Characterisation of Saline Land in the Woady Yaloak Catchment, Victoria

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Abstract

Sustainable Grazing of Saline Lands (SGSL) a nation-wide project which aims for sustainable agricultural production from saline land. In conjunction with the Corangamite Catchment Management Authority (CCMA), and the Woady Yaloak Catchment Group (WYCG) three sites in the Woady Yaloak catchment have been chosen as SGSL sites investigated in this research. Characterisation of saline land to benchmark the condition of soils, streams, vegetation and groundwater, has been undertaken, and methods developed to record the changes to the sites resulting from changed land-use.

Characterisation of saline land has involved collecting soil samples to analyse soil profile, electrical conductivity (EC), pH, cation exchange capacity (CEC); carrying out a vegetation survey to assess the severity of salinisation; and conducting a geophysical survey to see where salinity occurs. Monitoring has involved testing surface water and groundwater for EC and pH; photograph point monitoring; and repeat soil and geophysical surveys.

All three sites at Mt Mercer, Illabarook and Pittong have been found to be highly saline with sodic duplex soils, saline indicator plants, and saline surface water and groundwater. The geophysical surveys have pin-pointed high concentrations of salt at each site which are related to the vegetation. Recommendations are made on the parameters to monitor and the monitoring frequency for each site.

Declaration

I hereby certify that the research within this thesis is entirely my own work unless otherwise stated. This work has not previously been submitted in part or whole for another degree or at another institution.

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Kane A. Church 2004

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1.0 Introduction

Dryland salinity has been acknowledged by the Australian government as being a major environmental problem since the 1950's. Many projects have been conducted within Victoria to rehabilitate saline affected areas. Sustainable Grazing of Saline Lands (SGSL) is a nation-wide research project, sponsored by Land and Water Australia, which aims for sustainable productive use from saline land. Sites have been chosen and investigated to benchmark the environmental condition of the sites and a monitoring program has been designed and implemented to ensure on-going monitoring of soils, surface water, vegetation and groundwater, which will record the changes to the sites resulting from changed land-use.

Three SGSL sites have been chosen in the Woady Yaloak Catchment which lie within target areas for salinity management in the Corangamite Salinity Action Plan (SAP) of the Corangamite Catchment Management Authority (CCMA). The salinity target areas have been chosen because of the increasing salinity in the Woady Yaloak River. Management actions have been developed in the target areas to try and reduce the increasing salinity in the river.

The three SGSL sites have been developed to be CCMA catchment health sites to monitor salinity changes in the Woady Yaloak River over time from the land-use changes implemented on the three sites.

1.1 Location

The study areas are situated at Mt Mercer, Illabarook and Pittong. Mt Mercer is situated 30 kilometres south of Ballarat; Illabarook is 40 kilometres SSW and Pittong 60 kilometres south west of Ballarat (Figure 1). Each site is approximately five hectares in size.

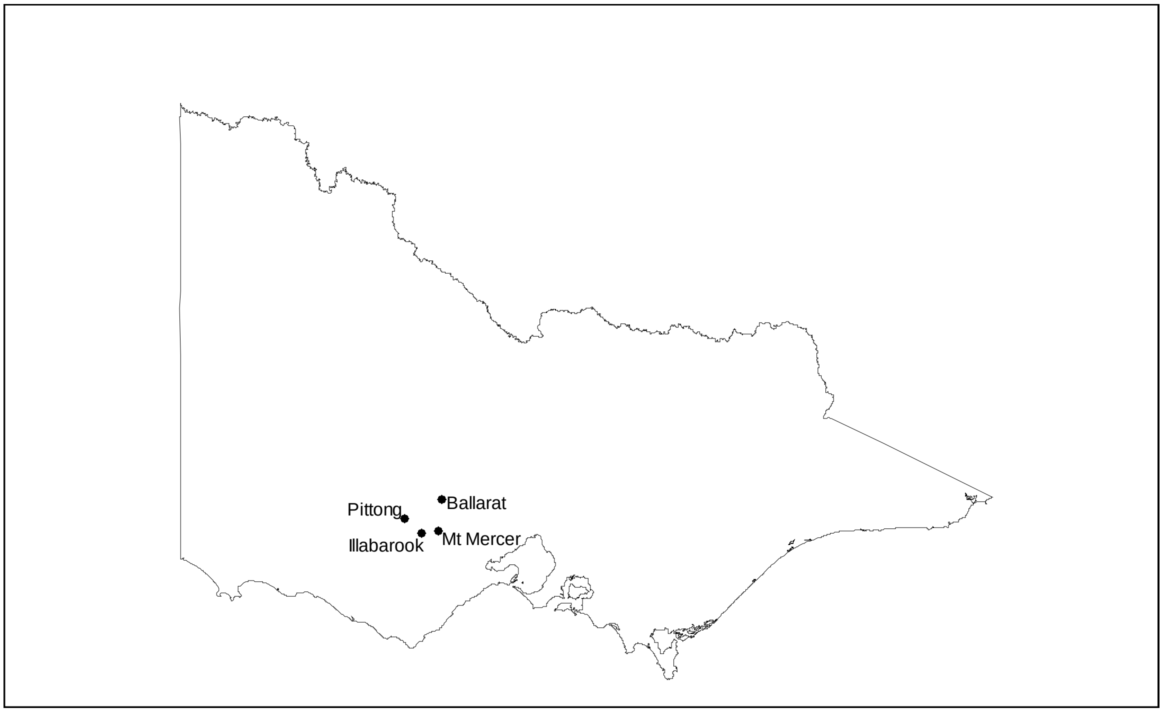


Figure 1 Location of the three Sites in Victoria

1.2 Aims

The aims of this investigation include:

- Characterising the soils, vegetation, surface water and groundwater at each site.
- Develop geological and groundwater models to understand the salt process at each site.
- Develop a monitoring program which can be used to evaluate changes to the environment, particularly the salinity of the Woady Yaloak River.

2.0 Characterisation of Saline Lands

Characterising the health of a saline site involves assessing soil, water (both surface and ground water) and vegetation health, just to name a few. The health of a saline site is continuously changing with the changes to the bio-physical environment, both annually and seasonally. A saline site is characterised to asses an area and to provide a basis for the monitoring that should take place to observe any changes in environmental health of the saline site over time.

Targets are certain goals, set to be achieved over a certain time. Targets are set by protocols of the National Framework for Natural Resource Management (NRM) Standards and Targets. A minimum set of protocol matters for which targets must be set have been devised. These are the area of land threatened by shallow or rising saline water tables, extent of native vegetation, surface water salinity, sediment/suspended solids, nutrients, river health, water allocation plan, extent of critical asset identified and protected from salinity and degrading water quality all must come into consideration when setting targets (NAP, 2003).

Aspirational, Resource Condition, and Management Action are all targets. Aspirational Targets are set to be achieved over the longer term (50^{+} years) and are intended to guide regional planning (Dahlhaus, *et al.*, 2003). Resource Condition Targets are specific, time-bound (usually 10 to 20 years) and measurable and must be pragmatic and achievable, and relate to the resource condition. For example, average salinity of X EC units at a specific end-of-valley site Y by year Z. Management Action Targets are short term (1 to 5 years) and relate to management actions to help achieve Resource Condition Targets. For example, X hectares of discharge areas within region Y to be revegetated by year Z.

Monitoring of targets is extremely important as it indicates that the chosen targets are reliable. Monitoring of Aspiration targets, which is carried out annually assesses the entire range of parameters of the resource condition and management action targets. The assessment confirms the status of achieving the Aspiration target. If the status of achieving the Aspiration target isn't on track, the resource condition and management action targets can be changed to ensure the Aspiration target is met (NAP, 2003)

2.1 Physical Characterisation

2.1.1 Texture

Soil texture is assed manually and describes the physical constituents of the soil in terms of the particle size (eg. Sandy clay, Silty clay loam, etc.). A description of how this is achieved is given in Appendix A. Monitoring soil texture indicates changes to soil structure and composition through erosion (loss of fine material), tillage and drainage which can have major affects on saline soil.

2.1.2 Colour

Colour is analysed by matching fresh soil to colour chips of the Munsell Soil Colour Chart, which is given semi-quantitative notation (eg. 7.5YR 4/3 (dark brown)) (McTainsh and Boughton, 1993). Monitoring of soil colour determines the type of drainage patterns occurring and identifies whether soil has been waterlogged, in a wet-dry cycle or in a well drained environment (Clarkson, 2003). Colour is strongly influenced by the drainage conditions of the soil. Well drained soils are red as the soil is well oxygenated implying that iron is in its ferric form, waterlogged soils can be light to dark grey as they are in a reducing environment causing iron to be in its ferrous form (McTainsh & Boughton, 1993). Mottling occurs by periodic waterlogging of the soil which causes oxidising and reducing conditions to occur, having both iron forms present to produce the mottling affect (McTainsh and Boughton, 1993). Soil colour is important in characterising a saline site as it show whether the site has been water logged or in a wet dry cycle.

2.1.3 Profile

A soil profile refers to a vertical section through a soil from the soil surface through all horizons to parent material. Horizons are layers of approximately parallel soil to the land surface, with morphological properties different from layers above and below (McDonald *et al*., 1990). Characterising and monitoring the soil profile shows changes in soil horizons, structure, porosity, colour, texture and vegetation through erosion (loss of fine material), tillage and drainage, which has major implications on saline affected areas.

2.1.4 Structure
Structure refers to the distinctness, size and shape of peds with in a soil. Peds are small individual aggregates of soil which form around roots of plants and describe the structure of soil (McDonald *et al.*, 1990). Peds can be blocky, angular, platy and prismatic. Monitoring structure indicates changes in water movement, aeration, and porosity of the soil, which affects the soil in a way which may make it erode, especially in sodic soils.

2.1.5 Porosity
Porosity is the amount of air or water filled pores in a soil. Monitoring porosity indicates the amount of compaction which affects oxygenation, infiltration and drainage rates, which has major implications on saline areas (Gunn *et al.*, 1988).

2.2 Chemical Characterisation

2.2.1 pH
pH refers to the amount of hydrogen ions in the soil, which determines whether a soil is basic or acidic. Monitoring pH is useful as it shows the severity of pH in the soil, which affects plant growth and cation exchange reactions, which have affects which lead to the deterioration of land (Rowell, 1994).

2.2.2 Electrical Conductivity (EC)
EC is a measure of how much salt is within a soil. The amount of salt in soil also affects plant growth, cation exchange reactions and soil structure. Monitoring EC is valuable as it shows where high values of salt occur, allowing the appropriate action to be engaged to counteract the salinity in the soil.

2.2.3 Cation Exchange Capacity (CEC)
CEC is the measure of different cations and anions present in soil (eg magnesium, sodium, potassium and nitrogen). An imbalance of ions may indicate that plant growth and soil structure are under threat. Monitoring CEC allows the ion balance to be analysed and management options to be implemented to restore a balance in soil chemistry for optimum vegetation growth. It also shows the Exchangeable Sodium Potential (ESP), which in well balanced soils is less than 6% (SWEP, 2004). ESP is usually higher than 6% in saline areas, which makes the soil prone to erosion.

2.3 Biological Characterisation

Biological indicators measure the amount of biomass within the soil which include bacteria, worms and micro organisms which help the plant obtain nutrients to survive. Monitoring biomass is valuable as it reflects changes in the ecosystem. Biomass regulates the decomposition of organic residues, cycles nutrients, degrades chemical pollutants and influences soil structure, which is very important in reducing saline areas (Walker & Reuter, 1996).

2.4 Water Health Indicators

Water health indicators provide information about the quality of surface water and groundwater, which is often related to the health of catchments.

2.4.1 Flow

Flow of water indicates the volume of water flowing down a creek over a period of time. Flow is vital in sustaining the health of the waters and rivers upon which ecosystems and humans depend. Flow is measured in megalitres per day (Ml/day) (SRW, 2004). Monitoring the timing, volume and duration of flows indicates interactions between catchment, floodplain, wetland, groundwater and stream (DEH, 2004). Monitoring the flow of water off a saline site may indicate the amount of salt washing down the system from the soil and groundwater.

2.4.2 Temperature

Temperature of water in streams and rivers generally varies from 0 to 30 degrees. Temperature of water affects some of the important physical and chemical characteristics of water, for instance density, viscosity, salinity, and dissolvable gasses (Mays, 1996). These all have implication on vegetation and aquatic life. Monitoring is there for crucial to assess water health, to see affects on vegetation and aquatic life on a saline area.

2.4.3 Electrical Conductivity (EC)

Electrical Conductivity (EC) is used as a surrogate measure of salinity, which has implications associated with it like plant growth and soil structure. EC is the ability of water to conduct an electrical current which measures the ion concentration of water. The more ions present in the water the more conductive the water becomes. EC is usually measured in micro siemens per centimetre (μS/cm) at 25 degrees Celsius (Bordin, 1996). Monitoring of EC is valuable as it shows the level of salt in surface and groundwater over time, which helps find the source of the salt and changes in salt storages in a saline area.

2.4.4 Turbidity

Turbidity is measured using the light-transmitting properties of water and is measured in Nephelometric Turbidity Units (NTU). Turbidity is an indication of how much suspended material is present in water, which may carry micro-organisms, viruses and bacteria, which may be harmful to humans and other animals (Mays, 1996). Monitoring turbidity generally indicates the amount of erosion occurring in a landscape, as the more suspended material present in the water the higher the turbidity reading, which indicates more erosion occurring in the landscape. Turbid water may also be due to suspended organic matter, chemical contamination or immiscible fluids such as hydrocarbons. Monitoring turbidity of water washing off a saline area may indicate poor soil structure as if the water is turbid erosion will most likely be occurring.

2.4.5 Colour

Colour is primarily an aesthetic indicator, as if the water is coloured (eg. Brown) it gives the appearance of being unfit for human consumption (Mays, 1996). Colour can also indicate the presence of organic substances, hazardous or toxic, such as blue-green algae (Mays, 1996). Monitoring of colour indicates changes in vegetation and any pollutants occurring in the system.

2.4.6 pH

pH is the measure of how many hydrogen ions are present in water, or whether the water is acidic or basic, which has implications on the solubility and availability of nutrients, and how they can be acquired by aquatic organisms (Bordin, 1996). Monitoring pH is important as it can affect organism’s growth and presence. Low pH (acid) waters can be toxic to many fish.

2.4.7 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of how much oxygen is dissolved in water and is measured in milligrams per litre (mg/L) (Bordin, 1996). DO is important in the survival of aquatic organisms (If DO becomes low the majority of aquatic life is unable to survive). DO has a relationship to temperature, turbidity and pH of the water. Monitoring of DO is important as it shows the amount of oxygen available in water for aquatic organisms.

2.4.8 Detailed Chemistry

Detailed chemistry is done on water to analyse the major anions, cations and nutrients in the water which affect plants and aquatic life (Bordin, 1996). Monitoring of water chemistry indicates changes in composition which may affect erosion rates, aquatic organisms and vegetation on saline areas.

2.5 Vegetation Health

Salt-tolerant species can be used to asses the level of salinity at a site. Matters 1987 classified a number salt-sensitive (glycophytic) and salt-tolerant (halophytic) plant species in Victoria, which are commonly used for mapping saline sites (Allan, 1996). The salt-tolerant plant species are divided into obligate halophytes (species that require salt for growth) and facultative halophytes (species which grow in both saline and non-saline areas) (Allan, 1996). The most common obligate halophyte plant species include Beaded Glasswort, Water Buttons and Streaked Arrow Grass and facultative halophyte plant species include Spiny Rush, Sea Barley Grass and Bucks Horn Plantain (Allan, 1996). Halophytic plant species are native or introduced. Three soil classes have been developed from plant classifications, based on standards developed by the United States Department of Agriculture (Allan, 1996). The soil classes range from slight (class 1) to extreme (class 3) and can be found in Matters and Bozon (1995). Monitoring vegetation is useful as it indicates the severity and area of saline affected land.

2.6 Planning

First the reason why the characterisation of the saline area is required must be identified. Once the problem has been identified, indicators will be chosen to assess the problem and to make sure the site is characterised properly. Indicators are important as the data collected may be used in the future to assess the condition of the catchment. A field sampling and laboratory program will be implemented to assure the catchment is being monitored sufficiently. Data from the monitoring program will be interpreted and reported. Factors which are also included in a characterisation study are climate, history, geology, hydrology, evolution and stratigraphy. After all of the planning is carried out the site should be characterised with maps and models of what is occurring at the site.

2.7 Case Studies

2.7.1 DPI State Monitoring Sites

Monitoring of dryland (non-irrigated) salinity has taken place since the 1950's when dryland salinity was acknowledged as being a major environmental problem. Government agencies began assessing the magnitude of the problem and found it to be varied from site to site. From this a project was funded by the National Soil Conservation Project to develop a standard method for identifying, assessing and recording salinity (DPI, 2004).

2.7.1.1 Site Selection

Site selection is granted after consultation between hydrogeologist, DPI field staff, landholder groups, individuals and the Salinity Monitoring Project Officer. Sites are placed in environmentally sensitive areas and can be used to monitor change in the extent and severity of saline areas within a catchment (DPI, 2004). Paired sites are also used to assess the effectiveness of preferred salinity control options within a catchment. One site is placed where the recharge or discharge zones have been treated and a second control site is place where recharge or discharge zones haven't been treated to observe changes. It is important to pick sites which are comparable in all other aspects (DPI, 2004)

2.7.1.2 Characterisation

Geology is determined by discussion with a hydrogeologist with reference to any available geological maps. The Bureau of Meteorology can supply the climate data needed as they have several reliable sites across the state collecting data. Site history, land use and management is collected from the landholder to certify any changes and impacts they may have on the site. A visual record is kept by photographing the landscape from known points, so photographs can be repeated over time, dominant vegetation species are also photographed at the site.

Mapping of the site selected involves a vegetation assessment, a quick and accurate method using salt-tolerant species used to assess the level of salinity at a site. An electromagnetic induction survey (EMI) using an EM38 instrument is also carried out, which calculates the apparent electrical conductivity of the soil at different depths. A soil sampling program is carried out to ground truth results from both the vegetation survey and the EM38 plus acquire a soil profile and description (e.g. texture, colour etc) (DPI, 2004). Groundwater data is also acquired by monitoring water levels in piezometers which are used to determine the nature of the groundwater system.

2.7.1.3 Monitoring

Monitoring of a site is carried out every three to five years and includes a reassessment of the climate, history, photography, vegetation, EM38, soil survey and water levels in piezometers. The reassessments are carried out every three to five years as a budget restricts resources available to reassess the sites. Monitoring of the piezometers can be carried out by the land owner as needed, but the land owner must agree to do it and be willing to acquire training from the Department of Primary Industries.

2.7.2 West Dale Catchment

The West Dale Catchment Group consists of 10 properties and covers 8506 hectares east of Perth in the Beverley and Brookton shires (WDCG, 1998). West Dale catchment has an average annual rainfall of 600- 650 millimetres with the main falls occurring during the growing season between April and October (Graeffe, 1998). The West Dale catchment drains to the Avon River, a tributary of the Swan River, which is the major river which runs west through the City of Perth to the coast.

West Dale catchment was cleared prior to 1980 for cropping and grazing. Records show that the salinity problem arose 10 years after clearing and appears to have stabilised 20 years after the first appearance of salinity in the area (Graeffe, 1998).

2.7.2.1 Landscape Description

This agricultural region of Western Australia has some of the oldest known rocks of the Earth’s crust. The underlying geology forms part of the Yilgarn Craton, which is a relatively stable block of the Earth’s crust formed around 2400 million years ago and consists of gneisses, granites and migmatites. The typical lateritic regolith profile found in the West Dale catchment comprises a top layer of sand followed by a laterite or ironstone layer, which is underlain by weathered granite and then granitic bedrock. The depth to the granitic bedrock depends on the amount of erosion which has taken place, and can be between 1 and 50 metres from the surface (Graeffe, 1998).

The West Dale catchment has relatively high undulating hills with deep incised flat valleys, creating the ideal situation for valley floor salting to occur (Figure 2).

Figure 2 Deep valleys at Stan and Carol Dorman's property Lookout.

2.7.2.2 Catchment Issues

In the beginning, the main aim of the West Dale Catchment Group was to improve salinity and waterlogging problems. In 1990 the West Dale Catchment Group successfully obtained sponsorship from Alcoa World Aluminium Australia Limited. The sponsorship was given to enable the farmers to change their landscapes and reclaim some of their degraded land from salinisation (WDCG, 1998).

The salinity and waterlogging affecting the West Dale farmers resulted in soil erosion, acidity and loss of native vegetation. These problems have been tackled by undertaking revegetation, applying lime, fencing, planting perennials pastures, and earth works. Since 1990 the West Dale Catchment Group has planted over 224,000 trees in alleys, along drainage lines and creeks, in recharge areas and discharge sites (WDCG, 1998).

2.7.2.3 Salinity Management

On Stan and Carol Dorman’s property, the major problem was waterlogging which created secondary salinity. Their farm comprises a undulating landscape with highly weathered granite underlying surficial sands. The granite acts as an aquaclude, allowing the shallow groundwater to discharge at the surface, resulting in waterlogging and salination of the valley floors.

The Dorman’s have had their demonstration sites on their farm characterised by a set of protocols which enables comparison with other SGSL project sites around Australia. The protocols include characterising the specific treatments, land use history, geophysical surveys, vegetation analysis, hydrological modelling, geological mapping and soil sampling. These surveys have enabled the Dorman’s to identify recharge sites as the geophysical surveys show the location and extent of the sands, and those in elevated areas area planted. The geophysical surveys also showed that there are intrusions through the granite (dykes) which have weathered to create clay barriers which have restricted groundwater flow.

Waterlogging has been treated on the Dorman’s farm by surface water drainage. “W” and “V” shaped drains were constructed to carry water away, moving it onto the neighbouring down stream property. A W-shaped drain consists of one low lying bank (which is still able to be cropped) in the middle with a drain on either side of the bank (Figure 3). A V-shaped drain is deeper (around 1 metre) and has spoil on both or one side (Figure 4).

Figure 3 W-shaped drain at Stan and Carol Dorman's property.

Figure 4 W-shaped drain at Stan and Carol Dorman's property.

V-shaped drains have also been constructed along contours to harvest water in holding dams, creating more water storage and less runoff which reduces the waterlogging of the valleys. Planting of deep-rooted perennial grasses also has taken place to reduce the amount of recharge on paddocks which have a low cropping yield, as they are sandy and do not hold moisture. The Dorman's have also fenced off saline areas and planted them out with salt tolerant species. A farm management plan has been implemented to control the length of time that sheep are in a paddock, reducing soil erosion. Crop rotation has been developed to make sure there is as little as possible recharge to the ground water table.

Monitoring the environmental changes at the Dorman's farm is carried out using piezometers (to measure groundwater levels), photographs (taken both from the air and on the ground at certain locations) and a geophysical survey every few years.

Since 1990 when the Dorman's first started the land care project they have planted thousands of trees and carried out earth works, which have improved their property. Parts of their farm which were once waterlogged saline areas, unable to sustain sheep and with little to no cropping yield are now able to sustain sheep for a few weeks at a time and some parts are coming back into cropping rotation. The average crop yield of the West Dale catchment was 2.56 tonnes per hectare in 1990, since the implementation of minimum tillage and salinity management practices the 2002 average crop yield was 3.06 tonnes per hectare which is an increase of 19.5 percent (WDCG, 2002).

Figure 5 Stan and Carol Dorman's property, 1994.

Figure 6 Stan and Carol Dorman's property, 2002.

2.7.3 South Tammin Catchment

The South Tammin Catchment Group area consists of 26 000 hectares farmed by 16 families in the south western part of the Shire of Tammin. South Tammin has an annual rainfall of around 350 millimetres a year with the main proportion of it falling during the growing season between April and October (STB, 1998).

The South Tammin catchment is drained by three tributaries of the Warrengidging Brook River, which then runs into the Mortlock River system, and eventually runs into the Swan River.

2.7.3.1 Landscape Description

The agricultural region of Western Australia has some of the oldest known rocks of the Earth's crust. The underlying geology forms part of the Yilgarn Craton, which is a relatively stable block of the Earth's crust formed around 2400 million years ago and consists of gneisses, granites and migmatites. The South Tammin area has lower undulating hills and more extensive areas of flats than the West Dale catchment which make drainage a problem, causing waterlogging and recharge to occur to the water table (Figure 7). The catchment has a mix of soils created by the lateritic profile and a mixed vegetation of Tamar Scrub and areas of Salmon, White and York Gums (Rogers, 2004).The salinity in the South Tammin catchment ranges from slight to extreme.

Figure 7 A low undulating landscape South Tammin.

2.7.3.2 Catchment Issues

The South Tammin Catchment Group was formed in 1989 by farmers who were concerned about the degraded state of their farms. Although land conservation had taken place prior to the group's formation, it was only in small amounts.

The main problems affecting the South Tammin farmers were salinity and waterlogging and the resultant soil erosion, acidity and loss of native vegetation. The waterlogging and salinity has been encouraged by the clearing of the land for cropping and grazing prior to 1980. Before clearing, primary salinity existed in a balanced cycle and only a small proportion of land was affected. The clearing of the native vegetation for cropping and grazing caused an increase in recharge and over time the aquifers of the South Tammin area were filled and the rising groundwater began to affect the land in the 1960's. The affect of the increased storage in the aquifers is that the valley floors become waterlogged, and over the hot dry summers the water evaporates from the soil, causing salt pans to develop (Rogers, undated).

Similarly to the West Dale farmers the demonstration sites of the South Tammin Catchment Group have been characterised by geophysical surveys, geological mapping, soil sampling, vegetation analysis, electrical conductivity measurements of the regolith, groundwater, surface run off and farm dams, and monitored over the past years.

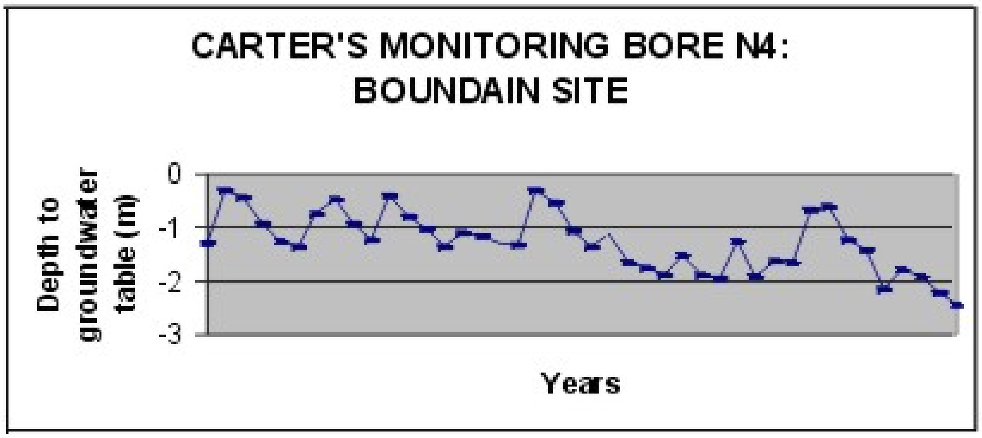
2.7.3.3 Salinity Management

The South Tammin farmers have implemented many treatments to try and overcome their salinity problem. The main treatments have been recharge and discharge management as well as soil development by applying gypsum, lime and fertilisers. Recharge management has involved alley farming, Tagasaste planting, commercial tree planting and water harvesting on high recharge areas identified by geophysical surveys. Discharge management has involved constructing drains and installing groundwater bores and pumps to lower the water table.

Alley farming is used for both recharge and discharge management and involves planting two rows of trees five metres apart and with 50 metres between each two rows to allow for cropping (Figure 8).

Figure 8 Alley farming.

One alley farming trial at Bruce and Lexie Carter's place has saved a low-lying flat from salinisation. The ground water table had risen to with in 50 centimetres of the surface and has now been lowered to more than a metre below (Figure 9) (SSC, 2001). A medium-yielding wheat crop used to be preferred, but now barley and pasture are in rotation. The barley crop yields two tonnes per hectare and the pasture sustains several sheep per hectare. The cost of planting the 48 hectare alley farming system was $2010 for the trees, machinery hire, labour and site preparation, which is around $42 per hectare.



1991-2001

Figure 9 A bore hydrograph of Bruce and Lexie Carter flat.

Tagasaste, a plant similar to Lucerne but with a scrubby habit, is able to be used for grazing and is a high water-user, so it is used in recharge areas (Figure 10). At the Wendy Diamond lookout south of Tammin, Tagasaste has been established on a high recharge area. Paul, the farmer who lived down slope of the planting, has observed that in years when Tagasaste was not planted the driveway to his house was subject to heavy waterlogging. However, since the Tagasaste has been established the lane way has remained dry. It only took two years for the Tagasaste to have an impact on the driveway once planted (SSC, 2001).

Figure 10 Tagasaste plantation.

Water harvesting has also been used as a recharge management option and allows the farmer to sustain more stock over summer. Water harvesting utilises contour drains directing water off the slopes and into holding dams (SSC 2001). Commercial tree farming, or agro-forestry, is an emerging industry as it was previously thought that the South Tammin area didn't have enough rainfall to sustain agro-forestry (SSC, 2001).

Discharge management includes tree planting, draining and groundwater pumping. Trees have been planted along creek lines and in low lying areas to reduce the groundwater levels and stop discharge. Drains have been constructed to increase the efficiency of high volume water flow down the creeks. Groundwater pumping is also used to lower the water table. The water from the bores on Geoff Hocking's farm is pumped two km away into a stream (Figure 11). This has been allowed because the groundwater is less saline than the water in the stream. The area where Geoff Hocking's groundwater pumps have been placed are around his house and machinery sheds. The salinity of this area is extreme with salt pans developing and threatening infrastructure. The pumps are holding the water table at bay, but other management options are needed to protect his land.

Figure 11 Groundwater pumping on Geoff Hocking's farm.

Derrick and Fay Chatfield's discharge management option has been to pump groundwater to lower the water table. The water is pumped into a series a dams where Cod, Yellow Belly and Silver Perch are grown for market (Figure 12).

Figure 12 One of Derrick and Fay Chatfield's dams used for commercial fish production.

Monitoring in the South Tammin Catchment includes reading 229 piezometers, photography, vegetation analysis, soil sampling and a geophysical survey every few years to measure changes.

Since 1990 the South Tammin Catchment group have planted 323,200 trees, developed 81 kilometres of shelter belts, erected 238 kilometres of fencing, applied 475 tonnes of gypsum and 2,470 tonnes of lime, constructed 22 kilometres of earthworks and installed 229 piezometers (STCG, 1998).

2.8 Summary of Literature Review

The Department of Primary Industries case study shows the main way to characterise a site is by land use history, geophysical surveys, vegetation analysis and hydrological modelling. The main focus is on vegetation and geophysical surveys. The Western Australia SGSL case studies have been characterised by a set of protocols, which enables comparison with other sites around Australia. All of the SGSL sites have had their specific treatments and land use history documented. Geophysical surveys, vegetation analysis, hydrological modelling, geological mapping and soil sampling has also been carried out to characterise the soils and hydrology aspects of the sites.

Treatments have included earth works for drainage, many recharge and discharge management options as well as soil development by applying gypsum, lime and fertilisers. Recharge management has involved, alley farming, Tagasaste planting, commercial tree planting and water harvesting on high recharge areas found from geophysical surveys. Discharge management has involved constructing drains and installing ground water bores to pump groundwater out and lower the water table.

Monitoring of both the DPI and Western Australia SGSL sites have been much the same in that piezometers have been monitored regularly, photographs, vegetation analysis, soil sampling and geophysical survey are carried out every few years to see what changes have taken place.

Characterisation of the three sites in the Woady Yaloak Catchment is required to comply with both the SGSL and the DPI state-wide monitoring. The sites are also Catchment Health sites, which are need to monitor progress towards the Resource Condition Targets in the Corangamite SAP.

3.0 Regional Characteristics

3.1 Climate

Climate of the Ballarat area ranges from hot dry summers to a cold wet winters with seasonal rainfall. The average temperature being a minimum of 7.7 ^{0}C and a maximum of 16.8 ^{0}C. The average rainfall of the Ballarat area is 703.9 mm per year with an average 162.9 rain days per year. The soil profile tends to become saturated during the winter months (BOM, 2004).

Month	Total Mean Rainfall (mm)	Total Median Rainfall (mm)	Total Rain Days	Average Maximum Temperature	Average Minimum Temperature
January	35.8	32.5	7.7	24	11.2
February	37.4	26.4	6.5	24.9	12.1
March	50	39.6	8.9	22	11
April	59	53.9	12.8	17.1	8.3
May	63.8	64.3	16	13.3	6.4
June	73.4	76.5	18.9	10.1	4.6
July	65.5	64.7	19.6	9.2	3.7
August	74.4	70	19.4	10.5	4.1
September	73.3	70.9	16.8	13.2	5.5
October	64	65.4	15.2	16.3	7
November	54.8	46.9	11.2	19.7	8.6
December	52.4	45.7	10	22.8	10.4
Annual	703.9	672	162.9	16.8	7.7

Table 1 Long term mean (45yr) of Ballarat, Mount Pleasant weather station (BOM, 2004).

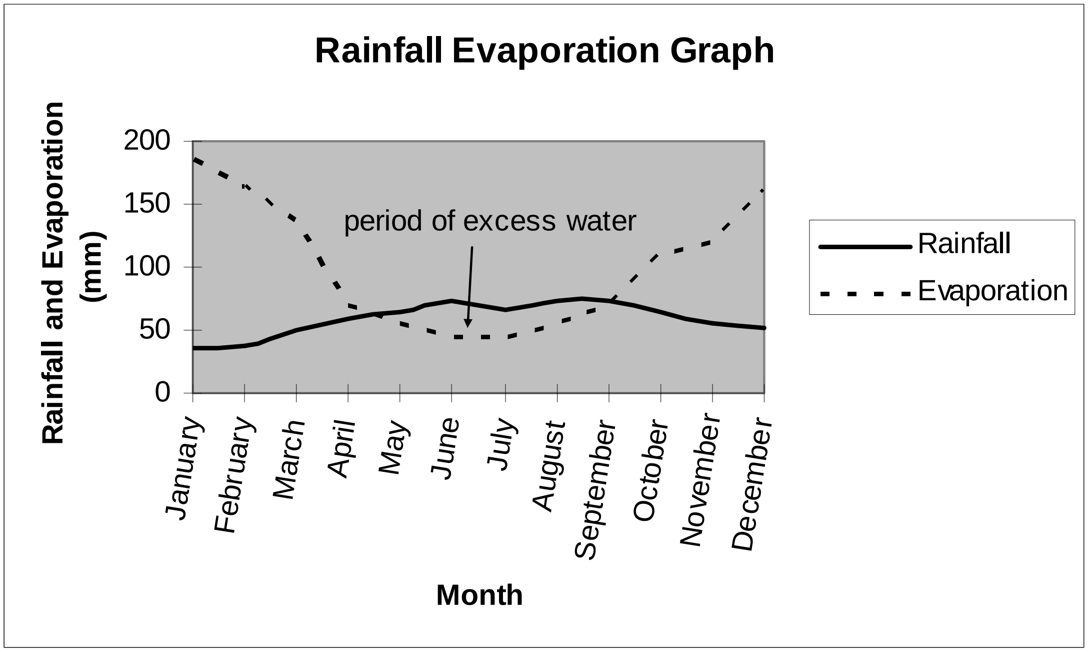


Figure 13 Rainfall verses Evaporation (BOM,2004)

3.2 Vegetation

Prior to European settlement the area consisted of mainly open grassy woodlands. The volcanic plains consisted mostly of grasslands and the dissected highlands consisted mostly of Ironbark, Box and Yellow Gum woodlands. The areas were cleared rapidly for agriculture and use in mining (Birch, 2003).

3.3 Land Use

Prior to European settlement 150 years ago, the *Borneghurk* and *Wathaurang* Aboriginal tribe's occupied the Ballarat area (BHS, 2004). Intense clearing of native vegetation to produce agricultural land, resources for mining, and urban development have resulted from European settlement.

During the mid to late 19th century, Illabarook was subjected to intense mining with a large amount of earth being over turned. Since mining has ceased, agriculture has been the dominant land-use at Illabarook.

Mt Mercer station was created as a large grazing property and the timber cleared from the land was used in mine workings. The historical account of Louisa Meredith, a visitor to

Mt Mercer homestead in 1856, records a densely treed landscape. On her journey from Mt Mercer to Ballarat she encountered a narrow track, which had tall straight trees along side it which needed a “highly skilled driver to steer amongst them” (Church, 2003).

The area around Pittong was originally settled for pastoral agriculture. The native vegetation was cleared to provide timber for mining and agricultural land for grazing and cropping. Since the 1960’s the mining and processing of Kaolin clay minerals has been a substantial industry in the region.

3.4 Regional Geology

Regional Geology of the three areas consists of Cambrian, Cambro-Ordovician, Devonian, Tertiary and Quaternary age rocks. The following summary is sourced from Taylor *et al.*, 1996:

3.4.1 Cambrian

Cambrian age rocks (560 million years) consists of meta-volcanic greenstones, which have faulted to the surface along the Avoca Fault Zone in small slices, but do not out crop and have only been described from drill core and mine tailings. It is thought that the greenstones have formed in a deep marine environment and comprise glassy to porphyritic intrusives and gabbroic to basalt lavas which represent oceanic crust .

3.4.2 Cambro-Ordovician

Cambro-Ordovician age rocks (490 million years) consist of a thick sequence of deep marine sedimentary rocks consisting of two groups: the Saint Arnaud Group; and the Castlemaine Supergroup, which are the underlying bedrock for the Ballarat region. The Saint Arnaud Group and the Castlemaine Supergroup comprise similar lithologies of thickly and thinly bedded turbidites, sandstone, mudstones and shales.

3.4.2.1 Saint Arnaud Group

The Saint Arnaud Group has two formations associated with it: the Beaufort and Pyrenees Formations. The Beaufort Formation is characterized by thinly bedded turbidites and mudstones including black shales. The Beaufort formation is thought to be the lower portion of the Saint Arnaud Group as it only occurs where lower structural levels have been exposed. The Pyrenees Formation is assumed to be the upper portion of the Saint Arnaud Group and consist of thickly bedded turbidites and only contains small amounts of black shale. Both Formations are assumed to be from a fan depositional environment with the Beaufort Formation being middle to outer and the Pyrenees Formation being proximal.

3.4.2.2 Castlemaine Supergroup

The Castlemaine Supergroup comprises thickly bedded turbidites meters to tens of metres thick, which may be coarse grained sands to mudstones. The thickly bedded turbidites suggest deposition in a middle fan marine environment. The Castlemaine Supergroup forms the bed rock east of the Avoca Fault Zone.

3.4.3 Devonian

Devonian age rocks (360 million years) consists of a suite of granites which have intruded the Cambro-Ordovician at depth and are now uncovered low lying hills in the landscape. The granite considered with the three study areas is the Mount Bute Adamellite which is an I-type granite with a slightly magnetic aureole. The Mount Bute Adamellite has a pale grey appearance with a medium to coarse grain texture. Weathering of the Mount Bute Adamellite has formed sandy colluvium around the core of the pluton.

3.4.4 Tertiary

Tertiary age sediments (60 million years) cover around 15 percent of the Ballarat area and overly bedrock in a series of thin sheet deposits. There are a number of Tertiary sediments in the area, but only the White Hills Gravel and the Moorabool Viaduct Sand are relevant to the salinity investigation sites.

3.4.4.1 White Hills Gravel

The White Hills Gravel and the Moorabool Viaduct Sand are similar and were initially mapped as the same unit. White Hills Gravel consists of a coarse grained, quartz cobble conglomerate with well rounded to angular pebbles to boulder size quartz. The matrix of the conglomerate consists of ferruginised clayey sand. Depositional environment suggested for the White Hills Gravel is a high energy fluvial environment, driven by rainfall. The thickness of the deposit ranges between 10 and 30 metres and may cap tops of hills and be traced from south of the Great Dividing Range to the north into the Murray Basin.

3.4.4.2 Moorabool Viaduct Sand

Moorabool Viaduct Sand consists of coarse grained to pebbly quartz sand with a clay matrix. The Moorabool Viaduct Sand unconformably overlies bed rock as a thin sheet two to 30 metres thick and rarely disconformably overlies the White Hills Gravel. The thin sheet of sand has been deposited by a localised incursion of the sea, which has been subjected to uplift forming a tableland, which has since been partly dissected and ferruginised.

3.4.5 Quaternary

Quaternary age rocks (two million years) consist of a number of basaltic lava flows covering around 55 percent of the Ballarat area. Individual flows are metres to tens of metres thick and consist of fine grained porphyritic basalt. Other flows have been found to be very coarse grained or highly vesicular. Deposition of the lava flows consisted of filling valleys creating deep leads and eventually filling the valleys to create sheet flows. Since the lava flows have ceased erosion has formed alluvium, colluvium and out wash fan deposits, which are still forming today.

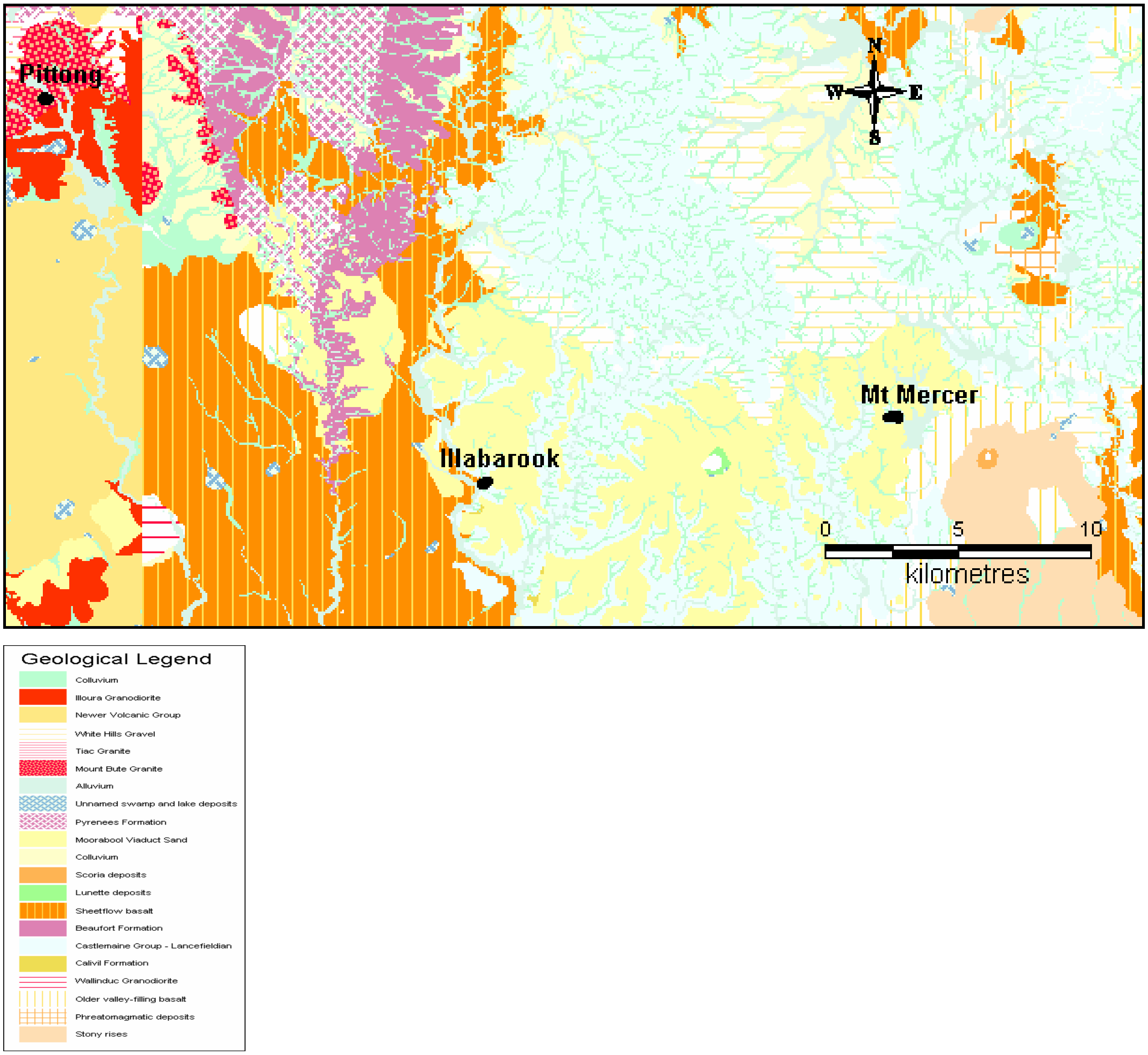


Figure 14 Regional Geology (GSV, 2003).

3.5 Geomorphology

Mt Mercer, Illabarook and Pittong have similar geomorphologies associated with the descriptions from the Ballarat Geological Report. The Ballarat Geological Report splits the geomorphology up into four different landforms the Midlands, Central Uplands, Basalt plains and Dissected Tableland (Figure 15). The study sites are concerned with the Midlands, Central Uplands and Dissected Tableland.

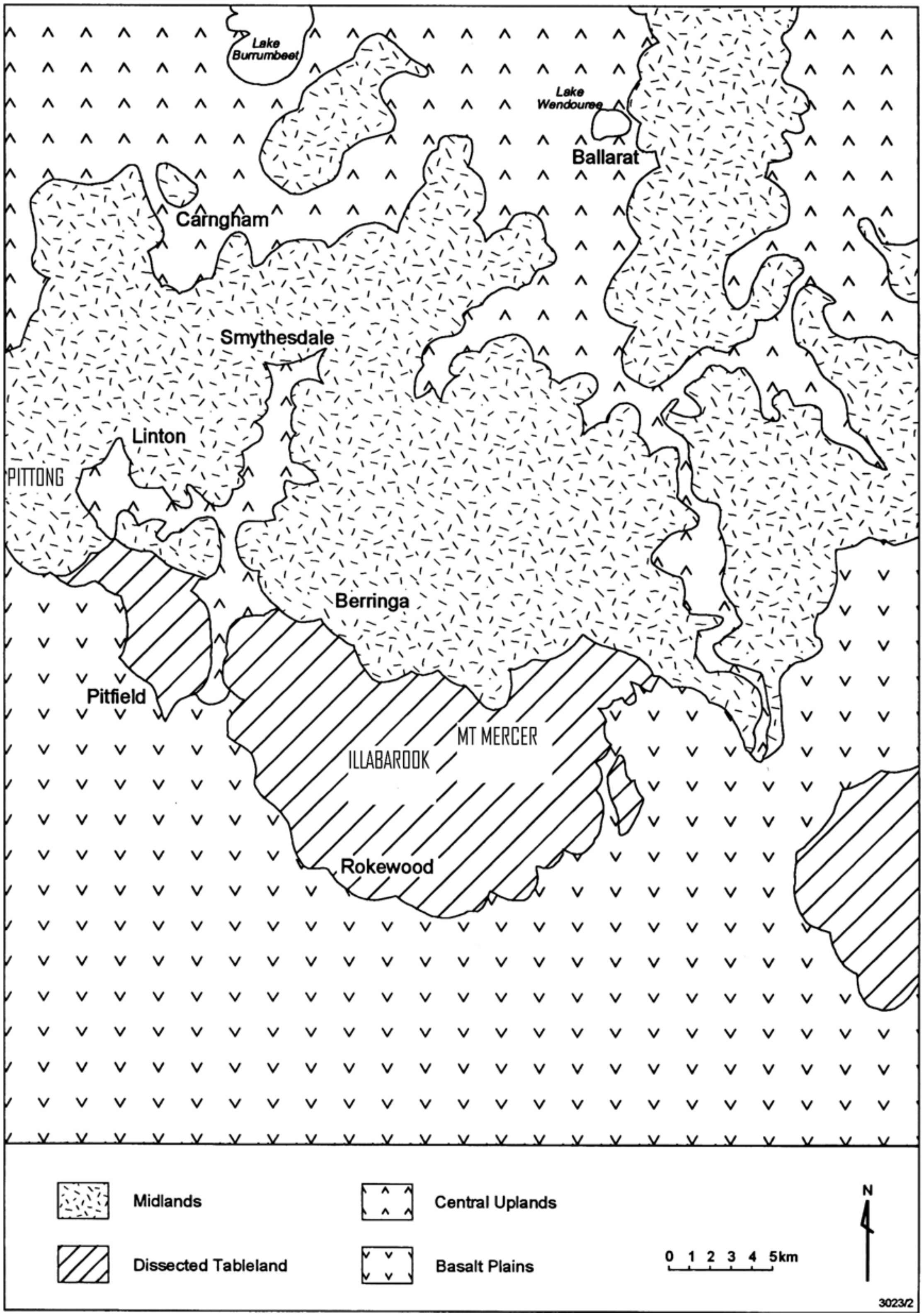


Figure 15 Geomorphic Divisions of the Ballarat Area (Taylor *et al.*, 1996).

3.5.1 Midlands

The Midlands consists of Palaeozoic sedimentary and igneous rocks. Midlands sedimentary rocks are characterised by low undulating hills, dissected by broad round valleys, with a dendritic drainage pattern and ferruginised soils. Igneous rocks are characterised by low hills consisting of weathered kaolinised rock and poorly developed drainage. The Midlands supports poor soils with remnant vegetation. Where younger sediments or volcanics have filled basins remnant vegetation has been cleared for agricultural activity as the soils are richer.

3.5.2 Dissected Tableland

Across the southern fringe of the Midlands dissection of the Moorabool Viaduct Sand has occurred forming a dissected tableland. Weathered bedrock outcrops in rugged valleys supporting remnant vegetation, as most of the tableland has been cleared. The Moorabool Viaduct Sand has been strongly ferruginised by groundwater processes around the margins of the tableland. The dissected tableland is currently under threat by soil erosion and saline discharge, which is degrading the landscape.

3.5.3 Central Uplands

The Central Uplands consists of large areas of Newer Volcanics which have filled large valleys. The basalts have been cleared for agricultural activity as they support rich soils. The basalt flows are usually fringed by alluvial deposits developed by lateral streams, which skirt the edges of the plains. The lava flows consist of hummocky stony rise and plain surfaces, which have created swampy areas and large lakes from lava flows impounding streams.

4.0 Site Geology and Hydrology

4.1 Geology

4.1.1 Mt Mercer

Colluvium, alluvium, Moorabool Viaduct Sand and Ordovician sediments are present at the Mt Mercer site (Figure 16). Moorabool Viaduct Sand consists of partly ferruginised coarse grained to pebbly quartz sand with a clay matrix. The Moorabool Viaduct Sand unconformably overlies bedrock (Ordovician sediments) as a thin two to ten metre sheet.

The thin sheet of sand has been deposited on Ordovician sediments (formed 490 million years ago in a fan depositional environment) by a localised incursion of the sea during the Pliocene. The incursion was controlled substantially by the Enfield Fault, which may have formed or reactivated at this time (Birch, 2003). The Enfield Fault caused uplift of up to 150 metres to occur, causing the regression of the sea forming a tableland, which has since been partly dissected and ferruginised (Birch, 2003). Colluvium and alluvium have formed from small valleys incising the Moorabool Viaduct Sand and Ordovician sediments over time.

Figure 16 also shows a deep lead running south of the site. The deep lead has formed from ancient rivers and streams being in filled with sediment and lava. The in filled rivers and streams create underground rivers which are able to carry substantial amounts of water in them. The deep lead has been defined by drilling in 1889 which indicated two distinct channels (Gillies, 1889).

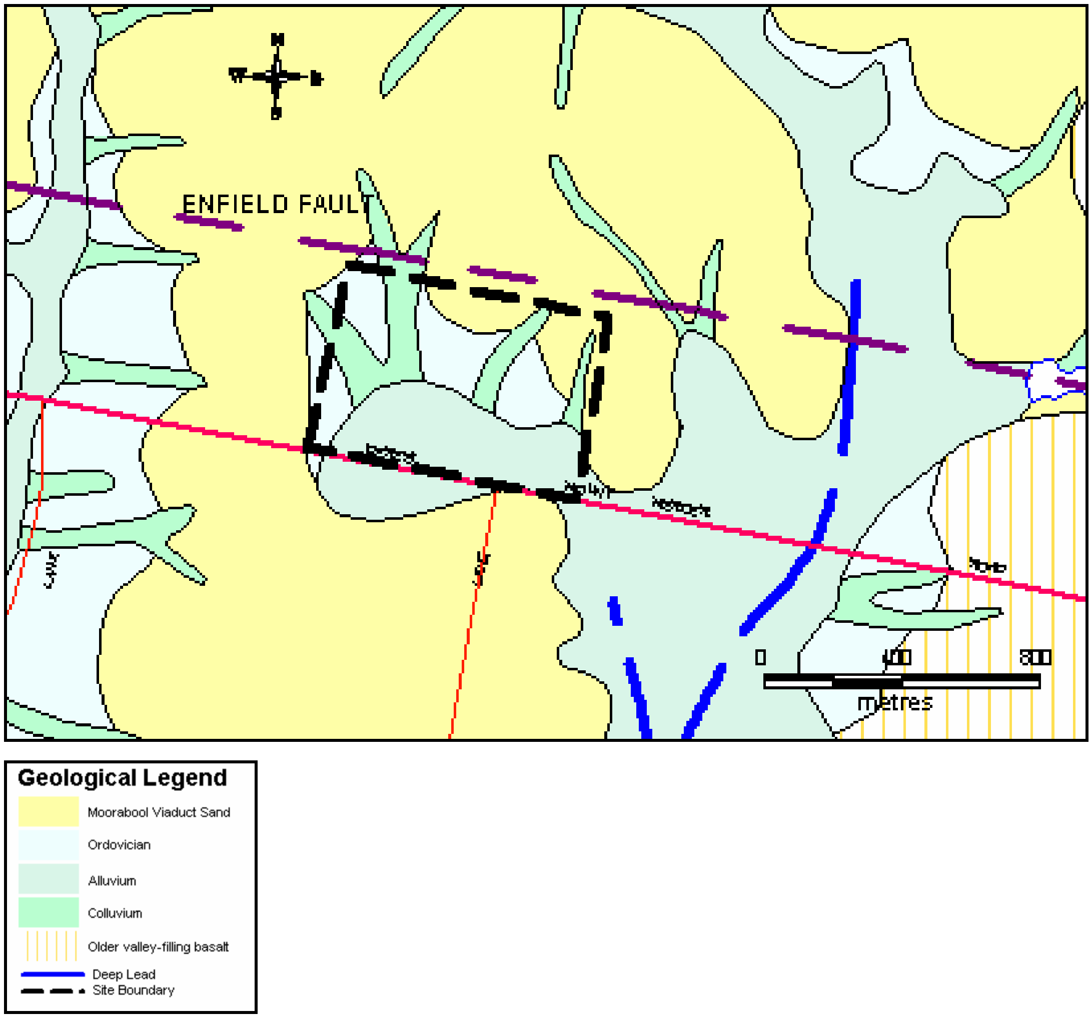
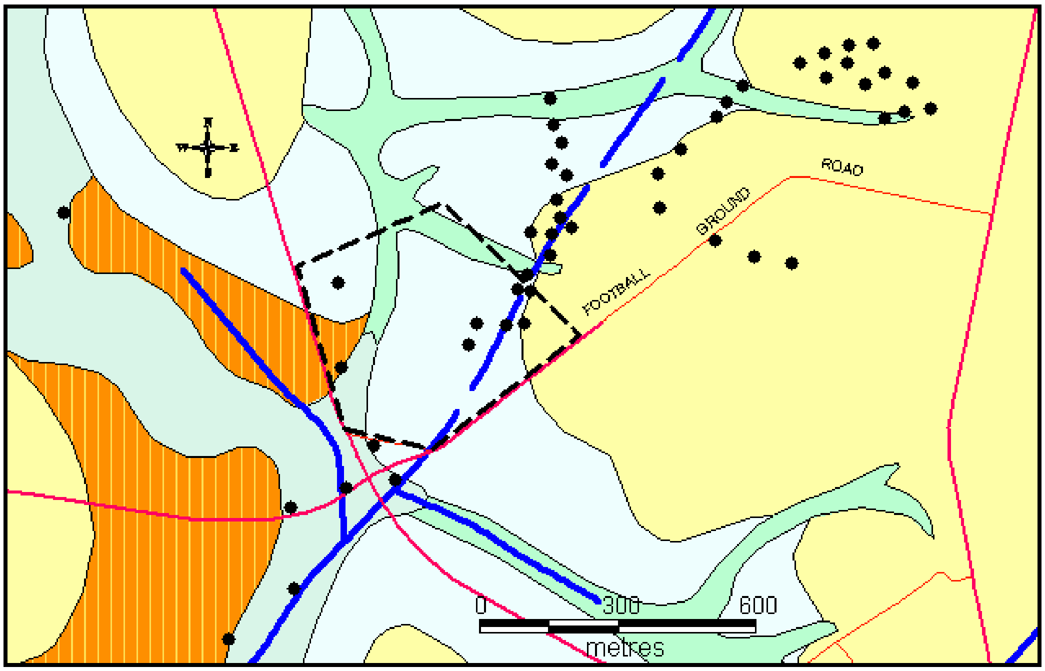


Figure 16 Geological map of the Mt Mercer Site (GSV, 2003)

4.1.2 Illabarook

Colluvium, Alluvium, Moorabool Viaduct Sand, Ordovician sediments and sheet flow basalts are present at the Illabarook site (Figure 17). As Figure 17 shows the geology of this area is a great deal similar to Mt Mercer site. The Moorabool Viaduct Sand consist of coarse grained to pebbly quartz ferruginised sand with a clay matrix two meters thick overlying Ordovician sediments (bed rock) on low undulating hills. The Enfield Fault is not present at the Illabarook site, but runs east-west north of the site controlling the placement of the Moorabool Viaduct Sand. Sheet flow basalts have formed during the Pliocene after the regression of the sea infilling valleys and flowing over the Moorabool Viaduct Sand (Birch, 2003). Alluvium and colluvium have formed since from small incising valleys.

A deep lead also runs through the Illabarook site (Figure 17). The deep lead has formed from ancient rivers and streams being in filled with sediment and lava. Evidence of the deep lead is from the number of mines which intersected the buried river gravels, which have alluvial gold associated with them.



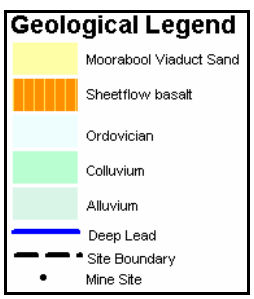


Figure 17 Geological map of the Illabarook site (GSV, 2003)

4.1.3 Pittong

Granite, colluvium and alluvium are present at the Pittong site (Figure 18). The Pittong site is situated within a granite pluton the Mount Bute Adamellite, which intruded the Cambrian and Cambro-Ordovician sediments at depth during the Devonian and was uncovered during the Carboniferous (Church, 2003). Ultimately over time the granite has become deeply weathered forming saprolite. Erosion has occurred in the centre of the pluton forming colluvium and alluvium in round flat valleys.

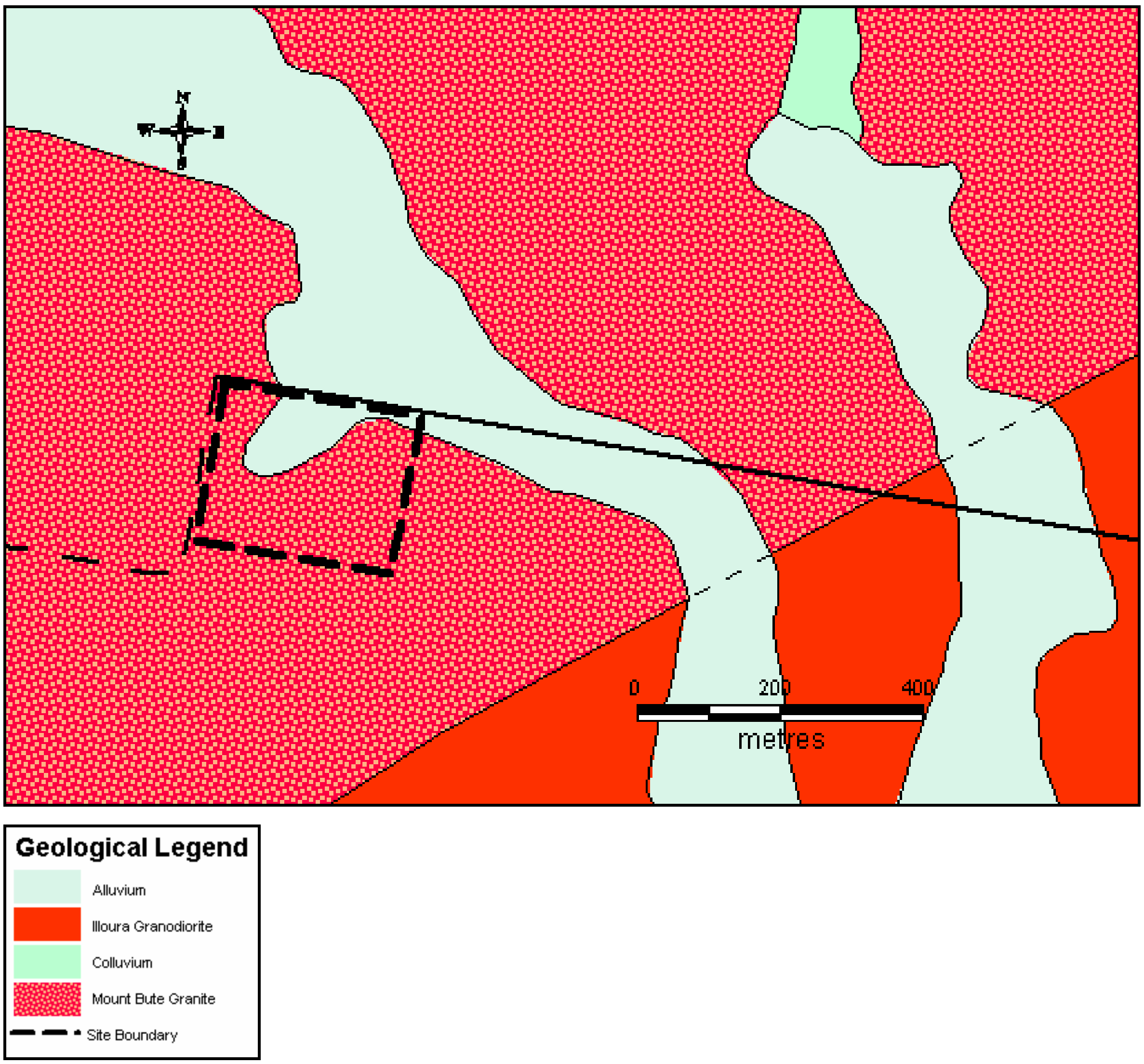


Figure 18 Geological map of the Pittong site (GSV, 2003).

4.2 Hydrogeology

4.2.1 Mt Mercer

A three-dimensional oblique view provides a landscape context for the Mt Mercer site (Figure 19). It shows the Moorabool Viaduct Sand overlaying the Ordovician sediments on low undulating hills, with colluvium and alluvium in broad flat valleys.

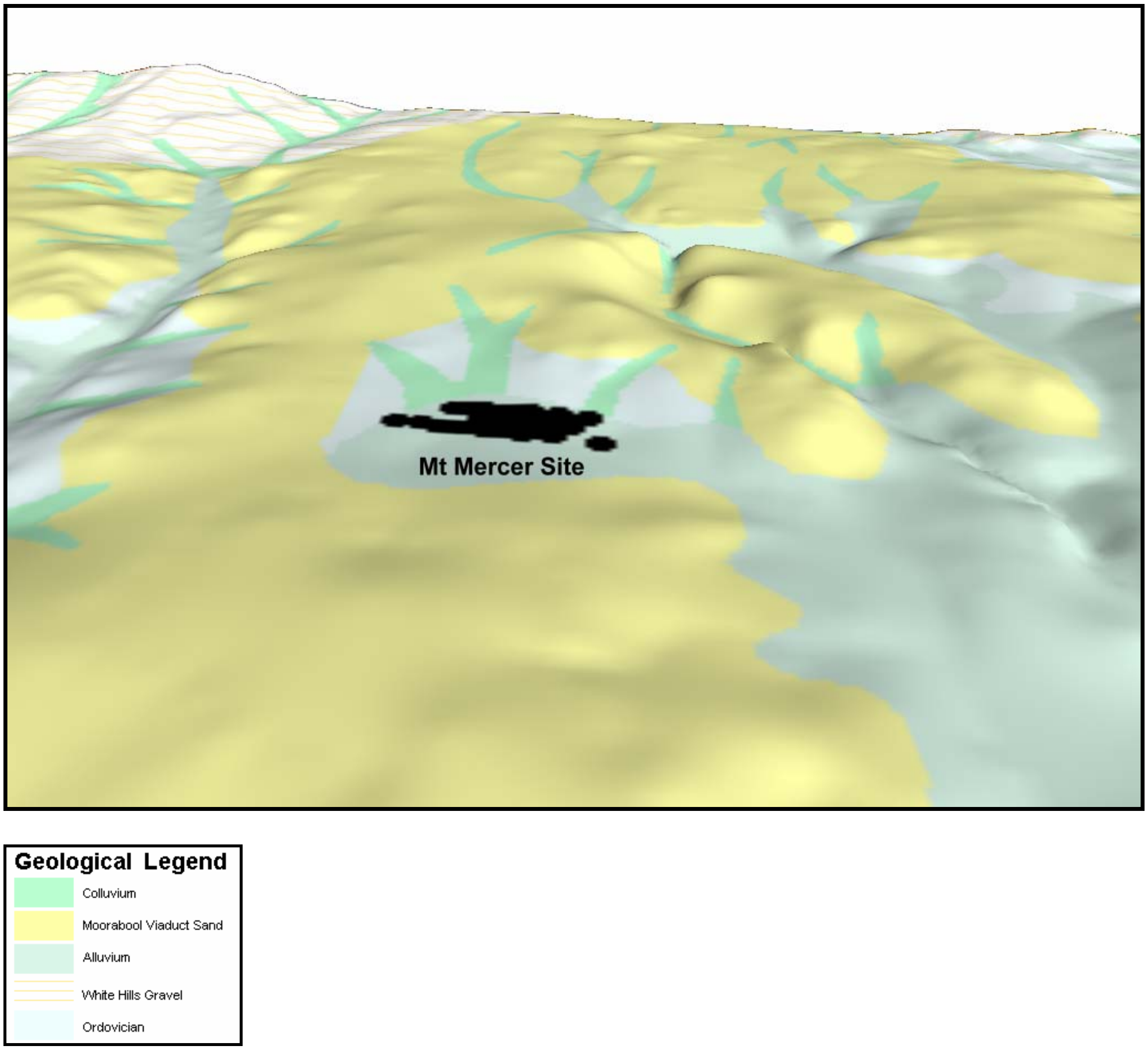


Figure 19 A three dimensional oblique view of geology at the Mt Mercer site (GSV, 2003).

Moorabool Viaduct Sand is an unconsolidated deposit overlying a highly compacted and deeply weathered Ordovician turbidite. Textbook values for hydraulic conductivity of unconsolidated sands are typically orders of magnitude greater than for a fractured rock aquifer of compacted Palaeozoic sediments (Fetter, 2003). Therefore it is logical to assume that the Moorabool Viaduct Sand will be recharged faster and water will be transmitted through the Moorabool Viaduct Sand at rates which are much greater (orders of magnitude) than the Palaeozoic. These facts lead to the development of a conceptual model as shown in Figure 20. The infiltrated rainwater moves vertically through the Moorabool Viaduct Sand, but cannot percolate into the Palaeozoic rock at the same rate, therefore the recharge is diverted laterally down the slope of the terrain and discharges where the Moorabool Viaduct Sand wedges out and in the valley floor.

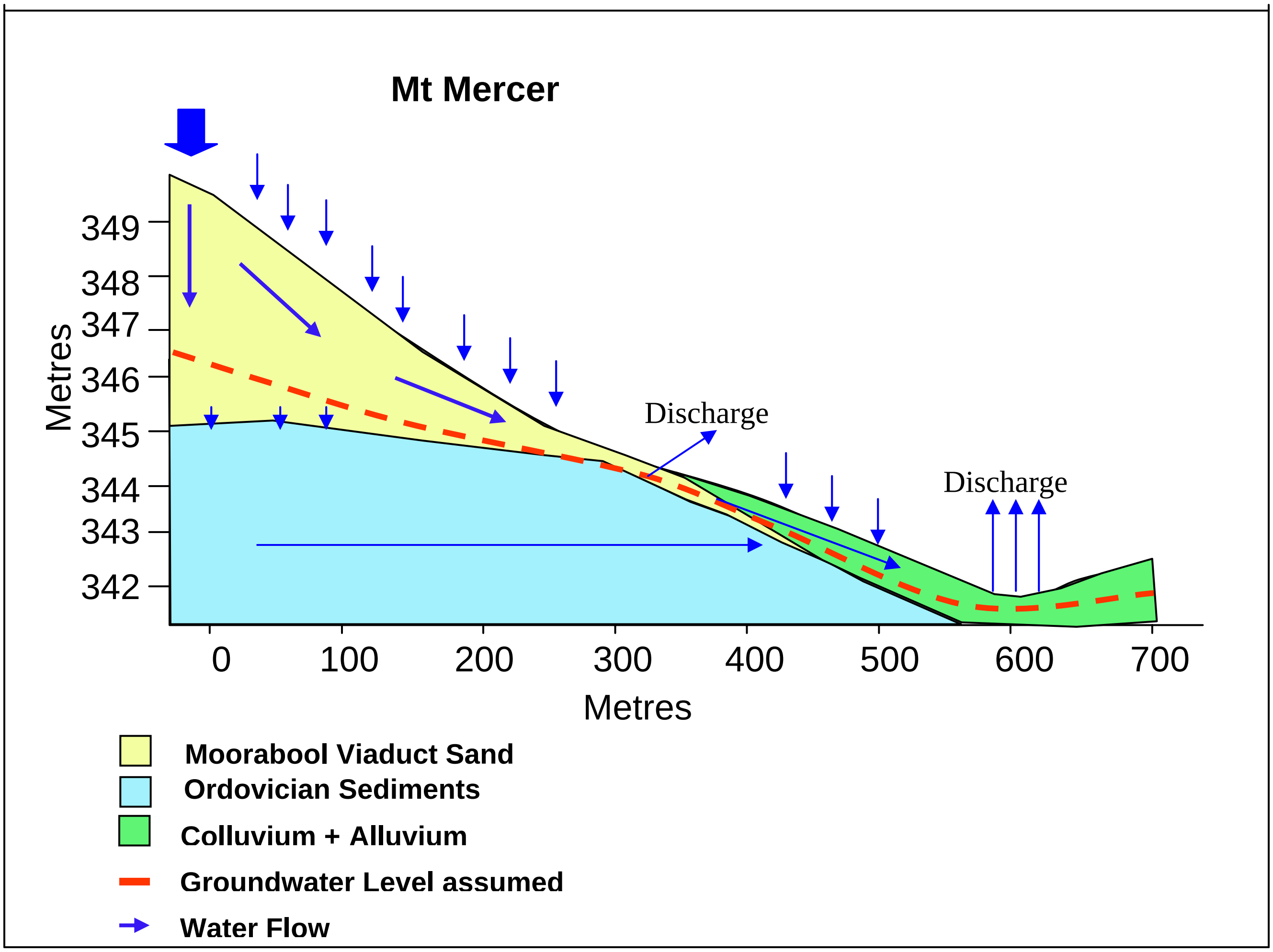


Figure 20 Hydrogeological cross section of the Mt Mercer site (Exaggerated by 37)

4.3.2 Illabarook

A three-dimensional oblique view provides a landscape context for the Illabarook site (Figure 21). It shows the Moorabool Viaduct Sand overlaying the Ordovician sediments on low undulating hills.

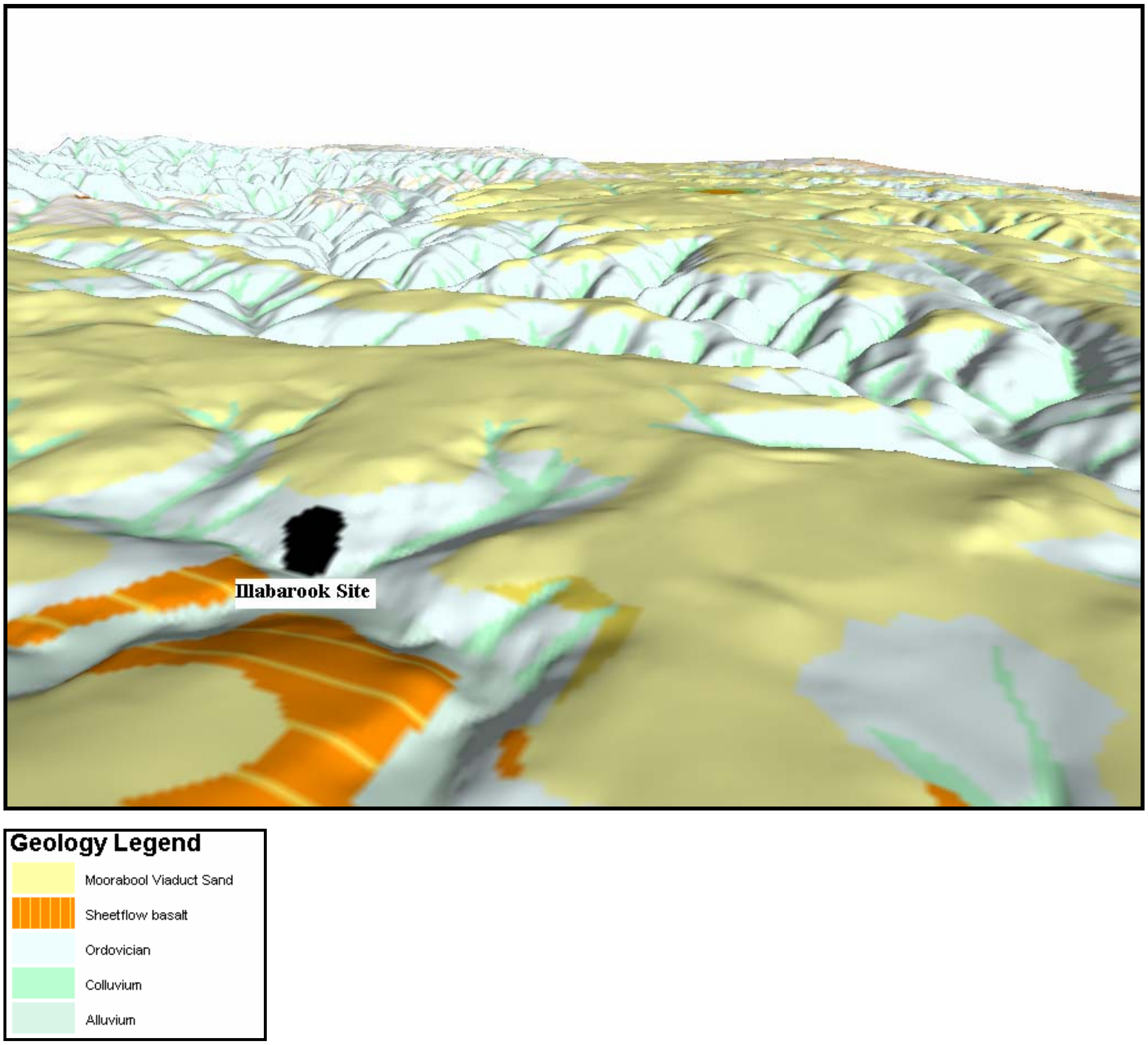


Figure 21 A three dimensional oblique view of geology at the Illabarook site (GSV, 2003).

Figure 22 Road cutting near the Illabarook site showing Pliocene sands on top of Ordovician sediments

Figure 22 shows Moorabool Viaduct Sand overlying Ordovician (Palaeozoic) compacted sediments, which is situated in a road cutting west of the Illabarook site. As the Moorabool Viaduct Sand has a higher hydraulic conductivity than the compacted Palaeozoic sediments rainwater percolates down through the Moorabool Viaduct Sand reasonably quick and hits the highly compacted Palaeozoic sediments, which inhibits water flowing vertically. Water then pools and flows laterally on top of the Palaeozoic sediments creating a perched aquifer, which discharges at the side of the hills where Moorabool Viaduct Sand wedges out (Figure 23). The deep lead at the Illabarook site is also causing discharge at the base of the hill where it surfaces. The deep lead obtains water from both the groundwater table in the Ordovician sediments and through mine shafts which have a very high hydraulic conductivity and create easy paths for recharge into the deep lead (Figure 23).

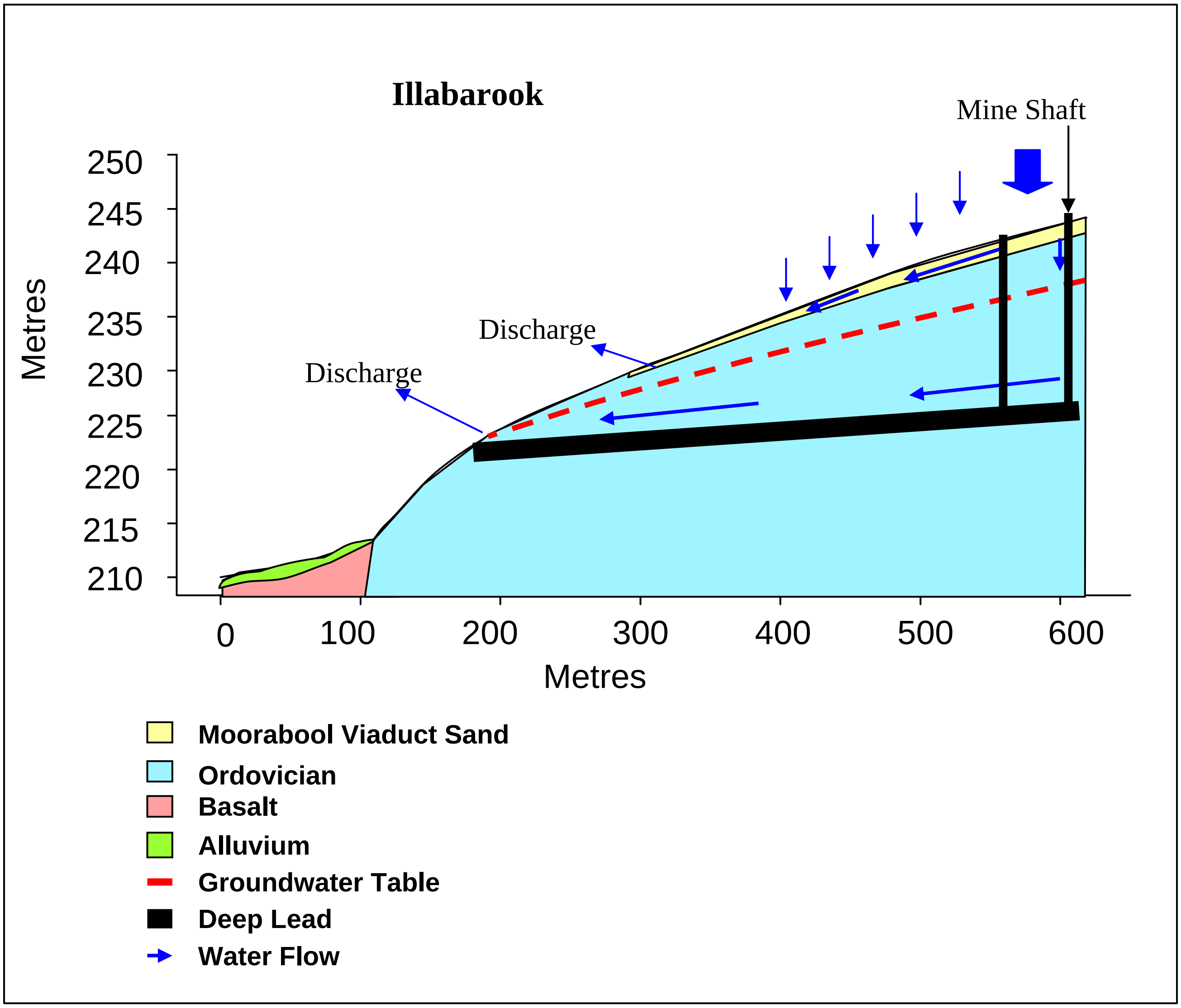


Figure 23 Hydrogeological cross section of the Illabarook site (Exaggerated By 7)

4.3.3 Pittong

Pittong consists of weathered granite (saprolite). Saprolite is a highly weathered (chemical) igneous or metamorphic rock which is very clay-rich and still possesses the structure of the unweathered rocks. Saprolite generally has a low hydraulic conductivity due to its a high clay content. Erosion has caused sandy colluvium and alluvium to develop on the sides of low undulating hills and in round valleys, as the weathered igneous rock contains quartz which has been weathered and mixed in with clay. As colluvium and alluvium have a higher hydraulic conductivity than the saprolite, rainwater infiltrates the colluvium and alluvium at a higher rate than the saprolite is able to withstand, and water flows laterally and discharges at the base of the hill (Figure 24). As the water flows laterally it comes into contact with deep percolating water discharging from saline springs. The saline springs develop by high pressured deep percolating water navigating its way through joints of the now highly weathered igneous rock. A small proportion of rainwater infiltrates through the colluvium and alluvium and enters the saprolite raising the water table making valley floors waterlogged.

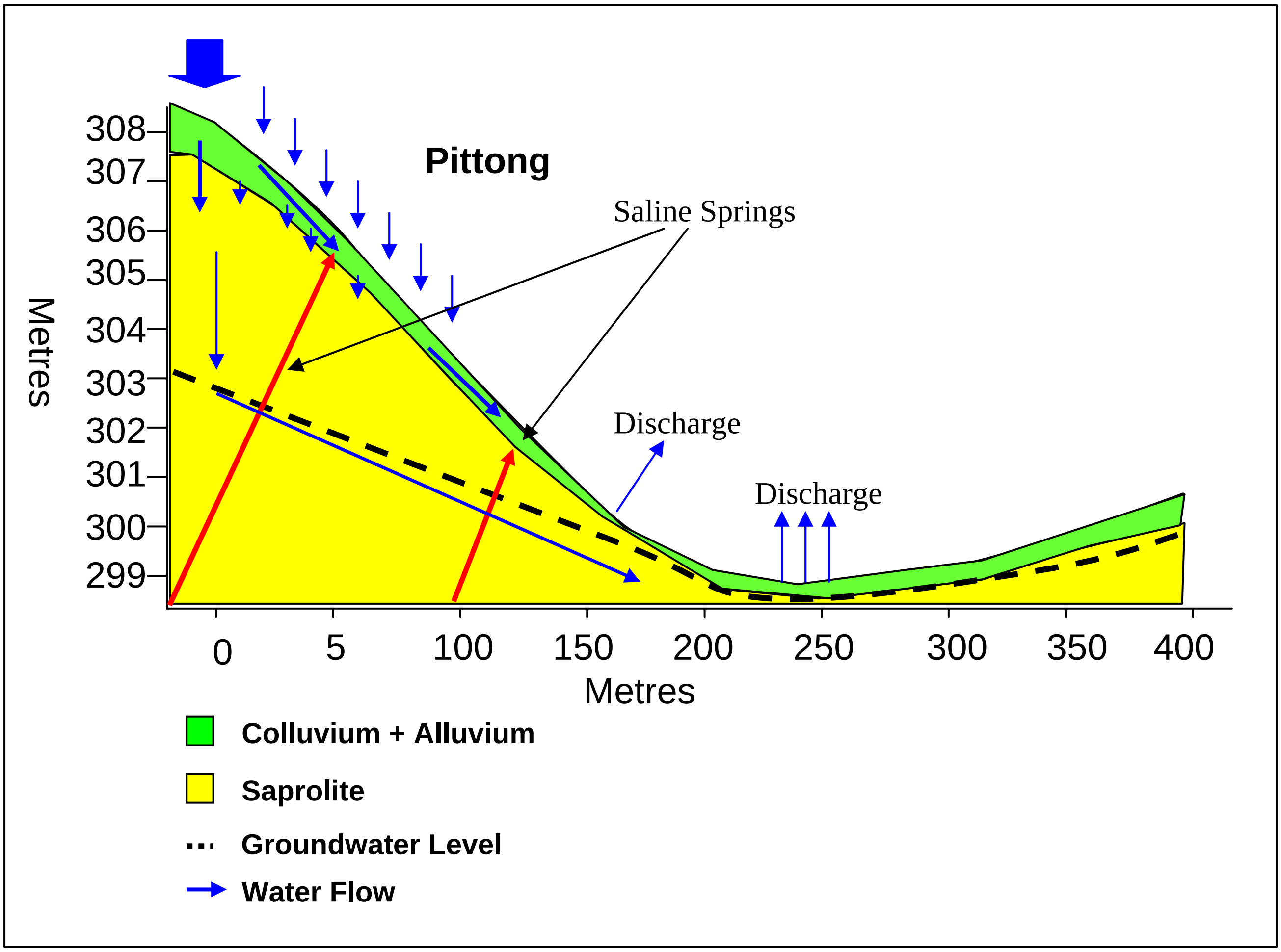


Figure 24 Hydrogeological cross section of the Pittong site (Exaggerated By 20)

5.0 Methods

5.1 Field Methods

5.1.1 Soil Survey

A soil survey was undertaken at each site to identify the soil profile and soil salinity. A powered hydraulic corer was used to extract 50-80 centimetre cores (Figure 25). The soil cores were transported back to the laboratory with minimum disturbance, where they could be manipulated and analysed (Figure 26). A GPS was used to locate soil cores and measure out distances between core samples. Core samples were taken around every 20 by 20 meters along a straight line through the saline areas and into less affected areas. This was done to show differences in salinity and soil texture throughout the site.

Figure 25 Soil coring at Mt Mercer

Figure 26 Soil profiling in the Soil lab

5.1.2 Water Measurements

Groundwater levels were measured in any accessible bores within one kilometre of the sites. Groundwater levels were recorded in each bore using a fox whistle suspended on the end of a measuring tape. Groundwater was analysed by bailing out (obtaining a sample) some groundwater into a plastic bucket and testing for pH and EC using portable meters. A EUTECH ECscan metre was used for obtaining EC and a HANNA pHep 3 metre with ATC (automatic temperature correction) was used to obtain pH. Similarly surface water analysis was conducted at selected testing sites using a plastic bucket to obtain a sample and testing for pH and EC using the same pH and EC portable meters. Both were carried out monthly. Selecting suitable surface water sites involved finding where water left or had not travelled far from the sites.

5.1.4 Vegetation Survey

A vegetation survey was carried out by Sandra Wagenfeller, a University of Ballarat TAFE student, for the Woady Yaloak Catchment Group. The survey conducted involved identifying saline indicator plants, area affected and classification according to Matters and Bozon (1995).

5.1.5 Photography

Photograph monitoring points were set up at each of the sites. Photograph monitoring involves locating points in the landscape with a GPS and taking photographs in a certain direction to capture the vegetation of a particular area over time. A two mega-pixel Kodak CX 4200 digital camera was used to obtain photographs of the sites. Photograph site locations were chosen to get an overview of the whole site as it changed from season to season.

5.1.6 Geophysical Survey

An EM38 and EM31 survey was carried out by Advanced Soil Mapping Deniliquin. A Geonics EM 38 (Trailing) and Geonics EM 31 (Mounted on front) were mounted on an all terrain vehicle and the survey was completed (Figure 27). An EM 38 and EM 31 produce a magnetic field inducing a current which flows through the soil. Because the magnetic field is of constant intensity the induced currents strength will only change as a result of varying conductivity of the soil, therefore giving an apparent electrical conductivity of the soil (Bates, 2004). Appended is the operational guide for using an EM38 (Appendix 2).

Figure 27 EM38 Survey

5.2 Laboratory Analysis

Figure 28 Soil testing in the soil lab

5.2.1 Method for the determination of soil pH1:5, pH (cacl2), EC 1:5

Both pH and EC were found by using MacEwan (1999) method for the determination of soil pH1:5, pH ($CaCl_2$) and EC 1:5;

1 Place 10 grams of air dried and sieved (two millimetre) soil into a 100 millilitre capacity phial, weigh accurately to two decimal places.

2 Add 50 millilitres of distilled water.

3 Tightly cap and place on mechanical end over end shaker for one hour.

4 Calibrate pH meter with pH= 7 and pH= 4 calibration buffers. Make sure that the electrode has been thoroughly rinsed with distilled water and dried with a tissue before and after being placed in solution.

5 Calibrate EC meter using 0.01 mol potassium chloride (KCl) and make sure EC electrode has been rinsed with distilled water and dried with a tissue before and after being placed in solution.

6 Remove phial from the mechanical shaker after one hour and let phials stand for 20 minutes.

7 Place pH electrode into the solution and measure pH at 50 percent of the solution depth.

8 Place EC electrode into the solution and measure EC at 50 percent of the solution depth.
9 Pipette two millilitres of 0.25 mol Calcium Chloride (CaCl2) into the phials.
10 Place phial back into mechanical shaker and shaker for 15 minutes.
11 Remove phials after 15 minutes and let stand for 20 minutes.
12 Repeat step six

Figure 29 Soil being tumbled in the soil lab

5.2.3 Soil Description

Each core brought back to the laboratory was described by its profile, texture, colour and structure.

A soil profile refers to a vertical section through a soil from the soil surface through all horizons to parent material. A soil profile is described by horizons, which are layers of approximately parallel soil to the land surface, with morphological properties different from layers above and below (McDonald et al, 1990). Description of different types of horizons were used from McDonald *et al.* (1990) to find the soil profile of the saline sites.

Soil texture was assed manually by using MacEwan (1999) method for determining texture:

1. Take a sample of soil sufficient to fit comfortably into the palm of the hand.
2. Moisten the soil with water, a little at a time, and work the water into the soil. Water is added until the soil reaches a consistency where further water added would cause the soil to stick to the hands.
3. Knead and moisten the soil until there is no further change in the soil ball – very dry clayey samples may need considerable working to break down fine aggregates. A working time of one to ten minutes may be needed depending on the material. Usually one to two minutes is sufficient.
4. The behaviour of the bolus during manipulation and its response to pressing between the thumb and forefinger indicate the soil texture. Attempt to make a ribbon by using your thumb to squeeze the bolus of soil over the side of your first finger. The tendency of a soil to form a thin, strong ribbon is what is known as “resistance to shearing”. Appendix 1 shows a flow chart used to asses the behaviour of the bolus, which indicates the soils texture.

Colour is analysed by matching freshly broken, undisturbed, moist soil to colour chips of the Munsell Soil Colour Chart, which is given in semi-quantitative notation (eg. 7.5YR 4/3 (dark brown)) (McTainsh and Boughton, 1993).

5.2.4 Soil CEC

Six samples from each site of varying salinity and depth were sent away to Farmright Technical Services Pty. Ltd where CEC, EC and pH were analysed. CEC tests the availability of certain cations, the main being Calcium, Magnesium, Sodium, Potassium and Aluminium which are important to asses soil health. (Refer to section 2.2.3)

6.0 Results

6.1 Mt Mercer

6.1.1 Vegetation Assessment and Aerial Photography

Sandra Wagenfeller conducted the on-ground vegetation assessment for the Mt Mercer site. Historic aerial photography, obtained from the Land Victoria library at Laverton, was also used to asses the trend in vegetation on the site over time.

Spiny Rush, Bucks Horn Plantain and Annual Beard Grass were mapped at the Mt Mercer site, which are all class 1 and 2 salt indicator species. Figure 30 shows the five hectare area affected by the salt indicator plants on a 2002 aerial photograph.

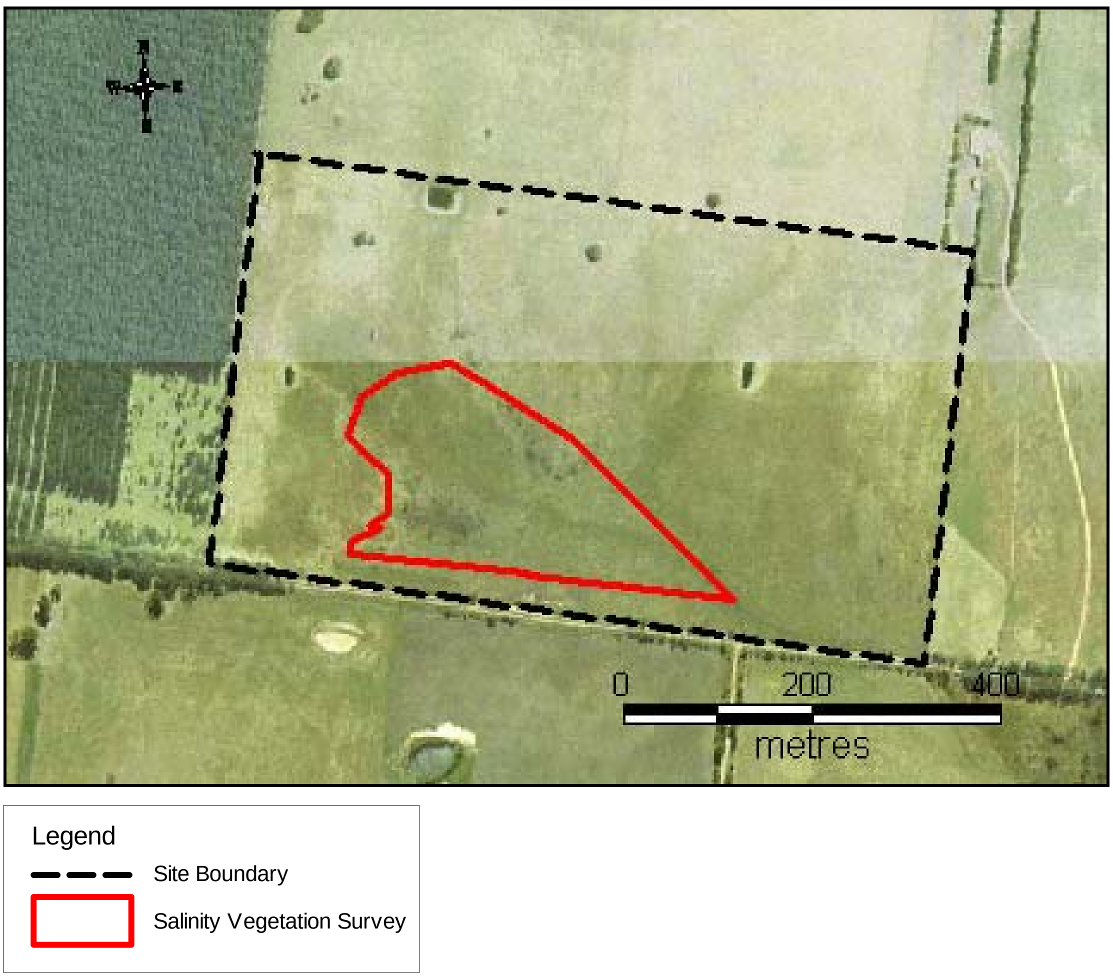
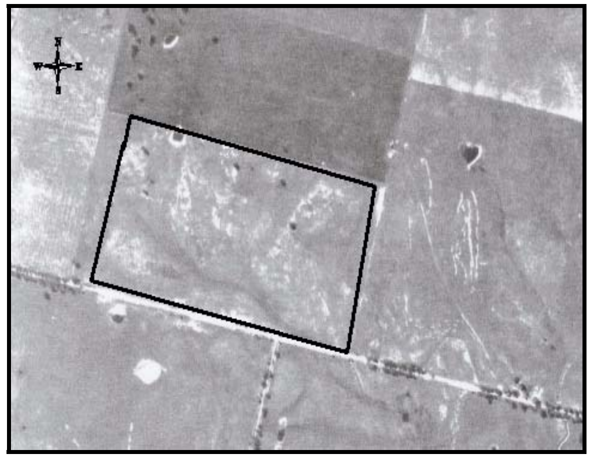
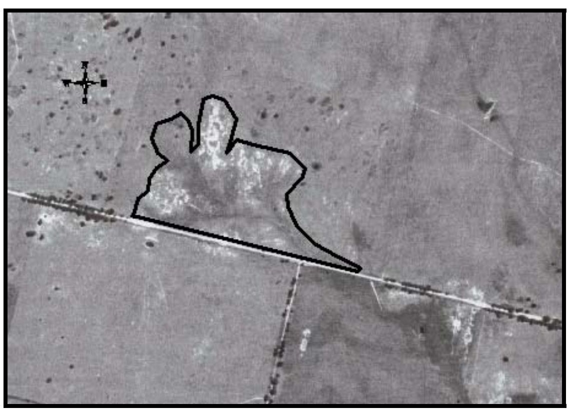


Figure 30 Mt Mercer 2002 Aerial photograph with salinity outlined

A



B



C

Figure 31 Historical air photography showing saline areas A) Mt Mercer 1990 B) Mt Mercer 1981 C) Mt Mercer 1970

Three historical aerial photos were selected to asses the severity of salinity at the site over the past 30 years (Figure 31). The photo history clearly shows that the area affected by salinity at the site has decreased over 30 years. The estimated decrease is around 60 percent.

6.1.2 Soil

Twenty-six soil cores were taken from the Mt Mercer site to map the soil profile, EC, pH and soil textures (Figure 32). Appendix 3 lists the GPS points and total depth of each core taken.

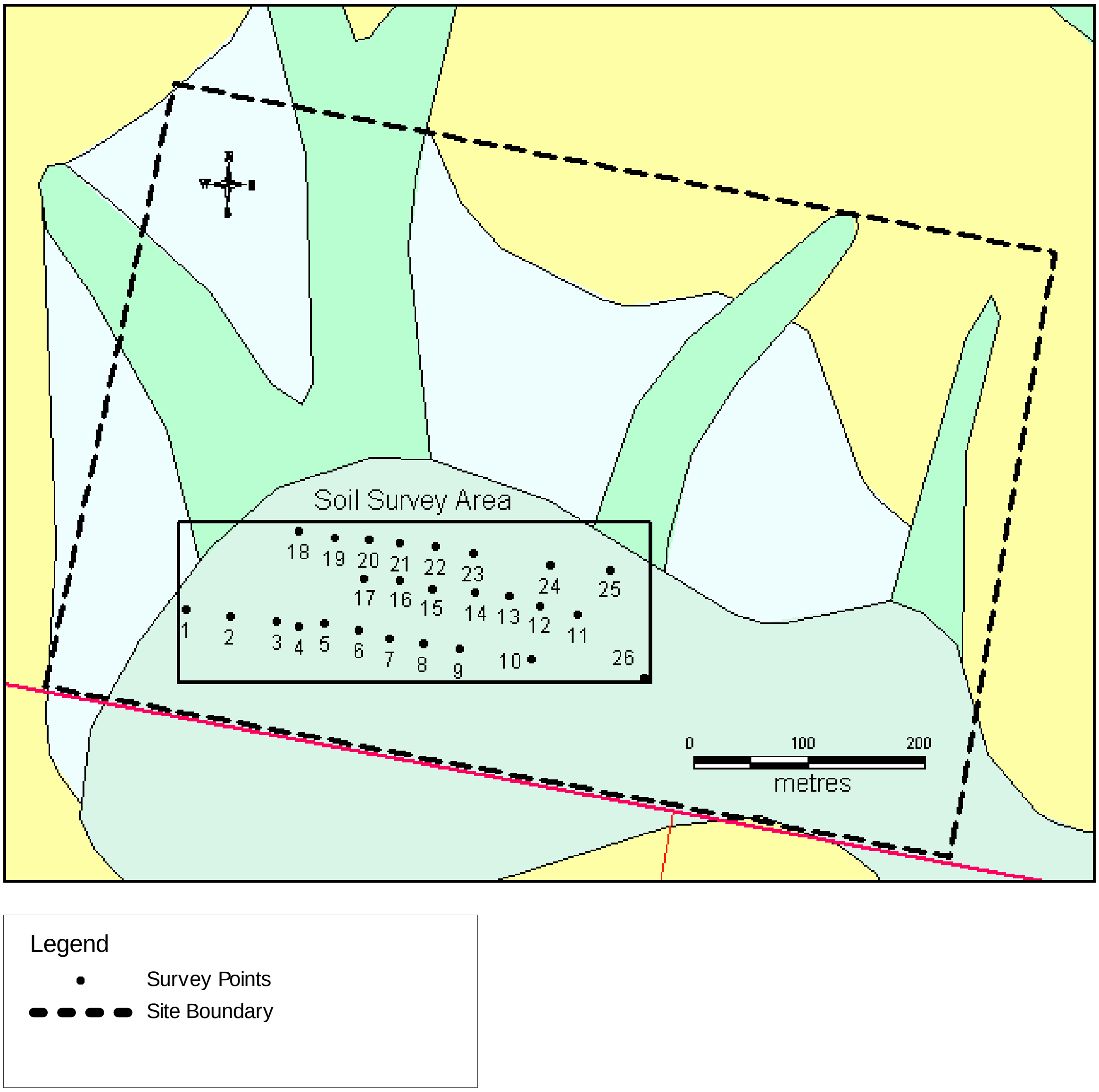


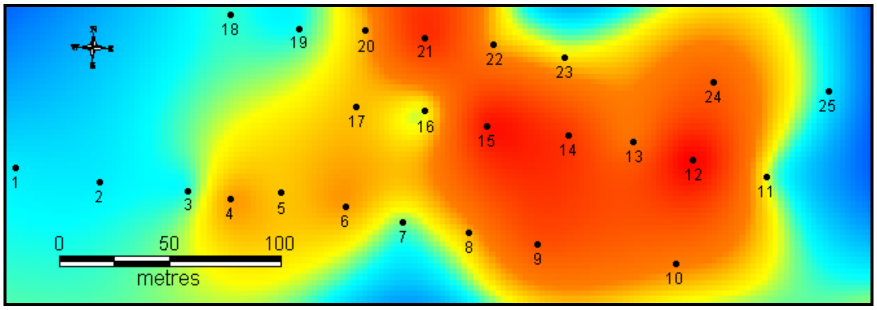
Figure 32 Mt Mercer geological map with the location of the soil survey (GSV, 2003).

The soil profile of the Mt Mercer site tends to be duplex in that there is a contrast between the A horizon and the B horizon texturally. The A and B soil horizon textures range from sandy loam to mottled heavy clay. The average depth of the A horizon is 40 centimetres. The recorded soil profiles and photographs are listed in Appendix 4.

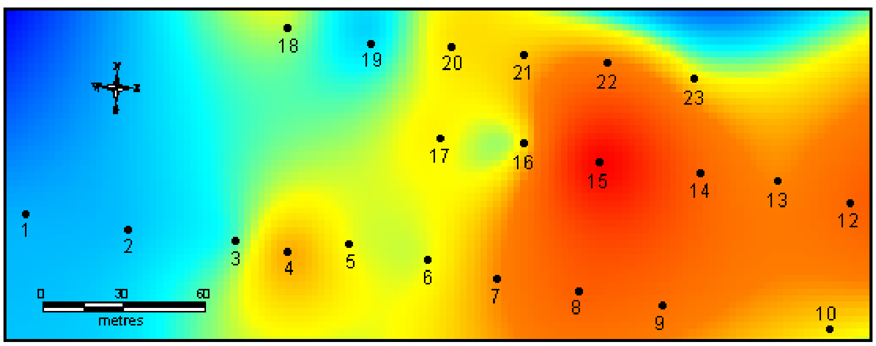
6.1.3 Electrical Conductivity

EC measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 33) using a histogram equalisation colour stretch with values ranging from low (0.3 mS/cm) to very high (>0.9 mS/cm) (Bates, 2004). The complete data set is appended (Appendix 5).

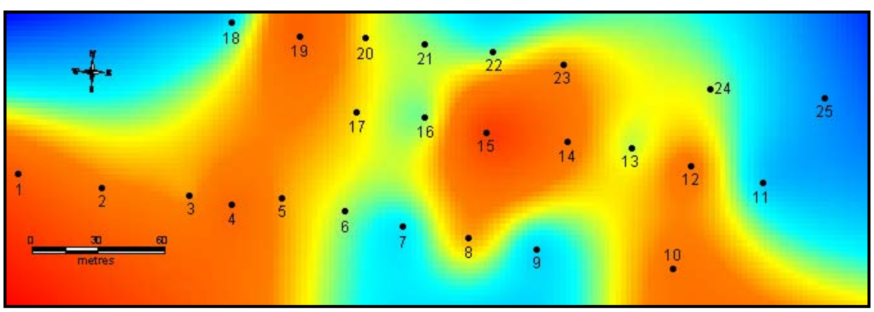
A



B



C



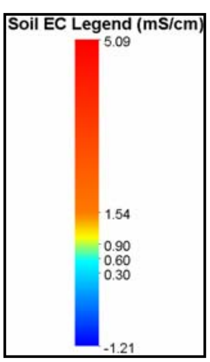


Figure 33 Soil EC of different soil horizons A) EC of Mt Mercer A1 horizon B) EC of Mt Mercer A2 horizon

Soil EC of the Mt Mercer site ranges from low to very high. Low ranges from 0.0 to 0.30 mS/cm, Moderate ranges from 0.30 to 0.60 mS/cm, High 0.60 to 0.90 mS/cm and Very High is anything greater than 0.90 mS/cm (Bates, 2004). The values illustrate (Figure 33) that the Mt Mercer site has an area of very high salinity down through the soil profile.

Soil Core Site Number	**June EC mS/cm**	**September EC mS/cm**	**Soil Salinity**
3	0.1	0.53	Increased
4	0.56	0.68	Increased
5	0.4	0.53	Increased
6	0.54	0.61	Increased
7	0.18	0.46	Increased
13	0.54	1.62	Increased
14	1.21	0.54	**Decreased**
15	1.63	1.22	**Decreased**
16	0.15	0.29	Increased
17	0.44	0.26	**Decreased**
20	0.39	0.59	Increased
21	1.39	0.5	**Decreased**
22	0.4	1.38	Increased
23	0.31	1.74	Increased

Table 2 Comparing Soil EC of the A soil horizon

The soil survey was repeated to detect any changes in soil salinity which had occurred over the winter months, when the soil tends to becomes waterlogged. Table 2 shows that the majority of reassessed soil increased in salinity.

6.1.4 Geophysical Survey

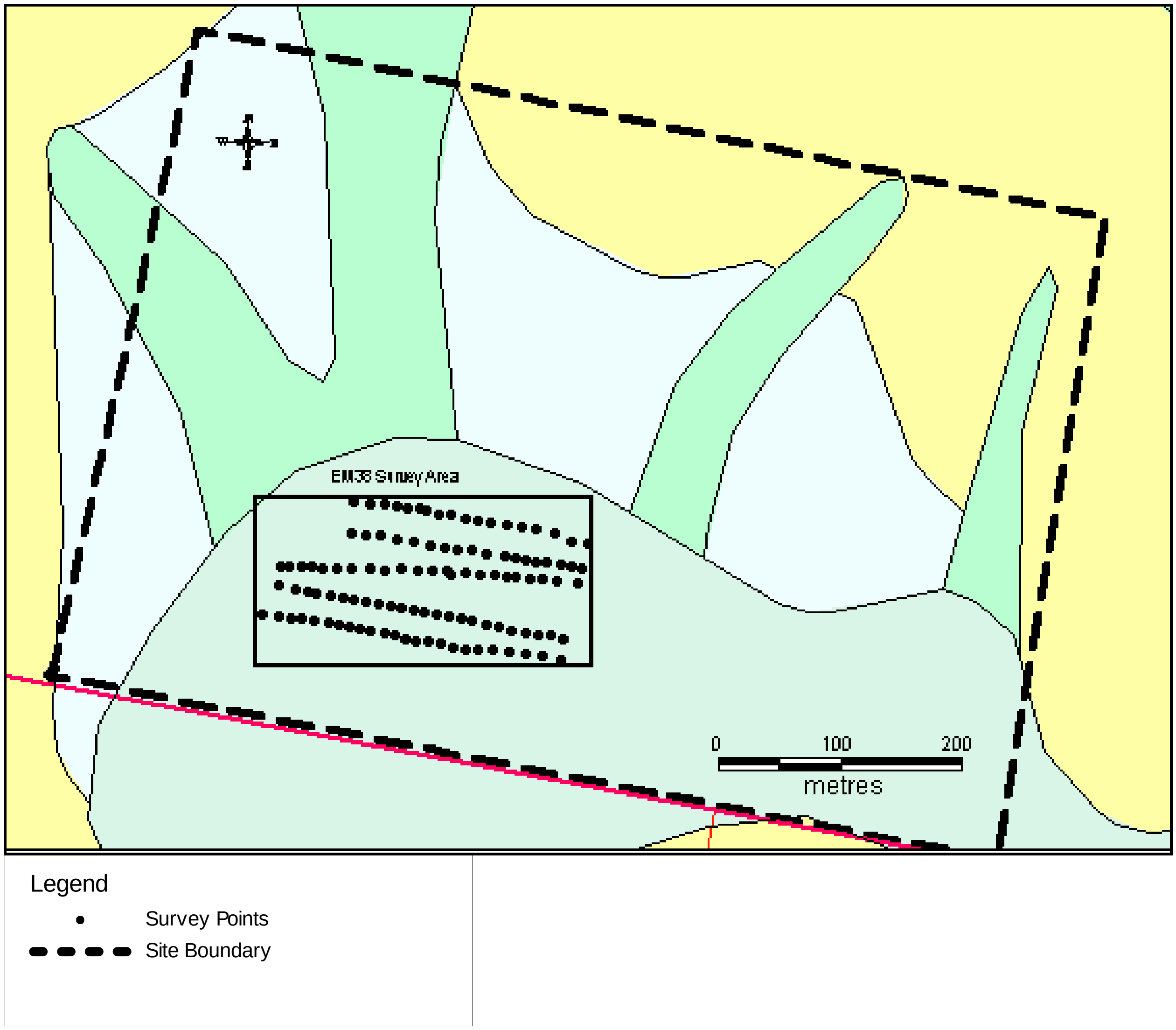


Figure 34 Mt Mercer geological map with EM survey points (GSV, 2003).

The results of the geophysical survey were provided by Advanced Soil Mapping (Bates, 2004) and are appended (Appendix 6). The values were analysed using minimum curvature interpolation griding algorithm with two metre grid cells in Discover v.6.1 (Encom, 2004). The resulting numeric surfaces are displayed (Figure 35) using a histogram equalisation colour stretch with values ranging from low (30 mS/m) to very high (>90 mS/m) (Bates, 2004).

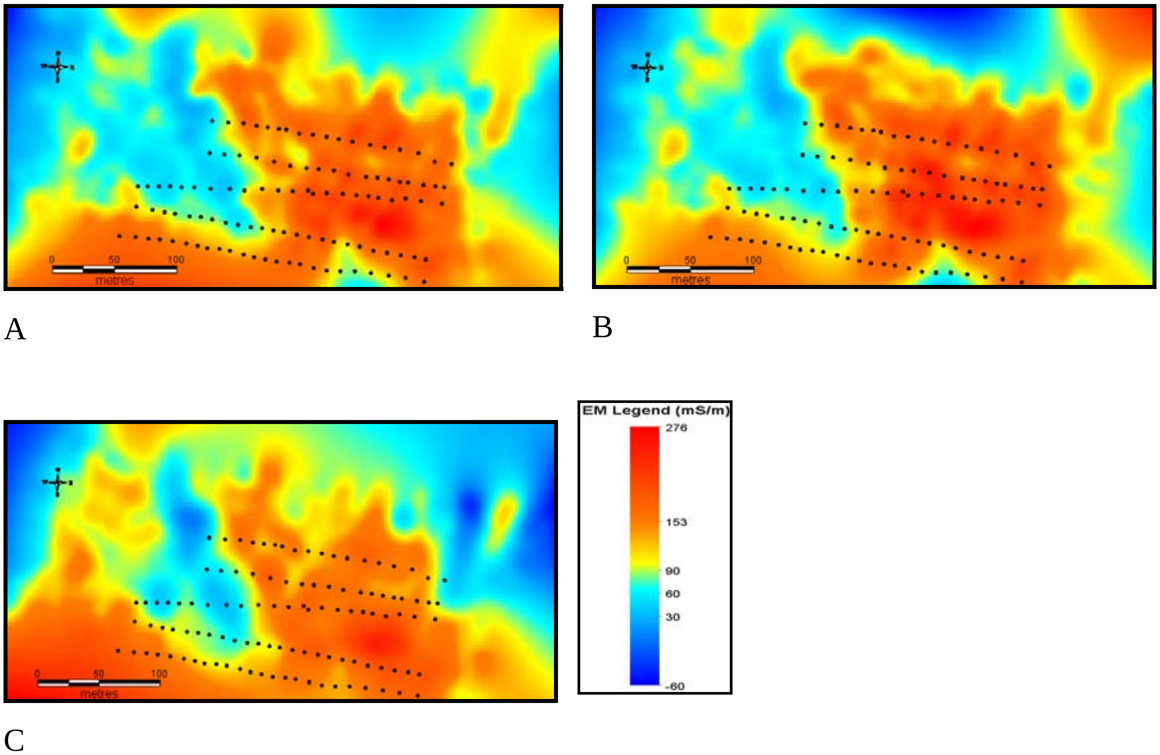


Figure 35 Advanced Soil Mapping Deniliquin Geophysical Survey at different soil depths with the reassessed EM38 data point on it A) Mt Mercer EM38V B) Mt Mercer Em38H C) Mt Mercer EM31

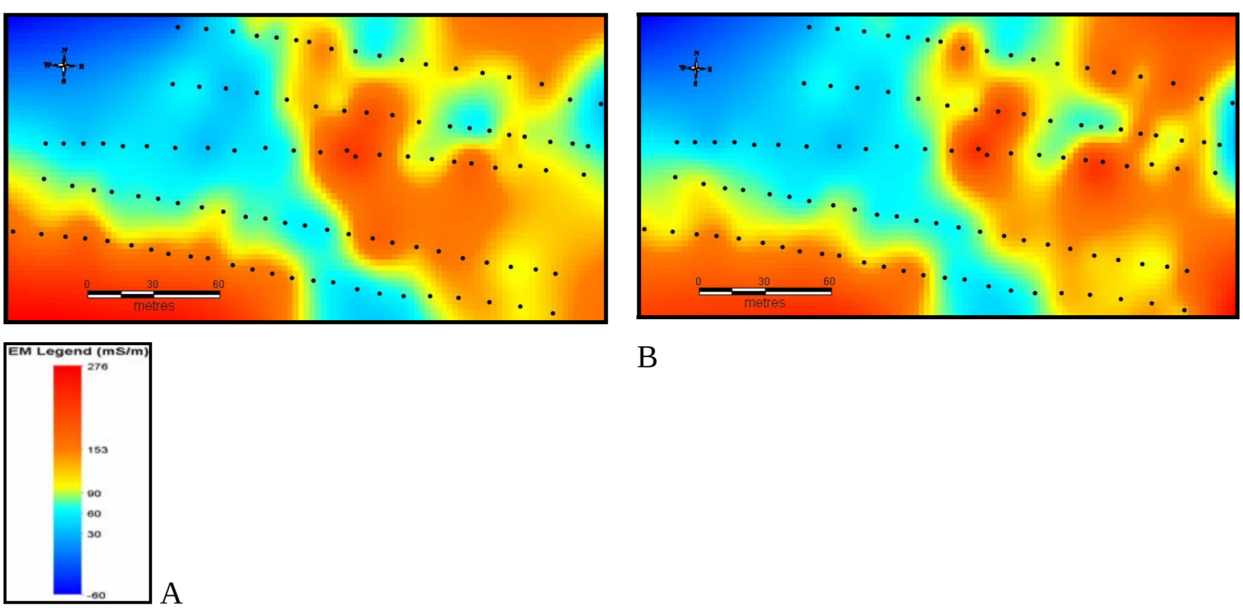


Figure 36 Reassessed Geophysical survey A) EM38 Vertical B) EM38 Horizontal

The geophysical surveys produce apparent electrical conductivity readings. Different depths of investigating are obtained by orientating the EM38 instrument in the horizontal and vertical orientation. Horizontal orientation of the EM38 averages the EC over a depth of 0.75 metres and the vertical orientation averages over two metres (Bates, 2004). The EM31 instrument averages the EC over five metres. The Mt Mercer site ranges from low to very high. Low ranges from 0 to 30 mS/m, Moderate ranges from 30 to 60 mS/m, High 60 to 90 mS/m and Very High anything greater than 90 mS/m (Bates, 2004). However, as the initial surveys were carried out when the soil was dry a seconded survey was completed using the University of Ballarat EM38 which is a very similar instrument to Advanced Soil Mapping's EM38. The complete data set is appended (Appendix 7). As Figure 35 shows the geophysical data shows a very high salinity area down the profile. Figure 36 the reassessment of the Mt Mercer site shows there is little difference between the two, as thought before.

6.1.5 pH

pH measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 37) using a histogram colour stretch with values ranging from 4.7 to 6.03, which are highly acidic to acidic and in the pH range for optimum pasture growth (Gunn *et al.*, 1988). The complete data set is appended (Appendix 5)

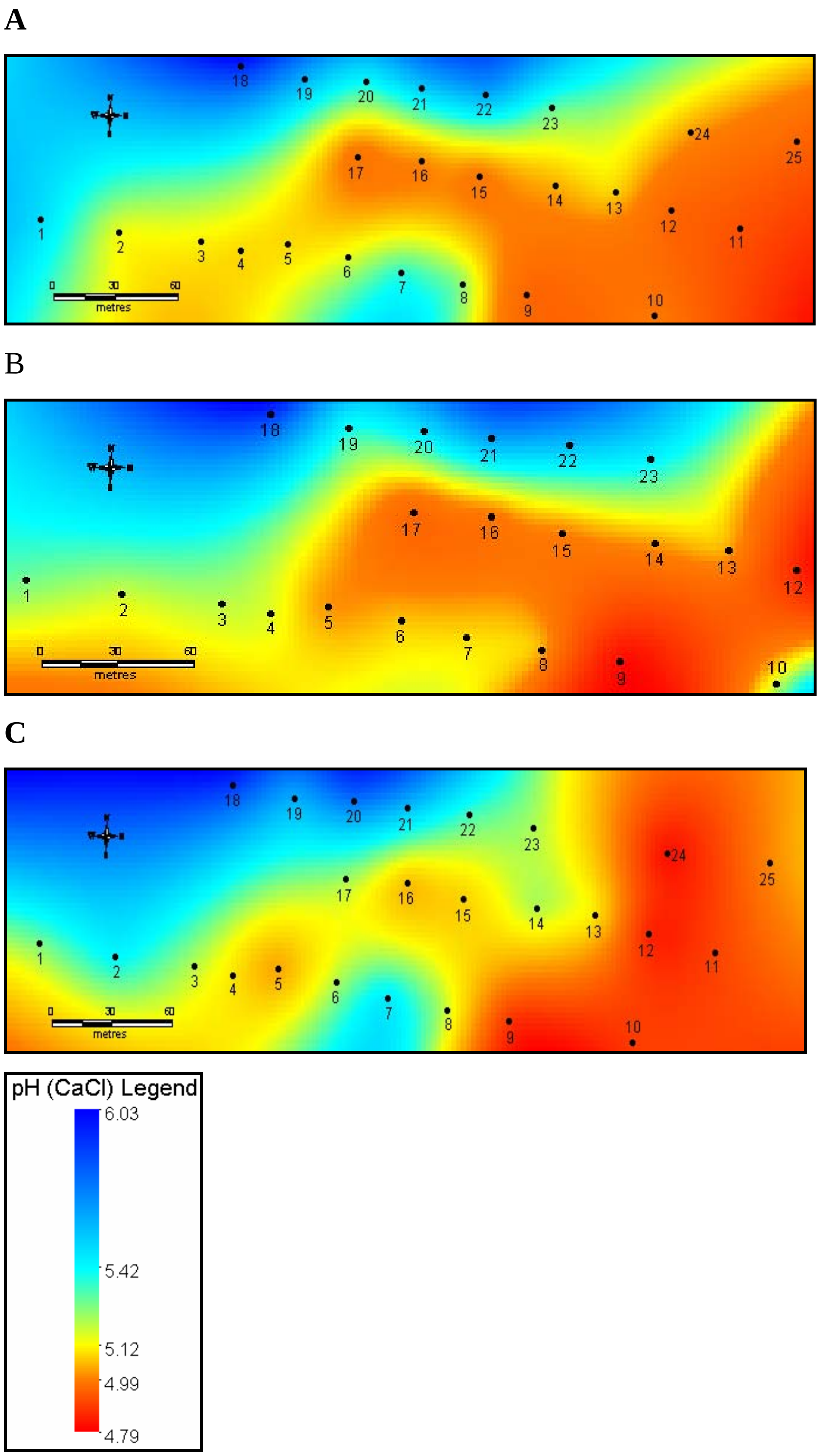


Figure 37 Soil pH of different soil horizons A) Mt Mercer A1 horizon B) Mt Mercer A2 horizon C) Mt Mercer B horizon

Figure 37 shows the Mt Mercer site has varying soil pH. Soil with a pH ranging from 5.5 to 8 are said to be normal (Gunn *et al.*, 1988). Mt Mercer soil is mostly under 5.5 making the soils acidic. The high acidic soils tend to correlate with the high EC readings from Figure 33.

6.1.6 Soil Test

Six samples with varying salinity and depth were sent away to Farmright Technical Services Pty. Ltd where CEC, EC and pH were analysed. Full test report is appended in Appendix 8.

ANALYSIS		**UNITS**	**M9 0-30**	**M9 53-73**	**M16 0-20**	**M16 50-76**	**M21 0-20**	**M21 30-65**
pH	(1:5water)		4.9	5.3	5.5	5.1	5.0	5.2
pH	(CaCl2)		4.4	4.4	4.6	4.5	4.6	4.6
Salinity (EC)	(1:5water)	mS/cm	1.03	0.22	0.13	0.39	1.33	0.45
Calcium	(Exch)	meq/100g	0.62	0.15	0.69	0.14	0.84	0.24
Magnesium	(Exch)	meq/100g	4.35	1.73	2.97	4.04	4.39	3.64
Sodium	(Exch)	meq/100g	3.85	1.30	0.73	2.26	6.11	2.43
Potassium	(Exch)	meq/100g	0.17	0.07	0.17	0.13	0.13	0.08
Aluminium	(Exch)	meq/100g	0.41	0.43	0.50	0.35	0.43	0.25
Calculations								
Sum of cations	(CEC)	meq/100g	9.40	3.68	15.29	6.92	11.90	6.64
Calcium/Magnesium ratio			0.1	0.1	1.9	0.0	0.2	0.1
Sodium % of cations	(ESP)		41.0%	35.3%	4.8%	32.7%	51.3%	36.6%
Aluminium % of cations			4.4%	11.7%	3.3%	5.1%	3.6%	3.8%

Table 3 Soil Test analysis

Table 3 shows the soil CEC test results, which indicates that the soil at Mt Mercer has a nutrient imbalance for pasture productivity. The desirable levels for Calcium, Magnesium, Sodium, Potassium and Aluminium for a balanced soil are:

Cation	**Desirable Levels percentage**
Calcium	65-75
Magnesium	12-15
Sodium	0.5-5
Potassium	5
Aluminium	<5

Table 4 Desirable levels for CEC cations (SWEP)

As Table 3 shows some cations are insufficient and some are over supplied for pasture production. The main outcome from Table 3 is the calculation of CEC's which indicate a balanced soil. Calculations for a balanced soil are:

Calculations	Desirable levels
Sum of cations	>10 meq/100g
Calcium/Magnesium ratio	2 to 4
Sodium % of cations	<5
Aluminium % of cations	<5

Table 5 Desirable levels for CEC calculations

The CEC calculations illustrate that the sum of cations and the Calcium/Magnesium ratio is low indicating a nutrient imbalance for pasture productivity. Sodium percentage of cations is very high indicating sodic soils, which can have implications on soil structure. The Aluminium percentage of cations is high in one sample but is reasonable in all other samples.

6.2 Illabarook

6.2.1 Vegetation Assessment and Aerial Photography

Sandra Wagenfeller also conducted the on-ground vegetation assessment for the Illabarook site. Historic aerial photography, obtained from the Land Victoria library at Laverton, was also used to asses the trend in vegetation on the site over time.

Spiny Rush, Streaked Arrow Grass, Toad Rush, Sea Barley Grass, Annual Beard Grass and Buck's Horn Plantain were mapped at Illabarook shown on the 2002 aerial photograph (Figure 38). The site has a severity rating of 50/50 class 1 and class 2.

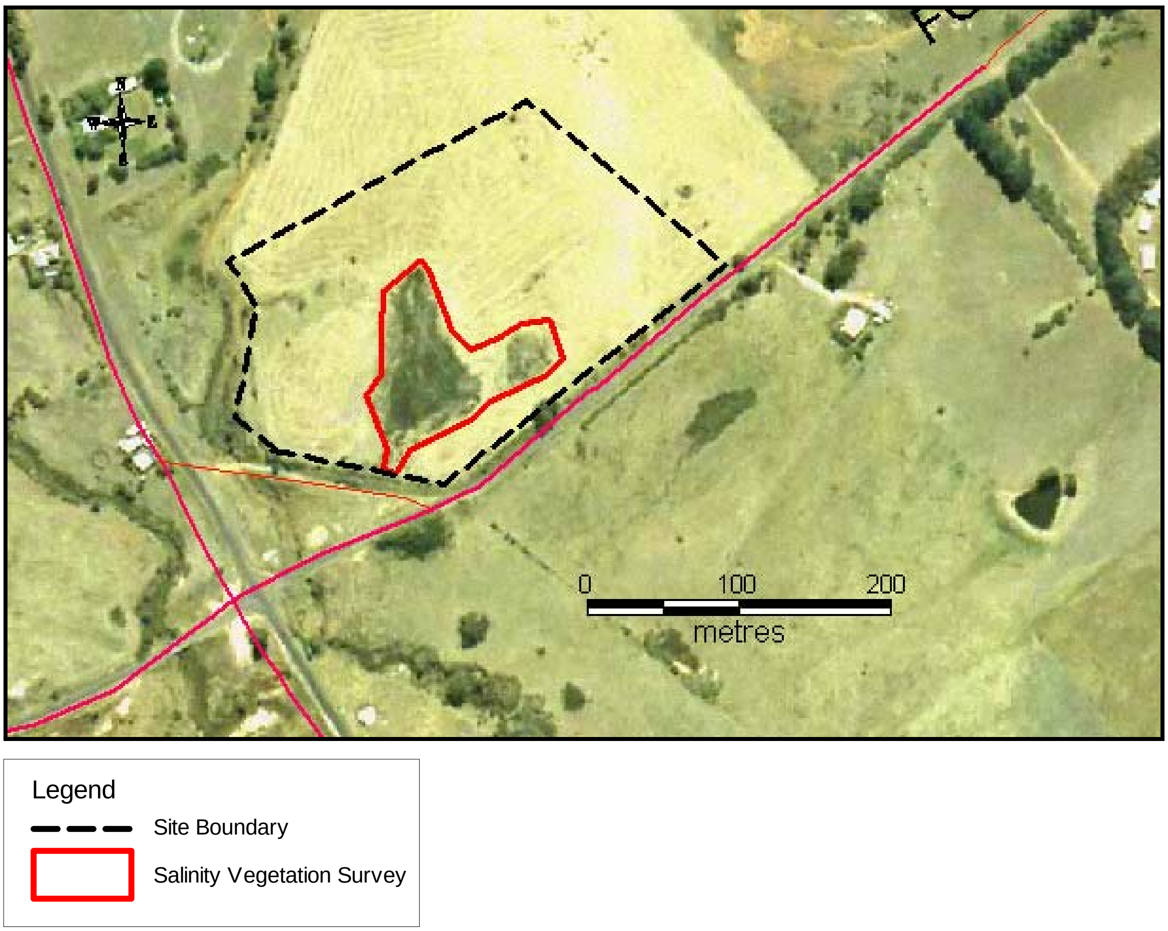
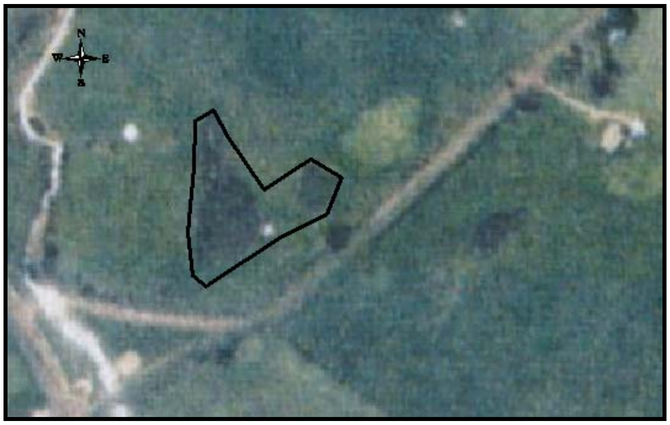
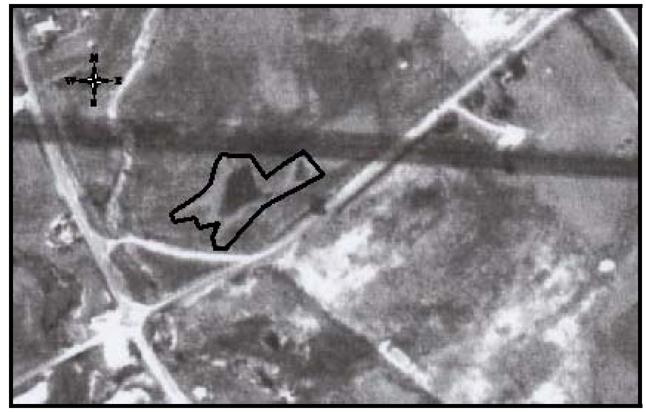


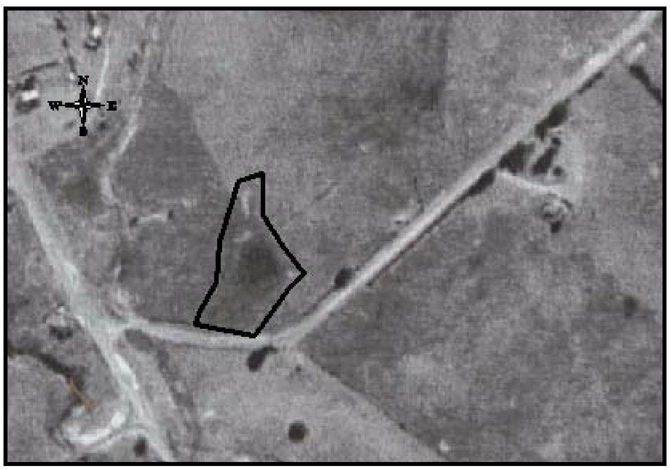
Figure 38 Illabarook 2002 Aerial photograph with salinity outlined



A



B



C

Figure 39 Historical air photography of Illabarook A) Illabarook 1990 B) Illabarook 1981 C) Illabarook 1970

Three historical aerial photos were selected to asses the severity of salinity at the site over the past 30 years (Figure 39). The photo history clearly shows that the area affected by salinity at the site has increased over 30 years. The estimated increase is 40 percent.

6.2.2 Soil

Twenty-two soil cores were taken from the Illabarook site to map the soil profile, EC, pH and soil textures (Figure 40). Appendix 9 lists the GPS points and total depth of each core taken.

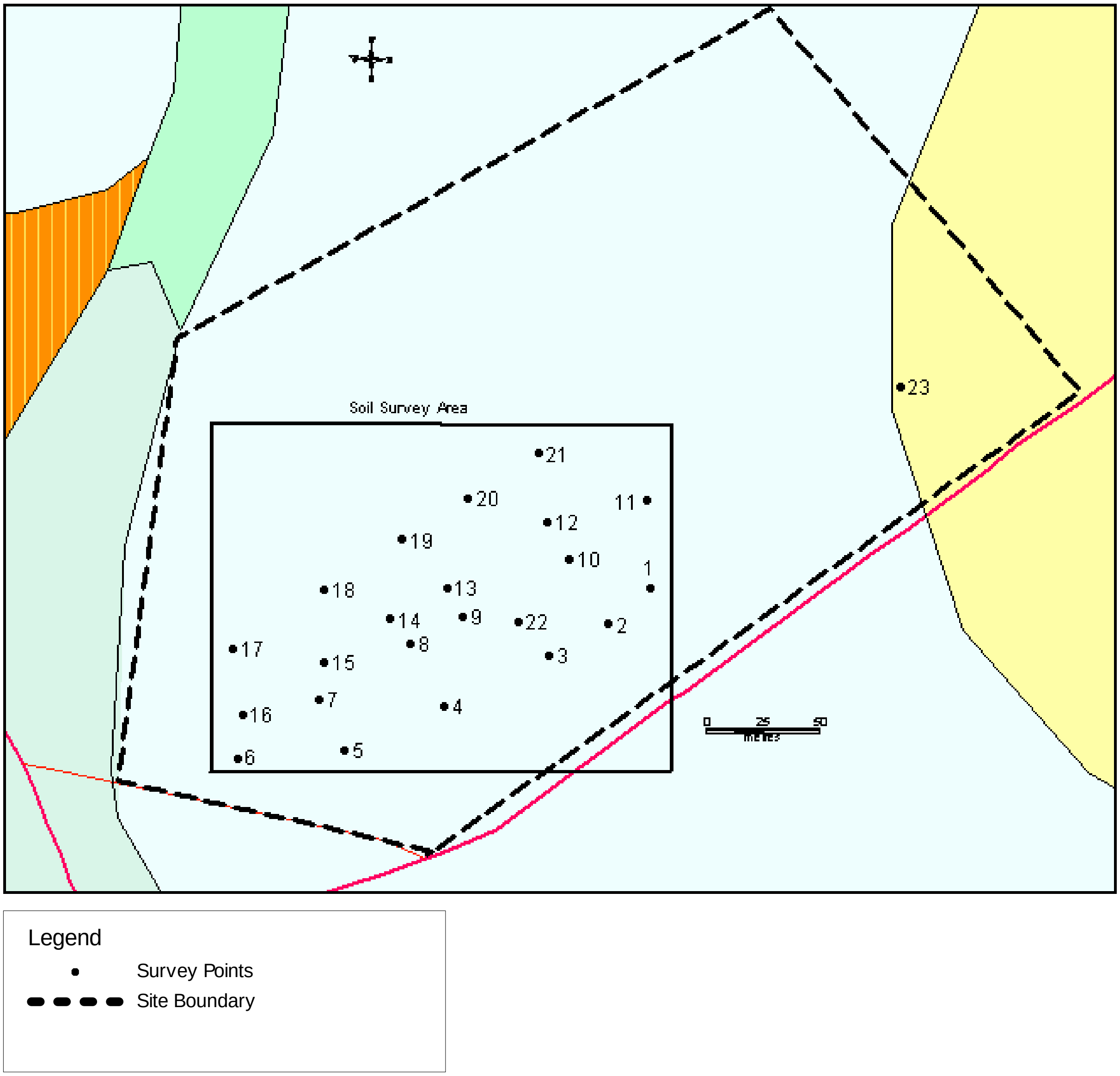


Figure 40 Illabarook geological map with soil survey points (GSV, 2003).

The soil profile of the Illabarook site tends to be duplex. The A and B soil horizon textures range from clay loam to mottled heavy clay. The A horizon averages a depth of 30 centimetres. Profile description appended in Appendix 10.

6.2.3 Electrical Conductivity

EC measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 41) using a histogram equalisation colour stretch with values ranging from low (0.3 mS/cm) to very high (>0.9 mS/cm) (Bates, 2004). The complete data set is appended (Appendix 11).

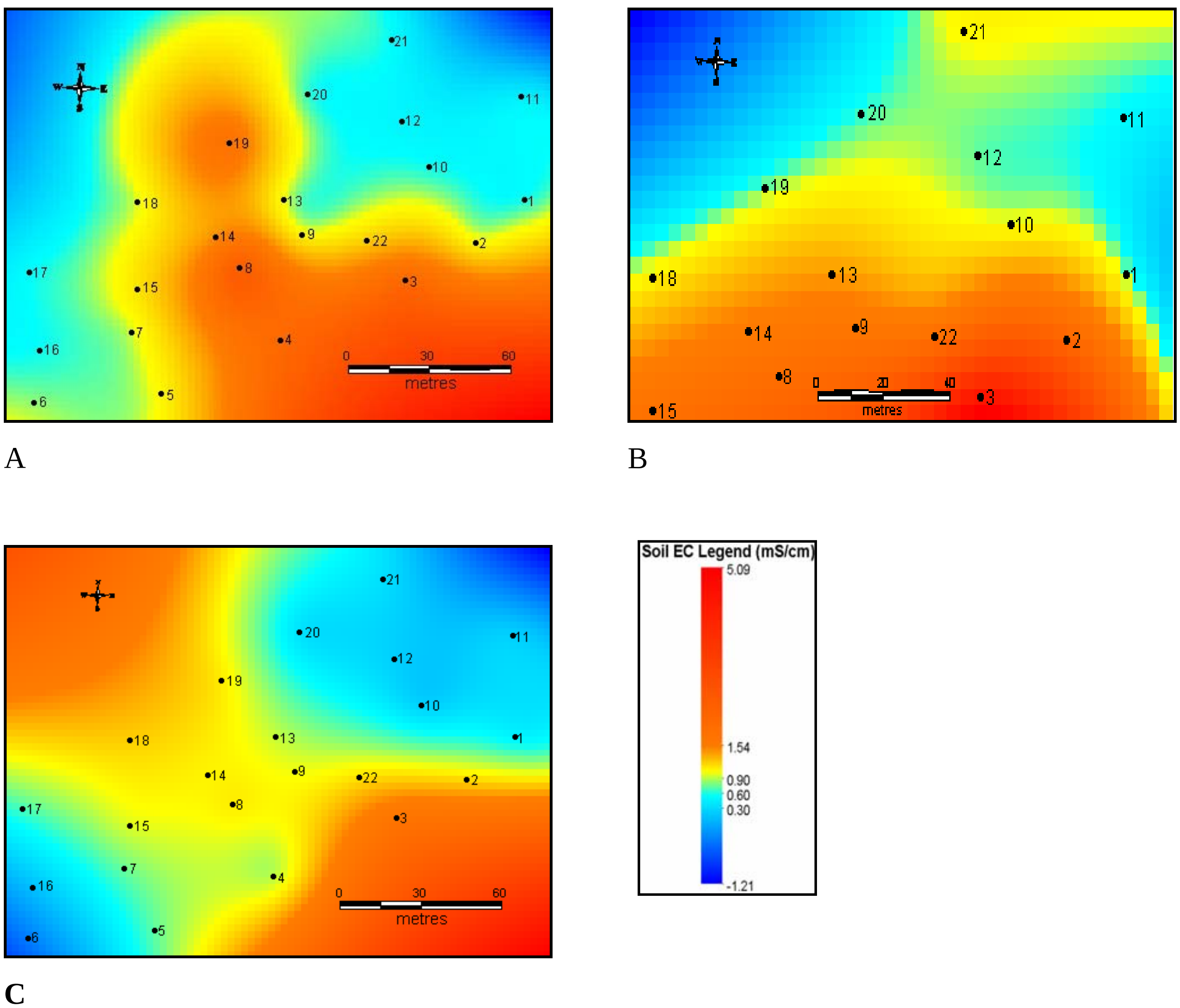


Figure 41 Soil EC of different soil horizons A) Illabarook A1 horizon B) Illabarook A2 horizon C) Illabarook B horizon

Figure 41 shows that very high EC readings appear through the middle of the Illabarook site down through the soil profile. The highest readings tend to be in the A1 horizon of the soil (Figure 41 A).

Soil Core Site Number	June EC mS/cm	September EC mS/cm	Soil Salinity
2	0.37	0.34	**Decreased**
3	2.45	1.82	**Decreased**
4	2.23	1.29	**Decreased**
5	0.46	1.29	Increased
7	0.33	0.99	Increased
8	3.09	2.12	**Decreased**
9	0.3	0.29	**Decreased**
13	0.31	0.19	**Decreased**
14	1.23	1.96	Increased
15	0.7	0.43	**Decreased**
18	0.32	0.35	Increased
19	2.28	1.16	**Decreased**
22	0.76	0.39	**Decreased**

Table 6 Comparing Soil EC of the A soil horizon

The soil survey was repeated to detect changes in soil salinity which had occurred over the winter months, when the soil tends to becomes waterlogged. Table 6 shows that the majority of reassessed soil decreased in salinity.

6.2.4 Geophysical Survey

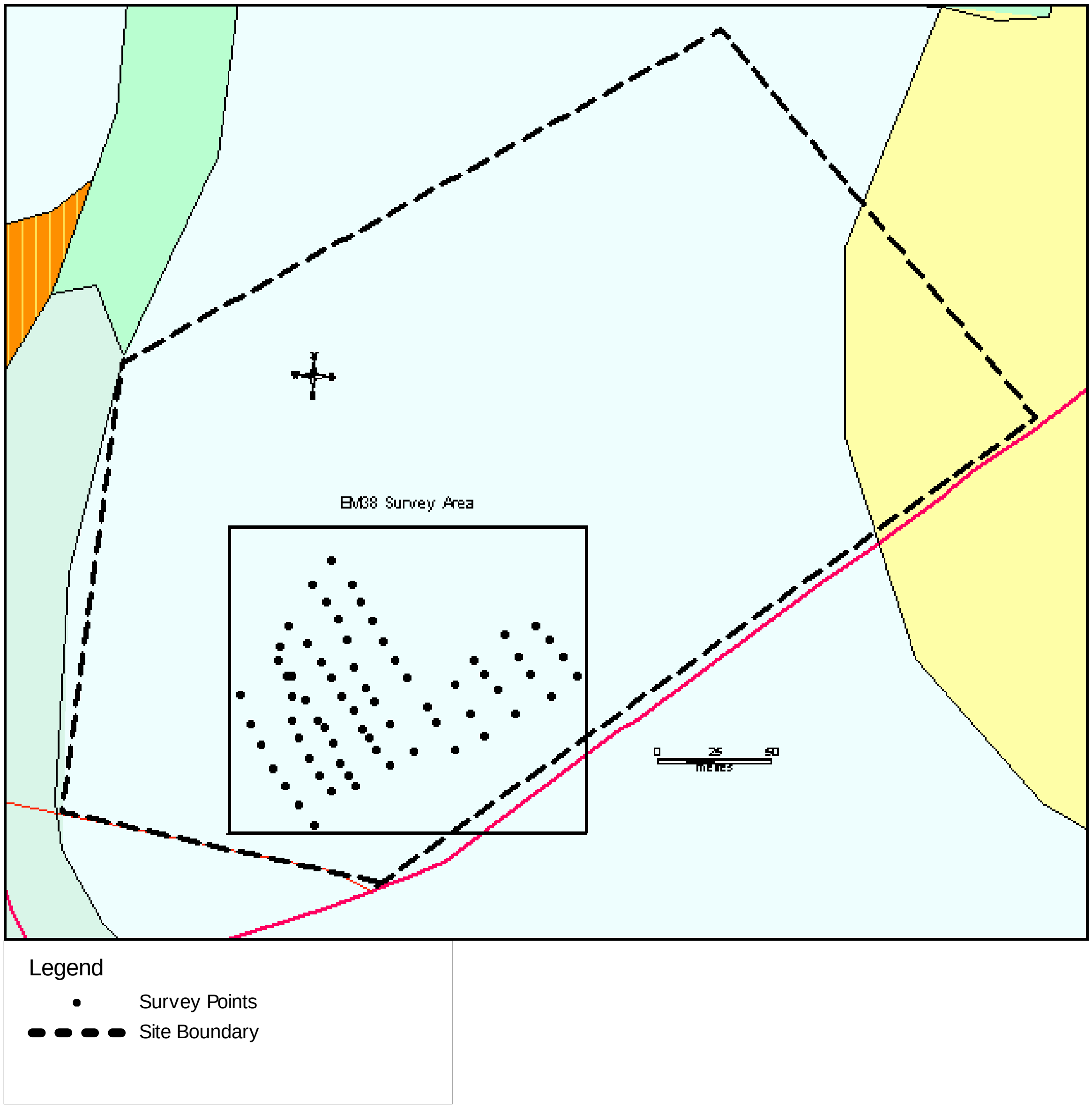
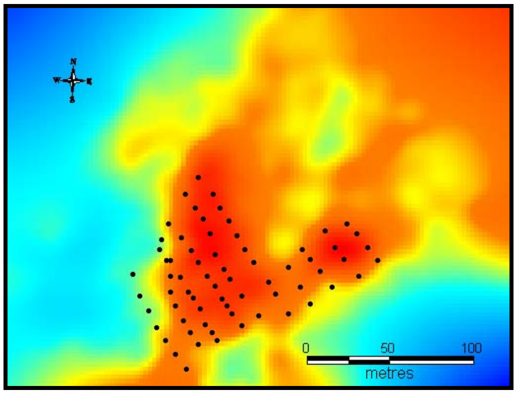
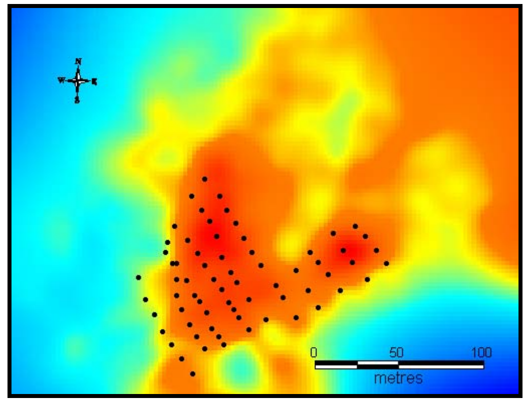


Figure 42 Illabarook geological map with EM survey points (GSV, 2003).

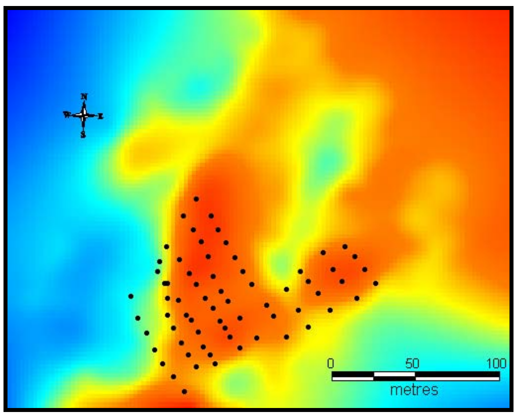
The results of the geophysical survey were provided by Advanced Soil Mapping (Bates, 2004) and are appended (Appendix 12). The values were analysed using minimum curvature interpolation griding algorithm using a two metre grid cell in Discover v.6.1 (Encom, 2004). The resulting numeric surfaces are displayed (Figure 43) using a histogram equalisation colour stretch with values ranging from low (30 mS/m) to very high (>90 mS/m) (Bates, 2004).

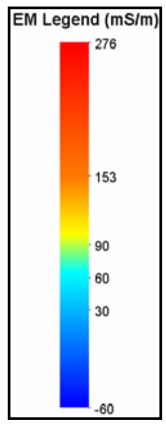


A



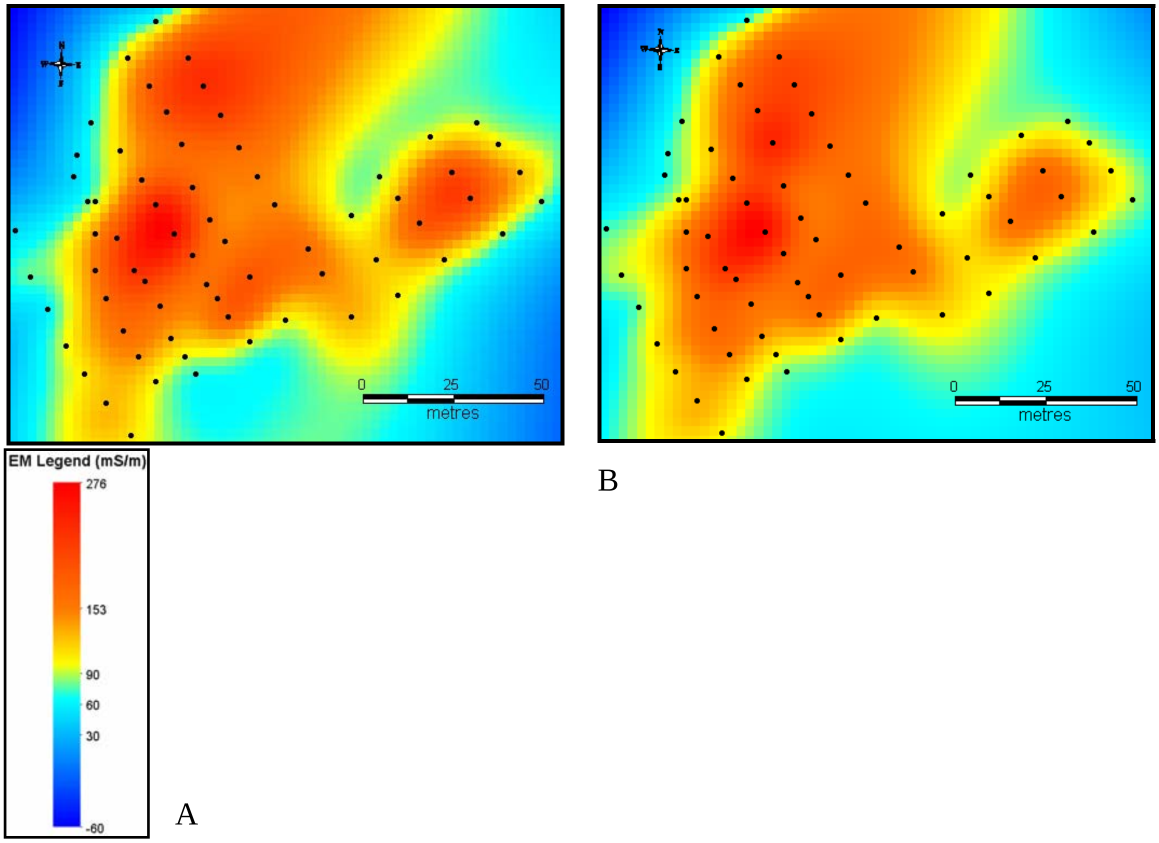
B





C

Figure 43 Advanced Soil Mapping Deniliquin Geophysical Survey at different soil depths with the reassessed EM38 data point on it A) Illabarook EM38V B) Illabarook EM38H C) Illabarook EM31



A

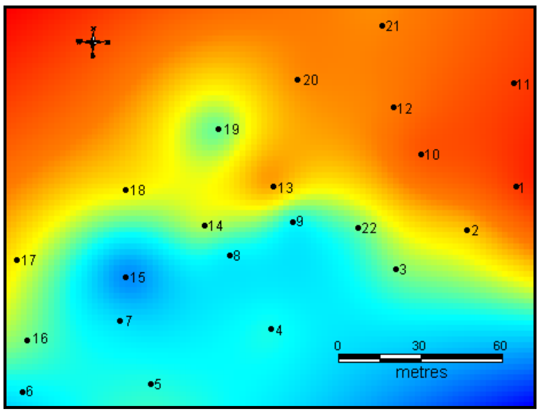
B

Figure 44 Reassessed Geophysical survey A) EM38 Vertical B) EM38 Horizontal

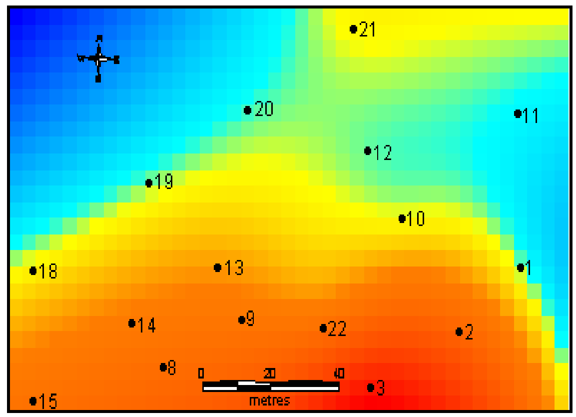
As Figure 43 shows the geophysical data shows a very distinct high salinity area down the profile. However, as the initial surveys were carried out when the soil was dry a seconded survey was completed using the University of Ballarat EM38 which is a very similar instrument to Advanced Soil Mapping’s EM38. The complete data set is appended (Appendix 13). Figure 44 the reassessment of the Illabarook site shows there is little difference between the two, as thought before.

6.2.5 pH

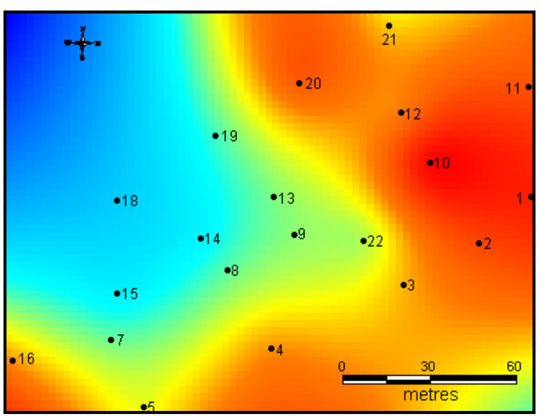
pH measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 45) using a histogram colour stretch with values ranging from 4.7 to 6.03, which are highly acidic to acidic and in the pH range for optimum pasture growth (Gunn *et al.*, 1988). The complete data set is appended (Appendix 11)



A



B



C

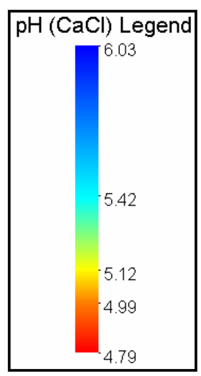


Figure 45 Soil pH of different soil horizons A) Illabarook A1 pH (CaCl) B) Illabarook A2 pH (CaCl) C) Illabarook B pH (CaCl)

Figure 45 demonstrates that the Illabarook site has varying soil pH. Normal pH ranging from 5.5 to 8 is in conjunction with the high salinity values of Figure 41 and the below 5.5 pH values surround the highly saline area.

6.2.6 Soil Test

ANALYSIS		**UNITS**	**Il 8 0-23**	**Il 8 23-67**	**Il 15 0-28**	**Il 15 28-65**	**Il 22 0-26**	**Il 22 40-69**
pH	(1:5water)		7.7	7.9	7.4	7.7	6.6	7.7
pH	(CaCl2)		7.5	7.5	7.0	7.2	6.2	7.0
Salinity (EC)	(1:5water)	mS/cm	3.94	1.27	0.50	0.91	1.03	1.15
Calcium	(Exch)	meq/100g	5.30	1.73	3.43	4.05	1.67	3.07
Magnesium	(Exch)	meq/100g	4.14	4.16	3.93	4.15	4.20	4.19
Sodium	(Exch)	meq/100g	11.68	5.18	3.39	6.91	4.93	11.02
Potassium	(Exch)	meq/100g	0.20	0.14	0.37	0.79	0.29	0.44
Aluminium	(Exch)	meq/100g	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Calculations								
Sum of cations	(CEC)	meq/100g	21.32	27.88	11.12	15.90	11.09	18.72
Calcium/Magnesium ratio			1.3	1.9	0.9	1.0	0.4	0.7
Sodium % of cations	(ESP)		54.8%	18.6%	30.5%	43.5%	44.5%	58.9%
Aluminium % of cations			< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%

Table 7 Soil test analysis

Table 7 shows the soil CEC test results, which indicates that the soil at Illabarook has a nutrient imbalance for pasture productivity. Full test report Appendix 14. As Table 7 shows some cations are insufficient and some are over supplied for pasture production. The CEC calculations illustrate that the Calcium/Magnesium ratio and the Aluminium percentage are low indicating a nutrient imbalance for pasture productivity. Sodium percentage of cations is very high indicating sodic soils, which can have implications on soil structure. The sum of cations is above 10 indicating a soil which will have a high exchange of cations.

6.3 Pittong

6.3.1 Vegetation Assessment and Aerial Photography

Sandra Wagenfeller also conducted the on-ground vegetation assessment for the Pittong site. Historic aerial photography, obtained from the Land Victoria library at Laverton, was also used to asses the trend in vegetation on the site over time.

Sea Barley Grass, Annual Beard Grass, Spiny Rush, Toad Rush, Buck's Horn Plantain and Ruby Salt Bush were mapped at Pittong shown on the 2002 aerial photograph (Figure 46). The site has a severity rating of 40 percent class 1 and 60 percent class 2.

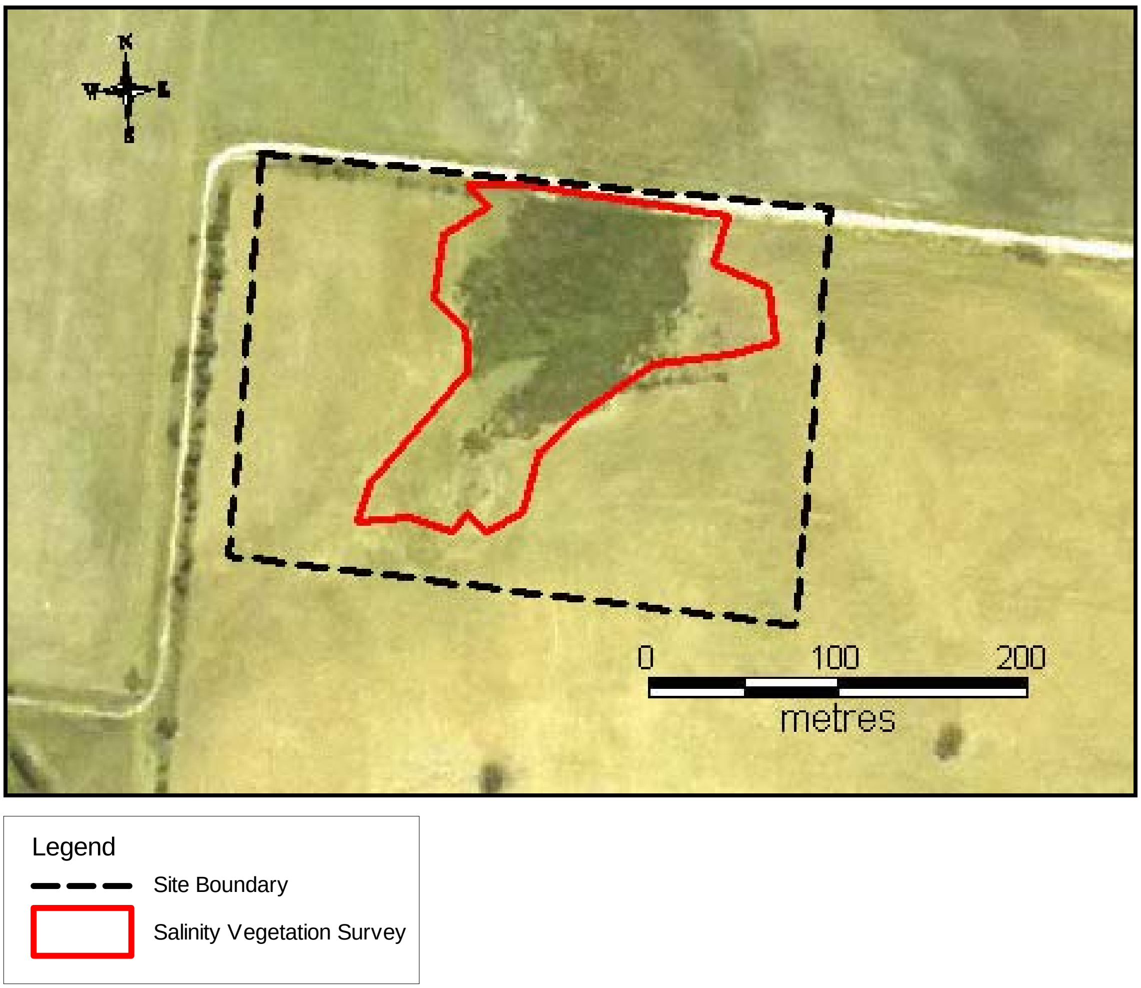
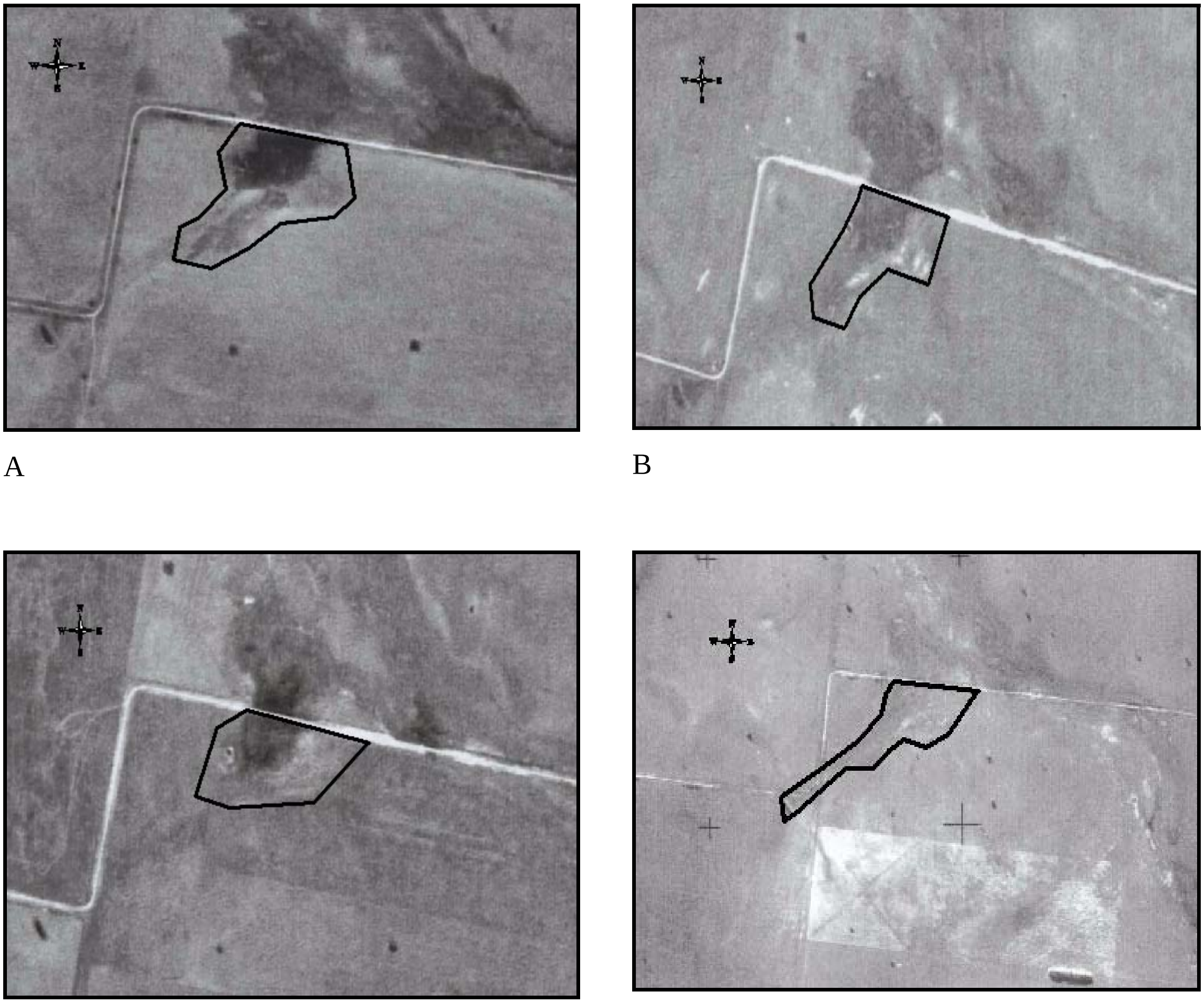


Figure 46 Pittong 2002 Aerial photograph with salinity outlined



A B C D

Figure 47 Historical air photography showing saline areas A) Pittong 1988 B) Pittong 1979 C) Pittong 1971 D) Pittong 1946

Four historical aerial photos were selected to asses the severity of salinity at the site over the past 42 years (Figure 47). The photo history clearly shows that the area affected by salinity at the site has increased over 42 years. The estimated increase is 50 percent.

6.3.2 Soil

Twenty-seven soil cores were taken from the Pittong site to map the soil profile, EC, pH and soil textures (Figure 48). Appendix 15 lists the GPS points and total depth of each core taken.

Figure 48 Pittong geological map with soil survey points (GSV, 2003).

The soil profile of the Pittong site tends to be duplex. The A and B soil horizon textures range from clay loam to mottled sandy heavy clay. The average depth of the A horizon is 40 centimetres. Profile descriptions and photos appended in Appendix 16.

6.3.3 Electrical Conductivity

EC measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 49) using a histogram equalisation colour stretch with values ranging from low (0.3 mS/cm) to very high (>0.9 mS/cm) (Bates, 2004). The complete data set is appended (Appendix 17).

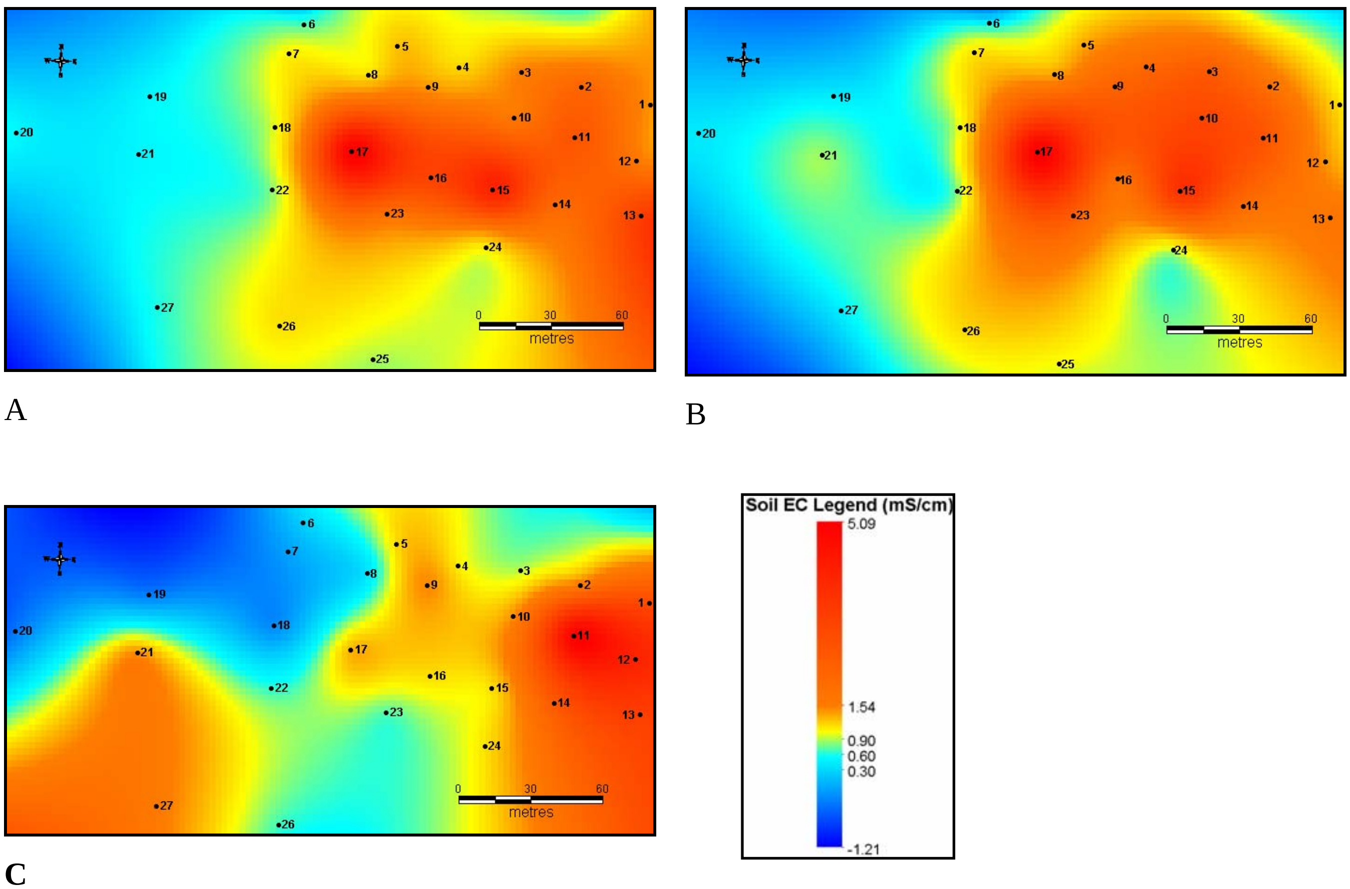


Figure 49 Soil EC of different soil horizons A) EC of Pittong A1 horizon B) EC of Pittong A2 horizon C) EC of Pittong B horizon

Figure 49 shows that very high EC readings appearing through the middle of the Pittong site down through the soil profile. The highest readings tend to be in the A1 horizon of the soil (Figure 49 A).

Soil Core Site Number	June EC mS/cm	September EC mS/cm	Soil Salinity
2	1.82	1.16	**Decreased**
3	1.43	2.52	Increased
4	0.75	2	Increased
5	1.08	1	**Decreased**
8	0.56	0.55	**Decreased**
9	1.15	1.26	Increased
10	1.26	1.75	**Decreased**
11	2.08	0.8	**Decreased**
14	1.63	2.22	Increased
15	3.22	3.14	**Decreased**
16	2.31	1.35	**Decreased**
17	3.84	1.46	**Decreased**
18	0.47	0.52	Increased
22	0.22	0.27	Increased
23	1.48	0.48	**Decreased**
24	0.47	0.46	**Decreased**

Table 8 Comparing Soil EC of the A soil horizon

The soil survey was repeated to detect changes in soil salinity which had occurred over the winter months, when the soil tends to becomes waterlogged. Table 8 shows that the majority of reassessed soil decreased in salinity.

6.3.4 Geophysical Survey

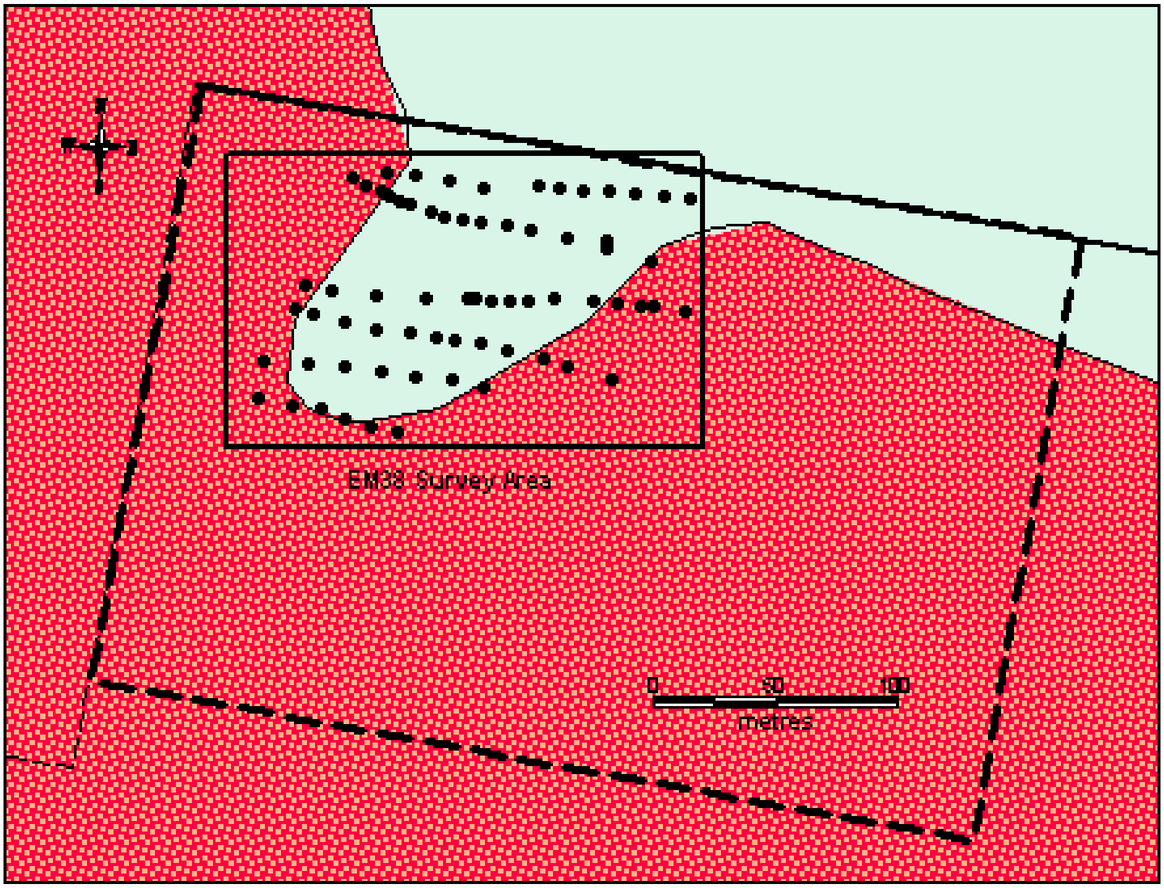
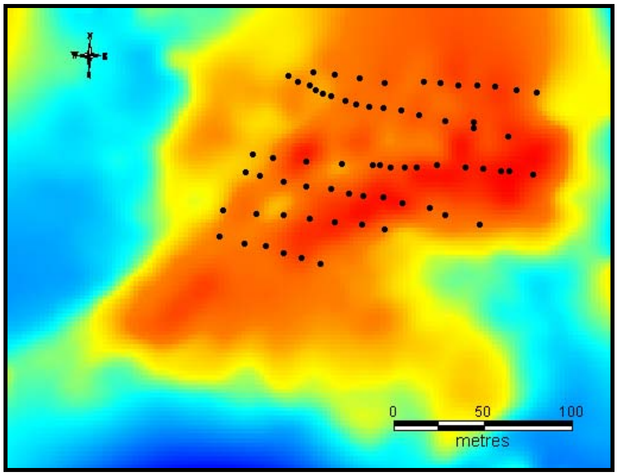
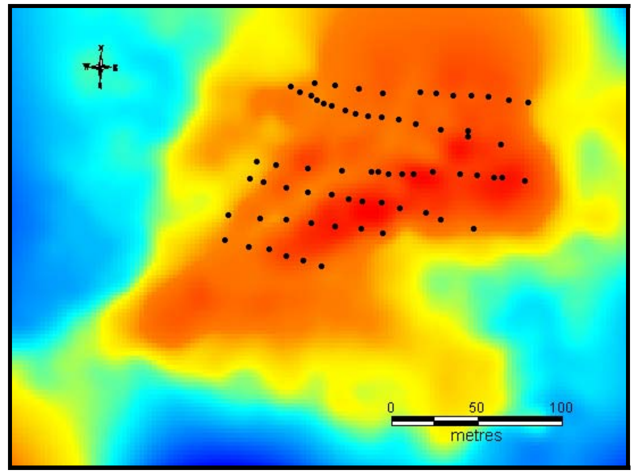


Figure 50 Pittong's geological map with EM survey points (GSV, 2003).

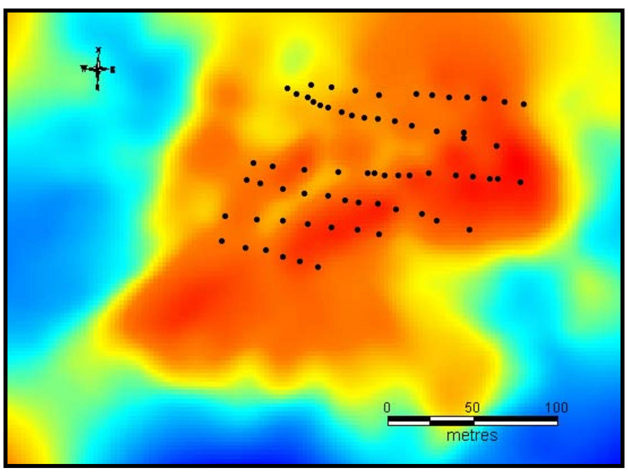
The results of the geophysical survey were provided by Advanced Soil Mapping (Bates, 2004) and are appended (Appendix 18). The values were analysed using minimum curvature interpolation griding algorithm with two metre grid cells in Discover v.6.1 (Encom, 2004). The resulting numeric surfaces are displayed (Figure 51) using a histogram equalisation colour stretch with values ranging from low (30 mS/m) to very high (>90mS/m) (Bates, 2004).

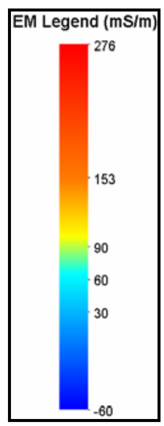


A



B





C

Figure 51 Advanced Soil Mapping Deniliquin Geophysical Survey at different soil depths with the reassessed EM38 data point on it A) Pittong EM38V B) PittongEM38H C) Pittong EM31

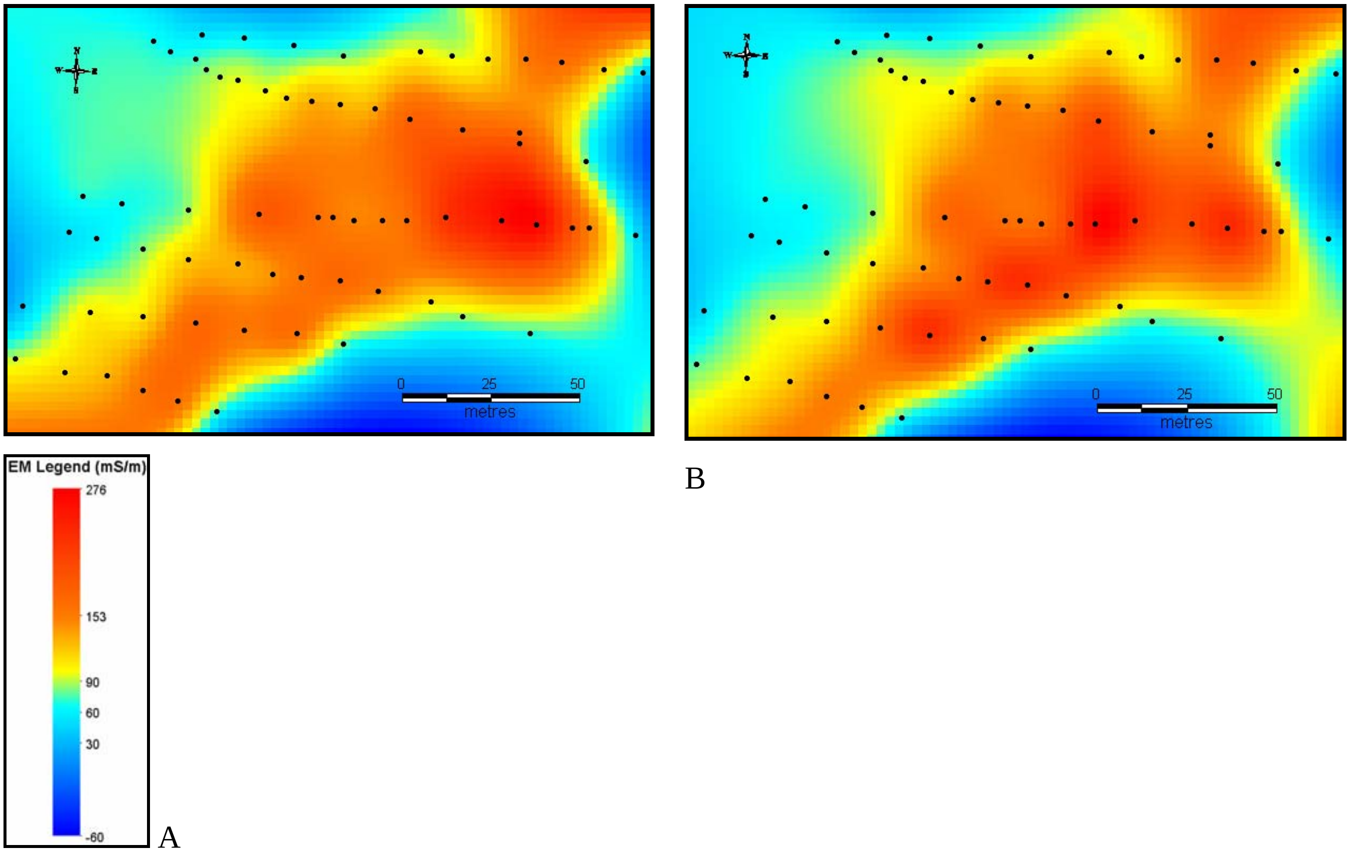
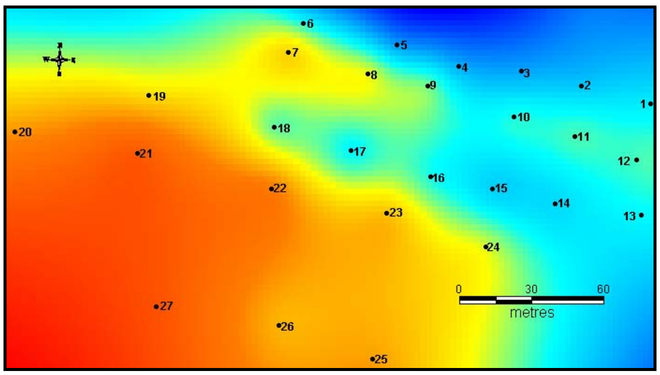


Figure 52 Reassessed Geophysical survey A) EM38 V 5/10 B) EM38 H 5/10

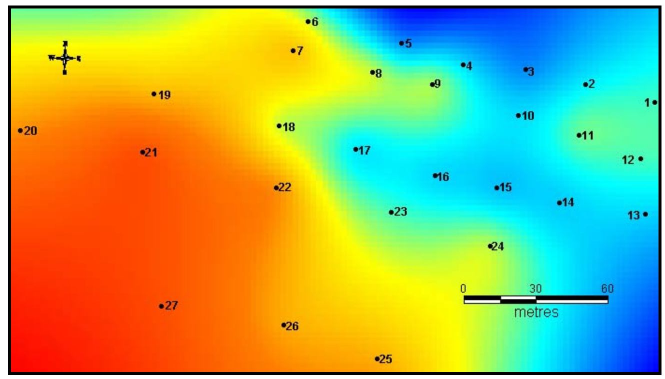
As Figure 51 shows the geophysical data shows a very distinct high salinity area down the profile. However, as the initial surveys were carried out when the soil was dry a seconded survey was completed using the University of Ballarat EM38 which is a very similar instrument to Advanced Soil Mapping's EM38. The complete data set is appended (Appendix 19). Figure 52 the reassessment of the Illabarook site shows there is little difference between the two, as thought before.

6.3.5 pH

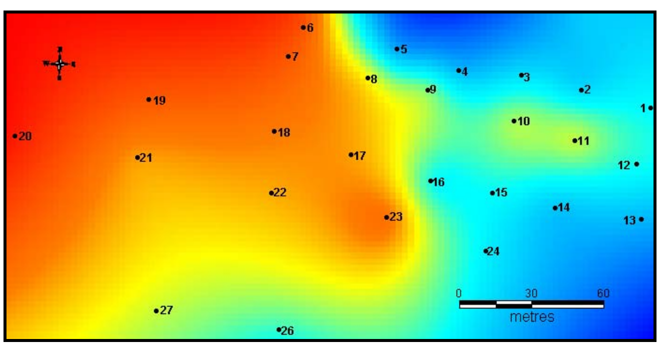
pH measurements on the soil samples have been grided using a minimum curvature interpolation algorithm with a two metre grid cell in Discover v.6.1 (Encom, 2004). The results are displayed for the three soil horizons tested (Figure 53) using a histogram colour stretch with values ranging from 4.7 to 6.03, which are highly acidic to acidic and in the pH range for optimum pasture growth (Gunn *et al.*, 1988). The complete data set is appended (Appendix 17)

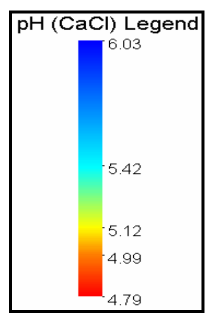


A



B





C

Figure 53 Soil pH of different soil horizons A) Pittong A1 pH (CaCl) B) Pittong A2 pH (CaCl)C) Pittong B pH (CaCl)

Figure 53 demonstrates that the Illabarook site has varying soil pH. Normal pH ranging from 5.5 to 8 is in conjunction with the high salinity values of Figure 49 and the below 5.5 pH values surround the highly saline area.

6.3.6 Soil Test

ANALYSIS		**UNITS**	**P 11 0-10**	**P 11 20-70**	**P 15 0-20**	**P 15 37-70**	**P 23 0-26**	**P 23 39-68**
pH	(1:5water)		5.1	5.5	5.9	5.8	6.0	6.4
pH	(CaCl2)		4.9	5.2	5.7	5.0	5.7	6.0
Salinity (EC)	(1:5water)	mS/cm	2.72	2.16	3.55	0.64	1.59	1.00
Calcium	(Exch)	meq/100 g	3.79	3.43	3.11	1.80	4.46	5.82
Magnesium	(Exch)	meq/100 g	4.57	3.80	4.26	4.13	4.30	4.24
Sodium	(Exch)	meq/100 g	9.75	10.33	11.33	6.10	5.76	5.41
Potassium	(Exch)	meq/100 g	0.19	0.42	0.15	0.19	0.18	0.44
Aluminium	(Exch)	meq/100 g	0.14	0.03	< 0.01	0.02	< 0.01	< 0.01
Calculations								
Sum of cations	(CEC)	meq/100 g	18.44	18.01	18.85	23.68	14.70	15.91
Calcium/Magnesium ratio			0.8	0.9	0.7	1.4	1.0	1.4
Sodium % of cations	(ESP)		52.9%	57.4%	60.1%	25.8%	39.2%	34.0%
Aluminium % of cations			0.8%	0.2%	< 0.1%	0.1%	< 0.1%	< 0.1%

Table 9 Soil test analysis

Table 9 shows the soil CEC test results, which indicates that the soil at Pittong has a nutrient imbalance for pasture productivity. Full test report Appendix 20. As Table 9 shows some cations are insufficient and some are over supplied for pasture production. The CEC calculations illustrate that the Calcium/Magnesium ratio and the Aluminium percentage is low indicating a nutrient imbalance for pasture productivity. Sodium percentage of cations is very high indicating sodic soils, which can have implications on soil structure. The sum of cations is above 10 indicating a soil which will have a high exchange of cations.

6.4 Surface Water and Groundwater Analysis

Monitoring of surface water and groundwater were carried out monthly obtaining EC and pH for each of the three sites. Surface Water and Groundwater Monitoring Data are appended in Appendix 21 and 22.

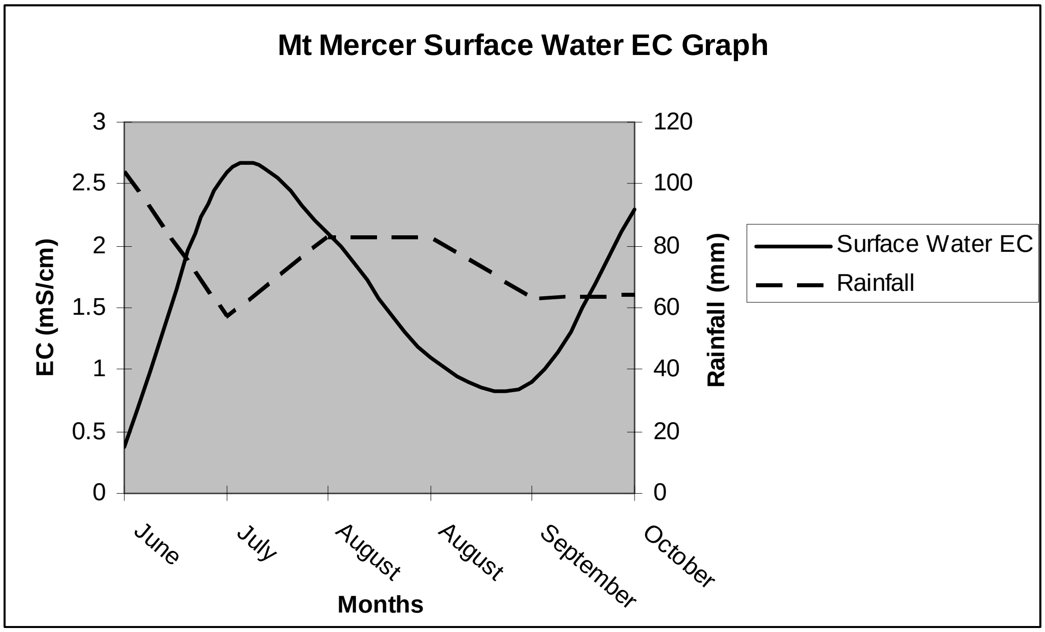


Figure 54 Mt Mercer surface water graph

Mt Mercer's surface water monitoring graph (Figure 54) indicates an inverse correlation between EC and rainfall. As from June to July rainfall decreased and EC increased. From August to September rainfall increased and EC decreased. Mt Mercer's groundwater EC averaged 5 mS/cm and a water level of 0.70 metres from July to October. As monitoring has only been going for five months there is only a small amount of data to evaluate for trends.

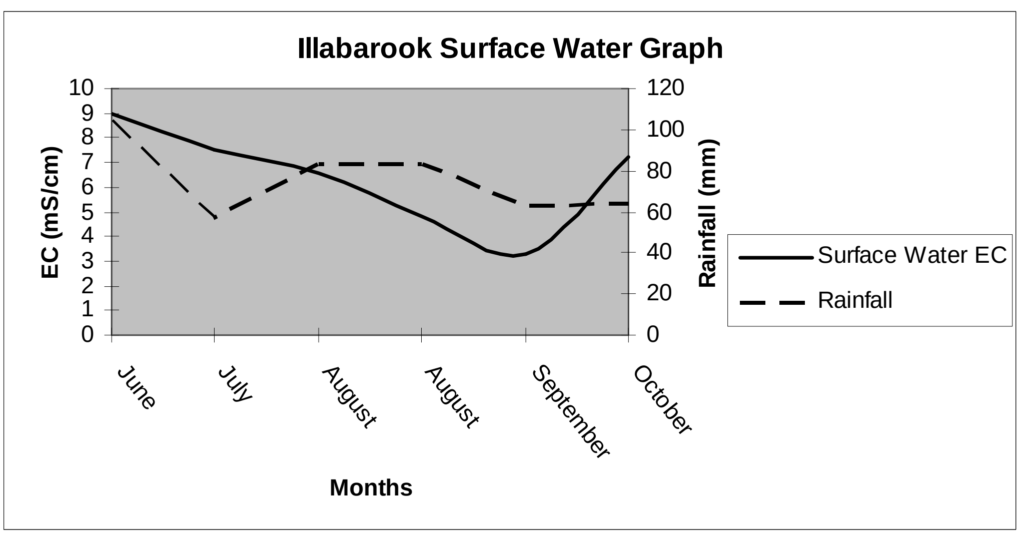


Figure 55 Illabarook surface water graph

Illabarook's surface water monitoring graph (Figure 55) also indicates an inverse correlation between EC and rainfall. As from July to September rainfall increased and EC decreased. From September to October rainfall decreased and EC increased. Illabarook's groundwater EC averaged 10 mS/cm and a water level of 2.4 metres from August to September. As monitoring has only been going for five months there is only a small amount of data to evaluate for trends.

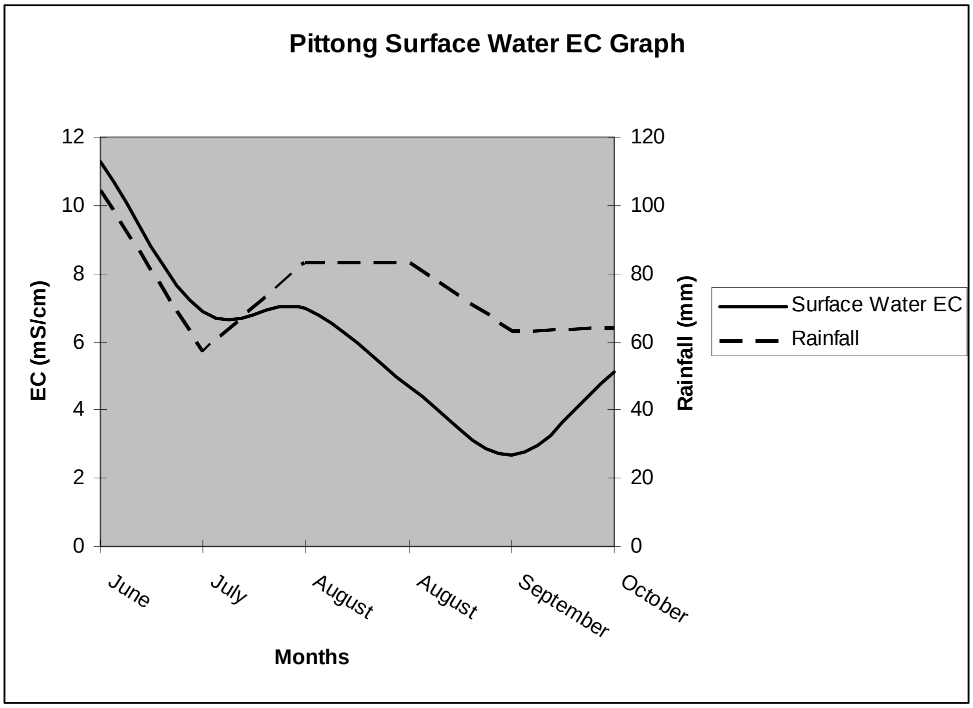


Figure 56 Pittong surface water graph

Pittong's surface water monitoring graph (Figure 56) shows a correlation between EC and rainfall. As from June to July and August to September both rainfall and EC decreased. From July to August and September to October both rainfall and EC increased. Pittong only had 1 month when groundwater was recorded in its piezometer (September) which was installed by Advanced Soil Mapping in June 2004. The EC was 1.05 mS/cm and the water level was 2.35 metres. As monitoring has only been going for five months there is only a small amount of data to evaluate for a correlation.

6.6 Photographic Monitoring

Photograph monitoring points were established at each site (refer to section 5.1.4 for details).

6.6.1 Mt Mercer

Autumn

Winter

Spring

Figure 57 Mt Mercer photograph monitoring

As Figure 57 illustrates from Autumn to Spring there is a substantial change in vegetation growth and the visual state of the saline site. Appendix 23 obtains GPS locations and the direction the photographs were taken.

6.6.2 Illabarook

Autumn

Winter

Spring

Figure 58 Illabarook photograph monitoring

As Figure 58 illustrates from Autumn to Spring there is a substantial change in vegetation growth and the visual state of the saline site. Appendix 23 obtains GPS locations and the direction the photographs were taken.

6.6.3 Pittong

Winter

Spring

Figure 59 Pittong photograph monitoring

As Figure 59 illustrates from Winter to Spring there is a substantial change in vegetation growth and the visual state of the saline site. Appendix 23 obtains GPS locations and the direction the photographs were taken.

7.0 Discussion

Characterisation of the three saline areas has involved a vegetation survey, soil sampling for profiling, EC, pH and CEC's, a geophysical survey, water monitoring, and photograph monitoring.

7.1 Mt Mercer

7.1.1 Vegetation

Spiny Rush, Bucks Horn Plantain and Annual Beard Grass at Mt Mercer indicates a salinity class of 1 and 2, which are associated with levels of soil EC of less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995). The vegetation suggests that the site has become saline from secondary processes as no native halophyte (salt loving) vegetation is present. A primary salinity site has native halophyte species associated with it (Ruby Salt Bush, Beaded Glasswort) as they are poor dispersers. A secondary site is associated with high dispersive introduced halophytes species (Spiny Rush, Bucks Horn Plantain and Annual Beard Grass) (Allen, 2004). Historical photographs indicate that the area of saline land has decreased over 30 years. This may have occurred as a pine plantation west of the site has been planted for at least 10 years and may be taking water out of the system and lowering the water table at the site.

7.1.2 Soil profile

The B horizon of the duplex soil at Mt Mercer has a texture of heavy clay, which is mottled and suggests that waterlogging occurs for extended periods. The A horizon is heavily leached in the lower parts with little to no soil structure making the soil spongy when waterlogged. The soil profile is contributing to the saline area as it has little to no soil structure, which impedes drainage, air and root growth.

7.1.3 Soil EC

Soil EC for Mt Mercer ranges from 0.06 mS/cm (Low) to 1.85 mS/cm (Very High) with an average soil salinity of 0.47 mS/cm, which matches the vegetation in that it indicates salinity classes 1 and 2, which are associated with levels of soil EC of less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995). The high area of soil salinity is associated with the presence of spiny rush suggesting that the spiny rush holds salt in its root zone causing soil salinity to rise around the rushes. The source of the salt is most likely coming from the groundwater which has an average EC of 8.0 mS/cm in bores of the region. The evaporation of the groundwater discharge accumulates salt in the near-surface over time. The groundwater table rises over winter as rain falls on top of low undulating sand capped hills. The water percolates down the soil profile and runs laterally as it hits the heavy clay B horizon saturating the A horizon down in the small valley. A second soil survey carried out in winter was done to see what changes in soil salinity took place as the soil became waterlogged. The soil tended to increase in surface salinity indicating that the groundwater table has risen and is mobilising the accumulated salt in the soil to the surface.

7.1.4 Geophysical Survey

The high conductivity values shown in the geophysical surveys correlate with the high soil EC values occurring around spiny rush. The average EC for the geophysical survey is 74 mS/m which converts to 0.74 mS/cm. The geophysical survey penetrates the soil at depth giving an indication that the top five metres of the soil has a high salinity or salt store.

7.1.5 Soil pH

Soil pH for the Mt Mercer site ranges from 4.37 to 5.09 with the average soil pH of 4.7. With an average soil pH of 4.7, which is highly acidic, the Mt Mercer site is prone to stunting of plant growth, aluminium toxicity and greatly reduced symbiotic nitrogen fixation by legumes (Glendinning, 2000). The lower readings from the pH survey tend to surround the higher readings on the actual saline site. This may be because the soils are sodic, which have soil pH values ranging from acid to basic and saline soil tends to be less acidic (Glendinning, 2000).

7.1.6 CEC

There are five essential nutrients which are required in certain amounts by pastures and crops to grow to full potential and be healthy. If these values are not met than the soil will be considered unbalanced for pasture and crop production. CEC calculations are carried out to make characterisation of the soil easier. Calculations include calculating the sum of cations, calcium/magnesium ratio, sodium percentage of cations and aluminium percentage of cations. The values of each for a balanced soil are as follows for the sum of cations anything above 10, calcium/magnesium ratio between two and four, and the percentage of cations for sodium and aluminium anything less than five percent (SWEP).

For the six samples tested at the Mt Mercer site the values (Table 3) indicate that the Mt Mercer site has an unbalanced soil. The sum of cations is low which has implications on how much nutrients is available in the soil for plants to use. The calcium/magnesium ratio is low implicating that calcium levels are low and magnesium levels are high. Calcium stimulates root growth, activates plant enzyme systems and aids in the mechanical strength of the plant to name a few, so these actions will be suppressed in the Mt Mercer soils as the calcium levels are low (Glendinning 2000). High amounts of magnesium in the soil affects soil structure making the soil hard and compacted (Incitec, 1999).

The sodium percentage of cations or exchangeable sodium percentage (ESP) is very high. A very high ESP affects the structure of the soil by dispersing soil colloids, which result in blockages of soil pores impeding roots, air and water (Ghassemi *et al.* 1995). Once a high ESP soil is waterlogged it loses structure and is readily eroded. The aluminium percentage of cations in the Mt Mercer soil is relatively balanced as the average is close to optimum pasture growth.

7.1.7 Water Monitoring

Mt Mercer's surface water monitoring shows that during periods of higher rainfall there is more water running off the site, diluting the salt concentration and lowering the EC. Conversely, less rainfall results in less water running off the site and water EC increases as the salts are more concentrated. The groundwater EC is high and has an affect on the soil as it is only 20 centimetres from the surface causing it to become waterlogged and spongy.

7.1.8 Photo monitoring

Typical seasonal changes from Autumn to Spring show a substantial change in vegetation growth and the visual state of the saline site. During the summer months the falling water table and increasing evaporation dries the soil, leaving salt stores which kills off plants. During winter the salt is washed out of or down the soil profile allowing plants to survive as there is an amount of fresh water to sustain plant growth in the saline area.

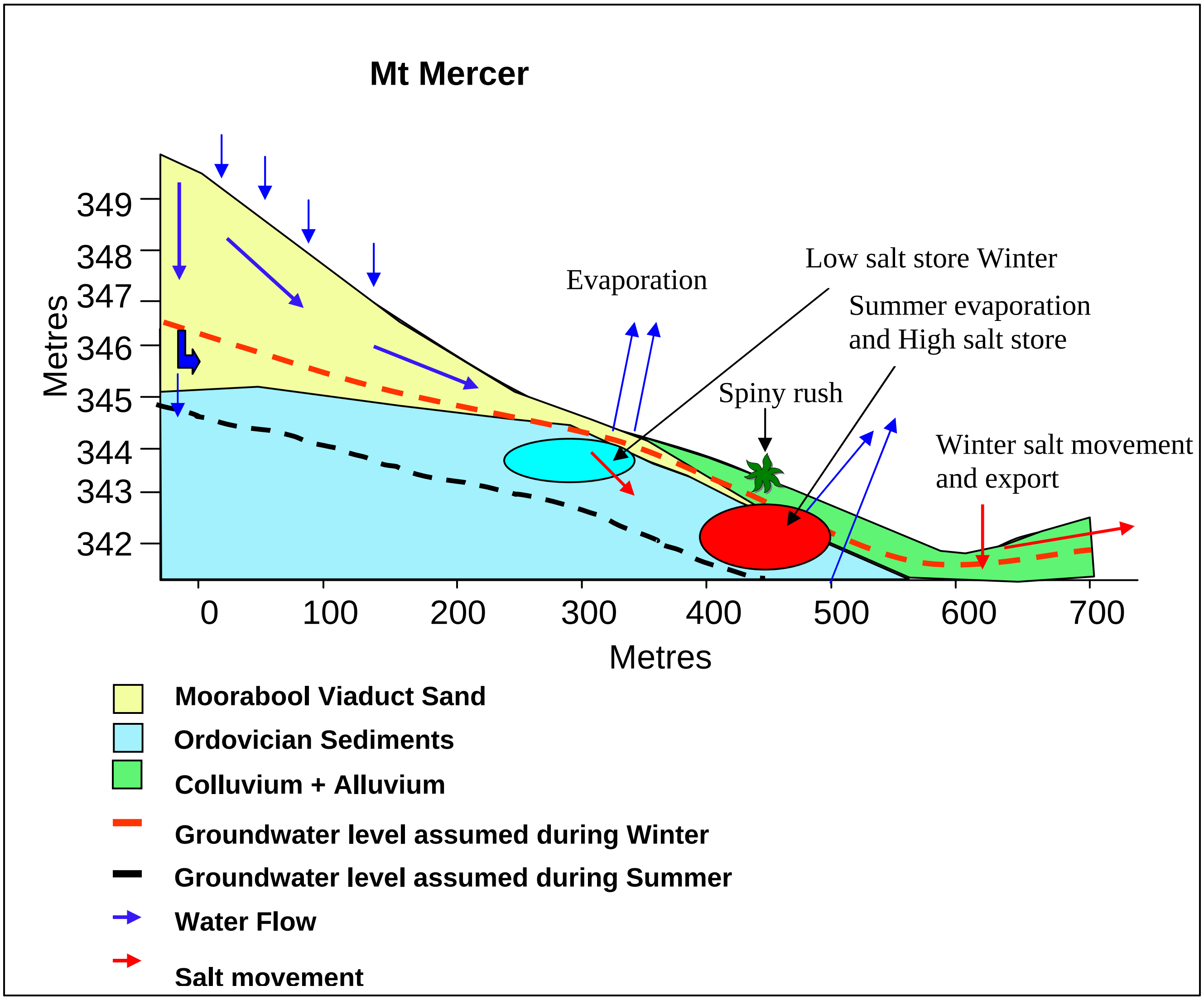


Figure 60 Conceptual model of Mt Mercer

7.1.9 Mt Mercer Summary

Figure 60 shows both winter and summer scenarios at Mt Mercer. During the summer months rainfall is at its lowest and evaporation is at its highest lowering the water table down to around two metres drying out waterlogged areas. Drying of the waterlogged areas creates salt stores near the surface as water evaporates concentrating the salt. Groundwater drown up by capillary action also evaporates at the surface accumulating salt. The accumulation of salt at or near the surface causes plants to suffer and some to even die. During the winter months when evaporation is at its lowest and rainfall is at its highest, rain water infiltrates the A horizon percolating down to the highly compacted B horizon, which impedes the majority of water percolating vertically. Water flows laterally on the compacted B horizon to the bottom of the round flat valley rasing the water table rapidly waterlogging it. The substantial amount of rain and rising water table flushes and dilutes the salt stored in the soil out allowing plants to re-establish.

7.2 Illabarook

7.2.1 Vegetation

The distribution of Spiny Rush, Streaked Arrow Grass, Toad Rush, Sea Barley Grass, Annual Beard Grass and Buck's Horn Plantain indicates that the site is saline with 50 percent class 1 and 50 percent class 2, which are associated with levels of soil EC less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995). The vegetation also suggests that the site has become more saline from secondary processes. Streaked Arrow Grass, Toad Rush are native halophyte species which indicate that the site is a primary salinity site. As the site has become more saline by secondary salinity processes secondary halophyte species have become more favourable and competitive as they can tolerate higher salinities than most native halophytes (Allen, 2004). Historical photographs indicate that the area of saline land has increased over 30 years. Although only slightly, which indicates that the area is a point source of salt discharging from a spring or deep lead. It also indicates that a new equilibrium following the hydrological changes associated with clearing has not been reached.

7.2.2 Soil profile

The B horizon of the duplex soil at Illabarook has a texture of heavy clay, which is mottled and suggests that waterlogging occurs for extended periods. The A horizon consists of clay loam and is heavily leached in the lower parts with little to no soil structure making the soil spongy when waterlogged. The A horizon averages a depth of 30 centimetres. The soil profile is contributing to the saline area as it has little to no soil structure, which impedes drainage, air and root growth.

7.2.3 Soil EC

Soil EC for Illabarook ranges from 0.06 mS/cm (Low) to 3.09 mS/cm (Very High) with an average soil salinity of 0.59 mS/cm, which matches the vegetation in that it indicates salinity classes 1 and 2, which are associated with levels of soil EC of less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995).The high area of soil salinity is associated with the presence of spiny rush suggesting that the spiny rush holds salt in its root zone causing soil salinity to rise around the rushes. A deep lead also runs through the area which has been extensively mined and may be causing the saline area to be confined where it out crops.

The source of the salt is most likely coming from the groundwater which has an average salinity of 7 mS/cm in bores of the region. The evaporation of the groundwater discharge accumulates salt in the near-surface over time. The groundwater table rises over winter as rain falls on top of low undulating sand capped hills. As the water percolates down the soil profile it picks up salt stored in sediments and hits the heavy clay B horizon and runs laterally in the A horizon, discharging at the edge of the hill where the capped sand wedges out. Mining has created shafts into the deep lead, creating an easy path for recharge to occur, as water can easily flow down through the shafts into the deep lead, which discharges at the side of the hill.

A second soil survey carried out in winter was done to see what changes in soil salinity took place as the soil became waterlogged. The soil tended to decrease in surface salinity indicating that salt has washed out of the soil profile. More evidence for this is that three deeper samples were also taken, showing that EC decreased down the soil profile, indicating that the salt has been washed out of the soil profile and not washed down in to it.

7.2.4 Geophysical Survey

The high conductivity values shown in the geophysical surveys correlate with the high soil EC values occurring around spiny rush. The average EC for the geophysical survey is 58 mS/m which converts to 0.58 mS/cm. The geophysical survey penetrates the soil at depth giving an indication that the top five metres of the soil has a high salt store.

7.2.5 Soil pH

Soil pH for the Illabarook site ranges from 4.7 to 6.04 with the average soil pH of 5.4. With an average soil pH of 5.4, which is moderately acidic, the Illabarook site is in the desirable level for many crops to grow (Glendinning, 2000). The lower pH readings surround the higher pH readings on the saline site. This may be because the soils are sodic, which have soil pH values ranging from acid to basic and saline soil tends to be less acidic (Glendinning, 2000).

7.2.6 CEC

The results of the Illabarook soil test (Table 7) indicate that the soil is unbalanced. The sum of cations is above 10 which, indicates that the soil is able to exchange cations readily, but because other cations are out of balance the exchange doesn't occur as easy. The calcium/magnesium ratio is low implicating that calcium levels are low and magnesium levels are high. Calcium stimulates root growth, activates plant enzyme systems and aids in the mechanical strength of the plant to name a few, so these actions will be suppressed in the Illabarook soils as the calcium levels are low (Glendinning 2000). High amounts of magnesium in the soil affects soil structure making the soil hard and compacted (Incitec, 1999). The sodium percentage of cations or exchangeable sodium percentage (ESP) is very high. A very high ESP affects the structure of the soil by dispersing soil colloids, which result in blockages of soil pores impeding roots, air and water (Ghassemi *et al.* 1995). Once a high ESP soil has waterlogged it loses structure and is readily eroded. The aluminium percentage of cations in the Illabarook soil is low, which is excellent for optimum pasture growth, as if aluminium becomes greater than five percent pasture has stunted growth as aluminium becomes toxic to the plants (Ghassemi *et al.* 1995).

7.2.7 Water Monitoring

Illabarook's surface water monitoring shows that during periods of higher rainfall there is more water running off the site, diluting the salt concentration lowering the EC. Conversely, less rainfall results in less water running off the site and water EC increases as salts are more concentrated. The groundwater EC is reasonably high and is most likely the main salt producer of the site.

7.2.8 Photo monitoring

Typical seasonal changes from Autumn to Spring show a substantial change in vegetation growth and the visual state of the saline site. During the summer months the falling water table and increasing evaporation dries the soil, leaving salt stores which kills off plants.

During winter the salt is washed out of or down the soil profile allowing plants to survive as there is an amount of fresh water to sustain plant growth in the saline area.

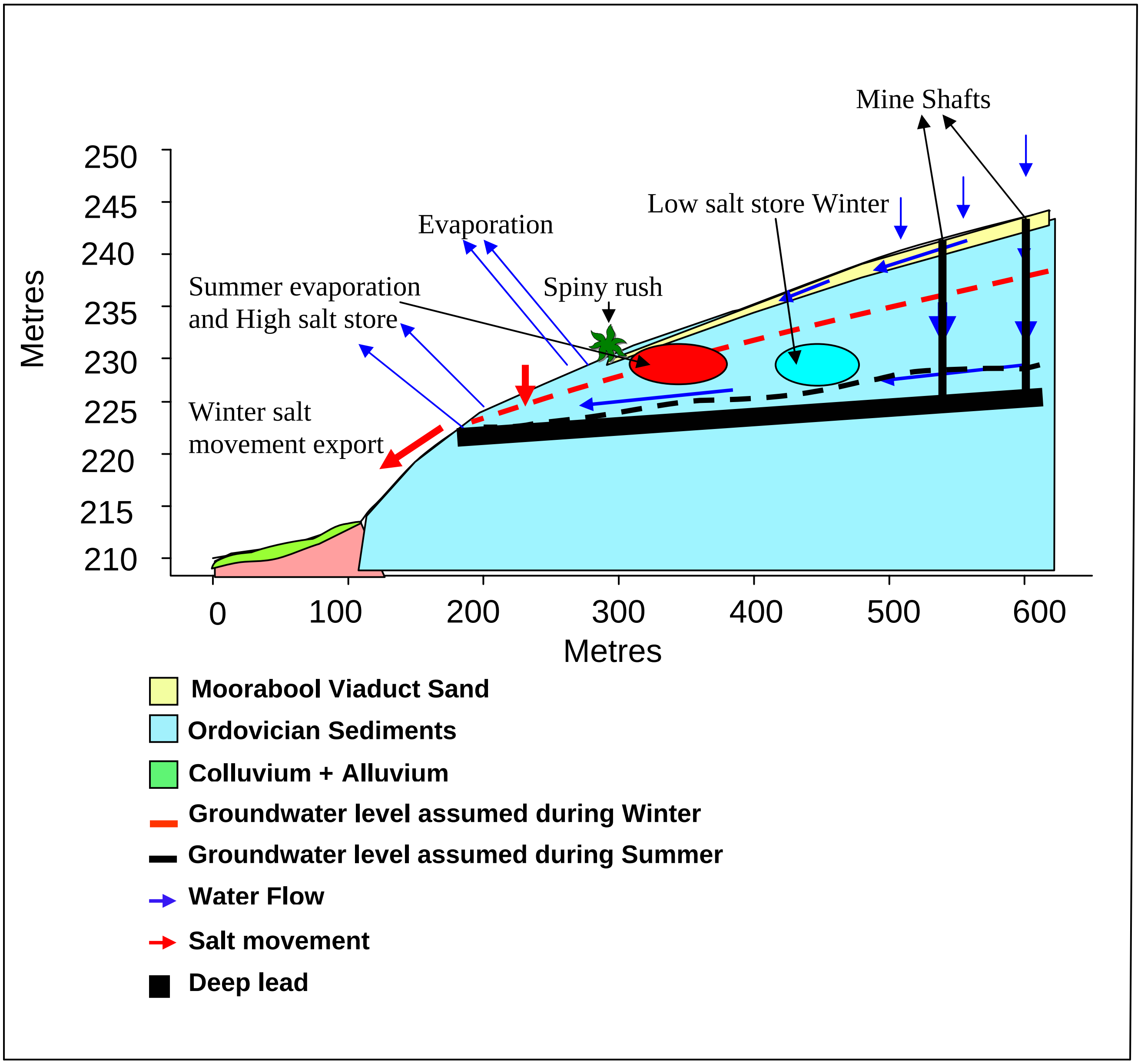


Figure 61 Conceptual model of Illabarook

7.2.9 Illabarook Summary

Figure 61 shows both winter and summer scenarios at Illabarook. During the summer months rainfall is at its lowest and evaporation is at its highest lowering the water table down to around two metres drying out waterlogged areas. Drying of the waterlogged areas creates salt stores near the surface as water evaporates concentrating the salt.

Groundwater drown up by capillary action also evaporates at the surface accumulating salt. The accumulation of salt at or near the surface causes plants to suffer and some to even die. During the winter months when evaporation is at its lowest and rainfall is at its highest, rain water infiltrates the A horizon percolating down to the highly compacted B horizon, which impedes the majority of water percolating vertically. Water flows laterally on the compacted B horizon discharging at the side of the hill and down old mine shafts into a deep lead which also discharges at the side of the hill waterlogging the area. The substantial amount of rain, rising water table and water flowing in the deep lead flushes salt stores out of the soil profile allowing plants to re-establish.

7.3 Pittong

7.3.1 Vegetation

The distribution of Sea Barley Grass, Annual Beard Grass, Spiny Rush, Toad Rush, Buck's Horn Plantain and Ruby Salt Bush at Pittong indicates that the site is saline with 40 percent class 1 and 60 percent class 2, which are associated with levels of soil EC of less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995). The presences also suggest that the site has become more saline from secondary processes. Ruby Salt Bush and Toad Rush are native halophyte species which indicate that the site is a primary salinity site. As the site has become more saline by secondary salinity processes secondary halophyte species have become more favourable and competitive as they can tolerate higher salinities than most native halophytes (Allen, 2004). Historical photographs indicate that the area of saline land has increased over 40 years, which may be due to clearing and farming practises.

7.3.2 Soil profile

The B horizon of the duplex soil at Pittong has a texture of sandy heavy clay, which is mottled and suggests that waterlogging occurs for extended periods. The A horizon consists of clay loam and is heavily leached in the lower parts with little to no soil structure making the soil spongy when waterlogged. The A horizon averages a depth of 40 centimetres. The soil profile is contributing to the saline area as it has little to no soil structure, which impedes drainage, air and root growth.

7.3.3 Soil EC

Soil EC for Pittong ranges from 0.04 mS/cm (Low) to 3.84 mS/cm (Very High) with an average soil salinity of 0.83 mS/cm, which matches the vegetation in that it indicates salinity classes 1 and 2, which are associated with levels of soil EC of less than 0.6-1.4 mS/cm to 1.4-3.5 mS/cm (Matters & Bozon, 1995).The high area of soil salinity is associated with the presence of spiny rush suggesting that the spiny rush holds salt in its root zone causing soil salinity to rise around the rushes. Waterlogging occurs from rainfall recharging up slope of the saline area and percolating into the A horizon hitting the sandy heavy clay B horizon and moving laterally in the A horizon to discharge at the saline site. During the journey the infiltrating water comes into contact with highly saline springs, which are percolating through joints in the highly weathered granite altering the percolating water into highly saline water, which discharges at valley floors. A second soil survey carried out in winter was done to see what changes in soil salinity took place as the soil became waterlogged. The soil tended to decrease in surface salinity indicating that salt has washed out of the soil profile. More evidence for this is that 3 deeper samples were also taken, showing that EC decreased down the soil profile, indicating that the salt has been washed out of the soil profile and not washed down in to it.

7.3.4 Geophysical Survey

The high conductivity values shown in the geophysical surveys correlate with the high soil EC values occurring around spiny rush. The average EC for the geophysical survey is 75 mS/m which converts to 0.75 mS/cm. The geophysical survey penetrates the soil at depth giving an indication that the top five metres of the soil has a high salinity or salt store.

7.3.5 Soil pH

Soil pH for the Illabarook site ranges from 4.23 to 5.71 with the average soil pH of 5.2. With an average soil pH of 5.2, which is moderately acidic, the Pittong site is in the desirable level for many crops to grow (Glendinning, 2000). The lower readings from the pH survey tend to surround the higher readings on the actual saline site. This may be because the soils are sodic, which have soil pH values ranging from acid to basic and saline soil tends to be less acidic (Glendinning, 2000).

7.3.6 CEC

The results of the Pittong soil test (Table 8) indicate that the soil is unbalanced. The sum of cations is above 10 which, indicating that the soil is able to exchange cations readily, but as other cations are out of balance the exchange doesn't occur as easy. The calcium/magnesium ratio is low implicating that calcium levels are low and magnesium levels are high. Calcium stimulates root growth, activates plant enzyme systems and aids in the mechanical strength of the plant to name a few, so these actions will be suppressed in the Pittong soils as the calcium levels are low (Glendinning 2000). High amounts of magnesium in the soil affects soil structure making the soil hard and compacted (Incitec, 1999). The sodium percentage of cations or exchangeable sodium percentage (ESP) is very high. A very high ESP affects the structure of the soil by dispersing soil colloids, which result in blockages of soil pores impeding roots, air and water (Ghassemi *et al.* 1995). Once a high ESP soil has waterlogged it loses structure and is readily eroded. The aluminium percentage of cations in the Pittong soil is low, which is excellent for optimum pasture growth, as if aluminium becomes greater than five percent pasture has stunted growth as aluminium becomes toxic to the plants (Ghassemi *et al.* 1995).

7.3.7 Water Monitoring

Pittong's surface water monitoring shows that during periods of higher rainfall there is more water running off the site, diluting the salt concentration lowering the EC. Conversely, less rainfall results in less water running off the site and water EC increases as salts are more concentrated. The groundwater EC is reasonably high and is most likely the main salt producer of the site.

7.3.8 Photo monitoring

Typical seasonal changes from Winter to Spring show a substantial change in vegetation growth and the visual state of the saline site. During the summer months the falling water table and increasing evaporation dries the soil, leaving salt stores which kills off plants. During winter the salt is washed out of or down the soil profile allowing plants to survive as there is an amount of fresh water to sustain plant growth in the saline area.

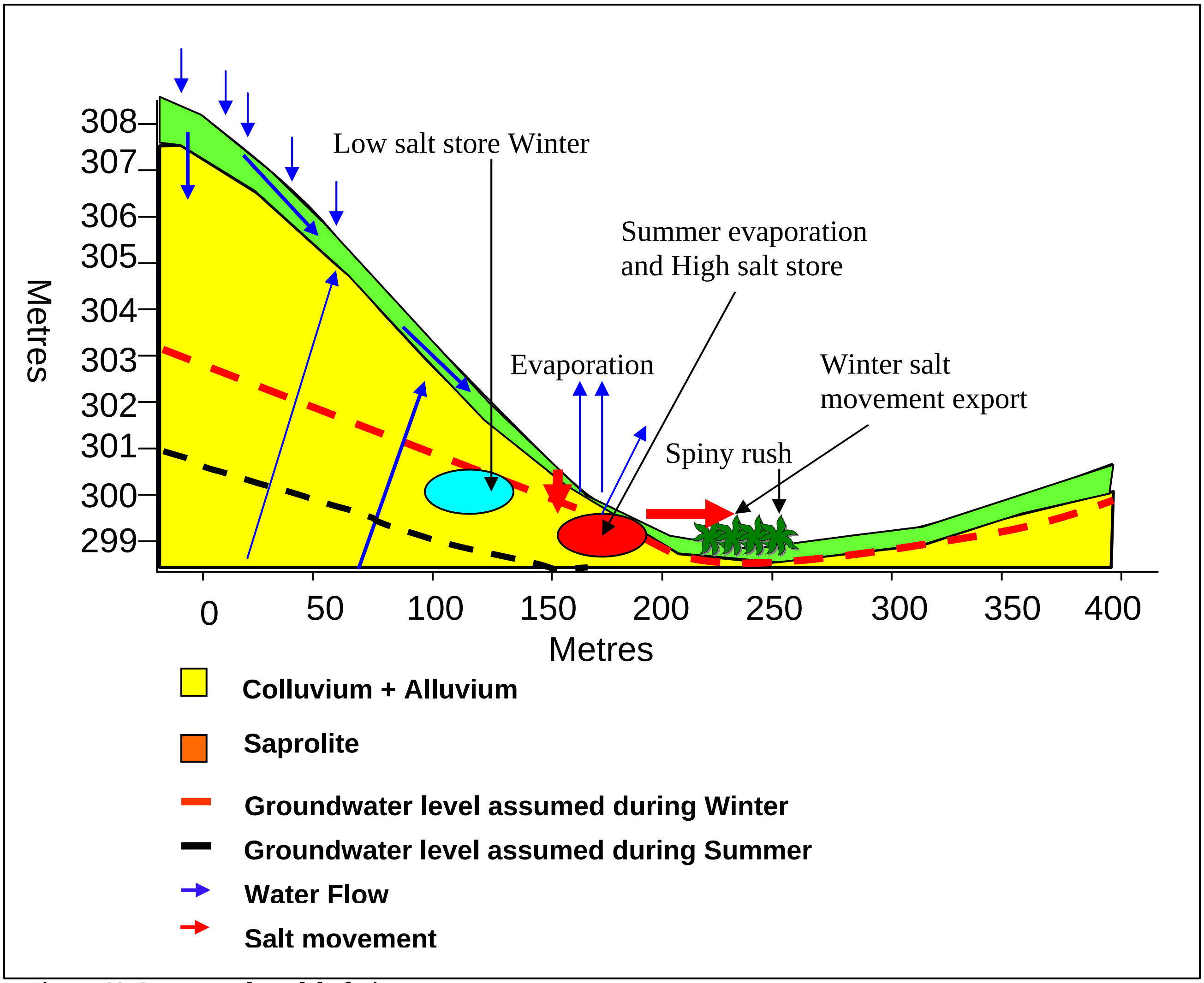


Figure 62 Conceptual model of Pittong

7.3.9 Pittong Summary

Figure 62 shows both winter and summer scenarios at Pittong. During the summer months rainfall is at its lowest and evaporation is at its highest lowering the water table down to around two metres drying out waterlogged areas. Drying of the waterlogged areas creates salt stores near the surface as water evaporates concentrating the salt. Groundwater drown up by capillary action also evaporates at the surface accumulating salt. The accumulation of salt at or near the surface causes plants to suffer and some to even die. During the winter months when evaporation is at its lowest and rainfall is at its highest, rain water infiltrates the A horizon percolating down to the resistant B horizon, which impedes the majority of water percolating vertically. Water flows laterally on the compacted B horizon to the bottom of the round flat valley rasing the water table rapidly waterlogging it. The substantial amount of rain and rising water table flushes and dilutes the salt stored in the soil out allowing plants to re-establish.

8.0 Conclusion

The soils, vegetation, surface water and groundwater have been characterised at the Mt Mercer, Illabarook and Pittong sites. Geological and groundwater models have also been developed to understand the salt process at each site and a monitoring program has been devised to evaluate changes to the environment.

The three areas have unbalanced sodic duplex soils with saline indicator plants present, with saline surface water and groundwater. Geological models produced are all similar at the three sites in that water in the A horizon hits the dense B horizon causing lateral flow, which discharges at the base or side of hills creating waterlogged areas, which are prone to salinisation. The monitoring program includes monitoring vegetation, soil using geophysical surveying and soil sampling, water monitoring and photograph monitoring, which will indicate changes in the saline area over time.

9.0 Recommendations for Further Work

9.1 Monitoring

9.1.1 Vegetation

Carry out Vegetation surveys at all three sites every one to three years to indicate the changes in saline indicator vegetation, which indicates the severity of the salinity over time. The vegetation survey should also be carried out during spring when all plants are at optimum growth.

9.1.2 Soil Profile

Carry out a soil sampling program every one to three years in order to indicate changes in the soil profile including soil structure, colour and texture. Changes in soil structure, colour and texture will indicate if the treatments implemented at the sites are working or not to restore soil structure.

9.1.3 Soil Testing

Carry out soil EC, pH and CEC testing annually to observe changes. It is important that the time of year is set to do this as the soil changes throughout the year. An alternative for this is to do a soil sampling program every three months (seasonal) to see the changes in salinity occurring over different seasons.

9.1.4 Geophysical Survey

Conduct a geophysical survey every one to three years in order to see changes in size and severity of the salinity at each of the sites. It is also important that the time of year is set to do a geophysical survey as the soil changes throughout the year.

9.1.5 Water Monitoring

Groundwater and surface water monitoring should be continued monthly, three monthly or six monthly to indicate any changes in water levels and salinity.

9.1.6 Photograph Monitoring

Carry out photographic monitoring annually or seasonally to observe any changes in the saline site. Aerial photographs should be obtained when reassessment of the sites are carried out.

9.2 Geology and Hydrology

- Drill piezometers at the Illabarook and Mt Mercer site to indicate the thickness of the Moorabool Viaduct Sand and to indicate groundwater movement.
- Dig soil pits to indicate the three-dimensional view of the soil profile.
- Insert EC electrodes in the soil to indicate the change in soil EC during Winter and Summer indicating salt storage.
- Construct permanent water monitoring stations to indicate the amount of salt washing off the sites.

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Appendix 1 Soil Texture flow chart

(MacEwan, 1999)

Texture symbol	**Field texture grade**	**Behavior of moist bolus**	**Approx. clay content (%)**
S	Sand	Coherence nil to very slight, cannot be moulded; sand grains of medium size; single sand grains stick to fingers.	Less than 5%
LS	Loamy Sand	Slight coherence; sand grains of medium size can be sheared between thumb and forefinger to give minimal ribbon of 5 mm.	Approx. 5%
CS	Clayey sand	Slight coherence; sand grains of medium size; sticky when wet; many sand grains stick to fingers; will form a minimal ribbon of 5-15 mm; discolours fingers with clay stain.	5-10%
SL	Sandy loam	Bolus coherent but very sandy to touch; will form a ribbon of 15-25 mm; dominant sand grains are of medium size and are readily visible.	10-20%
FSL	Fine sandy loam	Bolus coherent; fine sand can be felt and heard when manipulated; will form a ribbon of 13-25mm; sand grains are clearly evident under a hand lens.	10-20%
SCL	Light sandy clay loam	Bolus strongly coherent but sandy to touch; and sandy to touch; sand grains dominantly medium sized and easily visible; will form a ribbon of 2-2.5cm.	15-20%
L	Loam	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or 'silkiness', may be somewhat greasy to the touch if much organic matter present; will form ribbon of 25 mm.	About 25%
Lfsy	Loam, fine sandy	Bolus coherent and slightly spongy; fine sand can be felt and heard when manipulated; will form a ribbon of about 25 mm.	Approx. 25%
ZL	Silty Loam	Coherent bolus; very smooth to often silky when manipulated; will form a ribbon of approx. 25 mm.	Approx. 25% and with silt approx 25% or more
SCL	Sandy clay loam	Strongly coherent bolus, sandy to the touch; medium sized sand grains visible in finer matrix; will form a ribbon of 25-40 mm.	20-30%
CL	Clay loam	Coherent plastic bolus; smooth to manipulate; will form a ribbon of 40-50 mm.	30-35%
CLS	Clay loam, sandy	Coherent plastic bolus; medium sized sand grains visible in finer matrix; will form a ribbon of 40-50 mm.	30-35%
ZCL	Silty clay loam	Coherent smooth bolus, plastic and often silky to the touch; will form a ribbon of 40-50 mm.	30-35% and with silt 25% or more.

SC	Sandy clay	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form a ribbon of 50-75 mm.	35-40%
ZC	Silty clay	Plastic bolus; smooth and silky to manipulate, will form a ribbon of 50-75 mm.	35-40%
LC	Light clay	Plastic bolus; smooth to touch; slight resistance to shearing; will form a ribbon of 50-75 mm.	Clay: 35-40% Silt: 25%+
LMC	Light medium clay	Plastic bolus; smooth to touch; slight to moderate resistance to forming a ribbon; will form a ribbon of 75 mm.	40-45%
MC	Medium clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has moderate resistance to forming a ribbon; will form a ribbon of 75 mm +.	45-55%
MHC	Medium heavy clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has a moderate to firm resistance to forming a ribbon; will form a ribbon of 75 mm or more.	50%+
HC	Heavy clay	Smooth plastic bolus; can be moulded into rods without fracturing; has firm resistance to forming a ribbon; will form a ribbon of 75 mm +.	50%+