SALINITY

IN THE WOADY YALOAK RIVER

CATCHMENT

Joanne G. Mananis

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Statement of Authorship

The research in this thesis is entirely my own, and has not been published elsewhere or submitted as part or whole of another degree or to another institution. The work that has been used from other authors has been acknowledged in the text and References.

……………………………………

Abstract

The salinity of the Woady Yaloak River, which is located within the Corangamite region, reveals an increasing end-of-valley salinity trend as measured at the Cressy gauging station. The focus of this research is on identifying the source of salinity over the entire catchment, which is contributing to the end-of-valley salinity. This was achieved by examining all existing salinity data available for the catchment, which encompassed groundwater salinity and flow system data, in order to assess all possible aspects, which contribute to the rising surface water salinity.

An extensive surface water sampling program was conducted on a monthly basis, from February to October, from up to 30 locations across the Woady Yaloak River catchment. The sampling concentrated on the Woady Yaloak River and all its major tributaries. Six sub-catchments were delineated within the Woady Yaloak River catchment, in order to examine the relative salt loads discharging from each of the major streams. Monthly results of Electrical Conductivity (EC), and peak discharge rates derived from the rational method, were used to calculate the relative salt loads discharging from each sub-catchment. Integrated sampling of groundwater bores was also carried out, in order to gain a clearer perspective on surface water and groundwater interactions, which may be influencing the surface water salinity.

Increased evaporation and groundwater baseflow contributions, have contributed to the increase in surface water salinity over the catchment. The surface water sampling revealed that the tributaries of the Woady Yaloak River were carrying greater amounts of salts per unit area than the Woady Yaloak River, which were contributing to the end-of-valley salinity in the Woady Yaloak River catchment.

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1. Introduction

Salinity within the Corangamite Catchment Management Authority (CMA) region has developed in the landscape for at least 20,000 years and has been recognised as a problem that requires management since the 1840's (Nicholson *et al*. 2006). The region extends over an area of 13,340 km^2 in western Victoria, from Ballarat to Geelong and west along the coast to Peterborough. The region is divided by four main river catchments, one of which - the Woady Yaloak River Catchment - is the focus of research for this thesis.

The accelerating salinity problem within the Corangamite CMA region has led to the recent development of the second-generation Salinity Action Plan (SAP), (Nicholson *et al*. 2006) which supersedes the original Corangamite salinity management plan "*Restoring the Balance*" (Nicholson *et al.* 1992). The SAP is based on a framework provided by the National Action Plan (NAP) for Salinity and Water Quality (COAG 2000) and the Victorian Salinity Management Framework (2000) (NRE 2000a). The SAP provides the investment plan to protect catchment assets which are threatened by changes in salinity.

The Woady Yaloak River is a major river in the Corangamite region and its health is of concern due to the rising levels of salinity recorded in the river, particularly at the end of valley where it contributes water to the ecologically important wetland of Lake Corangamite. Target areas for salinity management in the Woady Yaloak River Catchment have been identified in the SAP, as priority regions for investment.

1.1 Research Aims and Objectives

The aim of this research is to determine the relative contribution of salt coming from individual sub-catchments within the Woady Yaloak River catchment, as determined by end-of-valley surface water salinity values.

The objectives of the research are to: (1) present a brief review of dryland salinity in a national, state and regional view, with a major focus on the salinity processes and management endeavours in the Woady Yaloak River catchment; (2) conduct a comprehensive survey of surface water and groundwater salinity within the Woady Yaloak River catchment; (3) delineate individual sub-catchments by determining where the water is being shed throughout the different areas of the catchment; (4) calculate relative surface water salt loads for the sub-catchments from monthly sampling records of Electrical Conductivity (EC) and compare and analyse monthly salt loads; and (5) draw conclusions regarding the contribution of salt from each sub-catchment in relation to the landscapes of the Woady Yaloak River catchment.

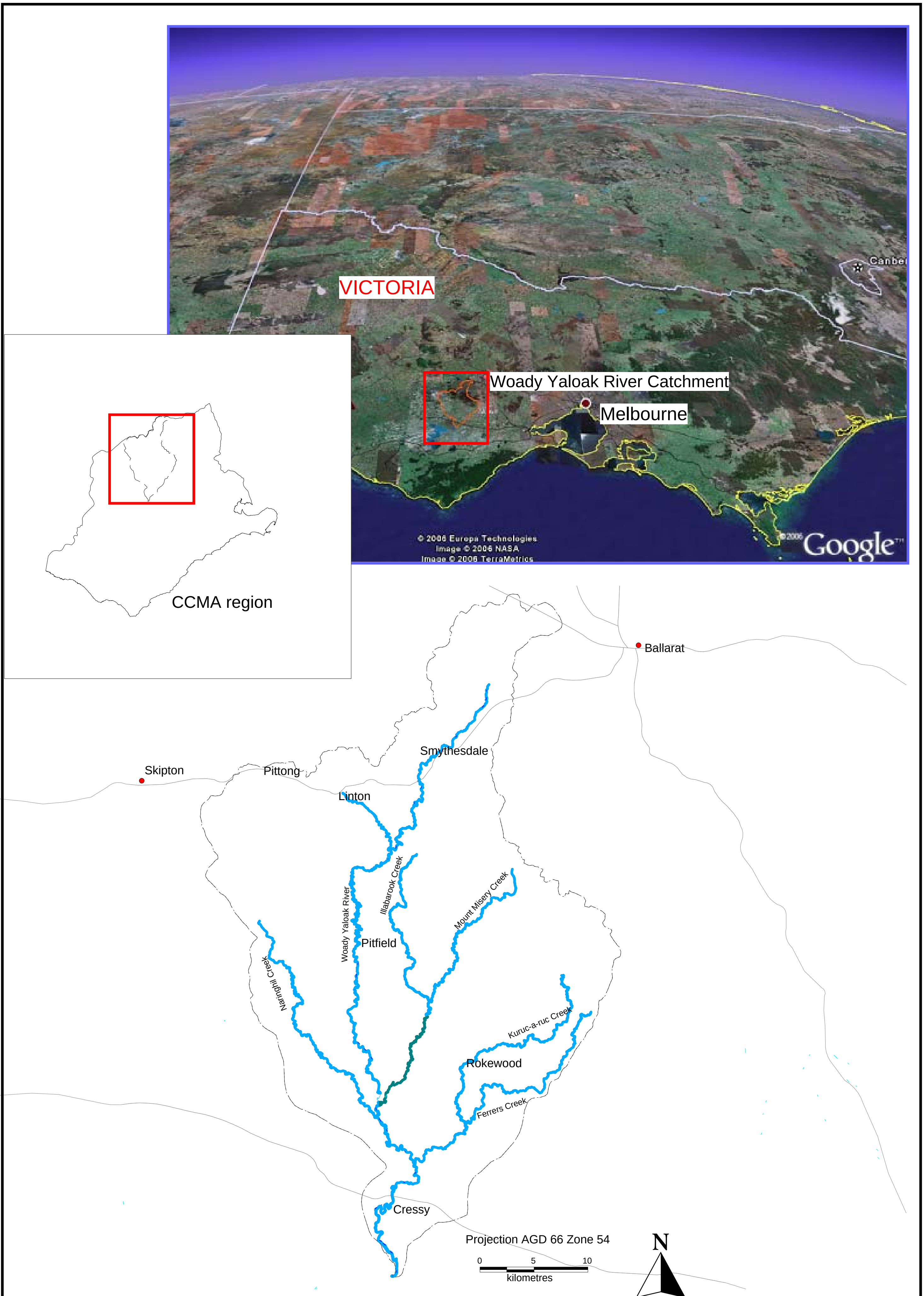


Figure 1.1 Location Map of the Woady Yaloak River Catchment

1.2 Physiography

The Woady Yaloak River catchment covers an area over 1,200 km^2 west of Ballarat, in Western Victoria. The elevation around the north of the catchment is approximately 450m AHD and drops to 130m AHD on the Volcanic Plains around the south of the catchment. The average annual rainfall over the catchment is approximately 600-700 mm/year. The average monthly precipitation to the north of the catchment is approximately 50mm in January and 80mm in June. Monthly precipitation in the southern areas of the catchment is approximately 35mm in January and 50mm in June. Average monthly Pan-Evaporation in the northern areas is approximately 180mm in January and 25mm in June, and for the southern areas is approximately 200mm in January and 40mm in June.

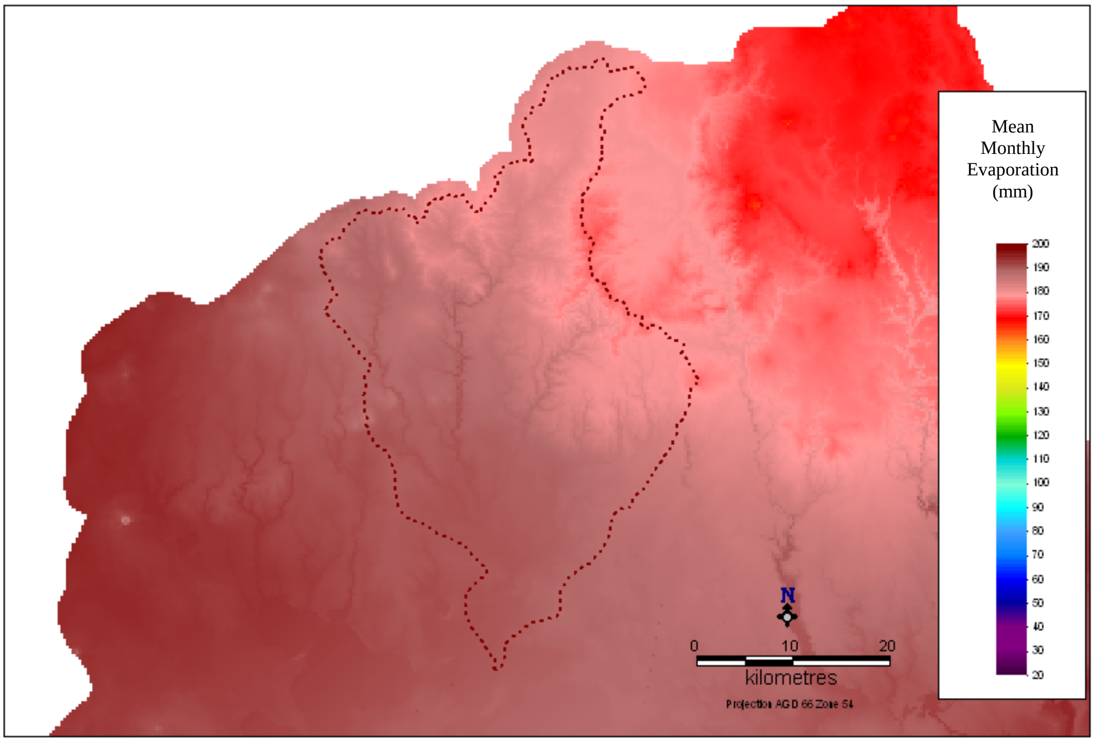


Figure 1.2 Mean Monthly Evaporation Map for the Woady Yaloak River Catchment for the Month of January

The dissected upland landscapes, consist of broad ridges and low to moderately steep undulating hills of sedimentary rock, which occur to the north of the Woady Yaloak River catchment. The high points rise to 470m AHD in the northern upland areas and decrease in the south uplands to approximately 320m AHD. The ridges tend to follow the strata along a north-south axis. The sedimentary rocks are highly weathered and dissected by many dendritic streams, such as Illabarook, Moonlight, Mount Misery, Kuruc-a-ruc and Corindhap creeks (Figure 1.1).

The sedimentary rocks in the region are deeply weathered and have formed clayey soils with bleached regolith profiles, sometimes with silicious or ferruginous duricrusts. Younger fluvial sheet sediments mainly around the southern areas of the dissected uplands, overlie these sedimentary rocks in some areas. These younger sediments have eroded to coarse-grained conglomerates and occur as mesas, around the towns of Illabarook and Rokewood. A characteristic feature of this landscape is that it is susceptible to gully and tunnel erosion (LCC 1980), especially in cleared areas around the Illabarook district. Soils are often sodic, texture contrast, gradational, bleached or mottled and are suitable for grazing.

The southern part of the Woady Yaloak River catchment is in the western Victorian Volcanic Plains, with high points that rise up to 360m AHD in the northern areas, near Scarsdale. Further south through the Pitfield Plains, the elevation drops to 210m AHD and then to approximately 140m AHD at the southern areas of the catchment. There are several volcanic eruption points to the north of the catchment, where lava flows poured down the river valleys and created the generally flat and hummocky Volcanic Plains landscape. Basalt boulders usually outcrop from the thin soils on the plains south of Rokewood.

Some of the volcanic flows are relatively young, such as the ‘stony rise’ flow which occurs south-east of Rokewood and is less than 1 Ma old. Some stony rise flows are reported to be less than 100,000 years old (Skeats & James 1937). Basalt usually outcrops on the surface as corestones and the soils that have developed are thin dark clay, gradational or sodic texture contrast soils with poor drainage. Lateral streams have developed alongside lava flows and usually follow flow boundaries. Many lakes have formed on the plains, such as the lakes present south of the Woady Yaloak River catchment, including Lake Corangamite. These lakes are examples of depressions within the lava flows that have filled (LCC 1976).

The older flows that are present south-west of Rokewood, have developed deeper drainage and thicker soils, exhibiting deep kaolinitic clay profiles consisting of “mottled clay and nodular ironstone” (Joyce 1999). Overall the soils developed on the Newer Volcanics Formation are fertile and have sandy, loam or clay textures. The soils of the Volcanic Plains span over the southern half of the Woady Yaloak River catchment and have relatively high phosphorous levels, which makes the soils quite fertile and able to support the growth of crops. Poorly sorted alluvial sands, silts and gravels have been deposited in and around the existing drainage lines in the catchment and form the youngest sediments in the region.

The granite landscape to the western area of the catchment consists of low hills and deeply weathered regolith. The soils are sandy, uniform to gradational and exhibit deep kaolinitic clay profiles up to 40m thick in some locations. The kaolinitic soils have developed in the Pittong area from the intense chemical weathering of the granites. The kaolin has developed silcrete duricrusts in some areas of the Pittong region (Phillip Kinghorn *pers comm*.), which is an indication of acidic weathering conditions, which has induced the dissolution and precipitation of silica. Granitic Grassy Wood-land Forests occur on undulating and weathered granite landscapes and consist of an open Eucalypt forest with trees up to 15m high.

The native vegetation classes of the area outside of the Volcanic Plains include: Grassy Dry Forests dominated by Eucalypt trees of low to medium height up to 20m; Heathy Dry Forests dominated by low to medium Eucalypt trees and a ground cover of Epacridaceae (Heaths); and Valley Grassy Forests which include medium sized Eucalypt trees that are restricted to valley floors, low hills and on alluvial and colluvial soils (DSE 2004). Some of the tree species include, *Eucalyptus radiata, Eucalyptus viminalis, Eucalyptus obliqua, Eucalyptus rubidia, Eucalyptus ovata, Eucalyptus pauciflora and Callitris columellaris.* Around the headwaters of Mount Misery Creek, Red Stringybark and broad-leaf Peppermint have been noted (LCC 1980).

The indigenous vegetation types on the Volcanic Plains landscape are largely uncertain due to the removal of native vegetation for agriculture. The Volcanic Plains mainly supported native grasslands, dominated by kangaroo and wallaby grasses. Eucalypts such as Swamp Gum and Red Gum may have inhabited drainage areas, however pastures have currently replaced much of the land areas. The swamp areas of the Volcanic Plains support some remnant wetland vegetation.

Figure 1.3 Remnant Vegetation along Naringhil Creek in the Volcanic Plains Landscape

Prior to European settlement, aboriginal populations that inhabited the open forests in the Corangamite region were estimated to be between two to three thousand people (LCC 1976). They were nomadic people whose population was severely reduced to approximately 600 by the year 1876, which coincided with the rapid European settlement. The Volcanic Plains landscape in the Corangamite region contained natural grassland such as Kangaroo Grass (*Themeda australis*), Spear Grass (*Stipa species*) and Wallaby Grass (*Danthonia species*) where presently, only little natural grassland remains.

A major focus for gold exploration began in the town of Illabarook in 1861 where many shallow diggings for alluvial gold concentrated around the deep leads in the Illabarook and Rokewood region in the central part of the catchment (LCC 1980). Quartz reefs were discovered at Berringa in 1864 and in 1897 the major discovery of the rich Birthday Quartz Lode was made which led to the establishment of the Jubilee and Williams Mines in the Mount Misery, Berringa and Rokewood gold areas. The major lead in the catchment is the Scarsdale-Pitfield Trunk Lead (Figure 1.5), which is mapped as the Pitfield Trunk Lead (Taylor *et al.* 1996). It is a meandering lead with an approximate trend of N-S. The tributary leads are the Bulldog and Mackayst leads, which branch off the Pitfield Trunk Lead to the east. Many shallow diggings occurred along the Grand Trunk, and the main gold rush occurred in 1855 around Salt-creek, Pigoreet and Happy Valley.

Later in 1890 deep lead mining commenced around the town of Pitfield and ceased in 1909. Nimon's Bridge, which is now a disused railway line approximately 5km south of Scarsdale (Figure 1.4), was constructed in 1890 and was used as a transport service for the gold and kaolin clay industries. It is the largest constructed timber trestle bridge along the line, which spans over 114m and was named Nimon's Bridge because it was constructed on the property of A. Nimon (Houghton & McLean 1986). In 1916 the railway began operations, and ceased in 1983. The Woady Yaloak River, which was formerly known as Smythes Creek at this location, presently flows from north to south underneath the disused bridge.

In the 1940's, the Woady Yaloak River catchment experienced extensive cultivation and grazing of natural pastures (grasses, herbs and shrubs). These were the dominant land use practices that were established across the fertile basaltic soils in the catchment. Current land use practices vary across the catchment, reflecting the composition of soils and the different landscapes. Current land uses identified include cropping, grazing, natural forests, timber plantations, non-agricultural cleared land areas and residential and lifestyle properties. Cropping, and grazing of modified pastures, are the dominant land use practices adopted across the Volcanic Plains in the catchment (Figure 1.6). Forested areas, hardwood and softwood plantations, state forests, nature reserves and national parks are restricted to the north, around the dissected uplands within the higher elevations and is increasing in the Dereel area (Dahlhaus *et al.* 2002).

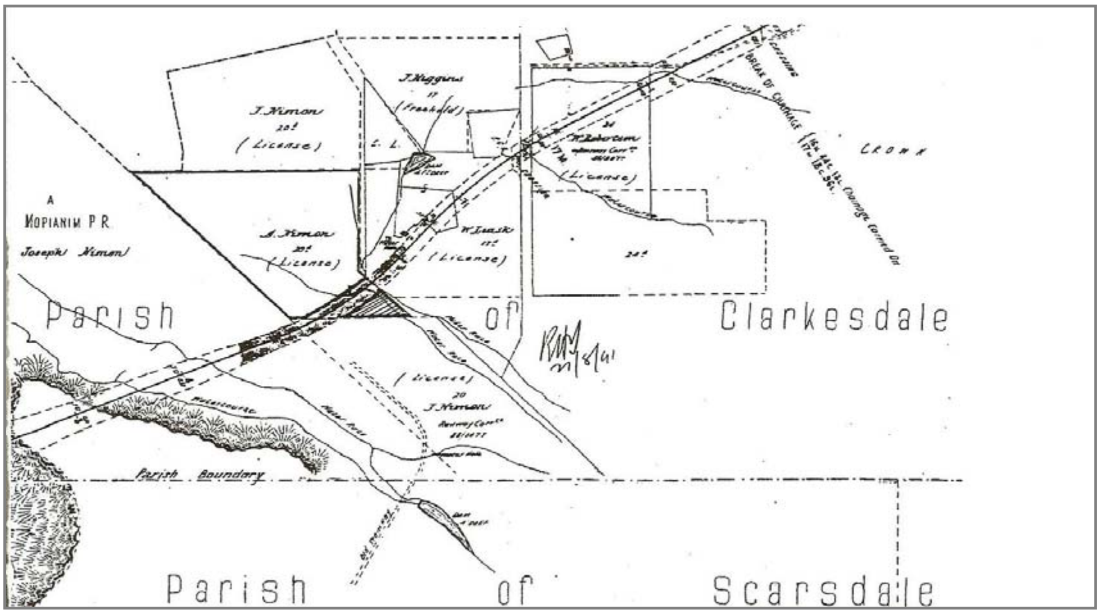


Figure 1.4 The Victorian Railways Plan for the Ballarat-Skipton Railway Line
as it crosses Smythes Creek (now the Woady Yaloak River).
Courtesy of the Woady Yaloak Historical Society.

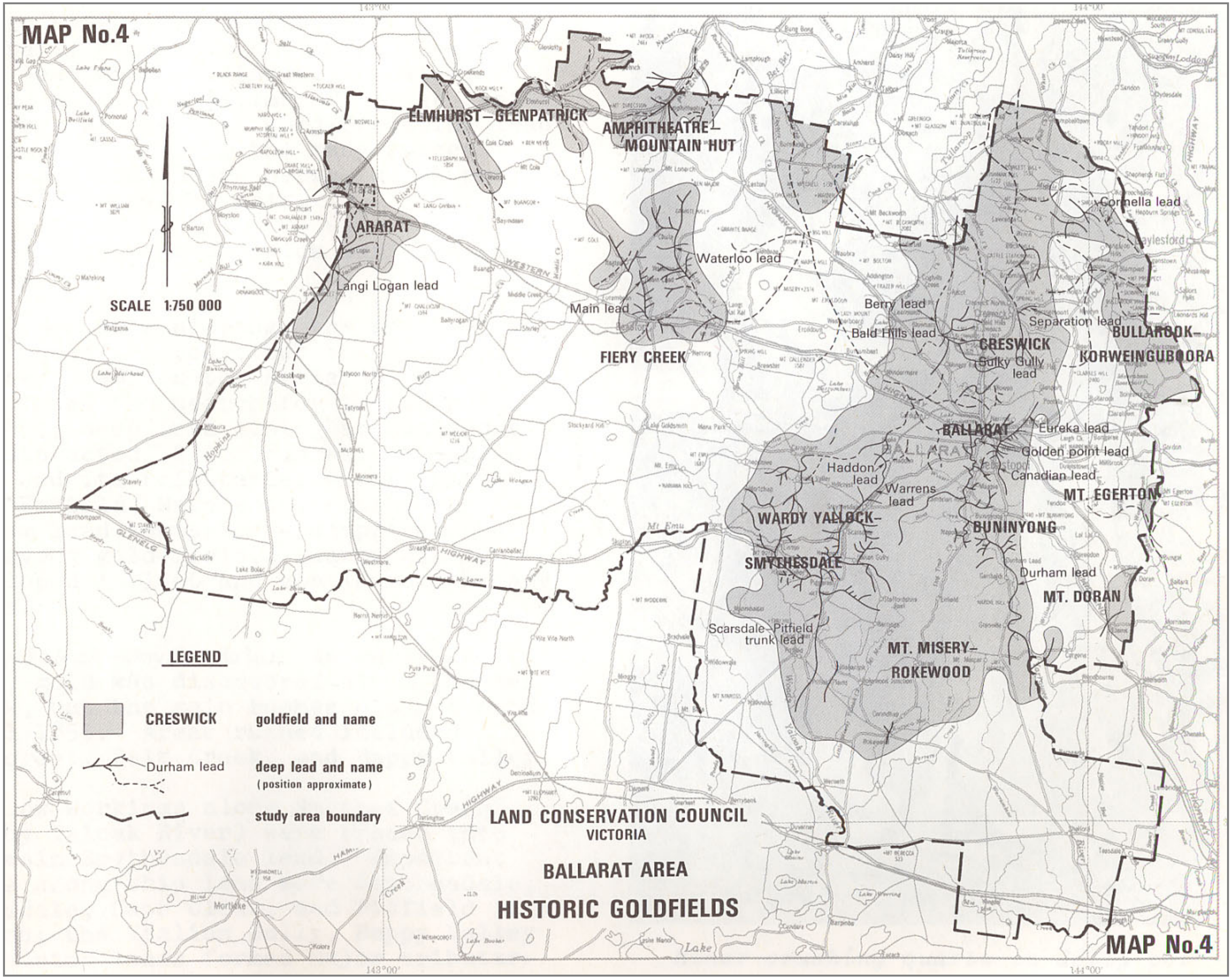


Figure 1.5 Gold Mining Areas in the Woady Yaloak River Catchment (Source: LCC 1980)

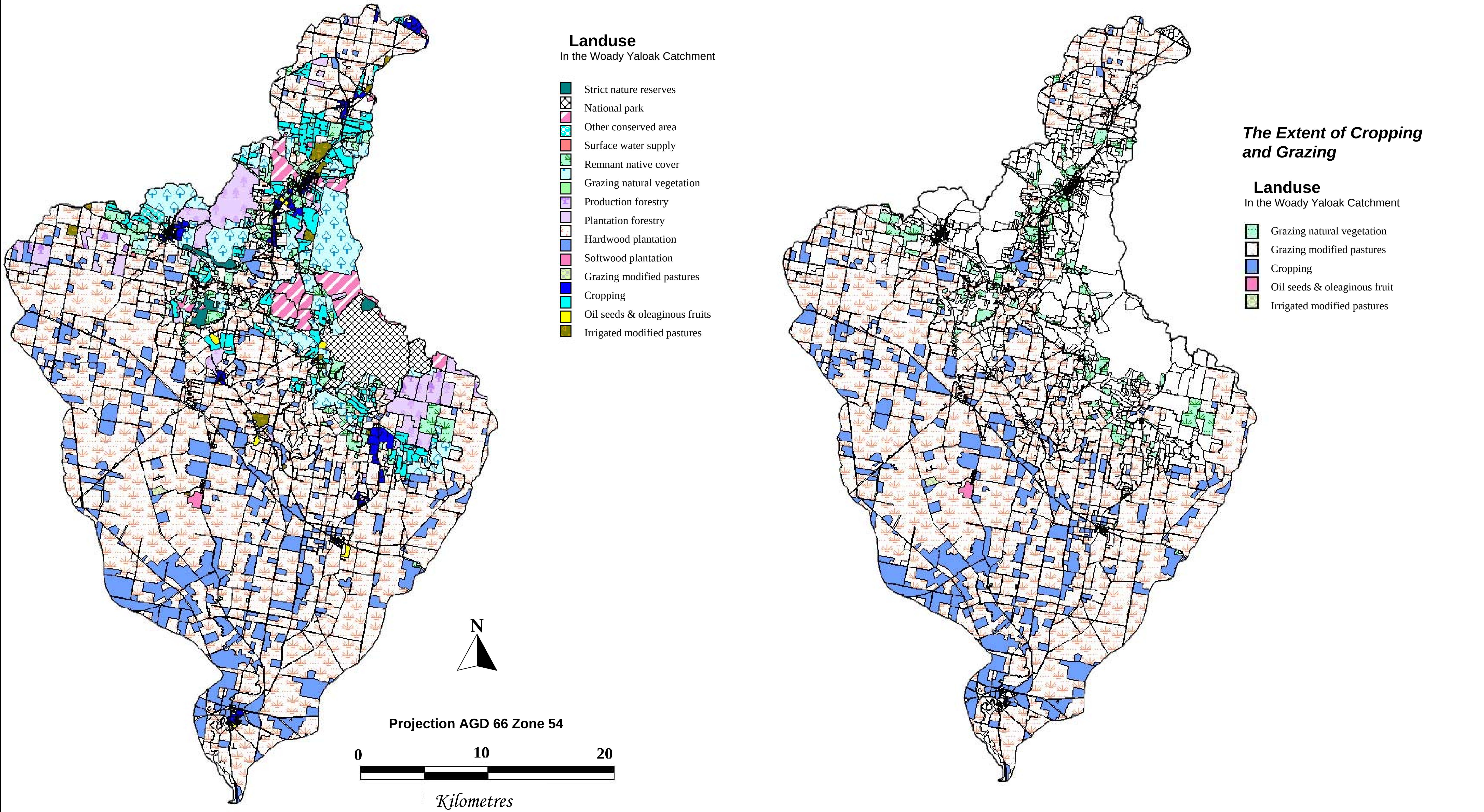


Figure 1.6 Current Land Use Practices for the Woady Yaloak River Catchment
Adapted from PIRVic 2001

2. The Salinity Problem

This chapter presents an overview of the salinity problem in the Australian landscape. The intention is to provide a National, State, regional and local context for the salinity in the Woady Yaloak River catchment.

2.1 Land and Stream Salinity

Primary salinity occurs in soils and water by natural processes (Ghassemi *et al.* 1995) and was present before widespread land-use changes brought about by European settlement. The development of agriculture has led to the removal of deep rooted native vegetation from the landscape and replaced it with relatively shallow rooted pastures and crops. This has allowed groundwater levels to rise close to or at the land surface level, which has altered the water balance in catchments across Australia. The rising groundwater is believed to have induced secondary salinity (Dyson 1993).

In most regions the exact date of clearing of large forested areas and native vegetation remains vague, and early reports such as those by the Soil Conservation Authority (1940-1985) confirm that major increases in dryland salinity across the Victorian landscape simply “followed settlement” (Nathan 1998). Saline discharge areas were noticed at the foot of slopes, which is believed to have resulted from the clearing of timber from these slopes. This allowed the infiltration of rainwater into the soil A-horizon, to re-mobilise the salts that were stored in the soil profile, to travel as interflow until the saline water discharged downslope. These observations and investigations of saline areas led to the reclamation of salt affected areas, which emphasised replacing less salt tolerant plants and trees with more salt tolerant ones.

These initial management endeavours came about because of the increased erosion on land, with the purpose of stabilising land and stream areas to prevent further erosion.

Primary salts in the Australian landscape have been delivered from a number of sources, these include, (1) oceanic salts which have precipitated onto land, (2) depositional salts from marine rocks and wind blown salts, and (3) salts added to the landscape by anthropogenic processes including the application of fertilisers and nutrients to land (Nicholson *et al.* 2006).

Secondary salinity may occur through the expansion of primary salinity and the two forms are difficult to distinguish (Ghassemi *et al.* 1995). It is a widespread view that secondary salinity is human induced, and is manifested as an increase in the total dissolved salts (TDS) in soils and water. Secondary salinity has two forms, irrigation salinity and dryland salinity. Where the two are similar is that excess water percolates below the surface, recharges the water table and causes it to rise to the surface.

The way groundwater is transported to the surface is influenced by the topography of the land to which it underlies, and on the characteristics of the aquifers. For example, impermeable layers that are present below the surface can produce springs or perched water tables on hilltops and slopes, and in unconfined aquifers, valley floor salting can discharge groundwater in areas with low topographic relief. Groundwater can be brought to the land surface by capillary fringe action or through geological structures which exist in sub-surface geology such as faults or joints in the bedrock (Fetter 2001).

Saline groundwater can run off the land surface and enter the stream as either return flow, where the seepage flows overland, or by interflow, where it joins the stream at the footslope. The majority of saline groundwater discharges directly to the stream as baseflow. This addition of saline water to surface water bodies, can affect the quality of water and the ecology of the waterbody. The impact that salinity has on rivers is the decline in the overall water quality, whereas the TDS of the waterbody increases, a decrease in species diversity occurs, as the abundance of salt-tolerant species replaces less tolerant ones (Bailey 2000). A decline in macrophytes and microalgae can reduce the plant cover in a waterbody and result in more light penetrating the water and thus promote the abundance of phytoplankton and algal blooms. The decline in macrophyte populations can result in less food and breeding grounds for many waterbird species, which migrate to a waterbody (Bailey 2000). These waterbodies are usually significant and sometimes protected, such as Lake Corangamite in SW Victoria, which is listed as a wetland of international importance under the Ramsar convention (Nicholson *et al.* 2006).

Dryland salinity processes influence both baseflow and surface runoff to a stream. As watertables rise, the baseflow to the stream will increase due to the increased hydraulic gradient, and may contribute more saline groundwater to surface water rivers, lakes and wetlands. When the saline watertable is close to the surface, it may discharge and then travel as overland flow and enter the surface waterbody. Irrigation can also cause surface waterbodies to increase in salinity. If water is extracted from rivers for irrigation, then the volume of water will diminish in the stream and it will be less effective in the dilution of salts in the waterbody (NRM 2006).

2.2 *The Extent of Salinity*

2.2.1 Australian Salinity

Salinity is greatest in the deeply weathered landscapes across Australia, and consistent with mediterranean climates experienced across southern Australia, typically of wet cool winters and dry hot summers (BOM 2006). The deeply weathered profiles have allowed the regolith to store large volumes of salts, which are often contained within materials of low permeability. As the groundwater system is recharged, the salts stored in the regolith are re-mobilised and as the watertable rises the salts are accumulated onto the surface. Due to the increasing recharge, some groundwater systems have become full and cannot store any more water, as a result the water discharges to the surface.

Australia has approximately 663 million hectares of arid land. This constitutes 11% of the world's total dryland area and makes up 75% of the Australian continent (Ghassemi *et al.* 1995). Salinity of land, surface water and wetlands is widespread across the Australian continent, occurring extensively in Western Australia, South Australia, New South Wales and in parts of Victoria. The history pertaining to the extent of salinisation in Australia has been underestimated, and after detailed surveys have been undertaken in a salinised area, almost all always showed the extent of salinity was greater than what was previously thought (Robertson 1993).

Prior to European settlement, primary salinity was noted across regions in Australia. For example in Western Australia, 28.2 million hectares of land was affected by primary salinity, and salts were commonly gathered from streams and used to cure sheep which had been slayed (Robertson 1993). Salinity in the Murray River in South Australia, was regularly recorded in the early 1900's, before and after settlement, where salinity was shown to be high. It was revealed that the salinity of the river was increasing upstream due to the downstream influence of seawater. Dams and weirs were constructed at the mouth of the river in 1935–1940 and salinity ceased to increase as a result (Williams 1999).

Dryland salinity occurs copiously across the southern continent. The climate is typified by dry hot summers, currently represented by drought, and has a history of cool wet winters which implies that the southern continent experiences a great amount of recharge due to the lack of transpiration from plants, which controls recharge and removes water from the soil (Dyson 1993). The rate of transpiration from plants decreases due to high atmospheric humidity and high soil moisture contents (Knox, Ladiges, Evans & Saint 2001). Evaporation generally exceeds rainfall, except in the winter months (June-August) (BOM 2006a) and as the groundwater at the surface evaporates, it concentrates the salts onto the surface and results in salinisation of the land.

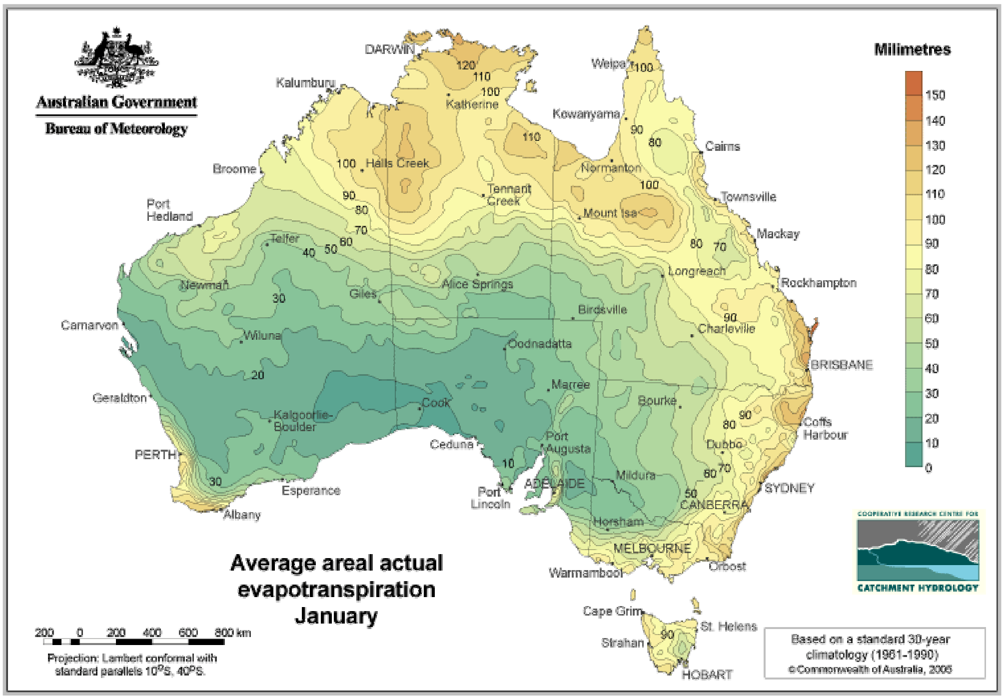


Figure 2.1 Mid Summer Evapotranspiration Areal Actual Map for Australia.
(Source: BOM 2005).

Current knowledge on salinity has increased since the establishment of the National Dryland Salinity Program (NDSP) in 1993, which has invested funds across the country to coordinate current thinking and to share new knowledge in the form of new technologies and products to help improve management of dryland salinity.

The National Land and Water Resources audit commenced in 1997, and estimated the risks associated from rising watertables over the next 50 years. The estimated risk is 5.7 million hectares of land across Australia, which is predicted to increase to 17 million hectares by 2050 (DEH 2004) under current land-use scenarios. Predicted losses to the Corangamite region due to shallow watertables were estimated at $29 million a year, this figure was based on losses from agricultural production, infrastructure damage and costs relating to the increasing salinity of water (Nicholson *et al.* 2006).

The Corangamite CMA together with the Glenelg Hopkins CMA have been listed, as one of the 21 priority regions in Australia in the National Action Plan (NAP) for salinity and water quality. The NAP requires the priority areas to comply with the National Framework for Natural Resource Management (NRM) Standards and Targets, where regional targets must be established to comply with a range of environmental issues including land salinity and surface water salinity in freshwater aquatic environments (Nicholson *et al.* 2006).

2.2.2 Victorian Salinity

Victoria's Salinity Management Framework *Restoring Our Catchments* (NRE 2000b) provides a framework to help manage Victoria's growing salinity problem. This framework follows on from *Salt Action: Joint Action*, which is a strategy that began in

1988 to help manage salinity on land and in water, and led to the establishment of nine CMA's in 1997 across rural areas of the state. There are 21 regional salinity management plans over Victoria which focuses on building landholder's skills and knowledge on dealing with salinity, land use changes and economical water usage (NRE 2000b).

2.2.3 Regional Salinity

The establishment of the Corangamite CMA led to the development of the Corangamite Regional Catchment Strategy (RCS), which incorporated salinity management over the region. Two Salinity Action Plans (SAP) for the Corangamite region have emerged from the Corangamite RCS, the first plan, *Restoring the Balance* (Nicholson *et al.* 1992) and more recently the second-generation *Corangamite Salinity Action Plan 2003-2008* (Nicholson *et al.* 2006). The purpose of the SAP is to highlight salinity target areas within the CMA region and to describe the current salinity processes within those target areas, catchment management issues and prioritisation of risks and assets within the region. (Nicholson *et al.* 2006).

Assets include the primary and secondary industries which rely on the regional resources and the natural environment, and recreation and tourism which also require the forests, coastal areas and earth's resources. Primary salting was often noted from the early settlers where large areas throughout the region were severely salinised over 200 years ago, prior to European settlement (Dahlhaus & Cox 2005).

The high watertables noted in the region today have sufficiently risen closer to the ground surface over time, however, high watertables within the Western Victorian Volcanic Plains have been a feature in the region for over 200 years. The aquifers of the Volcanic Plains are thin and the hydraulic gradients are low to very low. The movement of water within the aquifer corresponds to the amount of water that is discharging, so as the ground- watertable is recharged this means that the water must exit to a discharge point. More recharge to these aquifers will consequently result in the expansion of discharge areas in the region, and this will affect large areas that are occupied by agriculture.

Costs to agricultural land and wetlands affected by the rising salinity in the CCMA region have been estimated to cost $29 million per year. It has been predicted that by the year 2050, 48.5% of agricultural land will be at risk from high watertables and less than half of the regions wetlands will be affected (Nicholson *et al.* 2006).

The Volcanic Plains in the Corangamite CMA region constitute most of the salinity, where an area of 21,000 hectares of saline land has been mapped. It has been proposed that by 2050 the area will further deteriorate, resulting in losses of agricultural land, and the degradation of water resources, particularly within the significant wetlands of the region.

Dryland Salinity in the Corangamite CMA, currently affects 17,250 hectares of land (Nicholson *et al.* 2006).

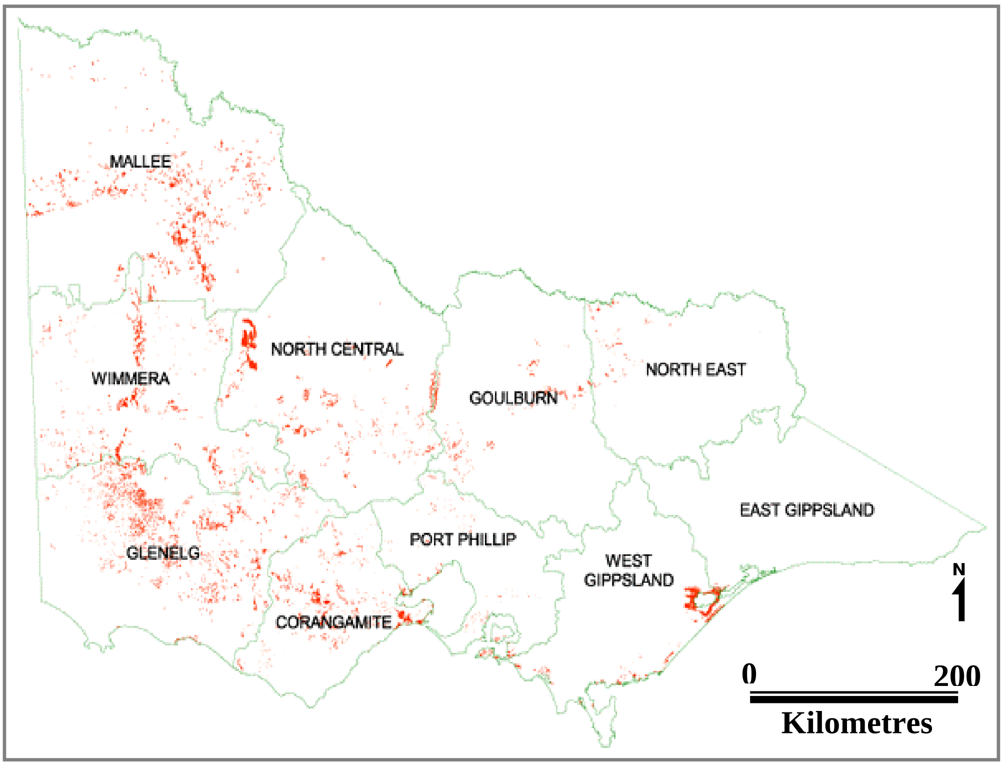


Figure 2.2 CMA Regions across Victoria
The red polygons represent the land affected by dryland salinity.
(Source: DPI 2005)

2.3 Salinity Management Options

Controlling dryland salinity, in regions across Australia, with the use of biological or engineering management options will improve economic losses from agriculture and infrastructure damage, and prevent further deterioration to the biological environment. It has been estimated that costs to infrastructure could increase to 70% of the current costs by 2020, totalling 70% of the costs associated with dryland salinity (NDSP 2004c). The remaining 30% of costs are attributed to losses from agricultural yield. Current estimated annual costs of salinity damage to infrastructure are $89 million.

2.3.1 Recharge Area Management

A recharge driven system is dependent on the rate at which water is entering an aquifer and which is able to support more water entering the system, than is usually available on an annual basis.

2.3.1.1 Water Harvesting

To control recharge to the watertable, water harvesting is used as a method to control the amount of water that sits on the land, by directing it into drains along a contour. The drains collect water off slopes, which can then be stored in a dam. The construction of W or V-shaped drainage lines are an effective engineering option to control recharge and waterlogging on land, as water can be diverted from waterlogged and high recharge areas (NDSP 2004b).

2.3.1.2 Plant-Based Management

Planting deep-rooted perennials pastures such as lucerne have been trialled in Western Australia to reduce groundwater recharge and have showed positive signs of lowering ground-watertables, which reside under local aquifer systems (NDSP 2000). On sandy and unproductive soils, planting perennials can reduce the amount of recharge, as these soils are effective in recharging the watertable. Other studies have shown that perennial pastures of clover and phalaris in environments where rainfall exceeds an average of 600mm/year slightly improved the water balance and that in higher rainfall environments deep-rooted perennials need to be combined with trees in order to effectively improve the water balance (NDSP 2000). The conclusions drawn from these studies confirm that perennial pastures were more successful than annual pastures for controlling deep-drainage and for lowering the water table. A study by Day, Kevin & Ryan (1993) demonstrated that lucerne pastures are more effective in moderate rainfall environments (450 mm/yr) however, in higher rainfall environments (approximately 700mm/yr), additional trees should be combined with the pastures to control recharge, so agroforestry for salinity control is recommended for higher rainfall zones.

Planting out salt affected areas with salt tolerant species has also been adopted across Australia (NDSP 2004). Plant-based management options offer the rehabilitation of saline land, which can prevent saline water entering nearby streams from surface runoff. The efficacy of this management option will be dependent on the spacing between trees and on the variety of species planted, which should be suitable to the salinised areas, as transpiration rates vary for different tree species under different environmental conditions, such as humidity variations which control transpiration rates from plants.

2.3.1.3 Farm Management

Farm management can help to reduce waterlogged and saline areas, resulting in less recharge to the watertable and improved land areas (NDSP 2004c). Management on farms can include fencing off cattle on different areas of the land, this can help reduce soil erosion by controlling the amount of time that the animals spend on an area, as cattle can compact soils by procuring salts and nutrients from the land, which accelerates soil erosion. Crop rotation can also minimise the amount of recharge to the watertable. Primary saline areas suited for fencing off, include riparian zones and flood plains (Borg 2005).

2.3.2 Discharge Area Management

A discharge driven system is dependent on the rate at which water is leaving an aquifer and where excess recharge cannot enter the aquifer instead flows as interflow or surface runoff.

2.3.2.1 Plant-Based Management

To control discharge onto land, hydrophilic trees[1] can be planted where the watertable is close to the surface, as the roots of trees can tap into the groundwater and utilise the water to stop it from discharging onto bare land. To control groundwater discharging on slopes, trees planted on the break of slope can intercept shallow watertables (within 5-10 metres from the surface), which impedes discharge to the surface, by lowering the groundwater at this position in the landscape. The rate of recharge must be acknowledged when considering planting trees on slopes, to determine just how much water is discharging at the break of slope and how many trees need to be planted. Sufficient amount of water needs to be made available to the trees for their growth, and the distance between plantings can help ensure their nourishment is met (NDSP 2004c).

In Victoria, lucerne pastures were sown above discharge zones of regional groundwater flow systems of fractured Ordovician sandstones and slates, in the eastern Wimmera region in 1986. A one-metre drop in the ground-watertable occurred after three years of the establishment of the lucerne pasture. The effectiveness of the water level drop was also noted 100 metres from the site underneath a cropped paddock. It was contributed to the low storage capacity of the groundwater flow system and on the low permeability of the aquifer (Day, Kevin & Ryan 1993). This

[1] Where the groundwater is saline the vegetation will also need to be halophilous.

demonstrates that the effectiveness of lucerne pastures and other plant-based management options that are used to control discharge can be verified by comparisons of the groundwater level fluctuations, under the established and adjacent area.

Salt tolerant plants for grazing can be sown over areas affected by saline soils. The salinity of the soil must be suited to the plants. For example tall wheat grass (Dundas and Tyrell varieties) are highly tolerant of saline soils (EC_e = 12 to 25 dS/m). Varieties such as sub-clover and ryegrass are sensitive to salts and can only tolerate very low salinities (EC_e < 2 dS/m) for the former species and low salinity (EC_e <4.5 dS/m) for the latter species (Borg 2005).

2.3.2.2 Engineering Options

Sub-surface, deep open and shallow open drains can be constructed to manage areas affected by dryland salinity. Drains can control discharge on land, by diverting saline water off land. The groundwater may then be directed into dams or streams as long as the disposal of the saline water does not pose a threat to the environment.

Groundwater may also be pumped from bores to prevent discharge onto land, which has the effect of lowering the watertable (Nicholson *et al.* 2006).

2.4 Salinity in the Woady Yaloak River Catchment

Salinity of the Woady Yaloak River measured at the Cressy gauging station (234210) suggests a maximum EC of 5300 µS/cm and a minimum EC of 5000 µS/cm is predicted by the year 2012 under a no change scenario in salinity management over the catchment (Figure 2.3). These figures were construed from trends in the existing data. Current EC trends between the years 1976 to 2005 are 3.4 +/- 23.7 µS/cm/yr. Higher EC values of 8450 µS/cm and above were recorded during the autumn-winter periods between the years 1997-1998 and 2000-2001 (Dahlhaus *et al.* 2005a).

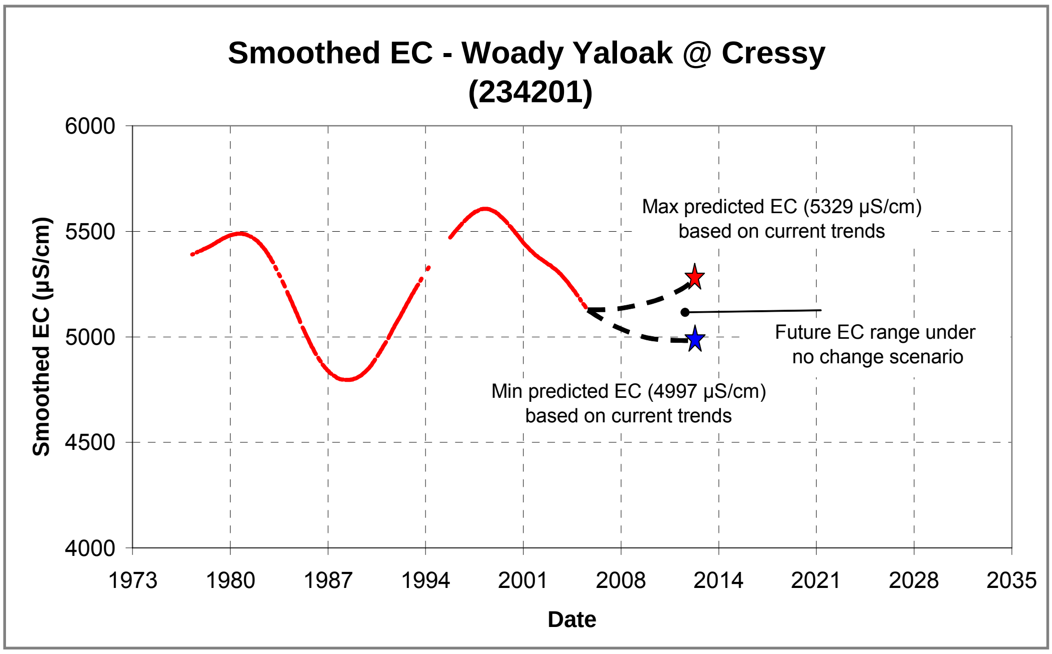


Figure 2.3 Non-Linear EC Trend for the Woady Yaloak River 1976-2005
(Source: Dahlhaus *et al.* 2005a).

In 2004 the various land management groups in the Woady Yaloak River catchment received 73% of their funds from the Federal programs, the NAP on Salinity and Water Quality, the National Heritage Trust (NHT) and the National Landcare Program (NLP). Smaller funds were contributed by the Corangamite CMA (8%), State government (2%), the Woady Yaloak Catchment Group (WYCG) (6%) and other sponsors (5%). The WYCG also won the National Landcare Catchment award (Nicholson 2004).

The Pittong area in the Woady Yaloak River catchment is a chosen discharge monitoring site, for the Victorian Dryland Salinity Monitoring Network (VDSMN). It was chosen for assessment from 1996 to 2000, which revealed that salt affected areas for the Pittong region showed an increase of 8% over this period and revealed that groundwater levels were slightly lower (Dahlhaus *et al.* 2005a)

A research project undertaken by Church (2004) indicates that salt wash off from saline sites at Pittong and Illabarook, contribute to the rising salinity in the Woady Yaloak River. Soils were tested at two sites in the Illabarook area and one site in the Pittong area, and it was found that salinity decreased in the A horizon of the soil in September, compared to June recordings. This would indicate that with greater amounts of rainfall, the salts were being washed off or diluted in the soil profile. The results also showed that salinity decreased with depth in the soil in September, this indicated that the salts were carried down through the A horizon until they reached a heavy B clay horizon where they then travelled laterally until the saline water discharged at the land surface.

The same process occurred at Pittong, where water that infiltrated through the soil reached the B horizon and then travelled laterally to low-lying areas. The results inferred that as the infiltrated water travelled downslope, it met with saline springs that rose up through fractures in the granite aquifer, which ultimately discharged saline groundwater in low-lying areas.

2.4.1 Salinity Management in the Woady Yaloak Catchment

Twelve salinity sites have been identified in the SAP (2006) across the Corangamite region, which are priority areas for management. Salinity management in the target areas within the Woady Yaloak River catchment includes discharge area control, recharge area control and rehabilitation of saline land. The target areas identified in the SAP are Pittong and Illabarook (discussed further in section 2.4.1.1 & 2.4.1.2).

Engineering management options have been proposed for the Woady Yaloak River's diversion scheme, with aims to improve the water quality in Lake Corangamite, which is the ultimate discharge point for the river. The diversion scheme was introduced in 1959 following heavy rains from 1951, which increased the level of Lake Corangamite to 114.7 m AHD. Heavy rains continued in the subsequent years, thus flooding a few thousand hectares of agricultural land when the lake rose to 117.9 m AHD. Fifty percent of the water was diverted into the Warrambine Creek, which then entered the Barwon River. In 47 years since the operation of the scheme the water level in the lake has remained constant and has recently fallen considerably. This has concentrated the existing salts in the lake because of the volume decline of water and increased the salinity of the lake. During the course of this study, the adjacent lakes Gnarpurt and Martin dried up completely.

A review of the diversion scheme was undertaken by GHD Pty Ltd as a foundation project by the NAP and under the Review of Regional Drainage Schemes (2004). The study suggests closing 25% of the Woady Yaloak's diversion scheme to increase the levels of Lake Corangamite to 115.28 m AHD. The water will only be diverted when the lake level rises above 115.28 m AHD. In the year 2009 the diversion channel will be closed and private land up to 118.1 m AHD will be purchased. The changes to the

Woady Yaloak diversion scheme will come into effect from July 2006 until June 2009 (Dahlhaus *et al.* 2005a).

Twelve Resource Condition Targets (RCTs) have been established for the CCMA region, four of which focus on the target areas of Pittong and Illabarook in the Woady Yaloak Catchment (Nicholson *et al.* 2006).

The RCTs are:

Pittong:	Maintain an EC of <8000 μS/cm 90% of the time at Cressy gauge (234201)
Pittong:	By 2012 establish EC targets for Naringhil Creek at the boundary of the Pittong target area
Pittong:	By 2015 no net increases in the area affected by land salinity (from the 2005 affected areas)
Illabarook:	Maintain an EC of <8000 μS/cm 90% of the time at Cressy gauge (234201)
Illabarook:	By 2012 establish EC targets for Woady Yaloak tributaries at the boundary of the Illabarook target area

A hydrographic monitoring station to be established downstream of the Pittong area (at Naringhil Creek) has been proposed as a high priority target, following a study by Sinclair Knight Merz (SKM) which examined existing gauging station data across the CCMA region (Dahlhaus *et al.* 2005a). It is understood that the monitoring station will be implemented in 2007 (Dahlhaus, *pers comm*.).

2.4.1.1 Pittong

In the Pittong region, an area encompassing 63 km^2 has been identified as a salinity target area in the Corangamite SAP. The Pittong area is believed to be a contributing source of salt to the rising salinity of the Woady Yaloak River, where a geological boundary at a granite pluton and the surrounding country rocks is believed to be the controlling factor of groundwater discharging onto the surface (Nicholson *et al.* 2006).

Salinity in the Woady Yaloak River has increased due to the addition of groundwater to the river, derived partly from the hydrogeological factors occurring in the Pittong target area. The salinity processes have been conceptualised by Dahlhaus & MacEwan (1997), where saline groundwater is thought to rise up through fractures within the underlying granite aquifer, which then travels as interflow (with the transient soil water flows) through the sandy overlying regolith, then discharges to the surface and enters waterbodies (Figure 2.4).

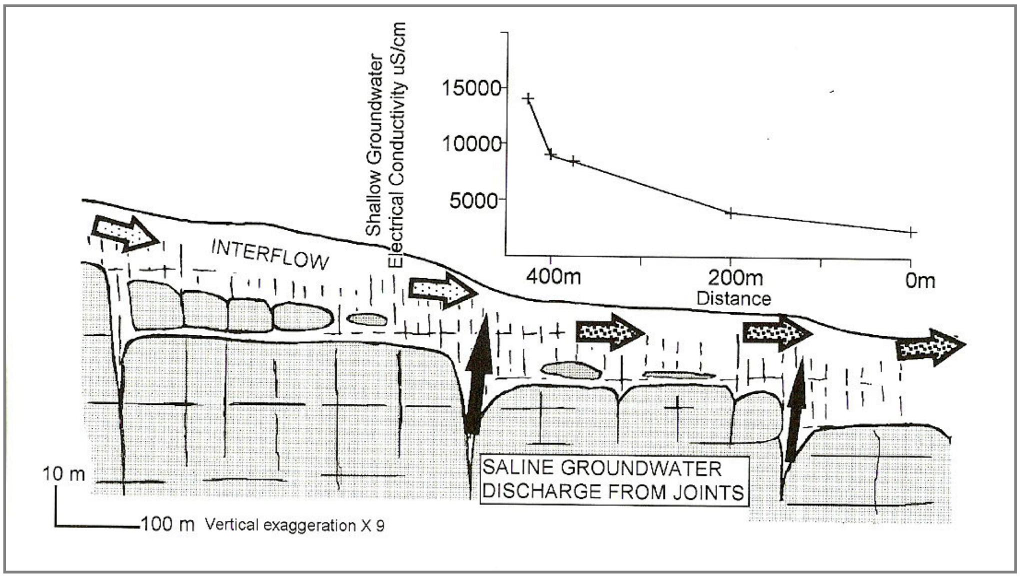


Figure 2.4 Conceptual Model of the Salinity Processes at Pittong.
(Source: Dahlhaus & MacEwan 1997).

What the salinity model suggests is:

- Deep regional groundwater from the granite aquifer rises up through fractures and joints, where it meets with shallow groundwater interflow that occurs in the deeply weathered granite aquifer. It is then added to the infiltrated water and then travels through the soil profile.

- Shallow groundwater travels close to the surface from the local recharge areas down to the discharge areas, which leads the groundwater to intercept the surface at the discharge areas. Groundwater springs occur where the deep regional groundwater emerges from the fractures.

Recent work in the region by Church (2004) in the Pittong region, verified that the water that infiltrates through the soil reaches the B horizon and then travels laterally through the A horizon where it discharges to low-lying areas. The infiltrated water meets with saline springs rising up through the deeper granite aquifer, which adds salts to the water travelling towards the discharge areas. The research involved sampling soils in June and September, and it was found that salinity in the A horizon had decreased due to rainfall. The salts were shown to travel downslope and not further into the soil profile, as sampling revealed that salinity had decreased with the depth in the soil, indicating that the infiltrated water carried the salts downstream.

Management options considered in the Pittong area are engineering and plant-based options, which target the shallow granite aquifer. The granite landscape features topographical highs, gentle undulating slopes and broad valleys. Recharge is common on the topographical highs at approximately 25 mm/yr. Groundwater flow paths must be intercepted in order to prevent discharge onto slopes, this can be achieved by planting trees to intercept the groundwater that resides close to the surface on slopes, which can lower the watertable and its hydraulic gradient. Diversion of water from slopes and crests can prevent saline water from becoming waterlogged on the surface. Drainage lines can direct the water flow downstream, where it can be stored in a dam or flow into a creek (Figure 2.5).

Figure 2.5 Discharge Site at Pittong

Parallel constructed drainage lines (raised beds) on Francis Lane to control waterlogging on land. The puddle is a groundwater discharge spring which flows to the east into a tributary which then joins Naringhil creek.

The local Landcare Group have been at the forefront of salinity management since the early 1980's. Current management techniques include experimental sites using interceptor drains, tree belts and raised bed agriculture. A Sustainable Grazing on Saline Land (SGSL) site is located in the Pittong area as part of a nation-wide trial of salinity management techniques (Nicholson *et al.* 2006).

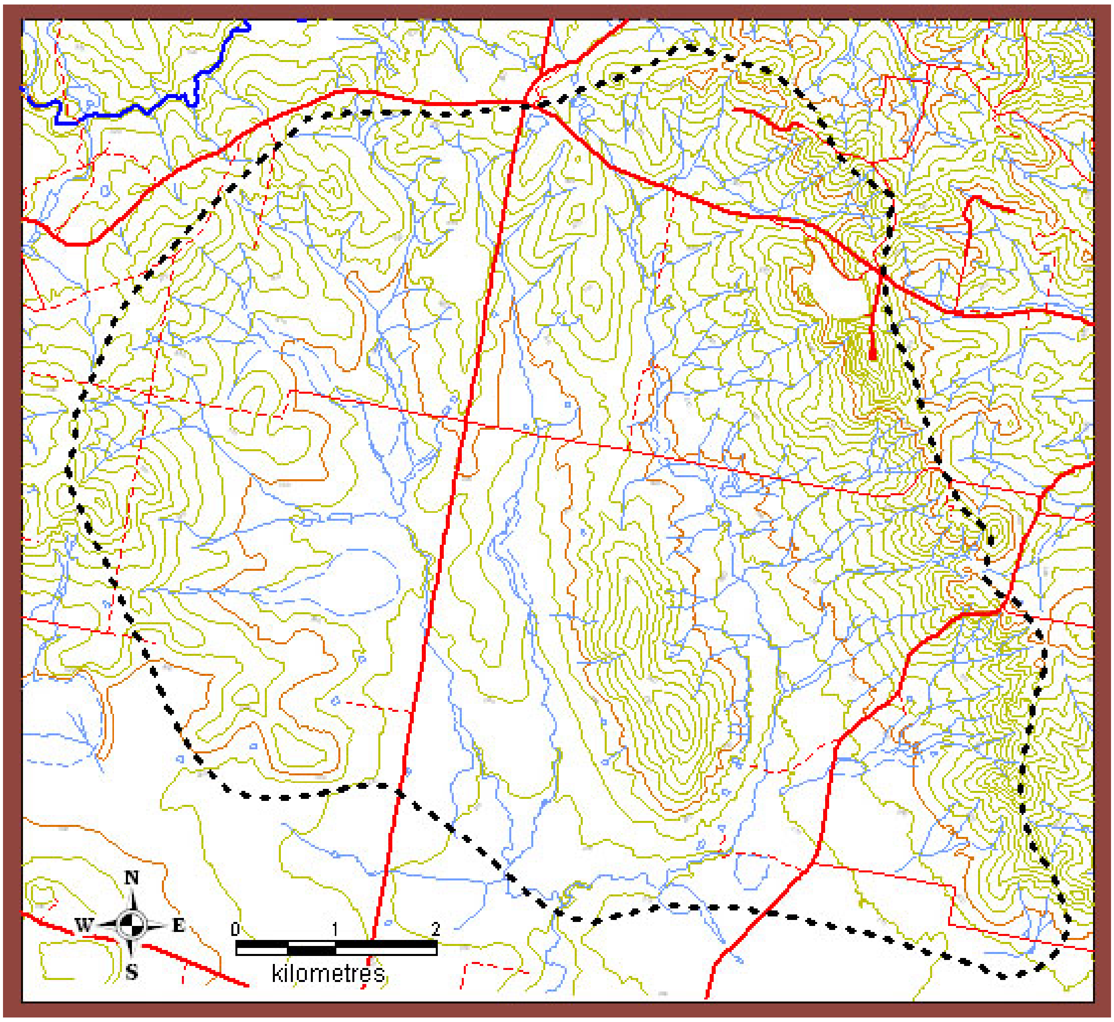


Figure 2.6 Topographical Map of the Pittong Salinity Target Area

2.4.1.2 Illabarook

The Illabarook target area encompasses an area of 205 km^2 and extends around the towns of Illabarook and Rokewood in the central area of the Woady Yaloak River catchment. Recharge management is matched to approximately 103 km^2 while discharge management is matched to more than 8 km^2. The increased recharge to the watertable may be a result of past mining activities where soil profiles were stripped away or overturned in exploration attempts for gold, which allowed more water to infiltrate below the surface and recharge the ground-watertable (Nicholson *et al.* 2006).

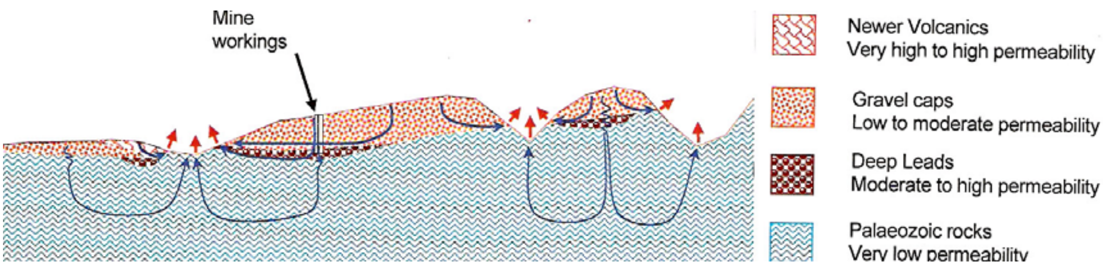


Figure 2.7 Conceptual Model of the Salinity Processes at Illabarook
(Source: Nicholson *et al.* 2006).

There are three main groundwater flow systems present in the Illabarook area they are (1) the Palaeozoic sedimentary rocks, which contain local and intermediate flows; (2) the Tertiary gravels, which contain local flows; and (3) the deep leads, which contain intermediate and regional flows (Figure 2.7).

Salinity occurs within the drainage lines and alluvial flats in the area. The Tertiary sands aquifer overlies the Palaeozoic sedimentary bedrock in the region, and recharge occurs on the gentle slopes of these gravel capped hills. Saline discharge commonly occurs at the boundaries of the gravel unit (Figure 2.7).

Figure 2.8 Tunnel and Gully Erosion on the Gravel Capped Hills in Illabarook.

Gold was discovered in Ballarat and Buninyong in 1851 and mining activities were also focussed around the towns in the Illabarook target area, concentrating exploration and mining within the alluvial deposits and drainage lines. European cultivation techniques and mining have left the landscape susceptible to erosion, and the area is prone to extensive gully and tunnel erosion (Figure 2.8). Discharge occurs at low topographic reliefs in the landscape and at the break of slope, where it makes it way through various groundwater flow systems.

Discharge management options are a viable option in low lying areas and around drainage lines, where rehabilitation can be aimed at slowing down the degradation to the landscape and preventing further erosion of the discharge site. Rehabilitation of discharge sites may also prevent groundwater from discharging into the many tributaries and stream in the region.

Recharge control is proposed for areas where past mining activities have taken place, where recharge to the ground-watertable is accelerated due to the unprotective cover. Controlling the amount of recharge to the watertable is beneficial in the Tertiary gravel and sand aquifers, as they have a low storage capacity (Dahlhaus *et al.* 2005b), and as a result this aquifer becomes pressurised and discharges saline groundwater to areas downslope.

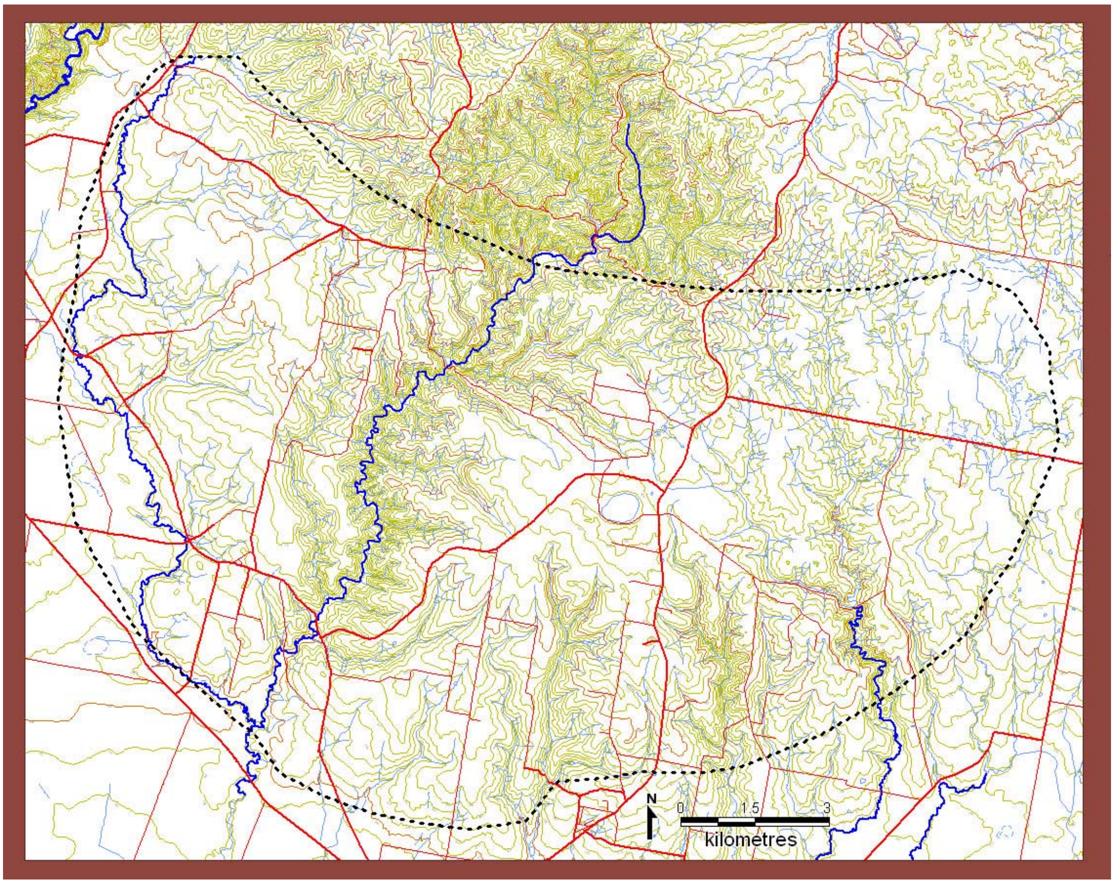


Figure 2.9 Topographical Map of the Illabarook Salinity Target Area

2.4.2 Summary of Literature Review

The monitoring station located at Cressy indicates salinity levels for the Woady Yaloak River are 6,900 μS/cm (median), which shows an increase over the last three decades.

Within the Woady Yaloak River catchment dryland salinity is a feature which is represented across the different landscapes, and where the main focus for salinity management has been for the Pittong and Illabarook areas. The groundwater is contained in a variety of systems and discharges to the surface in low-lying areas, at the break of slope and at hydrogeological boundaries, or travels up through fractures and joints in the aquifers. The hydraulic gradient of the watertable generally reflects the topography of the landscape, which decreases downstream in the catchment, causing the water to travel south at a sluggish rate through the Volcanic Plains.

Trends in surface water salinity are not well known for the tributaries of the Woady Yaloak River. The existing surface water salinity data has mainly focused on the Woady Yaloak River (Appendix 1), so establishing regular monitoring sites to measure surface water salinity for all major creeks in the catchment is needed, for example at Naringhil, Illabarook, Mount Misery, Kuruc-a-ruc, Ferrers creeks and their tributaries. This data will present the contribution of salt that comes from each of these creeks and influences the end of valley salinity in the Woady Yaloak River. The rising salinity of the major creeks recorded over the catchment may be of concern because they all join the Woady Yaloak River at some point along its length, therefore regular monitoring of these streams must be undertaken, because they may be a major contributor to the rising salinity in the river.

Groundwater salinity surrounding the Woady Yaloak River at the bottom of the catchment is extremely high and equal to that of seawater, and is relatively close to the surface in these areas. This requires immediate attention for the issue of groundwater which may be contributing to the stream flow in the catchment, and ways to minimise these groundwater and surface water interactions to prevent further salinisation.

A five year direction plan (2003-2007) implemented by the Woady Yaloak Catchment Group, will see 450 hectares of revegetation of discharge areas, therefore an understanding of the groundwater and surface water salinity processes is needed, in order to define future target areas (WYCG 2003).

3. Woady Yaloak River Catchment: Geology, Geomorphology and Hydrology

3.1 Structural Geology and Palaeozoic Rocks

The following classifications and geological interpretations, (except where stated otherwise) have been obtained from the Geology of Victoria 2003, where Birch (2003) has been used as a general reference.

Victoria's Palaeozoic rocks form part of the Tasman Orogenic System which was once part of the former Gondwana Orogenic System, and evolved from the Neoproterozoic to the Triassic period for a duration of 400 million years. Continental accretion occurred over the eastern Australian continent after the separation of Gondwana and the accreted sediments were deformed at different stages throughout the Palaeozoic.

The orogenic events of the Tasman Orogenic System include the Delamerian, Lachlan/Thomson and the New England Oregens. The Palaeozoic rocks of the Victorian landscape are predominantly deep-marine oceanic turbidites, mafic volcanics and granites. The middle Palaeozoic Lachlan Oregen is the westernmost oregen of the Tasman System and the bedrocks of the Woady Yaloak River catchment were derived from this system.

The Woady Yaloak River catchment resides in the structurally distinguished sub-provinces of the Stawell and Bendigo zones (Figure 3.1). The Linton and Avoca Faults are high strain zones and are present in the Stawell Zone. Turbidites with chevron style folds dominate the landscape across the Lachlan Orogen, and within the catchment the main lithotypes are turbidites and granites from the Palaeozoic. The time of deformation for the Stawell and Bendigo zones has been dated at 455 – 420 Ma based on Ar-Ar dating of micas (Birch 2003).

The Stawell Zone is represented by Cambrian and Cambro-Ordovician rocks of the Saint Arnaud Group, west of the Avoca Fault, and the Bendigo Zone is represented by Ordovician rocks of the Castlemaine Group, east of the fault (Birch 2003).

The western most fault in the Woady Yaloak River catchment is the Linton Fault and further east is the Avoca Fault. Both faults have an approximate trend of N-S and are 15 to 20 km in length. The Avoca fault is exposed at Devil's Kitchen towards the headwaters of the Woady Yaloak River, at Pigoreet.

3.2 Stratigraphy

The bedrock in the Woady Yaloak River catchment is made up of rocks from the Cambrian, Ordovician and Devonian periods and is discussed below.

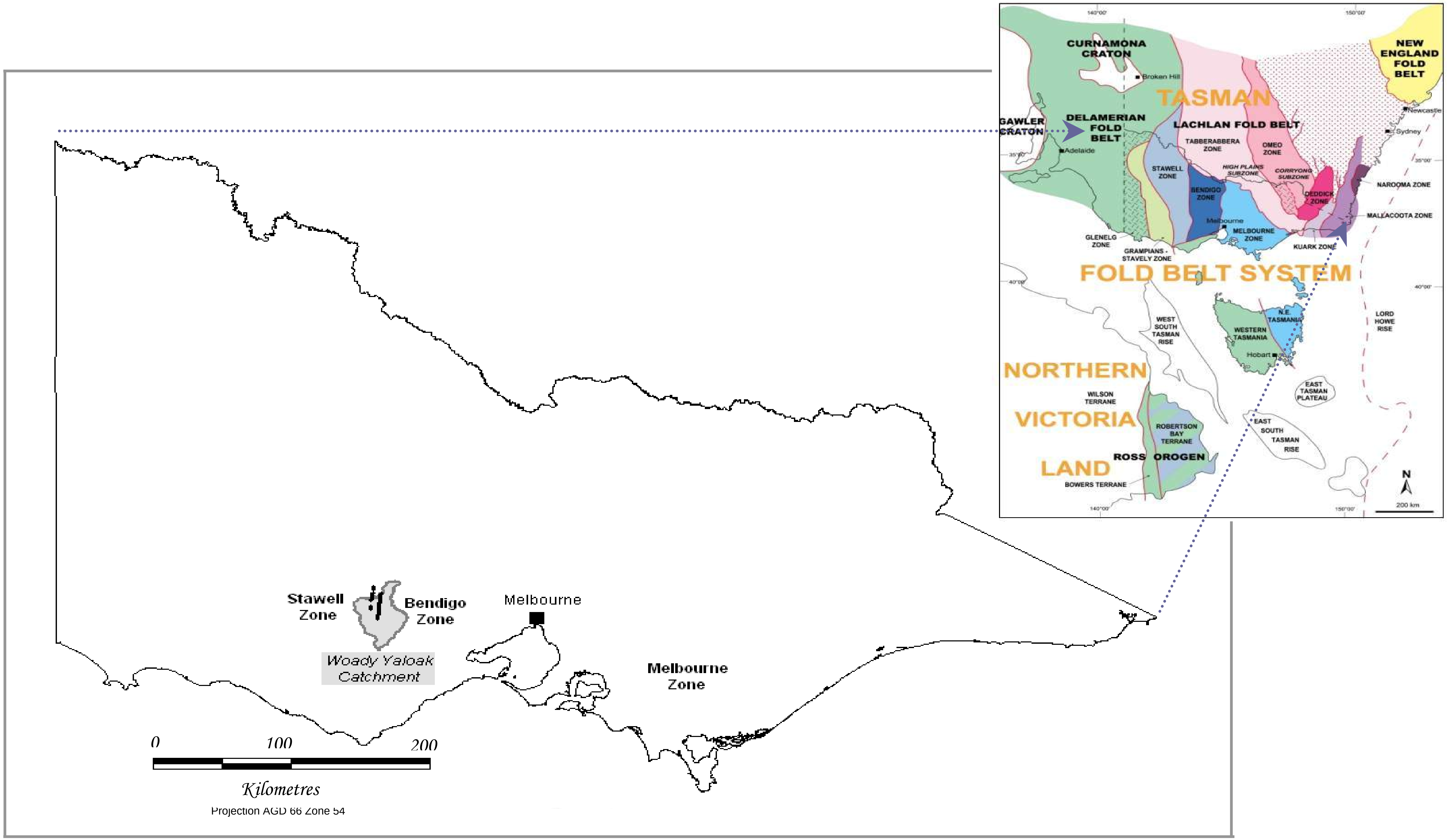


Figure 3.1 **Structural Zones in the Woady Yaloak River Catchment.**
Top Right: Structural zones of the Tasman Fold Belt System (Source: DPI 2005)
Centre: Map of Victoria and the structural zones within the Woady Yaloak River Catchment.

3.2.1 Cambrian-Ordovician

Massive ultramafic basalts with minor gabbro to dolerite and green-schist facies. comprise the ocean-floor basement which is believed to lie beneath the turbidite sediments of the Lachlan Fold Belt and are present in the hanging wall of the Avoca Fault and other major fault zones in Victoria. In the Woady Yaloak River catchment the Pitfield Volcanics are representative of the basement which has been noted from drill cores. They are tholeiitic in composition and show serpentinised peridotite, however these outcrops are not exposed within the catchment (Taylor *et al.* 1996).

The Cambrian and Ordovician basin has evolved by a series of sedimentary accumulations from a deep sea environment and represents wide-spread accumulation of deep sea deposits, dominated by turbidites and hemi-pelagic and pelagic black shales.

3.2.1.1 Saint Arnaud Group

The Saint Arnaud Group consists of marine sedimentary rocks and within this group are the Warrak, Beaufort and Pyrenees formations. These formations consist of marine sandstones, mudstones and shales that were deposited by turbidity currents and slurry flows. The sedimentary structures identified in these sediments are flame structures, Bouma sequences, lamination and cross lamination. The age given to the Saint Arnaud Group sediments is Late Cambrian approximately 530 – 507 Ma, however this age remains uncertain because the unit lacks fossils (Taylor *et al.* 1996)

The Saint Arnaud Group sandstones are poorly to moderately sorted and grain shapes are angular and not well rounded which suggests that the sediments were transported in a slurry, with the current being quite dense which allowed less movement and rounding of the grains. Quartz grains are abundant as well as lithic fragments and feldspars in this group. The composition of the feldspar is mainly orthoclase and albite with minor perthite, plagioclase and microcline. The rocks are strongly deformed, lack representative fossils, contain less black shale than the younger Castlemaine Group sediments, and contain minor conglomerates which are representative of mass flow conditions (Taylor *et al.* 1996).

The Pyrenees and Beaufort Formation represent the upper and lower portions of the Saint Arnaud Group sediments. Within the Woady Yaloak River catchment these formations are exposed in the hanging wall of the Avoca Fault at Devils Kitchen towards the headwaters of the Woady Yaloak River (Beaufort Fm) and at road cuttings near Linton (Pyrenees Fm). These rocks are of Middle-Late Cambrian age and consist of thick and thin bedded turbidites, dependent on the formation. Mudstones, black shales (sometimes altered to quartz-mica or graphitic schist) (Taylor *et al.*1996) and intermingling mudstone and sandstone facies are present within these formations. The intermingling facies suggest middle to outer fan turbiditic sedimentation, where deposition occurred at the fan fringe, lobe fringe and suprafan lobe.

3.2.1.2 Castlemaine Group

The Ordovician rocks in the Woady Yaloak are from the Castlemaine Group, and their age is dated at Lower to Middle Ordovician approximately 500 – 460 Ma. The geology consists of thick-bedded turbidites, which are coarse grained and dominated by sandstone with thicknesses measuring up to tens of metres. The turbidites are interbedded with mudstone facies. The thicknesses of the sandstone facies suggest middle fan turbiditic sedimentation, where deposition occurred at the suprafan lobe and distributary channel. The interbedded mudstone facies suggest deposition from interlobe and interchannel regions of the middle fan. These rocks also contain abundant graptolites found in the black shale unit. The Castlemaine Group contacts the Saint Arnaud Group at the Avoca Fault, and the two groups are very similar, except for the abundance of black shales and graptolites in the Castlemaine Group. The St Arnaud Group rocks may underlie the Castlemaine Group rocks in this area (Taylor *et al.* 1996).

3.2.2 Devonian

In the Lower Devonian two I-type granites intruded the underlying Cambrian rocks in the western parts of the Woady Yaloak River catchment. These are the Wallinduc Granodiorite and the Mount Bute Adamellite. The Wallinduc Granodiorite belongs to the Mount Cole Suite and the Mount Bute Adamellite has recently been reclassified as belonging to the Ararat Supersuite (Birch 2003). The southernmost granite in the catchment, mapped on the Rokewood 1:50 000 geology sheet, (Taylor *et al*. 1996) is the Wallinduc Granodiorite which is a medium grained, pale-pinkish grey, hornblende and biotite granodiorite. This pluton is mafic and oxidised, with enclaves and calc-silicate inclusions. Mount Bute is made up of the Mount Bute Adamellite, and this I-type pluton occurs west of the Linton Fault around Linton and Pittong, mapped on the Linton 1: 50 000 geology sheet, (Taylor *et al.* 1996). The Mount Bute Adamellite is a medium to coarse grained, pale grey, hornblende biotite adamellite. This pluton is felsic to mafic and oxidised. Secondary salinity occurs at the granite boundaries of this unit between the Quaternary sand, silt and clay sediments. The granites of the Stawell Province fall within the ages of 390 - 400 Ma (Birch 2003).

3.2.3 Mesozoic

The development of rift basins trending east-west across the south east Australian continent, occurred in the Jurassic and Early Cretaceous periods, and developed due to north-south tensions caused by the separation of Antarctica from Australia. The basins that formed were the Otway, Bass, Gippsland and Murray basins. The tension began in the Early Permian and continued until the final separation of Gondwana in the mid-Cretaceous. The Otway Basin extends across two states, Victoria and South Australia and forms an elongate depression that extends for over 500 km.

The Otway Basin began subsiding in the Late Jurassic to Early Cretaceous due to crustal extension, and accumulated thick piles of fluvial non-marine sediments from the surrounding flanks of the rift valleys. Volcanic activity dominated in the Early Cretaceous and ceased during the Albian stage, which coincides with the final stages of the separation of Antarctica from Australia. Much of the sediment comprises clastic sandstones and mudstones derived from the erosion of the volcanic rocks.

In the mid-Cretaceous, uplift of the Otway and Strzelecki ranges occurred as the Southern Ocean opened between Australia and Antarctica. Widespread erosion and dissection of the Mesozoic plains followed and the eroded highland sediments were transported across the plains. The rifting and uplift separated the drainage between the basins, forming the Great Dividing Range between the Otway and Murray basins.

3.2.4 Tertiary (Palaeogene and Neogene)

The Tertiary formations present in the middle and eastern parts of the catchment are the Moorabool Viaduct Sand and the White Hills Gravel. The White Hills Gravel was deposited in the Early Palaeogene in a fluvial non-marine environment. The Moorabool Viaduct Sand appears more extensively across the catchment and was deposited by an incursion of the sea during the Late Neogene that occurred over the Otway Basin.

In the Late Palaeogene to Early Neogene reworked gravels were brought into the new valleys, as streams cut into the landscape, these contained gold and Palaeozoic rocks, and were deposited over the extensive river valleys and over the White Hills Gravel. The lava flows of the Newer Volcanics Formation then covered these sediments, which are known as the deep leads and also disrupted the drainage patterns across the landscape. The current pattern of drainage in the catchment is mainly restricted to the edge of the ancient lava flows (Birch 2003).

3.2.4.1 White Hills Gravel

The White Hills Gravel Formation is a name given to the fluvial non-marine deposits of the uplands on the Palaeogene plains, which were deposited following the mid-Cretaceous uplift and weathering and dissection of the Mesozoic plains. At time of deposition the Palaeogene plains consisted of low relief hills and plains, which were relatively close to sea level (Birch 2003).

The gravel, sand, silt and clay of the White Hills Gravel was deposited from an alluvial fan in a high-energy fluvial system (Taylor *et al.* 1996). The gravel size particles, rounded quartz boulders and poorly sorted sediments are representative of this depositional environment. The rocks are coarse grained conglomerates, with sub-angular to sub-rounded quartz clasts and contain a matrix of clay and sand. Stratification occurs between gravel and sand beds and sedimentary structures, which are indicative of the environment, are present in the rocks. The depositional event was followed by erosion where deep valleys were cut into the Palaeozoic bedrock, and so transported quartz gravels and sand conglomerates filled these valleys that were later buried by the Newer Volcanic Formation in the Quaternary.

Palaeocene and Early Eocene marine regressions occurred resulting in erosion and a cessation of sedimentation across the Otway Basin. Deep chemical weathering occurred (probably in the Neogene) which produced thick solid crusts of iron and silica (ferricretes and silcretes) on the White Hills Gravel Formation. In the Woady Yaloak River catchment the gravels cap the hilltops, often forming hard ferricrete and silcrete crusts (duricrusts), which overly the Palaeozoic bedrock and represents the earlier drainage in the area. Many areas which were mapped as White Hills Gravel have recently been reclassified (Carey & Hughes 2002) due to the discovery of the Pliocene shoreline which came up north around Buninyong and where the sediments were noted to match the Pliocene marine sediments of the Moorabool Viaduct Formation (marine and fluvial sheet sediments) further east of Ballarat towards the Brisbane Ranges.

3.2.4.2 Moorabool Viaduct Formation

The Late Miocene to Early Pliocene formation present in the central and eastern part of the catchment is the Moorabool Viaduct Formation. The formation is a thin sheet of shallow marine deposits, which can occur up to 21 metres thick (Birch 2003). The geology consists of quartz pebbles and silts in a calcareous silt matrix, ferruginised and sometimes kaolinised.

The thin sheet deposits, which also include the Newer Volcanics, were deposited after tectonic uplift 10Ma. This was followed by erosion and regression of the sea in the Late Miocene, which unearthed the Otway Ranges in the southern Otway Basin. The basin was then flooded due to marine transgressions and the Moorabool Viaduct Formation was deposited across the weathered surface as the seas retreated at the end of the Pliocene.

3.2.5 Quaternary

Lava flows from the Newer Volcanics Formation are present in the Woady Yaloak River catchment as valley sheet flows and stony rise flows. At Devils Kitchen four flows have been recognised and are exposed along the river. The extensive lava flows of the Newer Volcanics were basaltic and pyroclastic in composition, and poured into the ancient stream valleys (deep leads) in and around Ballarat which raised stream levels. Valley and sheet flows (Qvn2) occurred around Linton and southwest of Rokewood and younger stony rise flows (Qvh) occurred southeast of Rokewood (Figure 3.2). The age of the flows around Linton has been dated at 5.10+/-.08 Ma (Taylor *et al.* 1996). Older rocks separate the Newer Volcanics by a disconformity. The different lava flows are commonly separated by a thick sequence of sediments, representing palaeosols and inter-flow sediment deposition.

The Newer Volcanic flows commenced in the Pliocene around 5.5 million years ago and continued until approximately 100,000 years ago. The lava flows of the Newer Volcanics are tholeiitic to minor alkaline basalts with minor scoria and ash (Taylor *et al.* 1996). The lava flows of the Newer Volcanics flowed down valleys, preserving the deep leads and making up the broad basalt plains which form the surface geology for the bottom half of the catchment, as well as disrupting the drainage of the river systems. The disruption of the drainage patterns caused by the lava flows of the Newer Volcanics caused new streams to develop and renewed alluvial sedimentation. The Quaternary alluvial sediments (Qra) were deposited in the Woady Yaloak River catchment within and around the lava flows where the current drainage exists. Older colluvium sediments have filled the deep lead valleys around Smythesdale and fringe the lava flows.

Lakes in the Volcanic Plains landscape exist in shallow depressions such as in maars and in between lava flows. The features around these lakes include river and lake terraces and lunettes, that consist of sand, silt, clay and tuff, which are a result of the reducing water levels in the lakes. The valley flows also damned some rivers which formed lakes and shallow swamp deposits across the region, particularly around the south of the catchment where the basalt flowed down the valleys.

During the Pleistocene to the Holocene, alluvium and colluvium was deposited by the stream systems. These deposits are non-marine and are predominantly around the southern boundary of the catchment and around the lakes including Lake Corangamite. The Pleistocene saw dramatic changes in sea levels and climate changes, where sea levels were much lower than present, and began to rise after the last glaciation approximately 18 thousand years ago (Dahlhaus 2005b).

Aeolian material was added to the Palaeozoic bedrock and volcanic rocks during the last glaciation approximately 20,000 years ago. The materials consisted of calcareous clays and silt. Local wind-blown material was also added to the landscape from lunettes.

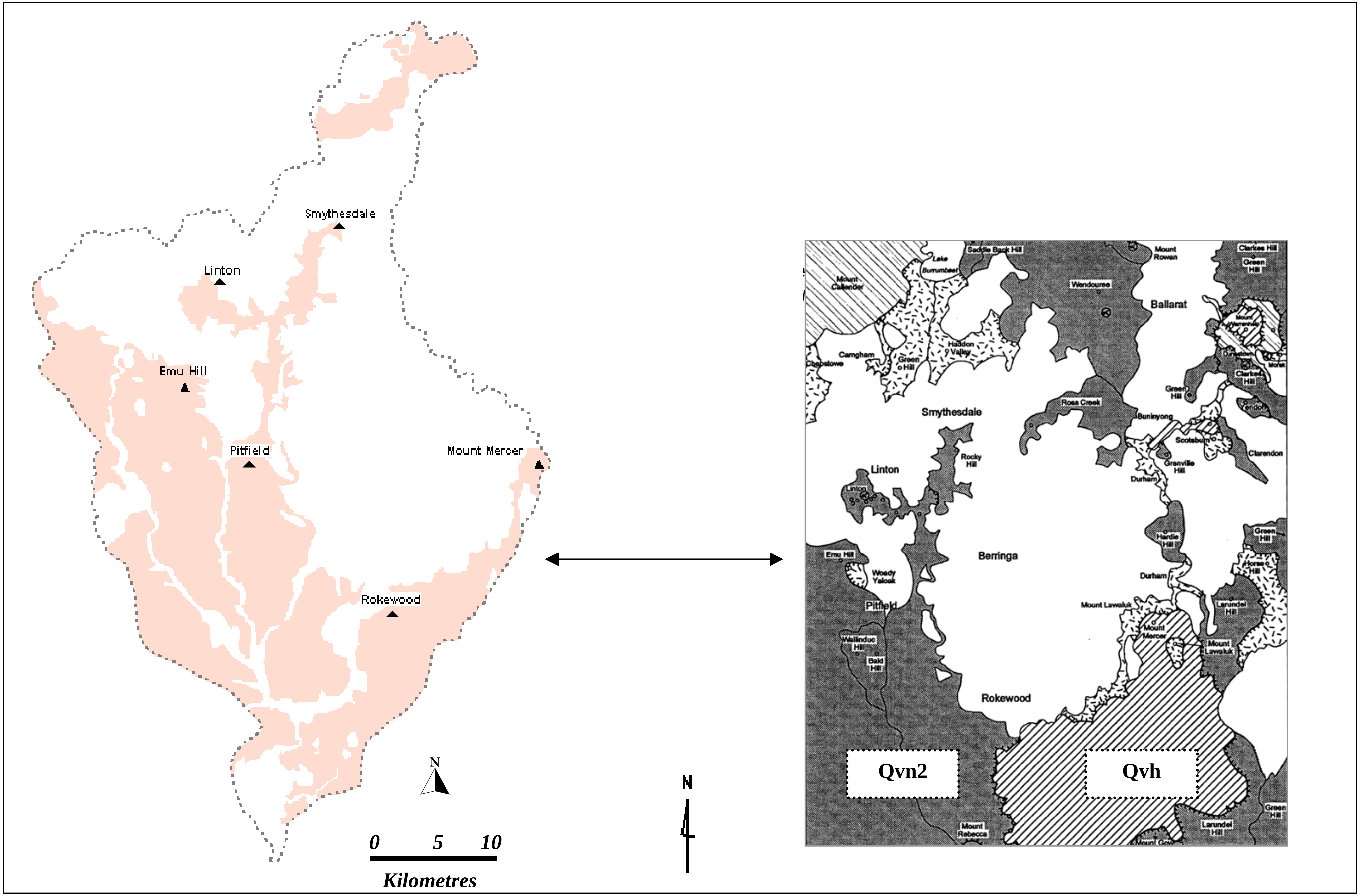


Figure 3.2 Distribution of Newer Volcanic Flows in the Woady Yaloak River Catchment

(Left) Extent of flows in the Woady Yaloak River Catchment. (Right) Qvh flows are present south-east of Rokewood, and Qvn 2 flows are present south of Smythesdale and Linton. Adapted from Taylor *et al.* 1996.

3.3 Geomorphology

The following geomorphic divisions differentiated for the Woady Yaloak River catchment are based on the classifications listed in the Geology of Victoria 3rd Edition 2003 (pp. 541 – 561).

3.3.1 Western Uplands

There are three sub-regions that make up the Western Uplands, these are the Dissected Uplands, the Grampians and the Tablelands. The Woady Yaloak River catchment lies within the Dissected Uplands. Tectonic activity involving upwarping and block faulting, which began in the Early Cretaceous and has continued to the present day has caused the eastern and western uplands across Victoria to be lifted above the rest of the landscape. The two areas, east and west, differ in that the Western Uplands are less rugged and topographically lower than the eastern uplands. The Western Uplands topography is undulating and dissected by many streams. The Dissected Uplands include Palaeozoic sediments, volcanic, granitic and metamorphic rocks, within rugged and gently undulating terrain.

3.3.1.1 Dissected Uplands

The Palaeozoic landscape of the Dissected Uplands consists of low undulating hills dissected by broad valleys. Drainage patterns are dendritic in style and soils are poor, ferruginised and contain remnant vegetation (Rees 2000). The towns in the Woady Yaloak River catchment within this landscape include Berringa, Enfield, Smythesdale, Linton and Pittong. Drainage lines are parallel to the strike of the beds and are controlled by faults and lithological boundaries. Iron from the groundwater has precipitated through fractures from the rocks and created a ferruginous profile in the regolith. Soils within the deeply weathered Palaeozoic rocks are generally well weathered and have developed strong soil horizons are irregular and often form "*pallid kaolinitic profiles up to 15m thick*" (Joyce 1999).

Granite plutons are common across the Dissected Uplands and are often exposed as high peaks in the landscape. However, the granite landscape in the Woady Yaloak River catchment is highly weathered. The intense weathering has resulted in the formation of kaolin, which is currently being mined around the Pittong area. The landscape consists of low hills and weathered ridges, and the granites outcrops as grus on Flagstaff Hill at Pittong. Soils are sandy, ferruginous and exhibit strong textures (Rees 2000). Hornfels have formed within the contact aureoles and quartzite has formed from contact metamorphism. The granite drainage patterns occur between the granite pluton and the surrounding rocks, as running water easily erodes and cuts its path through the less resistant minerals in this area.

3.3.1.3 Tertiary Alluvial Deposits

The gravels of the White Hills Gravel Formation, and the sediments of the Moorabool Viaduct formation, cover the low hills of Palaeozoic bedrock hills across the Woady Yaloak River catchment. These Tertiary alluvial deposits have been weathered to coarse grained conglomerates, which are often ferruginised by groundwater processes and cemented thus forming duricrusts. The gravel caps form mesas over the Palaeozoic rocks at Napoleon, and around Haddon the gravels fringe the overlying basalts in broad areas (Rees 2000).

3.3.1.4 Newer Volcanics

The Newer Volcanics covers large areas of the landscape where the lava flows poured over and filled large valleys. This basalt landscape consists of fertile soils which are desirable in agricultural production and has seen the removal of native vegetation from this land for that purpose. At the edges of the flows alluvial deposits are present at these flow boundaries, where the basalt flowed it covered existing streams and valleys (deep leads) and also displaced drainage lines. On the surface the landscape consists of hummocky stony rise basalts, large basalt plains and lakes which formed as a result of the lava flows displacing streams. Devil's Kitchen in Pigoreet is an example of where a stream has flowed through the basalt creating a gorge in the landscape.

3.3.2 Western Plains

The Western Plains include the Volcanic Plains and Sedimentary Plains, both of which occur within the Woady Yaloak River catchment. The vast majority of the southern catchment is in the Volcanic Plains with only a very small portion of the Sedimentary Plains on the western boundary.

3.3.2.1 Volcanic Plains

The Volcanic Plains consist of lava flows mainly of basalt but with some fragmental volcanic deposits. The Volcanic Plains have developed shallow drainage lines and thin regolith profiles which forms an extensive sheet across the southern portion of the Woady Yaloak River catchment. The landscape is generally flat or slightly undulating with scattered extinct volcanoes across the plains, commonly scoria cones. Soils can be stony gradational, red duplex to brown sodic duplex, or grey sodic clay, depending on the degree of erosion and age of the lava flows (Rees 2000).

The youngest flows are the stony rise flows, which have thin soils and where basalt outcrops at the surface. The oldest flows are 3-5 Ma in age and have developed thicker soils with kaolinitic profiles and deeper stream incisions. The water from within some of these drainage lines drains into ephemeral wetlands. Other geomorphic features of the Volcanic Plains landscape are lunettes, lakes and swamps. Some of these lakes are groundwater discharge lakes, such as Lake Beeac, and these lakes vary in their salinity. The lunettes, such as around Lake Corangamite represent the falling of the lake levels over time. Alluvial sediments have been deposited across the catchment following the Newer Volcanic flows.

3.4 Hydrogeology

Local, intermediate and regional groundwater flow systems have been distinguished for the Woady Yaloak River catchment based primarily on the differences in flow paths from groundwater recharge to discharge where:

- Local flow systems are characterised by <5km flow paths
- Intermediate flow systems are characterised by 5-30 km flow paths, *and*
- Regional flow systems are characterised by >50 km flow paths

The following groundwater flow systems for the Woady Yaloak River catchment are based on the classifications according to Dahlhaus *et al*. (2002).

3.4.1 Local Flow Systems

There are three local groundwater flow systems present in the Woady Yaloak River catchment these are the Quaternary Sediments, the Granitic Rocks and the Highlands Gravel Caps.

3.4.1.1 Quaternary Sediments

Local flows in the Quaternary sediments occur in unconfined, unconsolidated gravel, sand, silt and clay sediments of river alluvium, swamp and dune deposits. They are widespread and sporadic throughout the catchment. Primary salinity occurs in flat areas and at the break of slope and typical groundwater discharge is estimated at 3,000-10,000 mg/L and has the largest mapped area of salinity of any other groundwater flow system in the Corangamite CMA region. Gravels and sands occur in channels, and sands, silts and clays occur on flood plains. The groundwater flow paths occur at lava flow boundaries, present streams, and gullies and at the bases of hills.

The management options that would prove most effective in controlling salinity within this unit include:

- Recharge and discharge area management: planting perennial pastures suited in areas where rainfall is less than 700mm annually, which is the case for most of the Woady Yaloak River catchment; establishing lucerne crops; and establishing tree plantations to intercept the groundwater.

- Planting out a salt affected area with salt-tolerant pastures.

3.4.1.2 Granitic Rocks

Local flows in the granitic rocks occurs in unconfined and semi-confined fractured rock, saprolite, soil and grus, which occur at Pittong and Mount Bute. Salinity occurs in drainage lines, springs and broad valley floors and typical groundwater discharge is estimated at 3,000-10,000 mg/L. The granite plutons are I-Type granites, medium grained, made up of hornblende and biotite, they are generally weathered or kaolinised. Waterlogging is common within the granite unit, due to the low permeability of the clay in the area. Groundwater springs are common in this unit and lateral groundwater movement is suspected in areas with strongly developed A2 horizons.

The management options that would prove most effective in controlling salinity within this unit include:

- Recharge area management: planting perennial pastures suited in areas where rainfall is less than 700mm annually; and establishing tree plantations to intercept the water from slopes, to prevent recharge to the aquifer.

- Engineering options such as surface drainage can divert saline water from waterlogged areas.

3.4.1.3 Highlands Gravel Caps

Local flows in the highlands gravel caps occur in unconfined gravel, sand, silt and clay. They are sporadic in their spatial distribution and occur around Haddon, Illabarook and Dereel. The gravels often form ferricrete and silcrete crusts, which are a feature preserved on the Palaeozoic hilltops, where this unit is preserved. The cementation caused by the precipitation of iron and silica, restricts the permeability of the unit in some places, therefore groundwater flows may find alternative routes and discharge at hill slopes and at gravel boundaries. Salinity often occurs at or near the base of the unit and at its boundaries, and typical groundwater discharge is estimated at 1,000-10,000 mg/L. The gravel caps landscape has been severely altered during the gold mining era, where soil profiles were stripped away and resulted in more erosion and recharge to the watertable within this unit.

The management options that would prove most effective in controlling salinity within this unit include:

- Engineering options such as surface drainage can direct saline discharge from slopes.

- Planting out saline discharge areas with salt-tolerant pastures and then fencing off the affected area.

3.4.2 Intermediate Flow Systems

There are three intermediate groundwater systems present in the Woady Yaloak River catchment these are the Palaeozoic Sedimentary Rocks, the Central Highlands Volcanics and the Pliocene Sands.

3.4.2.1 Palaeozoic Sedimentary Rocks

Local and intermediate flows in the Palaeozoic sedimentary rocks occur in unconfined fractured rock and saprolite. The groundwater flows through the northern area of the Woady Yaloak River catchment around the towns of Cape Clear, Dereel and Illabarook, making its way through highly weathered and fractured rocks. Salinity occurs at the break of slopes, as hillside seeps and on the valley floor, and typical groundwater discharge is estimated at 1,000 – 8,000 mg/L. The geology consists of marine thin and thick-bedded turbidites (dependent on formation), mudstone, black shales, with intermingled mudstone and sandstone facies. The flow path within this system is estimated between 5 to 25 km.

The management options that would prove most effective in controlling salinity within this unit include:

- Recharge area management: planting trees to intercept water will benefit local and intermediate flow systems.

- Engineering options such as groundwater pumping can lower the watertable where assets are at risk.

- Planting out saline discharge areas with salt-tolerant pastures is recommended for salinity affected areas.

3.4.2.2 Central Highlands Volcanics

Intermediate and regional flows in the Central Highlands Volcanics occur in unconfined fractured rock and soil. The rocks have developed deep weathering clay profiles with varying thicknesses. Widespread basaltic and pyroclastic lavas filled deep lead valleys and raised stream base levels. This flow system occurs around Devil's Kitchen, Smythesdale and Haddon. Salinity occurs in swamps, drainage lines and broad depressions and typical groundwater discharge is estimated at 1,000 to 10,000 mg/L.

The management options that would prove most effective in controlling salinity within this unit include:

- Engineering options such as groundwater pumping can lower the watertable where assets are at risk.

- Planting out saline discharge areas with salt-tolerant pastures is recommended for salinity affected areas.

3.4.2.3 Pliocene Sands

Intermediate and local flows in the Pliocene sands occur in unconfined gravel, sand, silt, clay and ferruginised or silicified rock. Local flows occur where the unit caps the Palaeozoic dissected hills. The fluvial and marginal marine deposits of Miocene-Pliocene were deposited across the Corangamite CMA region by a shallow sea, depositing sediments across the plains and low hills, palaeo-strand lines, and dissected coastal plains. Much of the area of deposition has been covered by the flows of the Newer Volcanics Formation. Salinity occurs along drainage depressions and basalt boundaries and typical groundwater discharge is estimated at 1,000–10,000 mg/L. Salinity occurs in two very small patches, one on the western flanks of Mount Bute and the other just west of Cressy.

The management options that would prove most effective in controlling salinity within this unit include:

- Recharge area management: broad scale pastures would need to be established, in some cases on the overlying basalts; revegetating hilltops to minimise recharge.

- Engineering options such as groundwater pumping can lower the watertable where assets are at risk.

3.4.3 Regional Flow Systems

There are two regional groundwater flow systems present in the Woady Yaloak River catchment these are the Deep Leads and the Volcanic Plains Basalt.

3.4.3.1 Deep Leads

Regional and intermediate flows in the Deep Leads occur in confined gravel, sand, silt and clay sediments. The Deep Leads have been the major target for gold mining and occur extensively around the northern part of the Woady Yaloak River catchment, for example around Smythesdale, Haddon, Scarsdale and Pitfield. The Deep Leads have been buried by the lava flows of the Newer Volcanics and generally surround the Woady Yaloak River and its tributaries. Flow volumes and permeability within this unit are high. Saline baseflow to streams is likely to be a cause of salinity along streams and saline groundwater discharge occurs on plains, and is typically estimated at 200-3,000 mg/L.

The management options that would prove most effective in controlling salinity within this unit include:

- Engineering options such as groundwater pumping can lower the watertable where assets are at risk, and groundwater pumping can also be used to extract the resource.
- Planting out saline discharge areas with salt-tolerant pastures is recommended for salinity affected areas.

3.4.3.2 Volcanic Plains Basalt

Regional and intermediate flows in the Volcanic Plains Basalt occur in unconfined fractured rock. The Volcanic Plains have a history of widespread primary salinity, where brackish to saline baseflow to streams was common. The Volcanic Plains flow system span over the southern half of the Woady Yaloak River catchment and contain many high value assets, such as agricultural land, biodiversity sites, heritage sites and infrastructure, which are at risk from the rising salinity of water bodies. Salinity occurs in lakes, swamps and drainage lines and typical groundwater discharge is estimated at 2,000-10,000 mg/L. Lava flows extend across the broad flat plains and on undulating plains and low rises.

The management options that would prove most effective in controlling salinity within this unit include:

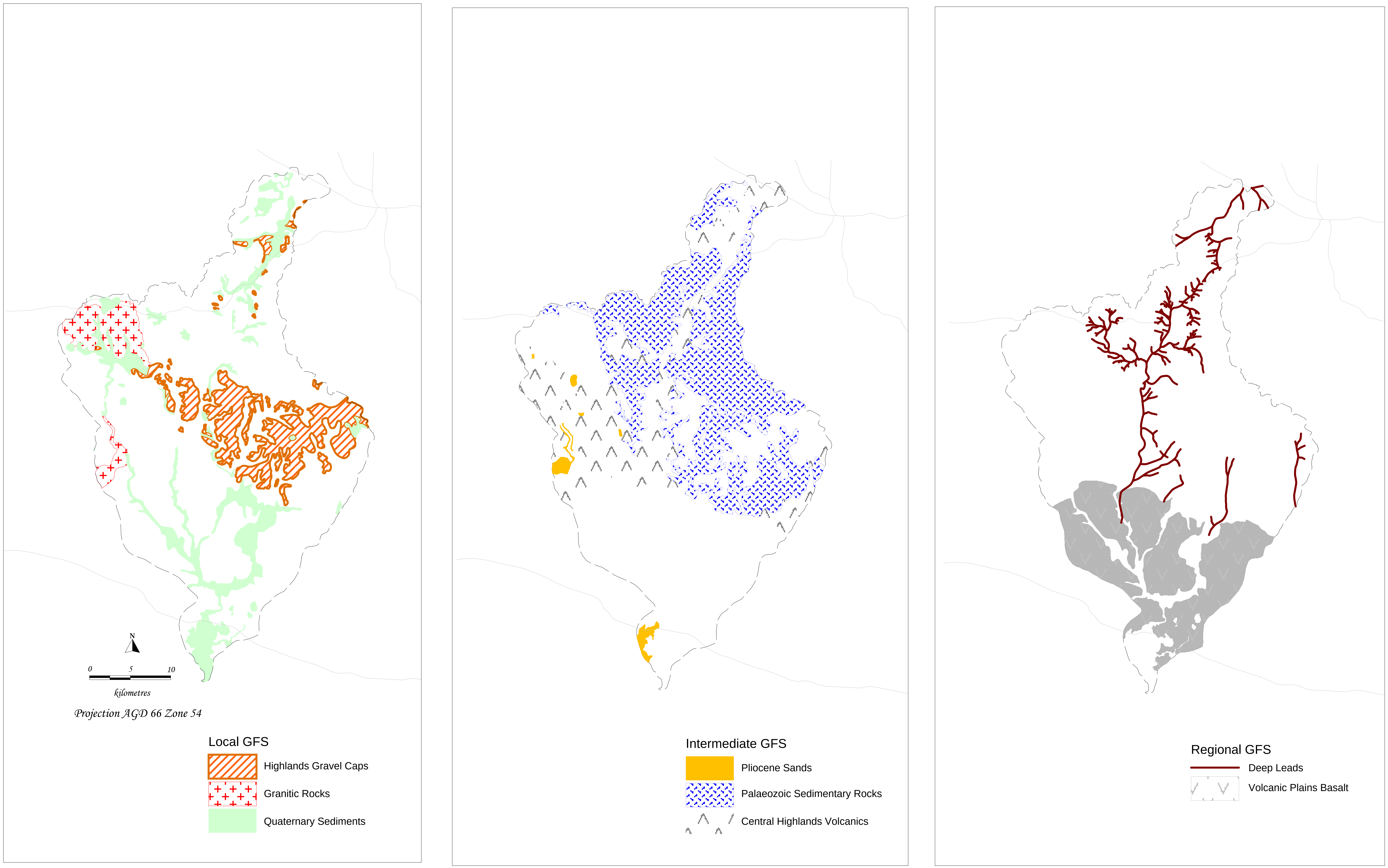
- Engineering options such as groundwater pumping can lower the watertable where assets are at risk.

- Planting out saline discharge areas with salt-tolerant pastures is recommended for salinity affected areas.

Table 3.1 Groundwater Flow Systems in the Woady Yaloak River Catchment.

GFS	***Description***	***Landscape***	***Hydraulic Conductivity m/day***	***Transmissivity m_2/day***	***Hydraulic Gradient***	***Recharge mm/yr***	***Groundwater Salinity mg/l***	***Salinity Occurrences***
1	Quaternary sediments	River flats, swamps, dunes, lunettes, terraces	10-6 to 100	< 20	Low to locally steep	Variable with location	3000 to 10000	Flats and break of slope
3	Highlands gravel caps	Ridge caps & gentle slopes	10-4 to 10	< 50	Low to steep at edge of caps	Not known	1000 to 10000	Boundaries, and at or near base of unit
7	Granitic rocks	Low undulating hills to slightly steep land & broad valleys	10-6 to 10-1	< 50	Moderate to locally steep	25	3000 to 10000	Valley floor, drainage lines, small springs
10	Pliocene sands	Plains, low hills, dissected plains, palaeo strand lines	10-2 to 10	< 20	Very low to moderate	Variable with location	1000 to 10000	Drainage depressions, basalt boundaries
12	Palaeozoic sedimentary rocks	Gentle undulating hills	.00001 to 1		Moderate to steep	40 to 50	1000 to 8000	Break of slope,hillside seepage, valley floor
13	Central Higlands Volcanics	Undulating plains/low rises	10-3 to 100	< 50 - 200	Low to very low	50	1000 to 10000	Swamps, drainage lines, broad depressions
14	Volcanic Plains Basalt	Undulating plains/low rises	10-3 to 100	< 50 - 200	Low to very low	10 to 25	2000 to 10000	Lakes, swamps, drainage lines
15	Deep leads	Buried river valleys	10-2 to 100	<1000	Low to very low	Not known	200 to 3000	Unconfirmed discharge on plains

Figure 3.3 Groundwater Flow Systems for the Woady Yaloak River Catchment



4. Methods

4.1 Surface Water Sampling

A comprehensive survey of surface water salinity within the Woady Yaloak River catchment was conducted, to compare the variations in salinity seasonally. Initially 20 sampling locations were selected across the catchment, which increased to 30 locations in the month of July. Field sampling was conducted according to the Australian/New Zealand Standards for Water quality–Sampling (1998) where the detailed surface water procedures are appended (Appendix 2).

The sampling of surface water involved:

- Sampling of the six major streams in the Catchment and their tributaries. As the months progressed additional stream sampling locations were also added due to the discovery of these easily accessible sites during the sampling sequence (Figure 4.2).
- Selecting sampling locations from topographical maps using GIS (MapInfo) software where locations were chosen where the streams intersected a road, which provided easy accessibility to collect the samples from the streams and also above and below stream junctions.
- Spot sampling was decided on for surface water monitoring, in order to depict the overall water quality of the river catchment. What this meant was that a large quantity of sampling could be obtained daily, also the reduced costs of obtaining results in the field, coincided with this project.

- Testing of in field electrical conductivity (EC), pH and temperature using the TPS Aqua pH – mV and Temperature meter, with an accuracy of +/- 0.01pH, 1mV.

4.1.1 Frequency, Accuracy and Contamination

An interval of one-month between surface water sampling was decided on, where testing the quality of the surface water across the selected sites was carried out during the last few days of each month. Large oscillations in the results were not expected over the 9-month sampling regime (from February to October), so a more frequent interval of sampling did not seem necessary for the purpose of this research, which was to produce general distinctions between seasonal changes and the variations in surface water salinity.

The accuracy and contamination of sampling was taken into account, due to the large number of samples obtained daily, which relied on using the same equipment over the entire day without being sterilised until the end of the day. The equipment which were possible sources of contamination were, was the pvc bailer, which was used to bail surface water that was inaccessible at stream level, and two glass beakers used to pour the bailed water into. Two beakers were used in the field, to avoid using the same beaker several times during the day. After a sample was gathered in the beaker or bailer, the equipment was washed out twice with distilled water, after the sample water had been removed from them.

Possible contamination from this equipment was then tested for on two occasions throughout the year. This was done in the field after a sample had been gathered using the bailer and the beaker, where the bailer was then filled with distilled water and this water was then poured into the beaker where EC values were then recorded. EC values were less than 500 μS/cm, which shows that the bailer was carrying some contamination, however given the values of the EC recorded from the samples, +500 μS/cm would not greatly impinge on the elucidation of the results.

Figure 4.1 PVC Bailer used to Bail Surface Water

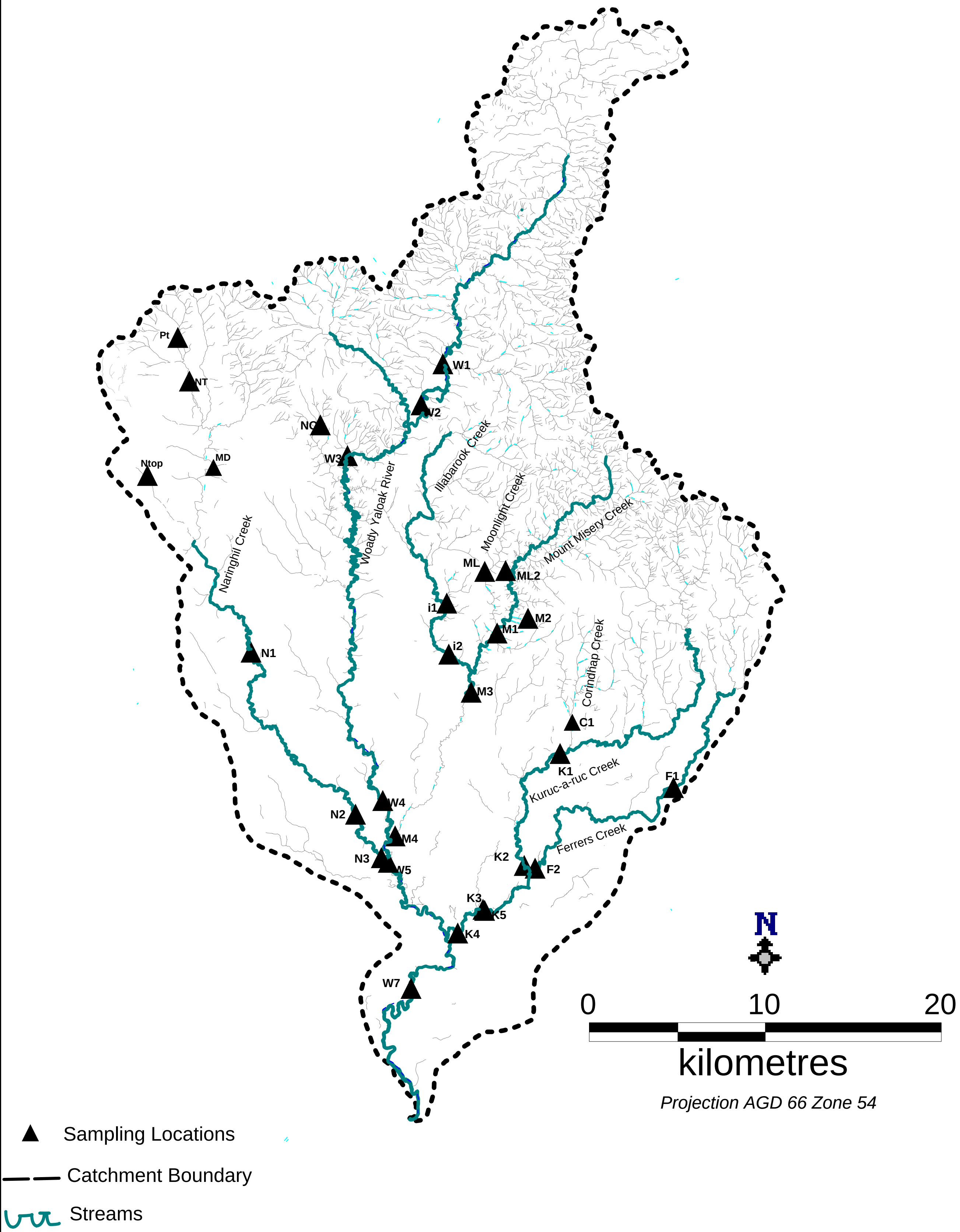


Figure 4.2 Surface Water Sampling Locations

Figure 4.3 Aqua TPS Conductivity/pH meter
with probes immersed in a beaker filled with sample water

4.2 Groundwater Sampling

Groundwater sampling was conducted randomly throughout the year, in March, April, May and September, to show the changes in groundwater levels seasonally and to test for major ions as well as in-field measurements of EC, pH and temperature. Random sampling of the groundwater was decided on, as groundwater changes were expected to be less apparent and fluctuate less during the year than the surface water, owing to less rapid flushing of the watertable even after rainfall events.

Groundwater sampling in March was conducted independently for 4 bores in the Pittong area. Groundwater sampling in April and May was conducted independently for 2 bores in the Haddon area and for 3 bores in the Illabarook area. The groundwater sampling in the month of April was carried out in collaboration with the Victorian Volcanic Plains (VVP) bore sampling project for the CCMA region, where a number of bores where chosen throughout the Volcanic Plains region in the CCMA, encompassing several bores in the Woady Yaloak River catchment (Figure 4.4).

For the independent sampling during the months of April and May, shallow groundwater bores were chosen throughout different areas of the catchment, ideally for their close proximity to streams. The reason for choosing bores close to streams was to test the salinity in the groundwater that resides in these areas, which may be a possible source for adding salts to the streams from baseflow contributions.

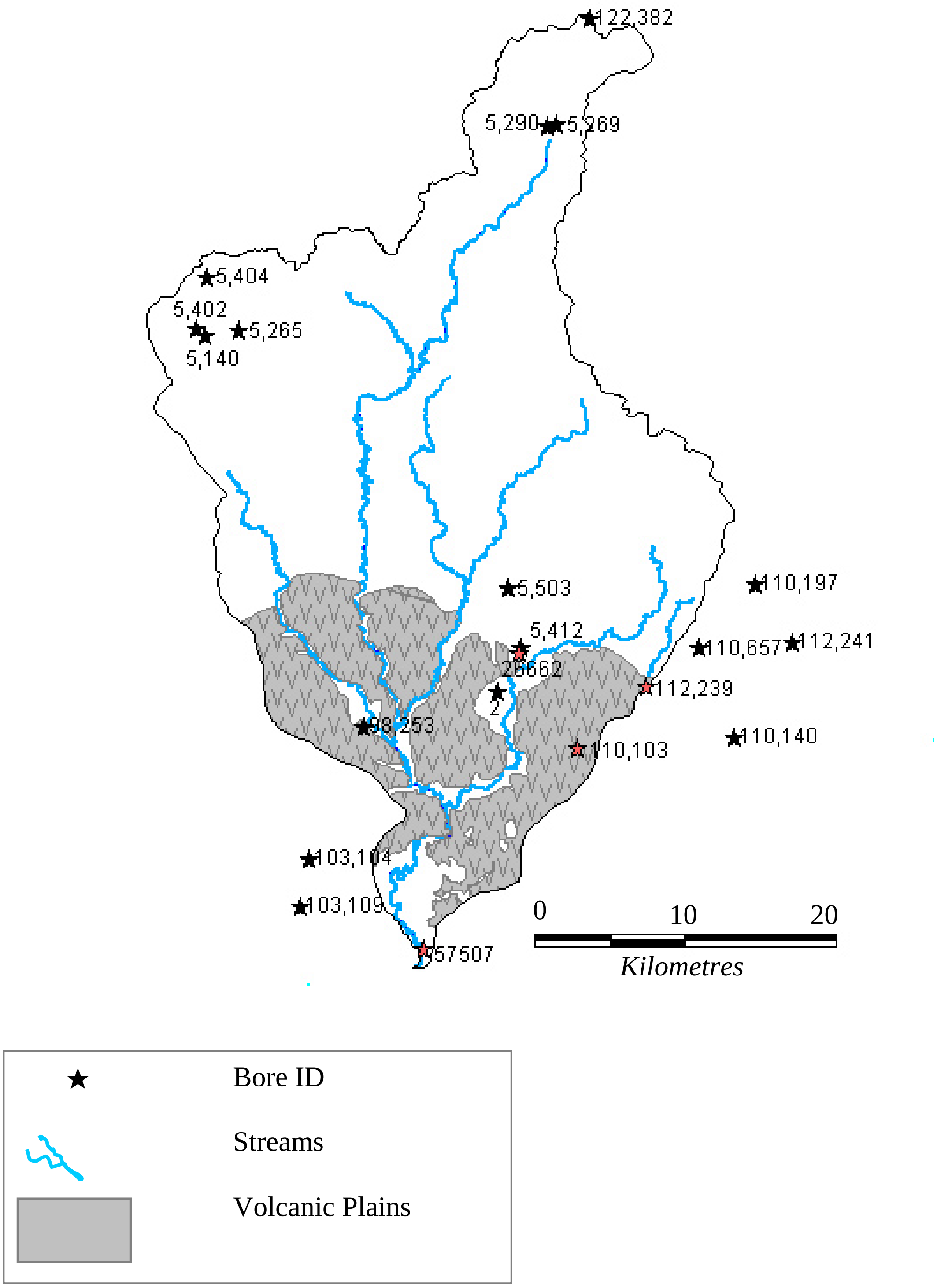


Figure 4.4 Groundwater Bores Sampled across the Woady Yaloak River Catchment.

The sampling was conducted according to Water quality-Sampling guidelines: Part 11, (1998) where bores were sampled to observe changes in the watertable levels, and to monitor groundwater salinity levels seasonally.

Groundwater sampling involved:

- The extraction of three bore volumes, to obtain a representative sample of the groundwater.
- The use of an electric submersible SI/MP1 115-230V Grundfos pump, with a variable frequency drive; the pump rate was set between 160-250 Hz to minimise any drawdown effect and was altered according to the rate of flow from the aquifer. In some bores with shallow watertables and smaller diameter, a battery-operated submersible "Whaler" pump was used.
- A fox whistle attached to a measuring tape was used to measure the depth to the groundwater in the bore.
- Samples were filtered before being bottled, with a 0.45 μm mesh filter attached to a 60ml syringe.
- Samples were obtained for anion and cation analysis, where the sample water was filtered in plastic bottles (supplied by the CSIRO in Adelaide) with 120ml of the sample water. Anion samples were filtered and bottled and cation samples were acidified with 3 drops of HNO_3 (Nitric Acid), after filtration.
- Samples were stored below 4°C were sent by road transport to the laboratory at the CSIRO (Adelaide) for analysis, within 48 hours.

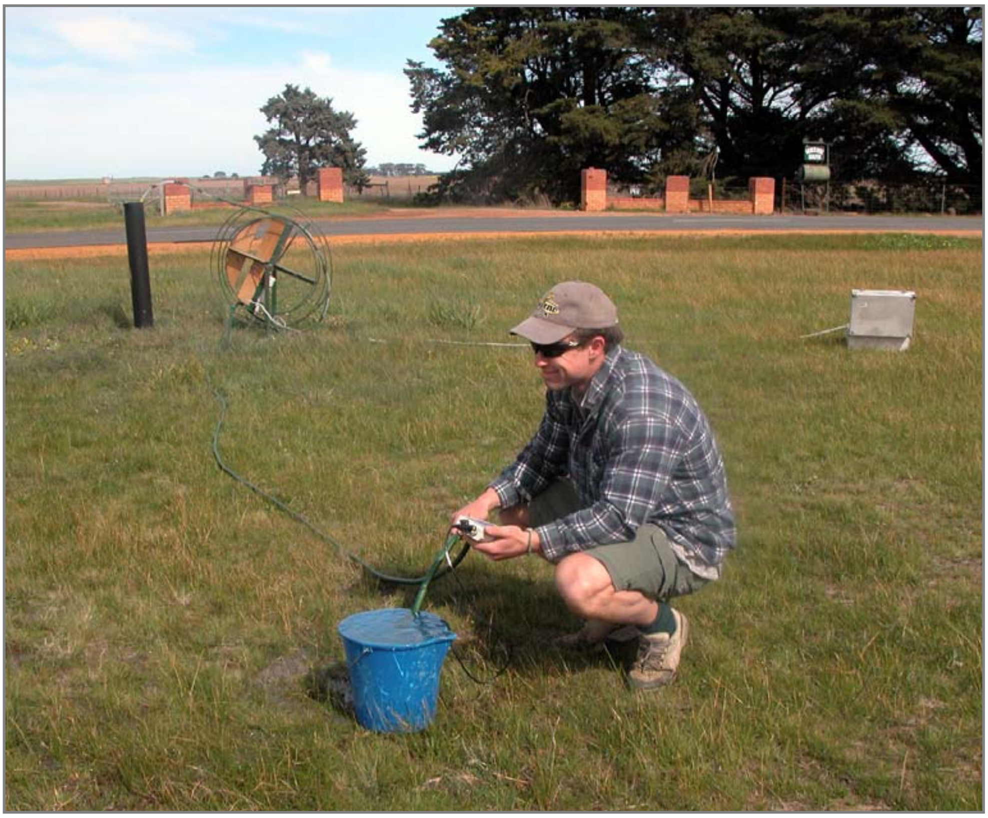


Figure 4.5 Groundwater Field Recordings

4.3 Sub-Catchment Delineation

Sub-catchments within the Woady Yaloak River Catchment were delineated (section 5.1) in order to calculate the relative peak discharge and partition the salts coming from different areas. This way done by using a digital elevation model and a topographic map with 10 metre contour intervals, along with digital surface water maps using MapInfo software. Sub-catchments were then differentiated by geomorphic reasoning, by where surface water flowed to, in various streams in the catchment.

The Woady Yaloak River catchment has been delineated into 6 sub-catchments using this method, and these sub-catchments represent the area surrounding existing streams in the greater catchment.

4.4 The Rational Method for Flow Partitioning

The Rational Method is an Australian standard used for calculating the design peak discharge rate of a stream or catchment. For this project the rational method is used as a comparative approach to distinguish the relative peak discharge rates between the six sub-catchments, and should not be mistaken for absolute peak discharge values. The Rational equation was obtained from the Australian Rainfall and Runoff Database, and features in Book IV in section 1.4.3 (Pilgrim 2001).

Rainfall Intensity, Frequency and Duration curves (IFD) are available for many locations and major towns where rainfall intensity data has been collected. They are presented as diagrams which show the average rainfall intensity (mm/hr) for the average recurrence intervals (ARI) of *1, 2, 5, 10, 20, 50* and *100* year rainfall events for the location on the IFD curve. The average rainfall intensity equals the time to concentration (hrs), which is the duration of time taken for water to flow across the entire catchment, or from the furthest point in the catchment to the point of discharge. For this project four IFD curves were purchased from the Bureau of Meteorology, for different locations across the Woady Yaloak Catchment, which were chosen as a representation of the rainfall occurring within each of the sub-catchments (Appendix 3). Where the sub-catchment spanned over more than one town and where more than one IFD curve was made available for that sub-catchment, the peak discharge was worked out for both locations and the average answer was calculated to be used as the representative rainfall intensity value.

4.4.1 Calculating the Runoff Coefficient

The design runoff coefficient contour map for western Victoria for a 10 year average recurrence interval was obtained from Figure.5.3a from the Australian Rainfall and Runoff accompanying CD-Rom and was used to determine the coefficients of the different sub-catchments in the Woady Yaloak. The runoff coefficient (C) is expressed in a series of contours on a map, which varies for different locations (Appendix 4). The contours are expressed in percentages; for example an area that is forested may have a runoff coefficient of 5%, which means that only 5% of the rainfall hitting that surface will runoff. Coefficient values increase the more impervious the surface becomes, when more rainfall is likely to wash off instead of infiltrating. The C values on the map represent the average runoff coefficient for various parts of Victoria as calculated from the gauged discharge in the streams and rivers (Pilgrim 2001).

To calculate the runoff coefficient, the coefficient value on the map is multiplied by the Frequency Factor (FF), which can be obtained from Australian Rainfall and Runoff: Volume 1, Book IV, Table 1.4. The FF varies slightly for each recurrence interval and when multiplied by the C, makes up the C_y part of the Rational equation.

Peak discharge is determined by:

$$Q_y = 0.00278\ C_y\ It_c yA$$

Where:

Q_y is the peak discharge for an ARI of y years, expressed as m^3/sec

0.00278 is the value used to convert the mixture of units to balance out the equation

C_y is the runoff coefficient for an ARI of y years

I_{tcy} is the rainfall intensity which equals the time to concentration for an ARI of y years, expressed in mm/hr which is read off the IFD curves

A is the area of the catchment expressed in hectares

The time to concentration is determined by:

$$t_c = 0.76A^{0.38}$$

Where:

A is the area of the catchment in km^2.

Shown below is a worked example for the Peak Discharge for the Naringhil Creek sub-catchment for an ARI of 2 years.

$Q_y = 0.00278\ C_y\ It_c yA$

$$\mathbf{t_c = 0.76A^{0.38}}$$

So $251.7^{0.38}$ x 0.76
Time to concentration = 5.9 hours

C_y

Runoff Coefficient for the Naringhil sub-catchment is 0.08 and the Frequency Factor for a 2 yr ARI is 0.75

So C_y = 0.06

$It_c yA$

The rainfall intensity (I) with a 5.9 hour t_c for a 2 year ARI (y) = 5.5mm/hr (from the IFD curve)

A

The area of the Naringhil sub-catchment in hectares is 25,167 (from the GIS)

So Peak discharge is:
0.00278 x 0.06 x 5.5 x 25,167 = 23 m^3/sec or 1,994 ML/day (approx. 2GL/day)

4.5 Partitioning the Salt

Once the relative peak discharges were calculated, the relative salt contribution was calculated by multiplying the relative discharge by the concentration of salt in the stream.

Example calculation for Ferrers Creek:

Where the discharge calculated from the 2year ARI has been used.

The salt concentration of 13,000 mS/cm x 0.6 = 7,800 mg/L salt

0.6 is the conversion factor (Fetter 1994)

1181.6 ML/d of discharge x 7,800 mg/L / 1000

9,216 tonnes/d of salt that is discharging from the sub-catchment

5. Results

5.1 Sub-Catchments

Naringhil

The Naringhil Creek sub-catchment is an area encompassing over 251 km^2 (Figure 5.2) It receives its waters from a number of tributaries which flow from Mount Bute, a granite pluton (364m AHD) and from other high points in the granite landscape, in the north-western corner of the Woady Yaloak River catchment around the locality of Pittong. Naringhil Creek is the major creek in the granite landscape of the Woady Yaloak River catchment and its course is influenced by the weathering of the granites and surrounding country rocks. The differential weathering of the granite compared to the resistant hornfels that rise above the weathered granite and created the depression that is now occupied by the creek. The approximate length of the main creek (excluding tributaries) is over 28 km.

Woady Yaloak

The Woady Yaloak River sub-catchment is an area encompassing over 407 km^2 (Figure 5.2). The Woady Yaloak River flows into Lake Martin, before entering Lake Corangamite, which is a permanent saline wetland with international ecological importance and is located south of the catchment at the mouth of the river system. The length of the river is greater than 66 km. The Woady Yaloak River flows through Palaeozoic bedrock where it begins its journey south of the town of Haddon. Sugar Loaf Hill (378m AHD) is located south of Haddon towards the headwaters of the Woady Yaloak River, and further south is Black Hill (391m AHD) west of the town of Scarsdale. A tributary to the west of the river, receives its water from Emu Hill, a Newer Volcanics eruption point for valley flow basalts, south of the town of Linton.

The river deviates past many mullock heaps along the course of the deep leads and then through Devils Kitchen at Pigoreet, where it travels through Newer Volcanic basalts and is surrounded by Cambrian rocks to the west and Ordovician rocks to the east. Approximately 5.5 km south of the Enfield Fault, Pliocene Sands surround the river as it travels through the Cambrian sediments and then makes it way through the Newer Volcanic sheet flows, where it flows south.

Figure 5.1 The Woady Yaloak River at Cressy.

Illabarook

The Illabarook Creek sub-catchment is an area encompassing over 113 km^2 (Figure 5.2). Around the Illabarook area, landscapes have been deeply to moderately dissected and shaped by the drainage in the region. Illabarook Creek starts it journey south of the town Pigoreet within the Ordovician sediments then travels along the edges of the Newer Volcanic flows and through the Tertiary gravels, which surround the alluvial sediments towards the headwaters of the creek. It then flows southeast through the Quaternary and Ordovician sediments, surrounded by sheet flow basalts to the west, and Pliocene sands to the east, until it meets with Mount Misery Creek to the east. The approximated flow length of Illabarook Creek is 20 km.

Mount Misery

The Mount Misery Creek sub-catchment is an area encompassing over 190 km^2 (Figure 5.2). The headwaters of Mount Misery Creek begin south of the Enfield Forest Park and Bald Hill (470m AHD) where water from these topographical highs feed into the creek. The landscape surrounding Mount Misery Creek is dissected by many erosion gullies, most of which do not contribute much water and intersect Mount Misery Creek to the north of the sub-catchment. Mount Misery (370m AHD) is made up of Ordovician sediments and is located approximately 2 km south of the headwaters. The creek deviates around the base of the mountain from which water runs off and contributes to the creeks flow. The creek journeys through the Ordovician sediments (sandstones, mudstones and shales) where it is surrounded by Pliocene Sands. The creek crosses the Rokewood - Skipton highway before it turns and flows southwest along the edge of the Newer Volcanics, and then meets with the

Woady Yaloak River. The approximated flow length of Mount Misery Creek is 35 km.

The entire length of Mount Misery Creek is considered in this thesis, and differs from others uncovered in this research project, which indicated that the Mount Misery Creek terminates north of the Rokewood - Skipton highway, and south of the highway became the Little Woady Yaloak Creek. The position of the Little Woady Yaloak Creek from the official place name Gazette website suggests that the Little Woady Yaloak Creek is approximately 5 kilometres south from the locations specified in the locality maps. The Little Woady Yaloak River as it appears on some maps, is actually a continuation of Mount Misery Creek and so has been retained as Mount Misery Creek in this thesis.

Moonlight Creek is the major tributary, which flows southeast to join Mount Misery Creek just above the road junction in the town of Rokewood. Moonlight Creek receives its waters from the weathered Ordovician hills, flanked with the Neogene gravel caps, which represent part of the extensively dissected weathered landscape. The creek then flows through Ordovician sediments, where it is surrounded by Pliocene sands as it drains into Mount Misery Creek.

Gully and tunnel erosion susceptibility for the area north of Rokewood has been classified as high to very high (Feltham 2005) and gullies are an obvious feature at the boundaries of the gravels and sands that flank the Ordovician hills.

Kuruc-a-ruc

The Kuruc-a-ruc Creek sub-catchment is an area encompassing over 157 km^2 (Figure 5.2). Kuruc-a-ruc Creek begins its journey within the weathered Ordovician sediments and flows south where it straddles the Newer Volcanics flow boundary. It then travels west where it flows through alluvial sediments and where the Newer Volcanics are present on either sides of the creek. The approximated length of the creek is 36 km. Kuruc-a-ruc Creek is fed by several tributaries which flow into it from the north. They begin in the Ordovician sediments just at the boundary with the Pliocene sands where the drainage is confined within the dissected Ordovician landscape. The tributaries then flow through Quaternary sediments bounded on both sides by sheet flow basalts (to the west) and stony rise basalts (to the east).

Ferrers

The Ferrers Creek sub-catchment is the smallest area, encompassing over 88 km^2 (Figure 5.2). Ferrers Creek begins its journey in the Newer Volcanics and is the eastern-most tributary to the Woady Yaloak River. It joins Kuruc-a-ruc Creek to the west and both then flow into the Woady Yaloak River through the sheet flow basalts to the west. The approximated length of Ferrers creek is 23 km.

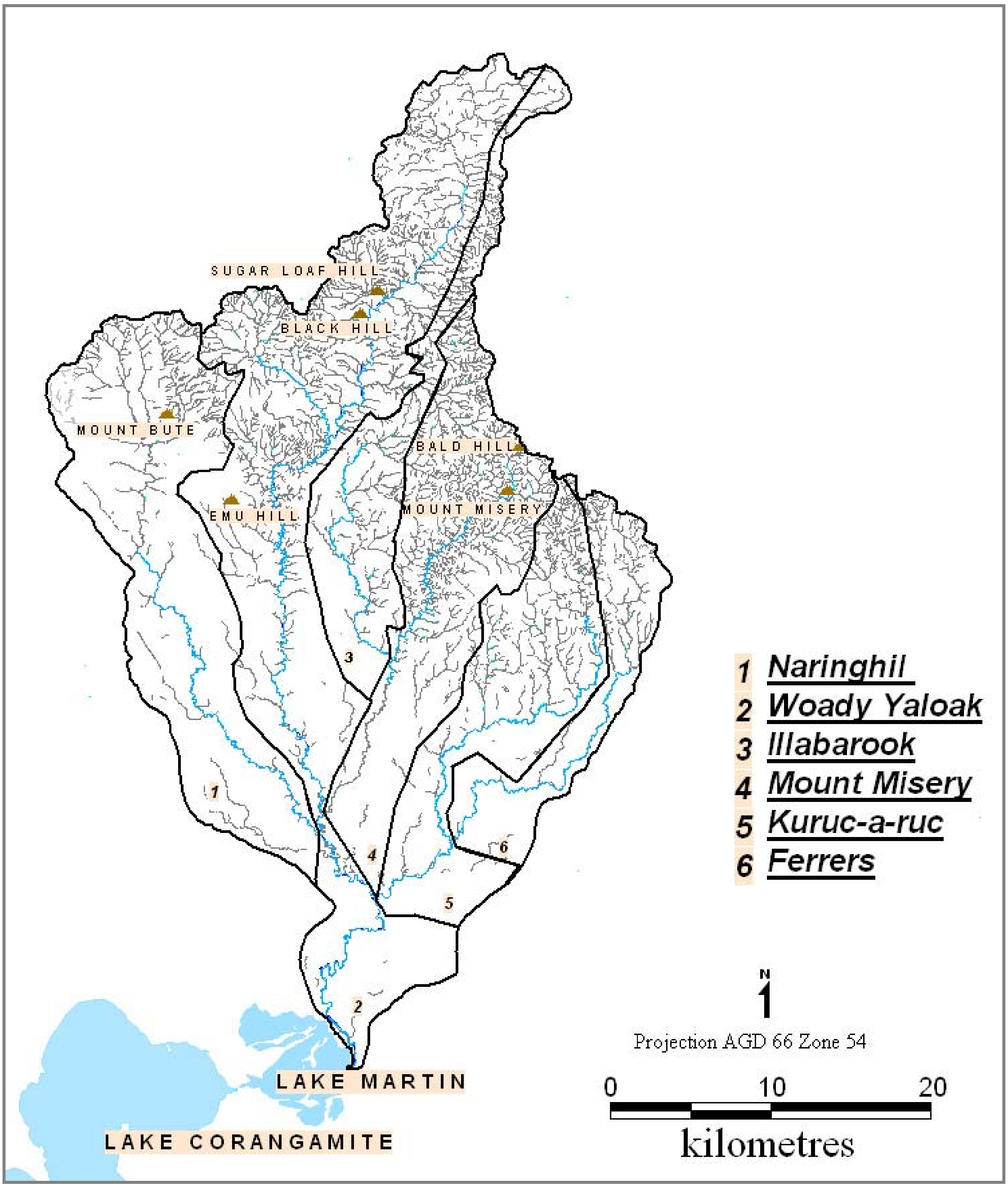


Figure 5.2 Sub-Catchments Delineated for the Woady Yaloak River Catchment.

5.2 Surface Water Salinity

Salinity of the surface water in the Woady Yaloak River catchment was tested on the last days of each month, and for most sites the sampling commenced from February through to October. The results of the surface water salinity are presented as EC readings in milliSiemens per centimetre (mS/cm), where 1 mS is equivalent to 1,000 microSiemens per centimetre (μS/cm), a unit often used for water EC. The surface water salinity will be discussed for the six sub-catchments in the Woady Yaloak River catchment, which were delineated in the previous section. The EC from all the surface water sites have been graphed within their sub-catchments and are presented in Figures 5.3 – 5.8. All results and field sheets are included in Appendix 5.

In order to analyse trends, in relation to surface water salinity increases and climatic variations, current monthly rainfall data was used, alongside surface water salinity results. The monthly rainfall data was obtained from the Bureau of Meteorology (BOM 2006b) for the Ballarat Aerodrome, and although it does not fully represent the rainfall across the catchment, it was the only data readily available. End-of-valley surface water salinity values, recorded for each sub-catchment monthly, have been graphed with the monthly rainfall data (Figure 5.9). Some of the sites where EC values were obtained represent locations slightly upstream of the actual end-of-valley location. This is because the actual end-of-valley sampling locations have incomplete monthly records of surface water salinity, due to (1) the absence of flow in the streams during certain months, or (2) the inclusion of these sites in the sampling regime, in later months.

5.2.1 Naringhil Creek

In the Naringhil Creek sub-catchment all surface water locations show an increase in EC from September to October. The highest EC recordings came from sites Pt and Nt, which are tributaries to the north of Naringhil Creek. Sites N1, N2 and N3 represent the main section of the Creek as it leaves the granite landscape and flows into the Volcanic Plains further south in the catchment. These sites show a similar pattern of rising and falling EC, with the end-of valley reading at N3 escalating to over 16 mS/cm in October, followed by increases in all the sites sampled.

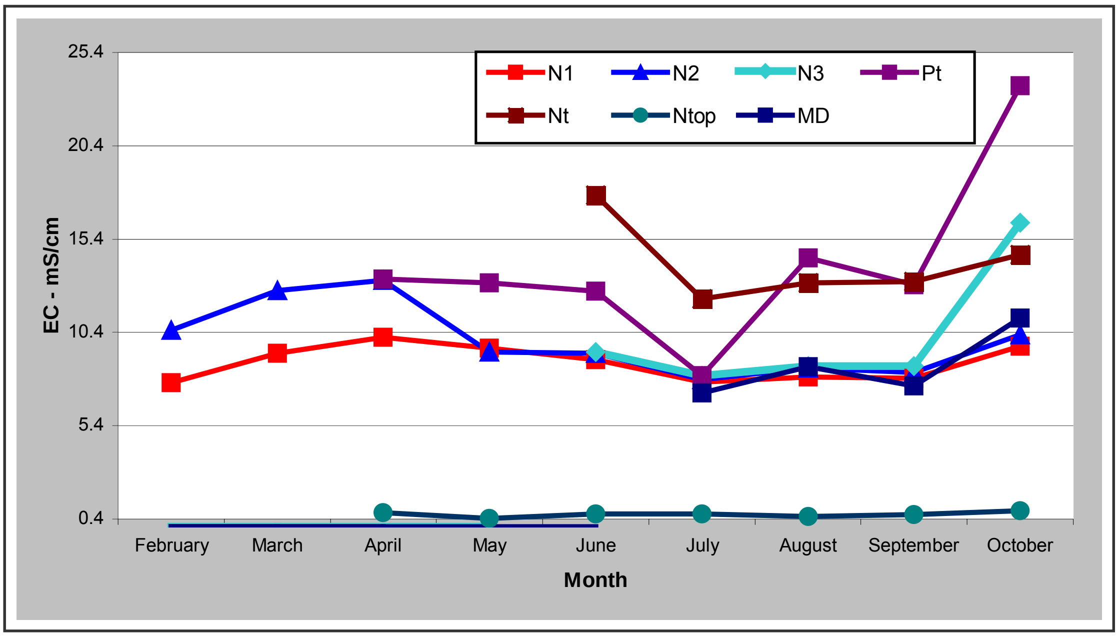


Figure 5.3 Salinity at Surface Water Sites along Naringhil Creek

5.2.2 Woady Yaloak River

The EC trends for the Woady Yaloak River sub-catchment show similarities between the upper reaches of the river, at sites W1, W2, W3 & NO, where the quality of water is fresh to brackish (under 4mS/cm). Site NO is a tributary of the Woady Yaloak River, which travels northeast to join the Woady Yaloak River at site W3. The water from this tributary remains slightly higher in EC than the Woady Yaloak River at the northern reaches and also contains a much lower volume of water than at site W3.

Sites W4 and W5 show a similar EC trend, where W4 is positioned upstream of the Naringhil Creek junction and W5 represents the area downstream of the junction. Salinity within the Woady Yaloak River is shown to be greater downstream of the junction. Even further downstream, between sites W5 and W7 is where Kuruc-a-ruc and Ferrers Creek join the Woady Yaloak River. Salinity below this junction recorded from W7 is greatest of the entire sub-catchment from the months of May to October.

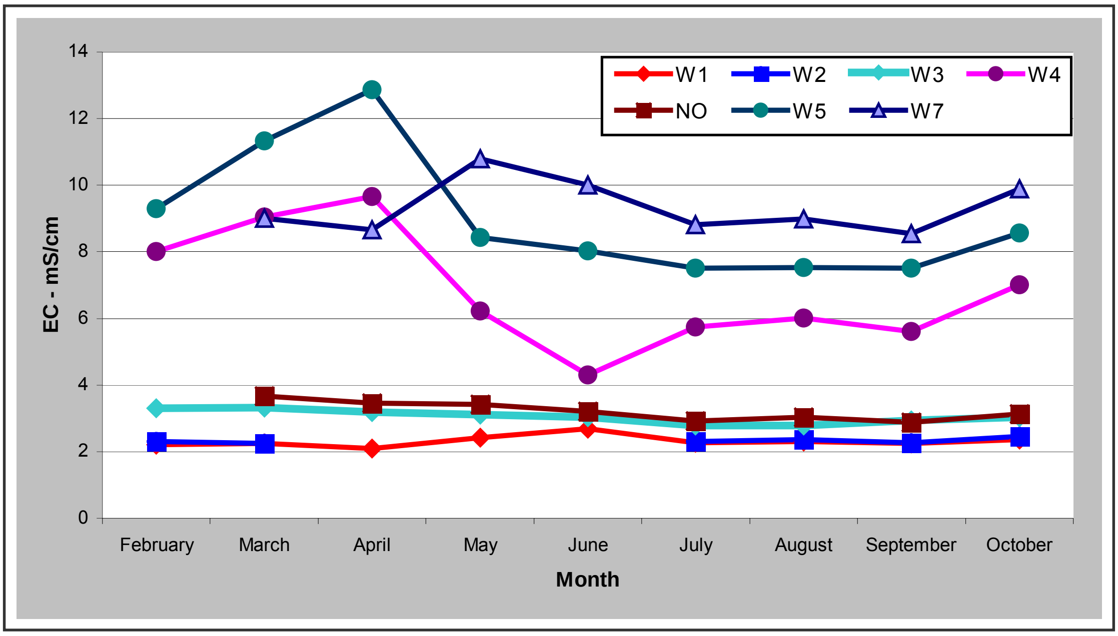


Figure 5.4 Salinity at Surface Water Sites along the Woady Yaloak River

5.2.3 Illabarook Creek

The two sites sampled along Illabarook Creek show similar values of EC, however in October the EC escalates at site I2, which represents the area downstream of I1. The quality of water at both sites throughout the year is saline, where it is only suitable for some livestock.

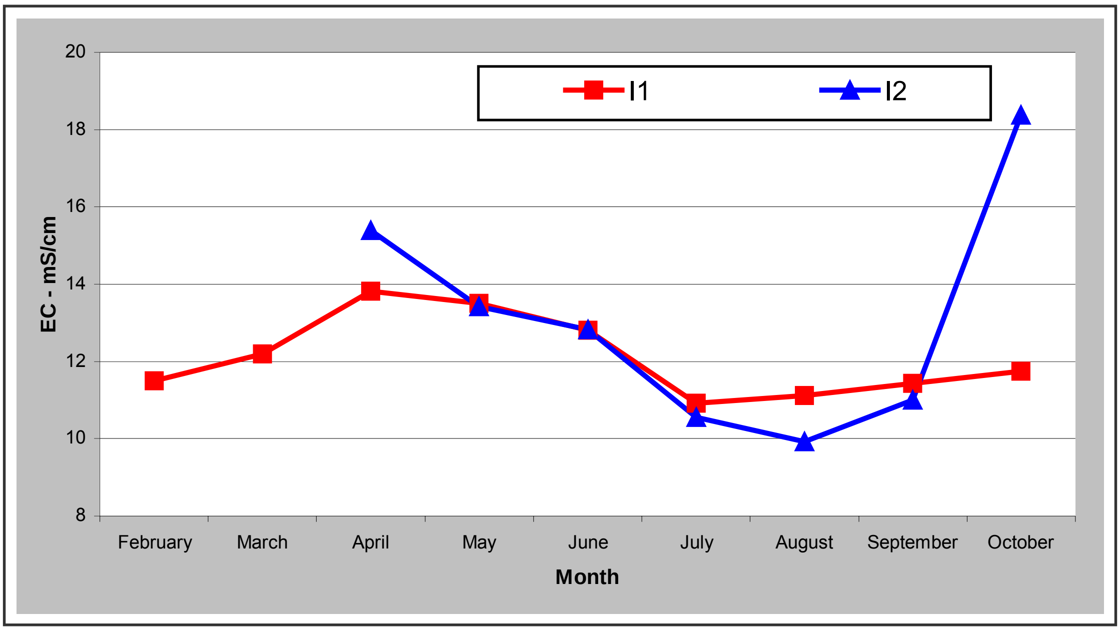


Figure 5.5 Salinity at Surface Water Sites along Illabarook Creek

5.2.4 Mount Misery Creek

The EC trend shown in the Mount Misery Creek sub-catchment is most prominent from July to October where EC increases (particularly around September and October) at all the surface water sites. Similar EC trends exist between sites M2 & M4, where M4 represents the end-of-valley site for the sub-catchment. Site M2 is a tributary of Mount Misery Creek and joins the Creek just below site M1 and above site M3. Salinity at M2 was higher than M1 in every month, and also higher than M3 except in the months of May and June.

Sites ML and ML2 are the tributaries to the north of the Mount Misery Creek and the surface water quality is generally saline. Salinity at site ML dropped considerably in May and June.

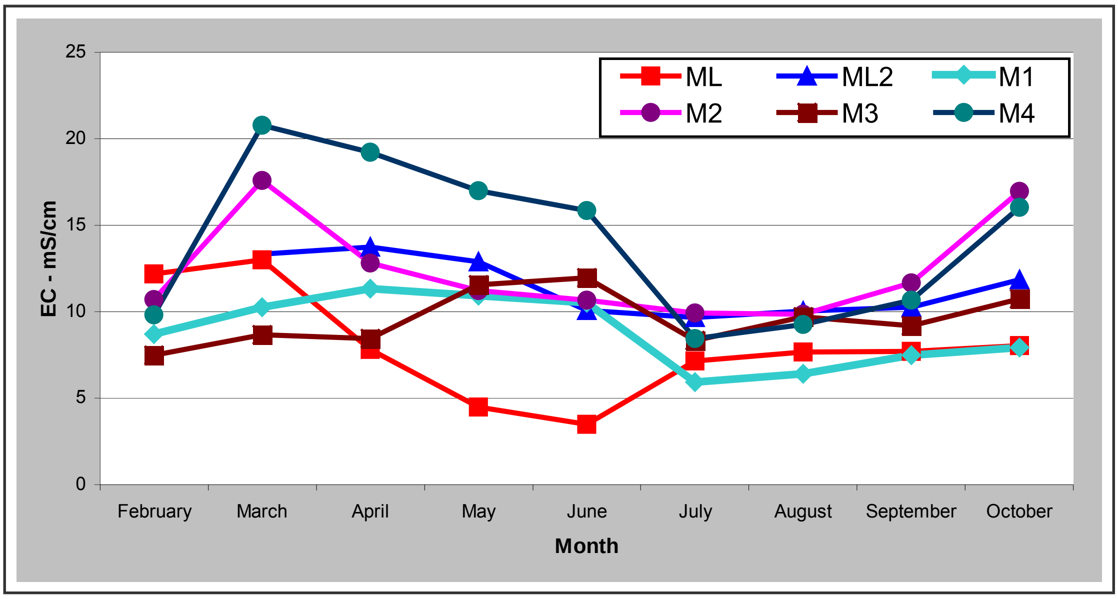


Figure 5.6 Salinity at Surface Water Sites along Mount Misery Creek

5.2.5 Kuruc-a-ruc Creek

The EC recorded over the Kuruc-a-ruc Creek sub-catchment generally increases in March and then again in October. The EC trend between sites K1 and K4 are similar except that K4 which represents the end-of-valley sub-catchment site, is much more saline than K1. K1 is the northernmost surface water site in the sub-catchment. Site K2 is also quite saline, and this site is located adjacent to the Ferrers Creek junction, slightly downstream of site K1. Site C1 is a tributary of Kuruc-a-ruc Creek that flows into it from the north at site K1, and the results show that it is generally less saline than the water along Kuruc-a-ruc Creek, which journeys south of C1.

The highest overall EC came from the areas downstream of the Kuruc-a-ruc Creek junction with Ferrers Creek, at sites K3 and K5. Site K3 is a saline tributary of Kuruc-a-ruc Creek which flows into the Creek from the west. Site K5 is located along the

Creek and is the second most southern site in the sub-catchment, before site K4, and before the Creek joins the Woady Yaloak River.

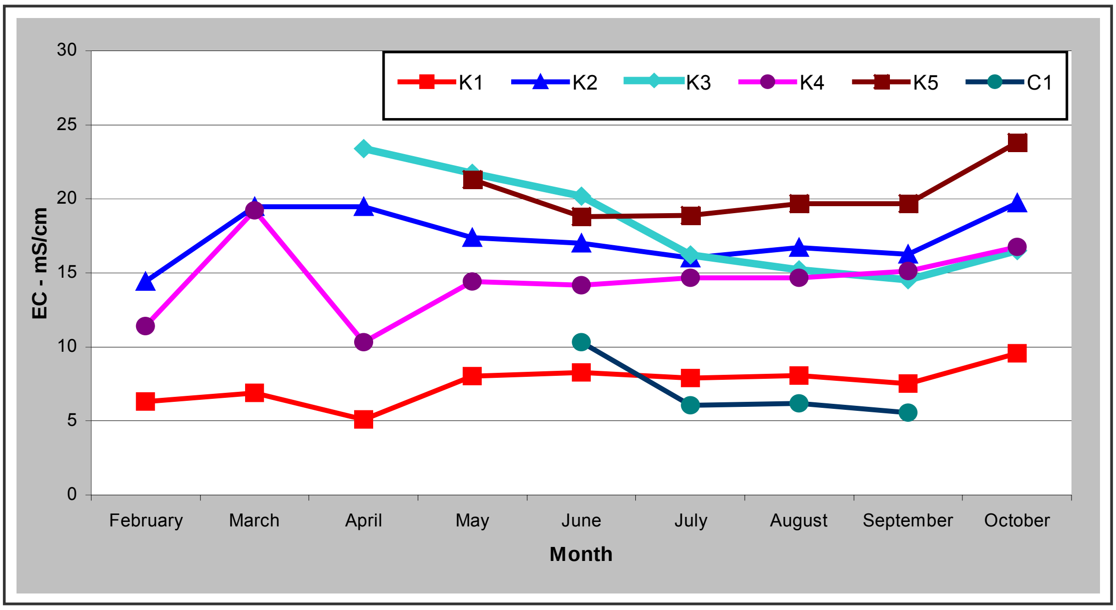


Figure 5.7 Salinity at Surface Water Sites along Kuruc-a-ruc Creek

5.2.6 Ferrers Creek

Site F1 is located along the northern reaches of Ferrers Creek, however the results show that it was not flowing from February to June. Site F2, further downstream, is located adjacent to the Kuruc-a-ruc Creek junction, within the Volcanic Plains and is more saline than the creek upstream.

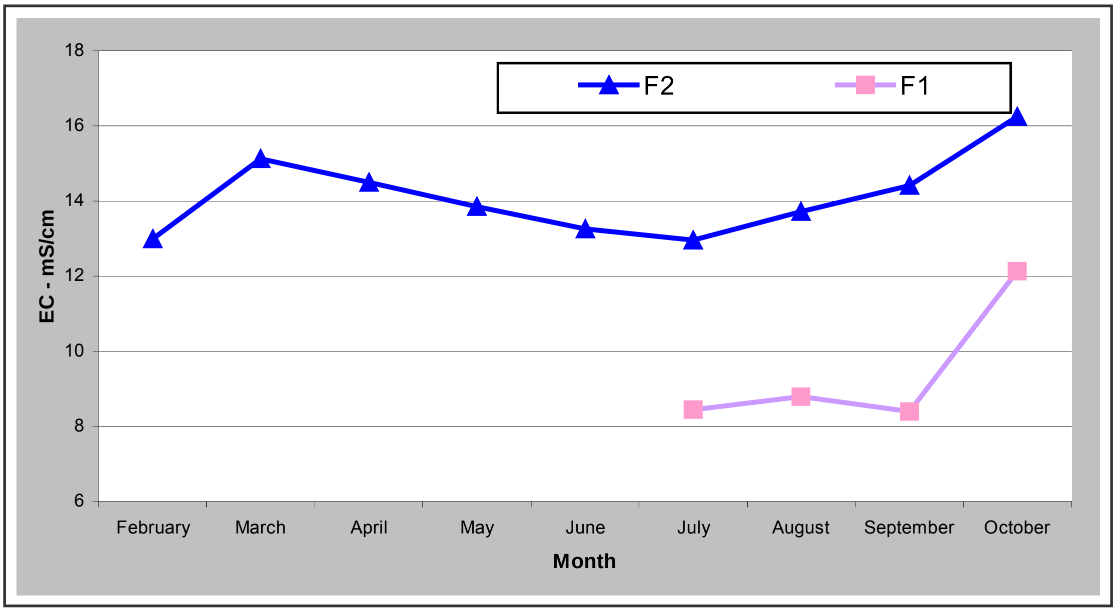


Figure 5.8 Salinity at Surface Water Sites along Ferrers Creek

5.3 Rainfall versus EC

The end-of-valley surface water sites for each sub-catchment have been graphed against monthly rainfall data and shown in Figure 5.9. The individual sub-catchments show various trends, in relation to the monthly rainfall, however some similarities exist. A general increase in salinity occurs from the end of summer to the start of autumn, and after the peak rainfall event in April, a decreasing trend follows in the later months of autumn. The sharpest declines in surface water salinity occur in the mid-late autumn months. In the early winter months, surface water salinities generally decrease and then increase at the end of winter and early spring.

The surface water salinity, graphed against the rainfall data, show similar trends for Kuruc-a-ruc and Ferrers creeks between the months of May and October. Similar trends also exist for Naringhil Creek and the Woady Yaloak River, and also for Illabarook and Mount Misery creeks (however the end-of-valley EC is much greater in the earlier months of the year for Mount Misery Creek). All the sub-catchments display an increase in surface water salinity during the lowest rainfall event in October.

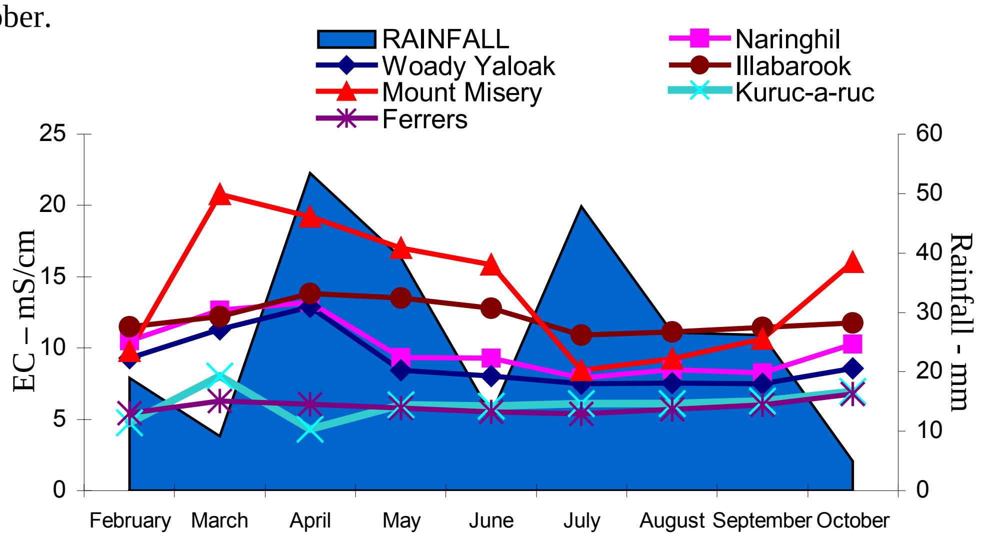


Figure 5.9 Rainfall versus EC for End-of-Valley Surface Water Sites for each Sub-Catchments

5.3 Peak Discharge

The Peak Discharge values for the Woady Yaloak River Catchment, determined from the Rational Method are presented below:

Table 5.1. Peak Discharge for the Woady Yaloak Sub-Catchments
ML/day

Sub-catchment	*Average Recurrence Interval*						**Percentage of Discharge**
	2yr	**5yr**	**10yr**	**20yr**	**50yr**	**100yr**	
Naringhil	1994	3155	4111	5320	7254	8801	16.7
Woady Yaloak	3302	5173	6726	8744	11887	14627	27.5
Illabarook	1327	2204	2858	3743	4899	6369	11.7
Mount Misery	2228	3701	4798	6283	8225	10693	19.6
Kuruc-a-ruc	1627	2546	3395	4565	6111	7847	14.2
Ferrers	1182	1891	2451	3209	4481	5462	10.2

Peak discharge calculations are included in Appendix 4.

5.4 Salt Loads

The relative salt loads discharging from each of the sub-catchments, was calculated from peak discharge volumes and end-of-valley salinity EC readings (calculations are appended in Appendix 7). The monthly salt loads have been grouped seasonally and are presented in Figure 5.11.

In summer, sampling was only conducted in February, and so the highest salt loads came from the Mount Misery Creek sub-catchment. Salt loads were also highest at this sub-catchment throughout autumn, at the start of winter and also at the end of spring in the last month of sampling (October). The Woady Yaloak River sub-catchment produced the highest overall total salt loads (Figure 5.14) and the highest monthly salt loads in the months when the salt loads from the Mount Misery Creek sub-catchment declined (except in March). This was mainly in the winter months and in the first month of spring. Overall, the Mount Misery creek sub-catchment contained the highest salt loads even though the Woady Yaloak River sub-catchment is over twice its size in area (see Figure 5.12).

The next major salt loads came from Kuruc-a-ruc Creek, which escalated at the beginning of autumn, containing the second highest salt loads after Mount Misery Creek. The Kuruc-a-ruc Creek sub-catchment encompasses the third largest area (Figure 5.12) and contained the second highest salt loads in the mid to late winter months.

Ferrers and Illabarook Creek sub-catchments have the smallest catchment areas compared with the other sub-catchments (Figure 5.12) and their total salt loads were also the lowest of all the sub-catchments (Figure 5.14). The percentage of salt loads from Ferrers Creek, increased slightly in the winter months and again at the beginning of spring, whereas Illabarook recorded its highest salt loads in the last month sampled in spring, and for the previous months remained pretty consistent. The Illabarook Creek sub-catchment dropped to its lowest percentage of salt load at the beginning of autumn.

The Naringhil Creek sub-catchment encompasses the second largest catchment area after the Woady Yaloak River, however as the Woady Yaloak River's salt loads increased substantially at the end of autumn, the few percentage difference which separated them in the earlier months, grew, as Naringhil's salt loads dropped at the end of autumn. In October, Naringhil recorded its highest percentage of monthly salt loads, which equalled the salt loads from the Woady Yaloak River.

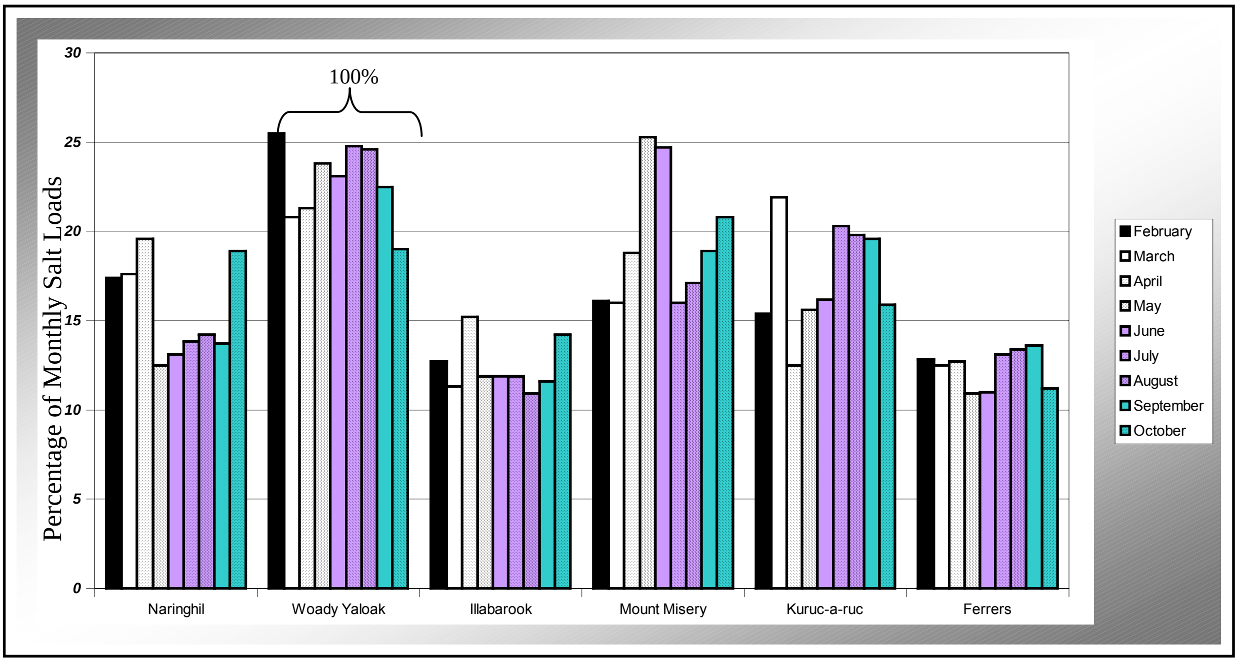


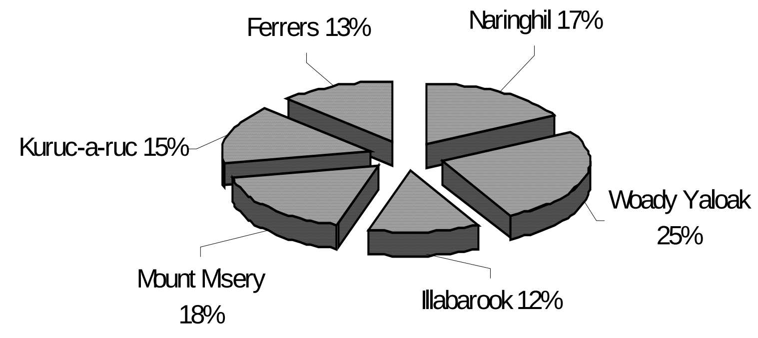
Figure 5.10 Percentage of Monthly Salt Loads Calculated for Individual Sub-Catchments. Seasons grouped by colours.

Summer

December
(not sampled)

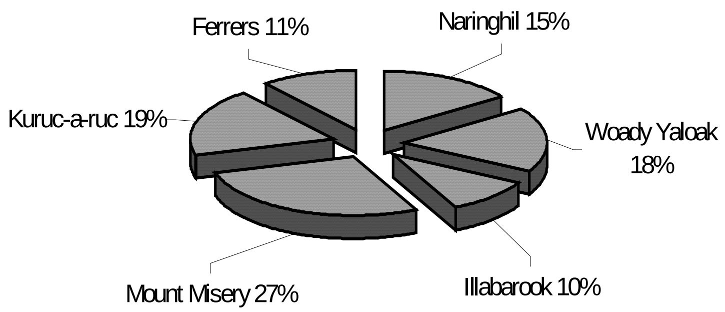
January
(not sampled)

February

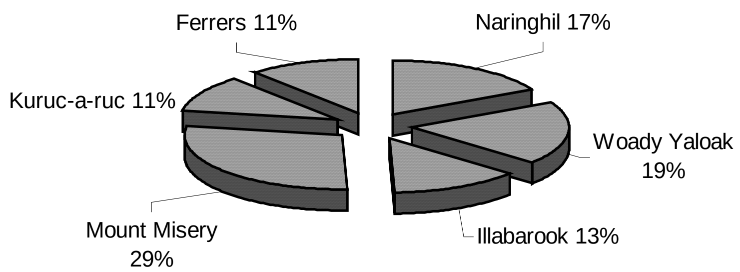


Autumn

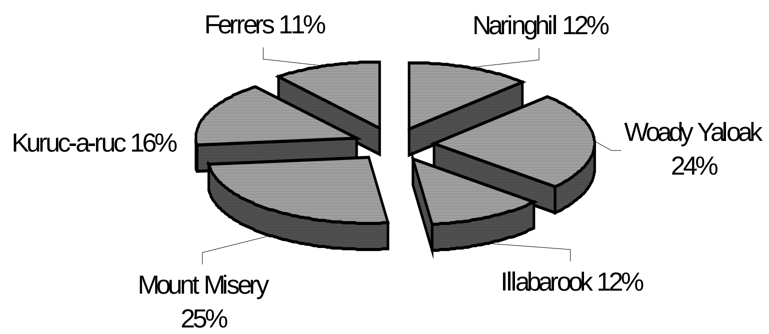
March

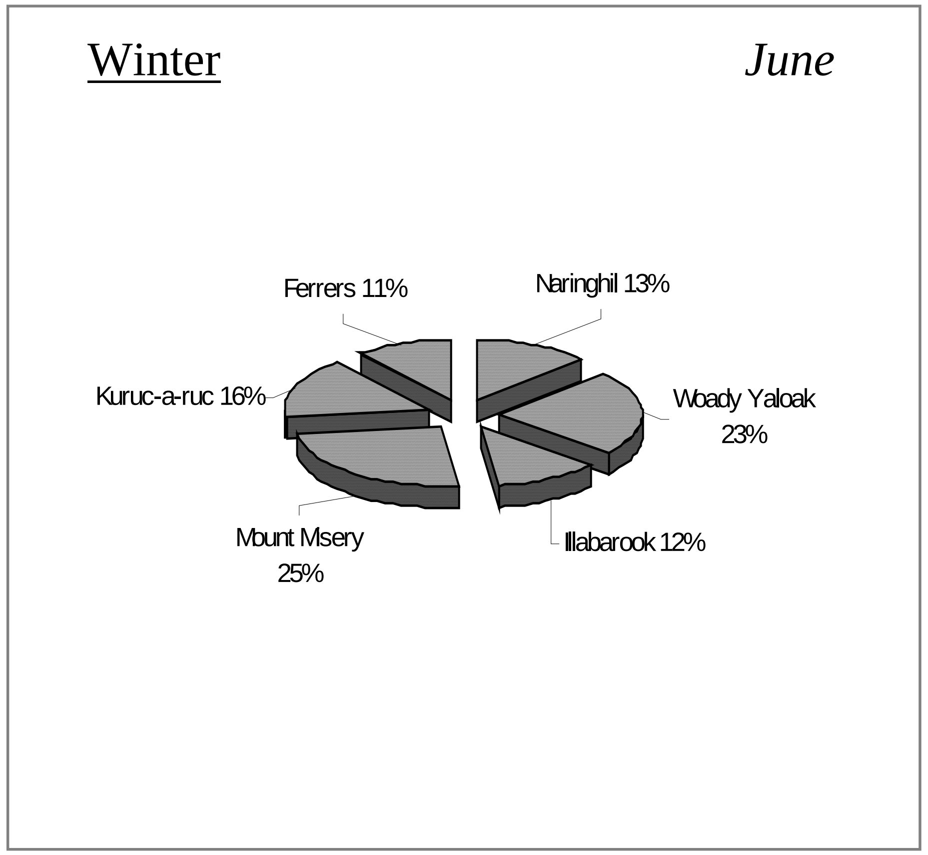


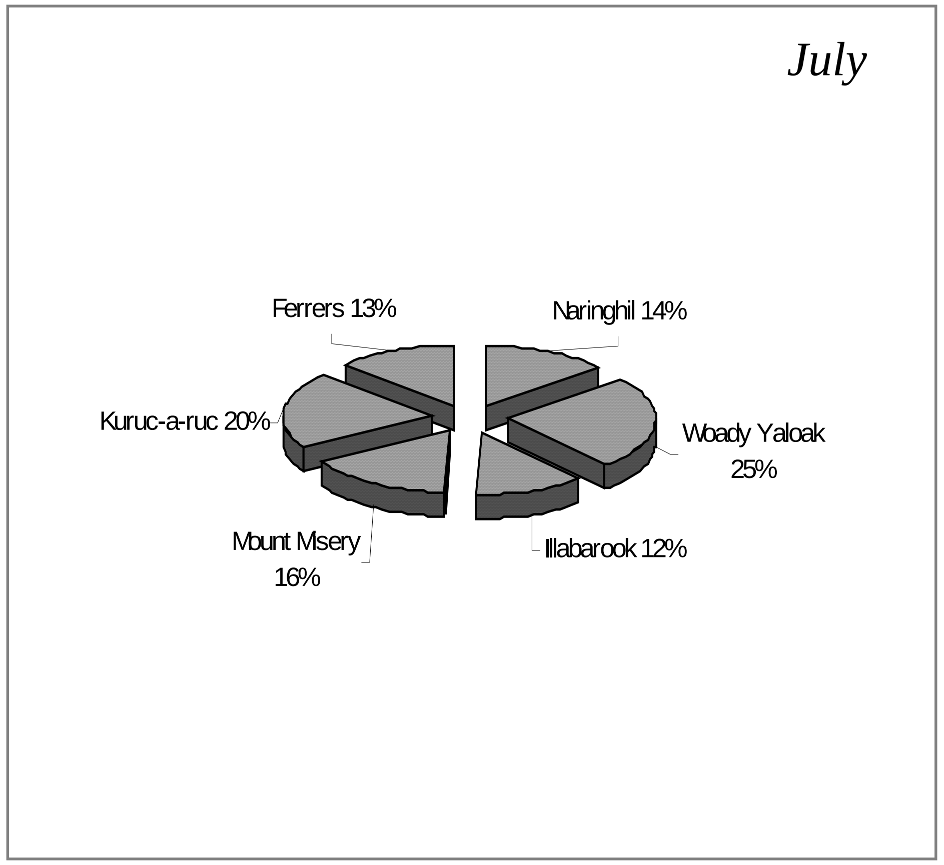
April

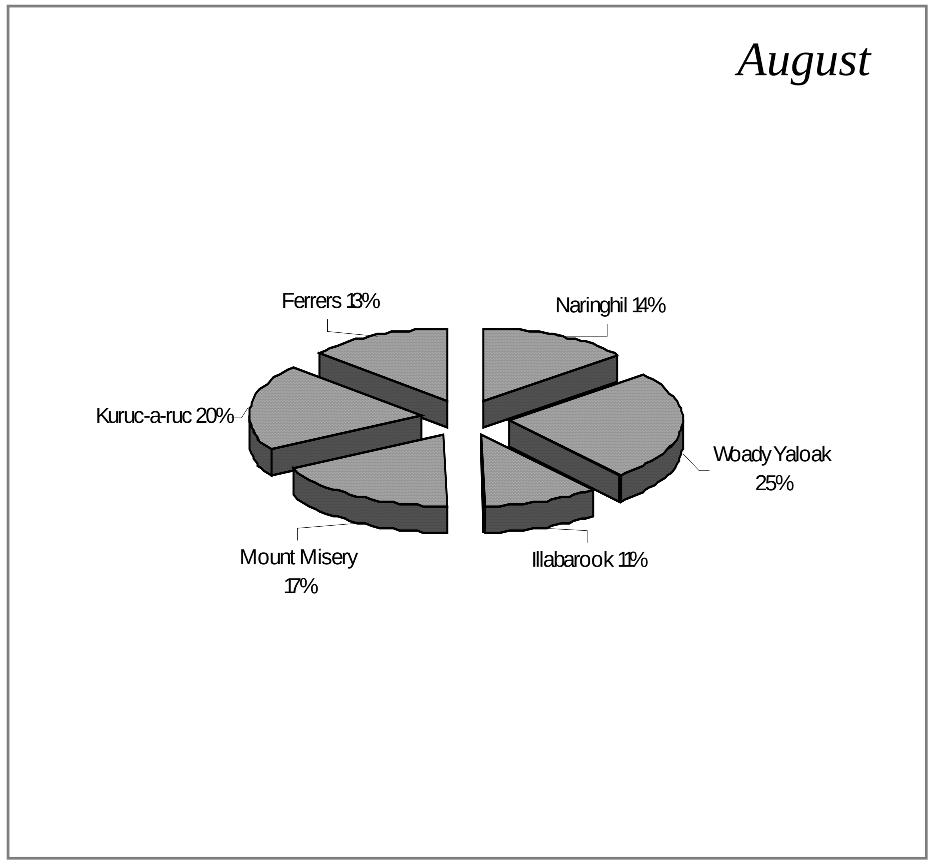


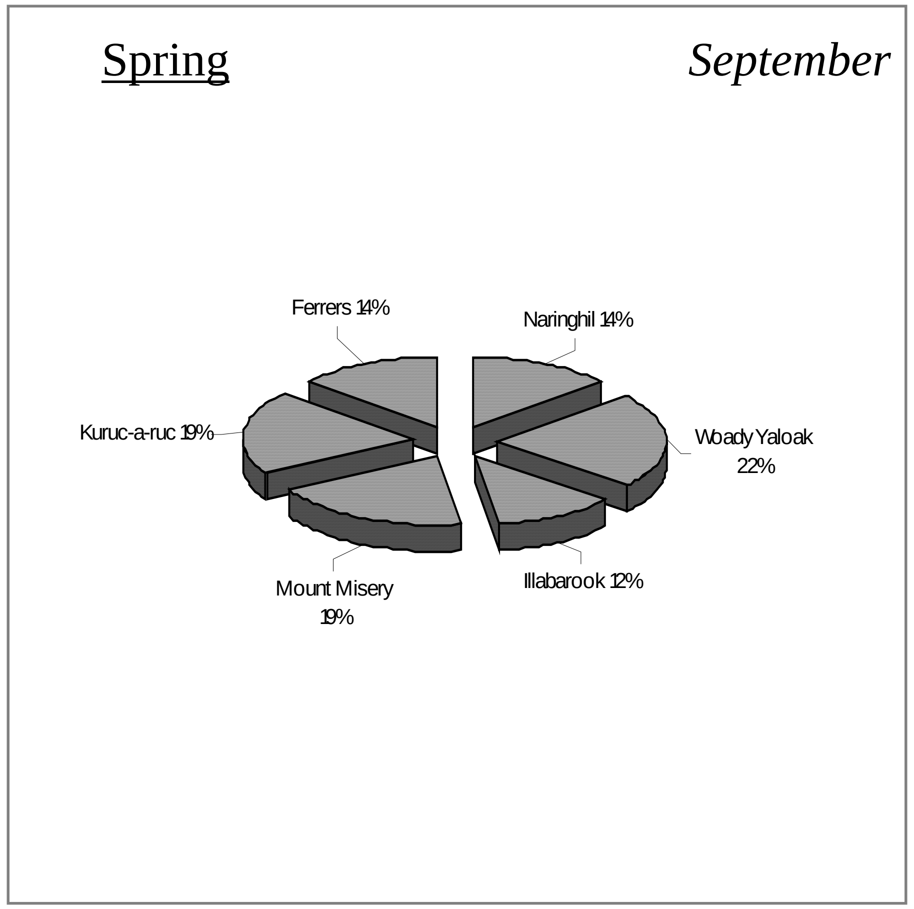
May

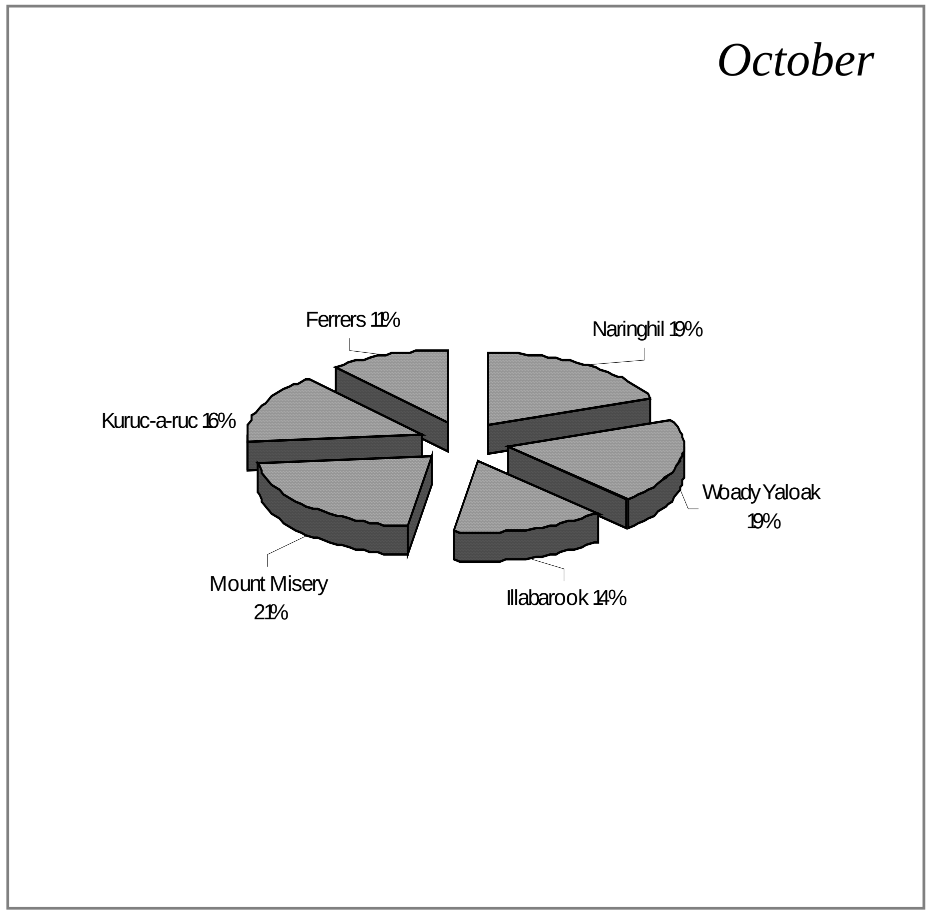












November
(not sampled)

Figure 5.11 Monthly Salt Loads

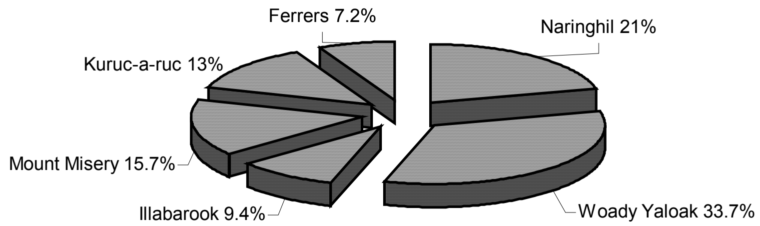


Figure 5.12

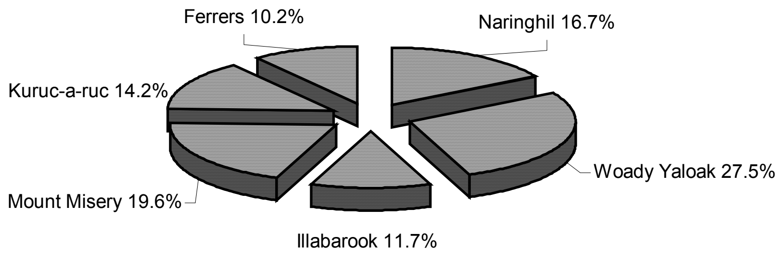


Figure 5.13

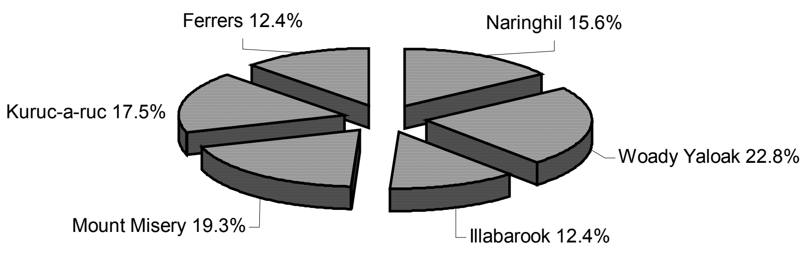


Figure 5.14

Figures 5.12 – 5.14: (Top) Area Percentage of Sub-Catchments, (Middle) Discharge Percentage for Sub-Catchments and (Bottom) Total Percentage of Salt Load for each Sub-Catchment

5.5 Groundwater Salinity

The following bores were sampled in the Woady Yaloak River catchment, and salinity of the groundwater as EC is presented below:

Bore ID	EC mS/cm	Flow System	Quality
5265	10.45	Granite	Saline, most livestock
5402	10.09	Granite	Saline, most livestock
5404	9.76	Granite	Saline, most livestock
5503	6.7	Gravel Caps	Saline, most livestock
5269	7.87	C.H.Volcanics	Saline, most livestock
5290	1.5	C.H.Volcanics	Fresh, most purposes
122382	1.329	C.H.Volcanics	Fresh, most purposes
2	7.7	Alluvium	Saline, most livestock
5412	21.28	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)
103104	11.16	Volcanic Plains	Saline, most livestock
103109	17.17	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)
110533	3.97	Volcanic Plains	Brackish, Limited irrigation, all livestock
110103	14.305	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)
110140	13.85	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)
112239	8.06	Volcanic Plains	Saline, most livestock
110657	4.31	Volcanic Plains	Brackish, Limited irrigation, all livestock
112241	2.51	Volcanic Plains	Brackish, Limited irrigation, all livestock
110103	13.68	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)
110197	3.05	Pliocene Sands	Brackish, Limited irrigation, all livestock
112239	7.77	Volcanic Plains	Saline, most livestock
57507	31.4	Volcanic Plains	Saline, Limited industrial use, ore processing
98253	6.945	Volcanic Plains	Saline, most livestock
26662	17.52	Volcanic Plains	Saline, some livestock (beef, cattle, sheep)

Table 5.2 Groundwater Salinity in the Woady Yaloak River Catchment.
Water Quality Source: Department of Fisheries (2001).

The highest EC values came from the groundwater located within the Volcanic Plains aquifer, where the water quality ranged from brackish to saline. The freshest water came from the groundwater located within the Central Highlands Volcanics aquifer. Only one sampled was obtained from the Pliocene sands aquifer (Bore 110197) and this sample revealed brackish water, which is lower in EC than the majority of the groundwater from the Volcanic Plains aquifer. The three bores sampled within the granite aquifer revealed saline water at around 10 mS/cm.

5.6 Groundwater Chemistry

The major ionic composition of the groundwater from the bores analysed, was predominantly sodium (Na^{+}) and chloride (Cl^{-}), where the sodium and chloride ions made up more than half of the total cations and anions. The next major constituents were, of the cations species: Magnesium, sulfur (S) calcium (Ca^{2+}), potassium (K^{+}) strontium (Sr^{+}), with minor Boron (B) and Iron (Fe^{3+}); and for the anion species: Sulfate (SO_4^{2-}) nitrate (NO_3^{-}) bromine (Br), with minor fluorine (F^{-}).

The accuracy of the chemical analysis was determined by balancing the cation and anion species, where that the sum (Σ) contained only a small percentage variation. The cation and anion results were balanced for 4 groundwater samples (Bore ID's: 112239, 110103, 57507 & 26662) and showed an average of 0.975-mmol/L variation.

The major ions of the groundwater that was sampled are presented in Figure 5.15. The bores have been labelled according to the groundwater flow system in which they reside, in order to show variations in groundwater chemistry throughout the different flow systems. The bores that were sampled for major ions are presented in Chapter 4 (Figure 4.4).

The majority of the groundwater sampled was predominantly sodium and chloride water. Magnesium, calcium and bicarbonate were the next major constituents, with the greatest magnesium and calcium concentrations contained within the Volcanic Plains and Granite aquifers (Figure 5.15).

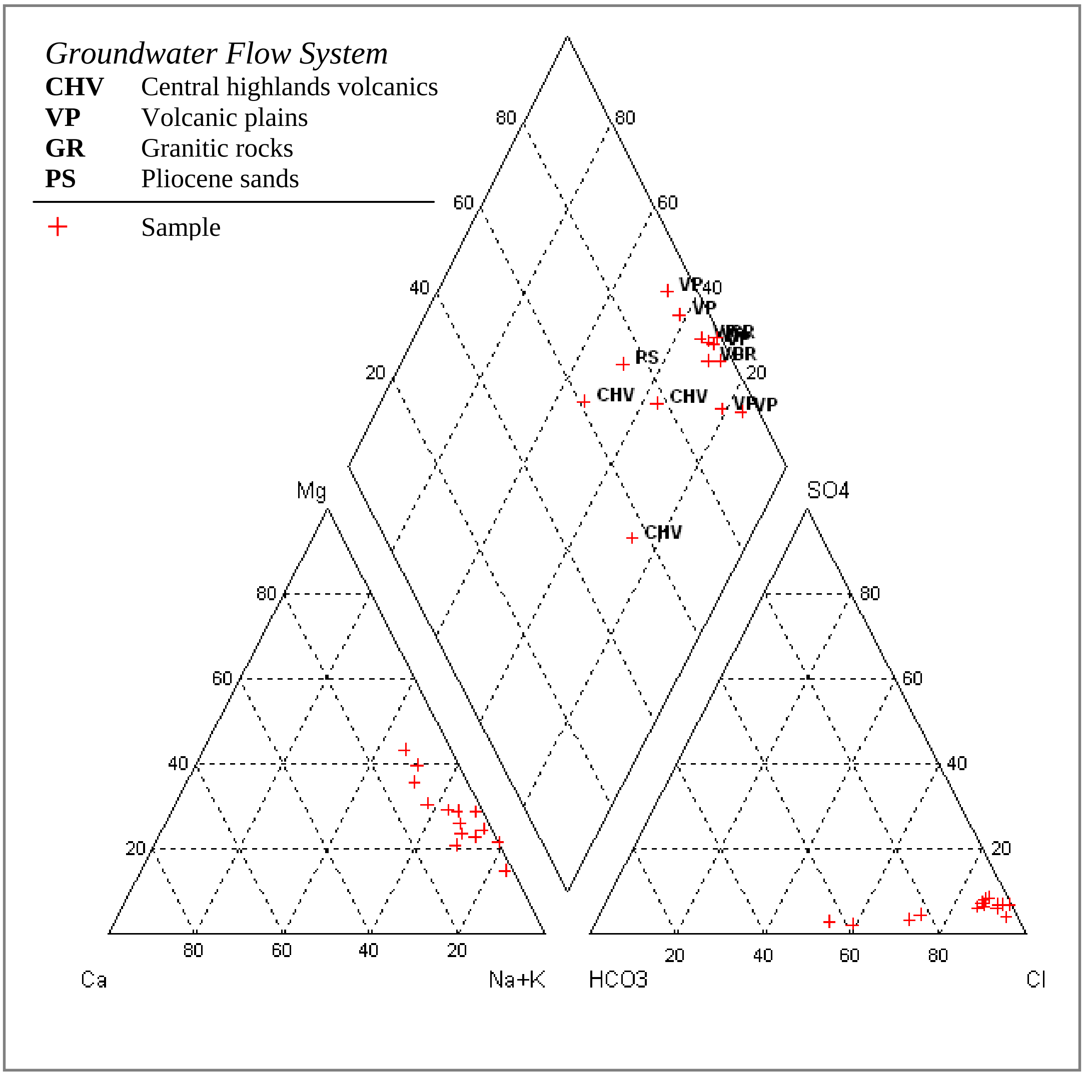
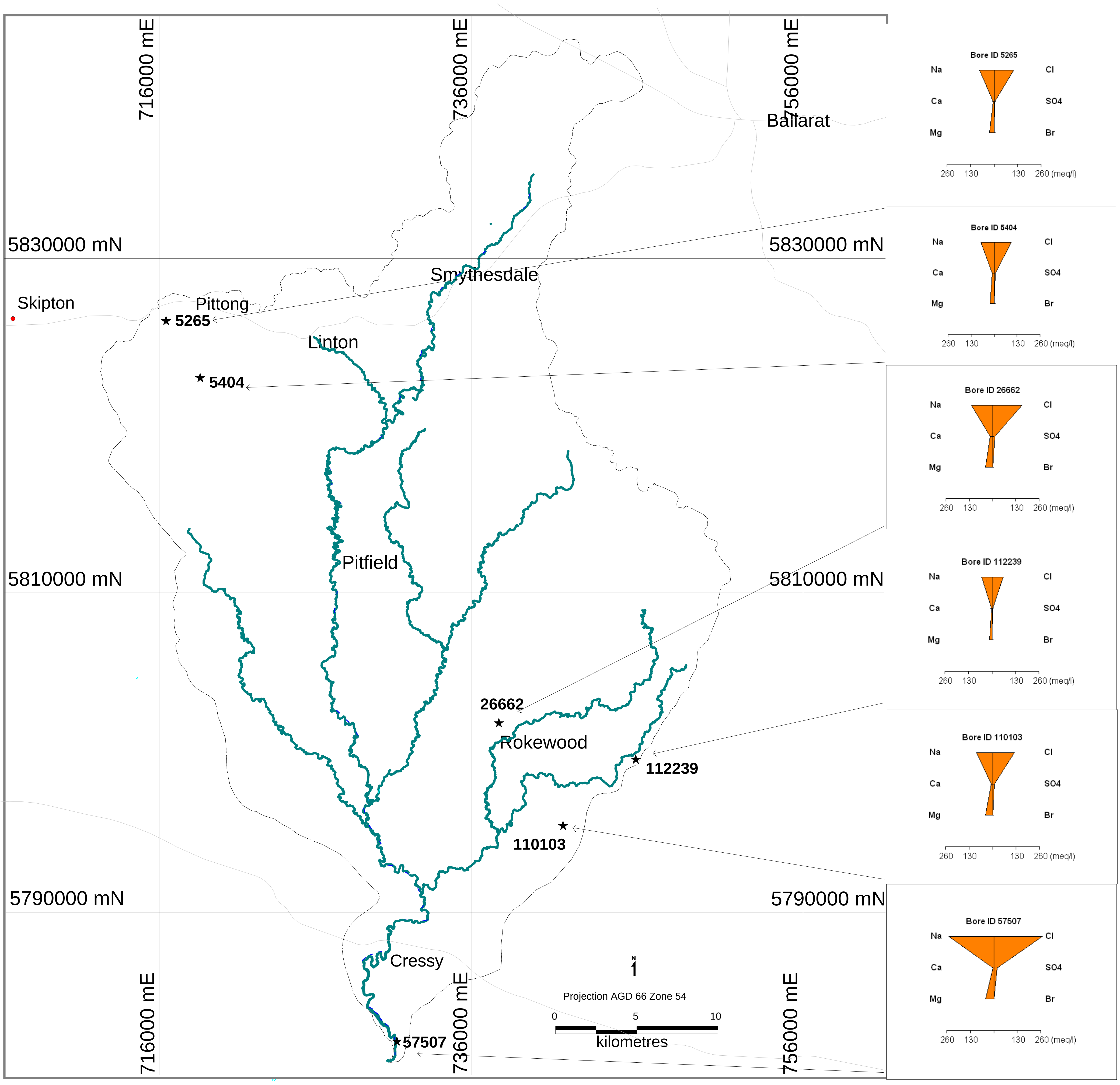


Figure 5.15 Piper Plot Displaying the Major Ions of the Groundwater

Ions	112239 VP	57507 VP	26662 VP	110103 VP	110140 VP	103104 VP	103109 VP	98253 VP	110197 PS	5265 GR	5404 GR	122382 CHV	112241 CHV	110657 CHV
					BORE ID & Groundwater Flow System									
Na	1320	5680	2730	2020	2150	1480	2660	743	349	1838	1669	115	410	592
Mg	175	535	491	474	469	415	540	270	144	308	266	58	73	145
Ca	8.1	107	252	152	42	260	224	151	57	102	212	23	9.5	63
K	16	54	14	21	21	16	28	12	3.7	20	12	4	4.2	10
Cl	2200	9550	5780	4280	4393	3528	5943	2030	770	3810	3460	224	454	1061
SO_4^-	220	840	590	550	544	399	618	208	46	212	338	11	33	87
HCO_3	366.1	671.2	238	366.1	482.1	463.7	341.7	262.4	463.7	183.1	36.6	250.2	634.6	543.1
AGE (yrs)	-	-	-	100	1,000	100	14,000	2,500	6,500	-	-	-	-	100

Table 5.3 Major Ion Analysis of the Groundwater in mg/L.



LEGEND

Stream

Major Road

Catchment Boundary

Bore Location and ID

Stiff Plot: Groundwater Chemistry

Figure 5.16 Stiff plots displaying the major ions of the groundwater in the Woady Yaloak River catchment

6.0 Discussion

The year in which surface water EC recordings were obtained, represents an uncharacteristic year for the Woady Yaloak River catchment due to some of the lowest rainfalls experienced on record, where the rainfall across Victoria was very much below average or the lowest on record (BOM 2006c). Therefore the creeks were uncharacteristically dry and the lack of flow has no doubt skewed the results. This means that much of the surface water salinity was probably a result of baseflow rather than overland flow. Also the monthly spot (or grab) samples are not necessarily indicative of the true salinity loads, as in-between salt slugs may have been missed.

6.1 Surface Water Salinity

6.1.1 Naringhil Creek

The surface water trend for Naringhil Creek generally shows an inverse correlation between surface water salinity and rainfall. When rainfall was lowest in March and October, salinity of the Creek escalated due to the low amount of surface runoff water available to dilute the concentration of salts in the creek. In May, the water was observed to be flowing strongly in the creek following the peak rainfall in April, and this coincides with a small decrease of salinity in the Creek due to the dilution of salts from the rainfall. The salinity values then oscillate from May to September and rise to 10.29 mS/cm in October, following a decline in rainfall.

Surface water was sampled at seven locations within the Naringhil Creek sub-catchment, three of which (N1, N2 & N3) were from the main waterbody of Naringhil Creek, and the other four sites were from tributaries, which feed into Naringhil Creek from the north.

Naringhil Creek receives waters drained from the granite pluton to the north of the sub-catchment, and the sites sampled that occur within the granite landscape are Nt and Pt. Salinity at these two sites was the highest recorded over the entire sub-catchment, which is probably attributed to the saline groundwater discharge, which is making the surface waters more saline. The site Pt was in fact a groundwater spring, from which the water is diverted into a tributary which then flows into Naringhil Creek. The extent of the discharge puddle at the site grew as the months progressed, even with the diminishing amount of rainfall, and finally disappeared in October, which means that the groundwater level had dropped. A study by Church (2004) sampled the same site in 2004, and results show that EC has risen, particularly in August to October.

	Site Pt: EC (mS/cm)	
Month	**Pt (2004)**	**Pt (2006)**
February	-	-
March	-	-
April	-	13.26
May	-	13.05
June	11.3	12.62
July	6.9	8.09
August	7	14.4
September	2.7	12.96
October	5.1	23.6

Table 6.1 EC Comparisons for Site Pt (2004 & 2006).

The dramatic increase in the 2006 recordings can probably be attributed to the lack of rainfall over late winter and spring. For example the rainfall in September was over 60mm in 2004 and in 2006 it was less than half this amount.

The site located further south of Pt, was Ntop, and this site recorded the lowest level of salinity. The water here appears to be unaffected by the saline surface waters upstream, because the waters from the saline tributaries from Pittong probably do not add to this surface waterbody. Ntop flows into Naringhil Creek from a separate branch further west of the tributaries, which enter Naringhil Creek from Pittong (located further east). This would suggest that the higher salts come from the north-easterly tributaries, which connect sites Pt, Nt and MD (Figure 6.1).

Site Ntop has formed within the depression of the Newer Volcanics lava flow, so does not receive the same saline groundwater discharge component as the northern areas of the sub-catchment, which are underlain by the granite aquifer. The groundwater aquifer that underlies the surface water at site Ntop is apart of the Central highlands flow system. The groundwater salinity, surrounding this surface water site is unknown due to the absence of monitoring bores in the area, so to suggest that the water is relatively fresh because of the groundwater input is only a speculation.

There are many variations in salinity along the Naringhil Creek flow path, however there are some similarities that exist, and these coincide with the underlying groundwater flow systems that occur beneath the surface water bodies. For example the surface water salinity at Pittong are similar, and then further south into the Volcanic Plains the surface water sites also show similar salinity values.

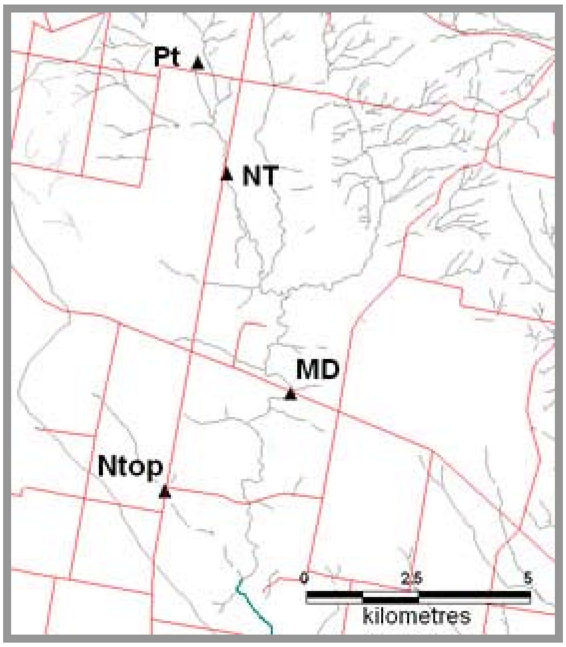


Figure 6.1 Sample Locations along Naringhil Creek and Tributaries.
The darker green line represents Naringhil Creek and the grey lines are the tributaries.

The surface water sites of N1, N2 and N3, get progressively more saline further south into the catchment, which can probably be attributed to more saline groundwater baseflow which enters the stream due to the lower elevations further south in the catchment. The groundwater from the bores sampled during the year shows that there is a general increase downstream in the catchment, particularly within the Volcanic Plains aquifer (discussed further in section 6.3).

Site N3, which did not contain any water from February to May, is a losing section of the stream, where surface water was being lost to the groundwater. Groundwater also contributed to the water in the stream in the month of October, when all the surface water had evaporated and only a small puddle of water accompanied by heavy iron staining was present (Figure 6.2).

Figure 6.2 Iron Staining at Naringhil Creek
Left behind from evaporated groundwater (Site N3) in October.

	Site ID for Naringhil Creek & EC (mS/cm)						
Month	**Pt**	**Nt**	**Ntop**	**MD**	**N1**	**N2**	**N3**[2]
February	-	-	-	-	7.7	10.5	-
March	-	-	-	-	9.28	12.65	-
April	13.26	-	0.737	-	10.14	13.18	-
May	13.05	18.77	0.418	-	9.54	9.35	-
June	12.62	17.75	0.667	-	8.95	9.27	9.35
July	8.09	12.2	0.681	7.17	7.74	7.89	8.09
August	14.4	13.06	0.533	8.55	8	8.5	8.61
September	12.96	13.11	0.65	7.55	7.94	8.24	8.6
October	23.6	14.55	0.862	11.18	9.67	10.29	16.27

Table 6.2 Naringhil Creek Surface Water EC

[2] The only site that did not record salinity values due to no water being present was N3. All other sites were added to the sampling regime in later months.

6.1.2 Woady Yaloak River

The correlation of trends for the Woady Yaloak River between surface water salinity and rainfall is not an obvious one (Figure 5.9). Salinity of the river at site W5 rises to a peak of 12.87 mS/cm in April. This peak in salinity can probably be attributed to the drop in rainfall in February and March, which concentrated the existing salts in the river. A decline in river salinity occurs in May until July, and then from July to September, salinity remains pretty constant with no great variations.

The river in the northern areas of the catchment was intermittent, and specifically did not flow in April through to June at location W2. The surface water that was tested at this site, in February and March was most probably groundwater that had discharged into the river. Ballarat experienced 19mm of rainfall in February so the water at this site may have either been left over surface water or temporal groundwater discharge following the recharge event in February. The sample tested in February and March, was taken from a small puddle, which by April, had evaporated. Water did not reappear in the stream until July following the second highest rainfall peak. A strong oxidised iron layer was present on the puddle in March and the salinity recorded was 2.3 mS/cm. Further upstream of this site the groundwater sampled was relatively fresh (from 1.1 to 1.5 mS/cm). This would indicate that groundwater contributions to the upstream surface waters of the Woady Yaloak River are not very saline or very voluminous and would not greatly salinise the waterbody.

Existing salinity data for 2005, for the Woady Yaloak River, was obtained from the Pitfield and Cressy gauging stations. The 2005 trends in river salinity measured at the gauging stations have been compared to the 2006 salinity trend for the end-of-valley Woady Yaloak River (Figure 6.3). The Pitfield station is located approximately 17 km north of the site W5, and the Cressy station is located approximately 12 km south of W5. The difference between the data from 2005 and 2006 is the increase in salinity of the river in 2006. The comparison between the data from the two gauging stations shows that the salinity of the river increases in Cressy, which means that the stream water gets progressively more saline downstream.

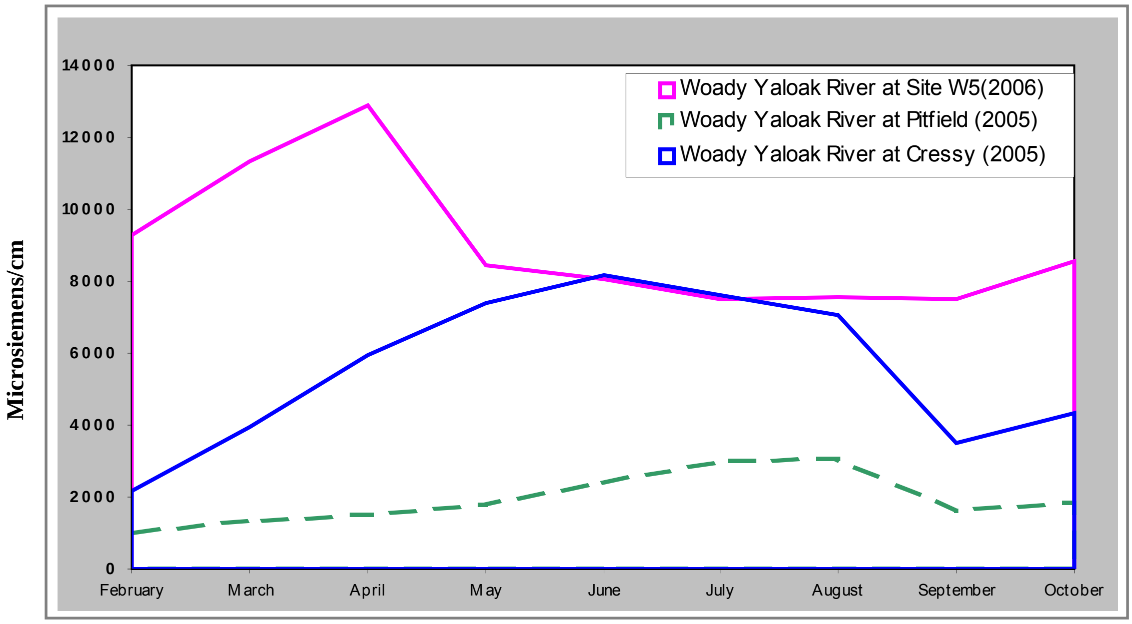


Figure 6.3 Surface Water Salinity Trends for 2005 Compared with 2006 Recordings

6.1.3 Illabarook Creek

The correlation for Illabarook Creek between surface water salinity and rainfall is not an obvious one (Figure 5.9). When rainfall was low in February and March, the salinity of the creek began to rise and reached a peak of 13.81 mS/cm in April during the peak monthly rainfall. The rise in salinity during the time of peak rainfall may be attributed to surface runoff from saline land, or baseflow contributions. The area surrounding the creek has been extensively mined, so land areas are degraded and recharge to the watertable will have accelerated compared to the undisturbed state. This has resulted in many discharge sites across the region, so it is likely that either runoff from saline land or groundwater baseflow is contributing to the increase in salinity.

Illabarook Creek at site I2 was heavily stained with precipitated iron in October, also adjacent to this site is a class 3 saline discharge area (Figure 6.4). There is a lack of monitoring bores surrounding Illabarook Creek, however visual observations of high watertables, shown by wet patches on roads near the stream, and also saline land areas, would that the water tables are high in the region. Bores 5412 and Bore 2, which are located to the south of the Illabarook target area, reveal shallow watertables of around 5 metres from the surface (see Appendix 6). The heavy iron staining present in the area was also restricted to the creek bed, so it is likely that groundwater baseflow is adding saline water to the Creek.

Surface water salinity at site I2, in October, was 18.38 mS/cm and was the highest recording of salinity at this site. This would suggest that the salinity of the groundwater is high or that the lack of rainfall has concentrated the salts in the stream. Salinity along Illabarook Creek may also be attributed to surface runoff, where the water observed along the river at both sample locations was quite turbid, which may suggest that saline surface runoff from the eroded landscape, is carrying salts into the nearby stream.

Figure 6.4 Saline Discharge Site Adjacent to Illabarook Creek (Site 12)

Site ID for Illabarook Creek & EC (mS/cm)		
Site ID	**I1**	**I2**
February EC	11.5	-
March EC	12.2	-
April EC	13.8	15.4
May EC	13.5	13.4
June EC	12.8	12.8
July EC	10.9	10.6
August EC	11.1	9.92
September EC	11.4	11
October EC	11.7	18.4

Table 6.3 Illabarook Creek Surface Water EC

6.1.4 Mount Misery Creek

The two samples sites (ML & ML2) in the northern area of the Mount Misery Creek sub-catchment were located along Moonlight Creek, which flows into Mount Misery Creek to the south (Figure 6.6). An additional four samples were taken along the length of Mount Misery Creek and these were: M1, which represents the creek downstream of the Moonlight Creek junction; M2, which represents a tributary of Mount Misery Creek (Willies Gully) that joins Mount Misery Creek to the west; M3 which is located further downstream of M1; and M4 which is located further south of M3 and represents the end-of–valley site for the Mount Misery sub-catchment (all locations shown in Figure 6.6). The surface water trend for Mount Misery Creek shows an inverse correlation between surface water salinity and rainfall. When rainfall was lowest in March and October, salinity of the creek at site M4 escalated to a peak of 20.76 mS/cm in March due to the low amount of water available to dilute the salts in the creek. After the peak rainfall in April, salinity of the creek only slightly decreased owing to the greater volume of water in the creek. The creek recorded its lowest levels of salinity of 8.44 mS/cm in July following the second highest rainfall event.

The water tested at sites ML and ML2 along Moonlight Creek, both receive their waters from the Palaeozoic hills, which are capped by Tertiary gravels and sands. The water from these tributaries was quite saline, and may be a source for the high salinity recorded within Mount Misery Creek.

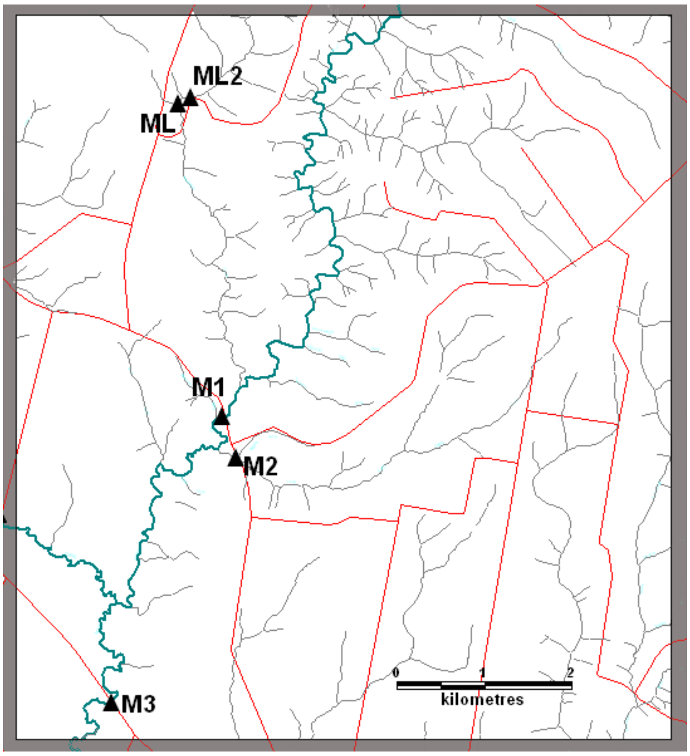


Figure 6.5 Sample Locations along Mount Misery Creek and Tributaries.

The darker green line represents Mount Misery and the grey lines are the tributaries.

An unknown volume of water in Moonlight Creek is likely to be derived from groundwater baseflow, especially at site ML2, which received its waters off the Tertiary capped hills. A permanent groundwater discharge spring was always present at the base of the hill, even when there was no water flowing into the creek upstream. This would suggest that the groundwater probably discharges at the base of the gravel capped hill, where the creek is located. The salinity recorded at this site was on average 11.5 mS/cm, and recording higher values of around 13 mS/cm in March and April.

Further downstream, after the junction with Illabarook Creek, Mount Misery Creek flows off the Palaeozoic landscape and travels alongside the Newer Volcanic flows. Sample M3 and M4 were taken from the creek within this landscape and the highest salinity values recorded within the Mount Misery sub-catchment, occurred mostly at site M4 (Table 6.4). Groundwater contributions may be contributing to the high surface water salinities within this sub-catchment.

	Site ID for Mount Misery Creek & EC (mS/cm)					
Month	**ML**	**ML2**	**M1**	**M2**	**M3**	**M4**
February	12.2	-	8.7	10.7	7.5	9.8
March	12.99	13.33	10.25	17.58	8.65	20.76
April	7.82	13.74	11.33	12.8	8.46	19.21
May	4.5	12.9	10.92	11.22	11.56	17.01
June	3.5	10.09	10.52	10.67	11.97	15.85
July	7.13	9.66	5.94	9.92	8.35	8.44
August	7.67	10.05	6.42	9.85	9.71	9.25
September	7.72	10.27	7.5	11.65	9.18	10.65
October	8.05	11.86	7.93	16.96	10.75	16.04

Table 6.4 Mount Misery Creek Surface Water EC

6.1.5 Kuruc-a-ruc Creek

The surface water trend for the end-of-valley Kuruc-a-ruc Creek, mainly shows an inverse correlation between surface water salinity and rainfall (Figure 5.9). When rainfall was lowest in March and October, salinity of the creek escalated. The low amount of rainfall over March (9.2 mm) and the very small isolated puddle of water that was present at site K4 where the sample was taken, would indicate that the water sampled was in fact groundwater, which had discharged onto the otherwise dry creek bed. As the water evaporated this concentrated the salts to the creek bed, and a high salinity reading was recorded.

After peak rainfall in April, surface water salinity was at its lowest at 10.3mS/cm, and from field observations the area of the creek was gaining a larger volume of water so the salts were getting diluted (see Appendix 5). As rainfall started to decline in May, salinity began to rise steadily. Salinity continued to rise gradually even after rainfall highs in July, this was probably due to either baseflow components, as the watertable had risen after the higher rainfall period, or that there was still insufficient amounts of water at this location to dilute the salts.

Figure 6.6 Saline Tributary of Kuruc-a-ruc Creek (Site K3) On the Volcanic Plains Landscape.

	Site ID for Kuruc-a-ruc Creek & EC (mS/cm)				
Month	**K1**	**K2**	**K3**	**K4**	**K5**
February	6.3	14.4	-	11.4	-
March	6.9	19.46	-	19.23	-
April	5.08	19.49	23.4	10.3	-
May	8.01	17.4	21.74	14.4	21.3
June	8.26	17.01	20.2	14.18	18.8
July	7.88	16	16.23	14.65	18.9
August	8.05	16.7	15.22	14.65	19.67
September	7.53	16.27	14.52	15.12	19.67
October	9.55	19.72	16.5	16.74	23.83

Table 6.5 Kuruc-a-ruc Creek Surface Water EC

The surface water EC values show an increase in the creek along its length. The regional Volcanic Plains aquifer underlies the surface in this region, and is relatively close to the surface in some areas. Upstream of K2, a private bore was sampled in May (Bore 2) and revealed that the groundwater was only 7 metres from the surface. The addition of saline groundwater into the Creek, may be responsible for the high salinities recorded over the creek.

Site K4 represents the end-of-valley surface water site for the Kuruc-a-ruc Creek sub-catchment, however is not the most saline surface waterbody. Sites K3 and K4 have recorded the highest salinity values over the catchment, where K3 is a tributary of Kuruc-a-ruc Creek and K5 is located on Kuruc-a-ruc Creek. Both sites are located below the junction of where Ferrers Creek joins Kuruc-a-ruc Creek, so another source for the salts may be coming from Ferrers Creek. However high salinity values were also recorded at Site K2, which is located above the junction of Ferrers Creek, so the source is salts is most probably coming from the underlying aquifer.

6.1.6 Ferrers Creek

The surface water trend for Ferrers Creek shows an inverse correlation between surface water salinity and rainfall. When rainfall was lowest in March and October, salinity of the creek escalated probably due to the low amount of water available to dilute the salts in the creek and groundwater baseflow components from the underlying regional aquifer. After the peak rainfall in April, a greater volume of water was observed in the creek and surface water salinity began to decline. Salinity escalates from July until October due to a decline in rainfall. The quality of water in Ferrers Creek at site F2 gradually declined as the months progressed (Figure 6.8) which suggests that some form of pollutant has probably contributed to the decline in water quality, which may have entered the water from surface runoff.

The sites sampled along Ferrers Creek were F1 and F2, and both were located within the Volcanic Plains landscape. Site F1 did not have any water until July and the salinity of the creek at this location was lower than the salinity recorded at F2, which was located further south in the catchment.

Site ID for Ferrers Creek & EC (mS/cm)		
Site ID	**F1**	**F2**
February EC	-	13
March EC	-	15.12
April EC	-	14.5
May EC	-	13.85
June EC	-	13.25
July EC	8.44	12.96
August EC	8.8	13.72
September EC	8.4	14.41
October EC	12.14	16.25

Table 6.6 Ferrers Creek Surface Water EC

Figure 6.7 Water Quality along Ferrers Creek (site F2).
Variation in water quality in August (left) and September (right)

6.1.7 Woady Yaloak River Catchment

The increasing evaporation and decreasing rainfall experienced across the catchment, increases the concentration of salts within the surface water, as the salts in the stream cannot be diluted. The stream salinity in the northern part of the catchment is not very saline, however as the surface waters travel down to the south of the catchment, a major increase of salinity follows (Figure 6.8). This implies that the input of salts, as measured from the surface waters to the north of the catchment, are much lower than the salt outputs, as measured by the Cressy gauge and end-of-valley EC recordings from this research. This suggests that the system is not in equilibrium, and that other processes are adding the salts to the surface water, besides salts that are precipitated in rainfall. The salt additions are most probably saline groundwater contributions or salts derived from surface runoff.

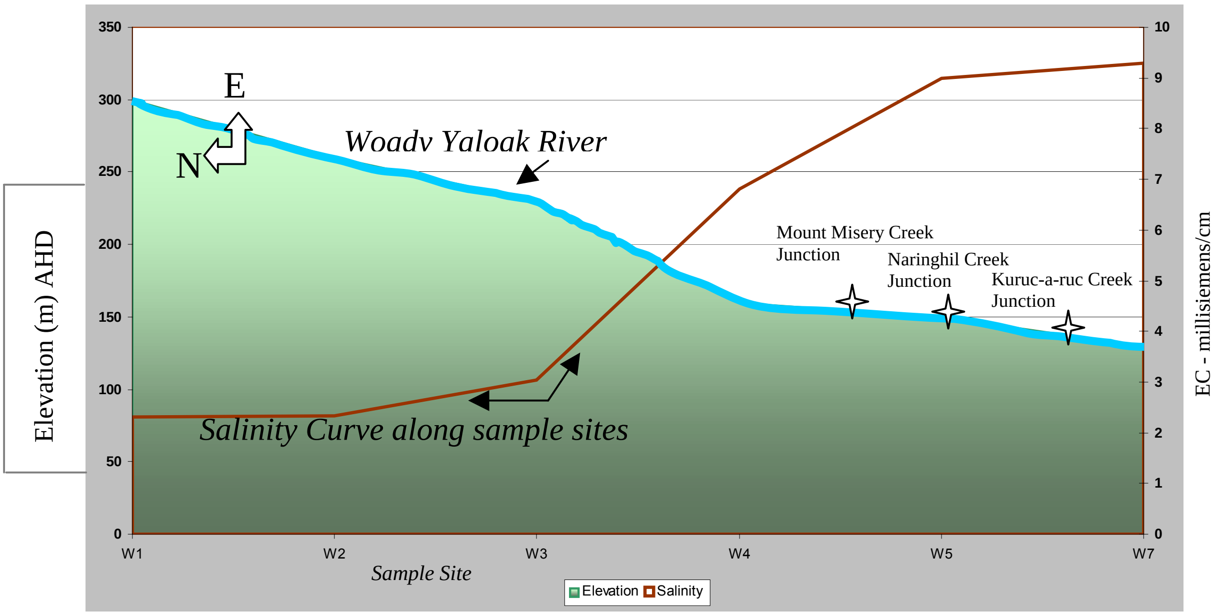


Figure 6.8 Cross Section of the Woady Yaloak River and its Tributaries
Showing variations in surface water salinity along its length.

The average surface water salinity for all the sites sampled across the Woady Yaloak River is shown in Figure 6.8. The blue line represents the Woady Yaloak River as it travels from north to south (approximately 66 km in length), decreasing in elevation as its tributaries join its length from sample site W4 through to W7. The red line represents the average salinity of the river at the site sampled, which shows a great increase at W5, which is where Mount Misery Creek (and Illabarook Creek, which is a tributary of Mount Misery Creek) flow into the Woady Yaloak River. The salinity of the Woady Yaloak River is also high at Site W7, which is located at Cressy and downstream of where the tributaries join the river. This may suggest that the tributaries are adding the salts to the river; however groundwater baseflow and runoff contributions cannot be ignored.

The increase in surface water salinity downstream was observed throughout the 2006 sampling (see Figure 6.8) where salinity of the Woady Yaloak River increased especially for the surface waters travelling through the Volcanic Plains landscape. This suggests that salts are being added to the river from either one or most likely a combination of the following processes:

(1) The tributaries that join the Woady Yaloak River are adding substantial amount of salts into the river, as they meet the river along its length

(2) Groundwater baseflow, from the Volcanic Plains aquifer, or saline surface runoff from groundwater discharge sites is adding salts into the River or into its tributaries.

When the winter rainfall is more likely to recharge the groundwater storage, then the baseflow contributions to the streams in the catchment can increase. The result of the surface water salinities recorded over the winter period, show that they do not always get less saline as would be expected due to the dilution from rainfall. Surface water salinity generally increases over the winter period for Kuruc-a-ruc and Ferrers Creeks (see Figure 5.9) and then continues to rise in spring. These increases may be a result of saline groundwater baseflow which is discharging into the streams in the lower portions of the catchment.

The quantity of baseflow in the streams has not been calculated in this thesis, however the groundwater from within the Volcanic Plains aquifer has been sampled and shows that the water gets progressively more saline further south along its flow path, particularly around Cressy where the salinity of the groundwater sampled in September from bore 57507 was 31.4 mS/cm or 31,400 µS/cm (see section 6.3).

The addition of saline groundwater to surface waters is probably a major factor for the surface water salinity within the streams around Illabarook and Rokewood. The creeks in this region were heavy stained with iron, which would suggest that the iron, which is commonly present as Fe^{2+} within the groundwater (Hem 1985), when brought to the surface or exposed in the unsaturated zone, was oxidised to Fe^{2+}. The groundwater that precipitated the iron probably resides close to the surface and adds water to the drainage lines in the catchment. Due to the absence of bores, the groundwater levels cannot be known for certainty, particularly around the creeks. However, visual observations identified the presence of shallow watertables around the creeks and in other areas of the catchment (discussed in section 6.1.7.1).

Figure 6.9 Iron staining along Moonlight Creek (ML2)
This site is a groundwater discharge puddle, where water discharges from the base and slopes of hills in the Illabarook region.

6.1.7.1 Field Investigations

Field investigations of saline areas across the catchment, was assisted by the presence of vegetation species, typically of salt tolerant species (Appendix 9), which have been given a salinity class of 1 to 3 (DPI 2006). The vegetation identified for the Woady Yaloak Catchment include, for class 1 salinity: *Lophopyrum elongatum* (Tall Wheat Grass), for class 2 salinity: *Annual Beard Grass* (Rabbit-Foot Grass), *Juncus acutus* (Spiny Rush), and *Lophopyrum elongatum* (Tall Wheat Grass), and for class 3 salinity: The identification of large areas of bare ground, or the dominance of two or three species, suggests that salinity in these areas is in class 3, which is above 1400 μS/cm. Only highly salt tolerant plants are present, and large areas of bare ground can be seen.

Saline discharge areas over the catchment, of Class 3 salinity sites, which appear as barren salt scalds, were identified around the Illabarook and Rokewood region, typically across the Volcanic Plains landscape (Appendix 9).

Turbidity in the surface waters of the Woady Yaloak River catchment may have come from stream bank erosion, from falling stream levels, erosion from shallow lakes or dams, or erosion off land areas such as in the Illabarook and Rokewood region. The sediments that are washed off the land are added to the streams and may be contributing to the salinity levels in the surface water. During this research soils and sediments were not tested for salinity across the region so to state that eroded sediments are causing the high salinity in the streams is only a speculation.

The surface waters that were observed to be highly turbid were Ferrers Creek, Illabarook Creek and Kuruc-a-ruc Creek. The Woady Yaloak River was not very turbid, and was relatively clear especially in the upper reaches, possibly due to the greater volume of water in the river to flush the sediments, the vegetated stream areas and the constant supply of water, which kept the stream banks in tact. However for the more stagnant parts of the other streams in the catchment, the water was very turbid. A previous study by Church (2004) which tested soils in the Pittong and Illabarook region, revealed that the soils from both areas were sodic duplex soils which contained high exchangeable sodium percentages (ESP) so once they become waterlogged, they can be dispersed quite easily, which would suggest that surface runoff in these areas may be adding salts into the streams.

The existing turbidity data for the surface water within the upper reaches of the Woady Yaloak River around Scarsdale (Appendix 1), noted freshwater macro invertebrates and microorganisms.

6.2 Discharge and Salt Loads

The design peak discharge for the sub-catchments was worked out by using the Rational Method, which is a relative method for determining peak discharge. The accuracy of the method was tested against actual stream flow data gathered for five of the major streams in the Woady Yaloak River catchment from 1999 records of stream flow volumes. The existing records were not complete for the major streams in the catchment, as they did not include flow volumes for Illabarook Creek and the extent of Mount Misery Creek remained questionable, so these values were not used in the estimations of salt loads, and only used as a comparative analysis to the Rational Method. When the natural or absolute data was compared with the relative data, they showed that the Rational Method had greatly overestimated the discharge from streams. The large overestimation of the discharge from streams in ML/day could be a result of a number of factors, which include:

- The below average rainfall which has been experienced across the catchment, resulting in a lesser amount of discharge from streams.

- The lowest ARI of 2 years, which was used to calculate the salt loads, was used because it is the closest to the current rainfall conditions, however is still not representative of the current rainfall. Also the same calculated discharge rate for the 2 year ARI applies for the whole year and does not vary for summer or winter conditions.

- The discharge records of 1999 were not current, so were not an adequate comparison.

The approximated ratios of the calculated discharge compared to actual discharge were quite similar, except for Mount Misery Creek, which had the lowest actual discharge recorded of all the streams. The actual discharge ratio for Mount Misery Creek was much lower than the calculated discharge, possibly because the actual discharge readings only encompassed the upper section of the Creek, and not it’s extension from the south of the Rokewood - Skipton highway. This section of the Creek (as discussed in section 5.2) has been labelled the “Little Woady Yaloak Creek” in some maps, but was considered as Mount Misery Creek in this research. The salt loads which were worked out from the calculated discharge values, were compared with salt loads calculated from the actual discharge values and these are appended (Appendix 8).

6.2.1 Salt Loads

Salt is contributed from the entire catchment, although the proportion from each sub-catchment is not the same and is discussed below. The calculated mean daily tonnage of salt at the end-of-valley of the Woady Yaloak River catchment, has been calculated as 242 t/day based on the 30-year gauging station record at Cressy (Dahlhaus *et al.* 2005a). Assuming that the proportion of salt loads calculated here are correct, then the daily salt tonnage from each of the sub-catchments can be worked out.

The salt loads determined for the Naringhil Creek sub-catchment, decreased in April, and rose slightly from May to July, then dropped in September and rose again in October. The increase in the October salt loads is attributed to an increase in EC of around 8 mS/cm in September, which is the greatest increase in salinity recorded from September to October over the entire catchment. The average salt load percentage discharging from the Naringhil Creek sub-catchment is 15.6%, which contributes the fourth highest percentage of salts in the Woady Yaloak River catchment, following Kuruc-a-ruc. The calculated daily salt tonnage is 37.7 t/day, which contributes to the end-of-valley catchment (assuming peak discharge conditions).

The highest overall monthly salt loads came from the Woady Yaloak River sub-catchment, where monthly salt loads were greatest in February and then from July to September. The Woady Yaloak River did not record the highest end-of valley salinity of all the sub-catchments, however due to the greater discharge rates estimated for the river, the salt loads were the highest. The average salt load percentage discharging from the Woady Yaloak River sub-catchment is 22.8%, which is the greatest percentage of salts in the greater catchment. The calculated daily salt tonnage is 55.2 t/day, which contributes to the end-of-valley catchment.

The most significant decrease in salt loads from Illabarook Creek sub-catchment, occurred from May to August, and was then followed by an increase in September to October. The increase in October is attributed to the increase of over 7 mS/cm from surface water salinity recordings in September, which is the second greatest increase in salinity (after Naringhil Creek) that was recorded in October. The average salt load percentage discharging from the Illabarook sub-catchment is 12.4%, which is the lowest contributor of salts in the Woady Yaloak River catchment (along with Ferrers Creek). The calculated daily salt tonnage is 30 t/day, which contributes to the end-of-valley catchment.

One of the highest calculated salt loads for March, came from the Mount Misery Creek sub-catchment, which contributed 27% of the total salt loads. The high percentage of salt loads is attributed to an increase in salinity of around 11 mS/cm from surface water salinity recordings from February to March. The high salt load percentage follows on in April, even when there is a drop in EC of around 1.5 mS/cm. The major drop in salt loads in July is attributed to the drop in surface water salinity of over 7 mS/cm from June to July. This coincides with the second highest rainfall period which occurred in July. The average salt load percentage discharging from the Mount Misery Creek sub-catchment is 19.3%, which contributes the second highest percentage of salts after the Woady Yaloak sub-catchment. The calculated daily salt tonnage is 46.7 t/day, which contributes to the end-of-valley catchment.

The salt loads from Kuruc-a-ruc Creek sub-catchment increase in March and then drop considerably in April due to the decrease in EC of around 9 mS/cm. This represents the greatest decrease in monthly salt loads from March to April. The 8% decline in salt loads coincides with the peak rainfall period, which occurred in April.

The average salt load percentage discharging from the Kuruc-a-ruc Creek sub-catchment is 17.5%, which contributes the third highest percentage of salts after the Woady Yaloak River and Mount Misery Creek sub-catchments. The calculated daily salt tonnage is 42.4 t/day, which contributes to the end-of-valley catchment.

The salt loads from the Ferrers Creek sub-catchment remains pretty consistent. Salt loads fluctuate up to 2.2% during the sampling months. The greatest increase which occurs from June to July of 1.7%, is not attributed to a rise in surface water salinity, but to a decrease of 0.3 mS/cm, when the surface water salinities in the other sub-catchments decreased during the winter months. The rise in the percentage of the salt load from June to July is due to the other sub-catchments decreasing in salinity more considerably, which raised the percentage for Ferrers Creek. The average salt load percentage discharging from the Ferrers Creek sub-catchment is 12.4%, which is the lowest contributor of salts in the catchment, along with Illabarook Creek. The calculated daily salt tonnage is 30 t/day, which contributes to the end-of-valley catchment.

Sub-Catchment	**Grams/hectare**
Naringhil Creek	150
Woady Yaloak River	135
Illabarook Creek	260
Mount Misery Creek	245
Kuruc-a-ruc Creek	270
Ferrers Creek	340

Table 6.7 Calculated Salts per Hectare for the Sub-Catchments.

6.3 Groundwater Salinity

6.3.1 Gravel Caps

Salinity of the groundwater that was sampled in Illabarook was 6.7 mS/cm for bore 5503, 21.3 mS/cm for bore 5412 and 7.7 mS/cm for bore 2. Bore 5503 is located in the recharge area on the Gravel Caps aquifer, residing on a hill with an elevation of approximately 250 m AHD (Figure 6.10). Bores 2 and 5412 are shallow bores, located downstream of 5503 within the Quaternary alluvial flow system and close to the boundary of the Volcanic Plains groundwater flow system. Bore 5412 is just a few hundred metres south of the Gravel Caps flow system and is targeted as a salinity management site by the Woady Yaloak Catchment management authority.

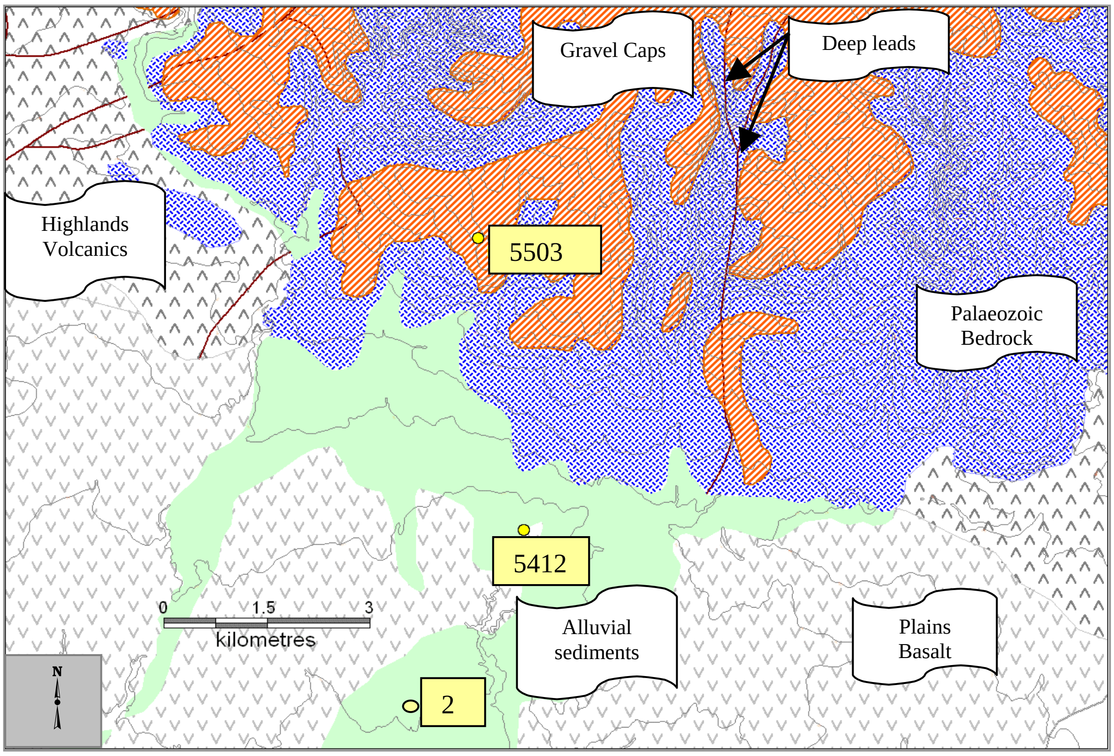


Figure 6.10 Groundwater Flow Systems in the Illabarook/Rokewood Area and Location of Bores.

As groundwater is recharged on the Palaeozoic hills which are overlain by the gravel caps, the groundwater discharges at the base of the gravel caps aquifer due to the differences in permeabilities of the gravels (Dahlhaus *et al.* 2002). Instead of infiltrating vertically the water travels laterally and discharges at the break of slope and at the boundary of the unit.

The reason for the high salinity revealed from the bores downslope, could probably be attributed to the increased recharge to areas upslope, which has remobilised the salts to the discharge areas downstream. Due to the recent decline in rainfall, landowners John and Marlene have noticed that the groundwater level in their downstream bore (5412) has fallen approximately two metres over the last eight years. As rainfall is not present to dilute the concentration of salts, then the shallow watertables downstream in the discharge areas at Rokewood and Illabarook (Appendix 8) indicates that the increase in salinity is due to evaporation and evapotranspiration processes.

6.3.2 Granite

Salinity of the groundwater recorded at Pittong showed saline values of approximately 10mS/cm (Appendix 6). One sample which showed <1 mS/cm (Bore 5140) was rejected from the dataset as not representative, due to the difficulty in obtaining a sample of the groundwater from the low permeability of the deeply weathered granite aquifer.

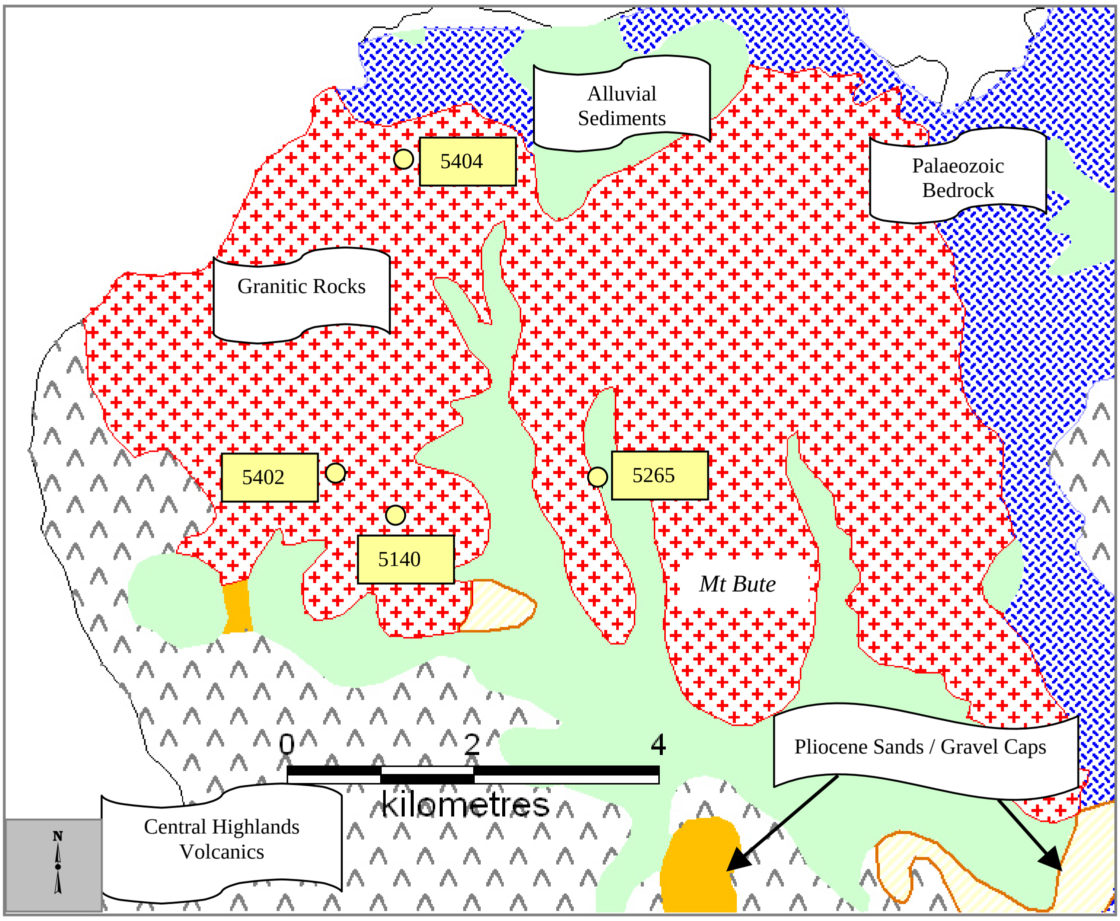


Figure 6.11 Groundwater Flow Systems in the Pittong Area and Location of Bores.

Saline groundwater discharge in the Pittong area occurs along the drainage lines, low-lying areas and as ephemeral springs (Dahlhaus *et al.* 2002). The saline groundwater and the low permeability of the deeply weathered aquifer material, concentrate the salts until they are released to the surface. The weathering of the granites has developed thick clay profiles over fractured granite, where their ability to retain water is high, so as a result shallow watertables and seasonal waterlogging has developed across the region.

The shallow watertables in the region have increased in salinity over recent years. This was shown at the groundwater discharge site at Pt (Table 6.1) where groundwater has probably increased in salinity (in addition to surface waters) due to the evaporative processes and the diminishing rainfall in recent years over the catchment. This can ultimately pose a threat to surface waters in the region, where the saline groundwater discharges into the nearby streams. The high salinities that were recorded from the tributaries to the north of the Naringhil Creek sub-catchment (Table 6.2) were more saline than the southern portion of the sub-catchment, due to the saline groundwater discharging in this area and the concentration of salts by evaporation.

6.3.3 Central Highlands Volcanics

Of the three groundwater bores that were sampled in the Central Highlands Volcanic aquifer in Haddon, only the values from bore 5290 will be used and salinity values for bore 5269 will be disregarded. Salinity of the groundwater from bore 5269 recorded an EC value of 7.8 mS/cm however, is not representative of the groundwater, because the groundwater could not be pumped the 3 bore volumes to yield a representative sample from this site, due to the low permeability of the material encountered. The water resided less than 2 metres from the surface, and smelled of sulfur (H_2S), which means that the water was probably residing in the well for some time. Therefore, the value for bore 5269 will not be discussed.

The EC of the groundwater, around the north of the catchment was in the range of 1.3 to 1.5 mS/cm, which is considered fresh (refer to Table 5.2). Recharge occurring around the higher elevations to the north of the catchment is unknown, however is expected to be greater within the fractured rock aquifer. This would indicate that the aquifer is regularly flushed, and salts are not concentrated.

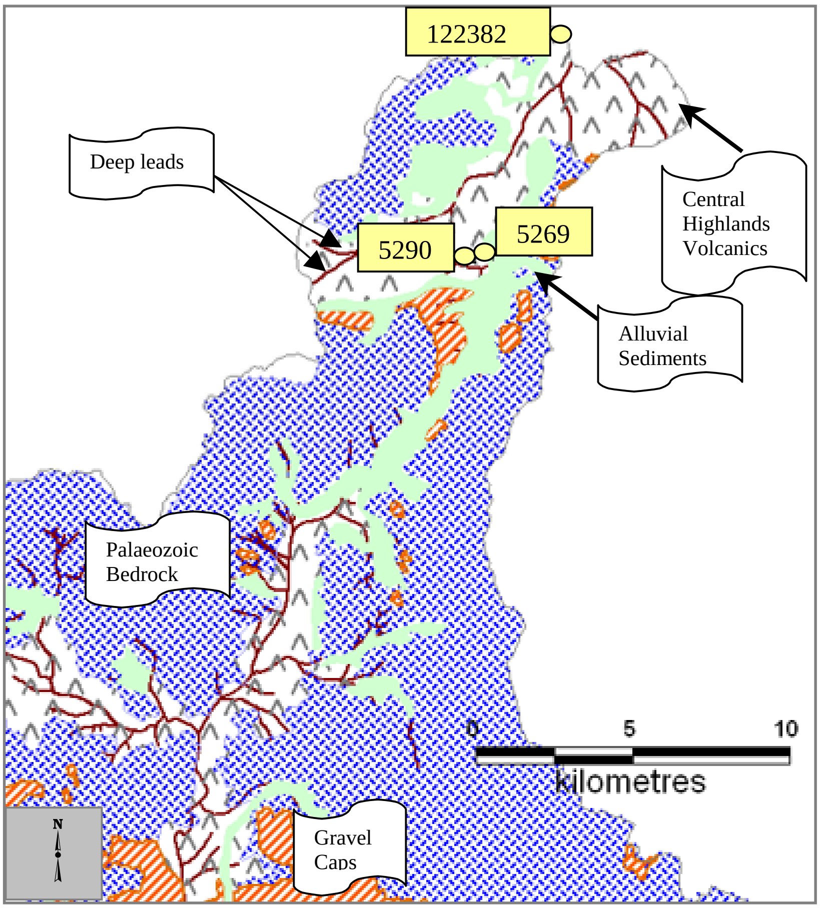


Figure 6.12 Groundwater Flow Systems in the Northern Area of the Catchment.

Bore 122382, revealed an age of <1000 years which is relatively modern. However, was the only bore where the age was determined within the Central Highlands Volcanic aquifer and is not enough of a representation of the age from this groundwater flow system. This would indicate that the groundwater spends only a short amount of time with primary minerals and so has developed less concentrated water.

6.3.4 Volcanic Plains

As groundwater travels through the regional flow system of the Volcanic Plains aquifer, it gets progressively more saline as it travels south through the catchment.

The flat topography of the Volcanic Plains landscape and the deep clay soil horizons, restrict winter recharge and result in an intermediate to regional flow system, across the southern catchment. As water infiltrates slowly through the thick clay soils, evapotranspiration increases and concentrates the salts which are then added to the saturated zone. This has also been noted for shallow watertables across the plains in the Murray basin, where Cartwright & Weaver (2004) proposed that the major increases in salts loads from the regional groundwater flow systems, are a result of evaporative processes. The saline groundwater sampled across the plains (see Appendix 6), and where it lies close to the surface, is probably a major source of the salinity of the surface water bodies that travel through this landscape.

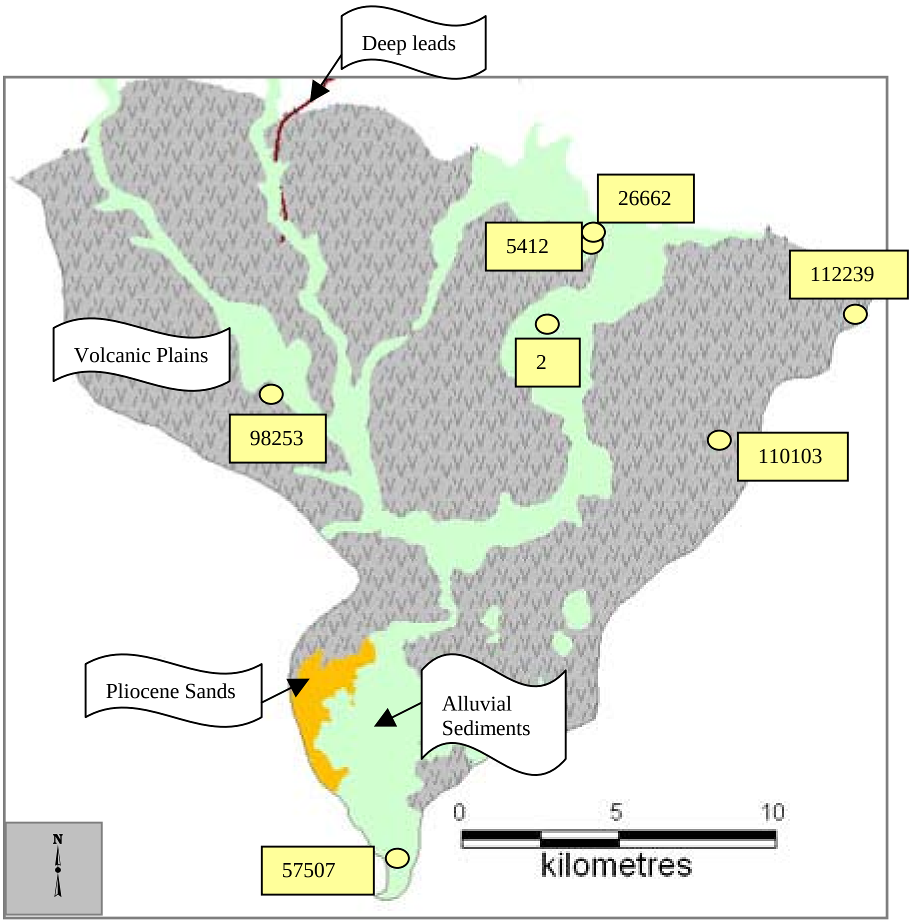


Figure 6.13 Groundwater Flow Systems across the Southern Area
Of the Woady Yaloak River Catchment and Location of Bores.

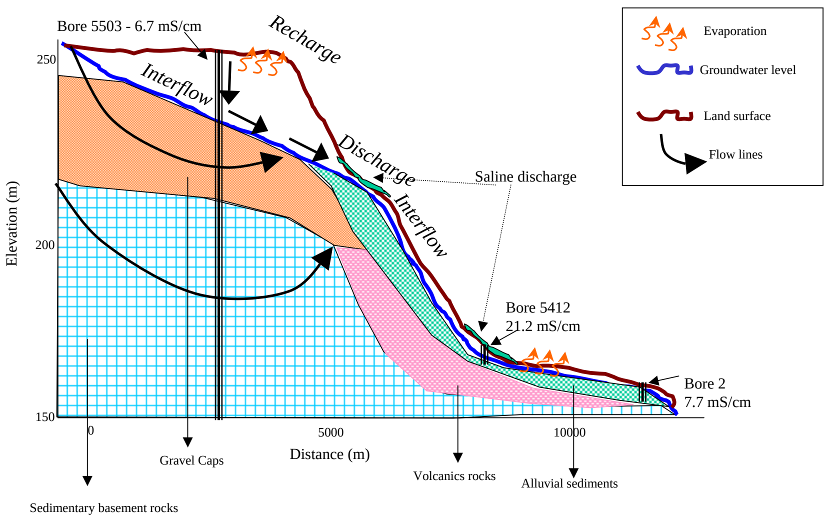


Figure 6.14 Conceptual Model of the Illabarook/Rokewood Area

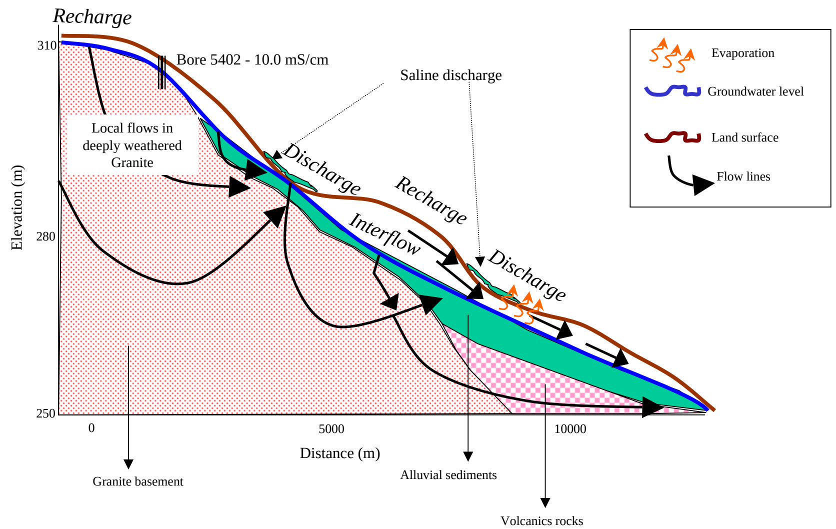


Figure 6.15 Conceptual Model of the Pittong Area

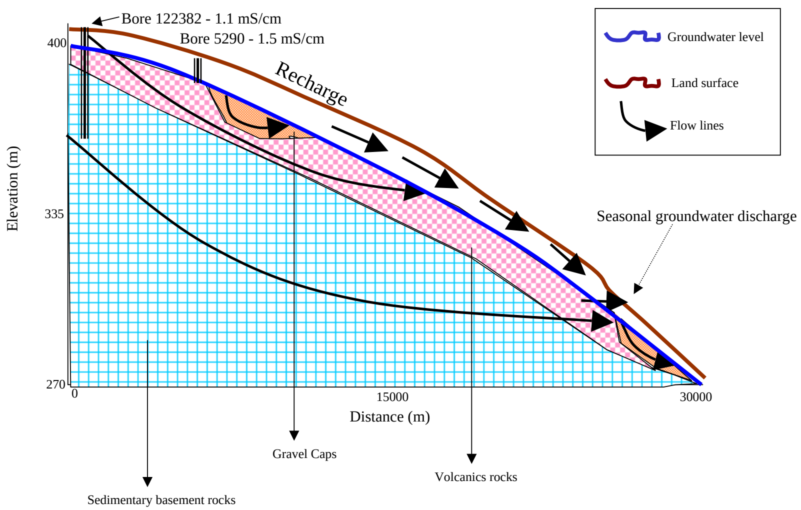


Figure 6.16 Conceptual Model of the Northern Area of the Catchment

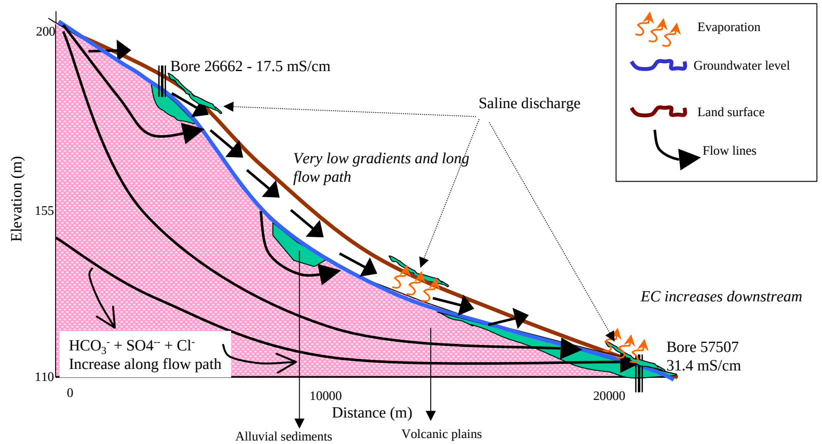


Figure 6.17 Conceptual Model of the Southern Area of the Catchment

6.4 Groundwater Chemistry

The groundwater throughout the Woady Yaloak River catchment is predominantly sodium chloride type, where sodium and chloride ions made up more than half of the total cations and anions. Calcium ions were always less than magnesium ions and probably occurred from the dissolution of calcium and magnesium bearing minerals.

The groundwater chemistry revealed similar ionic compositions throughout the different aquifers with only minor differences. The groundwater within the Central Highlands Volcanic aquifer and the Pliocene sands aquifer generally contained greater bicarbonate concentrations compared to chloride concentrations (Figure 5.15). This may be a result of the shorter flow paths taken within these aquifers and their relatively young ages. In comparison the groundwater to the south of the catchment within the Volcanic Plains flow system, generally increased in chloride and major ions along its length, which represents greater flow paths and longer residence times of some of the groundwater within this system (see Table 5.3 & Appendix 6). Only one sample was analysed from the Pliocene sands aquifer so it is an insufficient representation when comparing groundwater flow systems.

The ^{14}C ages show a general increase in age further south in the catchment. However, the lack of chemical data from the groundwater within all the flow systems in the catchment means that detailed groundwater correlations have not been attempted in this research.

7. Conclusions and Recommendations

The Rational Method & Salt Loads

The rational method showed to be a great overestimation of the discharge from streams, when compared to actual flow data from 1999. However, the approximated ratios of the calculated discharge compared to actual discharge were quite similar. This indicates, that the rational method is not entirely realistic when compared to natural conditions, however, it has presented a useful overview of the salt loads in different areas of the catchment.

The salt load percentage discharging from the sub-catchments, were greatest for the Woady Yaloak River, followed Mount Misery Creek, Kuruc-a-ruc Creek, Naringhil Creek, and equally lowest in Ferrers and Illabarook creeks. However the salts per unit gram per hectare, were greatest in Ferrers Creek, followed by Kuruc-a-ruc Creek, Illabarook Creek, Mount Misery Creek, Naringhil Creek and lastly, the Woady Yaloak River. This revealed that the Woady Yaloak River's tributaries even though smaller in catchment size, contribute more saline water into the Woady Yaloak River.

Recommendations for further sampling where salt loads would need to be quantified should rely on in field flow measurements, taken at the discharge point from all major streams and tributaries. This would produce more accurate salt loads, which is discharging from the catchment and would be closer to current conditions.

Surface Water and Groundwater Salinity

The surface water in the Woady Yaloak River catchment was generally quite saline. This was shown within all of the sub-catchments, at certain sections along the length of the streams, as they travelled south and joined the Woady Yaloak River. The salinity was shown to increase in the southern parts of the catchment as they travelled through the Volcanic Plains landscape, and also in the discharge areas at Pittong and Illabarook, where groundwater contributions were the most likely source for the high salinities.

Saline discharge areas were widespread across the Volcanic Plains landscape and in the areas of Illabarook, Rokewood and Pittong. Discharge generally occurred across the low lying plains, at the break of slope and bases of hills or above highly weathered, fractured rock aquifers. The saline groundwater, which appeared as stagnant or iron rich puddles on the land surface, was further concentrated by evaporation and evapotranspiration. The additions of saline groundwater into streams was most likely occurring, however the interactions have not been proved in this research.

Therefore, recommendations for further work should concentrate on groundwater and surface water interactions, within the areas of high surface water salinity. This can be done by placing monitoring bores around the major streams in the catchment, where currently they do not exist in close proximity to the streams that were sampled throughout the year. Also detailed chemical analysis on the surface water may be needed to prove the interactions in these areas.

With the increasing amount of monthly rainfall over the catchment, a decrease in river salinity generally followed. However more commonly, low amounts of rainfall were experienced within the catchment at the time of sampling, which meant that the reducing streams levels concentrated the existing salts and as a result recorded higher EC values. This was seen in October, when all the surface water sites increased in salinity, due to the lowest amount of rainfall and high evaporation rates.

Surface Water Sampling

The surface water sampling which was conducted from February to October, proved to be a useful way of examining the surface water salinity over an entire catchment area. However, the spot or “grab” sampling technique to obtain in field results, even though is quite time efficient, does has some limitations when obtaining representative results of the waterbody.

Recommendations for further sampling could include more extensive and thorough parameters when obtaining results in the field, such as depth profile readings within the body of water. This method may discern salt slugs, which are derived from groundwater baseflow. However, due to the lack of rainfall in recent years, this may not be achievable for a number of the tributaries of the Woady Yaloak River.

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Figure 2.2 CMA Regions across Victoria. Source DPI 2005. http://www.dpi.vic.gov.au/dpi/nrenmp.nsf/FID/0AFF4E93BB2DE5A4CA256C71000C1C19?OpenDocument. Accessed 15th June 2006.

Figure 2.4 Topographical Map of the Pittong Salinity Target Area. Source: Dahlhaus 2004.

Figure 2.6 Topographical Map of the Illabarook Salinity Target Area. Source: Dahlhaus 2004.

Water Quality Sampling Guidelines obtained from:
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Appendices

Appendix 1 *Existing Surface Water Salinity Data*

The Woady Yaloak River at Smythesdale.
Data recorded from the Woady Yaloak Primary School.

reportid	siteno	Test Date	AirT (C)	DO (mg/L)	EC (S/cm)	PH (pH Units)	ReactP (mg/L P)	Temp (C)	Turb (NTU)
1	WDY050	21/10/1999			2800		0.045		20
1	WDY050	18/10/2000			2500	7.5	0.03	13.9	0
1	WDY050	30/01/2001	18.7	1	2750	7	0.06	18.7	15
1	WDY060	21/10/1999			2600		0.03		10
1	WDY060	18/10/2000			2250	7	0.045	14.3	0
1	WDY060	30/01/2001	30	3	2100	6.5	0.03	18.1	10
1	WDY070	21/10/1999			2600		0.03		0
1	WDY070	18/10/2000			17.5	7	0.03	15.1	0
1	WDY070	30/01/2001	30	3	2340	7	0.03	19	10

Sample_id	Test Date	DO (mg/L)	EC (µS/cm)	PH (pH Units)	Temp (°C)	Turbidity (NTU)	Water Quality
1	22/3/05	10	1.3	6.1	19.4	20	Macroinvertebrates are plentiful, many small Gambuzia, Water boatmen and Caddisfly.
1	14/6/05		150	6.3	15.9	10	Dragon fly larvae, diving beetle larvae, mayfly nymph, water boatman. Creek fairly high, not many creatures, water clear & flowing steadily.
1	20/7/05	8	2200	6.6	9.3	10	Mayfly nymphs, arthropods, watermite, damselfly, stick caddis, waterflea, waterboatman, mosquito larvae casing, snail, midge larvae, water strider.
1	11/4/06		2400	7.3	15.5	<10	

Appendix 2 *Surface Water Sampling Procedures*

Field sampling of surface water was conducted according to the Australian/New Zealand Standards for Water quality–Sampling (1998).

Where:

1) The Conductivity/pH meter was placed directly into the surface waterbody to obtain monthly readings of salinity as (EC) pH and temperature.
2) When the water was not accessibility at stream level, a PVC bailer was lowered into the water and the sample was collected and then poured into a glass beaker where the reading was then taken.
3) The precise point of sampling along the stream was chosen according to the Water quality-Sampling guidelines: Part 6 in section 5.1.1, where the main focus was to sample a point in the body of water with easy accessibility, which coincided with the purpose of the sampling, to gain a general idea of the water quality in the stream. Sample points were consistent every month, where the reading was taken from the same location along the surface water body at each site.
4) Glass beakers and the pvc bailer that were used to collect and carry the sample water, were thoroughly washed with detergent and tap water before use, as indicated in the Water quality-Sampling guidelines Part 1 in section 7.3.3. The beakers and bailer were then rinsed twice with filtered water and drained on paper towels until dry.

Appendix 3 *Design Rainfall Intensity Diagrams*

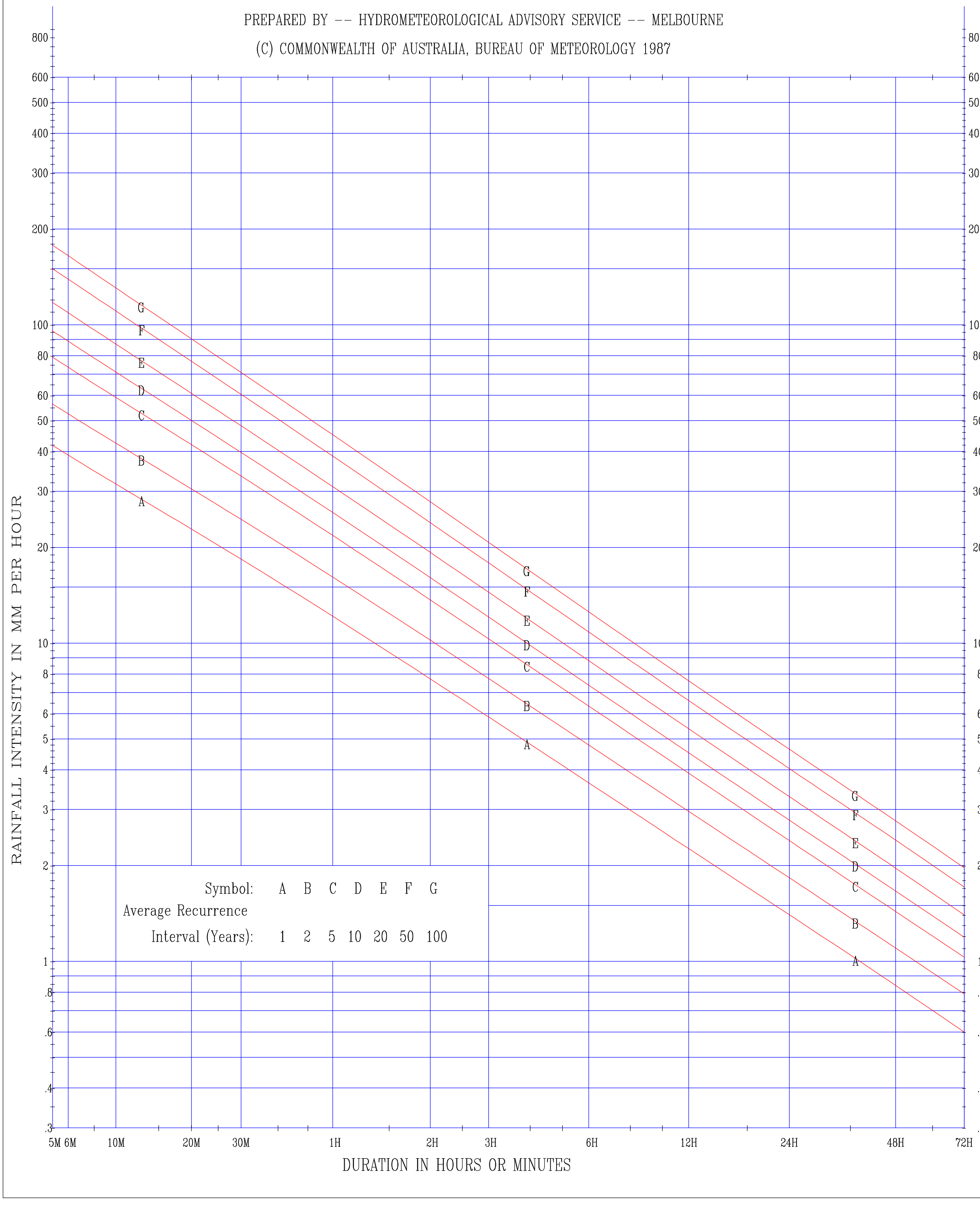
For Cressy, Pittong, Haddon and Dereel

DESIGN RAINFALL INTENSITY DIAGRAM

LOCATION 38.025 S 143.625 E* NEAR.. Cressy VIC

* ENSURE THE COORDINATES ARE THOSE REQUIRED,
SINCE DATA IS BASED ON THESE AND NOT THE LOCATION NAME.

ISSUED 31ST JULY 2006



LOCATION 38.025 S 143.625 E * NEAR.. Cressy VIC ISSUED 31ST JULY 2006

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE

* ENSURE THE COORDINATES ARE THOSE REQUIRED SINCE DATA IS BASED ON THESE AND NOT LOCATION NAME.

LIST OF COEFFICIENTS TO EQUATIONS OF THE FORM

ln(i) = a + b*(ln(T)) + c*(ln(T))**2 + d*(ln(T))**3 + e*(ln(T))**4 + f*(ln(T))**5 + g*(ln(T))**6

T = TIME IN HOURS AND I = INTENSITY IN MILLIMETRES PER HOUR

RETURN PERIOD (YEARS)	a	b	c	d	e	f	g
1	2.4973	−0.6290	−0.0422	0.00934	0.001019	−0.0004148	−0.0000041
2	2.7808	−0.6343	−0.0415	0.00892	0.000963	−0.0003635	−0.0000072
5	3.0818	−0.6503	−0.0391	0.00983	0.000617	−0.0004225	0.0000121
10	3.2476	−0.6574	−0.0386	0.00887	0.000771	−0.0002912	−0.0000145
20	3.4349	−0.6650	−0.0380	0.00891	0.000759	−0.0002765	−0.0000188
50	3.6558	−0.6734	−0.0371	0.00866	0.000767	−0.0002250	−0.0000279
100	3.8102	−0.6795	−0.0363	0.00869	0.000674	−0.0002152	−0.0000262

RAINFALL INTENSITY IN MM/HR FOR VARIOUS DURATIONS AND RETURN PERIODS

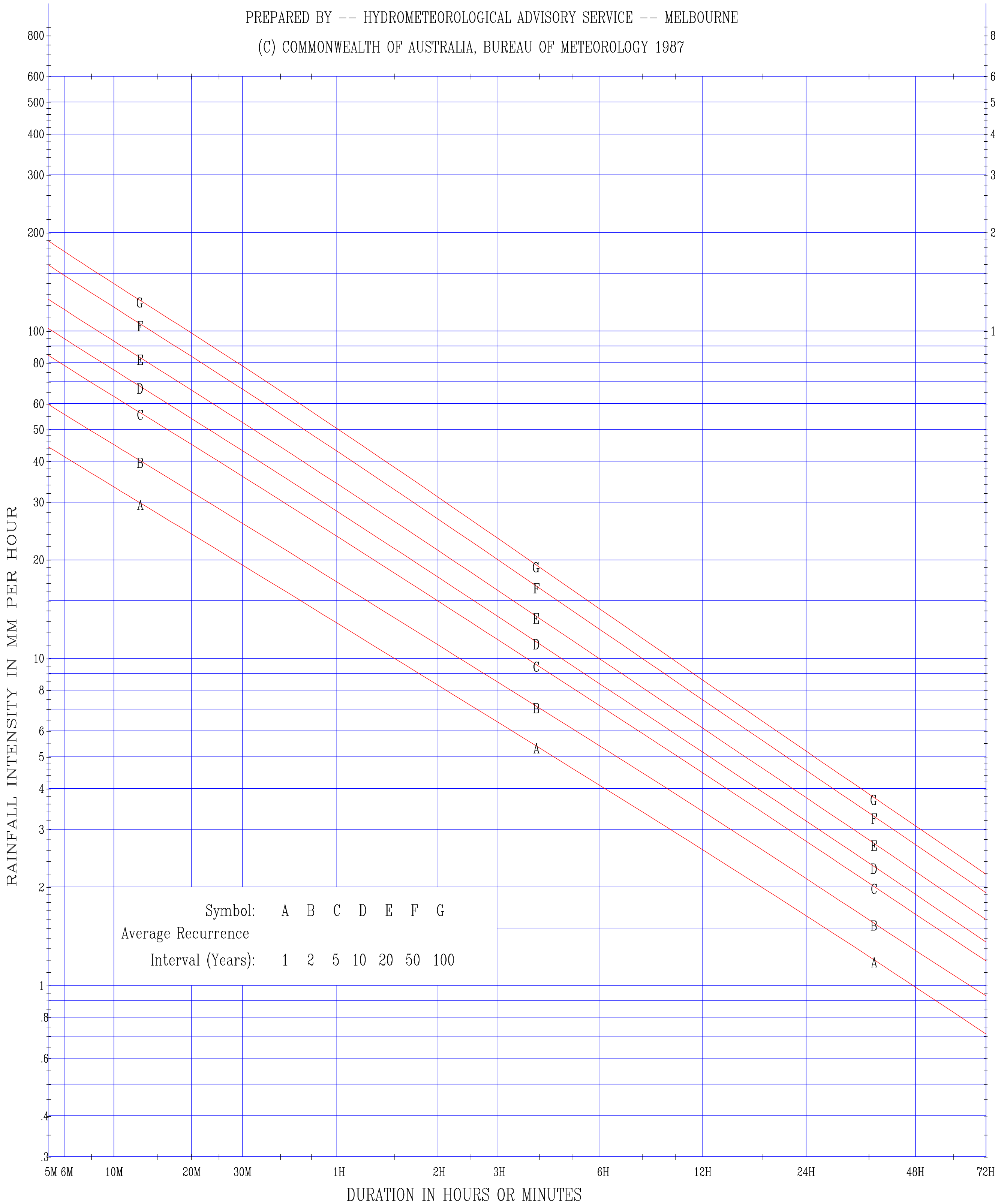
	RETURN PERIOD						
DURATION (HOURS)	1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
0.083	41.8	56.4	79.2	95.6	118.	150.	178.
0.100	39.0	52.5	73.6	88.8	109.	139.	165.
0.167	31.6	42.5	59.1	71.1	87.0	110.	130.
0.333	22.8	30.5	42.0	50.1	60.9	76.8	90.3
0.500	18.4	24.5	33.5	39.7	48.2	60.5	70.9
1.000	12.2	16.1	21.8	25.7	31.0	38.7	45.2
2.000	7.72	10.2	13.7	16.1	19.3	23.9	27.8
3.000	5.86	7.74	10.3	12.1	14.5	17.9	20.7
6.000	3.64	4.78	6.34	7.38	8.80	10.8	12.5
12.000	2.26	2.96	3.90	4.53	5.38	6.60	7.62
24.000	1.40	1.83	2.40	2.78	3.29	4.04	4.64
48.000	.841	1.10	1.43	1.66	1.96	2.41	2.76
72.000	.600	.790	1.03	1.19	1.40	1.71	1.97

DESIGN RAINFALL INTENSITY DIAGRAM

LOCATION 37.675 S 143.475 E* NEAR.. Pittong VIC

* ENSURE THE COORDINATES ARE THOSE REQUIRED,
SINCE DATA IS BASED ON THESE AND NOT THE LOCATION NAME.

ISSUED 31ST JANUARY 2005



LOCATION 37.675 S 143.475 E * NEAR.. Pittong VIC ISSUED 31ST JANUARY 2005

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE

* ENSURE THE COORDINATES ARE THOSE REQUIRED SINCE DATA IS BASED ON THESE AND NOT LOCATION NAME.

LIST OF COEFFICIENTS TO EQUATIONS OF THE FORM

ln(i) = a + b*(ln(T)) + c*(ln(T))**2 + d*(ln(T))**3 + e*(ln(T))**4 + f*(ln(T))**5 + g*(ln(T))**6

T = TIME IN HOURS AND I = INTENSITY IN MILLIMETRES PER HOUR

RETURN PERIOD (YEARS)	a	b	c	d	e	f	g
1	2.5517	-.6104	-.0293	.00861	-.000048	-.0003354	.0000125
2	2.8409	-.6182	-.0291	.00973	-.000422	-.0004622	.0000500
5	3.1624	-.6344	-.0337	.00993	.000064	-.0004677	.0000348
10	3.3379	-.6424	-.0365	.00928	.000462	-.0003780	.0000073
20	3.5321	-.6498	-.0384	.00910	.000661	-.0003468	-.0000038
50	3.7607	-.6595	-.0406	.00958	.000767	-.0003949	.0000026
100	3.9200	-.6661	-.0424	.00978	.000913	-.0004161	.0000019

RAINFALL INTENSITY IN MM/HR FOR VARIOUS DURATIONS AND RETURN PERIODS

DURATION (HOURS)	RETURN PERIOD 1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
.083	44.2	59.6	84.2	102.	125.	159.	188.
.100	41.2	55.5	78.3	94.5	116.	148.	175.
.167	33.4	44.9	63.1	76.0	93.1	118.	140.
.333	24.0	32.2	45.0	54.0	66.0	83.5	98.5
.500	19.3	25.8	36.0	43.1	52.5	66.4	78.1
1.000	12.8	17.1	23.6	28.2	34.2	43.0	50.4
2.000	8.31	11.0	15.0	17.8	21.5	26.8	31.2
3.000	6.40	8.48	11.4	13.5	16.2	20.1	23.4
6.000	4.08	5.39	7.16	8.34	9.95	12.2	14.1
12.000	2.60	3.41	4.47	5.17	6.12	7.47	8.58
24.000	1.64	2.12	2.76	3.18	3.75	4.55	5.20
48.000	.989	1.28	1.65	1.90	2.23	2.70	3.08
72.000	.712	.932	1.19	1.36	1.59	1.92	2.19

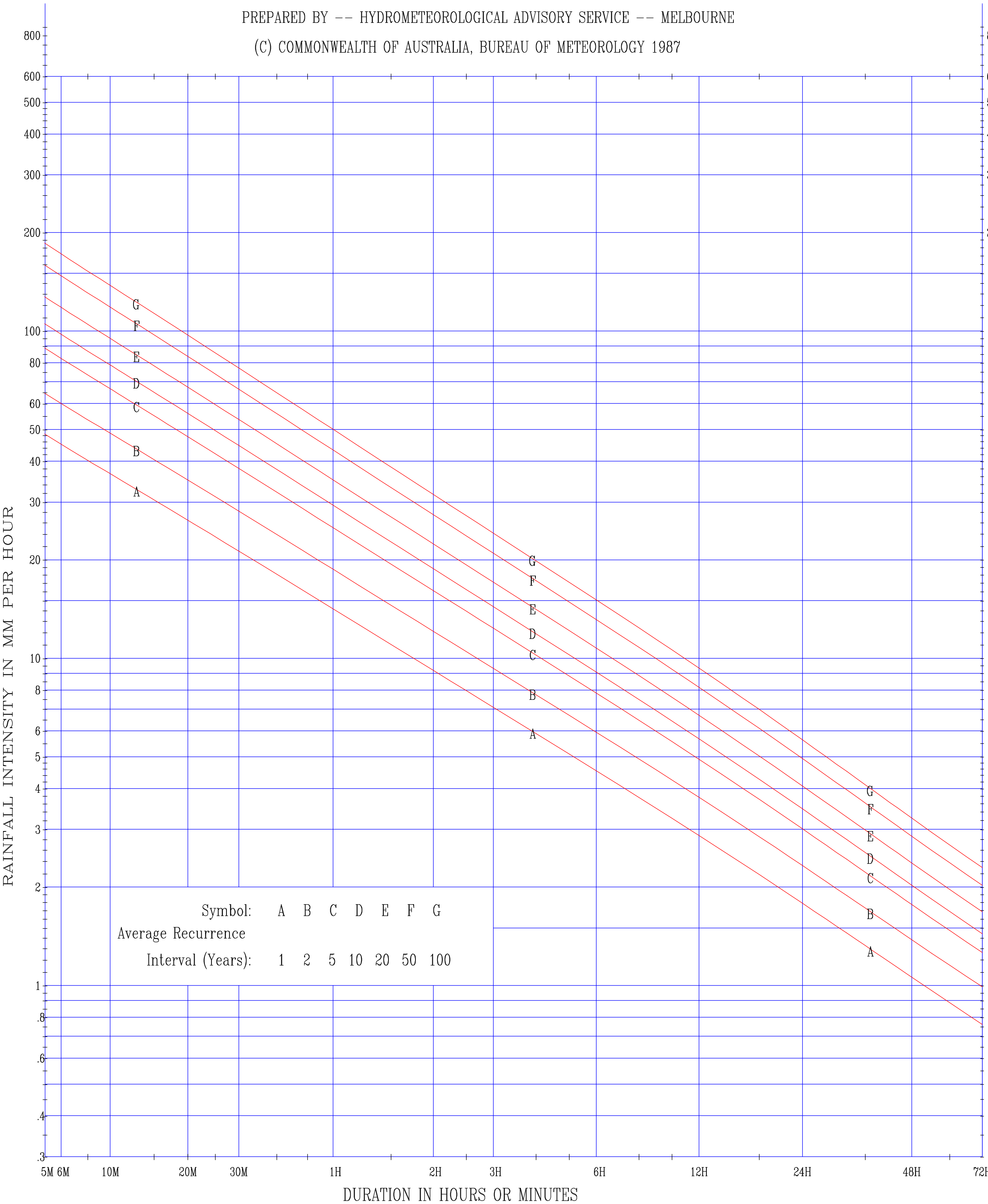
DESIGN RAINFALL INTENSITY DIAGRAM

LOCATION 37.600 S 143.725 E* NEAR.. Haddon VIC

* ENSURE THE COORDINATES ARE THOSE REQUIRED, SINCE DATA IS BASED ON THESE AND NOT THE LOCATION NAME.

ISSUED 31ST JULY 2006

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE



LOCATION 37.600 S 143.725 E * NEAR.. Haddon VIC ISSUED 31ST JULY 2006

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE

* ENSURE THE COORDINATES ARE THOSE REQUIRED SINCE DATA IS BASED ON THESE AND NOT LOCATION NAME.

LIST OF COEFFICIENTS TO EQUATIONS OF THE FORM

ln(i) = a + b*(ln(T)) + c*(ln(T))**2 + d*(ln(T))**3 + e*(ln(T))**4 + f*(ln(T))**5 + g*(ln(T))**6

T = TIME IN HOURS AND I = INTENSITY IN MILLIMETRES PER HOUR

RETURN PERIOD (YEARS)	a	b	c	d	e	f	g
1	2.6508	-0.6105	-0.0284	0.01027	-0.000608	-0.0005529	0.0000650
2	2.9291	-0.6147	-0.0282	0.01042	-0.000686	-0.0005665	0.0000704
5	3.2220	-0.6245	-0.0275	0.01008	-0.000780	-0.0005192	0.0000652
10	3.3800	-0.6304	-0.0277	0.01030	-0.000776	-0.0005404	0.0000678
20	3.5582	-0.6360	-0.0273	0.01060	-0.000894	-0.0005664	0.0000753
50	3.7680	-0.6419	-0.0272	0.01064	-0.000906	-0.0005628	0.0000745
100	3.9134	-0.6460	-0.0270	0.01071	-0.000963	-0.0005673	0.0000767

RAINFALL INTENSITY IN MM/HR FOR VARIOUS DURATIONS AND RETURN PERIODS

DURATION (HOURS)	RETURN PERIOD 1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
0.083	48.4	64.5	88.6	105.	127.	159.	185.
0.100	45.1	60.1	82.5	97.7	118.	147.	172.
0.167	36.6	48.7	66.6	78.7	94.9	118.	138.
0.333	26.4	35.0	47.5	56.0	67.3	83.6	97.1
0.500	21.3	28.2	38.0	44.7	53.6	66.4	77.0
1.000	14.2	18.7	25.1	29.4	35.1	43.3	50.1
2.000	9.18	12.1	16.1	18.8	22.4	27.5	31.7
3.000	7.08	9.32	12.4	14.4	17.1	20.9	24.1
6.000	4.53	5.94	7.83	9.07	10.8	13.1	15.1
12.000	2.87	3.76	4.91	5.67	6.70	8.15	9.33
24.000	1.78	2.33	3.01	3.47	4.07	4.94	5.63
48.000	1.06	1.38	1.77	2.03	2.37	2.86	3.25
72.000	.761	.991	1.26	1.44	1.68	2.02	2.29

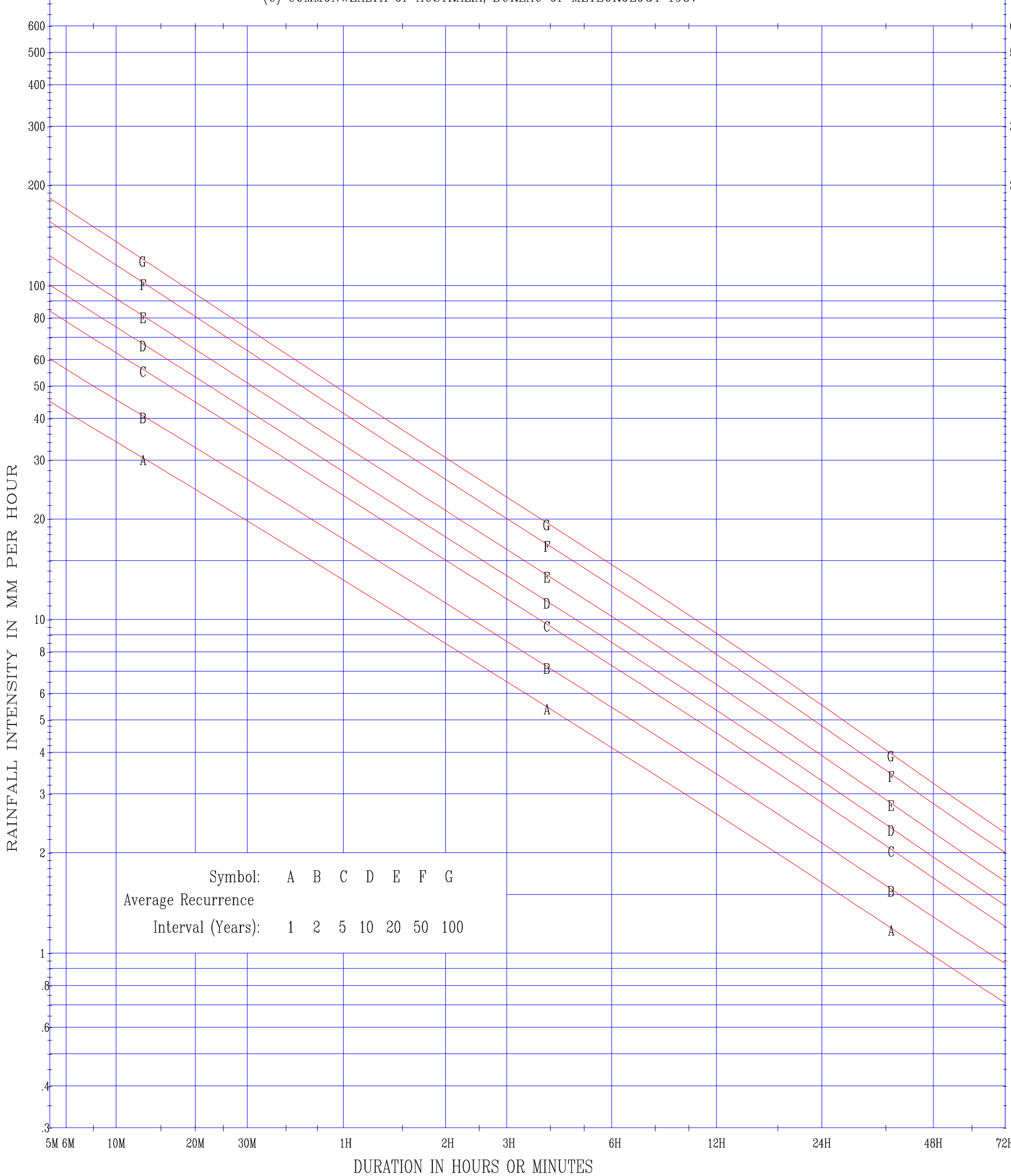
DESIGN RAINFALL INTENSITY DIAGRAM

LOCATION 37.825 S 143.750 E* NEAR.. Dereel VIC

* ENSURE THE COORDINATES ARE THOSE REQUIRED,
SINCE DATA IS BASED ON THESE AND NOT THE LOCATION NAME.

ISSUED 31ST JULY 2006

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE



LOCATION 37.825 S 143.750 E * NEAR.. Dereel VIC ISSUED 31ST JULY 2006

PREPARED BY -- HYDROMETEOROLOGICAL ADVISORY SERVICE -- MELBOURNE

* ENSURE THE COORDINATES ARE THOSE REQUIRED SINCE DATA IS BASED ON THESE AND NOT LOCATION NAME.

LIST OF COEFFICIENTS TO EQUATIONS OF THE FORM

ln(i) = a + b*(ln(T)) + c*(ln(T))**2 + d*(ln(T))**3 + e*(ln(T))**4 + f*(ln(T))**5 + g*(ln(T))**6

T = TIME IN HOURS AND I = INTENSITY IN MILLIMETRES PER HOUR

RETURN PERIOD (YEARS)	a	b	c	d	e	f	g
1	2.5751	−0.6151	−0.0320	0.00991	−0.000108	−0.0004972	0.0000443
2	2.8570	−0.6198	−0.0308	0.01047	−0.000353	−0.0005610	0.0000632
5	3.1581	−0.6283	−0.0289	0.00958	−0.000362	−0.0004339	0.0000383
10	3.3214	−0.6352	−0.0263	0.01040	−0.000803	−0.0005125	0.0000646
20	3.5063	−0.6396	−0.0250	0.01012	−0.000891	−0.0004718	0.0000593
50	3.7242	−0.6452	−0.0233	0.01007	−0.001082	−0.0004578	0.0000629
100	3.8755	−0.6489	−0.0223	0.00988	−0.001153	−0.0004264	0.0000589

RAINFALL INTENSITY IN MM/HR FOR VARIOUS DURATIONS AND RETURN PERIODS

DURATION (HOURS)	RETURN PERIOD 1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
0.083	45.0	60.4	84.0	101.	123.	155.	183.
0.100	41.9	56.2	78.1	93.5	114.	144.	170.
0.167	34.0	45.5	62.9	75.1	91.4	115.	135.
0.333	24.5	32.7	44.7	53.2	64.4	80.7	94.4
0.500	19.7	26.3	35.7	42.3	51.1	63.9	74.5
1.000	13.1	17.4	23.5	27.7	33.3	41.4	48.2
2.000	8.47	11.2	15.1	17.7	21.2	26.3	30.5
3.000	6.51	8.60	11.5	13.5	16.2	20.1	23.3
6.000	4.13	5.45	7.27	8.53	10.2	12.6	14.6
12.000	2.61	3.44	4.57	5.35	6.38	7.86	9.09
24.000	1.63	2.14	2.83	3.29	3.91	4.80	5.53
48.000	.982	1.28	1.68	1.94	2.30	2.81	3.23
72.000	.710	.931	1.20	1.39	1.64	2.00	2.30

Appendix 4	*The Rational Method for Peak Discharge*

	Time to Concentration ($tc = 0.76A^{0.38}$) hours
Naringhil	5.9
Woady Yaloak	7.7
Illabarook	4.6
Mount Misery	4.6
Kuruc-a-ruc	5.5
Ferrers	4.2

	Design Rainfall Intensity Diagram Used
Naringhil	Pittong (on top-right hand corner of sub - catchment boundary)
Woady Yaloak	Haddon & Cressy
Illabarook	Dereel
Mount Misery	Dereel (at boundary of Kuruc & Misery)
Kuruc-a-ruc	Dereel (at boundary of Kuruc & Misery)
Ferrers	Dereel

	Runoff Coefficients
Naringhil	0.08
Woady Yaloak	0.1
Illabarook	0.1
Mount Misery	0.1
Kuruc-a-ruc	0.1
Ferrers	0.11

	Rainfall Intensity Woady at (Haddon)
100 year	12.5
50 year	11.25
20 year	9.25
10 year	7.75
5 year	6.5
2 year	5

Rainfall Intensity Woady at (Cressy)	
100 year	10.5
50 year	9
20 year	7
10 year	6
5 year	5.25
2 year	4

Rainfall Intensity Naringhill at (Pittong)	
100 year	14
50 year	12.5
20 year	10
10 year	8.5
5 year	7.25
2 year	5.5

Rainfall Intensity Illabarook at (Dereel)	
100 year	18
50 year	15
20 year	12.5
10 year	10.5
5 year	9
2 year	6.5

Rainfall Intensity Mount Misery at (Dereel)	
100 year	18
50 year	15
20 year	12.5
10 year	10.5
5 year	9
2 year	6.5

Rainfall Intensity Kuruc-a-ruc at (Dereel)	
100 year	16
50 year	13.5
20 year	11
10 year	9
5 year	7.5
2 year	5.75

Rainfall Intensity Ferrers at (Dereel)	
100 year	18
50 year	16
20 year	12.5
10 year	10.5
5 year	9
2 year	6.75

Calculated runoff coefficient with frequency factors for each sub-catchment

Frequency Factors (FF)	
100 year	1.3
50 year	1.2
20 year	1.1
10 year	1.00
5 year	0.9
2 year	0.75

Naringhil Creek	
100 year	0.104
50 year	0.096
20 year	0.088
10 year	0.08
5 year	0.072
2 year	0.06

Woady Yaloak River	
100 year	0.13
50 year	0.12
20 year	0.11
10 year	0.1
5 year	0.09
2 year	0.075

Illabarook Creek	
100 year	0.13
50 year	0.12
20 year	0.11
10 year	0.1
5 year	0.09
2 year	0.075

Mount Misery Creek	
100 year	0.13
50 year	0.12
20 year	0.11
10 year	0.1
5 year	0.09
2 year	0.075

Kuruc-a-ruc Creek	
100 year	0.13
50 year	0.12
20 year	0.11
10 year	0.1
5 year	0.09
2 year	0.075

Ferrers Creek	
100 year	0.143
50 year	0.132
20 year	0.121
10 year	0.11
5 year	0.099
2 year	0.0825

Area of Sub-Catchment Km^2	
Naringhil	251,673
Woady Yaloak	407,332
Illabarook	113,327
Mount Misery	190,247
Kuruc-a-ruc	157,059
Ferrers	88,3402

Peak Discharge Calculations

2-year ARI

Kuruc 0.00278 x 0.075 x 5.75 x 15,706

Misery 0.00278 x 0.075 x 6.5 x 19,025

Woady 0.00278 x 0.075 x 4.5 x 40,733

Naringhil 0.00278 x 0.06 x 5.5 x 25,167

5-year ARI

Kuruc 0.00278 x 0.09 x 7.5 x 15,706

Misery 0.00278 x 0.09 x 9 x 19,025

Woady 0.00278 x 0.09 x 5.875 x 40,733

Naringhil 0.00278 x 0.072 x 7.25 x 25,167

10-year ARI

Kuruc 0.00278 x 0.1 x 9 x 15,706

Misery 0.00278 x 0.1 x 10.5 x 19,025

Woady 0.00278 x 0.1 x 6.875 x 40,733

Naringhil 0.00278 x 0.08 x 8.5 x 25,167

20-year ARI

Kuruc 0.00278 x 0.11 x 11 x 15,706

Misery 0.00278 x 0.11 x 12.5 x 19,025

Woady 0.00278 x 0.11 x 8.125 x 40,733

Naringhil 0.00278 x 0.088 x 10 x 25,167

50-year ARI

Kuruc 0.00278 x 0.12 x 13.5 x 15,706

Misery 0.00278 x 0.12 x 15 x 19,025

Woady 0.00278 x 0.12 x 10.125 x 40,733

Naringhil 0.00278 x 0.096 x 12.5 x 25,167

100-year ARI

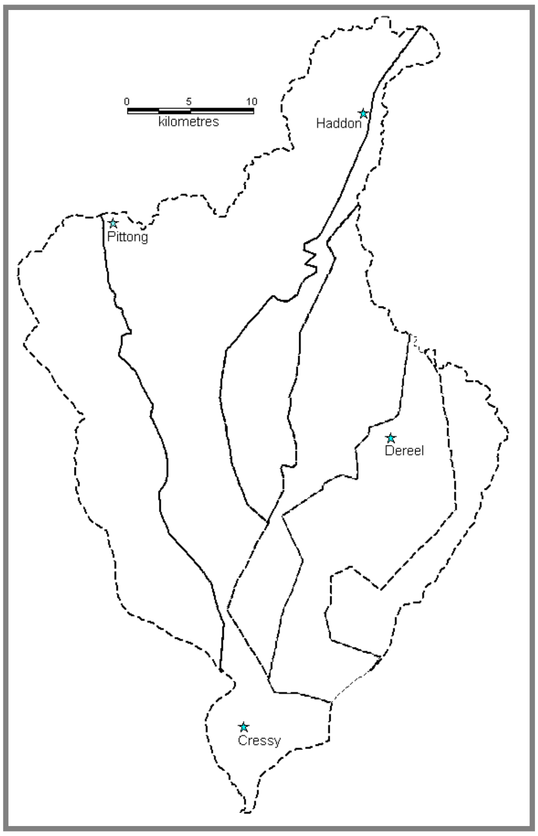
Kuruc 0.00278 x 0.13 x 16 x 15,706

Misery 0.00278 x 0.13 x 18 x 19,025

Woady 0.00278 x 0.13 x 11.5 x 40,733

Naringhil 0.00278 x 0.104 x 14 x 25,167

Locations where IFD graphs were obtained.



Appendix 5 *Monthly Surface Water Sampling Data*

Additional data on sample sites, are appended on the CD-Rom.

February

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	27-February-2006	2.2	7.5	19.1	yellowey-very murky
W2 (DEVILS)	27-February-2006	2.3	6.8	14.9	
W3	27-February-2006	3.3	7.4	21.7	looks pretty clear
i1	28-February-2006	11.5	7.2	17.7	slightly yellow water
i2	28-February-2006				no water here, was dry
M3	28-February-2006	7.5	7.2	25	Water was slightly yellow, plenty of water under bridge
M1	28-February-2006	8.7	7.4	25.1	Water was stagnant in a shallow puddle, could not measure flow
M2	28-February-2006	10.7	7.6	18.4	
ML	28-February-2006	12.2	6.9	19.7	Small water cascade on sth side of road
N1	27-February-2006	7.7	7.5	18.7	Plenty of water under bridge, plenty of little dark fish. SOB present here also.
N2	27-February-2006	10.5	7.3	18.2	Plenty of water under bridge
W4	27-February-2006	8	7.5	17.5	
M4	27-February-2006	9.8	7.4	18.7	Water looks very yellow under bridge, very cool environment, lots of smelly mud
N3	27-February-2006				no water here, was dry
W5	27-February-2006	9.3	7.3	24.5	looks pretty clear, water is quite deep under bridge
K4	28-February-2006	11.4	7.8	25.5	water is very green under bridge, in puddles, quite stagnant
K1	28-February-2006	6.3	6.7	11.3	plenty of water under bridge
F1	28-February-2006				no water here, was dry
K2	28-February-2006	14.4	7.2	20.7	
F2	28-February-2006	13	7.2	22.5	Water is yellowish in colour

March

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	27-March-2006	2.25	7.79	16.7	Quite Clear, light drizzle of rain
W2 (DEVILS)	27-March-2006	2.255	7.05	17.9	Orangey-red iron layer on water, strong unpleasant smell
W3	27-March-2006	3.32	7.84	21.6	Looks clear
i1	28-March-2006	12.19	7.61	18.7	Looks dull grey/brown colour, quite shallow under bridge
i2	28-March-2006				
M3	28-March-2006	8.65	7.67	23.6	Looks clear
M1	28-March-2006	10.25	7.88	22.3	Water looks stagnant, murky & dark
M2	28-March-2006	17.58	8.13	17.6	Yellowey-brown colour, lots of hairy vegetation inside water
ML	28-March-2006	12.99	8	25.3	Water draining under road from a dam on nth side of road (groundwater spring)
N1	27-March-2006	9.28	8.3	17.4	
N2	27-March-2006	12.65	7.84	17.3	
W4	27-March-2006	9.05	8.06	18	Water is a light yellow colour
M4	27-March-2006	20.76	7.87	17.5	Water at edge of stream are filmy, maybe algae
N3	27-March-2006				no water here, was dry
W5	27-March-2006	11.33	7.88	21.7	
K4	29-March-2006	19.23	8.04	23.2	Water much lower than last month, only 1 puddle under bridge, satgnant discharge puddle
K1	29-March-2006	6.9	7.6	16.5	
F1	29-March-2006				no water here, was dry
K2	29-March-2006	19.46	8.32	19.6	
F2	29-March-2006	15.12	8.93	20.7	Water is very green, a dull-bright green, smells very bad
W7	27-March-2006	9.01	7.94	19.8	Lots of vegetation in the water at edges of stream under bridge
N0	27-March-2006	3.66	7.59	16.7	Water a strong yellow colour
ML2	28-March-2006	13.33	7.26	21.2	Pond on the nth side of the road, the stream that crosses the road is totally dry, so water is probably a gw discharge area, water has iron film on it

April

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	26-April-2006	2.09	7.95	10.6	Quite Clear
W2 (DEVILS)	26-April-2006				No water in river, completely dry
W3	26-April-2006	3.18	8	11.1	Looks clear
i1	27-April-2006	13.81	7.38	11.5	Water is slightly yellow with vegetation particles inside the water, not clear
i2	27-April-2006	15.39	7.11	10.6	
M3	26-April-2006	8.46	7.64	15.2	Yellow-brown colour, plenty of little black fish in water
M1	27-April-2006	11.33	6.77	12.5	Sludgy film on water, not clear, yellow colour. More water than last month 10x10m puddle under bridge.
M2	27-April-2006	12.8	8.18	13.7	Yellowey-brown colour, lots of hairy vegetation inside water
ML	27-April-2006	7.82	7.83	15.3	Water draining under road from a dam on nth side of road (groundwater spring)
N1	26-April-2006	10.14	7.96	12.7	Plenty of water under bridge, looks slightly yellow
N2	26-April-2006	13.18	7.79	11.7	Water is a light yellow colour
W4	26-April-2006	9.66	6.92	13	Water is a light yellow colour
M4	26-April-2006	19.21	7.81	12.7	Water is yellow-brown colour
N3	27-April-2006				no water here, was dry
W5	26-April-2006	12.87	7.98	15.1	Water looks deep under nrth side of bridge, yellow colour
K4	27-April-2006	10.3	7.55	10.6	Lots more water under bridge, last month just 1 tiny gw discharge puddle, more water is present in a couple of puddles, and EC values are lower
K1	26-April-2006	5.08	7.64	15.2	Water is slightly yellow
F1	27-April-2006				no water here, was dry
K2	26-April-2006	19.49	8.23	11.9	Water is a strong yellow-orange colour
F2	27-April-2006	14.5	8.96	13.4	Water is very green, a dull-bright green, smells very bad
W7	26-April-2006	8.66	7.72	12.4	quite clear looking, slightly yellow
N0	26-April-2006	3.45	7.48	11.7	Water a slightly grey colour
ML2	27-April-2006	13.74	7.39	17.6	Pond on the nth side of the road, the stream that crosses the road is totally dry, so water is probably gw discharge, water has iron film on it.
K3	27-April-2006	23.4	8.59	11.7	
Ntop	27-April-2006	0.737	8.45	19.1	Top of Naringhill Ck, very large stream, at the headwaters
Pt	27-April-2006	13.26	7.07	21.2	Salt Spring. Yellow water

May

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	26-May-2006	2.42	7.34	8.8	Quite Clear
W2 (DEVILS)	26-May-2006				No water in river, completely dry
W3	26-May-2006	3.11	7.96	9.2	Looks clear
i1	27-May-2006	13.5	7.54	10.1	Water is fimly, not clear looking
i2	27-May-2006	13.42	7.34	10	
M3	27-May-2006	11.56	7.85	12.6	
M1	27-May-2006	10.92	7.08	9.4	Sludgy film on water, not clear, yellow colour. Stagnant water on sthn side of bridge
M2	27-May-2006	11.22	8.06	9.6	
ML	27-May-2006	4.5	7.78	11.8	Water draining under road from a dam on nth side of road (groundwater spring)
N1	26-May-2006	9.54	7.92	10.7	Plenty of water under bridge, looks slightly yellow
N2	26-May-2006	9.35	7.71	10.1	Water flowing strongly
W4	26-May-2006	6.23	7.4	9	Water is clear looking
M4	26-May-2006	17.01	7.47	9.6	Water is yellow-brown colour, very murky looking
N3	26-May-2006				no water here, was dry
W5	26-May-2006	8.43	7.84	9.6	Water looks deep under nrth side of bridge, yellow/orange colour
K4	26-May-2006	14.4	6.92	9.2	
K1	26-May-2006	8.01	6.25	10.2	
F1	26-May-2006				no water here, was dry
K2	26-May-2006	17.4	7.3	9.8	
F2	26-May-2006	13.85	8.3	10.9	Sample was taken on east side of bridge, was most likely dry last month.
W7	26-May-2006	10.8	7.4	13.6	quite clear looking, slightly yellow
N0	26-May-2006	3.42	7.28	10.1	
ML2	27-May-2006	12.9	6.45	12.3	Stream that crosses the road is flowing slightly, last mth was dry so water is probably mixed with groundwater. Water has iron film on it.
K3	26-May-2006	21.74	7.63	10.1	More water than last month, on E side of Rd in a pond. Sample not taken at this pond, but the salt that was circulating it looks to be decreasing.
K5	26-May-2006	21.3	7.18	13.4	Water is murky, an iron film is presnt on edges of pond.
Ntop	27-May-2006	0.418	7.79	11.2	Top of Naringhill Ck, plenty of water present
Pt	27-May-2006	13.05	7.07	11.7	Discharge area is much bigger than last month, occupying both sides of road. Area on the land past the fence to the north is really muddy
NT	27-May-2006	18.77	7.55	11.6	Water is lightly flowing on eastern side of road and is deeper on western side. This tributary joins Narinhal Ck further east.

June

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	28-June-2006	2.68	7.38	6.5	Quite Clear
W2 (DEVILS)	28-June-2006				No water in river, completely dry
W3	28-June-2006	3.03	7.88	6.7	Looks clear looking, over 1 metre to the bottom.
i1	30-June-2006	12.8		9	
i2	30-June-2006	12.83		8.4	Water is a dark colour, almost black, lots of sediment inside.
M3	30-June-2006	11.97		10.3	Water looks clear, less salty than i1 & i2, perhaps some salt gets diluted from the greater volume of water present here at LW.
M1	30-June-2006	10.52		7.9	Water shallow, not enough to bail from bridge.
M2	30-June-2006	10.67		9.5	Water a clear colour, lots of vegetation inside, deep under bridge
ML	30-June-2006	3.5		10.4	Small trinkle of water present.
N1	28-June-2006	8.95	7.94	8.4	
N2	29-June-2006	9.27		8.5	
W4	29-June-2006	4.31		8.2	
M4	29-June-2006	15.85		8.5	
N3	29-June-2006	9.35		9.1	Plenty of water under bridge
W5	29-June-2006	8.03		9.1	Water clear looking
K4	29-June-2006	14.18		8.1	Water clear and a slightly yellow colour.
K1	29-June-2006	8.26		8.2	Water very yellow/orange and deep under bridge.
F1	29-June-2006				no water here, was dry
K2	29-June-2006	17.01		7.4	Water a strong yellow colour
F2	29-June-2006	13.25		8	Water a yellow colour
W7	29-June-2006	10		8.4	
N0	28-June-2006	3.21	7.45	9	Water slightly yellow but clear looking, few vegetation particles inside.
ML2	30-June-2006	11.09		10.8	Water flowing slightly but steadily into moonlight creek. More water on side of road this month.
K3	29-June-2006	20.2		10.3	Stagnant puddle under bridge
K5	29-June-2006	18.8		8.5	Salty pond
Ntop	28-June-2006	0.667	8.02	7.8	Water flowing quite strongly, muddy brown colour
Pt	28-June-2006	12.62	6.48	9.5	Plenty of water on sides of road.
NT	28-June-2006	17.75	6.86	7.8	
C1	29-June-2006	10.32	7.92	9.4	Shallow water under bridge, deepest part about 40cm. Water flows to the east is clear looking a little filmy on top

July

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	24-July-2006	2.269	7.48	6.3	
W2 (DEVILS)	24-July-2006	2.31	7	8.8	Quartz pebbles clear on stream bed. Deepest part of water in middle of stream is about 1m deep.
W3	24-July-2006	2.78	8.07	7.2	
i1	25-July-2006	10.92	7.41	10.1	Water was strong yellow colour, turbid, lots of vegetation, fine dark particles inside.
i2	25-July-2006	10.55	7.71	9	
M3	25-July-2006	8.35	8.16	10.4	Water is clear looking.
M1	25-July-2006	5.94	7.45	7.8	
M2	25-July-2006	9.92	8.33	7.1	Water looked scumy, lots of vegetation particles inside, not clear.
ML	25-July-2006	7.13	7.32	9.3	
N1	24-July-2006	7.74	8.09	8.6	
N2	24-July-2006	7.89	8.23	10.3	Water looks clear and is quite deep.
W4	24-July-2006	5.74	8.02	9.7	Water looks clear, and deep under bridge.
M4	24-July-2006	8.44	7.97	11.6	Water is brown and murky. Vegetation particles inside, fine and dark particles.
N3	24-July-2006	8.09	8.13	10	Water is shallow but flowing strongly. Box culvert under bridge, approx 8m across.
W5	24-July-2006	7.5	8.26	11.5	Water looks clear, very deep under bridge on both sides or Rd.
K4	24-July-2006	14.65	7.5	9.6	
K1	25-July-2006	7.88	7.55	8.5	
F1	25-July-2006	8.44	8.37	10.8	Water is about 1m deep in middle of stream.
K2	25-July-2006	16	7.51	8.2	Water is deeper than last month.
F2	25-July-2006	12.96	8.54	9.7	Water a yellow colour.
W7	24-July-2006	8.82	8.01	11.1	
N0	24-July-2006	2.91	7.48	9.3	
ML2	25-July-2006	9.66	7.8	10.3	Lots of iron in water, you can see it settling to bottom, and mixing as probes are placed in water.
K3	25-July-2006	16.23	8.05	10.2	
K5	25-July-2006	18.9	7.29	12.4	
Ntop	24-July-2006	0.681	7.83	10.2	
Pt	24-July-2006	8.09	7.32	13	
NT	24-July-2006	12.2	7.2	8.2	
C1	25-July-2006	6.04	8.26	12	Water is very shallow under bridge. Bailed from top of bridge, sediment rich water.
MD	24-July-2006	7.17	7.47	9.2	Lots of vegetation in water

August

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	29-August-2006	2.302	7.41	9.5	Water shallow at path crossing where culvert is located, water is heard flowing continuously
W2 (DEVILS)	28-August-2006	2.363	6.94	10	Plenty of water on both sides of stream, lots of filmy vegetation inside, and frogs in water
W3	28-August-2006	2.79	8.1	10.6	Water deep under road crossing, about 30-40cm below the road
i1	29-August-2006	11.12	7.63	10.4	Water dark grey colour, turbid, smells like rotten eggs (sulfur)
i2	29-August-2006	9.92	7.76	10.1	
M3	29-August-2006	9.71	8.12	12.2	
M1	29-August-2006	6.42	7.42	10.4	
M2	29-August-2006	9.85	8.28	10	Water deep under bridge
ML	29-August-2006	7.67	7.97	13.5	
N1	28-August-2006	8	8.09	12.1	
N2	28-August-2006	8.5	8.05	11.7	
W4	28-August-2006	6.02	7.87	11.6	
M4	28-August-2006	9.25	7.81	12.6	Water looked muddy, brown colour in stream, lots of muddy exposed river terraces possibly erosing into stream.
N3	28-August-2006	8.61	7.91	13.2	Water visible along entire creek from the road, looks clear
W5	28-August-2006	7.53	8.19	12.1	Water a little brown in colour but is clear
K4	29-August-2006	14.65	7.4	12	
K1	29-August-2006	8.05	7.5	10.1	Approx depth of water is 1 metre, water has yellow/orange colour to it possibly iron staining
F1	29-August-2006	8.8	8.3	11.9	Water slightly yellow, lots of veg particles inside
K2	29-August-2006	16.7	7.58	11.6	Colourful iron film on water, iron rich
F2	29-August-2006	13.72	8.46	12.2	
W7	28-August-2006	8.98	7.73	13.1	Water looks very clear
N0	28-August-2006	3.03	7.39	11.7	Dark brown/green coloured water, very turbid, lots of veg particles inside
ML2	29-August-2006	10.05	6.9	13	
K3	29-August-2006	15.22	8.01	11.8	Water slightly yellow, lots of veg particles inside
K5	29-August-2006	19.67	7.42	11.5	Very murky, turbid, and water almost a black colour, smells of sulphur, no iron staining this month
Ntop	28-August-2006	0.533	7.68	12.1	Water looks quite brown in creek, large body of water here
Pt	28-August-2006	14.4	7.78	10.1	Large puddles of water on both sides of the road
NT	28-August-2006	13.06	6.49	10.4	Water cascading down strongly
C1	28-August-2006	6.18	?8.15	13	Water is yellow colour, very shallow under bridge
MD	28-August-2006	8.55	7.23	11.9	Water over 1m deep on nth side of bridge. Water clear with small reddish couloured veg particles inside

September

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	26-September-2006	2.252		9.1	Water is clear, 10cm deep read from ruler in water.
W2 (DEVILS)	26-September-2006	2.275	6.46	11	Plenty of water on both sides of stream, lots of filmy vegetation inside, and frogs in water, water pretty still and clear.
W3	26-September-2006	2.94	7.93	9.5	Water deep under road crossing, clear looking.
i1	26-September-2006	11.43		10.4	Water is close to a black colour, very turbid
i2	26-September-2006	11		9.9	Water looks a little cloudy.
M3	26-September-2006	9.18		13.7	Clear looking, a little filmy on top layer of water
M1	26-September-2006	7.5		9.7	Water looks clear, is only slightly moving
M2	26-September-2006	11.65		8.4	Water deep under bridge, flowing more strongly than M1 this month.
ML	26-September-2006	7.72		13.9	Water looks clear
N1	25-September-2006	7.94		13.3	Water looks a little cloudy.
N2	25-September-2006	8.24	8.07		Water looks clear, flowing.
W4	25-September-2006	5.61	7.96	10.21	Water slightly yellow but clear looking
M4	25-September-2006	10.65	8.12	9.4	Water looked muddy, brown colour in stream, deepest part in stream about 1m.
N3	25-September-2006	8.6	8.23	12.6	Water visible along entire creek from the road, flowing strongly across boxed concrete culvert, shallow.
W5	25-September-2006	7.51	8.22	10.8	Water about 2 m deep under bridge, looks clear.
K4	25-September-2006	15.12	7.5	11.2	Water slightly yellow, veg particles inside. Over 1m deep in middle of creek under bridge, water present on both sides of road.
K1	25-September-2006	7.53	7.41	9.6	Water looks cloudy, orange colour in parts of the pond under bridge.
F1	25-September-2006	8.4		9.4	Water strong yellow colour
K2	25-September-2006	16.27	7.02	10.3	Water turbid, yellow colour, stream is a losing stream, disappears at southern side into the ground.
F2	25-September-2006	14.41	8.42	11	Yellow to green coloured water
W7	25-September-2006	8.55	7.94	11.8	Water slight yellow colour but clear.
N0	26-September-2006	2.88	7.38	11.5	Lots of vegetation particles in water, water a grey colour, very turbid.
ML2	26-September-2006	10.27		14.6	Iron staining on edges of ponded water.
K3	25-September-2006	14.52	8.29	9.8	Water slightly yellow, lots of veg particles inside, salty pond on other side of road looks clearer/deeper.
K5	25-September-2006	19.67	7.64	9.3	Water a ylw-bwn colour, veg particles inside.Losing stream on E side of road, stream is dry directly beside the rd but water present to the east
Ntop	25-September-2006	0.65		11.4	Water looks quite brown in creek, very turbid
Pt	25-September-2006	12.96		15.6	Large puddles of water on both sides of the road, looks clear.
NT	25-September-2006	13.11		13.9	Water cascading down strongly, veg in water which is pretty filmy.
C1	26-September-2006	5.55		13.4	Water orange colour, veg partciles inside, very turbid. Shallow under bridge only a few cm.
MD	25-September-2006	7.55		11.4	Plenty of water on Nth side of road.

October

SITE	DATE SAMPLED	EC	PH	TEMPERATURE	WATER CHARACTERISTICS
W1 (NIMONS)	26-October-2006	2.37	7.67	14.7	Lots of vegetation particles in water, quite turbid.
W2 (DEVILS)	26-October-2006	2.46	7.1	13.2	Lots of vegetation particles in water, quite turbid.
W3	26-October-2006	3.03	8.05	15.3	Clear looking water, shallower than last month
i1	26-October-2006	11.74	7.51	14.9	Cloudy and dark colour water, with veg.particles inside
i2	26-October-2006	18.38	7.52	15.4	Heavy iron staining on stream bed
M3	26-October-2006	10.75	7.68	20.9	Clear looking water
M1	26-October-2006	7.93	7.48	12.6	Layer of iron staining in water, stagnant and murky
M2	26-October-2006	16.96	8.26	12.4	Clear looking, with mossy/slimy plants in water
ML	26-October-2006	8.05	7.94	20.8	Clear looking
N1	27-October-2006	9.67	8.36	12	Cloudy water, and shallow
N2	27-October-2006	10.29	8.13	13.3	Plenty of water this month, mostly brown and turbid
W4	27-October-2006	7.01	7.73	12.4	Clear, slightly yellow water, couple of metres deep
M4	27-October-2006	16.04	8.06	12.2	Shallow, approx.30cm, grey and very turbid water
N3	27-October-2006	16.27	8.2	16.2	Just little puddle of water, heavily stained with iron
W5	27-October-2006	8.56	8.23	14	Water slightly cloudy
K4	26-October-2006	16.74	7.7	14.8	Water turbid, orange/brown colour
K1	26-October-2006	9.55	7.78	12.9	Cloudy, green coloured mud around edges of pond, slimy and shallow water, approx.30cm deep
F1	26-October-2006	12.14	7.94	14.1	Shallow water and filmy water on nthn side of road
K2	26-October-2006	19.72	7.44	17.3	No water on west. Side of rd. only on east side. Iron staining evident, esp. in drier areas of stream
F2	27-October-2006	16.25	8.4	13.9	
W7	26-October-2006	9.89	7.93	19.5	clear looking water
N0	26-October-2006	3.13	7.63	16.5	Vegetation particles in water, clear looking
ML2	26-October-2006	11.86	7.22	16.2	Very turbid, heavily stained with iron
K3	26-October-2006	16.5	8.37	16.4	Smells really sulfurous, water is very dark colour, very turbid
K5	26-October-2006	23.83	7.65	12.6	Looks clear. Dry on sth side of rd, plenty of water on nthn side.
Ntop	27-October-2006	0.862	7.63	15.5	Looks turbid
Pt	27-October-2006	23.6	8.59	15.9	No water at usual location, sample taken on pond on opposite side of road, where the stream flows to
NT	27-October-2006	14.55	7.28	13.3	
C1	27-October-2006				Very shallow water, not enough to bail off bridge
MD	27-October-2006	11.18	7.33	12.7	Looks clear

Appendix 6 *Groundwater Sampling Data*

Bores located at Haddon

More detailed groundwater data is appended on CD-ROM

BORE NUMBER	Location	Eastings / Northings	Elevation (mAHD)	EC (mS/cm)	pH	TEMP (°C)
5290	Haddon, on Racecourse Rd. Pvc bore is next to a SOB.	739368 / 5836438	390	1.5	7.26	14.6
5269		739922 / 5836584	394	7.87	6.90	14.7

BORE NUMBER	Depth of Bore (m)	Diameter (mm)	SWL (m)	Volume of Bore x3 (L)	Comments
5290	12	50	4.59 From top of PVC casing	43.6	Water Cloudy, greyish colour.
5269	14.5	45	1.72 From top of PVC casing	58.3	Bore was pumped dry after at 6m. PVC casing is 0.61 m from ground level (new casing put in?)

Bores sampled across the Volcanic Plains

BORE ID	DISSOLVED OXYGEN (mg/L)	EC (mS/cm)	pH	TEMP (°C)	ALKALINITY (mg/L)	WATER DESCRIPTION
110197	1.43	3.05	7.11	16.8		Dark Orange, remained that way for entire pumping time
110657	5.37	4.31	7.69	17.3		Clean looking/clear
110140	2.89	13.85	7.8	19.5		Lots of organic matter when started pumping, colour of water is slightly grey
112239	8.94	8.06	7.94	15.6		Clean looking/clear
103104	3.15	11.10	7.02	17.6	420 (Units: 210)	Clean looking/clear
88137	6.95	22.3	7.46	17.7		
103109	2.88	17.17	7.40	18.1		
142660	1.43	9.98	7.61	16.7		

BORE ID	DISSOLVED OXYGEN (mg/L)	EC (mS/cm)	pH	TEMP (°C)	ALKALINITY (mg/L)	WATER DESCRIPTION
142668	1.39	2.03	8.20	17.2	454 (Units:227)	
142666	5.58	1.01	7.56	16.1	332 (Units:166)	

BORE ID	SWL	SCREENED FROM (m)	DIAMETER OF BORE (mm)	VOLUME (L) x 3	PUMPING TIME (minutes)	DEPTH OF PUMP
110197	16.15	30 - 36	101	471	35	
110657	10.85	30 - 42	101	734	86	
110140	16.77	22 - 28	101	264	26.4	25
112239	22.03	38 - 41	90	362	36.2	30
103104	12.41	12 - 18	90	106	11	20
88137	13.68	18 - 24	100	243	28.35	20
103109	20.1	26 - 32	75	338	34	
142660	12.54	19 - 22	100	222	22	20

BORE ID	SWL	SCREENED FROM (m)	DIAMETER OF BORE (mm)	VOLUME (L) x 3	PUMPING TIME (minutes)	DEPTH OF PUMP
142668	13.56	19 - 20	100	141	17	
142666	15.48	26 - 29	100	319	27	

Private Bores in Pittong Region

Bore ID	**SWL** Top of casing/ & ground level (m)	**Depth of Bore** (m)	**Bore Casing** (mm)	**Bore Volume** (L)	**Pumped from** (m) *From top of casing*	**Bore Description**
5266	1.4/1.22	4.7m to silt	50			PVC pipe & cap
5409	-	1.9 to silt	50			PVC pipe & cap
5140	6.88/6.58	17.11	50	20	10	Galvanised pipe with a pvc cap
5265	1.57/1.35	11.75 to silt	40	12.7	6	PVC pipe & cap
5143	0.73/0.3	1.5 to silt	50			PVC pipe & cap
5402	1.92	9m to silt	50	13.7	5	PVC pipe & cap
5403	1.63/1.3	7.25 to silt	50			PVC pipe & cap
5404	1.37/1.1	14.4 to silt	50	25.5	6	PVC pipe & cap
5405	2.2/1.85	6.7 to silt	50			PVC pipe & cap
5406	4.6/4.35	17.45 to silt	50			PVC pipe & cap
5141	0.03	0.9 to silt	50			PVC pipe & cap. Bore might have been broken somewhere along its length, it is at a very shallow depth
5407	Dry	1.9	50			PVC pipe & cap. Bore is broken or dry
5290	4.59/KN	12 to silt	50	14.5	9	PVC pipe & cap. Located next to a SOB

Bore ID	**EAS/NRTH** (z54)	**ELEVATION** (mAHD)	**EC** (mS/cm)	**TEMP** (°C)	**pH**	**Water Description**
5266	718977 / 5822934	284				
5409	752618 / 5837183	292				
5140	716796 / 5822566	304	0.52			Water level kept falling, bore was not recharging
5265	718977 / 5822934		10.45	15.5		Very murky at first but cleared after 5 buckets

						were filled
5143	716833 / 5822953	304				
5402	716200 / 5823000	289	10.09	16.9		Very murky & silty, brown-yellow colour, water could not be filtered for analysis
5403	716866 / 5826391	292				
5404	716866 / 5826391	292	9.76	16.1		
5405	716850 / 5826386	322				
5406	716836 / 5826303	317				
5141	716800 / 5822200	304				
5407	716836 / 5826303	317				
5290	739368 / 5836438	390	1.5	14.6	7.26	Water Cloudy, greyish colour.

Bore ID	**DATE SAMPLED**
5266	24/03/06
5409	24/03/06
5140	24/03/06
5265	24/03/06
5143	24/03/06
5402	24/03/06
5403	24/03/06
5404	24/03/06
5405	24/03/06
5406	24/03/06
5141	24/03/06
5407	24/03/06
5290	08/05/06

ADDITIONAL SAMPLES

SITE	EAS/NRTH (z54)	ELEVATION (mAHD)	EC (mS/cm)	TEMP (°C)	Water Description	Time / Date Sampled
Bob Vaggs Dam	717089 / 5821932	288	8.5	23		3.00 PM / 24/03/06
SGSL Site	716915 / 5824957	298	9.8	24	Groundwater spring on side of road	1.00 PM / 24/03/06

SAMPLES SENT FOR ANALYSIS Sent on 26/03/06
Bob Vaggs Dam
Bore: 5265
Bore: 5404