>Minimum</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
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<td>5.8</td>
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<tr>
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<td>51.1</td>
<td>90</td>
<td>30</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Table 1 and Figure 6 reveal that the agricultural catchment is producing approximately twice the amount of suspended sediment as the logged catchment and over six times that of the undisturbed catchment. While the logged catchment is producing approximately three times the suspended sediment load as the undisturbed catchment.
It can be clearly seen that the land management of the agricultural catchment is contributing the greatest suspended sediment load to the stream.

There is an apparent trend in the turbidity response of the logged catchment with an underlying increase in turbidity over the dryer period between January and May. It can be seen that the stream turbidity is rising over that period of time while the turbidities of the other catchments seem to remain stable. This was occurring even though less that 15% of the catchment has been logged.

Inspection of the full length of the stream and drainage lines of the logged catchment revealed uncharacteristically large areas of bioturbation within the humid zone along the stream bank. The subsoil was effectively mixed with the surface leaf litter and along the saturated zones extensive crayfish and yabby burrows were evident.

Bioturbation was defined by Aldrick et al. (1988) as: “The overturning and/or mixing of soil materials by animals and plants”. Hazelhoff et al. (1981) observed that the importance of earthworms in the erosion process lies in the fact that they generate bare soil; thus promoting erosion. Litter removal begins in the spring and reaches a maximum during moist periods in the summer. They stated; however, that the actual amount of erosion depended on the erosivity of the rainfall, the erodibility of the soil and the angle of slope.

The trend in increasing low flow turbidity indicates that bioturbation may be the major contributor of suspended sediment to the stream especially given the very limited amount of logging which has occurred in the catchment.

Inspection of the undisturbed catchment yielded dramatically different results from the logged catchment whereby the leaf litter cover remained intact for most to the length of the
stream. The main difference between the catchments is that logged catchment riparian zone is classified as Central Highlands Cool Temperate Rainforest while the undisturbed catchment is classified as Wet Forest. The Cool Temperate Rainforest may provide habitat for a wider range of fauna, including threatened species, than the Wet Forest vegetation. This may explain why bioturbation was substantially more evident in the logged catchment resulting in the higher turbidity results.

**Electrical Conductivity**

Finlayson (1979) explains that spatial variations of stream water quality is related primarily to geology, and within individual geological formations there are also variations due to different land uses. In addition, seasonal variations in water quality occur because at low flows (baseflow), the dissolved solids concentration will be at their highest, since water in the stream has been in storage in the catchment for sufficient time to come into chemical equilibrium with the soils and/or bedrock. Finlayson (1979) continues by explaining that at higher flows, the baseflow water is diluted by water which passes quickly through the catchment (quickflow) and the larger the proportion of quickflow the more diluted the stream water.

<table>
<thead>
<tr>
<th>Table 2 Preliminary electrical conductivity results</th>
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</thead>
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<tr>
<td><strong>Electrical Conductivity (µs/cm) at 25°C</strong></td>
</tr>
<tr>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Undisturbed Catchment</td>
</tr>
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<td>Agricultural Catchment</td>
</tr>
</tbody>
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Figure 7 and Table 2 highlight that the electrical conductivity (EC) of the stream is increased in areas under intense land uses such as grazing. Although the electrical conductivity of the logged and undisturbed catchments are very similar, the EC of the agricultural catchment is about 1.7 times higher than the undisturbed catchment. A slight seasonal variation is also evident with the EC readings rising for each of the catchments during the drier summer period between December and May. “Spikes” occur when the system is flushed by heavy rains after an extended period of dry weather. These are also evident on in Figure 7.
FIGURE 7 Electrical Conductivity versus Time

CONCLUSIONS

Water quality indicators have traditionally been used to measure the water quality and ecological health of waterways. The use of water quality indicators for the measurement of environmental impacts related to various land management approaches and to map the erosion processes in catchments is evident in literature particularly in Europe and North America; however, their use in monitoring environmental health of the Strzelecki is not evident.

This project aims to use continuous turbidity monitoring as a generic indicator of catchment health and to determine which areas are contributing to increased turbidities to be able to better target land management approaches and mitigation measures.

The paired catchment approach of continuous turbidity monitoring supplemented by weekly measurement of electrical conductivity and turbidity seem to provide a cost-effective way of monitoring the processes in each sub-catchment.

The initial observations suggest that the practices associated with agriculture, specifically cattle grazing, are providing the greatest impact on the water quality in the Morwell River catchment in the Strzelecki Ranges. It is also evident that bioturbation plays a large role in the generation of suspended sediment as observed in the logged catchment.

The undisturbed catchment proved to be a good base for comparison since it provided consistent water quality over the period of the study. However, the lower level of bioturbation clearly demonstrates the extreme variability and uncertainty encountered when performing experimental work in the field.
Given that this project is not yet completed, clear conclusions cannot be drawn at this stage. Results will be published upon completion of the research project.

ACKNOWLEDGEMENTS

The research project is supported and supervised by a steering committee of interested stakeholders who have sponsored the project. The authors would like to thank Mr. Graeme Jackson of the West Gippsland Catchment Management Authority, Ms. Jenny Jelbart of Gippsland Water, and Ms. Judy Alexander of Grand Ridge Plantations for their valuable input and continued support.

REFERENCES


The Relative Environmental Impacts of Forestry and Agriculture in the Strzelecki Ranges of Southeast Victoria, Australia

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Abstract

Prior to European settlement, the Strzelecki Ranges in South East Victoria, Australia were densely populated by temperate rainforest-type vegetation similar to remnant populations presently found in local reserves and parks. Since the early 1900’s, European settlement dramatically changed the landscape of the Strzeleckis by clearing the native vegetation for timber harvesting, agricultural pastures, and for the establishment of homesteads and communities. These activities have exposed highly erodible soils and created areas prone to significant erosion and landslips.

This research project is focussing on the upper reaches of the Morwell River. The Morwell River is a tributary to the Latrobe River, which provides approximately 30% of the inflow and 39% of the suspended sediment load into the environmentally sensitive Gippsland Lakes.

The project is comparing the relative impacts of major land uses in the upper reaches of the Morwell River. The major land uses include forestry, agriculture, and protected forests. The water quality indicators of turbidity and electrical conductivity were used to measure the environmental impacts associated with land management practices.

Observations indicate that agricultural practices are contributing approximately two times more suspended sediments and about 1.5 times more dissolved solids than forestry practices. It has also been observed that the natural processes of stream bank erosion, landslips, and bioturbation are direct contributors to the sediment loads in the streams and rivers. With evidence that bioturbation is a major source of suspended sediment in temperate rainforest catchments.

The findings of this work will provide valuable information on appropriate catchment management and land use planning measures leading to more sustainable land management practices.

1. INTRODUCTION

The Latrobe River has been the subject of numerous studies related to water quality since the 1950’s, despite the large amount of routinely collected data, the relative contributions of sediment and nutrients from different sources have not been identified. In this research project, the water quality indicators of turbidity and electrical conductivity have been used to measure the impact of the major land uses on water quality in the upper reaches of the Strzelecki Ranges as highlighted in Figure 1. This information will help with the identification of sources of pollutants contributing to the degradation of the Gippsland Lakes.

1.1. Background to the Study

Soil erosion is a natural process occurring in most environments but is more frequent or potentially more damaging in landscapes with high rainfall intensity combined with steep slopes such as the ones found in the Strzelecki Ranges. Where the protective vegetation cover is removed or degraded by clearing, tillage, grazing, or recreational use, the risks of erosion can be substantially increased. The removal or destruction of riparian vegetation further enhances the risks and impacts of erosion by allowing direct delivery of sediments to the watercourses and by destabilizing the banks; thus,
accelerating streambank erosion processes. Increased turbidity at the catchment outlet may, in fact, be related to increased channel erosion due to changed streamflow conditions after land use changes. The problem is particularly complex in mixed land-use catchments where it is almost impossible to separate sediment contributions from different land-use practices and sources (Croke et al. 1999).

Soil erosion can reduce on-site productivity through loss of fertile topsoil, and associated water-holding capacity and nutrients. Extensive erosion leads to soil structural decline and poor plant growth. Soil erosion also has the potential for downstream impacts on creeks, rivers, reservoirs, lakes, and estuarine and marine environments. Moore et al. (2001) report that, by volume, fluvial sediments are largest water pollutant in the United States. They affect aquatic habitat, drinking water treatment processes, and recreational use of rivers, lakes, and estuaries.

Impact have been observed in the Gippsland Lakes. The ecology of the lakes system is under stress as evidenced by large variations in lake-bed vegetation cover, toxic algal blooms, and the perception of fishermen and recreational boaters that the lakes are becoming shallower all of which have been attributed to land use changes in the upper catchments (Erskine, Rutherford & Tilleard 1990).

Prior to European settlement, the Strzeleckis were densely vegetated by wet sclerophyll and temperate rainforest-type vegetation similar to that found at the Tarra and Bulga National Parks and other remnant populations in the area. In the time period from 1870 to 1900, farmers settling the Strzeleckis largely destroyed the stands of high quality mountain ash (Eucalyptus regnans) forests. By the 1930’s dairying and grazing had become uneconomic in the steeper, eastern part of the ranges because of weeds, pest animals, isolation from transport and markets, increasing labour costs, and lower returns. This led to many farms being abandoned and overgrown by weeds and scrub (Aldrick et al. 1988).

Present land uses in the Strzeleckis include agriculture, forest plantations, protected forest habitats and small communities. In general, the western Strzeleckis remain as farmland, unlike most of the eastern Strzeleckis where farms were abandoned early last century. Much of the abandoned farmland has been reforested, mainly with mountain ash (Eucalyptus regnans) or converted to pine (Pinus radiata) plantations (Rice 1988).

This clearing exposed erodible soils and combined with the high rainfall in the area, accelerated the erosion processes and caused major landslips. It has been estimated that the soil loss in the cleared areas of the Strzeleckis is in the order of about 0.3mm of soil per year. This is coming from point sources, bank erosion and other erosion in the
Agriculture usually has effects of a greater magnitude on water systems than forestry in a forested catchment. However, the importance of these effects often needs to be considered in a different frame of reference, as the rivers and streams being affected have usually been disturbed for a long period of time and have far less nature conservation value than the highly natural systems. In order to assess their importance, an analysis of the conservation values of the modified rivers and streams in the region is required. This needs to be determined to assess whether any modification of agricultural or forestry practices are needed to maintain or improve these values (Rice 1988).

1.3. Climate and Geology

Major factors influencing the climate of the region are the easterly movement of low and high-pressure systems and the development of low-pressure systems off the east coast of southern Australia. Official figures show an average maximum temperature range from 23.3°C in January to 11.1°C in July, and the average minimum from 9.6°C in February to 2.3°C in July. The highest reading recorded was 39.7°C and the lowest –6.1°C (Noble 1986).

The oldest rocks in the Gippsland Lakes catchment are in the Strzelecki Ranges, chiefly arkose (feldspathic sandstone) and shale with characteristic steep slopes, rounded ridgetops and brown soils (Nicholson 1978). The hills of the Strzelecki Ranges and surrounding foothills consist of early cretaceous (approximately 100 – 140 million years old) sandstones which occur in three north-east to south-west trending blocks. The northern and central areas of the Strzeleckis are overlain by weathered volcanics with sub-volcanics Tertiary sediments (Childers formation) occurring over large areas of the Central Narracan Block (Brumley 1993). Remnants of older Basalt occur on the crests producing their characteristic red soils (Nicholson 1978).

Deposition and subsidence proceeded rapidly throughout the Early Cretaceous in Victoria, resulting in great thicknesses of sediment in the major basins, and rocks of this age outcrop over large subsequently uplifted areas such as the Strzelecki Group in the Gippsland Basin as seen in Figure 2. The beds are principally feldspathic sandstone, mudstone, and shale with conglomerate occasionally prominent at the base. Plant remains are the most common fossils and deposition was predominantly fluviatile (Douglas & Ferguson 1976).

The low runoff compared to the relatively high rainfall can be explained by the fact that the Strzeleckis are basically unwarped, faulted and extremely eroded areas of Mesozoic sandstones and mudstones, which in parts are capped by Older Basalt and minor amounts of Lower Tertiary formations. They are deeply dissected by valleys of comparatively recent formation, with steeply sloping sides and sharp ridges (Noble 1986). The infiltration capacity and surface soil permeability are extremely high and as a result, overland flow is low under nearly all rainfall events (Aldrick et al. 1988).

Figure 2 Location of the Strzelecki Group

1.4. Methodology

Using a paired catchment approach, three study areas were selected representing a logged forest plantation, agricultural land, and undisturbed forest area. To ensure that no other land use would affect the results in each of the study areas, the selected sub-catchment areas were located at the head of the Morwell River catchment.

The following points detail the experimental approach for this research project:

1. Sites were selected representing each major land uses in the Strzeleckis. Site selection was accomplished using topographic maps, a geographic information system-based database (GIS), and aerial photographs. The sites were judged on the following features:
   • safe and convenient access under the various climatic conditions,
   • continuous year-round water flow,
   • suitable location on the stream to construct a weir or small dam,
• ease of concealing the monitoring equipment to prevent vandalism.

2. Monitoring stations were constructed at the base of each sub-catchment. The monitoring stations consisted of the following equipment:
   • Greenspan TS100 Turbidity sensor with a turbidity detection range from 0 to 250 NTU.
   • 6508 B 2m Pressor Sensor Probe.
   • Micrologger Data Logger 2 X 4-20 mA inputs. The data logger is programmed with STARLOG Version 3.

3. The sites were accessed on a weekly basis for regular maintenance and data collection.

The manual EC readings were taken using a YSI Model 30 Handheld Salinity, Conductivity, and Temperature meter.

1.5. Results and Discussions

The research project is still in the data analysis stage. Some interesting trends have been observed.

The agricultural catchment is a typical cattle grazing area as found in the Strzeleckis. The features include:
• fully cleared steep slopes,
• gravel and natural surface road adjacent to the stream running to the top of the catchment,
• multiple houses, and hobby farms of which the driveway access to one of the homesteads runs directly through the streambed,
• cattle with unrestricted access to most of the catchment area including drainage lines and streams,
• no defined stream boundary with protected riparian vegetation or buffer strips, and
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The logged catchment was selected under the understanding that the timber was going to be harvested carefully following the requirement of the Code of Forest Practices for Timber Production (Department of Natural Resources and Environment 1996). Features of the logged catchment include:
• steep slopes,
• established hardwood plantation forest with Central Highlands Cool Temperate Rainforest (Ecological Vegetation Class (EVC) 31-01, a threatened ecological community) scattered along the main stream on which GRP placed a larger than prescribed stream buffer zone,
• gravel and natural surface access road running the length of the catchment,
• snig tracks, and
• continuously flowing stream.

The undisturbed catchment was selected to be the control area for this paired catchment study. Features of this catchment include:
• steep slopes,
• established hardwood plantation forest with Wet Forest (EVC 30) riparian vegetation,
• healthy riparian vegetation,
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Turbidity

The preliminary turbidity results are illustrated in Figure 3 and a basic statistical analysis in Table 1 was performed to provide a basis for comparison. General comments regarding the plot of Turbidity versus Time is that the peaks result from rain events. It is evident that the rain events affected each site at the same time and as expected increased the stream turbidities. However, it is the baseflow characteristics that are illustrating which mechanisms are important in the transport and delivery of suspended sediment to the streams.

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It can be seen that on average the agricultural catchment is producing approximately twice the amount of suspended sediment as the logged catchment and over six times that of the undisturbed catchment. While the logged catchment is producing approximately three times the suspended sediment load as the undisturbed catchment.

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Inspection of the full length of the stream and drainage lines of the logged catchment revealed uncharacteristically large areas of bioturbation within the humid zone along the stream bank. The subsoil was effectively mixed with the surface leaf litter and along the saturated zones extensive crayfish and yabby burrows were evident.

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**Electrical Conductivity**

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**Table 2 Electrical conductivity results**

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<th>EC(µs/cm) at 25°C</th>
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<td>Logged Catchment</td>
<td>111.6</td>
<td>129.8</td>
<td>98.9</td>
<td>8.8</td>
</tr>
<tr>
<td>Agricultural Catchment</td>
<td>167.0</td>
<td>198.4</td>
<td>121.5</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Figure 4 and Table 2 highlight that the electrical conductivity (EC) of the stream is increased in areas under intense land uses such as grazing.
EC of the agricultural catchment is about 1.7 times higher than the undisturbed catchment. A slight seasonal variation is also evident with the EC readings rising for each of catchments during the drier summer period between December and May. “Spikes” occur when the system is flushed by heavy rains after an expended period of dry weather.

1.6. Conclusions

This project used continuous turbidity monitoring as a generic indicator of catchment health to determine which areas are contributing to increased turbidities, to be able to better target land management approaches and mitigation measures. The paired catchment approach seems to provide a cost-effective way of monitoring the processes in each sub-catchment.

The initial observations suggest that the practices associated with agriculture, specifically cattle grazing, are providing the greatest impact on the water quality in the Morwell River catchment in the Strzelecki Ranges. It is also evident that bioturbation could play a large role in the generation of suspended sediment as observed in the logged catchment.

The undisturbed catchment proved to be a good base for comparison since it provided consistent water quality over the period of the study. However, the lower level of bioturbation clearly demonstrates the extreme variability and uncertainty encountered when performing experimental work in the field.

2. ACKNOWLEDGMENTS

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THE SUSTAINABILITY OF LAND USES IN THE STRZELECKI RANGES IN VICTORIA, AUSTRALIA

Intended Category: Sustainability Science

ABSTRACT

Integrated catchment management and the preservation of water and soil resources are essential in developing more sustainable land and water management initiatives. The implementation of catchment management methodologies faces a variety of social and technical obstacles. Social obstacles may include the willingness of landowners to participate in catchment management initiatives; however, these can usually be overcome by effective community engagement and economic incentives. Technical obstacles include reliable water quality monitoring and data collection. These are essential to ensure that research across catchments is meaningful, comparable, and reproducible. Data collection remains a major issue in water quality monitoring and analysis of catchment health. A simple and reliable methodology is required to enable the general community to monitor and develop an understanding of the issues related to their local environments.

The landscape of the Strzelecki Ranges features a mixture of land uses including agriculture and forestry. The Strzeleckis form the headwaters of major streams and rivers flowing east to the Gippsland Lakes and south to Bass Strait. The intensive nature of land uses in catchments of the Gippsland Lakes has generated significant environmental impacts. To protect the values of the lakes, pollutant sources need to be identified and appropriate mitigation measures implemented. A comprehensive catchment management strategy in the Strzeleckis will lead to improved environmental health both inland and in the coastal/estuarine areas receiving their flows. A strategy incorporating careful management of landscape values and proper land management approaches would ensure that forestry and agriculture become sustainable land uses in this sensitive environment.
The definition of sources and assessment of land management practices requires accurate estimates of pollutant load levels. The suspended sediment load in streams is strongly dependent on supply factors and is rarely transport limited. The analysis of water quality within a stream, over a period of time, may be helpful in isolating possible water quality trends in the catchment; thereby, identifying how land use change may impact the catchment.

This paper outlines research conducted for the development and implementation of a straightforward methodology based on the use of reliable and readily measurable water quality indicators to monitor the variations in water quality associated with land uses in the Strzeleckis. A paired catchment methodology was adopted using turbidity, stream temperature and electrical conductivity as the primary indicators. Adoption of this methodology will enable agencies, community groups and / or land managers to determine which land management practices are generating the greatest impact in any given catchment.

These water quality indicators were demonstrated to be good indicators of land use impacts in the catchments. The differences found between forestry, agriculture, and the control catchment linked the degradation of water quality with the intensity of land management.

Agriculture is generating the greatest impact on the local water quality. Results demonstrated that turbidity was increased by more than three times the natural rate or more than twice the maximum Default Target for Upland Rivers as published by the Australian Department of Environment and Heritage (2003). A key in reducing impacts associated with grazing is the establishment and protection of healthy riparian zones. This can only be achieved by controlling livestock access to the riparian zone and stream channels. These basic measures would help to improve catchment health, provide habitat connectivity, and lead to a more sustainable industry.

Forestry also created water quality impacts. These impacts were more of an indirect nature resulting from increased streamflows and concentration of fauna along the moist stream channel zones. Indicators of these impacts included extensive baring of soils through bioturbation and enhanced streambank erosion in more vulnerable stream reaches. Bioturbation dramatically increases the potential for suspended sediment generation especially during the low flow conditions encountered during the summer period. These enhanced natural processes were not as evident in the control catchment.

INTRODUCTION

The study was based in the Strzelecki Ranges in Gippsland, Southeast Victoria. It targeted the headwaters of the Morwell River. The Morwell River is a tributary to the Latrobe River, the catchment of which is outlined in Figure 1.
Prior to European settlement, the Strzeleckis were densely vegetated by wet forest and cool temperate rainforest-type vegetation similar to remnant communities still found at Tarra and Bulga National Parks. In the time period from 1870 to 1900, settlers largely destroyed the stands of high quality mountain ash (*Eucalyptus regnans*) forests. Today, the landscape of the Strzeleckis consists of a mosaic of land uses ranging from protected forests to plantation forests to agriculture with small settlements and hobby farms interspersed throughout the area.

Current agricultural practices in the Strzeleckis are based on traditional practices, including unabated livestock access to drainage lines and streams, which enhances stream bank erosion processes. The lack of protected riparian vegetation heightens sediment and nutrient delivery to the local waterways. Colman et al. (1991) highlight that approximately 60% of the State of Victoria’s surface area is utilised for agriculture. The impacts of agricultural practices have a very high potential to affect water quality through the delivery of sediment and other pollutants to the local waterways.

The forests of Victoria are rich, renewable resources that play an important role in providing for sustainable economic development through the production of timber, water and other products. They provide for the conservation of water, soils, flora and fauna, and catchment and landscape values (Department of Natural Resources and Environment 1996). Forests make up approximately 30% of Victoria’s total surface area, with most of the forests located in the steep humid headwaters of the State’s major rivers. Colman et al. (1991) emphasise that the timber industry poses a large potential for impacts on the aquatic environment, second only to agriculture. However, forest streams are perceived as being in a more natural state than streams flowing through agricultural areas; therefore,
the public is likely to consider them as more sensitive and more deserving of conservation.

The majority of the plantation areas in the Strzeleckis are currently owned and managed by Grand Ridge Plantations (GRP). Forestry operations primarily consist of clearing mature stands of Mountain Ash or Radiata Pine for sawlogs and pulpwood. However, timber production and timber harvesting activities on public land and private land are governed by the Code of Forest Practices. Department of Natural Resources and Environment (1996) developed the Code to ensure that forestry operations are carried out in such a way that:

- they promote an internationally competitive forest industry;
- they are compatible with the conservation of the wide range of environmental values associated with forest; and
- they promote the ecologically sustainable management of native forests proposed for continuous timber production.

**METHODOLOGY**

A paired catchment approach was adopted to measure the relative impacts of each land use. Jayasuriya and O'Shaughnessy (1988) reported that paired catchment studies provide a quick and reliable means of establishing, quantifying and comparing trends within catchments. The three catchments that were selected all lie within the same geographical area with similar landform and soil types.

Identical automated data loggers fitted with turbidity probes and level sensors were installed at the outlet of each catchment. Remote turbidity and flow data was collected on a 5-minute interval for a period of approximately 18 months. This data was supplemented with weekly manual turbidity observations using a simple turbidity tube.

In addition to the weekly turbidity readings, manual electrical conductivity and stream temperature observations were recorded using a hand-held probe. This ensured that the accuracy and operation of the automated equipment was not only being verified for quality control purposes but also to determine which indicators best reflected the impacts of land management practices resulting in environmental degradation.

Simple statistics and trending were used for the data analysis to identify changes in water quality resulting from forestry and agriculture in the catchment of the Morwell River. These results were compared to the data collected from a control catchment. The results are also considered in the context of the *Default Target Values for Upland Rivers* as published by the Commonwealth Department of the Environment and Heritage (2003),

- 2 – 25 Nephelometric Turbidity Units (NTU) for turbidity, and
- 30 – 350 microSiemens per cm (µS/cm) for electrical conductivity (EC) (at 25°Celsius).

Each catchment was visually surveyed to determine the main mechanisms for sediment generation and delivery to the waterways. The visual survey concentrated on the
“saturated’ zone adjacent to the streams. Erosion and sediment source indicators that were being sought included:

- the extent of leaf litter and presence of bare earth along the stream channel and embankments,
- areas exhibiting clear indications of lateral corrosion,
- tree fall,
- bioturbation such as the evidence of foraging and crayfish burrows,
- newly incised drainage channels, and
- landslips.

The project methodology and data analysis was kept simple to encourage its use as a tool to carry out catchment studies resulting in comprehensive and successful catchment management strategies. The key to sustainable land management is the availability and use of affordable, low tech, and reliable water quality monitoring equipment such as the turbidity tube and electrical conductivity / temperature probes. This equipment combined with a simple and adaptable paired catchment methodology, such as the one used in this study, can cater for detailed large scale catchment studies whilst still being within reach of the individual land owner or stakeholder. It generates readily reproducible and comparable results, providing a good indication of catchment health and enabling targeted mitigation programs.

CATCHMENT FEATURES

Features of the control area included:

- steep slopes;
- established Mountain Ash plantation reafforested in 1972 and 1973;
- remnants of Wet Forest (Ecological Vegetation Class - EVC 30) riparian vegetation;
- natural surface track 1850 meters long, running up the southern ridge of the catchment (Grey Gum Track);
- small unkept fire access track 2650 metres long along the north ridge;
- extensive damage to tracks caused by recreational use by 4WD vehicles and dirt bikes; and
- healthy continuously flowing stream supporting a variety of flora and fauna.

Features of the plantation area included:

- combination of forested and cleared steep slopes;
- established hardwood plantation forest with remnants of Central Highlands Cool Temperate Rainforest (EVC 31-01, a threatened ecological community) as riparian vegetation;
- approximately 3550 metres of unsealed roads and tracks; and
- healthy continuously flowing stream supporting a variety of flora and fauna with evidence of extensive biological activity along the moist zones of the catchment.

Features of the agricultural area included:

- fully cleared slopes;
- main gravel road, maintained by the local Shire, approximately 3900 metres long running alongside the stream and crossing it in two locations by means of culverts;
- numerous privately owned natural surface tracks for access to the paddocks and trafficking livestock;
- 8 homes with outbuildings, all with gravel driveway access (one home’s access runs through the stream channel);
- continuous grazing with unrestricted access to the steam and drainage lines;
- visible damage to the streambanks resulting in accelerated erosion;
- no riparian vegetation or buffer strips; and
- continuously flowing stream intercepted by a total of seven farm dams constructed directly in the stream channel.

RESULTS AND DISCUSSIONS

The data collected made it possible to establish an indicative baseline water quality for each sub-catchment. These findings should be considered in the context of having been collected over a relatively short period of time. Other catchment studies cited in literature have spanned a much longer time period (ie. some as long as 30+ years) resulting in findings which could be considered more representative of the longer term mechanisms occurring in their respective catchments. Mechanisms affecting catchment dynamics are dependent of a number of factors including climate change, changes in land management practices, catchment-scale land use change, large scale events such as fires or large landslides, economics, plus a number of other natural and anthropogenic factors.

The averaged baseline water quality results for each sub-catchment summarised in Table 1 are based on the data collected during low flow conditions.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Turbidity (NTU)</th>
<th>EC (µS/cm)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantation</td>
<td>28</td>
<td>112</td>
<td>10.2</td>
</tr>
<tr>
<td>Agriculture</td>
<td>52</td>
<td>168</td>
<td>12.6</td>
</tr>
<tr>
<td>Control</td>
<td>9</td>
<td>101</td>
<td>10.3</td>
</tr>
</tbody>
</table>

Baseflow refers to the steady-state flow of watercourses in the absence of precipitation or rain events typically during summer or dry periods. It provides a strong indication of instream mechanisms affecting water quality. Gippel (1989) states that most streams transport the bulk of their suspended sediment load during relatively infrequent storm events. However, Grayson et al.(1997) emphasise that from a point of view of water quality and ecological health, the low flow period is generally the most critical time for the system.
The water quality at steady-state flow in the control catchment was typically high. The turbidity was normally below 10 NTU with instances where the turbidity tube tests returned a 0 reading. As expected, higher sediment flows were observed during rain events of high intensity and short duration. Sediment sources generally being the stream channel itself.

As highlighted in Table 1, the baseline water quality in the plantation area exhibited a higher NTU reading. If compared to the control catchment, the turbidity value was three times that observed in the control area. However, if taken in the context of the Default Target Values for Upland Rivers (Department of the Environment and Heritage 2003) the turbidity value is only slightly above the maximum value of 25 NTU. The site survey revealed extensive bioturbation along the saturated zone of the stream and within the stream channel. This high degree of disturbance may be responsible for the majority of baseflow turbidity. This suggests that the riparian zone of this stream is providing habitat for a large concentration of burrowing and foraging fauna. The higher turbidity values may not be a direct result of timber harvesting but a product of natural processes. However, increased streamflows and loss of habitat resulting from the timber harvesting can potentially enhance the natural processes of bioturbation and streambank erosion.

Baseflow water quality in the agricultural catchment was consistently poorer than that observed in the other two catchments. Turbidity was generally twice the maximum default target value for upland streams and more than five times that observed in the control catchment. The obvious effects of unabated livestock access to the stream combined with the absence of riparian vegetation for the majority of the stream length are the major contributors to the lower water quality, especially during baseflow conditions. In addition, higher light levels reaching the stream and resultant higher water temperatures changes the instream characteristics by promoting the growth of aquatic organisms. The presence of a number of farm dams directly in the stream channel also provides for ideal conditions for enhanced growth of these organisms affecting turbidity.

The importance of EC during baseflow conditions is based on the fact that at low flow conditions the dissolved solids concentration will be at its highest since the stream water has been in storage in the catchment for sufficient time to come into chemical equilibrium with the surrounding environment (Tchobanoglous & Schroeder 1987). Although a slight difference in the electrical conductivities for each catchment has been observed, EC values fall within the recommended Default Target Values for Upland Rivers (Department of the Environment and Heritage 2003). However, if EC is used as a means of measuring land use impacts; the higher EC values observed in the agricultural catchment suggests a slight degradation in water quality based on current land use. Herricks & Milne (1998) suggest that EC is the most reliable indicator of changing water quality in a catchment. Variations in stream water EC is related to a number of parameters such as soil type, geology, groundwater, land use, vegetation cover, and precipitation regime (Fletcher 1995). Spatial variations in EC are primarily related to geology; however, within individual geological formations variations in EC have been attributed to differing land uses (Finlayson 1979). Condina (1990) reported values in the
upper Morwell River between 80 and 160 $\mu$S/cm. Grayson et al. (1997) state that since the upper Morwell River catchment is predominantly underlain by Cretaceous sediments, runoff should produce natural EC values in the range of 150 to 200 $\mu$S/cm. However, the lower EC values measured in this and other studies, even in the agricultural catchment is a result of the high rainfall regime in the Strzeleckis (Nicholson 1978).

These results highlight that intensively managed landscapes contribute to the degradation of water quality and overall environmental health. It is quickly being recognised that the preservation and enhancement of healthy riparian zones in combination with changes to management approaches can dramatically increase water quality, ecological viability, and improve the sustainability of land uses. Adherence of the forest industry to the prescriptions of the Code of Forest Practices (Department of Natural Resources and Environment 1996) will improve the general management of timber production area and harvesting coupes. However, as highlighted by the Review of the Code of Forest Practices for Timber Production (CSIRO Forestry and Forest Products 1996) and by O'Shaughnessy (1995) there are a number of areas where the Code can be improved. These include:
- mechanisms for the protection of habitat and water quality;
- definition and protection of rainforest;
- silvicultural practices for native forests;
- guidelines operations on steep slopes and proximity to streams; and
- wet weather operations.

**CONCLUSIONS AND RECOMMENDATIONS**

Sustainable land use in the Strzeleckis can only be achieved through considered and honest approaches to the management of local resources, understanding the nature of the environment, and by respecting its limitations. It is clear that it takes commitment and foresight to properly manage the landscape in an environment as sensitive as the Strzeleckis. A proactive approach in implementing proper management procedures and tending to the trouble areas will lead to improved environmental quality and sustainability.

Changes to agricultural practices are key to maintaining and improving the health of the landscape. Key measures include:
- restricting livestock access to the stream channels;
- use of bridges over streams rather than crossing within the stream channel;
- establishing healthy riparian zones where streams flow throughout the year and establishing filter strips in drainage lines;
- upgrading of access tracks;
- more appropriate siting of drainage structures;
- extensive use of sediment trapping measures;
- upgrading, resurfacing and/or sealing of roads or tracks to prevent the generation of sediment;
- restrict wet weather operations;
- rapid and effective rehabilitation of redundant tracks;
effective rehabilitation of livestock tracks including fencing off of degraded areas to allow for re-establishment of vegetation; and

- the development and implementation of a Code of Practices for Agriculture similar to the Code of Forest Practices.

The forest industry has taken significant steps in the right direction to reduce and mitigate the effects cause by its activities. Improved practices and continued responsible stewardship of the land will ensure that the forest industry also becomes sustainable in the Strzeleckis. The project has shown that elements of the Code of Forest Practices are very relevant to the conditions found in the Strzeleckis. However, recommendations for continued work and advances on the following points in the Code of Forest Practices will ensure that the forest industry will be more sustainable in the Strzeleckis:

- proper resurfacing and maintenance of haul roads and tracks,

- effective closure and rehabilitation of unused tracks,

- better drainage works including extensive use of sediment trapping measures,

- redirection of surface runoff away from steep coupes, streams and drainage lines,

- maintenance and protection of healthy riparian zones of appropriate width designed for the specific harvest areas,

- better control of wet weather operations,

- smaller coupes in steeper areas or during wet weather, and

- rapid rehabilitation and reafforestation of harvested areas.

It is also critical to minimise and mitigate the impacts of recreational use. The popularity of 4WD and dirt bike ridding is quickly increasing. If the trend towards irresponsible recreational use of the area continues, this will increase the risk of wide scale erosion and degradation of water quality. Gullying and erosion of tracks not only reduces the amenity of the area but also restricts access to other vehicles in case of fire or other emergencies. Proper surfacing and maintenance of these tracks is required, including closure and effective rehabilitation of some tracks. A Code of Practice for Recreational Use and Wet Weather Trafficking may lead to a more responsible approach. The promotion of a “FRIENDS OF” group or other similar community organisation charged with community engagement and maintenance of tracks could result in well-maintained and safer tracks.

Conclusion of the study will result in recommendations guiding the development of a strategic framework for forestry and agricultural practices. This framework will provide management directions leading to the sustainability of these land uses in priority areas.

Further work is required in the areas of:

- Catchment surveys and water quality monitoring to determine the extent and magnitude of bioturbation in the Strzeleckis and its impact on the local water quality.

- Quantify the extent and magnitude of damage caused by recreational use of the catchment and its effects on local water quality.

- Detailed streamflow and turbidity monitoring to generate site specific and catchment wide suspended sediment load models.

- Further research in the use of electrical conductivity and temperature as cost effective and reliable indicators of land use impacts on water quality.
ACKNOWLEDGEMENTS

The research project has been supported and supervised by a steering committee whose membership includes stakeholders who have sponsored the project. The authors would like to thank Mr. Graeme Jackson of the West Gippsland Catchment Management Authority, Ms. Jenny Jelbart of Gippsland Water, and Ms. Judy Alexander of Grand Ridge Plantations for their valuable input and ongoing support.

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