A case study of integrated hydrology research in the Hunter Catchment: Plaschett and Howick Key Site

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1. Introduction

The NSW Department of Primary Industries (DPI) Key Sites Project was developed from three existing NSW Salinity Strategy projects in 2004. The three separate projects were undertaking research into the effect of land use change on the movement of salt and water in the landscape. The research sites were eight typical upland dryland catchments across NSW and at all sites components of the water balance were measured. One of the eight catchments is the eponymous Hunter site which was initially developed to address several hydrological knowledge gaps in the Hunter catchment of environmental importance.

To date both NSW and Australian governments have invested $13.9 million dollars in establishing and maintaining these sites. This includes $6.8 million dollars the NSW Salinity Strategy and $7.1 million dollars from the NSW government ($3.8M) and National Action Plan for Salinity and Water Quality ($3.3M). This funding has allowed the sites to be fully instrumented and staffed from mid 2001 to 30 June 2008.

Hydrological knowledge gaps in the Hunter catchment

- There is existing high background salinity in the Hunter catchment due to the large presence of Permian marine sediments (HRC, 2002; DLWC, 2000; DLWC, 1996; Hannan, 1994). Site specific background salinity loads from the natural catchment are critical in understanding impacts from varied land uses on the catchment.
- Open cut coal mining can exacerbate these naturally high salinity levels by exposing saline rocks to runoff, accelerate natural leaching and weathering processes, and create changed flow paths (ACARP C11050,2003; DLWC, 1996; DLWC, 2000; Muschal, 2006). Quantification of the effects of these processes on groundwater quality and quantity is currently undetermined.
- As mines are decommissioned, no account of the impact of mine closure and the fate of salt within voids on future salt pollution has been done (DLWC, 2001).
- There is uncertainty about the medium to long term cumulative impact of mining on the quantities of salts and water which can be exchanged between surface water systems of the Hunter region and the regional groundwater aquifers. There is a need to develop a regional groundwater model to quantify these impacts (ACARP C11050, 2003).

The Hunter Key Site's continued operation is a testament to the ongoing co-operation between all collaborators which include Coal & Allied, Macquarie Generation, NSW Department of Primary Industries, NSW Department of Natural Resources and the University of Technology Sydney (UTS). Staff turnover and subsequent replacement at the site has been an issue, with the original researcher, Hassan Abbas leaving in 2005 not being replaced by Belinda Ronai till late 2006 until her resignation inn October 2007. Continued involvement with UTS is uncertain at this stage with Dr. Bryce Kelly moving to another institution.

2. *The Study Sites*

An open-cut rehabilitated coal mine is compared with a natural (un-mined) site in close proximity. Understanding the natural salt contribution to the watershed is critical to the development of site-specific background concentrations for comparison with alternate uses of land within the same watershed.

The paired catchments are located north of the Hunter River between Singleton and Muswellbrook in northeast New South Wales, Australia (Figure 1). The natural and rehabilitated sites lie within 5km of each other in adjacent sub-catchments of Lake Plashett and Parnell Creek respectively. The natural site is approximately 800 ha in size within the Plashett Dam catchment located on unmined land owned by Macquarie Generation. Within this catchment, sub-catchments of Saltwater Creek and No Name Creek are selected as the unmined study area to capture the hydrological differences arising from the distinct geological origins, soil landscapes and vegetation of the two sub-catchments. The rehabilitated open cut coal mine site is around 50 ha in size part of Coal & Allied Howick Colliery originally part of the Parnell Creek sub-catchment.

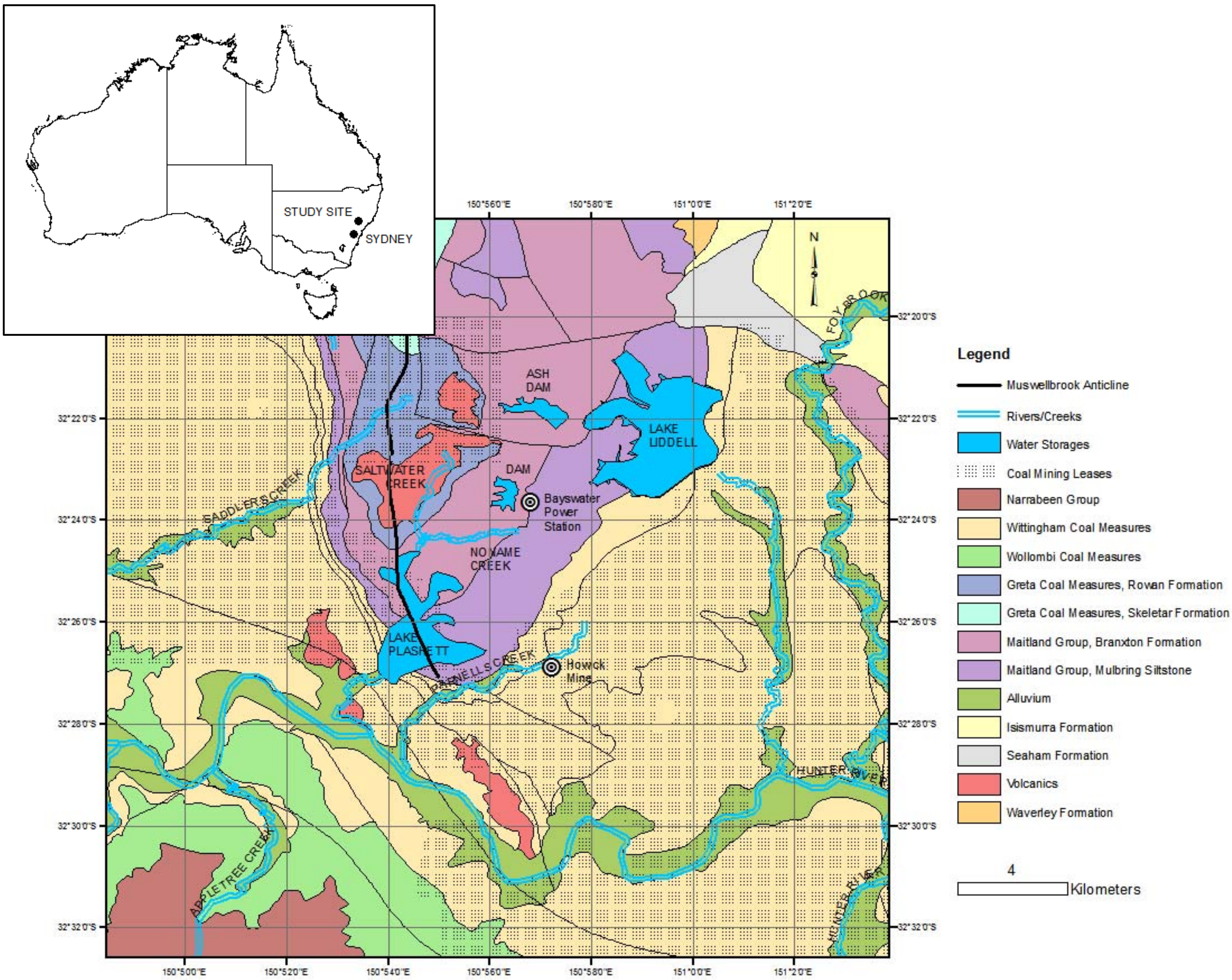

Figure 1 Geological setting of study sites. Natural site comprises sub-catchments of Saltwater and Noname Creeks in the Lake Plashett catchment. Rehabilitated open cut coal mine site on Howick mine is located in the Parnells Creek catchment. Map data sourced from Geoscience Australia (1991), Glen et. al. (1993) and Liu et. al. (2005).

Natural Site:

The natural site (**Figure 1**) is composed of two major drainage lines: Saltwater Creek running north-south and Noname Creek running east-west, joining Saltwater Creek in the south which then drains into Lake Plashett. The two sub-catchments exhibit distinct differences in geology, soil composition and vegetation. A number of other perennial streams also drain into Lake Plashett that are not the subject of this study. Water is pumped from the Hunter River into Lake Plashett which is used as a storage reservoir for Bayswater power station.

The major geological feature of the natural site is the southward plunging Muswellbrook anticline (**Figure 1**). The Branxton formation of the Maitland Group underlies the south-east half of the site, roughly comprising the sub-catchment area of Noname Creek with lithology consisting of sandstone, siltstone and conglomerate. The Saltwater Creek sub-catchment can be divided into three distinct geological formations. Initially, thin strips of the Branxton Formation of the Maitland Group, followed by the Rowan Formation of the Greta Coal Measures are encountered as you head upstream from Lake Plashett. The Rowan Formation consists of sandstone, siltstone, shale and mudstone with intercalated coal seams. The remainder and the majority of the Saltwater Creek sub-catchment is underlain by a volcanic tertiary igneous intrusion known as the Savoy Sill comprising dolerite, syenite and basalt. The Maitland Group and Greta Coal Measure formations are of late to early Permian age with geological deposits originating from alluvial or marine environments.

Soils on the site are similarly divided between the two sub-catchments. The Liddell Soil Landscape dominates the Noname Creek sub-catchment and the Brays Hill Soil Landscape dominates the Saltwater Creek sub-catchment and coincides with geological regions of volcanic origin. The soils described in these landscapes include silty clay loams, fine sandy loams, sand to sandy loams, reddish brown clays with strong structure, Colluvial brownish black silty clays, yellowish brown light clays, brown light to medium clays and reddish brown light sandy clay loams, all in the top soils. The subsoils constitute orange-bright brown medium-heavy clays, red to yellow light to medium clays – moderate to slightly acidic, brown or orange dull sandy clays, medium heavy clays – neutral to alkaline at 7m-9m depth, some times highly saline, heavy clays, yellow orange or grey mottles with pH increasing with depth.

The division between vegetation on the site is again defined by the sub-catchment boundaries. The Saltwater Creek sub-catchment is dominated by pasture lands utilised for grazing. Small clusters of trees are present along stream banks. Alternately, the Noname Creek sub-catchment can be described as a woodland savannah environment comprising mostly Eucalypt species of varying stand thickness, underlain by grasses and shrubs.

Figure 2 Panoramic view of natural site with Lake Plashett and Bayswater power station in background. Grazing land of Saltwater Creek sub-catchment dominates the image. Thin tree line in centre of image represents Saltwater Creek.

Rehabilitated Mine Site:
The rehabilitated open cut coal mine site forms part of Coal &Allied Howick Colliery. The study area is a hill slope which rises approximately 40m above the surrounding area. Contour banks have been landscaped across the slope and surfaces revegetated to help control overland flow, runoff and consequent erosion.

Pre-mining soils at Howick are generally poor quality agricultural soils with a shallow and erodible horizon and with a high dispersible clay component. Top soil availability for rehabilitation is limiting and direct planting over the over burden is necessary (Sinclair Knight & Partners, 1989). This suggests that spoil soils show significant variability in particle size and chemistry and with very little to negligible O horizon.

The pre-mining lithology of the Howick site belongs to the Wittingham Coal Measures which comprised 12 coal seams with dominant rocks in the interburden sequences being lithic sandstone of fluvial origin and varying grain size. Minor amounts of siltstone and, to a lesser extent shale were present (Sinclair Knight & Partners, 1989). These interburden sequences, broken and mixed up into the mine spoils, form the subsurface down to approximately 60-70m under the rehabilitated land.

The rehabilitated land is planted with pastures and trees. Typical pasture seed mix applied to rehabilitated area includes Rye Grass, Rhodes Grass, Marra Sub Cover, Couch and Lucerne. Rhodes Grass is the most dominant form. Acacia and Eucalyptus are the main species planted for tree cover.

Figure 3 Rehabilitated open cut coal mine spoil looking from south to north.

Climate:
Sinclair, Knight and Partners (1989) described the climate in the upper Hunter Valley as being a warm temperate climate due to its elevation, latitude and location relative to the western ranges and coastal lowlands. The temperature and rainfall are seasonal with the heaviest rainfalls occurring in summer. The summers are hot, while the winters are cool to mild with occasional severe frosts. They determined the average annual rainfall of 635 mm, with the number of rain days per month averaging 6 to 7 and the intensity being highest in the summer months when thunderstorm activity is at its peak. McMahon (1964) defined the region as a sub-humid zone with rainfall reaching a maximum in the summer months, with a secondary peak in July. The potential for evapotranspiration most always exceeds rainfall.

Instrumentation:
Two stream gauging sites are installed to measure surface runoff; a Bowen ratio unit or micro-meteorological station for estimating evapotranspiration; two sets of shallow and deep piezometers to measure groundwater level fluctuations and water quality; weather stations to collect air temperature, relative humidity, solar radiation, wind speed and direction data; Enviroscan sensors to estimate soil moisture changes from the surface down to 1.7m; drainage meters to detect deep drainage; rain gauges to record rainfall amounts and quality
Figure 4). Most instrumentation is automated, with data being recorded to data loggers on site and downloaded fortnightly. Some stations have modems installed to monitor data off-site to ensure early detection of faults for rectification. Manual measurements are made on site visits where possible to ensure validity of the data collected.

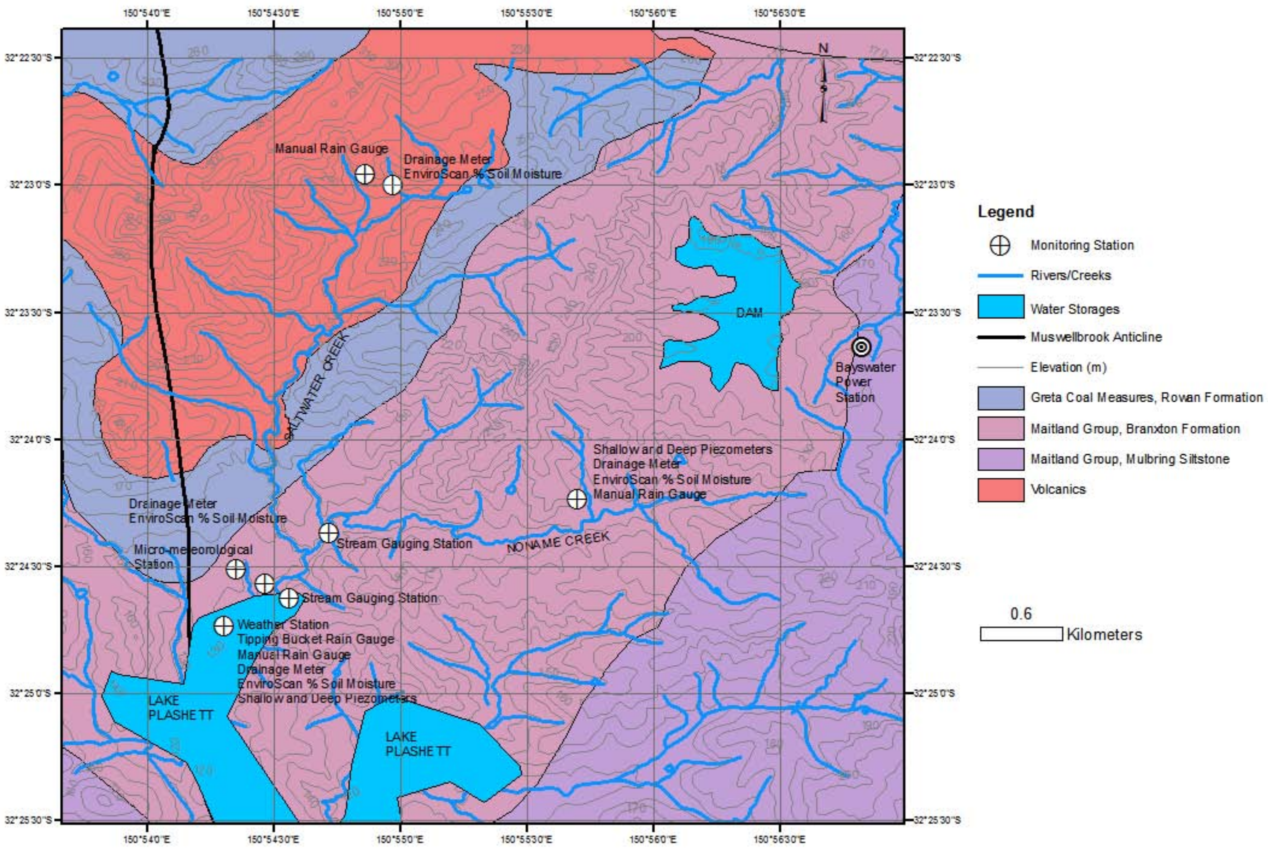

Figure 4 Monitoring station locations and elevation in metres for natural site. Elevation data obtained from the NSW Department of Lands Digital cadastral Database (DCDB). Map data sourced from Geoscience Australia (1991), Glen et. al. (1993) and Liu et. al. (2005).

Due to the heterogeneity of the spoil material in which traditional methodologies for determining water balance components are not applicable, instrumentation on the mine site is limited to a weather station and a gauging station (Figure 5). The weather station is used to estimate potential evapotranspiration and to detect differences in climate between the rehabilitated and natural site. The gauging station monitors overland runoff and water quality.

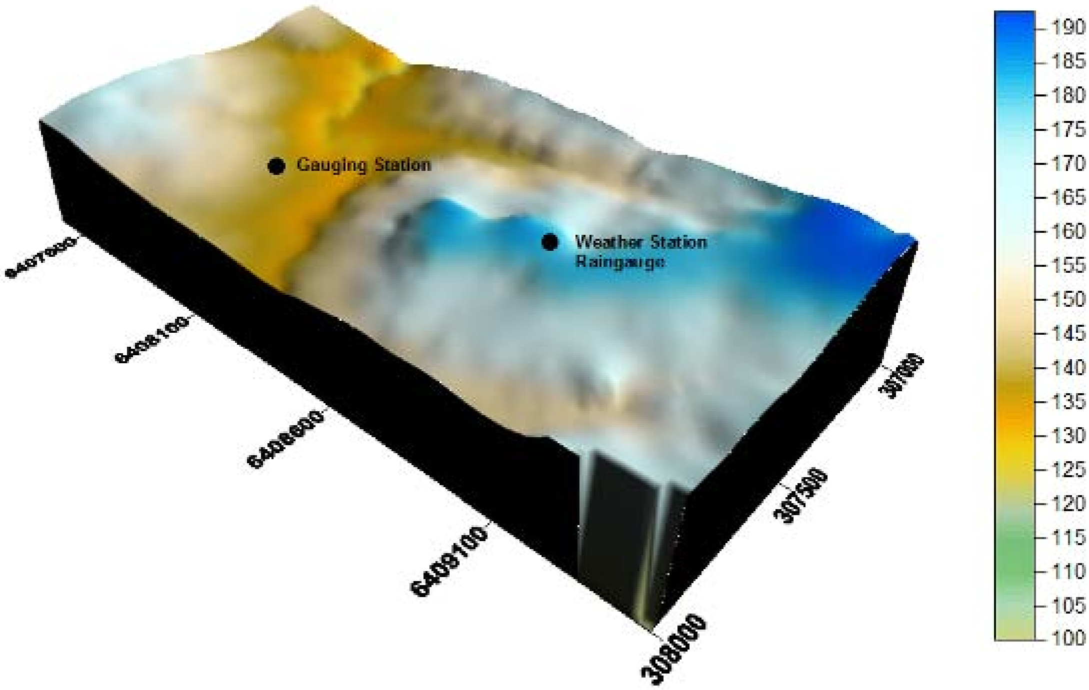

Figure 5 Instrument locations and elevation in metres (see colour scale) for rehabilitated mine spoil. Map co-ordinates in AMG84. Elevation data obtained from the NSW Department of Lands Digital cadastral Database (DCDB).

Heterogeneities introduced during mining and reclamation cause spoil to exhibit a dual-flow groundwater system. Macro voids within the spoil heap behave similar to a karst (fractured) aquifer which is capable of storing and transporting large quantities of water, whereas spoil material itself behaves as a highly transmissive unconsolidated porous medium (Hawkins, 2004). Infiltration and recharge into the mine spoil material is hard to capture by traditional methodologies due to its dual-flow nature, heterogeneous composition and the presence of thick unsaturated zones. Infiltration into these systems is controlled by a combination of local climatic conditions, physical properties of rocks comprising the mine spoil, geometry and structure of the rock pile along with vegetative cover (Wels, 2002). There is limited data on flow in these highly heterogeneous systems and modelling studies alone cannot significantly advance our understanding of water flow and transport in such an environment. There is a critical need for experiments carried out over a wide range of spatial and temporal scales so that defensible conceptual frameworks and models can be developed and tested (Nichol, 2005).

Methodologies need to be developed and implemented to address the unmonitored water balance components on the rehabilitated mine spoil. A review of historical research addressing water quality and recharge on mine spoils is currently being conducted. So far it has highlighted that there is no current set methodology to examine these issues and a combination of a variety of innovative techniques and modelling needs to be adopted.

3. *History of the region*

The main corridor of the Hunter River valley (Figure 6) consists of Permian rocks (conglomerate, sandstone, shale and coal) and is derived from ancient marine sediments high in salt (DLWC 2000). These sediments are thought to contribute up to 75% of the Hunter catchment salt budget (HRC 2002, DLWC 2000, DLWC 1996, Hannan 1994). Major fault lines in the hunter catchment contribute substantial amounts of saline groundwater to surface-waters by intersecting with the course of the Hunter River (DLWC 2000, Creelman 1994, AGC 1982). Sources of salinity to the Hunter River have been identified from the Goulburn River, Wollombi Brook, Wybong Creek, Dart Brook, Martindale Creek, Foy Brook and Black Creek (Muschal 2006, DLWC 2004, DLWC 2000). Creelman (1994), Bembrick (1993) and Kellett (1989) have estimated contributions of various geologies to the salt budget. Mitigation measures are in place to manage point source discharges of salinity in the Hunter River, and revegetation schemes exist in recharge and discharge areas to manage diffuse sources of salinity.

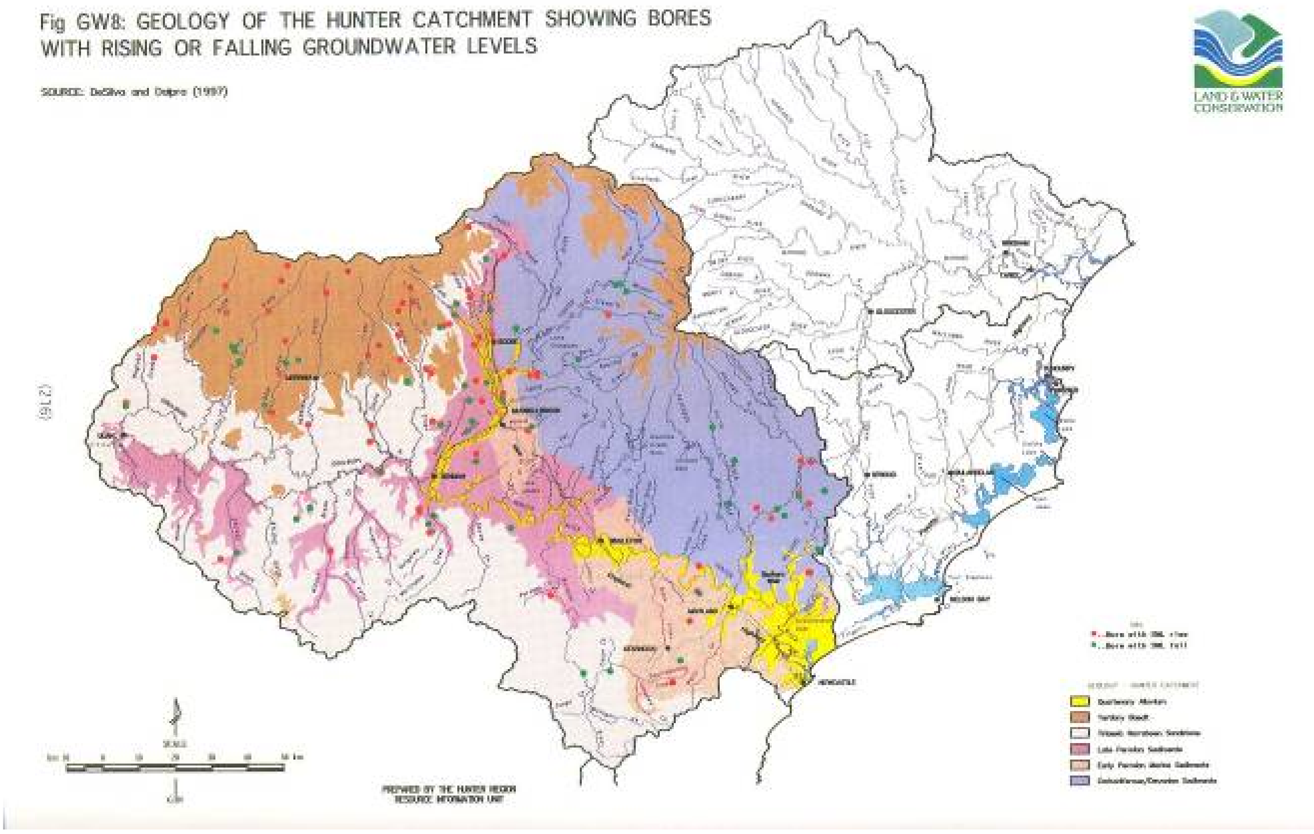

Figure 6 Geology of the Hunter Catchment (DLWC, 2000).

Although the natural geology of the Hunter catchment is the major cause of salinity in the region making up roughly 75% of the total salt load, the remaining salt load can be attributed to agriculture (15%) and mine and power station discharges (10%).

Open cut coal mining has the potential to exacerbate the naturally high salinity levels in the Hunter Valley catchment. The exposure of saline rocks to runoff provides a point source of salinity in the region's surface waters by accelerating natural leaching and weathering processes, creating new connections between separate aquifers and creating changed flow paths (DLWC 1996, DLWC 2000, Muschal 2005).

The extensive coal resources within the catchment provide cost effective locations for coal fired power stations. Electricity generation uses large volumes of water for cooling and as it evaporates, concentrations of salt are formed in the remainder (EPA 2003). Consequently, there is a requirement by by both the mining and power generation industries to expose of excess saline water into the Hunter River.

The Hunter River Salinity Trading Scheme (EPA 2003) was introduced to manage point sources of salinity discharges from coal mines and power stations on a catchment scale. The central idea of the scheme is to only discharge saline water when there is lots of low salt, fresh water in the river. Freshwater releases from Glenbawn and Glennies Creek dams are also used to dilute salinity levels. Discharges are managed using the IQQM model (Simons 1996). Discharges of approximately 11,000 tonnes/year are managed through this system (DLWC 2001).

Research:
Australian Coal Mine Spoil Research:

- Hancock, 2005: Long-term final void salinity prediction for a post-mining landscape in the Hunter Valley, New South Wales, Australia. This study used a mass balance approach to calculate water volumes and salt loads for a post-mining mine lake at Mount Arthur North Mine in the Hunter Valley using available hydrological, geological and water quality data over the long term. The results demonstrated a steady increase in salinity of the void water through time. This study found that the two major influences on salt load in the void were groundwater inflow and evaporation from the void water body surface, and that the size of the void water body surface controls evaporative loss. Rainfall salt and salt released from the overburden were relatively minor components. At all times the salinity values in the void are greater than the range observed for the Hunter River.

  Modelled equilibrium of void water volume occurred at approximately 250 years, with the void being filled to approximately 50% of its volume. Consequently, it is likely that the void will continue to be a net sink for groundwater in the long-term and will impact upon the Hunter River by reducing the annual flow (Younger *et al*., 2002).

  There is an absence of data on pit lake behaviour in the Hunter Valley to understand seasonal behaviour. The spoil flow rate calculations are based on Mackie (1999) and need revision. Pan factor for mine voids are not known for the Hunter Valley (used QLD). A further and necessary step in this type of analysis is a Monte Carlo type assessment for water quality (Younger and Robins, 2002) applying statistical variation in hydrological and geological inputs.

- ACARP C12043, 2005: A Model of Long-Term Salt Movement in Reconstructed Soil Profiles Following Open Cut Coal Mining in Central Queensland. A simple model was developed that predicts average salinity in the root zone from the initial average salinity (EC0), cumulative rainfall since rehabilitation establishment, and two terms describing the amount of rainfall required to initiate leaching and the rate of leaching. The model predicts downward salt migration over longer time periods, and is not intended to predict periods of capillary rise.

- ACARP C11050, 2003: management of issues for closure of open cut coal mines, identified the following knowledge gaps:
  - Spoil and final void monitoring network to verify and improve estimates of time for void to fill after mine closure.
  - Research on different recovery processes.
  - Prediction of water chemistry of final void.
  - Recharge rates under current and potential land uses. Affected by infiltration rates, root zone drainage rates, rainfall, vegetative cover, hydraulic properties of soils.
  - Changes to salt transport mechanisms and geochemistry during mining and post-mining.
  - Salinity consequences of current and future land and water management practices.
  - There is uncertainty about the medium to long term cumulative impact of mining on the quantities of salts and water which can be exchanged between surface water systems of the

Hunter region and the regional groundwater aquifers. Need to develop a regional groundwater model to quantify these impacts.

- AGC (1984) and Croft (1983) looked at the effects of coal mining on groundwater resources. The primary source of saline water at coal mines is interception of groundwater in the Permian strata, which is naturally highly saline. The local drawdown effect from pumping causes groundwater to flow towards the workings during the mine's life, ensuring that contamination cannot escape into the regional groundwater system. On completion of mining, equilibrium groundwater levels are eventually restored, albeit very slowly.

  Monitoring of bores installed in the backfilled overburden over the past 10 years indicates that salinity is little different to that in the surrounding, undisturbed aquifers. Although AGC, 1982 found that at one mine site salinity levels in overburden groundwater were twice that of groundwater in adjacent undisturbed areas. Six piezometers were installed at the base of the spoil. At best only partial restoration of the spoil had occurred, as some holes were saturated and others were dry at the bottom of the spoil. Tens to several hundreds of years are required to re-saturate the sediments. Salinity levels in surface runoff from overburden were found to be comparable with runoff from areas of natural pasture.

  Croft calculated in 1983 that discharges from all mines at that time would contribute around 2.4% of the total annual salt load in the Hunter River. Adjustment for current mining activity brings it up to 5 to 7%. Under average seasonal conditions and River flows, natural groundwater accessions to the river account for about 7.5% of the annual salt load. The largest contribution (around 87%) comes from normal surface runoff, although seepage and tail water from irrigation is included in this figure.

  During drought periods groundwater accessions to the river were the most important source of salinity. Coal mining, had virtually no effect on groundwater flow or quality, but the pumping of saline groundwater to the surface of active mine workings had the potential to affect surface water quality.

- Huxtable, 2005: Establishment of native and exotic grasses on mine overburden and topsoil in the Hunter Valley, New South Wales.
- ACARP C7007, 2002: Water Quality and Discharge Predictions For Final Void and Spoil Catchments.
- Brown, 2000: Nutrient status of pasture ecosystems established on rehabilitated overburden and topsoil sites in the Hunter Valley, New South Wales.
- Loch, 1997: Changes in some properties of topsoil at Taron Coal-Meandu Mine coalmine with time since rehabilitation.

International Mine Spoil Research:
A wider range of research has been carried out internationally on overburden from various mining activities. See Appendix A, for an overall summary of methodologies employed to monitor/evaluate mine spoil water fluxes.

Other Relevant Projects:
Ground and surface water interactions Wollombi and Wybong Catchments Upper Hunter: Dr. Ben MacDonald, ANU.
The aims of this project are to understand salinity and the extent of interactions between ground and surface waters in the sections of the Wybong Creek and Wollombi Brook and to develop assessment tools and conceptual models that permit both early identification of salinity sources and trends as well as critical appraisal of remediation strategies.

In order to achieve those aims the project has the following objectives:

- Identify priority saline sub-catchments of the Hunter River for detailed study.
- Review and collate information on the physiography, soils, climate, hydrogeology, surface and groundwater hydrology, geochemistry and land uses of these priority saline sub-catchments.
- To identify and characterise conceptual models of salinity causal processes in the study sub-catchments.
- Construct water and salt balances for the study catchments.
- Characterise the dynamics of the interaction of alluvial and fractured rock aquifers in the study sub-catchments and their connectivity with surface streams.
- Investigate the applicability of parameter-efficient models of surface and groundwater behaviour and water quality to the study-catchments.
- Develop and apply methods for rapidly assessing sources and trends in salinity and the efficacy of remediation strategies to the study and other sub-catchments in the Hunter.
- Endeavour to identify the degree to and nature by which salinity processes are able to be influenced by land management change in the study sub-catchments

Sustainable Pasture Management in the Hunter Coal Fields: Glenda Briggs, DPI, Tocal.
There is a current project sourcing funding run by Glenda Briggs at Tocal looking at sustainable pasture management in the Hunter coalfields. They are going to employ a consultant to carry out soil and pasture sampling on a variety of mine spoils, farm land and buffer land. It might be useful for us to suggest using Howick and Macquarie Generation land as the data will have extra applications by combining it with our hydrological and meteorological data and it might be useful in any modelling that may eventuate from the project.

4. *Initial Catchment Classification*

Natural Site:

The flow system on the natural site has two components. Recharge occurs by infiltration of rainfall over large areas. Groundwater within unconsolidated rocks is part of a shallow alluvium system which is characterised by rapid groundwater flow due to the high permeability of these sediments. Groundwater in consolidated rocks occurs within fractures, joints, cleats of coal seams. Groundwater within these strata is under pressure and represents a separate regional groundwater flow system to the alluvial river flats although they are connected. Regional flow in coal strata of the area is predominantly towards the Hunter River with a tendency for upward flow to the alluvium. This has the effect of diluting the slow discharging natural saline seepage from the coal strata.

During wet periods, the creeks rise and the majority of the flow through the catchment is the result of rainfall with significant variability in stream flow over similar rainfall events. The rainfall infiltrates into the surface soils, where it flows laterally along preferential pathways towards the creeks. Evidence of water seepage between the A and B horizons was noted during site visits. During dry periods, the creeks dry up significantly and the low flow (if there is any flow at all) is a result of base flow. Since the freshwater reservoir and the brine dam are both situated topographically higher than Noname Creek, it is believed that either of these bodies could also contribute to the base flow or lateral flow of water to the creek.

The geochemistry of the Hunter Coalfield geology influences the salinity of both the surface and ground waters of the region. It is believed that the water quality of the Hunter River is controlled by geology, particularly by the saline groundwater seeping to the surface from Permian aquifers (Kellett *et al*., 1989; Bembrick, 1993; Creelman *et al*., 1995). Looking at the division of geology over the natural site between volcanic and Permian (marine) origins, it might be reasonable to expect a higher salt load in the Noname Creek sub-catchment. In addition an EM31 apparent conductivity survey was carried out in 1995 by the DLWC for Pacific Power across the entire natural site (Figure 7). ECa across the site ranged from about 10 to 126 mS/m. Upstream Noname Creek exhibits much higher ECa values (concentrated along the drainage line) than the majority of Saltwater Creek. The south-eastern half of the larger Plashett Dam catchment exhibits similar ECa values to those in upstream Noname Creek, however high ECa concentrations are more wide spread, not concentrated along drainage lines.

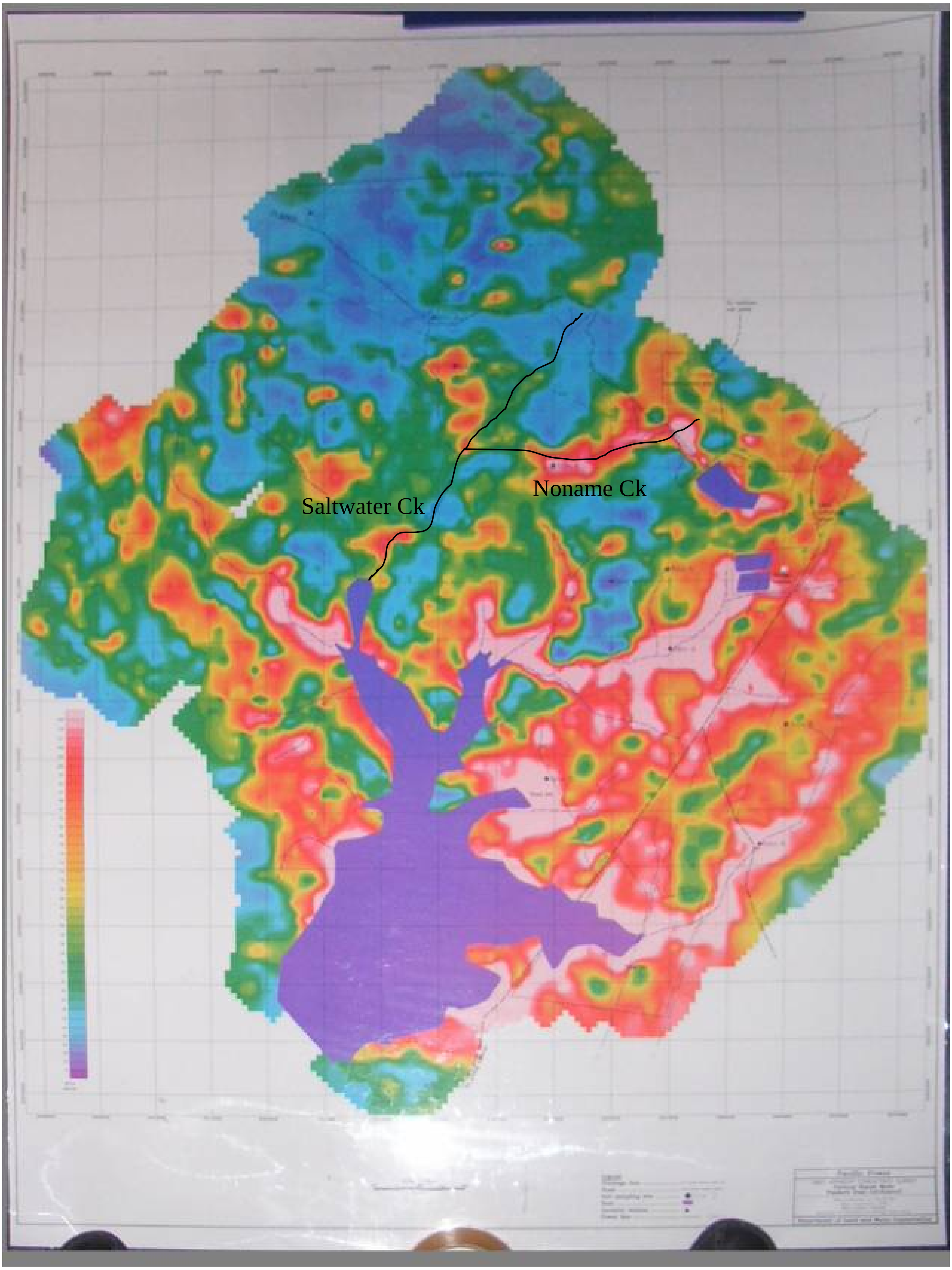

Figure 7 EM31 apparent conductivity survey by Pacific Power over the Plashett Dam Catchment.

Rehabilitated Mine Spoil:
Conceptually, water flow through spoil material is well documented; the challenge lies in being able to parameterise this flow to accurately model water transport processes. A simple conceptual model for a rehabilitated spoil pile is presented in Figure 8.

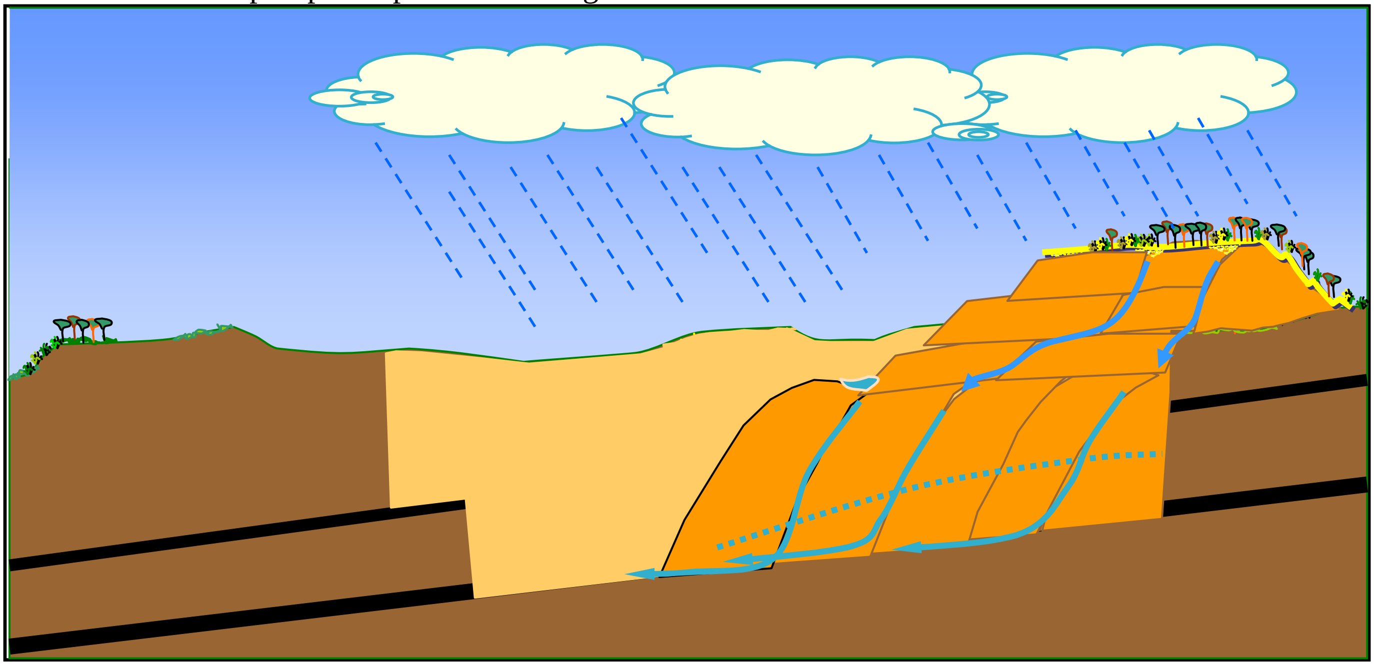

Figure 8 Rehabilitated mine spoil conceptual model.

Figure 9 Heterogeneous spoil material.

Heterogeneities introduced during mining and reclamation cause spoil to exhibit a dual-flow groundwater system. Macro voids within the spoil heap behave similar to a karst (fractured) aquifer which is capable of storing and transporting large quantities of water, whereas spoil material itself behaves as a highly transmissive unconsolidated porous medium (Hawkins, 2004). Infiltration into these systems is controlled by a combination of local climatic conditions, physical properties of rocks comprising the mine spoil, geometry and structure of the rock pile along with vegetative cover (Wels, 2002). Mine spoil behaves as an unconsolidated aquifer under most circumstances (Hawkins, 1998).

A study made of spoil piles indicates permeabilities in the range of 0.037 to 10 m/day. This indicates that spoil material has a better water yielding capacity than the original coal seams (0.11m/day) (AGC, 1984). Cederstrom (1971) contend that mining may improve the recharge potential from undisturbed catchments. Herring (1977) observed that the overall recharge and surface water runoff to reclaimed surface mines in the Illinois basin were greatly increased. The increased recharge was attributed to the dramatic increase in the permeability of the cast overburden.

Larger spoil particles tend to roll towards the base of the spoil ridges into the valleys, while the midsized and smaller fragments tend to stay on the sides and top of the spoil piles (Rehm et al, 1980). Phelps 1983, observed that spoil bulk density generally decreases with depth. This appears to be caused by the creation of a significant volume of interstitial voids when the large spoil fragments, commonly sandstone, roll to the base of spoil piles. The surface voids will only recharge the spoil when runoff is occurring. In contrast lateral recharge is controlled primarily by hydraulic properties of the adjacent aquifer and the hydraulic gradient. The processes of mining and reclamation may further facilitate spoil heterogeneity by creating zones comprised predominantly of one lithology.

During mining, a dragline or frontend loader often will remove overburden in layers, spoiling strata composed of mainly one lithology at a time.

Because surface mine spoil is a highly heterogeneous and anisotropic medium, groundwater flow paths are difficult to determine. The water table tends to reflect the overlying topography but is also influenced by permeability variations, local structure and the adjacent unmined areas. Groundwater tends to flow down dip and perpendicular to the strike of the pit floor. Direction of mining and the configuration of the backfill can dramatically impact the direction of the groundwater flow. Aquifer testing indicates that groundwater velocity in mine spoil is substantially greater than that of the undisturbed overburden. Most spoil velocities measured were below groundwater velocities commonly measured in true karst aquifers, however they were similar to velocities in unconsolidated glacial sands and gravels. The location of haul roads across the backfill can also influence groundwater flow. Spoil underlying haul roads can become highly compacted (less transmissive) and the spoil on each side of the road will be more transmissive. Groundwater may flow along the road edge until a pathway exists or impound behind these haul roads.

Piping and differential compaction of fine grained spoil material in response to vertical movement of recharging waters through the unsaturated portion and horizontal movement of groundwater in the saturated portion may be the cause of increased void communication.

Initially after reclamation, diffuse recharge from the surface is generally well below pre mining levels because of the destruction of soil structure, soil compaction by mining equipment, low vegetative growth, which tend to promote surface water runoff rather than infiltration (Razem 1983). After this initial period, as soil structure and vegetation re-establishes, diffuse recharge form the surface begins to increase.

Hancock (2005) conceptualised inputs and outputs from final voids. At mine closure following opencast mining, in mines with low overburden to coal ratios (such as those in the Hunter Valley), a void is left in the final landform (Bowell, 2002; Younger *et al*., 2002) (Figure 10). In the final landform, the void is a local sink for both surface and groundwater and will often act as a water store. Mining also often occurs below the water table, depressurizing the aquifer locally and causing groundwater to seep preferentially into the void (Eary, 1998; 1999; Shevenell, 2000; Younger *et al*., 2002; Bowell, 2002). Seepage will continue well after mining because of the slow dynamics of groundwater systems. If the void is large enough, the evaporation will continue to drive the groundwater flow into the void and the local and regional groundwater may never fully return to pre-mining conditions (Mackie, 1999).

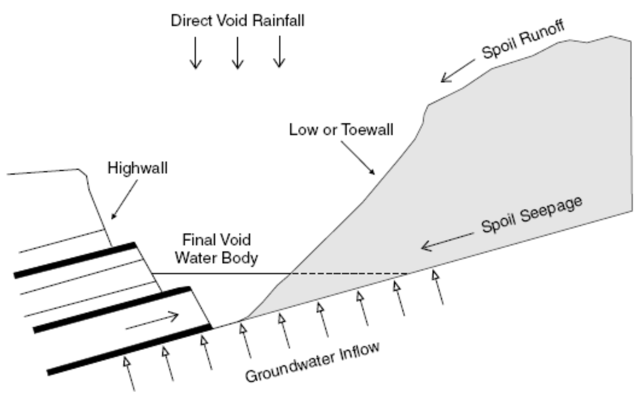

Figure 1. Water and salt inputs and outputs to a post-mining landscape final void

Figure 10 Final void conceptual model (Hancock, 2005).

5. The Key Site Research Program

Aims:

- Provide data for validation of prediction models for salt and water movement.
- Describe salt mobilisation processes and their likely effect on surface and groundwater flows in natural and rehabilitated mine landscapes.
- Devise methodology for the direct assessment of recharge and water quality on rehabilitated mine spoils.

Research questions

- Where does rainfall go, how is salt mobilised, and where and how do salt and water move in the landscape?
- How do we account for water at a paddock scale and how does this relate to the catchment water balance?
- Are water and salinity models consistent with measured data and catchment observations?
- What are the long-term effects of rehabilitated mined landscape on surface and groundwater quantity and quality?

Potential Outcomes:

- Long term monitoring of salt and water fluxes in a natural Hunter sub-catchment and the collection of comprehensive long term data sets (micro-meteorological, climate, soil moisture, stream gauge and ground water data) associated with these fluxes.
- A hydrological comparison between pre and post open cut coal mining landscapes, including identification of salt mobilisation processes and consequent land use change impacts. Knowledge to allow hydrological comparison between pre and post open cut coal mining landscapes, including identification of salt mobilisation processes and consequent land use change impacts
- Establishment of methodology to quantify salt and water fluxes on rehabilitated mine spoils, currently a knowledge gap.
- Ability to predict salt exports from coal mine rehabilitation areas to improve whole of catchment salt load and future trend predictions.

Broad Methodology:

- An open-cut rehabilitated coal mine is compared with a natural (un-mined) site in close proximity. Understanding the natural salt contribution to the watershed is critical to the development of site-specific background concentrations for comparison with alternate uses of land within the same watershed.
- Traditional hydrology methods monitor changes in soil water with capacitance sensors, deep drainage with drainage meters, evapotranspiration with micro-meteorological instrumentation, piezometers for groundwater levels and EC, stream gauging for stream flow and EC and weather stations for climate data at natural site.
- Pathways of water and salt are identified by analysing the chemical composition of water and soils from different parts of the catchment and geophysical techniques are used to map salt stores and water pathways.
- Conceptual and physical models will be developed to test understanding of the sub-catchments. These models will be continually revised and refined as data is collected and analysed.

6. *Some Key Results and Conclusions*

Climate:

At both the natural and rehabilitated sites the highest average rainfall occurs in February with a secondary peak occurring in June (Figure 11a). The minimum monthly rainfall occurs in April. Rainfall is generally higher at the rehabilitated site compared to the natural site and this may be due to differences in elevation or rainfall variability. At the natural site 93% of rainfall events result in rainfall intensities < 5mm/hr, 6% of events are between 5 and 10mm/hr and 1% of events are > 10mm/hr. The three largest rainfall events had intensities of 51.4, 30.0 and 28.8 mm/hr occurring on the 15/2/2006, 5/11/2004 and 23/1/2007 respectively. There is some spatial variability in rainfall between the south and east of the natural site, with the east consistently receiving more rainfall (Figure 11b).

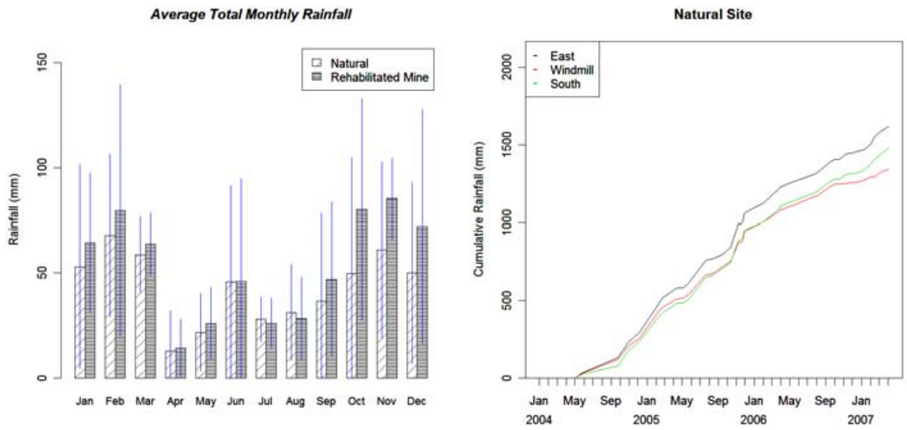

Figure 11 a) Total monthly rainfall at the natural and rehabilitated sites. Blue bars represent monthly standard deviations. b) Cumulative rainfall differences from manual rain gauges on natural site.

Air temperature (Figure 12a) and rainfall (Figure 11a) are consistently higher at the mine site compared to the natural site. This may be due to spatial variability in rainfall, differences in elevation between the sites or the longer operating time of the weather station at the natural site.

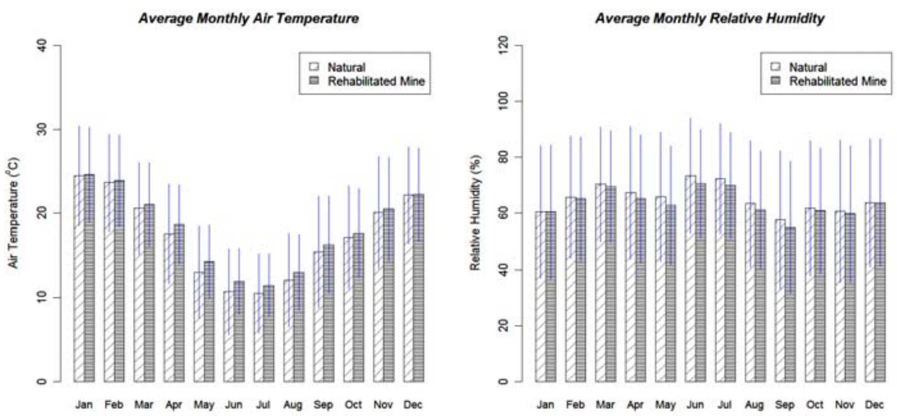

Figure 12 Monthly air temperatures (a) and monthly relative humidity values (b) at the natural and rehabilitated sites. Blue bars represent monthly standard deviation values in each parameter.

Natural Site Water Balance:

Rainfall and Evapotranspiration:

Evapotranspiration (ET) was estimated at the natural site using the Bowen ratio method and data from the micro-meteorological station (Figure 13).

Table XX ET and precipitation for natural site Hunter Key Site

Year	Precip	ET mm	ET % (precip)
2004/05	739	621	84%
2005/06	706	748	106%

Evapotranspiration exceeding rainfall is indicative of depletion in soil water stores over this drier period.

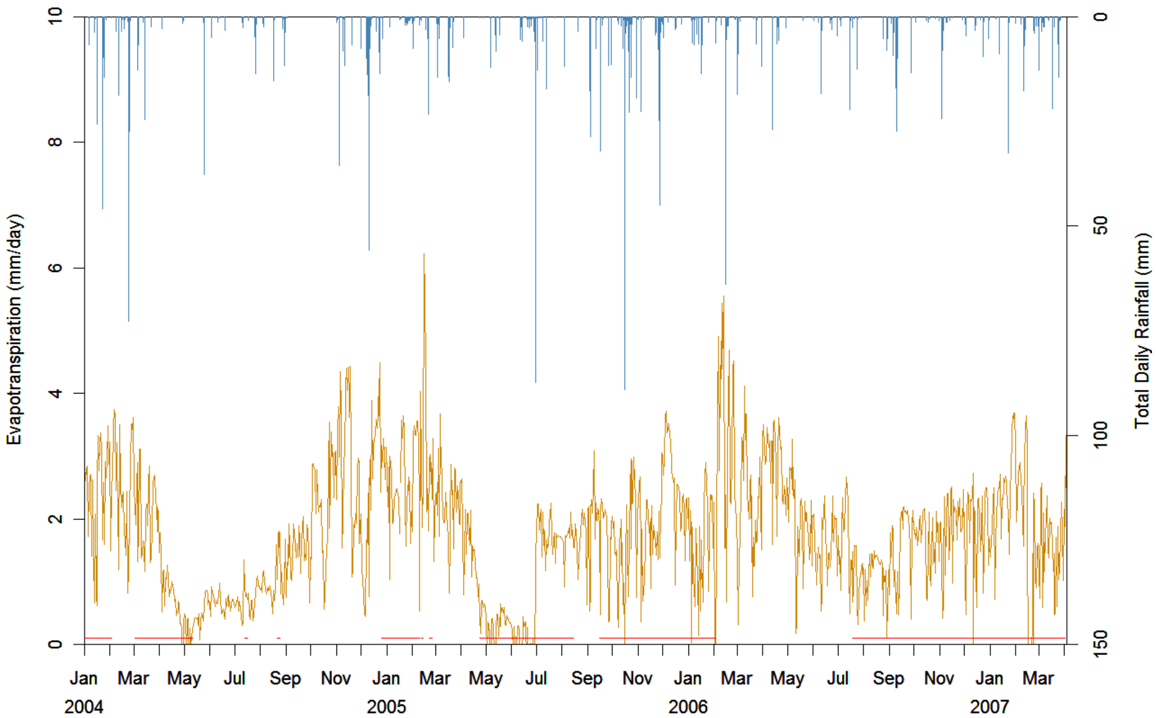

Figure 13 Daily evapotranspiration (tan), rainfall (blue) and periods of missing data where ET was estimated from potential ET and total soil water at 00:00 (red) at the natural site.

Changes in Soil Moisture:

Changes in total soil moisture were calculated between 00:00 and midnight daily at the four soil moisture monitoring sites across the natural catchment. Enviroscan soil moisture sensors are placed at depths of 20, 40, 60 (one site only), 80, 120 and 170 cm for the surface. The sensor range of influence was assumed to be 10mm to calculate total soil water and missing depths were interpolated over. Figure 14 shows the daily changes in total soil water between 00:00 and midnight at the four sites by 10mm rainfall bin. All sensors with the exception of the east site are showing soil moisture changes exceeding rainfall by large amounts, with the South site showing the most extreme changes.

We are using the default calibration parameters for each sensor at the moment that applies to a range of Australian sands, loams and clay loams. Soil sampling is required around each of the sites to determine changes in soils with depth at each of the monitoring locations. Hopefully there will be some pre-existing calibration parameters for our specific soil types that we can apply for each sensor, else full calibrations will be needed which is an intensive and expensive process.

Other physical scenarios that might also be causing the excessive changes in soil moisture include water in the access tube, poor sealing of the tube and pooling water at surface (access tube installed in a depression).

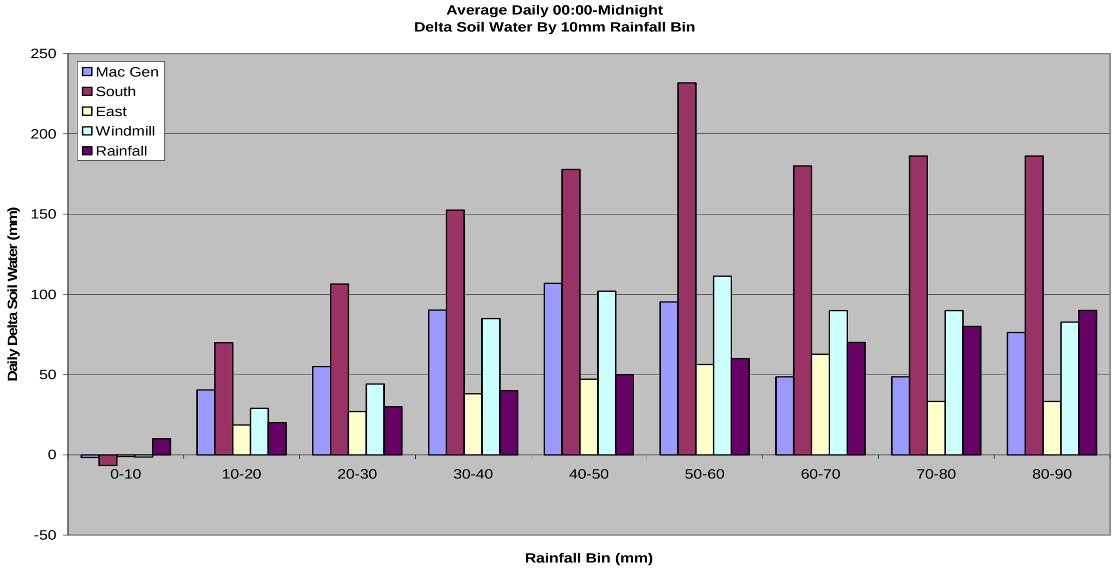

Figure 14 Daily changes in total soil water between 00:00 and midnight at the four sites by 10mm rainfall bin.

An assessment was made as to whether the resolution of the sensors with depth was an issue with calculating soil moisture changes. We compared the changes in soil water over a fixed period from our Sentek sensors at fixed depths to manually measured soil moistures every 10cm down to 1.7m using the Diviner 2000 (Figure 15). We used identical calibration parameters for the Sentek sensors and the Diviner.

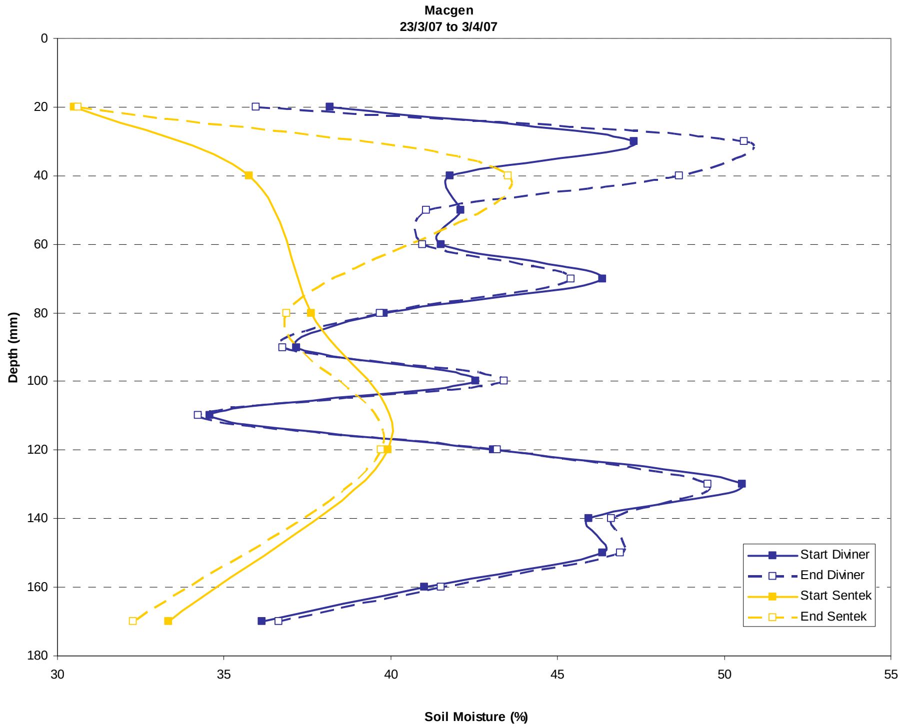

Figure 15 Differences to changes in soil moisture profiles with depth from the surface after a 20mm rainfall event between Sentek and Diviner 2000 measuring devices.

The soil moisture profiles between Sentek and Diviner look very different. Peaks in soil moisture at 30, 70 and 130cm are missed in the Sentek profiles. Sentek sensors assume a moisture increase down to close to 80cm whereas in actual fact using the higher resolution diviner data the soil started drying out at 50cm. These graphs highlight some of the invalid assumptions we are making about soil moisture changes in the soil profile when we are interpolating over depth. We have to look at installing more sensors especially in the upper profile to more accurately capture the changes that are occurring.

Deep Drainage:
There have been no significant changes in soil water potential at each of the four monitoring sites since the project inception (Figure 16) until June 2007 as a result of a 250mm rainfall event falling over 55 hours. This needs further investigation. The Mac Gen site only shows the start of a change as the junction box became flooded and instrumentation damaged.

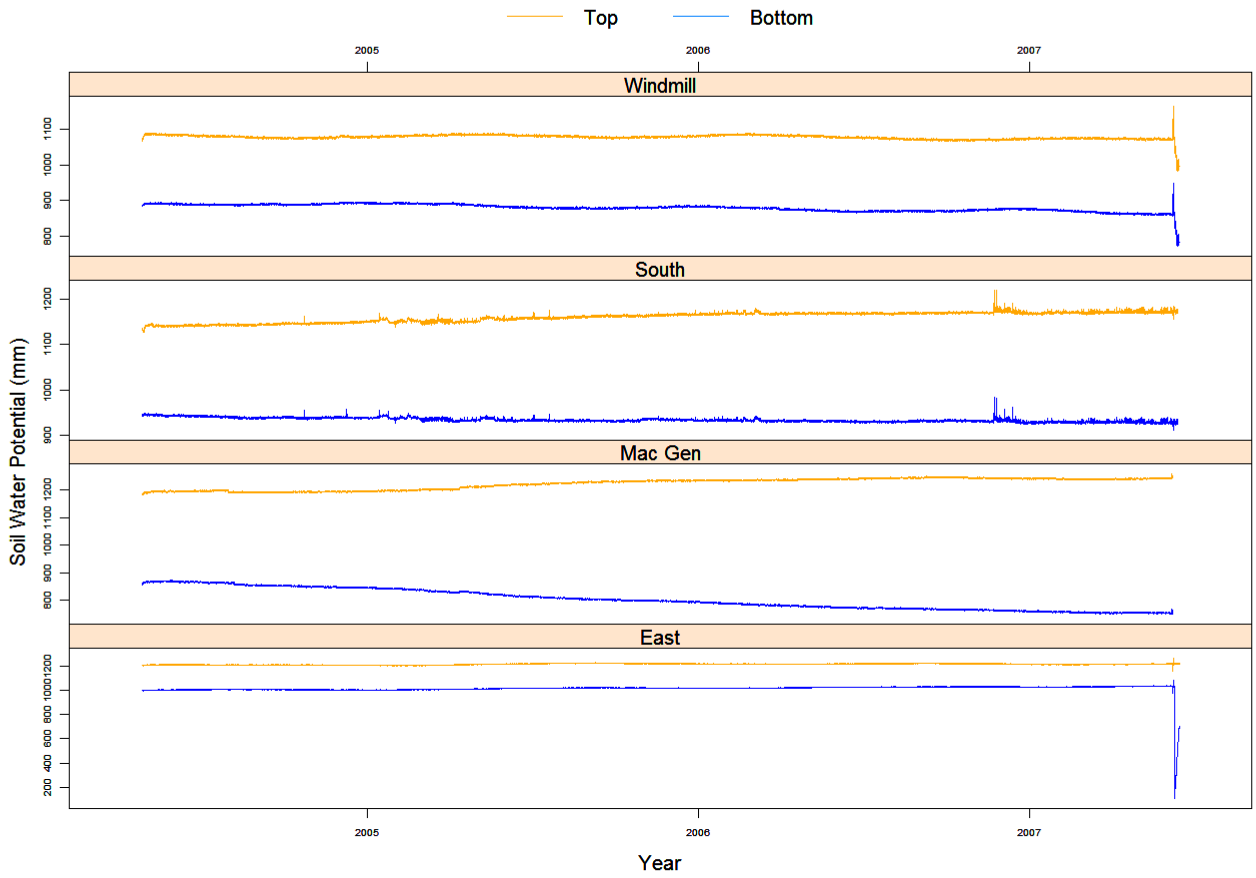

Figure 16 Changes in soil water potential across natural site with time.

Runoff:
Historical volume transport calculations at this stage are held up until velocity measurements are made to calibrate the non-standard weir design at the Saltwater Creek gauging station. Spot measurements are practically impossible with the perennial nature of the creek. Flow through Saltwater Creek occurred a lot more frequently at the start of the project but the ground has dried out so much now that there appears to be limited (if any) base flow (prior to flood event of June 2007). Weir was destroyed in 1.5m flood Jan 2006, and rebuilt Jan 2007. In June 2007 left hand bank eroded looking downstream (Figure 17 and Figure 18).

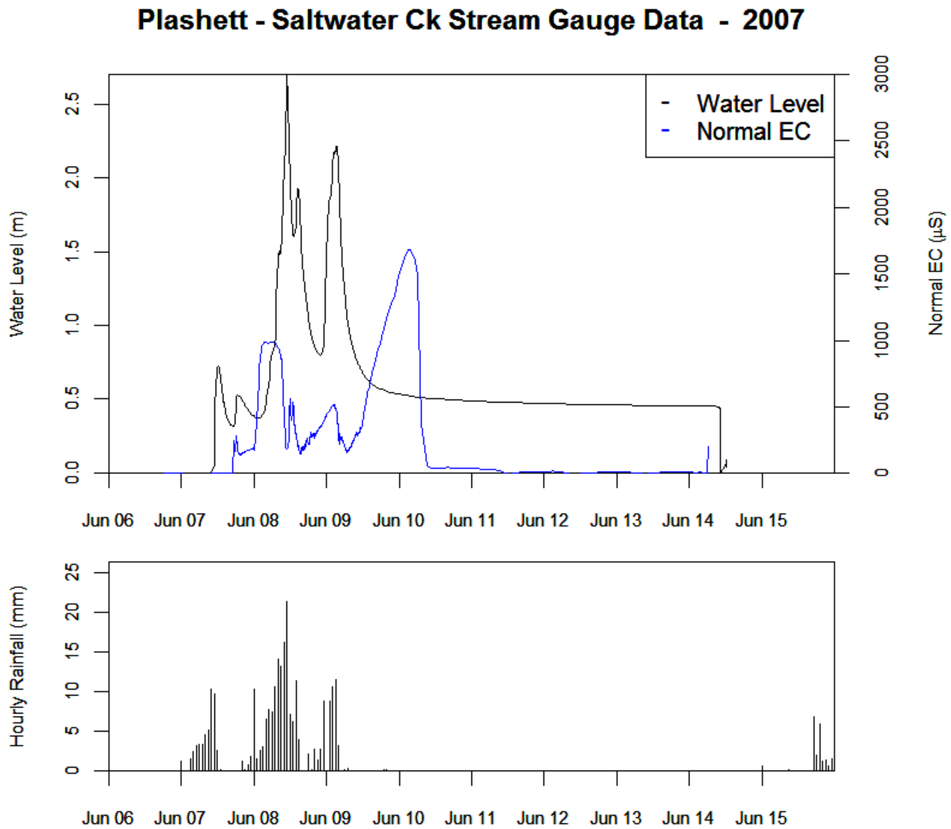

Figure 17 Stream gauge data (water level and EC) during flood event in June 2007.

Figure 18 Bank erosion during flood event June 2007.

Ground Water Fluctuations:

At the south site situated in downstream Saltwater Creek an overall falling trend has been evident since January 2004. This may be related to pumping by Bayswater power station from Plashett Dam. Access to pumping rates and water levels from Plashett Dam is required to verify and remove this effect from our data. The east site situated in upstream Noname Ck has not shown this declining trend, and may be outside of the influence of Plashett Dam pumping. Groundwater level responses to rainfall events are evident in this data with the most marked rise of over one metre at both sites a result of the June 2007 rainfall event of close to 250 mm over 55 hours. Recharge rates can be calculated from these water table fluctuations over time in response to rainfall events and the specific yield of the aquifer. A suitable method for determining specific yield at our sites needs to be identified and employed.

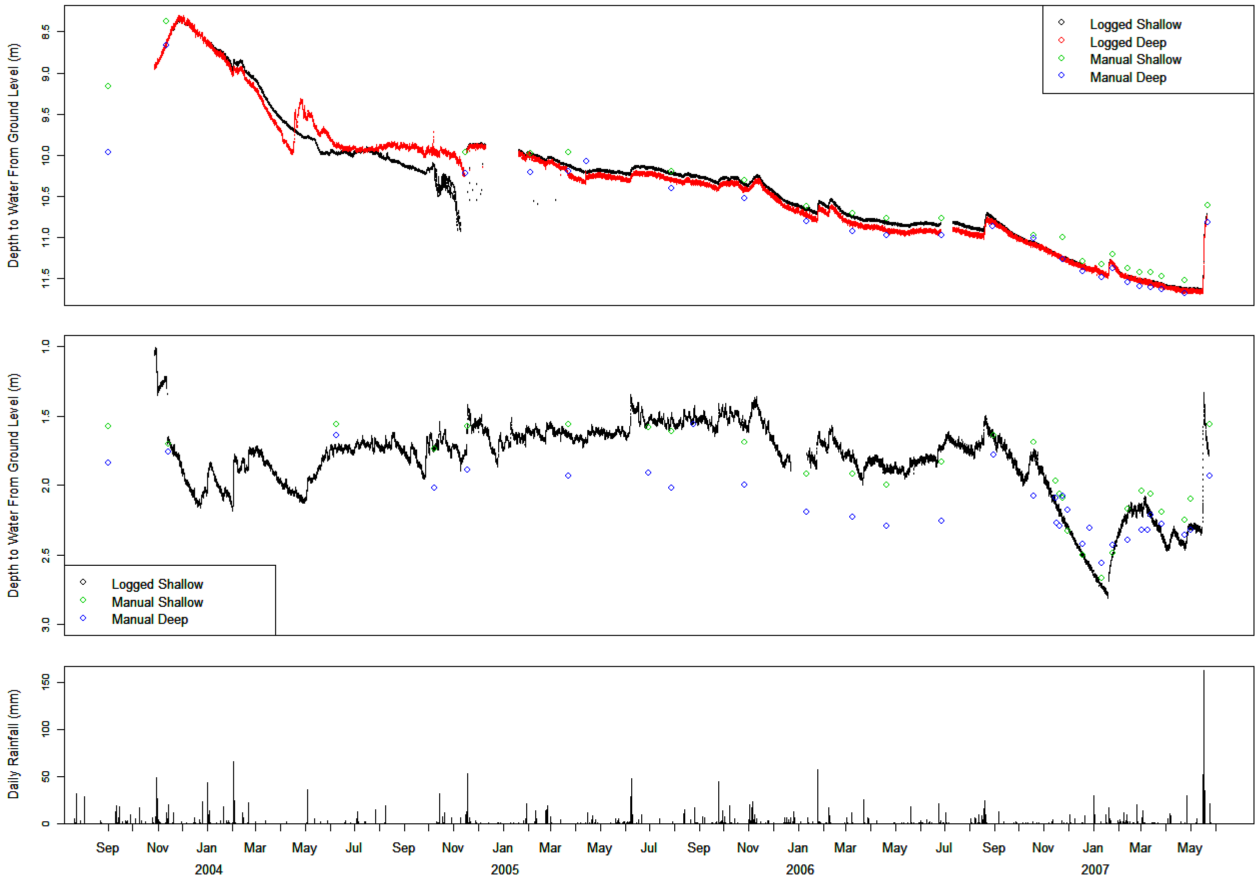

Figure 19 Ground water levels at south (top) and east (middle), along with total daily rainfall (bottom).

Salt Sources:

Initial observations show that surface runoff on the mine spoil is two orders of magnitude less saline than surface runoff on the natural site. Average mine spoil surface runoff has normal EC 93 ± 43 µS/cm compared to 2149 ± 3181 µS/cm for the natural site. Initial rehabilitation of the mine spoil occurred 15 years ago, but monitoring only began late 2005. One possible reason for the very low EC values from the mine spoil may be that the surface spoil went through a high period of leaching initially before monitoring began where salts were washed off via surface runoff or leached downwards into the spoil itself. Historical final void EC data may help tease this out.

Rapid surface and ground water sampling for EC was carried out in April 2003 on the natural site. Some interesting results were found in that upstream of the junction between the Saltwater and Noname Creeks, Saltwater Creek had EC values around 2000 µS/cm, but Noname Creek EC values were closer to 8000 µS/cm. Consequently, Saltwater Creek becomes saltier downstream of input from No Name Creek. The ground water EC levels had a similar pattern. Upstream Noname Creek had ground water EC levels around 40,000 µS/cm, but downstream Saltwater Creek values were down to 4,000 µS/cm. The immediate question to answer is why Noname Creek is saltier than Saltwater Creek and where is the salt coming from? The possibility of leachate into the system from a brine dam in upstream Noname Creek drew immediate concern.

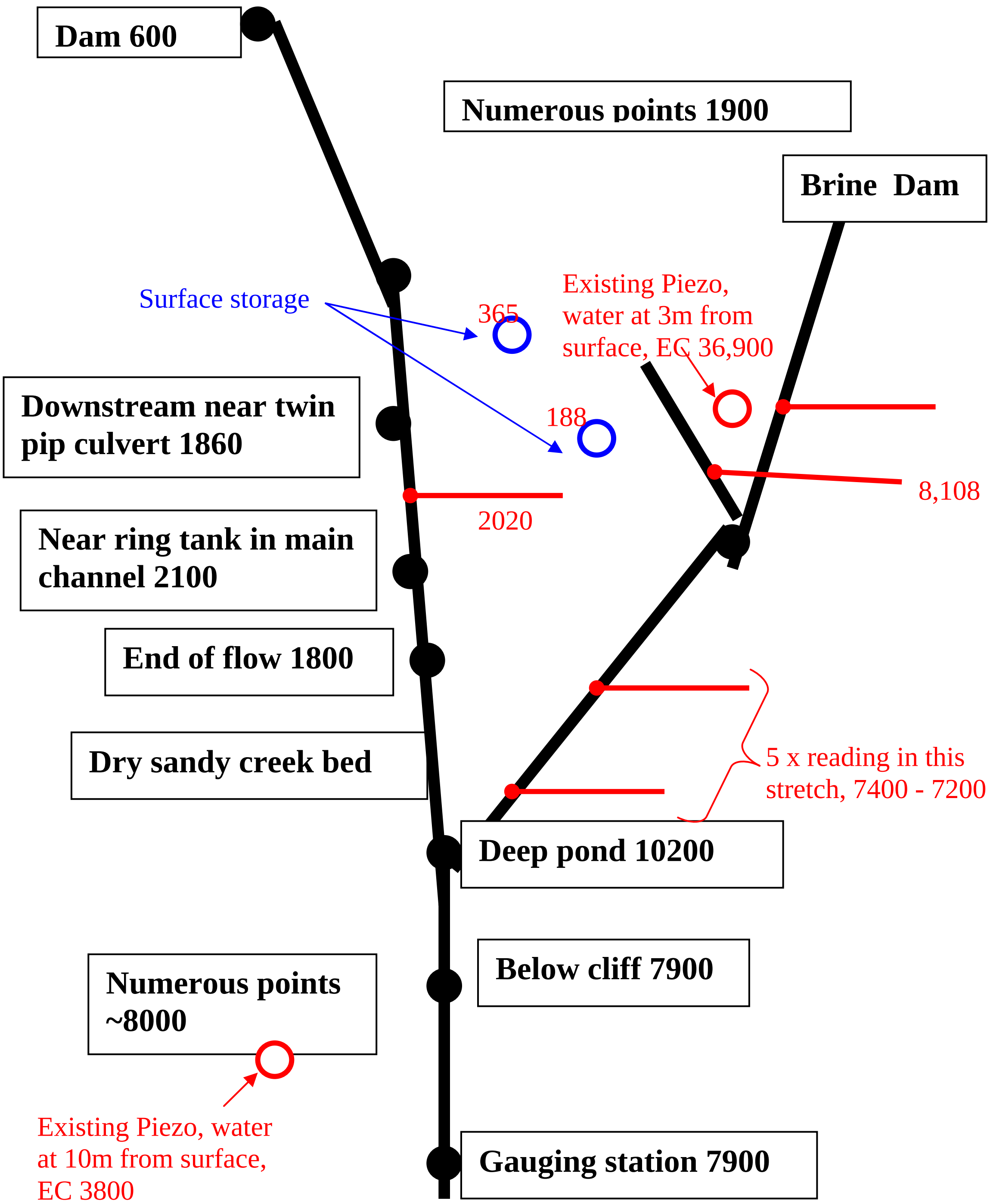

Figure 20 Schematic diagram showing variation in EC in μS/cm within Plashett Dam catchment (not to scale). Saltwater Creek left branch; Noname Creek right branch.

The sources and distributions of salt across the catchment where investigated further throughout 2003 by UTS honours candidate Micah Silvey. His work was submitted in November 2003 to UTS incomplete, but he did provide some conclusions and recommendations for future work. An outline of his project follows, including results. Most of the raw data he collected is listed in the report in appendices. We have permission to use the data freely provided the source is cited.

The objectives of the project were to acquire a minimum number of samples that would identify the salt distribution within the surface water, ground water and soil across the catchment and to trace water movement through the catchment to differentiate between water sources. Sample numbers were limited to budget and time constraints.

Water sampling was carried out 14 surface water sites and 4 ground water sites whose locations are in Figure 21. EC, pH and temperature were measured in the field. Samples were submitted to Sydney Analytical Laboratories for analysis of major cations (Na, K, Ca, Mg), major anions (Cl, SO_4, Alkalinity (HCO_3 + CO_3) and metals (Cu, Pb, Zn, Cd, Cr, Ni, Fe, Mn, Al, As, Mg).

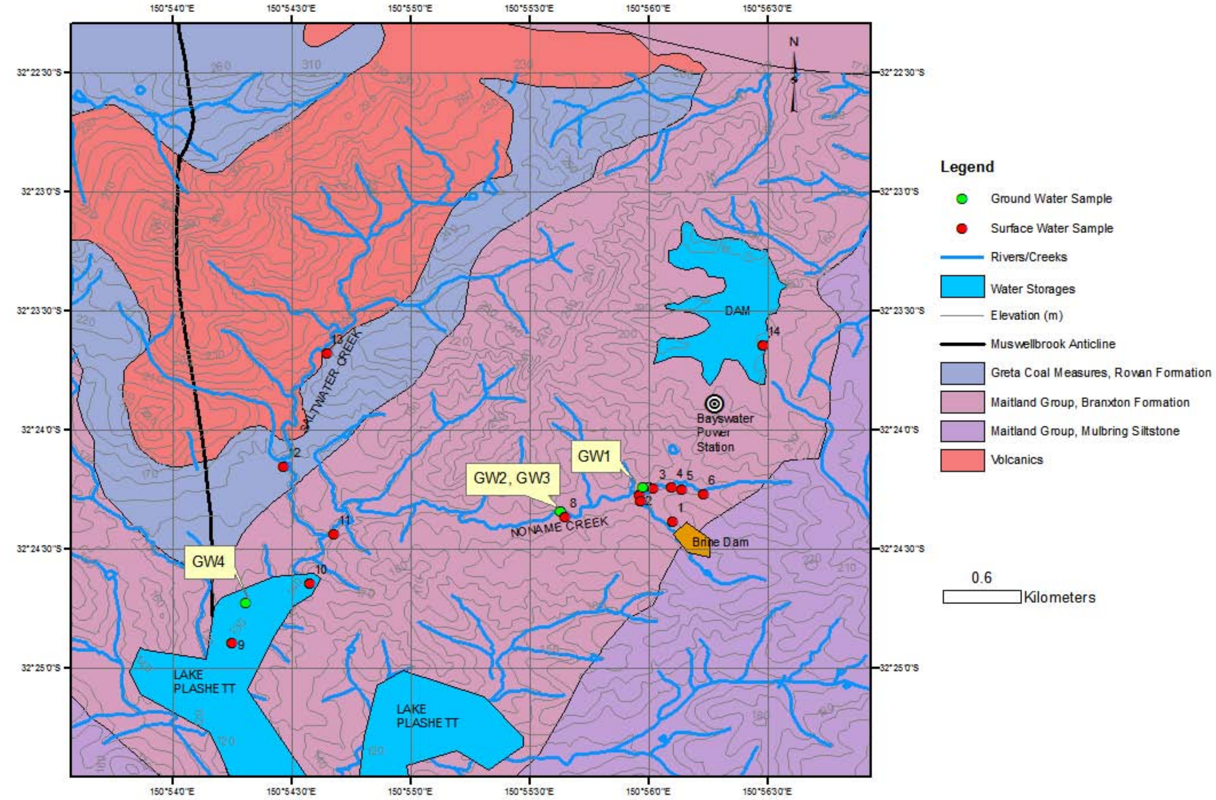

Figure 21 Surface and ground water sampling sites in natural catchment.

Four distinct water types were identified using Ca, Na, HCO_3, Cl, SO_4, Mg concentrations from both surface and ground water samples (Figure 22 and Figure 23).

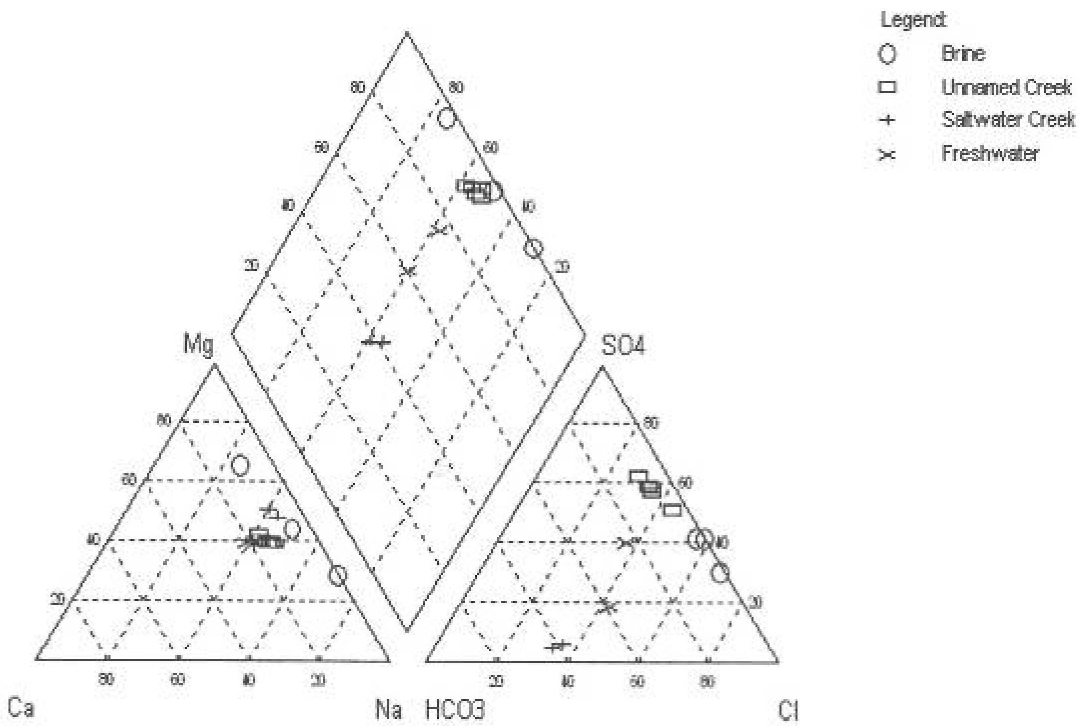

Figure 22 Piper plot of surface and ground water samples illustrating distinction between water types (Silvey, 2003).

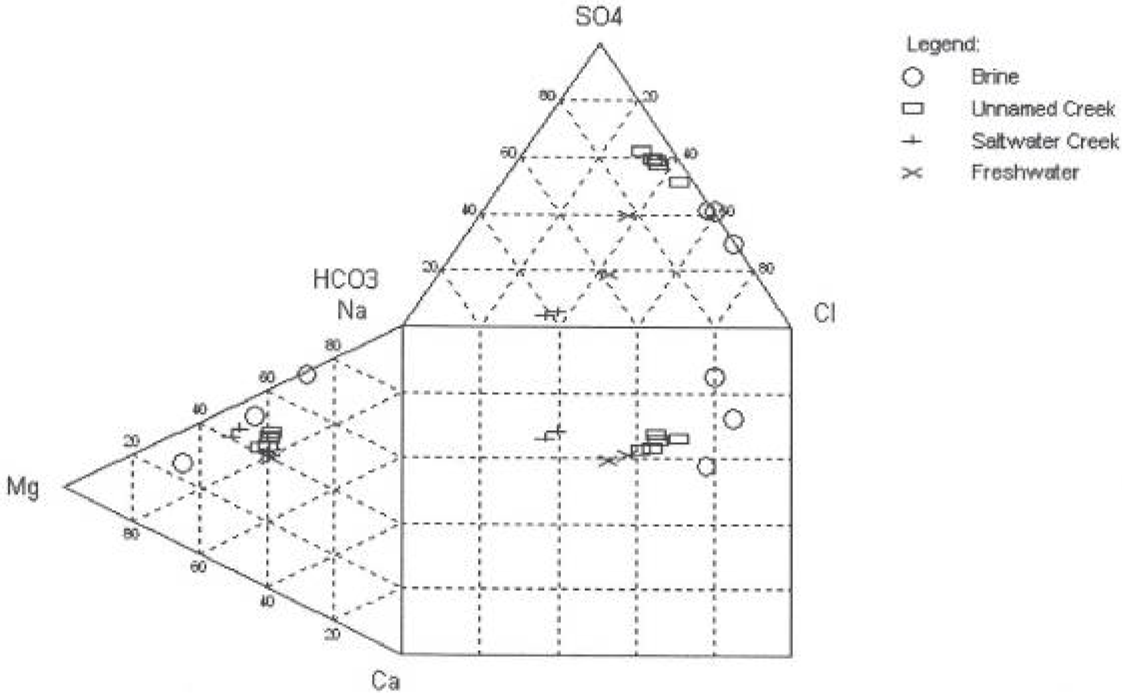

Figure 23 Durov plot of surface and ground water samples illustrating distinction between water types (Silvey, 2003).

One water source labelled brine water due to their high EC values comprised surface water samples from the brine dam (sample 1), the gully flowing away from the brine dam (sample 7) and ground water sample GW1. The second water source comprises the upstream Noname Creek surface water samples 2,3,5,8 and 10. It is unclear why surface water samples 4, 6 and 11 also from upstream Noname Creek have been excluded from the analysis. Both the brine and Noname Creek water types are dominated by Na, Mg, SO_4, Cl ions. The third distinct water type represents surface water samples from Saltwater Creek upstream of the Noname Creek junction (samples 12 and 13) which have increased alkalinity and decreased sulphate comparatively. The final water source identified as freshwater includes surface water samples 9 and 14 from Lake Plashett and the freshwater dam respectively.

Groundwater samples GW2, GW3 and GW4 fall somewhere between these distinct water types. GW2 and GW3 have similar ion ratios and measured EC as Noname Creek and GW4 looks like a mixture of both creek water types.

Looking in closer detail at the brine water samples, the only difference evident is the decrease in the amount of Na between the samples, which is compensated for by an increase in Ca and Mg. This is common where brine moves through clay rich soil with a high CEC. The large volume of Na acts to displace the Ca and Mg from the clay surfaces in a process called reverse softening or reverse ion exchange. It is clear that the plume emerging from the brine dam has reached as far as GW1, although diluted (by a factor of almost seven) due to the decrease in Cl.

The effect of the brine dam on Noname Creek is not obvious even having found two water samples with distinct origins from the brine dam. Log chloride concentrations were plotted against log sodium concentrations for all water samples (Figure 24).

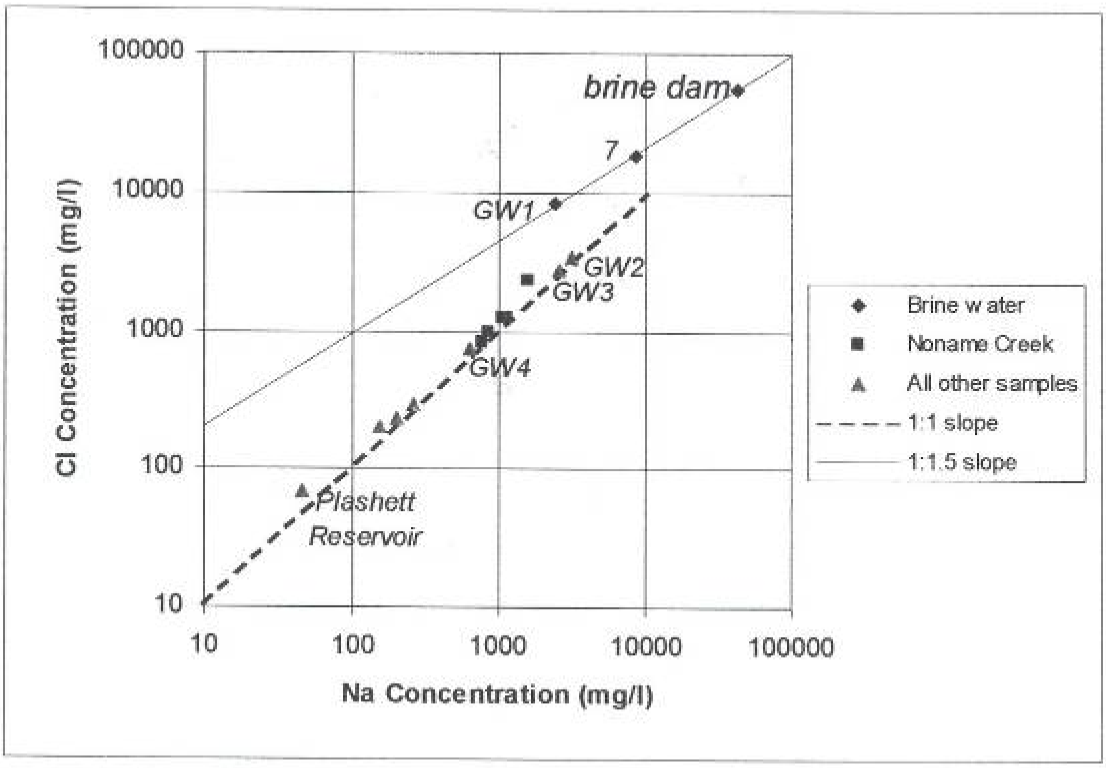

Figure 24 Log Cl versus log Na for all water samples from natural site (Silvey, 2003).

The brine samples plotted along a 1:1.5 Cl:Na slope. Tracing the line from the brine pond down to GW1, the Na concentration is decreasing faster than the Cl concentration, further evidence of reverse ion exchange occurring downstream of the brine pond. All remaining samples plotted along a 1:1 Cl to Na ratio. At the time of sampling, the low flow in the creek was being fed by base flow. If the elevated salt levels in Noname Creek were due to influence from the brine water dam they would appear as a dilution of water sampled from GW1 and this is not the case.

A salt supplying process that does not result in an increase in Na:Cl ratio downstream (as observed in Figure 24 with the exception of the brines) is the dissolution of halite (NaCl). Small halite crystals have been observed along creek banks and along exposed cliff sections in the Noname Creek sub-catchment. The geological formations in the Noname Creek sub-catchment are Permian with marine origins where halite is common. Contrastingly, the majority of the Saltwater Creek sub-catchment is underlain by a volcanic tertiary intrusion. These differences and the presence/absence of halite could account for the differences in EC observed between the two sub-catchments. It was intended that x-ray diffraction analyses could be used as a tool to identify mineralogy variations across the site, specifically in regards to the presence of halite crystals.

Looking at the variation in EC with distance from the brine dam over two sampling events (Figure 25), there is a marked drop in EC which is believed to be a result of freshening from the freshwater dam. The major drop occurs right in front of a gully leading up to the edge of the freshwater dam.

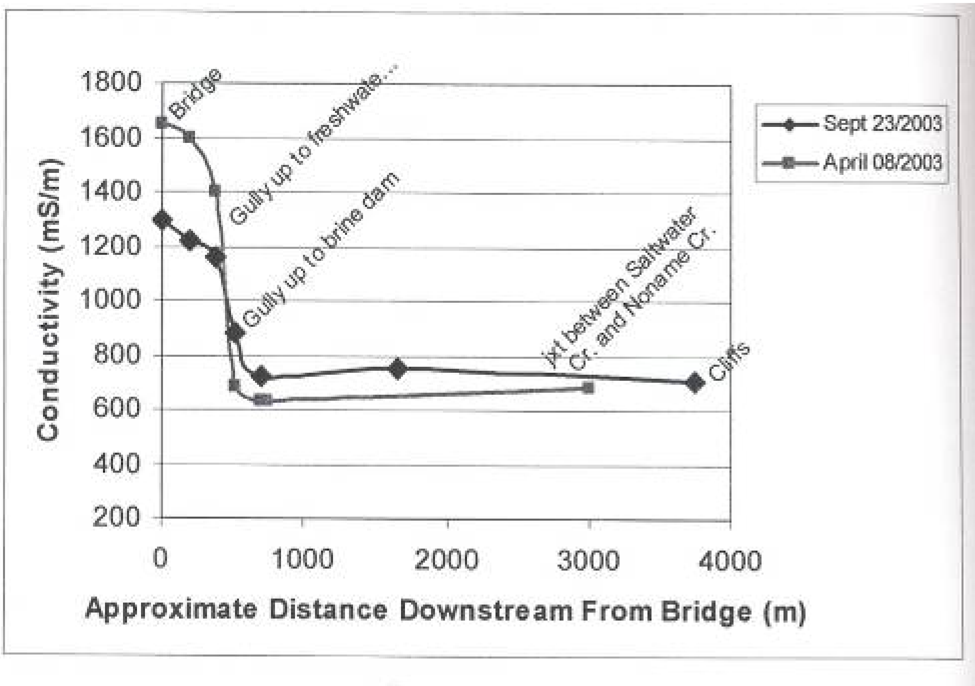

Figure 25 Variation in conductivity with distance downstream of brine dam (Silvey, 2003).

Soil samples were collected using a hand auger at 8 sites at depths of 15, 40 and 80 cm to determine gravimetric soil moisture, EC (1:5 soil/water extract) and cation exchange capacity (CEC). Sample locations are seen in Figure 26. EM38 point measurements in vertical dipole mode were made at each of the soil sampling locations to correlate laboratory measured soil EC with EM38 readings. Four horizontal EM38 surveys were also carried out to get a better understanding of the salt store distribution across the catchment.

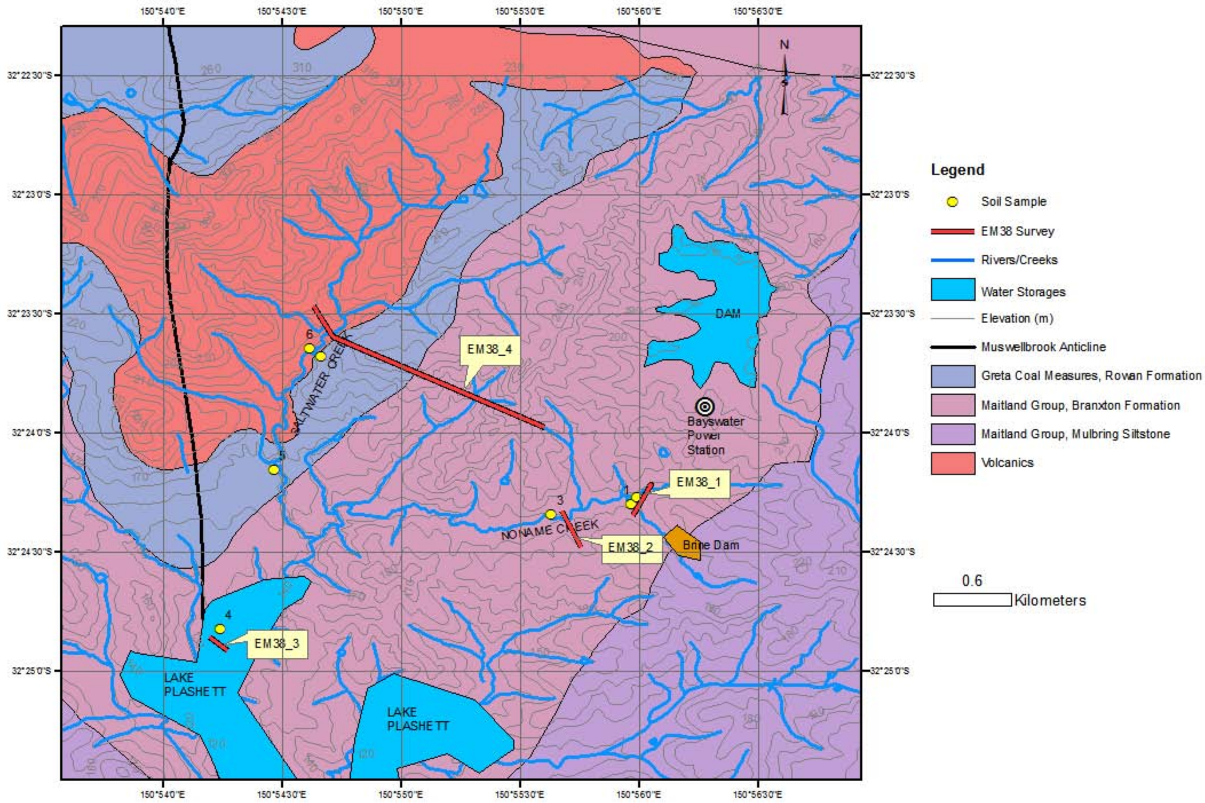

Figure 26 Soil sampling sites and EM38 transects in the natural catchment.

Soil moisture maximum was found to be at 40cm for all samples (although there were only samples at 3 depths taken). Soil conductivities were measured using 1:5 soil to water extracts. The Noname Creek sub-catchment has a significantly higher salt load than the Saltwater Creek sub-catchment (Figure 27).

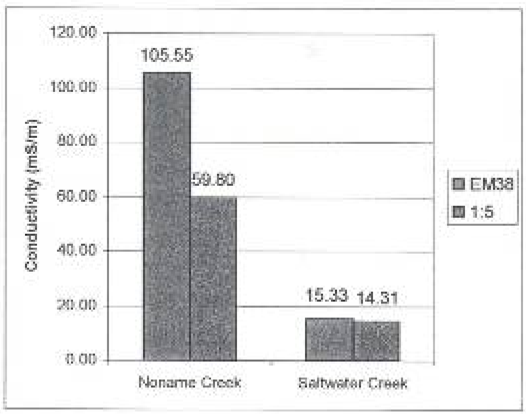

Figure 27 Average soil conductivity across natural site (Silvey, 2003).

Some work was done on assessing the suitability of EM38 surveys to accurately reflect conductivity variations across the site. The results gave reasonable assurance that a detailed EM38 survey could conducted effectively across the site, if a higher level of soil EC spatial data is needed. Given that we already have the EM31 data across the entire site, further EM38 work is unnecessary.

Resistivity:
The resistivity survey was planned with two aims:

1. To compare the scale of heterogeneity at the mine site and the unmined site in a spatial sense.
2. To relate the change in resistivity values over time to changes in corresponding moisture fluxes.

With these two aims, two identical survey patterns were planned for both sites (Figure 28 and Figure 29). One pattern was aimed at capturing spatial variability and the other temporal variability.

Spatial Variability Surveys:
A transect was run at 10m electrode spacing (270m long). These were completed at both sites. Another transect with high resolution (lesser electrode spacing) was done in the same line to compare high and low resolution differences. Then every 10m along the 270m transect, a perpendicular transect was run. A total of 28 perpendicular transects were planned, the required 28 were not completed on either site. At the mined site 14 perpendicular high resolution transects were completed starting from the weather station end. No perpendicular transects were completed at the natural site.

Temporal Variability Surveys:
Perpendicular transects were planned to be measured approximately once every two weeks, at the centre of 270m transect on either site. Transects had common center and same electrode spacing.

Issues:
The resistivity of soil varies with clay content, salt content and amount of pore water. We can assume some of these influences remain constant such as clay content. Inversion of the data produces non-unique solutions, according to these variables. Realistic results can only be obtained if we can constrain the inversion process. Constraint can be achieved by having drill core information at the start and end of transects so we know the changes in geological composition with depth. Inversion of the data assumes a layered earth model. Each layer of this model is assumed to be of infinite lateral extent with a uniform and isotropic resistivity. This assumption may well be invalid on the mine spoil due to its heterogeneous composition.

Resistivity measurements have accuracy of +-10% even with constraint using core data. Changes in the depth of the water table due to rainfall events are going to be much less than this and won’t be evident. Cotton furrow experiments showed that movement of the water table was only evident after simulated rainfall events > 100mm. These are not going to occur naturally on site. Can we then simulate rainfall on the mine site, but where do we get the water from? In short: not feasible.

Mine site pumping adds another complexity; the water table would have been drawn down, much lower than the maximum depth resolved by resistivity (30m). To identify the extent of this problem we would need to get a record of pumping from the mine site, which it is doubted they have an accurate record of. After speaking to Doug Stewart C&A environmental officer briefly, he thinks the water table has been drawn down to the level of the coal seam they are currently mining and there is no water in the spoil.

Correlations of changes in resistivity with water saturation are governed by laws developed on fine grained soils (for example Archie’s Law), so cannot be applied on the mine site.

We can look at contrast changes between summer and winter or dry versus wet, and get a description of preferential flow pathways and distribution, but we cannot get quantitative information on recharge which is one of our initial aims. The depth scale of features can be skewed. Even looking at changes can be misinterpreted if the internal chemical composition of the spoil has changed through downward leaching of salts. Do we attribute changes to water or salts? Interpretation is only possible with physical analysis which requires drill cores.

Dr. Bryce Kelly, formerly UTS was going to go through Hassan's data to determine the usefulness of continuing the resistivity surveying. He needed more detail on Hassan's methodology and processing before he could make an assessment. We are yet to finalise a meeting to get this progressed and are unsure of his future involvement given his new employment at UNSW. He had some alternate modelling suggestions for continuation of the project.

Installation of piezometers on the mine site:
- Due to the heterogeneous nature of the spoil material (large boulders, fine silt, voids) the drilling crew required would need to be excellent and in NSW at the moment it is hit and miss due to the demand of drillers with the mining boom.
- Coal & Allied had agreed to pick up the surplus cost (any amount over 10K, the amount funded by HCMA) which is one bonus, however we are not sure if this is still the case since Hassan's departure. Speaking to Doug Stewart recently they are not that keen (meeting soon to discuss this).
- Overall, along with the other problems with the resistivity technique for estimating recharge, the overall consensus was that the bores would probably be of little value in comparison to cost.

Geophysical alternatives to resistivity:
- EM34 surveys (horizontal and vertical modes) twice per year over whole site (or match last survey) covering wet and dry seasons. No data inversion necessary. You can get the equipment from DNR or CMA. Need 2 people, methodology is very fast and easy to learn.
- TEM surveys are more temperamental than EM surveys. Gives rapid profiling to much greater depths than resistivity and EM surveys, which may be of interest for the mine site.

Data:
No data is presented here as I only have access to the raw resistivity files. The data needs to go through an inversion process before being utilised. Hassan has done some inversions as can be seen by some images in his presentations, but those files are missing. I have been in contact with Hassan, but no luck.

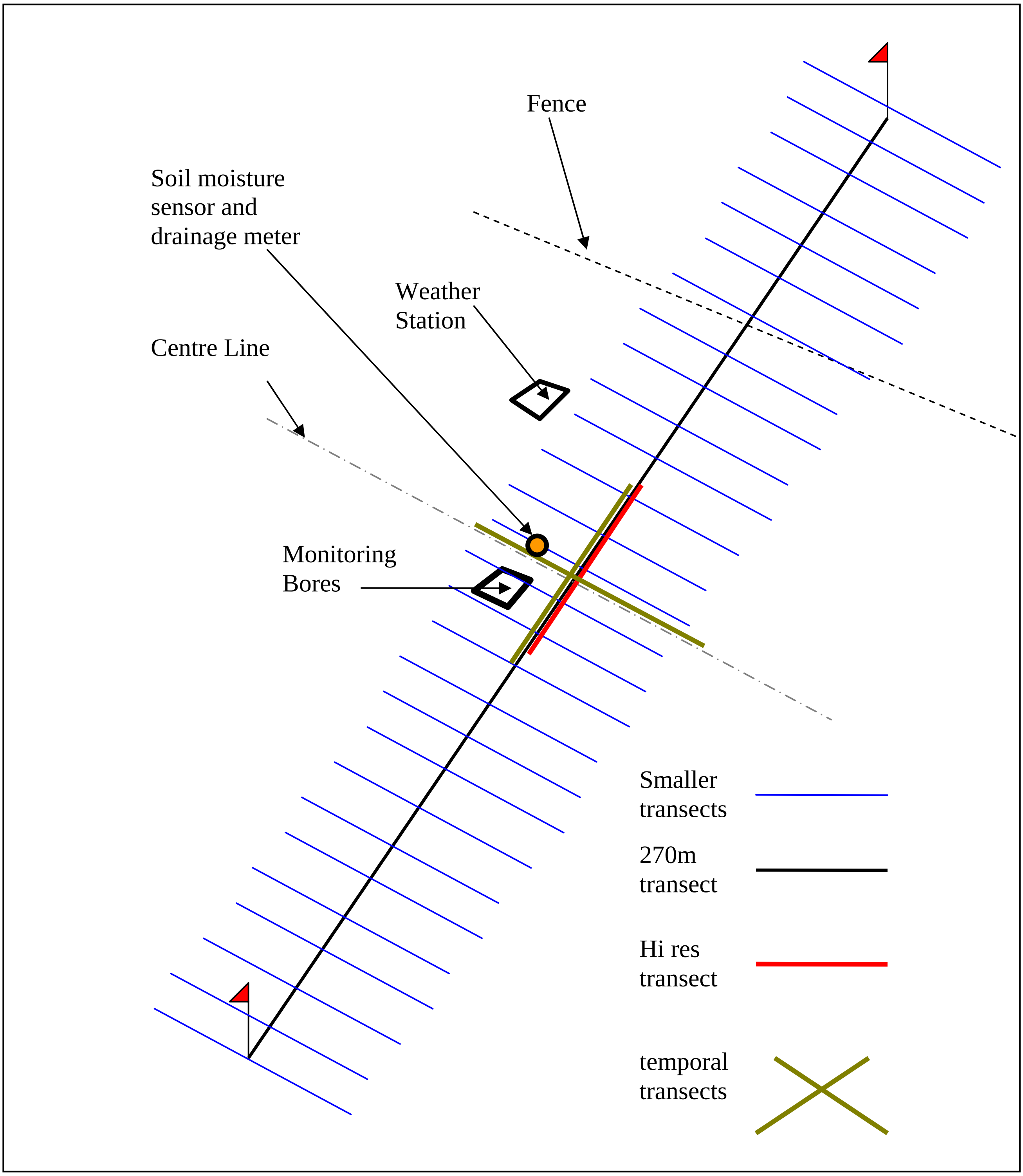

Figure 28 Natural Site Resistivity Survey Design

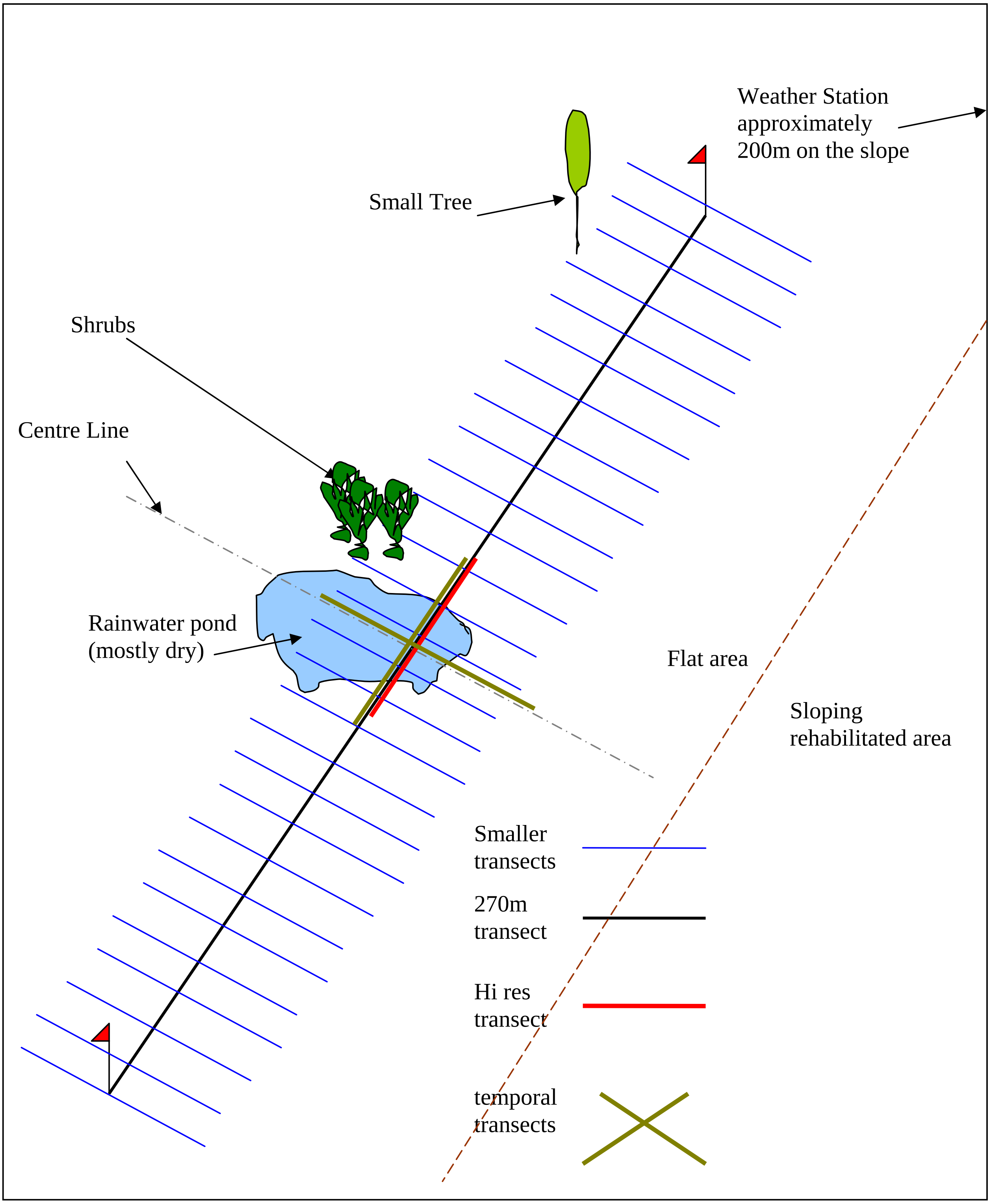

Figure 29 Rehabilitated Mine Site Resistivity Survey Design

Natural Site Future Research Directions:

Estimation of volume transports of water and salt from Saltwater and Noname Creek.
The installation of a velocity sensor at the Saltwater Creek gauging site is required to obtain sufficient data to estimate volume transports. These estimates will enable rainfall/runoff relationships for the site to be established and predictions made for future runoff events. This information is valuable in obtaining site specific background salt loads for the catchment for comparison with potential salt loads from the rehabilitated mine site. Results will also be compared to historical DNR stream gauge #210045 data operational on Saltwater Ck from 1956 to 1981. Erosion to the left hand embankment of the weir at Saltwater Creek looking downstream needs to be rectified if future flows are to be monitored.

Identification of geological sources of salt to Saltwater and Noname Creek and their distributions across the catchment.
The study conducted by Micah Silvey contains a series of recommendations for future work. X-ray diffraction (XRD) analyses of soil samples can be used to map variation in soil mineralogy across the site and verify the presence/absence of halite. Isotope analyses can be used to determine the origin of water in Noname Creek to explain the sudden drop in electrical conductivity.

Enviroscan soil moisture sensor calibration.
Soil sampling has been carried out at 20cm intervals from the surface down to 2m at two locations near each Enviroscan installation. These samples need to be analysed for particle size distribution and moisture content to establish if we can use existing Enviroscan calibration parameters. If no existing calibration parameters exist for our soil types, full Enviroscan calibrations will be required.

Groundwater trend analysis.
Data on pumping from Lake Plashett is required to extract pumping effects from groundwater level records. An Australian Height Datum survey at each of our piezometer locations should be carried out so levels can be compared between sites. Recharge rates need to be estimated using specific yield and water table fluctuations with time and rainfall.

Water balance closure.
Water volume transport estimation from Saltwater and Noname Creeks will enable estimation of runoff for rainfall events. Enviroscan soil moisture calibration will allow accurate estimates of changes in stored soil moisture. Both of these components, along with rainfall, evapotranspiration and groundwater levels are required to close the water balance and partition water into and out of the catchment with an estimation of the errors involved.

Rehabilitated Mine Site Future Research Directions:

Research to date has focused on the natural site due to difficulties inherent in setting up a monitoring project on the rehabilitated mine site to address our aims. Significant investment needs to be getting the mine spoil research up to speed.

Crude water balance.
We have rainfall, runoff and potential evapotranspiration data. We should be able to convert potential ET to actual ET using crop factors. Spatial distributions of trees and pastures need to be differentiated across the spoil. Apply different crop factors to percentage distributions of vegetation. Crude estimates of changes in soil water/deep drainage can be attributed to the remainder. Development of a rainfall-runoff model for the mine spoil.

Historical data collection.
Access to historical and ongoing environmental monitoring data collected by Coal & Allied is vital in the modelling stages of this project. Data sets identified in Sinclair, Knight & Partners (1989) we would like access to includes:

- surrounding bore water levels and chemistries (section 5.6.2)
- exploration bore hole core data (section 5.5.2):lithology, pH, conductivity, saturation moisture extract, soluble cations/anions
- monthly surface water quality data (section 5.6.3): pH, EC, TSS, Sulphate, Turbidity, Carbonate Alkalinity, Bicarbonate Alkalinity
- high wall ground water quality data (section 5.6.2)
- information on exact origins of S2 spoil to correlate with pre-mining lithology
- pumping rates and times (if available)
- pre and post mining elevation data to estimate spoil swell.
- mining lease layout

Tracers.
Use a tracer (tritium) at several locations on mine site and investigate the pathway time of the tracer. A good guess would produce pathway times of meters/day. If we can get access to samples of water from the pumping station on the site, we can look for evidence of the tracer in these samples. We could do some kind of stochastic modeling between actual pathway time and conceptual model time. One problem in this methodology may be that 90% of the water has probably already been pumped out of the spoil. Samples are $200 each. We need an estimate on number of samples required to resolve the issue. Dr Bryce Kelly can help with estimating costs but needs more info such as where the mine spoil sits in relation to the pumping site and what the pumping rates are.

Effective Medium Theory to Derive Model Parameters.
Possibility of using effective medium theory to derive relationships for different materials, which is an untouched area for rehabilitated spoil piles and would fill a knowledge gap for model parameters.

Final Void Water Properties.
Look at a conglomerate of final void water properties, there has already been a lot of work done on how the voids fill. Tom Mackie has done a lot of work on modeling mine pit chemistry, and University of Newcastle has done some work on mixing models for the final voids and predicted EC values.

Modelling.
If we could get access to some DNR bores that were monitored for chemistry before mining commenced, within the vicinity of the mining zones, but outside the immediate areas, we could look for draw downs during mining, followed by a gradual trend back to normal post mining after the mine has gone through its natural life cycle. We could look at chemistries, recovered responses, and isotopes for aging. Some work has been done on the permeability of coal seams, so we may be able to get some model parameters from there.

Conduct scenario modelling, crude boundary on fluxes from existing data and best guesses, get a probability distribution of head recovery and potential for offset migration. Storage of water should reflect the cumulative departure from rainfall. At the mine site, should see a mismatch between the two, but after the full cycle there should be some recovery. Modelling options:

- Modflow
- Modflow + mtd3 chemistry available
- Modflow + fast (combination of mtd3 and freak)

- Modhms (combined surface and groundwater model) which you could apply to both sites separately would involve some big guesses for the mine site, but at least something. Currently bring used for modelling on Cox Creek. Noel Merrick is best person to speak to about this.

7. *Major Conclusions and Recommendations*

Conclusion 1:
A salt source exists in the Noname Creek sub-catchment that is not present in the Saltwater Creek sub-catchment. The differing geological origins of the two sub-catchments are determined as the primary cause for their differing salt loads, with Noname Creek having Permian (marine) origins and Saltwater Creek comprising materials of volcanic origin. The process by which salt is transferred to the surface waters within the Noname Creek sub-catchment was determined to be through the dissolution of halite, although this requires further confirmation.

Conclusion 2:
Surface runoff from the mine spoil, fifteen years after initial rehabilitation is of better quality than that in the natural sub-catchment. This may be because the salts within the surface spoil went through a period of high leaching initially, before vegetation was established to control runoff. Alternately, salts may have been leached downwards through the spoil itself and have a bigger effect on final void EC.

Appendix A – Review of Methodology to Quantify Mine Spoil Water Fluxes

A review of methodology employed to quantify water fluxes on rehabilitated mine spoils has been carried out (Figure 30). The predominant methodologies used are most often a combination of geophysical and hydrological methods and there is no clear method that outweighs any other in terms of quantitatively resolving water fluxes on rehabilitated mine sites. Results have been varied due to the complex and heterogeneous nature of mine spoils.

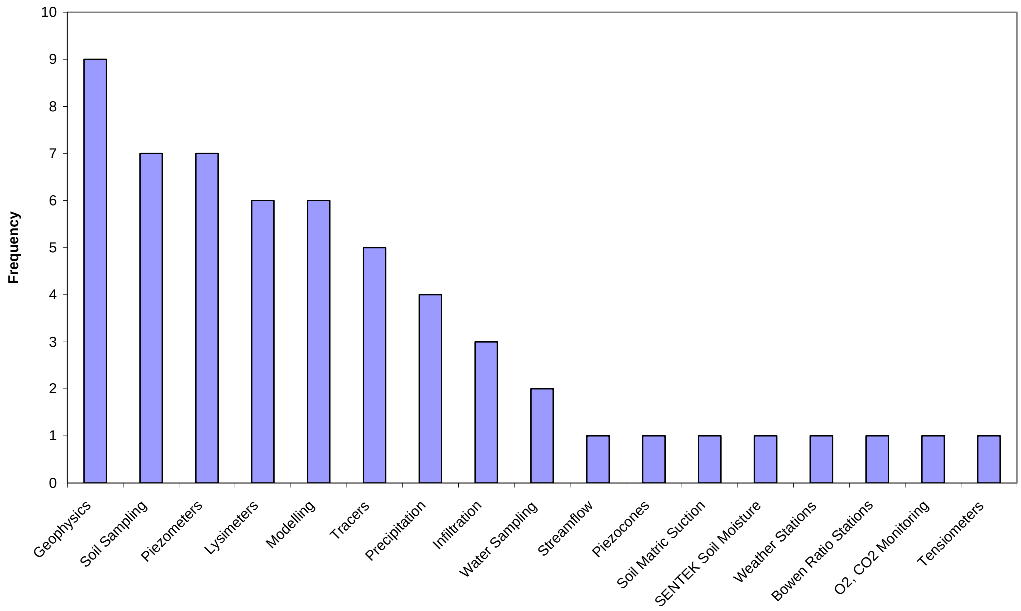

Figure 30 Histogram of methodologies employed to determine water fluxes on rehabilitated mine spoils from a total of 20 papers reviewed.

A review of the five main techniques that have been used to characterise water fluxes on rehabilitated mine spoils follows:

Geophysical surveys:
A review by Campbell (2000) summarised geophysical techniques applicable for studying rehabilitated mine sites. These included Direct Current resistivity (DC) for detection of shallow water tables less than 10 m (Pellerin, 2002; Kemna, 2002; Buselli, 1998); Time-domain ElectroMagnetics (TEM) for detection of water tables with depths between 10 and 30 m (Buselli, 1998); Controlled Source Audio-MagnetoTellurics (CSAMT) which measures electrical resistivity in the deep 10-50 m bottom section of mine waste piles; Time Domain Reflectometry (TDR) for tracking saline tracers in lysimeter/tracer experiments; Induced Polarisation (IP) to detect concentrations of sulphides and possible prediction of Acid Mine Drainage (AMD); frequency domain ElectroMagnetics (EM) for tracing AMD plumes (DeVos, 1997). DC and CSAMT are better at detecting extreme resistivity layers whereas multi frequency EM and TEM are better at detecting extremely conductive layers (Campbell, 2000). At Howick, the possibility of AMD is low, and the ground water is expected to be highly saline so useful techniques include EM and DC for shallow, TEM and CSAMT for deeper water table detection. Some DC work has already been carried out on site, and results are currently being assessed as to whether this method can be utilised to address our initial aims of quantifying recharge on the rehabilitated mine spoil or whether an alternate technique needs to be selected. Geophysical methods are limited in their accuracy and are most often used to qualitatively to identify mine spoil features such as contaminant plumes or water tables, and sampling is always

required for physical confirmation. They are dependent on a significant network of piezometers to constrain results within acceptable bounds.

Soil sampling:
Soil sampling across the mine spoil can provide information on spatial variability in soil properties such as texture, particle size, bulk density, porosity, hydraulic conductivity, volumetric water content, aggregations, EC and pH. Geochemical testing can include modified acid base accounting, multi element Inductively Coupled Plasma spectrometry (ICP) analyses for chemical composition, forward acid titration tests and leach extraction tests. This data can provide valuable information for modelling surface infiltration processes and can be used in comparisons between the mined and natural site.

Piezometer networks:
Piezometer networks are used to: determine changes in spoil composition with depth; track water level fluctuations and changes in water quality in time and space; estimate groundwater flow directions; and to provide hydraulic conductivity estimates. Water level fluctuations after rainfall events, may give us spot measurements on recharge to the mine spoil. Drill logs and core samples provide estimates on the changes in lithology, particle size, moisture content, shear strength, permeability, compaction, chemical composition, salinity and pH with depth. This information in turn can be used to constrain and verify geophysical survey data.

Tracer and lysimeter studies:
A variety of combination tracer and lysimeter studies have been carried out on rehabilitated mine spoils attempting to define effective hydraulic parameters which capture both matrix and preferential pathway flow with varied success. Different tracers have been used including Bromide (Buczko, 2005), Lithium chloride (Nichol, 2005), Sodium bromide, Tritium (Haefner, 2002) and Rhodamine WT (Dinger, 1990). Most often simulated small scale spoil piles are constructed on top of nested lysimeters and tracers injected. Tracer concentrations are measured in lysimeter outflows with time. Buczco (2005) found measured water fluxes exhibited much stronger heterogeneity than simulated ones and the observed preferential flow processes could not be adequately described using different spatial distributions of hydraulic parameters.

Modelling:
Vrugt (2004) estimated vadose zone parameters, using Inverse Modelling (IM) techniques that accounts for the uncertainty of the estimated large scale parameters and the associated prediction uncertainty. Seven calibration parameters were estimated using IM against spatially distributed, weekly drainage data. The calibrated vadose zone model parameters, including the soil hydraulic functions, represent effective soil properties, whose values can generally not be obtained by direct measurements. Three models were tested: BUCKET, MODHMS 1D and MODHMS 3D. Vrugt found that despite the large uncertainty in most of the calibration parameters, the fit to the observed drainage data was good for all models and the predictive ability of the simple BUCKET model is about equal to that of the MODHMS 3D model.

Haefner (2002) used conceptualisation of the flow system, data obtained from wells, core samples and surface geophysical surveys to construct a 3D groundwater flow model. Objectives were to simulate groundwater flow directions and estimate advective travel times of particles from the water table to off-site areas. Groundwater flow simulations were substantiated by analyses of tritium in groundwater.
Kemna (2002) illustrated how concentration maps from Electrical Resistivity Tomography (ERT) can be used to quantify spreading of a solute plume resulting from heterogeneities in the longitudinal and transverse directions. Spreading is quantified in terms of dispersivity parameters in an equivalent convection-dispersion model (CDM). Such CDM's consider the

actual transport properties in the heterogeneous medium in terms of equivalent transport properties in an idealised homogenous porous medium.

MODFLOW was used to produce a regional Powder River Basin model of pre-mining water levels and consequent draw down (Applied Hydrology Associated inc. et al, 2002). The study identified that precipitation that does not become runoff, makes no significant contribution to groundwater recharge. VMODLFOW was also used for a small scale site specific model of active surface mining. Matching of model-projected draw downs to actual draw downs over an extended period provided the best information on the vertical permeability of the claystone confining layer that separates the coal from the overlying sandstone.

Wels (2001) used SOILCOVER to assess the influence of cover thickness and vegetation of an alluvial cover to control infiltration in to a mine spoil utilising weather station, Bowen ratio, soil suction, volumetric water content and measured lysimeter outflow data.

SOILVISION has been used to predict Soil Water Characteristic Curves (SWCC) for mine spoil material based on a combination of theoretical and knowledge based approaches to increase accuracy of infiltration estimates for well graded spoil materials (Swanson, 1999).