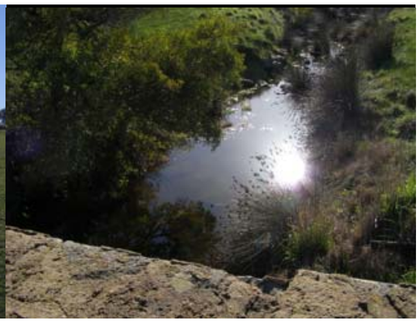
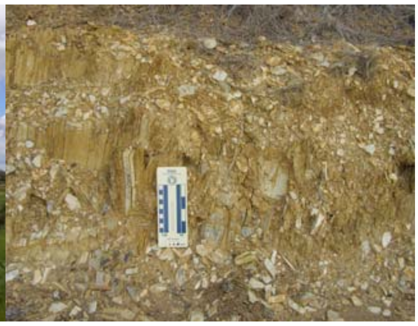
HYDROGEOLOGY AND SALINITY PROCESSES IN THE MT MERCER – ILLABAROOK AREA





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ABSTRACT

The Illabarook salinity target area is identified in the Corangamite Catchment Management Authority's Salinity Action Plan 2005 – 2008 as contributing to the rising salinity in the Woady Yaloak River, threatening the river ecosystem and Lake Corangamite. This investigation of the hydrogeology and salinity processes occurring in the target area involved geophysical surveys, soil analysis, installation of groundwater monitoring bores, downhole salinity assessment, aquifer recovery testing and surface water sampling.

The geophysical survey delineated salinity and saline discharge across three sites at Illabarook and Mount Mercer. The mapping identified salinity is primarily associated with drainage areas underlain by Palaeozoic (Ordovician) sedimentary rocks of the Castlemaine Group.

Installation of groundwater investigation and monitoring bores at Illabarook and Mount Mercer, determined that groundwater flow systems are variable across the target area. Neogene sediments originally considered the main source of saline discharge, were found to be spatially variable and contributing to a lesser extent that previously hypothesised. Flow systems in the weathered Palaeozoic (Ordovician) rocks were identified by geophysical mapping and piezometer installations to be the principal source of saline discharge.

The influence of groundwater flow within Deep Lead systems was also investigated and it is concluded that the influence of these highly variable systems on saline discharge is considered greater than previously hypothesised. Although the exact extent and nature of these systems is yet to be determined, it is believed they have a major influence on the location of saline groundwater discharge in some areas.

Surface water sampling was conducted at ten sites across the target area and enabled greater definition of stream salt loads eminating from subcatchments within the target area. The data indicated a strong relationship between rainfall and stream electrical conductivity (salinity). The analysis indicated that in certain areas, groundwater-surface water interaction is contributing to stream salt loads.

This investigation concludes that the occurrence of salinity is strongly controlled by the groundwater flow systems driving it. Revised conceptual hydrogeological models were developed based on the research findings. In line with flow system characteristics contributing to saline groundwater discharge, the plantation of broadscale tree belts targeting recharge and discharge areas is believed an appropriate management response.

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DECLARATION

The content in this thesis in its entirety is that of my own research, unless acknowledged in the text and reference list.

No section of this thesis has been published or submitted as part of another degree or to another institution.

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1 INTRODUCTION

The Illabarook salinity target area is one of twelve priority salinity management areas in the Corangamite Catchment Management Authority (CMA), Salinity Action Plan (SAP) 2005 - 2008. Using an asset-based approach to manage the growing salinity problem in the region, the Illabarook area was delineated on the basis of its potential threat to stream water quality in the Woady Yaloak River and Lake Corangamite system. The target area covers approximately 204km^2 and includes some of the tributaries to the Woady Yaloak River system (Nicholson et al. 2006). The site was adapted from the original "Hot Spot" or Land Management Unit (LMU) developed under the initial Corangamite salinity management strategy '*Restoring the Balance*' (Nicholson et al. 1992).

The Cressy stream gauge (#234201) on the Woady Yaloak River shows a minor increasing trend of 3.4 µS/cm/yr in Electrical Conductivity (EC). Initial conceptual modelling of hydrogeological and salinity processes in the Illabarook area which may contribute to the rising trend was completed by Dahlhaus (2003b). He believed that recharge control is the primary method by which to mediate salinity in the region with the planting of wide tree belts on Neogene gravel caps, close to the boundary with the underlying Palaeozoic bedrock. The management targets the local groundwater flow systems operating in the gravel caps, which are believed to be the principal source of saline groundwater discharge.

This thesis, which forms one-year full-time study as part of the Bachelor of Applied Science – Geology (Honours) program, conducted at the University of Ballarat, is primarily concerned with identifying the hydrogeological and salinity processes operating in the Mount Mercer – Illabarook area (Figure 1-1). The overall objective of this research is to test the hypothesis put forward by Dahlhaus (2003b).

Figure 1-1 An example of salinity in the Illabarook target area.

(McKenzie property, Recreation Road. Illabarook. Source: Peter Dahlhaus, 2007)

1.1 RESEARCH AIMS & OBJECTIVES

This research project aimed at developing knowledge of the hydrogeology and salinity processes in the Mt. Mercer – Illabarook area. The main research questions are as follows:

i. What are the processes that cause the salinity in the Illabarook target area?
ii. How much salinity is contributed to the Woady Yaloak River system from the groundwater discharge in the Illabarook target area?
iii. Are broadscale tree plantations an effective method to control the salinity contributed from the Illabarook target area to the Woady Yaloak River system?

The project is designed to further understand the link between groundwater flow systems and salinity processes, outlined in the conceptual hydrogeological model proposed in the Corangamite SAP (Nicholson et al. 2006).

1.2 LOCATION AND PHYSIOGRAPHY

The Illabarook salinity target area covers approximately 20 492 hectares in the Corangamite region (Figure 1-2), between 73 0102 to 75 0479 East and 58 04013 to 58 19730 North (MGA 94, Zone 54).

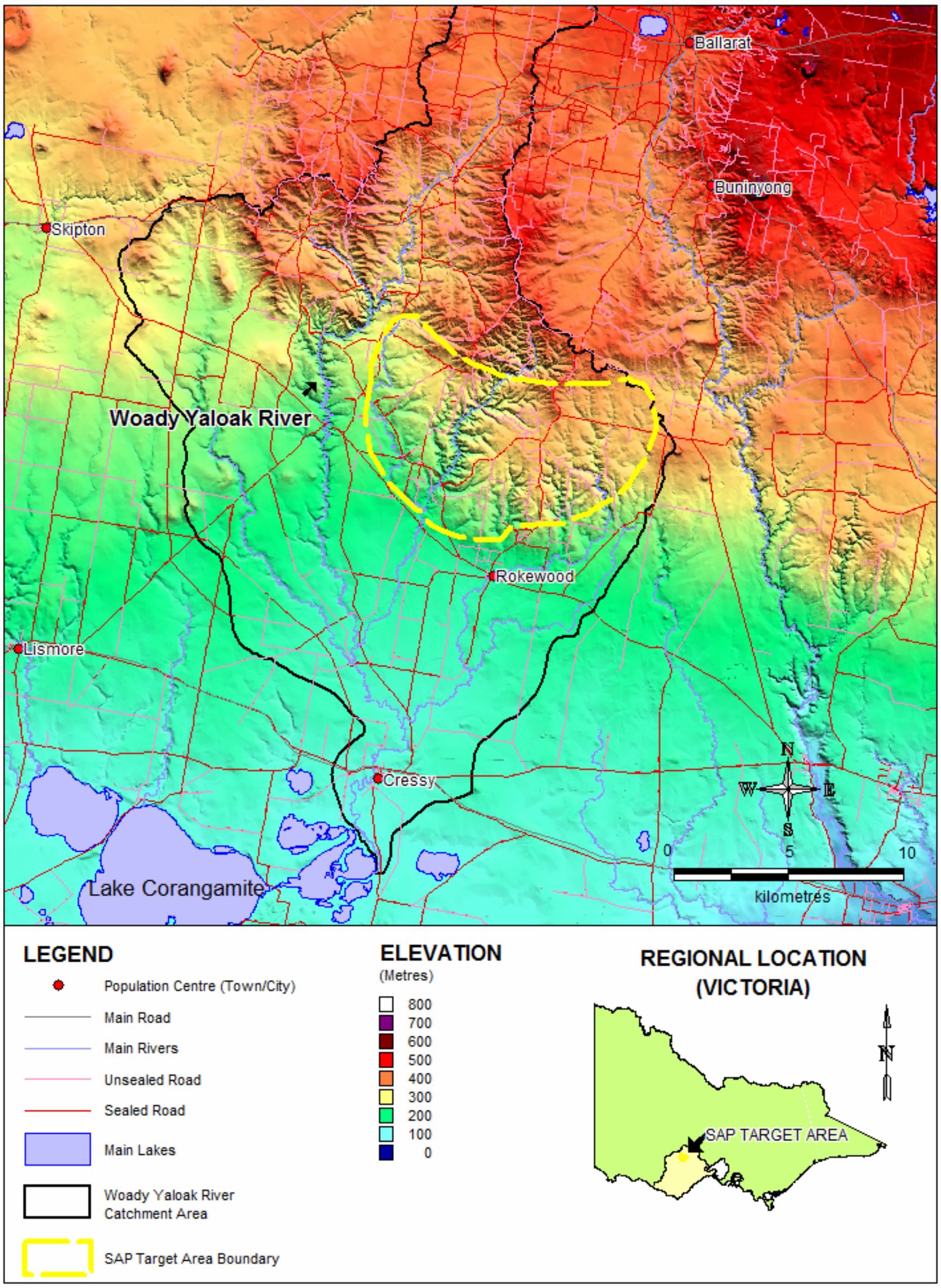


Figure 1-2 The Illabarook salinity target area. Corangamite CMA, Victoria. Australia.

The Illabarook salinity target area occurs at the junction of two main physiographic units: the Victorian Western Uplands, and the Victorian Western Plains. The terrain is generally planar to gently undulating with a regional slope to the south. Elevation in the target area varies from a peak of 425 metres AHD in the northern region of the area, to a low of 185 metres at the valley of Mount Misery Creek at the southern boundary. The area is dissected by the Illabarook, Moonlight, Mount Misery, Corindhap, Pinchgut and Kuruc-A-Ruc Creek systems, with moderate to steep valleys along the respective creek courses (Dahlhaus, 2005).

Drainage in the target area is dendritic in the north and east but becomes rectilinear, forming predominantly straight pathways to the west (Figure 1-3; Dahlhaus, 2005). In areas of volcanic rocks, drainage follows the ancient lava flow boundaries and junction with the Palaeozoic bedrock (Jenkin, 2001).

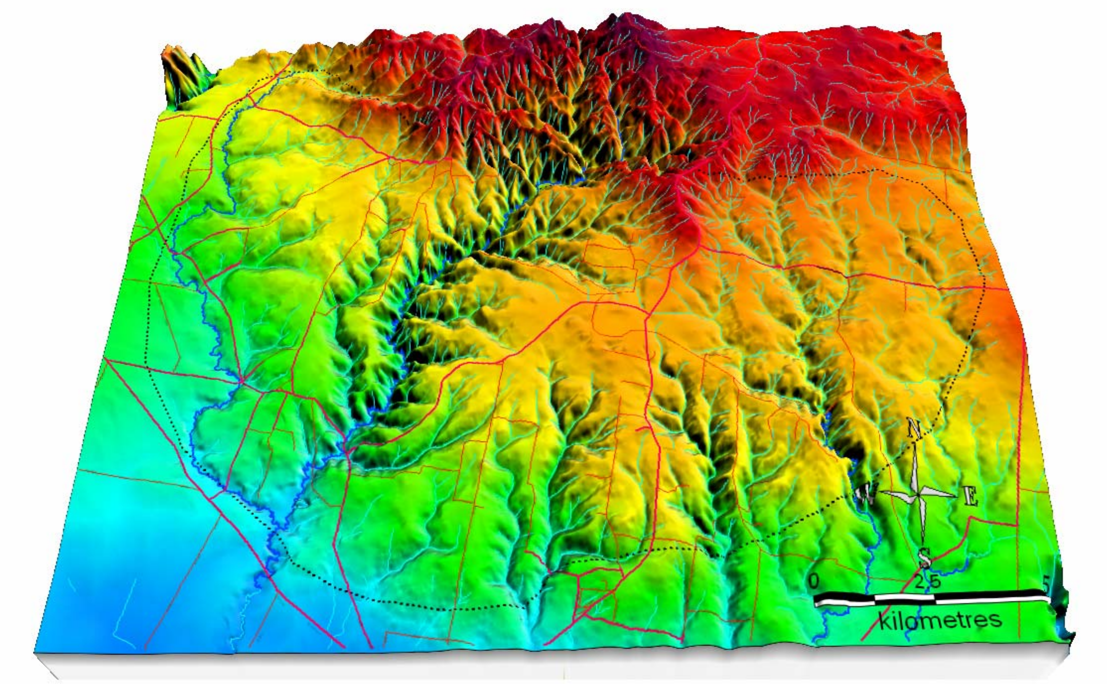


Figure 1-3 Vertically exaggerated terrain model of the Illabarook salinity target area.

(Transition from the Western uplands to the Western Plains)

Soils associated with the Palaeozoic bedrock vary from thin stony gradational profiles to duplex soils, with yellow colour and locally mantled by colluvium, with abundant quartz vein fragments in the soil and as surficial lag deposits. Those on the Neogene sands and gravels are characterised by mottled ferralitic soils, with occasional duricrust development and a brown/yellow stained matrix. The volcanic soils are predominantly grey, clayey, gradational and/or duplex soils, with alkaline subsoils and variable weathering of parent material (Smith, 2001).

1.3 CLIMATE

The Corangamite region has a predominantly temperate climate, with prevailing westerly winds, moderated precipitation and cool temperatures. Rainfall and evaporation are the most influential climatic parameters in relation to salinity and are tabulated below (Table 1-1; Dahlhaus, 2005). The occurrence of salinity in the region indicates a strong relationship to rainfall.

<table>
<tr><th>Parameter</th><th>Maximum</th><th>Minimum</th><th>Model</th><th>Source</th></tr>
<tr><td>Average Annual Rainfall</td><td>735 mm</td><td>561 mm</td><td rowspan="3">ANUCLIM</td><td rowspan="3">Dahlhaus, 2002</td></tr>
<tr><td>Average Annual Rain Days</td><td>169 days</td><td>163 days</td></tr>
<tr><td>Average Annual Pan Evaporation</td><td>1167 mm</td><td>1062 mm</td></tr>
<tr><td>Average Annual Aerial Actual Evapotranspiration</td><td>594 mm</td><td>573 mm</td><td rowspan="3">BoM/ ANU</td><td rowspan="3">BoM, 2002</td></tr>
<tr><td>Average Annual Aerial Potential Evapotranspiration</td><td>1039 mm</td><td>1016 mm</td></tr>
<tr><td>Average Annual Point Potential Evapotranspiration</td><td>1314 mm</td><td>1256 mm</td></tr>
</table>

Table 1-1 Climatic data for the Illabarook salinity target area.

(Source: Dahlhaus, 2005)

The rainfall events across the region are generally attributed to orogenic precipitation on the ranges, resulting in higher rainfalls particularly on windward sides, while the plains are distinguished by relatively lower rainfalls (LCC, 1980). The majority of rainfall occurs during winter and spring months, with August generally the wettest month (Figure 1-4). The occurrence of salinity in the region indicates a strong relationship to rainfall.

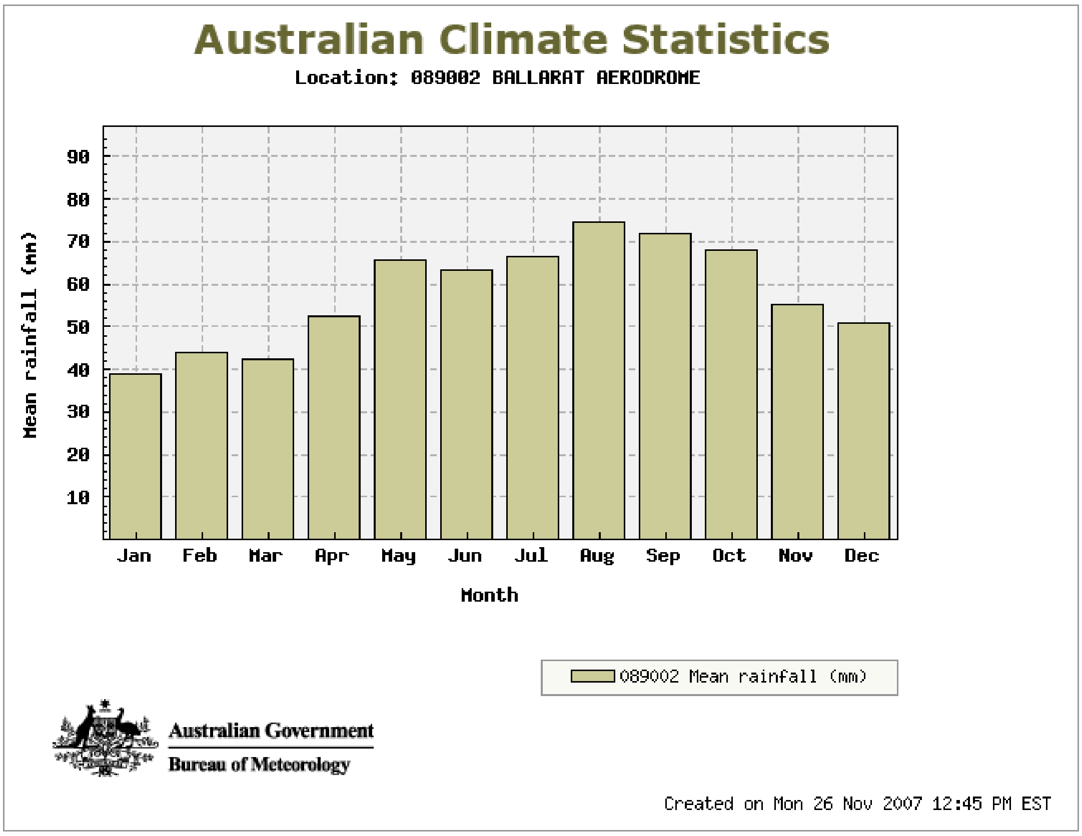


Figure 1-4 Graph of average yearly rainfall for the Illabarook Region.

(Ballarat Aerodrome Observations 1908 – 2007. Source: www.bom.gov.au, 2007)

1.4 HYDROLOGY

The Illabarook salinity target area is located within the Lake Corangamite Basin, one of four drainage basins in the Corangamite CMA. The Lake Corangamite Basin is a land-locked drainage system that has developed to form a number of interconnected lakes, the largest of which is Lake Corangamite (SKM, 2005). It total the basin consists of 788 wetlands covering a total area of 47 812ha (GHD, 2004). The basinal system is composed of the Woady Yaloak River, Pirron Yallock Creek, Mundy Gully Creek, the Gnarkeet Chain of Ponds, Deans Creek and Barongarook Creek.

Stream flow is variable and appears to be controlled relative to seasonal precipitation changes, with the highest flows generally occurring during the July to October period. Stream flow may cease in certain tributaries as a factor of low average rainfall and high absorption rates, resulting in a reduction in runoff. Summer and Autumn months produce reduced or no-flow in minor tributaries and streams (LCC, 1980). A mean average runoff in the study area of 54 Ml per square kilometre was calculated by the Land Conservation Council (LCC; 1980). Approximately 10% of this precipitation enters the waterways as stream flow, with the further 90% lost to groundwater systems and evaporation (LCC, 1980).

The Woady Yaloak River forms the main watercourse in the Lake Corangamite catchment and is fed by a number of tributaries including Naringhil, Little Woady Yaloak, Illabarook, Kuruc-A-Ruc and Ferrers Creeks. The river flows through predominantly cleared farmland, towards Lake Corangamite. Its catchment area constitutes approximately 1 200 square kilometres of the Corangamite CMA above the gauging station #234201 at Cressy (LCC 1980).

1.5 VEGETATION

The Corangamite region has undergone major changes in native vegetation cover, since the arrival of Europeans in the region during the late 1830's. The 1851 gold rush brought a large population of foreign settlers to the region, resulting in extensive clearing of vegetation for mining, agriculture and timber supply (Dahlhaus et al. 2005a). Since settlement only 25% of the original native vegetation remains in the region, with native grasslands and grassy woodlands reduced to approximately 1% of their initial extent in the area (CCMA, 2005).

The development of Corangamite Native Vegetation Plan provided a means by which to evaluate the extent and status of vegetation communities, by segregating the Corangamite region into five bioregions and delineating the various vegetation communities in the region into Ecological Vegetation Classes (EVCs; CCMA, 2005).

The Victorian Uplands and the Victorian Volcanic Plain bioregions are found in the Illabarook study area. EVCs are diagnostic vegetation types based on structure, relating to the physical/spatial arrangement on plants and floristics, referring to the species of plants that are present (CCMA, 2005). The proceeding maps (Figures 1-6 and 1-7), illustrate the EVCs for the study area as estimated for 1750 and mapped in 2004 respectively.

Major vegetation classes estimated to have been present in the region during 1750 included Heathy Dry Forest (EVC 20), Grassy Dry Forest (EVC 22), Grassy Woodland (EVC 175), Plains Grassy Woodland (EVC 55), Creekline Herb-rich Woodland (EVC 164) and Valley Grassy Forest (EVC 47; Figure 1-6). These compare to predominant vegetation classes observed circa 2004 which include Healthy Dry Forest (EVC 20), Grassy Dry Forest (EVC 22), Grassy Woodland (EVC 175), Heathy Woodland (EVC 48) and Plantations (EVC 987; Figure 1-7). The figures are decisive in illustrating the major changes in vegetation classes since settlement and indicate that remnant vegetation in the area is sparse, with a large majority of native vegetation cleared or severely disturbed.

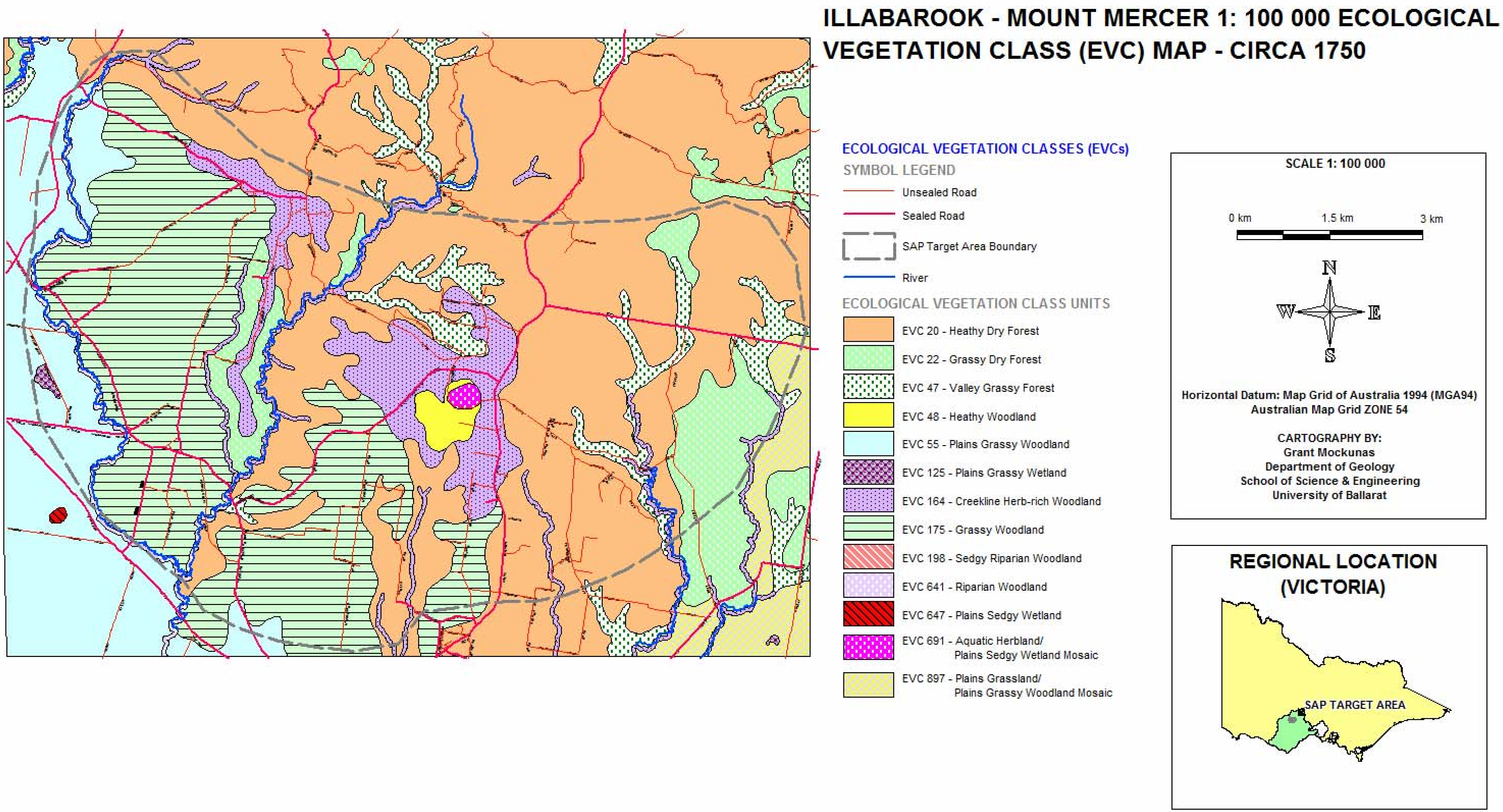


Figure 1-5 **Ecological Vegetation Classes (EVCs) for the Illabarook Salinity Target area, circa 1750.**

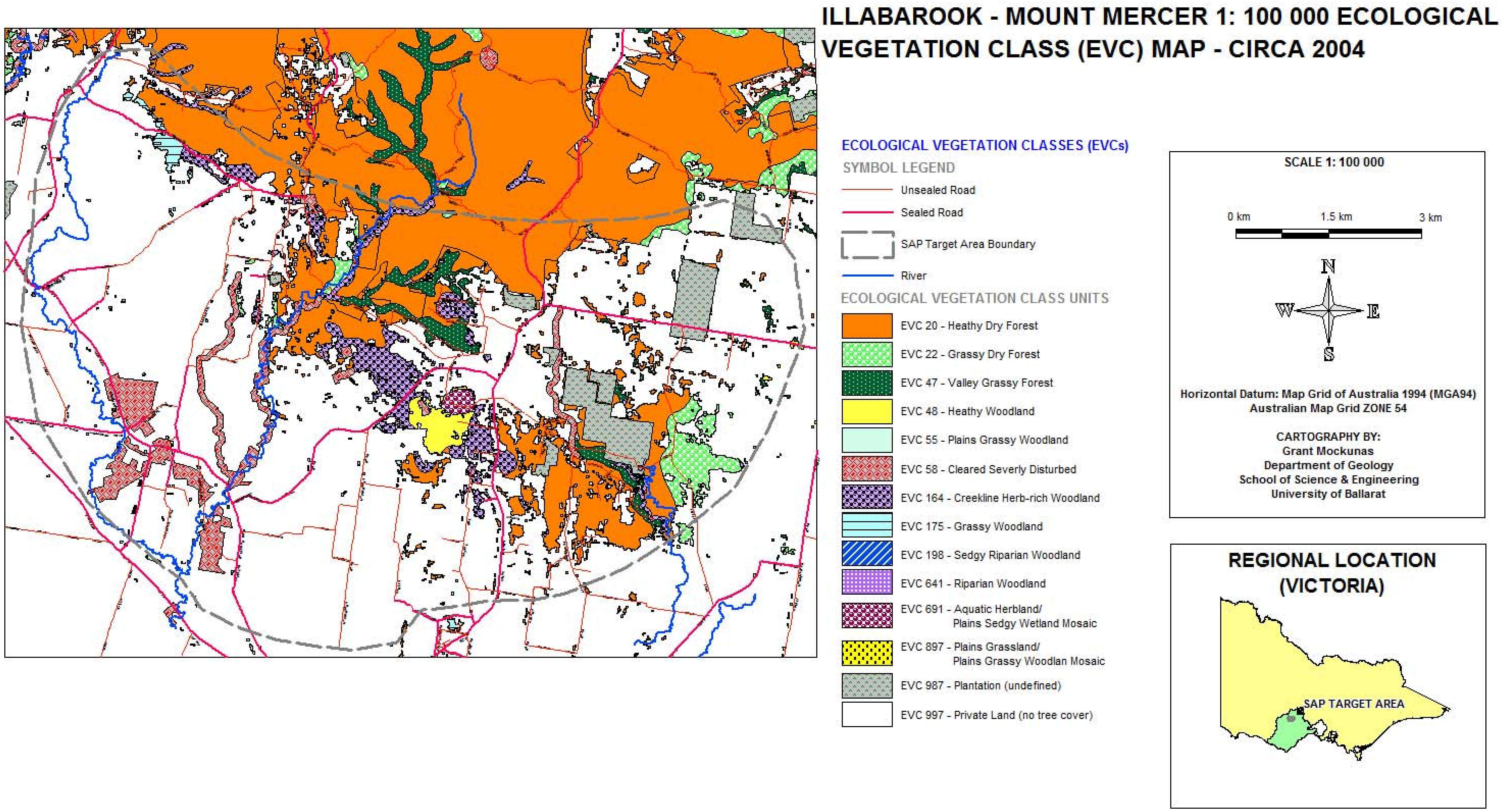


Figure 1-6 **Ecological Vegetation Classes (EVCs) for the Illabarook Salinity Target area, circa 2004.**

1.6 LAND USE

Since the end of mining in the region, grazing and mixed farming have remained the principal land practices in the area. There has however been an increase in small hectare rural properties, particularly over the past 30 years (Dahlhaus, 2005). The principal agricultural ventures in the Illabarook target area are constituted by stock and grazing with 57% wool sheep, 19% cattle, 9% first cross and prime lambs. It is estimated that approximately 14% of the target area is used for crops, where typical crop yields approximate 3.8 t/ha for wheat, 3.5 t/ha barley, 3.7 t/ha oats and 2.1 t/ha for canola. Agroforestry is an emerging agricultural scheme and represents a portion of the land-practices employed in the target area (Nicholson et al. 2003).

1.6.1 **Historical Land Use**

The presence of Aboriginals in the region is suggested to be at least 35 000 years, although little is known about these early peoples (Dahlhaus et al. 2005a). The native aboriginal community at the time of the first foreign explorers was that of the Wathaurong language group. The exploration and settlement of the Illabarook region by non-indigenous people commenced from the mid to late 1830's, when settlers extended inland searching for pastoral runs (CPA, 1957). The land was quickly colinised and by 1840 squatters had ventured to all parts of the Corangamite region, particularly those regions available to agriculture without need to remove vegetation and with a good source of water (Nicholson et al. 2006).

The foreign settlers' influences upon the landscape at this time included the removal of native vegetation, changes to drainage to reduce waterlogging and draining of wetlands, in order to adapt the land for agricultural purposes (Dahlhaus, 2005). The discovery of gold in Ballarat and Buninyong in 1851 was an important factor in land-use changes in the region. Mining eventually expanded to Grenvile, Mount Mercer, Dereel, Corindhap, Rokewood, Berringa, Illabarook, Rokewood Junction and Cape Clear. The gold rush extended for most of the last half of the 19th century and some of the early 20th century. A revival of mining in the area was brought about by the economic depression in the 1930's however, it was short-lived and much of the land was returned to grazing and other agricultural purposes. Approximately 798 mine locations have been placed within the boundaries of the Illabarook target area, with the possibility of hundreds more (Dahlhaus, 2005).

The establishment of mining in the area brought about change from the grazing practices introduced by early settlers in the area and replaced it with cropping and dairy farming, particularly on volcanic landscapes. The gold rush also saw to the construction of the regions first dams and the establishment of water authorities, in which to regulate water use (Nicholson et al. 2006). It had a particular influence on the regions hydrological systems, with alteration to natural drainage and disturbance of the regolith. Removal of tree stumps also had a similar effect to that of mining, resulting in numerous perforated pathways into the groundwater systems. This was exacerbated post mining activities such as mine-site restoration and urban development (Dahlhaus, 2005).

2 GEOLOGY, GEOMORPHOLOGY & HYDROGEOLOGY

2.1 GEOLOGICAL EVOLUTION OF THE ILLABAROOK – MOUNT MERCER REGION

The Illabarook salinity target area is located in the Bendigo Zone of the western subprovince of the Lachlan Orogen, within the Tasman Fold Belt System. The Tasman Fold Belt system is a sequential arrangement of geological events that have resulted in the development of the south-eastern portion of the Australian continent since the end of the Pre-Cambrian (VandenBerg et al. 2000). The geological evolution of the Western Victorian subprovince of the Lachlan Fold Belt Zone, can be segmented into three geochronological divisions: the Palaeozoic, Mesozoic and Cainozoic.

2.1.1 **Palaeozoic**

The Palaeozoic basement in the Bendigo zone consists of sedimentary and igneous rocks, formed over a period of approximately 280 – 320 million years from the Cambrian (Webb, 1991). The majority formed as a result of marine deposition of volcanics and sediments, along the margins of the Pre-Cambrian Gondwana Craton. These sediments and volcanics were subsequently deformed, uplifted and accreted to the continental margin of south-eastern Australia (Taylor et al. 1996).

The Early Cambrian (570 – 540 Ma) is represented in the Bendigo Zone by greenstones of the Pitfield Volcanics (Taylor et al. 1996). These are metamorphosed volcanic and intrusive rocks, with some ultramafics of tholeiitic affinity. They are located as small localised fault-bounded portions, along a section of the Avoca Fault Zone (along the western margin of the Illabarook target area; refer section 2.3). The rock types include basalts which are foliated to massive, minor gabbro to dolerite and some greenschist facies assemblages. Geochemical analysis of the assemblages suggests chemical signatures consistent with that of depleted mid-oceanic ridge basalts, formed in back-arc basins (Crawford et al. 2003).

The Middle Cambrian to Late Ordovician (540 – 440 Ma) marked a period of deposition of continentally derived sediment, forming quartz –mica turbidites over the Pitfield Volcanics. The sediments were deposited predominantly of the eastern portion of the Australian craton, in the deep marine environs (VandenBerg et al. 2000). Taylor et al. (1996) suggests that the sediment source for the turbidite sequence was probably a quartz-rich, deeply dissected terrain which had low-grade metamorphic sedimentary rocks and granitic intrusions.

The period between the Early Silurian and lasting to the end of the Early Devonian (440 – 425 Ma), is marked by a series of tectonic events. The Benambran Orogeny occurred in the Early to Middle Silurian and resulted in shortening of the upper crustal elements, resulting in tight, closely spaced folds with near vertical hinges and high angle thrusting. Metamorphism of rocks developed grades from zeolite to lower greenschist facies (VandenBerg et al. 2000). The end of the Benambran Orogeny marked the cratonisation and accretion of the rocks to the Gondwana margin. Granitic intrusions also played a part in shaping the Early Devonian (405 – 390 Ma), with intrusions to the regionally deformed rocks at sub volcanic levels (Taylor et al. 1996).

The Middle Devonian (380 Ma) is characterised by the Tabberabberan Orogeny, which was a secondary weaker deformation (Taylor et al. 1996). The Orogeny was the first major deformational event, which affected all areas of the Lachlan Fold Belt in Victoria (VandenBerg et al. 2000). Brittle faulting in bedrock and in some of the Early Devonian granite plutons, are attributed to the minor deformation in the Bendigo zone. The late Middle Devonian saw the drawing to the close of the Tabberabberan and the process of cratonisation and accretion in south-eastern margins of the Australian continent (Duddy, 2003). The Late Devonian (360 – 350 Ma) is characterised by the intrusion of post-tectonic granitic plutons, which mark the final events in the evolution of the Palaeozoic bedrock in the Bendigo zone (Taylor et al. 1996).

The granitic plutons that marked the end of the Late Devonian and the Palaeozoic, were followed by an extended period of tectonic stability. Late Devonian and Early Carboniferous sediments were deposited in thick sequences in distinct basins, as a result of rapid erosion to expose the granitic intrusions. The Late Carboniferous is speculated to have experienced widespread uplift and erosion and may account for the absence of Late Carboniferous rocks in Victoria. The Early

Permian on the other-hand marked by widespread glaciation, with limited preservation of glacial, fluvioglacial and minor marine sediments (Duddy, 2003). The result was a period of erosion which produced a low relief landscape termed the ‘Mesozoic palaeosurface,’ and has remnants in the Bendigo zone (Taylor et al. 1996).

2.1.2 **Mesozoic**

The Mesozoic spans the Triassic to the Cretaceous and lasted about 185 million years. Following glacial retreat at the end of the Early Permian, Victoria remained a dry land until the end of the Jurassic. At this stage Australia was still connected with Antarctica, forming part of the Gondwanan Supercontinent (Webb, 1991).

The Late Jurassic to Early Cretaceous heralded the beginning of renewed tectonism in the region, with the rifting apart of the Australian and Antarctic continents (Taylor et al. 1996). The initial stages of the rifting event resulted in a series of parallel east-west faults, forming the Otway Basin to the south of the Illabarook target area. The next 20 million years was characterised by continued rifting events and volcanism. During the Late Jurassic approximately 160 – 150 Ma, Lamprophyre dyke swarms developed in western Victoria and were widespread across the region (VandenBerg et al. 2000). The slow infilling of the Otway Basin with Early Cretaceous sediments, occurred as large braided streams brought sediment from the north-east (Webb, 1991).

2.1.3 **Cainozoic**

Following the break-up of Australia and Antarctica, inland areas were rejuvenated by uplift of the divide separating the Murray and Otway basins, as a result of the rifting event (Phillips, 2003). A period of higher rainfall lead to the deep dissection of the Mesozoic Palaeosurface and formation of an inland drainage divide, which was the precursor to the Great Dividing Range. The landscape was characterised by meridional ridges of bedrock, flanked by broad valleys containing scree, outwash and braided river deposits, of the early Tertiary environs (Taylor et al. 1996).

The Oligocene to Miocene (40 – 5 Ma) represented a change from the weathering event seen in the early Tertiary stages. The exact cause of the change is unknown but is generally attributed to changes in rainfall, resulting in reductions in stream flows and development of smaller dendritic streams. Continued down-cutting proceeded and drainage patterns eventually cut through the White Hills Gravel deposits formed during early Tertiary erosion processes (Taylor et al. 1996). The White Hills Gravel can be observed in the north of the study area and are locally ferruginised, forming a coarse grained cobble conglomerate (Dahlhaus, 2005). The down-cutting continued throughout to the end of the Oligocene, when changes in base level attributed to marine regressions and transgressions in the Miocene and Pliocene occurred (Taylor et al. 1996).

The region was also subject to extensive block faulting during the mid-Miocene (15 Ma) attributed to changes in regional stresses from extension to compression, as the Australian Plate changed direction of movement (Dahlhaus et al. 2005b). The Pliocene marine transgression and regression about four million years ago, resulted in the deposition of marine sediments (Moorabool Viaduct Formation) within the target area consisting of gravel, sands and silts (LCC, 1976). Volcanism also commenced with the Pliocene marine transgression/regression, forming the Newer Volcanics in the region. Volcanic flows are present in the target area and is observed both above and below the Pliocene sands (Dahlhaus, 2005).

Uplift followed the deposition of the Pliocene sands in the area and is attributed to movement on along the east-west Enfield fault, which is located in the target area (Dahlhaus, 2005). The result was down-cutting of the uplifted block, which resulted in the current dissected landscape. It also accounts for the remnant Neogene gravel caps which are observed on the hill tops in the region (Dahlhaus, 2005). Groundwater movement within the gravel caps (Moorabool Viaduct Formation) caused extensive ferruginisation and silicification. In some areas uplift prevented the outpouring of basalts of the Newer Volcanics and gave some measure as to the extent of uplift. Many river valleys were also changed as a result of lava flooding of drainage lines and thus, altered the current drainage divide to its current location north of Ballarat (Taylor et al. 1996).

2.2 STRUCTURAL GEOLOGY

The Illabarook salinity target area is characterised by a multitude of structural features, which can be attributed to its diverse tectonic history (Figure 2-1). Structures within the Palaeozoic (Ordovician) sedimentary rocks of the Ballarat region show a north-south trend, with steeply dipping strata to the east and west (Finlay and Douglas, 1992). The Palaeozoic bedrock has undergone significant deformation during the Benambran Orogeny and a secondary but much weaker deformation during the Tabberabberan Orogeny (Gray et al. 2003). The first deformation event was characterised by low grade metamorphism, tight chevron folding, cleavage development, thrusting and faulting, within the Palaeozoic turbidite sequences. The second minor deformational event resulted in the brittle deformation of the bedrock, including faulting and fault reactivation of past-fault/thrust zones. Some deformation and minor faulting has also occurred in Tertiary rocks, as a result of fault movement in the Avoca Fault Zone (Taylor et al. 1996).

The post-Palaeozoic rocks of the region are generally undeformed except for those locally deformed, due to fault movement (i.e. the Avoca Fault Zone). This suggests that the Benambran and Tabberabberan Orogen's, resulted in the cratonisation of the area and relative tectonic stability. The break-up associated with Australia and Gondwana is however reflected in the present day distribution of the Tertiary rocks. The presence of north-west trending dykes and the Moorabool Viaduct Formation (Neogene) on hilltops suggest the elements of rifting and fault reactivation, may have helped shape the Tertiary Landscape. Uplift events in the Tertiary are noted by the presence of Moorabool Viaduct Formation and older Newer Volcanic flows, which have elevation and dip contrasting to that of younger Newer Volcanic flows (Taylor et al. 1996). The Enfield fault can be attributed to Tertiary uplift events and the effects of which are visible in the study area. The Enfield fault is believed to have influenced fluvial drainage, the landform of the Western Uplands, the distribution of the uplifted plains and deposition from shallow marine incursions (Phillips et al. 2003).

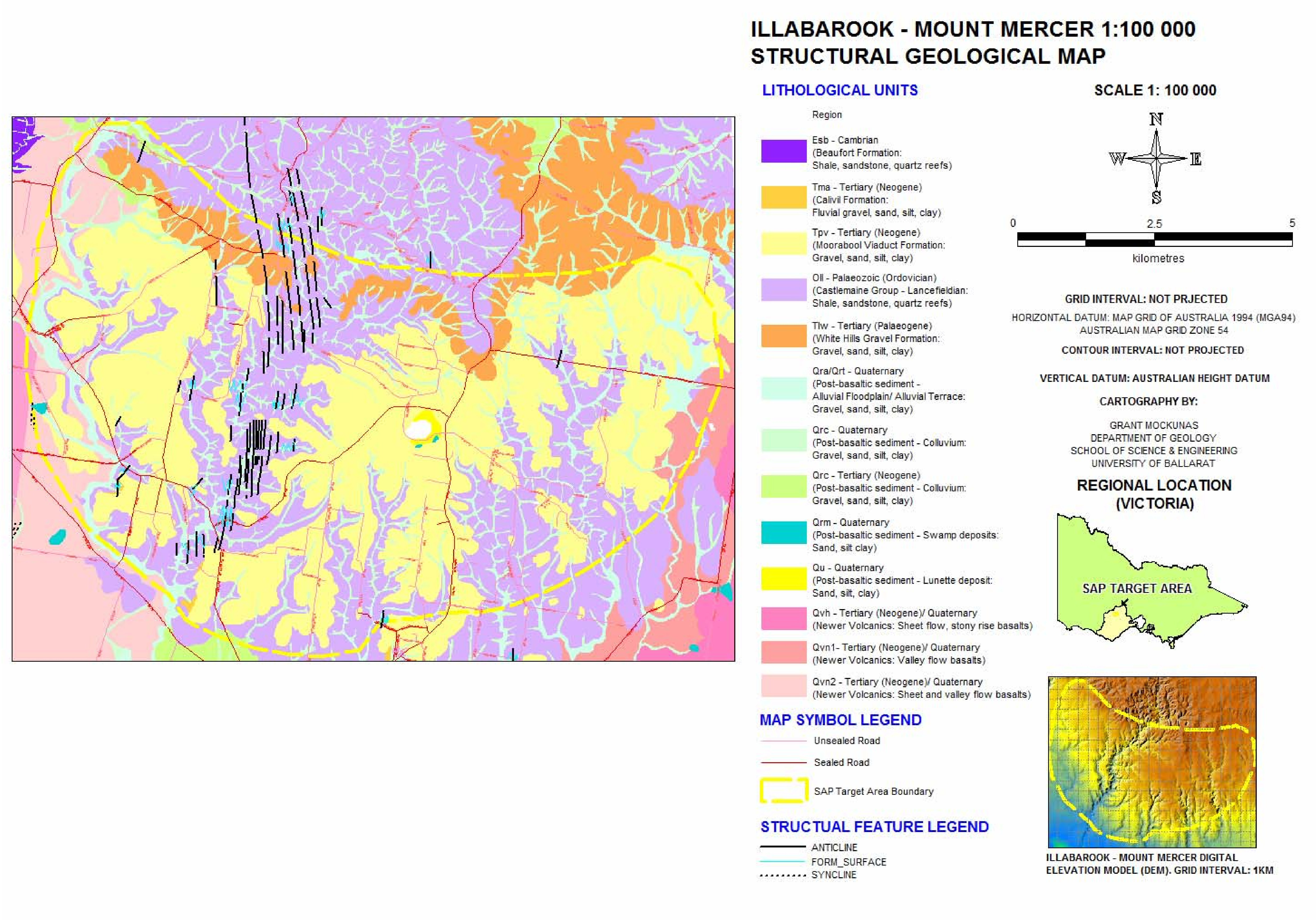


Figure 2-1 **Structural geology of the Illabarook salinity target area.**

2.3 STRATIGRAPHY

The stratigraphy of the Illabarook target area is comprised predominantly of a Palaeozoic basement, with overlying Tertiary sediments and Newer Volcanics. The area is located within the Ballarat 1: 100 000 Geological Map Sheet and the geological descriptions are detailed in the geological report by Taylor et al. (1996). The geology of the Illabarook study area is illustrated in Figure 2-2.

Initial investigations into the geology and stratigraphy of the region were sparked by the discovery of gold at Buninyong and Ballarat in 1851, with subsequent mining and exploration extending into many parts of the study area. Early mining exploits focused on the coarse alluvial gold that was readily found along creeks and drainage lines in the region. This was followed by the mining of 'Deep Lead' or ancient riverbed deposits and hard-rock mining of quartz reefs (Dahlhaus, 2005). As a result of mining and exploration in the region a number of stratigraphic investigations where undertaken in the area.

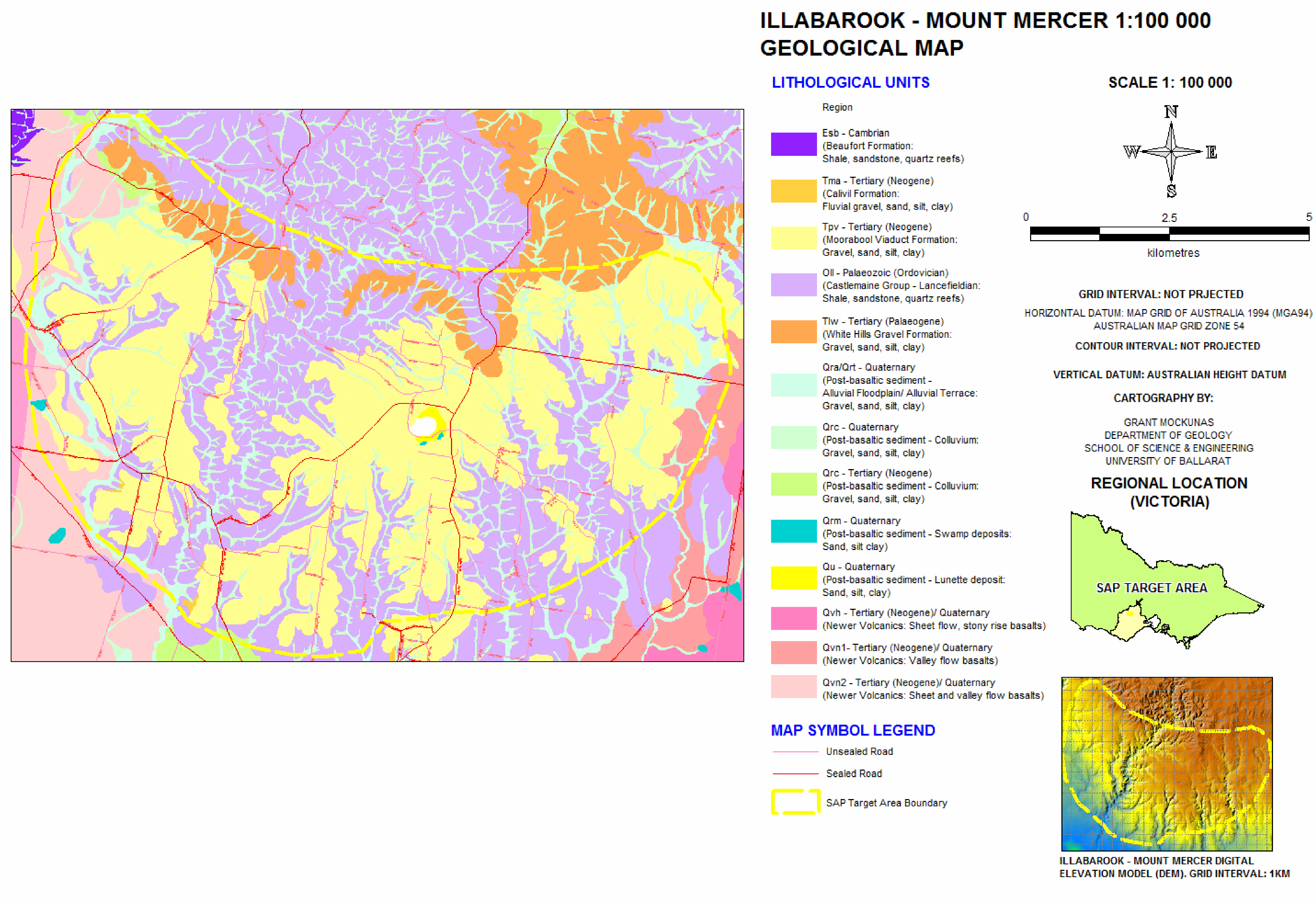


Figure 2-2 **Geology of the Illabarook Salinity Target Area.**

2.3.1 **Palaeozoic**

The Palaeozoic is primarily represented in the study area by the Ordovician age Castlemaine Supergroup which forms the bedrock of the Bendigo Zone. The Saint Arnaud Group occurs just outside the target area to the north-west and are Cambrian in age and the Devonian granitic rocks discussed in the previous section are not found in the study area itself (Taylor et al. 1996).

2.3.1.1 *Castlemaine Supergroup*

The Palaeozoic bedrock is comprised of thick sequences of deep marine sedimentary rock, characterised by greywackes and sandstones with features typical of those generated by deposition from turbidity currents (Taylor et al. 1996). The group is typified by an abundance of graptolites, which occur in thin black shales throughout the zone (Fergusson and VandenBerg, 2003). The average thickness of the entire Castlemaine Group is approximately three kilometres, with bedding thicknesses ranging from less than a metre to tens of metres (VandenBerg et al. 2000).

Individual turbidite sequences are characterised by sedimentary features including flame structures, rip-up clasts, Bouma sequences and cross-lamination/laminations at the top of bedding. Interbedded with the turbidite sequences are thick occurrences of massive hemipelagic black shale (Taylor et al. 1996). Sandstone grains consist predominantly of clear plutonic quartz, with polycrystalline metamorphic and vein quartz grains also evident (VandenBerg et al. 2000).

The graptolite rich black shales of the Castlemaine Group are important for age correlation and allow for subdivision into biostratigraphic zones. The Early and Middle stages of the Ordovician can be split into thirty zones which have been grouped into six stages. These include the Lancefieldian, Bendigonian, Chewtonian, Castlemainian, Yapeenian and Darriwilian respectively. Each of these stages are characterised on there particular fossil characteristics (Fergusson and VandenBerg, 2003). Only the Lancefieldian (Oll) outcrops in the study area.

Oll – Lancefieldian

The Lancefieldian (Oll) is represented in the area by deep marine sediments, generally sand rich turbidite facies, moderate to well sorted and composed of variably rounded of grains, with feldspar and lithic fragments (Figure 2-3). Grains are predominantly found within a quartz silt or clay matrix (Taylor, 1996a). Sediments exhibit local faulting and upright, tight chevron folding and localised strong cleavage (VandenBerg et al. 2000).

Figure 2-3 Palaeozoic (Ordovician) sediments of the Lancefieldian (Castlemaine Supergroup).

(Photo: Road cutting, Cape Clear – Rokewood Road, Illabarook)

2.3.2 Cainozoic

Early Tertiary deposits flank hillsides of Palaeozoic bedrock and are comprised predominantly of fluvial material, derived from the Mesozoic Palaeosurface. Middle to late Tertiary sediments including marine sediments occur and are the result of marine incursions from the south. Quaternary deposits are chiefly represented in the area by the Newer Volcanics and are comprised principally of basaltic lava flows. A number of alluvial, colluvial and fluvial deposits associated with post-volcanic drainage systems have also developed in the area (Taylor et al. 1996).

2.3.2.1 *Palaeogene/Neogene*

Tlw – White Hills Gravel

The White Hills Gravel Formation consists of coarse fluvial gravels that are generally composed of well rounded vein-quartz pebbles (Figure 2-4). The deposits are located on hills and ridges in the region, with some found on valley slopes (Phillips et al. 2003). The formation overlies the Palaeozoic bedrock with an angular unconformity. The gravel has been deposited in a number of cycles in areas where it can be observed by incisions into previously deposited sediments. The rocks consist of ferruginised coarse grained, quartz cobble conglomerate and have a framework of well sorted, well rounded, vein quartz clasts up to cobble size. Some more angular vein quartz has also been recorded in the framework. This indicates that clasts have been both transported or locally sourced. The matrix is composed predominantly of clay and sand which has been strongly ferruginised or silicified. Sedimentary structures include bedding with discernable stratified layers of both sand and gravel deposits. Broad shallow channels are present within the deposits, the lowermost of which incise the Palaeozoic bedrock. Ferruginised and silicified caps protect a deep weathering profile in areas, particularly the underlying mottled zone and strongly kaolinised pallid bedrock (Taylor et al. 1996).

The unit is believed to have formed in a high energy fluvial environment. Poor sorting of some deposits indicates scree and outwash fan deposits, rather than that of deposition by river transportation (Taylor et al. 1996). Gravels are believed to have been deposited in broad, low-relief but defined valleys. It is important to note that recent studies have suggested that some sediment in particular areas has been reviewed as Pliocene marine and fluvial sediments, rather than that of White Hills Gravel. Revised estimates have suggested that the Pliocene marine shoreline may have extended as far inland as 10 kilometres south of Buninyong (Phillips et al. 2003).

Figure 2-4 White Hills Gravel.

(Photo: Berringa Road., north of Illabarook)

Tma – Calivil Formation

The Calivil Formation is delineated as the deposits lying at the base of large Tertiary valleys, which have been subsequently filled by younger depositional units. The unit has been referred to as 'Deep Leads' when covered by Newer Volcanics lava flows. The proto-divide is believed to have been the headwaters for the Calivil Formation depositional river system, with dendritic tributaries leading into major Leads to both the north and south of the divide. The south flowing Leads which are observed in the study area extended up to 45 kilometres south of the proto-divide, before meeting the palaeoshoreline of the Miocene sea. Their course was reasonably straight and cut deep, gorge-like valleys, as the rivers made their way to the sea (Taylor et al. 1996).

The Calivil Formation had a long period of deposition extending from the late Eocene and eventually terminating in the Pliocene due to the Newer Volcanic basaltic lava changing the regions drainage systems. The formation is variable due to the multiple cycles of deposition, governed by factors such as eustacy (sea-level variations) and changes in local drainage systems (Taylor et al. 1996).

The Calivil Formation unconformably overlies the underlying strata of the White Hills Gravel and the Palaeozoic bedrock. The sediments are generally located within deep valleys, covered in prebasaltic sediment and older colluvium. The Newer Volcanics cover the Leads by extensive amounts of basaltic lava in localised areas with variable thicknesses. Headwater deposits were generally above the Newer Volcanics and are covered in older colluvium or more recent colluvium. The depth and extent of the Deep Leads is variable but an average depth of 2 to 4 metres, with width of 30m has been recorded from previous mining exploits (Taylor et al. 1996).

The composition of the Leads is generally devised of poor to moderately sorted polymitic (composed of lithic fragments) cobbles, pebbles, gravel, sand and clay. In areas silicification or ferruginisation of sediments has occurred due to groundwater processes. Clasts are generally angular to rounded with angular clasts devised from local sources and rounded clasts attributed to recycling of bedrock, vein quartz and the White Hills Gravel. Some material is ascribed to the late Mesozoic palaeosurface and is described as deeply weathered ferruginised and kaolinised material. The framework consists of clasts in a clay and sand matrix, with some plant material (Taylor et al. 1996).

Tpv –Moorabool Viaduct Formation

The Moorabool Viaduct Formation (Tpv) is a late Miocene to early Pliocene (Neogene) unit which was deposited by local marine transgressions from the south (Figure 2-5). It forms thin sheets of ferruginous sand, which has been uplifted and dissected. The unit grades into the Hanson Plain Sand to the south of the study area, forming a pebbly shoreline facies. The sands are covered in areas by the younger basalts of the Newer Volcanics, such as around the Mt. Mercer area (Taylor et al. 1996).

The formation unconformably overlies the Palaeozoic bedrock and in some rare cases on the White Hills Gravel or the Calivil Formation (Taylor et al. 1996). Taylor et al. (1996) suggests that this can be attributed to the erosion of the older Tertiary material such as the White Hills Gravel, resulting in deposition directly on top of the Palaeozoic bedrock. The unit deposits are locally variable in thickness but were estimated by Taylor et al. (1996) between 10 to 30m thick.

The unit is comprised of generally quartzose calcareous sandy clay to coarse grained quartz sandstone. The sandstone is composed of sorted, polished, well rounded vein and granitic quartz grains. The framework is closed and the matrix is composed predominantly of clay. Sedimentary structures evident include bedding that is poor to well bedded, with the coarsest bedding to the south (pebbly) and with stratification and cross-stratification also present. The unit is locally ferruginised or silicified in areas (Taylor et al. 1996). Shelly microfossils have also been identified in the sands but the formation is generally less fossiliferous towards the upper strata (Holdgate and Gallagher, 2003).

Figure 2-5 Moorabool Viaduct Formation – Ferruginous gravel/sand.

(Photo: Imries Lane, Illabarook)

2.3.2.2 *Quaternary*

Qvn1, Qvh, Qvn2 – Newer Volcanics

Significant basaltic volcanism during the Pliocene to Holocene (5 – 0 Ma) formed extensive basaltic lava fields and valley flows, throughout the area (Price et al. 2003). Taylor et al. (1996) describes the stratigraphic nature of lava flows based on geomorphic features, superposition criteria and geophysical attributes. The sequence is divided into four main sequences, three of which are found in the study area and listed below (Taylor et al. 1996):

- **Qvh** – The youngest fresh stony rise flows and have a positive remnant magnetism;
- **Qvn1** – Older valley flows and a negative remnant magnetism; and
- **Qvn2** – Sheet and valley flows with positive remnant magnetism.

The Newer Volcanics extend from the Western District basaltic plains to the Midland areas, were localised plains and valley flows occur (Taylor et al. 1996). Qvn1 flows are associated with the Deep Leads and infilled palaeovalleys (Figure 2-6). Qvn2 flows form extensive sheet flows and can be found in the south-west region of the target area (Cape Clear; Figure 2-7). Qvh flows occur in the west of the target area and comprise of sheet, valley flow and stony rise basalts. Age determination of the flows has placed the units Qvn1 and Qvn2 at between 2.49 and 5.10 Ma (Taylor et al. 1996).

The Newer Volcanics of the region disconformably overlie all older strata. The Qvn1 flows in Deep Lead valleys and sheet deposits, were emplaced before the deposition of the Moorabool Viaduct Formation whereas subsequent lava flows in the region were emplaced after the deposition of the Neogene marine unit (Taylor et al. 1996). The regions drainage was extensively disrupted as a result of lava flows infilling palaeovalleys and resulted in the creation of swamps and lakes in the region (Cupper et al. 2003), and includes marshes formed in depressions on top of flows, with associated lunette (Ql) development (Taylor et al. 1996).

Unit thickness is variable with individual flows metres to tens of metres in thickness, and some deeper flows over 100 metres. Flows consist of fine grained basalt with low porhyricity and conversely, coarse grained highly vesicular basalt. The chemistry of the basalt lava flows is however generally that of porphyritic olivine basalt. Chemical differences between older flows to younger flows mark a stark change from tholeiitic compositions to minor mildly alkalic hawaiites transitional compositions, to younger basalts of nepheline-normative alkalic compositions of basanite, hawaiite and mugearite (Taylor et al. 1996).

The nature of the depositional environment acted as a control on the flow patterns of the basaltic lava flows. Initial flows were generally restricted to the dissected valleys of the landscape, infilling valley areas including the Deep Leads. Following the filling of the valleys lava spilled out to the surrounding landscape, forming sheet flow deposits (Taylor et al. 1996).

Figure 2-6 Qvn1 basaltic flows of the Newer Volcanics.

(Photo: Mount Mercer)

Figure 2-7 Qvn2 basaltic flows of the Newer Volcanics.

(Photo: Imries Lane, Illabarook)

Qrc, Qu, Qrm, Qrt & Qra – Post-basaltic sediment

Following the volcanism of the Newer Volcanics, new drainage systems subsequently developed and sedimentation resumed. River terraces (Qrt; Figure 2-8), river alluvium (Qra; Figure 2-9), colluvium both older and younger (Qrc; Figure 2-10), swamp deposits (Qrm; Figure 2-11) and lunettes (Qu; Figure 2-12), all relate to present deposition from streams, lakes and swamps established post-Newer Volcanics. Some older colluvium may be Pliocene in age but all other deposits extend from the Pleistocene to Recent (Taylor et al. 1996).

The units are of variable thickness with younger units rarely more than a few metres thick. Older colluvium is somewhat thicker, with lava flows causing localised damming of sediment to 50 plus metres in thickness. Colluvial (Qrc) deposits consist of generally massive but occasionally stratified or laminated polymictic to monomictic sand, silt, clay and gravel, which is poorly sorted and has minor rounding of grains. Alluvial deposits (Qra) range from channels and point bars deposits consisting of polymictic gravel and sands, to floodplains consisting of sand, silt and clay. Alluvial deposits may show a degree of sorting and rounding of grains and illustrate sedimentary features such as stratification and laminations but may also be massive. River terraces (Qrt) also have similar consistency to that of alluvial deposits and are likewise, composed of gravel, sand, silt and clay. Lunette (Qu) deposits are generally composed of well sorted, rounded grains of sand and clay, in windblown laminated deposits. Swamp deposits (Qrm) generally consist of clays and some sand (Taylor et al. 1996).

The depositional environment of post-basaltic sediment is attributed to that of the controls of the differing drainage systems across the region. Local streams are generally low energy environments, with low water flow attributed to low rainfall. The development of swamps and lakes due to basalt flows cutting off drainage lines, has also aided in the development of specific sediment deposits (Taylor et al. 1996).

Figure 2-8 Alluvial Terrace deposits at Mount Mercer.

(Photo: Laffan property. Dereel – Mount Mercer Road, Mount Mercer)

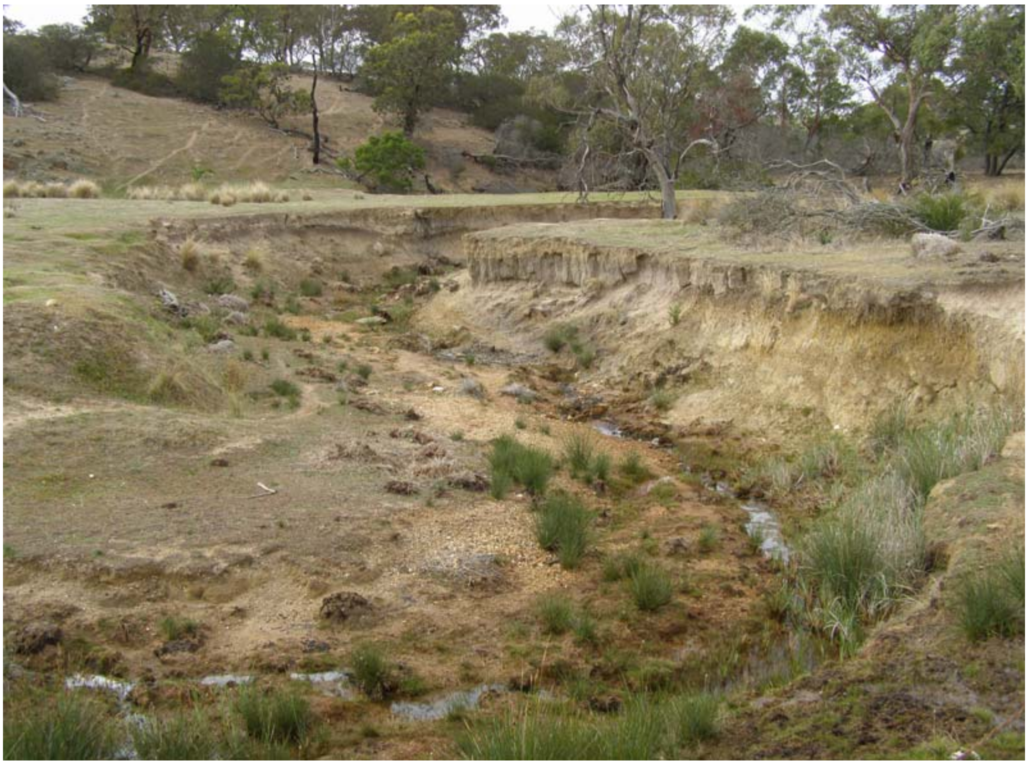


Figure 2-9 Alluvial Flat deposits at Moonlight Creek.

(Photo: Illabarook – Berringa Road, Illabarook)

Figure 2-10 Colluvial Deposits.

(Photo: Golden Plains Shire Property, Recreation Road, Illabarook)

Figure 2-11 Swamp deposits.

(Photo: Dereel Lagoon, Dereel)

Figure 2-12 Lunette deposits.

(Photo: Dereel Lagoon, Dereel. Looking along the lunette marking the eastern boundary of the lagoon)

2.4 GEOMORPHOLOGY

The Western Victorian Uplands (Midlands) and the Western Victorian Plains define the physiographic units which constitute the Illabarook salinity target area. These geomorphic divisions and their associated landforms are important in delineating groundwater systems and provide a basis for modelling salinity management (Nicholson et al. 2006).

2.4.1 **Western Uplands**

The geomorphic unit which constitutes the Western Uplands in the Illabarook are primarily composed of the dissected uplands according to Robinson et al. (2003; Refer Appendix H for descriptions).

Dissected Uplands (Midlands)

The Dissected Uplands (or Midlands) is characterised by undulating hills of low relief, which have been dissected by broad valleys forming a dendritic drainage pattern. The drainage trends parallel to strike of bedrock except where controlled by faulting, and north-east or north-west drainage may subsequently develop (Taylor et al. 1996). The current landscape is largely the remnants of the deeply weathered Palaeogene (Tertiary) palaeosurface, with weathering profiles up to 100 metres below surface in the Ballarat area.

Regolith development is variable but secondary minerals such as kaolin clay development, which produce a typically bleached and pallid regolith in Palaeozoic material also form. Groundwater circulation has also influenced duricrust development in the upper regolith, with iron-rich groundwater precipitating to form ferruginous cement (Robinson et al. 2003).

Palaeogene alluvial deposits (White Hills Gravel) form elevated sheets on hilltops and on the upper slopes of bedrock ridges, overlying highly weathered Palaeozoic bedrock. The gravel is an erosional remnant which forms sequestered flat-topped mesas overlying the Palaeozoic bedrock; break-of-slope deposits separating underlying Palaeozoic bedrock and overlying basalt; and broad tablelands fringing the overlying basalt (Robinson et al. 2003).

More extensive sand plains (Moorabool Viaduct Formation) cover the margins of the Illabarook salinity target area across the southern verge of the Dissected Uplands. The sand has been strongly ferrunginised by groundwater processes, resulting in iron-cemented duricrust development. The unit has undergone extensive soil erosion as a result of vegetation removal (Taylor et al. 1996).

The Newer Volcanics are characterised by eruption points including prominent composite cones, lava cones and low shield volcanoes. The most relevant is Mount Mercer which is a moderately inclined low cone, which has in-filled palaeovalleys and formed sheet flow basalts (Robinson et al. 2003).

2.4.2 **Western Victorian Plains (Western Plains)**

The Illabarook area is characterised by volcanic plains with poorly developed drainage and thin regolith development. The plains form part of the Newer Volcanic basalts that extruded onto the landscape during the Late Pliocene and Pleistocene and occur along the southernmost margin of the study area (Robinson et al. 2003).

2.5 HYDROGEOLOGY

Hydrogeological systems within the Corangamite region are based on the Groundwater Flow Systems (GFS) framework discussed in Chapter 3.

In the Illabarook target area four main GFS have been identified according to Dahlhaus (Figure 2-15; 2003b):

i. Intermediate and local flow systems in fractured Palaeozoic sedimentary rocks;
ii. Local flow systems in the Highlands gravel caps;
iii. Intermediate and regional flow systems in the Western Uplands Newer Volcanics; and

iv. Regional and intermediate flow systems in Deep Lead aquifers.

A brief description of the groundwater systems in the Illabarook area, follows (Dahlhaus et al. 2002). Appendix F can be referenced for more comprehensive information regarding groundwater flow system particulars (according to Dahlhaus et al. 2002).

i. Intermediate and local flow systems in fractured Palaeozoic sedimentary rocks.

The movement of water in Palaeozoic units is generally slow, moving through fractured rocks and regolith. The aquifers are unconfined to semi-confined systems, with aquifer type dependent on fractured rock porosity and saprolite (secondary porosity). Hydraulic conductivity through the material is highly variable but considered slow moving, with saprolite from 10^{-5} m/d to 10^{-1} m/d and fractured rock varying from 10^{-5} m/d to 1 m/d. The aquifer transmissivity is highly variable in the low to moderate range, generally less than 50 m^2/d, with a hydraulic gradient moderate to steep in intermediate and local systems respectively. Its flow length is variable but <25km for intermediate systems and <5km for local systems. Recharge estimates are between 40 – 50 mm annually for aquifer systems.

The salinity of the groundwater systems within this unit is variable between 1000 mg/l to 8000 mg/l, and the GFS has a moderate to high salt storage. Discharge occurs at the valley floor, break-of-slope and hillside seeps, with salt load contributions to tributaries via baseflow and surface wash-off.

ii. Local flow systems in the Highlands gravel caps.

The Highland gravel caps in the Illabarook target area include the White Hills Gravel and Moorabool Viaduct Formation. Groundwater movement within the units form local flow systems, with short, localised flow paths that emerge at or near the base of the gravel caps suggesting lateral movement of water along the base of the unit and the underlying Palaeozoic bedrock. It is suggested that some vertical recharge of underlying groundwater systems may also occur.

Aquifer systems in this unit are unconfined to semi-unconfined and confined, comprising of gravels to fine sands, silts and clays (primary porosity) and ferrunginised or silicified rock (secondary porosity). The hydraulic conductivity is highly variable and generally unknown, but is estimated to range from 10^{-4} m/d to 10 m/d. Aquifer transmissivity is variable but considered moderate range, generally less than 50 m^2/d with a low hydraulic gradient. Flow length is locally variable and is constrained by the specific geological parameters driving the system, with flow varying from tens of metres to hundreds of metres and possibly several kilometres in sub-crop, covered by overlying basalts. Approximate recharge rates of the aquifer system are unknown.

The salinity of the local systems is approximated between 1000 mg/l and 10 000 mg/l, with a moderate salt store. The discharge area is generally located at or near the margins of the unit, with salt exported via run-off from discharge areas. The salt therefore impacts both the immediate discharge area and may affect other areas, via surficial relocation of salts.

iii. Intermediate and regional flow systems in the Western Uplands Newer Volcanics.

Groundwater flows through fractured and weathered rock (secondary porosity) and clayey soils (primary porosity), at highly variable rates. Some leakage is postulated to occur into underlying Deep Lead GFS. The aquifer systems are unconfined to semi-unconfined, with variable hydraulic conductivity from 10^{-3} m/d to 10^{2} m/d in fractured rock and 10^{-6} m/d to 10^{-2} m/d in soils. The hydraulic gradient is low for intermediate systems and very low for regional systems. Flow length is estimated at less than 10 kilometres for intermediate systems and greater than 50 kilometres in length, along palaeovalleys.

The groundwater salinity is generally in the range of 1000 mg/l to 10 000 mg/l, with a moderate salt store. Saline discharge is prominent at swamps, drainage lines, broad depressions and at the boundaries of basalt flows.

iv. Regional and intermediate flow systems in Deep Lead aquifers.

The Deep Lead systems occur in palaeovalleys as regional groundwater systems, but little is known about the effect such systems have on salinity. Aquifer types are confined and may outcrop at headwater areas with aquifer systems comprised of gravel, sand, silt and clay. The hydraulic conductivity of the aquifer systems is unknown but estimates range from 10^{-2} m/d to 10^{2} m/d. Transmissivity of aquifers is estimated to be less than 1000 m^2/d, with a low to very low hydraulic gradient and flow length of up to 30 kilometres. Recharge estimates of the system are unknown.

Salinity values of the regional groundwater systems are in the range of 1000 mg/l to 8000 mg/l, with a moderate to high salt store. Saline discharge generally occurs at the valley floor, break-in-slope and on hillside seeps, with salt contributed to streams via baseflow and surficial wash-off.

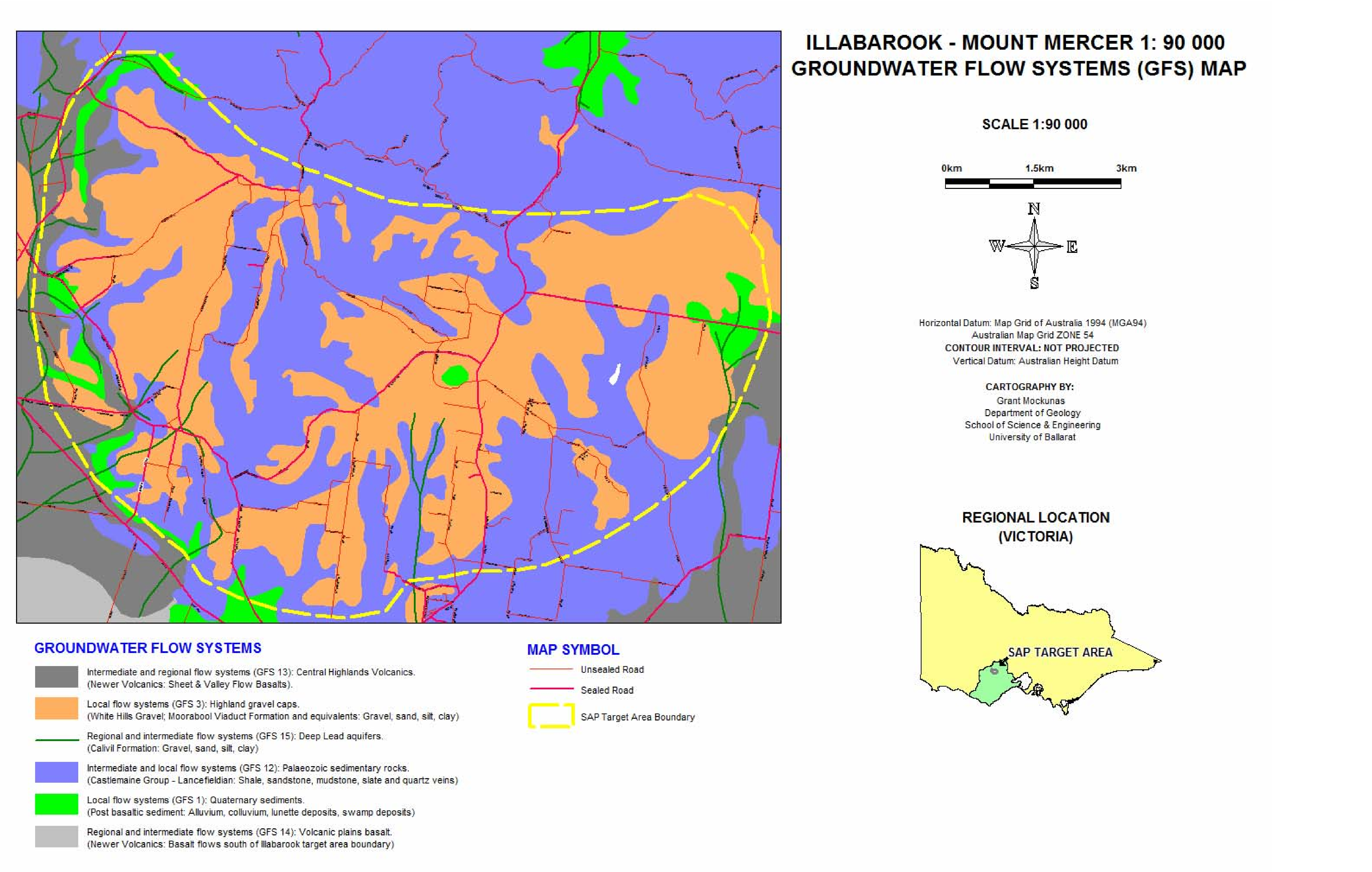


Figure 2-13 **Groundwater Flow Systems (GFS) of the Illabarook salinity target area.**

3 THE SALINITY PROBLEM – A LITERATURE REVIEW

3.1 INTRODUCTION

Salinisation and salinity processes have developed as a result of both natural and human influences in the evolution of contemporary Australian landscapes. The degree to which the current salinity at a particular locality is attributed to natural processes or human influences is unknown and thus, investigative processes and conceptual modelling are essential in understanding cause and effect scenarios. In the Australian landscape the origins and processes of the current salinity may be understood by investigating the origins of salt, the influence of hydrology, groundwater flow systems (GFS), conceptual models of salinity processes and the history of land-use changes.

3.1.1 **Salinity: Types & Processes**

Salinity refers to the presence of excessive concentration of salts in soils and in water (Baragwanath, 1993). Salts occur naturally in the subsoil and in groundwater systems of the Australian landscape (Walker et al. 2003). This presence of natural salts is known as primary salting, which can be observed in salt marshes and salt flats (including naturally saline lakes such as Lake Corangamite; Baragwanath, 1993). The salts originate principally from deposition of oceanic salt contained in rain and transported by wind. These naturally occurring salts are concentrated in groundwater and subsoils through evaporation and transpiration processes (NLWRA, 2001).

Natural salts are mobilised and concentrated in the landscape as a result of changes to land use (Walker et al. 2003). The effects of human activities such as clearing of native vegetation, and the introduction of agriculture and irrigation, can hasten or initiate salt accumulation and concentration, and is termed secondary salting (Baragwanath, 1993). The general cause is an excess of water entering the water table, resulting in the mobilisation of natural salts and their subsequent discharge at the land surface (NLWRA, 2001). In Victoria, Baragwanath (1993) states that salting of soils and water can be attributed to rising watertables, resulting from anthropogenic activities. The causes and effects of secondary salinity can be categorised by processes such as dryland salinity, irrigation salinity, stream salinity and groundwater salinity (Baragwanath, 1993).

Dryland salinity is inclusive of all areas where dryland agriculture (no irrigation) is being conducted and salting is occurring, presumably as a result of clearing of native vegetation and subsequent increased groundwater recharge (Figure 3-1; Baragwanath, 1993). Increased recharge is attributed to a change in land use, since crops and pastures use less water, although factors such as climate, land cover, soil characteristics, salt stores, hydrogeology and geomorphology of the particular landscape, will determine the effect of increased recharge into groundwater systems (Coram et al. 2001).

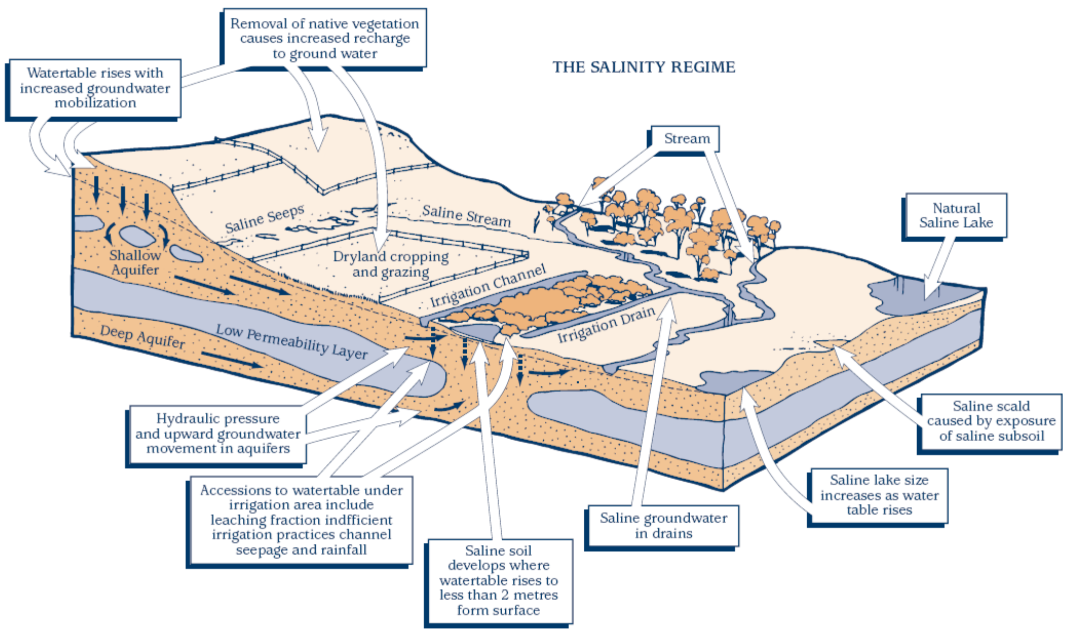


Figure 3-1 The general processes driving dryland salinity.

(Source: NDSP, 1998)

Dryland salinity in Australian landscapes is usually observed as either seepage or scalds. Scaled areas are caused by wind or water erosion of topsoil, from soils with saline or sodic subsoils and little or no vegetative cover. A saline seep on the other hand is the result of saline groundwater discharge at or near the surface. The location of the seep is governed by influential factors such as climate, topography, land cover, geology, geomorphology and hydrogeology. Increased land denudation can lead to greater groundwater flows and accumulation of salts, at discharge areas (Ghassemi et al. 1995).

Irrigation salinity is the result of increased recharge into groundwater systems and a subsequent rise in watertables, as a result of ineffective irrigation practices. Baragwanath (1993) states that seepage from irrigation channels and poor surface drainage contribute to a general rise in watertables. Irrigation efficiency is primarily determined by the operational aspects of farm irrigation (i.e. irrigation method – sprinkler, spray, drip, furrow, etc.), although physical landscape controls (i.e. climate, hydrogeology, etc.) also influence recharge rates and the development of salinity. In addition, the socioeconomic conditions of a particular area have major bearing on the effect irrigation will have on salinity processes (Ghassemi et al. 1995).

Rising watertables of saline shallow aquifer systems due to increased recharge not only results in land salinisation, but an increase in stream salinity (Ghassemi et al. 1995). This increase in stream salinity can be attributed to run-off from salinised land and increased saline groundwater discharge directly into waterways. Cyclic salt has always contributed some amount to stream salinity, but an increase in stream salinity is attributed to a change in the salt balance of a catchment. Stream salinity can have a detrimental effect on the ecological health of wetlands, swamps and lakes, and contaminate urban water supplies (Baragwanath, 1993).

Almost all groundwater contains some degree of soluble salt and the concentration varies by orders of magnitude depending on the aquifer system. The Victorian Auditor General’s report on salinity suggests that increased groundwater salinity can be attributed to factors including contributions from irrigation areas and saline streams, unsealed water channels and reservoirs, clearing of vegetation (natural/remnant), weathering of surface materials, rainfall infiltration through saline subsoils and effects of geology, geomorphology, climate and hydrogeology (Baragwanath, 1993).

3.2 SALINITY AND THE AUSTRALIAN LANDSCAPE

The natural accumulation of salts in soils and water of the Australian landscape can largely be attributed to the continent's geological, geomorphological and climatic history. Naturally occurring or primary salinity has been identified over approximately 29 million hectares across Australia. This area comprises of 14 million hectares of salt marshes, salt flats and salt lakes, which are all associated with highly saline groundwater systems and internal drainage. The further 15 million hectares is land in arid and semi-arid regions, which have naturally saline subsoils but no groundwater within them (Ghassemi et al. 1995). At present approximately 5.7 million hectares of land is affected or at risk of secondary salinity (dryland salinity), as a result of human influences on the landscape (Figure 3-2). It is estimated that by 2050 that this number could increase three-fold from 5.6 million to 17 million hectares (Walker et al. 2003).

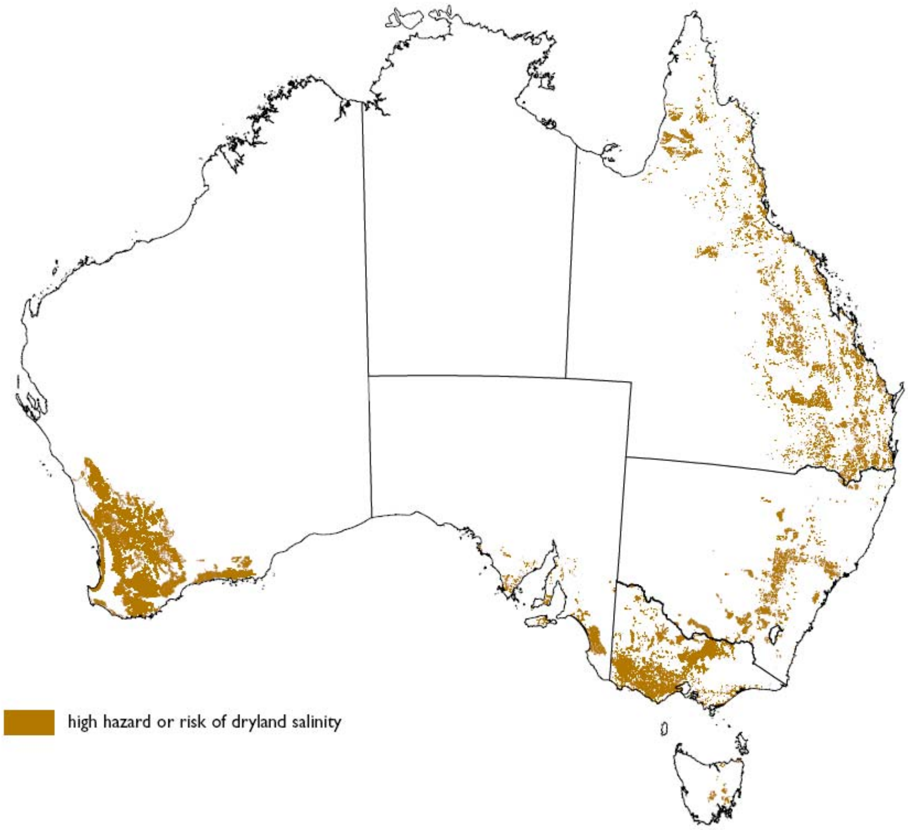


Figure 3-2 Areas at high risk from dryland salinity on the Australian Continent.

(Source: NLWRA, 2001)

The largest areas of dryland salinity are in the south-west of Western Australia. In this region dryland salinity coincides with those agricultural zones in which natural vegetation has been replaced with agricultural systems that use less water than previously. It is estimated that over four million hectares of land is at risk in this zone, with groundwater levels still rising. Large areas of dryland salinity and areas at potential risk have also been identified in South Australia, Victoria and New South Wales (NLWRA, 2001).

The need for identifying appropriate methods of management for salinity across the country was discussed in the report, 'National Classification of Catchments for land and river salinity control' (Coram, 1998). The development of this national approach is based on the identification of hydrogeological systems which govern the individual occurrences of salinity. The report provided the basis for a national hydrogeological framework that could be applied in determining probable causes and effects of dryland salinity (Coram, 1998).

In response to the growing salinity crisis, the meeting of Commonwealth and State/ Territorial governments announced a 'National Action Plan for Salinity and Water Quality' (Commonwealth of Australia, 2000). The National Action Plan (NAP) set six main objectives to better engage the growing salinity problem (Commonwealth of Australia, 2000):

- Set targets and standards for natural resource management – Particularly in regard to salinity and water quality. These must include State and Territory involvement at multilateral levels;
- Integrated catchment/regional management plans – To be developed by the community, in 21 regions or catchments that are highly affected by salt. These plans must delineate areas in which if immediate action was implemented, it would greatly help in meeting salinity reduction targets. The State and Territory governments need to agree upon appropriate targets on a basin wide scale and for each catchment or region, within the particular basin;

- Capacity building for communities – Assisting landholders to develop and implement integrated catchment management plans, coupled with support of scientific, engineering and technical aids;
- An improved governance structure – In order to maximize efficiency of investments at a Commonwealth and State/Territory level and provide long term action, including property rights, pricing and regulatory reforms (i.e. for water and land use);
- Clearly articulated roles for the Commonwealth, State/Territory, local governments and the community – To replace the current system of frameworks with a more holistic approach, in which to oversee the implementation of the NAP; and
- Establishment of a public communication program – to support widespread knowledge of the NAP and promote it within the community, in order to further understanding and support.

Contemporaneous with the NAP in 2000, the 'Australian Dryland Salinity Assessment 2000' (NLWRA, 2001) was undertaken under the National Land and Water Resources Audit (NLWRA). The assessment targeted a catchment water balance approach for salinity management. It adopted the hydrological framework based on groundwater flow system (GFS) characteristics, in order to institute appropriate development, monitoring and appraisal of management responses. It provided information on a regional scale of the effects of dryland salinity and has helped identify a number of information gaps and method constraints in the ability to evaluate the situation. The report particularly targets the effect of salinity on biodiversity, infrastructure, agriculture and water resources, thus forming a strategic guide to the management of dryland salinity and development of current understanding on the causes and extent of the problem (NLWRA, 2001).

The assessment was also aimed at facilitating greater natural resource management, by setting a number of key objectives (NLWRA, 2001):

- Greater definition of risk areas and the impact of dryland salinity in Australia;
- Recognition that increases in dryland salinity are likely to continue to 2050, assuming a continued rate of increase and no changes to the current water balance;

- Consideration of the fact that management options and their feasibility are dependent on variable hydrogeological aspects of the Australian landscape and thus, planning should consider this;
- Classification of hydrological landscapes and catchment characterisation using a GFS framework, which seeks to explain differences in salinity problems across catchments and delineate appropriate management options;
- The development of understanding where trade-offs will be required between salinity management and living with the problem; and
- Identification of key monitoring components that track changes in salinity impact over time, in order to determine the effectiveness of particular management options.

The implementation of the NAP will deliver a broad ranging national perspective on the future direction of dryland salinity management at a Federal, State/Territorial, local government and community level (Commonwealth of Australia, 2000).

3.2.1 **Salinity Processes**

In determining the causes, processes and management of dryland salinity, the landscape parameters of geology, geomorphology, hydrogeology, climate and physiography need to be understood. In recognition of this, the GFS classification was developed, where a GFS is defined by Coram et al. (2001) as follows *"Groundwater flow systems characterise similar landscapes in which similar groundwater processes contribute to similar salinity issues, and where similar salinity management options apply."*

3.2.1.1 *Groundwater Systems*

Hubbert in 1940 originally presented the idea of flow patterns, in the context of regional groundwater flow and this was later built upon by Tóth in 1963. Tóth proved that the depth and lateral extent of a basinal aquifer flow was a function of relief and thus, could be segmented into a series of cells or systems that are vertically separated (Figure 3-3; Freeze and Cherry, 1979).

The vertically separated cells which constitute the groundwater flow within a basin are depicted in terms of local, intermediate and regional flow systems. If surface topography is well defined and has high relief, local groundwater systems will form. A local groundwater system has a recharge zone at a topographic high point and discharge zone at a topographic low. If the ratio of basin depth-to-width increases, intermediate and regional flow systems may form. Intermediate flow systems have at least one local flow system between its topographical high point and its topographical low. Regional flow systems are defined by having the recharge area at the basin divide and discharge area at the basin valley (Fetter, 2001).

Tóth made some assumptions, in the construction of a representative groundwater flow model. These included that the flow medium must be isotropic and homogeneous to a specified depth, below which an impermeable basement exists. That flow is restricted to a two-dimensional vertical section, where the topography can be approximated by curves and the water table replicates topographical variation. Finally, the upper boundary of the two-dimensional section is the watertable, the lower forms the basement and the lateral boundaries are the groundwater divides (Figure 3-3; Domenico and Schwartz, 1990).

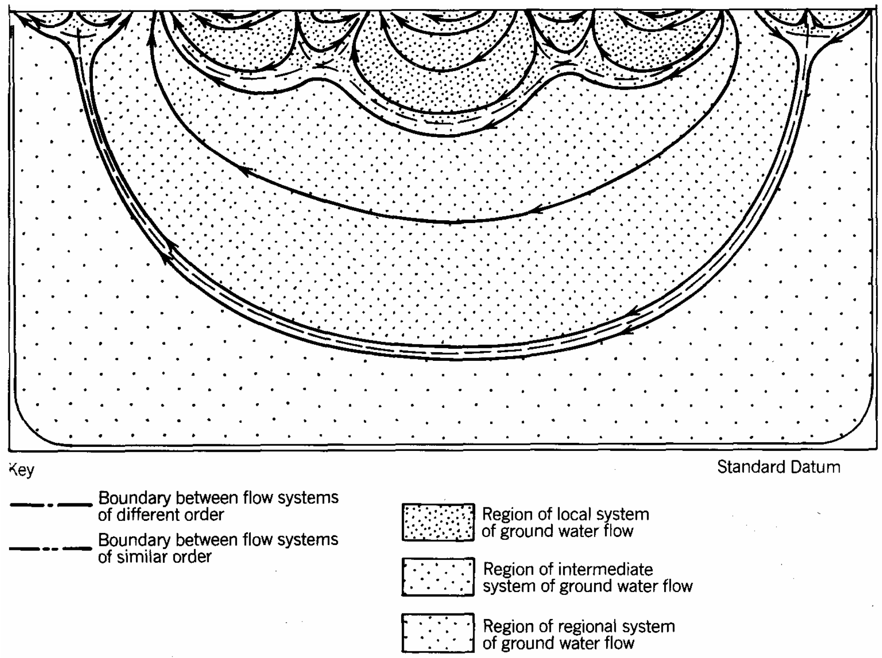


Figure 3-3 Local, Intermediate and Regional flow systems, as defined by Tóth, 1963.

(Source: Domenico and Schwartz, 1990)

In the Australian landscape, knowledge of the effect that the GFS have on salinity processes is important. To understand GFS in the Australian environment, a national catchment classification that categorises groundwater systems was introduced (NLWRA, 2001).

The classification is based on understanding recharge and flow behavior. Flow path lengths, aquifer permeability and pressure gradients are taken into account (NLWRA, 2001). Coram et al. (2000) suggests that the delineation of GFS in the Australian context requires overcoming difficulties including biophysical influences (geology, climate, physiography, soil type/ depth, drainage, etc.), their complexity, the spatial heterogeneity of controlling factors (i.e. structures on sub-regional scales to regional scales), and the influences such as spatial and temporal scales (i.e. interaction between flow systems, variation in salinity extent, etc.). In the catchment classification scheme, GFS are classified as local, intermediate and regional on their spatial extent and influence. This categorization of responsiveness to change in the water balance in turn influences the types of management options available (NLWRA, 2001).

Local groundwater flow systems occur in individual sub catchments within areas of high relief, over distances less than five kilometers (Dahlhaus, 2003a). The local systems have shallow circulation depths, are unconfined, with recharge and discharge areas close together (Coram et al. 2000). They are rapid to respond to increased groundwater recharge, resulting from native vegetation removal or agricultural practices. A rapid rise in the watertable generally results in saline discharge within 30 to 50 years of alteration. The system is quick to respond to any management or remediation practices, and thus management can be applied at farm scale (Figure 3-4).

Intermediate groundwater flow systems generally occur within individual catchments and sometimes flow between smaller sub catchments (Coram and Beverly, 2003). They are intermediate in scale between local and regional systems and normally extend over distances of five to ten kilometers, occurring in foothills and valleys (Coram et al. 2000). The system has a greater storage capacity and generally higher permeability than that of local systems. Increased recharge is slower to take effect, due to the greater lateral and vertical extent of the system.

Discharge will occur within a 50 to 100 year period following clearing of native vegetation (Figure 3-4).

Regional groundwater flow systems have deep circulation depths and recharge and discharge areas occur at a basin scale exceeding 50 kilometers, and are generally confined aquifers overlain by intermediate and local systems (Coram et al. 2000). They have a high storage capacity and a high permeability, resulting in long groundwater residency times. Lag periods between increased aquifer recharge and discharge due to the lateral and vertical extent of the system, delay the effects of anthropogenic changes for periods in excess of 100 years (Figure 3-4). Coram et al. (2000) state that the full effect of native vegetation removal on a regional system, may take thousands of years to become apparent. The scale of regional systems is too great for localised remediation methods, rather a catchment-wide approach is required in order to achieve appropriate management practices.

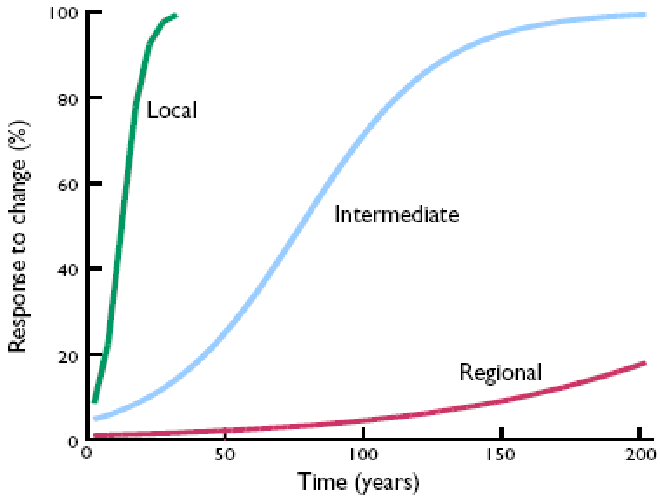


Figure 3-4 The Time – Response characteristics of GFS.

(Source: NLWRA, 2001)

A total of seventeen GFS were delineated in the Corangamite region, based on the classification system (Figure 3-5; Dahlhaus et al. 2002). The underlying assumption is that salinity is caused by increased recharge and a resultant rise in groundwater tables, due to changes in land management over the past 200 years. It is important to note that this assumption does not however, hold true to all areas (the Western Victorian volcanic plains for example) and other factors such as soil water logging and regolith hydrology have effects on salinity (Dahlhaus, 2003a).

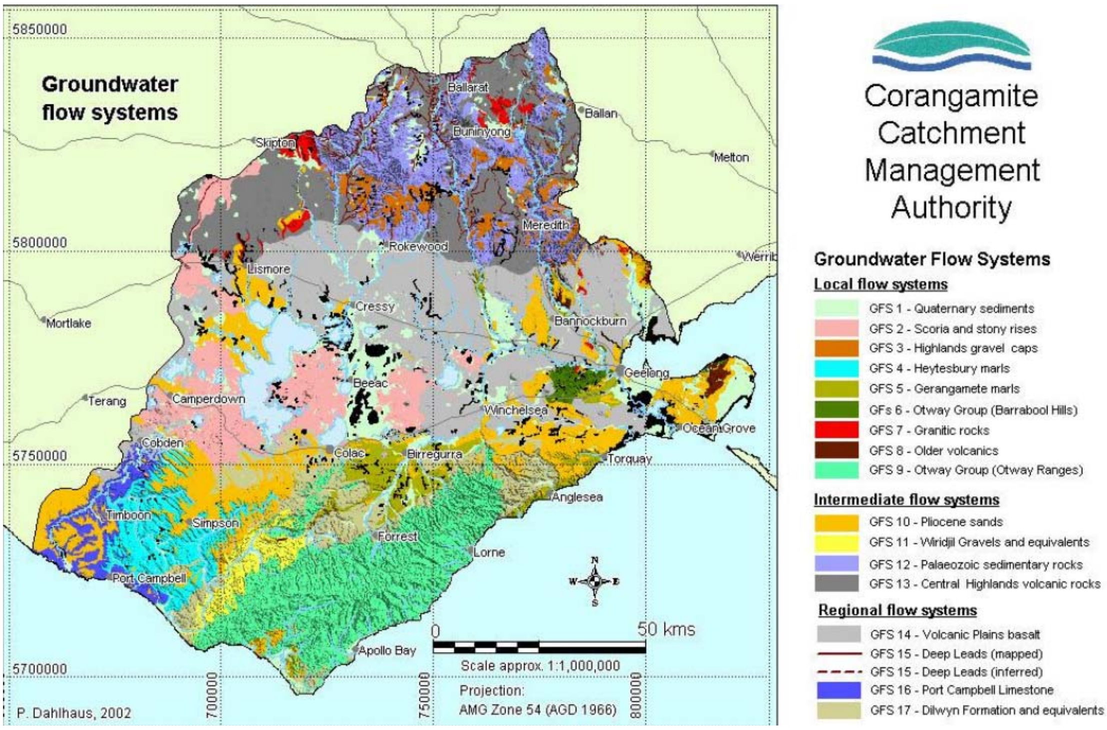


Figure 3-5 **GFS of the Corangamite region.**

(Source: Dahlhaus et al. 2002)

3.3 THE VICTORIAN SALINITY SITUATION

Dryland salinity in Victoria is a growing problem that has an estimated cost of $50 million per year, with over 120,000 hectares of land significantly affected (NRE, 2000). The increase in salt levels in soils and waterways is credited to the changes in land use over the past 200 years, with the effects of secondary salting (dryland salinity), becoming apparent in the 1940’s (Allan, 1996). The extent of secondary salting in Victoria while readily identifiable, is still growing and is expected to grow ten-fold by 2050 (Figure 3-6; NRE, 2000).

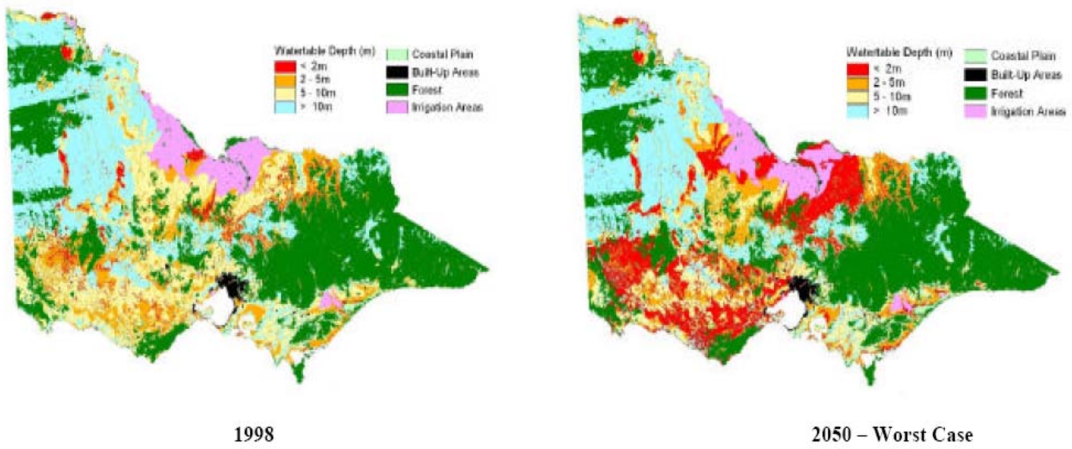


Figure 3-6 **Predicted changes in the extent of shallow watertables likely to cause dryland salinity in Victoria, from 1998 to 2050.**

(Source: Clifton, 2000)

Primary salinity has been present in the Victorian environment for thousands of years (Allan, 1996). It has developed by natural chemical and physical processes and is exemplified by the geomorphic evolution of naturally saline lakes and streams (Dahlhaus et al. 2005a). Geomorphic features and archaeological findings of human occupation in south-west Victoria, provide evidence of primary salinity in the region (Dahlhaus and Cox, 2005). In northern Victoria primary salinity is observed at locations including Lake Tyrrell and Pink Lakes, and form an essential component of the northern Victorian landscape (Macumber, 1991).

The rising trend of salinity in the Victorian landscape is attributed to the general rise in groundwater levels, which leach salts out of the soil and concentrate them within land and water systems. It is believed that the dynamic balance of groundwater systems has been disturbed by over 100 years of changed land management practices. The result has culminated into a salinity problem that is both insidious and invasive, with multiple inter-related effects on the landscape (Cameron, 2001).

The Auditor-General's report (Cameron, 2001) recognised that the factors which govern salinity are controlled by the landscape and GFS, operating within the particular catchment area. To coincide with the NAP and in recognition of Victoria's growing salinity problem the Department of Natural Resources and Environment (2000) released 'Victoria's Salinity Management Framework: Restoring our Catchments' (NRE, 2000). It was intended to compliment the NAP and update the previous state salinity strategy 'Salt Action: Joint Action (1988).' The revised salinity framework set new targets in order to measure progress:

- By 2005, there would be monitoring sufficient as to account for the impacts of groundwater rise and river salinity;
- By 2005 zones of recharge of a critical nature to be identified, with targets to have 50% of these revegetated by 2015;
- By 2005 a quarter of agricultural production will be produced from natural resources, managed at a sustainable level;
- By 2015 a real reduction in the impacts in terms of the environment and salinity, should be achieved;
- By 2015 investigation and practical reduction of rising groundwater, within the riverine environment and key wetlands; and
- Participation in Murray Darling Basin salt inception schemes, by 2015.

In order to accomplish the projected targets the state salinity framework set about developing a number of objective strategies. These included (NRE, 2000):

1. Partnerships for an integrated catchment management approach, to ensue better understanding of surface and groundwater processes at catchment scales. The development of nine Catchment Management Authorities (CMA) across the state facilitated the establishment of regional catchment strategies, in conjunction with single-issue advisory groups. Thus the CMA's provide an interface between the government and community groups, in the development of catchment strategies and their implementation.

2. The development of an understanding of catchment processes and implementing appropriate management actions, relevant to the individual catchment. The framework

indicates that building a current knowledge base, continual adaptation of strategies and plans and maximizing ecologically sustainable development, are key to advancing understanding of catchments.

3. The establishment of a skills base and diversifying the capacity for change, enabling more effective decision making to address the target problem. This is achieved by information about the resource base and its effect on long-term profits; knowledge of the impacts of management practices; greater understanding of the costs/benefits in the economic/environmental context for different management systems and the expectations of government/ community in terms of land management.

4. Greater efficiency in water use and regional growth. This recognises that water is a finite resource and balances must be reached between demand and environmental assets such as river health and biodiversity. It also recognises the entitlement holders and gives future planning directions, as well as encouraging more efficient water use practices.

5. Salinity management in the Murray Darling Basin system. This is a renewed support for the Murray Darling Basin Salinity and Drainage Strategy, including the need for a revision of the strategy. This is hoped to be achieved by the development of revised salinity management plans and 'end of valley' targets, in conjunction with CMA's, the local community and Natural Resources and Environment (NRE). The framework also outlines the development of joint inter-governmental salt inception schemes.

In the Auditor-Generals report (Cameron, 2001), NRE suggest that it is too late to control or eradicate the effects of salinity in Victoria. Rather, salinity needs to be recognised as part of the Victorian landscape and emphasis placed on salinity management practices. Therefore a balance between catchment management and achievable outcomes across a broad spectrum of stakeholders is needed, in order to maintain an effective focus on salinity (Cameron, 2001).

3.3.1 Salinity in the context of Corangamite CMA

The Corangamite CMA region covers 13,340 square kilometers in south-west region of Victoria and is one of ten in the state (Figure 3-7). The region has been subject to a number of studies at a Federal, State and catchment level, in order to further understanding of the salinity processes at work. At present mapped primary and secondary salinity covers 20,538 hectares of land. Furthermore, it is evident that the effect of salinity within the Corangamite region is still spreading and will continue to do so in the foreseeable future (Dahlhaus et al. 2005a).

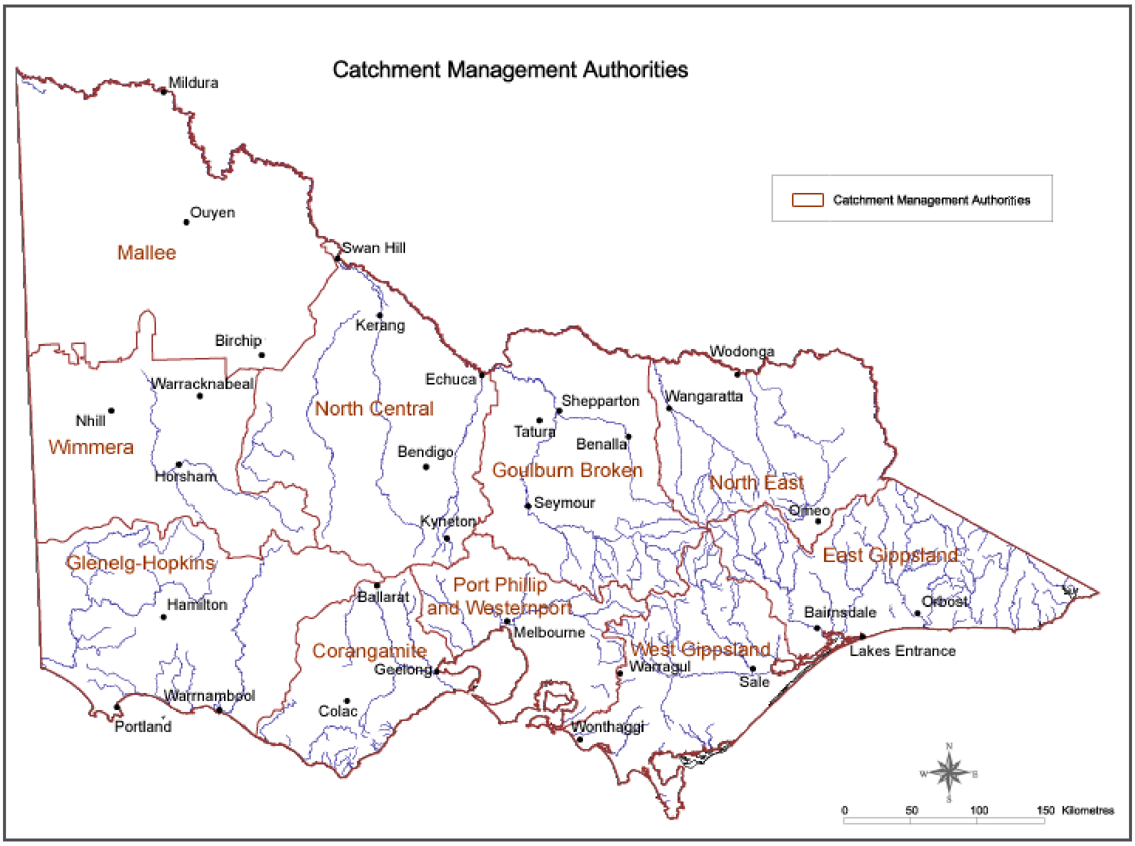


Figure 3-7 Victorian CMA regions.

(Source: www.dpi.vic.gov.au, 2007)

Primary salinity has played a part in the region for at least 20,000 years, through natural physical and chemical processes. Shallow groundwater tables have formed a natural part of the landscape within areas of the catchment and have remained relatively unaltered by land use change. Changes in soil waterlogging and regolith hydrology (and are not rising watertables) are responsible for the spread of secondary salinity in certain portions of the landscape. Secondary salinity is recognised as one of the symptoms of land-use modifications, where excessive water (due to native vegetation removal) has resulted in soil waterlogging and increases in shallow temporal water flows in the near-surface environment (Dahlhaus et al. 2005a).

It is understood that humans have been present for at least 35,000 years in the Corangamite CMA region. A number of Aboriginal communities were present in the area at the time of the arrival of Europeans and were maintained due to the diversity of food provided by the region's rivers, lakes and estuaries. Historical documented accounts of early explorers use the word 'salt' to describe lakes and creeks, and aid in understanding the presence of primary salinity in the region (Dahlhaus et al. 2005a). However, the water quality of many rivers, streams, lakes and wetlands has declined since the arrival of Europeans. The salinity of major rivers in the region including the Barwon, Leigh and Woady Yaloak are in excess of targets set under the Murray Darling Basin Commission benchmarks (Dahlhaus et al. 2005a).

The understanding of the ratio of primary:secondary salinity within the Corangamite CMA area is imprecise and attempts have been made in order to quantify the proportion of each. Pillai et al. (2003) advise of two contrasting views which propose that primary salinity constitutes twice the area than that of secondary salinity and conversely, primary salinity constitutes one-third of the saline area. The extent of the region that comprises primary/secondary salinity is postulated to be increasing in certain areas of the Corangamite CMA. A 2005 mapping survey covered 1300 saline sites across the Corangamite region of which 500 were examined in detail, based on vegetation indicators and photogrammetric techniques. The details of the mapped areas are listed in Table 3-1 (Dahlhaus et al. 2005a).

Type of Salinity	Area (ha)	% Mapped Area
Primary	957.5	18.55
Secondary	844.3	16.36
Primary & Secondary	3316	64.26
Undetermined	42.6	0.83
TOTAL	5160.4	100.00

Table 3-1 Primary/ Secondary salinity mapping during the 2005 period, for the Corangamite CMA.

(Source: Dahlhaus et al. 2005b)

In the 'Australian Dryland Salinity Assessment 2000' (NLWRA, 2001) the Corangamite region was targeted as a high risk area for the development of dryland salinity. It modelled the possible impacts of salinity on various assets of the region, to varying degrees of severity. The predicted effects until 2050 are listed as follows (NLWRA, 2001):

- Greater likelihood for future impacts on grazing land, with some effect on cropping land;
- Probable impacts on shallow water tables, including effects to infrastructure (i.e. roads, buildings, rail, etc.);
- An increasing trend in shallow water table area under wetlands (including Ramsar wetlands) within the region;
- By 2050 approximately 40% of wetlands are to be situated in landscapes with shallow watertables;
- Increases in rare or threatened flora/fauna species habitat, situated within shallow water table areas; and
- A suggested two- to three- fold increase in the length of stream or reservoir/lake/wetland perimeter, located in areas of shallow water table over the next 50 years. This has the potential to result in increased groundwater discharge into streams, greater salt wash off and increased stream salinity and salt load.

The accuracy of these predictions have to be viewed in a general sense, as they are based on a state-wide dryland salinity hazard assessment. However regardless of the scale of possible future effects, it is clear that land salinisation is still spreading and will continue to do so in the foreseeable future in the Corangamite region (Dahlhaus et al. 2005a).

Salinity in the Corangamite CMA region is governed by a number of factors including geology, physiography and climate, which have profound influence on salinity driving mechanisms. These parameters cannot be changed as readily as to those influenced by human actions, such as land use practices (Dahlhaus et al. 2005a).

Geological influences in the Corangamite CMA have varied over time, as the landscapes have evolved over the past 600 million years. The geological processes have helped shape and develop soils, ecosystems and the mechanisms/diversity of groundwater flow systems in the area.

Similarly, the climate of the Corangamite region determines the availability of water for groundwater recharge, and the rate of accumulation of evaporative salts in the soil profile. At times of low rainfall and high evaporation, there may be a greater concentration of salts in soils and the opposite during periods of high rainfall and low evaporation (Dahlhaus et al. 2005a).

3.3.2 **Corangamite Salinity Action Plan (SAP)**

The Salinity Action Plan (SAP) for the Corangamite catchment region, was developed in response to the NAP, the ‘Victorian Salinity Management Framework’ and the ‘Corangamite Regional Catchment Strategy 2003 – 2008.’ The plan is supported by nine background reports detailing the method applied in planning, data applications and data manipulation and the use of scientific logic (Nicholson et al. 2006).

The SAP was produced with an improved knowledge of salinity processes; greater definition of the salinity problem and its context within the scope of natural resource management; and emphasis on the relevance of asset protection, co investment and partnership building.

A seven-step approach was used in the development of the SAP. The steps were designed to produce a plan that could be adapted and modified as new information became available. Each step in the process involved a variety of tools, models and frameworks by which to construct the plan. The seven steps according to Nicholson et al. (2006) are:

1. Identify target locations using an asset based approach;
2. Determine the management actions and implications involved;
3. Identify asset managers were assets are at risk;
4. Consult with asset managers;
5. Undertake a Cost-Benefit analysis for the proposed target locality;
6. Determine the appropriate research, catchment health sites and the types of monitoring systems required; and
7. Devise a suitable implementation scheme.

The asset-based approach is the tool preferred by Federal and State governments by which to delineate and prioritise target locations. Recognition of key assets that are threatened by salinity within an area form the basis for this process. The SAP thus incorporated a consultation procedure involving asset managers who are directly threatened by salinity or whose participation was necessary in appropriate salinity management. The consultation approach identified the capacity and willingness of asset mangers to address the salinity problem, as well as the extent of technologies and techniques available, and the ability to target where salinity treatment is needed (Nicholson et al. 2006).

The SAP delineated twelve target areas using this approach (Figure 3-8; Nicholson et al. 2006).This was based on three key components, the disaggregation of landscape for consistency in methodology; salinity risk assessment based on a variety of asset classes and an analysis of trends in salinity values (Dahlhaus, 2003a).

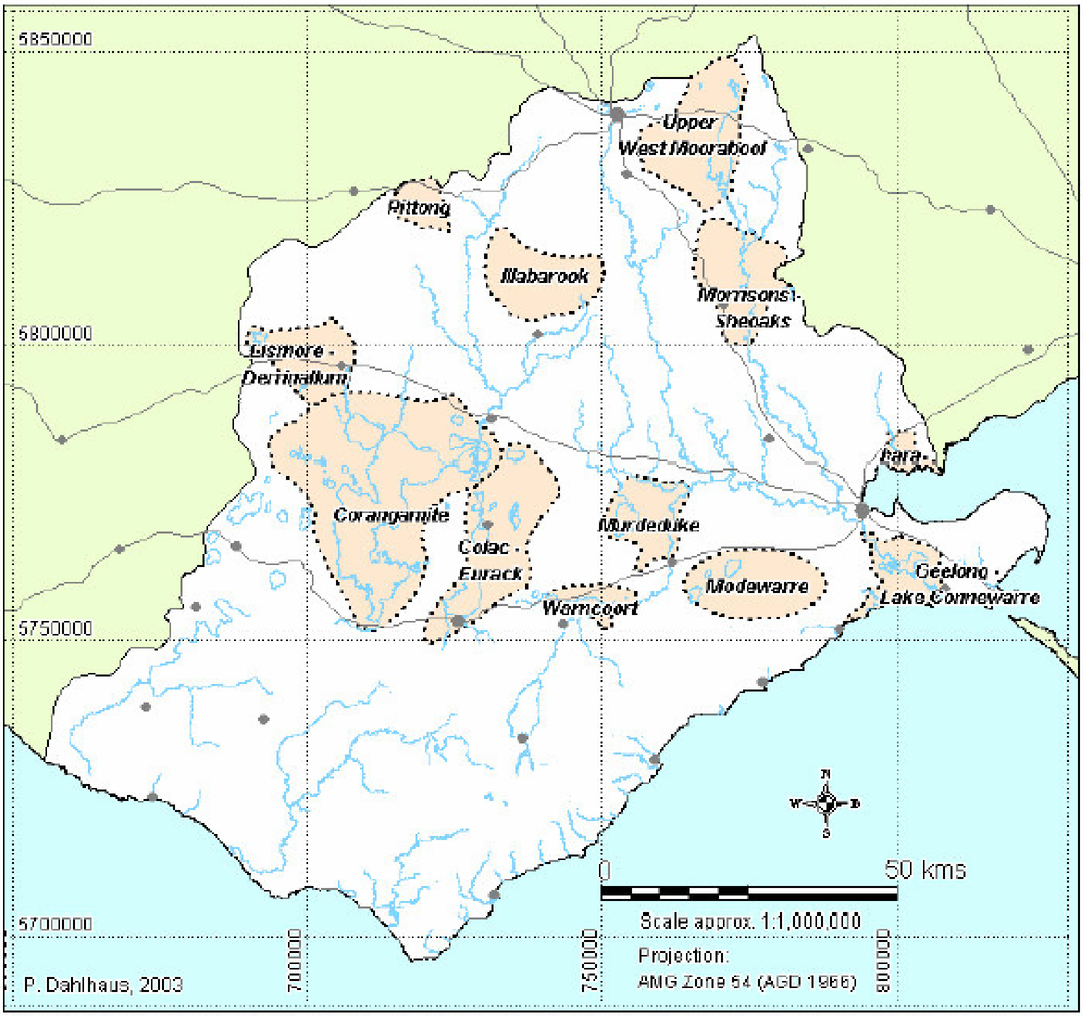


Figure 3-8 Corangamite SAP – Target areas for salinity management.

(Source: Dahlhaus, 2003b)

The disaggregation of the landscape was based on the characterisation of catchments, using GFS (Figure 3-3) consistent with the national classification system (NLWRA, 2001). The salinity risk to assets was determined using the Geospatial Salinity Hazard and Asset Risk Prediction (GSHARP). The method developed by the Centre for Land Protection Research (CLPR), Bendigo. GSHARP provided salinity hazard and salinity risk maps, which spatially identified assets at threat from dryland salinity and included a ranking of assets according to their perceived importance. Four possible scenarios were developed (Dahlhaus, 2003a):

1. Immediate-term asset risk maps showing asset intersections with the mapped salinity;
2. The near-term asset risk showing the intersection of assets with watertables at depths less than or equal to two metres below the natural surface;
3. The near and far term risk scenario in which groundwater less than or equal to five metres depth was intersected with assets; and
4. The far-term asset risk which showed intersections of assets with watertables at depths between two and five metres. The far-term risk was deemed to be considered highly speculative.

The immediate- and near-term risk scenarios provided the means to group higher risk values and define target areas for investment in salinity management practices (Dahlhaus, 2003a). Trend identification in the salinity of surface waters in the stream catchments was determined using monitoring records of the Electrical Conductivity (EC) at stream gauging stations, of the Victorian Water Quality Monitoring Network.

The combined processes of catchment characterisation, GSHARP modelling and salinity trend identification was used to determine the assets at risk and the most appropriate management options across the twelve salinity target areas. However the paucity of scientific data makes it difficult to link salinity symptoms and causes in most target areas. Dahlhaus (2003b) states that the modeled salinity processes are somewhat provisional and that detailed scientific investigation is required to validate the suggested models or develop new conceptual models.

3.4 THE ILLABAROOK TARGET AREA

The Illabarook salinity target area was selected on the basis of its probable influences on the Woady Yaloak River and Lake Corangamite systems (Dahlhaus, 2003b). The salinity in the Illabarook area potentially threatens assets such as the Woady Yaloak River and agricultural land (Nicholson et al. 2003). The site originally formed part of a “Hot Spot” in the initial Corangamite salinity management strategy ‘*Restoring the Balance*.’ The ‘Upper Woady Hot Spot – Corindhap Component’ encompassed a portion of the upper catchment of the Woady Yaloak River and its boundaries extended from Pitfield (west), Rokewood (south) Enfield Forest (north) and Grenville (east; Heislers and Pillai, 2000). The redefined target area in the 'Corangamite Salinity Action Plan 2005 – 2008' limited the area to including only those tributaries that which flow into the Woady Yaloak River. The resultant 'Illabarook Target Area' (Figure 3-9) covers an approximate area of 20, 492 hectares (Nicholson et al. 2006).

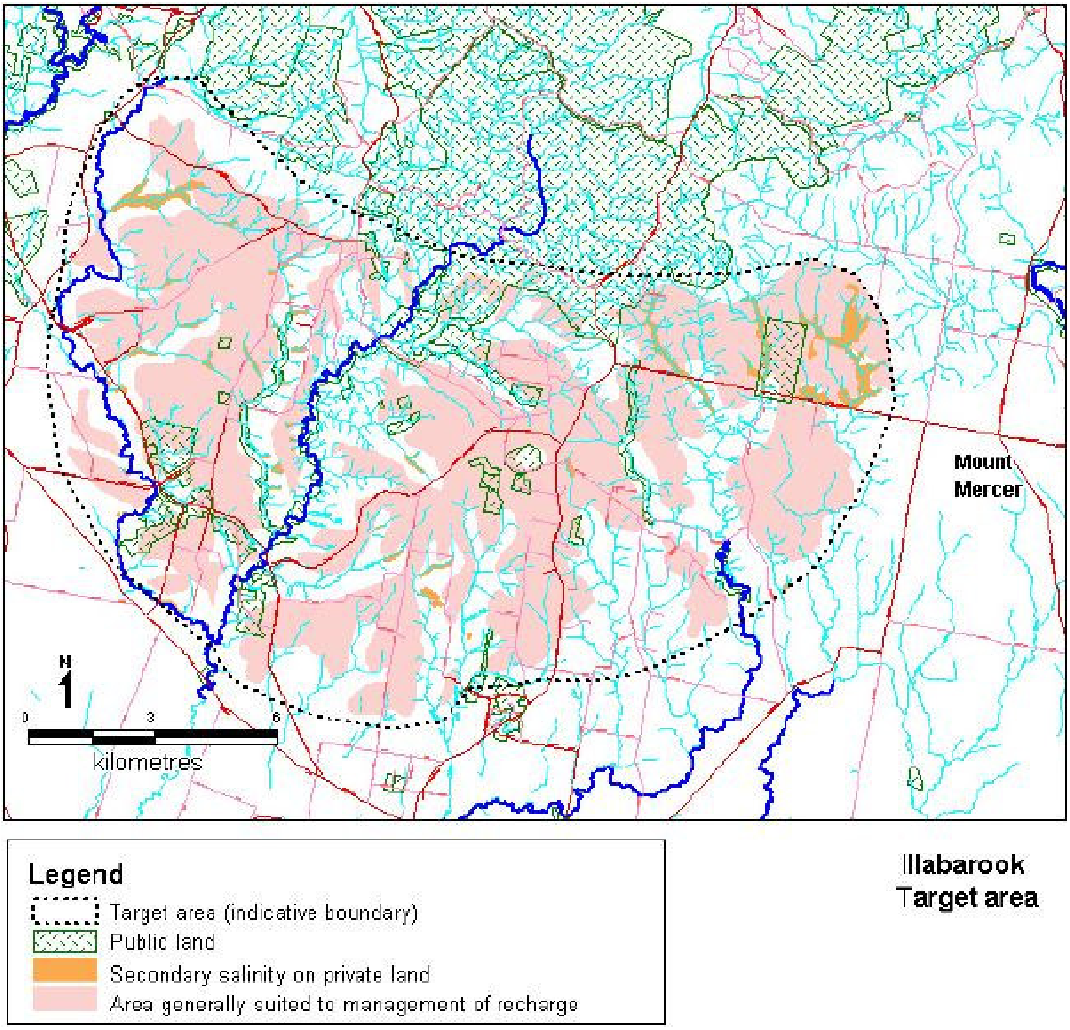


Figure 3-9 The Illabarook Salinity Target Area – Corangamite CMA.

(Source: Dahlhaus, 2003b)

In response to the current threat to assets a number of management actions are proposed, including: the refinement of recharge maps at a farm scale; tree planting in recharge and discharge areas; discharge management programs using advice on surface water management; development of commercial forestry plantations; greater controls on the rabbit population; and the commencement of resource condition monitoring in order to meet targets set under the NAP (Nicholson et al. 2003).

The current situation indicates a continuing rising trend in stream water salinity measured (as EC) at the gauging station at Cressy (#234201) on the Woady Yaloak River (Nicholson et al. 2006). Dahlhaus et al. (2005b) indicated a linear trend of 3.4 ± 23.7µS/cm/yr which is not statistically significant (since the variation is very large compared to the average). Since the recording of EC at the gauging station began in 1976 to the period up until 2005, the mean EC was 5265µS/cm, with a peak at 10500µS/cm and trough at 620µS/cm (Figure 3-10; Dahlhaus et al. 2005b). A total of 308 samples had been recorded with a mean daily salt load of 242 tonnes/day.

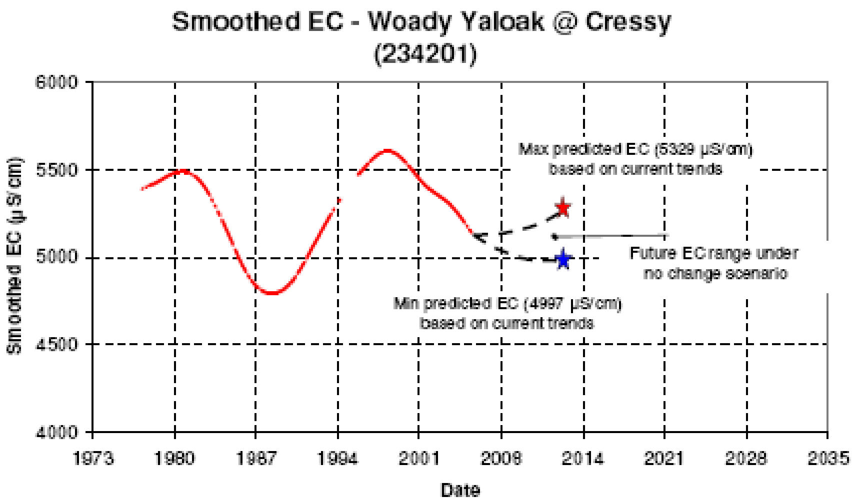


Figure 3-10 Smoothed EC – Woady Yaloak Gauge at Cressy.

(Source: Dahlhaus et al. 2005)

Future trends were modelled for two outcomes, these being the change and no change scenarios. The no change scenario predicts the future trends using the available data, the current conceptual model, and mapped salinity for the specific area. It effectively assumes no change to the current conditions and trends, which define the salinity problem. In the long-term no change scenario, it is predicted that salinity trends will continue to rise at current rates in the Woady Yaloak River (Dahlhaus, 2003b).

The change scenario assumes that the planned salinity management is implemented. Dahlhaus (2003b) using Flowtube to model the change scenario concluded that the establishment of block plantations of trees in particular landscapes (the Highland Gravel Caps), would reduce the salinity in the Woady Yaloak River by around 6 µS/cm for every 100 hectares treated. However, the figures were based on conceptual models and the precise nature of the salinity processes occurring in the area are yet to be determined.

There are four main GFS observed in the Illabarook target area (Refer Section 2.7). The conceptual model proposed for the salinity processes in the Illabarook area are illustrated below.

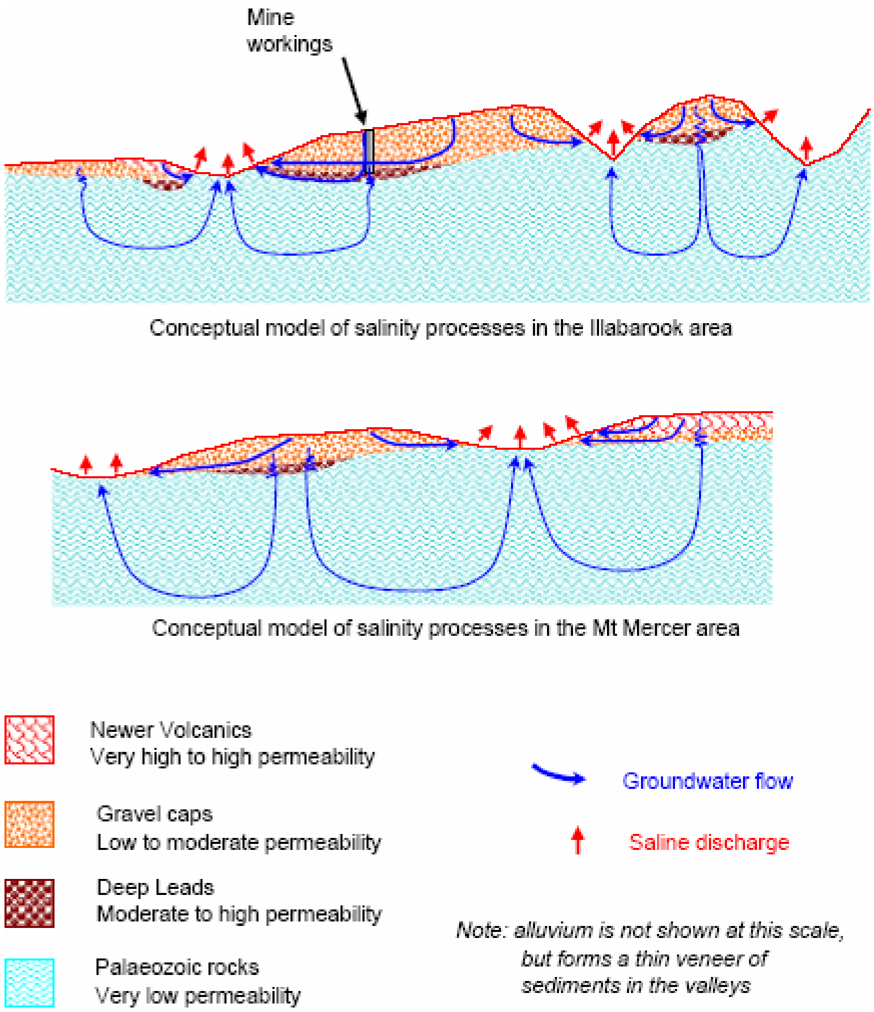


Figure 3-11 **Conceptual Hydrogeological Models for the Illabarook & Mt. Mercer areas, within the greater Illabarook salinity target area.**

(Source: Nicholson et al. 2006)

3.4.1 **Previous studies**

Initial studies of salinity in the Corangamite CMA region commenced around 1952. Cope in 1958 identified eight salt affected areas in the Lake Corangamite region and determined approximately 40 000 hectares of land was salt affected across Victoria (Duff, 1983).

A study by Duff (1983) investigated 'Soil Salting in the Lake Corangamite Region' and seeked to identify the extent of salt affected land. The project focus was development of an appropriate method to measure the extent and occurrence of salt affected soils; application of the method to map saline soils in the region; and postulated remediation actions. Mapping involved soil analysis, field observations, aerial photo interpretation and the identification of salt tolerant vegetation. Duff (1983) concluded that approximately 1% of the region's cleared land was affected by salting, with some areas increasing and remediation possibly including appropriate management techniques and salt tolerant vegetation.

Church (2004) conducted a study - 'Characterisation of Saline Land in the Woady Yaloak Catchment.' The study selected three sites at Mount Mercer, Illabarook and Pittong, where the soils, vegetation, hydrology and groundwater were examined in detail. This was achieved by soil sampling for analysis of EC, pH, cation exchange capacity (CEC); a vegetation survey to assess salinity severity; and a geophysical survey to ascertain the location of salinity in the landscape. The establishment of a monitoring program to evaluate changes in the environment, particularly surface water salinity in the Woady Yaloak River, was also undertaken (Church, 2004).

The study by Church (2004) concluded that the three sites are characterised by similar unbalanced sodic duplex soils and vegetation consisted of saline indicator species. Analysis of surface and groundwater delineated that it was saline at the three sites. Geological and hydrogeological modelling of research areas was similar for each area and indicated that groundwater is prone to discharge at the base or side of hills, creating saline waterlogged areas. The monitoring program involved the monitoring of vegetation, soil (using sampling and geophysical techniques), water (surface and ground) and photographic monitoring points, to measure visual changes over time (Church, 2004).

A study by Mananis (2006) further investigated the possible causes of salinity in the Woady Yaloak River Catchment, with a primary focus of the source of salinity in the region. Thirty stream sampling sites were selected in the catchment area particularly focusing on major tributaries, in order to determine major salt contributors to the end-of-valley salinity. Mananis's (2006) study delineated six sub-catchments within the Woady Yaloak River catchment, which enabled the partitioning of salt load contributions from each. The project used monthly testing of stream water for Electrical Conductivity (EC) and applying the rational method, calculated peak discharge rates in order to measure relative salt loads from respective sub-catchments (Mananis, 2006).

The project concluded that the rational method was not a realistic comparison to the natural observed conditions, but provided a relative overview of salt loads. It determined that the salt load percentage discharging from the sub-catchment was highest for the Woady Yaloak River, followed by Mount Misery Creek, Kuruc-A-Ruc Creek and Naringhil Creek, with Ferrers and Illabarook Creeks ranked lowest. Ferrers Creek however had the highest salt contribution in grams per hectare, followed by Kuruc-A-Ruc Creek, Illabarook Creek, Mount Misery Creek, Naringhil Creek, and Woady Yaloak River with the lowest. Thus, the study concluded that the tributaries contribute greater amounts of salt from smaller catchment areas into the Woady Yaloak River system (Mananis 2006).

4 METHODS

In addition to the review of previous research and investigations and geological reconnaissance of the area, the main research methods are:

1. Geophysics Survey
2. Soil Sampling
3. Groundwater Piezometer Drilling and Installation
4. Aquifer Recovery Testing
5. Stream Sampling

4.1 SITE SELECTION

The process of selecting specific study sites was based on the initial conceptual hydrogeological model shown in Figure 3-11. A literature review and field reconnaissance study provided primary sources of information, such as the geology, hydrology and groundwater flow systems. Initially five potential research sites were selected across the target area of which two specific sites were finally chosen, based on both their observed similarities and dissimilarities to the original model.

4.1.1 **Mount Mercer Site**

The Mount Mercer site is located on the Mt. Mercer – Dereel Road, west of Mt. Mercer on two properties, the Laffan property and Smith property. The Smith property is the same site that was investigated by Church (2004). The Mount Mercer site was chosen because observations indicate similar hydrogeologic processes illustrated in the initial conceptual hydrogeological model. The model suggested three possible salinity processes that may be occurring at the Mount Mercer site from field observations and literature reviews. These include discharge at the base of the Neogene gravels/sands and the underlying Palaeozoic sandstone/shale bedrock; discharge at the base of the Newer Volcanics and the Palaeozoic sandstone/shale bedrock; and discharge directly into river and stream systems from Palaeozoic sandstone/shale bedrock (Nicholson et al. 2006).

4.1.2 **Illabarook Site**

This site is located on Recreation Road, Illabarook on the McKenzie property and is the same site as investigated by Church (2004). The site is characterised by Moorabool Viaduct Formation overlying the Palaeozoic (Ordovician) bedrock. Old mine workings are located to the north of the study site and are the result of Deep Lead mining during the 1800's to the turn of the century. The site is of particular interest as it was used to construct the initial conceptual model for salinity processes in the Illabarook area in Nicholson et al. (2006).

The initial conceptual hydrogeological model suggests that saline discharge occurrs at the boundary of the gravel caps and the underlying Palaeozoic bedrock. Discharge is also believed to be occurring directly from Palaeozoic bedrock into streams and creeks based on field observations. Dahlhaus (2003b) suggests a strong association between the stratigraphic boundary and saline discharge.

4.2 GEOPHYSICS

The geophysical survey of the Illabarook target area employed a Geonics EM 38 instrument to measure the Electromagnetic Conductivity (EC) of the near-surface environment utilising frequency domain electromagnetic (FEM) techniques. A Bombardier All Terrain Vehicle (ATV), with a sled-mounted EM 38 trailing behind (Figure 4-1), was used by the contractor Martin Peters, of Farm Works, based at Meredith.

The EM 38 measured both topsoil and subsoil EC, using the horizontal and vertical axis dipoles. The device consists of a transmitting and receiving loop, with a coil separation of approximately one metre. The depth of the penetration of the instrument is dependent on the ground conductivity and separation of coils but is generally one metre below natural surface. The orientation depth for a horizontal dipole is 0.75 times the transmitter-receiver loop spacing, comparative to 1.5 times for that of the vertical dipole arrangement (Robinson et al. 2006). Nicoll et al. (1993) suggest that EM 38 apparatus generally measure the top metre or so of soil, although rock and soil below this can also influence readings. Soil properties such as moisture levels also have a critical influence on readings, due to the shallow operating depths of the instrument (Nicoll et al. 1993).

Figure 4-1 Geophysical Survey – Geonics EM38 device training behind a Bombardier ATV.

(Image: McKenzie Property, Illabarook – Pitfield Road, Illabarook)

4.2.1 Basic principles of EM for salinity mapping

The FEM method works on the principle of a transmitter coil, with an alternating current (AC) put through it. This results in the generation of a magnetic field around the transmitter coil. The coil is subsequently placed near the ground and an electrical field is induced in the earth with varying strengths, respective to the conductive nature of the ground. This induced or secondary field is then measured by a passive receiver coil and details the conductive natures of the near surface material (Fetter, 2001).

The secondary or induced field can vary in terms of phase, amplitude and orientation, as a function of subsurface conductivity and can be measured with either time or distance by the receiver (Fetter, 2001). Intercoil spacing, the operating frequency and the dipole moment of the transmitter, also govern the variation in the induced magnetic field (Woof, 1994). However, the primary magnetic field generated by the transmitter remains constant and secondary field development is primarily dependent on the conductive nature of the soil. Since the primary magnetic field is constant, the ratio of the primary:secondary magnetic fields are proportional to the apparent conductivity of the ground at low induction numbers. The apparent conductivity is defined as the sum of secondary fields developed by eddy currents induced in the conductive medium (Dickson, 1993).

Soil water and groundwater containing dissolved salts is conductive, and the conductivity increases in proportion to the salt concentration. For this reason, the EC is a surrogate measure for salinity.

4.2.2 **Geophysical Modelling**

Geophysical data modelling was completed using a multi-linear regression analysis of soil property data and electromagnetic data, from each sample location (Peters *pers. comm.* 2007). Jo Peters of Farm Works, Meredith, completed the modelling and analysis. Spatial Regression modelling (Stochastic Calibration) using the ESAP model developed by the United States Department of Agriculture – Agricultural Research Service (USDA – ARS), was used to interpolate the data. The model estimates, validates and predicts the values of a response such as soil salinity from the conductivity data (Lesch et al. 2000).

Stochastic Calibration (ESAP- Calibrate program) is multi-linear regression model, which includes conductivity and surface trend parameters. Determination of the soil salinity values (ECe) in the survey area from log transformed EM38 conductivity readings, is obtained using the following regression model equation (Lesch et al. 2000):

$$\ln(ECe) = b_0 + b_1[\ln(EMh)] + b_2[\ln(EMv)] + b_3[x] + b_4[y]$$

Where EMh and EMv are the horizontal and vertical dipole readings respectively obtained from the EM38 device and 'x' and 'y' represent the coordinate locations of the EM38 data. The purpose of this procedure is to estimate the regression parameters denoted above as b_0, b_1, b_2, b_3, b_4. Once the regression parameters have been determined, the salinity levels, calculated as the electrical conductivity of the soil-water extract (ECe), is then predicted for each site along with an estimate of the predictions accuracy (Appendix L; Lesch et al. 2000).

4.2.3 **Topographic data collection**

In addition to the EM data, topographic data is collected simultaneously using a Trimble kinematic Global Positioning System (GPS). A GPS base station was established at a point in the survey area and a portable GPS was carried on the ATV. The fixed base reference point allowed corrections to be applied to within centimetre accuracy, at any measurement point across the survey area.

All the datasets were grided in Discover v6.1 (Encom, 2004) using a minimum curvature interpolation algorithm, with a grid cell spacing approximately one quarter of survey transect line spacing. Grid files were manipulated and mapped using Vertical Mapper v3.1 (MapInfo, 2004).

4.3 SOIL SAMPLING

Soil sampling was conducted at randomly selected GPS reference points at each of the three survey areas. A thin-walled sampling tube was pushed into the soil using a powered hammer to extract soil samples to a depth of approximately one metre (Figure 4-2). Description of the soil in the field included colour, texture, organic material (i.e. roots) and soil structure, in order to classify the soil profile and distinguish between soil horizons (Refer to Appendix B for soil core descriptions). Appendix K outlines the methods for the field and laboratory analysis of soils.

Figure 4-2 Hydraulic Corer - used to sample soil to approximate depth of one metre.

(Photo: Martin Peters of Farmworks, Meredith)

4.3.1 Laboratory Analysis

Soil texture was determined using the procedures outlined by MacEwan (1998) and is detailed in Appendix K. Soil moisture was firstly described upon the general appearance and 'feel' of the soil but was then analysed according to the Australian Standard. Laboratory testing included the analysis of soil moisture, texture, $pH_{1:5}$, $pH_{CaCl2\ 1:5}$, $EC_{1:5}$ and particle size analysis.

4.3.1.1 *Soil Texture*

Soil texture was described using the method outlined by MacEwan (1998) and required the manual manipulation of a representative sample (Refer Appendix K). A sample of soil is taken and kneaded into a ball, it is then placed through a number of tests to determine the physical characteristics of the soil. Soil and water may be added during the testing procedure, in order to obtain the ideal soil condition. Soil manipulation determines the mouldability limits to determine a textural class, using rolling, bending and forming techniques. The texture of the soil is influenced by sand, silt, clay and organic properties and can also be observed during manipulation.

4.3.1.2 *Soil Moisture*

Soil moisture content was determined using the Australian Standard AS 1289.2.1.1 – 1992 (Standards Australia, 1992). The moisture content of a soil is determined as a percentage of its dry mass, using an oven to dry soil samples. A representative sample is taken, weighed and dried in an oven at 105^0C to a constant weight, as per the Australian Standard. The moisture content determined as a percentage of the weight loss compared to the weight of the dried sample. The procedure to determine the moisture content of soils is outlined in Appendix K.

4.3.1.3 *Soil $pH_{1:5}$, $pH_{CaCl2\ 1:5}$ and $EC_{1:5}$ analysis*

Soil analysis to determine $pH_{1:5}$, $pH_{CaCl2\ 1:5}$ and $EC_{1:5}$ was conducted using a representative fine earth fraction of the samples in line with standard procedures (MacEwan, 1998). The analysis of samples was conducted in the University's Soils Laboratory, under the supervision of Mrs. Wendy Cloke, Laboratory Technician - Environmental Management, School of Science. Data was recorded during the processes and anomalous or perceived non-conformable values were marked, and duplicate samples prepared and tested to ensure that all values were correct. The procedures used for the analysis of soils are detailed in the appendices (Appendix K).

4.3.1.4 *Particle Size Analysis*

The analysis of soil particle size distribution was conducted using the appropriate Australian Standard AS 1289.3.6.1 – 1995 for sieve analysis of soils (Standards Australia, 1995). The portion greater than 75µm of the washed soil sample was sieved using brass sieves and weighed and recorded appropriately. Particle sizing analysis for material less than 75µm, was conducted using a Malvern Instruments Ltd. – Mastersizer 2000 for analysis.

The Mastersizer 2000 provides quick and relatively easy analysis of fine soil particle sizing between 0 – 1000µm. The percentage of clay (<2µm) and silt material (<60µm) was then calculated, using the tabled data provided by the instrument. Dr. Stephen Carey, Lecturer - Department of Geology, School of Science & Engineering, University of Ballarat, assisted in instruction of equipment operation. The methods applied for laser particle sizing are appended in Appendix K.

4.4 GROUNDWATER INVESTIGATION BORES

The groundwater investigation method was specifically designed to test the initial conceptual hydrogeological model (Figure 3-11). The original model was based on field observations of features such as geology, groundwater flow systems, hydrology and salinity processes in operation, within the particular landscape (Nicholson et al. 2006).

Piezometer installation is designed to specifically target flow systems in the Palaeozoic bedrock and Neogene gravel/sand cap. This was conducted in order to test the initial conceptual model which suggested that increased salinity is attributed to greater infiltration into Neogene sediments.

The installation of groundwater monitoring bores is designed to test the current hypothesised conceptual model and develop understanding of the nature of groundwater systems at the site. This in turn will enable more concentrated management techniques to be applied, in salinity management and remedial work.

4.4.1 **Piezometer Construction**

The drilling and piezometer construction was carried out by Numac Drilling Services Pty Ltd, under approved licensing through Southern Rural Water (SRW). The bores were established as groundwater investigation bores, with the primary aim of investigating the GFS at each locality. Licenses for the bore construction were obtained through SRW, Licensing Division and the exact permission was negotiated with the landholders. All bores were located along the boundary fences in order to minimise the impact on agricultural activities.

A Geoprobe 7720DT drill rig equipped with 150mm diameter augers was utilised for the drilling program (Figure 4-3). The piezometers were constructed using Class 18, 50 millimetre PVC casing, with screw threads and a machine-slotted screen (0.5mm openings). Screens were placed at variable depths at each site (Appendix A). The construction of each piezometer generally followed the method described by Weight and Sonderegger (2001), with the screen (with end capping) at the base, and casing extending above the screen to the surface. The well is completed with placement of filter pack consisting of 8/16 grade silica sand, extending approximately 0.5 metres above the well screen. The sand is generally larger than the slot-size of the screen, with <10% of the sand passing through the slots. Above the filter pack a bentonite seal was installed and the well annulus is then backfilled to the surface.

The piezometer headworks comprise of galvanized steel casing, in order to protect the PVC casing of the bore. The headworks were fixed in place using 200×300×300mm concrete pad (area 0.09 m^2). The steel casing is 100mm in diameter, with a laser cut hinged, lockable lid. The installation of headworks is to ensure long life of the bores and continued future monitoring at the sites. All bores have keyed-alike padlocks to prevent bore tampering. Bore construction details are shown in Appendix A.

Figure 4-3 Piezometer construction using Geoprobe 7720DT.

(Photo: Drilling, McKenzie property - Recreation Road site, Illabarook)

4.4.2 **Logging Drill Samples**

The logging of samples collected during drilling details the geological units and their stratigraphic context, at each site. The sampling was conducted approximately every metre during drilling. Samples were placed in sealed plastic bags which were labeled for later reference. Further analysis of samples in the laboratory focused on colour, texture, mineralogy, grading, structure, moisture content, lithology and the size, composition and rounding of grains (Horgan, 2006). Representative samples were selected and soaked in tap water for one week, in order to disaggregate clay particles. Samples were then washed through a 75 µm wash sieve, dried in an oven for approximately one hour and described under a binocular microscope (Figure 4-4).

Figure 4-4 Logging samples in the laboratory.

The Corangamite CMA bore database was also utilised to assist in lithological determination and descriptions. The records of bores in close vicinity to the installed piezometers were accessed but were of marginal value because of there variable quality and were only useful as a reference. The descriptions of the samples in the laboratory and field formed the primary basis of the drilling logs, which are appended in the 'Bore Completion Report' (Appendix A).

4.4.3 **Piezometer Development**

Bore development was conducted using a twelve-volt battery-operated pump and both stainless-steel and plastic hand-bailers. Water and silt/sand material was extracted from the bore by firstly "bouncing" the bailer at the base of the well to stir up any settled sand/silt, which was then removed using the bailer. Pumping of the bores was conducted after hand-bailing had reduced the amount of sand/silt material being extracted. The aquifers were then pumped until the extracted water went clear (i.e. no longer turbid). The length of time required to develop each bore was dependant on the aquifer recovery, which varied considerably.

4.4.4 **Aquifer recovery testing**

Aquifer recovery tests were conducted for all six installed piezometers at Mount Mercer and Illabarook to determine the aquifer hydraulic parameters, within the particular GFS. Piezometers were installed in both the Paleozoic bedrock aquifer and the Neogene gravel/sand aquifer to variable depths (Figure 4-5).

The Hvorslev method was used to determine hydraulic conductivity values of aquifers based on rising head (water removed via pumping or bailing) principles. The details of the Hvorslev method are appended (Appendix R).

Figure 4-5 Aquifer recovery testing – Mount Mercer, MM3.

All bores were pumped using a twelve-volt battery operated pump with the exception of bore IR1 which was hand-bailed due to the in-ability of the pump to effectively remove water from the well. Aquifer recovery was measured using a Solinst Levelogger Gold (Model 3001, LT F30/M10). The device is a piezoresistive silicon pressure transducer packaged in 316L stainless steel housing. When placed in water the device calculated water and barometric pressure (barometric pressure was not applied in this study as it was considered statistically insignificant). The water level readings from the device are also temperature-compensated and the logger coverts the total pressure reading in the piezometer to its corresponding water level equivalent (Solinst, 2006).

Recording of measurements and methods at each site was consistent. The volume of water extracted and time of extraction was recorded. A water level indicator was then used to measure water level immediately after pumping and periodic measurements of the water level were also taken, to measure aquifer recovery. The level-logger data was downloaded to a laptop in the field and details logged for each piezometer. Levelogger settings were kept uniform for each test as follows:

a. Every 1 second for 15 minutes; then
b. Every 30 seconds for 15 minutes; then
c. Every 60 seconds for 30 minutes; then
d. Every 5 minutes for 30 minutes; and finally
e. Every 10 minutes for 60 minutes.

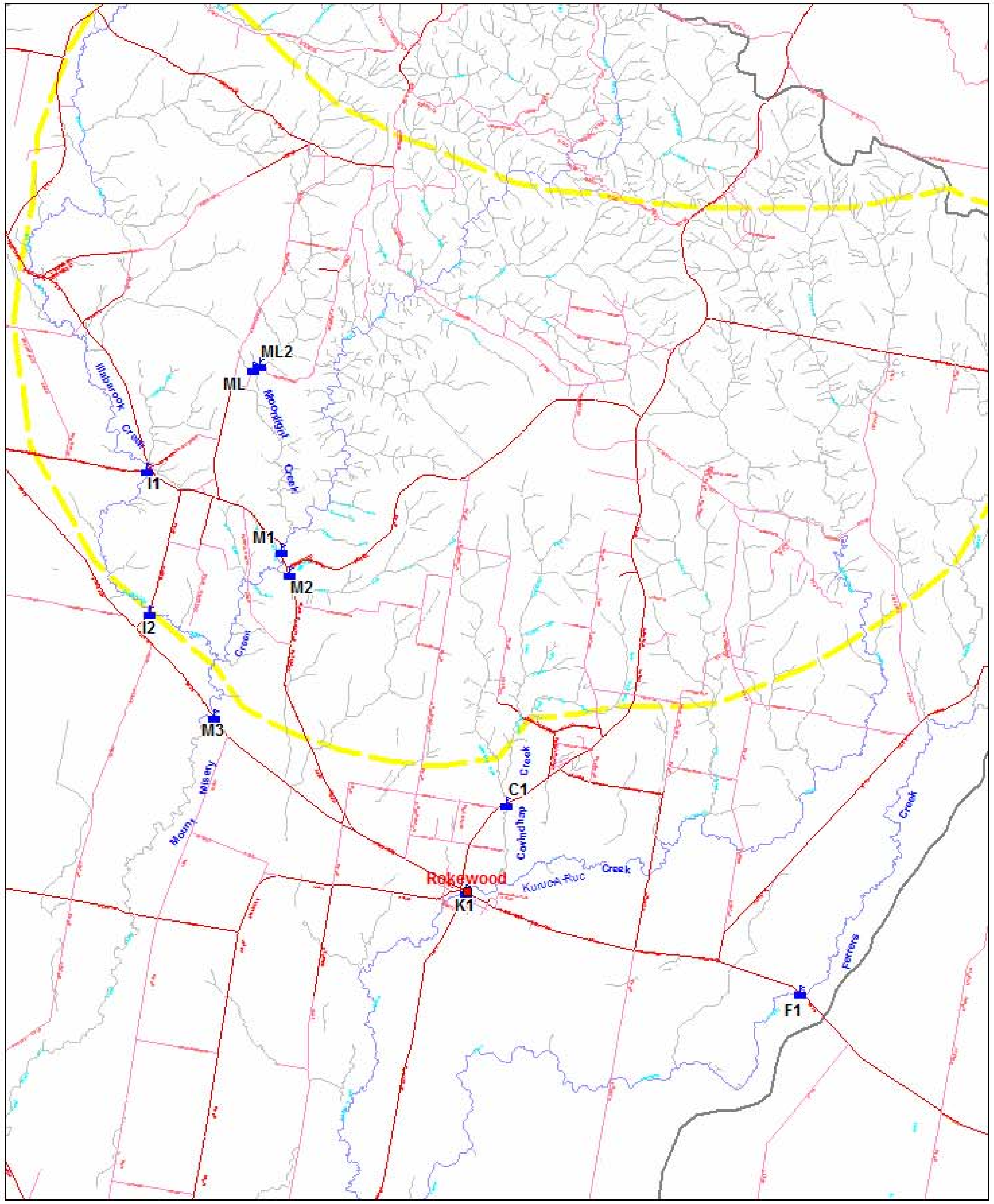
The instruments and pumps were cleaned as appropriate between sites, to ensure minimal transfer of contaminants.

4.4.5 **Downhole $EC_{1:5}$ and $pH_{1:5}$ Analysis**

An investigation of the salt store in the regolith was undertaken using $EC_{1:5}$/$pH_{1:5}$ analysis of the materials encountered during drilling. The $EC_{1:5}$/$pH_{1:5}$ analysis was conducted using the same method as that used for soil core analysis (Section 4.3). Analysis of variations in salt stores throughout the regolith profile will assist in locating the source of salt contribution to saline groundwater discharge. Analysis was applied to all six groundwater bore materials.

4.5 SURFACE WATER INVESTIGATION

The Illabarook target area encompasses a number of major tributaries which contribute to the Woady Yaloak River system. The tributaries are the Moonlight, Illabarook, Mount Misery, Corindhap, Kuruc-A-Ruc and Ferrers creeks (Figure 4-6). Surface water sampling aimed at delineating the seasonal variations and rainfall influences on stream salinity. Ten locations were selected for stream sampling, all of which were previous research sites selected by Mananis (2006). For consistency, sampling followed the Australian/ New Zealand Standards for Water Quality- Sampling (1998) as adopted by Mananis (2006).



WOADY YALOAK 1: 100 000 SAMPLING LOCATIONS MAP

MAP SYMBOL LEGEND

- Sampling Location
- Unsealed Road
- Sealed Road
- Lake Boundary
- Stream
- Stream
- River
- River
- SAP Target Area Boundary
- Woady Yaloak River Catchment Boundary
- Town

SCALE 1:100 000

0 2 4
kilometres

N
W E
S

GRID INTERVAL: NOT PROJECTED

Horizontal Datum: Map Grid of Australia (MGA94)
Australian Map Grid ZONE 54

CONTOUR INTERVAL: NOT PROJECTED

Vertical Datum: Australian Height Datum

CARTOGRAPHY BY:

Grant Mockunas
Department of Geology
School of Science & Engineering
University of Ballarat

ID	SAMPLING_LOCAT	EASTING	NORTHING
C1	Corindhap_Creek	739,784	5,803,277
F1	Ferrers_Creek	745,566	5,799,577
K1	Kuruc-A-Ruc_Creek	738,983	5,801,545
I1	Illabarook_Creek	732,706	5,809,855
I2	Illabarook_Creek	732,773	5,807,034
M1	Mount_Misery_Creek	735,370	5,808,260
M2	Mount_Misery_Creek	735,510	5,807,792
M3	Mount_Misery_Creek	734,040	5,804,983
ML	Moonlight_Creek	734,800	5,811,823
ML2	Moonlight_Creek	734,930	5,811,922

REGIONAL LOCATION (VICTORIA)

Figure 4-6 **Illabarook salinity target area – Surface water sampling locations (2007).**

The sampling was conducted around the middle of each month over the period of March to October 2007 and built upon previous sampling data collated during February to October 2006 by Mananis (2006). The chance of contamination was minimised by following sampling guidelines at each site and ensuring accurate recording of data. The EC (Electrical Conductivity) and pH meters were calibrated prior to each field sampling day and data obtained was compared to previous results. Any large anomalous values resulted in retesting of sampled water and/or use of a second meter, as to confirm or reject the initial reading. The sampling equipment was washed thoroughly after each sample was taken, and EC and pH probes were also washed and dried appropriately between sites, as to minimise cross-site contamination (Appendix D – Surface Water Sampling Procedures).

The equipment used included:

- A PVC bailer - used to obtain samples where direct access to the water was not possible and samples could only be obtained from a bridge;
- A plastic ten-litre bucket was utilised were a bailer was not required;
- Eutech Instruments/ Oakton Instruments ECTetsr11-Dual Range was used to measure EC values and temperature. The ECTetsr11-Dual Range had the ability to test both EC High and Low between 2000µS and 20.00mS. In cases where uncertainty in EC results was encountered a Eutech Instruments ECScan-high was used, which measured between 0 to 19.90mS; and
- Eutech Instruments/ Oakton Instruments pHTestr 10 was used to measure pH of each sample.

5 RESULTS

5.1 GEOPHYSICS

The EM38 geophysical survey of the three sites resulted in mapping near surface conductivity values as a surrogate for soil salinity. The surveys focused on landscapes where Neogene gravels/sands overlay Palaeozoic bedrock, and are considered a primary source of salinity. The results indicate that the association between Neogene sediments and salinity is limited to only some areas, while in other areas the Palaeozoic GFS influence salinity greater than previously hypothesised.

Salinity is modelled as ECe in deci-Siemens per metre, with 0-2 dS/m classified as 'Non saline,' 2-4 dS/m 'Slightly saline,' 4-8 dS/m 'Moderately saline,' 8-16 dS/m 'Very saline' and >16 dS/m 'Highly saline (Dahlhaus *pers. comm.* 2007).' The severity also relates to the effect on crops, with low conductivity values having little or no effect, comparative to highly saline areas limiting productivity to only very salt tolerant crops.

5.1.1 **Mount Mercer: Site 1 (Laffan Property)**

The EM38 survey of the Laffan property at Mount Mercer highlighted saline discharge areas and near surface salinity. The survey also accurately determined the extent of salinity which is postulated to have reduced in size over the past thirty years (Church, 2004).

The raw data obtained is an apparent electrical conductivity value (ECa) of the ground, averaged over the volume of the survey area, measured as milli-Siemens per metre (mS/m). The survey was conducted using thirty-metre transect line intervals, with readings taken every five metres (Figure 5-1). The ECa value is determined by the coil arrangement (horizontal and vertical dipole) and the conductivity of the soil profile (NRM, 2007). A number of factors affect soil conductive properties such as soil moisture content, soil texture and composition and temperature, and the ECa is calibrated against the soil test data from the survey sites. Applied corrections enable accurate correlation between soil electrical conductivity and salinity (Spies & Woodgate, 2004).

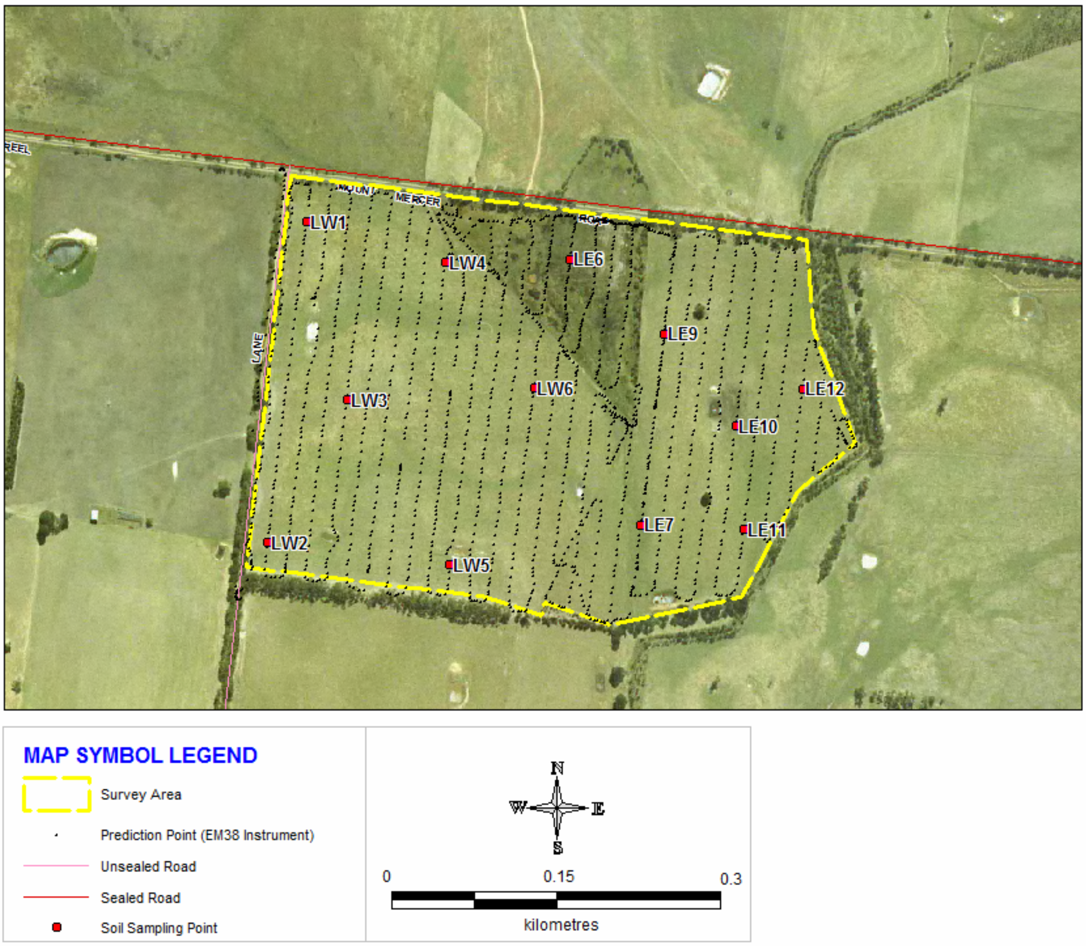


Figure 5-1 Mount Mercer survey site one, Laffan property.

5.1.1.1 *Soil Sampling*

Soil sampling was conducted at twelve selected sample sites which correspond to geophysical sampling points (Figure 5-1). The location of the sites was randomly chosen by the prediction algorithm (Section 4.1.2) to maximise the chance of a good correlation with the range of ECa data. Soil cores were described in the field to record their soil profile (Refer to 'Geophysics Completion Report,' Appendix B) and samples were taken for further examination in the laboratory. Samples were tested for soil moisture, texture, $EC_{1:5}$, $pH_{1:5}$ and $pH_{CaCl2\ 1:5}$ (Refer Appendix E & K).

The sampling indicates that soils across the site are variable in texture, ranging from sandy loams to silty clays for both the A and B soil horizons. The A-horizon is generally a dark brown colour and the B-horizon is generally grey-brown to yellow. Soil moisture is relatively consistent throughout soil profile, with a generally moist topsoil and subsoil. The A-horizon commonly has a greater percentage of gravel and sand and the B-horizon is composed predominantly of finer silt and clay.

Soil $EC_{1:5}$, $pH_{1:5}$ and $pH_{CaCl2\ 1:5}$ indicate a good correlation between soil EC and soil pH. Analysis of EC data indicates an average of 0.3 mS/cm for the A-horizon and 0.42 mS/cm for the B-horizon and is characterised by an increase in conductivity at depth within the upper regolith, particularly in discharge areas. The pH data averages 5.8 in the A-horizon and 5.4 in the B-horizon, showing a slightly more alkaline topsoil.

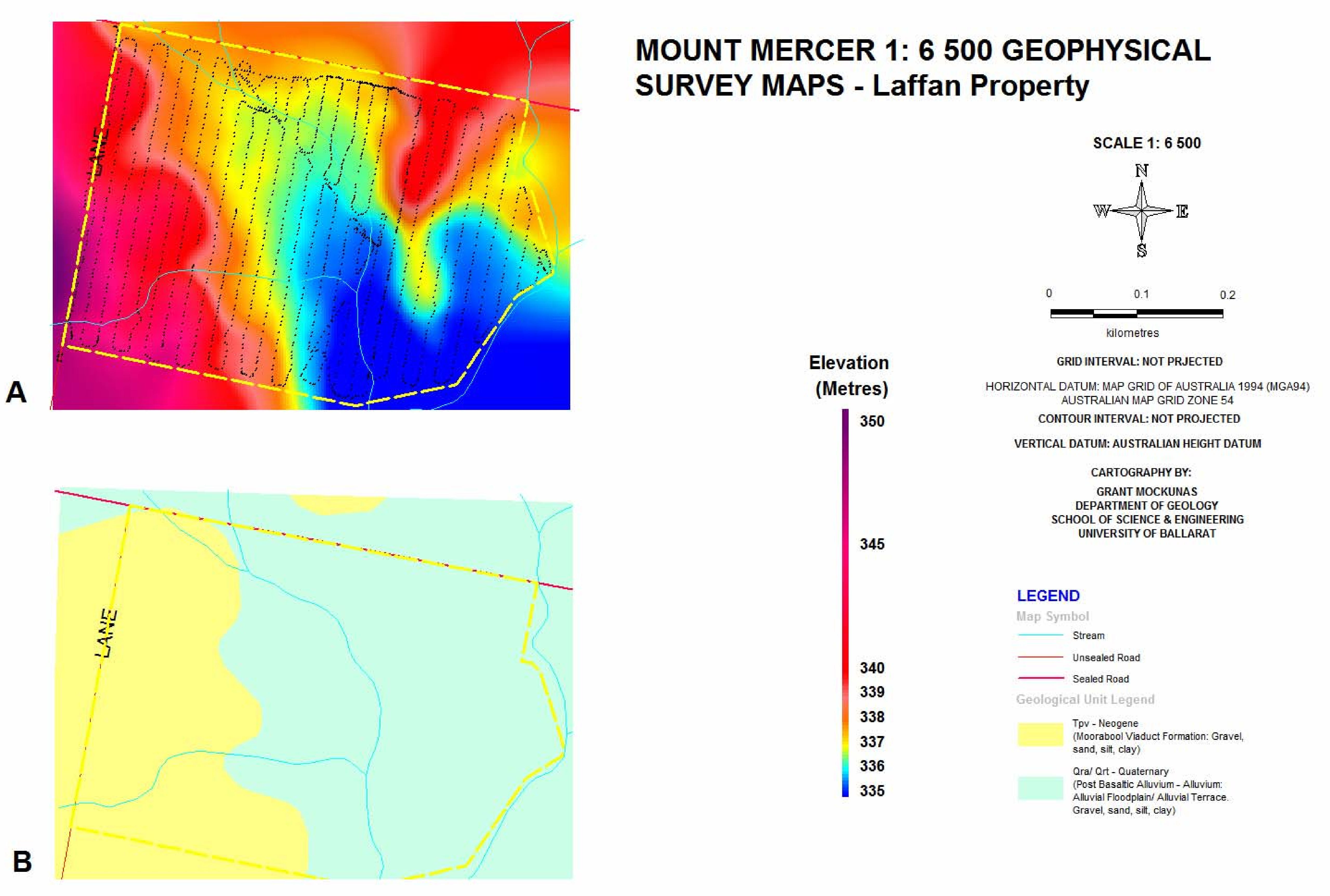


Figure 5-2 A) Elevation Map of the Mount Mercer site one survey site. B) Geological Map of the Mount Mercer site one survey site.

5.1.1.2 *Geophysical Analysis*

The electrical conductivity mapping produced apparent conductivity readings (ECa), from both the horizontal and vertical dipoles (Refer Appendix O). The soil conductivity (ECe) predicted from the soil data (measured in dS/m) provided details of near surface salinity at the site. Conductivity was analysed in the top 30 centimetres of the soil profile by the horizontal dipole and at 50-80 centimetres depth for the vertical dipole. The obtained values indicate EC responses are variable from low where little or no salinity occurs to highly saline, particularly in discharge and drainage areas (Figure 5-3 A/B).

Mapping displayed changes in conductivity values in the vertical profile, with values generally increasing with respect to depth in most areas. Correlation is also observed in soil pH readings, with soil ECe indicating a relationship between the two variables. High soil pH is matched with a relatively low soil ECe response, and conversely high ECe responses are coupled with low soil pH (Figure 5-4 A/B). Thus, as soil salinity increases, the soils become more acidic.

The EM38 mapping also showed spatial variation in salinity in relation to topographic features, where topographic highs (presumably recharge zones) are mapped as low predicted EC and elevated pH. Topographic lows (assumed discharge zones) however, are coupled with higher soil EC and more acidic soils.

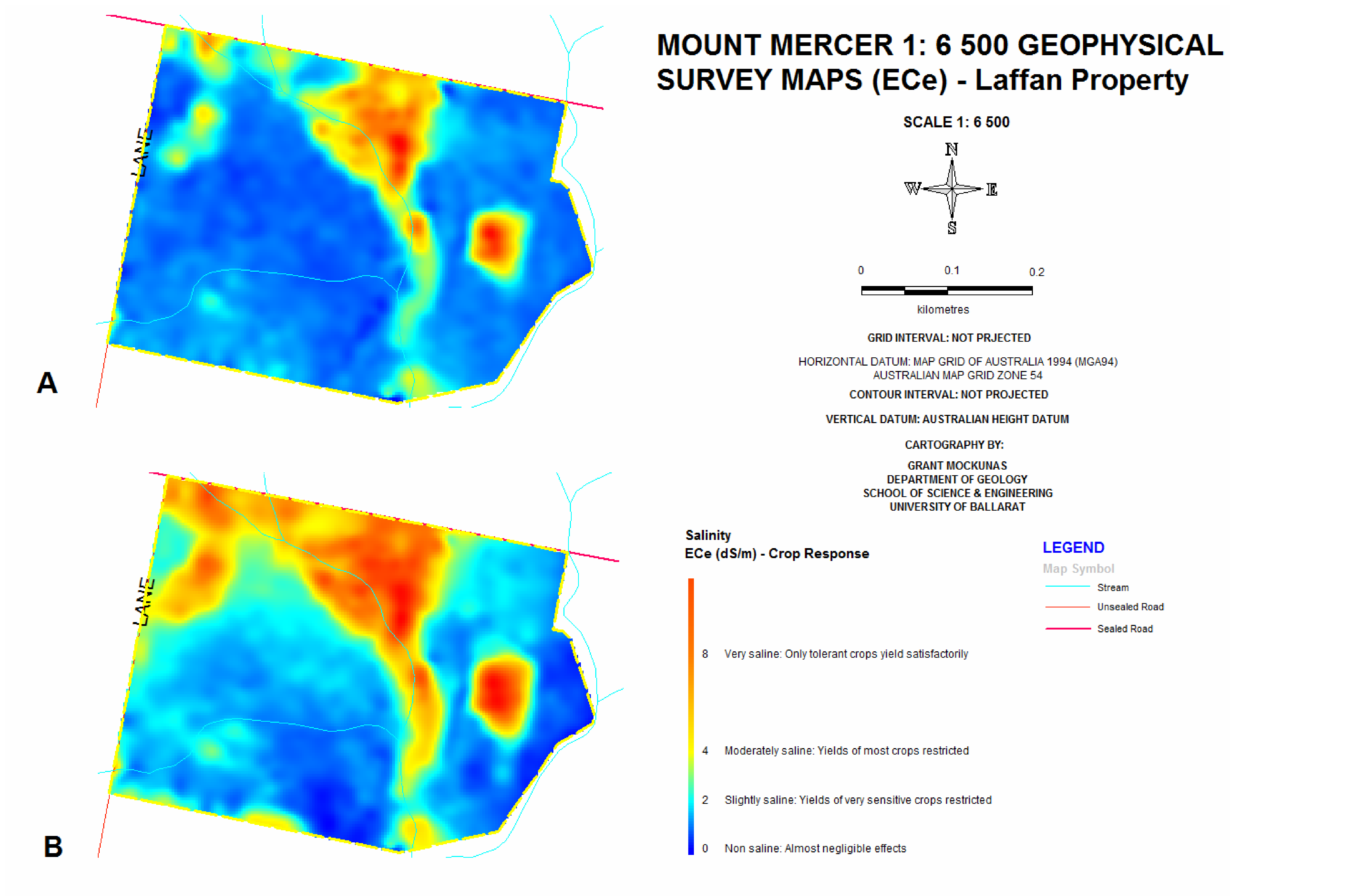


Figure 5-3 A) ECe 0 – 30 cm map for the Mount Mercer site one survey site. B) ECe 50-80cm map for the Mount Mercer site survey site.

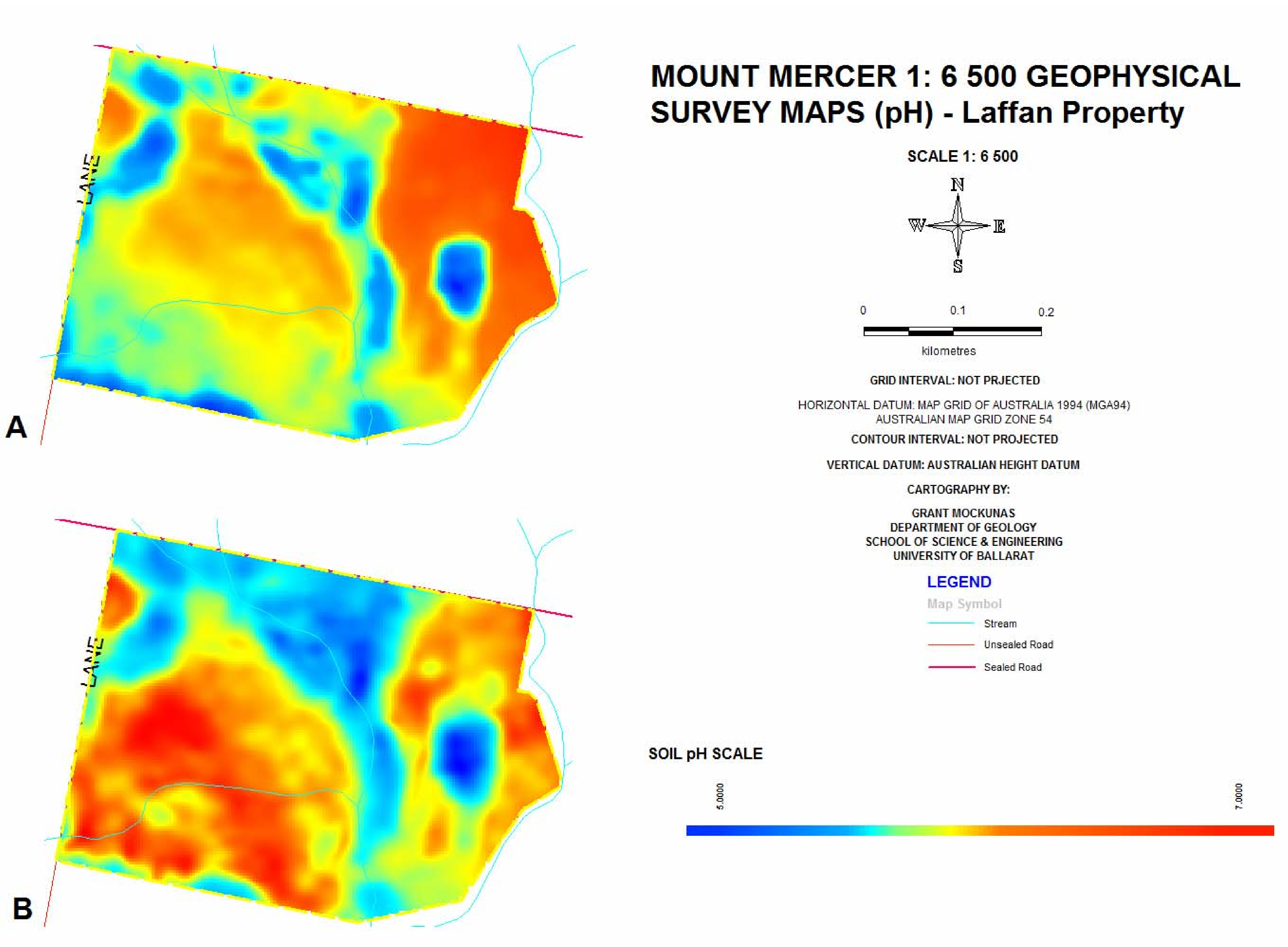


Figure 5-4 **A) pHH2O 0 – 30cm for the Mount Mercer site one survey site. B) pHH2O 50 – 80cm for the Mount Mercer site one survey site.**

5.1.2 Mount Mercer: Site 2 (Smith Property)

Geophysical analysis of the near surface environment using the EM38 instrument highlighted the changes in EC at depth at the Smith property at Mount Mercer. The survey aimed to delineate possible influences from Neogene gravels/sands on saline discharge at the site. Analysis of data indicates that the influence of Neogene gravels/sands is less than previously thought and flow systems within Palaeozoic bedrock and alluvial material may have a greater influence.

The geophysics survey was conducted using a twenty-metre transect line interval, with prediction points taken every five metres (Figure 5-5). The site has been previously surveyed for the Sustainable Grazing on Saline Lands (SGSL) investigation (Bates and Jones, 2004a). Church (2004) also investigated the site and conducted a hand-held EM38 geophysical survey, vegetation survey and, photogrammatic mapping to analyse change over time, and soil analysis. His study concluded that both class one and two salt indicator species were present at the site and that salinity has been gradually reducing over the past thirty-years.

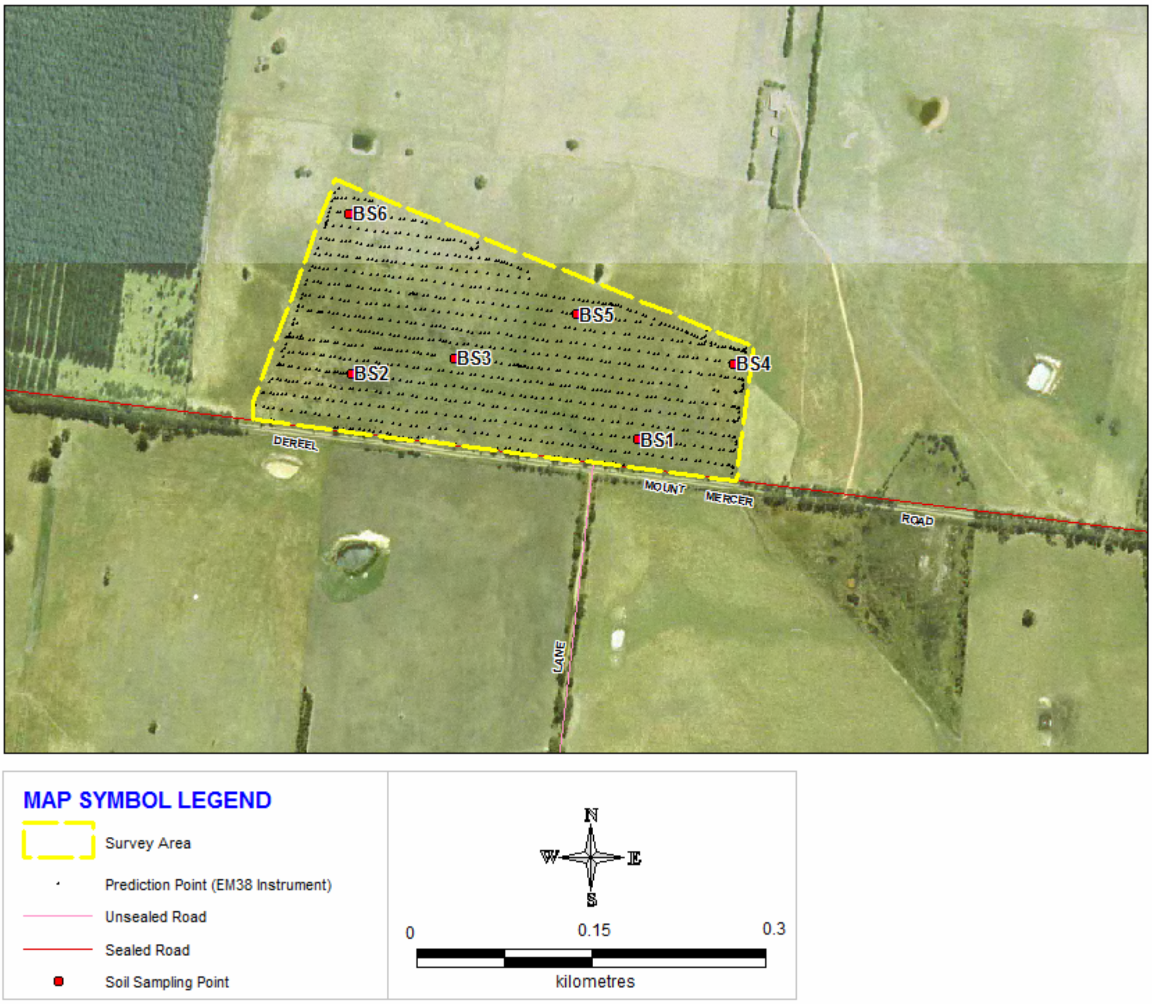


Figure 5-5 **Smith property, Mount Mercer. Geophysical survey site and survey lines, with prediction points illustrated.**

5.1.2.1 *Soil Sampling*

Six soil cores were taken across the survey area, for analysis of soil moisture, texture, $EC_{1:5}$, $pH_{1:5}$ and $pH_{CaCl2\ 1:5}$ (Figure 5-5). The soil analyses were used to predict the ECe data. The analysis of the soil determined that the A-horizon is generally composed of clay-loams, with a slightly higher percentage of coarse material, comparative to the B-horizon, which is predominantly composed of clays. Saline soils are primarily associated with topographic lows and drainage areas, with topographic highs determined to have negligible to slight salt content and higher alkalinity.

The analysis of soil EC indicates an average of 0.28 mS/cm for the A-horizon and 0.75 mS/cm for the B-horizon. Soil pH is similarly variable with pH averaging 5.9 in the A-horizon and 5.4 in the B-horizon. Soils are determined to be more alkaline in regions where lower soil EC is identified.

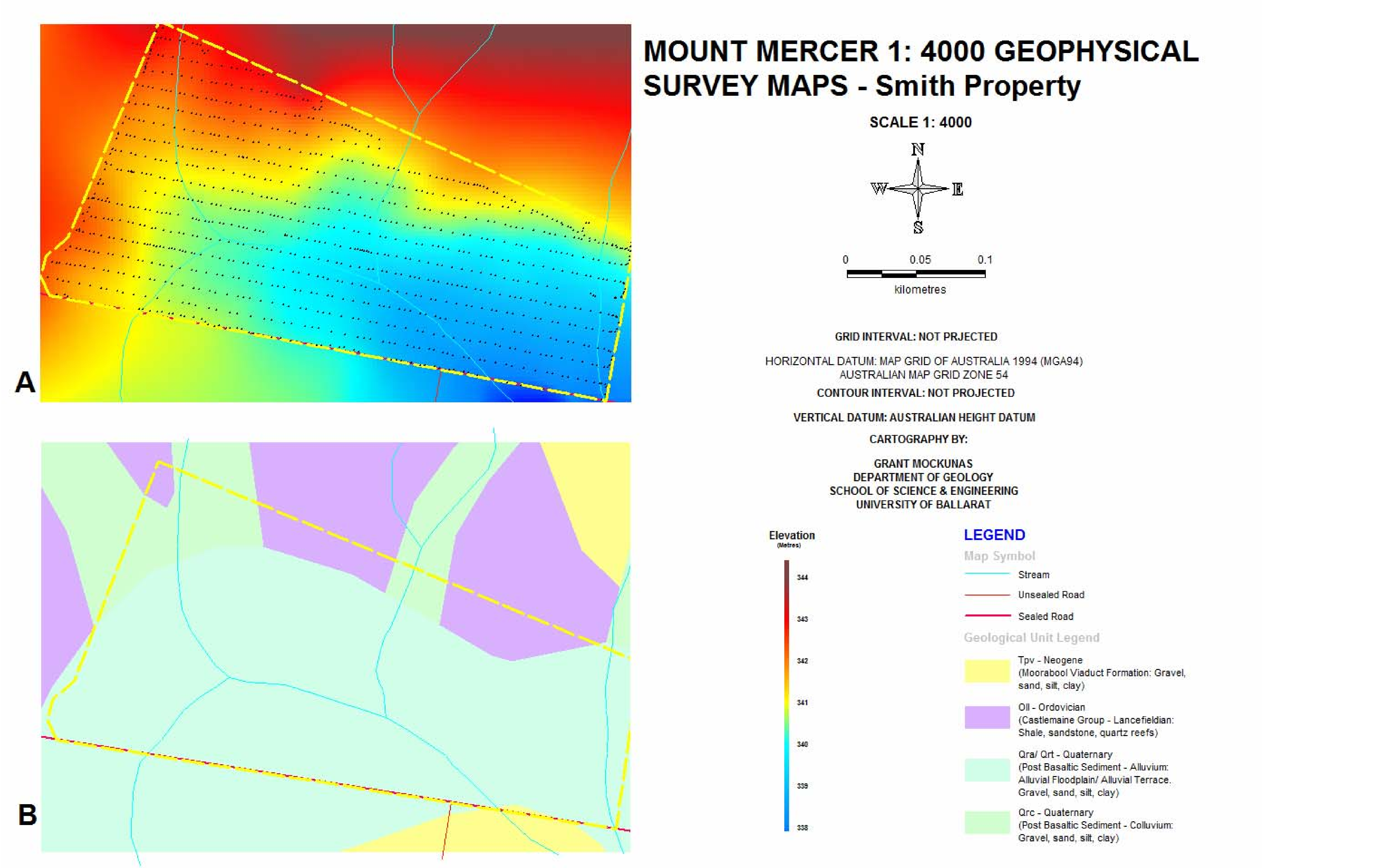


Figure 5-6 **A) DEM for the Smith property survey site, Mount Mercer. B) Geological map of the Smith property survey site.**

5.1.2.2 *Geophysical Analysis*

The apparent electrical conductivity (ECa) for the Smith property survey indicated the variable nature of subsurface conductivity, across the survey site (Appendix O). The predicted soil salinity (ECe) showed areas associated with post-basaltic alluvium and Palaeozoic bedrock (primarily drainage areas) have elevated soil salinity. A comparison of the data shown in Figure 5-7 A/B and Figure 5-8 A/B with Figure 5-6 A/B, indicates that discharge areas are associated with an elevated soil moisture (presumably a effect of the watertable being near-surface), higher soil EC and lower pH. The data indicates strong topographic influence on site salinity, suggesting saline soils is directly associated with groundwater discharge at topographic lows, which occurs from the underlying Palaeozoic bedrock.

The predicted ECe data shows greater values with respect to depth, due to the shallow watertable at the site or possible concentration of salts at depth as a result of rainfall infiltration transporting salts from the topsoil to subsoil. It may be possible the extended drought has allowed sufficient lowering of the watertable, to allow this process to occur. Soils with high ECe are generally very acidic (low pH) and as soil salinity decreases, soil pH concurrently increases. Thus, the pH data is useful in determining the extent and severity of predicted EC values across site and there associated sodic soils.

Previous analyses by Church (2004), indicate similar soil salinity values for both the A and B-horizons to that obtained by this survey. Church (2004) postulated that visible surface salinity has reduced by 60% over the past thirty years. A combination of drought and infiltration processes is therefore, accredited to higher salt concentration in the subsoil.

Bates and Jones (2004a) also conducted an EM38 survey of the site, and their data also showed ECe increasing with depth and concentrated in discharge and drainage areas. They undertook a EM31 survey which interpreted conductivity values to a depth of four to six metres in the vertical dipole and showed that in some areas, salt hotspots continue to depth within discharge areas, strongly suggesting discharge from GFS in the Palaeozoic bedrock (Bates and Jones, 2004a).

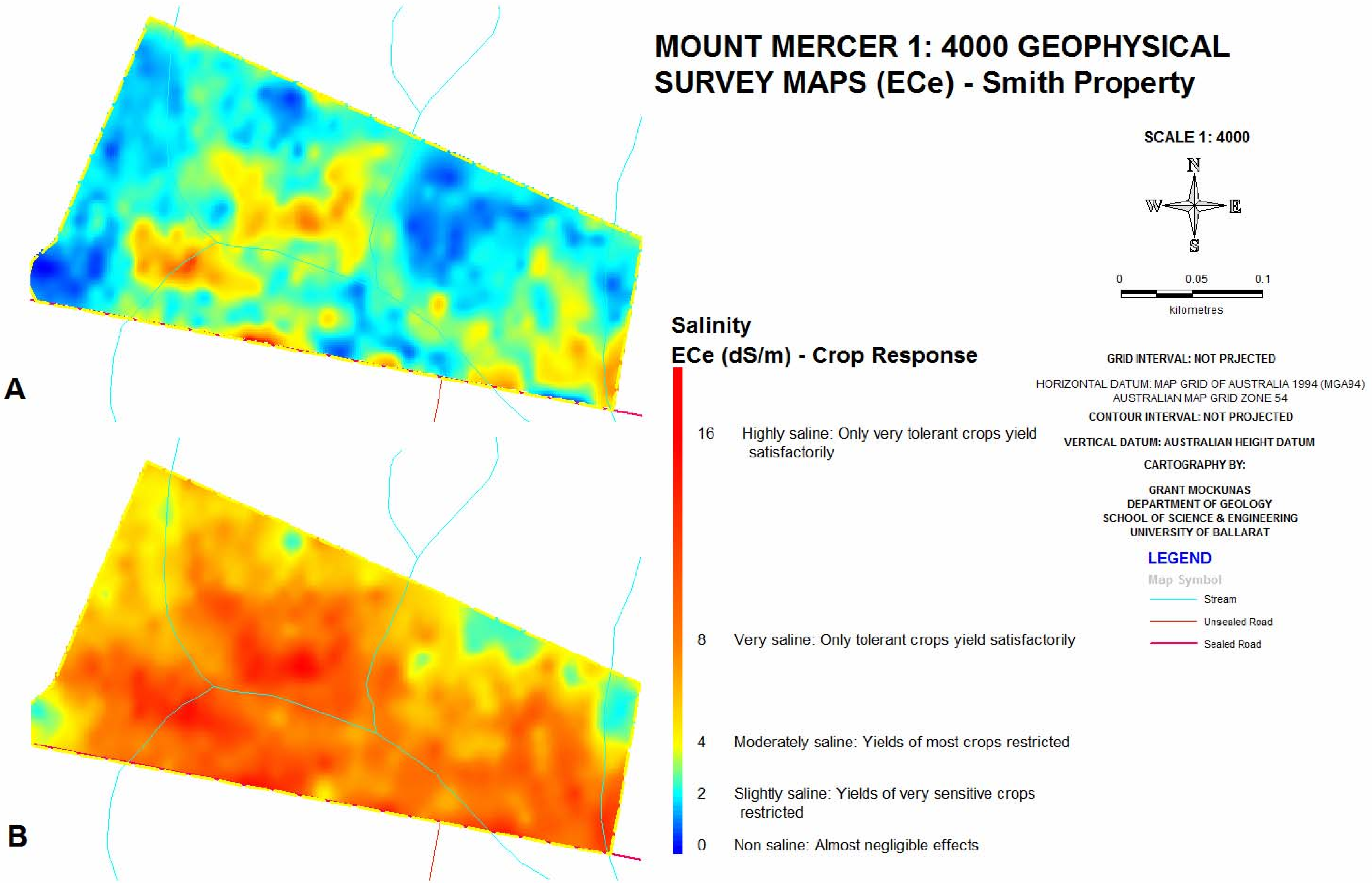


Figure 5-7 **A) ECe 0 – 30cm for the Smith survey site. B) ECe 50 – 80cm for the Smith survey site.**

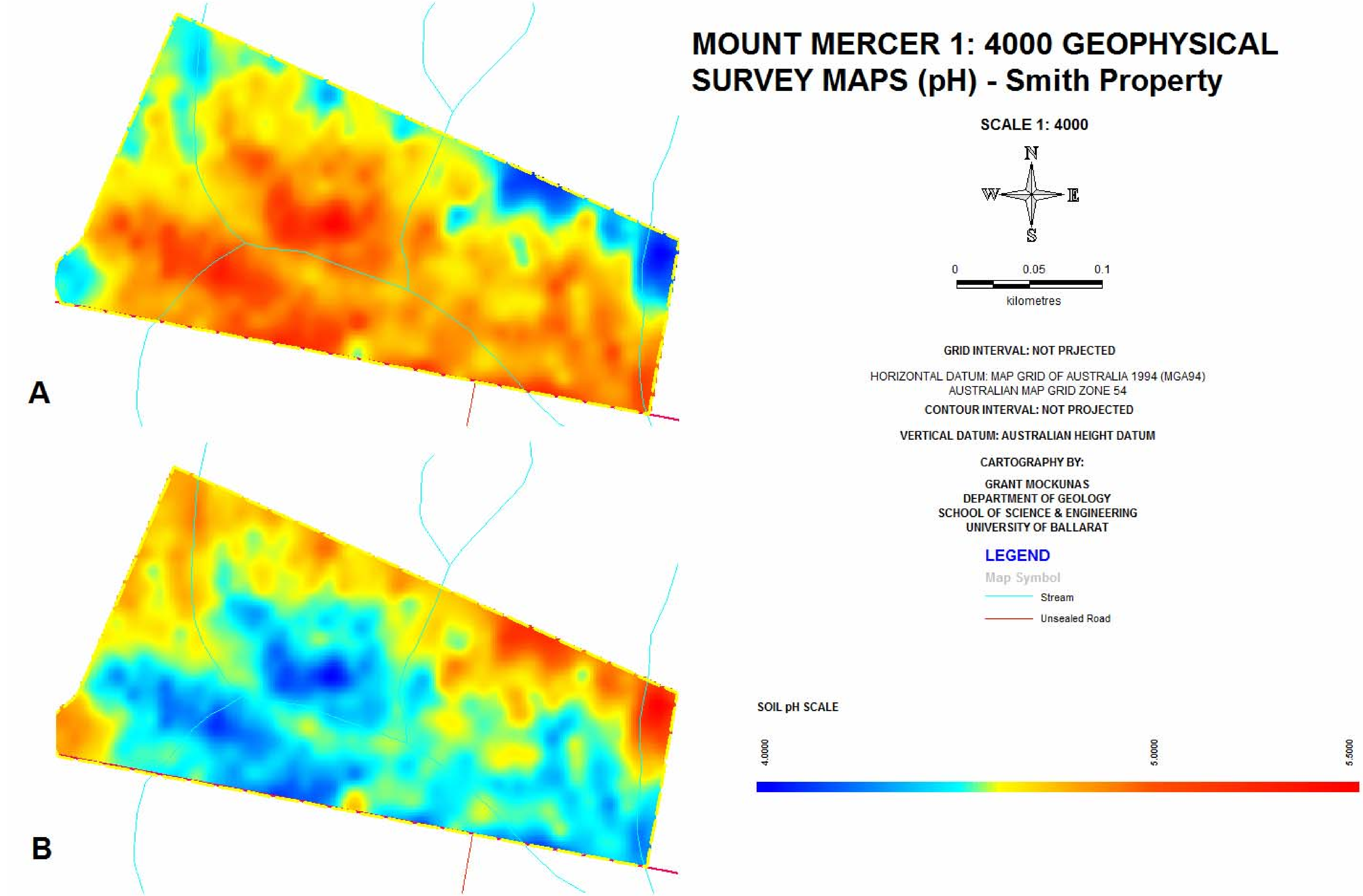


Figure 5-8 **A) pHH2O 0 – 30cm the Smith's survey site. B) pHH2O 50 – 80cm the Smith's survey site.**

5.1.3 **Illabarook (McKenzie Property)**

The Illabarook survey site located on the McKenzie property at Recreation Road and the Pitfield – Illabarook Road, mapped the across-valley near surface salinity. The EM38 survey determined the extent and severity of the salinity, particularly focusing on the mapped boundary between the Neogene gravels/sands (Moorabool Viaduct Formation) and the underlying Palaeozoic bedrock. The survey was conducted using ten metre transect lines, with readings every five metres (Figure 5-9), providing a high-resolution data set of the near surface conductivity.

The Recreation Road site was previously surveyed for the SGSL project using EM38, EM31 and soil analysis (Bates and Jones, 2004b). The site has also been investigated using a hand held EM38, soil sampling and a vegetation survey by Church (2004). Church (2004) used historical aerial photos to analyse change over time at the site and determined an increase in visible saline discharge, over the past thirty years.

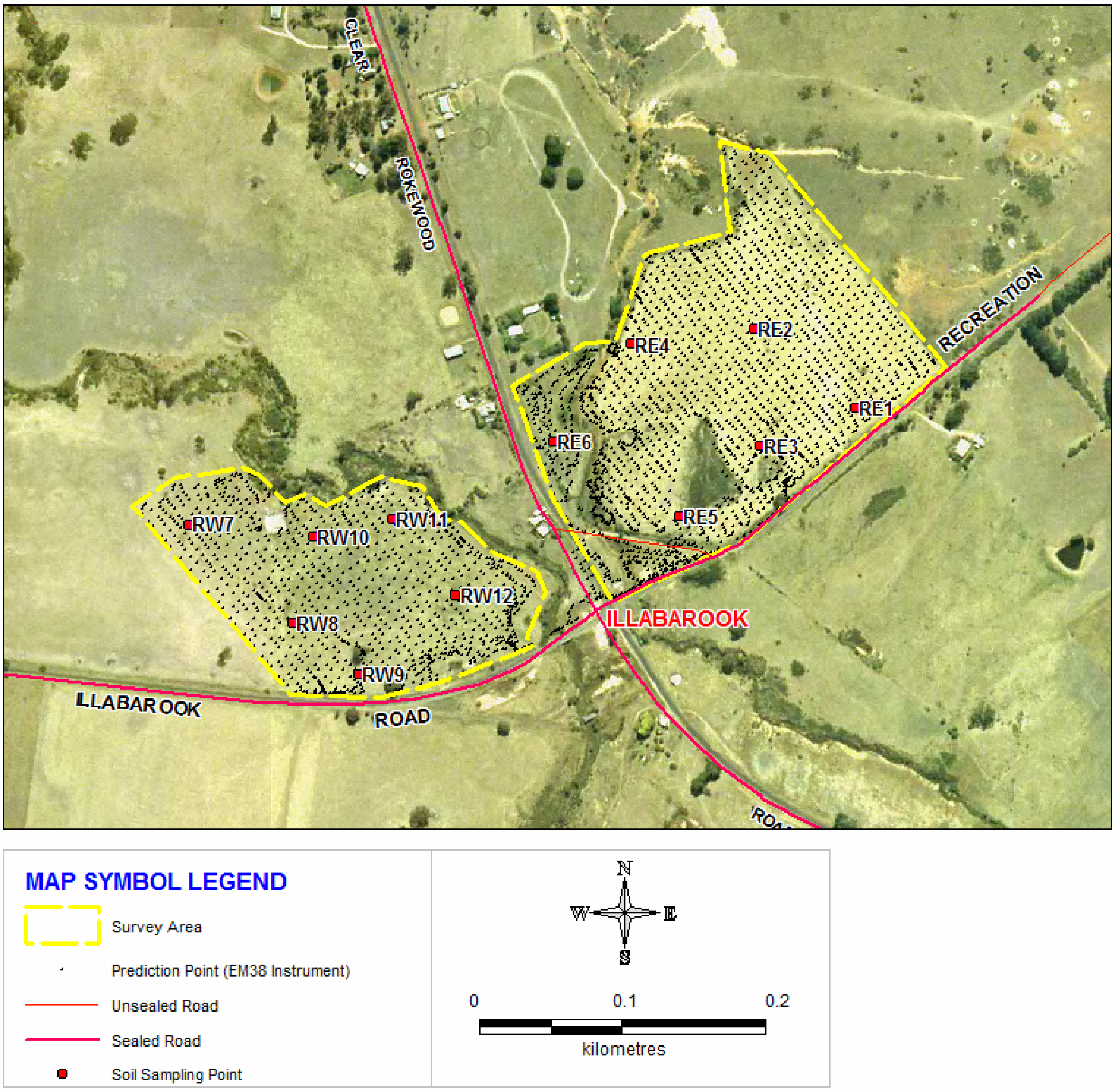


Figure 5-9 **Illabarook geophysical survey area, both Recreation Road and Pitfield – Illabarook Road sites highlighted.**

5.1.3.1 *Soil Sampling*

Soil sampling was conducted at twelve points across the survey area (Figure 5-9). Examination of soil profiles, moisture, texture, $EC_{1:5}$, $pH_{1:5}$ and $pH_{CaCl2\ 1:5}$, was undertaken to determine the physical and chemical properties of soils.

Soils are predominantly composed of sandy-loams to silty-loams at the Recreation Road survey area and clay-loams to loams (with some sandy-loams) at the Pitfield – Illabarook Road survey area. Across the two sites the vertical profile indicates a change from a normally more coarse A-horizon comprised of a higher percentage of gravel/sand, with the B-horizon predominantly composed generally of fine material such as silt and clay. Soils are generally duplex with a poorly structured A-horizon and parent rock features developing with depth (Bates and Jones, 2004b). The A-horizon has an average pH of 6.0 and B-horizon of 6.9, with the soil EC average of 0.2 mS/cm for the A-horizon and 0.5 mS/cm for the B-horizon.

The physical nature of the soils suggests some correlation with site geology and topography. Sample RE1 for example contained a large proportion of ironstone, derived from the ferruginous gravel caps on which the soils have developed. Other samples have minor fragments of siltstone and angular fragmented vein quartz, which is recognized as the development of an *in situ* regolith on Palaeozoic bedrock. Mining in the area approximately 100 years ago suggests some soils may have undergone a degree of disturbance, forming anthroposols, and is noted at site RE6. In drainage areas, soils are characterised by finer sands, silts and clay sediments.

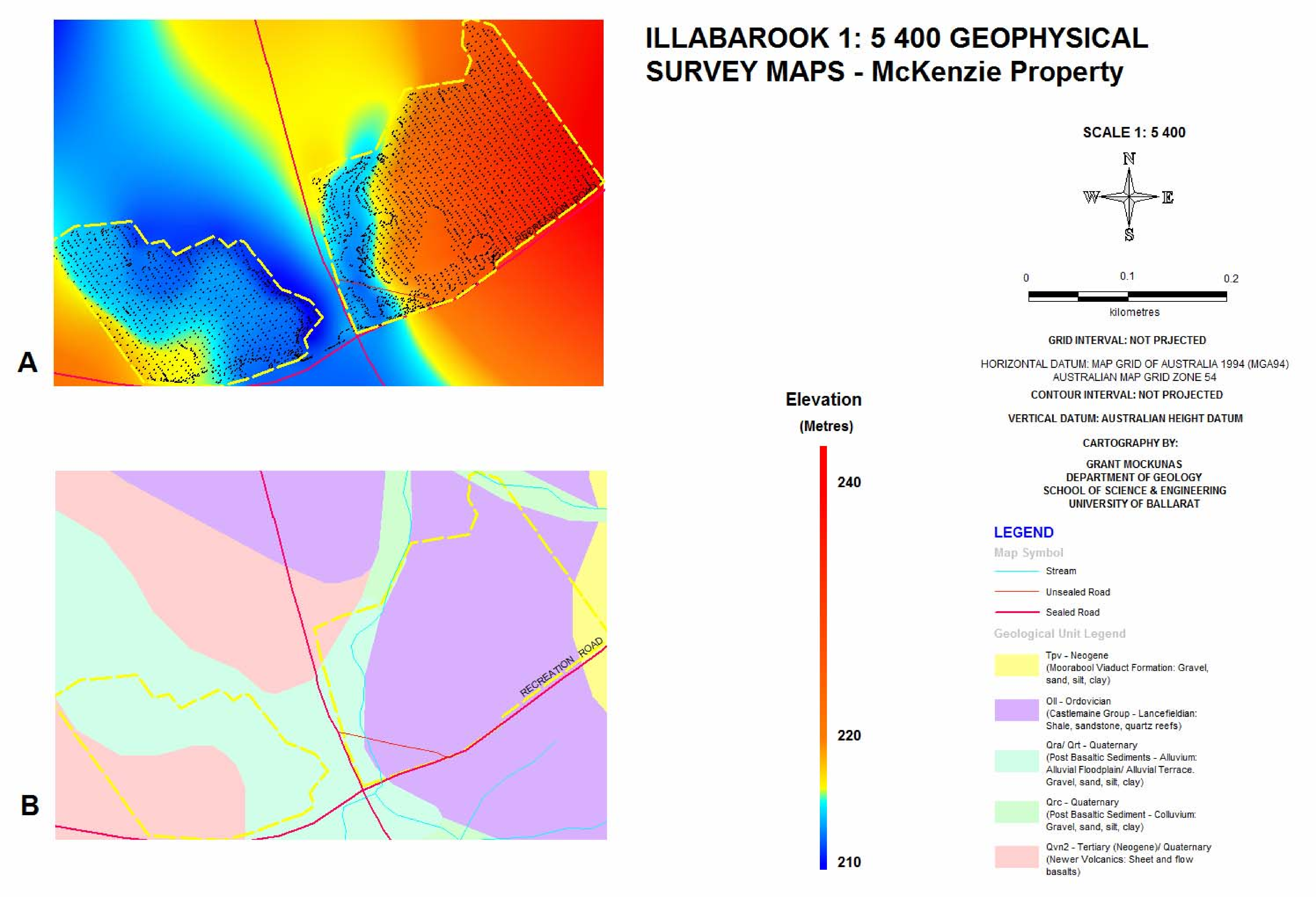


Figure 5-10 A) DEM for the Illabarook survey site. B) Geology of the Illabarook survey site.

5.1.3.2 *Geophysical Analysis*

The predicted ECe for both survey areas at Illabarook, suggests that spatial variation in near surface salinity is associated with a complexity of groundwater flow systems. Saline groundwater discharge and the occurrence of soil salinity is believed to be primarily concerned with subsurface geology and the flow systems associated with them.

Discharge areas with elevated soil salinity are primarily associated with post-basaltic alluvium and Palaeozoic bedrock sediments. Moorabool Viaduct Formation which forms extensive ferruginised sand/gravel caps on hilltops, also shows high ECe readings in the near surface. A Deep Lead aquifer system thought to outcrop at the Recreation Road site, is believed to have greater influence than previously hypothesised (Refer Chapter 6). High readings also occur at the boundary between the Newer Volcanics basalts and post-basaltic alluvium, which is seen at the Pitfield – Illabarook Road site.

An increase in both the severity and extent of near surface salinity around discharge zones is highlighted by the ECe of horizontal dipole (0-30 centimetre) readings (Figure 5-11 A). Vertical dipole data (50-80 centimetres) defines regions of near surface salinity not readily identifiable in the landscape (Figure 5-11B).

In contrast to the Mount Mercer survey sites the pH analysis indicates a more acid surface (0-30 centimetres), gradually becoming more alkaline with depth. Bates and Jones (2004b) suggest the change in soil chemical properties from acid to alkaline with depth, is related to the high sodicity (Figure 5-12 A/B).

The Bates and Jones (2004b) survey of the Recreation Road site delineated elevated ECe where saline discharge occurs on the hillslope. Their EM38 data shows an increase with depth in soil salinity but diminishing again at greater depth, using the horizontal EM31 instrument. Their EM38 vertical dipole data also highlights increasing soil salinity above the discharge site, primarily constrained to drainage areas within the Neogene sediments (Bates and Jones, 2004b).

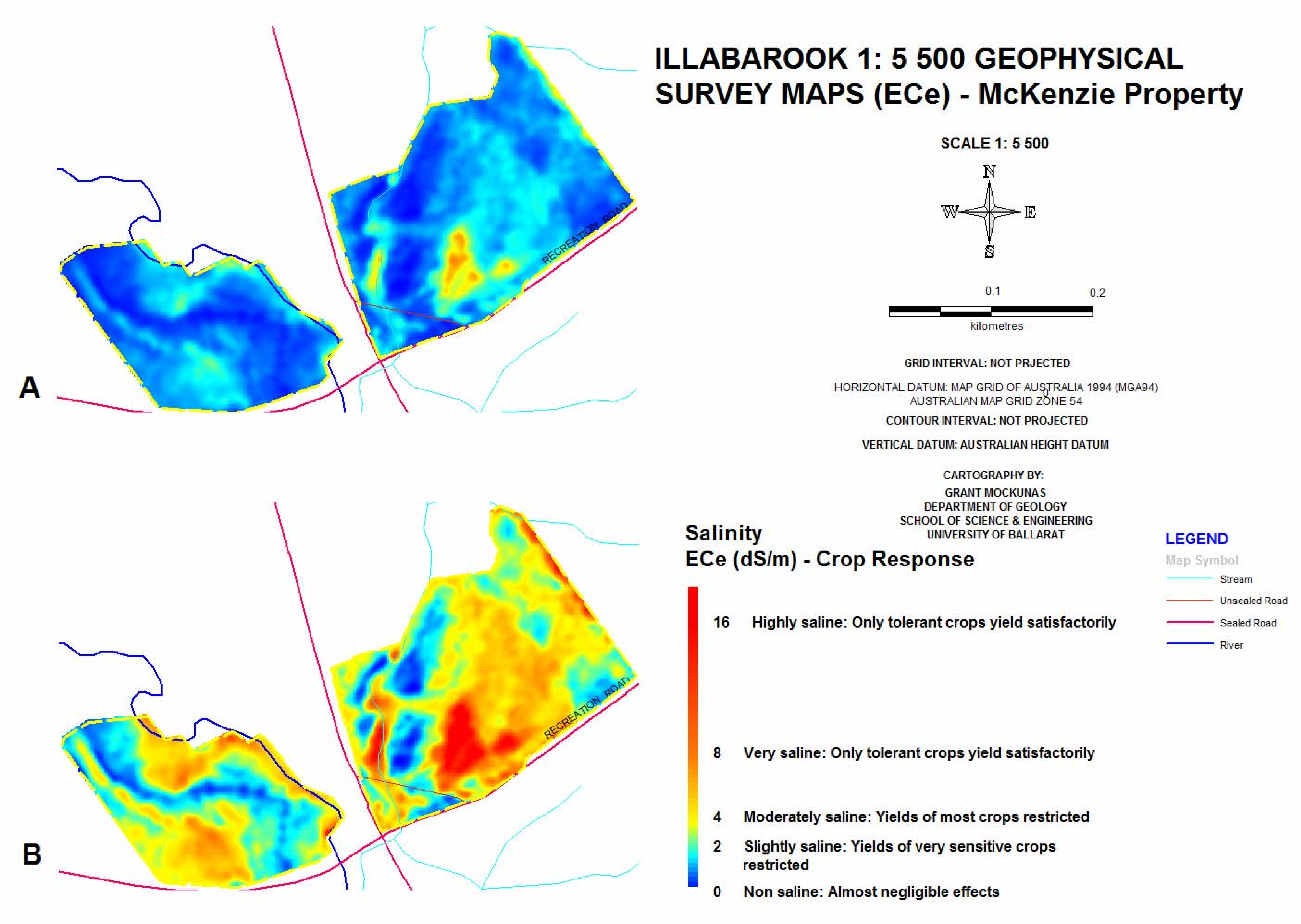


Figure 5-11 A) ECe 0 -30cm for the Illabarook survey site. B) ECe 50 – 80cm for the Illabarook survey site.

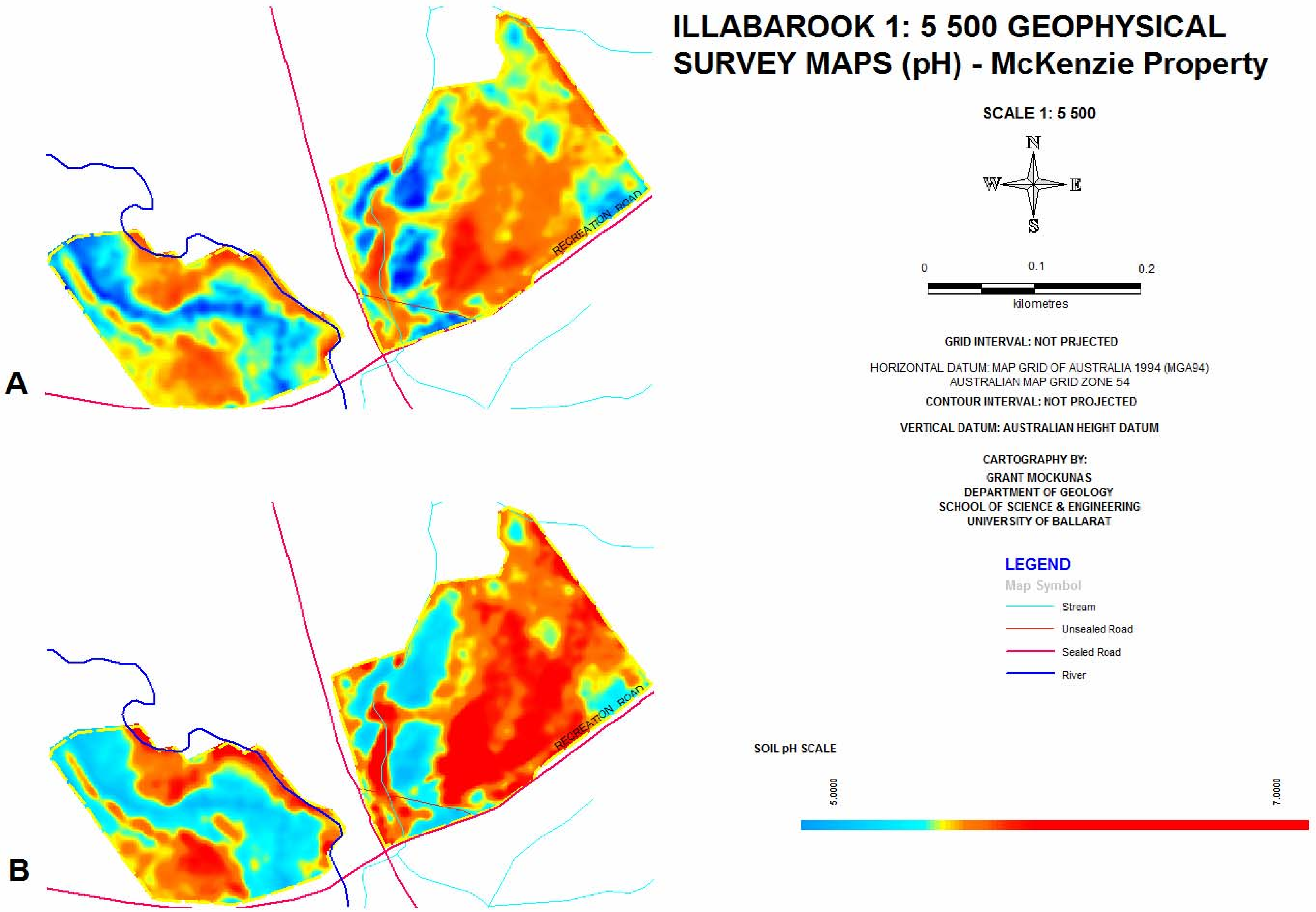
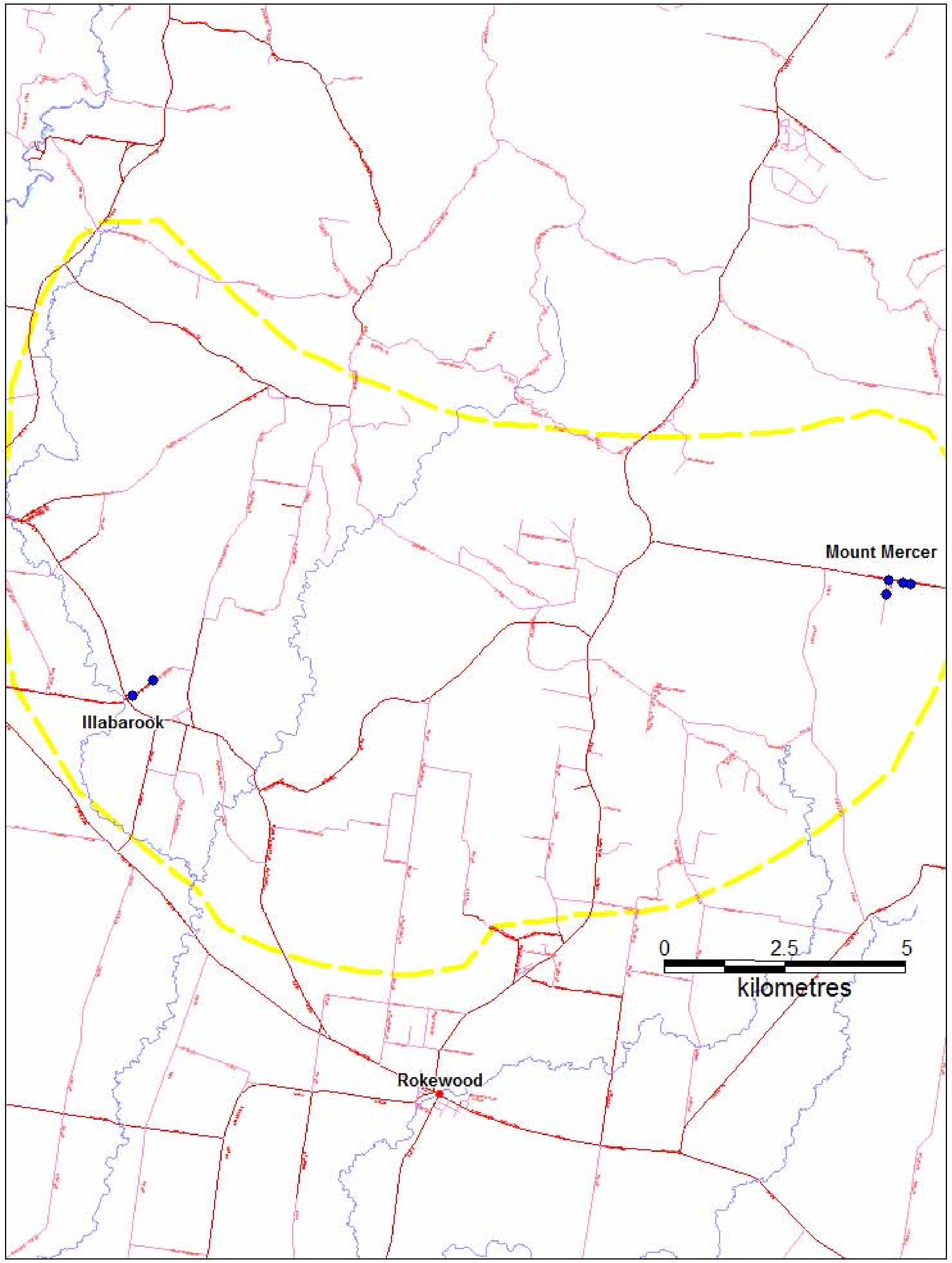


Figure 5-12 **A) pHH2O 0 – 30cm for the Illabarook survey site. B) pHH2O 50 – 80cm for the Illabarook survey site.**

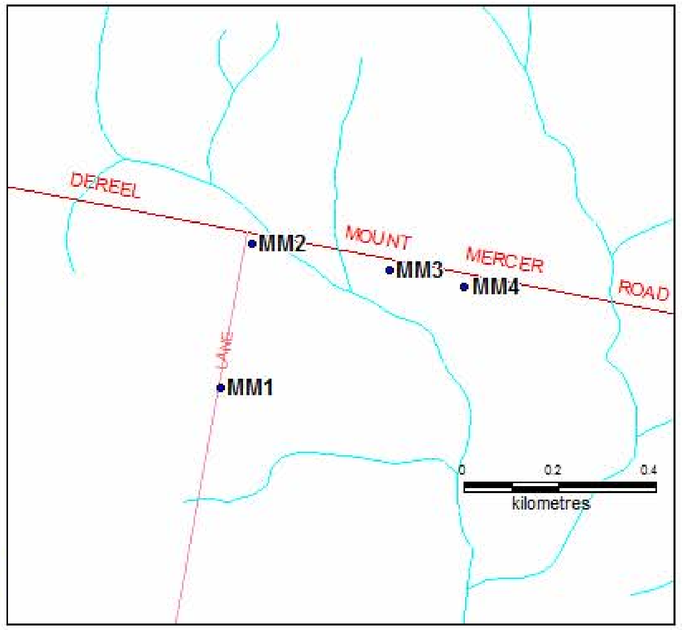
5.2 GROUNDWATER INVESTIGATION

The installation of groundwater investigation bores at Mount Mercer and Illabarook were designed to test the original conceptual hydrogeological model proposed in Nicholson et al. (2006). Six groundwater monitoring bores were installed: four bores on the Laffan property at Mount Mercer; and one on the McKenzie property at Illabarook (IR2); and one on the Golden Plains Shire reserve at Illabarook (IR1; Figure 5-13). Groundwater bores targeted specific GFS in order to investigate the three-dimensional geology of the sites, aquifer type and geometry, flow systems and hydraulic properties.

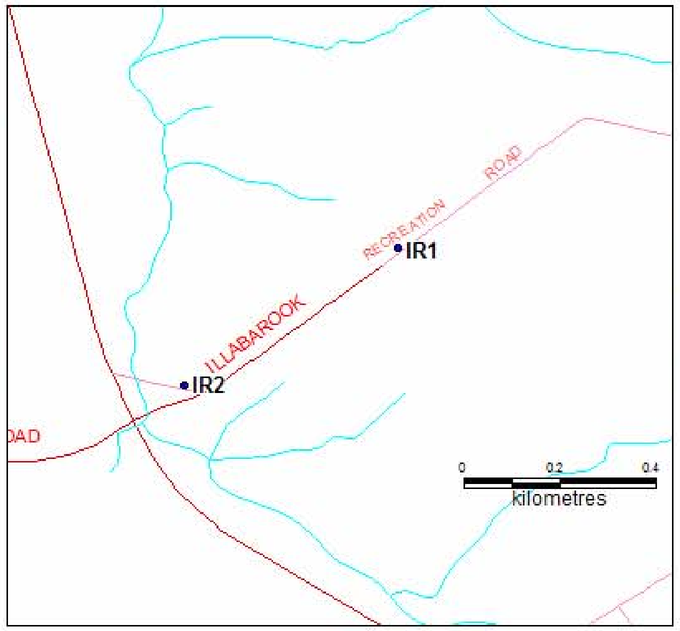
1: 100 000 GROUNDWATER MONITORING BORE LOCATION MAP: MOUNT MERCER - ILLABAROOK AREA



MOUNT MERCER 1: 1 300 PIEZOMETER LOCATION MAP



ILLABAROOK 1: 1 300 PIEZOMETER LOCATION MAP



N
W E
S

GRID INTERVAL: NOT PRJECTED

HORIZONTAL DATUM: AUSTRALIAN MAP GRID 1984 (AUS84)
AUSTRALIAN MAP GRID ZONE 54

CONTOUR INTERVAL: NOT PROJECTED

VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

CARTOGRAPHY BY:

GRANT MOCKUNAS
DEPARTMENT OF GEOLOGY
SCHOOL OF SCIENCE & ENGINEERING
UNIVERSITY OF BALLARAT

BORE_ID	EASTING	NORTHING	DEPTI	AQUIFER
IR1	54 733321	58 10254	15m	Palaeozoic
IR2	54 732878	58 09970	7m	Palaeozoic
MM1	54 748562	58 11580	12m	Palaeozoic
MM2	54 748630	58 11881	8m	Tertiary
MM3	54 748915	58 11826	12m	Palaeozoic
MM4	54 749 071	58 11790	12m	Palaeozoic

Figure 5-13 Location map of installed groundwater monitoring wells at Mount Mercer and Illabarook.

5.2.1 **Mount Mercer Investigation Site**

The installation of groundwater monitoring piezometers at Mount Mercer investigated GFS in Palaeozoic bedrock and Neogene sediments (Appendix A; Table 5-1). Piezometers MM1, MM3 and MM4 (Figure 5-13) determined a watertable at variable depth within Palaeozoic (Ordovician) siltstone, regarded as an aquifer semi-confined by overlying impermeable clay units. Similarly, MM2 placed in Moorabool Viaduct Formation gravel/sand indicated the presence of a semi-confined aquifer system, overlain by highly weathered sediments forming iron-rich clays. Due to budget constraints Deep Lead and Newer Volcanics basalt aquifer systems were not targeted as part of the piezometer installation program.

5.2.1.1 *Stratigraphic Interpretations*

The selection of specific bore sites was determined from both field observations and literature studies. Piezometers were placed at varying depths to the Palaeozoic bedrock (Castlemaine Group – Lancefieldian) and Neogene gravel/sand (Moorabool Viaduct Formation), in order to determine the nature of the GFS and possible influences on saline groundwater discharge (Table 5-1).

MM4 and MM3 piezometers were placed within the saline discharge site, targeting aquifer systems within post-basaltic alluvium and the underlying Palaeozoic bedrock. The watertable was intercepted at approximately nine to ten metres below natural surface within Palaeozoic bedrock sediments. Post-basaltic alluvial deposits varied in depth from two to nine metres, between site MM4 and MM3 respectively. An investigation in the late 19^{th} century for gold exploration had logged drill holes within close distance of the installed piezometers and had intercepted a Deep Lead system, in-filled with early valley flow basalts of the Newer Volcanics (Gillies, 1889). These valley flow basalts are covered by post-basaltic alluvial floodplain deposits and were not intercepted during this drilling program.

The installation of piezometers MM2 and MM1 targeted GFS within Neogene gravel/sand sediments and the Palaeozoic bedrock respectively. MM2 intercepted a semi-confined aquifer system within Neogene sediments at five metres. Drilling identified that the Neogene sediments are relatively thick, extending to at least eight metres in this section. MM1 was installed specifically with the intention of investigating the elevated areas within Palaeozoic bedrock GFS. A capillary fringe zone was intercepted in siltstone sediments at six metres, with a noticeable change in bedrock moisture. The inter-bedded sequence associated with Palaeozoic sediments, was evident with a change to a very fine grained sandstone at eight metres. This unit continued to eleven metres, where siltstone was again intercepted.

The analysis of $EC_{1:5}$/$pH_{1:5}$ from samples collected downhole determined that regolith is variable from acid to alkaline with differing electrical conductivity (EC) throughout the profile (Appendix Q). Results indicate that the upper regolith (0-2 metres) appears to be characterised by acid soils with elevated EC, which becomes more alkaline with depth. An increase in EC is again observed at the intercepted watertable and is concurrent with a reduction in soil pH. This is observed in both the Neogene and Palaeozoic sediments at the Mount Mercer site. Piezometers installed in discharge areas also registered higher EC in the overlying alluvial/colluvial sediments.

Drilling found that aquifer systems are semi-confined in discharge areas and appear to be semi-confined by overlying post-basaltic alluvial sediments. The fractured Palaeozoic bedrock appears to be a transmissive unconfined to semi-unconfined aquifer system. A semi-confined aquifer system also appears to exist within Neogene sediments with ferruginous clays restricting the vertical movement of water.

5.2.2 **Illabarook Investigation Site**

The construction of groundwater monitoring piezometers at Illabarook also targeted aquifer systems within the Palaeozoic bedrock and Neogene sediments (Appendix A; Table 5-1). Piezometer IR1 was constructed in Palaeozoic sediments within the elevated landscape, were recharge is postulated to occur. IR2 was established in a shallow aquifer within weathered Palaeozoic bedrock, down slope from IR1 (Figure 5-13).

5.2.2.1 *Stratigraphic Interpretations*

The selection of bore sites was based on testing the proposed groundwater flow systems and salinity processes, thought to occur in the Illabarook salinity target area by Nicholson et al. (2006).

Piezometer IR2 was constructed within the saline discharge area and targeted near surface aquifer systems. Highly weathered siltstones containing fragmented angular vein quartz of the Palaeozoic (Ordovician) bedrock was encountered and the watertable was intercepted within the unit at a depth of four metres. Bore IR1 investigated the depth to the watertable upslope in the proposed recharge zone and found the watertable within the Palaeozoic (Ordovician) bedrock. Drilling intercepted Neogene sediments to nine metres depth, which formed variably rounded sand and gravel sediments, with ferruginous material in the top two metres. Mottling and bleaching of sediments and clay at variable depths within Neogene gravels/sands indicated seasonal water-logging and suggested a similar relationship to that observed by Bates and Jones (2004b). The watertable was located at a depth of eleven metres within the highly weathered siltstone of the underlying Palaeozoic bedrock.

The downhole analysis of $EC_{1:5}$/$pH_{1:5}$ of the materials encountered by drilling, determined that regolith is similar to Mount Mercer (Appendix Q). High EC in the upper regolith to a depth of one to two metres diminishes with depth but again increases, at the zone of the intercepted watertable. Regolith pH is characteristically different to Mount Mercer, in that slightly acid to neutral soils are associated with high EC readings and low EC is associated with acid soils. The data indicated that Neogene sediments have relatively low EC down profile, with higher readings concentrated to the upper two metres. The Palaeozoic bedrock is considered the primary region of salt store, with elevated EC determined within the unit at piezometers IR1 and IR2.

BORE ID	EASTING	NORTHING	AQUIFER	BORE DEPTH (m)	SCREEN POSITION (m)	FILTER PACK (m)	BENTONITE SEAL (m)	BACKFILL (m)
IR1	54 733321E	58 10254N	Palaeozoic (Ordovician) Bedrock	15	15-11	15-10.5	10.5-8.5	8.5-0
IR2	54 732878E	58 09970N	Palaeozoic (Ordovician) Bedrock	7	7-4	7-3.5	3.5-2.5	2.5-0
MM1	54 748562E	58 11580N	Palaeozoic (Ordovician) Bedrock	12	12-6	12-5	5-3	3-0
MM2	54 748630E	58 11881N	Neogene Sediments (Moorabool Viaduct Formation)	8	8-5	8-4	4-2	2-0
MM3	54 748915E	58 11826N	Palaeozoic (Ordovician) Bedrock/ Quaternary Alluvium	12	12-6	12-5	5-2	2-0
MM4	54 749071E	58 11790N	Palaeozoic (Ordovician) Bedrock	12	12-8	12-7	7-5	5-0

Table 5-1 Summary of bore construction details and aquifer type for both the Mount Mercer and Illabarook sites.

5.3 AQUIFER RECOVERY TESTS

Aquifer recovery tests determined considerably lower hydraulic conductivities than previously hypothesised. Dahlhaus et al. (2002) had suggested highly variable flows of 10^{-5} to 10^{-1} m/d in the Palaeozoic bedrock (GFS12) and 10^{-4} to 10 m/d in Neogene sediments (GFS3). The results for the hydraulic conductivity testing are summarised in Table 5-2 and appended in Appendix P.

At Mount Mercer, piezometer MM1 intersected the most conductive aquifer, measuring $5.3*10^{-1}$ cm/d within the fractured Palaeozoic bedrock (Figure 5-14). Piezometer MM2 placed within Neogene sediments has the lowest hydraulic conductivity of $4.6*10^{-2}$ cm/d. MM3 situated in the discharge zone at the site, consists of the screen extending from the Palaeozoic bedrock into Quaternary alluvium and measures a minor increase in hydraulic conductivity to $7.6*10^{-2}$ cm/d. MM4 also situated in the discharge area is screened within Palaeozoic bedrock and indicates a hydraulic conductivity of $4.6*10^{-2}$ cm/d, similar to that determined in Neogene sediments.

Hydraulic values obtained for both IR1 and IR2 at Illabarook are relatively low, $3.7*10^{-2}$ and $3.8*10^{-2}$ cm/d respectively. The results indicated conductive properties considerably less than previously hypothesised (Dahlhaus et al. 2002).

The hydraulic conductivity values were checked against standard values in Fetter (2001), and compared well to those for clay to silt, sandy silt and clay sand material. The results are within the expected range for the highly weathered saprolith extending to depth across the sites, which appears to have an intrinsically low hydraulic conductivity but is locally variable.

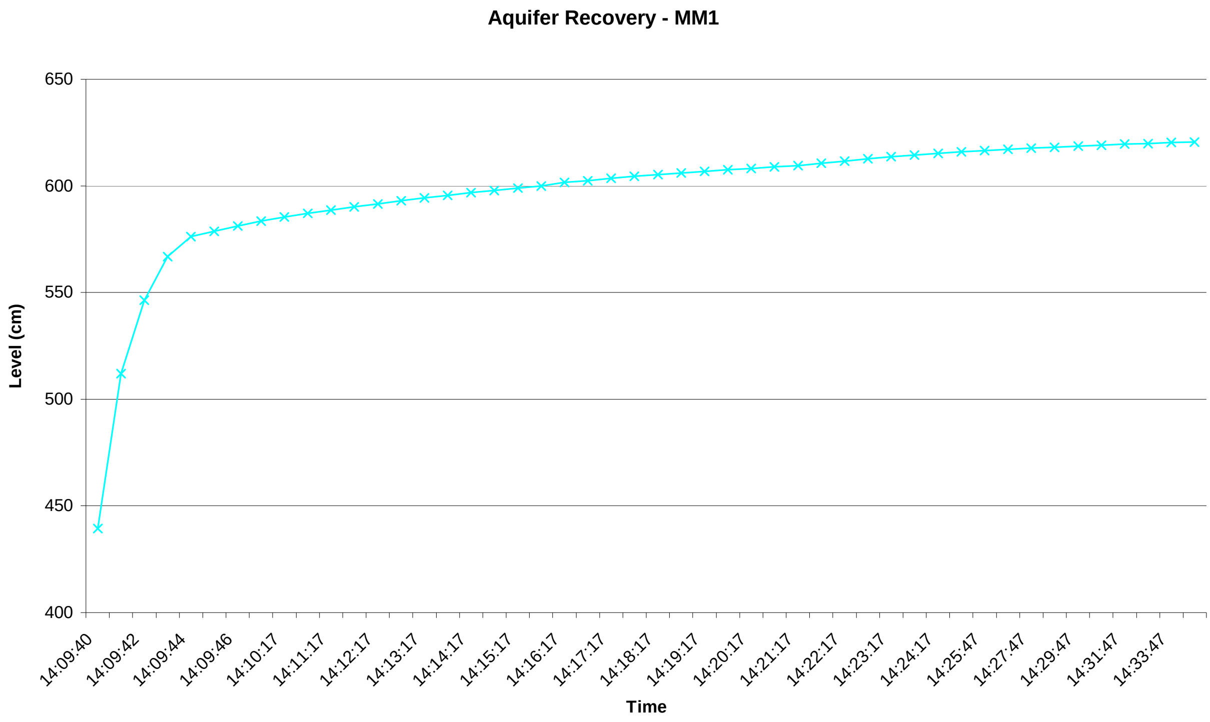


Figure 5-14 Aquifer recovery graph (Time/Level) for bore MM1 proceeding pumping.

Bore ID	**IR1**	**IR2**	**MM1**	**MM2**	**MM3**	**MM4**
Date	24/10/2007	24/10/2007	24/10/2007	24/10/2007	24/10/2007	24/10/2007
Initial SWL from TOC (m)	13.26	2.92	7.4	2.39	3.75	2.08
Temperature Range (^oC)	16.9-26.9	14.8-23.3	14.7-23.7	14.2-19	13.6-16.1	13.6-17.1
Logging start	10:44:37	12:10:27	13:54:47	14:55:27	16:06:13	16:52:38
Logging finish	11:54:37	13:15:27	14:45:47	15:46:27	16:40:13	17:41:38
Total time	**1 hr 10min**	**1 hr 5min**	**51min**	**51min**	**34min**	**49min**
Head at time zero '*Ho* (m)'	N/A	6.83	7.92	6.77	7.42	9.38
Hydraulic Conductivity (K), cm/day	$3.7*10^{-2}$	$3.8*10^{-2}$	$5.3*10^{-1}$	$4.6*10^{-2}$	$7.6*10^{-2}$	$4.6*10^{-2}$
Measured Electrical Conductivity – EC (mS/cm)	8.90	16.30	9.50	7.20	5.60	5.00

Table 5-2 Summary of aquifer recovery testing and groundwater EC analysis.

5.4 SURFACE WATER INVESTIGATION

Measurement of surface water salinity (as EC), pH and temperature was conducted between March and October 2007 and combined with previous data collected by Mananis (2006). Stream salinity (EC) was measured in milli-Siemens/per centimetre (mS/cm) which is equivalent to 1,000 micro-Siemens/ per centimetre (µS/cm). The data for surface water salinity has been analysed for both catchment and sub-catchments (Refer Appendix C for stream EC analysis data), by examining geology, hydrogeology, geomorphology and salinity occurrence. In the absence of more precise data being available, the monthly rainfall data for the Ballarat Aerodrome (station #089002) was obtained from the Bureau of Meteorology (Figure 5-16;

BOM, 2007a & BOM 2007b), providing approximate monthly rainfall for the Illabarook region. The monthly rainfall was compared with monthly EC data obtained during sampling, in order to analyse any relationships.

The extended drought was the dominant factor affecting the scope of data available for analysis. Ferrers Creek in particular was found to be dry, with no water present during the first few months of sampling. This was also the case at many of the other selected sites where stream flow was non-existent and small pools of water were present in the creek/ river bed. Testing of these pools of water often exhibited a high EC reading and they were assumed most probably to be groundwater discharge. Paucity of data from the previous years sampling was also due to the fact some sampling locations were not selected until later in the investigation thus, a gap in data exists (Mananis, 2006).

The Illabarook target area extends across a portion of four sub-catchments of the Woady Yaloak River. These sub-catchments are characterised by differing salinity processes and physical characteristics, which have bearing on surface water salinity. The data displayed in Figure 5-15 below illustrates the combined EC data for the sites, over the 2006 and 2007 sample periods.

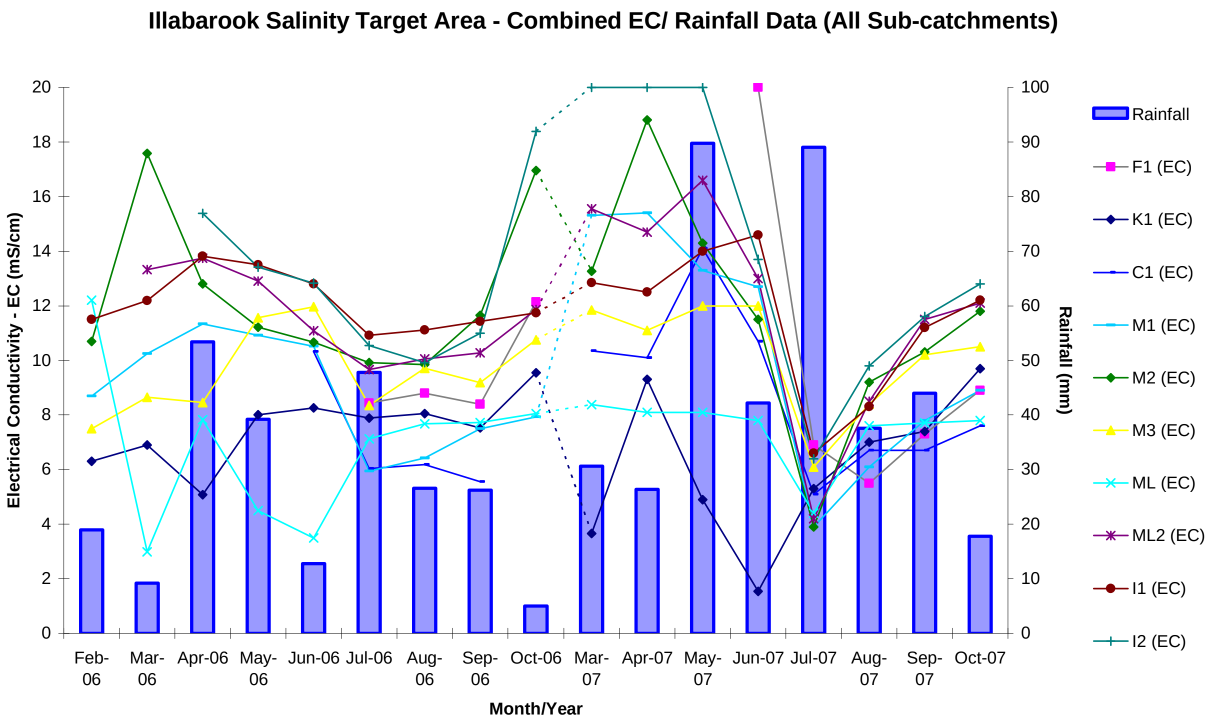


Figure 5-15 **Monthly EC values for Illabarook salinity target area, surface water sampling sites.**

(Data Set: Combined 2006/2007 data)

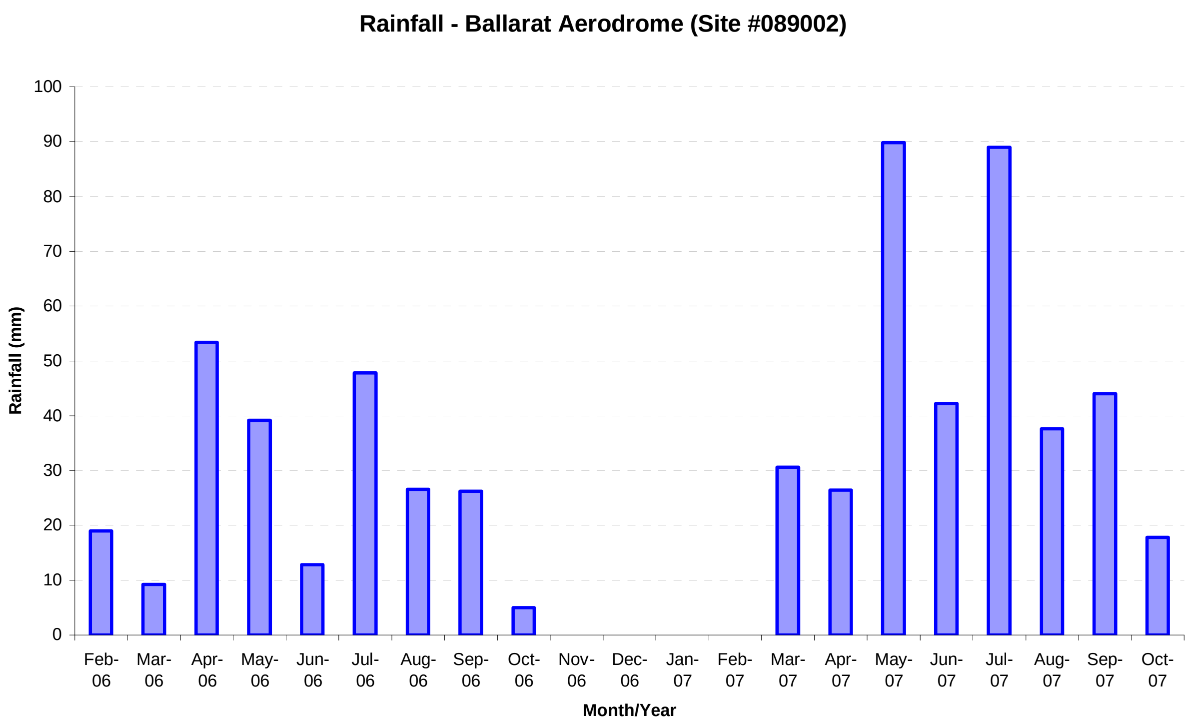


Figure 5-16 **Monthly rainfall data for Ballarat Aerodrome – Site #089002.**

(Data Source: BOM, 2007a/b)

5.4.1 **Illabarook sub-catchment**

The Illabarook sub-catchment is comprised of deeply to moderately dissected landscape, with dendritic drainage flowing into Illabarook Creek. Illabarook Creek has formed in the dissected Palaeozoic sediments of the Western Uplands. It then trends along the margins of the sheet flow basalts on the western portion of the target area, through Neogene gravel sediments and into the underlying Palaeozoic bedrock. The creek connects with Mount Misery Creek, which flows onto the Western Victorian Volcanic Plains and eventually into the Woady Yaloak River. Alluvial and colluvial deposits have developed along Illabarook Creek and its tributaries. The catchment area is approximated to be 113 km^2, with Illabarook Creek spaning a distance of approximately 20 km (Mananis, 2006).

In the Illabarook sub-catchment two sites, I1 on the Illabarook – Pitfield Road at Illabarook and I2 at Imries Lane, south east of Illabarook, were selected for surface water sampling (Refer Figure 4-6). I1 and I2 have variable EC recordings over the 2006 to 2007 period but appear to have similar EC values extending from April to September 2006 and May to October 2007 (Figure 5-17). The results for both sample sites appear to indicate a direct relationship between stream salt concentration and rainfall events.

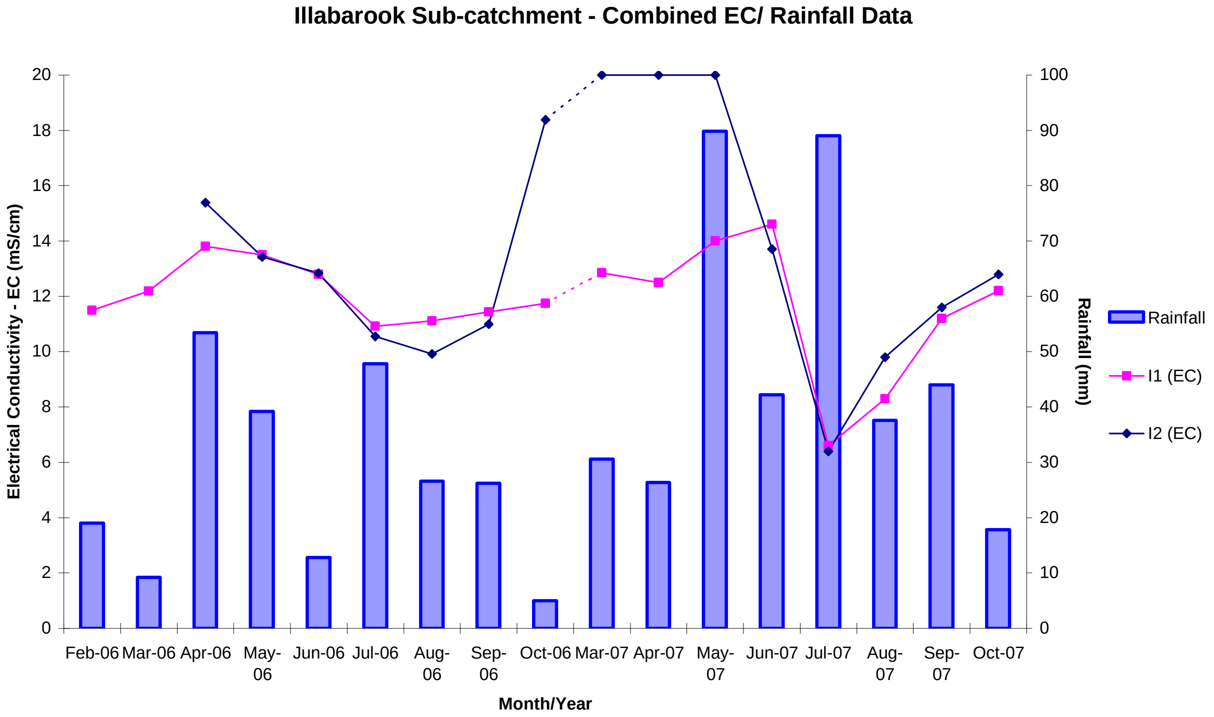


Figure 5-17 **Illabarook Sub-catchment – EC trend graph for combined 2006/ 2007 stream sampling data.**

5.4.2 **Mount Misery sub-catchment**

Mount Misery Creek forms the main watercourse in the Mount Misery sub-catchment but also gains water from Moonlight Creek sub-catchment. Mount Misery Creek has moderately to deeply dissected the Palaeozoic bedrock and has its headwaters in the Enfield Forest Park region. The underlying geology consists of Palaeozoic bedrock with overlying Neogene (Moorabool Viaduct Formation) capping on hill slopes and hilltops. The creek also dissects Palaeogene (White Hills Gravel) sediments in the northern region of the target area. Tributaries that feed into the Mount Misery Creek system are characterised by gully erosion and have down cut into the Palaeozoic bedrock, through Neogene gravels. Towards the margins of the Western Uplands and the Western Victorian Volcanic Plains, the creek is displaced by sheet flow basalts of the Newer Volcanics. The sub-catchment has an approximate area of 190 km^2 (Mananis, 2006).

Moonlight Creek is a major tributary that feeds the Mount Misery Creek system, near Rokewood Junction. Its headwaters form west to north-west of Berringa, on Palaeozoic bedrock and White Hills Gravel sediments. The creek has similarly down cut into the Palaeozoic sediments that are capped by Moorabool Viaduct Formation, further to the south. Tributaries feeding Moonlight Creek and the creek itself are eroded, with the landscape moderately to deeply dissected. The landscape surrounding the creek has not been altered by flows of the Newer Volcanics, but has numerous mine workings and Deep Lead (ancestral rivers) systems. Possible influences of these disturbances on groundwater systems are eluded to by Nicholson et al. (2006), suggesting that they created preferred pathways for infiltrating water into aquifer systems.

The EC data for the sites was variable but similar trends were evident. The Mount Misery Creek has the greatest variation between sample sites. M1, M2 and M3 all show some degree of similarity in relationship to rainfall events however, M1 and M3 indicate variance in amplitude variation in relation to such events. Dissimilarity also occurs between respective sample sites with M2 indicating greater average EC readings relative to M1 and M3. The graphed data illustrated on Figure 5-18 indicates that during periods of higher rainfall, EC levels initially rise and then proceed to drop. This trend is particularly illustrated during the April to June 2006 period and the March to April period 2007.

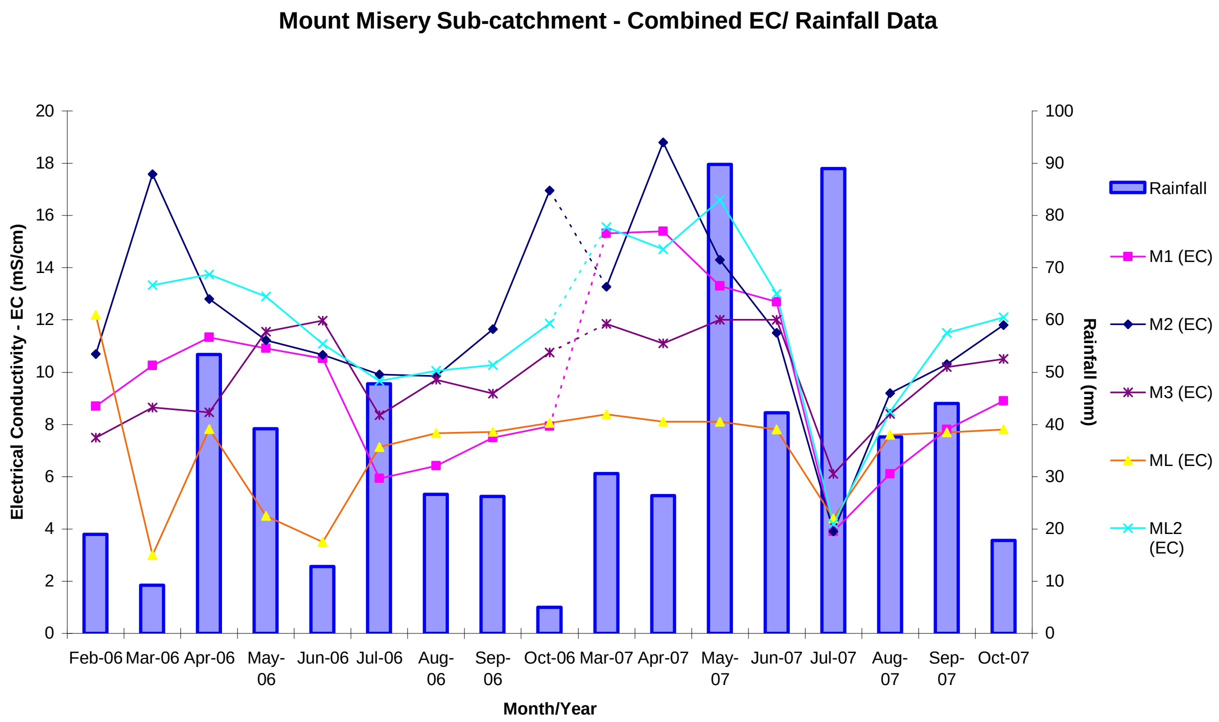


Figure 5-18 **Mount Misery Sub-catchment – EC trend graph for combined 2006/ 2007 stream sampling data. EC Sampling data for Mount Misery Creek and Moonlight Creek systems.**

5.4.3 **Kuruc-A-Ruc sub-catchment**

The Kuruc-A-Ruc sub-catchment is comprised of Kuruc-A-Ruc Creek and Corindhap Creek systems. The sub-catchment is characterised by gently to moderately undulating terrain in the south and moderately to highly undulating terrain in the north. Kuruc-A-Ruc and Corindhap creeks coalesce on the margins of the Western Uplands and the Western Victorian Volcanic Plains and Kuruc-A-Ruc Creek continues in a south-south-west direction where it is eventually met by Ferrers Creek. The creek system then continues on and joins the Woady Yaloak River approximately seven kilometres upstream of Cressy. The sub-catchment covers an approximate area of 157 km^2 (Mananis, 2006).

The Kuruc-A-Ruc and Corindhap creek systems form on dissected Palaeozoic (Ordovician) turbidite landscape of the Western Uplands, which has been caped by Neogene gravel sediments primarily consisting of Moorabool Viaduct Formation. Erosional processes have down cut through the Neogene sediments and incised the Palaeozoic bedrock, leaving remnants of the Neogene sediments on hilltops and hill slopes. East of the township of Corindhap at Wurrook, valley filling basalt flows of the Newer Volcanics have displaced the creek system. This has resulted in the creek trending the margins of the volcanic flows and cutting through it in places. Dendritic drainage feeds the creeks with prevalent gully erosion evident in both the main creek systems and tributaries. Alluvial and Colluvial material is also associated with gully and hill slopes, both in the Kuruc-A-Ruc and Corindhap creek systems.

The data shows strong correlation between precipitation events and stream EC. Site K1 is characterised by a fall in conductivity values associated with high rainfall periods and increased EC during low rainfall events, and analysis for site C1 indicates a similar pattern. Dissimilarity in the data-set is observed particularly during the July to September (2006) period, where a rainfall peak is associated with a slight rise in surface water EC across sites, before a reduction is observed (Figure 5-19).

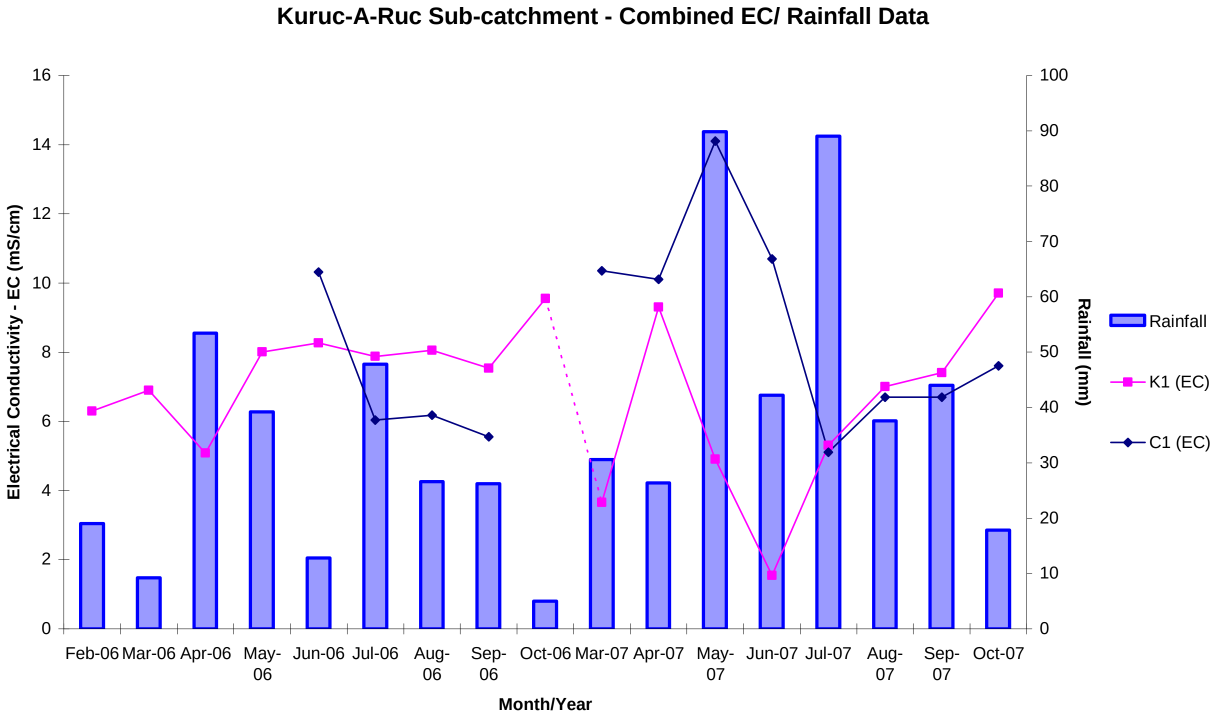


Figure 5-19 **Kuruc-A-Ruc Sub-catchment – EC trend graph for combined 2006/ 2007 stream sampling data.**

5.4.4 **Ferrers sub-catchment**

The Ferrers sub-catchment is comprised of low undulating terrain, with moderately developed drainage. During the 2006 period no flow was recorded from February to June and similarly, no flow was recorded during the March to June period in 2007. It forms the easternmost tributary of the Woady Yaloak River system and is approximately 23 kilometres in length, flowing into Kuruc-A-Ruc Creek to the southwest. Its total catchment area is approximately 88 km^2 (Mananis, 2006).

The headwaters of Ferrers Creek are located on the valley and sheet flow volcanics, Neogene gravel sediments and Palaeozoic sediments, around the southern and south-western portions of Mount Mercer. The tributaries form a dendritic drainage pattern which coalesce on the Palaeozoic and Neogene sediments in the upper headwaters and flow south, traversing the boundary of the Newer Volcanics as a result of displaced drainage. In areas the creek has cut through basaltic flows and gains from minor tributaries flowing off the Newer Volcanics.

There was only one sample site chosen for Ferrers Creek, at Bells Bridge east of Rokewood on the Rokewood – Shelford Road (F1). Data for the site is limited as a result of negligible water in the creek system (Figure 5-20). The partial data gives a limited understanding as to the link between rainfall and surface water EC, with high rainfall periods resulting in a reduction in stream salinity, which is considered a result of dilution of salts. Similarly, a low rainfall period appears to indicate a rise in stream EC and is illustrated during the June to October 2006 and August to October 2007 periods. A sample taken in June 2007 produced an EC reading greater than 20 mS/cm (Figure 5-20). The subsequent data indicates a drop in stream EC and elevated rainfall, indicating a correlation between stream salt concentration and rainfall events.

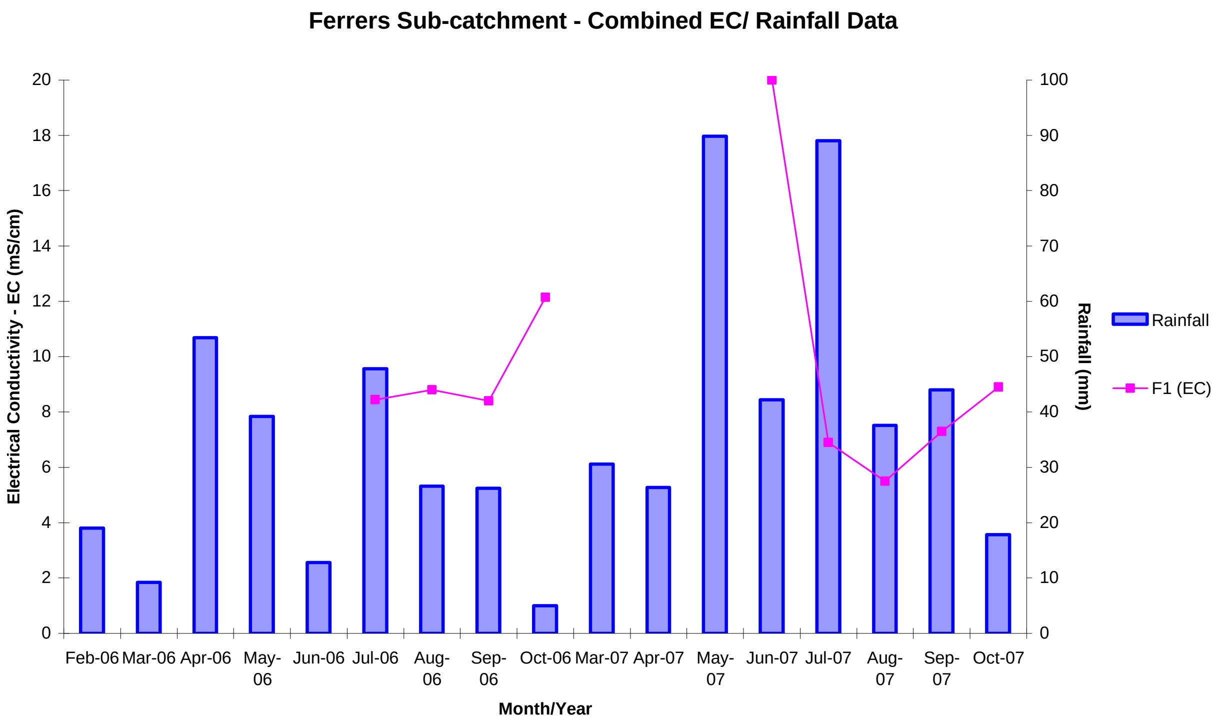


Figure 5-20 **Ferrers Sub-catchment – EC trend graph for combined 2006/ 2007 stream sampling data.**

6 DISCUSSION

The results of this investigation have mapped of soil salinity using geophysics; examined the hydrogeology and GFS contributing to saline groundwater discharge; investigated the storage of salt in the regolith and soils; and evaluated stream salt concentrations in the sub-catchments within the Illabarook target area. The combined results allow for a revision of the hydrogeological model, to provide a framework for future management applications. A revised model will also be used to evaluate whether broad scale tree plantations would provide an effective method to control salinity in the Illabarook target area and reduce the salt export to the Woady Yaloak River system.

6.1 SALINITY PROCESSES AT MOUNT MERCER

6.1.1 **Mount Mercer – Site One: Laffan Property**

The survey of the Laffan property determined that salinity at the site is characterised by saline discharge at topographic lows associated with a complexity of variable soils and GFS. Geophysical mapping indicates changes in severity and extent of near-surface salinity is associated with groundwater discharge particularly in drainage and discharge areas.

6.1.1.1 *Soils*

The analysis of soils at the site indicates that the spatial variability in EC and pH is controlled by landscape features. The B-horizon is generally composed of a higher percentage of fine material such as clays and silts, comparative to that of the A-horizon. The characteristically higher level of salt within the B-horizon is attributed to the elluviation of salts and fine particles from the topsoil. Dissolved salts are concentrated in clays forming the B-horizon through evapotranspiration and results in an increase in the salt store with respect to depth.

The elevated soil EC and reduced pH in discharge and drainage areas is attributed to the sodic nature of the B-horizon. Decreased rainfall over the past decade will have lowered the watertable allowing salts and move down the soil profile, accumulating in lower soil horizons (Charles-

Edwards and O'Keeffe, 2003). This is the normal soil-forming processes of elluviation of soluble salts, colloids and clay particles from the A-horizon and their illuviation in the B-horizon.

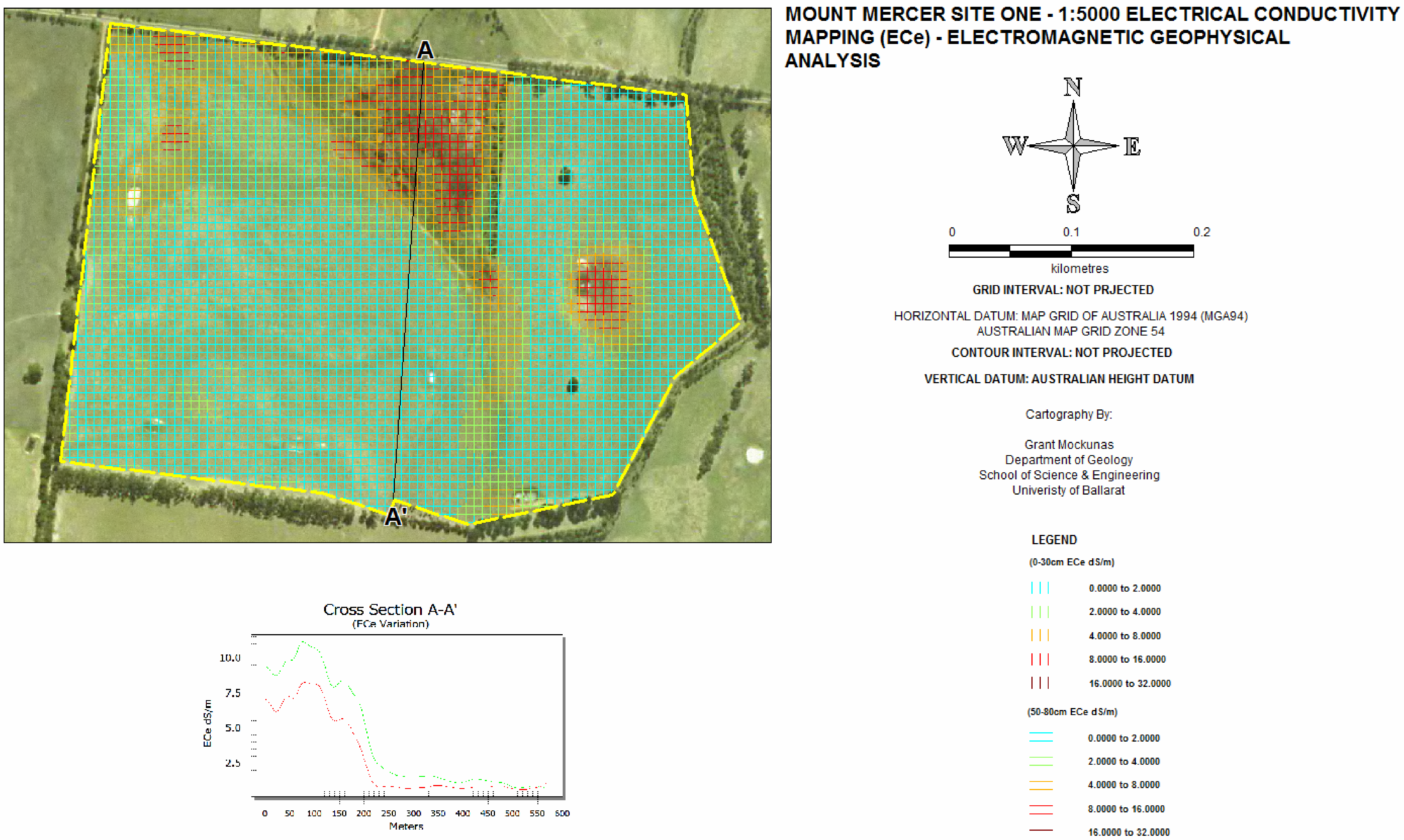
Church (2004) states that the B-horizon at Mount Mercer (site two) is mottled suggesting frequent waterlogging and has an A-horizon that is heavily leached, with little or no structure. Mount Mercer (site one) displays analogous characteristics in discharge and drainage areas with poorly structured A-horizon and mottled B-horizon in the soil profile. This observation suggests that salinity, particularly in discharge areas, is strongly controlled by the interactive processes of groundwater and surface water. When watertables drop due to the drought, the salt store moves deeper within the soil profile and may be responsible for a reduction in visible saline discharge. Conversely, when wet periods result in a rising watertable, the remobilised salt is moved higher in the profile.

6.1.1.2 *Geophysics*

The predicted soil conductivity (ECe) values for 0-30 centimetres and 50-80 centimetres indicate saline discharge is found predominantly at topographic lows underlain by Palaeozoic sediments and is associated with Neogene gravels/sand caps on hilltops and hill slopes (Figure 6-1).

The mapping indicates that salinity is predominantly associated with alluvial flats, underlain by Palaeozoic sediments of the Castlemaine Group. These areas of elevated soil salinity are generally characterised by sodic soils which become waterlogged during periods of extensive rainfall. Groundwater discharge is considered the primary source of salt since a piezometric watertable occurs at or near the natural surface. The data shows discharge areas are highly saline in both the horizontal and vertical dipoles and increases with depth. In Neogene gravel/sand caps, salinity is negligible in the horizontal dipole but increases to moderate in the vertical axis (Refer Figure 5-3).

Regional airborne magnetic data was also used to determine the extent and location of Deep Lead systems previously identified by Gillies (1889). Airborne total magnetic intensity (TMI) data identified that Deep Lead systems underlie the main discharge area at site one and form shortly northward of the site (Figure 6-2). Given the hydraulic gradients over a short distance it is possible that the Deep Lead underlying site one may have a slightly elevated pressure head, which could contribute to saline discharge but although without additional bore data this is not conclusive.



Cross-Section A-A' represented on map. Red line indicates ECe variation in the Horizontal dipole analysis (0-30cm) and Green line ECe variation in Vertical dipole analysis (50-80cm).

Figure 6-1 **Electrical Conductivity mapping of Mount Mercer (site one).**

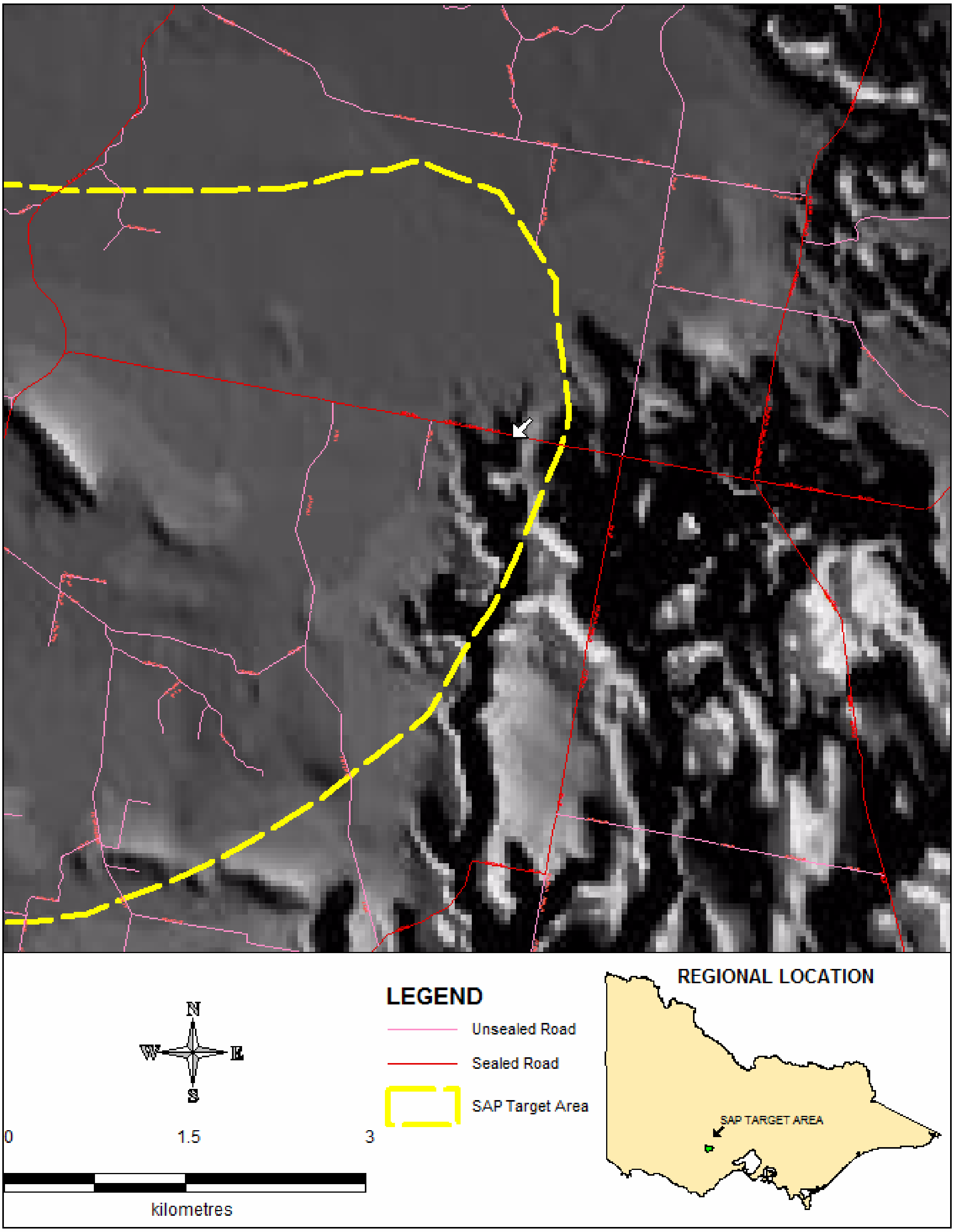


Figure 6-2 Airborne magnetic (TMI) map for Mount Mercer - Deep Leads identified underlying discharge area (site one).

6.1.1.3 *Groundwater Bores*

Groundwater bores gave indications as to possible sources of salt and flow systems contributing to saline groundwater discharge. During drilling, the initial encounter with the groundwater occurred at a deeper level than the final static water level, which implies that the GFS are semi-confined by the weathered regolith. The fact that the SWL is higher than the watertable encounted in drilling also indicates a potentiometric head which is sub-artesian. The sub-artesian nature of the GFS implies that there is a vertically upward gradient driving the discharge observed at the surface.

The hydraulic gradient was calculated using a three-dimensional triangulation of the standing water level (SWL) in piezometers, to determine the direction of groundwater flow. The direction of flow was calculated between MM1, MM2 and MM3 and a gradient of 0.006 from MM1 to MM3 and 0.005 between MM2 and MM3 was determined. Groundwater flow at the Mount Mercer site is believed to be east to north-east in direction (Figure 6-3).

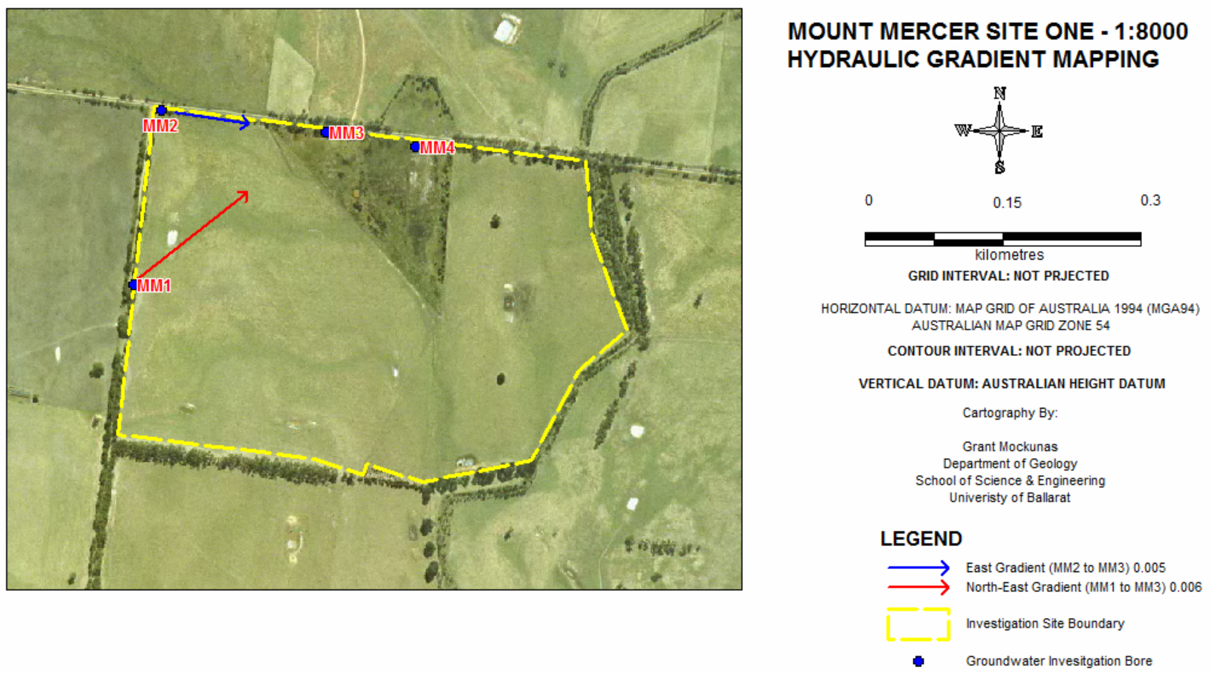


Figure 6-3 Hydraulic gradients for Mount Mercer (site one).

According to Dahlhaus et al. (2002) flow systems operating within GFS3 (Highland Gravel Caps) and GFS12 (Palaeozoic Sediments) operate between 10^{-4}/10 m/d and 10^{-5} to 10^{-1} m/d respectively. The investigation of aquifers indicates that conductivities are much less than previously hypothesised in the local and intermediate systems operating within the Palaeozoic bedrock and for local systems operating within the Neogene sediments.

The analysis of downhole $EC_{1:5}$ data for the Mount Mercer bores indicated that both Neogene and Palaeozoic sediments at the site are acidic and highly saline in the upper regolith, becoming alkaline and reducing in salinity with depth. At the watertable salinity rises and pH lowers. Data indicates that the salt is stored within Palaeozoic sediments and to a lesser extent within Neogene sediments (Figure 6-4).

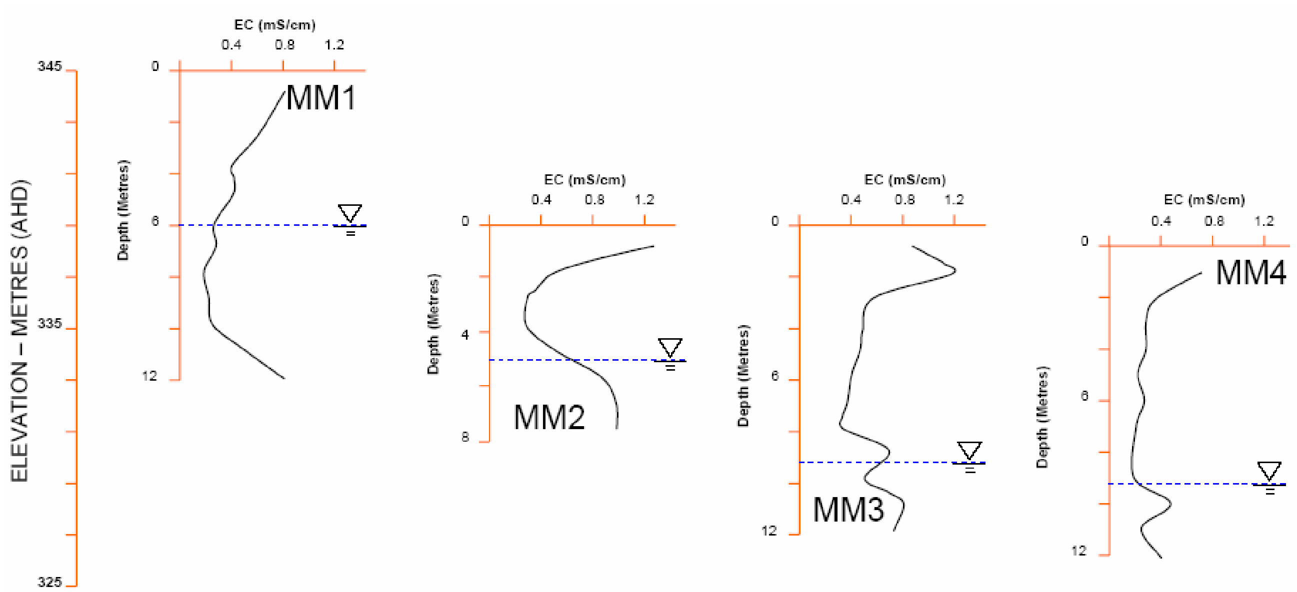


Figure 6-4 Downhole $EC_{1:5}$ for Mount Mercer.

The measurement of groundwater salinity (EC) determined that groundwater salt concentration is variable across site. The highest salinity (9.5 mS/cm) observed in Palaeozoic GFS at MM1, differs greatly from the lowest determined in Palaeozoic GFS at MM4. The variable nature of aquifer salinity highlights the changeability in aquifer characteristics across the site. Comparisons to groundwater salinity measured at Illabarook, indicate that the salinity of

Palaeozoic GFS differs across sites but is generally similar or less at the Mount Mercer investigation site.

The Corangamite Catchment Management Authority Groundwater Monitoring and Research Database (2004), was also accessed for historical drilling information to cross-reference groundwater bore data. Historical bore logs within Palaeozoic sediments to a distance of two to three kilometre radius from the Illabarook study site, had intercepted a number of GFS. Exploration drilling by the department of mines in 1937 intercepted 'Brackish' groundwater systems within Palaeozoic bedrock sediments, indicating the presence of saline groundwater systems. Historical drilling was also analysed at the Mount Mercer site to correlate lithological and GFS investigations but only lithological logs could be obtained.

6.1.2 **Mount Mercer – Site Two: Smith Property**

The investigation of the Smith property shows that salinity is generally constrained to drainage and discharge areas where alluvial and colluvial material, is underlain by Palaeozoic sediments.

6.1.2.1 *Soils*

Similarly to site one at Mount Mercer the concentration of salts in the clay-rich B-horizon suggests the dissolution of salts from near surface and their accumulation at depth, accounting for an increase in soil salt storage. As soil sodicity increases with respect to depth the salts become concentrated and account for the lack of structure in the B-horizon. The poor soil structure is defined as contributing to the saline area, as it impedes drainage, air, and root growth (Church, 2004).

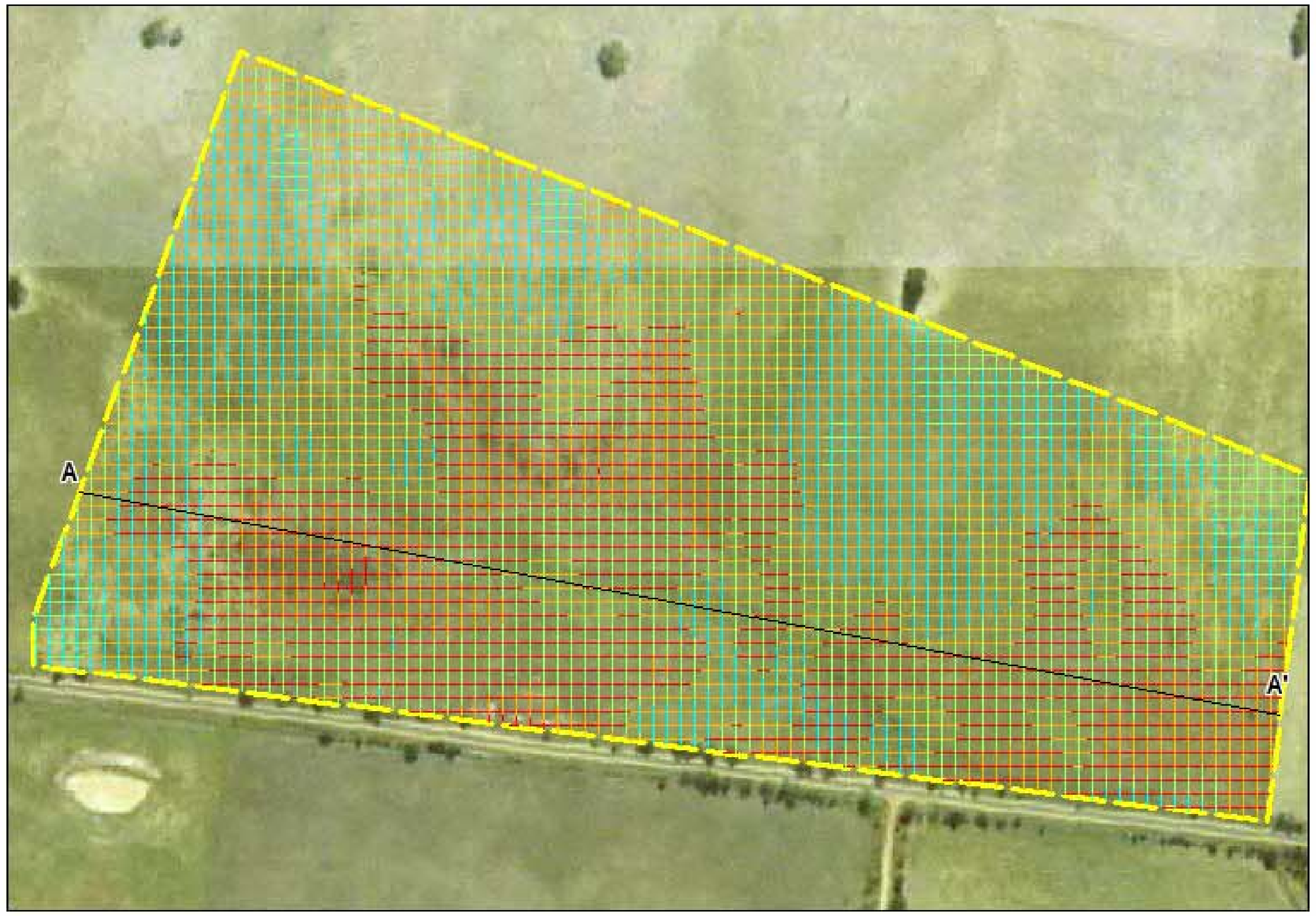
Bates and Jones (2004a) considered that the site was largely a discharge area, composed of duplex soils of loam to clay. They found that plant and grass roots diminished in the B1-horizon and were not observed in the B2-horizon. Mottling of subsoil, particularly the B-horizon, also suggested that the soils are seasonally waterlogged. The study conducted by Bates and Jones

(2004a) concurs with data obtained in this research and provides strong support that the discharge areas are strongly influenced by a single GFS (Bates and Jones, 2004a).

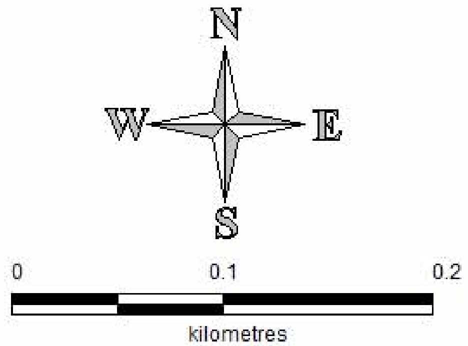
6.1.2.2 *Geophysics*

Geophysics highlights that local and intermediate GFS operating within the Palaeozoic bedrock are responsible for salinity occurrences in drainage and discharge areas, both directly from bedrock and at topographic lows covered in relatively thin post-basaltic alluvium and colluvium (Figure 6-5). Local ephemeral flow systems operating in Neogene gravel/sand caps, similar to those postulated to be occurring at Illabarook, may also provide minor contributions to saline discharge.

A slight to moderate EC response within Neogene gravels/sands in the vertical axis dipole was mapped. The installation of a number of groundwater monitoring bores appears to support the concept of saline discharge from Palaeozoic and Neogene sediments to differing extents.



MOUNT MERCER SITE TWO - 1:3500 ELECTRICAL CONDUCTIVITY MAPPING (ECe) - ELECTROMAGNETIC GEOPHYSICAL ANALYSIS



GRID INTERVAL: NOT PRJECTED

HORIZONTAL DATUM: MAP GRID OF AUSTRALIA 1994 (MGA94)
AUSTRALIAN MAP GRID ZONE 54

CONTOUR INTERVAL: NOT PROJECTED

VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Cartography By:

Grant Mockunas
Department of Geology
School of Science & Engineering
Univeristy of Ballarat

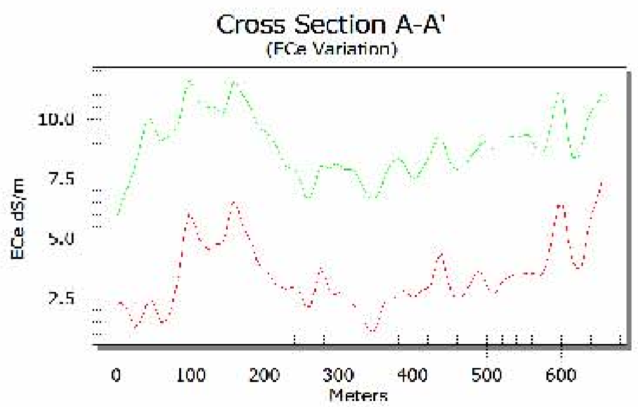
LEGEND

(0-30cm ECe dS/m)

0.0000 to 2.0000
2.0000 to 4.0000
4.0000 to 8.0000
8.0000 to 16.0000
16.0000 to 32.0000

(50-80cm ECe dS/m)

0.0000 to 2.0000
2.0000 to 4.0000
4.0000 to 8.0000
8.0000 to 16.0000
16.0000 to 32.0000



Cross-Section A-A' represented on map. Red line indicates ECe variation in the Horizontal dipole analysis (0-30cm) and Green line ECe variation in Vertical dipole analysis (50-80cm).

Figure 6-5 Electrical Conductivity map for Mount Mercer (site two).

6.2 SALINITY PROCESSES AT ILLABAROOK

6.2.1 **Illabarook Site: McKenzie Property & Shire Reserve**

The Illabarook survey was designed to provide an across-valley interpretation of near-surface salinity and determine salinity processes, driving saline occurrences. The mapping determined that saline discharge occurs at topographic lows including drainage areas, associated with Palaeozoic turbidite sediments overlain by post-basaltic alluvium. It also determined that hill slope discharge at the Recreation Road site is most probably influenced by Deep Lead systems. Neogene gravels/sands which cap hilltops and extend down hill slopes, and the boundaries of the Newer Volcanics basalts, are also associated with moderate to high salinity responses.

6.2.1.1 *Soils*

The sampling of soils across the valley at Illabarook revealed variability in the soil profiles associated with *in situ* weathering of Palaeozoic bedrock, Neogene gravels/sands and Newer Volcanics basalts. Soils have also developed on Recent alluvial and colluvial material found in topographic lows, such as valleys and drainage areas.

Soil EC and pH increases with depth in contrast to the observations at Mount Mercer. The difference between soil chemical analysis from Mount Mercer and Illabarook is attributed to the nature of the salinity. At Illabarook soils are generally acidic to slightly acidic at the surface and are associated with highly sodicity, but tend slightly more neutral at depth.

Soil salinity is characterised by an increase in severity and extent at depth and appears constrained to topographic lows (drainage areas). The elevated soil EC at hill slope discharge occurring at the Recreation Road site is attributed to discharge from the Deep Lead systems and is highlighted by the recent EM38 geophysics and airborne geophysical data (Refer to next section).

At the Recreation Road site Bates and Jones (2004b) described the soils as duplex and directly overlying the parent material. The A-horizon lacks structure and overlies an A2-horizon, which is seasonally saturated and is bleached. The B-horizon which is generally mottled is subject to seasonal waterlogging. The absence of buckshot, suggests waterlogging is not as long lasting in some parts of the landscape (Bates and Jones, 2004b).

6.2.1.2 *Geophysics*

Mapping of ECe indicates a concentration of salts at depth, associated with discharge and drainage areas (Figure 6-6). Sodic soils associated with low pH appear to be constrained to the upper regolith, with the EM38/EM31 and soil sampling data of the SGSL investigation, confirming that the soils become more alkaline at depth (Bates and Jones, 2004b).

Geophysics conducted for this research coupled with EM31 data from the SGSL survey, indicate complex GFS influence saline discharge. The Pitfield – Illabarook Road EM38 mapping illustrates that higher near-surface salinity is associated with discharge at the boundary of the Newer Volcanics basalts and the Palaeozoic bedrock, and directly into drainage areas from Palaeozoic bedrock overlain by post-basaltic alluvium.

The discharge from the Newer Volcanics basalts appears at the boundaries of the unit, which are inaccurately mapped. Drilling logs from the Victorian Department of Mines recorded in the Corangamite CMA Groundwater Monitoring and Research Database (2004), show the boundaries of the basalts are less extensive than thought and that groundwater discharge is most likely occurring at its boundaries. The discharge at or near the boundary of the Newer Volcanics is thought to be driven by flow systems extending from intermediate to regional scales. Discharge occurring at topographic lows and drainage areas, is believed to be associated with local and intermediate flow systems operating within the fractured Palaeozoic bedrock. (Dahlhaus et al. 2002).

The Recreation Road site is comprised of complex GFS as highlighted by the geophysics. Similarly to the Pitfield – Illabarook Road survey site across the valley, elevated EC is associated with Palaeozoic bedrock overlain by post-basaltic alluvium in drainage areas. However, up-slope discharge and high ECe values in Neogene caps are associated with a complexity of local, intermediate and regional flow systems, that can be determined by interpreting regional geophysics data.

The initial conceptual model devised by Nicholson et al. (2006), suggested that saline discharge was occurring at the boundary of Neogene gravel/sand caps and the Palaeozoic bedrock. Recent drilling however, has determined that gravels/sands are mottled to depth with variable bleaching and oxidation of layers to nine metres. This observation and that of the EM38 responses of increasing EC with respect to depth in the upper regolith profile, indicate that local ephemeral GFS are most likely to occur at the site and mid-slope discharge is driven by GFS not associated with Neogene gravel/sand caps.

Nicholson et al. (2006) and Church (2004) postulated intermediate and regional flow systems operating in Deep Lead aquifers could also be contributing to saline discharge. Analysis of regional airborne magnetic (TMI) data confirms the presence of an underlying Deep Lead system at the site, which appears to outcrop in the up-slope saline discharge area (Figure 6-7).

Saline discharge from the Deep Lead GFS, would account for the spatially restricted nature of the discharge site and explain why discharge is not observed to the same extent at the boundary of the Neogene gravels/sands and the Palaeozoic bedrock elsewhere in the immediate vicinity.

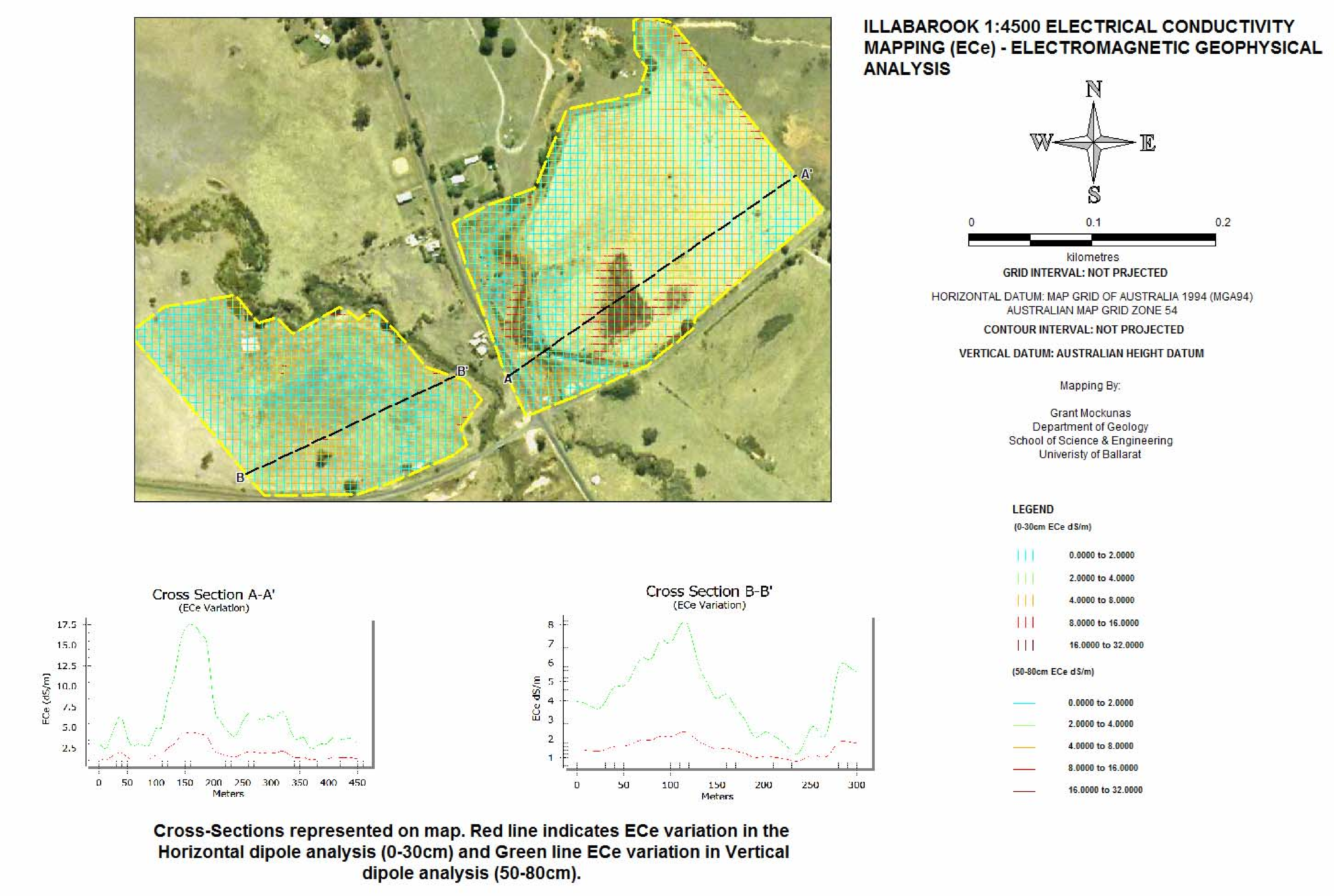


Figure 6-6 **Electrical Conductivity mapping & hydraulic gradient direction for the Illabarook investigation site**

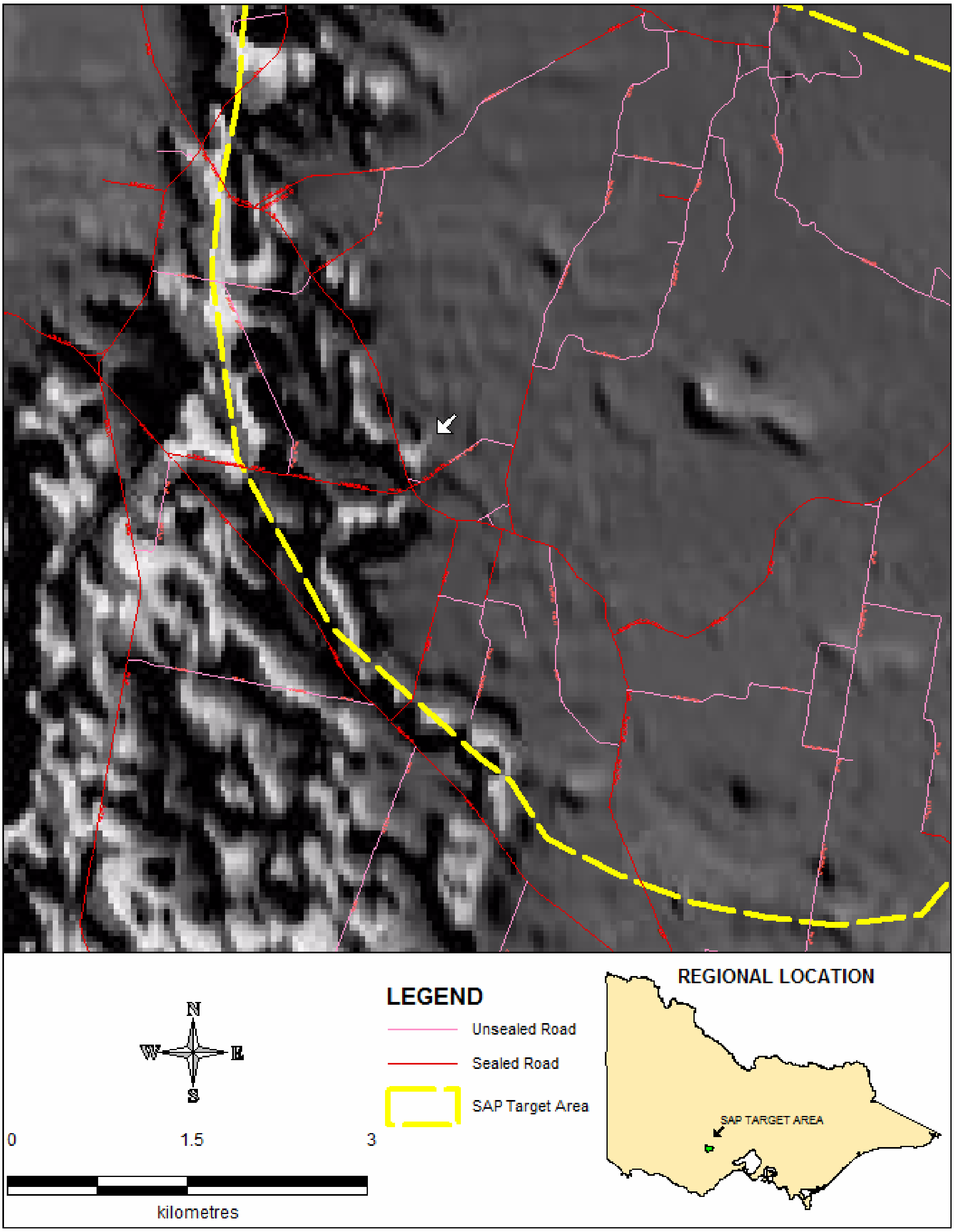


Figure 6-7 Regional airborne magnetic data, highlighting deep lead systems at Illabarook.

6.2.1.3 *Groundwater Bores*

The groundwater bores lithological samples indicated that Neogene gravel/sand caps are thicker than previously hypothesised. The bores delineated the GFS operating at the site, the lithological characteristics, associated hydraulic conductivities, salinity of the groundwater, depth to the watertable, and salt store within the vertical profile contributing to saline groundwater discharge.

The hydraulic gradient was calculated to determine the direction of groundwater flow between the two piezometers (Figure 6-8). The gradient was determined as 0.03 south-west but flow direction should be cautiously used as only a two dimensional gradient could be calculated from the available data. The downhill slope of groundwater flow conforms with saline discharge occurring in creeks and drainage areas to the south.

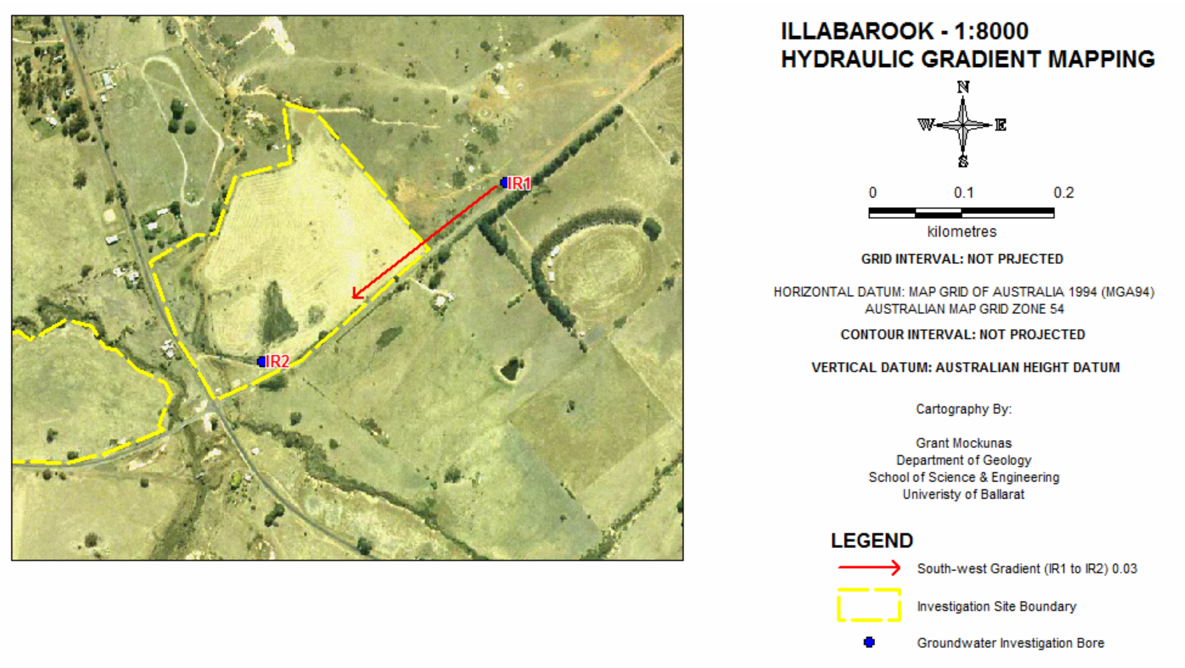


Figure 6-8 Hydraulic gradient for Illabarook.

Aquifer recovery testing indicated that little variation existed between the piezometers, with hydraulic conductivity values of $3.7*10^{-2}$ and $3.8*10^{-2}$ cm/d in recharge and discharge areas respectively, considerably slower than previously hypothesised (Dahlhaus et al. 2002). The slow conductive nature of the Palaeozoic bedrock may be attributed to the extent of the weathering and the presence of clays and fine silts.

The analysis of sediments determined that the main storage of salt (from the downhole analysis) is in the Palaeozoic sediments (Figure 6-9). The analysis concurs with that observed at Mount Mercer and suggests a strong association between salinity and Palaeozoic sediments, across the Illabarook target area. The downhole $EC_{1:5}$ data also confirms that salt concentration within Neogene sediments varies between localities, with low EC values determined for site IR1 (Figure 6-9).

The investigation of GFS determined that the salinity (EC) of groundwater increases downhill at Illabarook and salinities are similar or greater than, that observed at Mount Mercer. Measured salinity at site IR1 of 8.9 mS/cm is comparable with results obtained at Mount Mercer however, EC at site IR2 of 16.3 mS/cm is considered anomalously high in contrast to results obtained for GFS within Palaeozoic sediments.

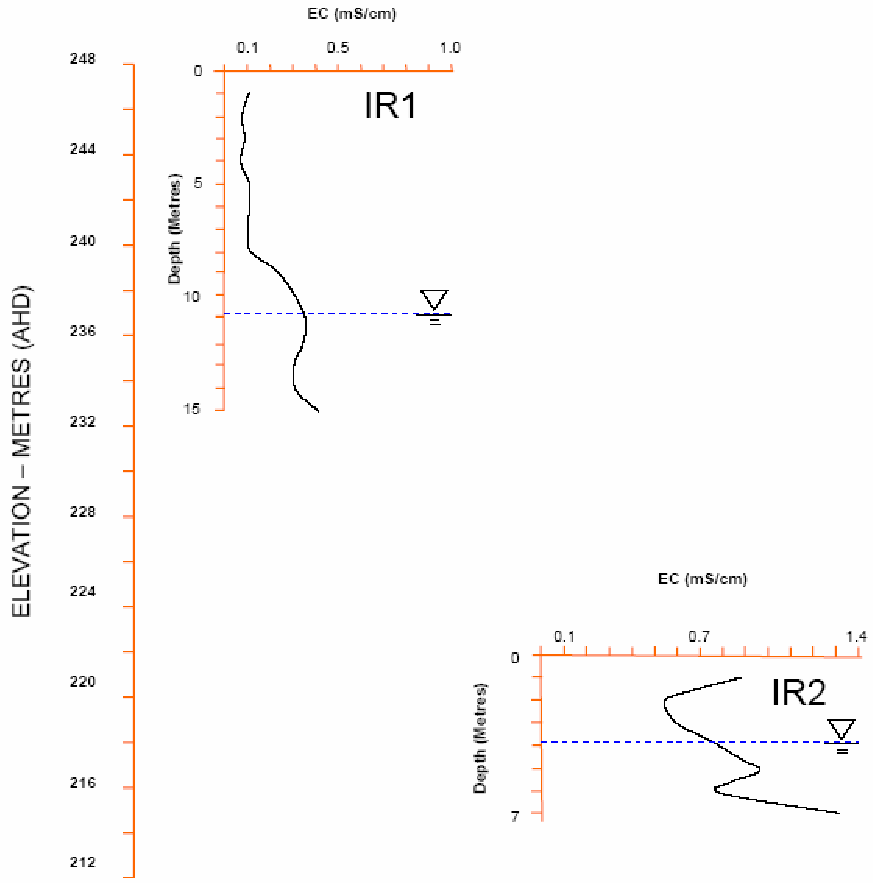


Figure 6-9 **Downhole $EC_{1:5}$ for Illabarook.**

6.3 SURFACE WATER SALINITY

Surface water data enabled an analysis of stream salt concentration across sub-catchment areas and connections between measured EC, rainfall and groundwater contributions. The data illustrated the variable nature of stream salinity across the target area and determined that salinity is variable across sub-catchments. Rainfall and physical parameters such as groundwater systems and salinity processes that constitute respective sub-catchments, appear to play important roles in stream salinity.

The surface water salinity monitoring program therefore aimed to answer two questions:

1. Is there evidence for salt wash-off from discharge sites?
2. Is there evidence for salt being contributed from groundwater baseflow?

6.3.1 **Evidence for salt wash-off**

The observation of stream salinity, its relationship to seasonal rainfall patterns and runoff, suggest that in some tributaries within particular sub-catchments, seasonal rainfall is the main control on stream salt concentration. The sub-catchments are thus controlled by two variables including seasonal rainfall and catchment area. The following discusses surface water systems influencing stream salt concentration:

The Mount Misery Creek sub-catchment sampling data illustrated a relationship between higher rainfall events and stream EC levels. Observations show increased rainfall events result in an initial rise in stream EC levels, which is attributed in concentration of salts due to surface wash-off from discharge areas. This initial concentration is then diluted by further inflow and a reduction in salt wash-off.

Corindhap Creek within the Kuruc-A-Ruc sub-catchment also reflects seasonal controls on stream salt concentrations, with high EC associated with seasonally high rainfall (autumn/winter periods). While high rainfall appears to reduce EC an initial lag time where EC temporarily rises occurs and C1 salt concentrations is at its greatest proceeding high rainfall events and at its lowest, during low rainfall periods.

Ferrers Creek forms the eastern-most tributary flowing into the Woady Yaloak River and, indicates a strong relationship between stream salinity and rainfall. The comparison of rainfall to measured stream EC indicates that seasonally wetter months, are coupled with a reduction in salinity. Conversely, a reduction in rainfall is matched with an increase in salt concentration. Primary salt source is believed to be from run-off from discharge areas. The concentration of salt may occur because of reduction or cessation of flow and evaporation processes result in concentration of salts. As only one sample site was chosen for analysis the exact nature of salinity processes occurring at the site remains speculative.

6.3.2 **Evidence for base flow**

Overall there is much stronger evidence for salt contributed by baseflow because stream salinity is recorded as increasing during low rainfall periods and decreasing, during seasonably wetter periods. The primary difference from runoff contributions is that no initial increase in stream salt concentration is observed (with the exception of site ML on Moonlight Creek), immediately following high rainfall events and rather a reduction in EC occurs. The following sites were determined as being influenced by GFS discharging as base flow into creek systems:

The Illabarook sub-catchment defined by Illabarook Creek is influenced by seasonally variable local and intermediate groundwater flow systems, operating within the fractured Palaeozoic sedimentary bedrock. Field studies have noted during that change in water level at site I1 appears to be slower than I2, although it should be noted that it is unsure whether similar circumstances existed during previous sampling by Mananis (2006). Extrapolated, this may suggest that stream water at site I1 is indicative of groundwater discharge at the stream, with salt concentration (via evaporative processes) increasing during seasonally dryer periods (spring/summer). Groundwater discharge is considered to be the primary reason for stability in stream pool size, during seasonably drier periods.

Sample site ML on Moonlight Creek within the Mount Misery Creek sub-catchment, is characterised by an increase in stream EC during wetter periods and subsequent reduction during periods of decreased rainfall. The site is considered as groundwater discharge contributing to baseflow, as flow is continuous (throughout the year) and the tributary is characterised by a small catchment area. Salts precipitated because of saline groundwater discharge, are believed to be re-dissolved and transported during increased rainfall events, contributing to elevated EC during seasonally higher rainfall periods.

The Kuruc-A-Ruc Creek sample site (K1) in the Kuruc-A-Ruc sub-catchment is characterised by increased stream salinity during low rainfall periods, possibly indicating salt concentration due to evaporative processes and GFS contributions as baseflow. Field observations indicate that GFS contributing salt to the system would account for the relatively consistent pool size and reduction in stream salt concentration (via dilution), associated with seasonally wetter periods (autumn/winter).

The contribution to base flow in the Ferrers Creek system was not determined as part of this study. However, observations indicate that groundwater discharge may be constrained to highly variable local flow systems, in which discharge ceases during seasonally dry periods.

6.4 THE ILLABAROOK CONCEPTUAL MODEL

The original hydrogeological conceptual model developed by Nicholson et al. (2006) suggested four main GFS were operating within the Illabarook target area and that local flow systems operating within Neogene gravel/sand caps (Highland Gravel Caps – GFS3) were the main source of saline groundwater discharge.

The evidence of this research project indicates that the main source of saline discharge is the GFS operating within the fractured Palaeozoic (Ordovician) turbidite sediments, forming the bedrock over much of the Illabarook target area. Field geophysics (EM38) and drilling indicate the association between Palaeozoic bedrock and saline groundwater discharge, particularly in drainage areas. When coupled with airborne magnetic data, the field data also suggests greater influence on saline discharge by Deep Lead aquifer systems although the extent to which these GFS influence saline discharge remains unclear. The fact that GFS operating within Neogene gravels/sands at the Illabarook site were not intercepted suggests that only ephemeral GFS may develop within this unit, during seasonally wetter periods.

The results of this investigation into salinity processes at Mount Mercer and Illabarook have resulted in the development of revised conceptual hydrogeological models for the respective sites. The models encompass interpreted GFS systems and their respective flow paths, hydraulic properties, subsurface geology and geomorphic features. They provide a framework for understanding of the hydrogeologic processes occurring within the Illabarook target area and form the basis of possible future management scenarios. The revised models highlight GFS implicated in saline groundwater discharge and sources of salinity in the Illabarook target area which contribute to the rising EC trend in the Woady Yaloak River.

The revised conceptual hydrogeological models for Illabarook and Mount Mercer are illustrated below (Figure 6-7):

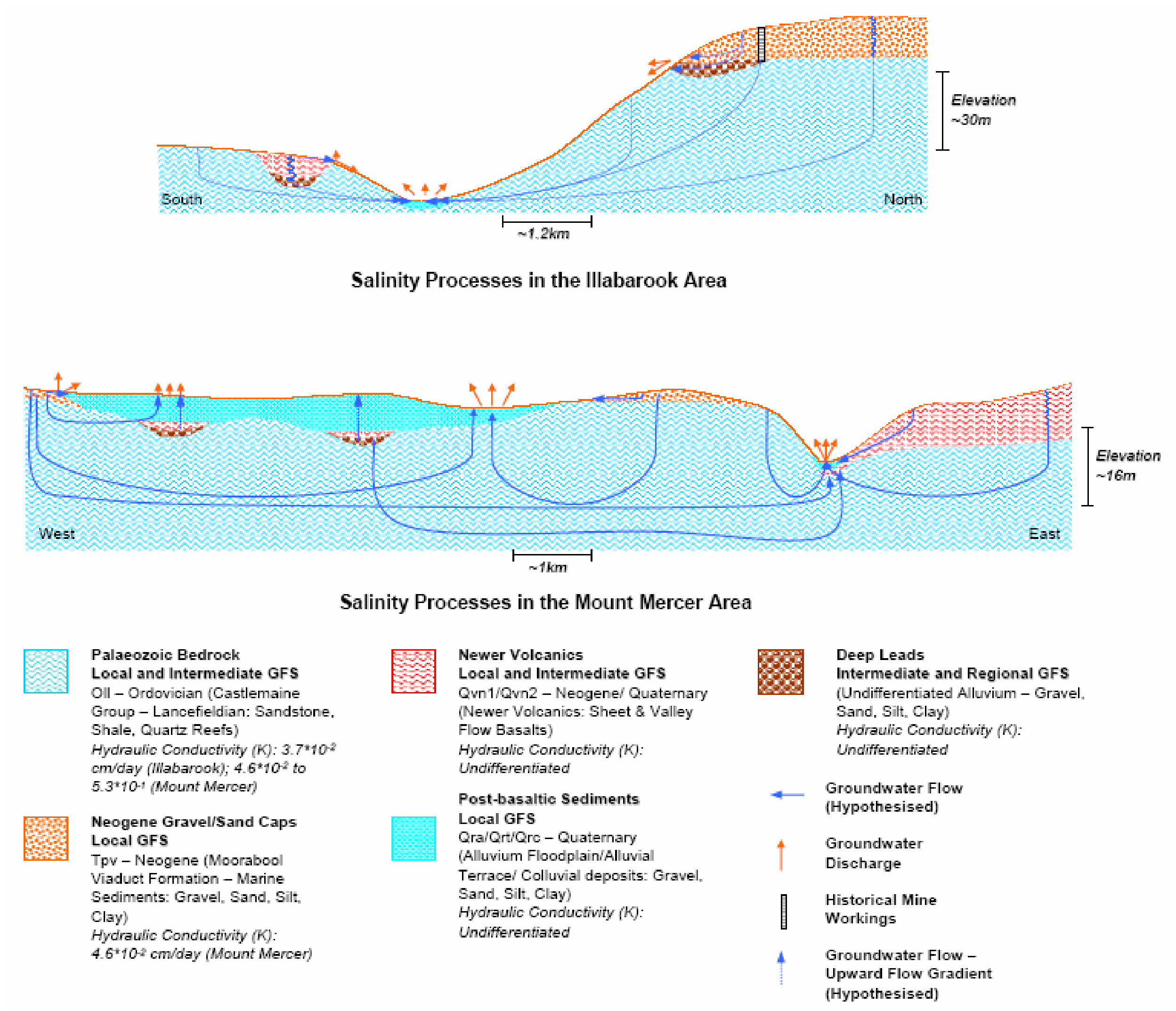


Figure 6-10 The revised Illabarook and Mount Mercer conceptual model.

6.4.1 GFS within Palaeozoic (Ordovician) Bedrock

The Palaeozoic bedrock of much of the Illabarook target area is considered a fractured rock aquifer and is variably faulted and fractured, forming numerous pathways for groundwater movement. The flow systems operating within the bedrock are considered highly variable on local and intermediate scales (Dahlhaus et al. 2002).

The hydraulic conductivity values show that groundwater in aquifer systems at Illabarook is slower in movement than those at Mount Mercer as illustrated by the difference between bores IR1 and MM1. The disparity in conductivity relates to aquifer properties, such as pore spacing and fractures, which in turn depends on the nature of the weathered saprolite, fragmentation of the bedrock and vein quartz content.

The Palaeozoic sediments at Mount Mercer are characterised by a highly weathered saprolite with minor fragmental bedrock and vein quartz becoming apparent with depth. Flow systems are considered local in scale at MM1 with the high conductivity interpreted as flow systems operating within the weathered saprolith over short distances in the elevated landscape. Local to intermediate systems are interpreted in discharge areas (MM3 and MM4), with lower hydraulic conductivities.

6.4.2 GFS within Neogene Gravel/ Sand Caps (Moorabool Viaduct Formation)

The analysis of Mount Mercer and Illabarook sites suggests the presence of differential changes in local flow system characteristics within Neogene gravels/sands across the target area. Dahlhaus et al. (2002) characterised coarse and fine grained Neogene sediments (Highland Gravel Caps – GFS3) as comprised of differentially weathered units (White Hills Gravel, Moorabool Viaduct Formation, etc), with generally high hydraulic conductivities and characterised by the presence of local GFS. Cross-site examination has delineated that the nature of the caps differs spatially across the target area, with sediments ranging from gravels to sands with variable iron-cemented, ferruginised to bleached sediments to depth at Illabarook, to unconsolidated clays and sandy-clays at Mount Mercer characterised by an iron-rich upper clay layer.

The absence of groundwater within Neogene sediments at Illabarook suggests that local ephemeral flow systems may only develop, during wetter periods where as local flow systems developed at Mount Mercer are more permanent. This may be due to a considerably lower hydraulic conductivities than previously estimated in this predominantly clay aquifer in which the GFS exists.

At Mount Mercer the GFS operating within the Neogene sediments undoubtedly has elevated salinity levels, however the extent to which this GFS contributes to saline discharge across the Illabarook target area is dependent on the flow system characteristics. Local ephemeral systems will contribute less salt to the system than those where saline discharge occurs year-round. The influence of the unit on stream salinity and the Woady Yaloak River system is therefore believed less extensive than previously hypothesised by Nicholson et al. (2006), with changeability in GFS indicating only minor contributions to saline discharge across the target area.

6.4.3 **GFS within Newer Volcanics**

The Newer Volcanics basalts are present at both Illabarook and Mount Mercer but are only considered a possible influence at the Pitfield – Illabarook Road survey site. The geophysical data indicates the presence of sodic soils developed on Newer Volcanic flows and an increase in soil salinity at depth. While it is possible that GFS operating within Newer Volcanics flows (Qvn2 – Sheet and valley flow basalts) may be contributing to saline discharge, the extent and influence on salinity is considered to be minimal at the research sites.

The exact extent and nature of GFS operating within Newer Volcanics basalt flows within the larger Illabarook target area is uncertain, and they may influence the hydrogeology of the underlying Deep Leads which is highlighted by the CCMA (2004) bore database. Dahlhaus et al. (2002) suggests that saline discharge generally occurs at the boundaries of basalt flows. Interpretation of mapped geology, geophysics data and bore log analysis from the CCMA (2004) database, indicate that the mapped boundaries of the Newer Volcanics at the Illabarook research site are incorrect. Therefore it is probable that saline discharge and near-surface salinity mapped at the Pitfield – Illabarook Road site, is occurring at the boundary of the Newer Volcanic basalts and the underlying Palaeozoic bedrock.

At Mount Mercer Newer Volcanics basalts probably infill buried Deep Lead systems at the investigation site (based on data from Gillies 1889). Surface flow basalts which are extensive to the east, are not present within the study area. The extent and nature of the aquifer systems is uncertain but is considered to be local to intermediate in scale, with intermediate to regional systems in underlying Deep Leads (Dahlhaus et al. 2002). Private (domestic) bores have been installed in a number of properties, intercepting groundwater systems in the Newer Volcanic flows. Laffan's (Farmer) domestic bore intercepted water at a depth of approximately 92 metres and stands at approximately 53 metres below natural surface. The farmer indicates that groundwater has a high yield and is described as "Fresh" (Laffan *pers. comm.* 2007).

Therefore, while information on the Newer Volcanic GFS is limited, the data suggests that saline discharge occurs at the boundary of Newer Volcanic flows and the underlying bedrock at Illabarook. Flow systems operating within the basalts at Mount Mercer are less certain but appear to be fresh water aquifers. Overall the influence of Newer Volcanics GFS on the conceptual model of salinity processes is relatively unknown, but is considered minor in the context of the Illabarook target area.

6.4.4 **GFS within Deep Lead Systems**

At both the Mount Mercer and Illabarook investigation sites Deep Lead aquifer systems have been interpreted from geophysical and bore log data. The extent and influence of the Deep Lead GFS appears to be greater than previously thought, based on their association with saline groundwater discharge.

The study site at Recreation Road, Illabarook, is characterised by mid-slope salinity previously attributed to saline groundwater discharge at the boundary of Neogene gravel/sand sediments and the underlying Palaeozoic bedrock. However it has been established that the influence of Neogene sediments on saline discharge is considerably less than previously thought (Section 6.4.2). Field evidence of Deep Lead material associated with old mine workings upslope of the site (Bulldog Lead) together with the geophysical interpretation indicates that the Lead system may outcrop at the site and be the main cause of saline groundwater discharge.

At the Mount Mercer site the underlying Deep Lead GFS is confirmed by airborne magnetic data and the exploration drilling, which found two Leads in-filled by Newer Volcanics basalts and covered in post-basaltic alluvial and colluvial material (Gillies, 1889). The influence of this GFS on saline groundwater discharge remains uncertain, but given that the systems outcrop a short distance north of the investigation site, they may account for the upward hydraulic gradients observed. The semi-confined Deep Lead systems underlying discharge areas may contribute to saline groundwater discharge (due to the upward movement of water within the aquifer). Since groundwater monitoring bores at the site did not intersect this GFS, the influence of the Deep Lead systems on the conceptual model remains speculative.

6.5 IMPLICATIONS FOR SALINITY MANAGEMENT

Dahlhaus (2003b) suggested that recharge control through tree plantations on Neogene sediments, constituted the most appropriate method of salinity management to reduce discharge and salt export to the Woady Yaloak River. The conceptual model resulting from this research demonstrates that saline discharge occurs in drainage areas, underlain by Palaeozoic bedrock and local flow systems in Neogene sediments contribute to a much lesser extent. Therefore, a combined salinity management approach incorporating recharge and discharge zones must be considered.

Tree plantations provide an effective method of watertable control on a variety of scales with recharge control best able to target aquifer systems operating at local and intermediate. Discharge control is also useful in targeting flow systems at all scales contributing to stream salinity, especially in areas characterised by a high discharge capacity (Marcar and Crawford, 2004).

It is believed that local flow systems on Neogene sediments should be managed using recharge management control techniques. The establishment of wide tree belts on Neogene gravel/sand caps may reduce recharge rates into the Neogene sediments and subsequently the underlying Palaeozoic bedrock. The tree belts would primarily target local flow systems operating in Neogene sediments and reduce recharge into the underlying Palaeozoic GFS.

The GFS in Palaeozoic bedrock is considered local in scale in dissected areas and as the landscape becomes flat, is considered to operate at intermediate distances. A combination of recharge and discharge control, is considered an appropriate management response for local GFS. Intermediate GFS targeted by discharge control techniques would provide effective management at such a scale, and is due to the changeability of aquifer systems to be able to successfully target recharge. The planting of salt tolerant trees, shrubs and grasses at or bordering discharge areas, is considered an effective control technique for intermediate GFS. It will locally lower high watertables, reduce erosion associated with saline soils and improve stream salinity. Other benefits include the provision of shelter and shade for stock and wildlife and carbon capture and storage (Marcar and Crawford, 2004).

7 CONCLUSION

The study of the processes causing salinity in the Illabarook target area has determined that GFS influencing salinity are spatially variable. The investigation has determined that saline discharge is primarily associated with GFS within Palaeozoic (Ordovician) turbidite sediments. Analysis of data suggests GFS operating within Neogene gravel/sand caps (Moorabool Viaduct Formation) are contributing to saline discharge to a lesser extent.

In summary, this research concludes that:

- Local and intermediate flow systems within Palaeozoic (Ordovician) turbidite sediments form the primary source of saline discharge in the Illabarook target area. Discharge identified in drainage areas and topographic lows are associated with GFS within the Palaeozoic bedrock. The installation of groundwater monitoring bores has confirmed the presence of local and intermediate flow systems within the unit;
- Local flow systems within Neogene gravel/sand (Moorabool Viaduct Formation) contribute to saline discharge to a lesser extent than previously thought, with GFS within Neogene sediments spatially variable;
- Intermediate and regional flow systems within Deep Lead aquifers are believed to have a greater influence on saline discharge than previously hypothesised. This is illustrated at the Illabarook investigation site, where saline groundwater discharge mid-slope is attributed to the outcrop of a Deep Lead system;
- Saline discharge associated with the Newer Volcanics basalts is spatially variable with saline discharge primarily concentrated at the boundaries of the unit, underlain by the Palaeozoic bedrock;
- Geophysics utilising EM38 techniques has mapped near surface salinity at two representative sites, highlighting discharge areas and GFS associations. Mapping indicates that salinity changes in spatial distribution and severity with respect to depth, across the sites;

- The installation of six groundwater monitoring bores provided data on the vertical extent and characteristics of lithological units, degree of weathering and the physical characteristics of aquifer systems;
- Aquifer recovery testing within the Palaeozoic bedrock and Neogene sediments, determined variability in aquifer properties. Testing of aquifer systems at Mount Mercer indicates higher hydraulic conductivity values within Palaeozoic sediments than those observed at Illabarook. The spatial variation in the hydraulic conductivity of Palaeozoic sediments suggests variable contributions to saline discharge across the target area;
- Stream EC analysis of surface water flowing into the Woady Yaloak River system, from across the Illabarook target area indicates differential stream salt concentrations. Analysis of data indicates strong correlation between stream EC and rainfall, with stream salinity a function of salt wash-off from discharge sites, saline groundwater discharge, precipitation and evaporation processes; and
- Tree plantations will provide an effective method for the control of salinity in the Illabarook target area. Targeting both discharge and recharge areas is however dependent on the GFS causing salinity. Treatment of flow systems within Neogene sediments would primarily focus on recharge control, with establishment of broad tree belts and salt tolerant shrubs and grasses. Salinity associated with Palaeozoic sediments would involve recharge and discharge management. Local Palaeozoic GFS would involve both recharge and discharge control measures, involving broadscale tree plantations on recharge areas and salt tolerant vegetation at discharge sites. Intermediate GFS in Palaeozoic bedrock would undergo discharge management, as recharge management over intermediate scales is considered inappropriate.

The removal of vegetation due to mining and farming practices is believed instrumental in increased infiltration into groundwater systems. Saline discharge from local and intermediate flow systems within Palaeozoic sediments are the main cause of the rising trend in salinity, measured at the Cressy gauging station on the Woady Yaloak River over the past 29 years. Contributions from Neogene sediments, Deep Lead aquifers and the Newer Volcanics basalts, are also considered a partial influence on the rising stream salinity.

8 RECOMMENDATIONS

The following lists a number of recommendations for further research investigating the processes causing salinity in the Illabarook target area:

8.1 HYDROGEOLOGICAL RESEARCH

- Groundwater bores would assist in determining contributions to saline discharge from varying GFS across the target area. Particularly of interest is the Deep Lead systems identified using airborne magnetic data at Illabarook and Mount Mercer. Investigation into their GFS characteristics will provide valuable information on their possible influences on salinity, which could then be extrapolated to the greater Illabarook target area;
- The installation of nested piezometers at Mount Mercer and Illabarook would determine the direction of groundwater flow (upward or downward) within the aquifer system, at the target point: This would provide data on the magnitude of the recharge and discharge processes;
- The installation of bores within Neogene sediments with continuous data-loggers, to measure ephemeral aquifer system properties and flow characteristics. Analysis of groundwater chemistry and stable isotopes within Neogene sediments would also give indications as to rainfall influence on GFS and chemical signatures within the sediments; and
- Surface and groundwater stable isotope and chemical analysis, coupled with CFC dating techniques, would enable greater scope and understanding of aquifer chemical properties, groundwater residency times and allow for partitioning of saline groundwater discharge.

8.2 GEOPHYSICAL RESEARCH

- Extending mapping of saline areas using EM38 geophysics to delineate near-surface salinity and possible GFS associations, in areas not encompassed within this study may provide areas for future investigation of groundwater systems;

- Mapping of sites and the greater target area using EM31 and EM34 geophysical techniques, to determine changeability in salinity to greater depth; and
- Detailed mapping of the target area using airborne magnetic and gravity geophysics techniques, to enable greater definition of Deep Lead systems.

8.3 SURFACE WATER MONITORING

- Measurement of stream flow from sub-catchments within the Illabarook target area, in order to calculate stream salt loads;
- The calculation of stream salt contributions from sub-catchments within the Illabarook target area using the Rational Method, to determine the amount of salt entering the Woady Yaloak River from the Illabarook target area; and
- Continued monitoring of stream salinity (EC) and pH at the ten selected monitoring sites across the target area. Sampling intervals should also vary as to cater for seasonal variations with monthly sampling during drier periods and bi-monthly sampling during wetter periods.

8.4 CONCEPTUAL MODELLING AND RESEARCH

- Appropriate modelling of management scenarios using Flowtube and Modflow, based on the revised hydrogeological model for Mount Mercer and Illabarook. These scenarios could be adjusted and re-interpolated in-conjunction with future investigations. This would provide quantitative data on the effectiveness of the salinity management (e.g. reduction in stream EC/ha planted).

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APPENDIX A

GROUNDWATER MONITORING BORES - COMPLETION REPORT

Grant Douglas Mockunas

Bachelor of Applied Science (Honours)

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2007

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The installation of groundwater monitoring piezometers in the Mount Mercer – Illabarook area, was conducted with the assistance of a number of persons and organisations. These included:

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- Mr. Robert Smith – Laboratory Technician, University of Ballarat;
- Mr. Daniel Laffan;
- Mr. Colin McKenzie;
- Jason, Lee & Matt – Numac Drilling Services Pty Ltd.;
- Corangamite Catchment Management Authority (CCMA) – Financial Assistance for project.

DECLARATION

The content of the following 'Groundwater Monitoring Bores – Completion Report' in its entirety is that of my own research, unless acknowledged in the text and reference list.

No section of this report has been published or submitted as part of another degree or to another institution.

……………………………….

Grant Mockunas

Bachelor of Applied Science Geology (Honours)

School of Science & Engineering

Department of Geology

University of Ballarat

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1 INTRODUCTION

The Illabarook salinity target area forms one of twelve study sites selected under the Corangamite Catchment Management Authority (CMA) - Salinity Action Plan (SAP), 2005 to 2008. It was selected on the basis of increasing salinity trends at the Cressy gauging station on the Woady Yaloak River and the potential threat to the Lake Corangamite system. The salinity threat to the Woady Yaloak River system is believed to being contributed to by Neogene sediments, within the target area.

The SAP listed the Illabarook target area as requiring priority investment, for the delineation of appropriate salinity management strategies. The area has been subject to a number of past and current investigations, to delineate the possible causes and remediation methods for salinity. Figure 1-1 below illustrates the topography and outlines the extent of the target area, including various river catchments, which flow into the Woady Yaloak River.

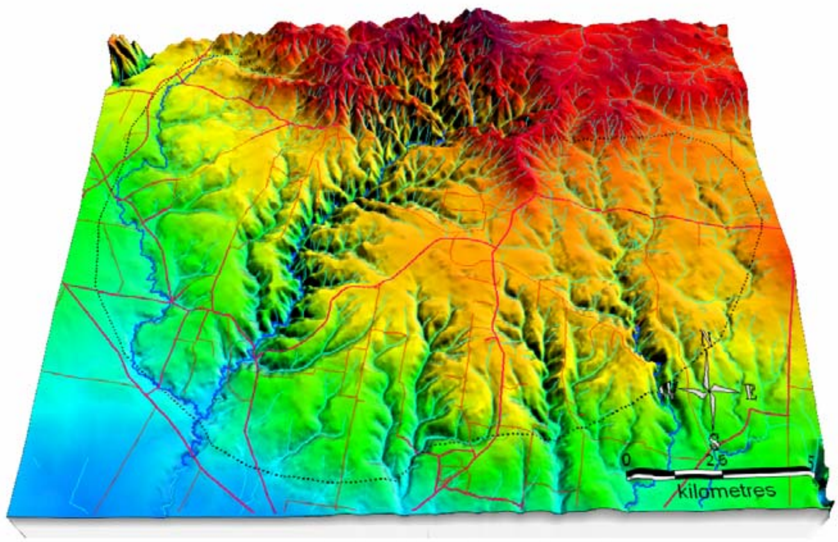

Figure 1-1 DEM for the Illabarook target area.

The gauging station at Cressy (#23420) has a marked increase of 3.4µS/cm/yr EC but is not considered statistically significant. Recording at the gauge at Cressy began in 1976 and during the period up until the end of 2005 a total of 308 samples were recorded. The mean daily salt load was then calculated at 242 tonnes/day and the mean EC (Electrical Conductivity) calculated over this period was 5265µS/cm, with a peak at 10500µS/cm and trough at 620µS/cm (Dahlhaus et al. 2005a).

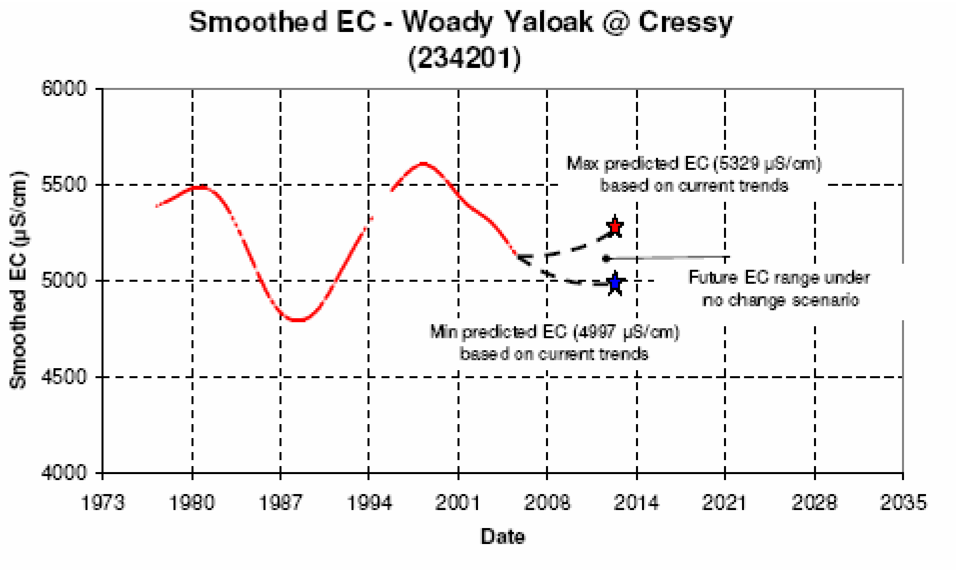

Figure 1-2 Smoothed EC diagram for the Cressy Gauging Station on the Woady Yaloak River.

(Source: Dahlhaus et al. 2005b)

Future trends for the Woady Yaloak are based on two possible outcomes, these being the change and no change scenarios. The no change scenario effectively models the consequence of current trends using available data, conceptual modelling, Flowtube and mapped salinity for the specific area. In the long-term no change scenario, it is predicted that salinity trends will continue to rise at current rates observed in the Woady Yaloak River (Figure 1-2; Dahlhaus et al. 2005a).

This report details the methodology and results of a groundwater investigation program within the target area, to delineate the validity of the initial conceptual hydrogeological model. The original model was developed from field observations of features such as geology, groundwater flow systems, hydrology and salinity processes in operation, within the particular landscape (Nicholson et al. 2006). In total six piezometers were installed over two sites in Illabarook and Mount Mercer, targeting differing geology and groundwater flow systems.

2 LOCATION

The Illabarook salinity target area covers approximately 204 km^2 in the Corangamite region (Figure 2-1). The area has a north – south boundary of approximately 12 kilometres and east – west boundary of approximately 20 kilometres. It is situated between 73 0102 to 75 0479 East and 58 04013 to 58 19730 North (MGA 94, Zone 54).

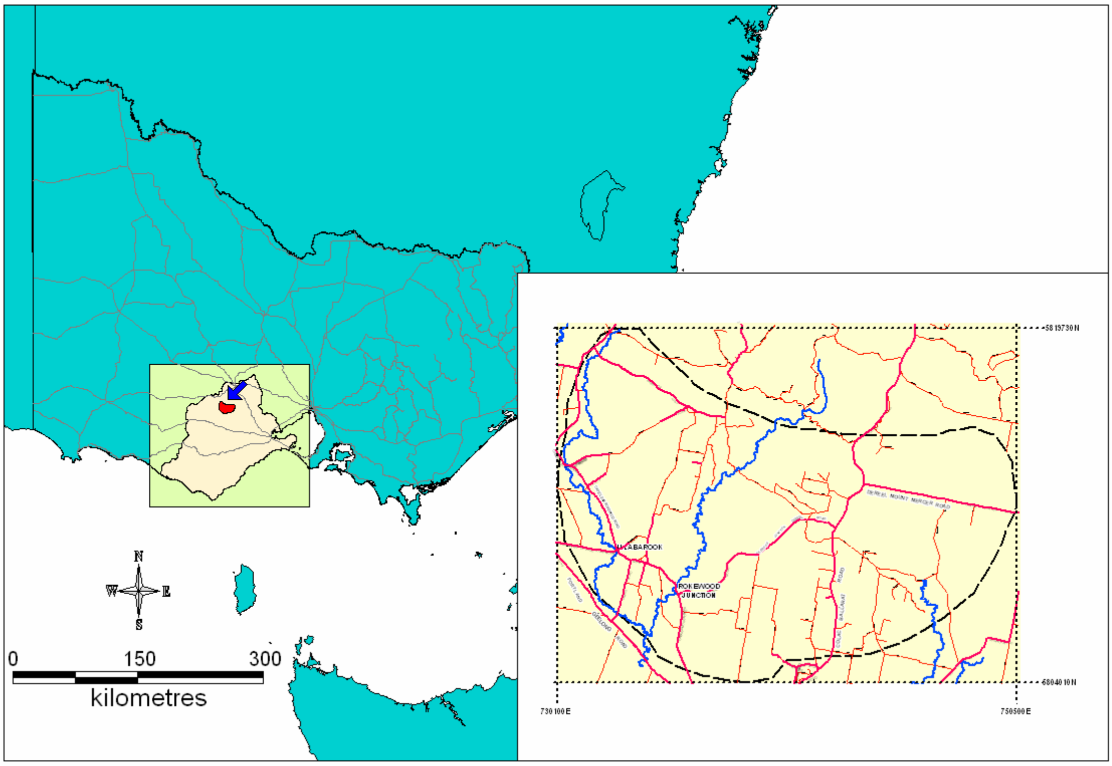

Figure 2-1 Location map of Illabarook Salinity Target Area, Corangamite Region, Victoria.

3 GEOLOGY & GEOMORPHOLOGY

3.1 REGIONAL GEOLOGICAL SETTING

The Illabarook salinity target area is located in the Bendigo Zone of the Lachlan Fold Belt in southeastern Australia, and is characterised by a number of geological unit types (Figure 3-1). The region is primary composed of Palaeozoic and Cainozoic units of sedimentary and volcanogenic origin, with recent mapping and descriptions completed by Taylor et al. (1996).

Palaeozoic rocks are primarily represented by the Castlemaine Supergroup which form the bedrock of the Bendigo Zone. The oldest rocks in the region are that of the Saint Arnaud Group, which occur to the north-west of the target area and are Cambrian in age (Taylor et al. 1996). The Palaeozoic bedrock is generally composed of Ordovician sandstones, slates and shales, which were originally deposited in a deep marine environment. The Benambran Orogeny during the Early to Middle Silurian generated a number of tectonic forces which lithified, folded and faulted the Ordovician sediments (Dahlhaus, 2005).

Tectonic stability existed across Victoria from the mid-Permian to the Jurassic and little deposition occurred during this time (Webb, 1991). The Late Cretaceous rifting along the eastern margins of Australia lead to a north-south down-warping. Concurrently, the rifting also resulted in the Victorian divide between the Otway and Murray Basin becoming more pronounced. Increased relief resulted in more active erosion of the Mesozoic palaeosurface and development of large fluvial sedimentary deposits of the White Hills Gravel in palaeovalleys (Phillips et al. 2003).

The Cainozoic Era is represented by both Tertiary and Quaternary rocks of marine and terrestrial origin. Early Tertiary deposits flank hillsides of Palaeozoic bedrock and are comprised predominantly of fluvial material, derived from the Mesozoic Palaeosurface. Middle to late Tertiary (Neogene) sediments including marine sediments, are also present in the area and are the result of marine incursions from the south-east (Taylor et al. 1996). Primarily lithology includes that of the Moorabool Viaduct Formation. Quaternary deposits are chiefly represented in the area by the Newer Volcanics and are comprised principally of basaltic lava flows. A number of alluvial, colluvial and fluvial deposits associated with post-volcanic drainage systems have also developed (Taylor et al. 1996).

An uplift event proceeded the deposition of the Neogene sands in the area and is attributed to movement on along the east-west Enfield fault, which bisects the area. Following the regional uplift event, the landscape was dissected by a number of waterways, which has helped form the current landscape (Dahlhaus, 2005).

3.1.1 Geology of the Mount Mecer – Illabarook investigation sites

The investigation sites are characterised by similar geology, described by Taylor (1996a/b) and Taylor et al. (1996) as follows:

Castlemaine Group (Oll) - These form the Palaeozoic (Ordovician) turbidite sequences, which are dominantly composed of sandstone, mudstone and shale (black) and are highly weathered. They are sand rich, well sorted, medium – thick bedded, contain variably rounded quartz with some feldspar and lithic grains, within a quartz silt to clay matrix (Taylor, 1996a/b). The turbidites have undergone low-grade metamorphism in areas forming slates.

Moorabool Viaduct Formation/Sand (Tpv) - These are shallow marine deposits which formed as a result of a marine incursion from the south-east and are Neogene in age. The sequence is generally composed of a coarse quartz sand in a quartzose-calcareous silt matrix, which has been dissected by erosion of the uplifted tablelands (Taylor et al. 1996).Grains are well sorted, polished, moderately bedded and have been extensively ferruginised (some localised kaolinisation; Taylor, 1996a/b).

Newer Volcanics (Qvn1) - The Newer Volcanics are represented by Deep Lead valley flows, which are generally the older flows of the Newer Volcanics. They are constrained to the Deep Lead valley systems in the area but do occur as sheet flows in other parts of the Ballarat region (Taylor et al. 1996). They are generally deeply weathered and are composed of tholeiite to mildly alkalic olivine-basalt (Taylor, 1996a/b).

Colluvium (Qrc) - Colluvium deposits are formed by active outwash fans, scree aprons, hill bases and gullies. They are composed primarily of clastic sediments including gravels, sands, silts and clay, which are poorly sorted and have variable degrees of rounding (Taylor, 1996a/b).

Alluvium (Qra/ Qrt) - The Alluvial deposits of the area can be divided into two separate alluvial systems, floodplain deposits (Qra) and terrace deposits (Qrt; Taylor, 1996a/b): Floodplain (Qra) deposits include point bar, channel lag deposits and active meandering drainage systems. They are composed predominantly of clastic sediments of gravel, sand, silt and clay that has variable sorting and rounding of grains. Sedimentary structures are erratic with sediments stratified, laminated or massive. Terrace deposits (Qrt) are dissected alluvial deposits, consisting of clastic sediment composed of gravel, sand, silt and clay. Sediments vary from stratified, laminated to massive are generally reasonably sorted and rounded.

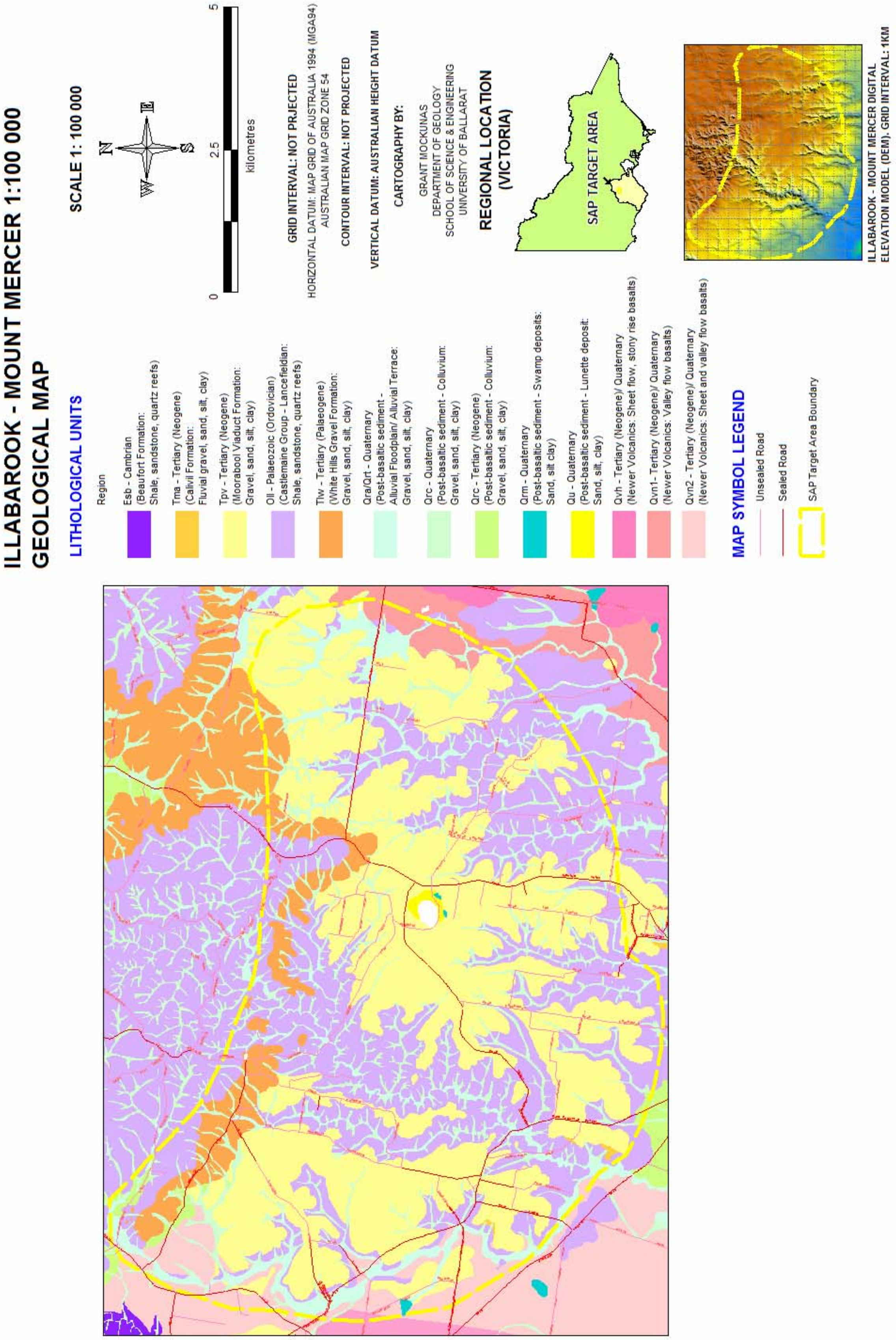

Figure 3-1 Geology of the Illabarook salinity target area.

3.1.2 Geomorphology

The Corangamite region has formed over 600 million years of geological evolution and is still continuing to change. Current mechanisms defining the landscape include earthquakes, landslides and groundwater discharge (Nicholson et al. 2006). Processes such as water movement, soil development, ecosystem establishment and salinity have helped shape landscape features (Dahlhaus et al. 2005a). The descriptive apparatus which define the current morphology of the Corangamite region are derived from the underlying geology and landscape evolution processes thus, the region can be separated into three broad physiographic units according to Nicholson et al. (Figure 3-2; 2006):

i. The Western Victorian Uplands (Midlands), which constitutes the northern highlands area of the Corangamite CMA;
ii. The Southern Uplands, which are defined by the Otway Ranges which are deeply dissected, the Barrabool Hills and low hills of the Bellarine Peninsula which have been moderately dissected; and
iii. The Western Victorian Plains, broad undulating plains comprised of both sedimentary and volcanic rocks.

The Western Victorian Uplands (Midlands) and the Western Victorian Plains define the physiographic units which constitute the Illabarook target area. These geomorphic divisions are further segmented by Robinson et al. (2003) into particular geomorphic units based on geologic landforms. The Western Uplands has four main physiographic features including the Dissected Western Uplands associated with Paleozoic sedimentary and metamorphic rocks; Dissected Western Uplands associated with Cainozoic gravel and sediments; Dissected Western Uplands associated with volcanic landforms; and alluvial terraces, floodplains and swamps of the Western Uplands. The Western Victorian Plains are composed of the Volcanic Western Plains with poorly developed drainage and the Volcanic Western Plains with well developed drainage (Robinson et al. 2003).

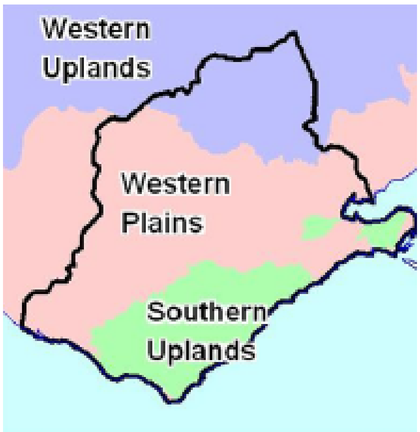

Figure 3-2 Physiographic units of the Corangamite CMA region.

(Source: Nicholson et al. 2006)

3.1.3 **Hydrogeology**

Groundwater Flow Systems (GFS) in the Corangamite region have been defined in terms of local, intermediate and regional scales. Local flow systems are generally fast to respond, are less than five kilometre long and occur within the confines of a sub-catchment; intermediate flow systems occur over distances between five and thirty kilometres, are intermediate to respond and can occur across sub-catchments; and regional flow systems, which occur over distances greater than fifty kilometres, have a long response time and can occur over basinal scale (Dahlhaus, 2003a).

In the target area four main groundwater systems have been identified including intermediate and local flow systems operating through fractured Palaeozoic sedimentary rocks, comprising of deeply weathered shales and sandstones with sporadic quartz veins; local flow systems in the Highlands gravel caps, comprising ferruginised and silcretised Neogene gravels/sands; intermediate and regional flow systems in the Western Uplands Newer Volcanics, comprising of basalt sheet and valley flows; and regional and intermediate flow systems in Deep Lead aquifers, comprising of gravel, sand, silt and clay in the beds of buried ancient river valleys (Dahlhaus, 2003b).

The groundwater flow systems are believed to be the driving mechanisms for three predominant salinity processes in the target area, including saline discharge at the base of the Neogene sand and gravels which overly Palaeozoic bedrock; saline discharge at the boundary of the Newer Volcanics and the underlying Palaeozoic bedrock and Neogene sands/gravels; and saline discharge as baseflow into the drainage areas in the Palaeozoic bedrock (Dahlhaus, 2005).

4 GROUNDWATER INVESTIGATION SITES

4.1 SITE ONE: MOUNT MERCER

The Mount Mercer site is located on the Mt. Mercer – Dereel Road, west of Mt. Mercer (Figure 4-1). The Mt. Mercer site has been selected on the basis of its applicability to the original hydrogeological model and the observed salinity processes. Field observations and literature reviews have delineated three possible processes occurring in the area, as indicated by Nicholson et al. (2006):

- Discharge is occurring at the base of the Neogene gravel/sand caps and the underlying Palaeozoic bedrock;
- Discharge is occurring at the base of the Newer Volcanics and the Palaeozoic bedrock; and
- Discharge directly from the Palaeozoic bedrock, into drainage areas.

The installations of groundwater monitoring bores aimed at testing the current hypothesised processes and develop greater understanding of the conceptual model.

Figure 4-1 Mount Mercer investigation site.

(Mount Mercer – Site One: Laffan Property)

4.1.1 Site Geology

The Mt. Mercer area is characterised by a number of geological units including Palaeozoic (Ordovician) turbidite bedrock (Oll), Moorabool Viaduct Foramation (Tpv), Newer Volcanics (Qvn1), Colluvium (Qrc) and Alluvium (Qra / Qrt). The Mt. Mercer region is also characterised by the presence of the Enfield Fault, which trends east-west through the study site.

4.1.2 Groundwater Flow Systems (GFS)

The extent and nature of the Groundwater Flow Systems in operation at the Mt. Mercer site was uncertain. Deep Lead systems may form regional and intermediate flow systems at the site and the gravel/sand/silt compositions, may form good conduits for groundwater flow. Local and intermediate flow systems are also believed to exits in the Newer Volcanics basalts. Flow systems in the Deep Lead systems and Newer Volcanics, were not targeted as part of the drilling program. Drilling determined local and intermediate flow systems exist in the Palaeozoic basement and local flow systems in the Neogene gravel/sand caps.

4.1.3 Bore Site Selection

The selection of specific bore sites was determined from both field observations and literature studies. Piezometers were placed at varying depths in different lithological units, in order to qualify the proposed GFS and determine the nature of the salinity processes occurring at the particular site. At the Mt. Mercer site four groundwater observation bores were installed and are illustrated in Figure 6-1.

4.2 SITE TWO: ILLABAROOK

This site is located on Recreation Road., Illabarook. The site is characterised by Neogene gravels/sands of the Moorabool Viaduct Formation overlying the Palaeozoic bedrock. Some basaltic sheet flows of the Newer Volcanics and post-basaltic sediment are also be found in the area. Old mine workings located above the target area are attributed Deep Lead mining during the 1800's to the turn of the century, in search of alluvial gold. The site is particularly relevant as it was used to establish the original hydrogeological model, proposed by Nicholson et al. (2006).

The initial conceptual hydrogeological model is believed to be illustrated by Neogene gravel caps overlying the Palaeozoic bedrock, with saline discharge occurring at the boundary of the gravel caps and the underlying Palaeozoic sequence. Dahlhaus (2003b) suggests a strong association between the boundary of the gravel caps/bedrock and saline discharge. The mine workings above the site are believed to have created numerous pathways for water to infiltrate into groundwater systems, resulting in subsequent saline discharge occurring at lower levels in the landscape (Nicholson et al. 2006).

Figure 4-2 Illabarook investigation site (Mackenzie Property).

4.2.1 **Geology**

The geology of the Illabarook site is characterised by The Palaeozoic (Ordovician) turbidite sequence of the Castlemaine Group (Oll), the Moorabool Viaduct Formation (Tpv), Newer Volcanics (Qvn2), Colluvium (Qrc) and Alluvium (Qra/ Qrt). The Enfield Fault is not located in this study area, however runs east-west north of the site and controlled emplacement of Neogene sediments (Church, 2004).

4.2.2 **Groundwater Flow Systems (GFS)**

It is believed that three main salinity processes are occurring in the Recreation Road site at Illabarook. Saline discharge believed to be occurring at the boundary of the Neogene sediments and the underlying Palaeozoic bedrock; discharging directly from Palaeozoic bedrock, as base flow in drainage areas; and at the boundary of the Newer Volcanics and underlying Palaeozoic bedrock. Local and intermediate GFS were intercepted in Palaeozoic sediments as part of the drilling program and it was established that local ephemeral flow systems may exist, in Neogene sediments forming gravel/sand caps on hilltops. Flow systems within Deep Leads and Newer Volcanics were not targeted as part of the groundwater investigation program.

4.2.3 Bore Site Selection

The selection of sites for bores at the Illabarook site was based on the ability to adequately test the proposed hydrogeological model. It was believed that the site represented a number of the salinity processes stipulated to occur in the Illabarook target area, in the original conceptual model developed by Nicholson et al. (2006). Two groundwater piezometers were installed at the site and intercepted GFS within the Palaeozoic bedrock (Figure 6-1).

5 PIEZOMETER CONTRUCTION

The drilling and piezometer construction is to be carried out by Numac Drilling Services Pty Ltd, under approved licensing through Southern Rural Water (SRW). A total of six bores were installed at the two sites, using Geoprobe 7720DT drill rig. The bores are located in the Mt. Mercer and Illabarook areas within the parishes of Warrambine and Dereel. Licenses for the bores were obtained through Southern Rural Water, Licensing Division and permissions of appropriate councils and landholders were obtained prior to drilling.

Piezometers were constructed using Class 18, 50 millimetre PVC casing, with a machine slotted screen (0.5mm openings). Screens were placed to variable depths at each sites (Appendix A). The establishment of each piezometer is similar to that described by Weight and Sonderegger (2001). The construction of each piezometer generally followed the method described by Weight and Sonderegger (2001), with the screen (with end capping) at the base, and casing extending above the screen to the surface. The well is completed with placement of filter pack consisting of 8/16 grade silica sand, extending approximately 0.5 metres above the well screen. The sand is generally larger than the slot-size of the screen, with <10% of the sand passing through the slots. Above the filter pack a bentonite seal was installed and the well annulus is then backfilled to the surface (Table 5-1).

The piezometer headworks comprise of galvanized steel casing, in order to protect the PVC casing of the bore. The headworks were fixed in place using 200×300×300mm concrete pad (area 0.09 m^2). The steel casing is 100mm in diameter, with a laser cut hinged, lockable lid. The installation of headworks is to ensure long life of the bores and continued future monitoring at the sites. All bores have keyed-alike padlocks to prevent bore tampering.

BORE ID	EASTING	NORTHING	AQUIFER	BORE DEPTH (m)	SCREEN POSITION (m)	FILTER PACK (m)	BENTONITE SEAL (m)	BACKFILL (m)	MEASURED EC (mS/cm)
IR1	54 733321E	58 10254N	Palaeozoic (Ordovician) Bedrock	15	15-11	15-10.5	10.5-8.5	8.5-0	8.9
IR2	54 732878E	58 09970N	Palaeozoic (Ordovician) Bedrock	7	7-4	7-3.5	3.5-2.5	2.5-0	16.3
MM1	54 748562E	58 11580N	Palaeozoic (Ordovician) Bedrock	12	12-6	12-5	5-3	3-0	9.5
MM2	54 748630E	58 11881N	Tertiary Sediments (Moorabool Viaduct Sand)	8	8-5	8-4	4-2	2-0	7.2
MM3	54 748915E	58 11826N	Palaeozoic (Ordovician) Bedrock	12	12-6	12-5	5-2	2-0	5.6
MM4	54 749071E	58 11790N	Palaeozoic (Ordovician) Bedrock	12	12-8	12-7	7-5	5-0	5.0

Table 9-1 Piezometer construction details for the Illabarook and Mount Mercer sites.

6 RESULTS & DISCUSSION

The groundwater monitoring bore program involved the construction and development of six bores, over the two selected sites at Mount Mercer and Illabarook. The bores defined aquifer parameters including aquifer geology, hydraulic properties, groundwater EC and salt store throughout the vertical profile.

Piezometer installation took place on the 08th to the 10th of October (2007), with bore development and testing carried out over subsequent weeks. Sampling conducted every metre during drilling for bore lithological descriptions, enabled greater definition of the three-dimensional geology. The samples were analysed in detail in the laboratory using the method adopted by Horgan (2006) where colour, texture, mineralogy, grading, structure, moisture content, lithology and the size, composition and rounding of grains were described.

6.1 MOUNT MERCER

Mount Mercer bores determined a watertable at variable depth across the site, within the Palaeozoic bedrock and Neogene gravel/sand sediments (Figure 6-1). MM1 which was placed above the discharge zone, intercepted the watertable in Palaeozoic sediments comprised of inter-bedded siltstone and fine grained sandstone, at an approximate depth of nine metres. MM2 intercepted a watertable at five to six metres, within Neogene sediments comprised predominantly of clays and silts. Bores MM3 and MM4 were constructed within the discharge area at the site and intercepted the watertable at nine meters respectively in Palaeozoic siltstone and are overlain by younger post-basaltic alluvial sediments.

Measurement of standing water level in bores determined a Piezometric watertable within one to three metres of the surface, for bores MM4 and MM3 respectively. Piezometers MM2 and MM1 indicated Piezometric watertables within two and three metres of the surface respectively. Corrections for differences in the piezometric watertable with the groundwater watertable were not applied as the piezometers are installed to relatively shallow depths and the differences are assumed negligible.

Aquifer recovery testing indicated that aquifer conductivities within the Palaeozoic bedrock are highly variable but are considerably less than previously hypothesised. MM1 measured the highest conductivity in Palaeozoic sediments and is attributed to the highly fractured nature of the bedrock (siltstones/sandstones). MM2 situated within Neogene sediments had the lowest observed conductivity and is believed to be due to the predominantly clay nature of the aquifer system. Piezometers MM3 and MM4 were situated in the discharge area and measured variable conductivities but were generally low, with MM4 similar to that of MM2.

Downhole $EC_{1:5}$ analysis indicated high salt content within the upper regolith and elevated salt content at depth, particularly in the region of the intercepted watertable (Appendix B). The investigation of sediments at the Mount Mercer site determined elevated salt content in the upper two metres of the profile, then diminishing with depth. Salt appears to then become concentrated within the intercepted watertable, with EC values increasing at the approximated watertable depth. This indicates that EC is primarily concentrated within the upper regolith and at depth (within the intercepted watertable), in both Palaeozoic and Neogene sediments.

It should be noted the analysis of Neogene sediments at Mount Mercer (MM2) was done so with the aid of Dr. Stephen Carey (Lecturer, University of Ballarat). Due to the uncertainty of mapped geologic boundaries at the site and the nature of drilled sediments, Dr. Carey was consulted. It was determined that given the nature of both the fresh samples and that observed under the microscope, the sediments could be Moorabool Viaduct Formation (Neogene gravels/sands; Carey *pers comm.* 2007). The iron rich upper which is characteristic of Neogene sediments at site IR1 (Illabarook) and grain rounding and sphericity was used to support this.

6.2 ILLABAROOK

The two installed piezometers at Illabarook determined watertable at variable depth, within the Palaeozoic bedrock (Figure 6-1). The discharge area (IR2) was drilled first as to determine the depth to the watertable and lithological characteristics, relevant to the site. The aquifer systems intercepted have low hydraulic conductivities and were particularly slow to develop. Flow systems operating within the Palaeozoic bedrock are considered to be local to intermediate flow systems, given there low hydraulic conductivity.

IR1 established above the discharge zone in the council reserve (Recreation Road, Illabarook) targeted aquifer systems within the Palaeozoic bedrock and the watertable was intercepted at eleven metres. Neogene sediments were drilled for the first nine metres and are more extensive in the vertical profile, than previously hypothesised. Drilling did not intercept any flow systems within the Neogene sediments but bleaching and mottling of sediments suggests seasonal waterlogging. Therefore, ephemeral local flow systems are postulated to develop in Neogene sediments, most probably proceeding periods of increased or prolonged rainfall and infiltration. The piezometer intercepted a watertable at approximately 11 metres within Palaeozoic sediments and was screened to fifteen metres.

IR2 drilled in the discharge area drilled through an *in situ* regolith formed on Palaeozoic sediments and intercepted the watertable at four metres. The bore was screened from four to seven metres. Analysis of drilling samples indicated that lithology is characterised by moderately to highly weathered (with depth) siltstones and a thin soil layer.

Aquifer recovery testing similarly to Mount Mercer determined that groundwater flow in the Palaeozoic bedrock, is slower than previously thought. The lowest conductivity was obtained in the recharge zone (IR1), although little difference in conductivities existed between IR1 and IR2.

The downhole $EC_{1:5}$ data indicated that Palaeozoic sediments at Illabarook show similar trends to Mount Mercer, but Neogene sediments are generally characterised by much lower salt concentration (Appendix B). Palaeozoic sediments within bore IR2 are characterised by high salt content within the upper regolith, diminishing with depth but again increasing at the intercepted watertable. IR1 situated within Palaeozoic sediments overlain by Neogene sediments shows low EC responses in Neogene sediments but increasing within Palaeozoic sediments at nine metres.

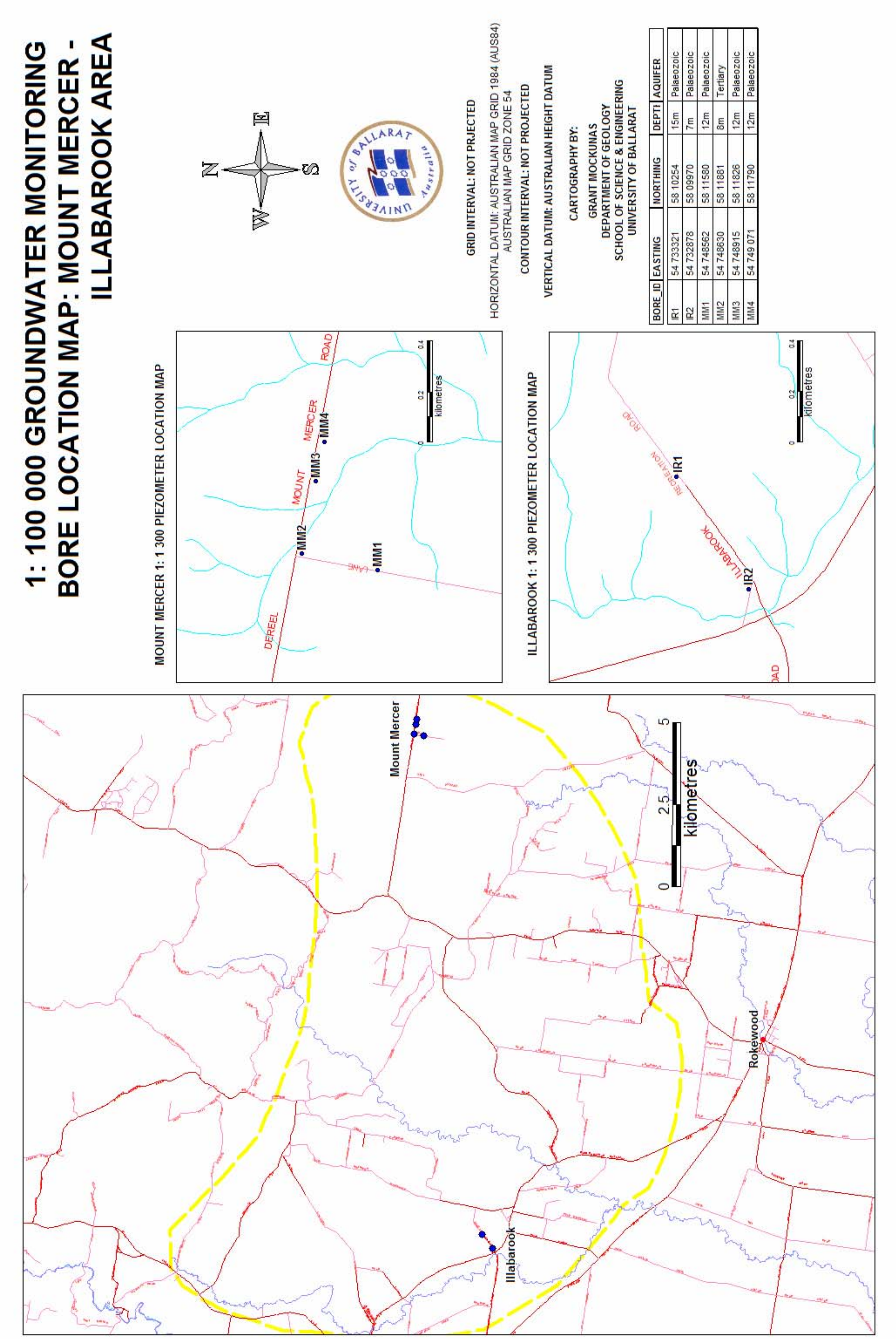

Figure 6-1 **Installed groundwater monitoring piezometers for the Mount Mercer – Illabarook area.**

7 CONCLUSION

The installation of groundwater piezometers at Mount Mercer and Illabarook identified the groundwater table is variable at both sites. Aquifer systems and there properties have been determined both within the Palaeozoic bedrock and Neogene sediments, and regions of salt concentration within the vertical profile has been identified.

The following conclusions can be drawn from the drilling and bore development program:

- Aquifer systems exist to variable depths within the Palaeozoic (Ordovician) bedrock, with variable hydraulic conductivities depicting aquifer changeability;

- Aquifer systems exist within Neogene sediments at Mount Mercer but drilling at Illabarook indicates the presence of seasonal waterlogging and suggests that ephemeral local GFS may develop, during high rainfall periods. The variable nature of Neogene units suggests strong spatial differences in GFS operating within the unit;

- Single-bore recovery tests indicate that aquifers within the Palaeozoic and Neogene sediments have considerably lower hydraulic conductivities than originally thought;

- Analysis of $EC_{1:5}$ data for downhole samples of Neogene sediments, specify a relatively low EC response at Illabarook but higher at Mount Mercer. This indicates that saline groundwater discharge from Neogene sediments is highly variable and spatial variance may be attributed to GFS associated with a particular locality; and

- $EC_{1:5}$ data for Palaeozoic sediments at Mount Mercer and Illabarook show that the profile is characterised by a regolith with saline upper decreasing with respect to depth and then increasing within the region of the intercepted watertable. The $EC_{1:5}$ data determined that salt in the vertical profile is primarily concentrated in Palaeozoic rocks, at both the Illabarook and Mount Mercer sites.

8 RECOMMENDATIONS

The investigation of groundwater systems across the site has increased knowledge of the geology, hydrogeology and salinity processes. Further investigative work may provide useful information in the development of understanding of groundwater systems and there properties, across the target area. The following suggests possible future research:

- The installation of groundwater monitoring bores in Neogene sediments at the Illabarook investigation site. The piezometer may be monitored using a data-logger, to measure the nature of possible ephemeral flow systems in the unit;

- The further installation of piezometers within Neogene sediments and Palaeozoic bedrock, particularly where saline discharge is observed. This would further understanding of the spatial variability in GFS and possible influences on saline groundwater discharge;

- The installation of groundwater bores at the Mount Mercer and Illabarook sites, targeting GFS within Deep Lead systems and the Newer Volcanics basalts. This would be used to determine the nature of GFS within these units;

- Conduct $EC_{1:5}$ analysis and chemical analysis for all installed piezometers, to determine the changeability in aquifer chemical properties across the target area; and

- Conduct age dating of groundwater to determine residency times, CFC dating is considered a possible technique to target local and intermediate GFS.

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9.1 PERSONAL COMMUNICATION

Carey, S. (2007). Moorabool Viaduct Sands (Tertiary Sediment) Analysis. Verbal communication. Dr. Stephen Carey, Lecturer, University of Ballarat. October, 2007.

APPENDIX A

BORE LOGS

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STRATIGRAPHY

Palaeozoic sedimentary rocks (Ordovician - Lancefieldian (Oll)) rocks.

Neogene gravels/sands (Moorabool Viaduct Formation (Tpv))

Quaternary Alluvium (Qra/Qrt)

OBSERVED ROCK TYPE

Soil/ Clay

Ferricrete

Sandstone

Siltstone

Alluvium

Sands

BORE CONSTRUCTION

Backfill

Bentonite

Filter Pack (8/16 Grade Silica Sand)

50mm PVC machine slotted (.5mm slots) screen

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Public - Golden Plains Shire
Coordinates:	733393E 5810314N (AGD 84, Zone 54)
Elevation:	
Location:	1m Inside Fence. Recreation Rd., Illabarook.

Bore Identification Details

Identification:	IR1
Bore Purpose:	Groundwater Investigation
Parish:	Dereel
Logged By:	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	Drillers Address:	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	Driller Contact:	(03) 9399-8559
Drilling Technique:	Auger	Driller:	J. Boyd
Date of Construction:	Monday 8th October, 2007	Drillers Offsider:	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	Hand Bailer.

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Moist	1			Red brown sandy CLAY with very fine to medium quartz sand, subrounded to rounded. Ironstone of variable rounding (40%) forming aggregates and becoming less occurrent with depth. Strongly consolidated in upper (Ferricrete). Dry.
			2			Red - whie mottled clay SAND, consisting of very fine to coarse quartz sand, subangular to rounded and minor ironstone (~10%). Strongly consolidated upper to moderately consolidated moving down the profile. Dry.
			3			Yellow-white mottled very fine to coarse quartz SAND, subrounded to rounded. Minor ironstone (<5%), subangular to subrounded. Loosely consolidated to non-consolidated sediments. Dry.
			4–9			White - grey very fine to coarse quartz SAND, subrounded to rounded. Loosely consolidated to non-consolidated sediments but becoming consolidated to strongly consolidated at depth. Dry to slightly moist and becoming moist at depth. Colour changeable between white-gray to yellow-brown/red - grey down profile. 
15		Very Moist; Wet	10–15			Grey-yellow silty CLAY with very fine quartz sand, angular to subrounded. SILSTONE fragments and angular vein quartz fragments (<10%) becoming aparent with depth and ranging from coarse sand to coarse pebble in size. Intermittant bleached layers indicating waterlogging. Consolidated. SILSTONE highly weathered but changing to moderately weathered down profile. Moist to very moist/wet with depth.

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area		
Client:	University of Ballarat	*Bore Identification Details*	
Site:	Public - Golden Plains Shire	**Identification:**	**IR2**
Coordinates:	733393E 5810314N (AGD 84, Zone 54)	**Bore Purpose:**	Groundwater Investigation
Elevation:		**Parish:**	Dereel
Location:	1m Inside Fence. Recreation Rd., Illabarook.	**Logged By:**	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	**Drillers Address:**	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	**Driller Contact:**	(03) 9399-8559
Drilling Technique:	Auger	**Driller:**	J. Boyd
Date of Construction:	Monday 8th October, 2007	**Drillers Offsider:**	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	12-Volt Pump + hand bailer

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Moist				Brown-yellow sandy CLAY with lithic fragments composed of vein quartz (50%) and SILTSTONE (50%). Sediments are consolidated and becoming loosely consolidated with depth. Moisture increasing with depth. Highly to moderately weathered (decreasing with depth). Colour changing to grey-brown at depth with minor ironstained layering.
			1			
			2			
			3			
			4			
			5			
		Wet				
			6			
7			7			

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	748539E 5811419N (AGD 84, Zone 54)
Elevation:	
Location:	Inside Fence. Fagg Ln, Mount Mercer.

Bore Identification Details

Identification:	**MM1**
Bore Purpose:	Groundwater Investigation
Parish:	Warrambine
Logged By:	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	**Drillers Address:**	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	**Driller Contact:**	(03) 9399-8559
Drilling Technique:	Auger	**Driller:**	J. Boyd
Date of Construction:	Tuesday 9th October, 2007	**Drillers Offsider:**	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	12-Volt Pump + hand bailer

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Moist	1			Yellow brown LOAMY SAND with very fine to coarse quartz sand, subangular to subrounded and coarse sand to fine pebble SILTSONE fragments, becoming evident with depth. Moderately consolidated. Slightly dry to moist.
			2, 3, 4, 5, 6			Grey CLAY with predominant SILTSTONE fragments, ranging from coarse sand to coarse pebble in size. Highly weathered bedrock reducing to moderately weathered bedrock at depth. SILTSTONE variably beached and forming yellow-brown at depth. Very fine to coarse quartz sand, subangular to angular increasing with depth. 
		Very Moist	7			
12		Wet	8, 9, 10, 11, 12			Yellow brown very fine grained SANDSTONE with minor very fine to coarse quartz sand and fine sand to coarse pebble sandstone fragments becoming less pronouced at depth. Non-consolidated highly weathered bedrock, becoming consolidated at depth. Moist/very moist and wet at depth.

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area		
Client:	University of Ballarat	***Bore Identification Details***	
Site:	Private (Daniel Laffan)	**Identification:**	**MM2**
Coordinates:	748539E 5811419N (AGD 84, Zone 54)	**Bore Purpose:**	Groundwater Investigation
Elevation:		**Parish:**	Warrambine
Location:	Inside Fence. Fagg Ln, Mount Mercer.	**Logged By:**	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	**Drillers Address:**	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	**Driller Contact:**	(03) 9399-8559
Drilling Technique:	Auger	**Driller:**	J. Boyd
Date of Construction:	Tuesday 9th October, 2007	**Drillers Offsider:**	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	12-Volt Pump + hand bailer

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Moist	1			Dark brown - red mottled CLAY with very fine to fine, subrounded to rounded (minor angular <5%) quartz sand. Iron rich upper clay layer, with minor ironstone in clay matrix (<10%). Strongly consolidated. Dry to slightly moist.
			2 3 4 5			Grey - red mottled CLAY with very fine to coarse quartz sand, subrounded to rounded. Lithics including ironstone variable from coarse sand to very fine pebble in size and subangular to angular. CLAY becoming yellow brown - grey mottled at depth with very fine to coarse, subrounded to rounded quartz sand, increasing with depth. Lithics, including ironstone reducing to coarse sand sized fragments with depth. Strongly consolidated to consolidated. Moist but increasing to very moist/wet with depth.
		Very Moist	6			
8		Wet	7 8			

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area		
Client:	University of Ballarat	*Bore Identification Details*	
Site:	Private (Daniel Laffan)	Identification:	**MM3**
Coordinates:	748539E 5811419N (AGD 84, Zone 54)	Bore Purpose:	Groundwater Investigation
Elevation:		Parish:	Warrambine
Location:	Inside Fence. Dereel Rd., Mount Mercer.	Logged By:	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	Drillers Address:	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	Driller Contact:	(03) 9399-8559
Drilling Technique:	Auger	Driller:	J. Boyd
Date of Construction:	Tuesday 9th October, 2007	Drillers Offsider:	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	12-Volt Pump + hand bailer

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Moist	1			Orange-brown silty CLAY, containing a fine to medium quartz sand with variable rounding from rounded to subangular. Cohesive structure with minor lithics (<5%) in clay matrix, composed of subrounded quartz and ironstone. Moist.
			2			Mottled grey-red CLAY LOAM with a very fine to coarse quartz sand with rounding from subrounded to angular. Some minor lithics composed of quartz fragments and minor ironstone (<5%). Moist and strongly cohesive.
			3			Mottled grey-yellow CLAY to CLAY LOAM with very fine to coarse quartz sand; variable rounding from angular to rounded. Lithics (~10%), composed of quartz and ironstone of variable rounding. Moist. Cohesive.
			4 5 6 7 8			Mottled grey-brown CLAY to CLAY LOAM with very fine to coarse quartz sand; variable rounding from angular to rounded. Lithics (~10%) composed of quartz and ironstone of variable rounding. Moist. Cohesive. CLAY continues to depth of 9.5 metres, with lithics diminishing with respect to depth. Moisture increasing with depth. 
		Very Moist	9			
12		Wet	10 11 12			Highly weathed SILTSTONE forming yellow-brown CLAY with very fine to coarse quartz sand with subangular to subrounded grains. SILTSTONE fragments increasing with depth from coarse sand to coarse pebble in size and weathering reducing from high to low-moderate with depth. Moisture also increasing with depth.

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Project:	Hydrogeology & Salinity Processesn in the Mount Mercer - Illabarook Area		
Client:	University of Ballarat	*Bore Identification Details*	
Site:	Private (Daniel Laffan)	Identification:	MM4
Coordinates:	748539E 5811419N (AGD 84, Zone 54)	Bore Purpose:	Groundwater Investigation
Elevation:		Parish:	Warrambine
Location:	Inside Fence. Dereel Rd., Mount Mercer.	Logged By:	Grant Mockunas

Contractor Details:

Driller:	NUMAC Drilling Services PTY LTD	Drillers Address:	P.O Box 502 Altona North, VIC. 3025
Drill Type:	Geoprobe 7720DT	Driller Contact:	(03) 9399-8559
Drilling Technique:	Auger	Driller:	J. Boyd
Date of Construction:	Tuesday 9th October, 2007	Drillers Offsider:	L. Martin

Bore Construction Details:

Casing:	Class 18 PVC (50mm)
Screen:	Class 18 PVC (50mm) - Machine Slotted (0.5mm slots)
Bore Diameter:	150mm
Gravel Pack:	8/16 Grade Silica Sand
Bore Casing Height:	0.9m (Above Natural Surface)
Development Technique:	12-Volt Pump + hand bailer

Depth (m)	Bore Construction	Moisture Content	Sample Depth (m)	Stratigraphic Interpretation	Graphic Log	Lithological Description (Type, Texture, Colour, Structure, Minor Components)
		Very Moist	1			Orange brown - grey mottled CLAY with fine subrounded to rounded quartz particles. Moist with cohesive structure and minor roots (grass). Minor subrounded ironstone.
			2			Orange brown - grey mottled CLAY with <5% fine to coarse grained quartz sand and minor lithics. Quartz and lithic fragments are subrounded to rounded, with minor angular fragments. Moist and with cohesive structure but no roots.
		Moist	3			Grey - Orange brown mottled CLAY, with fine variably rounded (subdrounded to angular) qartz sand and minor (<5%) lithic fragments. Moist with cohesive structure.
			4			Orange-grey highly weathered CLAY with SILTSTONE and angular vein quartz fragments (5-15%). Augered Siltstone frangments displaying minor bedding features (laminations). Moist.
			5			Grey to white CLAY with highly weathered SILTSTONE lithics and angular quartz vein fragments (5-15% and increasing with depth). Cohesive. Moist. Bleached with some thin layers of iron staining. SILSTONE changing from highly weathered to moderately weathere with depth and augued SILSTONE fragments from coarse sand to coarse pebble in size continuing at depth, within a CLAY matrix. Moisture increasing with depth.
			6			
			7			
			8			
		Wet	9			
			10			
			11			
12			12			

APPENDIX B

DOWNHOLE $EC_{1:5}$/ $pH_{1:5}$ ANALYSIS

Down-hole EC1:5 & pH 1:5 Analysis

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University of Ballarat

SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
IR1	1	0.11	6.95
IR1	2	0.08	6.63
IR1	3	0.09	6.21
IR1	4	0.08	6.59
IR1	5	0.1	6.73
IR1	6	0.11	6.5
IR1	7	0.1	6.56
IR1	8	0.11	6.68
IR1	9	0.24	6.38
IR1	10	0.31	6.17
IR1	11	0.36	6.62
IR1	12	0.35	5.99
IR1	13	0.31	6.03
IR1	14	0.51	5.64
IR1	15	0.41	5.99

Down-hole EC1:5 & pH 1:5 Analysis

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Department of Geology
University of Ballarat

SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
IR2	1	0.88	6.53
IR2	2	0.54	6.55
IR2	3	0.59	6.74
IR2	4	0.79	6.67
IR2	5	0.97	5.51
IR2	6	0.75	6.46
IR2	7	1.32	6.05

Down-hole EC1:5 & pH 1:5 Analysis

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University of Ballarat

SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
MM1	1	0.82	5.42
MM1	2	0.73	5.56
MM1	3	0.6	5.95
MM1	4	0.46	5.91
MM1	5	0.44	6.26
MM1	6	0.33	6.35
MM1	7	0.33	5.97
MM1	8	0.21	6.24
MM1	9	0.25	6.06
MM1	10	0.25	5.9
MM1	11	0.48	5.41
MM1	12	0.82	5.46

Down-hole EC1:5 & pH 1:5 Analysis

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University of Ballarat

SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
MM2	1	1.28	5.61
MM2	2	0.51	5.05
MM2	3	0.36	5.54
MM2	4	0.32	5.19
MM2	5	0.51	4.73
MM2	6	0.91	4.52
MM2	7	1.02	4.9
MM2	8	1.03	5.47

Down-hole EC1:5 & pH 1:5 Analysis

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Department of Geology
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SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
MM3	1	0.9	5.32
MM3	2	1.28	4.24
MM3	3	0.57	5.39
MM3	4	0.5	5.7
MM3	5	0.52	5.13
MM3	6	0.44	5.74
MM3	7	0.4	5.42
MM3	8	0.35	5.89
MM3	9	0.76	5.46
MM3	10	0.5	5.58
MM3	11	0.85	5.46
MM3	12	0.79	5.17

Down-hole EC1:5 & pH 1:5 Analysis

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SAMPLE ID	DEPTH (m)	EC 1:5	pH 1:5
MM4	1	0.74	4.79
MM4	2	0.42	5.05
MM4	3	0.32	5.13
MM4	4	0.33	5.72
MM4	5	0.25	5.16
MM4	6	0.31	5.48
MM4	7	0.24	5.62
MM4	8	0.23	5.69
MM4	9	0.2	6.55
MM4	10	0.53	6.32
MM4	11	0.29	5.88
MM4	12	0.41	6.17

APPENDIX B

GEOPHYSICS COMPLETION REPORT

Grant Douglas Mockunas

Bachelor of Applied Science (Honours)

University of Ballarat

School of Science & Engineering

Department of Geology

2007

ACKNOWLEDGEMENTS

The geophysical survey across the three selected sites in the Mount Mercer – Illabarook area, was conducted with the assistance of a number of persons and organisations. These included:

- Mr. Peter Dahlhaus – Honours Project Supervisor, Senior Lecturer, University of Ballarat;
- Mr. Robert Smith – Laboratory Technician, University of Ballarat;
- Mr. Martin Peters – Farm Works, Meredith;
- Mr. Daniel Laffan;
- Mr. Colin McKenzie;
- Mr. Allan "Blue" Smith; and
- Corangamite Catchment Management Authority (CCMA) – Financial assistance for project.

ii

DECLARATION

The content of the following 'Geophysics Completion Report' in its entirety is that of my own research, unless acknowledged in the text and reference list.

No section of this report has been published or submitted as part of another degree or to another institution.

………………………………

Grant Mockunas

Bachelor of Applied Science Geology (Honours)

School of Science & Engineering

Department of Geology

University of Ballarat

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1 INTRODUCTION

Electromagnetic (EM) geophysics provided details of the near surface salinity processes, over three selected sites in the Illabarook target area. The target area was initially selected on the basis of its possible contribution, to rising salinity trends in the Woady Yaloak River system and Lake Corangamite (Nicholson et al. 2006).

A minor rise of 3.4µS/cm/yr EC has been consistently noted at the Cressy Gauge (#234201) on the Woady Yaloak River (Figure 1-1). Saline groundwater discharge is believed to occur at alluvial flats and in drainage areas, underlain by the Palaeozoic bedrock sediments and at the boundaries Neogene gravel/sand caps. Flowtube modelling based on present information indicates a continuing but slow, rise in groundwater levels in gravel caps and an increase in the discharge areas by less than ten percent over the next 50 years (Nicholson et al. 2006).

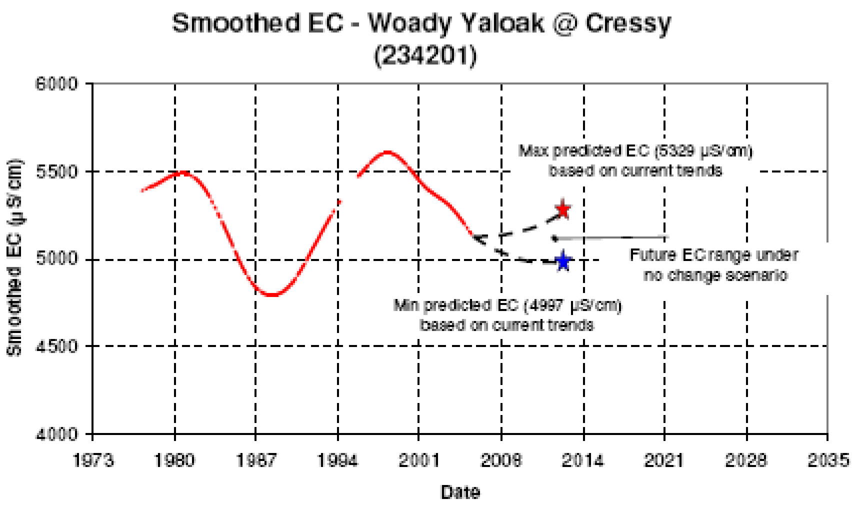

Figure 1-1 **Smoothed EC – Woady Yaloak Gauge at Cressy.**

(Source: Dahlhaus et al. 2005)

The Electromagnetic (EM) geophysics survey was conducted using a Geonics EM38 with horizontal and vertical dipoles, by Martin Peters of Farm Works, Meredith. Soil sampling was conducted in conjunction with the survey at randomised localities at each site, to determine the physical and chemical properties of the soil profile.

The survey and soil sampling forms part of a University of Ballarat Honours research program, in order to delineate the 'Hydrogeology and Salinity Processes of the Mount Mercer – Illabarook

Area' (Figure 1-2). The project aims to delineate and verify the validity of the initial hydrogeological conceptual model proposed by Nicholson et al. (2006) and identify possible causes and effects relating to salinity in the region. Funding for the survey was provided by the CCMA.

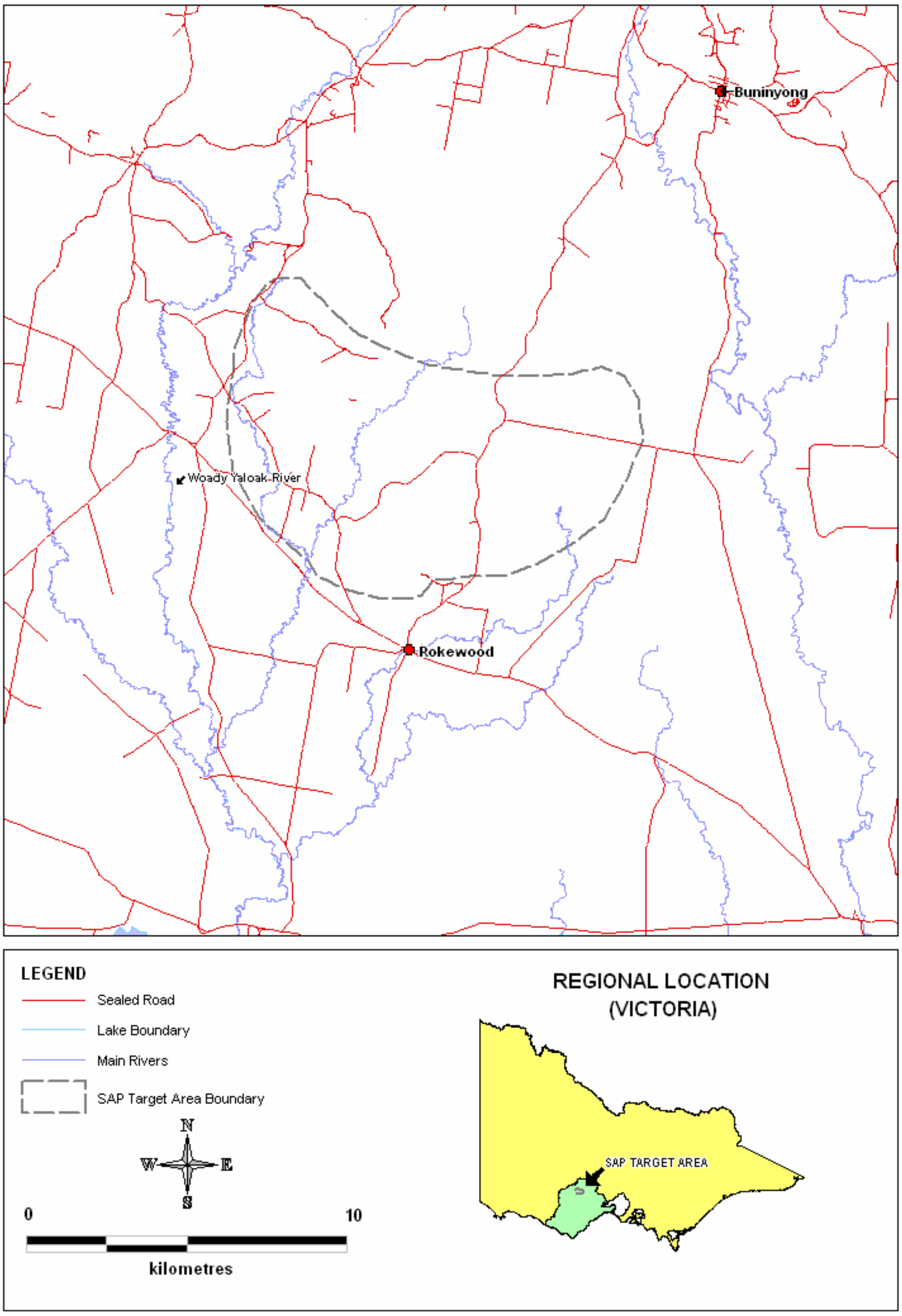

Figure 1-2 **The Illabarook salinity target area, Corangamite CMA, Victoria.**

2 AIMS & OBJECTIVES

The geophysical survey aims to delineate the near surface salinity processes, at three selected sites in the Mount Mercer and Illabarook areas. The data should detail saline discharge areas or regions of high/low near surface salinity and enable the development of a number of salinity maps. Comparisons between previously obtained data should also be drawn, in order to delineate changes in near surface salinity over time.

Soil sampling will provide an understanding of the top meter or so of the regolith profile, in order to delineate variations in the physical and chemical characteristics of soils across the target area. Laboratory analysis of soils will further develop knowledge of soil Electrical Conductivity (EC) properties and pH, as well as soil texture and moisture characteristics.

3 GEOLOGY, GEOMORPHOLOGY & HYDROGEOLOGY

3.1 GEOLOGY

The Illabarook salinity target area is located in the Bendigo Zone of the Lachlan Fold Belt in southeastern Australia, and is characterised by a number of geological units (Figure 3-1). The region is primary composed of Palaeozoic and Cainozoic units of sedimentary and volcanogenic origin, with recent mapping and descriptions completed by Taylor et al. (1996)

Palaeozoic rocks are primarily represented by the Castlemaine Supergroup which forms the bedrock of the Bendigo Zone. The oldest rocks in the region are that of the Saint Arnaud Group, which occur to the north-west of the target area and are Cambrian in age (Taylor et al. 1996). The Palaeozoic bedrock is generally composed of Ordovician sandstones, slates and shales, which were originally deposited in a deep marine environment. The Benambran Orogeny during the Early to Middle Silurian generated a number of tectonic forces which lithified, folded and faulted the Ordovician sediments (Dahlhaus, 2005).

Tectonic stability existed across Victoria from the mid-Permian to the Jurassic and little deposition occurred during this time (Webb, 1991). The Late Cretaceous rifting along the eastern margins of Australia lead to a north-south down-warping. Concurrently, the rifting also resulted in the Victorian divide between the Otway and Murray Basin becoming more pronounced. Increased relief resulted in more active erosion of the Mesozoic palaeosurface and development of large fluvial sedimentary deposits of the White Hills Gravel in palaeovalleys. The exact age of the White Hills gravels is uncertain but it is suggested that they were deposited sometime in the Tertiary - Palaeogene (Cainozoic Era; Phillips et al. 2003).

The Cainozoic Era is represented by both Tertiary and Quaternary rocks of marine and terrestrial origin. Early Tertiary deposits flank hillsides of Palaeozoic bedrock and are comprised predominantly of fluvial material, derived from the Mesozoic Palaeosurface. Neogene sediments were deposited as a result of a marine incursion from the south and form the current hilltop and hill slope deposits of the Moorabool Viaduct Formation, found in the region. Quaternary deposits are chiefly represented in the area by the Newer Volcanics and are comprised principally of basaltic lava flows. A number of alluvial, colluvial and fluvial deposits associated with post-volcanic drainage systems have also developed (Taylor et al. 1996).

Uplift proceeded the deposition of the Pliocene sands in the area and is attributed to movement on along the east-west Enfield fault, which bisects the area. Proceeding uplift the landscape was down cut by a number of waterways which resulted in the current dissected landscape. It also accounts for the remnant gravel caps which can be observed on the hill tops in the study area (Dahlhaus, 2005).

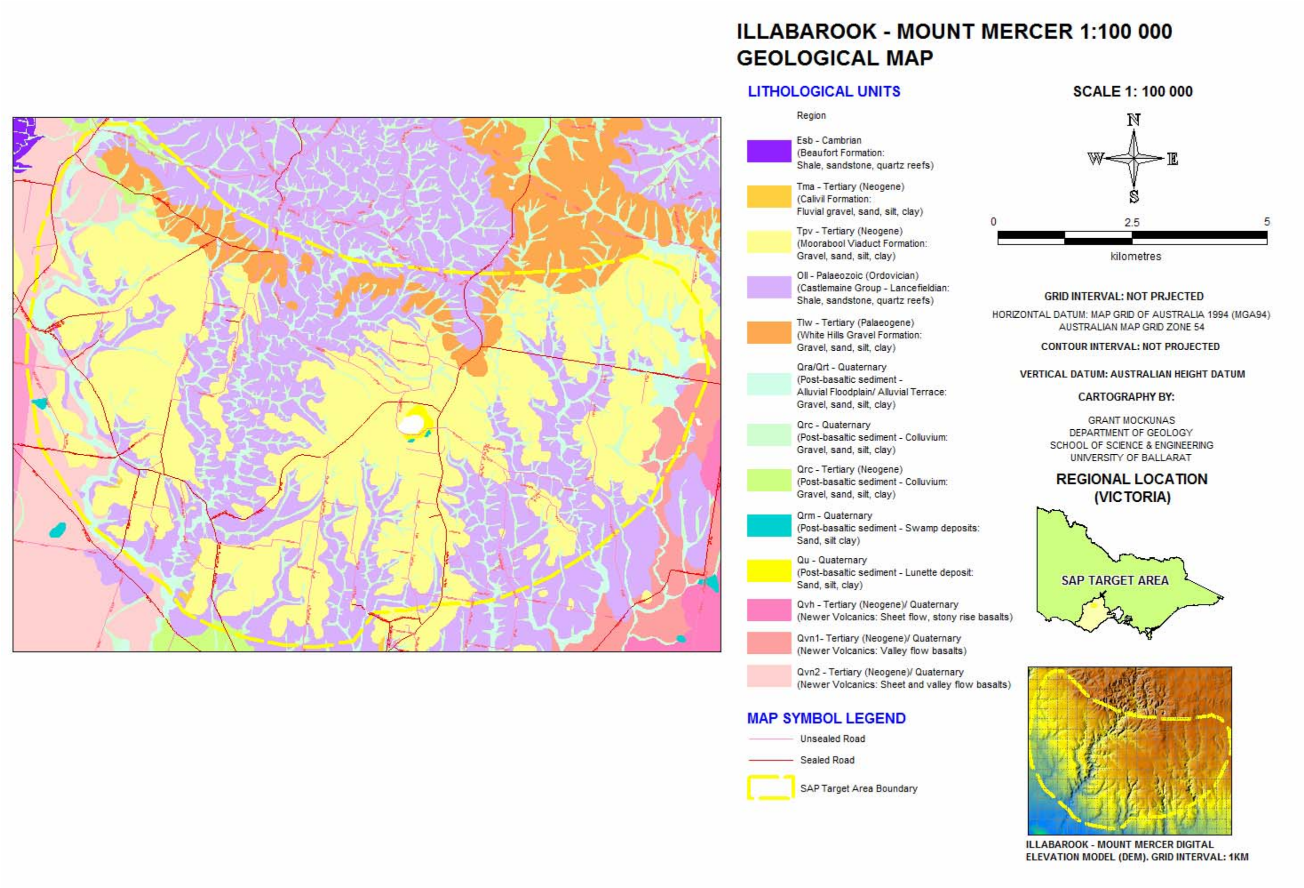

Figure 3-1 **Geology of the Illabarook target area.**

3.2 GEOMORPHOLOGY

The Corangamite region including the Illabarook target area has been the result of 600 million years of geological evolution, and is still continuing to change. Current mechanisms defining the landscape include earthquakes, landslides and groundwater discharge (Nicholson et al. 2006). Processes such as water movement, soil development, ecosystem establishment and salinity have helped shape landscape features (Dahlhaus et al. 2005a). The descriptive apparatus which define the current morphology of the Corangamite region are derived from the underlying geology and landscape evolution processes thus, the region can be separated into three broad physiographic units according to Nicholson et al. (Figure 3-2; 2006):

iv. The Western Victorian Uplands (Midlands), which constitutes the northern highlands area of the Corangamite CMA;
v. The Southern Uplands, which are defined by the Otway Ranges which are deeply dissected, the Barrabool Hills and low hills of the Bellarine Peninsula which have been moderately dissected; and
vi. The Western Victorian Plains, broad undulating plains comprised of both sedimentary and volcanic rocks.

The Western Victorian Uplands (Midlands) and the Western Victorian Plains define the physiographic units which constitute the Illabarook salinity target area. These geomorphic divisions are further segmented by Robinson et al. (2003) into particular geomorphic units based on geologic landforms. The Western Uplands has four main physiographic features including the Dissected Western Uplands associated with Paleozoic sedimentary and metamorphic rocks; Dissected Western Uplands associated with Cainozoic gravel and sediments; Dissected Western Uplands associated with volcanic landforms; and alluvial terraces, floodplains and swamps of the Western Uplands. The Western Victorian Plains are composed of the Volcanic Western Plains with poorly developed drainage and the Volcanic Western Plains with well developed drainage (Robinson et al. 2003).

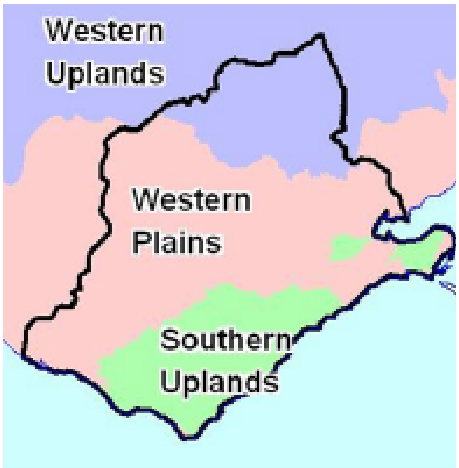

Figure 3-2 Physiographic units of the Corangamite CMA region (Source: Nicholson et al. 2006).

3.3 HYDROGEOLOGY

Groundwater systems in the region have been defined in terms of local, intermediate and regional flow systems. Local flow systems are generally fast to respond, are less than five kilometre long and occur within the confines of a sub-catchment; intermediate flow systems occur over distances between five and thirty kilometres, are intermediate to respond and can occur across sub-catchments; and regional flow systems occur over distances greater than fifty kilometres, have a long response time and can occur over basinal scale (Dahlhaus, 2003a). The

National Land and Water Resources Audit developed the framework for Dryland salinity management by the establishment of a Groundwater Flow Systems (GFS) framework (NLWRA, 2001).

In the Illabarook salinity target area four main groundwater systems have been identified according to Dahlhaus (2003b) including intermediate and local flow systems operating through fractured Palaeozoic sedimentary rocks comprising of deeply weathered shales and sandstones with sporadic quartz veins; local flow systems in the Highlands gravel caps, comprising ferruginised and silcretised sands and gravels of the Neogene; intermediate and Regional Flow Systems in the Western Uplands Newer Volcanics, comprising of basalt sheet and valley flows; and regional and intermediate flow systems in Deep Lead aquifers, comprising of gravel, sand, silt and clay in the beds of buried ancient river valleys.

The GFS are believed to be the driving mechanisms for three predominant salinity processes in the Illabarook area including saline discharge at the base of the Neogene sand and gravels which overly Palaeozoic bedrock; saline discharge at the boundary of the Newer Volcanics and the underlying Palaeozoic bedrock and Neogene gravels/sands; and saline discharge as baseflow into the drainage areas in the Palaeozoic bedrock (Dahlhaus, 2005).

4 METHODS

4.1 GEOPHYSICAL SURVEY

The geophysical survey of the Illabarook salinity target area employed a Geonics EM 38 instrument. The apparatus measured the Electromagnetic Conductivity (EC) of the near-surface environment in the frequency domain. The instrument was carried by a Bombardier All Terrain Vehicle (ATV), with the EM 38 trailing behind (Figure4-1). The survey was conducted by Martin Peters from Farm Works, Meredith.

The EM 38 was employed to determine both topsoil and subsoil salinity, due to the vertical and horizontal axis dipoles. This enables mapping of salt and its movement over time in the landscape (Woof, 1994). The device consists of a transmitting and receiving loop, with a coil separation of approximately one metre. The depth of the penetration of the instrument is dependent on the conductivity and separation of coils but is generally one metre below natural surface. The EM 38 has coils placed in both the vertical axis dipole position and the horizontal axis dipole position (LWA, 2007). The orientation depth for a horizontal dipole is 0.75 times the transmitter-receiver loop spacing, comparative to 1.5 times for that of the vertical dipole arrangement (Robinson et al. 2006). Nicoll et al. (1993) suggest that EM 38 apparatus generally measure the top metre or so of soil, although rock and soil below this can also influence readings. Soil properties such as moisture levels also have bearing on readings, due to the shallow operating depths of the instrument (Nicoll et al. 1993).

Figure 4-1 Geophysical Survey – Geonics EM38 device training behind a Bombardier ATV.

4.2 SOIL SAMPLING

Soil sampling was conducted at thirty randomised GPS (Global Positioning System) points over the three survey sites, using a powered hydraulic corer (Figure 4-2). Description of the soil in the field included colour, texture, organic material (i.e. roots) and soil structure, in order to classify the soil profile and distinguish between soil horizons. Refer to Appendix A for soil core descriptions. The samples were then taken for laboratory analysis of soil moisture, texture, $pH_{1:5}$, $pH_{(CaCl2)}$ and $EC_{1:5}$ and particle sizing.

Figure 4-2 Hydraulic Corer. Used to sample soil to an approximate depth of one metre.

(Coring completed by Martin Peters of Farmworks, Meredith)

5 RESULTS & DISCUSSION

The geophysical survey delineated the spatial distribution and severity of saline discharge in the near-surface environment. Mapping was calibrated with soil sampling data and corrected using an interpolation algorithm, to ensure accuracy in measurements. Results suggest similar salinity processes across sites and possible GFS associations, driving saline discharge. Surveys targeted units considered responsible to saline discharge, in the original conceptual hydrogeological model developed by Nicholson et al. (2006).

5.1 ILLABAROOK (MACKENZIE PROPERTY)

The geophysical survey of the McKenzie property at Illabarook highlighted saline discharge areas, at both the Recreation Road and Pitfield – Illabarook Road sites (Figure 5-1). Mapping determined that salinity increases with depth, particularly in discharge and drainage areas. The horizontal axis dipole determined the ECe (predicted electrical conductivity) for the top 0-30 centimetres and the vertical dipole, the top 50-80 centimetres (Figures 5-2). The data indicated that salinity (EC) and pH change with respect to depth.

Mid-slope discharge identified at the Recreation Road survey site, is believed to be influenced by underlying Deep Lead systems but does not form part of the EM38 geophysical investigation. The EM38 geophysics was designed to delineate the near-surface salinity at the site and highlight possible associations with the underlying geology. The mapping indicates that saline discharge appears to occur directly from Palaeozoic rocks and a minor increase in salinity, is observed in Neogene sediments (in the near-surface). A slight to moderate response at the boundary of the Newer Volcanics basalts and Palaeozoic sediments, is observed in data for the Illabarook – Pitfield Road site at Illabarook. The data indicates that the Neogene gravels contribute to salinity to a lesser extent than previously thought and Palaeozoic rocks are responsible for salinity.

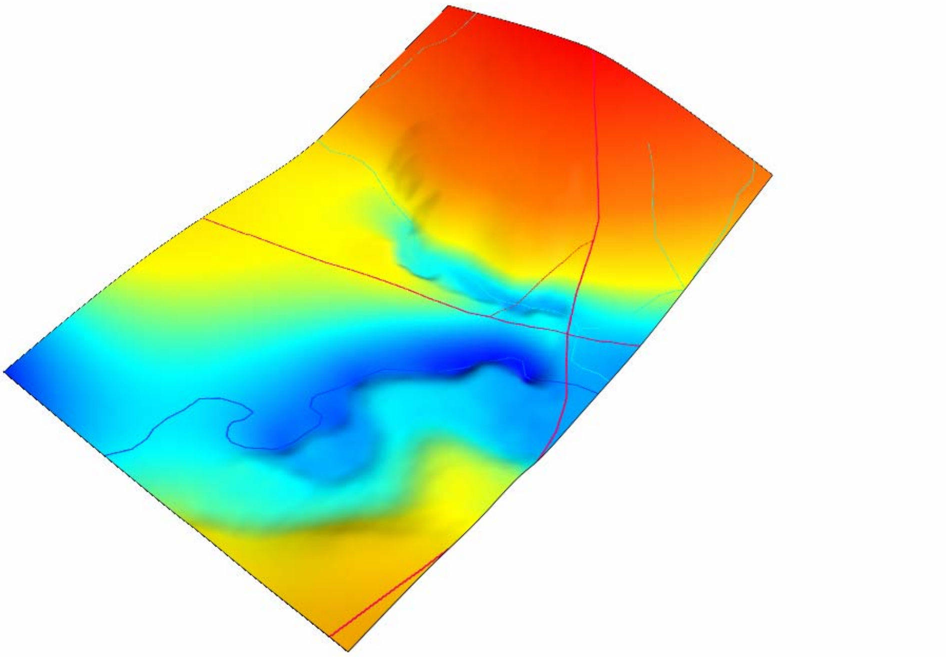

Figure 5-1 Illabarook Survey Site – DEM showing drainage areas and roads.

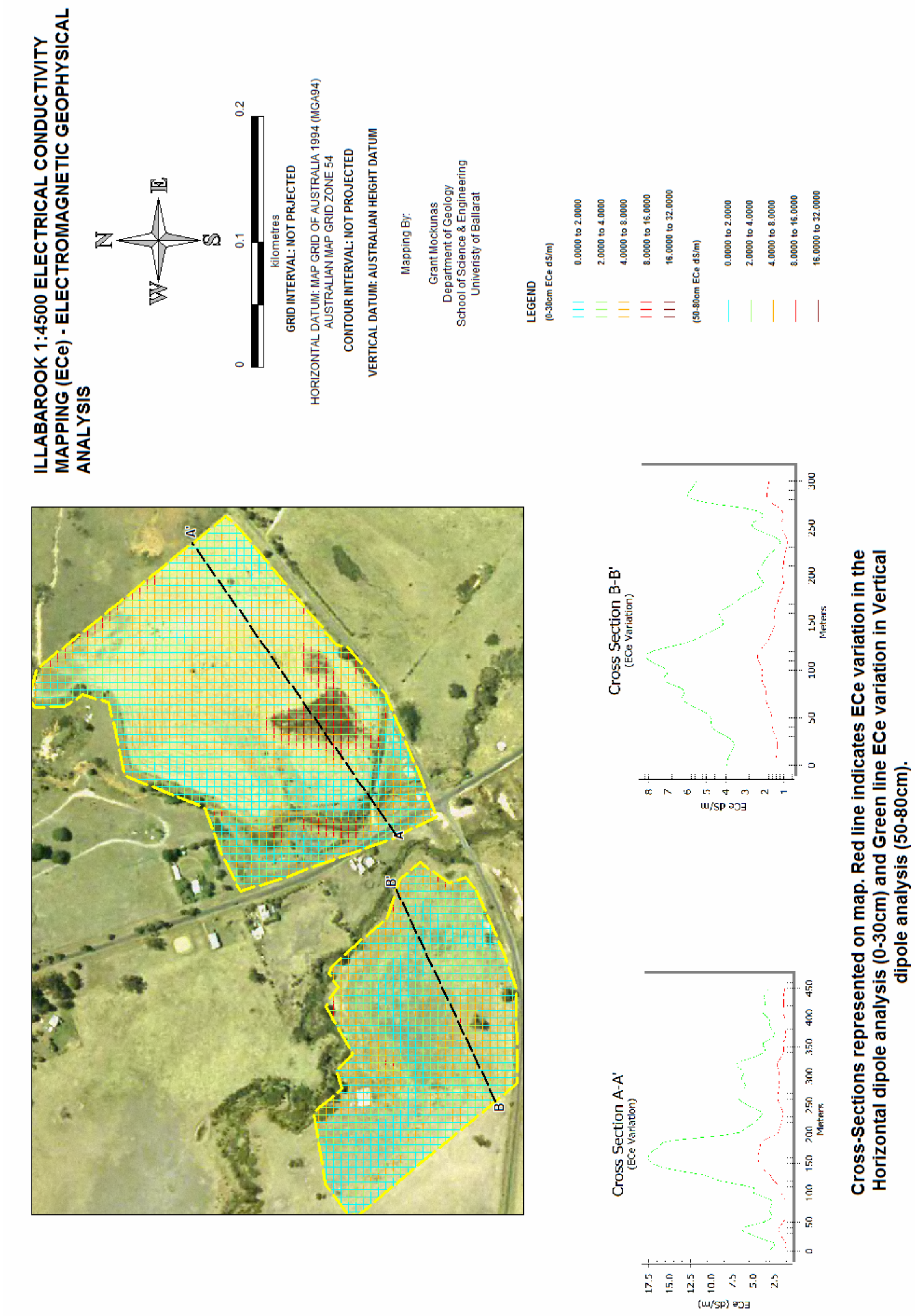

Figure 5-2 **Illabarook horizontal and vertical dipole ECe analysis.**

5.2 MOUNT MERCER SITE ONE (LAFFAN PROPERTY)

The geophysical analysis of the Laffan property at Mount Mercer, determined that near surface salinity is primarily associated with drainage areas (Figure 5-3). Similarly to the Illabarook survey site, salinity is found to increase with respect to depth (Figure 5-4). Soils were found to be slightly acid in the upper 30 centimetres of the profile but become more acid with depth. Neogene sediments which also outcrop at the site also are characterised by elevated salinity at depth but are spatially variable in severity. The Neogene gravels/sands are believed to be contributing to salt and saline discharge at the site but are not considered to be the primary source of salinity, as previously hypothesised. The ECe mapping determined that saline discharge is most probably associated with discharge occurring from Palaeozoic sediments, which underlie drainage areas.

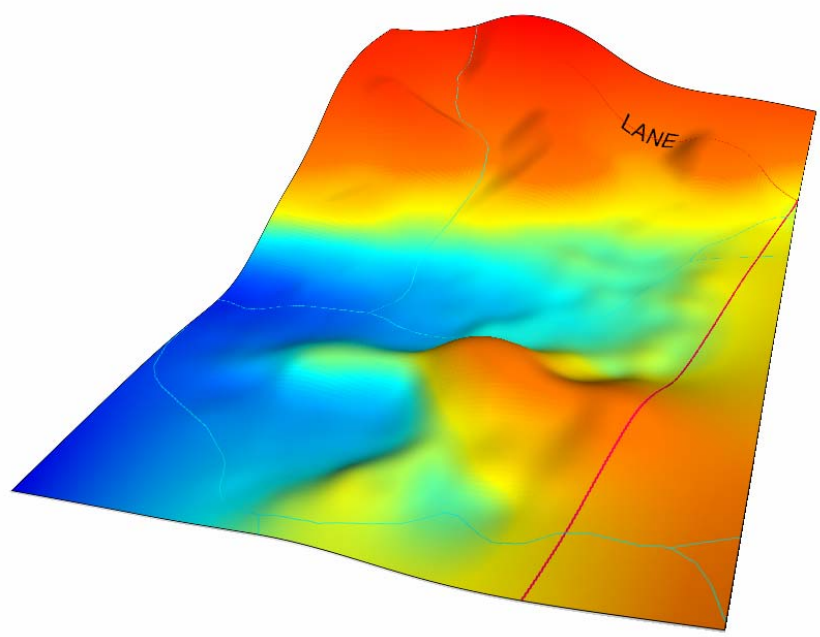

Figure 5-3 Mount Mercer Site One (Laffan Property) – DEM indicating drainage areas and major roads.

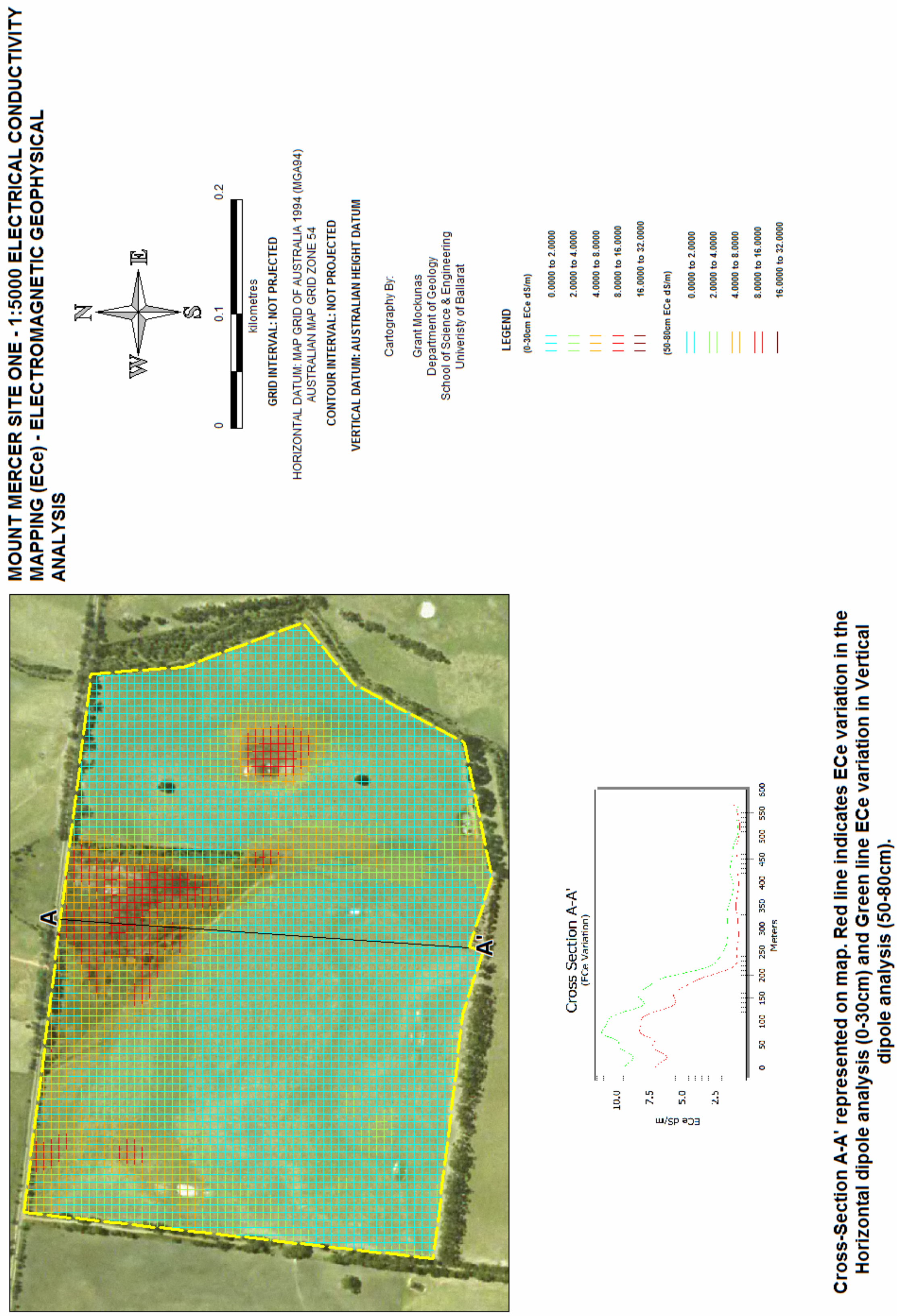

Figure 5-4 Laffan property horizontal and vertical dipole ECe analysis.

5.3 MOUNT MERCER SITE TWO (SMITH PROPERTY)

The analysis of the electrical conductivity properties at the Smith property, determined spatial variations in soil salinity across site. ECe data indicated that similarly to Mount Mercer site one and the Illabarook survey site, near-surface salinity is primarily associated with drainage areas (Figure 5-5). Figure 5-6 indicates that salinity and soil acidity increase with depth, in the near-surface.

The analysis determined that elevated ECe is most probably associated with discharge occurring from flow systems operating within the Palaeozoic bedrock. Neogene gravels/sands indicate only a slight to moderate increase in salinity at depth and are considered to contribute to a lesser extent than previously hypothesised.

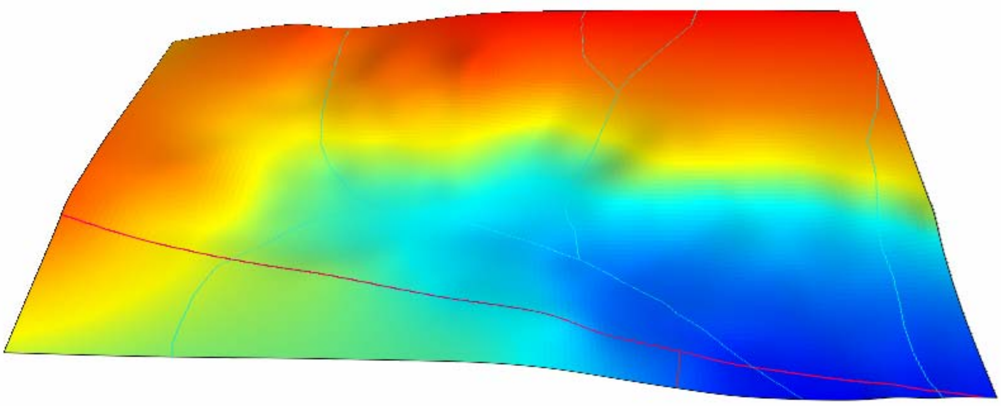

Figure 5-5 Mount Mercer Site Two – DEM model indication drainage areas and major roads.

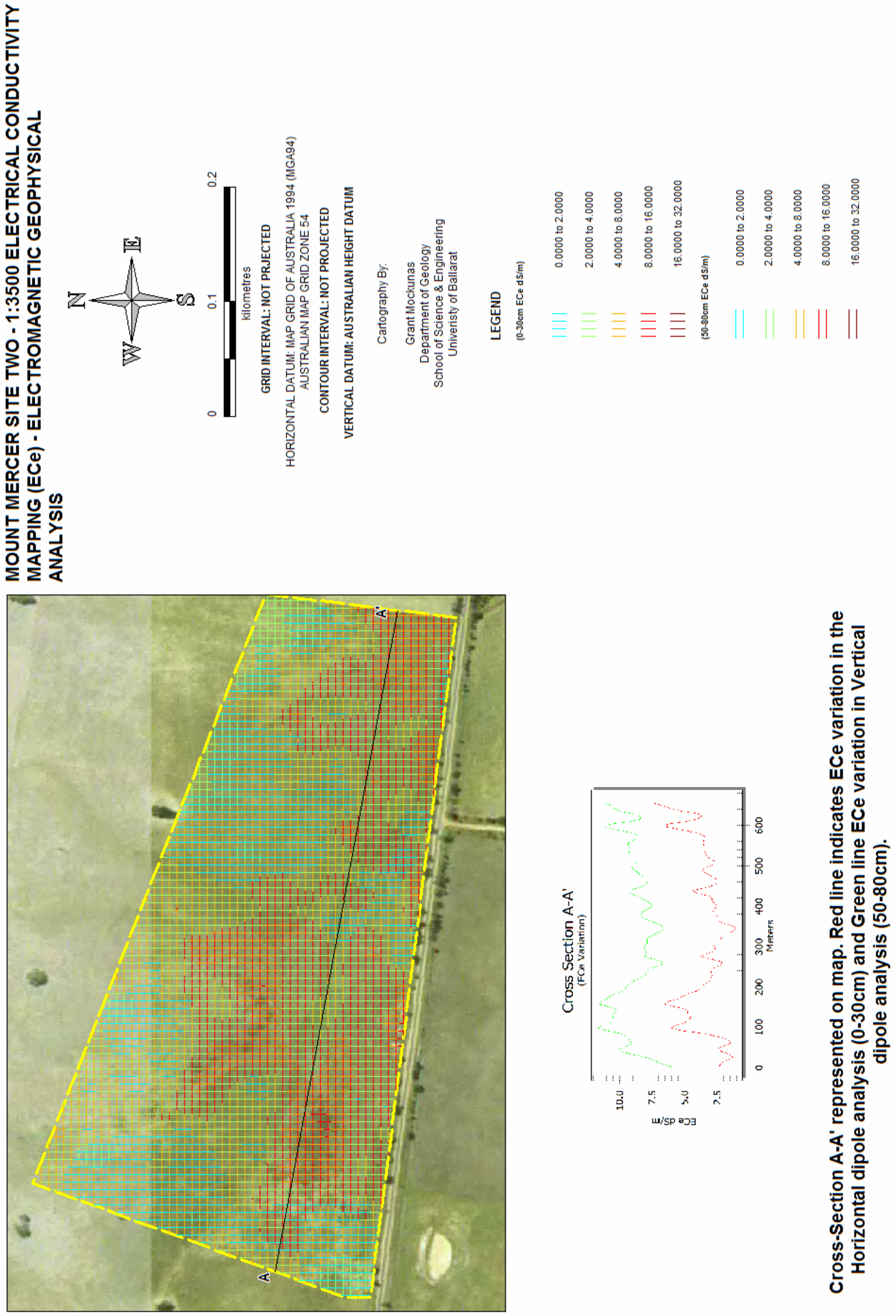

Figure 5-6 **Smith property horizontal and vertical dipole ECe analysis.**

6 CONCLUSION

The geophysical survey of the Mount Mercer and Illabarook areas using EM38 techniques, provided detailed maps of the near-surface electrical conductivity and helped define saline discharge areas. The mapping also helped determine possible GFS influencing saline discharge across sites. The following conclusions have been drawn from the results:

- Saline discharge is primarily constrained to drainage areas and appears to increase with respect to depth, but severity is spatially variable;

- The analysis of soil pH has confirmed that soils at Illabarook are characterised by a slightly acid topsoil becoming alkaline with depth in discharge areas. Mount Mercer (sites one/two) comparatively has a predominantly, slightly acid to neutral topsoil becoming more acid at depth in discharge areas;

- Mapping determined GFS discharging at drainage areas from Palaeozoic sediments, is associated with elevated soil salinity in the near-surface. For this reason, Palaeozoic GFS are considered the primary source of salt causal to salinity in the target area;

- Neogene sediments are believed to be associated with spatially variable responses in ECe values but are considered to be contributing to a lesser extent, than previously hypothesised; and

- Slight to moderate salinity appears to be associated with discharge mapped at the boundary of the Newer Volcanics basalts and the Palaeozoic bedrock at the Illabarook – Pitfield Road survey site, at Illabarook. The influence of GFS within the Newer Volcanics on salinity remains uncertain.

7 RECOMMENDATIONS

The geophysical surveys have highlighted the need for possible future research, to further understanding of salinity processes occurring in the Illabarook target area. These include:

- The EM38 mapping of saline discharge areas, considered to represent similar and dissimilar salinity processes over the greater target area;

- Further mapping of Neogene sediments (Moorabool Viaduct Formation) using EM38 techniques, to delineate spatial changes in salinity associated with the sediments;

- The application of EM31 & EM34 techniques to delineate changes in salinity to a depth of four to six metres, across the survey sites. This mapping could be extended to other regions of the target area, which are similarly to point one above, considered to represent similar and dissimilar salinity processes; and

- Detailed Total Magnetic Intensity (TMI) mapping using airborne magnetic techniques, to determine the extent of Deep Leads. This will help delineate possible intermediate and regional GFS across the target area.

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APPENDIX A

SOIL CORING LOGS

DEPARTMENT OF GEOLOGY
SCHOOL OF SCIENCE & ENGINEERING
UNIVERSITY OF BALLARAT

GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Grant Mockunas
Bachelor of Applied Science (Honours)

The proceeding are a list of thirty soil cores sampled at three specific study sites in the Illabarook Salinity Target area. Sampling was conducted on the 17/07/2007 using a hydraulic powered coring rig. Martin Peters of Farm Works conducted both the EM geophysical survey and the soil coring.

NOTE: Stratigraphic Interpretations are based on field and geological map observations.

The following legend relates to the proceeding soil logs:

SYMBOL LEGEND:

A1 Horizon

A2 Horizon

B1 Horizon

B2 Horizon

B3 Horizon

C Horizon

GEOLOGICAL LEGEND:

Qra & Qrt - Quaternary
(Alluvium: Alluvial Floodplain/ Alluvial Terrace)

Qrc - Quaternary
(Colluvium)

Tpv - Neogene
(Moorabool Viaduct Formation)

Oll - Ordovician
(Castlemaine Group - Lancefieldian)

Qvn2 - Tertiary: Neogene/ Quaternary
(Newer Volcanics: Sheet & Valley Flow Basalts)

	DEPARTMENT OF GEOLOGY SCHOOL OF SCIENCE & ENGINEERING UNIVERSITY OF BALLARAT *GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS*	Core Number: RE1

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Colin McKenzie)
Coordinates: 733198E 5810283N

Location: Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Dark brown colour; silty texture; organic matter (roots); grades into A2 horizon; consolidated.	
35				Mottled (dark brown/ red) colour; gravel and lithic fragments (ferruginised and subrounded) with some sand and silt; organic material (roots); grades into B1 horizon; loosely consolidated.	Gravel is probably indicative of Neogene gravel cap.
70	40-			Mottled (yellow-brown/ orange-brown) colour; clayey texture; no organic matter; strongly consolidated; sticky.	

DEPARTMENT OF GEOLOGY
SCHOOL OF SCIENCE & ENGINEERING
UNIVERSITY OF BALLARAT
GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **RE2**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	733090E 5810380N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10	-20			Dark brown colour; silty texture; organic material (roots); grades into B1 horizon.	
60				Mottled (yellow/ orange-brown) colour; clay texture; Peds (<10mm); gravel at base of B1; organic material (roots); sharp boundary with B2 horizon; consolidated.	Gravel is probably that of the Neogene gravel cap.
80	50-			Mottled (white/ yellow orange-brown) colour; clay texture - gravel at top; no organic matter; consolidated.	

DEPARTMENT OF GEOLOGY
SCHOOL OF SCIENCE & ENGINEERING
UNIVERSITY OF BALLARAT
GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **RE3**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	733089E 5810247N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Brown colour; silty sand texture; organic matter (roots); gradual boundary between A1 & A2 horizons; loosely consolidated.	
30				Dark brown colour; gravel/sandy silt texture; organic material (roots); gradual boundary between A2 & B1 horizons; moderately consolidated.	Neogene gravel/sand.
80	40-			Mottled (red/yellow/orange-brown) colour; clayey texture; no organic matter; consolidated.	

DEPARTMENT OF GEOLOGY SCHOOL OF SCIENCE & ENGINEERING UNIVERSITY OF BALLARAT *GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS*	Core Number: **RE4**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732951E 5810371N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20				Dark brown colour; organic matter (roots); silty; grades into B1 horizon; consolidated.	
25	-30			Yellow/brown colour; clay texture; roots; grades into B2 ; consolidated.	
40				Brown colour; gravely sand texture with minor quartz fragments; no organic material; grades into B3 horizon.	Gravel is probably related to mining here, rather than gravel cap (given its nature).
80				Mottled (Yellow/orange-brown); clayey; no gravel; no organic matter; consolidated.	
90	50-			Mottled (yellow/orange- brown) colour; Palaeozoic bedrock - shale; no organic matter; unconsolidated.	

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Core Number: **RE5**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Colin McKenzie)
Coordinates: 732993E 5810174N

Location: Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
15	-20			Dark brown colour; silt/sand; organic material (roots); grades into B1; consolidated.	
40				Mottled (grey/orange-brown/red); clay, some sand/gravel between 15 - 20cm; organic matter (roots); grades into B2; consolidated.	
60				Mottled (yellow/orange-brown); clay; grades to an abrupt C boundary; some organic matter (roots); consolidated.	
80	50-			White/yellow/orange; weathered bedrock - Palaeozoic (Ordovician) shale; unconsolidated.	The regolith is particularly shallow, similar to RE4.

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Core Number: **RE6**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732856E 5810267N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
35	-30			Dark brown; silty/sand; organic matter (roots); grades into A2 horizon; consolidated material.	Due to the nature of the soil and the nature of lithic fragments obtained in the core coupled with a site overview, it was established that the site was probably influenced by past mining and it was most probable, the soil profile developed post-mining.
65				Light brown/grey; silt/sand/gravel; some lithic fragments; no organic matter; grades into B1 horizon; consolidated.	
80	50-			Mottled (yellow/orange-brown/red); clay; no organic matter; consolidated.	

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Core Number: **RW7**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732443E 5810201N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10	-30			Dark brown; silty; organic matter (roots); grades into A2; consolidated.	
80				Light grey/brown; sandy texture; lithic fragments (quartz); sharp boundary between A2 and B1; unconsolidated.	Gravel cap is not evident comparative to recreation road. There is no ferruginous material evident in the soil profile.
110	50-80			Yellow brown; sand; unconsolidated.	

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Core Number: **RW8**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732552E 5810083N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20				Dark brown; sandy/silty; organic material (roots); gradational boundary with A2; loosely consolidated.	
45	-30			Light brown; silty/sand; organic material (roots); gradational boundary with B1; unconsolidated.	This layer was waterlogged (very moist, free water).
100	60-90			Mottled (Yellow/ orange-brown); silty/sand and some clay; organic material (roots); consolidated.	

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Core Number: **RW9**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732622E 5810020N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10				Dark brown; silt/sand; organic material (roots); gradational with A2 horizon; loosely consolidated.	
20	-20			Brown/grey; silt/sand; organic material (roots); gradational with B1 horizon; consolidated.	
80	45-80			Mottled (yellow-brown/grey/red); clay; organic material (roots); consolidated.	

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Core Number: **RW10**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Colin McKenzie)
Coordinates: 732581E 5810178N

Location: Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
15				Dark brown; silty; organic material (roots); grades into A2 horizon; moderately consolidated.	
23	-23			Light brown; silty; organic material (roots); grades in B1; consolidated.	
110	50-90			Mottled (yellow/orange-brown/grey); clay; organic material (roots - to depth of 70cm); abrupt boundary with C horizon; consolidated.	
130				Grey colour; gravely - sand, silt, gravel; no organic material; loosely consolidated.	Gravel material may represent Neogene gravels but most probably alluvial material or remnant mining material (not rounded).

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Core Number: **RW11**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Colin McKenzie)
Coordinates: 732671E 5810191N
Location: Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
35	-30			Dark brown; silty; organic material (roots); grades into B1 horizon; moderately consolidated.	
80	50-80			Mottled (Yellow/orange-brown); silt/clay - some lithic fragments (quartz); organic material (roots - to depth of 80 cm); consolidated.	

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Core Number: **RW12**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Colin McKenzie)
Coordinates:	732737E 5810101N
Location:	Recreation Road, Illabarook. Victoria.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
25				Dark brown; silty; organic material (roots); grates into A2 horizon; moderately consolidated.	
50	-30			Light brown; Gravel/sand/silt; organic material (roots); abrupt boundary with B1 horizon; not consolidated.	The A2 horizon was waterlogged. The silty/sandy material was not consolidated.
80	50-80			Mottled (grey/brown); sand/silt/clay; no organic matter; consolidated.	This horizon was much dryer and denser, than the above waterlogged layer.

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **BS1**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Blue Smith)
Coordinates: 748802E 58122109N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20				Dark brown; silt; organic matter (roots - strong root structure); gradational boundary with A2; consolidated.	
40	-20			Light brown; organic matter (roots - less than A1); gradational boundary with B1; unconsolidated.	Sloppy, waterlogged unit.
100	50-80			Mottled (yellow/orange-brown/grey); clay - sticky; some organic matter (roots); consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **BS2**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Blue Smith)
Coordinates: 748414E 58112223N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
30	-20			Dark brown; silty; organic material (roots); moderate to abrupt boundary with B1; consolidated.	Water in paddock. Water pooling on surface and soils waterlogged in areas.
80	50-80			Mottled (Yellow/grey/brown); clay; organic matter (roots - to 50cm depth); consolidated.	

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Blue Smith)
Coordinates:	748556E 5812236N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10				Dark brown; silt; organic matter (roots); gradational with A2; consolidated.	Both A1 and A2 waterlogged to a degree.
40	-20			Grey-brown colour; silt; organic material (roots); gradational with B1; consolidated.	
80	50-80			Mottled (Yellow/grey/red); clay; organic material (roots - to 60cm); consolidated.	

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Blue Smith)
Coordinates:	748941E 5812204N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
45	-20			Dark brown; silt; organic matter (roots - strong root structure); gradational boundary with B2; consolidated.	
100	50-80			Mottled (Yellow/grey); clay; organic matter (roots); consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **BS5**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Blue Smith)
Coordinates: 748728E 5812285N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
15				Dark brown; silt; organic material (roots); abrupt boundary with A2 horizon; consolidated.	
25	-25			Brown; silt - buckshot/gravel; organic material (roots); abrupt boundary with B1; loosely consolidated.	Assumed to be Neogene gravels (not mapped).
100	60-100			Mottled (Yellow/grey/red-ochre); clay; little or no organic material; consolidated.	

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Blue Smith)
Coordinates:	748424E 5812444N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
30	-20			Dark brown; silt; organic matter (forming roots to 30cm depth and topsoil); gradational boundary with B1; consolidated.	
80	50-80			Mottled (grey/brown); clay; no organic matter visible; consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **LW1**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	748758E 5811995N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Dark brown; silt/sand; organic material (roots); grades into the A2 horizon; moderately consolidated.	
40				Mottled (yellow/grey); silt and minor sand; organic material (roots); grades into B1 horizon; consolidated.	
100	50-80			Mottled (orange-brown/yellow/red); clay; organic material still present (roots - less structured than A1 and A2 horizons); consolidated.	

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Core Number: **LW2**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	748672E 5811530N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
15	-15			Dark brown; silt/sand; organic material (roots - strong root structure); grades into A2 horizon; consolidated.	
30				Dark brown; gravel/sand; organic material (roots - strong root structure); grades into B1 horizon; unconsolidated to loosely consolidated.	The gravel was assumed to be remnant gravel cap material, previously mapped.
50	30-50			Mottled (orange-brown/ yellow/grey); clay texture, no gravel material; consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **LW3**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Daniel Laffan)
Coordinates: 748801E 5811731N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-30			Dark brown; silty/sand; organic matter (roots - structured); grades into A2 horizon; consolidated.	
40				Light brown; silty; organic matter (roots - structured); grades into B1 horizon.	
100	60-100			Mottled (yellow/orange-brown); clay material; organic matter (roots - less structured than A1 & A2 but present); consolidated.	Most probable given location that this site is still on Neogene gravel cap, although no gravel was observed in the soil core.

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **LW4**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	748959E 5811924N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
18	-20			Dark brown; sand/silt texture; organic material (roots - strong root structure); gradational with A2 horizon; consolidated.	Gravel possibly remnants of Neogene gravel cap, although the unit is not mapped to this extent. However, gravel was sub-rounded and indicates some form of transport. Gravel was composed of quartz fragments and other minor lithic material.
30				Grey colour; sand/silt texture with minor gravel (between 25-30cm); organic material (roots); grates into B1 horizon; loosley consolidated.	
80	50-80			Mottled (yellow/grey/orange-brown); clay texture; some organic matter (minor roots); consolidated.	

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Core Number: **LW5**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Daniel Laffan)
Coordinates: 748935E 5811481N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Dark brown; silty texture; organic material (roots - structured); gradational with A2 horizon; consolidated.	
45				Grey-brown colour; silty/sand texture - minor gravel (between 35-45cm) composed of sub-rounded to rounded quartz and lithic fragments; organic material (roots - strucutred); gradational with B1 horizon; consolidated to loosely consolidated.	Minor gravel is most probably associated with Neogene gravel cap.
80	50-80			Mottled (grey/orange-brown/ yellow); clay texture; organic material (roots - good structure); consolidated.	

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749075E 5811731N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Dark brown; silty texture; organic material (roots - good structure); grades into A2 horizon; moderately consolidated.	
45				Brown; silty texture; organic material (roots - structured); grades into B1 horizon; moderately consolidated.	
80	50-80			Mottled (orange-brown/red); clay/silt texture with minor gravel (between 55-60cm) composed of subrounded and lithic fragments; consolidated.	Minor gravel in this locality is believed to be associated with alluvium and possibly colluvium. The Neogene gravel cap is not believed to extend to the flat area.

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Core Number: **LE7**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749219E 5811521N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-20			Dark brown; silty texture; organic material (roots - good structure); grades into A2 horizon; moderately consolidated.	
55				Grey/yellow-brown colour; silty texture with minor gravel (between 45-55cm) compsed of subrounded quartz and lithic fragments; organic matter (roots - structured); the boundary between the gravel and the B1 horizon is abrupt; moderately to loosely consolidated.	Gravels similar to site LW6 are assumed to be of alluvial or colluvial origin and are not indicative of the Neogene gravel cap.
80	55-80			Mottled (orange-brown/yellow); clay texture with some more resistant, subrounded to rounded quartz fragments; organic material (roots - minor); consolidated.	

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Core Number: **LE8**

Project: Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client: University of Ballarat
Site: Private (Daniel Laffan)
Coordinates: 749141E 5811917N

Location: Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10				Dark brown; silty texture; organic material (roots - structured); grades into A2 horizon; consolidated.	
40	-20			Grey colour; silty clay texture with minor sand; organic matter (roots - to 40cm depth); grades into B1 horizon; consolidated.	
80	50-80			Mottled (Yellow/orange-brown); clay texture; no organic material discernable; consolidated.	Quite moist clay. Had to use a hand auger due to boggy nature of site. After auguring, water had risen in the hole to within 10cm of the surface.

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749271E 5811798N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:

Contractor: Martin Peters - Farm Works

Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20	-25			Dark brown colour; silty sand texture; organic material (roots - structured); sharp boundary with B1; loosely consolidated.	
65	40-65			Yellow-orange colour; silty sand; organic material (roots - to depth of 35cm); strongly consolidated.	Material was well drained and quite hard.

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Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749367E 5811657N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
10				Dark brown colour; silty texture; organic material (roots); grades into A2; moderately consolidated.	
25	-25			Grey colour; sandy silt texture with some minor gravel (between 20-25cm) composed of subrounded quartz and lithic fragments; organic material (roots); grades into B1 horizon; poorly consolidated.	The A2 horizon was waterlogged.
60	40-60			Mottled (Dark brown/ yellow/orange-brown) colour; clay texture; little organic matter (roots); consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **LE11**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749369E 5811505N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20				Dark brown colour; silty texture; organic material (roots - structured); gradational boundary with A2; consolidated.	
40	-25			Grey colour; silty texture; organic matter (roots - structured); gradational with B1 horizon; consolidated.	
60				Mottled (yellow/grey) colour; clay texture; organic material (roots - minor); sharp boundary with B2 horizon; consolidated.	
80	50-80			Mottled (brown/yellow-brown) colour; clay texture with some minor subrounded quartz fragments; consolidated.	

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GEOPHYSICAL SURVEY - SOIL CORE DESCRIPTIONS

Core Number: **LE12**

Project:	Hydrogeology & Salinity Processes in the Mount Mercer - Illabarook Area
Client:	University of Ballarat
Site:	Private (Daniel Laffan)
Coordinates:	749468E 5811705N
Location:	Dereel - Mount Mercer Road, Mount Mercer.

Contractor Details:
Contractor: Martin Peters - Farm Works
Equipment: EM-38 (Horizontal and Vertical Dipoles)

Depth (Centimetres - cm)	Sampled (Depth - cm)	Stratigraphic Interpretation	Graphic Log	Description (Horizon, Texture, Colour, Structure, Horizontal Boundary, Plant Material and Minor Components)	Remarks
20				Dark brown colour; sandy texture; organic material (roots - well structured); grades into A2 horizon; poorly consolidated.	
45	-25			Yellow-brown colour; sandy texture; organic material (roots -minor); grades into B1 horizon; unconsolidated.	
80	50-80			Mottled (yellow/orange-brown) colour; sandy clay texture; no organic matter discernable; strongly consolidated.	This unit was very hard and appeared to have densely packed grains. The unit also appeared to have a low porosity and was distinctly dryer than the above A1 and A2 horizons.