# DWLBC REPORT

## Minimising Salt Accession in the South East of South Australia.

## The Border Designated Area and Hundred of Stirling Salt Accession Projects.

## Volume 2 - Analytical Technicques, Results and Management Implications

# 2008/23

Government of South Australia
Department of Water, Land and Biodiversity Conservation

# Minimising Salt Accession in the South East of South Australia.

## The Border Designated Area and Hundred of Stirling Salt Accession Projects.

## Volume 2 – Analytical Techniques, Results and Management Implications.

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**September 2007**

**Report DWLBC 2008/23**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

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ISBN 978-1-921528-14-9

**Preferred way to cite this publication**

Wohling, D 2007. *Minimising Salt Accession to the South East of South Australia. The Border Designated Area and Hundred of Stirling Salt Accession Projects. Volume 2 – Analytical Techniques, Results and Management Implications,* DWLBC Report 2008/23, Government of South Australia, through Department of Water, Land and Biodiversity Conservation, Adelaide.

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# FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

**Rob Freeman**
**CHIEF EXECUTIVE**
**DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION**

# ACKNOWLEDGEMENTS

The following people are acknowledged for their role in the project. Glenn Harrington (DWLBC) for his considerable leadership and comprehensive peer reviews. Nikki Harrington and George MacKenzie (DWLBC) for their guidance and technical support. Phil Davies and Fred Leaney (CSIRO Water and Land) for their assistance, direction and application of the regional recharge model and peer review of the final report. James de Barro (De Barro Agricultural Consulting) for his ongoing monitoring, reporting and collaboration. Megan Lefournour, Michelle Caputo and Adrian Beech (CSIRO Land and Water) for their assistance in soil and water analysis. The landholders who have taken part in the project are also acknowledged for permission to conduct these investigations on their properties.

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# SUMMARY


The groundwater resources of southeastern South Australia are generally of high quality and are the major water source for irrigated agriculture and reticulated municipal supplies. In northern parts of the South East region, including the Hundred of Stirling, groundwater is used primarily for flood irrigation of Lucerne for hay and seed production, and grazing sheep and cattle. Further south, through the Border Designated Area, groundwater use for irrigation is less extensive but still vital for premium wine grape, small seed and pasture production.

Groundwater in the South East is stored in two main aquifers; an unconfined limestone aquifer and an underlying confined sand aquifer. This study has focused on the unconfined aquifer, which has a depth to water ranging from less than 5 m to more than 40 m in the area of interest. Salinity in the unconfined aquifer ranges from around 3000 mg/L to greater than 7000 mg/L in the Hundred of Stirling and from less than 500 mg/L to around 3000 mg/L in the Border Designated Area. Increasing groundwater salinities (50–100 mg/L/y in the Hundred of Stirling and generally 0–20 mg/L/y but up to 100 mg/L/y in isolated areas of the Border Designated Area) may threaten the long-term sustainability and viability of existing and future groundwater users.

An improved understanding of the processes influencing groundwater levels and salinity ultimately leads to the development of more effective groundwater management strategies. Quantifying the magnitude of salt accession to shallow water tables first requires an understanding of the processes that occur in the unsaturated zone. In particular, the development (and subsequent remobilisation) of a “salt store” as a result of native vegetation using any incident rainfall and leaving the salts behind.

The unsaturated zone salt store has the potential to be displaced to the water table following native vegetation clearance and to a greater extent following the development of irrigation. In heavily developed flood irrigation regions, recycling irrigation drainage water generally causes increases in groundwater salinity. Within the Hundred of Stirling, groundwater extraction in excess of vertical recharge combined with the recycling of irrigation water has resulted in the accession of concentrated salts back to the unconfined aquifer. While for the Border Designated Area, the clearance of native vegetation has lead to an increase in drainage, which in turn had mobilised the historic salt store in the unsaturated zone.

Soil core samples were taken from the Hundred of Stirling (152 core samples from 17 sites) and Border Designated Area (905 core samples from 34 sites) between March 2005 and November 2006. Using analytical methods, we were then able to predict the rate of unsaturated soil water movement. Analysis of soil cores included particle size distribution, pore water chloride, gravimetric water content and soil water suction. Groundwater samples were collected and analysed for major ion chemistry, stable isotopes, CFCs and $^{14}C$ to gain a better understanding of groundwater recharge processes.

Comparison between numerous techniques provided a higher confidence in drainage and recharge rate estimates, while allowing for calculations under steady state and transient conditions. The water balance, daily soil water balance, chloride mass balance, chloride front displacement, 1-D recharge model and LEACHM techniques were used for calculating drainage and recharge rates in the Hundred of Stirling (mean drainage rates; 403 mm/y flood irrigation and 43 mm/y dry land). While for the Border Designated Area, the chloride front displacement, chloride mass balance and 1-D recharge model were applied (mean drainage rates; 130 mm/y irrigation, 42 mm/y dry land and 8 mm/y native vegetation).

Up scaling drainage estimates and predicted lag times for groundwater recharge and salinisation, enables prediction of the long-term environmental impact to the resource. Relationships between point estimates of drainage and clay content were used to up-scale point estimates of post native vegetation clearance drainage rates. A two-layer, one-dimensional recharge model was then used to describe the increase in recharge associated with an increase in drainage and lag time. An empirical correlation between soil salinity and clay content from representative native vegetation was used to spatially represent the potential salt load to the unconfined aquifer. The one-dimensional recharge model was then compared to real observation data and extrapolated based on the SLU coverage of clay content percentage (0–2 m) and depth to water table to give management scale groundwater recharge and salinisation maps for the Border Designated Area Zones 4A-7A (north of the Kanawinka Fault).

The salinity impact to the unconfined aquifer for the Border Designated Area Zones 2A and 3A (south of the Kanawinka Fault) and the Hundred of Stirling were calculated using alternative techniques to Zones 4A-7A of the Border Designated Area due to shallower unsaturated zones (shallower water tables). Drainage and recharge rate estimates were used to calculate the salinity impact under different soil association and land use combinations. The average spatial salinity impact was then calculated (Border Designated Area, 2.84 mg/L and Hundred of Stirling, 85.2 mg/L).

Spatial modelling of groundwater recharge and salinisation to the unconfined aquifer for the Border Designated Area required alternative up scaling techniques for Zones 4A-7A and Zones 2A and 3A due to climatic and geological constraints. The regional recharge model used for Zones 4A-7A indicates significant salt stores are located in areas having deep unsaturated zones and higher clay percentages. As higher clay percentages, depth of the unsaturated zone and lower precipitation rates slow the movement of saline drainage; the considerable unsaturated zone salt store (in particular in Zones 6A and 7A) has not been leached. Implying that increases in unconfined aquifer salinity are likely to occur in future. Significant salt has been leached from Zones 4A, 5A and parts of 6A, however for the majority of the study area, model predicts continued salt input into the future. The salinity of the unconfined aquifer may become more saline before any improvement is seen.

Modelling for Zones 2A and 3A suggest that the majority of the historical salt store has been flushed. Disregarding potential impacts from irrigation, groundwater salinities have the potential for improvement. Modelling for the Hundred of Stirling indicates a significant salt input to the groundwater system as a direct result of flood irrigation. Continued monitoring is required to further our understanding of the salinity impact differences between flood irrigation, pivot and subsurface drip style irrigation practices.

To sustain acceptable salinity levels across both the Border Designated Area and Hundred of Stirling, groundwater flow maintenance is important to ensure the lateral flushing of salts. Three-dimensional modelling which incorporates salt accession would facilitate the development of improved groundwater management strategies.

# 1. INTRODUCTION

Increasing groundwater salinities in the Border Designated Area and Hundred of Stirling (Figs 1.1, 1.2) may threaten the long-term sustainability of existing and potential groundwater users. Using rigorous scientific techniques and an improved understanding of the processes influencing groundwater and salinity fluxes, quantification those groundwater and salinity fluxes are being attained. Consequently, effective groundwater management strategies can be developed within the sustainable capacity of the groundwater resource.

The Minimising Salt Accession in the South East of South Australia Project purposely addresses the Border Designated Area Salt Accession Project separately from the Hundred of Stirling Salt Accession Project, even though funded from the same source. It is recognised that two differing mechanisms control the accession of salt to the unconfined aquifer and hence the techniques used to understand these mechanisms vary along with the objectives and outcomes of each project.

A complete description of the background, approach, methodology, instrumentation and site details for this project are given in Volume 1, DWLBC report book 2006/19 (Wohling D., 2006).

This report, Volume 2 – Analytical Techniques, Results and Management Implications, is the second and final report for the project. Specifically, the report describes all techniques used and details the findings of the Border Designated Area and Hundred of Stirling Salt Accession Project including the up scaling of site-specific results, while providing recommendations on groundwater management strategies and future work for the two areas.

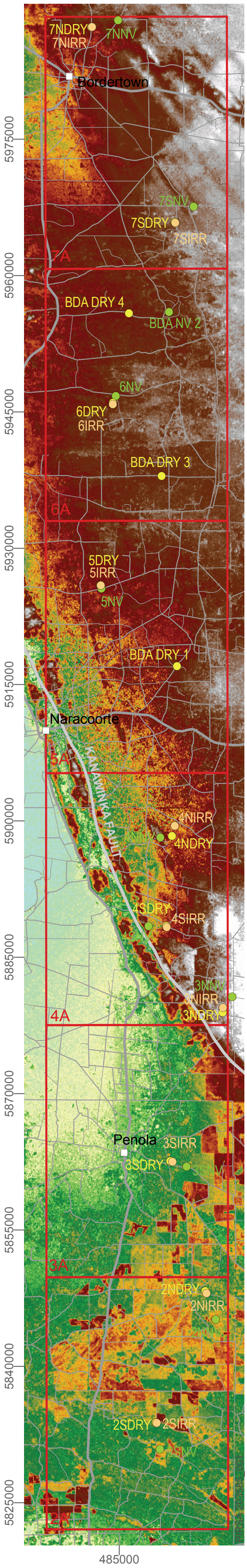
Comprehensive descriptions of all analytical techniques used in this study are given in Section 2. The analytical techniques are divided into three parts to describe:

1. groundwater recharge or irrigation drainage rate estimates,
2. groundwater recharge processes,
3. up scaling groundwater recharge and salinity fluxes to a management area scale.

Results for the Border Designated Area are presented and discussed in Section 3. Soil core properties, groundwater chemistry, isotopic composition and hydrogeological techniques are being used to establish the magnitude and timescales of salt accession within the Border Designated Area.

Results for the Hundred of Stirling are presented and discussed in Section 4. The water and salt balance at several sites located within and adjacent to the Hundred of Stirling have been established and quantified via a water balance approach using groundwater chemistry, isotopic composition, soil core properties and hydrogeological techniques.

Soil core data (soil physical parameters, gravimetric water content and soil water chloride) are inputs to a model developed by CSIRO Land and Water for up scaling predicted groundwater recharge rates and salt fluxes in Zones 4A–7A of the Border Designated Area. Up scaling in Zones 2A–3A of the Border Designated Area and the Hundred of Stirling uses a GIS approach, which assigns a salinity impact for each soil category under the various irrigation systems. Results for up scaling in both the Border Designated Area and Hundred of Stirling are presented and discussed in Section 5.

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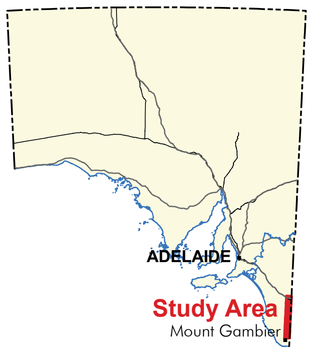


Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Digital Elevation Model

Value (m AHD)

High : 149

Low : 33

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

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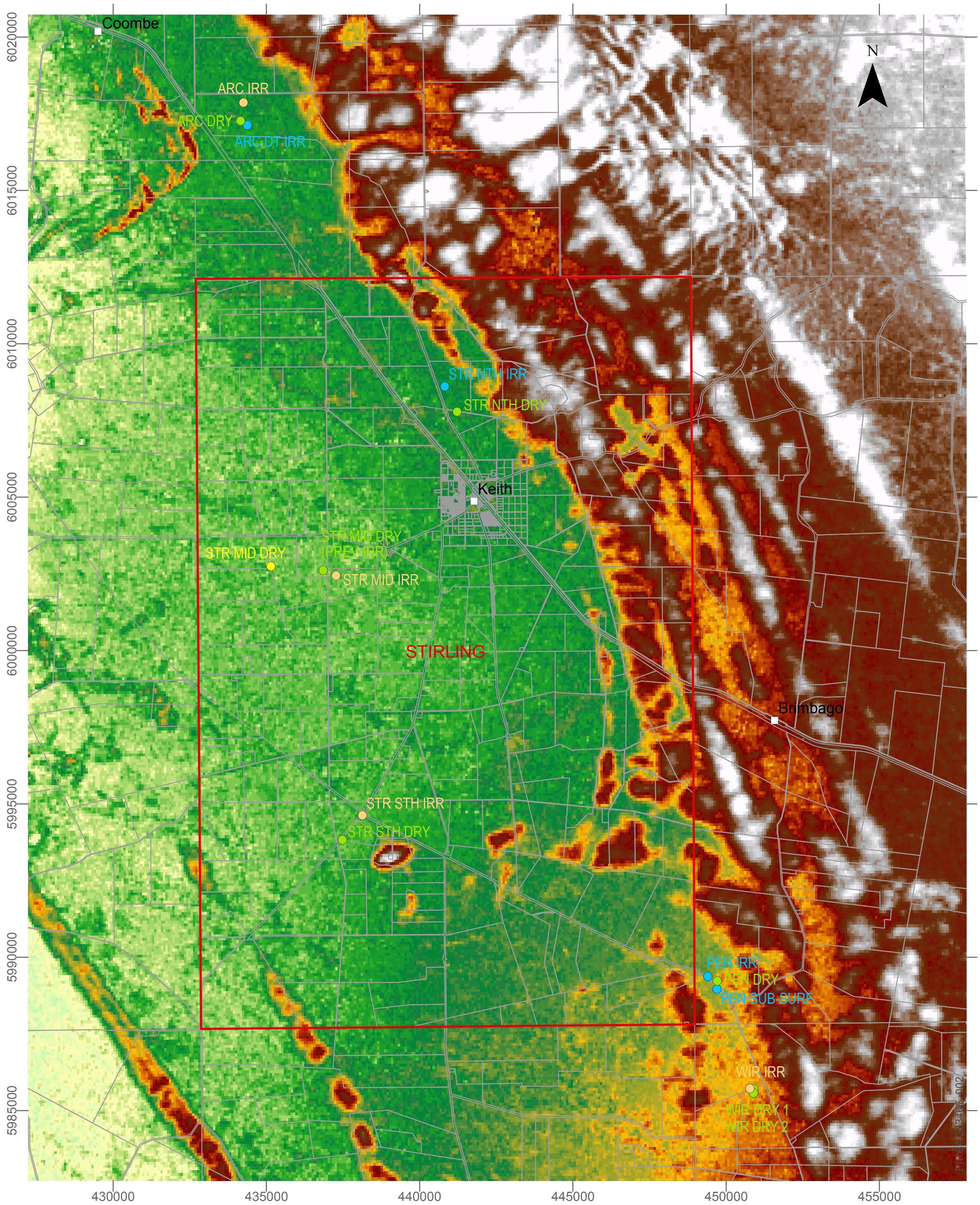
# Border Designated Area Salt Accession Project

## LOCALITY PLAN

**Figure 1.1**




0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007


Investigation Sites

- Established Dryland
- Established Irrigation
- New Dryland
- New Irrigation

Management Zone

Digital Elevation Model

Value (m AHD)

High : 103

Low : 13

Hundred of Stirling
Salt Accession Project

**LOCALITY PLAN**

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**Figure 1.2**

Section 6 provides a summary of the results and up scaling for both the Border Designated Area and Hundred of Stirling, details recommendations for improved groundwater management strategies and outlines potential future work.

# 2. ANALYTICAL TECHNIQUES

An estimate of groundwater recharge is essential in salinity studies and efficient groundwater resource management (Walker G.R. and Zhang. L., 2002). Given here is a précis of groundwater recharge estimation techniques used in this study. Comparison between numerous techniques provides for a higher confidence in recharge estimates, thereby allowing a rigorous platform from which sustainable groundwater management strategies are developed and implemented.

## *2.1 GROUNDWATER RECHARGE OR IRRIGATION DRAINAGE RATE ESTIMATES*

### 2.1.1 UNCONFINED AQUIFER POINT SOURCE RECHARGE ESTIMATES

Chloride can be used to estimate long-term mean annual groundwater recharge under steady state and transient conditions. Observations are made of the chloride profile in unsaturated soil columns for both steady state and transient conditions and implicitly assume water flow is one-dimensional and water that drains past the root zone will eventually recharge the unconfined aquifer (Walker G. R., 1998).

The chloride mass balance method can be used to estimate recharge under steady state conditions, i.e. beneath remnant native vegetation and long-term irrigation sites. Soil core data is used in conjunction with irrigation and groundwater monitoring data to estimate groundwater recharge rates.

$$D = (P + I) \times \frac{c_t}{c_d} \qquad \text{and} \qquad c_t = (Pc_p + Ic_i)/(P + I) \qquad (1)$$

where: D is the drainage (mm $yr^{-1}$), P is the average precipitation (mm $yr^{-1}$), I is the average irrigation (mm $yr^{-1}$), $c_t$ is the average chloride concentration of the water (mg $L^{-1}$), $c_d$ is the chloride concentration of the soil water at the base of the root zone (mg $L^{-1}$), $c_p$ is the chloride concentration of precipitation (mg $L^{-1}$) and $c_i$ is the chloride concentration of irrigation water (mg $L^{-1}$).

The potential for increased groundwater recharge and salinisation following the clearance of native vegetation in semi-arid areas of southern Australia has been discussed in numerous studies. The chloride front displacement technique developed by Walker et al (1991) is a transient method for estimating drainage below the root zone under non-steady state conditions. The clearance of native vegetation and replacement with shallow rooted, low water use pastures and crops causes an increase in drainage past the root zone. The increase in drainage generates a pressure front that displaces soil water downward though the unsaturated zone. When the pressure front reaches the water table an increase in groundwater recharge occurs, hence there is a lag time between an increase in drainage and an increase in recharge. Specifically, drainage refers to the movement of water through the unsaturated zone and recharge refers to the movement of water to the water table. Soil core data is used to estimate groundwater recharge using this method.

$$D = \int_{z_{cf}^{0}}^{z_{cf}^{n}} \theta dz + \int_{z_r}^{z_{cf}^{0}} \delta\theta dz + [\int_{0}^{z_r} \delta\theta dz](c_n / c_d) \qquad (2)$$

where: $z_{cf}^{0}$ and $z_{cf}^{n}$ are the depths (m) of the chloride fronts under the old and new land uses, $c_n$ is the new equilibrium concentration, $\delta\theta$ is the difference in volumetric water content between the old and new land uses ($m^3$ $m^{-3}$) and $z_r$ is the rooting depth of the crop or pasture and is assumed to be two metres to be consistent with previous studies (it can be described as the limit of evapotranspiration).

A major limitation of the chloride front displacement technique is establishing the position of $z_{cf}^{0}$ and determining $\delta\theta$ (Walker G.R., 1998). Ideally it is best to sample from beneath a control site that represents vegetation and soil conditions existing prior to a land use change. This situation is not often obtainable, however previous studies including Walker et al (1991), determined an empirical relationship between $z_{cf}^{0}$ and the mean clay content in the top 2 m of the soil profile (%clay(0–2m)).

$$z_{cf}^{0} = -0.21 \times \%clay(0-2m) + 3.86 \qquad (3)$$

A knowledge of the change in water content between the depths of $z_{cf}^{0}$ and $z_r$ is required, again Walker et al (1991) and similarly Cook et al (1992) determined empirical relationships estimating the correlation between the water content beneath native vegetation ($\theta_m$) and the soil clay content. Given below is the Cook et al (1992) relationship:

$$\theta_m = 0.0015 + 0.0038 \times \%clay(0-2m) \qquad (4)$$

This relationship should be established for each specific study area, however this is not always achievable due to a lack in appropriate or representative native vegetation sites. For the purposes of this project, Equation 4 was not changed.

### 2.1.2 WATER LEVEL AND SALINITY HYDROGRAPHS

Water table rise should be proportional to the amount or depth of water recharged with the constant of proportionality equal to the specific yield (Sy) of the material containing the water table (Armstrong D. and Narayan K., 1998). A water table level fluctuation will occur when the recharging water reaches the water table.

$$\Delta h = R / Sy \qquad (5)$$

where: $\Delta$h is the rise in water level (m), R is the recharge as a depth of water ($m^3$ $m^{-2}$) and Sy is the specific yield of the aquifer.

Water level records should be considered with caution when active production wells are in close proximity to the observation well. Analysis of groundwater levels should only occur after long non-pumping periods where water table fluctuations have stabilised.

Groundwater recharge can be differentiated into specific groundwater responses from single rainfall episodes or the net recharge to a groundwater system over a season. Shallow unconfined aquifer systems will show instantaneous response to recharge events where the water table is within a couple metres of the surface and surface soils are highly permeable. As depth to the water table increases and/or soils become less permeable, being able to distinguish individual recharge events and longer-term responses to increased rainfall or seasonal fluctuation becomes more difficult.

### 2.1.3 WATER BALANCE

Groundwater recharge is controlled by various elements including rainfall, irrigation, evapotranspiration and run-off; and can be challenging to measure directly. The water mass balance approach infers groundwater recharge by measuring or estimating the remaining water fluxes in the hydrological cycle (Zang L., Walker G.R., and Fleming M., 2002). Diligent measurement or estimation of the remaining water fluxes is critical for achieving reliable recharge approximations. Small errors in measuring or estimating large numbers, such as irrigation application and evapotranspiration, can lead to large residual errors in the calculation of recharge.

Run-off in the Stirling Management Area is negligible; therefore the water balance can be expressed as follows:

$$D = (P + I) - ET \pm \Delta S \qquad (6)$$

where: D is the drainage (mm), P is the precipitation (mm), I is the irrigation amount (mm), ET is the evapotranspiration (mm) and $\Delta$S is the change in soil moisture storage (mm).

Changes in soil moisture storage occur when 1) water is added to the soil zone via the infiltration of rainfall or irrigation, or capillary rise leading to an increase storage, or 2) water is removed from the soil zone via evapotranspiration or deep drainage leading to a decrease in storage.

Refer to Volume 1 for an overview of how components of the water balance have been measured or estimated for the project.

### 2.1.4 UNSATURATED SOIL WATER PHYSICS

Hydraulic conductivity in an unsaturated soil is controlled by the water content of that soil and therefore is not constant. When the water content of an unsaturated soil decreases, the hydraulic conductivity of that soil decreases quickly. The hydraulic conductivity of a fine textured soil will decrease more rapidly than that of a coarser textured soil with the same decrease in water content.

Water in an unsaturated soil is under a negative pressure or suction. When sufficient pressure is applied to water in an unsaturated soil it can be forced from the soil. The pressure at which water emerges from the soil is equal, but opposite, to the negative pressure or suction of the water in the soil, i.e. the soil water suction (Bond W. J., 1998). Greater pressure is required to remove water from soils that are more unsaturated therefore these have greater soil water suction. The relationship between the soil water suction and the degree of saturation or water content of the soil is called the soil water retention curve (Bond W.J., 1998).

The movement of water in an unsaturated soil is given by:

$$q = -K(\theta)[\Delta h(\theta) + \Delta z]/\Delta z \quad (7)$$

where: (θ) is the water content, K(θ) represents the hydraulic conductivity with respect to water content and h(θ) is the soil water suction with respect to water content.

Equation 7 can be used to calculate soil water flux at any instance in time or while in steady state. Water content in an unsaturated soil system is continually changing and generally not in steady state. Equation 7 is combined with the law of conservation of mass to derive the Richards equation. The Richards equation is used to model unsaturated soil water movement.

## 2.1.5 MODELS

Up scaling point scale water balance or recharge estimates to management boundary, sub-catchment or catchment scales is a valuable tool for making groundwater management decisions, however can prove challenging to carry out. Parameters such as soil characteristics, slope and vegetation cover, rainfall and irrigation application, and evapotranspiration can vary considerably over the area in question. Understanding how the water balance or recharge estimates will change over time may also prove difficult to determine.

Analytical and numerical models are used to help understand how the water balance changes over space and time. Models range from simple 1-dimensional bucket models to more complex models that take into account soil dynamics and vegetation cover.

The simplest form of the bucket model uses inputs such as rainfall and irrigation application, evapotranspiration, initial water content, seasonal changes in vegetation growth and plant-available water capacity (PAWC). PAWC is the storage capacity of the soil profile or more simply, the volume of the bucket. Drainage occurs when the PAWC is exceeded.

More complex models have multiple soil layers allowing changes in soil properties, may incorporate different vegetation types and crop rotations, be able to extrapolate over space and time, and can utilise the Richards equation to model soil water movement.

The solution of the Richards equation leads to the calculation of infiltration, redistribution, soil evaporation, plant water extraction, and deep-drainage and hence doesn't need to treat each of these process separately as the tipping bucket model does (Walker G.R. and Zhang. L., 2002).

## 2.1.6 DAILY SOIL WATER BALANCE

A daily soil water balance can be calculated using theoretical values for available soil moisture storage (van den Akker J., et at, 2005) following the work of Penman and Grindley (Penman H.L., 1948, 1949, 1950; Grindley J., 1967, 1969). Drainage occurs when the soil moisture deficit (SMD, mm) is less than zero (i.e. SMD < 0), however drainage can occur via preferential flow when the SMD >0. The SMD is given as:

$$SMD = WP \times RD \quad (8)$$

where: WP is the wilting point and RD is the rooting depth (mm).

WP can be calculated by the Hutson and Cass (1987) method, which is based on soil particle size distribution and soil bulk density. Estimates of RD were obtained from the analysis of soil pits excavated at each research site. WP then SMD were calculated for each 0.5 m interval in the top 3 m and summed up to get an average over the 0–3 m depth interval.

The term PAWC is more or less interchangeable with SMD and generally relates to the size of the 'bucket'. It is the amount of water held by the soil between field capacity (upper limit) and wilting point (lower limit). The distribution of plant roots is also important in determining PAWC, in particular the maximum rooting depth.

PAWC is defined as:

$$PAWC = \sum_{i=1}^{n} \frac{(FC - WP)_i \times BD_i \times \Delta Z}{\rho H_2O} \qquad (9)$$

where: FC is the field capacity (the upper storage limit), WP is the wilting point (the lower storage limit), BD is the bulk density at field capacity, RD is the rooting depth (mm), $\Delta Z$ is the depth interval (mm), $\rho H_2O$ is the density of water, i is the subscript referring to any one of n soil layers and n is equal to RD/ $\Delta Z$.

Using the Queensland Department of Natural Resources and Mines SILO database, daily reference evapotranspiration ($ET_o$) is evaluated using meteorological data via the FAO 56[1] Reference Evapotranspiration calculation, which is an adaptation of the Penman-Monteith equation (Fitzmaurice L. and Beswick A., 2005).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (10)$$

where: $ET_0$ is the reference evapotranspiration (mm day$^{-1}$), $R_n$ is the net radiation at the reference plant (grass) surface (MJ m$^{-2}$ day$^{-1}$), *G* is the soil heat flux density (MJ m$^{-2}$ day$^{-1}$), $T_{mean}$ is the daily mean air temperature at 2 m height ($^oC$), $u_2$ is the daily mean wind speed at 2 m height (m s$^{-1}$), $e_s$ is the daily mean saturation vapour pressure (kPa), $e_a$ is the daily mean actual vapour pressure (kPa), $\Delta$ is the slope of the saturation pressure curve (kPa $^oC^{-1}$) and $\gamma$ is the psychrometric constant multiplied by air pressure (kPa $^oC^{-1}$).

$ET_0$ is calculated using climatic parameters (daily weather data), while the reference surface is a well-watered, hypothetical grass crop with set characteristics. Actual or crop evapotranspiration ($ET_c$, mm day$^{-1}$) is calculated by multiplying $ET_0$ by a crop coefficient ($K_c$).

$$ET_c = K_c \times ET_0 \qquad (11)$$

The crop coefficient varies with specific crop characteristics and to a lesser extent, the climate. Primarily these characteristics are the crop height, albedo of the crop-soil surface, canopy resistance and evaporation from the soil (Allen R.G., et al, 1998). For this study, the crop coefficient data was sourced from Desmier R.E and Schrale G., (1988).

Calculation of the daily soil water balance then follows such that; the calculated SMD for a particular soil is entered at the beginning of the analysis period, subsequently each day the difference between $ET_c$ and rainfall plus irrigation is either added or deleted to or from the

[1] Food and Agriculture Organisation of the United Nations Irrigation and Drainage paper 56 – Crop Evapotranspiration

SMD running total. The SMD cannot be greater than the original SMD calculated for that particular soil i.e., once the SMD reaches its greatest value it will remain at that value until the inputs are greater than the outputs. When the SMD reaches or is less than zero, the amount less than zero for that day is deemed to be drainage. Following a day of drainage, the SMD resets to zero and again the difference between $ET_c$ and rainfall plus irrigation is either added or deleted to or from the SMD running total.

### 2.1.7 LEACHM

The Leaching Estimation and Chemistry Model (LEACHM) (Hutson J.L. 2003), is a one-dimensional model designed to simulate and quantify vertical water flow through the unsaturated zone based on the solution of the Richards equation. Input data for the model includes soil physical properties (particle size distribution, bulk density, and matric suction), weather data (daily rain and irrigation, weekly $ET_0$, air temperature and amplitude of air temperature) and crop data. LEACHM relates equations of volumetric water content, pressure potential and hydraulic conductivity and calculates water retention parameters to give an estimation of drainage.

## *2.2 GROUNDWATER RECHARGE PROCESSES*

### 2.2.1 GROUNDWATER CHEMISTRY AND ISOTOPIC SIGNATURES

The chemical and isotopic composition of groundwater can provide useful information about recharge conditions, evapotranspiration, groundwater flow paths and age.

#### 2.2.1.1 Major ion chemistry

The major ion chemistry of rain, soil water and groundwater is used to provide additional or supporting information on the hydraulic processes occurring in the Border Designated Area and the Hundred of Stirling.

#### 2.2.1.2 Stable isotopes

Stable isotope ratios of oxygen (O) and hydrogen (H) can be used to assess aspects of the groundwater recharge process. Stable isotope ratios are expressed in delta (δ) notation, which defines the difference between the stable isotope ratio of a sample to a standard reference according to the following expression (Cook P.G., 1998):

$$\delta = \frac{R_{sample} - R_{std}}{R_{std}} \times 1000 \ {}^{o}/_{oo} \qquad (12)$$

where: R is the isotope ratio ($^{18}O/^{16}O$ or $^{2}H/^{1}H$).

The standard reference that stable isotope concentrations are expressed relative to is the Vienna Standard Mean Ocean Water (V-SMOW) as 'per mil' ($^{o}/_{oo}$). If the value of δ is positive then the sample is enriched with the heavy isotopes relative to the standard and if the value is negative then the sample is isotopically light or depleted in the heavy isotopes (Fetter C.W., 1994).

Isotopic fractionation of oxygen and hydrogen develops unique isotopic compositions of the water molecule, which can illustrate processes undergone by the water molecule and/or the water molecules source. Water molecules become enriched or depleted in either the heavier ($^{18}O/^{2}H$) or light ($^{16}O/^{1}H$) isotopes depending on the fractionation process occurring. Fractionation processes occur in two forms; 1) equilibrium fractionation referring to slight differences in the thermodynamic properties of isotopes which commonly then leads to a greater reactivity of the lighter isotope, and 2) kinetic fractionation referring to the different diffusive velocities of isotopes which is relevant to evaporation and biological processes (Cook P.G., 1998).

To simplify how fractionation influences rainfall, the following generalisations can be made: 1) Rainfall at high altitudes becomes increasingly depleted in heavy isotopes, 2) Rainfall becomes increasingly depleted in heavy isotopes with distance form the coast, 3) The greater the amount of rainfall the more depleted in heavy isotopes compared to lighter showers of rain, and 4) Rainfall at cooler temperatures (i.e. during winter) is more depleted in heavy isotopes.

In general, worldwide precipitation has $\delta^{2}H$ and $\delta^{18}O$ compositions that can be characterised by a relationship known as the global meteoric water line (GMWL).

$$\delta^{2}H = 8\delta^{18}O + 10 \quad \text{(Craig H., 1961)} \qquad (13)$$

Groundwater isotope compositions can be used to describe the processes taking place during groundwater recharge and subsequent movement through a groundwater basin when plotted against the GMWL. Waters that have undergone evaporation are more enriched in heavy isotopes and tend to lie to the right of the GMWL. The amount of displacement of the isotopes from the GMWL should be proportional to the cumulative evaporation (Cook P.G., 1992).

For detailed isotopic studies, a local meteoric water line (LMWL) should be established. Again, the composition of groundwater determines how it plots against the LMWL; subsequently the source and processes undergone during recharge by the groundwater can be ascertained. Generally, the enrichment of deuterium ($^{2}H$) in soil water decreases exponentially with depth due to evaporation for saturated and unsaturated soils. Consequently, evaporation rates can be determined using stable isotope data.

#### 2.2.1.3 Chlorofluorocarbon (CFC)

Atmospheric concentrations of chlorofluorocarbons (CFC's) have been measured at stations around the world for approximately the past 25 years and prior to this, concentrations have been reconstructed using estimates of worldwide CFC production and their rate of release to the atmosphere (Cook P.G., 1998). Groundwater ages are obtained by converting measured CFC concentrations into equivalent air concentrations using known solubility relationships and the recharge temperature (Cook P.G., 1998), while to a lesser extent groundwater salinity and recharge elevation influence apparent groundwater residence time. Groundwater ages can be determined for waters that have recharged since the mid 1960s with a precision of $\pm$ three years. However, larger errors can arise from a range of other sources including possible degradation of CFC-11, contamination during sampling or incorrect estimates of recharge temperature and excess air (Cook P.G., 1998).

#### 2.2.1.4 Carbon 14 ($^{14}C$)

Carbon 14 ($^{14}C$) is the radioactive isotope of carbon formed naturally via the bombardment of cosmic rays on nitrogen 14 ($^{14}N$). Atmospheric carbon dioxide ($CO_2$) can therefore have a radioactivity due to the modern $^{14}C$ forming $CO_2$. If $CO_2$ is incorporated into a form that is isolated from modern $^{14}C$ then age can be determined from the $^{14}C$ radioactivity as a percentage of the original (Fetter C.W., 1994).

Burning of fossil fuels, nuclear weapons testing, biological activity and plant root respiration can influence the $^{14}C$ content of recharging groundwater. $^{14}C$ concentrations are expressed as percentage modern carbon (pmC) with reference to a standard that represents the atmospheric $^{14}C$ concentration in 1890 defined as 100 pmC (Cook P.G., 1998). To correct for dilution of $^{14}C$ by dissolution of old $CO_2$ minerals, the isotopic composition of stable carbon isotopes can be measured. The $^{13}C/^{12}C$ ratio (measured as $\delta^{13}C$ in units of $^{o}/_{oo}$ V-PDB) of carbon reservoirs can be quite different and therefore a mass balance can be applied to work out the relative amount of carbon from biological and inorganic sources (Cook P.G., 1998).

## *2.3 UP SCALING GROUNDWATER RECHARGE AND SALINITY FLUXES TO A MANAGEMENT AREA SCALE*

### 2.3.1 REGIONAL ESTIMATES OF RECHARGE AND SALINISATION

A regional estimate of groundwater salinisation over time first requires a regional estimate of groundwater recharge.

#### 2.3.1.1 The drainage vs. % clay content (0–2 m) relationship

Estimating groundwater drainage post land clearance over a large area is not practical using a point source technique such as the chloride front displacement method due to the cost of drilling and soil data analysis. Kennett-Smith et al (1994) identified an empirical relationship between post clearing drainage rates and the clay content in the top 2 m of the soil profile, which numerous studies (eg, Leaney and Herczeg, 1999; Cook et al 2004; Leaney et al 2004; Wohling et al 2006) have since used as a tool to upscale point estimates of drainage. A negative log-linear relationship can be observed (with some scatter to the data) between post-clearing drainage rates and the percentage clay content of the top two metres of the soil profile under dry land agriculture in varying rainfall zones. Depending on the amount and quality of drainage rate vs. % clay content (0–2 m) data, the relationship can be adjusted to suit varying rainfall and geological zones.

For example, after Leaney et al (2004) for the Tintinara area, the drainage (D) clay content (c) relationship given below was used:

$$D = 10^{(-0.035 \times c + 1.9)} \text{ (mm yr}^{-1}\text{)} \qquad (14)$$

Where as, Wohling et al (2006), used the following relationship based on additional drilling data and a wetter environment for the Naracoorte Ranges:

$$D = 10^{(-0.035 \times c + 2.23)} \text{ (mm yr}^{-1}\text{)} \qquad (15)$$

### 2.3.1.2 The 1-dimensional model for increasing recharge following an increase in drainage

An increase in drainage following vegetation clearance produces a pressure front that displaces soil water downward though the unsaturated zone. Only once the pressure front reaches the water table does an increase in recharge to the unconfined aquifer occur. Therefore a lag time is created between when vegetation is cleared, causing an increase in drainage, to when increased unconfined aquifer recharge begins.

The velocity of the pressure front is related to the drainage rate, soil texture and soil water content through the soil profile (Cook et al 2004). The following equation can be used to describe the velocity of the pressure front ($V_P$) for a homogeneous soil profile:

$$V_P = \frac{D}{\theta_w - \theta_d} \qquad (16)$$

where: D is the drainage rate, $\theta_w$ is the mean soil water content above the pressure front post clearing and $\theta_d$ is the soil water content pre land clearance.

Jolly et al (1989) and Cook et al (1989) showed that $\theta_w$ and $\theta_d$ can be approximated by the water contents above and below the pressure front, while Jolly et al (1989) and Walker et al (1991) showed that the matric potential soil profiles could be used to categorise the position of the pressure front (Cook et al 2004).

*A homogeneous soil profile*

The hydraulic conductivity – volumetric water content function can be defined in the following way:

$$\frac{K(\theta)}{K_m} = \left( \frac{\theta - \theta_0}{\theta_m - \theta_0} \right)^2 \qquad (17)$$

where: $\theta_0$ is the residual water content pre clearance (zero recharge or water content as a function of the initial drainage rate), $K_m$ is the reference value of hydraulic conductivity at a water content of $\theta_m$. $K_m$ should be greater than the drainage rate simulated (Leaney et al 2004).

If the velocity of the pressure front remains constant and where there is a large increase in drainage, then the lag time between land clearance (increase in drainage) and an increase in recharge is given by (Cook et al 2004 and Leaney et al 2004):

$$t_L = z_{WT} (\theta_2 - \theta_0) D_2^{-1} \qquad (18)$$

where: $z_{WT}$ is the watertable depth, $D_2$ is the final drainage rate and $\theta_2$ is the volumetric water content at hydraulic conductivities $D_2$.

Lag time between an increase in drainage and an increase in recharge to the unconfined aquifer is dependant on the depth to water table, magnitude of the drainage flux and pre and post clearing soil water contents (or the soil water contents above and below the pressure front).

$\theta_2$ is related to $D_2$ by the following equation (Cook et al 2004 and Leaney et al 2004):

$$\theta_2 = \left(\frac{D_2}{K_m}\right)^{0.5}(\theta_m - \theta_0) + \theta_0 \tag{19}$$

Therefore the recharge rate at any point can be given as a function of time by:

$$R = 0 \qquad t < z_{WT}(\theta_2 - \theta_1)D_2^{-1}$$

$$R = D_2 \qquad t \geq z_{WT}(\theta_2 - \theta_1)D_2^{-1} \tag{20}$$

Since mean values of drainage are used, a water table rise could be expected earlier due to localised areas of higher drainage rates. So a water table rise at a particular point may if fact not represent aquifer recharge at that point but rather reflects regional recharge (Cook et al 2004).

The regional recharge rate as a function of time can be estimated if the spatial distribution of drainage is known or assumed.

$$R_t = \int_{t^{-2}L}^{\infty} y f(y)dy \tag{21}$$

with,

$$L = z_{WT}{}^2 \frac{(\theta_m - \theta_0)^2}{K_m} \tag{22}$$

where: $R_t$ is the mean regional groundwater recharge rate at time t, $t^{-2}L$ (m year$^{-1}$) represents the minimum drainage rate that is contributing to aquifer recharge at time t and so the summation is of recharge rates between $t^{-2}L$ and infinity (Cook et al 2004 and Leaney et al 2004), and f(y) is the probability function of drainage (Cook et al 1989). The probability function for the log-normal distribution is then given by:

$$f(y) = \frac{1}{y\sigma\sqrt{2\pi}} \exp\left[-(\ln y - \mu)^2 / 2\sigma^2\right] \tag{23}$$

where: $\mu$ and $\sigma^2$ are the mean and variance of the log-transformed values $z = \ln y$.

The mean drainage rate is given by (Cook et al 2004):

$$\exp(\mu + \sigma^2/2) \tag{24}$$

### *A layered soil profile*

When a unsaturated zone is not homogeneous and can be represented by two soil layers a and b, that have thicknesses $z_a$ and $z_b$ so that $z_{WT} = z_a + z_b$, then the hydraulic conductivity function is given for each layer as:

$$\frac{K(\theta^a)}{K_m} = \left( \frac{\theta^a - \theta_0^a}{\theta_m^a - \theta_0^a} \right)^2 \qquad (25)$$

and,

$$\frac{K(\theta^b)}{K_m} = \left( \frac{\theta^b - \theta_0^b}{\theta_m^b - \theta_0^b} \right)^2 \qquad (26)$$

Time lag between an increase in drainage and an increase in recharge for a dual layered soil profile is then expressed by:

$$t_L = z_a(\theta_2^a - \theta_1^a)D_2^{-1} + z_b(\theta_2^b - \theta_1^b)D_2^{-1} \qquad (27)$$

Water contents for each soil layer relating to the drainage rate $D_2$ are then given by:

$$\theta_2^a = \left( \frac{D_2}{K_m} \right)^{0.5} \left( \theta_m^a - \theta_0^a \right) + \theta_0^a \qquad (28)$$

and,

$$\theta_2^b = \left( \frac{D_2}{K_m} \right)^{0.5} \left( \theta_m^b - \theta_0^b \right) + \theta_0^b \qquad (29)$$

Therefore recharge at any point as a function of time for a dual layered soil zone is given by:

$$R = 0 \qquad t < z_a(\theta_2^a - \theta_1^a)D_2^{-1} + z_b(\theta_2^b - \theta_1^b)D_2^{-1}$$

$$R = D_2 \qquad t \geq z_a(\theta_2^a - \theta_1^a)D_2^{-1} + z_b(\theta_2^b - \theta_1^b)D_2^{-1} \qquad (30)$$

If $z_a$ or $z_b$ are equal to zero, then Equation 30 reduces to Equation 20.

Again, for spatially variable drainage on a dual layered soil profile the regional recharge flux to the unconfined aquifer as a function of time due to an increase in drainage is given by:

$$R_t = \int_{t^{-2}L}^{\infty} y f(y) dy \qquad (31)$$

with L now:

$$L = \frac{1}{K_m} \left[ z_a(\theta_m^a - \theta_0^a) + z_b(\theta_m^b - \theta_0^b) \right]^2 \qquad (32)$$

For ease of calculation this can be re-written as:

$$R(t) = 0.5e^{\mu+\sigma^2/2}\left(1 - erf\left(\frac{\ln(L/t^2) - \mu - \sigma^2}{\sigma\sqrt{2}}\right)\right) \quad (33)$$

Some computer programs cannot calculate the error function of negative numbers, so the above equation can be re-written as:

$$R(t) = 0.5e^{\sigma^2/2+\mu}\left(1 - erf\left(\frac{\ln(L/t^2) - \mu - \sigma^2}{\sigma\sqrt{2}}\right)\right) \qquad \ln(L/t^2) \geq \mu + \sigma^2$$

$$R(t) = 0.5e^{\sigma^2/2+\mu}\left(1 + erf\left(\frac{-\ln(L/t^2) + \mu + \sigma^2}{\sigma\sqrt{2}}\right)\right) \qquad \ln(L/t^2) < \mu + \sigma^2 \quad (34)$$

#### 2.3.1.3 The soil salinity vs. % clay content (0–2 m) relationship

Soil water salinity from the unsaturated zone is proportional to the salt load entering the aquifer and is therefore an important parameter used to determine groundwater salinisation. Again, recent studies (including Leaney et al 2004 and Wohling et al 2005) used empirical relationships between the mean soil water salinity ($S_{SW}$, mg $L^{-1}$) of the unsaturated zone under what is assumed to be the 'pre-clearing' scenario of native vegetation and the clay content of the top two metres of the soil profile (%clay(0–2 m)) as a proxy measurement for up scaling.

The relationship between the soil water salinity and clay content requires modification to reflect local conditions. The greater the number of native vegetation sites analysed, the more confidence there will be that the relationship will accurately represent the 'pre-clearing' unsaturated salt load in the unsaturated zone. For example, Leaney et al (2004) used the relationship:

$$S_{sw} = 408 \times \%clay(0 - 2m) + 14580 \quad (35)$$

where as Wohling et al (2005) used the following relationship to reflect a wetter environment and lower salinity load in the unsaturated zone:

$$S_{sw} = 408 \times \%clay(0 - 2m) + 8000 \quad (36)$$

#### 2.3.1.4 Estimation of rates of groundwater salinisation following clearing

The flux of salt to the unconfined aquifer since native vegetation clearance can be estimated once the pre clearing salt store, and post clearing drainage and recharge rates have been characterised.

As previously stated, a pressure front in the unsaturated zone is created following the clearance of native vegetation and subsequent increase in drainage past the root zone. Recharge to the aquifer occurs when the pressure front reaches the water table, therefore a lag time between an increase in drainage and an increase in recharge exists.

As the pressure front moves towards the water table through the unsaturated zone, previously stationary saline soil water is displaced downwards. Initial recharge to the aquifer predominately consists of displaced saline soil water from the unsaturated zone. Over time, the recharging water will have an increasing component of fresh water, which is the start of the fresh waterfront.

The drainage rate for a soil landscape unit (SLU) is considered to have a log-normal distribution about the mean drainage value and is therefore not constant within the SLU. This means that the salt flux to the aquifer will reach a maximum value then decrease as the pre existing saline soil water is flushed from the unsaturated zone to the groundwater. A small amount of salt is present in post clearing drainage due to rainfall and post clearance practices and therefore the salt flux to the aquifer will not reach zero (Leaney et al 2004).

In order to determine the fraction of recharge water that is fresh water it is necessary to determine the rate of movement of the freshwater front. The development of equations that describe the rate of movement of the freshwater front are the same as those used to describe the pressure (wetting) front except the water content change is $\theta_2$ rather than $(\theta_2 - \theta_0)$ (Leaney et al 2004).

The following equation describes the movement of the freshwater front, $R_f(t)$:

$$R_f(t) = 0.5e^{\mu+\sigma^2/2}\left(1 - erf\left(\frac{\ln\left(L/t^2\right) - \mu - \sigma^2}{\sigma\sqrt{2}}\right)\right) \quad (37)$$

where,

$$L_f = \frac{1}{K_m}\left[z_a(\theta_m^a) + z_b(\theta_m^b)\right]^2 \quad (38)$$

The salt flux, (F(t)), can be estimated from:

$$F(t) = [R(t) - R_f(t)]S_{sw} + R_f(t)S_{fw} \quad (39)$$

where: $R(t)$ is the recharge rate, $R_f(t)$ is the rate of movement of the freshwater front, $S_{sw}$ is the salinity of the saline soil water and $S_{fw}$ is the salinity of the fresh soil water.

#### 2.3.1.5 Comparison of model result with field observations

Field data is used to refine the parameters and empirical relationships used in analytical modelling of recharge rates and salt fluxes. Modelled recharge rate lag times are compared to observed water level increases from monitoring wells. If modelled results are in close agreement with observed water level and salinity trends, then a high confidence is gained for extrapolating across an entire region.

#### 2.3.1.6 Spatial extrapolation of the 1-d model based on clay content in the root zone (0–2 m) and water table depth

*Regional recharge*

The mean clay content percentage for the top two metres of the soil profile is used as a proxy for determining drainage rates when spatially extrapolating data. For each SLU, a mean clay content for the top two metres of the soil profile is established from which a mean drainage rate for each specific SLU is determined. Therefore by using soil physical properties for each soil layer, GIS coverages of the clay content (based on the SLU coverage), drainage rate and depth to water table; the spatial distribution of recharge can be calculated as a function of time since clearing.

Groundwater recharge rates can be estimated at varying time steps, while cumulative recharge to the aquifer are also estimated at these time intervals. Mobilisation of the historical salt store since native vegetation clearance can occur more rapidly than depicted by this method in irrigated areas, as the input of irrigation water is greater than the mean annual rainfall.

*Regional salt flux*

Using the equations given previously, salt flux and cumulative salt load to the aquifer can be estimated based on spatial distributions of recharge, salt concentrations of soil water and a value for the soil water concentration of drainage above the freshwater front. An estimate of salt load and flux to the aquifer, displaced from the unsaturated zone to the groundwater, does not take into account increased inputs of salt from practices such as irrigation.

## 2.3.2 SALINITY IMPACT

A net salinity impact to the unconfined aquifer can be calculated using drainage rate and drainage water salinity estimates. Unsaturated zone drainage rates (D, mm $yr^{-1}$) can be estimated using a range of techniques. Determining a specific or adopted drainage value, if estimates differ, is based upon knowledge of previous work and knowing the limitations of each method.

The salinity of drainage water under flood and centre pivot irrigation is assumed to be equivalent to that of the soil pore water salinity below the root zone which is sampled at the two and three metre suction lysimeters. Where pore water salinities below the root zone cannot be determined via this method, the salinity of drainage water is inferred from the average soil water chloride concentrations measured from soil cores that are taken below the chloride bulge and above the capillary zone (Harrington N., et al 2006).

A salinity increase ($\Delta$sal, mg $L^{-1}$) due to the use of groundwater for irrigation is calculated as the difference between the estimated salinity of drainage water and the irrigation water that is applied (Harrington N., et al 2006).

The salinity impact to the aquifer (SI, t/ha/y) is then given by:

$$SI = \Delta sal \times D / 100000 \quad (40)$$

# 3. RESULTS AND DISCUSSION FOR THE BORDER DESIGNATED AREA

## 3.1 FIELD RESULTS

### 3.1.1 SOIL CORES

Analysis results from soil cores collected during drilling programs in 2005 and 2006 for the Border Designated Area are given in Appendix A.1. Continuous soil cores were collected from ground surface to the water table, where drilling permitted. Soil samples were analysed for particle size distribution, pore water chloride $[Cl]_{SW}$, gravimetric water content ($\theta_g$) and soil water suction (SWP).

### 3.1.2 GROUNDWATER CHEMISTRY AND ISOTOPIC SIGNATURES

Groundwater samples were collected from 44 Departmental (DWLBC) observation wells and piezometers located in the Border Designated Area between September 2006 and January 2007 (Fig. 3.1). All groundwater samples were collected after a minimum three casing volumes had been purged and readings of electrical conductivity (EC), pH and temperature at the pump discharge pipe became constant. Groundwater samples were analysed for major ion chemistry (App. B.1), stable isotopes (Fig. 3.2), CFC's (Table 3.1) and $^{14}C$ (Table 3.2).

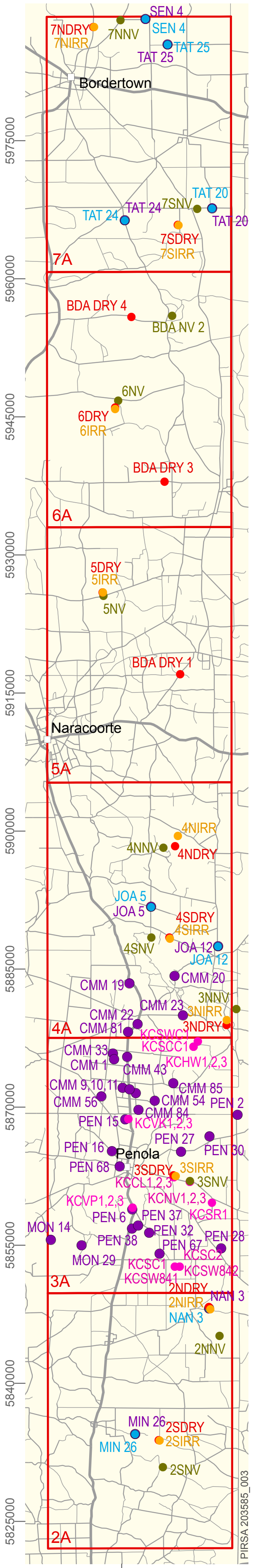
### 3.1.3 MAJOR ION CHEMISTRY

To examine the major ion chemistry of selected groundwater monitoring wells more thoroughly, data has been divided into the land use categories of native vegetation and dry land agriculture from where the samples were taken. A Piper diagram (Fig. 3.3) is used to display the data.

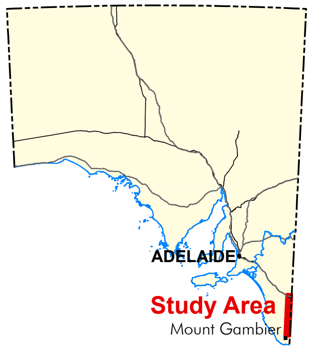
The Piper diagram shows a spread of major ion chemistry data, typically indicating the groundwater of the Border Designated Area is sodium chloride dominated, which can be an indicator of evaporation taking place prior to and/or during the groundwater recharge process. However, the major ion chemistry at two sites is slightly calcium carbonate dominated (being from sites located south of the Kanawinka Fault, having shallower depths to water, higher annual rainfall and higher groundwater recharge rates).

### 3.1.4 RAINFALL AND MONITORING WELL HYDROGRAPHS

Rainfall and monitoring well data has been considered to establish any link between long-term change in precipitation over the study area and a change in water level conditions. The rainfall station and monitoring well location map for the Border Designated Area (App. C.1) shows the broad scale of sites explored.




N




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation
- Zone 3A Project Sites
- Additional Chemical Analysis Well
- Isotope Analysis Well
- Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

**WELLS PUMPED FOR CHEMICAL ANALYSIS**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 3.1**

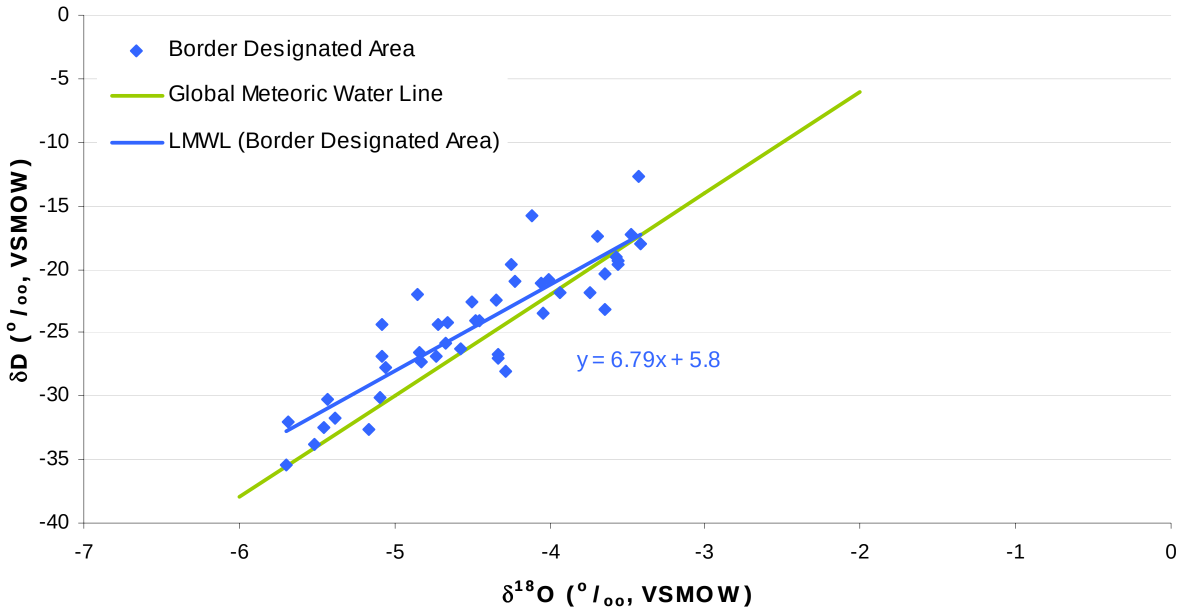



**Figure 3.2 Stable isotopes, Border Designated Area**

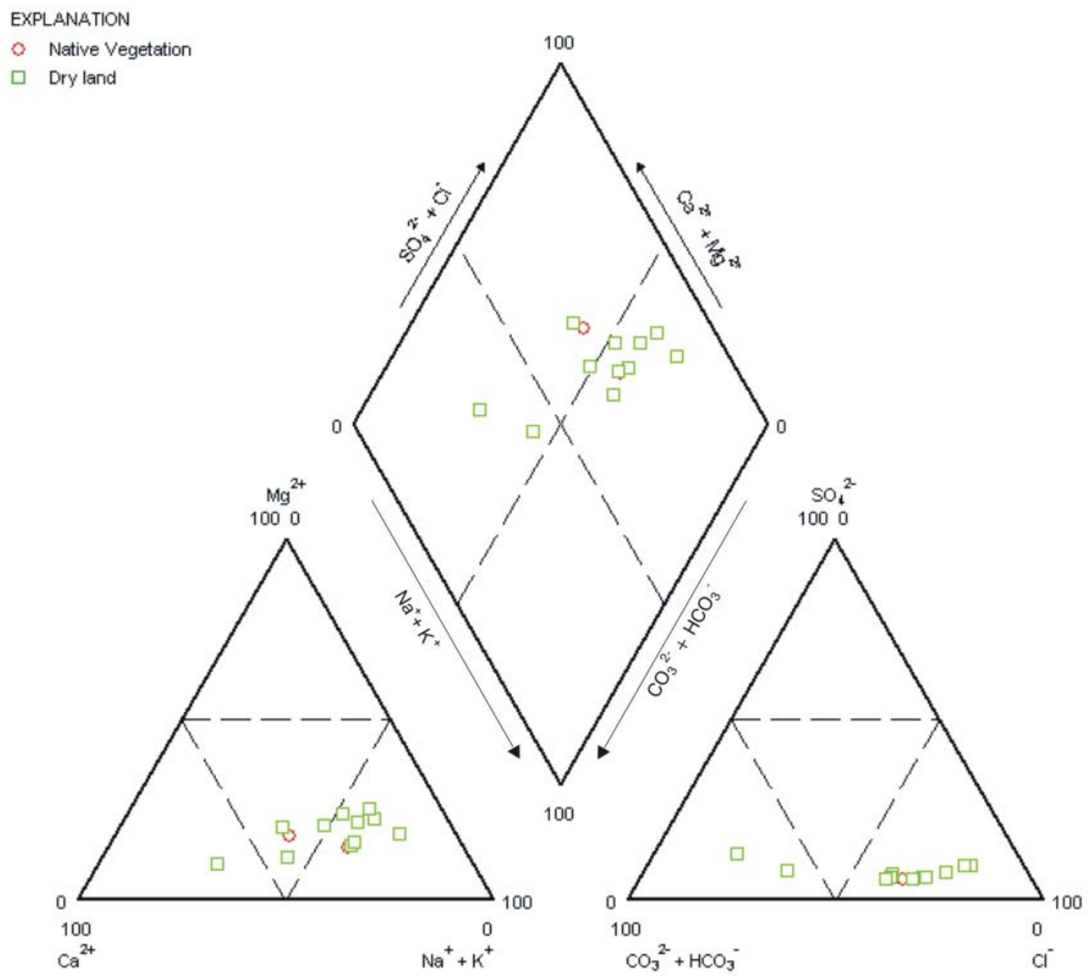



**Figure 3.3 Major ion chemistry piper diagram, Border Designated Area**

**Table 3.1 Chlorofluorocarbon (CFC11 and CFC12) apparent groundwater age data, Border Designated Area**

| Site | Apparent age | |
|---|---|---|
| | CFC11 | CFC12 |
| 4N-NV | 1975 | 1982 |
| BDA Dry1 | 1986 | 1981 |
| BDA Dry3 | <1965 | 1970 |
| BDA Dry4 | <1965 | 1974 |
| BDA NV2 | 1965 | 1975 |
| JOA 12 | 1972 | 1974 |
| JOA 5 | 1977 | 1989 |
| MIN 26 | 1977 | 1994 |
| NAN 3 | <1965 | 1970 |
| SEN 4 | <1965 | <1965 |
| TAT 20 | 1968 | 1969 |
| TAT 24 | 1973 | 1979 |
| TAT 25 | 1976 | <1965 |

**Table 3.2 Carbon isotope ($\delta^{13}C$ and $^{14}C$) data, Border Designated Area**

| Site | $\delta^{13}C$ | $^{14}C$ |
|---|---|---|
| | ‰ PDB | pMC±1σ |
| SEN 4 | -8.95 | 48.0 ± 1.1 |

Annual rainfall at selected rainfall stations has been graphed with the cumulative deviation from the mean annual rainfall (App. D.1). Cumulative deviation from the mean annual rainfall has been calculated for each station using rainfall data from 1900–2006, with the exception of the Mt Gambier Aero (26021) rainfall station, for which rainfall records only date back to 1942. Generally over the Border Designated Area there has been a declining rainfall trend since the early to mid 1990s (Bordertown, Frances, Naracoorte, Coonawarra and Penola Post Office). Mt Gambier Aero rainfall data contradicts this, generally having an increasing trend since the late 1990s. Preceding this, back to the early to mid 1980s, several rainfall stations (including Bordertown, Naracoorte, Coonawarra and Penola Post Office) had no definite trend. Where as Frances (increasing) and Mt Gambier Aero (declining) do not follow the general pattern of the Border Designated Area. Prior to this, back to the mid 1970s, all rainfall stations show declining rainfall trends to differing degrees.

The relationship between precipitation and water level trends is explored using cumulative deviation from the mean monthly rainfall data graphed against monitoring well water level data (App. E.1). Cumulative deviation from the mean monthly rainfall has been calculated for each rainfall station using data from January 1900 to March 2007, again with the exception of station 26021 (January 1942–March 2007), however all rainfall is displayed from January 1970 onwards to correspond with groundwater monitoring data. Regular groundwater monitoring commenced in the southeast region of South Australia during the early to mid 1970s.

Scale for both cumulative deviation from the mean monthly rainfall (mm) and water level (m) has been kept constant for all hydrographs to enable easy comparison between data from different regions of the Border Designated Area. Data from the northern portion of the Border Designated Area (Zone 6A and 7A) generally show relatively small changes in water level over the recorded period (<0.5 to <2.5 m), coinciding with deeper depths to water (>15 m up to 40 m). Generally, this region has rising water levels until the early to mid 2000s after which the water level flattens or declines (e.g. App. E.1, TAT 24 vs. Bordertown Rainfall). Changes in rainfall, as shown by cumulative deviation from the mean monthly rainfall, over this area have not been the major influence to changes in water level in the past. The rising water level table has been controlled primarily by the clearance of native vegetation, as changes in land use affect the drainage rate immediately (Cook et al 2004) and following a time lag, can affect the recharge rate. Typically, increases in the drainage rate due to vegetation clearance will out weigh changes to the drainage rate due to declining rainfall patterns alone at uncleared native sites. Drainage and recharge are approaching equilibrium; hence declining rainfall patterns have the potential to directly influence groundwater levels in the future.

Further south (Zones 2A to 5A), a combination of shallower water tables (generally <15 m) and greater annual precipitation lead to drainage and recharge rates reaching equilibrium soon after native vegetation clearance, hence groundwater level records mirror those of rainfall (e.g. App. E.1, JOA 5 vs. Naracoorte Rainfall).

## *3.2 DATA INTERPRETATION AND 1-D MODELLING*

### 3.2.1 UNCONFINED AQUIFER RECHARGE ESTIMATES

Using the analysis of soil core, groundwater, irrigation and rainfall data, estimates of point source recharge in the Border Designated Area have been made using three methods; including 1) chloride mass balance (refer to section 2.1.1), 2) chloride front displacement (refer to section 2.1.1), and 3) 1-D recharge model (refer to section 2.3.1). A range of methods allows for calculation of recharge values under different land use types while also allowing for comparison between techniques (Table 3.3).

The chloride mass balance method allows for recharge calculations under steady state conditions. For the purposes of this study, native vegetation and irrigation are classed as being in steady state. An assumption is made beneath irrigation investigation sites that drainage has reached a new equilibrium with recharge. Estimates of recharge using the chloride mass balance are given for all native vegetation and irrigation investigation sites with the exception of 5-IRR, which had very low soil water chloride. Average irrigation inputs for 3N-IRR, 3S-IRR, 2N-IRR and 2S-IRR were not available at the time of publication; therefore a value of 100 mm was used.

The chloride front displacement technique is used to estimate drainage rather than recharge, as the system is not in equilibrium. This generally applies to dry land agriculture where land clearance has previously taken place. A drainage estimate using the chloride front displacement method was also used on several irrigated sites, including non-annual irrigation

**Table 3.3 Recharge/drainage rate comparison – Border Designated Area**

| SITE | Recharge/drainage rate calculation method (mm) | | | | | |
|---|---|---|---|---|---|---|
| | **chloride mass balance** (section 2.1.1) | **chloride mass balance** (flushed profile) | **chloride front displacement** (section 2.1.1) | **CFC 12** (section 2.2.1.3) | **CFC 11** (section 2.2.1.3) | **1-D recharge model** (section 2.3.1) |
| 7N-NV | 0.7 | – | – | | | – |
| 7N-DRY | – | – | 46 | 26–13 | 36–13 | 53 |
| 7N-IRR | 64 | – | 29 | | | – |
| 7S-NV | 0.4 | – | | | | |
| 7S-DRY | – | – | 15 | 33–19 | 27–19 | 40–17 |
| 7S-IRR | 86 | – | | | | – |
| BDA NV2 | 0.7 | – | 1.6 | 18 | 14 | – |
| BDA DRY4 | – | – | 7.2 | | | 5.1 |
| 6-NV | 0.5 | – | 6 | | | – |
| 6-DRY | – | – | 15 | 26–20 | 20–18 | 22 |
| 6-IRR | 51 | – | 8.1 | | | – |
| BDA DRY3 | – | – | 9.7 | | | 2.9 |
| 5-NV | 0.9 | – | 6.6 | | | – |
| 5-DRY | – | – | 39 | 25 | 31 | 38 |
| 5-IRR | – | – | – | | | – |
| BDA DRY1 | – | – | 4.7 | | | 5.3 |
| 4N-NV | 18 | – | – | | | – |
| 4N-DRY | – | – | 27 | 30–19 | 18–15 | 68 |
| 4N-IRR | 119 | – | – | | | – |
| 4S-NV | 26 | – | – | | | – |
| 4S-DRY | – | – | 26 | 73–30 | 68–18 | 51 |
| 4S-IRR | 555 | – | – | | | – |
| 3N-NV | 11 | – | – | | | – |
| 3N-DRY | – | 140 | – | | | 95 |
| 3N-IRR | 134 | – | – | 4.5–51 | 4.5–40 | – |
| 3S-NV | 2.4 | – | – | | | – |
| 3S-DRY | – | – | – | | | 89 |
| 3S-IRR | 179 | – | – | | | – |
| 2N-NV | 39 | – | – | | | – |
| 2N-DRY | – | 258–155 | – | 17 | 15 | 97 |
| 2N-IRR | 73 | – | – | | | – |
| 2S-NV | 8 | – | – | | | – |
| 2S-DRY | – | 77–32 | – | 27 | 11 | 83 |
| 2S-IRR | 136 | – | – | | | – |

<table>
<tr><th rowspan="2">SITE</th><th colspan="7">Previous work</th></tr>
<tr><th>Latcham et al 2007</th><th>Brown et al 2006</th><th>Walker et al 1990</th><th>Leaney et al 2005</th><th>Stadter 1989</th><th>Herzeg & Leaney 1993</th><th>Stadter & Love 1989</th></tr>
<tr><td>7N-NV</td><td rowspan="3">Tatiara 15 mm</td><td rowspan="3">Tatiara 15 mm</td><td rowspan="6">Tatiara 4–6 mm</td><td>–</td><td rowspan="6">15 mm</td><td rowspan="6">6.4 mm</td><td rowspan="6">10–20 mm</td></tr>
<tr><td>7N-DRY</td><td>–</td></tr>
<tr><td>7N-IRR</td><td>–</td></tr>
<tr><td>7S-NV</td><td rowspan="3">Tatiara 15 mm Western Flat 20 mm</td><td rowspan="3">Tatiara 1 5 mm Western Flat 20 mm</td><td>–</td></tr>
<tr><td>7S-DRY</td><td>–</td></tr>
<tr><td>7S-IRR</td><td>–</td></tr>
<tr><td>BDA NV2</td><td rowspan="6">Bangham 20 mm Frances 30 mm</td><td rowspan="6">Bangham 20 mm Frances 30 mm</td><td rowspan="10">Binnum <2 mm</td><td>–</td><td rowspan="6">20 mm</td><td rowspan="6">6.4–30 mm</td><td>–</td></tr>
<tr><td>BDA DRY4</td><td>–</td><td>–</td></tr>
<tr><td>6-NV</td><td>–</td><td>–</td></tr>
<tr><td>6-DRY</td><td>–</td><td>–</td></tr>
<tr><td>6-IRR</td><td>–</td><td>–</td></tr>
<tr><td>BDA DRY3</td><td>–</td><td>–</td></tr>
<tr><td>5-NV</td><td rowspan="4">Zone 5A 40 mm</td><td rowspan="4">Zone 5A 40 mm</td><td>–</td><td rowspan="4">30 mm</td><td rowspan="10">~12 mm</td><td>–</td></tr>
<tr><td>5-DRY</td><td>–</td><td>–</td></tr>
<tr><td>5-IRR</td><td>–</td><td>–</td></tr>
<tr><td>BDA DRY1</td><td>–</td><td>–</td></tr>
<tr><td>4N-NV</td><td rowspan="3">Joanna 50 mm</td><td rowspan="3">Joanna 50 mm</td><td rowspan="6">Joanna1A 4 mm Joanna1B 12 mm Joanna2 (NV) Joanna3 ~2 mm Joanna4 ~80 mm</td><td>–</td><td rowspan="6">30–75 mm</td><td>–</td></tr>
<tr><td>4N-DRY</td><td>–</td><td>–</td></tr>
<tr><td>4N-IRR</td><td>–</td><td>–</td></tr>
<tr><td>4S-NV</td><td rowspan="3">Joanna 50 mm Comaum 60 mm</td><td rowspan="3">Joanna 50 mm Comaum 60 mm</td><td>–</td><td>–</td></tr>
<tr><td>4S-DRY</td><td>–</td><td>–</td></tr>
<tr><td>4S-IRR</td><td>–</td><td>–</td></tr>
<tr><td>3N-NV</td><td rowspan="3">Comaum 60 mm Zone 3A 120 mm</td><td rowspan="3">Comaum 60 mm Zone 3A 100 mm</td><td>–</td><td>–</td><td rowspan="6">75 mm</td><td>–</td><td>–</td></tr>
<tr><td>3N-DRY</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>3N-IRR</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>3S-NV</td><td rowspan="3">Zone 3A 120 mm</td><td rowspan="3">Zone 3A 100 mm</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>3S-DRY</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>3S-IRR</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>2N-NV</td><td rowspan="3">Zone 2A 140 mm</td><td rowspan="3">Zone 2A 95 mm</td><td>–</td><td rowspan="3">Site # 104219 375 mm Site # 104217 250 mm</td><td rowspan="6">75 mm</td><td>–</td><td>–</td></tr>
<tr><td>2N-DRY</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>2N-IRR</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>2S-NV</td><td rowspan="3">Zone 2A 140 mm</td><td rowspan="3">Zone 2A 95 mm</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>2S-DRY</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>2S-IRR</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
</table>

sites or where the native vegetation was sparse. At these sites it is not known whether the system has reached equilibrium. This method was found not to be valid for investigation sites with depth to water generally less than ~10 m. These also coincided with higher rainfall zones and flushed chloride profiles.

The 1-D recharge model uses empirical relationships to relate soil properties to salinity and drainage giving an estimate of recharge beneath dry land agriculture (refer to Section 5: Up Scaling Point Measurements to Management Scale, for detailed explanation).

Groundwater samples taken for CFC analysis are use to calculate the apparent age of that groundwater sample (refer to section 2.2.1.3). From the age of a groundwater sample, and the depth from which it was collected below the water table, point recharge estimates can be made (Table 3.3).

### 3.2.2 GROUNDWATER RECHARGE PROCESSES

Groundwater recharge processes can be further understood using stable $\delta^2$H and $\delta^{18}$O isotope compositions of groundwater, and how they relate to the global meteoric water line (GMWL) (refer to Fig. 3.2). Figure 3.2 summarises the isotopic composition of 44 groundwater samples from monitoring wells and piezometers, plotted with the GMWL (Craig H., 1961). Formation of a local meteoric water line (LMWL) was not undertaken as part this study as it was outside the scope of the project and deemed that the spatial variability of rainfall over such a large study area would not give conclusive results. A linear regression through the groundwater data has the equation of $\delta^2 H = 6.79\delta^{18}O + 5.8$. Generally, groundwater samples more depleted in $\delta^2$H and $\delta^{18}$O have been sourced in the northern zones of the study area, i.e. Zones 6A and 7A where there is lower rainfall, greater potential evaporation and greater distance inland.

The range, mean and median groundwater recharge estimates from the previous section are summarised in Table 3.4. Drainage rate estimates have been categorised into dry land, irrigation and native vegetation highlighting the variability of land use classes. There is considerable spread and overlap in the drainage estimates from the three land use sites. This is understandable and inevitable given the area, soil types and climate covered by the Border Designated Area.

**Table 3.4 Range of drainage estimates – Border Designated Area**

| Land Use | Drainage rate | | |
|---|---|---|---|
| | Range | Mean | Median |
| Dry land | 4.5–258 | 42 | 26 |
| Irrigation | 8–555 | 130 | 86 |
| Native Vegetation | 0.4–39 | 8 | 3 |

Valid recharge rates are estimated with the chloride mass balance using soil core data and a sound knowledge of rainwater and irrigation water quality and quantity. The chloride front displacement method requires thorough soil core data interpretation to gain valid recharge rate estimates beneath dry land agriculture. Both methods are applicable in the correct environment. The practitioner must determine whether the soil water/groundwater system is at equilibrium or steady state, or whether the system is transient moving towards a new steady state. Once resolved, the correct groundwater recharge estimation method can be selected.

The 1-D recharge model can be reliable method for estimating groundwater recharge especially when comparisons with actual monitoring well groundwater levels and salinity fluctuations are used to validate the model.

Using groundwater CFC data will provide a point scale estimate of recharge that reflects recharge over a larger, integrated area. Great care must be taken when sampling for CFC's, as contamination via contact with the atmosphere will give the groundwater sample an atmospheric signature. Groundwater samples were collected in triplicate at each investigation site and results only replicated when replicate results agree.

Apparent groundwater age estimates provided via CFC analysis, show observation well SEN 4 has low levels of CFC 11 and CFC 12, interpreted as groundwater recharged prior to 1965. Carbon 14 ($^{14}C$) dating of groundwater taken from SEN 4 was then used to estimate the age of groundwater. A $^{14}C$ of 48.0±1.1pMC gives an uncorrected age of 3000–5000 years (groundwater age has not been corrected even though a $\delta^{13}C$ value has been measured). Other observation wells in the immediate study area have indicated groundwater ages <50 years old. A $^{14}C$ age of 3000–5000 years old is indicative of mixing between more recently recharged groundwater and older groundwater recharged many millennia prior.

## 3.3 COMPARISON OF RECHARGE RESULTS WITH PREVIOUS WORK

As discussed previously, the methods used to estimate drainage (chloride front displacement) and groundwater recharge (chloride mass balance, CFC & $^{14}C$) in the Border Designated Area are valid when used under the correct conditions. Recharge estimates calculated by these methods are comparable for each land use category, giving higher confidence to those estimates. To gain further confidence that the recharge calculations are acceptable, a comparison with previously published work has been undertaken. Seven independent studies, which focus on understanding and estimating groundwater recharge in the Border Designated Area, have been examined and summarised (Table 3.3).

Latcham et al 2007 combined the results of two projects, including a review of the work of Brown et al 2006 (discussed below) and facilitated discussions on potential forestry impacts which resulted in changes to water balance calculations given in Brown et al 2006.

Brown et al 2006 used a 'Border Zone Weighted Average' to determine regional groundwater recharge to the unconfined aquifer in Zones 2A–7A. An assessment of the hydrological response to seasonal recharge events in combination with soil associations and land use categories for management sub-areas by Bradley et al 1995 was the basis of Brown et al 2006 recharge estimates for Border Designated Area management areas. Brown et al 2006 explicitly incorporated forestry into the groundwater assessment process and area weighted each existing soil related recharge rate.

Walker et al 1990 used the chloride front displacement method to calculate recharge beneath transient systems from Zones 4A–7A. While Leaney et al 2005 used a chloride mass balance approach to estimate recharge beneath cleared dry land sites in Zone 2A where high recharge rates have flushed the historical unsaturated zone salt store.

Stadter 1989 used a variety of methods to assess recharge in the Border Designated Area. For the area south of the Kanawinka Fault (Zones 2A, 3A and part of 4A), recharge was assessed via annual changes in groundwater storage. For the remainder of Zone 4A and part of Zone 5A aquifer recharge was assessed via changes in aquifer through flow along selected flow paths, then compared to the water table fluctuation method for the northern part of Zone 4A, and all of Zones 5A, 6A and 7A. Soil moisture chloride profiles were used to give a preliminary recharge assessment using chlorine-36.

Herczeg and Leaney 1993 used several methods (water balance, chloride mass balance and chloride front displacement) to determine groundwater recharge rates for Zones 4A, 5A, 6A and 7A, which were complimented by a regional hydrochemical study evaluating spatial and temporal changes in salinity. Finally, Stadter and Love 1989 used a water balance technique to estimate recharge for Zone 7A.

Overall, groundwater recharge rates calculated in this study compare favourably with the recharge results given in the aforementioned published work. Latcham et al 2007, Brown et al 2006, Stadter 1989, Stadter and Love 1989 and to some degree Herczeg and Leaney 1993 used methods that estimated regional groundwater recharge, averaging out the affects of land use. The methods undertaken by Walker et al 1990, Leaney et al 2005 and much of Herczeg and Leaney 1993 deals more with site specific results, particularly recharge beneath dry land agriculture. For this study, the variety of techniques used to describe groundwater recharge allows for estimates to be calculated site specifically and on a regional basis. Given the comparable groundwater recharge estimates calculated in this study and in the previously published studies, all techniques applied show value.

# 4. RESULTS AND DISCUSSION FOR THE HUNDRED OF STIRLING

## 4.1 FIELD RESULTS

### 4.1.1 SOIL CORES

Analysis results from soil cores collected during drilling programs in 2005 and 2006 for the Hundred of Stirling study area are given in Appendix A.2. Continuous soil cores were collected from ground surface to the water table where drilling permitted, while soil samples were taken at intervals along excavation pit walls when continuous coring was not possible. Soil samples were analysed for particle size distribution, pore water chloride $[Cl]_{SW}$, gravimetric water content ($\theta_g$) and soil water suction (SWP).

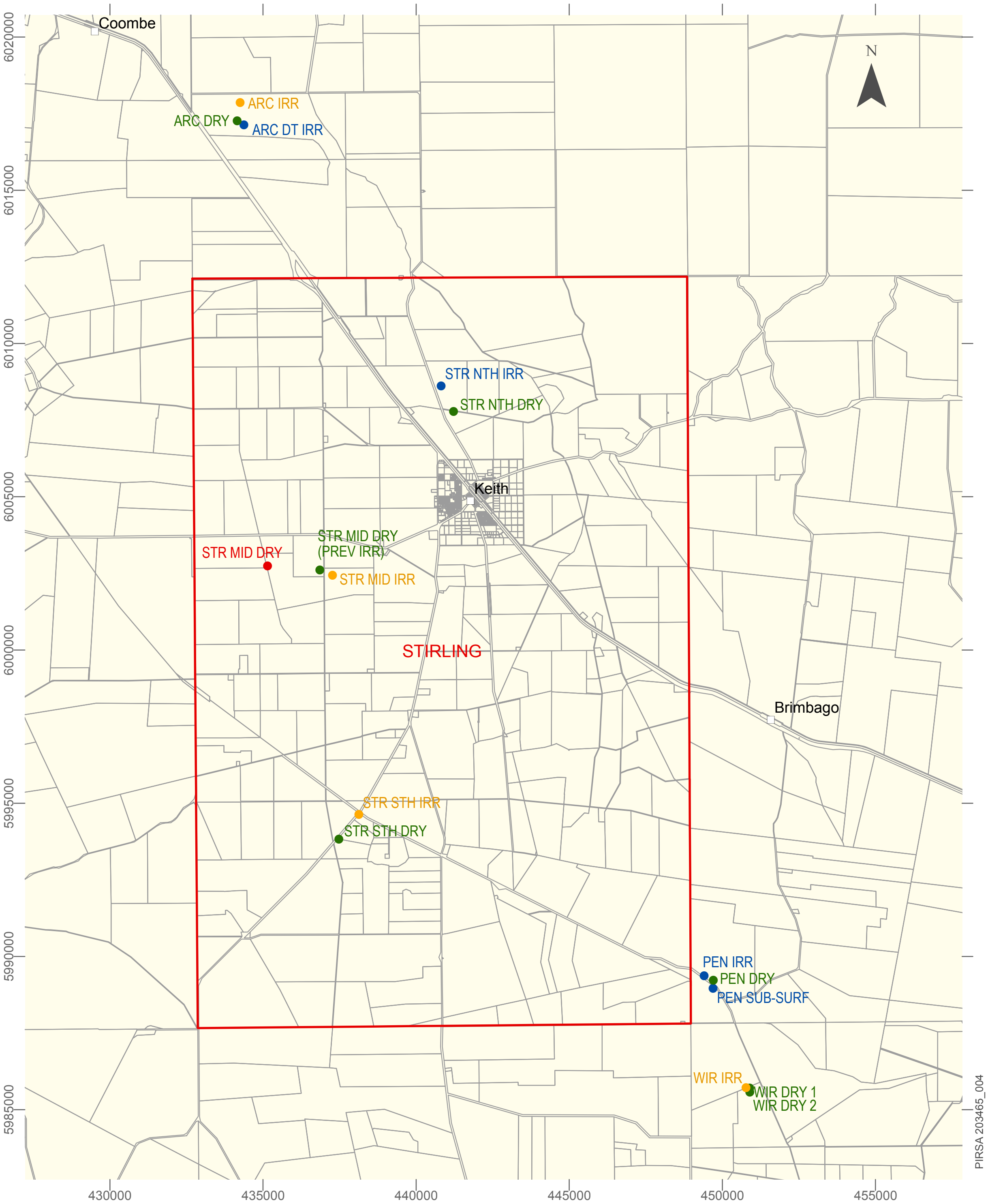
### 4.1.2 GROUNDWATER CHEMISTRY AND ISOTOPIC SIGNATURES

Groundwater and soil water samples were collected from 16 investigation sites located in the Hundred of Stirling study area between September 2006 and January 2007 (Fig. 4.1). All groundwater samples were collected after a minimum three casing volumes had been purged and readings of electrical conductivity (EC), pH and temperature at the pump discharge pipe became constant. Groundwater samples were analysed for major ion chemistry (App. B.2), CFC's (Table 4.1) and stable isotopes (Fig. 4.2).

**Table 4.1 Chlorofluorocarbon (CFC11 and CFC12) apparent groundwater age data, Hundred of Stirling**

| Site | Apparent age | |
|---|---|---|
| | CFC11 | CFC12 |
| ARC DT IRR | 1989 | NA* |
| ARC DRY | 1977 | 1984 |
| STR NTH IRR | 1976 | 1986 |
| STR MID IRR | 1979 | 1984 |
| STR MID DRY | 1973 | 1972 |
| STR STH IRR | 1986 | 1992 |
| STR STH DRY | 1985 | 1989 |
| PEN IRR | 1974 | 1980 |
| PEN DRY | 1974 | 1980 |
| WIR DRY 2 | <1965 | 1965 |

* NA indicates that the CFC-12 concentration in groundwater is greater than that expected for water equilibrated with modern air.





0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Investigation Sites

- Established Dryland
- Established Irrigation
- New Dryland
- New Irrigation
- Management Zone

Hundred of Stirling
Salt Accession Project

**WELLS PUMPED FOR CHEMICAL ANALYSIS**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 4.1**

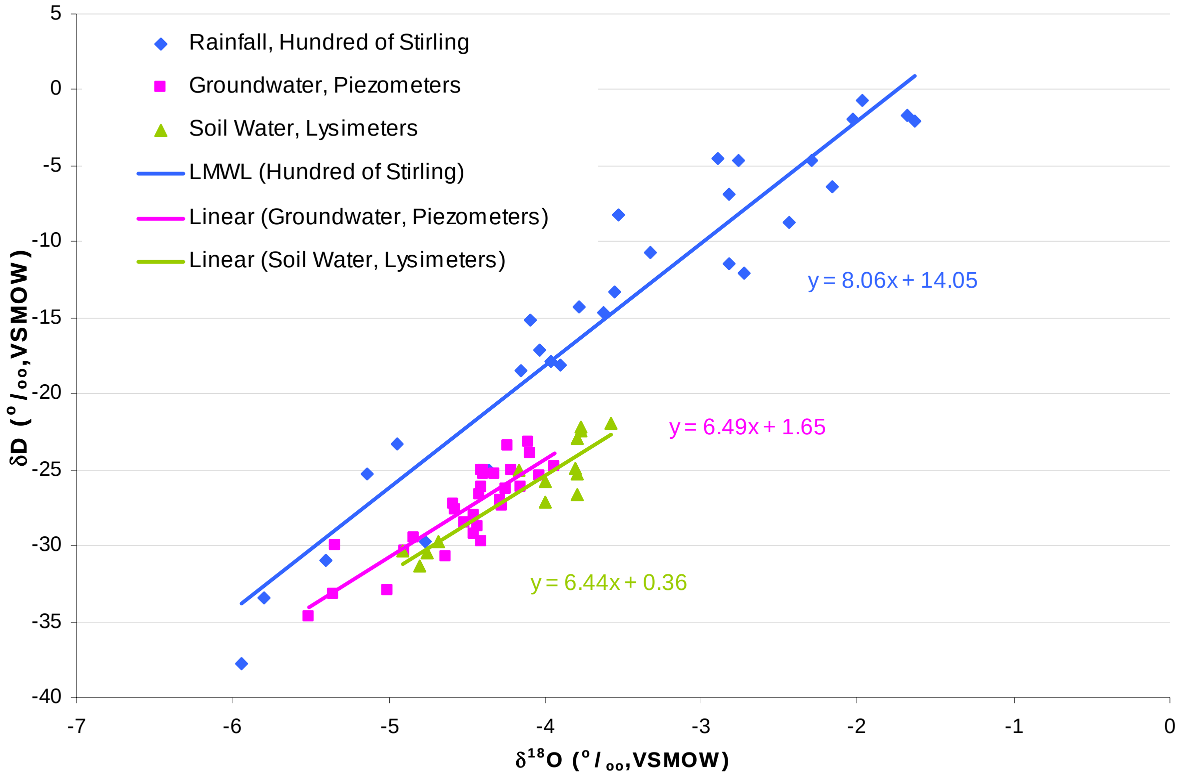



**Figure 4.2 Stable isotopes, Hundred of Stirling**

## 4.1.3 MAJOR ION CHEMISTRY

A piper diagram (Fig. 4.3) is used to examine the major ion chemistry of selected piezometers and lysimeters more thoroughly. Data has been divided into three categories: piezometers monitoring dry land agriculture, piezometers monitoring irrigated Lucerne and lysimeters monitoring irrigated Lucerne.

The piper diagram shows the major ion chemistry of groundwater and soil water in the Hundred of Stirling study area is entirely sodium chloride dominated. In particular, irrigation and lysimeter (under irrigation) data plots to the far right of the piper diagram, indicating very dominant chloride and sodium waters. Sodium chloride dominant waters can be an indicator of evaporation taking place during the groundwater recharge process. Due to the nature of the established flood irrigation regimes within the Hundred of Stirling significant evaporation would occur and sodium chloride type water would be expected.

## 4.1.4 RAINFALL AND MONITORING WELL HYDROGRAPHS

As with the Border Designated Area (Section 3.1.4), rainfall and monitoring well data has been considered in order to establish linkages between long-term change in precipitation and changes in water level conditions. The rainfall station and monitoring well location map for the Hundred of Stirling (App. C.2) shows the spatial relationship between the rainfall station and several monitoring wells.

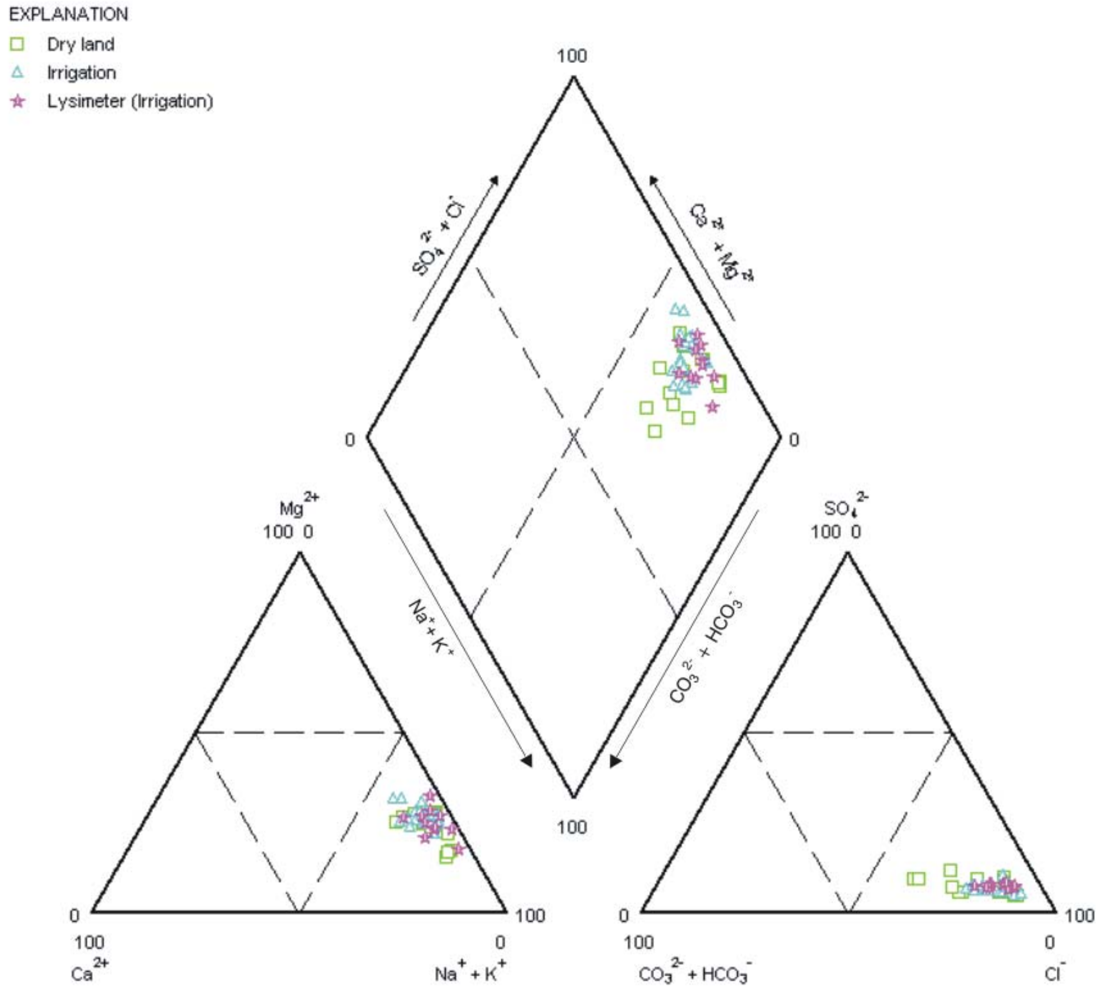



**Figure 4.3 Major ion chemistry Piper diagram, Hundred of Stirling**

Annual rainfall at the Keith rainfall station (25507) has been graphed with the cumulative deviation from the mean annual rainfall (App. D.2). Cumulative deviation from the mean annual rainfall has been calculated for each station using rainfall data from 1900–2006. The common rainfall pattern experienced through out the south east of South Australia is also reflected for the Hundred of Stirling, which has been in a declining rainfall trend since the early 1990s. Preceding this, back to the mid 1970s, there has been no definite trend associated with the rainfall pattern.

Precipitation and water level trends are studied further using cumulative deviation from the mean monthly rainfall data graphed with monitoring well water level data (App. E.2). Cumulative deviation from the mean monthly rainfall has been calculated for rainfall station 25507 using data from January 1900–March 2007. Only data post January 1970 is shown to correspond with groundwater monitoring data.

Scale for both cumulative deviation from the mean monthly rainfall (mm) and water level (m) has been kept constant for each hydrograph, enabling easy comparison between data within the Hundred of Stirling. Current water levels now commonly range between 5–10 m (SWL) in the Hundred of Stirling study area. Over the past 20 years, water levels have declined by

3–5 m (e.g. App. E.2; STR 110 vs. Keith Rainfall and ARC 7 vs. Keith Rainfall). Along with groundwater irrigation use, water level decline is also controlled by long-term rainfall trends.

At several investigation sites, groundwater level loggers have recorded responses to climatic trends and groundwater pumping for irrigation (Figs 4.4, 4.5). Installed during December of the 2005–06 irrigation season, both loggers missed the commencement of that irrigation season; however they clearly show a response to pumping and subsequent recovery period over the 2006 winter. Due to a relatively dry winter throughout the region, which was compounded by an earlier start to pumping for the 2006–07 irrigation season (late August 2006), groundwater levels did not recover to those of the previous year. Both PEN DRY and WIR DRY 2 show declining water levels over the spring and summer 2006–07 irrigation period to such an extent that the greatest depth to water reached in February 2007 is more than 0.5 m deeper than the corresponding time for the previous season. During autumn 2007 water levels started to recover, but again due to low rainfall, pumping has taken place to maintain stock feed through to winter.

### 4.1.5 WATER BALANCE

As part of an agreement with the DWLBC, De Barro Agricultural Consulting undertook monitoring of ET, rainfall, irrigation, groundwater and soil water; and calculated water balances for each site the Hundred of Stirling. These were reported to the Department in Milestone reports following each irrigation season. Table 4.2 includes a water mass balance recharge estimate for each investigation site over the past four irrigation seasons and compares those results to other recharge estimates using alternative calculation methods.

As a separate task, changes in soil water storage were estimated using calibrated Neutron Moisture Meter (NMM) data. Raw neutron measurements give an indication of soil wetness. However, to get an accurate estimate of the change in soil moisture storage, raw measurements have to be calibrated against local soil profile conditions (volumetric water content). Three separate calibration equations (factory, local and published) were used. Calibrated data from several sites over the region indicated a wetting up and drying of the soil profile during the irrigation season, followed by a drying or loss of stored water post irrigation and an increase in storage during winter. However, low confidence in the local calibration did not allow actual change in stored soil moisture to be calculated and no results will be given here.

### 4.1.6 DAILY SOIL WATER BALANCE

A daily soil water balance technique has been used to calculate drainage at all irrigated investigation sites in the Hundred of Stirling study area (Table 4.2). Daily weather data was sourced from the Queensland Department of Natural Resources and Mines SILO database; this included a measurement of reference evapotranspiration ($ET_o$) evaluated using the FAO 56 methodology (Equation 10). Daily $ET_o$ measurements were then multiplied with the corresponding crop coefficient ($K_c$) to give a daily crop evapotranspiration ($ET_c$) (Equation 11). Kc values sourced from Desmier and Schrale (1988) relate to Lucerne seed crops rather than Lucerne fodder, as Lucerne seed is the primary crop at all investigation sites. Daily irrigation quantities were added to daily rainfall measurements giving the total daily input per site.

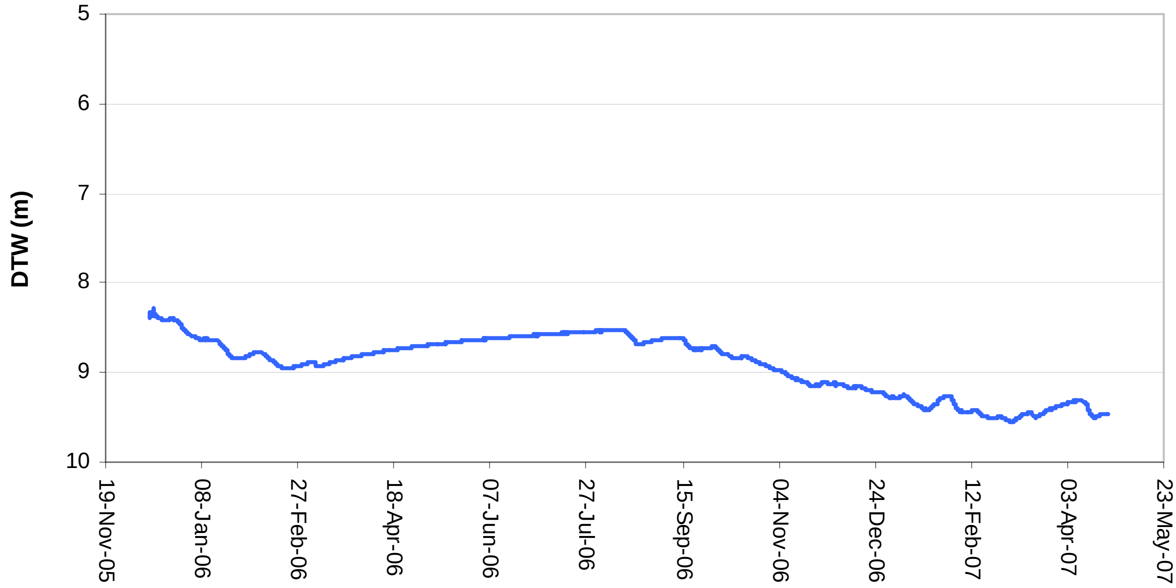



**Figure 4.4 PEN DRY, Logger data**

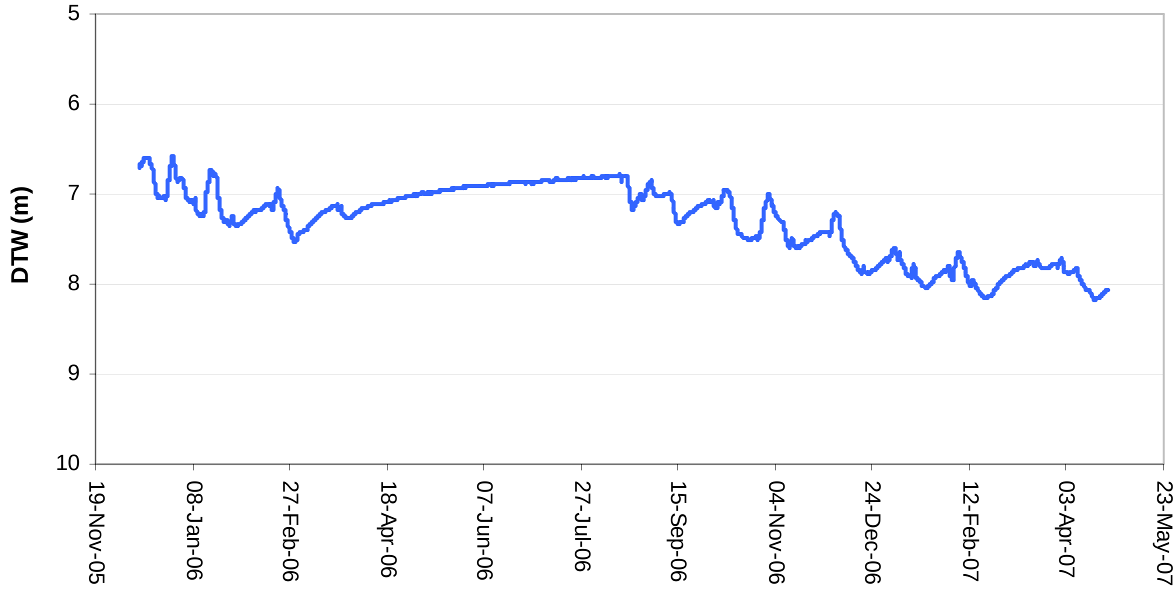



**Figure 4.5 WIR DRY 2, Logger data**

Calculation of the soil moisture deficit (SMD) requires knowledge of the wilting point (WP) and rooting depth (RD) at each investigation site. WP at 0.5 m intervals in the top 3 m of the soil profile at all investigation sites has been calculated using SOILPAR2[2]. Backhoe pits were used to determine an approximate RD for the Lucerne crop. A SMD is then calculated for each 0.5 m interval in the top 3 m using Equation 8. An average SMD was taken over the 3 m interval at each site for use in the daily water balance calculation (refer to section 2.1.6).

[2] Soil Parameters Estimate, SOILPAR v2.00, Research Institute for Industrial Crops, Italy.

**Table 4.2 Recharge/drainage rate comparison – Hundred of Stirling**

| | **Recharge/drainage rate calculation method** (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **SITE** | **Chloride front displacement (section 2.1.1)** | **Chloride mass balance (section 2.1.1)** | **Chloride mass balance (flushed profile)** | **CFC 12 (section 2.2.1.3)** | **CFC 11 (section 2.2.1.3)** | **1-D recharge model (section 2.3.1)** | **Water mass balance 06-/07 (section 2.1.3)** | **Daily soil water balance 06-/07 (section 2.1.6)** | **LEACHM 06-/07 (section 2.1.7)** | **Water mass balance 05-/06 (section 2.1.3)** |
| ARC DT IRR | – | 299 | – | 218 | 39 | – | 103 | 287 | 299 | – |
| ARC IRR | – | 363 | – | – | – | – | 61 | 363 | 366 | – |
| ARC DRY | 2.3 | – | – | 32 | 24 | – | – | – | – | – |
| STR NTH IRR | – | 561 | – | 14 | 9.3 | – | 314 | 309 | 164 | 321 |
| STR NTH DRY | – | – | – | – | – | – | – | – | – | – |
| STR MID IRR | – | 404 | – | 105 | 86 | – | 64 | 75 | 2.9 | 216 |
| STR MID DRY | – | – | – | 70 | 72 | 46 | – | – | – | – |
| STR MID DRY (PREV IRR) | – | – | – | – | – | – | – | – | – | – |
| STR STH IRR | – | 714 | | 125 | 88 | – | 720 | 506 | 557 | 570 |
| STR STH DRY | – | – | 47–69 | 22 | 19 | – | | | | |
| PEN IRR | – | 753 | – | 3.7 | 3.0 | – | 59 | 77 | 79 | 59 |
| PEN DRY | – | – | 43–85 | – | – | – | – | – | – | – |
| PEN SUB-SURF | – | 193 | – | – | – | – | 0.0 | 23 | 58 | 0.0 |
| WIR IRR | – | 732 | – | – | – | – | 1032 | 1078 | 1118 | 744 |
| WIR DRY 2 | – | – | – | 14 | 14 | – | – | – | – | – |

| SITE | **Recharge/drainage rate calculation method** (mm) | | | | | | | | **Previous work** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Daily soil water balance 05-/06 (section 2.1.6)** | **LEACHM 05-/06 (section 2.1.7)** | **Water mass balance 04-/05 (section 2.1.3)** | **Daily soil water balance 04-/05 (section 2.1.6)** | **LEACHM 04-/05 (section 2.1.7)** | **Water mass balance 03-/04 (section 2.1.3)** | **Daily soil water balance 03-/04 (section 2.1.6)** | **LEACHM 03-/04 (section 2.1.7)** | **Brown et al 2006** | **Stadter & Love 1989** |
| ARC DT IRR | – | – | – | – | – | – | – | – | – | – |
| ARC IRR | – | – | – | – | – | – | – | – | – | – |
| ARC DRY | – | – | – | – | – | – | – | – | – | – |
| STR NTH IRR | 321 | 239 | 288 | 329 | 203 | 514 | 565 | 442 | Stirling 50 mm | up to 50 mm |
| STR NTH DRY | – | – | – | – | – | – | – | – | | |
| STR MID IRR | 134 | 93 | 265 | 227 | 143 | 219 | 145 | 98 | | |
| STR MID DRY | – | – | – | – | – | – | – | – | | |
| STR MID DRY (PREV IRR) | – | – | – | – | – | – | – | – | | |
| STR STH IRR | 476 | 497 | 612 | 455 | 520 | 746 | 627 | 667 | | |
| STR STH DRY | – | – | – | – | – | – | – | – | | |
| PEN IRR | 21 | 21 | – | – | – | – | – | – | Wirrega 30 mm Stirling 50 mm | |
| PEN DRY | – | – | – | – | – | – | – | – | | |
| PEN SUB-SURF | 5.3 | 0.4 | – | – | – | – | – | – | | |
| WIR IRR | 799 | 788 | 718 | 862 | 919 | 1424 | 1656 | 1727 | | |
| WIR DRY 2 | – | – | – | – | – | – | – | – | | |

### 4.1.7 LEACHM

LEACHM (Hutson J.L., 2003), a one-dimensional model used to quantify vertical water flow through the unsaturated zone, has been applied at all irrigation investigation sites. Inputs to the model are based on real weather and soil physical data with assumptions made for the bulk density of soil and crop information.

The soil profile was modelled at a depth of 1200 mm, corresponding to the root zone thickness (based on backhoe pit excavations), with 12 layers at 100 mm spacings. Water flux in the unsaturated zone has been calculated using the Richards equation and a free drainage lower boundary condition. A free drainage boundary condition specifies a unit gradient along the lower boundary of the model, is used where the watertable is located well beneath the modelled domain and assumes gravity flow. Model inputs for soil physical properties and gravimetric water content were averaged data collected at each site for each interval. Soil retentivity parameters and field capacity were calculated using SOILPAR2 and the relevant soil physical data. Since measurements of bulk density have not been made, a constant bulk density of 1.5 kg/dm$^3$ was applied at each site for consistency. Various bulk densities were modelled, however since real data was unavailable, it was thought that the use of a constant bulk density would be a more transparent approach rather than adjusting bulk densities site by site to match, for example, groundwater recharge rate estimates determined previously. Again for consistency; one perennial crop grew per season, and for ease of setting up the models dates of germination, emergence, maturity and harvest were keep constant. Rainfall data from the Keith rainfall station was used for all of the model scenarios, while individual irrigation regimes were added for each investigation site.

For each modelled scenario, drainage outputs are illustrated in Figures 4.6–4.13 with annual recharge estimates given in Table 4.2.

### 4.1.8 SALINITY MEASUREMENTS

Salinity measurements at all stages of the water balance are required for an accurate assessment of the salinity impact to the unconfined aquifer. Regular water samples have been taken of rainfall, at the irrigation bore and monitoring piezometer, and within the soil profile. All water samples were analysed for total dissolved solids (TDS, mg/L) and chloride ($Cl^-$, mg/L). A measurement of TDS is used to give an overall assessment of the salinity, while $Cl^-$ helps distinguish between increases in salinity caused by evapotranspiration and soil/rock/water interaction.

Irrigation water, groundwater and soil water samples have been taken at regular intervals nominally during each irrigation event to further understand the effects of salts being introduced to the soil profile. Approximately monthly during winter and during major rainfall events to appreciate the effects of flushing salts from the soil profile. Lysimeters installed at investigation sites allow for measurements of soil water salinity. Calculation of the net salinity impact is the difference between salinities of applied water and soil water draining below the root zone multiplied by the drainage rate.

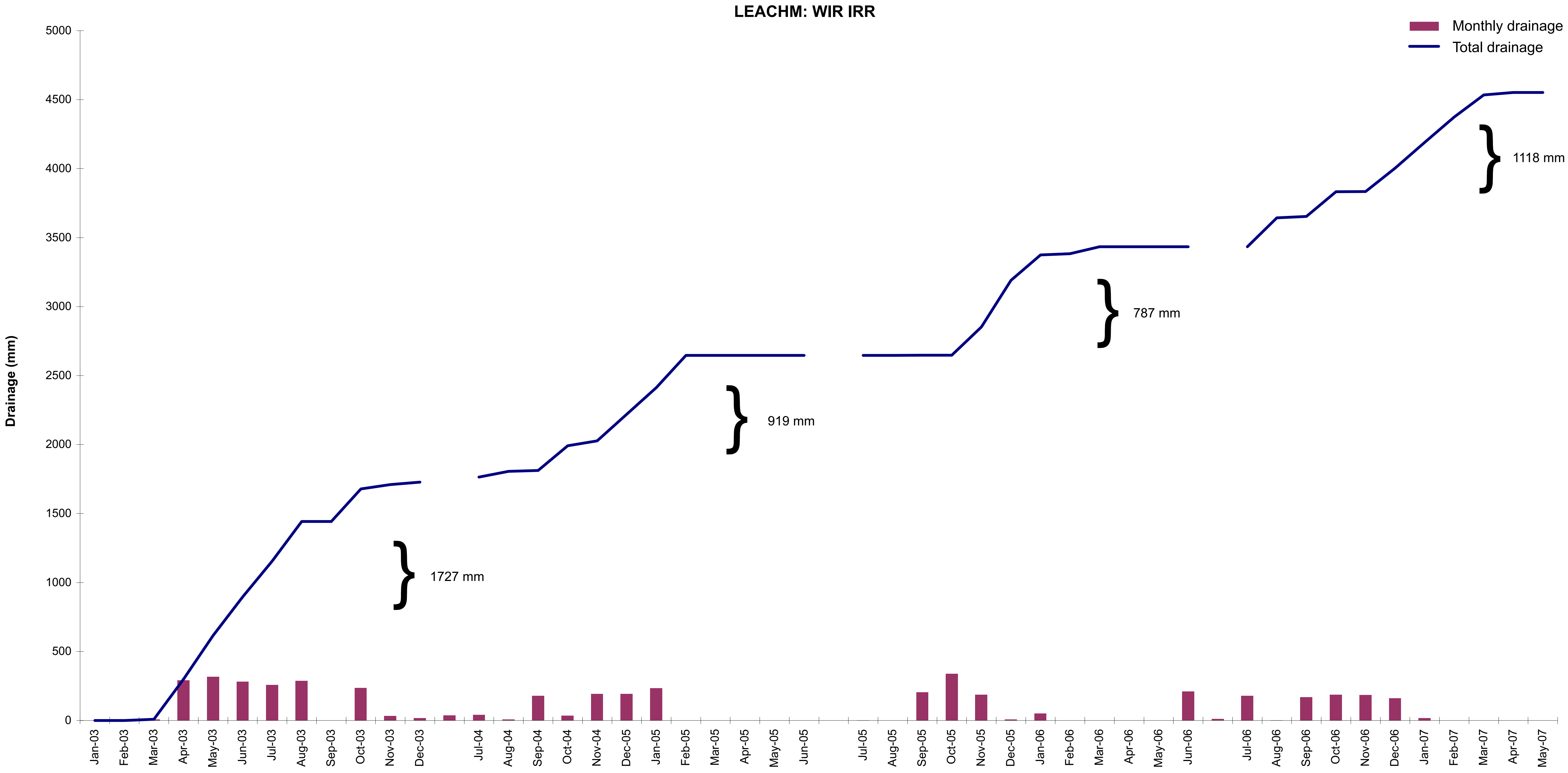



**Figure 4.6 LEACHM, WIR IRR**

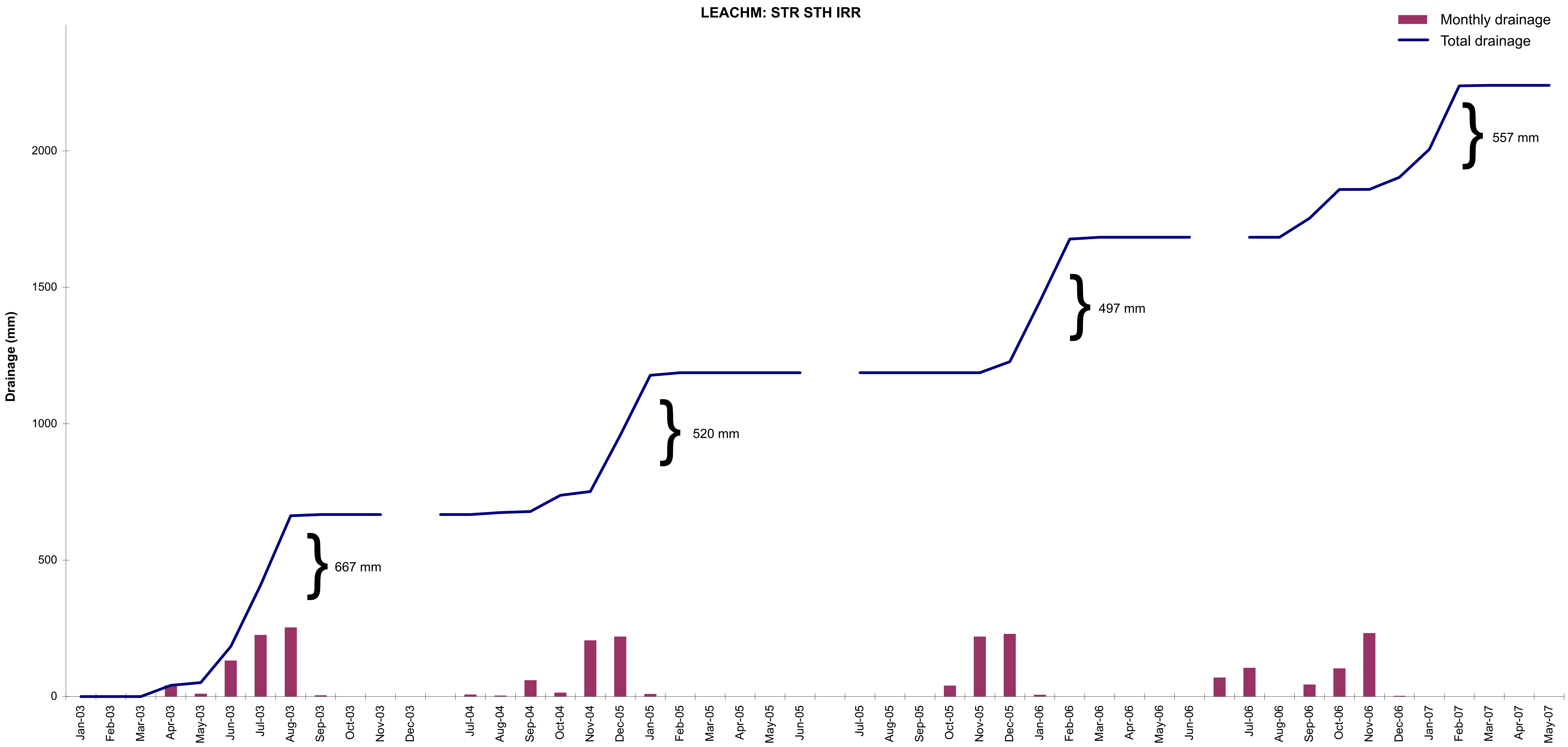



**Figure 4.7 LEACHM, STR STH IRR**

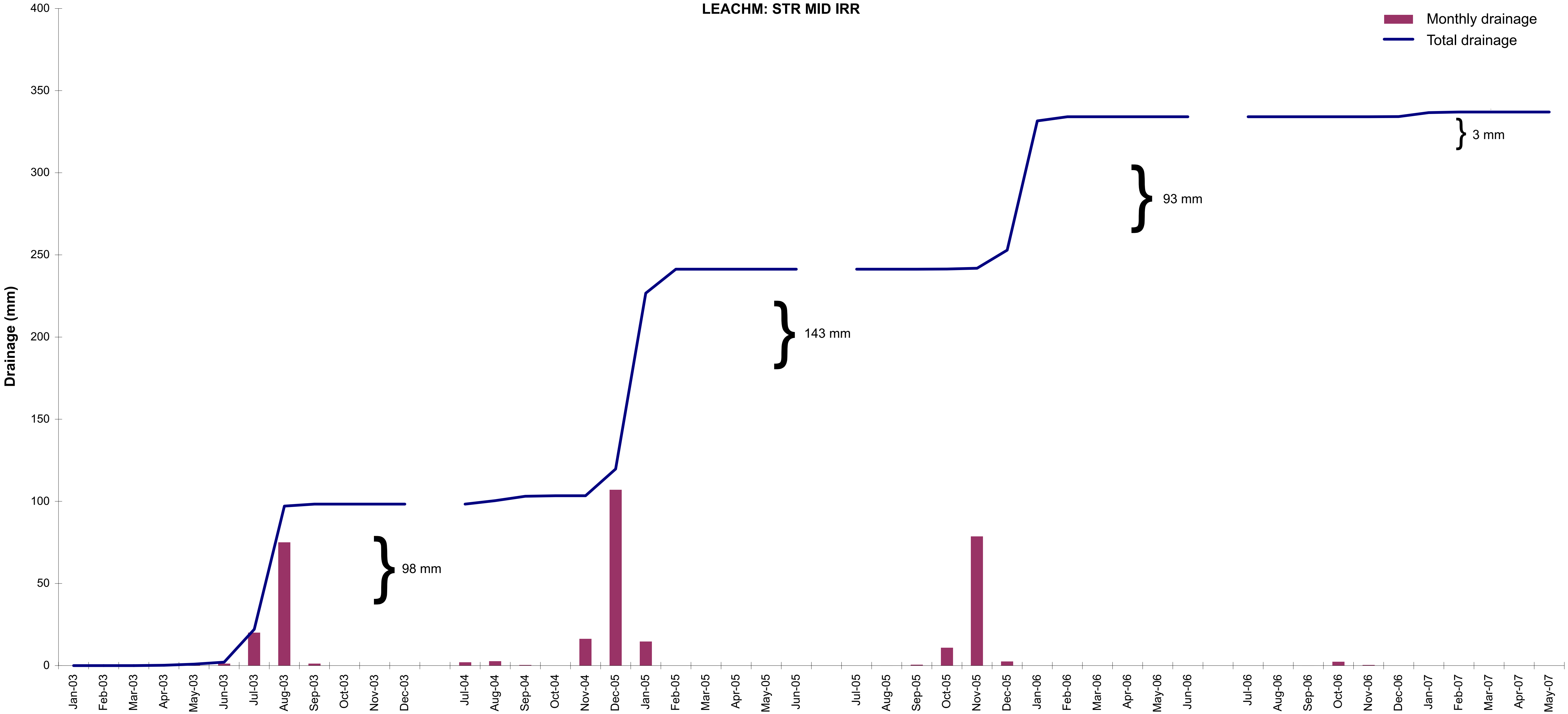



**Figure 4.8 LEACHM, STR MID IRR**

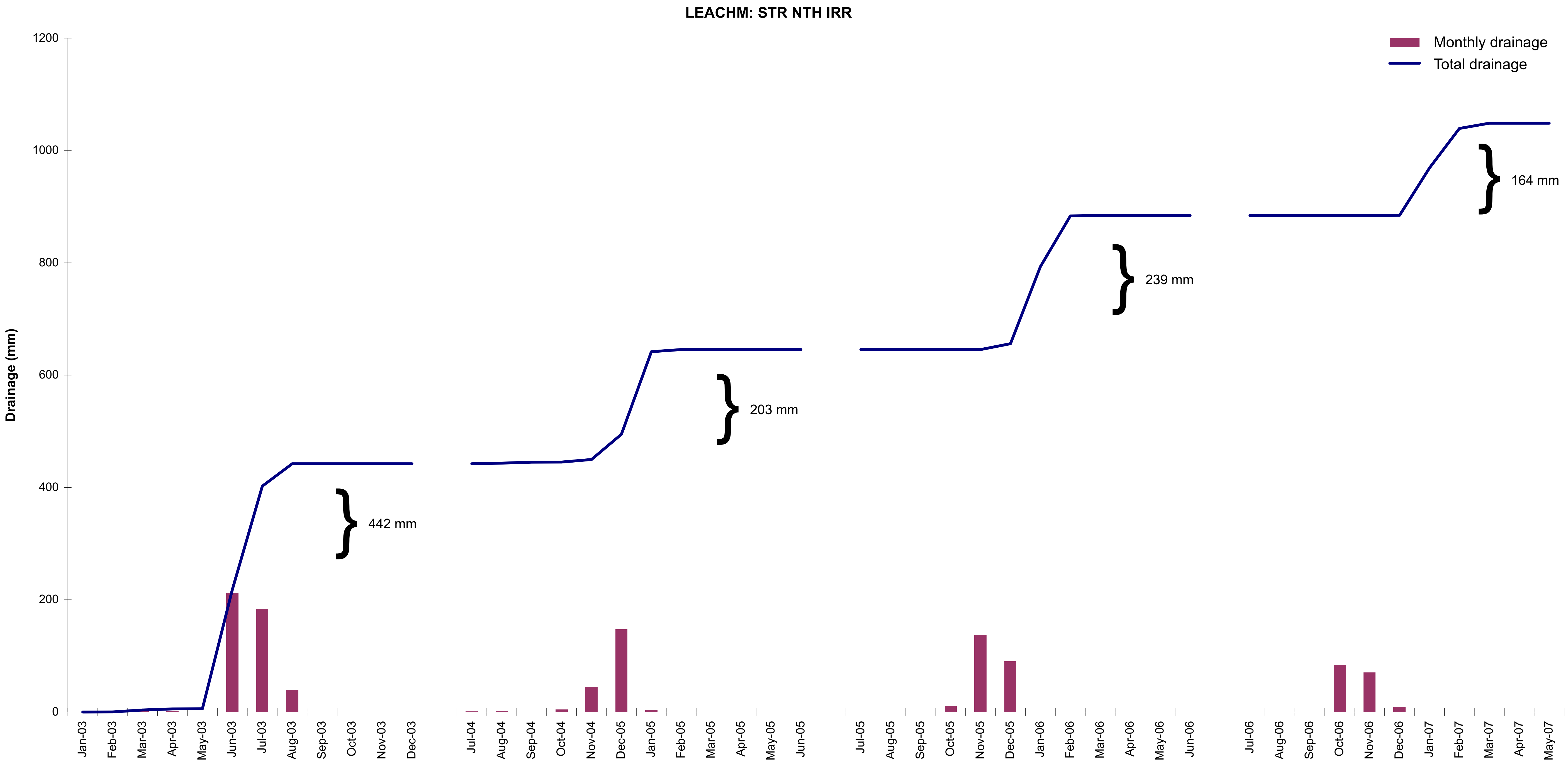



**Figure 4.9 LEACHM, STR NTH IRR**

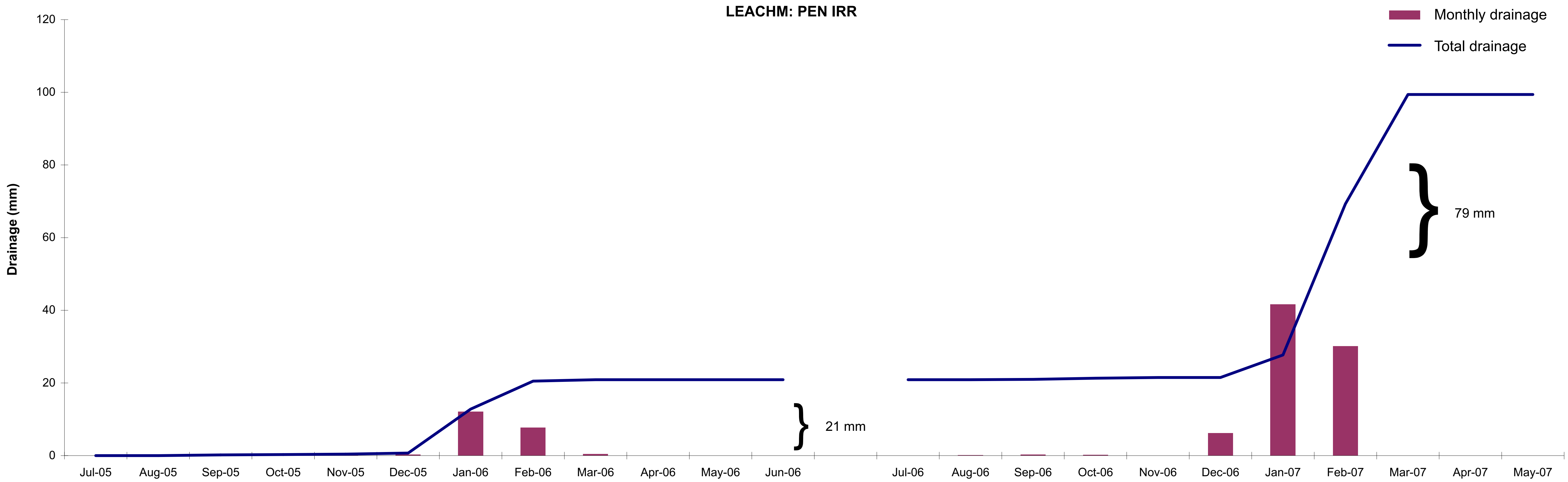



**Figure 4.10 LEACHM, PEN IRR**

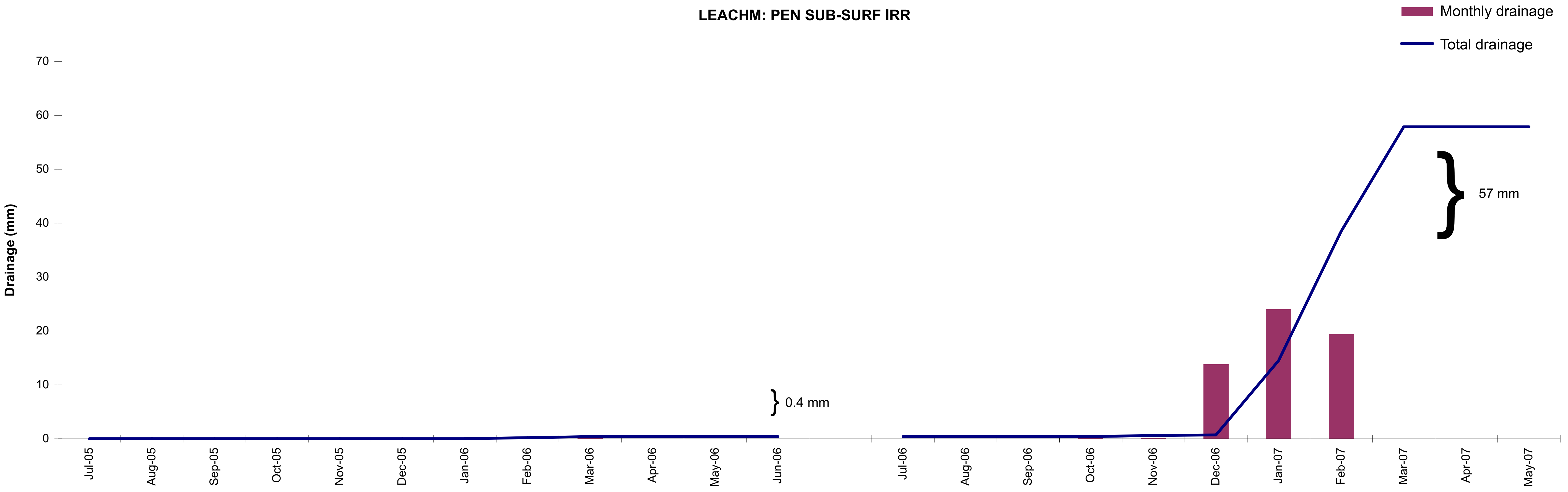



**Figure 4.11 LEACHM, PEN SUB-SURF IRR**

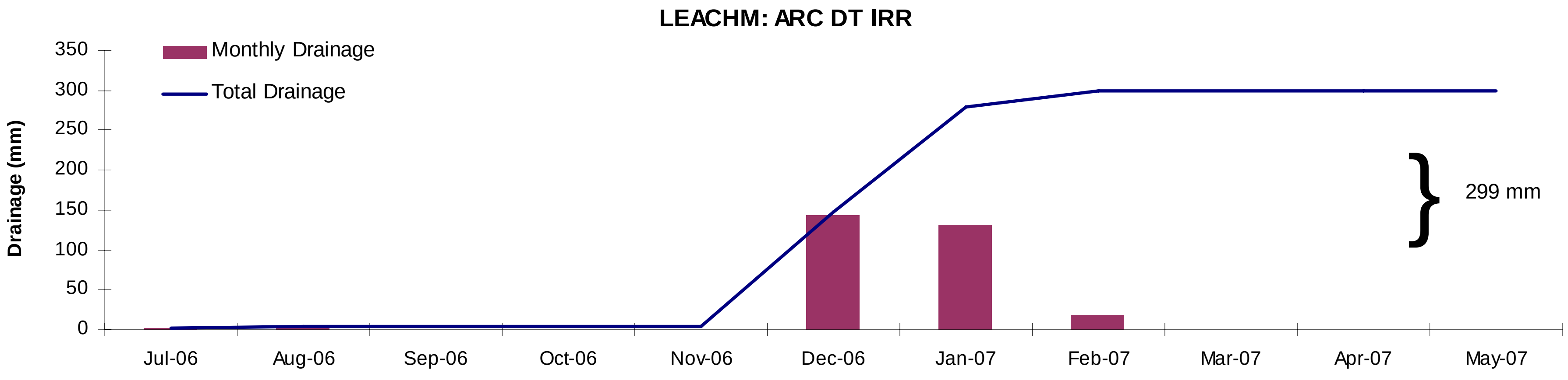



**Figure 4.12 LEACHM, ARC DT IRR**

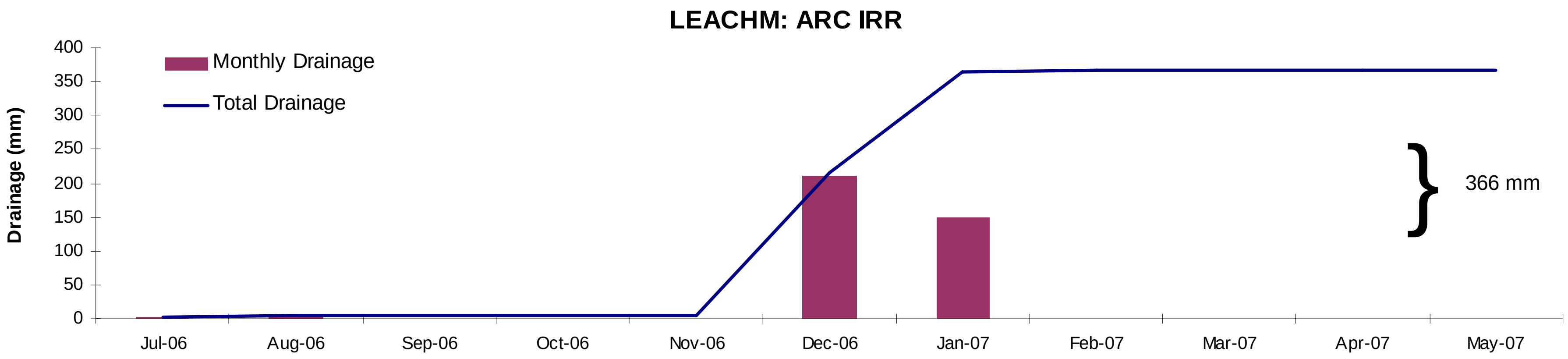



**Figure 4.13 LEACHM, ARC IRR**

Table 4.3, provides the averaged salinity measurements at irrigated investigation sites. In general, the percentage increase in $Cl^-$ is higher than the percentage increase in TDS. In part this is due to the amount of water that can be collected from lysimeters at certain times of the year under certain conditions and may also indicate that $Cl^-$ is more conservative than other anion and cations (particularly divalent $Ca^{2+}$, $Mg^{2+}$, $SO_4^{2-}$ etc) A minimum 5 mL of water is required to analyse for TDS, while $Cl^-$ analysis can be undertaken on a much smaller sample. At times of significant irrigation there was generally enough water at depth to analyse for both TDS and $Cl^-$. However more often than not, post large rainfall events (the optimal time to assess the salinity of soil water being flushed) the water sampled collected from the lysimeter was only sufficient to measure for $Cl^-$. Salinity of these samples, which represents the salinity of drainage that would eventually recharge the unconfined aquifer, were often more saline.

**Table 4.3 Percentage increase from bore to lysimeter following irrigation**

| Site | Average TDS (mg/L) | %↑ TDS | Average Cl (mg/L) | %↑ Cl |
|---|---|---|---|---|
| **Percentage increase from bore to lysimeter following irrigation** | | | | |
| STR NTH IRR bore | 6 348 | | 3 589 | |
| STR NTH IRR peizo | 7 694 | 21.21 | 4 513 | 25.73 |
| STR NTH IRR lysimeter 0.45 m | 8 721 | 37.39 | 5 229 | 45.69 |
| STR NTH IRR lysimeter 0.8 m | 8 032 | 26.52 | 4 817 | 34.21 |
| STR NTH IRR lysimeter 1.45 m | 12 208 | 92.30 | 8 123 | 126.32 |
| STR NTH IRR lysimeter 3.0 m | 9 802 | 54.42 | 5 487 | 52.88 |
| STR STH IRR bore | 4 670 | | 2 612 | |
| STR STH IRR peizo | 5 156 | 10.40 | 2 907 | 11.26 |
| STR STH IRR lysimeter 1.0 m | 9 447 | 102.26 | 8 496 | 225.19 |
| STR STH IRR lysimeter 2.0 m | 9 549 | 104.45 | 5 978 | 128.82 |
| STR STH IRR lysimeter 3.0 m | 7 240 | 55.02 | 4 299 | 64.53 |
| PEN IRR bore | 3 383 | | 1738 | |
| PEN IRR peizo | 3 430 | 1.38 | 2 019 | 16.19 |
| PEN IRR lysimeter 0.5 m | 6 066 | 79.30 | 3 308 | 90.36 |
| PEN IRR lysimeter 2.0 m | 7 205 | 112.96 | 4 227 | 143.29 |
| PEN IRR lysimeter 3.0 m | 5 689 | 68.14 | 4 187 | 140.98 |
| PEN SUB-SURF bore | 2 349 | | 1 260 | |
| PEN SUB-SURF peizo | 3 203 | 36.37 | 1 791 | 42.21 |
| PEN SUB-SURF lysimeter 0.45 m | 10 892 | 363.70 | 7 073 | 461.31 |
| PEN SUB-SURF lysimeter 1.45 m | 7 058 | 200.47 | 3 961 | 214.33 |
| WIR IRR bore | 2 785 | | 1 510 | |
| WIR IRR peizo | 3 469 | 24.57 | 1 935 | 28.11 |
| WIR IRR lysimeter 1.0 m | 4 389 | 57.62 | 2 728 | 80.64 |
| WIR IRR lysimeter 2.0 m | 3 852 | 38.34 | 2 139 | 41.66 |
| WIR IRR lysimeter 3.0 m | 4 877 | 75.15 | 2 700 | 78.79 |

| Site | Average TDS (mg/L) | %↑ TDS | Average Cl (mg/L) | %↑ Cl |
|---|---|---|---|---|
| ARC IRR bore | 3 058 | | 1 830 | |
| ARC IRR peizo | 5 429 | 77.53 | 3 161 | 72.74 |
| ARC IRR lysimeter 0.4 m | 6 188 | 102.34 | 4 183 | 128.55 |
| ARC IRR lysimeter 0.8 m | 13 598 | 344.68 | 10 870 | 493.99 |
| ARC IRR lysimeter 1.0 m | 14 247 | 365.90 | 9 895 | 440.71 |
| ARC IRR lysimeter 2.0 m | 6 527 | 113.44 | 3 960 | 116.39 |
| ARC IRR lysimeter 3.0 m | | | 64 610 | 3 430.60 |
| ARC DT IRR bore | 3 119 | | 1 768 | |
| ARC DT IRR peizo | 5 782 | 85.39 | 3 220 | 82.17 |
| ARC DT IRR lysimeter 0.4 m | 5 655 | 81.33 | 3 077 | 74.07 |
| ARC DT IRR lysimeter 0.8 m | 10 630 | 240.84 | 5 896 | 233.58 |
| ARC DT IRR lysimeter 1.2 m | 16 085 | 415.76 | 9 290 | 425.60 |
| ARC DT IRR lysimeter 2.0 m | 10 796 | 246.17 | 6 370 | 260.40 |
| STR MID IRR bore | 7 736 | | 4 327 | |
| STR MID IRR peizo | 7 716 | -0.25 | 4 378 | 1.18 |
| STR MID IRR lysimeter 1.0 m | 14 817 | 91.53 | 9 531 | 120.26 |
| STR MID IRR lysimeter 2.0 m | 12 269 | 58.59 | 7 491 | 73.13 |
| STR MID IRR lysimeter 3.0 m | 10 913 | 41.07 | 6 687 | 54.54 |

Salinity generally increases down the soil profile to a depth associated with the bottom of the root zone. Backhoe pit excavations throughout the region indicated that the bottom of the Lucerne crop root ball was located in the vicinity of 1.2 m from ground surface. Below this depth, the salinity often decreases.

Percentage increases in TDS and $Cl^-$ in the soil water profile with respect to the applied irrigation water have been studied for the four modes of irrigation; flood, sub-surface drip, conventional spray pivot and drop tube pivot. Five flood irrigation sites have been monitored in the Hundred of Stirling study area with maximum TDS increases of between 75–113% (occurring at depths between 1.0 m and 3.0 m) and maximum $Cl^-$ increases of between 80–225% (occurring at depths between 1.0 m and 2.0 m). Drop tube pivot irrigation, conventional spray pivot irrigation and sub-surface drip irrigation have maximum TDS increases of 415, 365 and 364% (at depths of 1.2 m, 1.0 m and 0.45 m) and maximum $Cl^-$ increases of 425, 494 and 461% (at depths of 1.2 m, 0.8 m and 0.45 m) respectively. Based on percentage salinity increases given above, the net salinity impact would be expected to be far greater beneath non-flood irrigation practices. However due to the volume of drainage occurring beneath drop tube pivot, conventional spray pivot and subsurface drip irrigation being significantly less than flood irrigation, the salinity impact is not as alarming as the salinity increases suggest (more detail given in Section 5).

# 4.2 DATA INTERPRETATION AND 1-D MODELLING

## 4.2.1 UNCONFINED AQUIFER RECHARGE ESTIMATES

An assessment of groundwater recharge rates beneath numerous irrigation and dry land investigation sites in the Hundred of Stirling study area was undertaken (Table 4.2).

Soil water, rainfall and irrigation water $Cl^-$ values are used in the chloride mass balance (refer to section 2.1.1) to estimate groundwater recharge assuming steady state conditions. An assumption is made that beneath irrigation and dry land sites with completely flushed $Cl^-$ profiles, drainage has reached a new equilibrium with recharge. Estimates of recharge using the chloride mass balance are given for all irrigation sites and two dry land sites (presenting flushed $Cl^-$ profiles).

Under non-equilibrium conditions, for example cleared dry land agriculture, an estimate of drainage rather than recharge can be made using the chloride front displacement technique (refer to section 2.1.1). As discussed previously, under conditions found during this investigation, the technique has been found invalid for investigation sites having a depth to water less than ~10 m. For this reason, the technique has been applied successfully to just one dry land investigation site in the Hundred of Stirling study area.

The water balance approach (refer to section 2.1.3) infers drainage past the root zone using a process measuring all remaining inputs and outputs to the mass balance. Drainage estimates at four flood irrigation investigation sites (STR NTH IRR, STR MID IRR, STR STH IRR and WIR IRR) have been calculated over the past four irrigation seasons with drainage estimates varying due to individual irrigation management practices and seasonal climatic variations. Drainage beneath flood irrigation has been estimated over the past two years at PEN IRR for direct comparison with sub-surface drip irrigation practices (PEN SUB-SURF). Drainage below conventional spray pivot and drop tube pivot irrigation (ARC IRR and ARC DT IRR) has been estimated for the 2006–07 irrigation season.

Two models, the daily soil water balance (refer to section 2.1.6) and LEACHM (refer to section 2.1.7) have been used to compare drainage rate estimates at the irrigation sites mentioned above, over the same time periods. Inputs to the models include real rainfall, irrigation and soil data. Published crop coefficient data has been used for the daily soil water balance.

Groundwater recharge rates can be estimated via CFC analysis (refer to section 2.2.1.3). CFC analysis of groundwater will provide an apparent age from which a recharge rate can be calculated providing an understanding of water table depth and screened intervals are known. Using this method, four background or dry land agriculture investigation sites (ARC DRY, STR MID DRY, STR STH DRY and WIR DRY 2), four flood irrigation sites (STR NTH IRR, STR MID IRR, STR STH IRR and PEN IRR) and one drop tube pivot irrigation sites (ARC DT IRR) have been sampled and analysed. Contact with the atmosphere can contaminate groundwater samples, therefore care must be taken when sampling for CFCs. Groundwater samples were collected in triplicate at each investigation site ensuring valid data. Because of potential degradation of CFC-11 and subsequent over estimate of groundwater age, results from CFC-12 are used.

Using various techniques to estimate groundwater recharge beneath both dry land agriculture and irrigated Lucerne, comparable rates have been calculated (Table 4.2). Moreover, the techniques selected for this project are appropriate and by selecting a range of methods, groundwater recharge is estimated with greater confidence.

### 4.2.2 GROUNDWATER RECHARGE PROCESSES

Recharge processes can be further understood using the isotopic composition of rainfall and groundwater through various stages of the irrigation cycle and how that relates to a local meteoric water line (LMWL). Rainfall samples collected at three locations (STR NTH IRR, STR STH IRR and WIR IRR) over the life of the project have been used to determine the LMWL (Fig. 4.2). Figure 4.2 summarises the isotopic composition of rainfall data to give the LMWL ($\delta^2 H = 8.06\delta^{18}O + 14.05$) while also displaying the isotopic composition of soil water and groundwater samples taken during the project. Linear regressions through the isotopic composition of soil water ($\delta^2 H = 6.43\delta^{18}O + 0.36$) and groundwater ($\delta^2 H = 6.49\delta^{18}O + 1.65$) for the Hundred of Stirling fall to the right of the LMWL. Data falling to the right of the LMWL can indicate waters have been evaporated prior to or during the recharging process. Allison (1982) showed that evaporation from unsaturated zone soil water could have a slope as low as 2, while evaporation from an open body of water will have a slope of around 5. With a slope of 6.43 given for the isotopic composition of soil water and 6.49 for groundwater, it does not appear that evaporation is greatly affecting drainage water within the soil zone or from an open body of water (e.g. flood irrigation). A linear regression through all data (soil water and groundwater) from the Hundred of Stirling gives an equation of $\delta^2 H = 6.02\delta^{18}O + 0.74$ (not shown in Fig. 4.2). Our understanding of the flood irrigation process in the Hundred of Stirling is that water freely and quickly drains through the unsaturated zone, thus not allowing time for significant evaporation to occur.

The range, mean and median of drainage estimates is summarised in Table 4.4. Drainage rate estimates have been categorised into irrigation and background to highlight the variability in land use classes. The large range given for irrigation is a consequence of the variety of irrigation and management practices utilised in the study area and annual climatic conditions.

**Table 4.4 Range of drainage estimates – Hundred of Stirling**

| Land use | Drainage rate (mm/y) | | |
|---|---|---|---|
| | *Range* | *Mean* | *Median* |
| Irrigation | 0–1727 | 403 | 309 |
| Background | 2.3–85 | 43 | 45 |

## *4.3 COMPARISON OF RECHARGE RESULTS WITH PREVIOUS WORK*

Two previously published studies have been considered and summarised (Table 4.2) to compare against the recharge estimates calculated in this study. Stadter and Love 1989 estimated diffuse recharge using chloride profiles and a mass balance approach assessing changes in groundwater storage. Brown et al 2006 adopted the previous recharge rates given in the Tatiara Water Allocation Plan. Brown et al 2006 attempted to use the water table fluctuation method, however found it not appropriate due to there being no representative hydrographs. Recharge rates given in the Tatiara Water Allocation Plan were calculated using a water storage mass balance approach.

Recharge rates estimated for the dry land investigation sites in this study compare well with the recharge rate results given in the published works of Brown et al 2006 (30–50 mm/y) and Stadter and Love 1989 (up to 50 mm/y). Both Brown et al 2006 and Stadter and Love 1989 used methods that calculate groundwater recharge regionally, averaging out the affects of land use.

# 5. UP SCALING POINT MEASUREMENTS TO MANAGEMENT SCALE

## 5.1 REGIONAL ESTIMATES OF RECHARGE AND SALINISATION – BORDER DESINGATED AREA

Up scaling point estimates of drainage and predicted lag times of groundwater recharge and salinisation to a regional scale establishes the long-term environmental impact to the resource and long-term economic viability of the resource to continue to support current and future agriculture and industry at management scales.

Soil water salinity, soil texture and soil physical properties, allow for a 1-D assessment of groundwater recharge and salinisation, which is then considered against real observed data. Suitable conditions for calculating point estimates of drainage using the chloride front displacement technique were found to include a depth to water of greater than 10 m, which for this study occurs north of the Kanawinka Fault. The historical chloride profile is flushed in environments with depth to waters of less than 10 m. Therefore, for the development of regional estimates of recharge and salinisation via up scaling point estimates of drainage, the model area is confined to the area north of the Kanawinka Fault.

### 5.1.1 THE DRAINAGE VS. % CLAY CONTENT (0–2 M) RELATIONSHIP

The purpose of the drainage vs. % clay content (0–2 m) relationship is to provide a proxy measurement for the post native vegetation clearing drainage rate, which can be applied spatially over the study area (refer to section 2.3.1.1).

Point estimates of drainage calculated using the chloride front displacement technique for dry land investigation sites (north of the Kanawinka Fault), give an actual drainage rate rather than a minimum drainage rate because the centre of mass of the chloride front has not yet flushed to the water table at any of these sites. In areas with low clay contents in the upper soil zone, negligible depths to water or very high rainfall, the historical salt profile can potentially be flushed from the unsaturated zone many times over. The historical salt profiles at all investigation sites have not been fully flushed in the modelled area (i.e. north of the Kanawinka fault); therefore all data can be plotted on a drainage vs. % clay content (0–2 m) graph. Previous studies have shown that the distribution of data on such a graph indicates a dependency on rainfall distribution, and therefore the relationship between drainage and % clay content (0–2 m) can require adjustment when analysing new data. As more drainage data becomes available, correlation between drainage vs. % clay content (0–2 m) and rainfall zones becomes more apparent. Moreover, the ability to assign certain drainage vs.% clay content (0–2 m) relationships to rainfall zones can be more easily substantiated.

Rainfall zones in the Border Designated Area vary considerably from the north to the south. A preliminary modelling scenario was under taking using the relationship given below.

$$D = 10^{(-0.035 \times c + 2.58)} \qquad (mm\ yr^{-1}) \qquad (41)$$

Using Equation 41, modelled drainage rates over much of the study area were considerably higher than the drainage rates determined via point source methods. Following this, four additional investigation sites were cored and analysed. As described in Wohling et al 2006, the drainage vs. % clay content (0–2 m) relationship can be improved by the analysis of additional data with selection of additional investigation sites being guided by the model results.

Drainage estimates (Equation 2) for all dry land investigation sites were plotted against actual clay percentages (0–2 m). Simple analysis revealed that adjustment of the drainage vs. % clay content (0–2 m) function was required when compared to the function used for preliminary modelling. Investigation sites within the Border Designated Area falls under a 470–570 mm rainfall zone, whereas drainage vs. % clay content (0–2 m) data given in Leaney et al 2004 for Tintinara falls under a 470 mm rainfall zone. A combined drainage vs. % clay content (0–2 m) plot (Fig. 5.1) for the Border Designated Area and Tintinara study areas (470–570 mm rainfall zone) provides an improved function.

$$D = 10^{(-0.026 \times c + 1.91)} \qquad (mm\ yr^{-1}) \qquad (42)$$

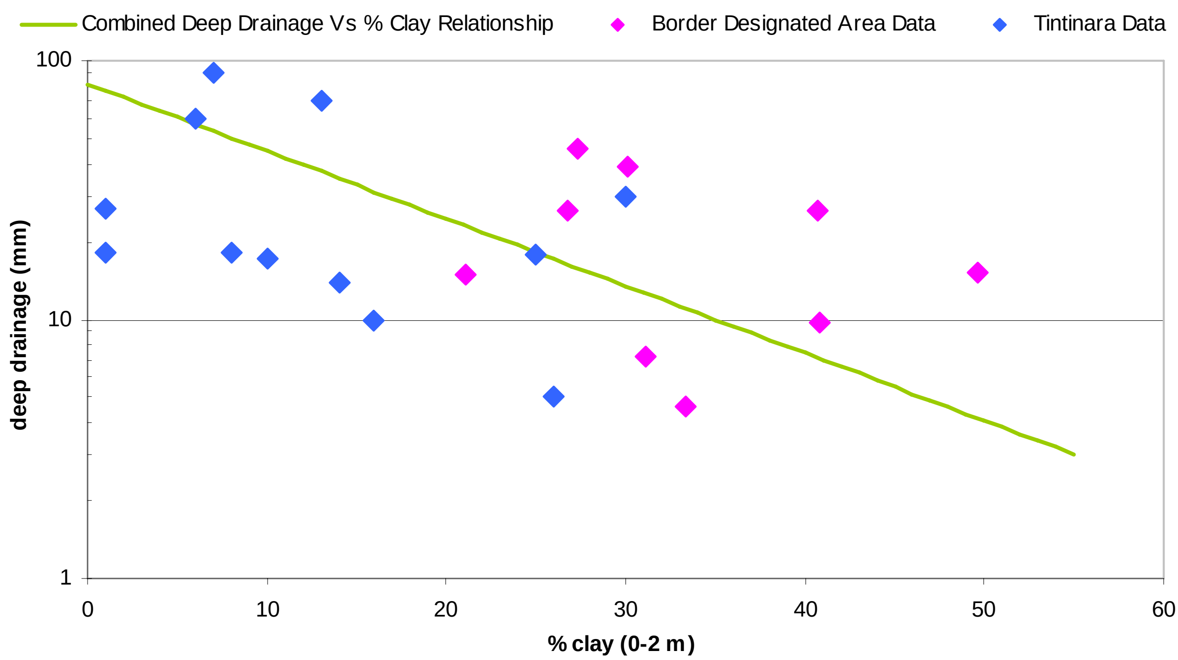



**Figure 5.1 Deep drainage vs. % clay function**

## 5.1.2 THE 1-DIMENSIONAL MODEL FOR INCREASING RECHARGE FOLLOWING AN INCREASE IN DRAINAGE

The underlying function of the 1-dimensional recharge model (Equation 36) is to predict the time lag for the increased drainage following land use change to impact as recharge at the watertable. Also predicted is the increase in salt load to the groundwater as a result of this process. Drilling in the Border Designated Area highlighted varying lithologies ranging from fine to coarse sand and sandstone with contrasting degrees of cementation; often inter-bedded with calcrete and bands of sandy clays to clays up to 10 m in thickness; deposited above marly, sandy or fossiliferous limestone.

A two-layer model, consisting of a 'clay' and 'loam' layer, has been chosen to characterise the hydraulic properties of the unsaturated zone (refer to section 2.3.1.2). Based on data collected during the drilling phase of the project, it is appropriate to design the model with two layers illustrating the heterogeneity of the unsaturated zone. For the purposes of this study, a 'clay' soil sample is taken to be one with at least 35% clay.

The soil parameters for the 1-dimensional model were selected based on the analysis of soil cores taken during drilling and are defined by the following: 'clay layer'; $\theta_0^a$ = 0.131, $\theta_m^a$ =0.372; 'loam layer'; $\theta_0^b$ =0.035, $\theta_m^b$ =0.216 (see App. A.1 for range of $\theta$ values). For both layers of the 1-dimensional model, $K_m$ = 0.9 m/y and n = 0.5 and as with previous studies, σ = 0.28 and μ varies according to the mean drainage rate based on the clay content (0–2 m) of any SLU (App. F).

### 5.1.3 THE SOIL SALINITY VS. % CLAY CONTENT (0–2 M) RELATIONSHIP

Historical salt stores within the unsaturated zone may be mobilised as a result of an increase in drainage following land use change. Then, as the pressure front reaches the water table, increasing the recharge rate, an increasing salt load will enter the saturated zone of the unconfined aquifer. Analysis of representative 'pre-clearing' soil salinity profiles provides an understanding of the historical salt store within the unsaturated zone (representing the potential salt load to the unconfined aquifer) (refer to section 2.3.1.3). A total of 11 native vegetation sites were sampled, of which five were deemed to be representative of 'pre-clearing' soil profiles. Further ground-truthing discovered that the remaining sites had been sampled within sparse, thinned or re-vegetated native vegetation stands and therefore are considered non-representative.

Average chloride concentrations (taken from below the root zone and above the capillary zone) are plotted against average clay contents (0–2 m). This soil profile zone represents the salt bulge associated with pre-clearing recharge under native vegetation. This may over estimate the unsaturated zone salt load due to the diffusion of salt nearer to the capillary zone. Assuming that the salinity of soil water is approximately double that of the chloride concentration of soil water, a linear regression through the soil salinity vs. % clay content (0–2 m) plot (Fig 5.2), giving an empirical correlation, provides a surrogate measurement that can be applied spatially.

$$S_{sw} = 270 \times \%clay(0-2m) + 4400 \quad (mgL^{-1}) \qquad (45)$$

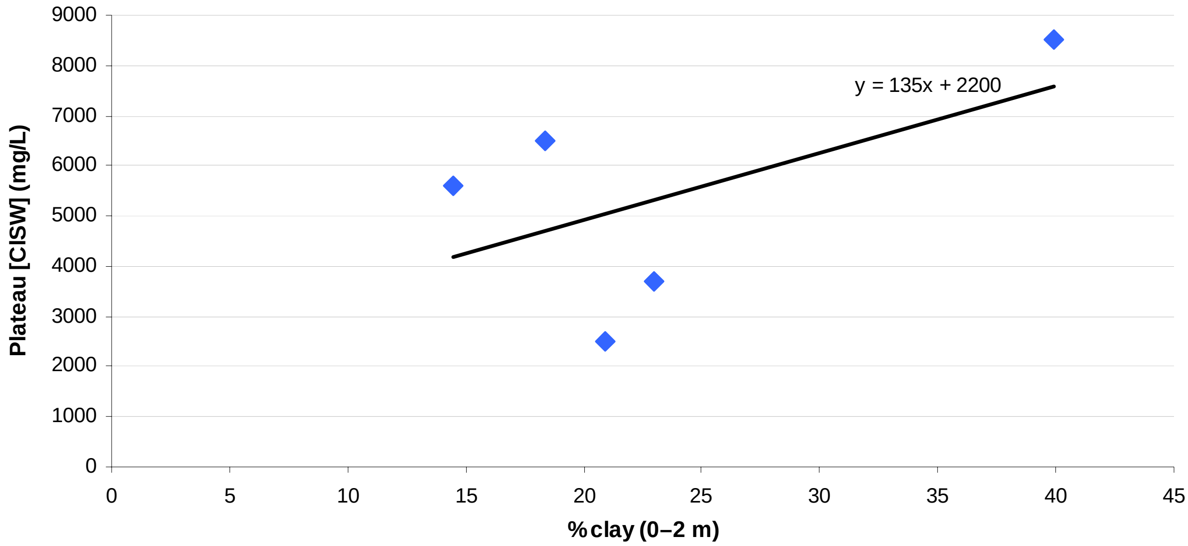



**Figure 5.2 Soil water salinity vs. % clay function**

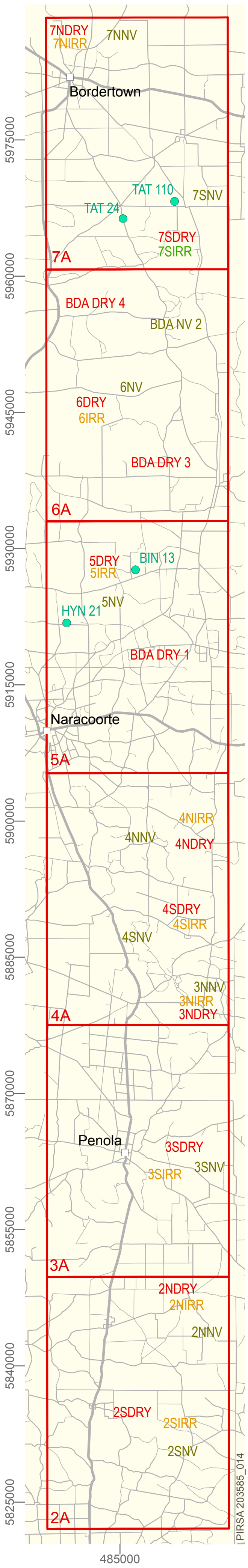
### 5.1.4 COMPARISON OF MODEL RESULTS WITH FIELD OBSERVATIONS

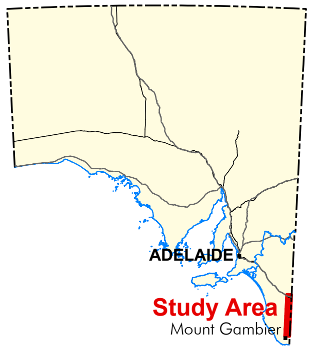
1-dimensional recharge model results have been compared against actual monitoring well observations within the study area (Fig. 5.3). Modelled lag time for TAT 24 (Fig. 5.4) closely matches actual TAT 24 monitoring data (Fig. 5.5). The increasing groundwater level trend shown at TAT 24 flattens during the late 1990s, which is suggested in the modelled data. About 45–50 years post vegetation clearance; the model suggests that increasing drainage due to clearance plateaus to a constant rate.

A declining annual rainfall pattern has occurred at Bordertown since the mid 1970s. However, this is not reflected in the groundwater level data with an increasing trend occurring for most of this period (Fig. 5.6).

The TAT 110 monitoring well (Fig. 5.7) is used as a comparison to the TAT 24 modelled data, as it is the closest salinity monitoring well with quality long-term data. Modelled salinity data indicates that after ~50 years post vegetation clearance, flushing of historic soil salinity will be completed. However, the TAT 110 salinity data shows a slightly increasing salinity past the late 1990s. Lag time in between the expected salinity trends and the observed data is not unusual due to mixing of recharge water over the screened interval in each bore.

Modelled data for BIN 13 (Fig. 5.8) indicates that increased recharge due to vegetation clearance should plateau ~25–30 years post clearance, corresponding to the beginning of water level records for BIN 13 (Fig. 5.9). This reflects what is happening at the water table, so salinity changes will be expected to continue after the water level has re-established. Therefore post 1980, when recharge has reached a new equilibrium, water level response is in direct correlation with rainfall. Groundwater response is largely affected by local rainfall conditions. With a shallow unsaturated zone and high rainfall, more rapid response and correlation to rainfall patterns are clearly shown (Fig. 5.10).




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation
- Wells Used For 1-Dimensional Model Comparison
- Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

## Border Designated Area
## Salt Accession Project

# COMPARISON OF ONE-DIMENSIONAL MODEL RESULTS WITH FIELD OBSERVATIONS AND INVESTIGATION SITES

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.3**

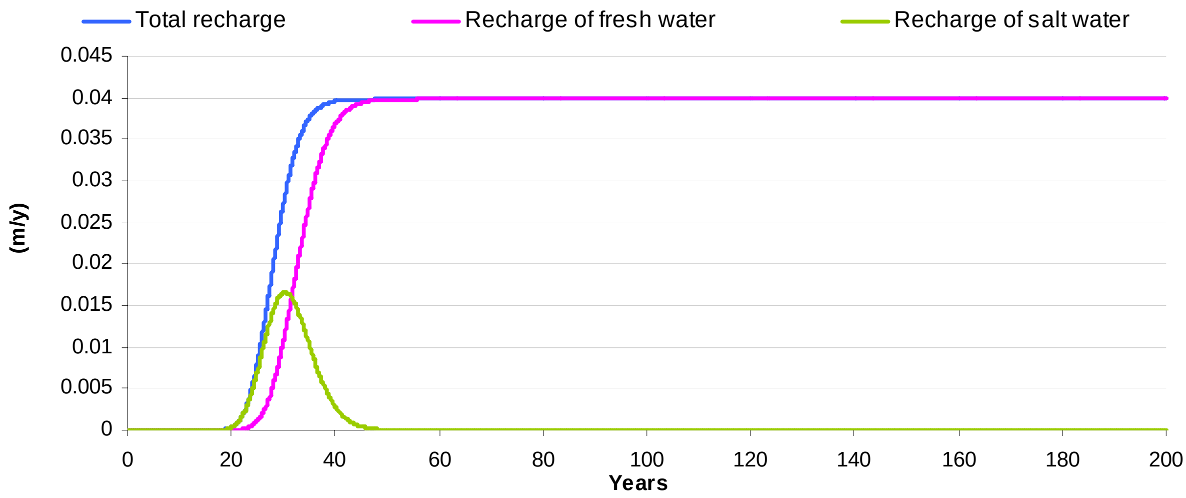



**Figure 5.4 Modelled data, TAT 24**

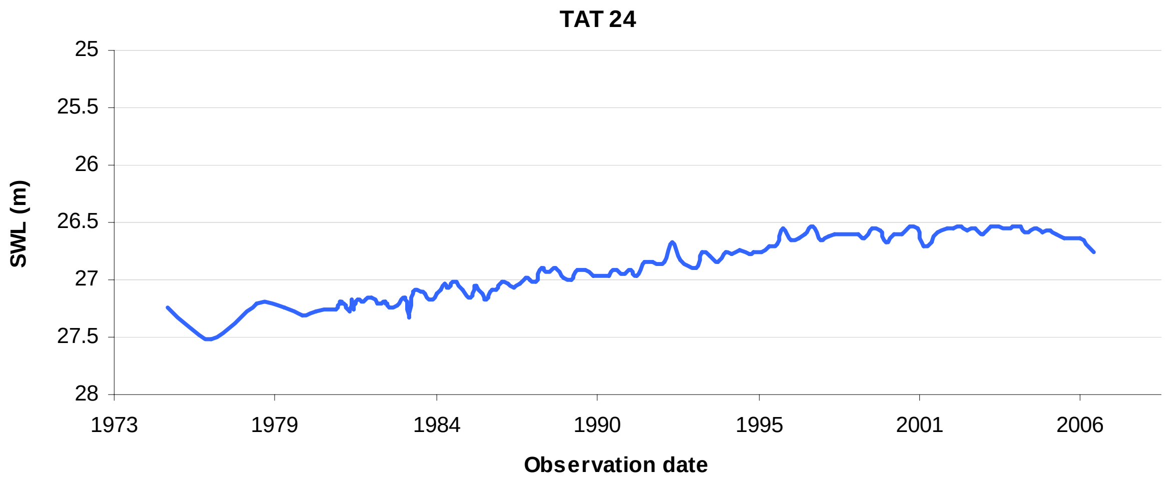



**Figure 5.5 Observation data (SWL), TAT 24**

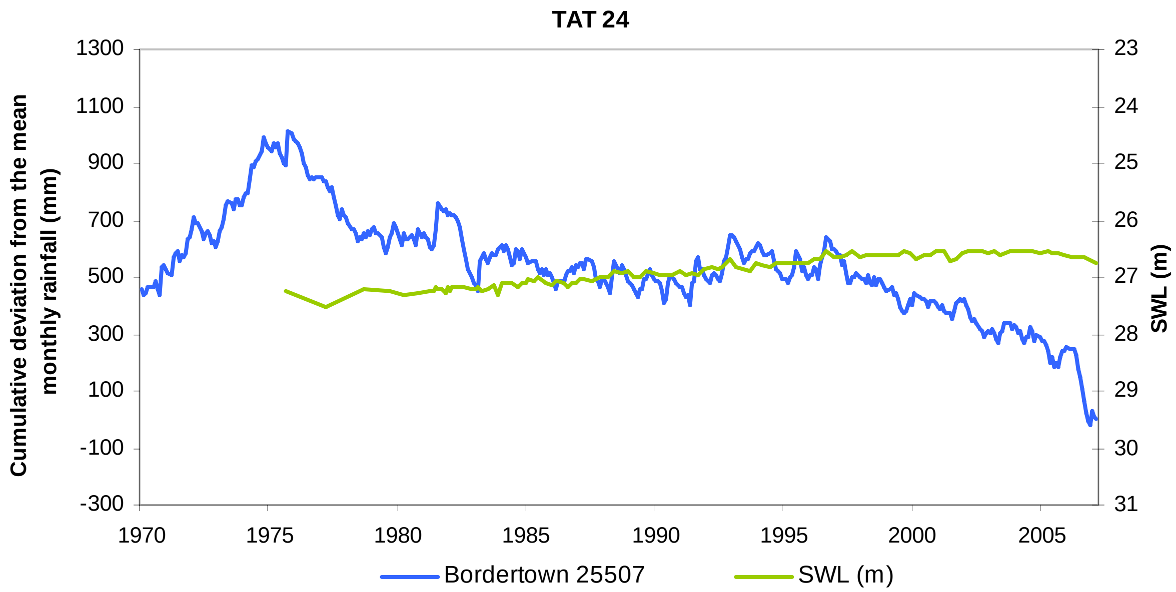



**Figure 5.6 TAT 24 (SWL) vs. Bordertown cumulative rainfall**

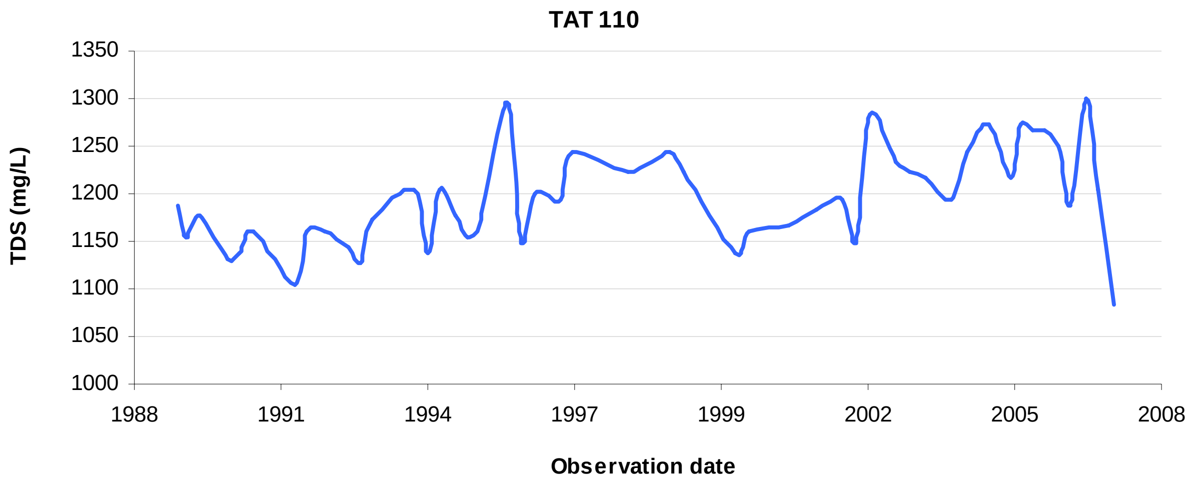



**Figure 5.7 Observation data (TDS), TAT 110**

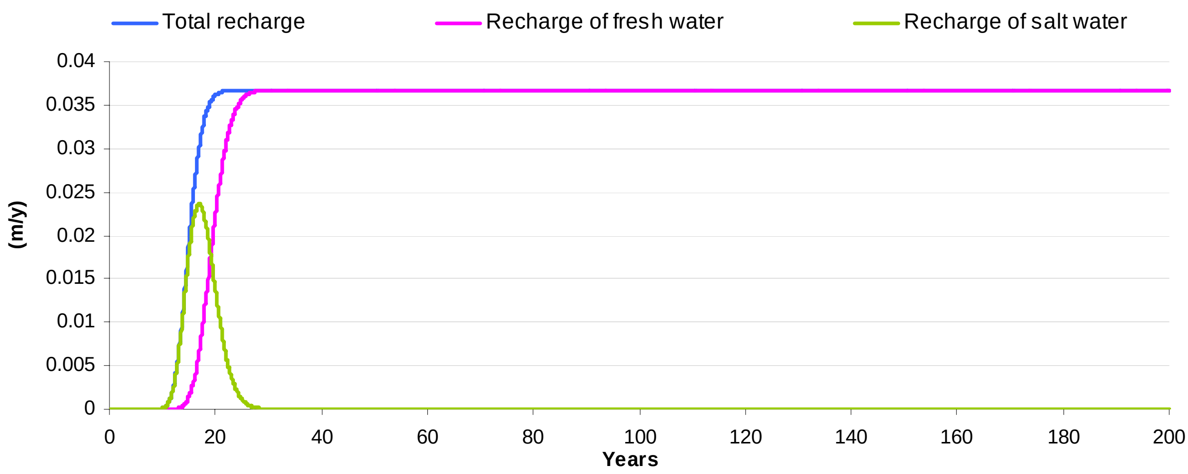



**Figure 5.8 Modelled data, BIN 13**

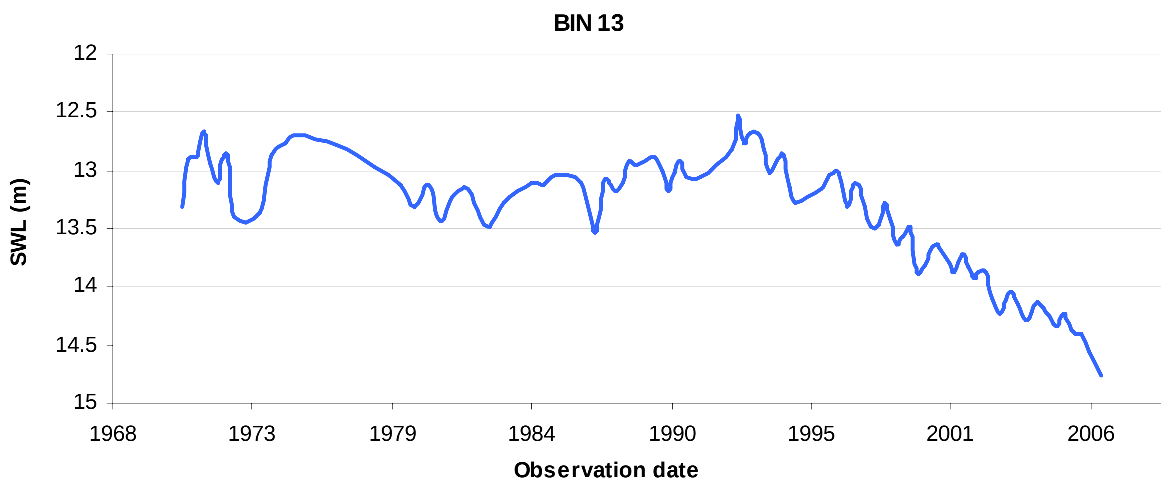



**Figure 5.9 Observation data (SWL), BIN 13**

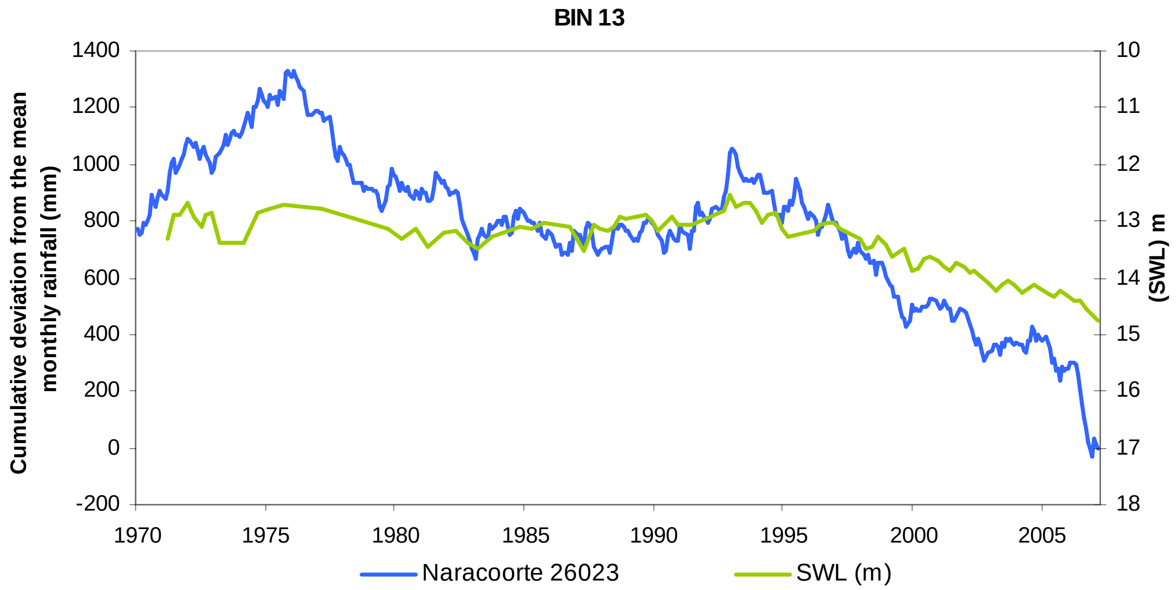



**Figure 5.10 BIN 13 (SWL) vs. Naracoorte cumulative rainfall**

HYN 21 monitoring well (Fig. 5.11) is used to compare salinity observations against the modelled BIN 13 results. The modelled BIN 13 salinity data indicates that historic soil salinity has been flushed by ~1980. HYN 21 indicates a lag time due to groundwater mixing with salinity increasing until the late 1980s after which salinity steadily declines. Therefore it can be assumed that the freshening effect observed in the groundwater system since the early 1990s is attributed to all historic soil salt loads being flushed previously.

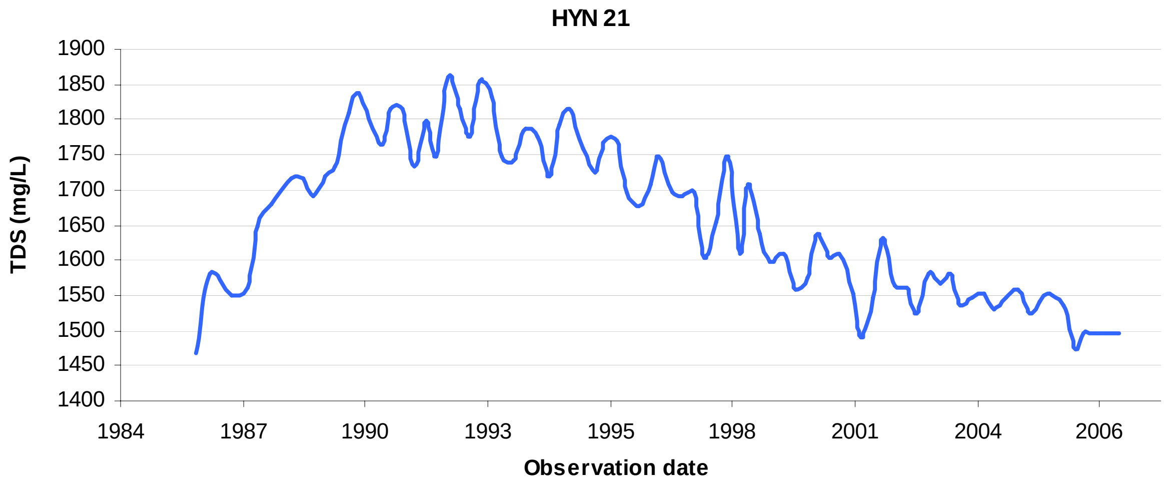



**Figure 5.11 Observation data (TDS), HYN 21**

Soil parameter data from all investigation sites within the Border Designated Area model area (being those north of the Kanawinka Fault) have been integrated (to determine $\theta_0^a, \theta_m^a, \theta_0^b$ and $\theta_m^b$) and averaged (% clay (0–2 m)), while $K_m$, n, σ and μ remain consistent with model scenarios described previously, for up scaling over the entire region (Fig. 5.12). As shown by modelled and observed data presented previously, groundwater recharge post vegetation clearance can be variable over a large area. Using average data for the area

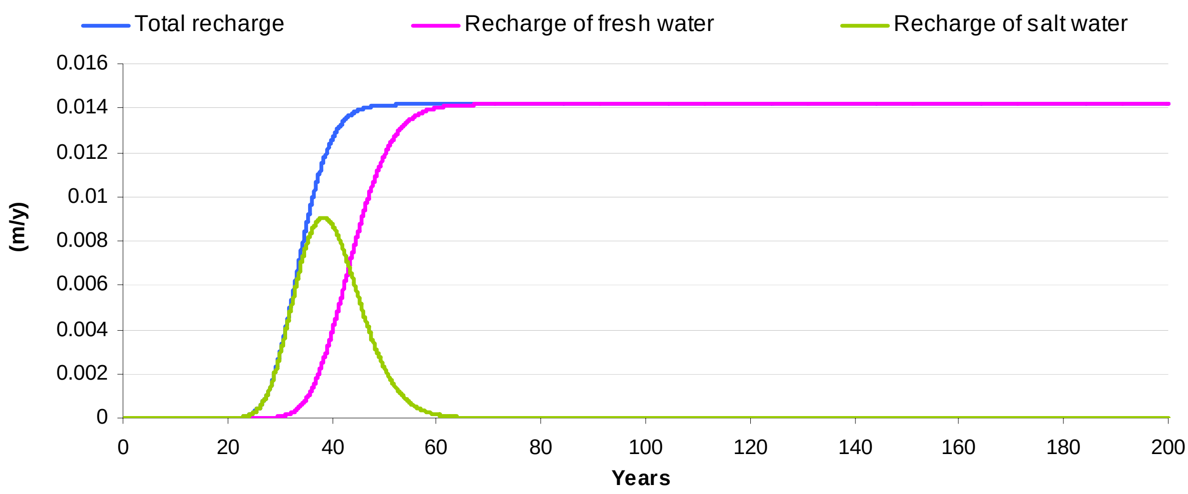



**Figure 5.12 Modelled averages zones 7A–4A**

allows for effective spatial up scaling. Data from Zones 2A and 3A however was not used in this up scaling scenario as conditions including depth to water and rainfall were deemed unsuitable for this model. Up scaling for Zones 2A and 3A is discussed along with up scaling for the Hundred of Stirling in Section 5.2.

## 5.1.5 SPATIAL EXTRAPOLATION OF THE 1-DIMENSIONAL MODEL BASED ON CLAY CONTENT IN THE ROOT ZONE (0–2 M) AND WATER TABLE DEPTH

### 5.1.5.1 Regional recharge

Spatial extrapolation of the 1-dimensional model assumes a one to one ratio between measured clay percentages established via drilling continuous core samples and clay percentages calculated for each SLU. Using Equation 42, verification between calculated deep drainage estimates and current day model outputs suggest that for high SLU clay percentages (above 35–40% clay), the model under estimates groundwater recharge. For mid to low clay percentages (for each SLU), modelled groundwater recharge predictions were within a suitable range compared to calculated point estimates of deep drainage.

In an attempt to improve spatial extrapolation using SLU clay percentages, measured drill data clay percentages (0–2 m) are plotted against SLU clay percentages (0–2 m) (Fig. 5.13). It is not possible to statistically substantiate any better correlation than a 1:1 line between measured clay percentage and SLU clay percentage. As more data becomes available, an improved correlation between measured and SLU clay percentage may develop.

Using a SLU coverage, the clay content of the top two metres of the soil profile over the Border Designated Area model area is calculated (Fig. 5.14). For each SLU, the clay content (0–2 m) of the soil profile is used as a proxy for up scaling drainage rates. Calculated using Equation 42, the mean drainage rate for each SLU ranges between 2.4–81 mm/y (App. F).

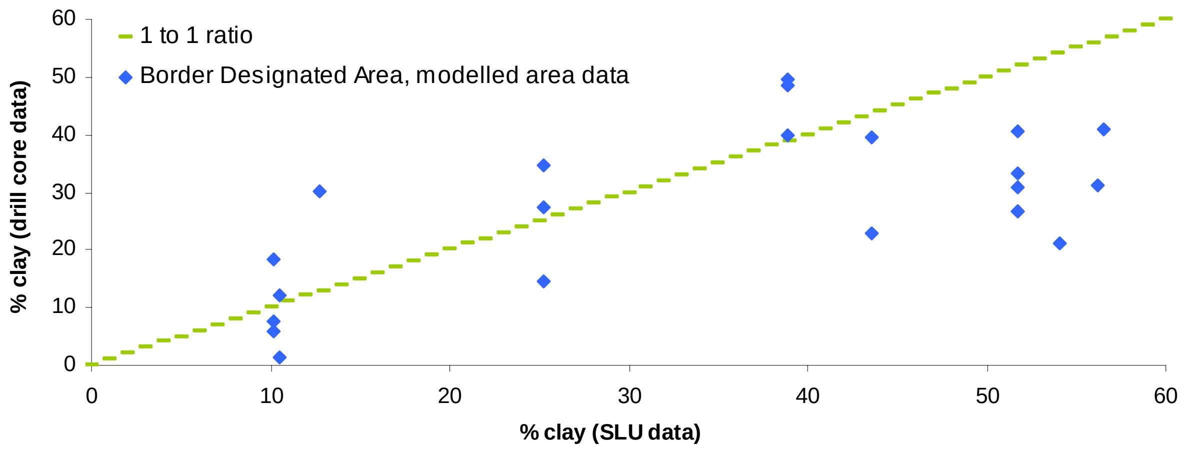



**Figure 5.13 Percentage clay (drill core data) vs. percentage clay (SLU data)**

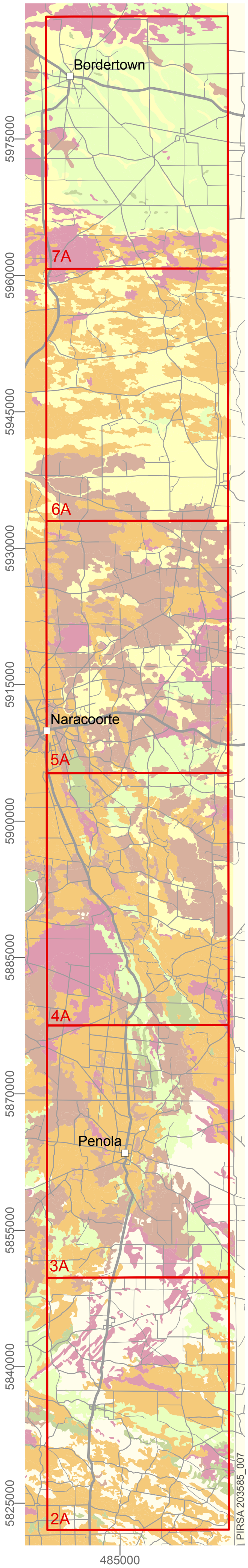
Spatial extrapolation of the 1-dimensional recharge model (Equation 34) as a function of time is achieved through the use of GIS coverages of clay content (0–2 m) (Fig. 5.14), drainage rate (App. F) and depth to water (Fig. 5.15). Assuming native vegetation clearance took place during 1950, predicted estimates of mean recharge (m/y) and cumulative recharge (m) are given for current day conditions (2007, 57 years post clearance) in Figures 5.16 and 5.17, respectively.

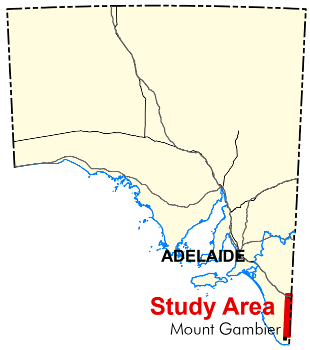
Mean recharge rate to the unconfined aquifer varies from 0–81 mm/y over the Border Designated Area study area. Higher recharge values are restricted to lighter textured soils, while regions having heavier textured soils and greater depth to water such as much of Zone 7A, any increase in drainage past the root zone has not resulted in a substantial increase in recharge to the groundwater. Current model predictions indicate a cumulative recharge of between 0–4.3 m has entered the groundwater system over the past 57 years (since native vegetation clearance). Again, higher cumulative recharge is controlled by lighter textured soils and shallower depth to water, found typically towards the south of the study area and through sections of Zone 6A. A maximum cumulative recharge of 4.3 m equates to an approximate mean recharge of 75 mm/y.

Predicted estimates of mean recharge (m/y) (App. G) and cumulative recharge (m) (App. H) to the unconfined aquifer have also been calculated for 10, 20, 45, 65, 90 and 145 year intervals post native vegetation clearance. Following native vegetation clearance, an increase in recharge occurred quickly along the southern boundary of the study area. Overtime, the area influenced by an increase in recharge due to native vegetation clearance expanded to current day conditions. During the next 10 years, model predictions suggest slight increases in recharge over various regions of the study area with the maximum mean recharge limited to 81 mm/y and maximum cumulative recharge of 5 m.

### 5.1.5.2 Regional salt flux

Salt flux (Equation 39) and the cumulative salt contribution to the unconfined aquifer as a function of time since clearance (refer to section 2.3.1.4) is determined using the estimated spatial distributions of recharge (refer to section 5.1.5.1), soil water salt concentrations (Equation 43) and a value of 100 mg/L for the soil water concentration of drainage water




% Clay

- 0-10%
- 11-20%
- 21-30%
- 31-40%
- 41-50%
- 51-60%
- Management Zone

0 5 10 15 20 Kilometers

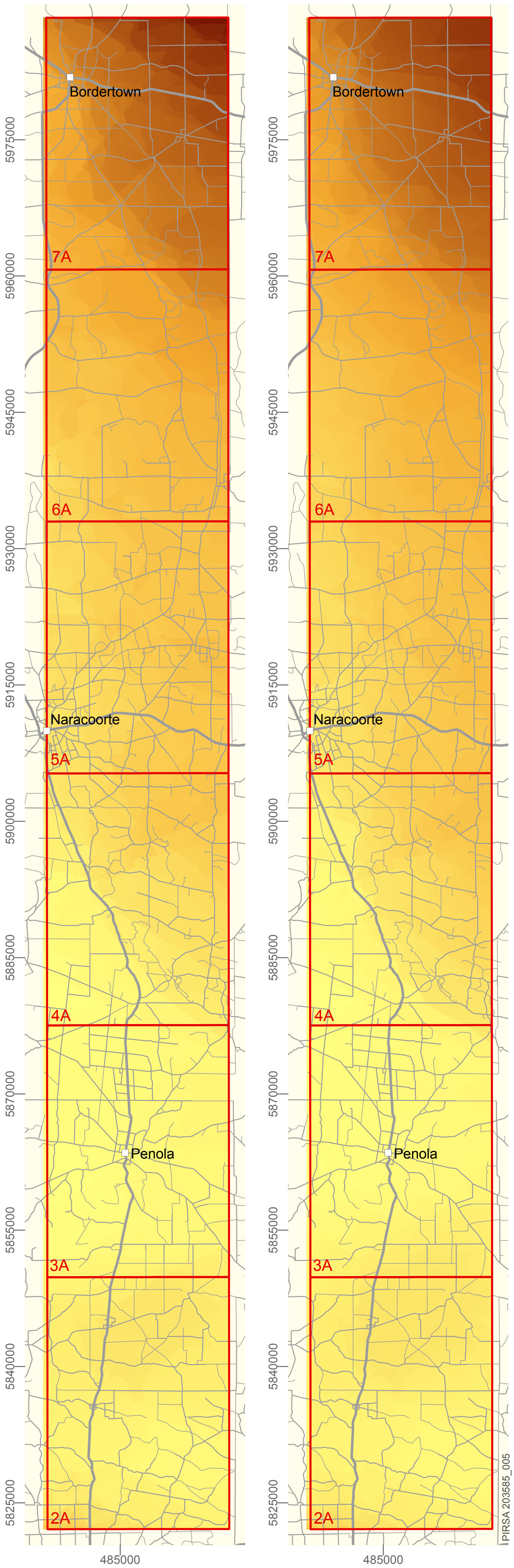
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

**PERCENTAGE CLAY CONTENT (0-2M)**
**BASED ON SOIL LANDSCAPE UNITS (SLU's)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.14**




N


Autumn 2006 (left)

SWL(m)

High : 45

Low : 3.5

Winter 2006 (right)

SWL(m)

High : 45

Low : 3.5

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Date: August 2007

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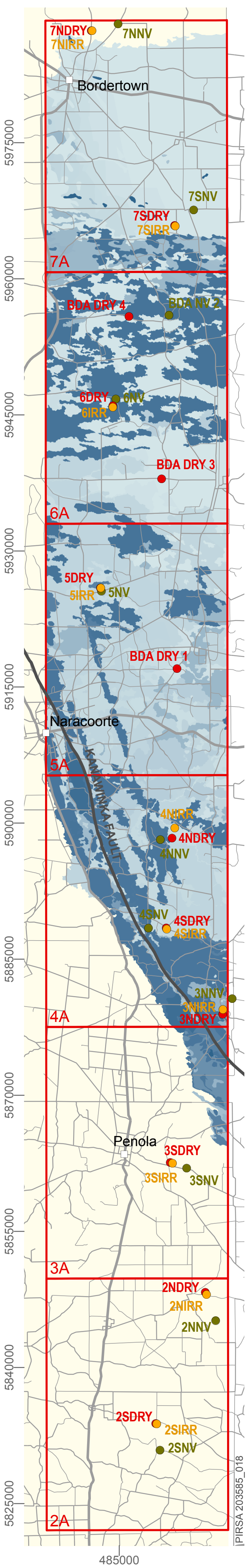
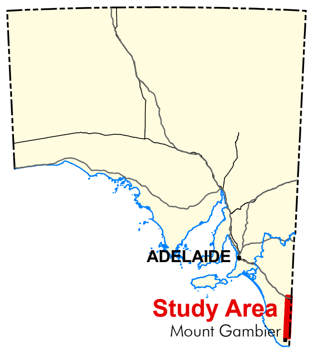
# Border Designated Area Salt Accession Project

## DEPTH TO WATER

**Figure 5.15**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge
Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

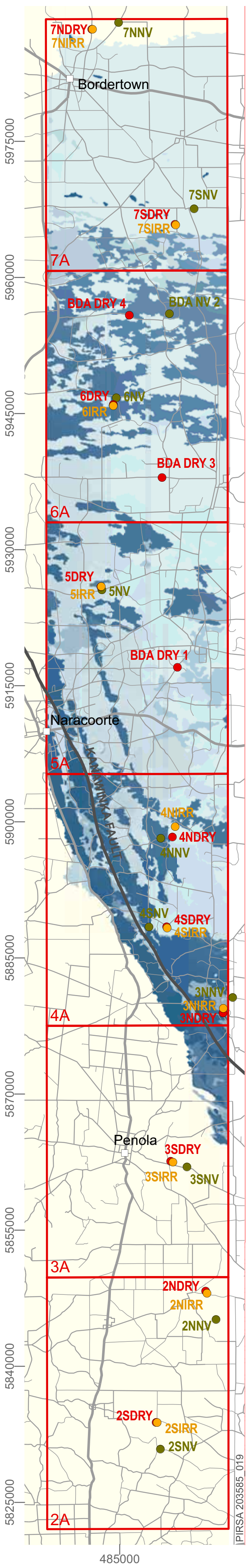
| | |
|---|---|
| Projection: | MGA Zone 54 Transverse Mercator |
| Datum: | Geocentric Datum of Australia 1994 |
| Produced by: | Publishing Services<br>Primary Industries and Resources SA |
| Date: | August 2007 |

## Border Designated Area Salt Accession Project

# UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 2007 (57 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.16**

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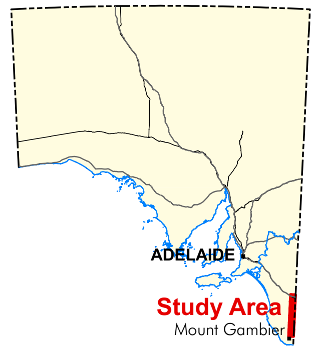



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge

Value (m)

High : 4.3

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 2007
# (57 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.17**

above the freshwater front (represents a decrease in salinity concentration draining below the limit of evapotranspiration, or a post clearing water salinity). As with regional recharge, a representative native vegetation clearance date of 1950 has been assumed, therefore predicted salt flux ($g/m^2/y$) and cumulative salt ($g/m^2$) given for 57 years post clearance represents the current day environment (Figs 5.18 and 5.19, respectively).

Model predictions indicate spatial variability for current day salt loads entering the unconfined aquifer. Between 0–116 $g/m^2/y$ of salt is presently entering the groundwater system via increased recharge resulting from the clearance of native vegetation which inturn increased drainage and mobilised the historical salt load. Currently, the cumulative salt load ranges between zero and over 2700 $g/m^2$. In areas with heavier textured soils such as parts of Zones 5A and 7A, none of the historical salt load has entered the groundwater system. While for lighter textured soils and relatively deep unsaturated zones such as in the lower parts of Zone 7A and top half of Zone 6A over 2000 $g/m^2$ of salt has entered the unconfined aquifer since native vegetation clearance. High recharge rates (Section 5.1.5.1) along the southern boundary of the study area has flushed the majority of the historical salt store from the unsaturated zone and therefore current cumulative salt predictions are low to medium in this region.

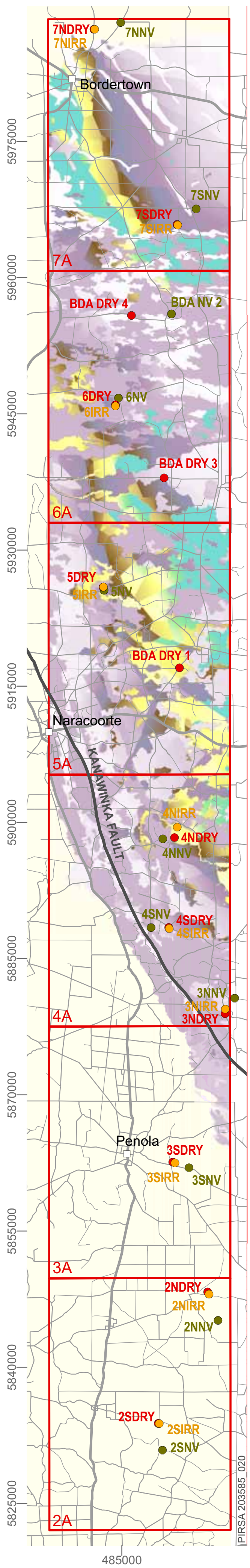
Predicted estimates of salt flux ($g/m^2/y$) (App. I) and cumulative salt ($g/m^2$) (App. J) are also estimated for 10, 20, 45, 65, 90 and 145 years post clearance. Predictions of salt flux post native vegetation clearance show the migration of salt entering the groundwater system, firstly impacting lighter textured soils with shallow depths to water, then migrating to heavier soil and deeper water tables. Over the next 10 years, the maximum salt flux is predicted to reduce to 90 $g/m^2/y$ with additional salt being introduced to the groundwater system in areas containing heavier textured soils and greater depths to water.

## *5.2 SALINITY IMPACT – GIS UP SCALING OF THE HUNDRED OF STIRLING AND ZONES 2A AND 3A*

Using groundwater recharge estimates via a range of techniques within Zones 2A and 3A of the Border Designated Area and the Hundred of Stirling (refer to sections 3 and 4), net salinity impact (refer to section 2.3.2) is calculated for each recharge estimate using Equation 40. The mean and median net salinity impacts are assessed for each land use and soil association to determine the most appropriate value to adopt for up scaling.

### *Border Designated Area Zones 2A and 3A*

Salinity impact to the unconfined aquifer has been up scaled differently for Zones 2A and 3A compared to Zones 4A through 7A (described above). Generally, shallower unsaturated zones and higher annual rainfalls are encountered throughout Zones 2A and 3A; consequently use of the chloride front displacement method was not valid. The 1-dimensional recharge model was useful for indicating that an increase in drainage followed by an increase recharge, due to native vegetation clearance, would have occurred rapidly post clearance with little lag time. Therefore when up scaling the regional model, a decision was made to limit the extent of the model to the Kanawinka Fault, to the north of which are the generally deeper unsaturated zones.

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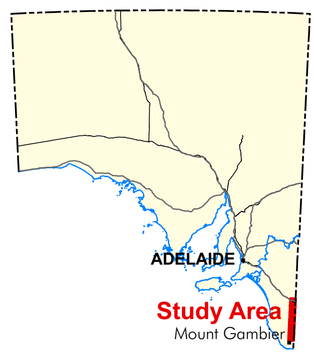


Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux

Value (g/m²/yr)

High : 116

Low : 0

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

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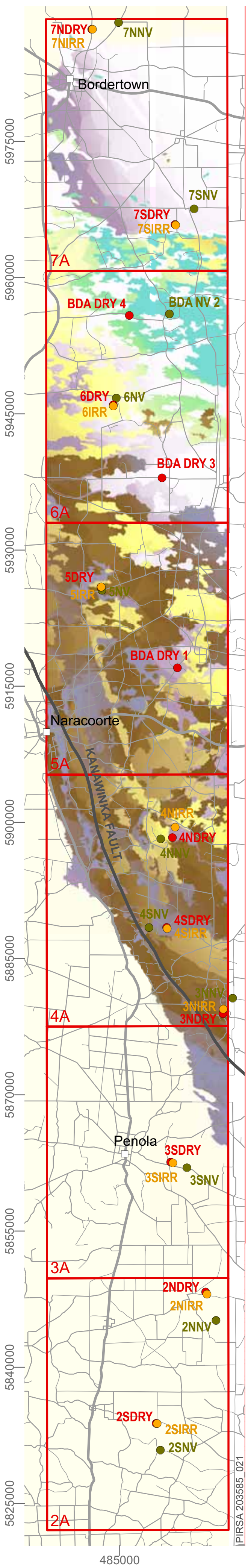
Salt Accession Project

**UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 2007 (57 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.18**

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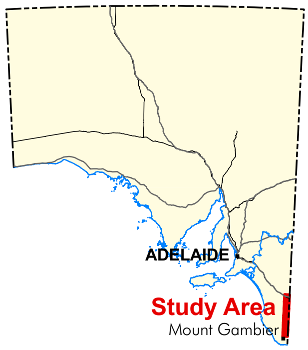


Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux

Value (g/m²)

High : 2730

Low : 0

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
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**UP SCALING PREDICTED**
**CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 2007**
**(57 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 5.19**

Six land use categories can account for the majority of the area of Zones 2A and 3A; they are dry land, hardwood, irrigation, native vegetation, softwood and other (Fig. 5.20). The "dry land" category encapsulates cereals and grazing, and similarly "irrigation" includes irrigated vines and irrigated pastures. Softwood and hardwood only include the areas of softwood and hardwood production, and native vegetation is the remnant area of woodlands and scrub. The 'other' land use type includes built up areas such as urban residential, roads and railways. These have not been included in the up scaling of salinity impacts. Zones 2A and 3A comprise a total of six distinct soil associations (Fig. 5.21), being shallow loam over limestone, deep sand, deep loam/clay, sand over clay, loam/clay over clay and all other (including inundated land and swamps).

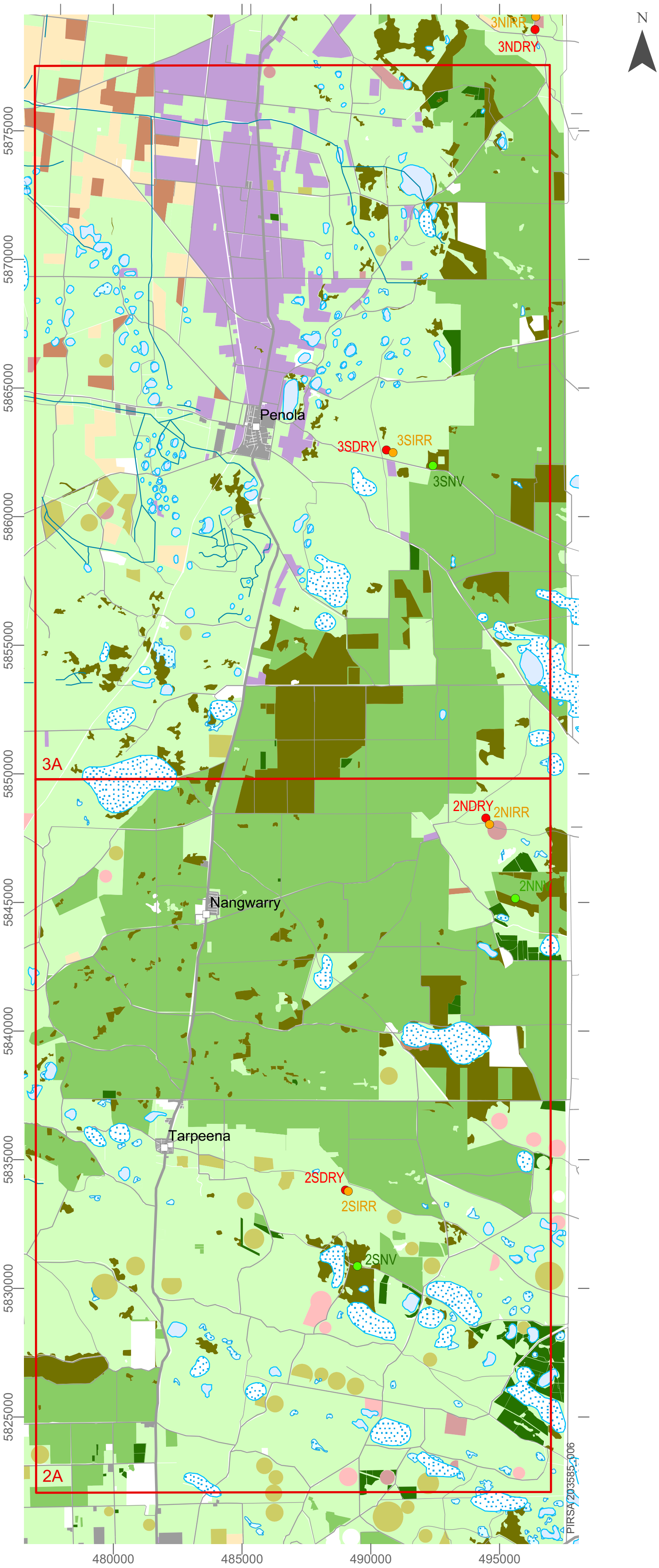
The range, mean, median, standard deviation and adopted net salinity impact (t/Ha/y), estimated for all investigation sites, are categorised into land use and soil associations (Table 5.1). The mean value for all but one salinity impact has been used as the adopted value for each particular land use/soil association category. The median value has been used for one of the native vegetation soil association categories, as the mean value appeared particularly high.

**Table 5.1 Salinity impact for Zones 2A and 3A – Border Designated Area**

| | **Salinity Impact Values** (t/Ha/y) | | | | |
|---|---|---|---|---|---|
| | **Range** | **Mean** | **Median** | **Std Dev** | **Adopted** |
| **Shallow loam over limestone soil association** | | | | | |
| Irrigation | 0.1–0.2 | 0.02 | 0.02 | 0.01 | 0.02 |
| **Deep sand soil association** | | | | | |
| Native vegetation | 0.05–1.21 | 0.48 | 0.11 | 0.54 | 0.11 |
| Softwood | 0.05–0.34 | 0.15 | 0.05 | 0.17 | 0.15 |
| **Sand over clay soil association** | | | | | |
| Hardwood | 0.07 | 0.07 | 0.07 | – | 0.07 |
| Softwood cleared | 0.03–0.1 | 0.06 | 0.06 | 0.03 | 0.06 |
| Irrigation | 0.01–0.29 | 0.15 | 0.15 | 0.10 | 0.15 |
| Dryland | 0.01–0.11 | 0.04 | 0.04 | 0.04 | 0.04 |
| Native vegetation | 0.13 | 0.13 | 0.13 | – | 0.13 |
| **All other (incl. inundated land and swamps) soil association** | | | | | |
| Dryland | 0.03–0.05 | 0.04 | 0.04 | – | 0.04 |

Groundwater recharge rates were calculated for both irrigated pastures and irrigated vines in Zones 2A and 3A of the Border Designated Area. The net salinity impact at individual investigation sites was similar for both irrigated vines and irrigated pastures throughout the study area. Therefore, for ease of the up scaling process, the mean of all irrigation calculations was used.

Table 5.2, lists each soil association with each land use category (including the area). It was not physically or financially feasible to have investigation sites monitoring all land use/soil association categories, hence a net salinity impact assessment was not possible for all combinations. Therefore, whilst not ideal and purely for the purpose of up scaling, where a





Zone 2A-3A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

South East Land Use 2002

- Cereals
- Grazing modified pastures
- Hardwood plantation
- Hay and silage
- Irrigated cropping
- Irrigated hay & silage
- Irrigated modified pastures
- Irrigated sown grasses
- Irrigated vegetables & herbs
- Irrigated vine fruits
- Legumes
- Marsh/wetland
- Rural residential
- Softwood plantation
- Urban residential
- Woodland

- Management Zone

0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
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Border Designated Area
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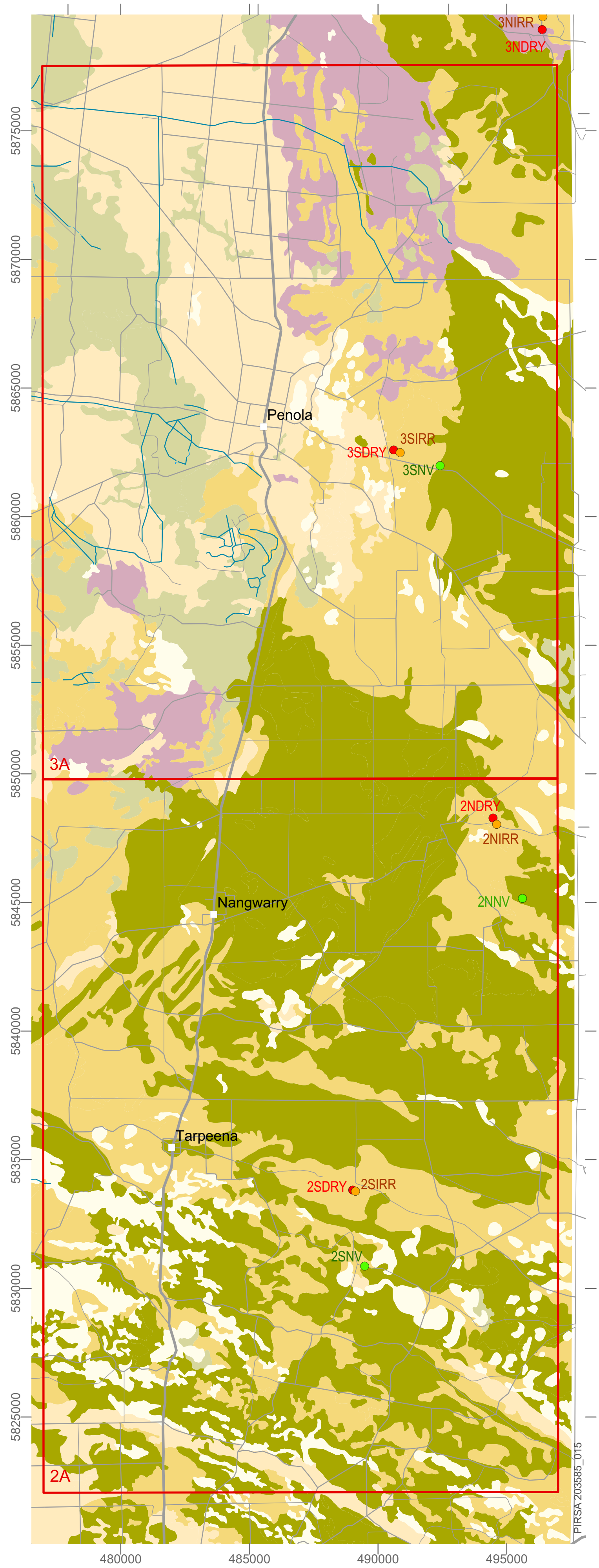
**LAND USE IN ZONES 2A AND 3A 2002**

**Figure 5.20**

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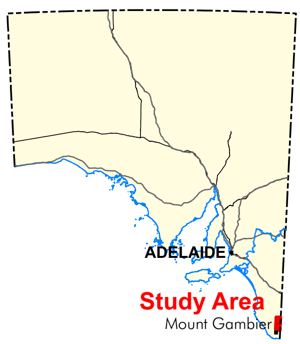


Zone 2A-3A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

**Soil description**

- Deep Loam/Clay
- Deep Sand
- Loam/Clay over Clay
- Sand over Clay
- Shallow Loam over Limestone
- All other (incl. inundated land/swamps)

Management Zone

0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Border Designated Area
Salt Accession Project

**SOIL ASSOCIATIONS ZONES 2A AND 3A**

**Figure 5.21**

**Table 5.2 Up scaling salinity impact for Zones 2A and 3A – Border Designated Area**

| Soil associations | Land use | **Land use area** (Ha) | **Adopted salinity impact up scale value** (t/Ha/y) | **Salinity impact** (t/y) |
|---|---|---|---|---|
| Shallow loam over limestone | Dryland | 10 825 | 0.04 | 453 |
| | Hardwood | 128 | 0.07 | 9 |
| | **Irrigation** | **4 171** | **0.02** | **70** |
| | NatVeg | 150 | 0.12 | 18 |
| | Softwood | 805 | 0.10 | 83 |
| Deep sand | Dryland | 11 346 | 0.04 | 475 |
| | Hardwood | 718 | 0.07 | 50 |
| | Irrigation | 893 | 0.08 | 74 |
| | **NatVeg** | **4 479** | **0.11** | **493** |
| | **Softwood** | **22 928** | **0.15** | **3 363** |
| Deep loam/clay | Dryland | 7 789 | 0.04 | 326 |
| | Hardwood | 3.9 | 0.07 | 0.3 |
| | Irrigation | 286 | 0.08 | 24 |
| | NatVeg | 157 | 0.12 | 19 |
| | Softwood | 33 | 0.10 | 3.5 |
| Sand over clay | **Dryland** | **19 053** | **0.04** | **834** |
| | **Hardwood** | **259** | **0.07** | **18** |
| | **Irrigation** | **983** | **0.15** | **148** |
| | **NatVeg** | **1 909** | **0.13** | **248** |
| | **Softwood** | **8 414** | **0.06** | **505** |
| Loam/clay over clay | Dryland | 4 364 | 0.04 | 183 |
| | Hardwood | 0.0 | 0.07 | 0.0 |
| | Irrigation | 512 | 0.08 | 43 |
| | NatVeg | 445 | 0.12 | 53 |
| | Softwood | 115 | 0.10 | 12 |
| All other (incl. inundated land/swamps) | **Dryland** | **4 761** | **0.04** | **190** |
| | Hardwood | 69 | 0.07 | 4.8 |
| | Irrigation | 121 | 0.08 | 10 |
| | NatVeg | 672 | 0.12 | 81 |
| | Softwood | 897 | 0.10 | 93 |

particular land use category does not have an investigation site on a particular soil association an adopted salinity impact value was assigned based on the mean salinity impact of that land use over all soil associations. For example, no investigation sites have been set up to monitor the salinity impact of either irrigation or dry land within the deep sand soil association (refer to Table 5.1). The adopted salinity impact for irrigation (0.8 t/Ha/y) and dry land (0.4 t/Ha/y) are the mean salinity impacts from irrigation and dry land investigation sites, respectively, on all soil associations in the study area. The measured salinity impact data from monitored investigation sites has been highlighted in bold in Table 5.2, while the remaining salinity impact data are the adopted mean salinity impacts of land use categories over all soil associations. The adopted salinity impact up scaling value is multiplied by the land use area to give the salinity impact (t/y) for each land use/soil association category.

Summing individual land use/soil association salinity impacts establishes the total salinity impact (t/y) to the unconfined aquifer in Zones 2A and 3A of 7882 t/y (Table 5.3). Having established this value, an average salinity impact (mg/L/y) can be calculated with knowledge of the volume of the unconfined aquifer and its porosity.

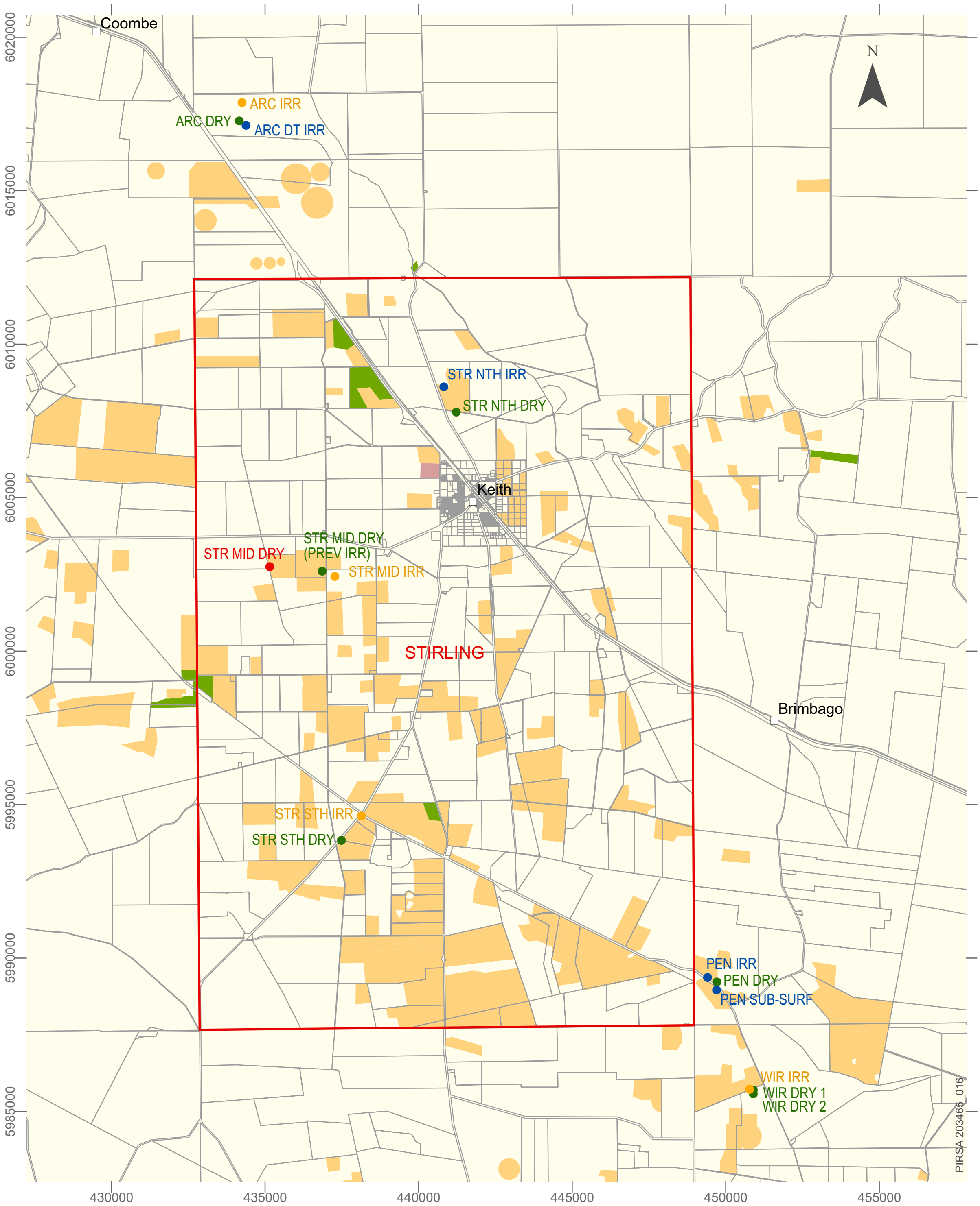
**Table 5.3 Overall salinity impact for Zones 2A and 3A – Border Designated Area**

| | |
|---|---|
| Total Salinity Impact for Zones 2A and 3A (t/y) | 7882 |
| Total Area of the Hundred of Stirling (Ha) | 110 941 |
| Thickness of Unconfined Aquifer (m) | **40** |
| Porosity of Unconfined Aquifer | 0.25 |
| Volume of Unconfined Aquifer ($m^3$) | $11.1 \times 10^9$ |
| Average Salinity Impact (mg/L/y) | **0.71** |
| Total Salinity Impact for Zones 2A and 3A (t/y) | 7882 |
| Total Area of Zones 2A and 3A (Ha) | 110 941 |
| Thickness of Unconfined Aquifer (m) | **10** |
| Porosity of Unconfined Aquifer | 0.25 |
| Volume of Unconfined Aquifer ($m^3$) | $2.77 \times 10^9$ |
| Average Salinity Impact (mg/L/y) | **2.84** |

Two scenarios are considered and discussed further. The volume ($m^3$) of the unconfined aquifer is dependant on its thickness (m). The first scenario assumes an unconfined aquifer thickness of 40 m (even though the thickness of the unconfined aquifer can be upwards of 100 m, e.g. MIN 22), giving an average salinity impact to the unconfined aquifer of 0.71 mg/L/y. However, the salinity impact may be limited to the upper portion of the unconfined aquifer where the majority of irrigation, stock and domestic bores are completed. In this instance, the second scenario assumes an unconfined aquifer thickness of 10 m giving an overall average salinity impact of 2.84 mg/L/y. This rate seems reasonable given that most of the historical salt load in the unsaturated zone had been flushed many years ago.

### *Hundred of Stirling*

The salinity impact owing to the recycling of irrigation water has been assessed at investigation sites monitored with in the Hundred of Stirling. Groundwater recharge rates have been estimated at all monitored investigation sites using a range of techniques. Using GIS, each investigation site has been categorised based on land use (Fig. 5.22) and soil associations (Fig. 5.23), meaning each soil association comprises a range of recharge rate estimates. Flood irrigation is currently the sole operational irrigation practice used for Lucerne stands within the Hundred of Stirling; therefore only data from flood irrigation sites are used for up scaling salinity impact results in the Hundred of Stirling (salinity impacts due to pivot and sub-surface drip irrigation practices, measured outside the Hundred of Stirling, are discussed later as alternatives to flood irrigation). The net salinity impact is calculated using an estimated recharge rate and net salinity increase (based on the difference between the applied irrigation water and the drainage soil water returning to the aquifer, refer to 2.3.2).





Projection: MGA Zone 54 Transverse Mercator
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Investigation Sites

- Established Dryland
- Established Irrigation
- New Dryland
- New Irrigation

South East Land Use 2002

- Irrigated cropping
- Irrigated hay & silage
- Irrigated modified pastures

- Management Zone

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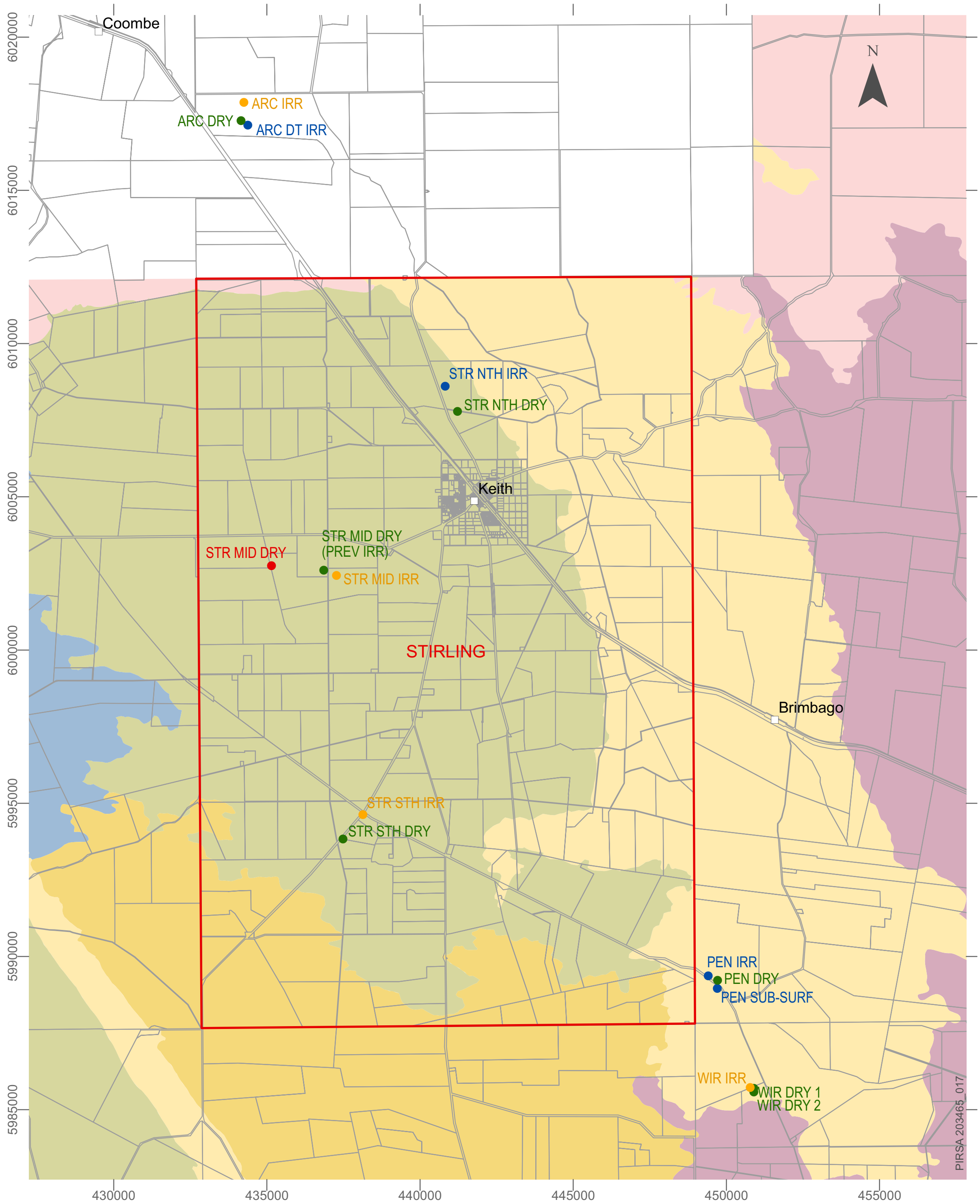
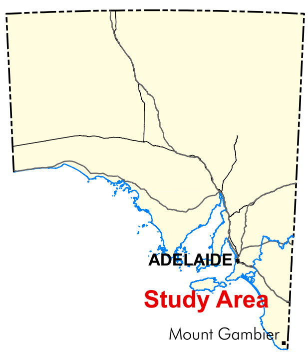
**IRRIGATED LAND USE, 2002**

**Figure 5.22**




0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
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**Investigation Sites**

- Established Dryland
- Established Irrigation
- New Dryland
- New Irrigation
- Management Zone

**Soil Description**

- Dune - swale systems
- Old coastal dunes
- Plains with low remnant calcarenite ridges
- Plains with mainly sand over clay soils
- Stony plains
- Wet flats with shallow saline water tables

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**SOIL ASSOCIATIONS**

**Figure 5.23**

The range, mean, median, standard deviation and adopted net salinity impact (t/Ha/y) attributed to irrigation is given for each soil association (Table 5.4). The mean salinity impact has been used as the adopted value for up scaling results for each soil association.

**Table 5.4 Salinity impact from irrigation in the Hundred of Stirling**

| | **Salinity Impact Values** (t/Ha/y) | | | | |
|---|---|---|---|---|---|
| | **Range** | **Mean** | **Median** | **Std Dev** | **Adopted** |
| **Stony plains and plains with mainly sand over clay soil association** | | | | | |
| | 2.68–19.37 | 10.63 | 12.36 | 5.81 | 10.63 |
| **Old coastal dunes soil association** | | | | | |
| | 0.08–23.81 | 11.52 | 15.31 | 10.38 | 11.52 |

For the purpose of up scaling salinity impacts from irrigation in the Hundred of Stirling, a GIS coverage of land use was overlayed on the soil association coverage to determine the total area of flood irrigated land for each soil association. Land use areas were multiplied by the adopted salinity impact up scaling value to give a salinity impact (t/y) for each irrigated land use/soil association category (Table 5.5).

**Table 5.5 Up scaling salinity impact from irrigation in the Hundred of Stirling**

| **Soil associations** | **Irrigated land use** | **Land use area** (Ha) | **Adopted salinity impact up scale value** (t/Ha/y) | **Salinity impact** (t/y) |
|---|---|---|---|---|
| Stony Plains | Modified pastures | 203 | 10.63 | 2 161 |
| | Pasture legumes | 136 | | 1 445 |
| | Grass mixtures | 41 | | 435 |
| | Cropping | 30 | | 321 |
| | Hay and silage | 6 715 | | 71 378 |
| Old Coastal Dunes | Hay and silage | 721 | 11.52 | 8 310 |

The total salinity impact (t/y) to the unconfined aquifer, due to flood irrigation, within the Hundred of Stirling (Table 5.6) is calculated by summing the individual land use/soil association salinity impacts. Approximately 84 000 t/y of salt, resulting directly from the recycling of flood irrigation water, is transported to the unconfined aquifer over the entire Hundred. Once the total salinity impact (t/y) to the unconfined aquifer has been established, an average spatial salinity impact (mg/L/y) can be calculated using knowledge of the volume of the unconfined aquifer and its porosity. Two scenarios are considered and discussed further. The Hundred of Stirling has a total area of 39 461 Ha and porosity in the order of 0.25. The volume ($m^3$) of water in the unconfined aquifer is dependant upon the saturated thickness (m). Drilling records and geological reports (accessed via the Departmental database, SAGeodata) of ten Departmental observation wells were used to estimate the thickness of the unconfined aquifer within the Hundred of Stirling. All ten wells were chosen to give a good spatial coverage across the Hundred of Stirling and had been drilled through the entire thickness of the unconfined aquifer to at least the confining bed of the Dilwyn sequence. The mean thickness was found to be 46.9 m, with a median of 41.5 m. For the purposes of up scaling over the Hundred of Stirling a rounded thickness of 40 m has been used.

**Table 5.6 Overall salinity impact from irrigation in the Hundred of Stirling**

| | |
|---|---|
| Total Salinity Impact for the Hundred Of Stirling (t/y) | 84 052 |
| Total Area of the Hundred of Stirling (Ha) | 39 461 |
| Thickness of Unconfined Aquifer (m) | **40** |
| Porosity of Unconfined Aquifer | 0.25 |
| Volume of Unconfined Aquifer ($m^3$) | $3.95 \times 10^9$ |
| Average Salinity Impact (mg/L/y) | **21.30** |
| Total Salinity Impact for the Hundred Of Stirling (t/y) | 84 052 |
| Total Area of the Hundred of Stirling (Ha) | 39 461 |
| Thickness of Unconfined Aquifer (m) | **10** |
| Porosity of Unconfined Aquifer | 0.25 |
| Volume of Unconfined Aquifer ($m^3$) | $9.86 \times 10^8$ |
| Average Salinity Impact (mg/L/y) | **85.20** |

Scenario one assumes an unconfined aquifer thickness of 40 m (above), giving an average spatial salinity impact of 21.3 mg/L/y to the unconfined aquifer. However most salinity impacts are generally limited to the upper portion of the unconfined aquifer where the majority of irrigation, stock and domestic bores are completed. In this instance, scenario two assumes an unconfined aquifer thickness of 10 m giving an average spatial salinity impact to the unconfined aquifer of 85.2 mg/L/y. This figure is comparable to published estimates of groundwater salinity increase in the Hundred of Stirling, which often range from 50–100 mg/L/y.

Salinity impact results for flood irrigated Lucerne within the Hundred of Stirling have come from investigations sites with two to typically four years of data, giving a high confidence to those results. In the later part of this project, alternative irrigation practices have been investigated, the locations of which are outside the Hundred of Stirling. Subsurface drip irrigated Lucerne, conventional spray pivot irrigated Lucerne and drop-tube pivot irrigated Lucerne have had operational investigation sites monitoring salinity impacts for just 1–2 years. The range, mean, median and standard deviation (t/ha/y) salinity impact of these alternative irrigation methods is given (Table 5.7), however no adopted up scaling value is provided due to the short monitoring period and consequently low confidence in those values. Additional long term monitoring is required to increase confidence in the data and inturn adopt reasonable up scaling values. Even with limited data, subsurface drip irrigation appears to have a lower salinity impact. However, further monitoring is required to assess management requirements including potential losses in plant yield with increases in root zone salinity.

**Table 5.7 Salinity impact – Non flood irrigation**

| | **Salinity Impact Values** (t/Ha/y) | | | |
|---|---|---|---|---|
| | **Range** | **Mean** | **Median** | **Std Dev** |
| Drop Tube Pivot Irrigation | 7.91–22.94 | 18.51 | 22.00 | 6.45 |
| Pivot Irrigation | 2.13–12.69 | 10.00 | 12.59 | 5.25 |
| Sub-Surface Drip Irrigation | 0.00–7.57 | 2.31 | 0.84 | 3.53 |

# 6. CONCLUSIONS AND RECOMMENDED FURTHER WORK

## 6.1 THE BORDER DESIGNATED AREA

Outcomes of 1-dimensional drainage and groundwater recharge estimates for the Border Designated Area, are summarised in Table 6.1.

**Table 6.1 Mean drainage estimates – Border Designated Area**

| | **Mean drainage rate** (mm) |
|---|---|
| Dry land | 42 |
| Irrigation | 130 |
| Native Vegetation | 8 |

Spatially up scaling drainage and groundwater recharge rate estimates within the Border Designated Area required alternative methods for ground-truthing deep drainage estimates for Zones 4A–7A compared to Zones 2A and 3A, due in the main to climatic and geological constraints. Spatial extrapolation of the regional recharge model used for Zones 4A–7A gives a firm indication that large stores of salt are located in areas with deep unsaturated zones and higher clay percentages. Higher clay percentages, deeper unsaturated zones and lower precipitation impede the movement of saline drainage through the unsaturated zone. Importantly, much of the historical salt load contained within the unsaturated zone, particularly in Zones 6A and parts of 7A, has not been leached, implying that in future increases in salinity in the unconfined aquifer are likely to occur through out these areas.

Modelled scenarios demonstrate two important lag periods. Firstly the lag time between an increase in drainage rates to increased recharge rates; and secondly the lag time from the beginning of the displacement of saline soil water to the aquifer (with the onset of a changing recharge rate) to the onset of the freshwater front, followed by the recharge rate reaching a new equilibrium, marking the displacement of historical salt store. The period of lag varies considerably depending on the thickness of the unsaturated zone, clay percentage and rainfall. Consequently, unsaturated zone salt stores (Zones 4A–7A) are described by one of the following three states; 1) not mobilised and/or yet to reach the unconfined aquifer, 2) flushing into the unconfined aquifer, and 3) completely flushed from the unsaturated zone to the unconfined aquifer. For example, current day cumulative salt model predictions for parts of Zones 6A and 7A indicate insignificant salt contributions to the aquifer, underpinned by the 7S-DRY chloride profile. However, for the majority of the study area, cumulative salt predictions illustrate continued salt input (or flushing of the unsaturated zone) to the groundwater system into the future. Cumulative salt predictions also highlight areas along the southern boundary of the study area that have been completely flushed, confirmed via chloride profile analysis (3N-DRY).

Overall, the model gives a definite indication that significant salt has been leached from the unsaturated zone, particularly from Zones 4A, 5A and parts of 6A; and that a considerable salt load, predominantly throughout Zones 6A and 7A, can potentially leach to the unconfined aquifer system over the next 40 years. However, predictions on time scales and magnitude of salt fluxes should only be used as a guide. It is unrealistic to make detailed predictions beyond the next 20-40 years using an empirical model.

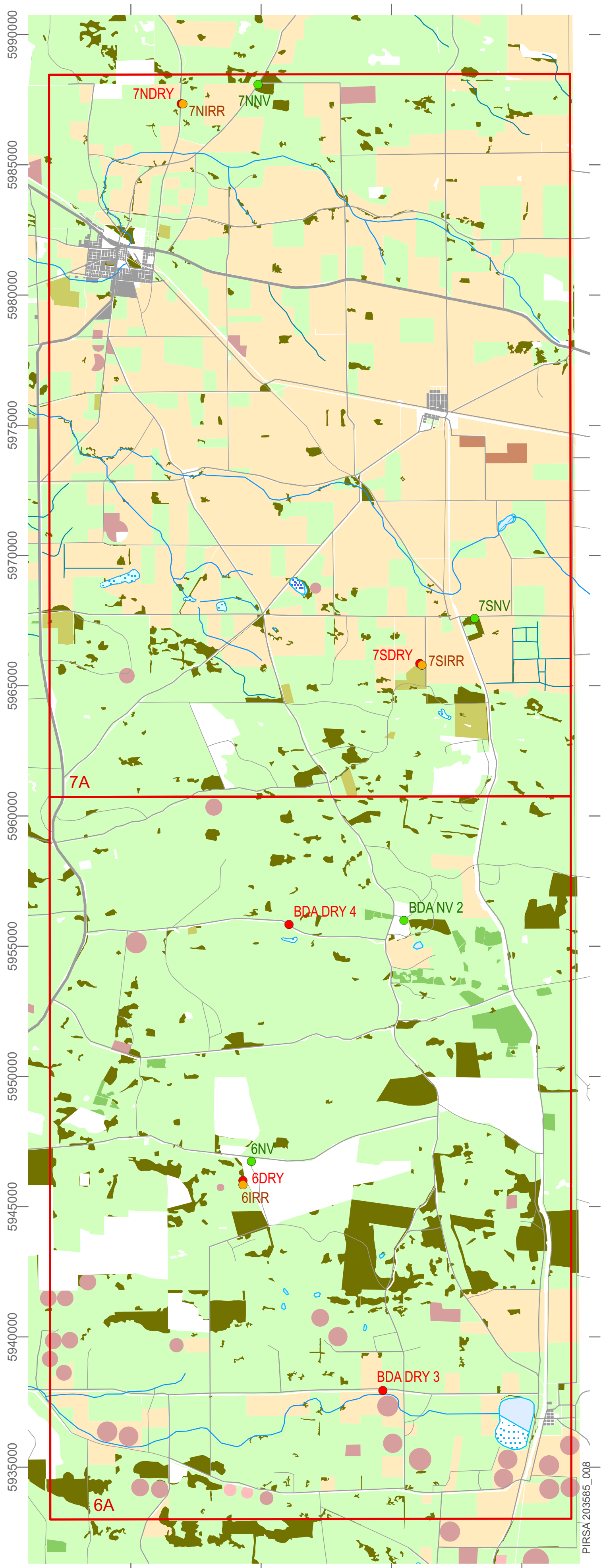
Prediction of groundwater salinisation via the use of this model does have limitations, leaving some uncertainties that require further work beyond this project. For example, the report does not address whether down gradient users will be affected by the potential increase in salinity to the unconfined aquifer or whether the potential salinity increases will be localised. Irrigation has not been accounted for using this model; therefore it does not predict how the recycling of irrigation water will increase drainage rates and hence increase flushing of salts and how significantly the post flushing recharge water salinity be affected. Figures 6.1 and 6.2; illustrate the areas of irrigation in Zones 6A–7A and Zones 4A–5A, respectively. Again, this does not indicate whether potential increases in salinity are limited to beneath the irrigated areas or whether down gradient users will be affected.

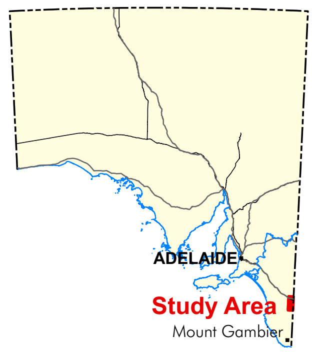
Limitations to the model include the sensitivity of the post-clearing drainage-clay (including how it is extrapolated using the clay content of SLU's and the effect of topography) and pre-clearing soil salinity-clay relationships, while the depth of the chloride front (pre-clearing) vs. clay and water content (beneath native vegetation) vs. clay functions are based on previous studies. Additional data beneath both cleared and uncleared land would decrease any uncertainty, and in future may provide enough reliable data to document these relationships based purely on rainfall zones.

Methods used to calculate groundwater recharge and salinisation in Zones 2A and 3A imply that the majority of the historical salt store has been flushed to the unconfined aquifer. A high recharge rate, due to the geological (shallow unsaturated zone) and climatic (high rainfall) nature of the region, creates a high potential for the flushing of salts. Up scaling adopted salinity impacts for each soil association (given here as a range based on land use) (Table 6.2) to the Zones 2A and 3A management boundary gives an average spatial salinity impact to the unconfined aquifer of about 3 mg/L/y (Table 6.3).

**Table 6.2 Adopted salinity impact rates – Border Designated Area (Zones 2A and 3A)**

| **Soil association** | **Adopted salinity impact rate** (t/Ha/y) |
|---|---|
| Shallow loam over limestone | 0.02–0.12 |
| Deep Sand | 0.04–0.15 |
| Deep loam/clay | 0.04–0.12 |
| Sand over clay | 0.04–0.15 |
| Loam/clay over clay | 0.04–0.12 |
| All other | 0.04–0.12 |




Zone 6A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Southeast Land Use 2002

- Cereals
- Grazing modified pastures
- Hardwood plantation
- Hay and silage
- Irrigated cropping
- Irrigated hay & silage
- Irrigated modified pastures
- Irrigated sown grasses
- Irrigated vegetables & herbs
- Irrigated vine fruits
- Legumes
- Marsh/wetland
- Rural residential
- Softwood plantation
- Urban residential
- Woodland
- Management Zone

0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Border Designated Area
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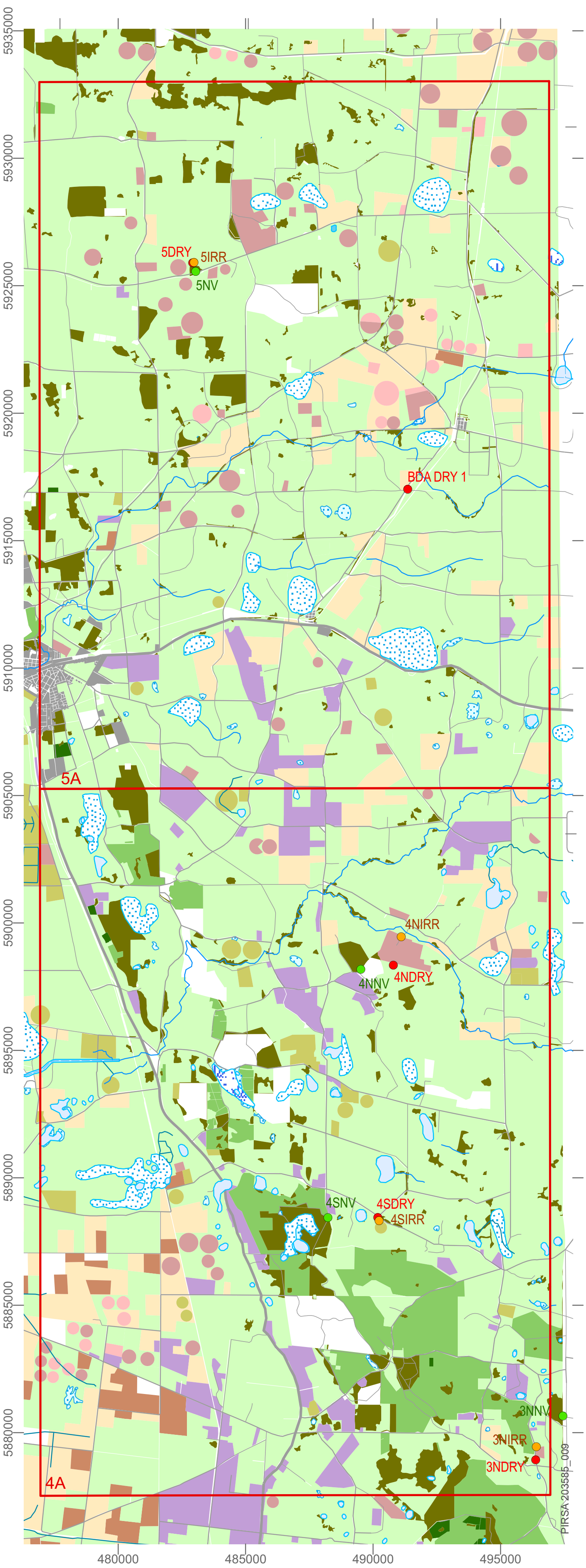
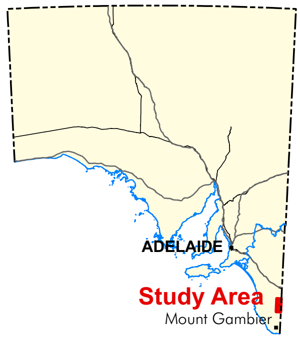
**LAND USE IN ZONES 6A AND 7A 2002**

**Figure 6.1**




Zone 4A-5A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

South East Land Use 2002

- Cereals
- Grazing modified pastures
- Hardwood plantation
- Hay and silage
- Irrigated cropping
- Irrigated hay & silage
- Irrigated modified pastures
- Irrigated sown grasses
- Irrigated vegetables & herbs
- Irrigated vine fruits
- Legumes
- Marsh/wetland
- Rural residential
- Softwood plantation
- Urban residential
- Woodland

Management Zone

0 2.5 5 Kilometers

Projection: MGA Zone 54 Transverse Mercator
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Border Designated Area
Salt Accession Project

**LAND USE IN ZONES 4A AND 5A 2002**

**Figure 6.2**

**Table 6.3 Average spatial salinity impact – Border Designated Area (Zones 2A and 3A)**

| **Unconfined aquifer thickness** (m) | **Spatial salinity impact** (mg/L/y) |
|---|---|
| 40 | 0.71 |
| 10 | 2.84 |

Potential for improved estimates of up scaled salinity impacts is great, however costly. Continued data collection on existing investigation sites would give greater confidence to the recharge rate calculations and salinity flux estimates already gathered; though this would not quantify groundwater recharge and salinisation beneath non-assessed land use/soil association combinations. The up scaling process also grouped all types of irrigation (for example drip irrigation and spray irrigation) and dry land (including cereals, legumes, pastures, hay and silage) into their respective singular categories and again the potential to improve up scaling of salinity impacts is significant. Additional investigation sites, monitoring the diversity of irrigation and dry land, land use processes, would improve salinisation estimates considerably.

The impacts of irrigation on soil structure, soil salinity and perched water tables have not been investigated here, but could be the focus of further studies.

## *6.2 THE HUNDRED OF STIRLING*

A wide range of techniques have been used to estimate drainage below the root zone or recharge to the unconfined aquifer from irrigation and background investigation sites (Table 6.4).

**Table 6.4 Mean drainage estimates – Hundred of Stirling**

| | **Mean drainage rate** (mm) |
|---|---|
| Irrigation | 403 |
| Background | 43 |

Given the comparable agreement between techniques, high confidence is attained that the adopted salinity impact up scaling value per soil association (Table 6.5) would be representative of the salinity contribution owing to irrigation over the entire Hundred of Stirling.

**Table 6.5 Adopted salinity impact rates – Hundred of Stirling**

| **Soil association** | **Adopted salinity impact rate** (t/Ha/y) |
|---|---|
| Stony Plains | 10.63 |
| Old Coastal Dunes | 11.52 |

The average spatial salinity impact (Table 6.6) via irrigation to the unconfined aquifer has been calculated to be 85 mg/L/y, which falls within the 50–100 mg/L/y range documented in previous work and illustrated with Departmental observation well trends.

**Table 6.6 Average spatial salinity impact – Hundred of Stirling**

| **Unconfined aquifer thickness** (m) | **Spatial salinity impact** (mg/L/y) |
|---|---|
| 40 | 21.3 |
| 10 | 85.2 |

Only groundwater recharge estimates below flood irrigation have been used to up scale salinity impacts in the Hundred of Stirling, as flood irrigation is currently the sole operational irrigation practice within the Hundred. Sub-surface drip irrigation, conventional spray pivot irrigation and drop tube pivot irrigation practices have been studied, however are located outside the Hundred of Stirling. Research into sub-surface drip, conventional spray pivot and drop tube pivot systems was undertaken to examine the salinity impact differences compared to traditional flood systems.

Based on a limited data set (the two pivot investigation sites have only been operational as part of the study for one full season), the pivot irrigation systems have comparable salinity impacts to flood irrigation. Salt built up at the root zone is greater beneath pivot irrigation compared to flood irrigation, however flood practices have greater drainage volumes through the soil profile. In effect, this evens out the salinity impact to the aquifer via flood and pivot systems. More research is needed to accurately describe the salinity impact associated with the pivot systems and the differences between conventional spray pivot and drop tube pivot practices. Comparisons of salinity increase from the bore through the soil profile to the piezometer between drop tube pivot and conventional spray pivot indicate the following; mean bore water TDS and $Cl^-$ values are comparable, while the mean impact recorded at the piezometer is barely different. With a limited data set, no positive conclusion can be made regarding which irrigation practice maintains a lower salinity impact.

Sub-surface drip irrigation accumulates salt in the soil profile, however with low drainage rates, lower short-term salinity impacts to the aquifer are likely to be experienced compared with all other irrigation practices. Differences in crop production or yields were not part of this study and are not discussed here.

# 7. MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

## 7.1 BORDER DESIGNATED AREA

Considerable potential exists for high salt loads to be flushed to the unconfined aquifer over the next few decades, particularly in Zones 6A and 7A of the Border Designated Area. For example, analysis of the up scaled model predictions for Zones 6A and 7A demonstrate the potential for continued leaching of salts to the water table due to the vast historical salt store remaining within the unsaturated zone. In these regions, the salinity of the unconfined aquifer may become more saline before any improvement is seen. On the other hand, groundwater salinities within Zones 2A and 3A have the potential for improvement, disregarding salinity impacts due to irrigation. The majority of the historical salt store has been flushed from the unsaturated zone hence groundwater salinities in these areas may freshen in areas where salt inputs to the system are solely via rainfall.

To maintain salinity levels across the Border Designated Area, it is imperative that groundwater through flow is maintained, ensuring the regional flushing of salts. Three-dimensional groundwater flow modelling, incorporating salt accession, of the Border Designated Area would enable consideration of varying rainfall, groundwater recharge and groundwater pumping scenarios. In turn predictions of groundwater through flow and salt fluxes would facilitate the development of strategies to better manage the resource.

## 7.2 HUNDRED OF STIRLING

Further research is required to advance our understanding of the processes underpinning salinity accession within the Hundred of Stirling. Continued monitoring and investigation is required to completely appreciate salinity impact differences between flood irrigated Lucerne and conventional spray pivot, drop-tube pivot and sub-surface drip irrigated Lucerne stands. A better understanding of recharge rates beneath different irrigation systems and climatic conditions may provide for an improved awareness of the longer-term salt loads to the unconfined aquifer. Knowledge of the salinity impacts via alternative irrigation methods and incorporating them into water allocation plans should be an essential factor when determining how irrigation within the Hundred of Stirling is developed sustainably in future.

Given the high salt loads delivered to the unconfined aquifer, maintaining the hydraulic gradient of the unconfined aquifer to ensure lateral flushing remains important. As discussed above, 3-D modelling incorporating salinity fluxes will provide scenarios that predict groundwater through flow, facilitating the development of improved management strategies.

This project has not explored any relationships between irrigation systems and crop yield. Future investigations could focus on the benefits of high drainage irrigation systems, leaching high salt loads versus more efficient irrigation systems with lower salinity impacts to the aquifer which inturn concentrate salts in the unsaturated zone.

Further chemistry sampling could provide a link between increases in salinity and changes in the chemistry of water down gradient through the system, which have not been investigated within the objectives of this project.

## 7.3 GENERAL

As discussed previously (Sections 3.3 and 4.3), several authors have used an array of techniques to previously assess groundwater recharge rates within the South East of South Australia. The most recent of study (Latcham et al 2007) has revised groundwater recharge estimates for Zones 2A and 3A from 95 mm and 100 mm to 140 mm and 120 mm respectively. These revised recharge estimates are noticeably higher compared to recharge estimates calculated via the 1-D recharge model and CFC techniques in this study. However they are similar in magnitude to estimates using the chloride mass balance beneath flushed dry land profiles. If groundwater recharge rates are higher in reality than estimated through this study, it then follows that there are implications for up scaling salinity impacts within Zones 2A and 3A. Further investigation is warranted to accurately determine groundwater recharge rates within Zones 2A and 3A enabling more precise up scaling of salinity impacts to the unconfined aquifer.

Groundwater recharge estimates for Zones 4A, 5A, 6A and 7A of the Border Designated Area and for the Hundred of Stirling are comparable between the rates calculated for this investigation and those from studies discussed previously.

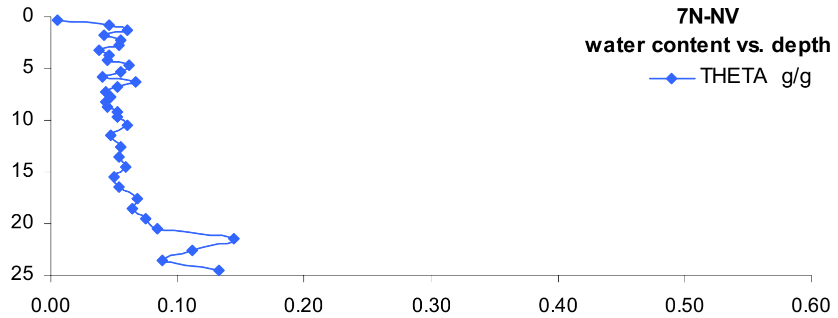
Finally, some general recommendations are as follows:

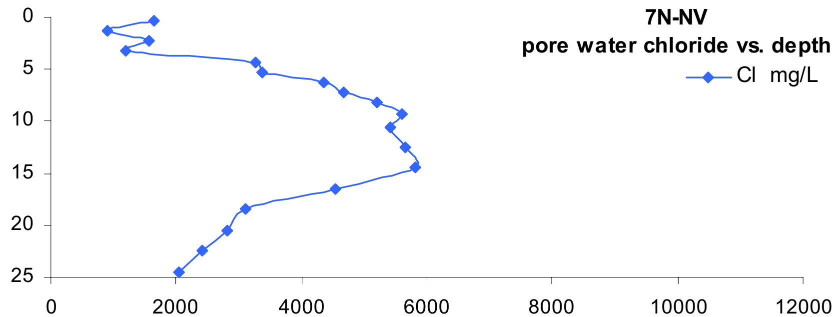
- Update the South East land use GIS coverage. This project used the latest land use coverage available (2002).
- Ensure future projects investigate salinity impacts beneath soil association/land use combinations not specifically addressed in this and other projects.

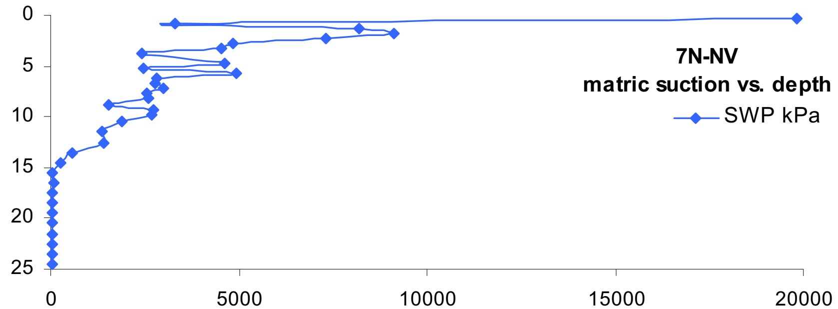
# APPENDICES

## A.1. SOIL CORE DATA, BORDER DESIGNATED AREA

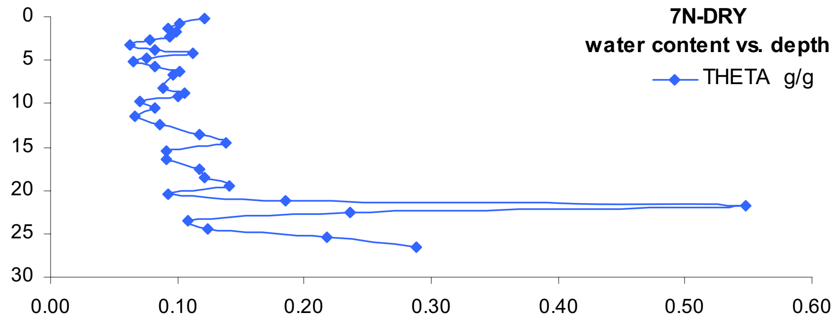
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7N-NV | 0–0.5 | 0.005 | 1639 | 19821 | 43.6 | 53.0 | 0.9 | 2.5 | 0.25 |
| | 0.5–1.0 | 0.046 | | 3315 | | | | | 0.75 |
| | 1.0–1.5 | 0.061 | 911 | 8188 | 33.5 | 41.3 | 2.1 | 23.1 | 1.25 |
| | 1.5–2.0 | 0.042 | | 9134 | | | | | 1.75 |
| | 2.0–2.5 | 0.056 | 1563 | 7334 | 40.5 | 40.7 | 2.6 | 16.2 | 2.25 |
| | 2.5–3.0 | 0.054 | | 4860 | | | | | 2.75 |
| | 3.0–3.5 | 0.038 | 1206 | 4545 | 60.2 | 22.9 | 3.1 | 14.8 | 3.25 |
| | 3.5–4.0 | 0.045 | | 2425 | | | | | 3.75 |
| | 4.0–4.5 | 0.045 | 3262 | | 44.8 | 32.7 | 3.3 | 19.1 | 4.25 |
| | 4.5–5.0 | 0.061 | | 4642 | | | | | 4.75 |
| | 5.0–5.5 | 0.055 | 3381 | 2485 | 40.9 | 37.6 | 3.3 | 18.2 | 5.25 |
| | 5.5–6.0 | 0.041 | | 4915 | | | | | 5.75 |
| | 6.0–6.5 | 0.066 | 4348 | 2812 | 56.5 | 36.6 | 1.4 | 5.5 | 6.25 |
| | 6.5–7.0 | 0.052 | | 2764 | | | | | 6.75 |
| | 7.0–7.5 | 0.044 | 4664 | 2976 | 54.0 | 35.2 | 1.0 | 9.8 | 7.25 |
| | 7.5–8.0 | 0.047 | | 2537 | | | | | 7.75 |
| | 8.0–8.5 | 0.043 | 5215 | 2617 | 61.2 | 27.1 | 3.1 | 10.4 | 8.25 |
| | 8.5–9.0 | 0.045 | | 1564 | | | | | 8.75 |
| | 9.0–9.5 | 0.052 | 5592 | 2737 | 82.7 | 8.2 | 1.3 | 7.7 | 9.25 |
| | 9.5–10.0 | 0.053 | | 2700 | | | | | 9.75 |
| | 10.0–11.0 | 0.061 | 5403 | 1907 | 88.2 | 6.6 | 0.6 | 4.7 | 10.50 |
| | 11.0–12.0 | 0.047 | | 1371 | | | | | 11.50 |
| | 12.0–13.0 | 0.055 | 5650 | 1409 | 78.3 | 12.3 | 2.2 | 7.2 | 12.50 |
| | 13.0–14.0 | 0.054 | | 565 | | | | | 13.50 |
| | 14.0–15.0 | 0.059 | 5817 | 269 | 46.6 | 37.6 | 1.8 | 13.9 | 14.50 |
| | 15.0–16.0 | 0.050 | | 66 | | | | | 15.50 |
| | 16.0–17.0 | 0.054 | 4529 | 84 | 50.3 | 37.4 | 3.2 | 9.1 | 16.50 |
| | 17.0–18.0 | 0.068 | | 56 | | | | | 17.50 |
| | 18.0–19.0 | 0.064 | 3114 | 52 | 1.4 | 89.1 | 2.0 | 7.5 | 18.50 |
| | 19.0–20.0 | 0.074 | | 52 | | | | | 19.50 |
| | 20.0–21.0 | 0.084 | 2801 | 56 | 0.9 | 81.1 | 3.5 | 14.5 | 20.50 |
| | 21.0–22.0 | 0.144 | | 49 | | | | | 21.50 |
| | 22.0–23.0 | 0.112 | 2424 | 50 | 1.5 | 82.1 | 2.7 | 13.7 | 22.50 |
| | 23.0–24.0 | 0.088 | | 53 | | | | | 23.50 |
| | 24.0–25.0 | 0.133 | 2033 | 38 | 1.0 | 82.9 | 2.4 | 13.6 | 24.50 |

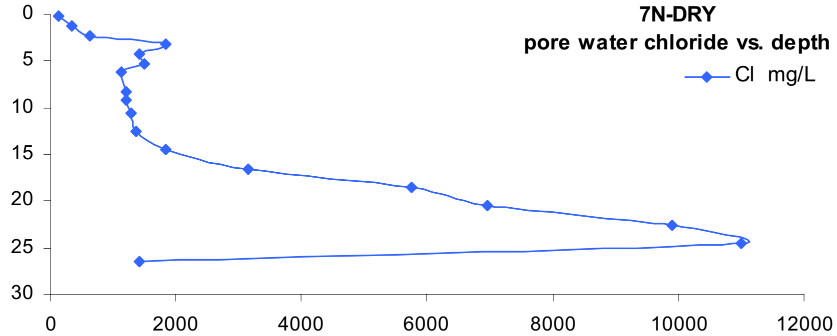


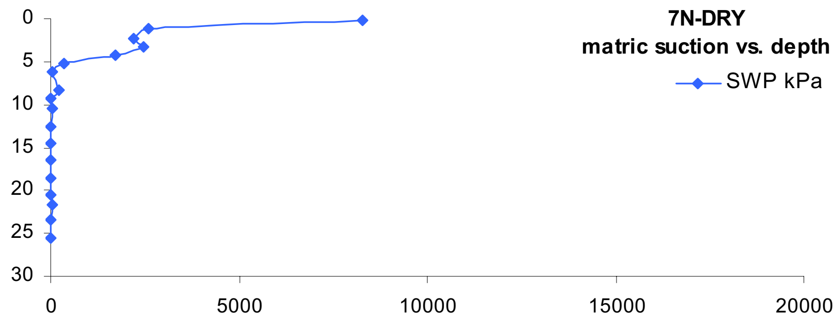



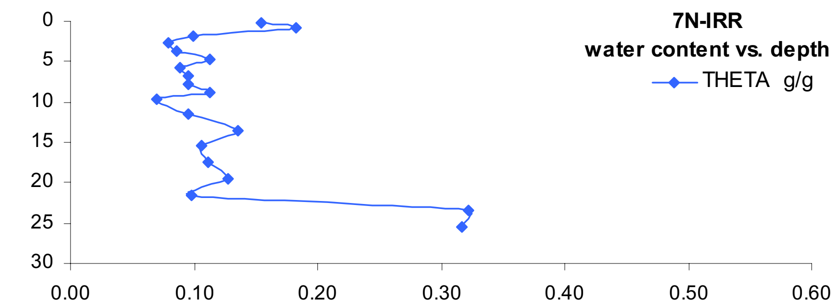
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7N-DRY | 0–0.5 | 0.121 | 124 | 8266 | 26.3 | 32.7 | 0.8 | 40.3 | 0.25 |
| | 0.5–1.0 | 0.101 | | | | | | | 0.75 |
| | 1.0–1.5 | 0.093 | 334 | 2581 | 57.8 | 22.3 | 0.7 | 19.2 | 1.25 |
| | 1.5–2.0 | 0.100 | | | | | | | 1.75 |
| | 2.0–2.5 | 0.094 | 625 | 2196 | 51.3 | 26.9 | 1.2 | 20.6 | 2.25 |
| | 2.5–3.0 | 0.078 | | | | | | | 2.75 |
| | 3.0–3.5 | 0.063 | 1836 | 2454 | 66.9 | 16.2 | 0.6 | 16.4 | 3.25 |
| | 3.5–4.0 | 0.083 | | | | | | | 3.75 |
| | 4.0–4.5 | 0.112 | 1406 | 1717 | 54.5 | 20.7 | 2.3 | 19.7 | 4.25 |
| | 4.5–5.0 | 0.076 | | | | | | | 4.75 |
| | 5.0–5.5 | 0.065 | 1500 | 366 | 41.3 | 45.2 | 3.1 | 11.6 | 5.25 |
| | 5.5–6.0 | 0.083 | | | | | | | 5.75 |
| | 6.0–6.5 | 0.101 | 1125 | 32 | 34.6 | 53.4 | 1.1 | 10.9 | 6.25 |
| | 6.5–7.0 | 0.096 | | | | | | | 6.75 |
| | 8.0–8.5 | 0.089 | 1209 | 214 | 21.5 | 57.0 | 5.2 | 16.3 | 8.25 |
| | 8.5–9.0 | 0.105 | | | | | | | 8.75 |
| | 9.0–9.5 | 0.101 | 1209 | 18 | 70.5 | 18.2 | 0.7 | 10.6 | 9.25 |
| | 9.5–10.0 | 0.070 | | | | | | | 9.75 |
| | 10.0–11.0 | 0.082 | 1291 | 37 | 60.1 | 29.4 | 1.7 | 8.8 | 10.50 |
| | 11.0–12.0 | 0.066 | | | | | | | 11.50 |
| | 12.0–13.0 | 0.086 | 1365 | 20 | 69.3 | 19.4 | 1.3 | 10.0 | 12.50 |
| | 13.0–14.0 | 0.117 | | | | | | | 13.50 |
| | 14.0–15.0 | 0.138 | 1826 | 6 | 1.0 | 84.5 | 2.9 | 11.5 | 14.50 |
| | 15.0–16.0 | 0.091 | | | | | | | 15.50 |
| | 16.0–17.0 | 0.092 | 3163 | 14 | 4.0 | 86.0 | 2.9 | 7.2 | 16.50 |
| | 17.0–18.0 | 0.117 | | | | | | | 17.50 |
| | 18.0–19.0 | 0.121 | 5763 | 11 | 0.2 | 90.3 | 2.5 | 7.0 | 18.50 |
| | 19.0–20.0 | 0.141 | | | | | | | 19.50 |
| | 20.0–21.0 | 0.093 | 6953 | 14 | 2.9 | 88.6 | 2.7 | 5.8 | 20.50 |
| | 21.0–21.5 | 0.185 | | | | | | | 21.25 |
| | 21.5–22.0 | 0.547 | | 37 | 11.2 | 28.1 | 16.6 | 44.1 | 21.75 |
| | 22.0–23.0 | 0.237 | 9908 | | | | | | 22.50 |
| | 23.0–24.0 | 0.108 | | 22 | 42.7 | 46.5 | 7.2 | 3.7 | 23.50 |
| | 24.0–25.0 | 0.124 | 11009 | | | | | | 24.50 |
| | 25.0–26.0 | 0.218 | | 3 | 44.1 | 43.7 | 8.9 | 3.3 | 25.50 |
| | 26.0–27.0 | 0.288 | 1427 | | | | | | 26.50 |

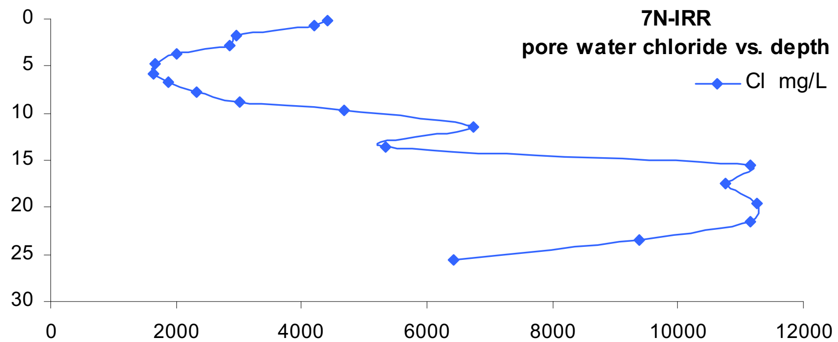


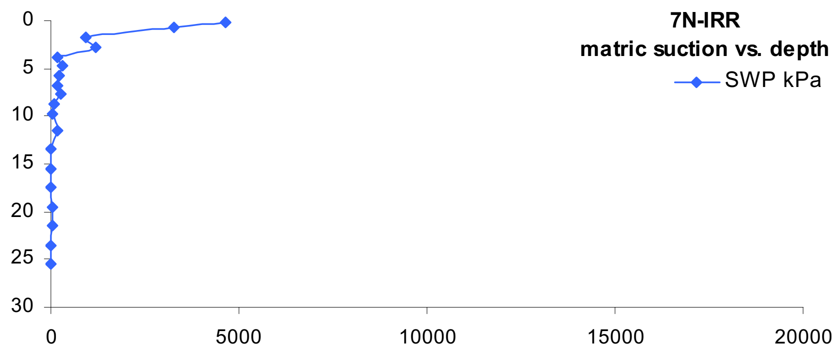



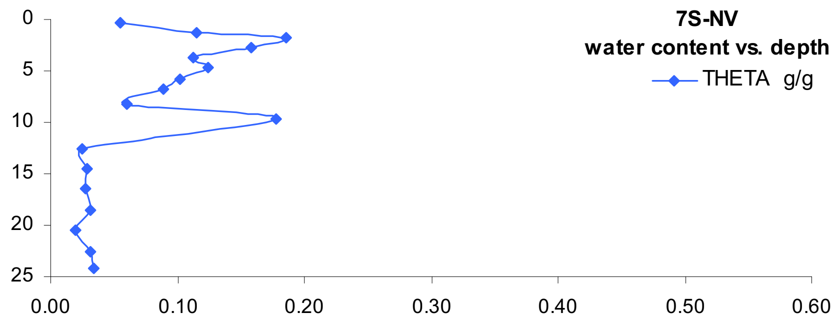
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7N-IRR | 0–0.5 | 0.155 | 4422 | 4653 | 12.8 | 35.9 | 2.4 | 48.9 | 0.25 |
| | 0.5–1.0 | 0.182 | 4205 | 3257 | 16.5 | 30.1 | 3.2 | 50.2 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.099 | 2970 | 908 | 30.7 | 58.4 | 1.5 | 9.4 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.079 | 2858 | 1175 | 22.2 | 69.0 | 1.6 | 7.2 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.086 | 2007 | 155 | 14.0 | 67.1 | 1.9 | 17.1 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.112 | 1652 | 324 | 18.3 | 57.4 | 2.5 | 21.8 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.089 | 1645 | 222 | 20.7 | 59.6 | 1.9 | 17.8 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.095 | 1876 | 164 | 23.1 | 70.8 | 1.1 | 5.0 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.096 | 2327 | 271 | 16.9 | 72.5 | 3.1 | 7.5 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.113 | 3000 | 89 | 22.1 | 71.0 | 2.0 | 4.9 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.070 | 4669 | 58 | 61.7 | 30.0 | 1.1 | 7.2 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.096 | 6748 | 170 | 61.3 | 28.5 | 2.6 | 7.5 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.136 | 5350 | 14 | 35.9 | 50.0 | 4.8 | 9.3 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.107 | 11161 | 15 | 0.4 | 82.9 | 1.9 | 14.7 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.111 | 10745 | 14 | 0.5 | 85.8 | 3.1 | 10.6 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.127 | 11262 | 25 | 0.3 | 77.1 | 5.6 | 17.1 | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |
| | 21.0–22.0 | 0.098 | 11141 | 32 | 1.6 | 80.5 | 4.1 | 13.8 | 21.50 |
| | 22.0–23.0 | | | | | | | | 22.50 |
| | 23.0–24.0 | 0.323 | 9391 | 7 | 10.0 | 36.7 | 40.3 | 13.1 | 23.50 |
| | 24.0–25.0 | | | | | | | | 24.50 |
| | 25.0–26.0 | 0.317 | 6428 | 4 | 23.5 | 43.2 | 23.1 | 10.1 | 25.50 |
| | 26.0–27.0 | | | | | | | | 26.50 |

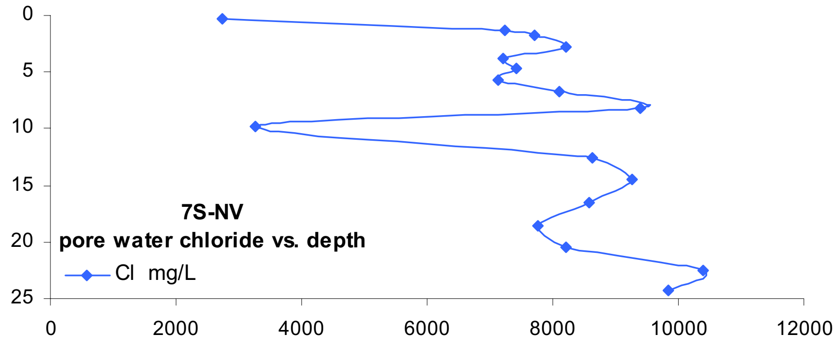


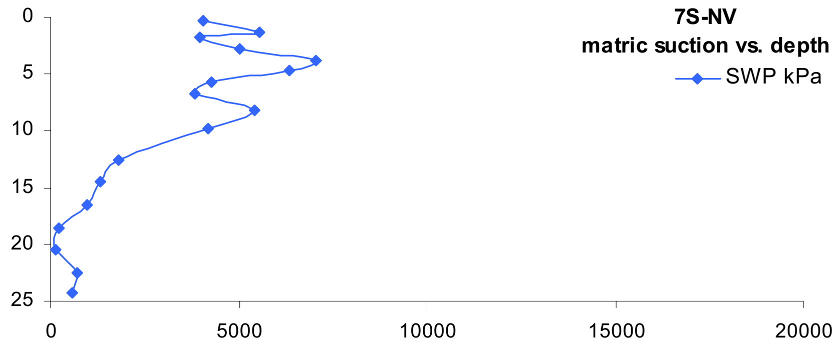



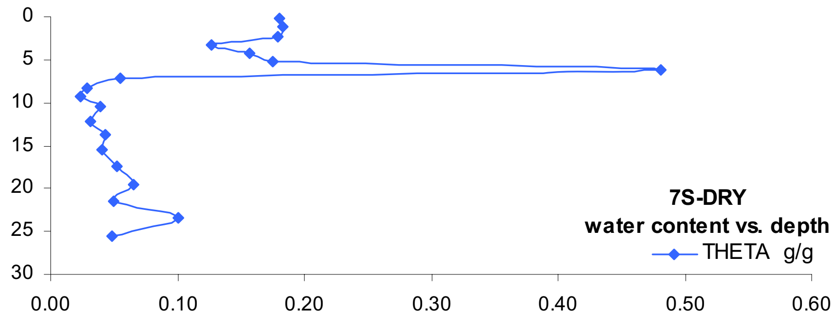
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7S-NV | 0–0.5 | 0.055 | 2746 | 4072 | 18.4 | 60.0 | 6.6 | 15.0 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.115 | 7237 | 5541 | 8.9 | 30.3 | 3.5 | 57.3 | 1.25 |
| | 1.5–2.0 | 0.186 | 7711 | 3971 | 11.5 | 34.1 | 3.2 | 51.2 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.158 | 8209 | 5025 | 14.6 | 39.1 | 3.2 | 43.1 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.112 | 7201 | 7062 | 24.2 | 37.9 | 3.8 | 34.0 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.124 | 7408 | 6345 | 41.2 | 26.8 | 2.5 | 29.6 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.103 | 7140 | 4272 | 17.1 | 57.8 | 1.5 | 23.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.089 | 8099 | 3827 | 13.3 | 59.5 | 2.9 | 24.3 | 6.75 |
| | 7.0–8.0 | | | | | | | | 7.50 |
| | 8.0–8.5 | 0.061 | 9389 | 5430 | 5.9 | 71.6 | 4.2 | 18.3 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10 | 0.178 | 3252 | 4182 | 11.2 | 67.9 | 5.8 | 15.2 | 9.75 |
| | 10.0–12.0 | | | | | | | | 11.00 |
| | 12.0–13.0 | 0.025 | 8633 | 1802 | 3.4 | 94.5 | 1.0 | 1.1 | 12.50 |
| | 13.0–14.0 | | | | | | | | 13.50 |
| | 14.0–15.0 | 0.029 | 9276 | 1323 | 8.0 | 90.8 | 0.4 | 0.8 | 14.50 |
| | 15.0–16.0 | | | | | | | | 15.50 |
| | 16.0–17.0 | 0.028 | 8571 | 988 | 16.8 | 80.1 | 1.0 | 2.1 | 16.50 |
| | 17.0–18.0 | | | | | | | | 17.50 |
| | 18.0–19.0 | 0.032 | 7756 | 211 | 21.4 | 73.3 | 3.0 | 2.3 | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |
| | 20.0–21.0 | 0.020 | 8212 | 126 | 46.2 | 50.1 | 1.0 | 2.7 | 20.50 |
| | 21.0–22.0 | | | | | | | | 21.50 |
| | 22.0–23.0 | 0.031 | 10382 | 714 | 39.5 | 53.3 | 2.2 | 5.0 | 22.50 |
| | 23.0–24.0 | | | | | | | | 23.50 |
| | 24.0–24.5 | 0.034 | 9847 | 589 | 61.4 | 30.8 | 2.4 | 5.4 | 24.25 |

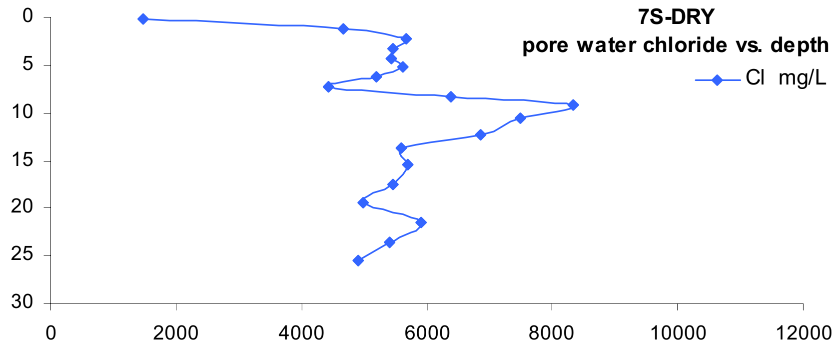


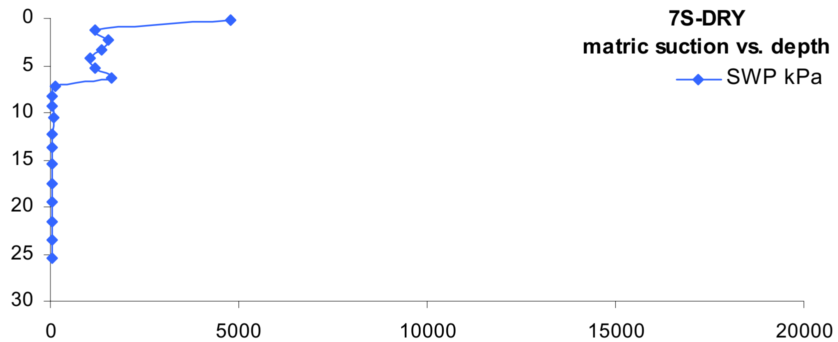



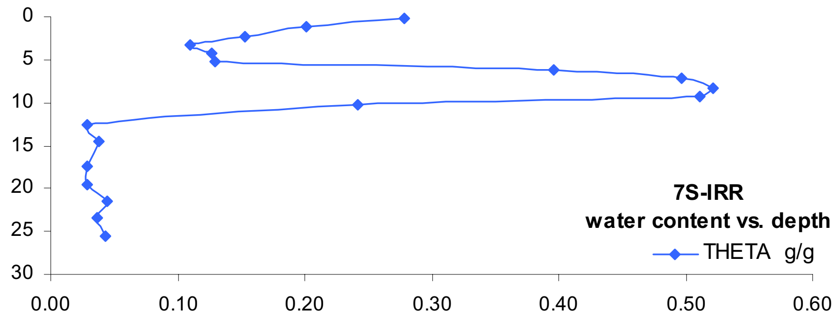
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7S-DRY | 0–0.5 | 0.181 | 1464 | 4763 | 7.0 | 26.1 | 7.2 | 59.7 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.183 | 4662 | 1203 | 18.1 | 34.7 | 3.9 | 43.2 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.179 | 5679 | 1516 | 17.9 | 32.4 | 4.5 | 45.2 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.127 | 5455 | 1373 | 18.6 | 28.0 | 5.2 | 48.2 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.156 | 5428 | 1035 | 43.6 | 28.0 | 2.8 | 25.7 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.175 | 5629 | 1192 | 24.6 | 31.0 | 3.3 | 41.1 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.481 | 5198 | 1629 | 1.7 | 8.4 | 3.8 | 86.1 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.056 | 4435 | 142 | 20.9 | 63.0 | 1.2 | 14.9 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.028 | 6387 | 38 | 33.6 | 60.7 | 0.8 | 4.8 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.023 | 8338 | 50 | 23.5 | 72.3 | 0.5 | 3.7 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–11.0 | 0.039 | 7481 | 95 | 13.6 | 79.6 | 0.7 | 6.2 | 10.50 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–12.5 | 0.031 | 6866 | 38 | 2.1 | 92.2 | 1.1 | 4.6 | 12.25 |
| | 12.5–13.5 | | | | | | | | 12.75 |
| | 13.5–14.0 | 0.043 | 5598 | 43 | 2.8 | 90.0 | 1.5 | 5.7 | 13.75 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.040 | 5688 | 33 | 2.2 | 90.6 | 2.0 | 5.2 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.053 | 5461 | 29 | 24.4 | 68.2 | 1.1 | 6.2 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.065 | 4980 | 33 | 63.1 | 27.8 | 2.0 | 7.1 | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |
| | 21.0–22.0 | 0.050 | 5903 | 42 | 25.7 | 68.6 | 1.1 | 4.6 | 21.50 |
| | 22.0–23.0 | | | | | | | | 22.50 |
| | 23.0–24.0 | 0.100 | 5417 | 35 | 7.9 | 83.9 | 1.4 | 6.8 | 23.50 |
| | 24.0–25.0 | | | | | | | | 24.50 |
| | 25.0–26.0 | 0.048 | 4917 | 35 | 2.0 | 92.4 | 0.9 | 4.7 | 25.50 |

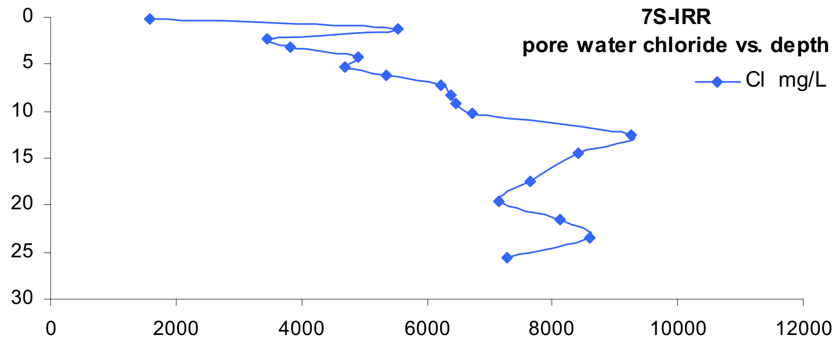


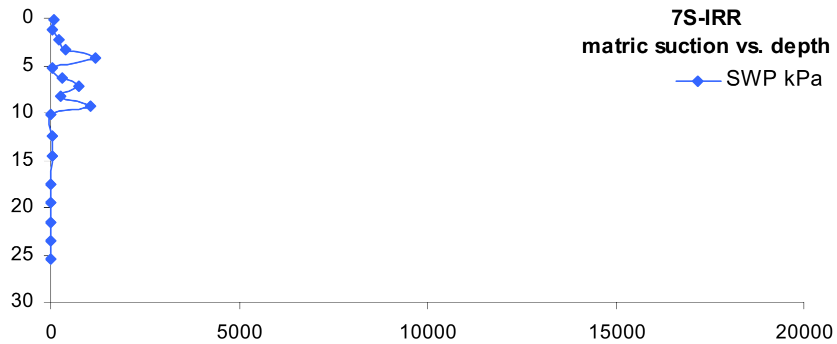



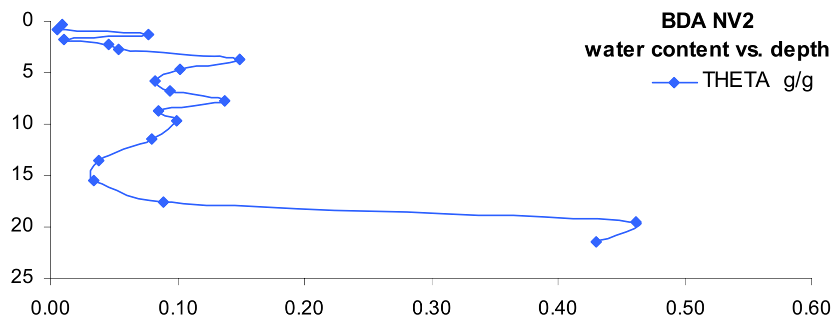
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 7S-IRR | 0–0.5 | 0.278 | 1576 | 75 | 10.5 | 34.8 | 5.8 | 48.9 | 0.25 |
| | 0.5–1 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.201 | 5542 | 26 | 17.9 | 26.5 | 2.8 | 52.7 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.153 | 3458 | 214 | 18.2 | 43.7 | 7.5 | 30.7 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.110 | 3814 | 404 | 23.5 | 49.2 | 3.4 | 23.9 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.127 | 4900 | 1172 | 48.0 | 24.7 | 2.2 | 25.1 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.129 | 4682 | 28 | 64.8 | 18.7 | 0.1 | 16.4 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.396 | 5343 | 294 | 3.5 | 8.1 | 7.6 | 80.9 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.497 | 6215 | 744 | 3.6 | 8.9 | 7.5 | 79.9 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.521 | 6372 | 244 | 1.7 | 4.8 | 5.4 | 88.1 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.512 | 6473 | 1062 | 0.7 | 3.7 | 6.6 | 88.9 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–10.5 | 0.242 | 6718 | 4 | 36.7 | 53.9 | 0.4 | 9.0 | 10.25 |
| | 10.5–12.0 | | | | | | | | 11.25 |
| | 12.0–13.0 | 0.029 | 9262 | 35 | 11.3 | 82.6 | 1.9 | 4.2 | 12.50 |
| | 13.0–14.0 | | | | | | | | 13.50 |
| | 14.0–15.0 | 0.038 | 8413 | 33 | 3.3 | 93.1 | 0.8 | 2.8 | 14.50 |
| | 15.0–16.0 | | | | | | | | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.028 | 7656 | 15 | 11.3 | 83.9 | 1.5 | 3.3 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.029 | 7159 | 15 | 9.8 | 85.9 | 1.2 | 3.1 | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |
| | 21.0–22.0 | 0.045 | 8131 | 18 | 58.6 | 37.5 | 1.1 | 2.9 | 21.50 |
| | 22.0–23.0 | | | | | | | | 22.50 |
| | 23.0–24.0 | 0.036 | 8589 | 21 | 73.6 | 23.7 | 0.4 | 2.3 | 23.50 |
| | 24.0–25.0 | | | | | | | | 24.50 |
| | 25.0–26.0 | 0.043 | 7270 | 15 | 2.5 | 92.2 | 1.1 | 4.2 | 25.50 |

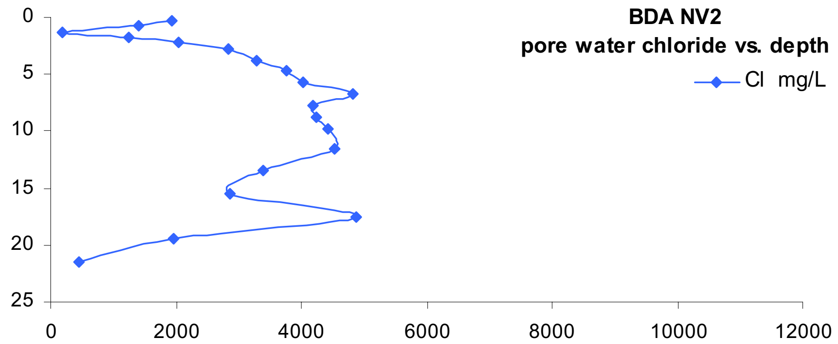


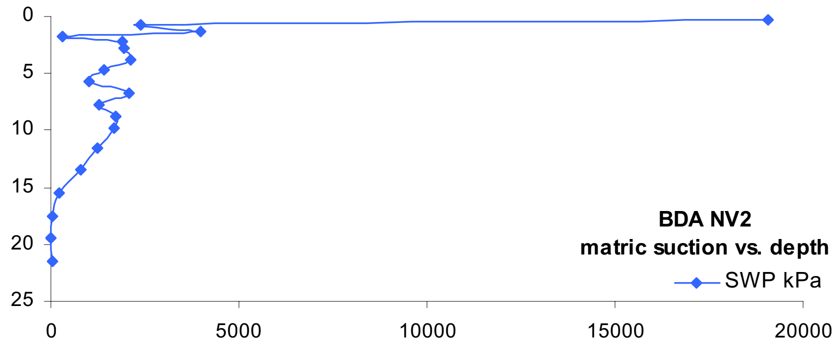



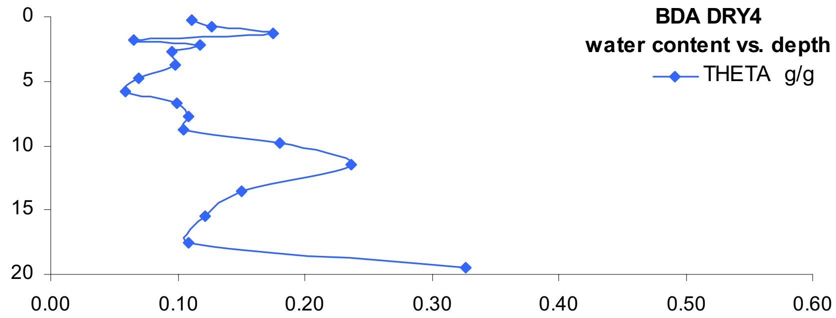
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| BDA NV2 | 0–0.5 | 0.009 | 1923 | 19062 | 48.8 | 49.5 | 0.9 | 0.8 | 0.25 |
| | 0.5–1.0 | 0.005 | 1393 | 2396 | 39.6 | 58.9 | 0.9 | 0.7 | 0.75 |
| | 1.0–1.5 | 0.078 | 195 | 3990 | 32.4 | 47.1 | 0.7 | 19.7 | 1.25 |
| | 1.5–2.0 | 0.010 | 1256 | 312 | 30.7 | 66.5 | 0.5 | 2.3 | 1.75 |
| | 2.0–2.5 | 0.046 | 2027 | 1903 | 30.4 | 56.1 | 0.5 | 13.0 | 2.25 |
| | 2.5–3.0 | 0.053 | 2828 | 1962 | 36.1 | 46.9 | 4.1 | 12.9 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.150 | 3298 | 2105 | 44.8 | 35.5 | 1.5 | 18.2 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.102 | 3774 | 1424 | 26.5 | 43.0 | 2.7 | 27.8 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.083 | 4037 | 1024 | 10.1 | 70.6 | 3.0 | 16.2 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.094 | 4814 | 2078 | 16.2 | 67.6 | 2.3 | 13.8 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.138 | 4176 | 1272 | 20.6 | 58.3 | 2.0 | 19.0 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.085 | 4237 | 1728 | 4.5 | 71.2 | 3.9 | 20.4 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.100 | 4436 | 1692 | 2.3 | 72.7 | 2.3 | 22.7 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.079 | 4518 | 1261 | 1.4 | 80.1 | 1.6 | 16.9 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.038 | 3394 | 805 | 9.0 | 82.5 | 0.6 | 8.0 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.033 | 2852 | 236 | 8.6 | 87.3 | 0.9 | 3.3 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.088 | 4872 | 55 | 12.8 | 80.7 | 1.7 | 4.9 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.461 | 1966 | 5 | 19.1 | 58.4 | 7.4 | 15.1 | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |
| | 21.0–22.0 | 0.430 | 441 | 37 | 39.7 | 23.8 | 24.4 | 12.1 | 21.50 |

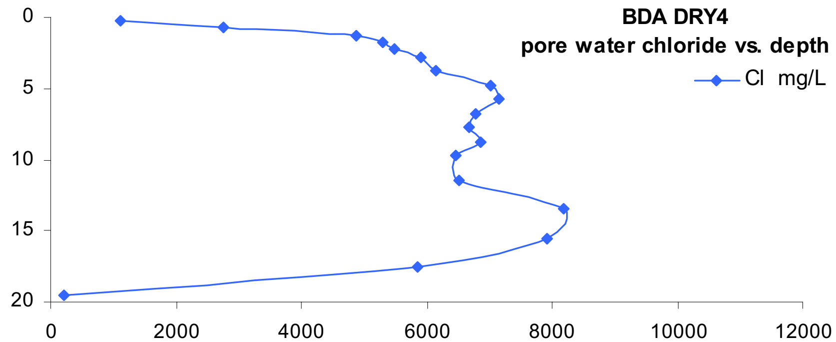


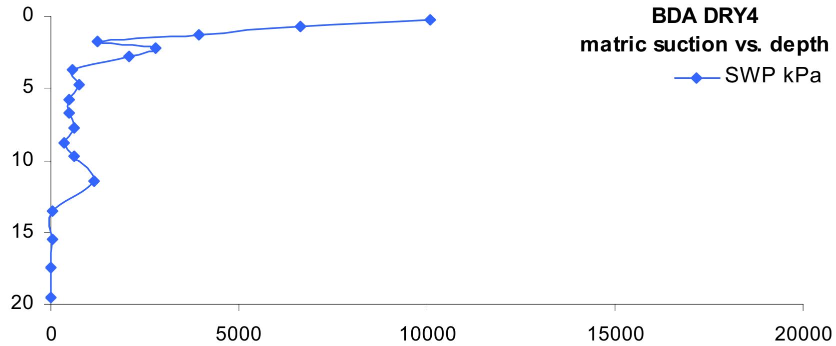



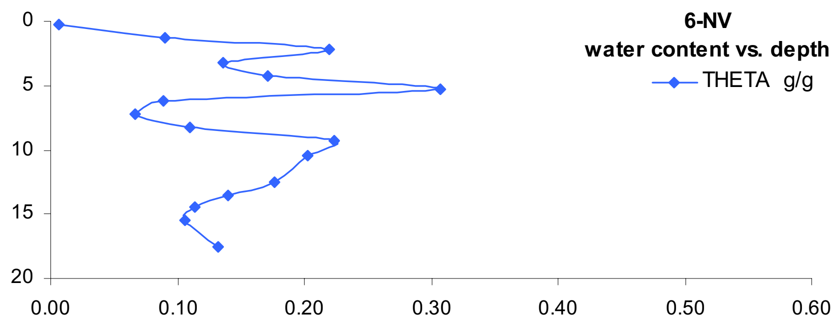
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| BDA DRY4 | 0–0.5 | 0.111 | 1116 | 10094 | 20.5 | 44.0 | 2.9 | 32.6 | 0.25 |
| | 0.5–1.0 | 0.127 | 2748 | 6626 | 17.8 | 41.9 | 2.6 | 37.7 | 0.75 |
| | 1.0–1.5 | 0.175 | 4885 | 3941 | 20.1 | 35.7 | 4.2 | 40.0 | 1.25 |
| | 1.5–2.0 | 0.065 | 5301 | 1256 | 32.4 | 52.6 | 1.2 | 13.9 | 1.75 |
| | 2.0–2.5 | 0.117 | 5491 | 2770 | 17.2 | 58.6 | 1.7 | 22.5 | 2.25 |
| | 2.5–3.0 | 0.095 | 5900 | 2096 | 25.7 | 53.8 | 1.8 | 18.7 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.098 | 6158 | 591 | 25.4 | 55.6 | 2.1 | 17.0 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.069 | 7020 | 745 | 5.6 | 81.3 | 2.6 | 10.6 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.058 | 7154 | 485 | 17.9 | 71.6 | 1.1 | 9.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.100 | 6781 | 470 | 21.1 | 51.0 | 7.2 | 20.7 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.108 | 6685 | 640 | 21.3 | 49.4 | 4.1 | 25.2 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.104 | 6848 | 375 | 19.2 | 60.9 | 4.4 | 15.6 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.181 | 6456 | 605 | 9.0 | 44.5 | 14.4 | 32.0 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.237 | 6506 | 1167 | 0.6 | 40.4 | 17.5 | 41.5 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.150 | 8198 | 50 | 28.3 | 48.7 | 7.4 | 15.6 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.121 | 7918 | 24 | 31.1 | 19.9 | 41.0 | 8.0 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.109 | 5848 | 9 | 55.3 | 24.4 | 15.5 | 4.9 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.327 | 217 | 6 | 54.5 | 19.3 | 21.4 | 4.8 | 19.50 |

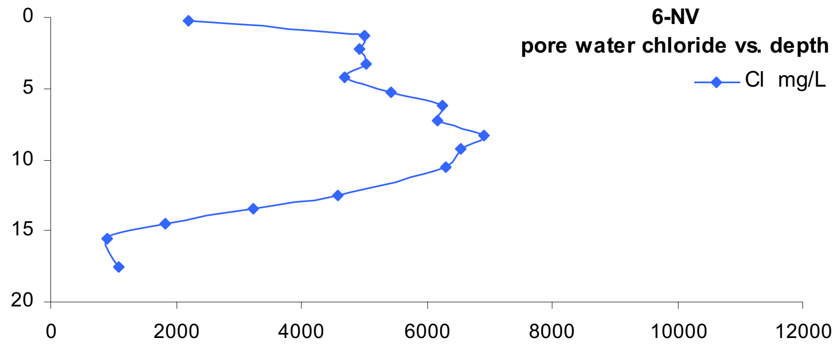


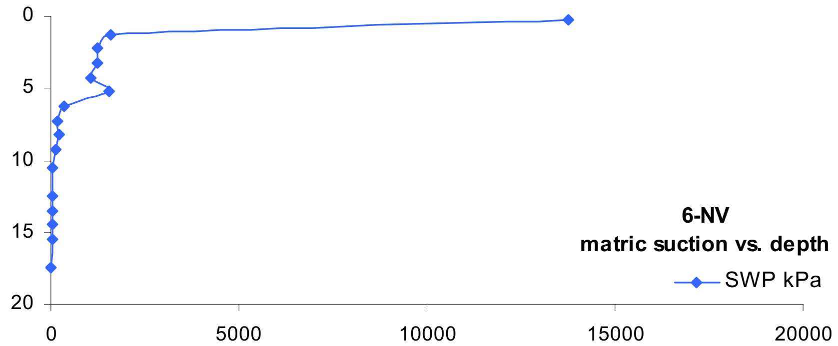



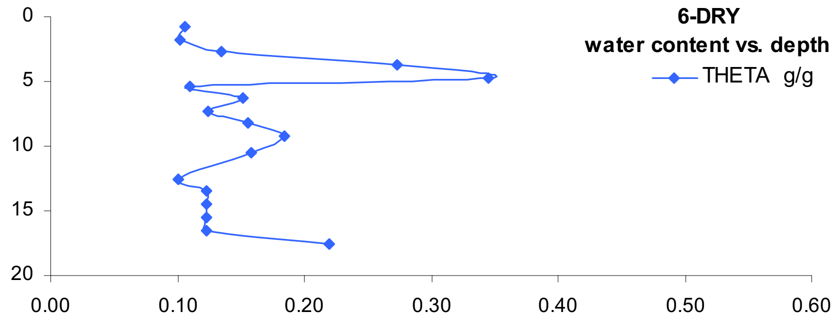
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 6-NV | 0–0.5 | 0.006 | 2205 | 13746 | 33.7 | 60.9 | 2.3 | 3.0 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.091 | 4997 | 1573 | 24.8 | 49.5 | 2.0 | 23.6 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.220 | 4930 | 1248 | 12.6 | 39.7 | 4.4 | 43.2 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.137 | 5043 | 1228 | 25.2 | 66.2 | 2.2 | 6.4 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.171 | 4691 | 1057 | 28.2 | 60.3 | 4.1 | 7.4 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.307 | 5432 | 1540 | 1.4 | 40.8 | 24.8 | 33.0 | 5.25 |
| | 5.5–5.8 | | | | | | | | 5.75 |
| | 5.8–6.5 | 0.089 | 6249 | 340 | 1.9 | 79.6 | 2.8 | 15.6 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.066 | 6180 | 184 | 1.2 | 88.0 | 1.6 | 9.2 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.110 | 6916 | 234 | 2.5 | 77.3 | 1.7 | 18.6 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.224 | 6539 | 124 | 28.8 | 31.9 | 2.8 | 36.5 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–11.0 | 0.202 | 6304 | 54 | 13.1 | 42.7 | 29.7 | 14.5 | 10.50 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–13.0 | 0.177 | 4570 | 43 | 16.2 | 34.5 | 38.7 | 10.7 | 12.50 |
| | 13.0–14.0 | 0.139 | 3238 | 43 | | | | | 13.50 |
| | 14.0–15.0 | 0.114 | 1816 | 32 | | | | | 14.50 |
| | 15.0–16.0 | 0.106 | 898 | 35 | 52.5 | 34.6 | 8.3 | 4.5 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.132 | 1092 | 4 | 22.9 | 34.5 | 25.2 | 17.3 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |

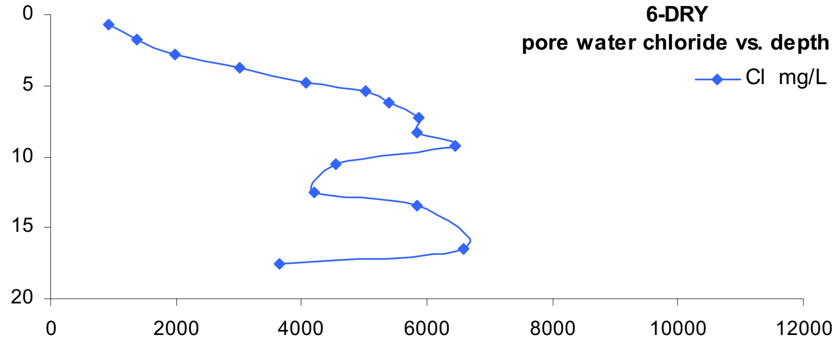


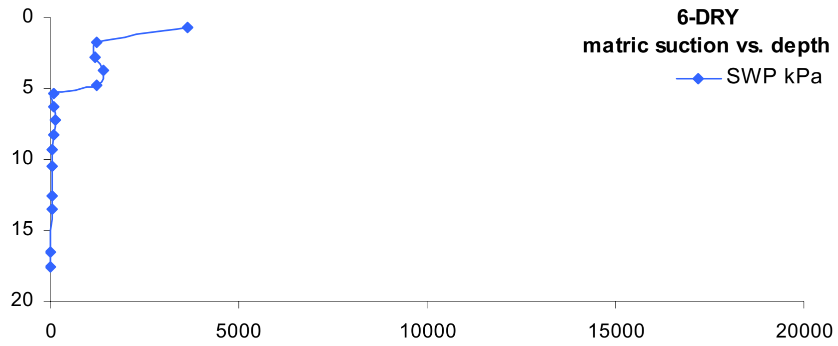



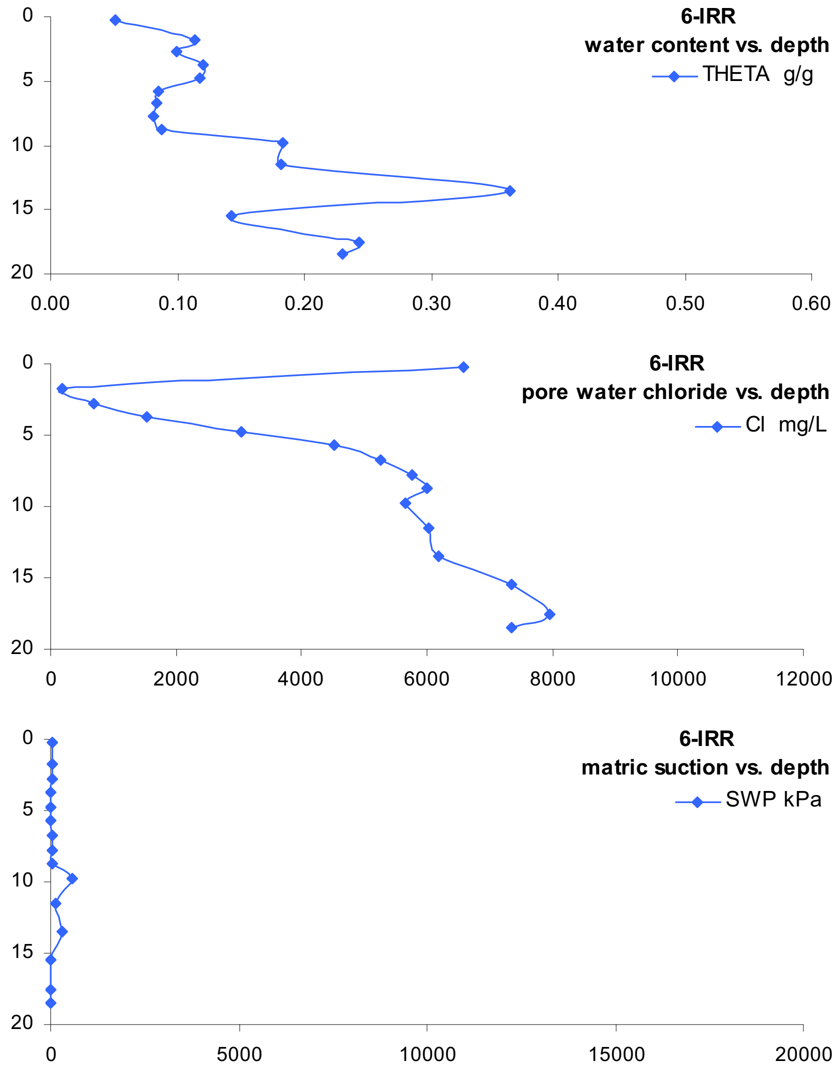
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 6-DRY | 0–0.5 | | | | | | | | 0.25 |
| | 0.5–1.0 | 0.106 | 922 | 3636 | 25.8 | 48.4 | 0.6 | 25.2 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.102 | 1372 | 1230 | 33.5 | 47.6 | 1.8 | 17.0 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.135 | 1972 | 1204 | 15.5 | 53.9 | 9.5 | 21.1 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.273 | 3019 | 1398 | 5.9 | 33.9 | 16.8 | 43.4 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.345 | 4063 | 1225 | 4.3 | 27.4 | 18.2 | 50.2 | 4.75 |
| | 5.0–5.2 | | | | | | | | 5.10 |
| | 5.2–5.5 | 0.110 | 5016 | 105 | 5.5 | 88.5 | 2.1 | 3.9 | 5.35 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.151 | 5393 | 73 | 6.1 | 64.6 | 4.3 | 25.0 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.124 | 5860 | 129 | 3.8 | 70.4 | 1.6 | 24.2 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.156 | 5841 | 69 | 3.8 | 64.5 | 7.5 | 24.1 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.184 | 6437 | 45 | 35.0 | 27.4 | 25.6 | 12.0 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–11.0 | 0.158 | 4551 | 27 | 35.5 | 29.4 | 23.3 | 12.8 | 10.50 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–13.0 | 0.101 | 4211 | 42 | | | | | 12.50 |
| | 13.0–14.0 | 0.123 | 5837 | 35 | 24.8 | 48.8 | 16.9 | 9.5 | 13.50 |
| | 14.0–15.0 | 0.123 | | | | | | | 14.50 |
| | 15.0–16.0 | 0.123 | | | | | | | 15.50 |
| | 16.0–17.0 | 0.123 | 6573 | 15 | | | | | 16.50 |
| | 17.0–18.0 | 0.219 | 3641 | 3 | 32.6 | 43.2 | 15.3 | 8.8 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |



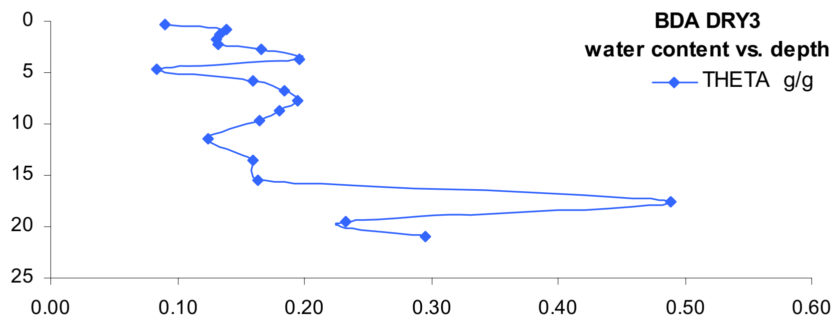



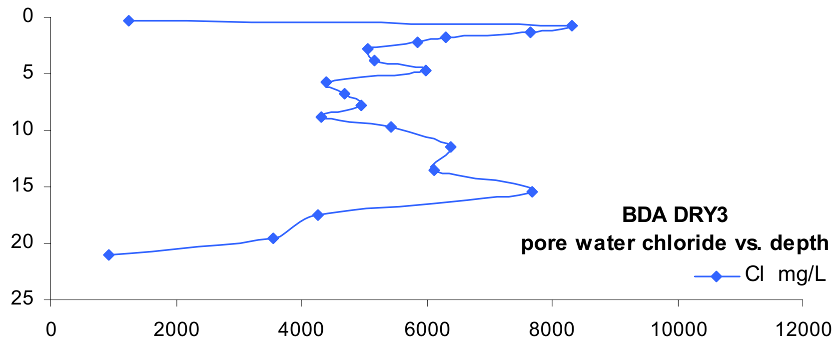



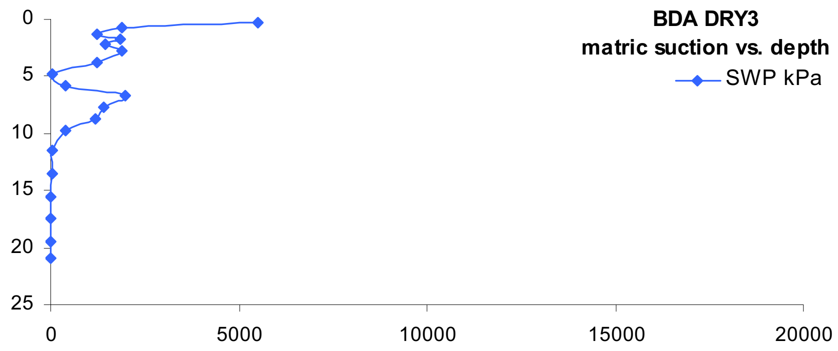
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 6-IRR | 0–0.5 | 0.051 | 6590 | 23 | 40.6 | 43.6 | 0.6 | 15.1 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.114 | 178 | 25 | 48.1 | 49.7 | 0.4 | 1.8 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.099 | 678 | 29 | 55.9 | 40.4 | 0.3 | 3.5 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.121 | 1541 | 18 | 24.1 | 59.1 | 2.7 | 14.1 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.118 | 3044 | 5 | 14.9 | 70.5 | 1.6 | 13.0 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.085 | 4508 | 11 | 24.9 | 67.2 | 2.0 | 5.8 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.083 | 5269 | 53 | 32.2 | 62.6 | 1.2 | 4.0 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.082 | 5767 | 51 | 25.3 | 63.3 | 2.5 | 8.9 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.087 | 6004 | 45 | 24.2 | 64.1 | 2.4 | 9.2 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.183 | 5667 | 594 | 17.5 | 56.9 | 4.8 | 20.8 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.182 | 6020 | 148 | 1.2 | 73.0 | 3.4 | 22.4 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.362 | 6189 | 287 | 6.1 | 31.6 | 2.5 | 59.8 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.142 | 7344 | 13 | 52.8 | 23.6 | 14.4 | 9.2 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.243 | 7948 | 5 | | | | | 17.50 |
| | 18.0–19.0 | 0.230 | 7335 | 3 | 57.7 | 22.0 | 14.8 | 5.5 | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |



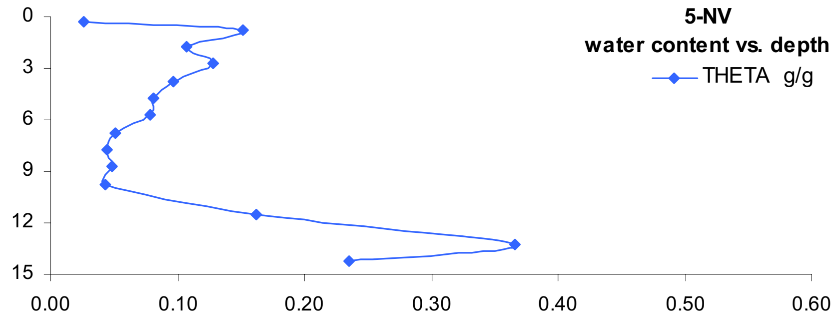
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| BDA DRY3 | 0–0.5 | 0.090 | 1242 | 5505 | 24.1 | 43.4 | 8.9 | 23.7 | 0.25 |
| | 0.5–1.0 | 0.139 | 8318 | 1896 | 11.2 | 24.5 | 7.2 | 57.2 | 0.75 |
| | 1.0–1.5 | 0.133 | 7648 | 1217 | 17.2 | 29.1 | 6.7 | 47.0 | 1.25 |
| | 1.5–2.0 | 0.131 | 6300 | 1851 | 28.3 | 30.5 | 5.7 | 35.5 | 1.75 |
| | 2.0–2.5 | 0.133 | 5851 | 1433 | 27.7 | 27.5 | 6.9 | 37.9 | 2.25 |
| | 2.5–3.0 | 0.166 | 5047 | 1879 | 32.1 | 25.7 | 6.3 | 35.9 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.196 | 5155 | 1241 | 21.4 | 38.7 | 2.5 | 37.3 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.083 | 5986 | 59 | 31.7 | 54.4 | 0.7 | 13.1 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.160 | 4400 | 412 | 23.1 | 52.0 | 5.5 | 19.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.184 | 4689 | 1985 | 3.9 | 36.6 | 17.0 | 42.6 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.194 | 4947 | 1388 | 1.1 | 34.0 | 21.5 | 43.4 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.181 | 4316 | 1177 | 0.4 | 32.9 | 26.6 | 40.1 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.165 | 5441 | 418 | 2.2 | 14.4 | 41.0 | 42.4 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.124 | 6376 | 33 | 11.2 | 77.3 | 4.4 | 7.2 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.160 | 6114 | 52 | 11.8 | 64.8 | 6.9 | 16.6 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.163 | 7690 | 22 | 48.7 | 29.5 | 16.4 | 5.4 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.489 | 4260 | 5 | 41.6 | 39.1 | 15.0 | 4.4 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.232 | 3553 | 4 | 43.7 | 37.1 | 15.3 | 3.9 | 19.50 |
| | 20.0–20.5 | | | | | | | | 20.25 |
| | 20.5–21.5 | 0.295 | 918 | 6 | 30.2 | 23.5 | 39.9 | 6.5 | 21.00 |

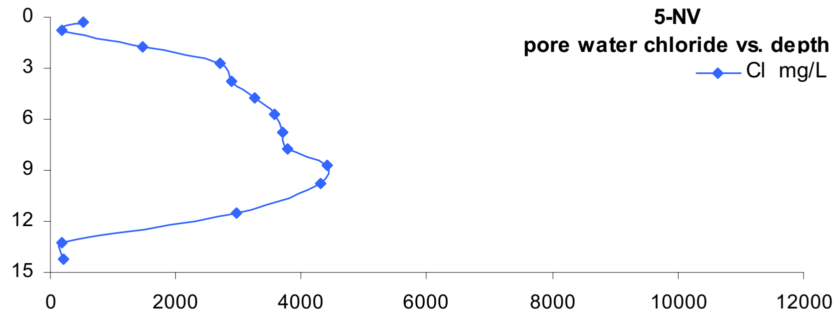


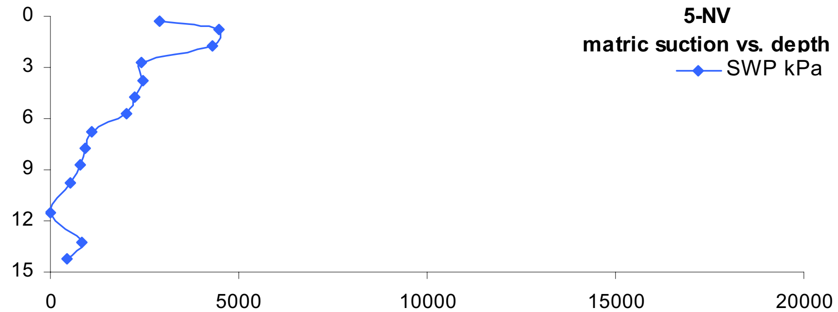



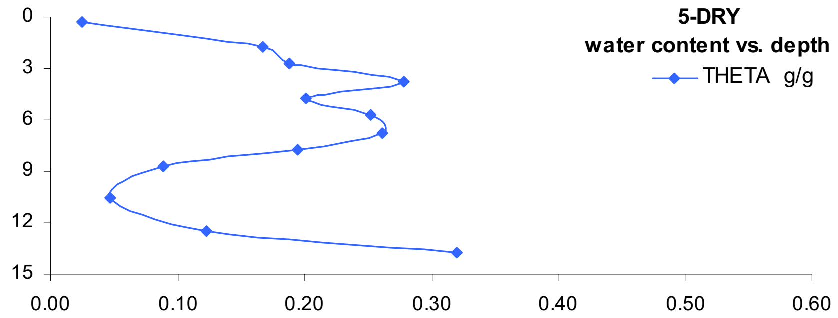
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 5-NV | 0–0.5 | 0.026 | 537 | 2894 | 51.6 | 39.9 | 3.2 | 5.3 | 0.25 |
| | 0.5–1.0 | 0.152 | 188 | 4488 | 38.8 | 31.8 | 3.3 | 26.0 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.108 | 1478 | 4296 | 35.3 | 29.7 | 3.2 | 31.8 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.127 | 2708 | 2395 | 30.4 | 22.8 | 3.8 | 42.9 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.096 | 2898 | 2468 | 42.4 | 33.3 | 4.6 | 19.7 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.081 | 3244 | 2250 | 70.4 | 21.6 | 1.3 | 6.7 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.079 | 3564 | 1997 | 59.2 | 23.3 | 2.0 | 15.6 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.051 | 3690 | 1093 | 71.1 | 17.8 | 0.7 | 10.3 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.044 | 3791 | 925 | 63.9 | 25.4 | 1.0 | 9.7 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.049 | 4407 | 773 | 62.2 | 28.2 | 0.5 | 9.1 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.043 | 4308 | 531 | 57.3 | 34.0 | 0.3 | 8.4 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.163 | 2980 | 4 | 49.3 | 36.1 | 1.2 | 13.3 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–13.5 | 0.366 | 190 | 838 | 9.3 | 18.1 | 6.0 | 66.6 | 13.25 |
| | 13.5–14.0 | | | | | | | | 13.75 |
| | 14.0–14.5 | 0.235 | 209 | 419 | 22.8 | 30.6 | 3.9 | 42.8 | 14.25 |
| | 14.5–15.0 | | | | | | | | 14.75 |

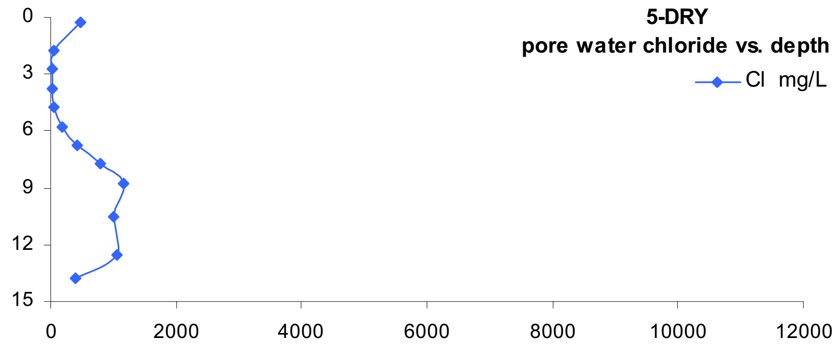


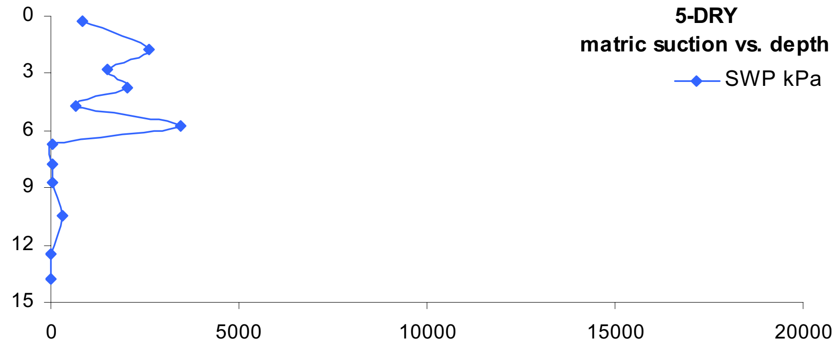



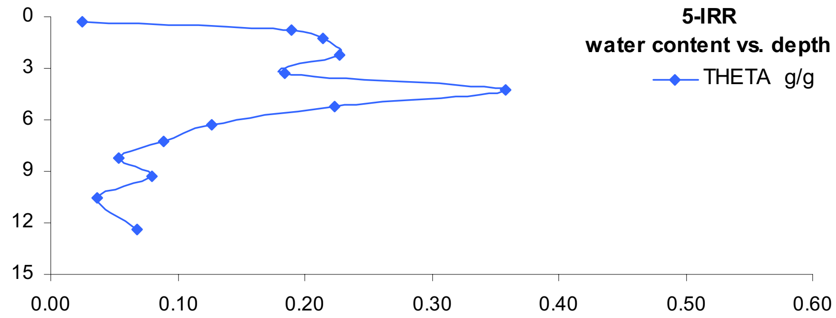
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 5-DRY | 0–0.5 | 0.025 | 477 | 846 | 29.7 | 60.4 | -0.5 | 10.4 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.168 | 40 | 2625 | 20.6 | 26.5 | 7.5 | 45.4 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.188 | 34 | 1496 | 29.3 | 27.0 | 1.7 | 42.0 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.278 | 35 | 2023 | 3.0 | 31.8 | 2.4 | 62.9 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.201 | 66 | 642 | 5.3 | 53.1 | 3.5 | 38.0 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.253 | 188 | 3441 | 21.7 | 15.3 | 3.6 | 59.4 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.262 | 413 | 57 | 20.3 | 17.1 | 11.3 | 51.4 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.195 | 796 | 41 | 34.2 | 24.5 | 18.9 | 22.4 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.089 | 1168 | 33 | 59.8 | 30.5 | 5.7 | 4.0 | 8.75 |
| | 9.0–10.0 | | | | | | | | 9.50 |
| | 10.0–11.0 | 0.047 | 998 | 309 | 36.3 | 39.7 | 15.3 | 8.6 | 10.50 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–13.0 | 0.124 | 1052 | 4 | 43.9 | 38.5 | 11.3 | 6.3 | 12.50 |
| | 13.0–13.5 | | | | | | | | 13.25 |
| | 13.5–14.0 | 0.320 | 408 | 4 | 57.8 | 35.5 | 2.8 | 3.8 | 13.75 |
| | 14.0–14.5 | | | | | | | | 14.25 |

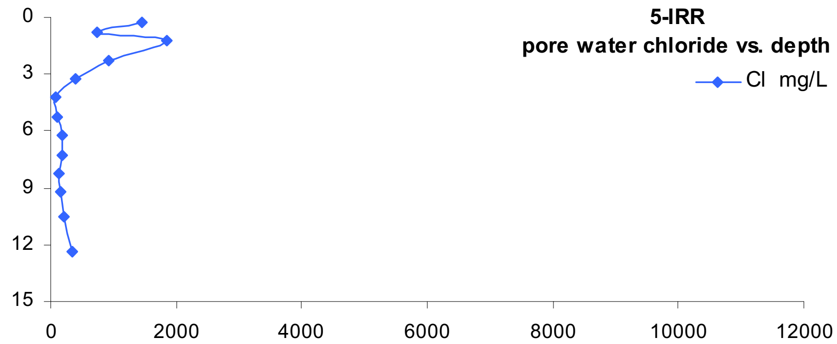


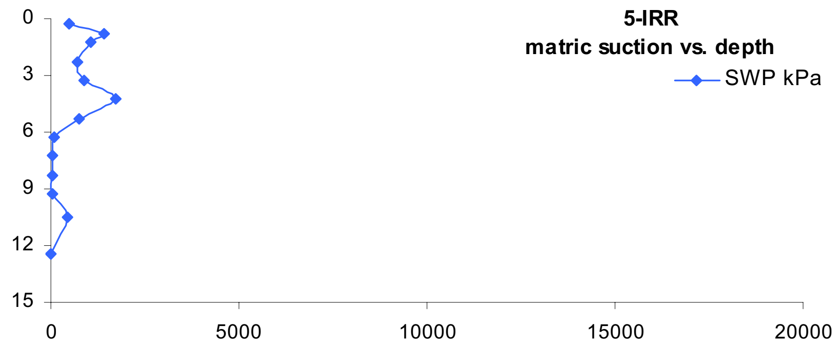



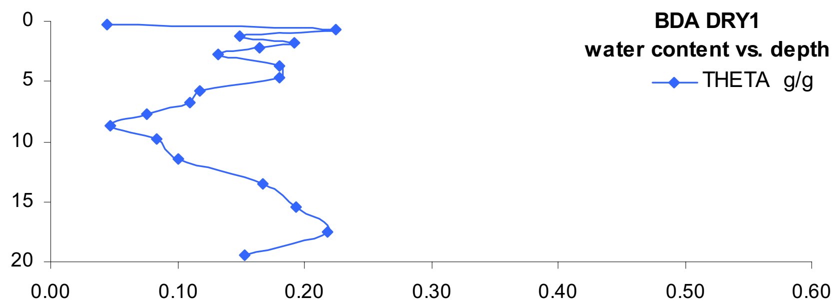
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 5-IRR | 0–0.5 | 0.025 | 1451 | 474 | 46.1 | 46.8 | 1.2 | 5.9 | 0.25 |
| | 0.5–1.0 | 0.190 | 751 | 1437 | 20.9 | 19.7 | 3.1 | 56.3 | 0.75 |
| | 1.0–1.5 | 0.215 | 1860 | 1083 | 24.3 | 23.6 | 3.0 | 49.1 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.228 | 932 | 724 | 21.6 | 30.0 | 3.4 | 45.0 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.184 | 393 | 877 | 3.5 | 45.1 | 2.1 | 49.2 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.359 | 78 | 1735 | 3.5 | 7.8 | 7.6 | 81.1 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.223 | 115 | 754 | 28.3 | 14.8 | 14.7 | 42.3 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.127 | 174 | 71 | 52.5 | 23.7 | 15.0 | 8.7 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.089 | 181 | 60 | 10.1 | 62.1 | 18.6 | 9.1 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.054 | 138 | 54 | 49.6 | 42.0 | 6.6 | 1.7 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.080 | 164 | 48 | 51.2 | 30.2 | 13.7 | 4.8 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–11.0 | 0.036 | 203 | 443 | 46.8 | 35.6 | 12.4 | 5.1 | 10.50 |
| | 11.0–11.8 | | | | | | | | 11.40 |
| | 11.8–13.0 | 0.068 | 334 | 15 | 33.0 | 40.9 | 17.1 | 9.0 | 12.40 |
| | 13.0–14.0 | | | | | | | | 13.50 |
| | 14.0–14.5 | | | | | | | | 14.25 |

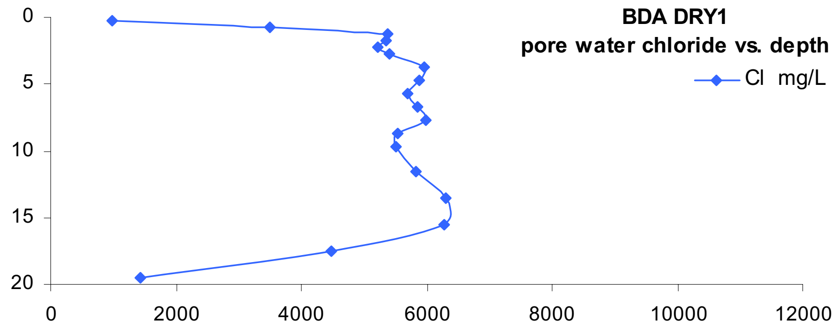


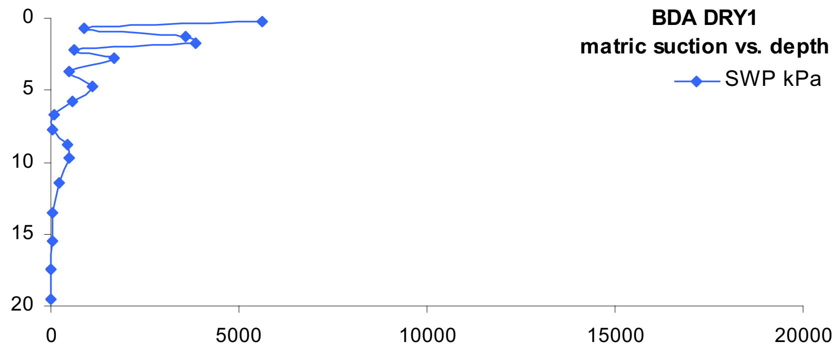



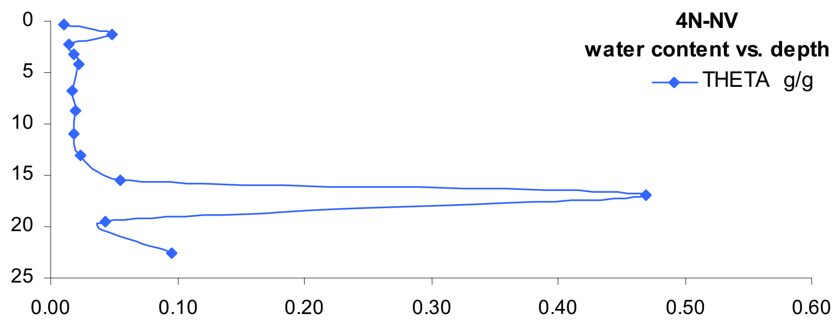
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| BDA DRY1 | 0–0.5 | 0.044 | 990 | 5631 | 16.3 | 52.6 | 11.2 | 19.9 | 0.25 |
| | 0.5–1.0 | 0.224 | 3489 | 895 | 10.1 | 35.4 | 9.2 | 45.4 | 0.75 |
| | 1.0–1.5 | 0.149 | 5370 | 3580 | 13.3 | 45.4 | 8.4 | 33.0 | 1.25 |
| | 1.5–2.0 | 0.192 | 5361 | 3863 | 18.6 | 40.7 | 5.5 | 35.3 | 1.75 |
| | 2.0–2.5 | 0.165 | 5226 | 631 | 22.7 | 49.6 | 2.4 | 25.2 | 2.25 |
| | 2.5–3.0 | 0.132 | 5394 | 1695 | 11.9 | 43.9 | 6.4 | 37.8 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.180 | 5955 | 497 | 13.1 | 47.4 | 2.4 | 37.1 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.180 | 5891 | 1119 | 9.9 | 36.6 | 8.4 | 45.1 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.117 | 5695 | 585 | 9.3 | 47.0 | 9.2 | 34.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.110 | 5855 | 103 | 29.2 | 51.2 | 2.3 | 17.3 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.075 | 5975 | 58 | 21.7 | 60.7 | 3.2 | 14.4 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.047 | 5542 | 450 | 2.8 | 83.3 | 1.7 | 12.3 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.083 | 5500 | 468 | 4.7 | 80.2 | 2.0 | 13.1 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.101 | 5821 | 208 | 20.0 | 50.3 | 7.6 | 22.1 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.167 | 6305 | 38 | 33.0 | 42.7 | 15.3 | 9.0 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.194 | 6287 | 27 | 35.8 | 30.6 | 30.5 | 3.0 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.218 | 4488 | 9 | 26.4 | 30.6 | 12.1 | 30.9 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.153 | 1441 | 3 | 56.3 | 28.0 | 13.3 | 2.5 | 19.50 |

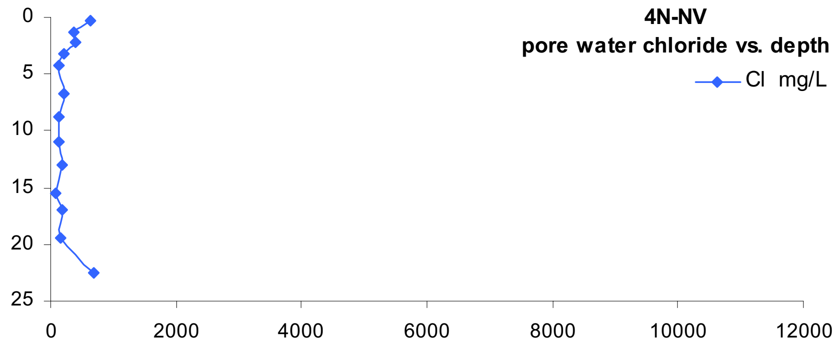


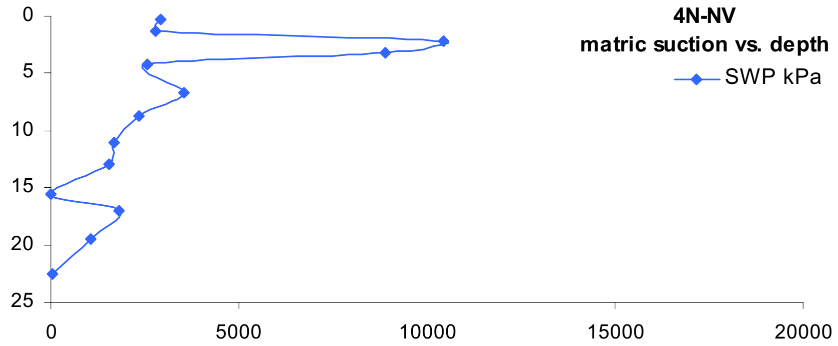



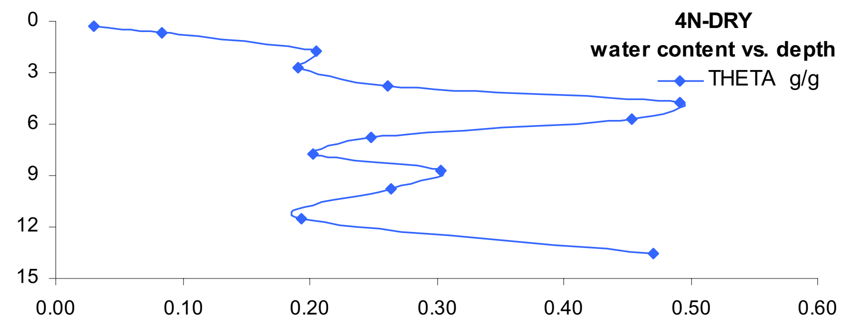
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4N-NV | 0–0.5 | 0.010 | 640 | 2921 | 34.3 | 60.8 | 1.2 | 3.8 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.048 | 365 | 2783 | 19.2 | 57.2 | 4.6 | 18.9 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.014 | 406 | 10454 | 48.1 | 28.1 | 13.2 | 10.7 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.018 | 217 | 8894 | 48.1 | 29.4 | 13.0 | 9.5 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.023 | 136 | 2549 | 48.3 | 25.5 | 18.5 | 7.7 | 4.25 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.017 | 221 | 3542 | 47.1 | 27.1 | 18.4 | 7.4 | 6.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.020 | 129 | 2361 | 55.8 | 19.9 | 16.2 | 8.1 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 10.5–11.5 | 0.018 | 135 | 1671 | 59.2 | 17.3 | 16.3 | 7.2 | 11.00 |
| | 11.5–12.5 | | | | | | | | 12.00 |
| | 12.5–13.5 | 0.024 | 188 | 1546 | 52.4 | 17.1 | 22.4 | 8.1 | 13.00 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.055 | 68 | 10 | 56.1 | 36.7 | 2.1 | 5.0 | 15.50 |
| | 16.0–16.5 | | | | | | | | 16.25 |
| | 17.5–18.5 | 0.469 | 193 | 1813 | 0.6 | 1.3 | 3.4 | 94.7 | 17.00 |
| | 18.5–19.0 | | | | | | | | 18.75 |
| | 19.0–20.0 | 0.043 | 172 | 1041 | 55.6 | 19.1 | 16.1 | 9.2 | 19.50 |
| | 20.0–21.0 | | | | | | | | 20.50 |
| | 22.0–23.0 | 0.095 | 690 | 58 | 45.0 | 26.3 | 18.5 | 10.2 | 22.50 |
| | 24.0–24.5 | | | | | | | | 24.25 |

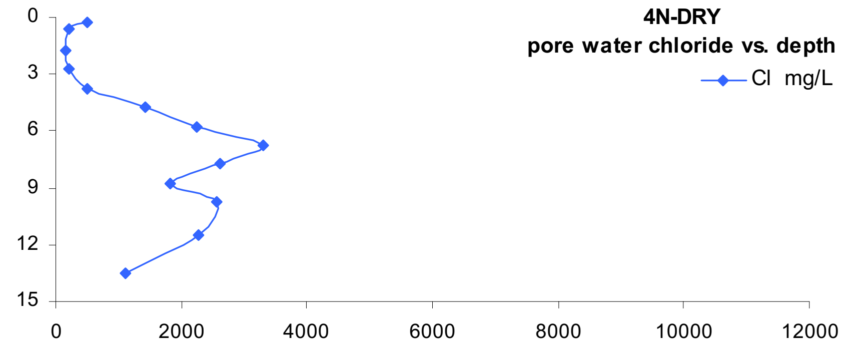


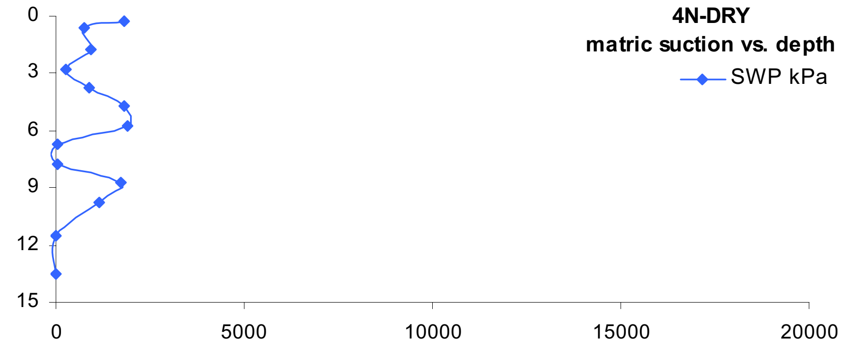



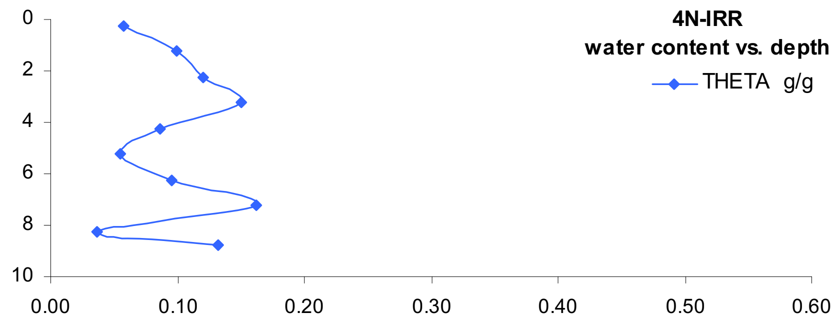
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4N-DRY | 0–0.5 | 0.030 | 511 | 1819 | 55.2 | 38.9 | 2.6 | 3.3 | 0.25 |
| | 0.5–0.8 | 0.083 | 207 | 751 | 19.9 | 41.9 | 5.7 | 32.5 | 0.65 |
| | 0.8–1.5 | | | | | | | | 0.90 |
| | 1.5–2.0 | | | | | | | | 1.25 |
| | 2.0–2.5 | 0.205 | 152 | 926 | 5.6 | 52.5 | 4.3 | 37.6 | 1.75 |
| | 2.5–3.0 | | | | | | | | 2.25 |
| | 3.0–3.5 | 0.191 | 209 | 267 | 6.3 | 40.6 | 5.5 | 47.6 | 2.75 |
| | 3.5–4.0 | | | | | | | | 3.25 |
| | 4.0–4.5 | 0.262 | 509 | 891 | 2.8 | 50.3 | 5.7 | 41.2 | 3.75 |
| | 4.5–5.0 | | | | | | | | 4.25 |
| | 5.0–5.5 | 0.491 | 1428 | 1815 | 0.7 | 11.1 | 3.8 | 84.4 | 4.75 |
| | 5.5–6.0 | | | | | | | | 5.25 |
| | 6.0–6.5 | 0.453 | 2249 | 1902 | 0.3 | 13.6 | 11.9 | 74.2 | 5.75 |
| | 6.5–6.8 | | | | | | | | 6.25 |
| | 6.8–7.0 | 0.249 | 3293 | 42 | 6.7 | 32.6 | 7.3 | 53.4 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.203 | 2622 | 48 | 11.9 | 47.5 | 2.7 | 37.9 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.303 | 1811 | 1733 | 14.8 | 12.4 | 8.0 | 64.8 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.264 | 2576 | 1161 | 1.5 | 45.4 | 11.6 | 41.5 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.194 | 2261 | 20 | 13.0 | 43.6 | 24.3 | 19.1 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.470 | 1114 | 11 | 9.9 | 47.0 | 26.5 | 16.6 | 13.50 |

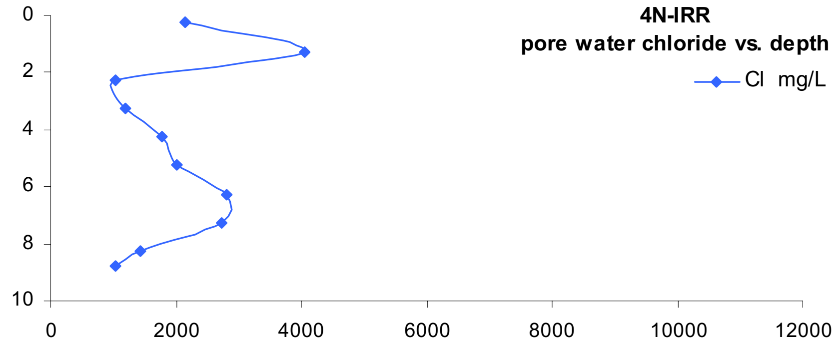


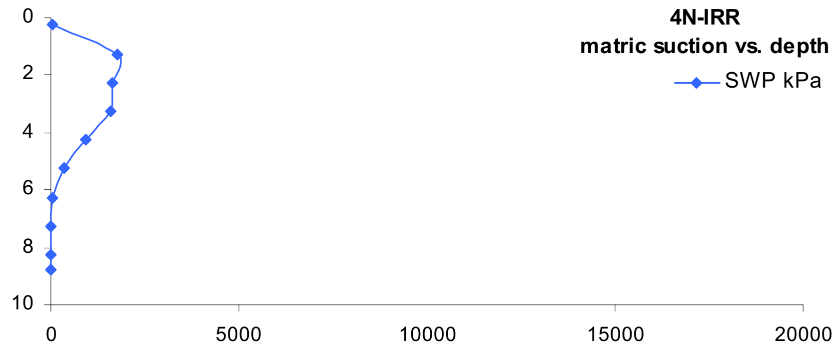



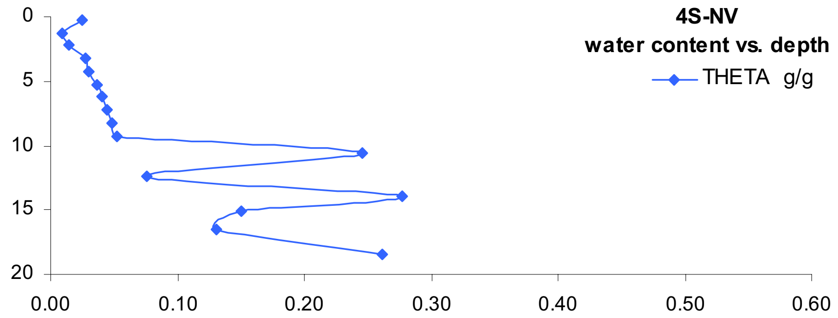
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4N-IRR | 0–0.5 | 0.057 | 2133 | 37 | 39.7 | 46.4 | 5.9 | 8.0 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.099 | 4050 | 1775 | 31.0 | 26.1 | 2.8 | 40.2 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.120 | 1033 | 1644 | 35.5 | 33.0 | 1.9 | 29.6 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.151 | 1197 | 1600 | | | | *7.2* | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.086 | 1783 | 944 | 47.5 | 37.2 | 1.0 | 14.3 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.055 | 2020 | 376 | 55.9 | 37.8 | 1.1 | 5.2 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.095 | 2805 | 31 | 2.4 | 78.9 | 4.2 | 14.5 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.162 | 2736 | 12 | 0.4 | 72.1 | 5.5 | 22.0 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.037 | 1434 | 3 | 93.0 | 4.2 | 0.7 | 2.1 | 8.25 |
| | 8.5–9.0 | 0.131 | 1021 | 2 | 82.8 | 10.2 | 0.5 | 6.5 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |

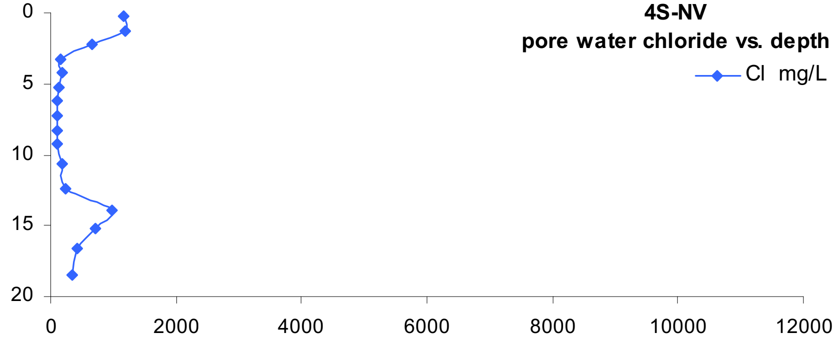


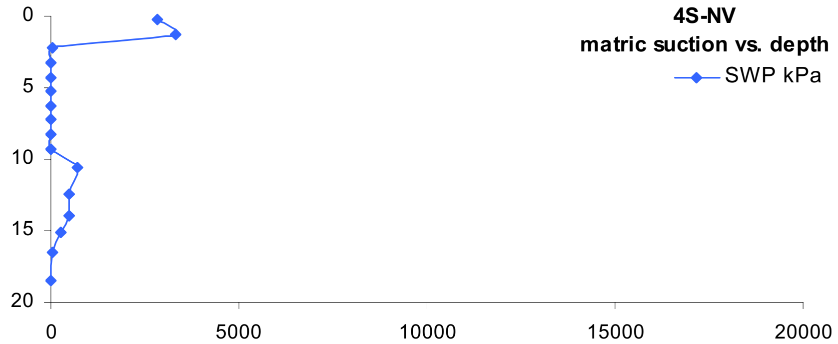



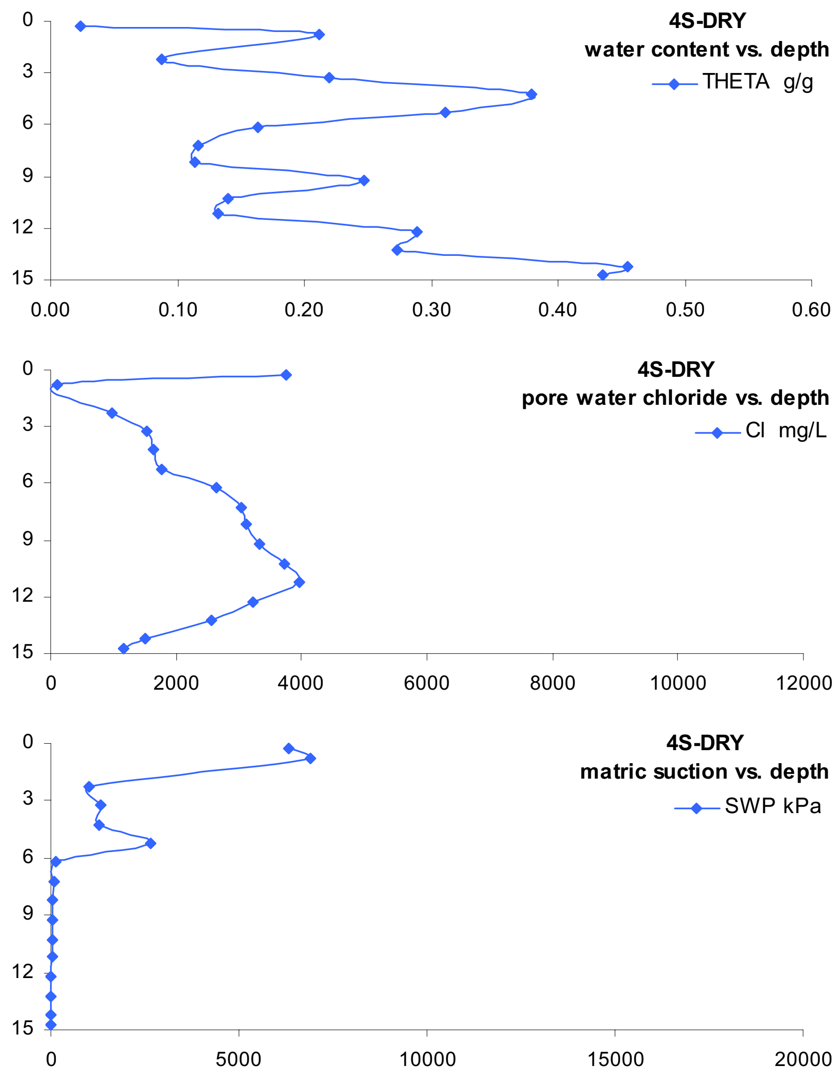
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4S-NV | 0–0.5 | 0.025 | 1171 | 2834 | 81.0 | 17.8 | 0.4 | 0.7 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.009 | 1197 | 3331 | 73.0 | 24.6 | 0.3 | 2.1 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.014 | 669 | 63 | 78.1 | 20.0 | 0.3 | 1.6 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.028 | 152 | 3 | 74.9 | 22.8 | 0.5 | 1.8 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.030 | 181 | 4 | 72.6 | 25.2 | 0.5 | 1.8 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.036 | 135 | 3 | 81.3 | 16.6 | 2.1 | 0.0 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.040 | 116 | 3 | 85.9 | 12.7 | 0.1 | 1.3 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.044 | 107 | 3 | 85.9 | 12.4 | 0.2 | 1.5 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.048 | 105 | 6 | 59.0 | 36.7 | 1.6 | 2.8 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.053 | 102 | 4 | 69.5 | 27.8 | 0.7 | 2.0 | 9.25 |
| | 9.5–10.2 | | | | | | | | 9.85 |
| | 10.2–11.0 | 0.245 | 172 | 707 | 39.1 | 23.6 | 1.9 | 35.4 | 10.60 |
| | 11.0–11.8 | | | | | | | | 11.40 |
| | 11.8–13.0 | 0.075 | 251 | 480 | 10.9 | 47.9 | 26.0 | 15.3 | 12.40 |
| | 13.0–13.5 | | | | | | | | 13.25 |
| | 13.5–14.4 | 0.277 | 978 | 473 | 35.1 | 20.4 | 4.1 | 40.4 | 13.95 |
| | 14.4–14.8 | | | | | | | | 14.60 |
| | 14.8–15.5 | 0.150 | 717 | 258 | 30.8 | 24.9 | 8.8 | 35.4 | 15.15 |
| | 15.5–16.1 | | | | | | | | 15.80 |
| | 16.1–17.0 | 0.131 | 436 | 24 | 14.5 | 53.2 | 22.2 | 10.1 | 16.55 |
| | 17.0–18.0 | | | | | | | | 17.50 |
| | 18.0–19.0 | 0.262 | 353 | 3 | 19.1 | 52.3 | 16.5 | 12.1 | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |



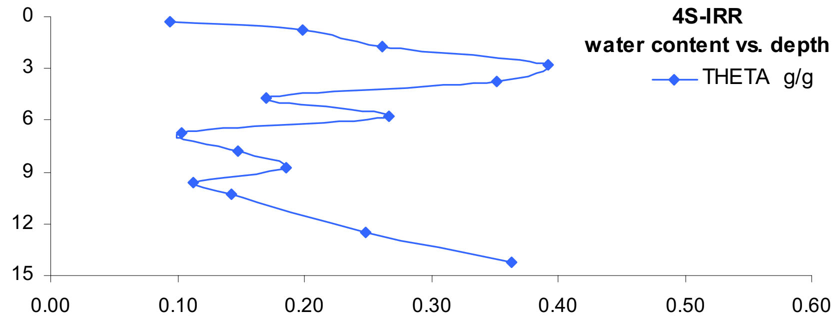



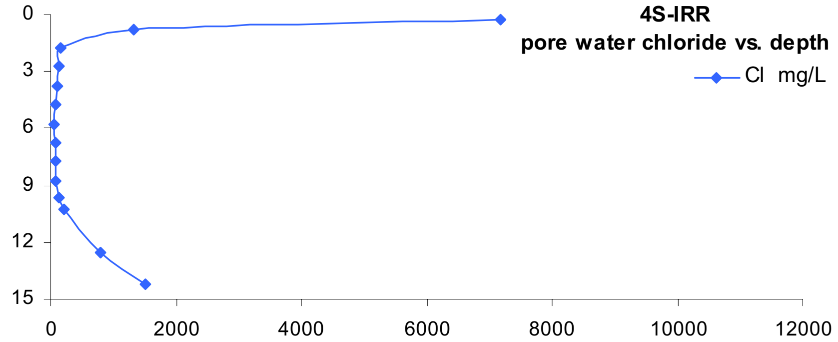



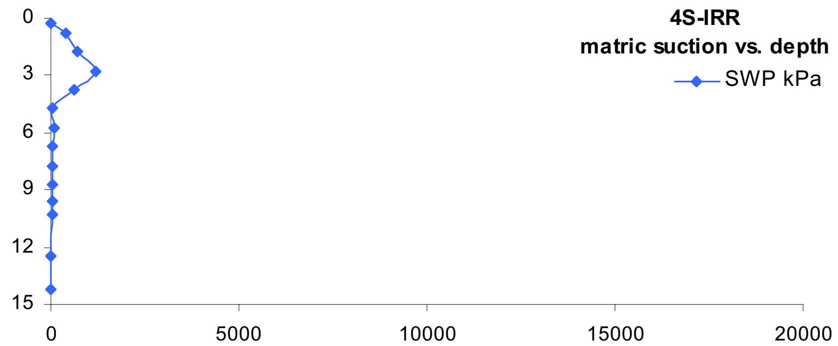
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4S-DRY | 0–0.5 | 0.024 | 3743 | 6324 | 44.1 | 42.7 | 4.8 | 8.4 | 0.25 |
| | 0.5–1.0 | 0.212 | 109 | 6881 | 14.7 | 8.7 | 2.3 | 74.3 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.087 | 982 | 1038 | 39.2 | 38.6 | 2.7 | 19.4 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.220 | 1521 | 1342 | 31.8 | 35.0 | 6.1 | 27.2 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.379 | 1647 | 1301 | 6.5 | 29.9 | 14.4 | 49.2 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.311 | 1782 | 2664 | 0.8 | 26.5 | 7.0 | 65.7 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.4 | 0.163 | 2635 | 150 | 4.0 | 33.9 | 32.8 | 29.4 | 6.20 |
| | 6.4–7.0 | | | | | | | | 6.70 |
| | 7.0–7.5 | 0.117 | 3031 | 84 | 18.9 | 32.9 | 32.7 | 15.4 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.4 | 0.114 | 3112 | 55 | 10.3 | 53.5 | 25.7 | 10.6 | 8.20 |
| | 8.4–9.0 | | | | | | | | 8.70 |
| | 9.0–9.5 | 0.247 | 3334 | 49 | 3.6 | 13.9 | 11.5 | 71.0 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–10.5 | 0.140 | 3738 | 36 | 12.5 | 39.0 | 33.5 | 15.1 | 10.25 |
| | 10.5–10.9 | | | | | | | | 10.70 |
| | 10.9–11.5 | 0.131 | 3953 | 40 | 13.4 | 31.7 | 41.7 | 13.2 | 11.20 |
| | 11.5–12.0 | | | | | | | | 11.75 |
| | 12.0–12.5 | 0.289 | 3217 | 17 | 7.3 | 29.5 | 43.9 | 19.3 | 12.25 |
| | 12.5–13.0 | | | | | | | | 12.75 |
| | 13.0–13.5 | 0.273 | 2567 | 5 | 7.4 | 41.6 | 38.9 | 12.2 | 13.25 |
| | 13.5–14.0 | | | | | | | | 13.75 |
| | 14.0–14.5 | 0.454 | 1495 | 5 | 5.8 | 29.5 | 40.8 | 23.8 | 14.25 |
| | 14.5–15.0 | 0.435 | 1157 | 7 | 5.4 | 34.4 | 39.1 | 21.2 | 14.75 |
| | 15.0–15.5 | | | | | | | | 15.25 |
| | 15.5–16.0 | | | | | | | | 15.75 |
| | 16.0–16.5 | | | | | | | | 16.25 |
| | 16.5–17.0 | | | | | | | | 16.75 |



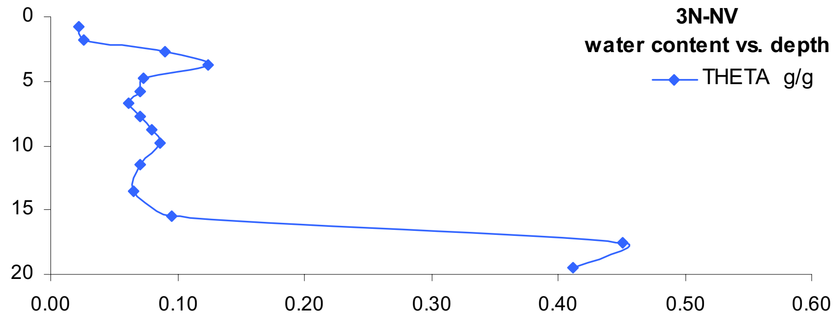
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 4S-IRR | 0–0.5 | 0.095 | 7178 | 8 | 42.0 | 45.8 | 4.1 | 8.1 | 0.25 |
| | 0.5–1.0 | 0.199 | 1320 | 400 | 21.4 | 22.3 | 7.0 | 49.4 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.261 | 157 | 696 | 34.6 | 32.8 | 5.3 | 27.3 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.393 | 142 | 1188 | 13.4 | 37.7 | 7.7 | 41.2 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.351 | 114 | 636 | 2.4 | 20.1 | 4.6 | 72.9 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.169 | 85 | 57 | 3.1 | 36.7 | 39.0 | 21.3 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.266 | 66 | 72 | 7.1 | 19.7 | 1.8 | 71.4 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.103 | 91 | 61 | 8.4 | 48.6 | 28.5 | 14.6 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.147 | 83 | 54 | 6.6 | 43.1 | 36.9 | 13.4 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.186 | 87 | 50 | 6.3 | 29.0 | 28.6 | 36.1 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–9.75 | 0.113 | 121 | 51 | 13.7 | 44.5 | 29.9 | 11.9 | 9.63 |
| | 9.75–10.5 | | | | | | | | 10.13 |
| | 10.5–11.0 | 0.143 | 202 | 43 | 13.1 | 37.6 | 35.4 | 13.9 | 10.25 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–13.0 | 0.249 | 786 | 19 | 6.7 | 29.7 | 35.1 | 28.5 | 12.50 |
| | 13.0–14.0 | | | | | | | | 13.50 |
| | 14.0–14.5 | 0.363 | 1518 | 3 | 7.6 | 30.5 | 53.3 | 8.6 | 14.25 |
| | 14.5–15.5 | | | | | | | | 15.00 |
| | 15.5–16.5 | | | | | | | | 16.00 |

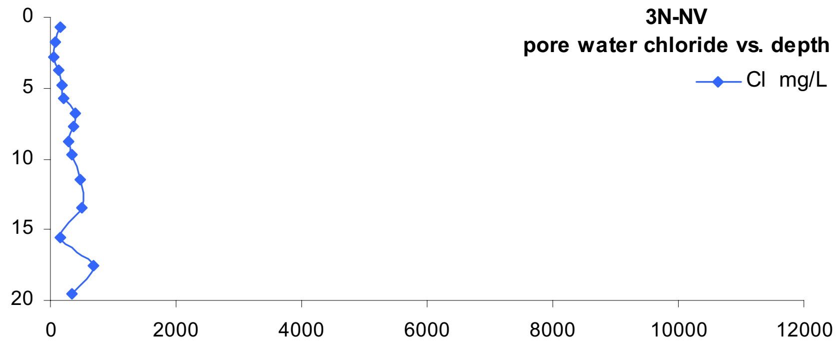


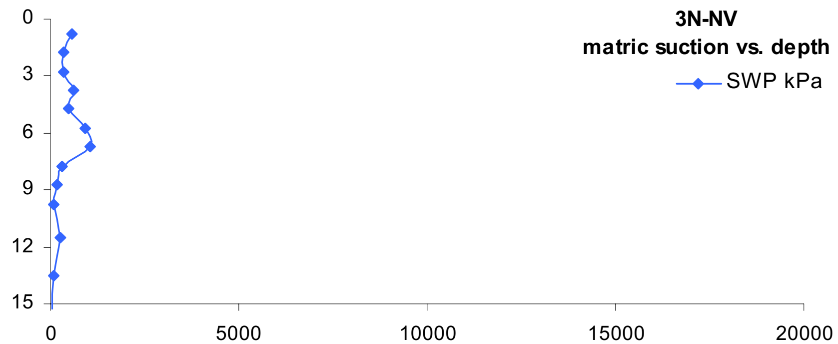



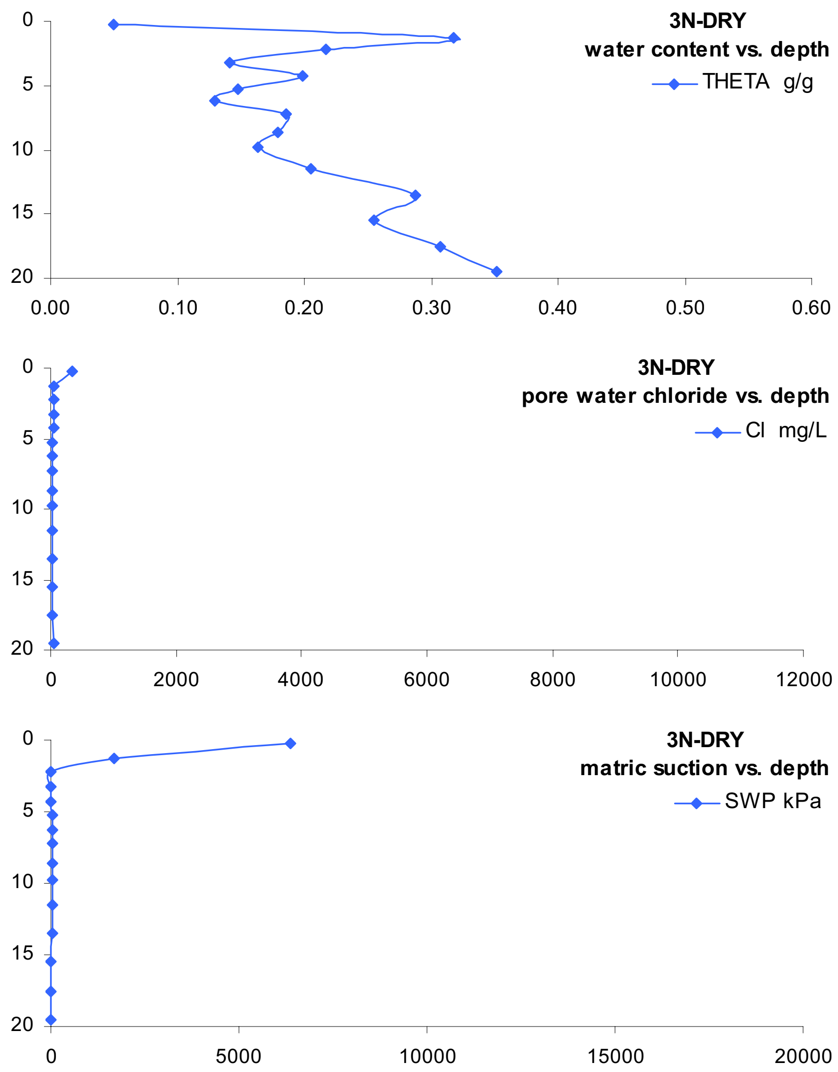
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3N-NV | 0–0.5 | | | | | | | | 0.25 |
| | 0.5–1.0 | 0.022 | 152 | 566 | 40.2 | 52.8 | 2.5 | 4.6 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.026 | 84 | 364 | 39.9 | 56.0 | 1.4 | 2.8 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.091 | 53 | 372 | 45.6 | 27.0 | 2.4 | 25.0 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.124 | 133 | 596 | 33.1 | 39.2 | 2.5 | 25.2 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.073 | 184 | 471 | 57.3 | 25.4 | 1.5 | 15.8 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.071 | 205 | 900 | 17.5 | 61.0 | 2.9 | 18.6 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.061 | 393 | 1035 | 6.7 | 66.3 | 7.3 | 19.7 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.071 | 381 | 324 | 11.3 | 70.5 | 4.8 | 13.5 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.079 | 285 | 171 | 8.7 | 71.4 | 4.5 | 15.4 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.087 | 331 | 75 | 12.0 | 69.8 | 3.4 | 14.7 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.071 | 463 | 269 | 15.2 | 66.8 | 5.1 | 13.0 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.065 | 487 | 77 | 29.5 | 53.3 | 4.2 | 13.0 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.095 | 166 | 28 | 1.6 | 78.3 | 5.2 | 15.0 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.2 | 0.450 | 682 | 207 | 6.2 | 50.2 | 12.6 | 31.0 | 17.60 |
| | 18.2–19.0 | | | | | | | | 18.60 |
| | 19.0–20.0 | 0.412 | 354 | 40 | 19.1 | 18.1 | 2.3 | 60.5 | 19.50 |



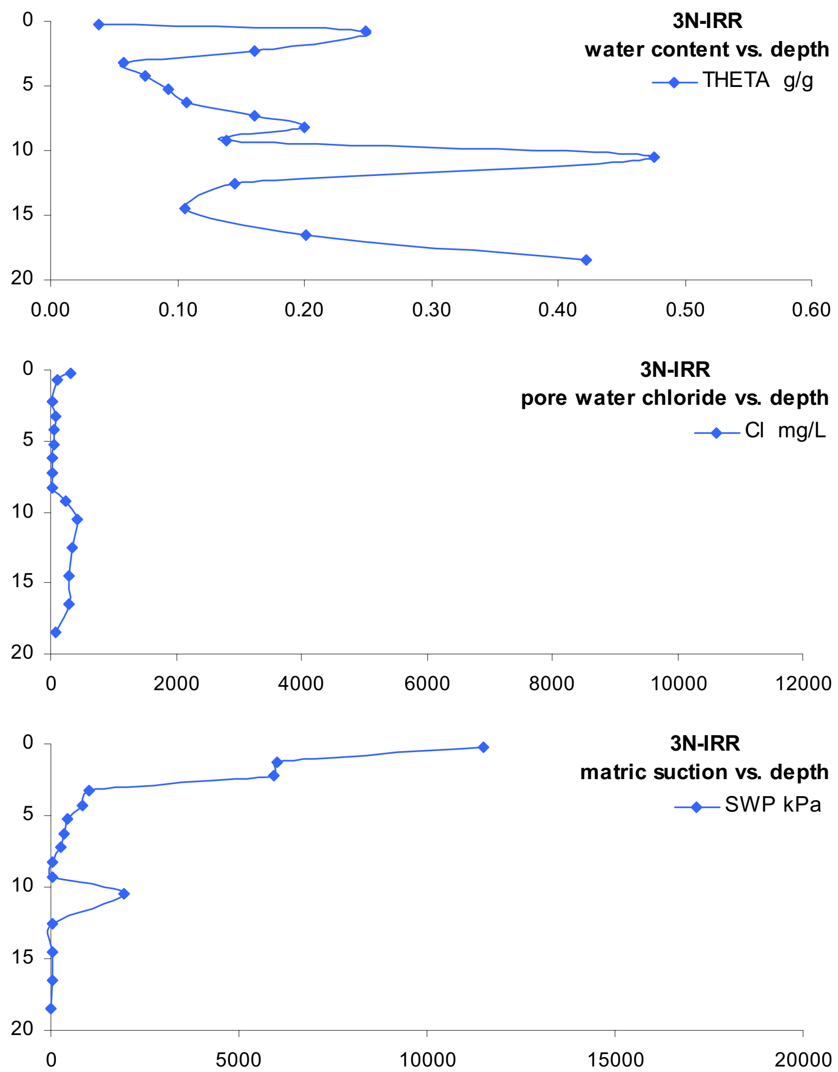



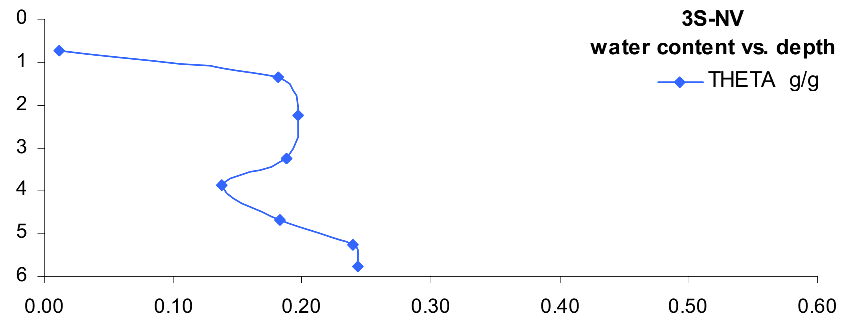
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3N-DRY | 0–0.5 | 0.049 | 356 | 6355 | 34.2 | 45.4 | 3.8 | 16.6 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.317 | 44 | 1688 | 7.3 | 10.6 | 8.8 | 73.4 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.217 | 51 | 15 | 16.3 | 42.5 | 30.7 | 10.5 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.141 | 50 | 22 | 25.0 | 45.7 | 19.1 | 10.2 | 3.25 |
| | 3.5–3.9 | | | | | | | | 3.75 |
| | 3.9–4.5 | 0.199 | 45 | 15 | 26.3 | 36.5 | 20.0 | 17.2 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.148 | 28 | 26 | 31.5 | 35.4 | 18.0 | 15.1 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.130 | 26 | 39 | 28.8 | 38.4 | 19.7 | 13.2 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.185 | 22 | 26 | 30.4 | 38.7 | 16.5 | 14.4 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.3 | | | | | | | | 8.15 |
| | 8.3–9.0 | 0.179 | 21 | 58 | 28.9 | 23.4 | 19.4 | 28.3 | 8.65 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.163 | 29 | 25 | 26.0 | 34.2 | 22.4 | 17.4 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.206 | 30 | 36 | 17.1 | 35.3 | 24.6 | 23.0 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.288 | 29 | 40 | 20.1 | 25.3 | 15.8 | 38.7 | 13.50 |
| | 14.0–15.0 | | | | | | | | 14.50 |
| | 15.0–16.0 | 0.255 | 28 | 22 | 6.0 | 37.7 | 40.2 | 16.1 | 15.50 |
| | 16.0–17.0 | | | | | | | | 16.50 |
| | 17.0–18.0 | 0.308 | 30 | 4 | 10.7 | 42.9 | 31.3 | 15.0 | 17.50 |
| | 18.0–19.0 | | | | | | | | 18.50 |
| | 19.0–20.0 | 0.351 | 53 | 3 | 21.8 | 13.0 | 7.7 | 57.6 | 19.50 |

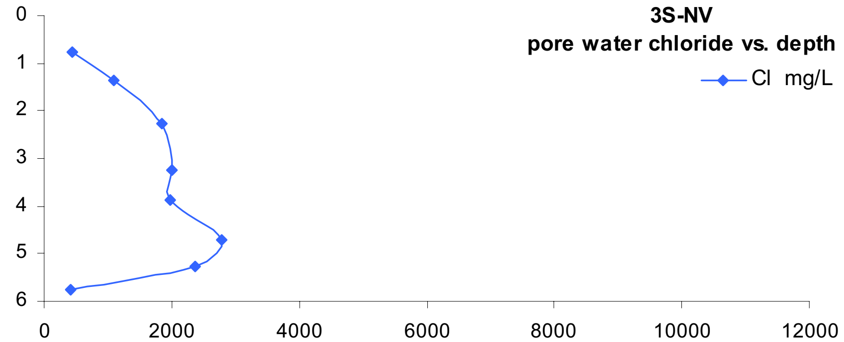


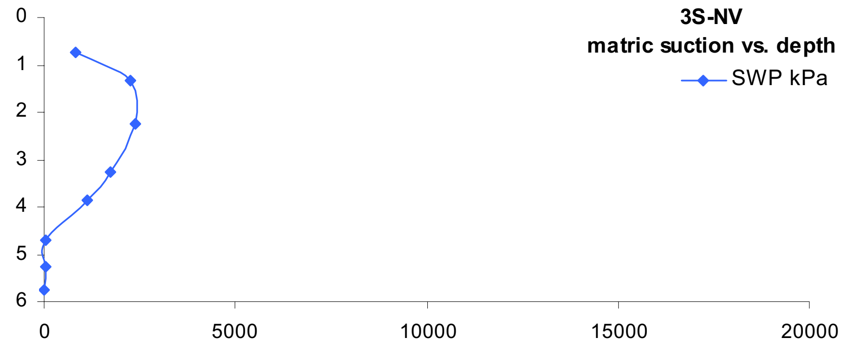
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3N-IRR | 0–0.5 | 0.038 | 305 | 11492 | 44.7 | 42.7 | 2.0 | 10.5 | 0.25 |
| | 0.5–1.0 | 0.248 | 114 | | 16.0 | 16.4 | 2.4 | 65.2 | 0.75 |
| | 1.0–1.5 | | | 5997 | | | | | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.161 | 25 | 5947 | 33.1 | 12.0 | 6.3 | 48.5 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.058 | 69 | 1020 | 35.3 | 35.0 | 17.3 | 12.4 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.075 | 58 | 852 | 32.5 | 26.9 | 24.1 | 16.6 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.092 | 46 | 442 | 39.2 | 36.9 | 11.5 | 12.4 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.108 | 37 | 360 | 29.5 | 49.9 | 9.4 | 11.2 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.160 | 27 | 244 | 29.1 | 27.8 | 9.8 | 33.2 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.200 | 21 | 57 | 21.4 | 27.8 | 22.8 | 28.0 | 8.25 |
| | 8.5–9.0 | | | | | | | | 8.75 |
| | 9.0–9.5 | 0.139 | 234 | 54 | 22.2 | 42.0 | 24.3 | 11.6 | 9.25 |
| | 9.5–10.0 | | | | | | | | 9.75 |
| | 10.0–11.0 | 0.476 | 411 | 1944 | 5.6 | 3.8 | 1.0 | 89.6 | 10.50 |
| | 11.0–12.0 | | | | | | | | 11.50 |
| | 12.0–13.0 | 0.146 | 339 | 62 | 29.0 | 28.7 | 2.3 | 39.9 | 12.50 |
| | 13.0–14.0 | | | | | | | | 13.50 |
| | 14.0–15.0 | 0.105 | 281 | 49 | 28.0 | 43.2 | 19.7 | 9.0 | 14.50 |
| | 15.0–16.0 | | | | | | | | 15.50 |
| | 16.0–17.0 | 0.201 | 283 | 30 | 9.2 | 25.1 | 19.0 | 46.6 | 16.50 |
| | 17.0–18.0 | | | | | | | | 17.50 |
| | 18.0–19.0 | 0.423 | 88 | 5 | 5.4 | 17.2 | 21.8 | 55.7 | 18.50 |
| | 19.0–20.0 | | | | | | | | 19.50 |



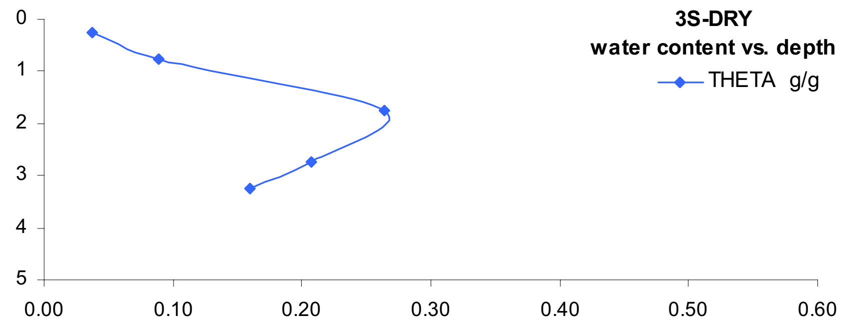
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3S-NV | 0–0.5 | | | | | | | | 0.25 |
| | 0.5–1.0 | 0.012 | 436 | 832 | 51.8 | 44.1 | 1.7 | 2.5 | 0.75 |
| | 1.0–1.2 | | | | | | | | 1.10 |
| | 1.2–1.5 | 0.182 | 1102 | 2266 | 32.0 | 22.4 | 6.3 | 39.4 | 1.35 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.197 | 1847 | 2403 | 30.4 | 24.9 | 4.3 | 40.3 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.188 | 2007 | 1744 | 31.1 | 24.3 | 5.0 | 39.6 | 3.25 |
| | 3.5–3.75 | | | | | | | | 3.63 |
| | 3.75–4.0 | 0.138 | 1972 | 1139 | 41.2 | 32.4 | 2.6 | 23.8 | 3.88 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–4.9 | 0.183 | 2787 | 39 | 40.7 | 27.0 | 2.5 | 29.8 | 4.70 |
| | 4.9–5.0 | | | | | | | | 4.95 |
| | 5.0–5.5 | 0.240 | 2360 | 26 | 41.3 | 17.6 | 3.5 | 37.5 | 5.25 |
| | 5.5–6.0 | 0.244 | 428 | 5 | 41.2 | 27.0 | 3.3 | 28.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |

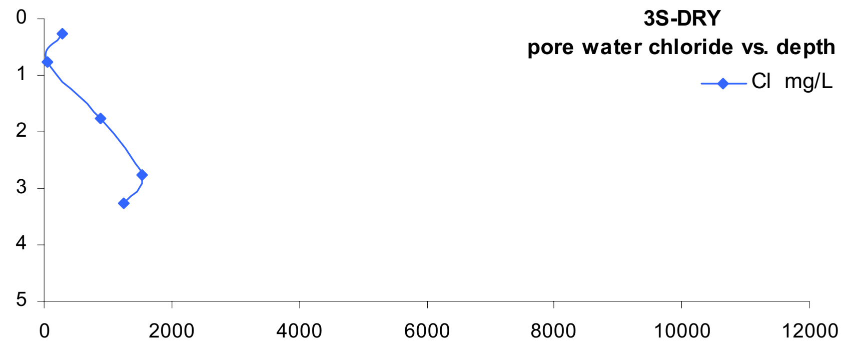


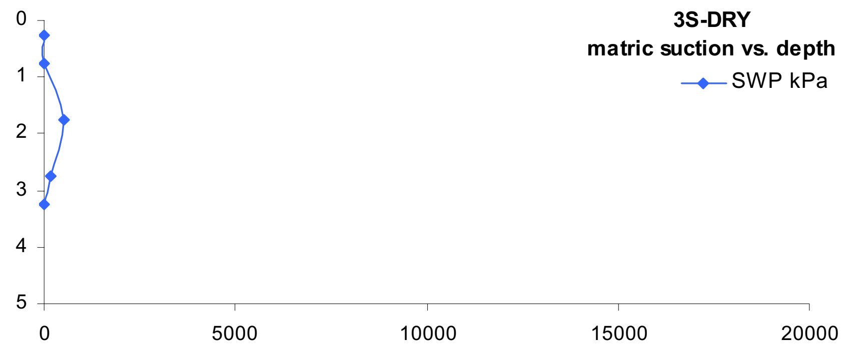



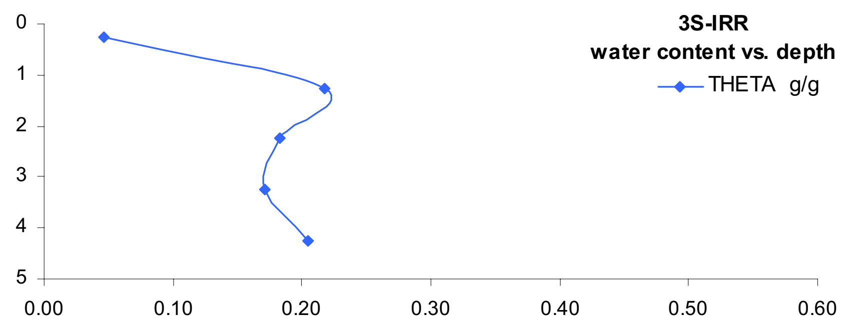
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3S-DRY | 0–0.5 | 0.037 | 278 | 17 | 54.5 | 41.2 | 1.5 | 2.9 | 0.25 |
| | 0.5–1.0 | 0.089 | 51 | 4 | 63.7 | 27.4 | 2.0 | 7.0 | 0.75 |
| | 1.0–1.5 | | | | | | | | 1.25 |
| | 1.5–2.0 | 0.264 | 879 | 506 | 53.0 | 30.0 | 2.2 | 14.8 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.208 | 1535 | 189 | 52.0 | 21.3 | 2.9 | 23.8 | 2.75 |
| | 3.0–3.5 | 0.160 | 1238 | 4 | 67.6 | 12.1 | 0.9 | 19.4 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |

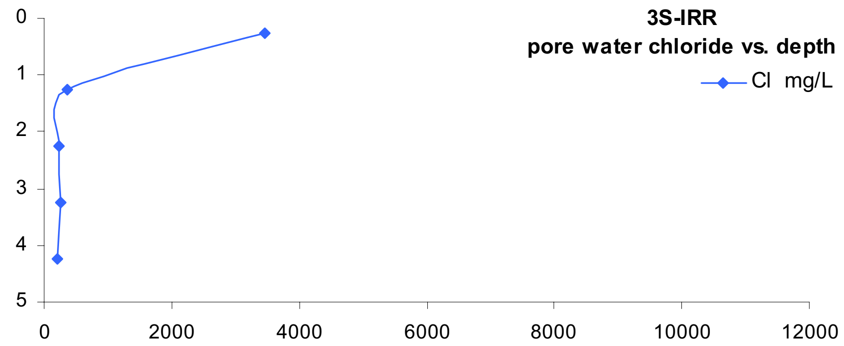


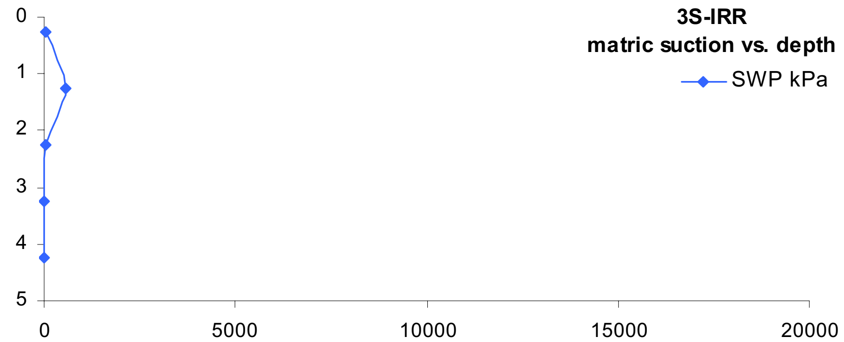



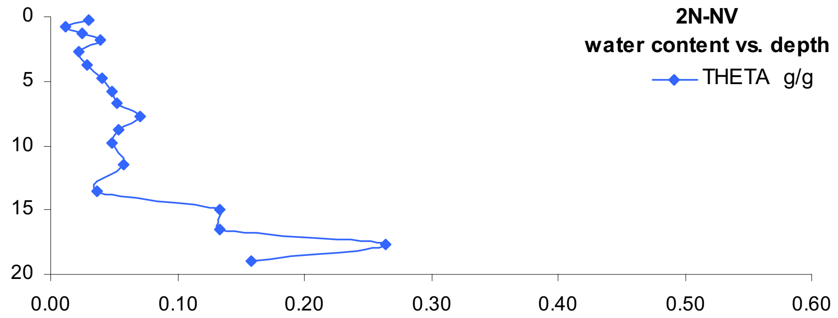
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 3S-IRR | 0–0.5 | 0.046 | 3474 | 22 | 26.8 | 16.3 | 12.6 | 44.3 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.218 | 353 | 548 | 56.9 | 39.5 | 1.3 | 2.4 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.182 | 245 | 55 | 35.0 | 19.9 | 12.5 | 32.7 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.172 | 259 | 5 | 51.8 | 16.6 | 2.8 | 28.9 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.204 | 218 | 4 | 48.4 | 38.5 | 6.1 | 6.9 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |

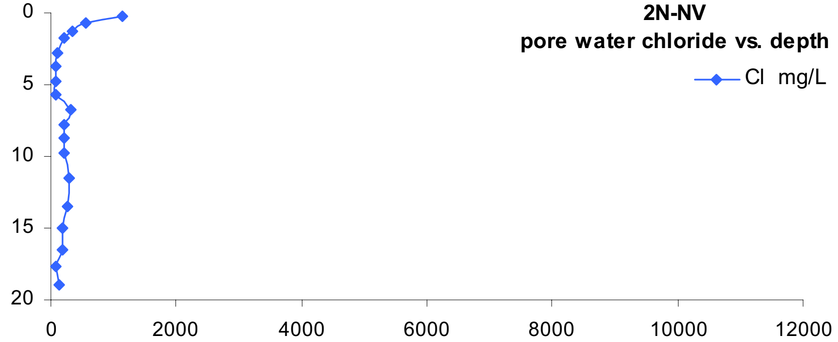


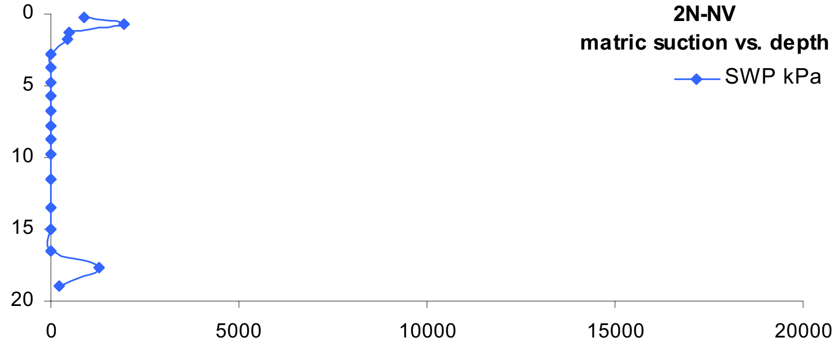



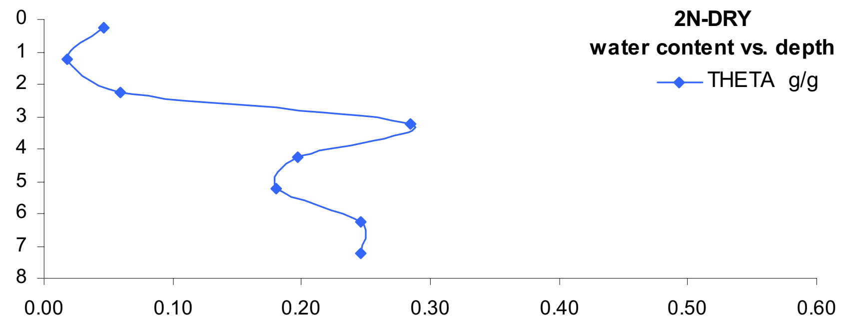
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2N-NV | 0–0.5 | 0.030 | 1146 | 891 | 64.2 | 34.1 | 0.5 | 1.2 | 0.25 |
| | 0.5–1.0 | 0.011 | 546 | 1928 | 41.0 | 56.3 | 0.5 | 2.1 | 0.75 |
| | 1.0–1.5 | 0.024 | 356 | 492 | 42.5 | 53.5 | 0.8 | 3.2 | 1.25 |
| | 1.5–2.0 | 0.039 | 206 | 451 | 38.3 | 54.9 | 2.1 | 4.7 | 1.75 |
| | 2.0–2.5 | | | | | | | | 2.25 |
| | 2.5–3.0 | 0.023 | 96 | 14 | 41.7 | 56.0 | 0.6 | 1.8 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.029 | 73 | 5 | 57.3 | 41.2 | 0.2 | 1.3 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.040 | 68 | 4 | 59.6 | 37.4 | 3.0 | 0.0 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.048 | 71 | 4 | 59.6 | 37.8 | 0.5 | 2.1 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.052 | 316 | 4 | 58.6 | 39.4 | 2.0 | 0.0 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.071 | 209 | 3 | 56.1 | 41.9 | 2.0 | 0.0 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.053 | 203 | 4 | 46.4 | 51.2 | 0.2 | 2.2 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.048 | 203 | 4 | 55.9 | 41.6 | 0.2 | 2.2 | 9.75 |
| | 10.0–11.0 | | | | | | | | 10.50 |
| | 11.0–12.0 | 0.057 | 285 | 4 | 9.3 | 87.7 | 0.4 | 2.6 | 11.50 |
| | 12.0–13.0 | | | | | | | | 12.50 |
| | 13.0–14.0 | 0.037 | 268 | 4 | 43.0 | 55.7 | 0.1 | 1.3 | 13.50 |
| | 14.0–14.7 | | | | | | | | 14.35 |
| | 14.7–15.2 | 0.133 | 184 | 4 | 38.8 | 53.2 | 0.6 | 7.3 | 14.95 |
| | 15.2–16.0 | | | | | | | | 15.60 |
| | 16.0–17.0 | 0.133 | 181 | 3 | 40.4 | 52.4 | 0.7 | 6.5 | 16.50 |
| | 17.0–17.5 | | | | | | | | 17.25 |
| | 17.5–17.9 | 0.264 | 79 | 1286 | 27.2 | 14.9 | 4.5 | 53.5 | 17.70 |
| | 17.9–18.5 | | | | | | | | 18.20 |
| | 18.5–19.5 | 0.158 | 132 | 235 | 32.8 | 19.3 | 5.7 | 42.2 | 19.00 |
| | 19.5–20 | | | | | | | | 19.75 |

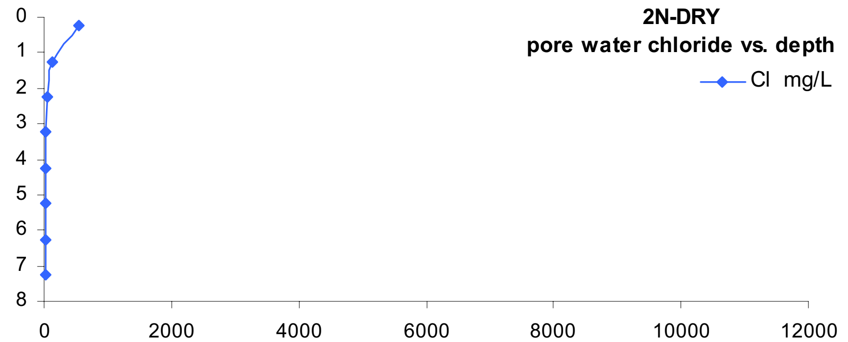


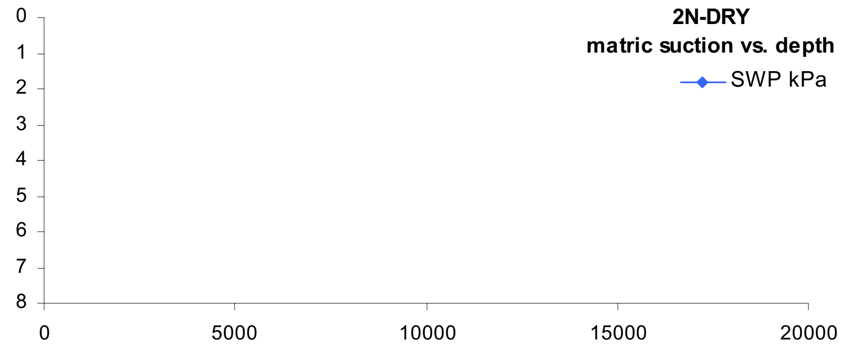



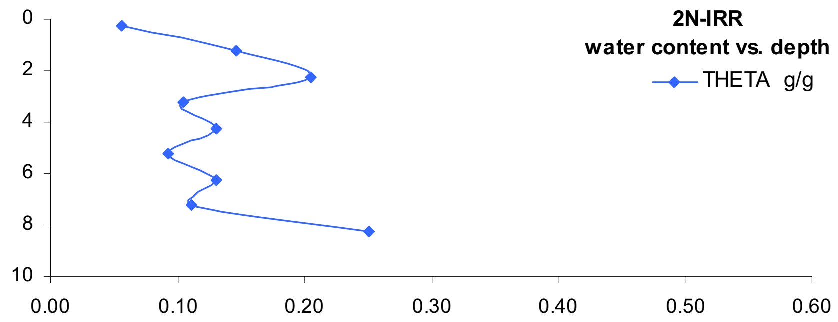
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2N-DRY | 0–0.5 | 0.046 | 536 | | 60.7 | 35.7 | 1.4 | 2.2 | 0.25 |
| | 0.5–1.0 | | | | 57.1 | 39.3 | 1.7 | 1.9 | 0.75 |
| | 1.0–1.5 | 0.018 | 131 | | 54.5 | 34.8 | 5.3 | 5.4 | 1.25 |
| | 1.5–2.0 | | | | 62.5 | 36.5 | 2.9 | 4.7 | 1.75 |
| | 2.0–2.5 | 0.059 | 52 | | 58.6 | 34.5 | 1.9 | 6.8 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.285 | 18 | | 25.3 | 9.2 | 14.9 | 50.6 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.196 | 35 | | 45.9 | 13.6 | 19.5 | 31.5 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.181 | 26 | | 66.9 | 4.3 | 0.7 | 28.1 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.246 | 31 | | 28.7 | 44.3 | 2.1 | 24.9 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.246 | 24 | | 49.2 | 20.2 | 0.9 | 29.7 | 7.25 |

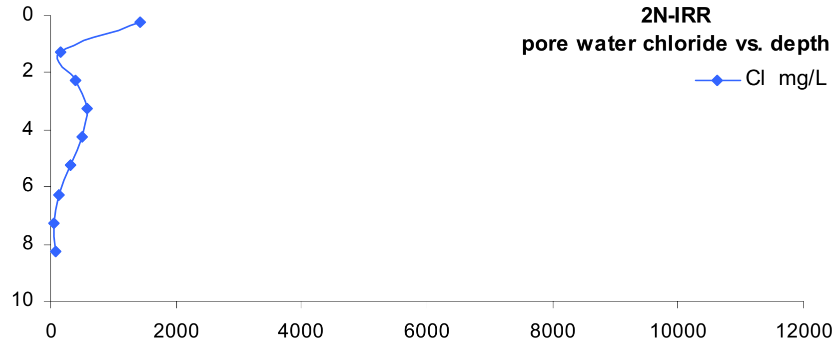


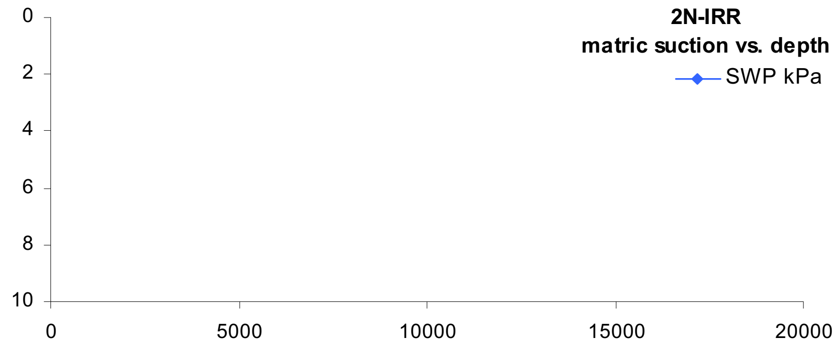



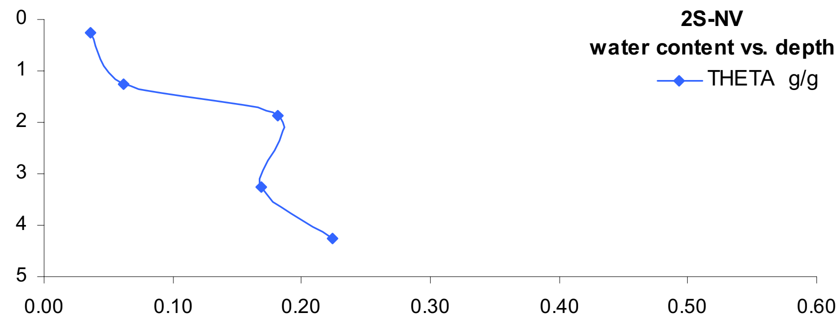
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2N-IRR | 0–0.5 | 0.056 | 1434 | | 68.9 | 28.0 | 0.8 | 2.3 | 0.25 |
| | 0.5–1.0 | | | | 63.3 | 30.6 | 1.6 | 4.5 | 0.75 |
| | 1.0–1.5 | 0.146 | 161 | | 41.7 | 17.4 | 2.4 | 38.5 | 1.25 |
| | 1.5–2.0 | | | | 37.5 | 14.6 | 5.5 | 42.3 | 1.75 |
| | 2.0–2.5 | 0.205 | 384 | | 39.3 | 10.4 | 4.7 | 45.6 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.104 | 574 | | 66.8 | 11.2 | 1.6 | 20.4 | 3.25 |
| | 3.5–4.0 | | | | | | | | 3.75 |
| | 4.0–4.5 | 0.131 | 508 | | 63.2 | 5.4 | 1.9 | 29.6 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | 0.093 | 324 | | 52.6 | 23.4 | 3.0 | 21.0 | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | 0.131 | 138 | | 33.8 | 49.9 | 4.6 | 11.7 | 6.25 |
| | 6.5–7.0 | | | | | | | | 6.75 |
| | 7.0–7.5 | 0.111 | 50 | | 34.7 | 56.1 | 3.0 | 6.2 | 7.25 |
| | 7.5–8.0 | | | | | | | | 7.75 |
| | 8.0–8.5 | 0.251 | 70 | | 38.8 | 52.5 | 2.6 | 6.1 | 8.25 |

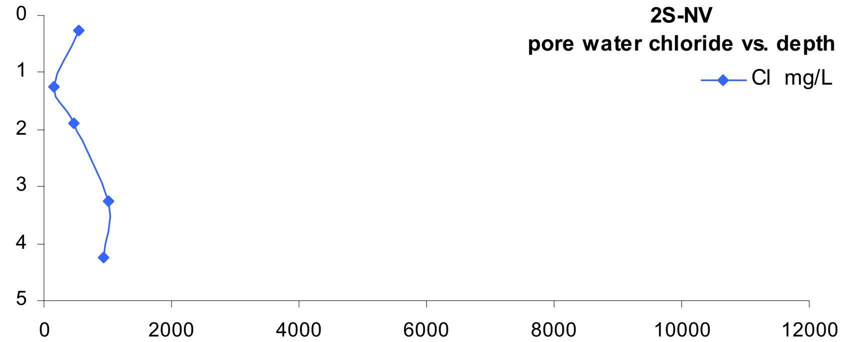


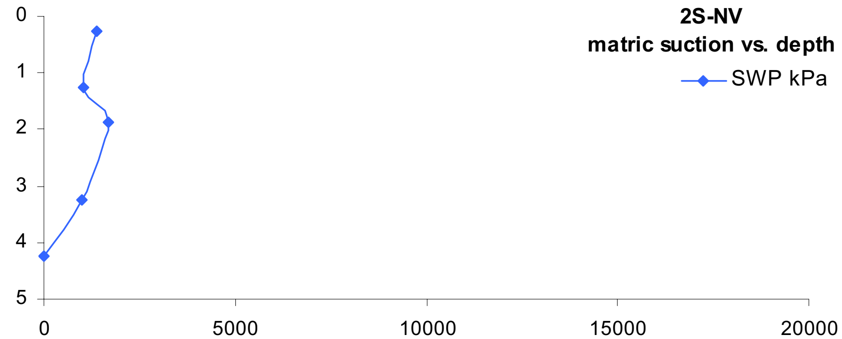



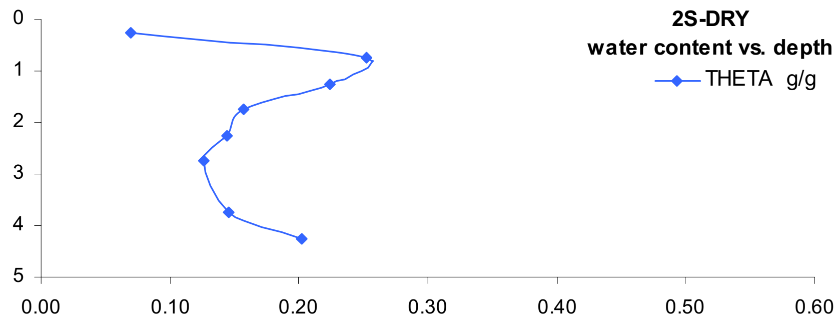
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2S-NV | 0–0.5 | 0.037 | 552 | 1378 | 17.6 | 75.7 | 2.1 | 4.7 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.062 | 153 | 1025 | 16.2 | 71.4 | 3.8 | 8.5 | 1.25 |
| | 1.5–1.75 | | | | | | | | 1.68 |
| | 1.75–2.0 | 0.182 | 457 | 1695 | 9.8 | 50.9 | 3.2 | 36.1 | 1.88 |
| | 2.0–2.5 | | | | | | | | 2.75 |
| | 2.5–3.0 | 0.169 | 1009 | 1002 | 7.7 | 57.4 | 3.9 | 31.0 | 3.25 |
| | 3.0–3.5 | | | | | | | | 3.75 |
| | 3.5–4.0 | 0.224 | 932 | 4 | 1.0 | 78.7 | 2.9 | 17.3 | 4.25 |
| | 4.0–4.5 | | | | | | | | 4.75 |
| | 4.5–5.0 | | | | | | | | 5.25 |
| | 5.0–5.5 | | | | | | | | 5.75 |
| | 5.5–6.0 | | | | | | | | 6.25 |

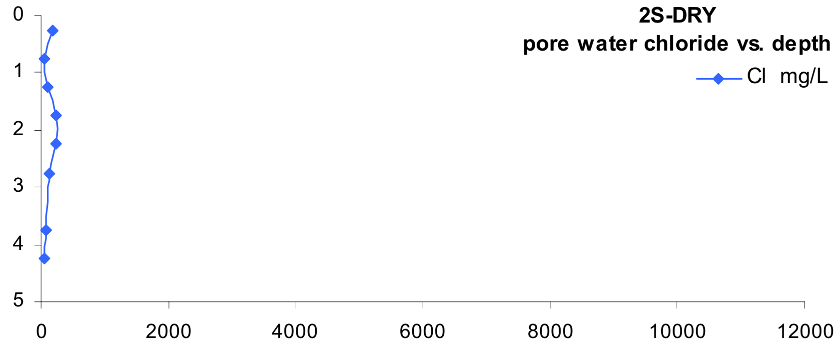


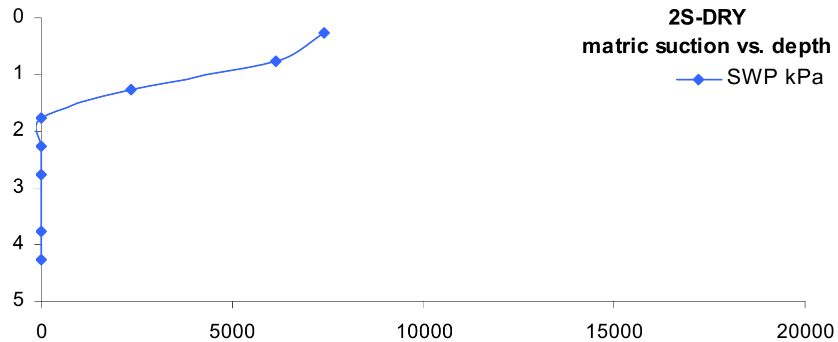



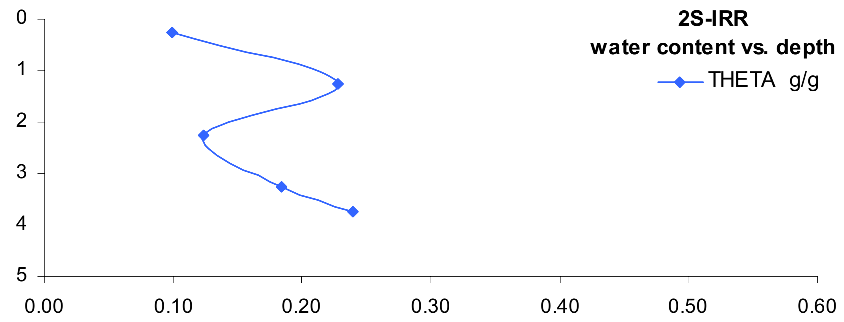
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2S-DRY | 0–0.5 | 0.069 | 192 | 7422 | 18.7 | 55.0 | 4.0 | 22.3 | 0.25 |
| | 0.5–1.0 | 0.253 | 58 | 6155 | | | | | 0.75 |
| | 1.0–1.5 | 0.224 | 102 | 2347 | 6.3 | 30.6 | 1.7 | 61.4 | 1.25 |
| | 1.5–2.0 | 0.157 | 246 | 15 | 26.2 | 48.1 | 11.1 | 14.6 | 1.75 |
| | 2.0–2.5 | 0.144 | 246 | 11 | | | | | 2.25 |
| | 2.5–3.0 | 0.127 | 140 | 11 | 19.1 | 68.1 | 6.4 | 6.4 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.146 | 85 | 6 | 20.6 | 71.4 | 4.5 | 3.6 | 3.75 |
| | 4.0–4.5 | 0.202 | 53 | 4 | 27.4 | 69.0 | 2.4 | 1.2 | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |

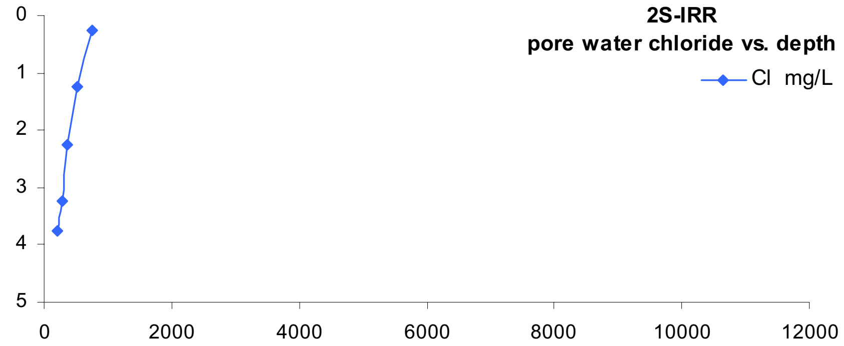


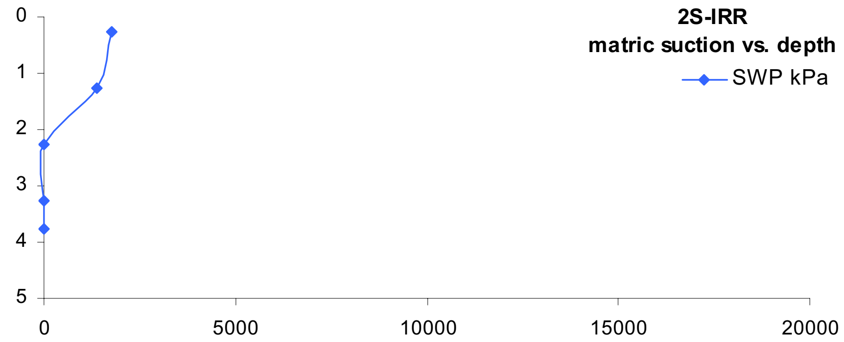



| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2S-IRR | 0–0.5 | 0.099 | 744 | 1759 | 20.8 | 51.4 | 4.0 | 23.8 | 0.25 |
| | 0.5–1.0 | | | | | | | | 0.75 |
| | 1.0–1.5 | 0.228 | 512 | 1372 | 4.1 | 36.6 | 3.4 | 55.9 | 1.25 |
| | 1.5–2.0 | | | | | | | | 1.75 |
| | 2.0–2.5 | 0.124 | 360 | 9 | 18.9 | 71.8 | 4.1 | 5.2 | 2.25 |
| | 2.5–3.0 | | | | | | | | 2.75 |
| | 3.0–3.5 | 0.184 | 295 | 4 | 18.8 | 71.5 | 5.7 | 3.9 | 3.25 |
| | 3.5–4.0 | 0.239 | 208 | 3 | 17.0 | 76.9 | 2.5 | 3.7 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | | | | | | | | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | | | | | | | | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |

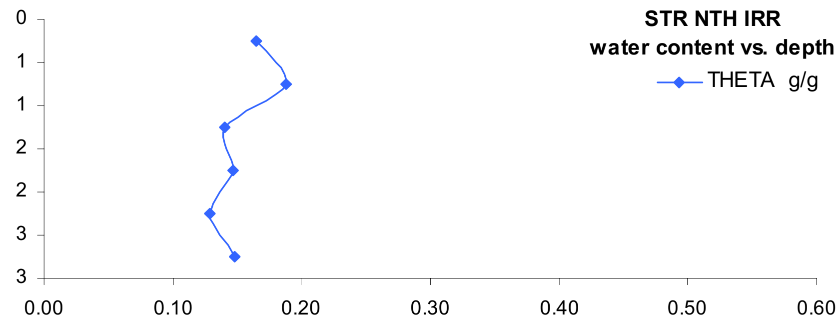


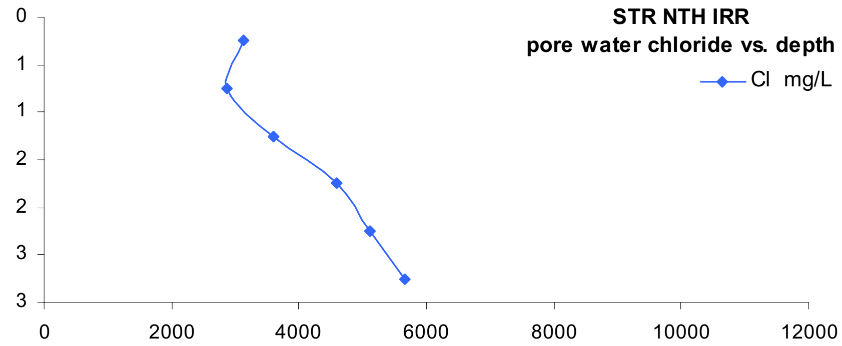



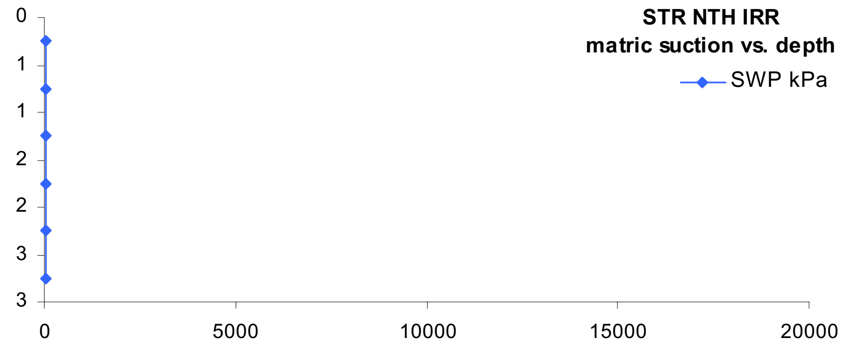



# A.2. SOIL CORE DATA, HUNDRED OF STIRLING

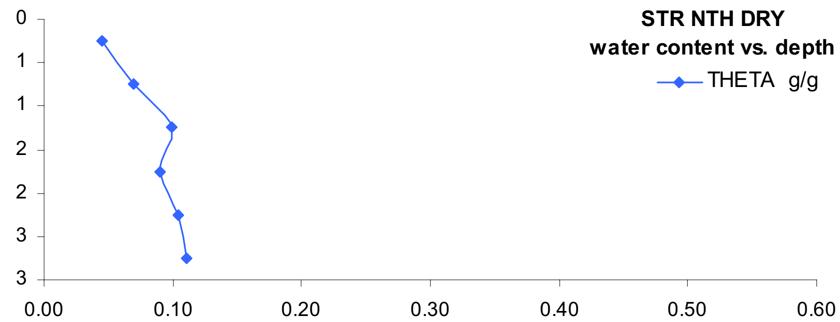
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR NTH IRR | 0–0.5 | 0.165 | 3133 | 37 | 12.7 | 56.9 | 4.3 | 26.1 | 0.25 |
| | 0.5–1.0 | 0.188 | 2864 | 39 | 25.7 | 41.1 | 9.3 | 23.9 | 0.75 |
| | 1.0–1.5 | 0.140 | 3611 | 39 | 20.5 | 55.3 | 6.4 | 17.7 | 1.25 |
| | 1.5–2.0 | 0.147 | 4600 | 31 | 17.3 | 54.6 | 5.4 | 22.8 | 1.75 |
| | 2.0–2.5 | 0.129 | 5103 | 32 | 20.8 | 62.1 | 2.0 | 15.2 | 2.25 |
| | 2.5–3.0 | 0.148 | 5651 | 24 | 18.4 | 60.7 | 2.5 | 18.5 | 2.75 |

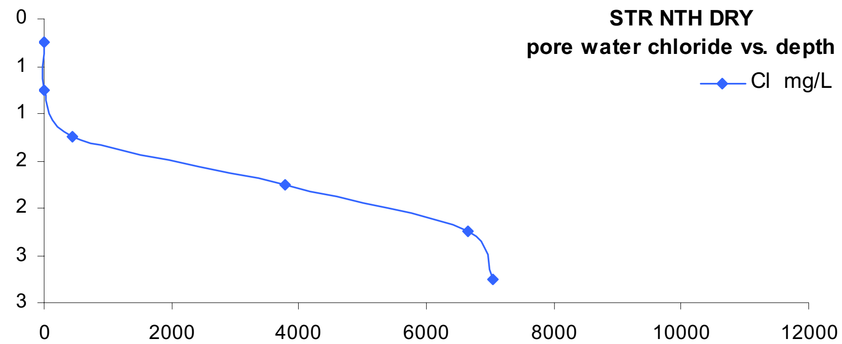


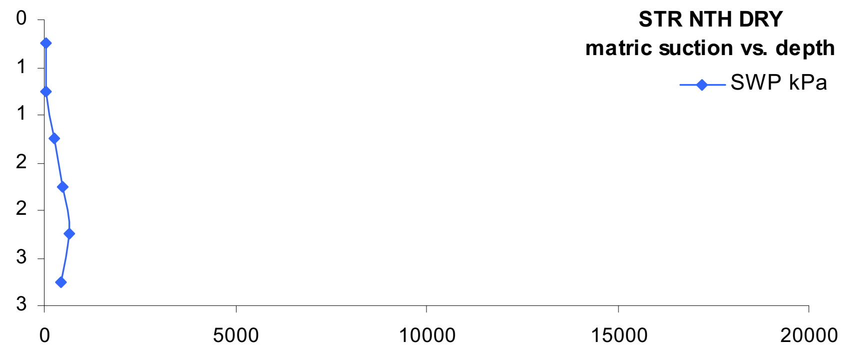



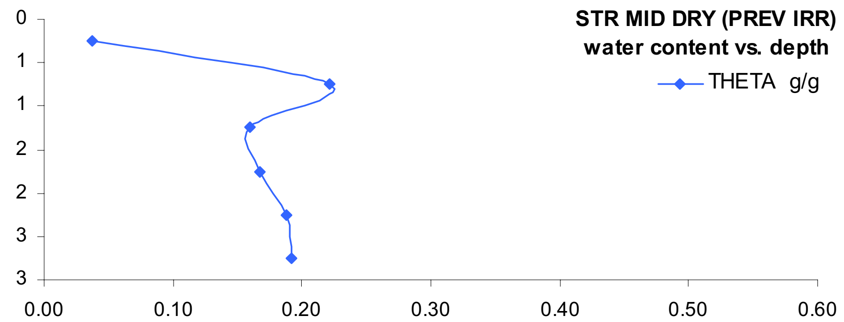
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR NTH DRY | 0–0.5 | 0.045 | 5 | 55 | 30.1 | 66.4 | 1.0 | 2.4 | 0.25 |
| | 0.5–1.0 | 0.069 | 8 | 62 | 33.2 | 63.6 | 1.2 | 2.0 | 0.75 |
| | 1.0–1.5 | 0.099 | 455 | 241 | 21.6 | 63.2 | 1.4 | 13.8 | 1.25 |
| | 1.5–2.0 | 0.091 | 3776 | 478 | 23.9 | 71.6 | 1.0 | 3.5 | 1.75 |
| | 2.0–2.5 | 0.104 | 6650 | 650 | 19.3 | 59.5 | 1.1 | 20.0 | 2.25 |
| | 2.5–3.0 | 0.111 | 7047 | 445 | 20.1 | 59.8 | 0.6 | 19.5 | 2.75 |

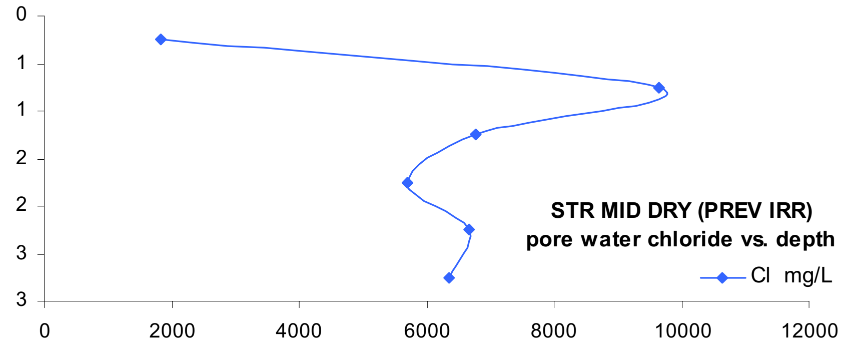


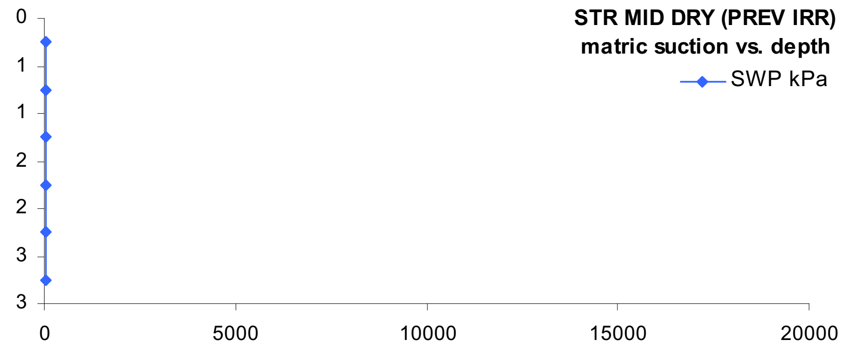



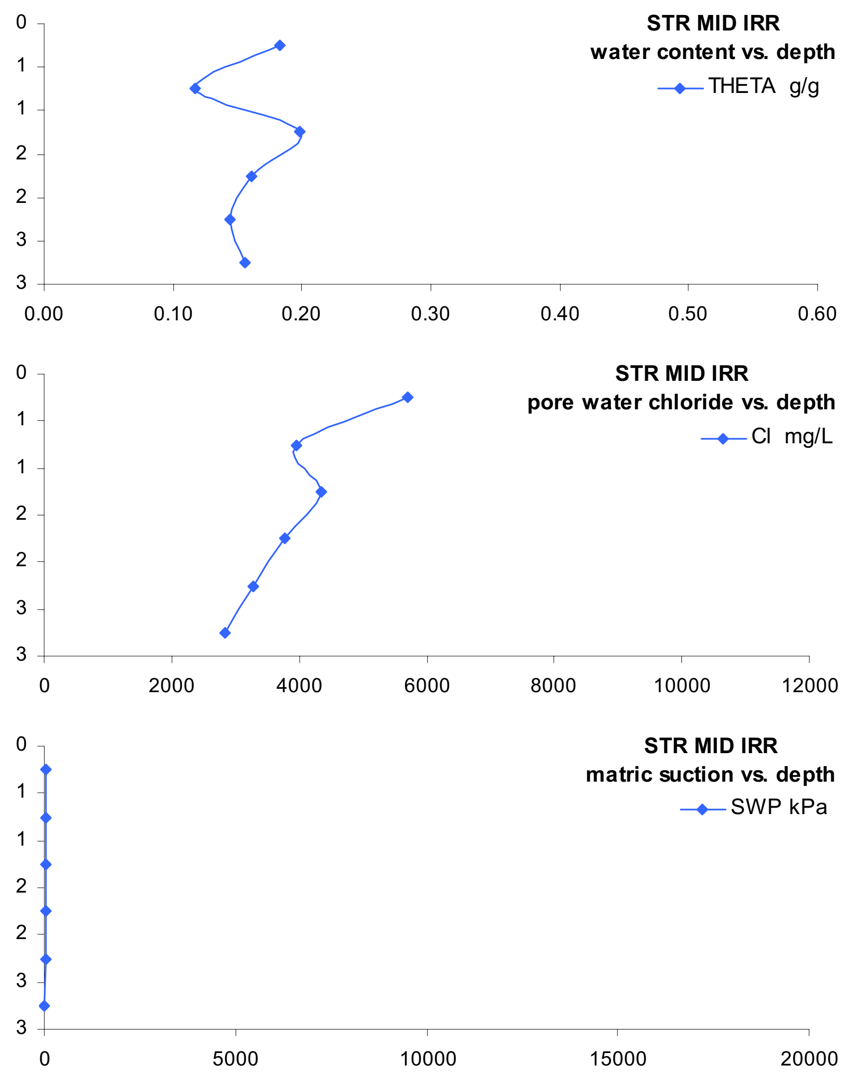
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR MID DRY | 0–0.5 | 0.037 | 1817 | 42 | 30.7 | 66.2 | 0.8 | 2.3 | 0.25 |
| (PREV IRR) | 0.5–1.0 | 0.221 | 9653 | 35 | 27.7 | 33.5 | 6.8 | 32.1 | 0.75 |
| | 1.0–1.5 | 0.159 | 6763 | 42 | 50.2 | 27.8 | 1.4 | 20.6 | 1.25 |
| | 1.5–2.0 | 0.167 | 5707 | 41 | 41.0 | 24.4 | 0.6 | 34.0 | 1.75 |
| | 2.0–2.5 | 0.188 | 6675 | 28 | 42.5 | 27.9 | 0.2 | 29.4 | 2.25 |
| | 2.5–3.0 | 0.192 | 6351 | 43 | 40.2 | 19.0 | 1.6 | 39.2 | 2.75 |



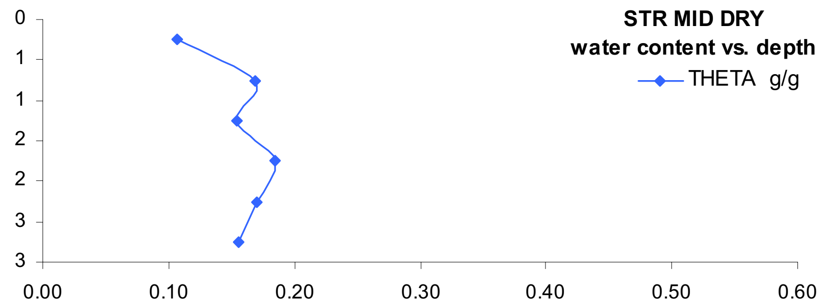



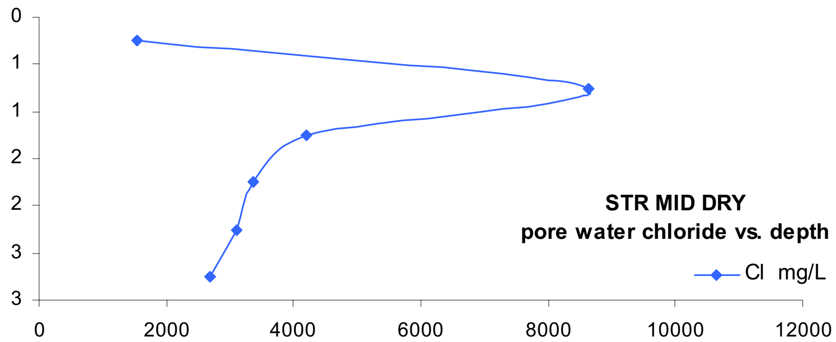



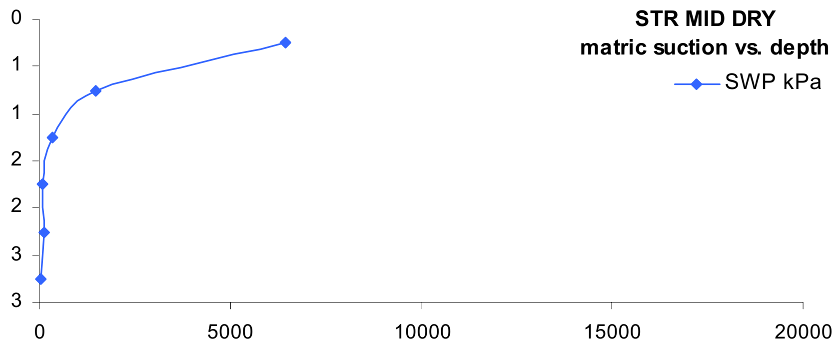
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR | 0–0.5 | 0.183 | 5693 | 44 | 23.6 | 57.1 | 0.7 | 18.6 | 0.25 |
| MID IRR | 0.5–1.0 | 0.117 | 3951 | 44 | 73.7 | 17.5 | 1.7 | 7.1 | 0.75 |
| | 1.0–1.5 | 0.198 | 4342 | 30 | 65.9 | 15.7 | 2.9 | 15.4 | 1.25 |
| | 1.5–2.0 | 0.161 | 3773 | 41 | 54.2 | 12.9 | 0.1 | 32.8 | 1.75 |
| | 2.0–2.5 | 0.144 | 3275 | 34 | 59.8 | 15.4 | 2.6 | 22.2 | 2.25 |
| | 2.5–3.0 | 0.156 | 2830 | 17 | 43.7 | 25.2 | 1.9 | 29.2 | 2.75 |



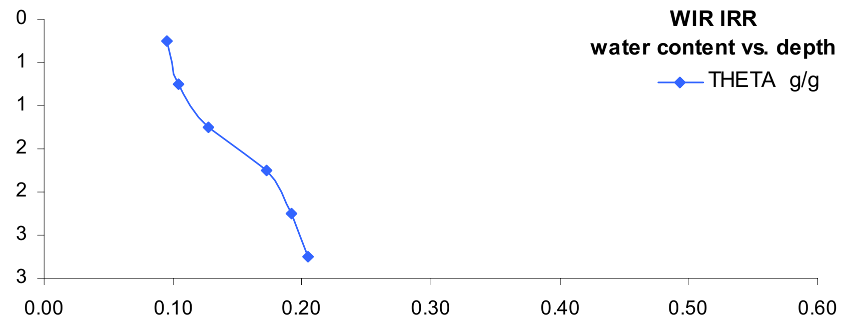
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR | 0–0.5 | 0.106 | 1545 | 6438 | 25.3 | 46.6 | 1.6 | 26.6 | 0.25 |
| MID DRY | 0.5–1.0 | 0.169 | 8643 | 1498 | 28.2 | 43.7 | 1.4 | 26.7 | 0.75 |
| | 1.0–1.5 | 0.154 | 4207 | 331 | 29.6 | 29.4 | 1.6 | 39.4 | 1.25 |
| | 1.5–2.0 | 0.185 | 3362 | 97 | 26.9 | 12.6 | 0.2 | 60.2 | 1.75 |
| | 2.0–2.5 | 0.170 | 3109 | 116 | 57.5 | 8.8 | 0.3 | 33.4 | 2.25 |
| | 2.5–3.0 | 0.155 | 2700 | 44 | 55.3 | 11.0 | 0.8 | 32.9 | 2.75 |

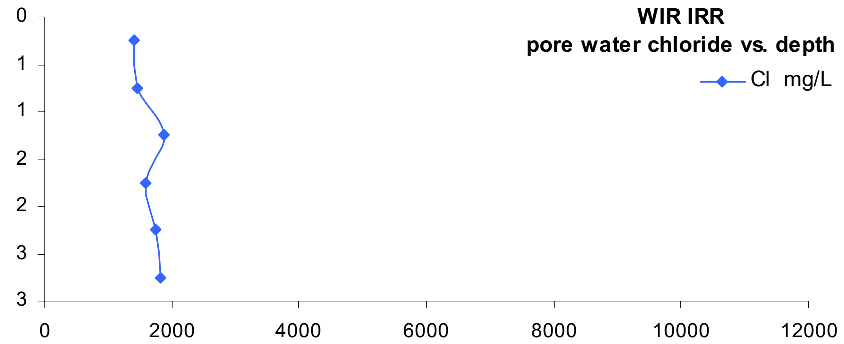


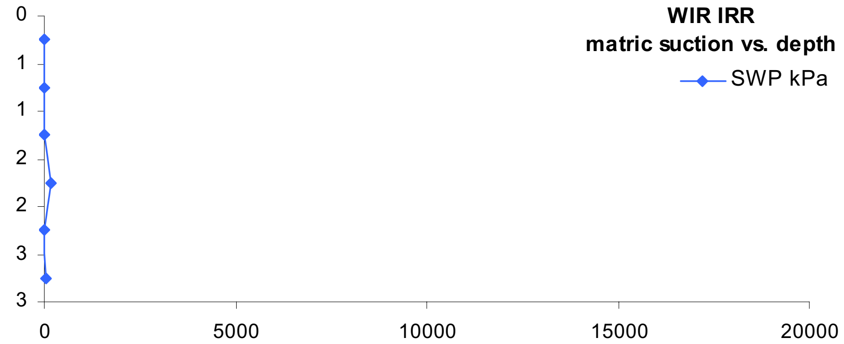



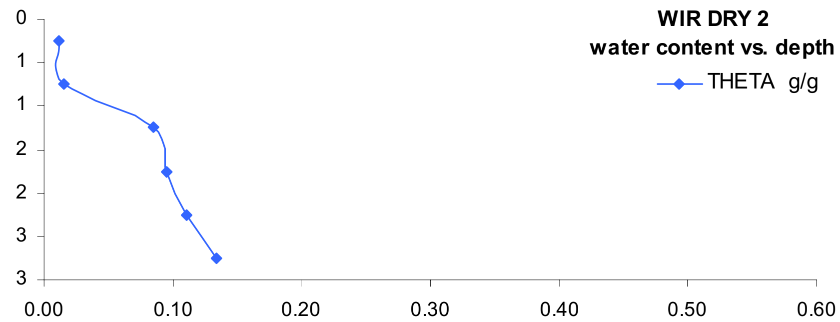
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| WIR IRR | 0–0.5 | 0.095 | 1414 | 6 | 6.0 | 85.3 | 0.9 | 7.8 | 0.25 |
| | 0.5–1.0 | 0.105 | 1465 | 10 | 5.5 | 81.2 | 0.9 | 12.5 | 0.75 |
| | 1.0–1.5 | 0.127 | 1886 | 9 | 17.3 | 70.1 | 1.8 | 10.8 | 1.25 |
| | 1.5–2.0 | 0.173 | 1589 | 179 | 19.5 | 39.5 | 1.2 | 39.8 | 1.75 |
| | 2.0–2.5 | 0.192 | 1752 | 20 | 29.7 | 34.0 | 3.4 | 32.9 | 2.25 |
| | 2.5–3.0 | 0.204 | 1835 | 36 | 16.2 | 36.2 | 0.9 | 46.7 | 2.75 |

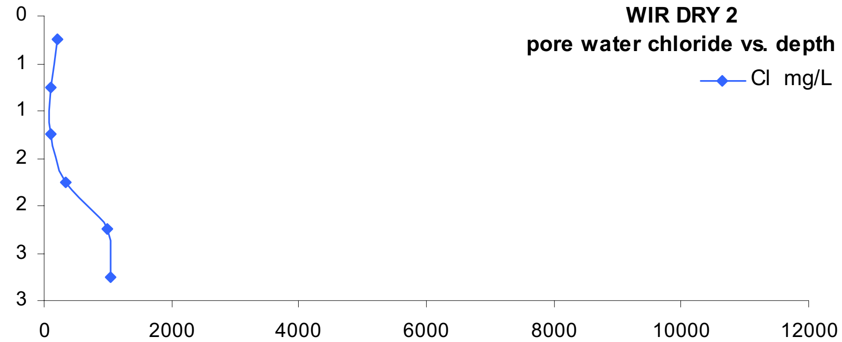


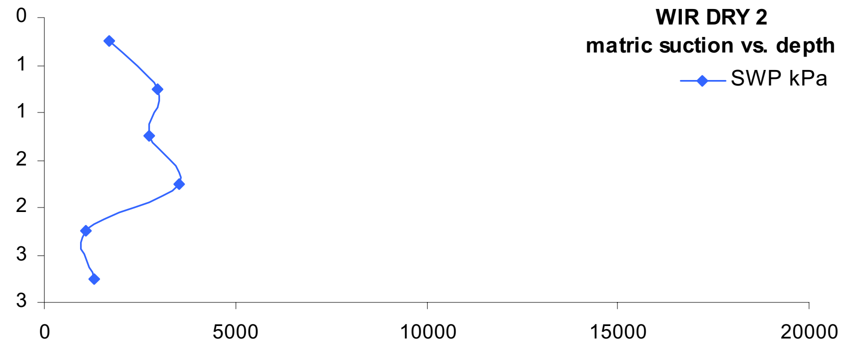



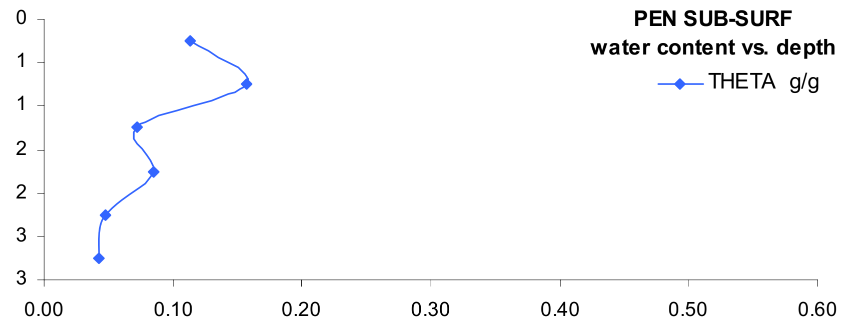
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| WIR DRY 2 | 0–0.5 | 0.012 | 210 | 1698 | 9.0 | 90.0 | 0.7 | 0.3 | 0.25 |
| | 0.5–1.0 | 0.016 | 103 | 2984 | 5.4 | 92.0 | 0.9 | 1.7 | 0.75 |
| | 1.0–1.5 | 0.085 | 102 | 2739 | 4.8 | 72.2 | 1.0 | 22.0 | 1.25 |
| | 1.5–2.0 | 0.095 | 349 | 3529 | 5.0 | 73.5 | 0.9 | 20.5 | 1.75 |
| | 2.0–2.5 | 0.110 | 1001 | 1092 | 6.3 | 73.1 | 1.6 | 19.0 | 2.25 |
| | 2.5–3.0 | 0.133 | 1050 | 1286 | 4.7 | 72.2 | 0.4 | 22.7 | 2.75 |

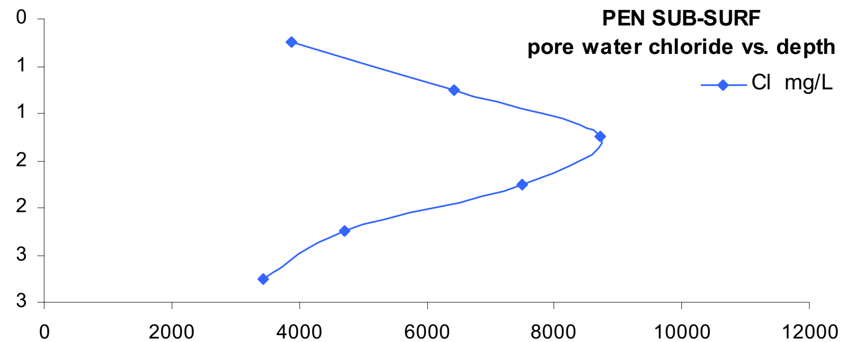


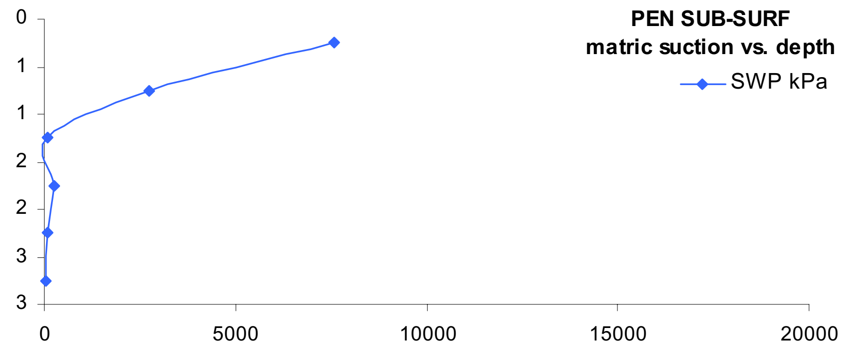



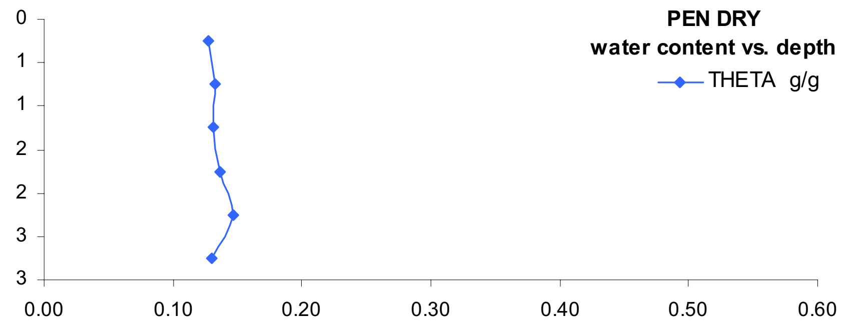
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| PEN SUB-SURF | 0–0.5 | 0.114 | 3883 | 7577 | 25.9 | 31.2 | 3.7 | 39.2 | 0.25 |
| | 0.5–1.0 | 0.157 | 6426 | 2733 | 18.2 | 24.5 | 0.6 | 56.6 | 0.75 |
| | 1.0–1.5 | 0.072 | 8710 | 78 | 41.4 | 46.0 | 5.2 | 7.4 | 1.25 |
| | 1.5–2.0 | 0.085 | 7488 | 243 | 35.6 | 45.6 | 2.3 | 16.5 | 1.75 |
| | 2.0–2.5 | 0.048 | 4721 | 70 | 37.4 | 54.7 | 3.4 | 4.5 | 2.25 |
| | 2.5–3.0 | 0.042 | 3437 | 47 | 36.7 | 58.7 | 2.3 | 2.3 | 2.75 |

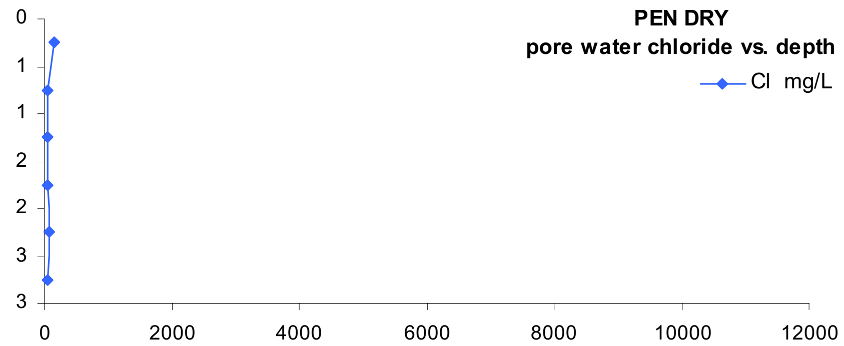


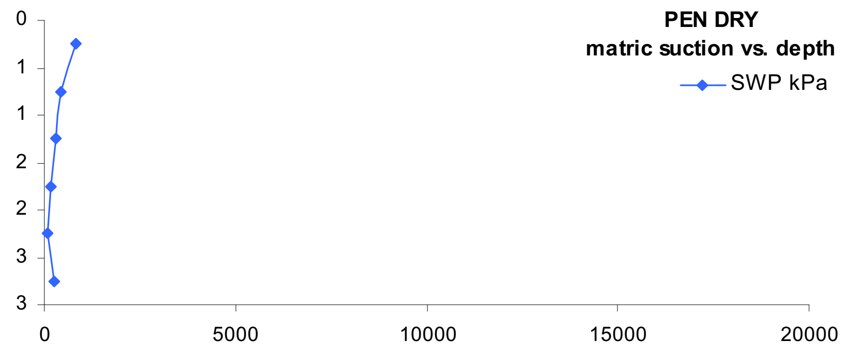



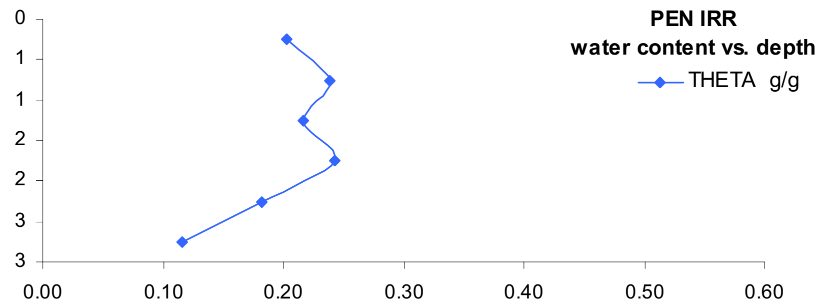
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| PEN DRY | 0–0.5 | 0.127 | 165 | 820 | 37.1 | 41.8 | 6.4 | 14.6 | 0.25 |
| | 0.5–1.0 | 0.132 | 52 | 450 | 12.6 | 56.7 | 1.4 | 29.2 | 0.75 |
| | 1.0–1.5 | 0.132 | 40 | 316 | 6.4 | 58.0 | 1.8 | 33.8 | 1.25 |
| | 1.5–2.0 | 0.137 | 42 | 163 | 5.8 | 61.4 | 2.8 | 30.0 | 1.75 |
| | 2.0–2.5 | 0.146 | 79 | 83 | 6.3 | 60.4 | 1.7 | 31.5 | 2.25 |
| | 2.5–3.0 | 0.130 | 54 | 241 | 6.8 | 60.3 | 0.4 | 32.5 | 2.75 |

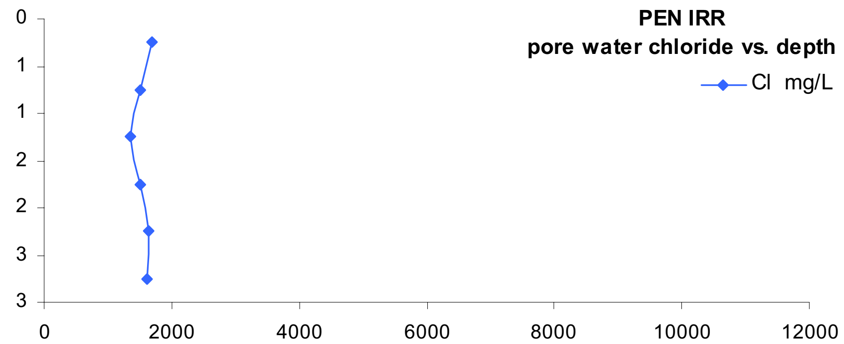


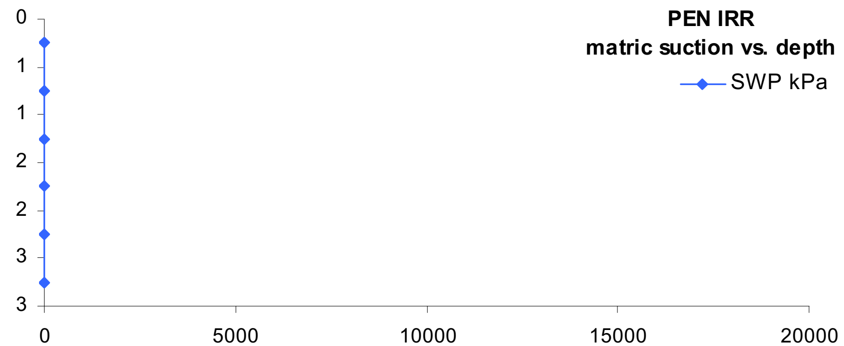



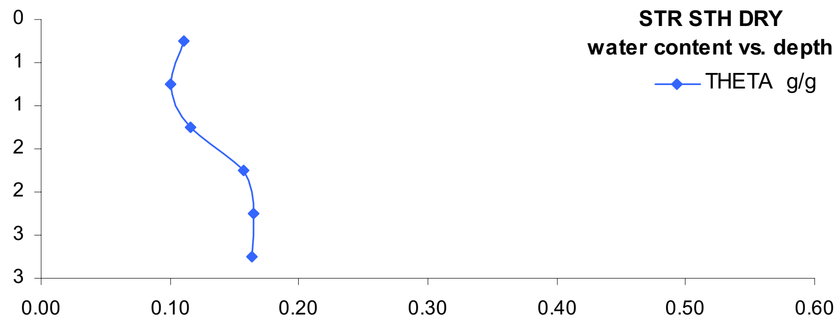
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| PEN IRR | 0–0.5 | 0.203 | 1687 | 15 | 48.4 | 22.3 | 3.6 | 25.6 | 0.25 |
| | 0.5–1.0 | 0.238 | 1497 | 9 | 16.0 | 35.5 | 12.1 | 36.3 | 0.75 |
| | 1.0–1.5 | 0.217 | 1352 | 7 | 27.7 | 30.8 | 11.5 | 30.0 | 1.25 |
| | 1.5–2.0 | 0.243 | 1521 | 5 | 15.5 | 42.7 | 4.9 | 36.8 | 1.75 |
| | 2.0–2.5 | 0.182 | 1628 | 5 | 11.2 | 51.7 | 9.5 | 27.6 | 2.25 |
| | 2.5–3.0 | 0.116 | 1619 | 6 | 26.2 | 63.3 | 4.8 | 5.7 | 2.75 |

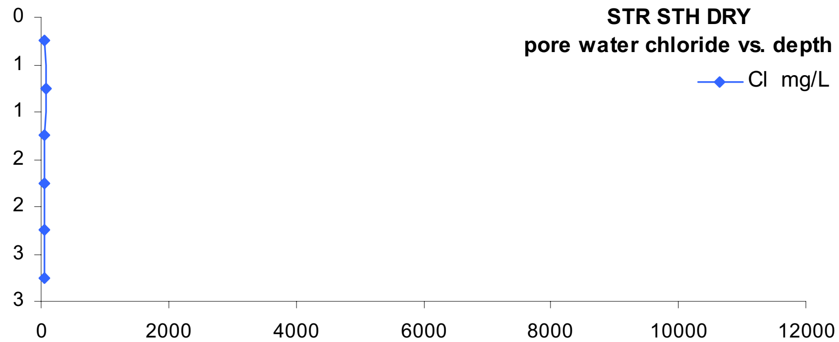


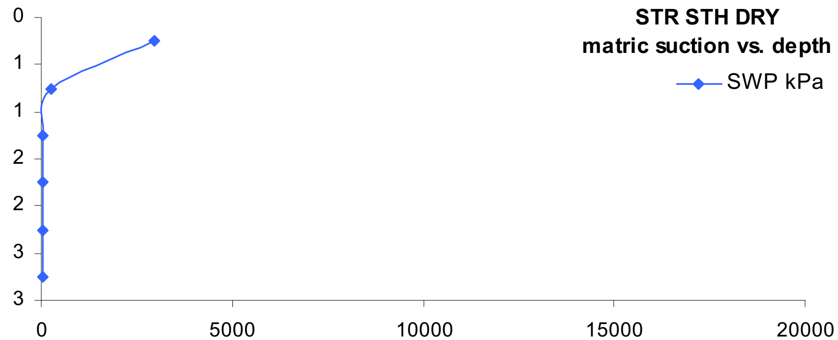



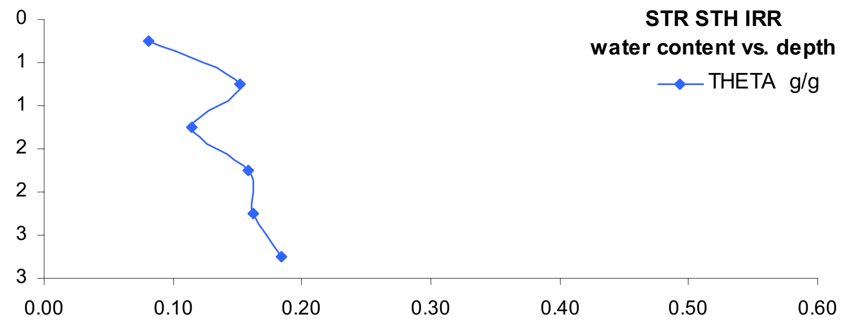
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR STH DRY | 0–0.5 | 0.111 | 58 | 2975 | 5.8 | 50.7 | 1.9 | 41.5 | 0.25 |
| | 0.5–1.0 | 0.100 | 72 | 258 | 62.6 | 18.2 | 4.6 | 14.7 | 0.75 |
| | 1.0–1.5 | 0.116 | 56 | 54 | 56.2 | 21.2 | 7.3 | 15.2 | 1.25 |
| | 1.5–2.0 | 0.158 | 51 | 36 | 28.4 | 26.3 | 12.6 | 32.7 | 1.75 |
| | 2.0–2.5 | 0.165 | 49 | 30 | 35.1 | 18.6 | 11.6 | 34.7 | 2.25 |
| | 2.5–3.0 | 0.164 | 49 | 44 | 31.9 | 22.0 | 12.3 | 33.7 | 2.75 |

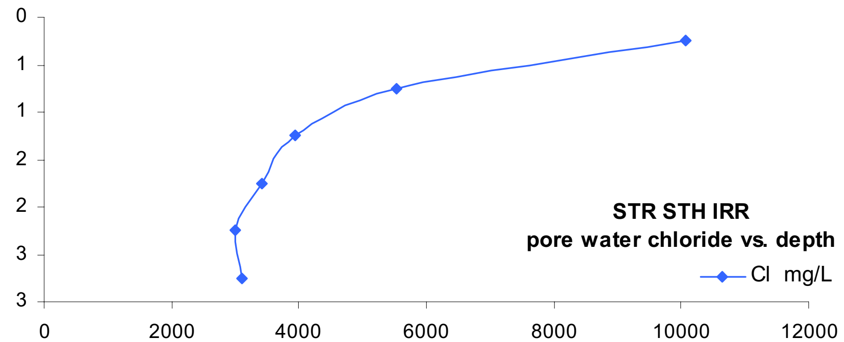


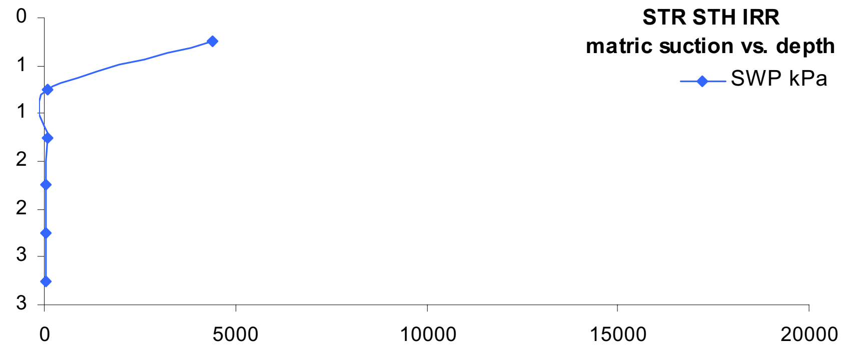



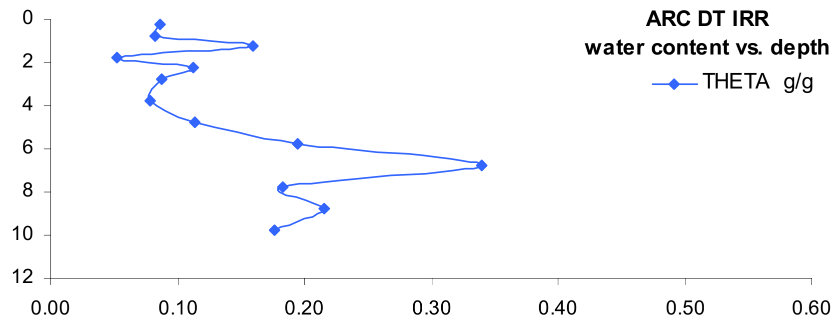
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR STH | 0–0.5 | 0.082 | 10063 | 4418 | 30.7 | 39.2 | 4.7 | 25.5 | 0.25 |
| IRR | 0.5–1.0 | 0.152 | 5532 | 79 | 32.9 | 26.5 | 9.0 | 31.6 | 0.75 |
| | 1.0–1.5 | 0.114 | 3936 | 70 | 27.4 | 23.6 | 15.2 | 33.8 | 1.25 |
| | 1.5–2.0 | 0.159 | 3415 | 51 | 33.3 | 16.1 | 0.8 | 49.8 | 1.75 |
| | 2.0–2.5 | 0.163 | 3012 | 36 | 35.2 | 20.7 | 0.8 | 43.4 | 2.25 |
| | 2.5–3.0 | 0.184 | 3101 | 54 | 34.4 | 20.2 | 2.1 | 43.3 | 2.75 |

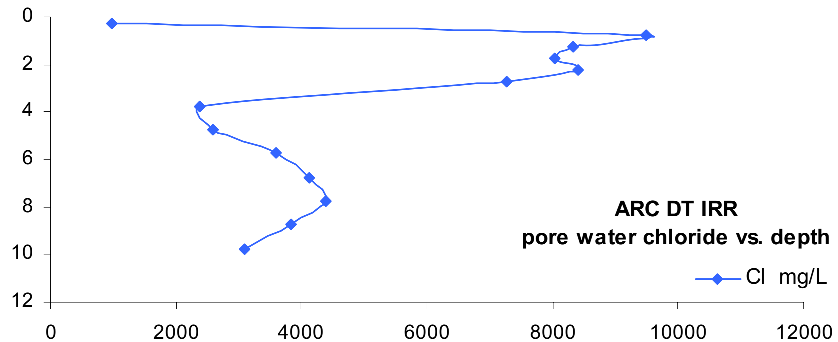


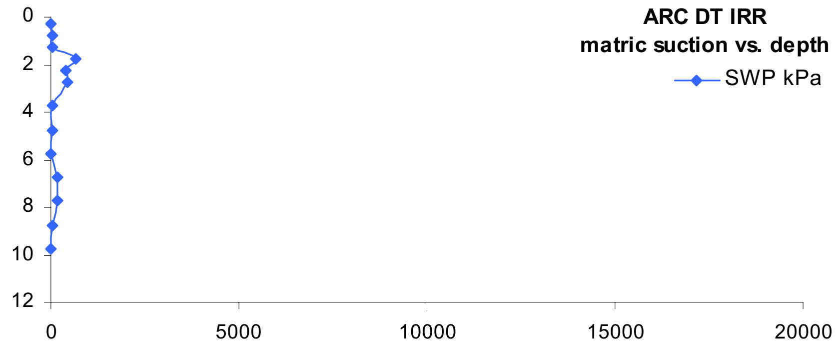



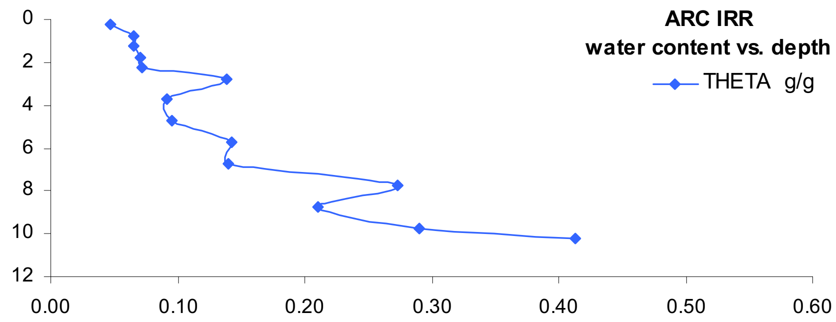
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| ARC DT | 0–0.5 | 0.087 | 973 | 3 | 38.4 | 57.8 | 1.5 | 2.4 | 0.25 |
| IRR | 0.5–1.0 | 0.082 | 9501 | 51 | 33.7 | 53.9 | 1.5 | 11.0 | 0.75 |
| | 1.0–1.5 | 0.159 | 8334 | 26 | 25.9 | 56.0 | 1.9 | 16.3 | 1.25 |
| | 1.5–2.0 | 0.053 | 8026 | 679 | 34.5 | 55.9 | 1.2 | 8.3 | 1.75 |
| | 2.0–2.5 | 0.112 | 8416 | 409 | 32.6 | 47.6 | 0.8 | 19.0 | 2.25 |
| | 2.5–3.0 | 0.087 | 7273 | 433 | 33.1 | 51.0 | 0.4 | 15.4 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.078 | 2383 | 37 | 28.5 | 65.4 | 1.4 | 4.7 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.114 | 2580 | 30 | 17.5 | 70.1 | 1.0 | 11.3 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.195 | 3600 | 7 | 3.9 | 77.6 | 1.5 | 17.0 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.339 | 4128 | 191 | 7.2 | 26.7 | 2.4 | 63.6 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.183 | 4393 | 160 | 9.9 | 25.1 | 6.8 | 58.2 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.215 | 3834 | 42 | 23.6 | 12.7 | 3.7 | 60.0 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.177 | 3082 | 7 | 21.3 | 42.3 | 4.8 | 31.6 | 9.75 |
| | 10.0–10.5 | | | | | | | | 10.25 |
| | 10.5–11.0 | | | | 35.3 | 51.8 | 1.4 | 11.5 | 10.75 |

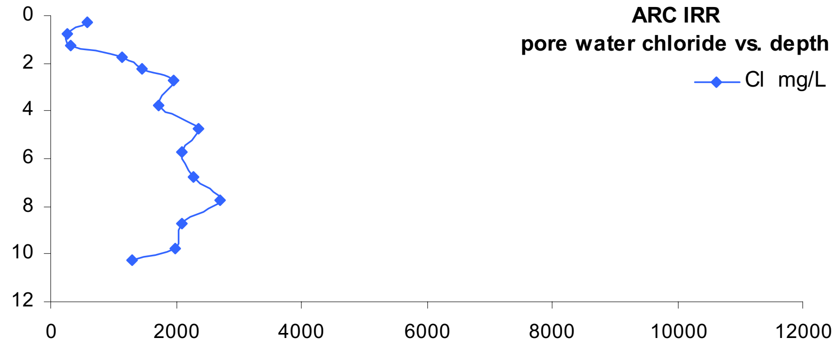


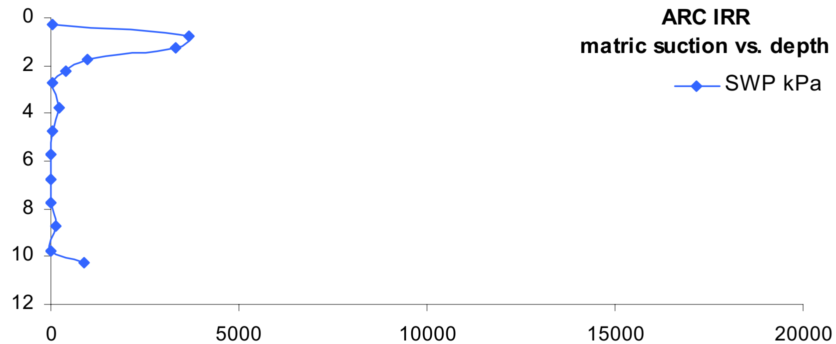



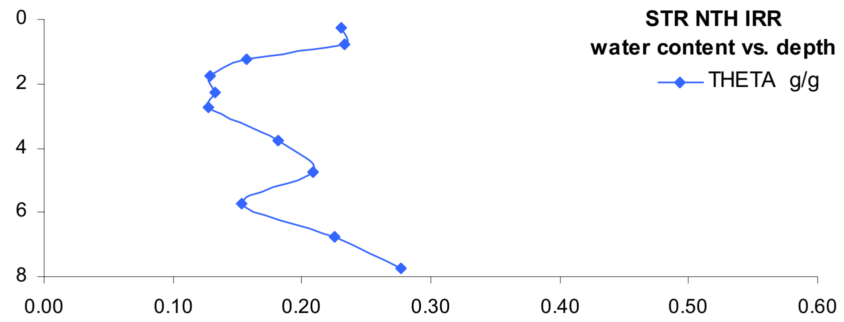
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| ARC DRY | 0–0.5 | 0.047 | 572 | 45 | 32.3 | 59.1 | 1.1 | 7.5 | 0.25 |
| | 0.5–1.0 | 0.065 | 267 | 3670 | 34.8 | 55.0 | 1.1 | 9.1 | 0.75 |
| | 1.0–1.5 | 0.066 | 315 | 3309 | 29.0 | 56.4 | 2.6 | 11.9 | 1.25 |
| | 1.5–2.0 | 0.070 | 1143 | 966 | 29.5 | 58.4 | 2.9 | 9.2 | 1.75 |
| | 2.0–2.5 | 0.072 | 1463 | 395 | 26.5 | 54.0 | 1.1 | 18.4 | 2.25 |
| | 2.5–3.0 | 0.139 | 1967 | 62 | 25.2 | 57.1 | 1.1 | 16.5 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.092 | 1724 | 221 | 28.9 | 54.6 | 2.1 | 14.4 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.095 | 2345 | 32 | 24.7 | 63.1 | 2.1 | 10.2 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.143 | 2086 | 20 | 29.4 | 53.5 | 1.6 | 15.5 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.140 | 2269 | 5 | 11.5 | 63.1 | 2.0 | 23.4 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.273 | 2697 | 13 | 15.0 | 52.6 | 4.2 | 28.1 | 7.75 |
| | 8.0–8.5 | | | | | | | | 8.25 |
| | 8.5–9.0 | 0.211 | 2086 | 142 | 12.8 | 47.3 | 2.7 | 37.2 | 8.75 |
| | 9.0–9.5 | | | | | | | | 9.25 |
| | 9.5–10.0 | 0.291 | 1975 | 8 | 3.1 | 10.7 | 3.2 | 83.0 | 9.75 |
| | 10.0–10.5 | 0.414 | 1285 | 905 | 2.4 | 12.3 | 2.4 | 82.9 | 10.25 |

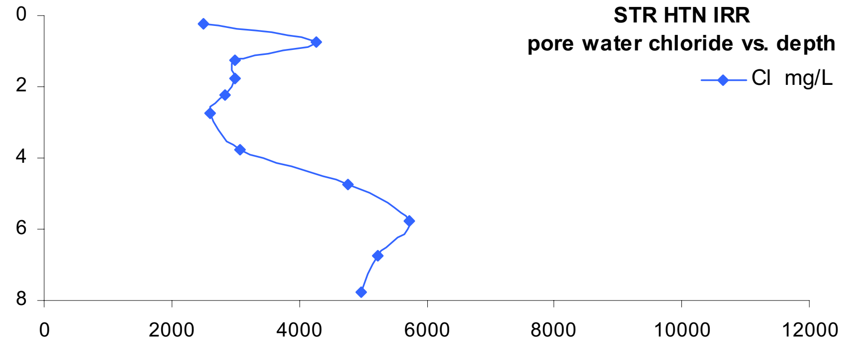


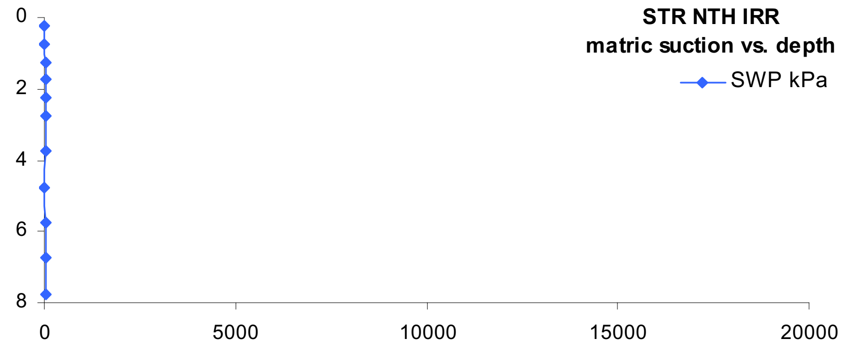



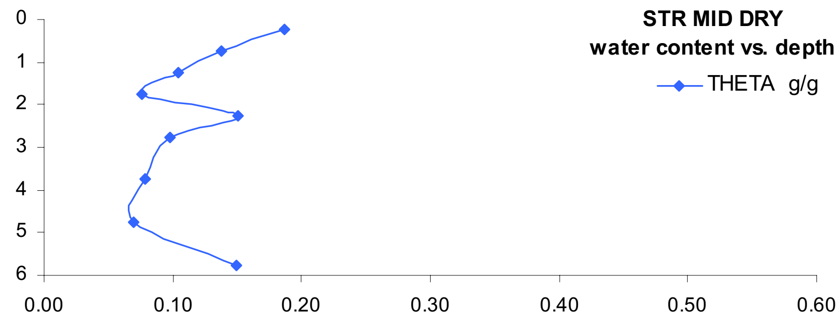
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR NTH IRR | 0–0.5 | 0.231 | 2497 | 1 | 13.9 | 73.8 | 2.4 | 9.8 | 0.25 |
| | 0.5–1.0 | 0.232 | 4267 | 3 | 15.8 | 59.9 | 4.3 | 20.0 | 0.75 |
| | 1.0–1.5 | 0.156 | 2986 | 35 | 13.7 | 62.8 | 1.0 | 22.5 | 1.25 |
| | 1.5–2.0 | 0.128 | 2993 | 38 | 20.7 | 60.7 | 1.0 | 17.5 | 1.75 |
| | 2.0–2.5 | 0.132 | 2832 | 39 | 14.6 | 66.2 | 1.7 | 17.6 | 2.25 |
| | 2.5–3.0 | 0.127 | 2605 | 49 | 13.8 | 65.7 | 1.7 | 18.8 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.182 | 3073 | 44 | 6.5 | 68.5 | 1.6 | 23.4 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.209 | 4764 | 18 | 6.3 | 75.8 | 0.6 | 17.2 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.153 | 5723 | 54 | 6.5 | 37.1 | 2.3 | 54.1 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.226 | 5231 | 59 | 3.7 | 47.0 | 4.2 | 45.1 | 6.75 |
| | 7.0–7.5 | | | | | | | | 7.25 |
| | 7.5–8.0 | 0.277 | 4970 | 51 | 3.3 | 31.5 | 6.4 | 58.8 | 7.75 |

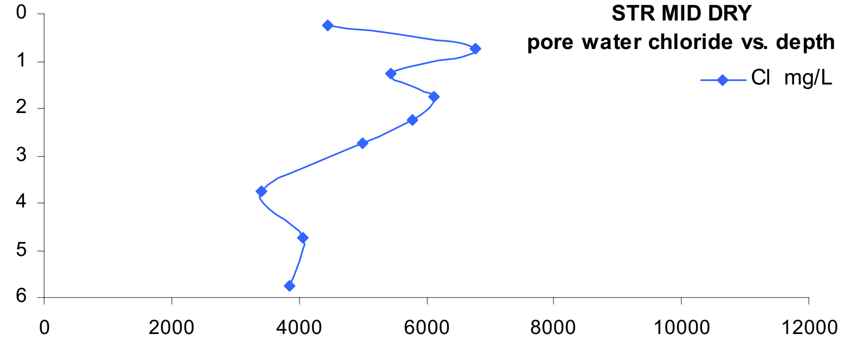


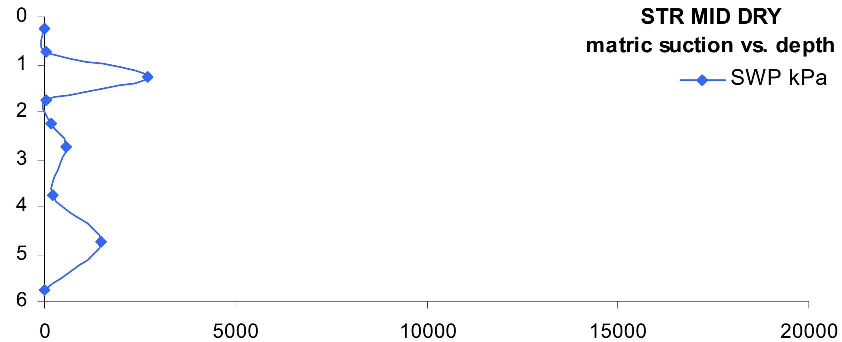



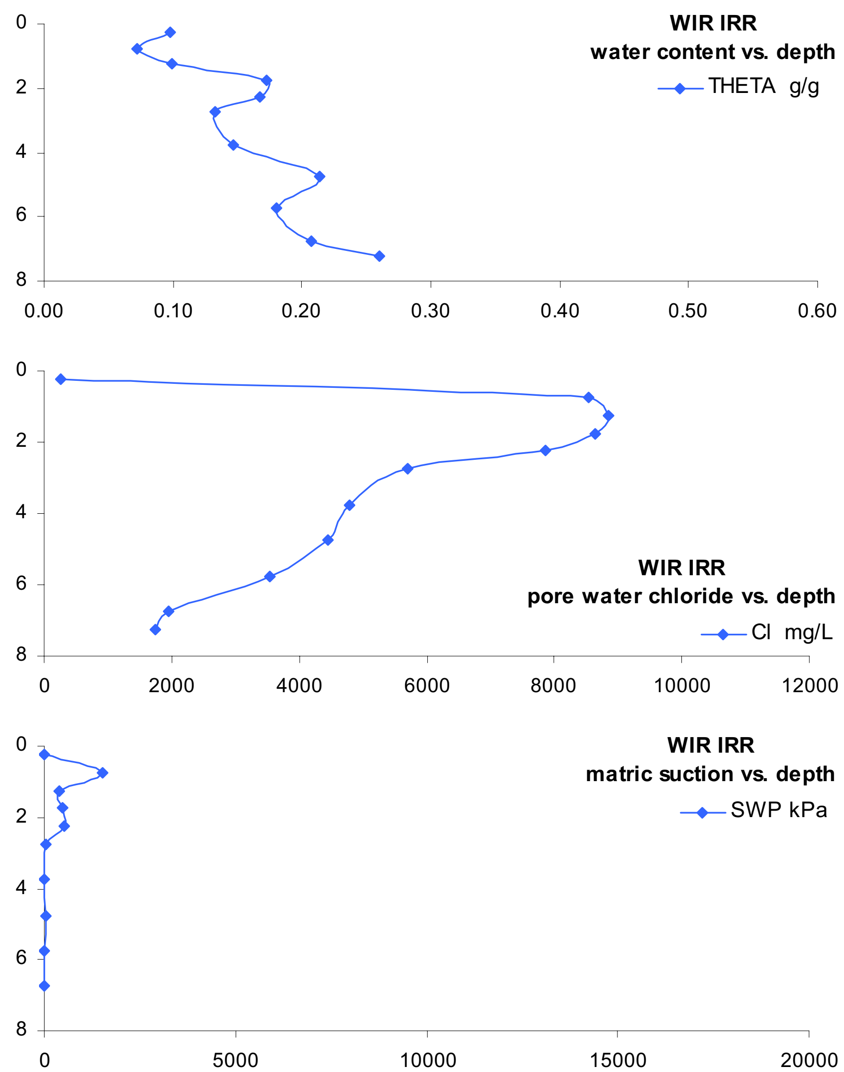
| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| STR MID | 0–0.5 | 0.187 | 4458 | 3 | 19.5 | 68.3 | 1.2 | 10.9 | 0.25 |
| DRY | 0.5–1.0 | 0.138 | 6778 | 60 | 23.2 | 26.5 | 5.0 | 45.3 | 0.75 |
| | 1.0–1.5 | 0.104 | 5446 | 2687 | 34.6 | 26.2 | 2.7 | 36.5 | 1.25 |
| | 1.5–2.0 | 0.075 | 6128 | 46 | 45.0 | 16.2 | 4.0 | 34.9 | 1.75 |
| | 2.0–2.5 | 0.150 | 5774 | 188 | 49.8 | 8.6 | 3.0 | 38.5 | 2.25 |
| | 2.5–3.0 | 0.098 | 4989 | 562 | 33.1 | 22.2 | 2.8 | 41.9 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.078 | 3418 | 204 | 34.6 | 23.6 | 8.1 | 33.8 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.070 | 4053 | 1465 | 9.5 | 20.1 | 20.7 | 49.7 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.149 | 3849 | 5 | 4.9 | 12.6 | 5.3 | 77.2 | 5.75 |



| Site | Depth (m) | THETA (g/g) | Cl (mg/L) | SWP (kPa) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | Midpoint (m) |
|---|---|---|---|---|---|---|---|---|---|
| WIR IRR | 0–0.5 | 0.098 | 252 | 3 | 6.1 | 74.2 | 1.5 | 18.2 | 0.25 |
| | 0.5–1.0 | 0.072 | 8536 | 1516 | 4.8 | 77.5 | 0.9 | 16.8 | 0.75 |
| | 1.0–1.5 | 0.099 | 8855 | 402 | 3.2 | 71.9 | 1.5 | 23.4 | 1.25 |
| | 1.5–2.0 | 0.173 | 8646 | 483 | 3.9 | 64.3 | 1.3 | 30.4 | 1.75 |
| | 2.0–2.5 | 0.167 | 7871 | 520 | 4.3 | 58.2 | 1.0 | 36.5 | 2.25 |
| | 2.5–3.0 | 0.132 | 5712 | 33 | 5.4 | 73.3 | 0.1 | 21.2 | 2.75 |
| | 3.0–3.5 | | | | | | | | 3.25 |
| | 3.5–4.0 | 0.146 | 4785 | 13 | 2.0 | 75.0 | 2.2 | 20.8 | 3.75 |
| | 4.0–4.5 | | | | | | | | 4.25 |
| | 4.5–5.0 | 0.214 | 4456 | 46 | 8.3 | 60.8 | 3.1 | 27.8 | 4.75 |
| | 5.0–5.5 | | | | | | | | 5.25 |
| | 5.5–6.0 | 0.180 | 3553 | 10 | 4.8 | 65.5 | 3.1 | 26.6 | 5.75 |
| | 6.0–6.5 | | | | | | | | 6.25 |
| | 6.5–7.0 | 0.208 | 1959 | 6 | 7.9 | 73.9 | 1.2 | 17.0 | 6.75 |
| | 7.0–7.5 | 0.261 | 1746 | | 5.0 | 52.6 | 9.7 | 32.7 | 7.25 |



## B.1. MAJOR ION CHEMISTRY ANALYSIS DATA, BORDER DESIGNATED AREA

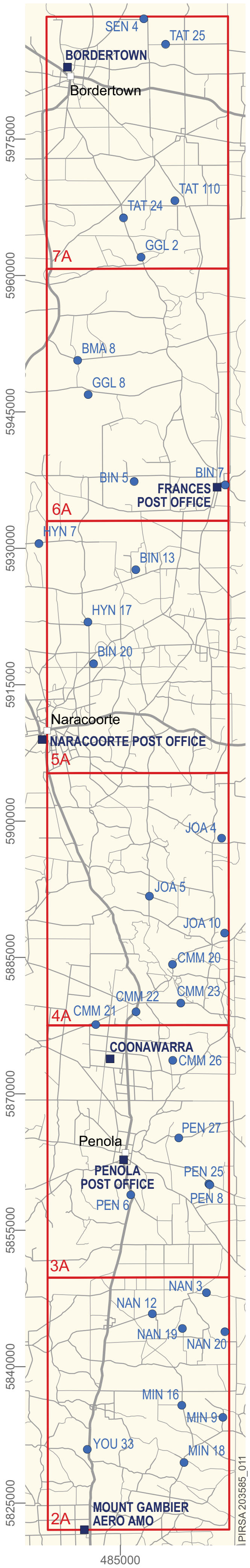
| Site | Depth to water (m) | Screened interval (m) | Sample date | E.C. (dS/m) | TDS (mg/L) | pH | Alkalinity (meg/L) | Alk as $CaCO_3$ | Bicarb (mg/L) | $F^-$ (mg/L) | $Cl^-$ (mg/L) | $Br^-$ (mg/L) | $NH_4$-N (mg/L) | $NO_3^-$ (mg/L) | NOX (mg/L) | $NO_2^=$ (mg/L) | $SO_4^=$ (mg/L) | Ca (mg/L) | K (mg/L) | Mg (mg/L) | Na (mg/L) | S (mg/L) | Al (mg/L) | B (mg/L) | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | P (mg/L) | Si (mg/L) | Sr (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Border Designated Area** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4N-NV | 26.13 | 25.0–31.0 | 04/09/2006 | 2.772 | | 7.36 | 7.659 | | | <0.25 | 617.67 | 1.57 | | 1.75 | | | 73.69 | 153.8 | 6 | 47.7 | 358.1 | 26 | <0.1 | 0.333 | <0.02 | <0.1 | <0.05 | <0.1 | 15.347 | 1.418 | <0.02 |
| BDA Dry1 | 20.60 | 21.0–24.0 | 19/12/2006 | 4.510 | 2500 | 7.40 | | 570 | 695 | 1.1 | 1230 | 4.1 | | 1.02 | 1.02 | <0.005 | 201 | 121 | 10.4 | 101 | 714 | 68.9 | 0.578 | 0.474 | 0.0036 | 0.759 | 0.107 | <0.05 | 27.600 | <0.0005 | 0.003 |
| BDA Dry3 | 21.33 | 22.0–25.0 | 19/12/2006 | 3.160 | 1800 | 7.30 | | 409 | 499 | 0.86 | 790 | 2.59 | | 0.042 | 0.047 | <0.005 | 131 | 109 | 11.5 | 83.2 | 425 | 43 | 0.102 | 0.287 | 0.0015 | 0.099 | 0.005 | <0.05 | 30.000 | <0.0005 | <0.003 |
| BDA Dry4 | 19.25 | 20.5–23.5 | 19/12/2006 | 1.840 | 1000 | 7.10 | | 510 | 622 | 0.27 | 332 | 1.08 | | 0.531 | 0.536 | <0.005 | 51.9 | 158 | 5.5 | 46.6 | 171 | 16.8 | 0.340 | 0.077 | 0.002 | 0.349 | 0.007 | <0.05 | 20.500 | <0.0005 | <0.003 |
| BDA NV2 | 21.76 | 22.0–25.0 | 30/01/2007 | 2.080 | 1100 | 7.00 | | 558 | 681 | 0.25 | 405 | 1.39 | | 0.079 | 0.084 | <0.005 | 47.1 | 171 | 6.3 | 44.8 | 203 | 16.2 | 0.139 | 0.201 | <0.001 | 0.402 | 0.01 | <0.05 | 24.600 | <0.0005 | <0.003 |
| JOA 12 | 20.00 | 27.43–32.0 | 04/09/2006 | 1.921 | | 7.36 | 5.901 | | | 0.44 | 377.81 | 0.78 | | 13.67 | | | 52.33 | 97.8 | 5.1 | 32.9 | 244.7 | 18.8 | 0.104 | 0.272 | <0.02 | <0.1 | <0.05 | <0.1 | 14.198 | 1.179 | <0.02 |
| JOA 5 | 11.74 | – | 04/09/2006 | 3.064 | | 7.16 | 7.473 | | | 0.52 | 699.63 | 1.49 | | 17.97 | | | 85.84 | 152.4 | 6.1 | 57.3 | 398.2 | 29.9 | <0.1 | 0.341 | <0.02 | <0.1 | <0.05 | <0.1 | 15.598 | 1.440 | <0.02 |
| MIN 26 | 6.07 | – | 06/09/2006 | 1.206 | | 7.27 | 6.578 | | | <0.25 | 140.57 | 0.25 | | 12.33 | | | 43.98 | 110.5 | 5.2 | 17.8 | 126.3 | 15.9 | <0.1 | <0.1 | <0.02 | <0.1 | <0.05 | <0.1 | 5.227 | 0.269 | <0.02 |
| NAN 3 | 9.00 | – | 06/09/2006 | 0.888 | | 7.32 | 4.877 | | | <0.25 | 52.05 | 0.14 | | 71.11 | | | 43.15 | 111.69 | 12.84 | 10.61 | 51.95 | 14.957 | <0.1 | <0.1 | <0.02 | <0.1 | <0.05 | <0.1 | 4.829 | 0.267 | <0.02 |
| SEN 4 | 30.87 | 30.0–36.0 | 05/09/2006 | 2.814 | | 7.34 | 6.836 | | | 0.93 | 660.7 | 1.85 | | 1.06 | | | 79.49 | 132.8 | 9.3 | 77.6 | 318.8 | 27.9 | 0.095 | 0.171 | <0.02 | <0.1 | <0.05 | <0.1 | 15.947 | 3.153 | <0.02 |
| TAT 20 | 37.16 | 37.0–43.0 | 05/09/2006 | 2.015 | | 7.57 | 5.343 | | | 0.36 | 438.95 | 1.28 | | 1.4 | | | 50.73 | 84.5 | 7.7 | 49 | 244.6 | 18.3 | 0.095 | 0.200 | <0.02 | <0.1 | <0.05 | <0.1 | 13.028 | 1.843 | <0.02 |
| TAT 24 | 27.39 | 28.0–34.0 | 05/09/2006 | 1.760 | | 7.49 | 5.823 | | | 0.27 | 345.63 | 0.9 | | 2.24 | | | 44.99 | 103.1 | 5.6 | 42.1 | 187.8 | 15.9 | <0.1 | 0.107 | <0.02 | <0.1 | <0.05 | <0.1 | 11.926 | 1.367 | <0.02 |
| TAT 25 | 40.68 | 42.0–48.0 | 05/09/2006 | 2.997 | | 7.48 | 5.649 | | | 0.96 | 746.06 | 2.03 | | 0.37 | | | 101.03 | 99.3 | 10.4 | 86.4 | 375.8 | 35.9 | 0.113 | 0.219 | <0.02 | <0.1 | <0.05 | <0.1 | 16.109 | 3.641 | <0.02 |

## B.2. MAJOR ION CHEMISTRY ANALYSIS DATA, HUNDRED OF STIRLING

| Site | Depth to water (m) | Screened interval (m) | Sample date | E.C. (dS/m) | TDS (mg/L) | pH | Alkalinity (meq/L) | Alk as $CaCO_3$ | Bicarb (mg/L) | $F^-$ (mg/L) | $Cl^-$ (mg/L) | $Br^-$ (mg/L) | $NH_4$-N (mg/L) | $NO_3^-$ (mg/L) | NOX (mg/L) | $NO_2^=$ (mg/L) | $SO_4^=$ (mg/L) | Ca (mg/L) | K (mg/L) | Mg (mg/L) | Na (mg/L) | S (mg/L) | Al (mg/L) | B (mg/L) | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | P (mg/L) | Si (mg/L) | Sr (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ARC DRY | 9.19 | 9–15 | 07/09/2006 | 10.69 | | 7.51 | 7.298 | | | 0.6 | 3320 | 9.65 | | 34.340 | | | 231.59 | 147 | 25.5 | 193.4 | 18400 | 77.5 | 0.099 | 1.111 | <0.02 | <0.1 | <0.05 | <0.1 | 13.114 | 3.531 | <0.02 |
| ARC DRY | – | 9–15 | 16/10/2006 | 10.58 | 6051 | 7.6 | 7.266 | | | 0.5 | 3020 | 7.7 | 0.03 | | 7.1 | | 224 | 95 | 24 | 203 | 1760 | 85 | <0.5 | 1.1 | <0.1 | <0.5 | <0.2 | <0.5 | 11.2 | | <0.1 |
| ARC DRY | 10.42 | 9–15 | 01/11/2006 | 10.38 | 5925 | 7.7 | 7.1 | | | <1 | 2990 | 8 | | 30 | | | 240 | 111 | 18 | 194 | 1723 | 88 | | | | | | | | | |
| ARC DT IRR | 9.38 | 9–15 | 07/09/2006 | 10.84 | | 7.26 | 9.266 | | | 0.6 | 3250 | 8.75 | | 81.970 | | | 363.4 | 218 | 30.2 | 324.4 | 1500 | 123.2 | <0.1 | 0.699 | <0.02 | <0.1 | <0.05 | <0.1 | 18.42 | 6.406 | <0.02 |
| ARC DT IRR | – | 9–15 | 16/10/2006 | 10.32 | 5891 | 7.5 | 8.335 | | | 0.5 | 2870 | 7.5 | 0.03 | | 14 | | 330 | 96 | 27 | 331 | 1470 | 125 | <0.5 | 0.7 | <0.1 | <0.5 | <0.2 | <0.5 | 14.9 | | <0.1 |
| ARC DT IRR | – | 9–15 | 25/10/2006 | 5.859 | 3286 | 7.9 | 8.3 | | | <0.5 | 1650 | 3.7 | | 10 | | | 209 | 86 | 17 | 199 | 881 | 78 | | | | | | | | | |
| ARC DT IRR LYSIMETER 0.4 m | | | 16/10/2006 | 9.26 | 5262 | 8.1 | 9.901 | | | 1 | 2450 | 5.8 | 0.15 | | 17 | | 318 | 207 | 105 | 296 | 1250 | 121 | <0.5 | 0.6 | <0.1 | <0.5 | <0.2 | 1.6 | 24 | | <0.1 |
| ARC DT IRR LYSIMETER 0.8 m | | | 16/10/2006 | 17.3 | 10136 | 7.9 | 20.75 | | | 2.2 | 4890 | 11 | 0.12 | | 3.5 | | 633 | 106 | 93 | 375 | 3160 | 222 | <0.5 | 0.5 | <0.1 | <0.5 | <0.2 | <0.5 | 20.7 | | <0.1 |
| ARC DT IRR LYSIMETER 1.2 m | | | 16/10/2006 | 21.87 | 13022 | 8.1 | 15.556 | | | 1.1 | 6950 | 18 | 0.09 | | 0.6 | | 769 | 345 | 72 | 726 | 3670 | 290 | <0.5 | 1.1 | <0.1 | <0.5 | <0.2 | 0.5 | 20.4 | | <0.1 |
| ARC DT IRR LYSIMETER 2.0 m | | | 16/10/2006 | 18.53 | 10915 | 8.2 | 16.714 | | | 1.2 | 5580 | 14 | 0.05 | | 4.6 | | 704 | 232 | 67 | 543 | 3130 | 264 | <0.5 | 0.9 | <0.1 | <0.5 | <0.2 | <0.5 | 25.2 | | <0.1 |
| ARC IRR | – | – | 16/10/2006 | 9.69 | 5515 | 7.6 | 6.866 | | | 0.5 | 2790 | 7.3 | 0.06 | | 4.5 | | 209 | 214 | 27 | 351 | 1190 | 76 | <0.5 | 0.6 | <0.1 | <0.5 | <0.2 | <0.5 | 16.5 | | <0.1 |
| ARC IRR | – | – | 25/10/2006 | 9.48 | 5392 | 7.9 | 5.4 | | | <0.5 | 2840 | 8 | | 23 | | | 214 | 173 | 23 | 345 | 1210 | 74 | | | | | | | | | |
| ARC IRR LYSIMETER 0.4 m | | | 25/10/2006 | 15.31 | 8904 | 8.5 | 20.1 | | | 0.7 | 4560 | 13 | | 9 | | | 519 | 174 | 128 | 451 | 2508 | 187 | | | | | | | | | |
| ARC IRR LYSIMETER 2.0 m | | | 25/10/2006 | 11.39 | 6527 | 8.6 | 8.1 | | | <1 | 3960 | 9 | | 107 | | | 468 | 54 | 62 | 508 | 1893 | 147 | | | | | | | | | |
| PEN DRY | 8.60 | 5.2–11.2 | 07/09/2006 | 4.344 | | 7.31 | 8.564 | | | 1.7 | 1170 | 3.31 | | 10.230 | | | 117 | 102.7 | 23.4 | 138.3 | 592.7 | 41.7 | <0.1 | 0.546 | <0.02 | <0.1 | <0.05 | <0.1 | 21.082 | 4.447 | <0.02 |
| PEN DRY | 8.82 | 5.2–11.2 | 17/10/2006 | 4.04 | 2251 | 7.7 | 8.376 | | | 1.5 | 1080 | 2.9 | 0.33 | | 2 | | 113 | 39 | 24 | 137 | 614 | 43 | 0.1 | 0.5 | <0.02 | <0.1 | <0.05 | 0.1 | 20.8 | | <0.02 |
| PEN IRR | 8.02 | 5.4–11.4 | 07/09/2006 | 6.536 | | 7.28 | 9.159 | | | 1.9 | 1970 | 5.58 | | 15.830 | | | 192.6 | 124 | 40.1 | 205.9 | 966.3 | 67 | <0.1 | 0.688 | <0.02 | <0.1 | <0.05 | <0.1 | 21.868 | 6.861 | <0.02 |
| PEN IRR | 8.23 | 5.4–11.4 | 17/10/2006 | 6.016 | 3377 | 7.6 | 9.017 | | | 1.6 | 1780 | 4.7 | 0.25 | | 3.2 | | 177 | 73 | 39 | 214 | 973 | 68 | 0.4 | 0.8 | -0.03 | 0.0 | -0.03 | 0.1 | 22.4 | | -0.05 |
| PEN IRR | 8.29 | 5.4–11.4 | 24/10/2006 | 6.447 | 3624 | 7.8 | 10.7 | | | 1.9 | 1810 | 5 | | 8 | | | 232 | 72 | 31 | 197 | 1075 | 86 | | | | | | | | | |
| PEN IRR | 8.31 | 5.4–11.4 | 25/10/2006 | 6.387 | 3590 | 7.9 | 8.9 | | | 1.7 | 1820 | 5.1 | | 18 | | | 181 | 79 | 34 | 213 | 975 | 69 | | | | | | | | | |
| PEN IRR CHANNEL | | | 24/10/2006 | 6.488 | 3647 | 8.0 | 10.8 | | | 1.9 | 1820 | 5 | | 6.3 | | | 230 | 72 | 31 | 199 | 1079 | 87 | | | | | | | | | |
| PEN IRR LYSIMETER 0.5 m | | | 25/10/2006 | 10.1 | 5766 | 8.4 | 13.7 | | | 1.6 | 2960 | 6.7 | | 11 | | | 352 | 195 | 72 | 267 | 1631 | 131 | | | | | | | | | |
| PEN IRR LYSIMETER 2.0 m | | | 17/10/2006 | 11.3 | 6475 | 8.2 | 14.836 | | | 2.5 | 3340 | 8.8 | 0.37 | | 12 | | 427 | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | | i.s |
| PEN IRR LYSIMETER 2.0 m | | | 25/10/2006 | 11.61 | 6665 | 8.3 | 10.1 | | | 2.1 | 3810 | 8 | | 65 | | | 513 | 43 | 34 | 348 | 2134 | 171 | | | | | | | | | |
| PEN SUB-SURF | – | 6–12 | 17/10/2006 | 6.15 | 3454 | 7.7 | 9.929 | | | 1.8 | 1650 | 4.3 | <0.02 | | 5.6 | | 167 | 51 | 43 | 197 | 928 | 65 | <0.5 | 0.9 | <0.1 | <0.5 | <0.2 | <0.5 | 23.1 | | <0.1 |
| PEN SUB-SURF | – | 6–12 | 25/10/2006 | 6.112 | 3433 | 7.9 | 10 | | | 1.9 | 1650 | 4.6 | | 22 | | | 173 | 37 | 39 | 198 | 949 | 66 | | | | | | | | | |
| STR MID DRY | 5.48 | – | 07/09/2006 | 12.14 | | 7.37 | 10.74 | | | 1.7 | 3720 | 11.05 | | 23.74 | | | 494.43 | 155.6 | 55.1 | 351.6 | 1930 | 163.9 | <0.1 | 1.076 | <0.02 | <0.1 | <0.05 | <0.1 | 24.761 | 10.763 | <0.02 |
| STR MID DRY (PREV IRR) | – | 6–12 | 17/10/2006 | 14.51 | 8424 | 7.6 | 10.87 | | | 1.6 | 4130 | 12 | 0.03 | | 7.4 | | 664 | 149 | 54 | 429 | 2330 | 244 | <0.5 | 1.2 | <0.1 | <0.5 | <0.2 | <0.5 | 26.4 | | <0.1 |
| STR MID IRR | 5.74 | – | 07/09/2006 | 13.96 | | 7.5 | 11.18 | | | 1.6 | 4300 | 13.13 | | 31.16 | | | 692.45 | 179.4 | 53.7 | 376 | 2300 | 228.2 | <0.1 | 1.103 | <0.02 | <0.1 | <0.05 | <0.1 | 25.07 | 10.765 | <0.02 |
| STR MID IRR | – | – | 17/10/2006 | 13.43 | 7754 | 7.8 | 10.19 | | | 1.4 | 3780 | 11 | 0.04 | | 0.31 | | 635 | 114 | 50 | 397 | 2170 | 235 | <0.5 | 1.2 | <0.1 | <0.5 | <0.2 | <0.5 | 24.2 | | <0.1 |
| STR NTH DRY | 7.71 | 6–12 | 07/09/2006 | 7.86 | | 7.25 | 11.2 | | | 0.7 | 2120 | 6.64 | | 0.59 | | | 342.41 | 118.5 | 31.8 | 224.1 | 1140 | 118.8 | 0.095 | 0.665 | <0.02 | <0.1 | <0.05 | <0.1 | 22.406 | 5.280 | <0.02 |
| STR NTH DRY | – | 6–12 | 16/10/2006 | 5.848 | 3280 | 7.8 | 11.54 | | | 1.2 | 1420 | 4.1 | <0.02 | | 1 | | 318 | 37 | 29 | 157 | 1000 | 121 | <0.5 | 0.7 | 0.01 | <0.5 | <0.2 | <0.5 | 12.7 | | <0.1 |
| STR NTH IRR | 7.69 | 5.8–11.8 | 07/09/2006 | 13.94 | | 7.18 | 10.83 | | | 0.9 | 4430 | 13.07 | | 24.58 | | | 523.46 | 200.5 | 50.4 | 473.80 | 2050 | 177.2 | 0.095 | 1.017 | <0.02 | <0.1 | <0.05 | <0.1 | 19.715 | 10.588 | <0.02 |

| Site | Depth to water (m) | Screened interval (m) | Sample date | E.C. (dS/m) | TDS (mg/L) | pH | Alkalinity (meg/L) | Alk as $CaCO_3$ | Bicarb (mg/L) | $F^-$ (mg/L) | $Cl^-$ (mg/L) | $Br^-$ (mg/L) | $NH_4$-N (mg/L) | $NO_3^-$ (mg/L) | NOX (mg/L) | $NO_2^=$ (mg/L) | $SO_4^=$ (mg/L) | Ca (mg/L) | K (mg/L) | Mg (mg/L) | Na (mg/L) | S (mg/L) | Al (mg/L) | B (mg/L) | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | P (mg/L) | Si (mg/L) | Sr (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STR NTH IRR | – | 5.8–11.8 | 16/10/2006 | 13.43 | 7754 | 7.6 | 10.76 | | | <1 | 3920 | 11 | 0.03 | | 5.1 | | 490 | 143 | 45 | 505 | 1980 | 183 | 0.5 | 1 | <0.1 | <0.5 | <0.2 | <0.5 | 18.6 | | <0.1 |
| STR STH DRY | 6.99 | 5.5–11.5 | 07/09/2006 | 8.38 | | 7.22 | 8.277 | | | 1 | 2450 | 6.56 | | 37.69 | | | 219.42 | 224.6 | 31.8 | 244 | 1110 | 76.3 | 0.096 | 0.476 | <0.02 | <0.1 | <0.05 | <0.1 | 21.313 | 7.456 | <0.02 |
| STR STH DRY | – | 5.5–11.5 | 17/10/2006 | 8.35 | 4729 | 7.7 | 8.380 | | | 0.9 | 2240 | 5.4 | 0.06 | | 7.5 | | 208 | 129 | 30 | 252 | 1090 | 77 | <0.5 | 0.5 | <0.1 | <0.5 | <0.2 | <0.5 | 21 | | <0.1 |
| STR STH IRR | 7.99 | – | 07/09/2006 | 9.02 | | 7.19 | 9.001 | | | 0.9 | 2690 | 6.75 | | 22.08 | | | 241.37 | 228.9 | 34.4 | 261 | 1200 | 82 | 0.098 | 0.535 | <0.02 | <0.1 | <0.05 | <0.1 | 21.608 | 7.806 | <0.02 |
| STR STH IRR | – | – | 17/10/2006 | 9.11 | 5175 | 7.9 | 8.392 | | | 0.6 | 2540 | 6.2 | 0.05 | | 4.6 | | 232 | 138 | 33 | 282 | 1210 | 85 | <0.5 | 0.6 | <0.1 | <0.5 | <0.2 | <0.5 | 21.6 | | <0.1 |
| STR STH IRR LYSIMETER 2.0 m | | | 17/10/2006 | 14.99 | 8702 | 7.9 | 12.92 | | | 1.3 | 4610 | 11 | 0.38 | | 3.4 | | 485 | 144 | 62 | 519 | 2310 | 183 | <0.5 | 0.8 | <0.1 | <0.5 | <0.2 | <0.5 | 27 | | <0.1 |
| STR STH IRR LYSIMETER 3.0 m | | | 17/10/2006 | 12.85 | 7405 | 8.2 | 9.462 | | | 1.1 | 3860 | 9.2 | 0.55 | | 11 | | 404 | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | | i.s |
| WIR DRY 1 | – | 4.5–10.5 | 17/10/2006 | 4.718 | 2635 | 7.7 | 9.727 | | | 2.1 | 1150 | 3.1 | <0.02 | | 1.1 | | 150 | 29 | 24 | 144 | 681 | 56 | 0.1 | 0.6 | <0.02 | <0.1 | <0.05 | 0.1 | 14.2 | | <0.02 |
| WIR DRY 2 | 7.24 | 6.5–12.5 | 06/09/2006 | 3.819 | | 7.48 | 11.09 | | | 2.4 | 871.18 | 2.31 | | 4.140 | | | 175.46 | 74.1 | 22 | 124.8 | 555.8 | 62.3 | 0.104 | 0.580 | <0.02 | <0.1 | <0.05 | <0.1 | 20.613 | 3.397 | <0.02 |
| WIR DRY 2 | 7.44 | 6.5–12.5 | 17/10/2006 | 3.91 | 2177 | 7.9 | 11.05 | | | 2.3 | 808 | 2.1 | 0.04 | | 0.6 | | 164 | 23 | 22 | 124 | 566 | 62 | 0.1 | 0.6 | <0.02 | <0.1 | <0.05 | 0.1 | 18.3 | | <0.02 |
| WIR IRR | – | – | 30/08/2006 | 6.287 | 3532 | 8.2 | 8.905 | | | 1.1 | 1740 | 4.5 | <0.02 | | 4.7 | | 191 | 48 | 33 | 201 | 1050 | 74 | <0.5 | 0.9 | <0.1 | <0.5 | <0.2 | <0.5 | 9 | | <0.1 |
| WIR IRR | 7.08 | – | 06/09/2006 | 6.652 | | 7.23 | 12.2 | | | 1.7 | 1930 | 5.42 | | 20.240 | | | 238.22 | 158.1 | 32.1 | 198.8 | 1010 | 81.4 | <0.1 | 0.795 | <0.02 | <0.1 | <0.05 | <0.1 | 18.924 | 5.706 | <0.02 |
| WIR IRR | – | – | 17/10/2006 | 6.526 | 3670 | 7.7 | 12.15 | | | 1.5 | 1750 | 4.6 | <0.02 | | 1.3 | | 198 | 109 | 32 | 206 | 1040 | 75 | <0.5 | 0.8 | 0.01 | <0.5 | <0.2 | <0.5 | 9.7 | | <0.1 |
| WIR IRR LYSIMETER 1.4 m | | | 30/08/2006 | 8.62 | 4888 | 8.6 | 7.203 | | | 1.1 | 2340 | 5.4 | 0.04 | | 12 | | 343 | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | i.s | | i.s |
| WIR IRR LYSIMETER 2.4 m | | | 30/08/2006 | 6.776 | 3813 | 8.2 | 11.2 | | | 0.9 | 1900 | 4.8 | <0.02 | | 5 | | 252 | 105 | 39 | 242 | 1100 | 97 | <0.5 | 0.6 | <0.1 | 0 | <0.2 | <0.5 | 13.9 | | <0.1 |
| WIR IRR LYSIMETER 3.4 m | | | 30/08/2006 | 8.83 | 5010 | 8.6 | 6.976 | | | 0.6 | 2470 | 6.4 | 0.02 | | 5.9 | | 322 | 51 | 38 | 289 | 1420 | 125 | <0.5 | 0.8 | <0.1 | <0.5 | <0.2 | <0.5 | 16.8 | | <0.1 |

# C.1. RAINFALL STATION AND MONITORING WELL LOCATION MAP, BORDER DESIGNATED AREA





■ Rainfall Station with Evaporation

● Monitoring Well

□ Management Zone

0 5 10 15 20 Kilometers

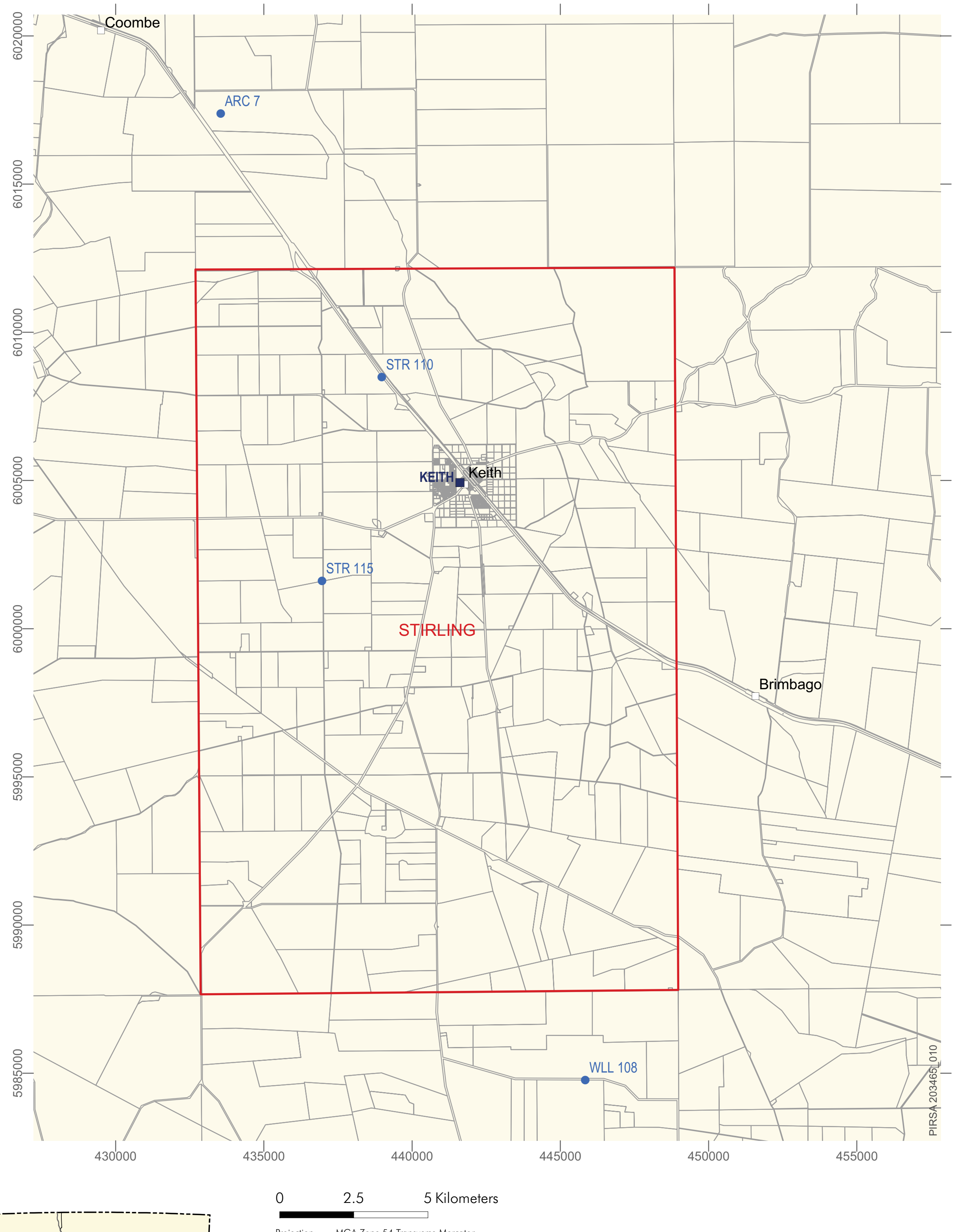
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

**RAINFALL STATION AND MONITORING WELL LOCATIONS**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix C.1**





Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: December 2006

- Monitoring Well
- Rainfall Stations with Evaporation
- Management Zone

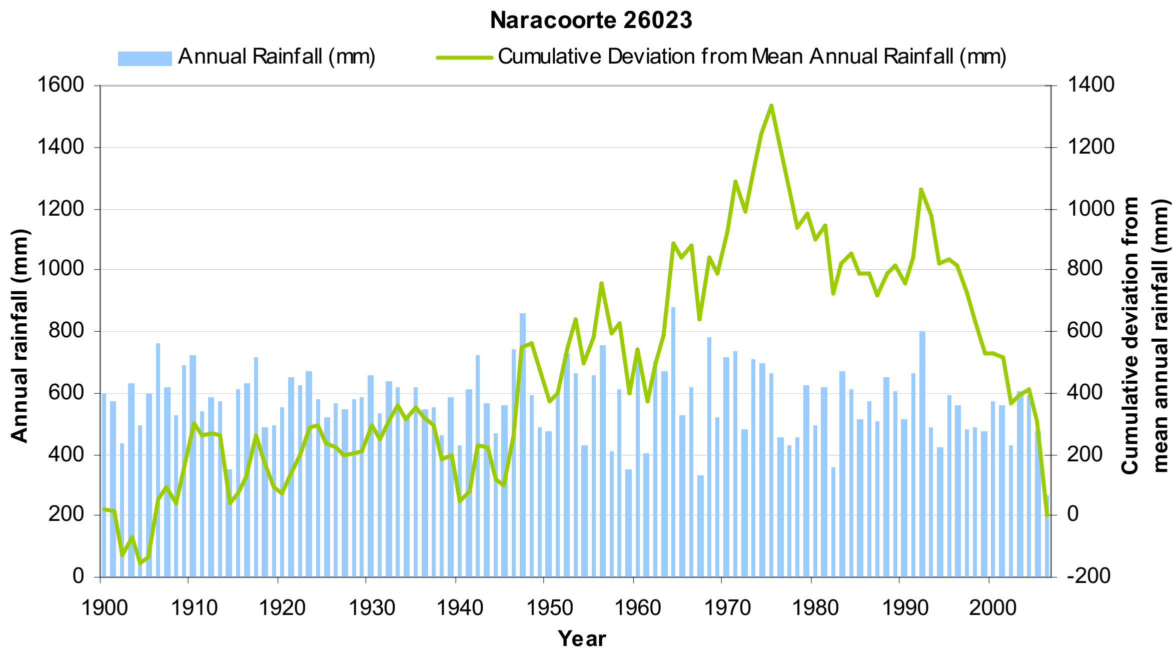
Hundred of Stirling
Salt Accession Project

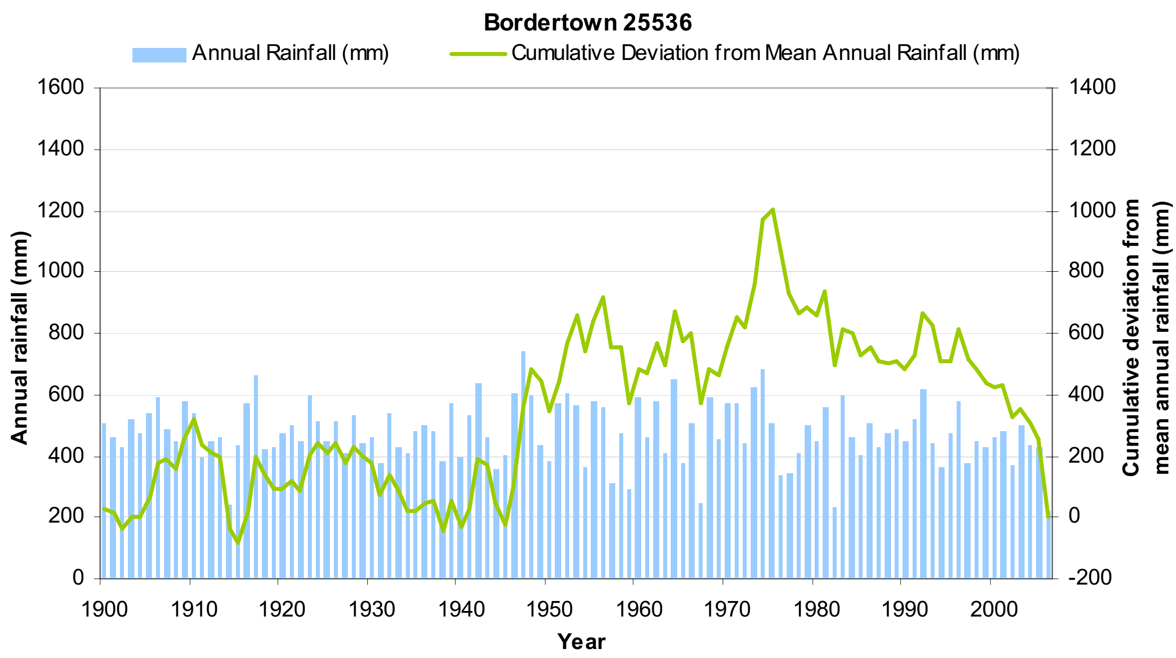
**RAINFALL STATION AND MONITORING WELL LOCATIONS**

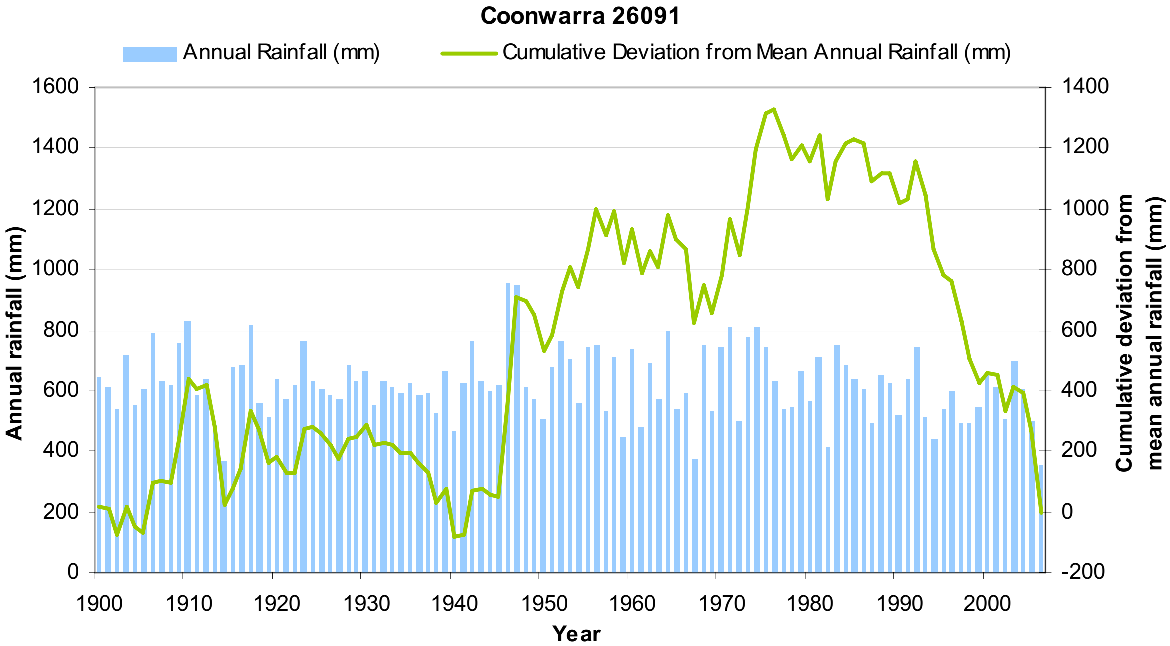
Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix C.2**

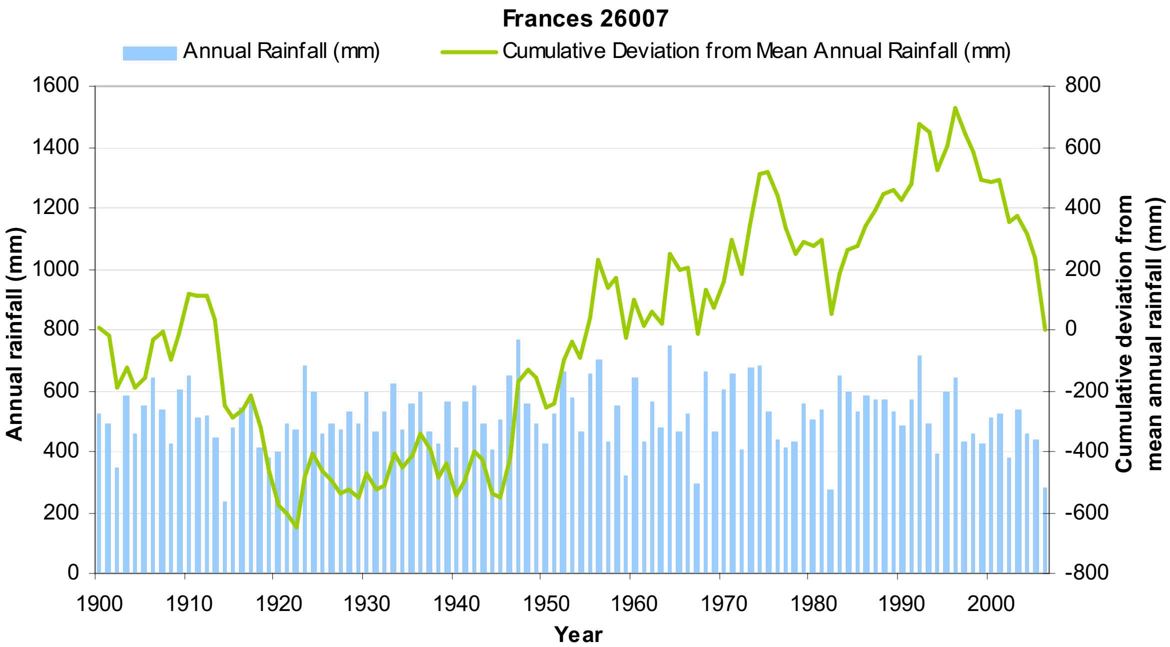
# D.1. ANNUAL RAINFALL VS. CUMULATIVE DEVIATION FROM THE MEAN ANNUAL RAINFALL, BORDER DESIGNATED AREA



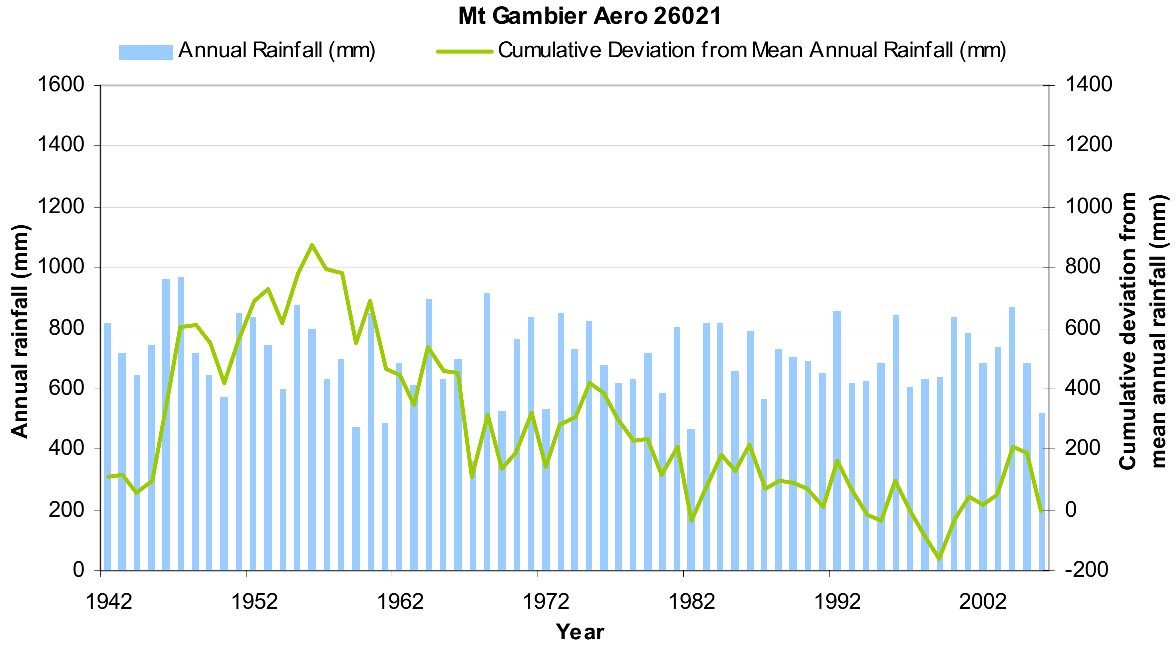



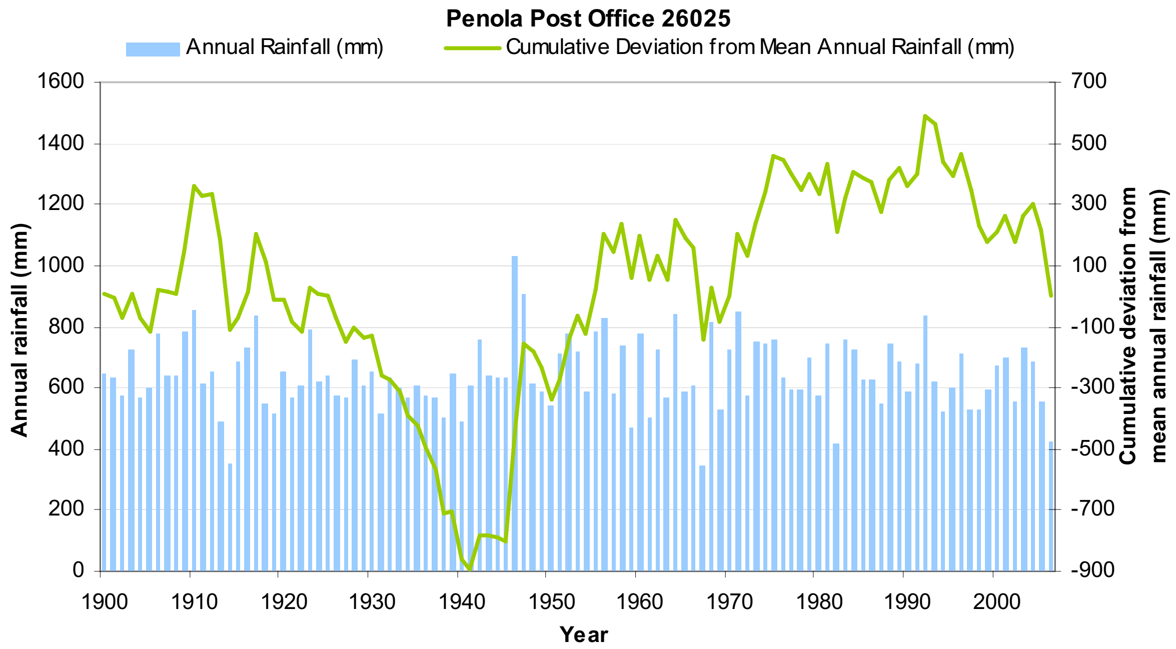


Coonwarra 26091
Annual Rainfall (mm)
Cumulative Deviation from Mean Annual Rainfall (mm)
Annual rainfall (mm)
Cumulative deviation from mean annual rainfall (mm)
Year

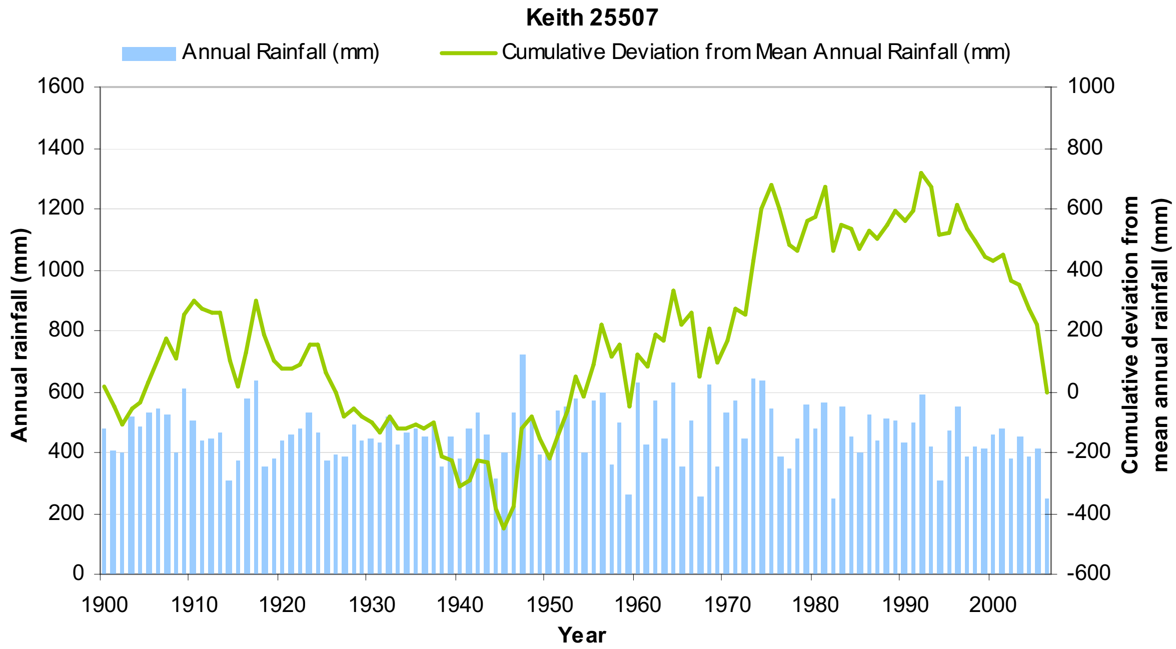



Frances 26007
Annual Rainfall (mm)
Cumulative Deviation from Mean Annual Rainfall (mm)
Annual rainfall (mm)
Cumulative deviation from mean annual rainfall (mm)
Year

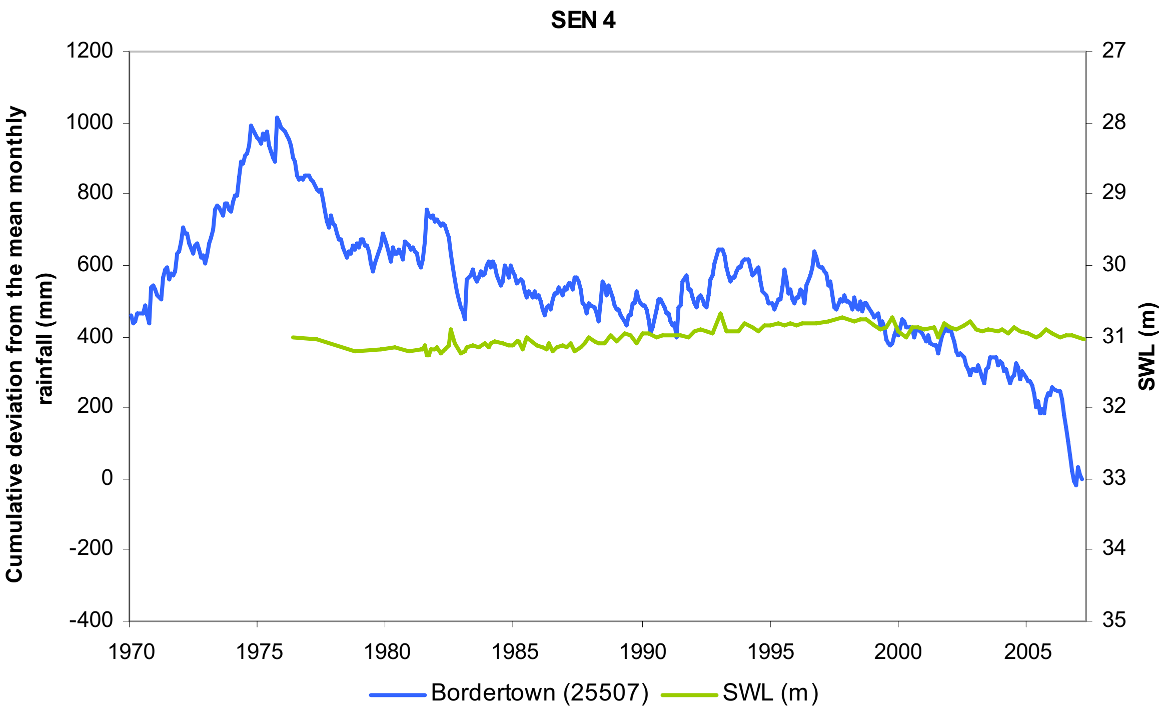

Mt Gambier Aero 26021
Annual Rainfall (mm)
Cumulative Deviation from Mean Annual Rainfall (mm)
Annual rainfall (mm)
Cumulative deviation from mean annual rainfall (mm)
Year
1942
1952
1962
1972
1982
1992
2002

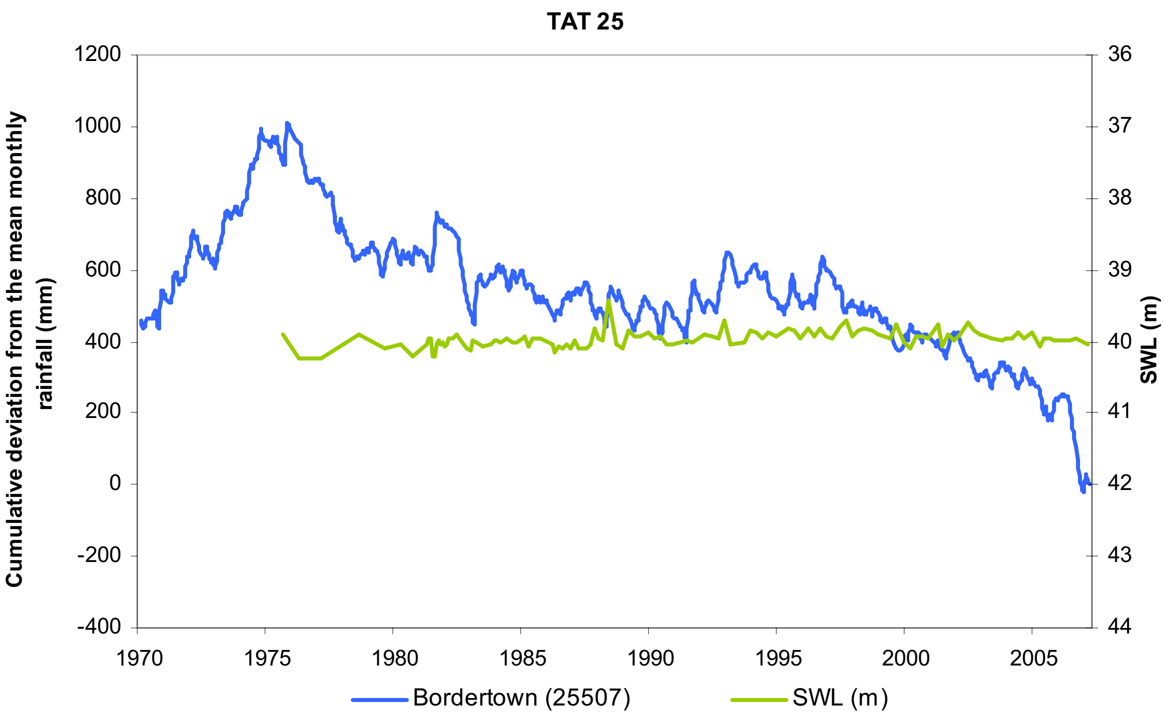

Penola Post Office 26025
Annual Rainfall (mm)
Cumulative Deviation from Mean Annual Rainfall (mm)
Annual rainfall (mm)
Cumulative deviation from mean annual rainfall (mm)
Year
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

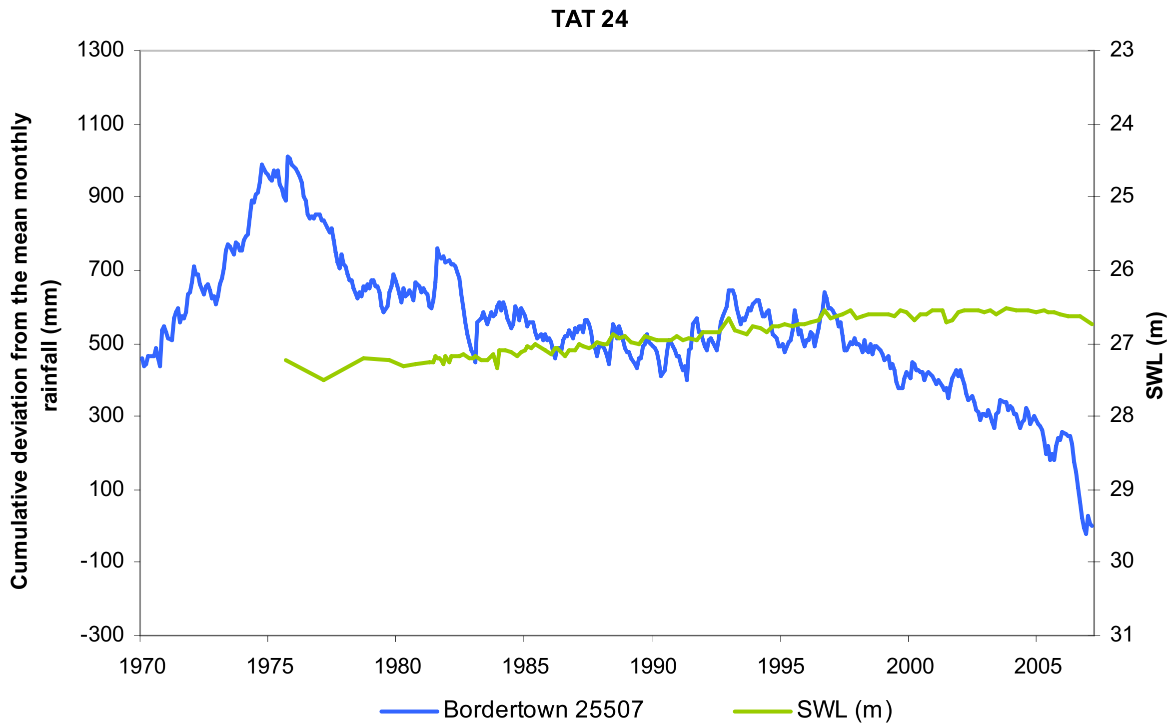
## *D.2. ANNUAL RAINFALL VS. CUMULATIVE DEVIATION FROM THE MEAN ANNUAL RAINFALL, HUNDRED OF STIRLING*

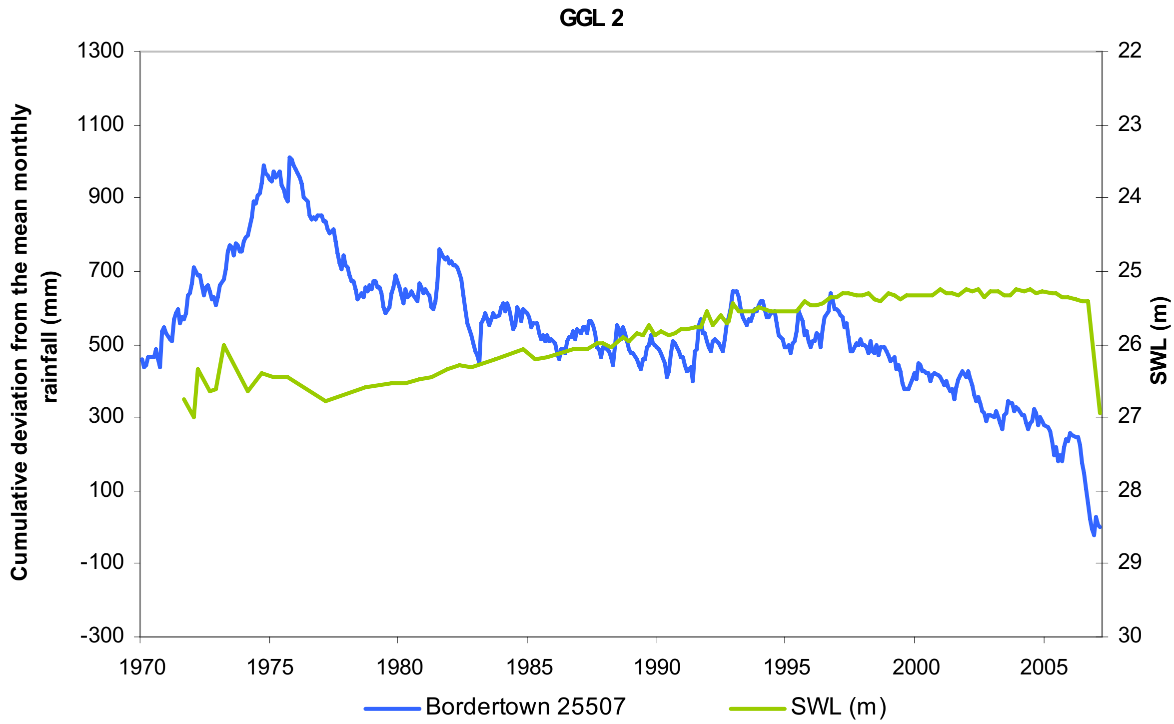


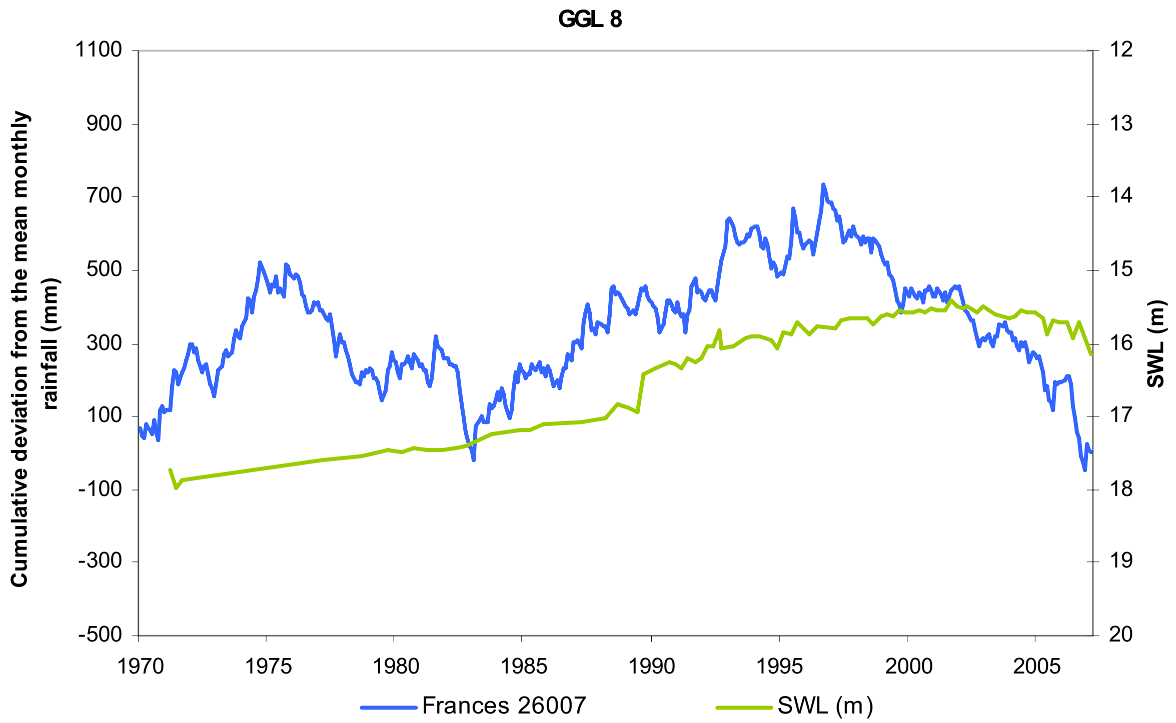
# E.1. CUMULATIVE DEVIATION FROM THE MEAN MONTHLY RAINFALL VS. MONITORING WELL HYDROGRAPHS, BORDER DESIGNATED AREA

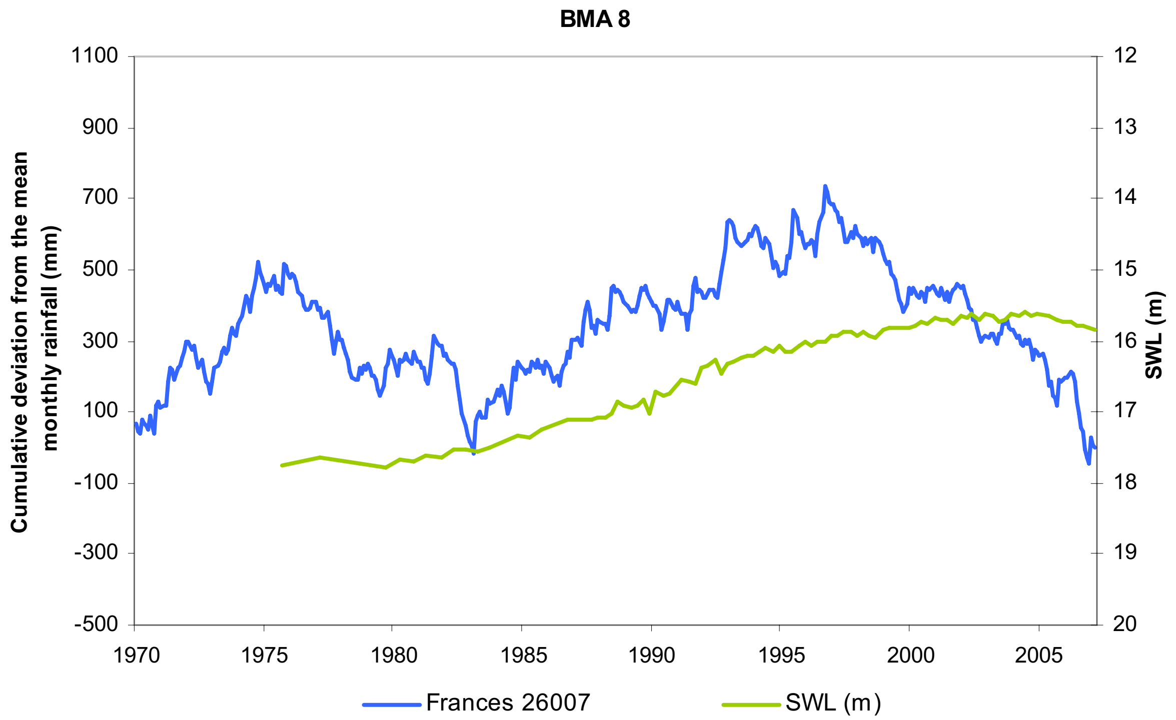


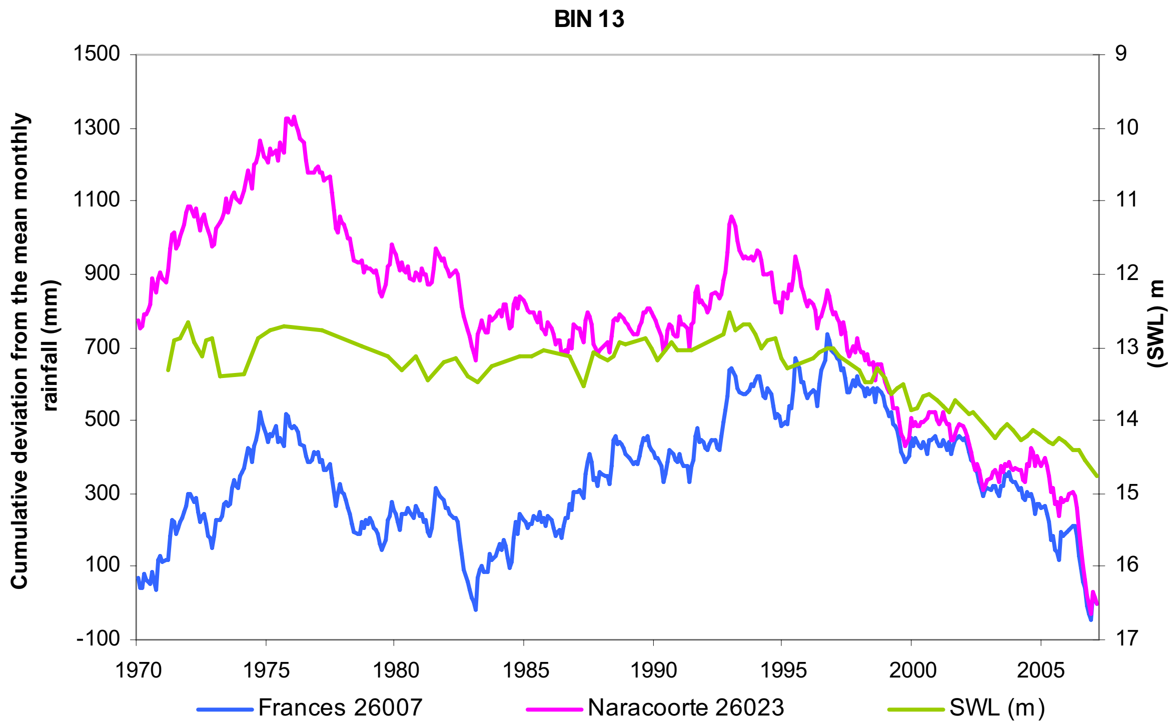



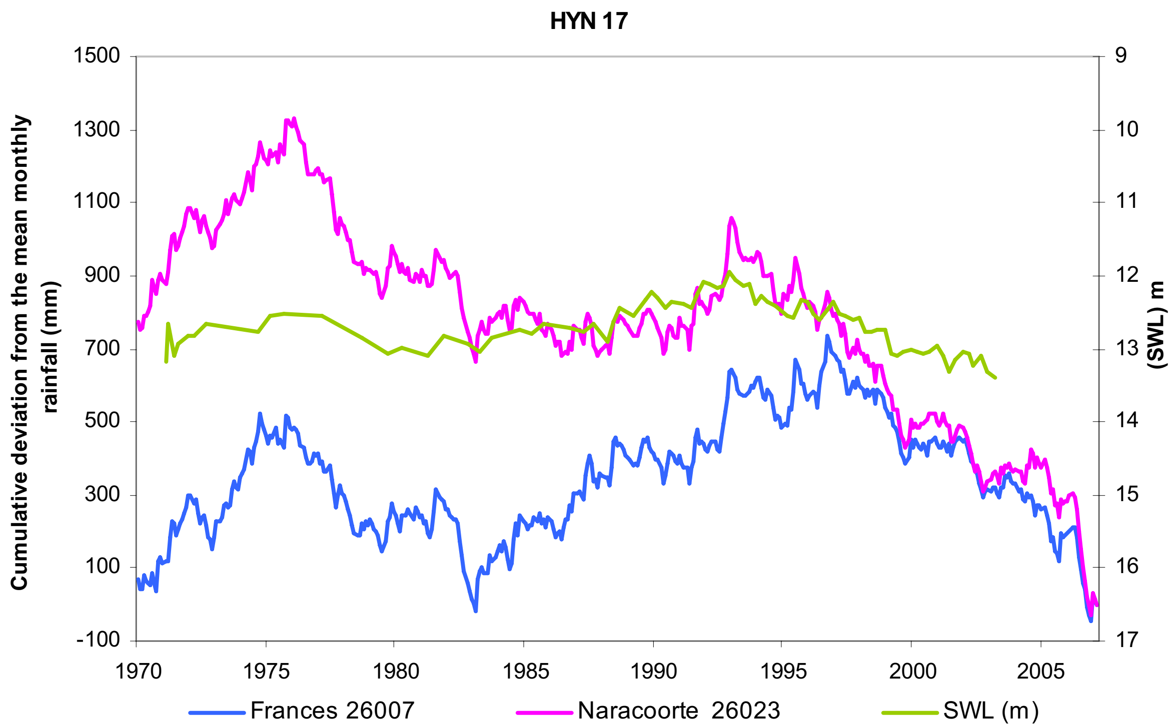

TAT 24
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1300
1100
900
700
500
300
100
-100
-300
23
24
25
26
27
28
29
30
31
1970
1975
1980
1985
1990
1995
2000
2005
Bordertown 25507
SWL (m)

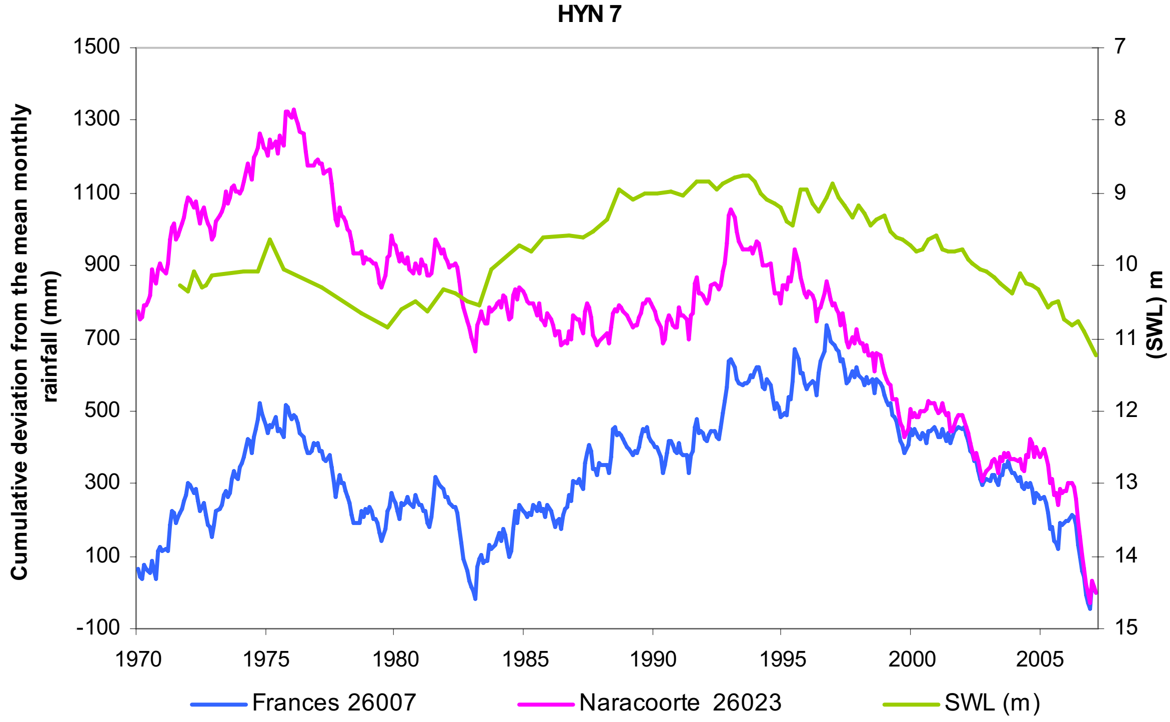

GGL 2
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1300
1100
900
700
500
300
100
-100
-300
22
23
24
25
26
27
28
29
30
1970
1975
1980
1985
1990
1995
2000
2005
Bordertown 25507
SWL (m)

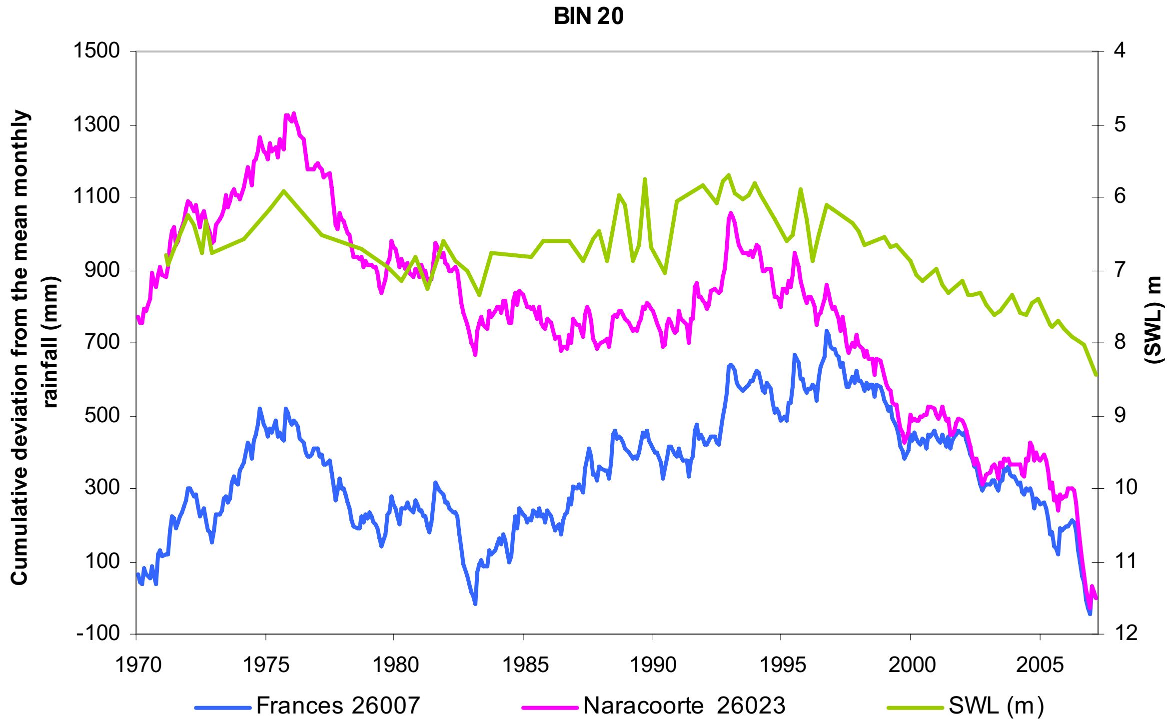

GGL 8
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1100
900
700
500
300
100
-100
-300
-500
12
13
14
15
16
17
18
19
20
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
SWL (m)

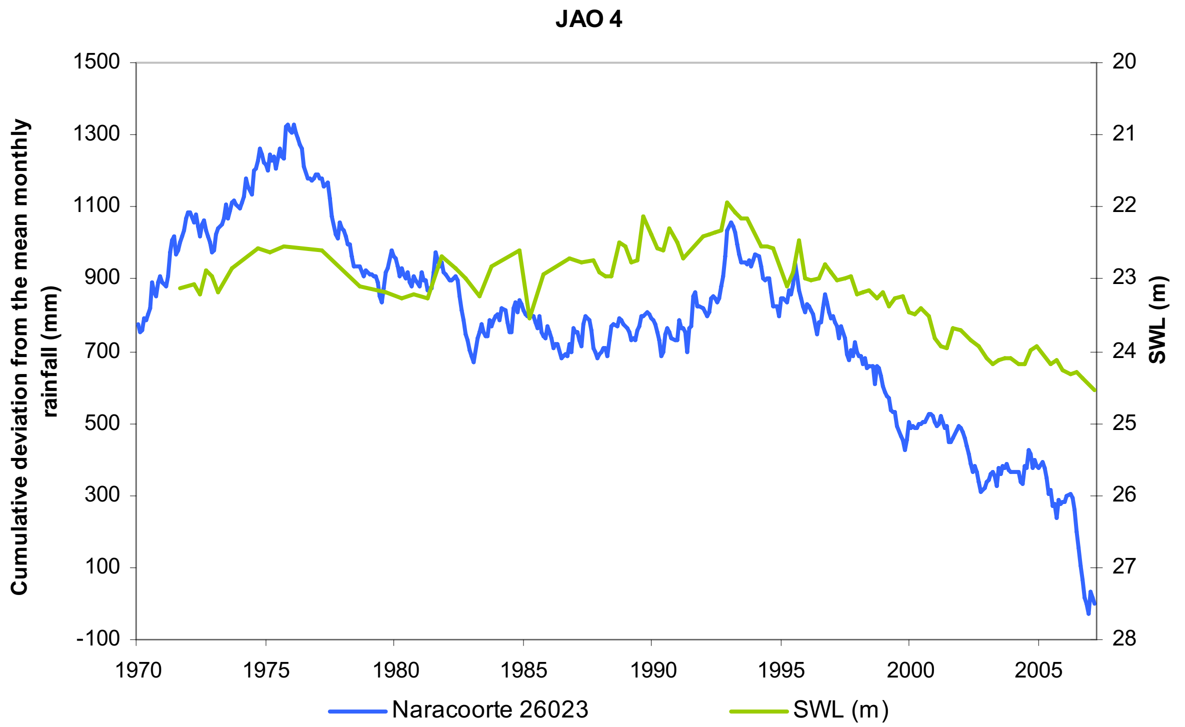

BMA 8
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1100
900
700
500
300
100
-100
-300
-500
12
13
14
15
16
17
18
19
20
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
SWL (m)

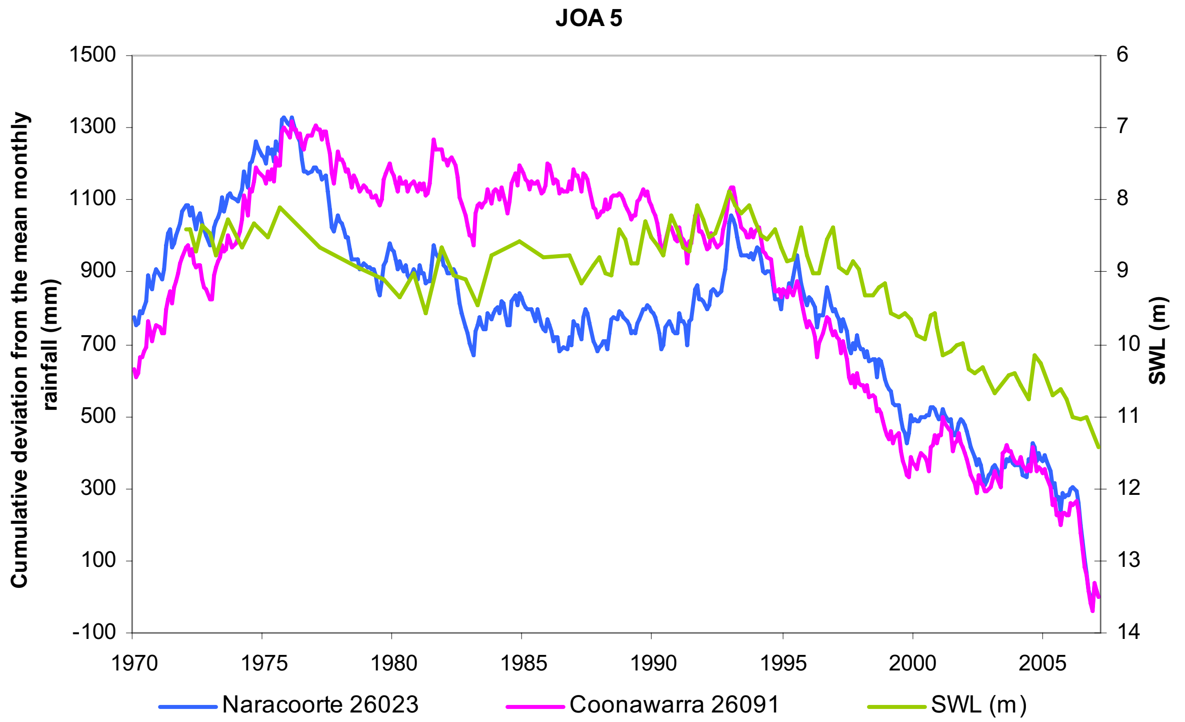

BIN 13
Cumulative deviation from the mean monthly rainfall (mm)
(SWL) m
1500
1300
1100
900
700
500
300
100
-100
9
10
11
12
13
14
15
16
17
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
Naracoorte 26023
SWL (m)

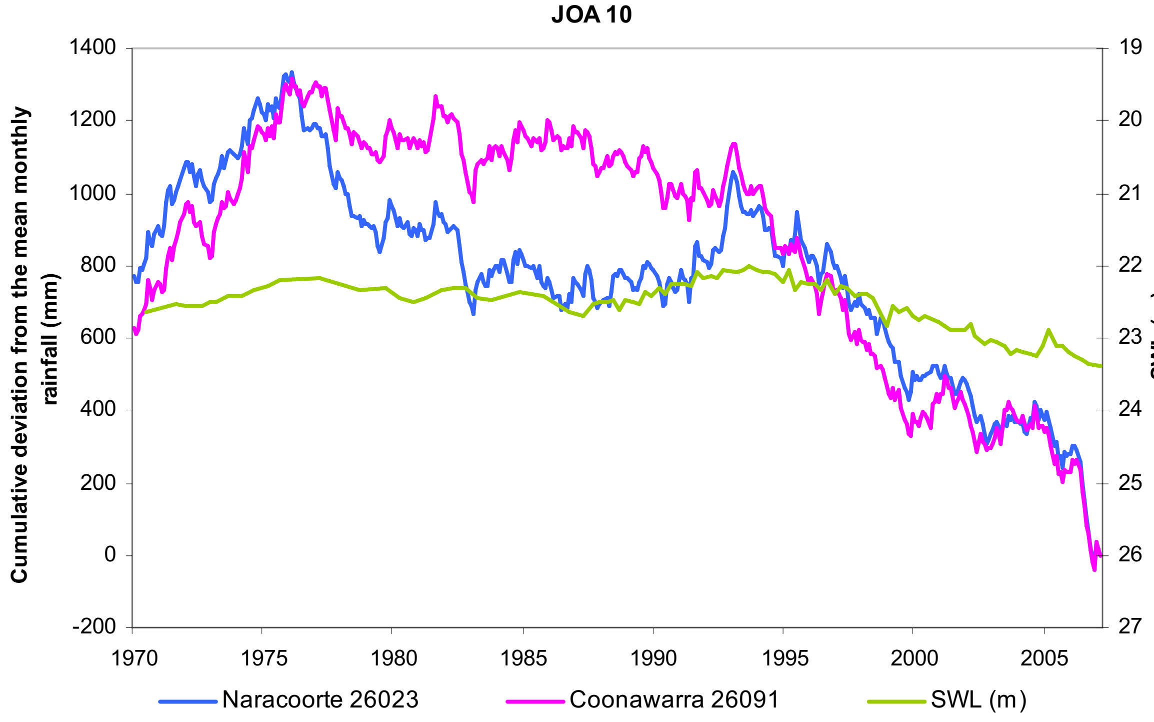

HYN 17
Cumulative deviation from the mean monthly rainfall (mm)
(SWL) m
1500
1300
1100
900
700
500
300
100
-100
9
10
11
12
13
14
15
16
17
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
Naracoorte 26023
SWL (m)

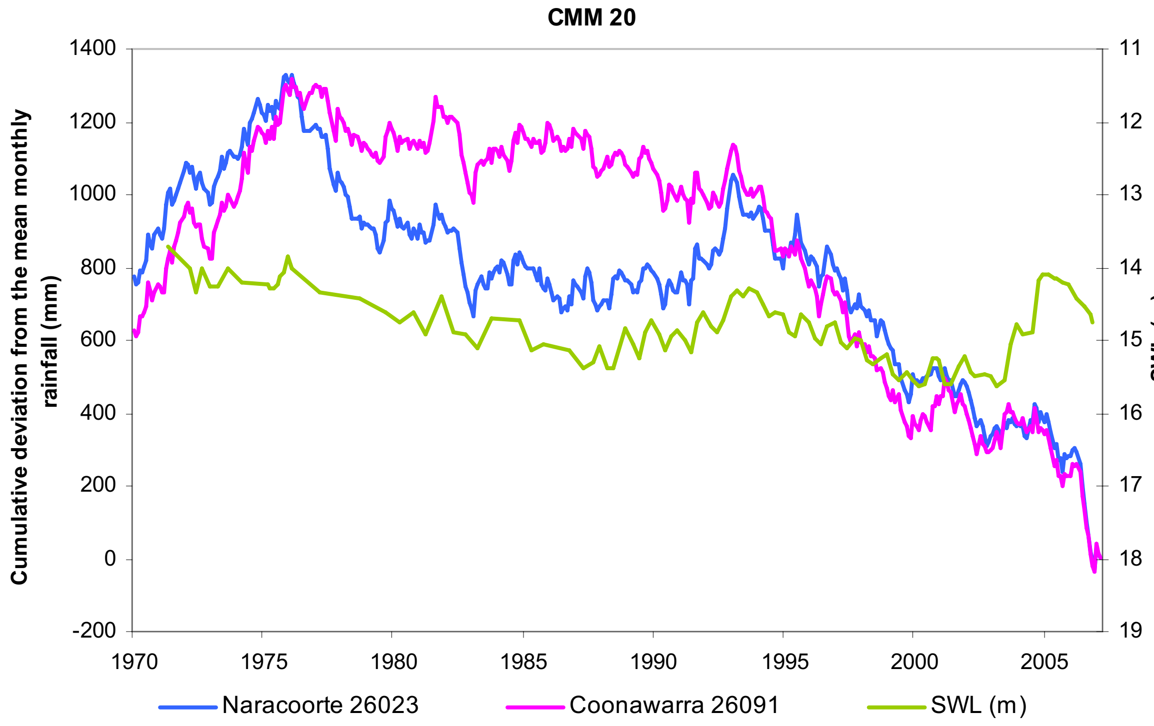

HYN 7
Cumulative deviation from the mean monthly rainfall (mm)
(SWL) m
1500
1300
1100
900
700
500
300
100
-100
7
8
9
10
11
12
13
14
15
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
Naracoorte 26023
SWL (m)

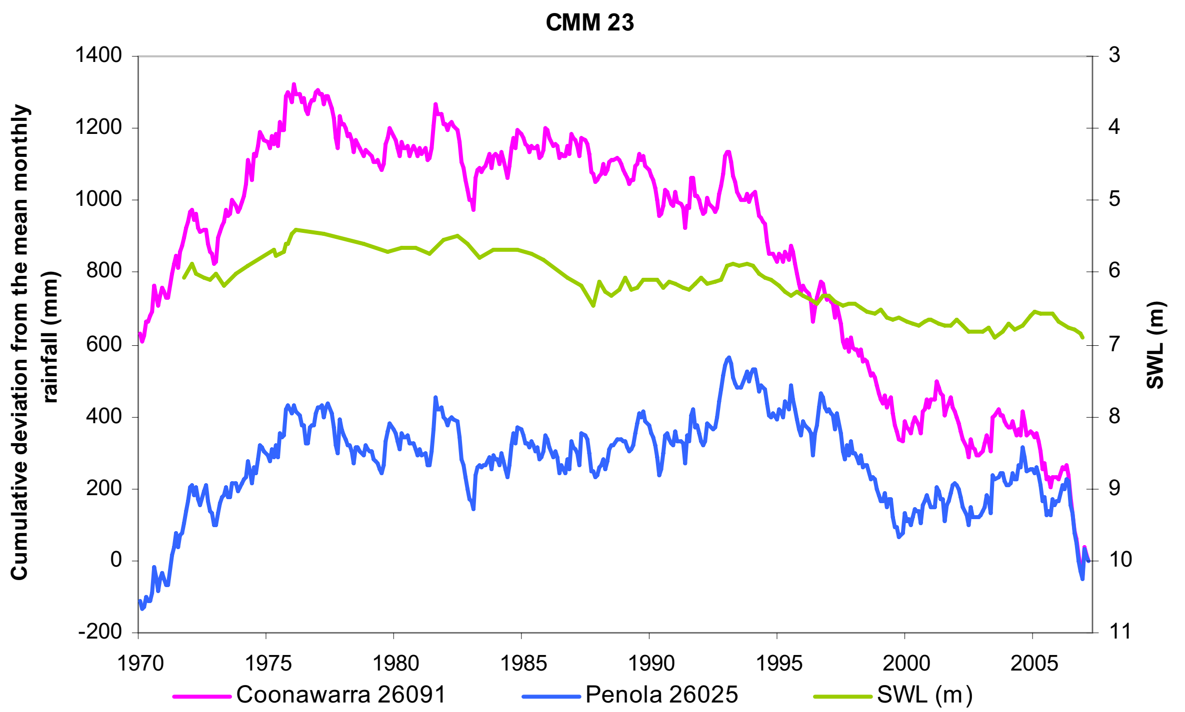

BIN 20
Cumulative deviation from the mean monthly rainfall (mm)
(SWL) m
1500
1300
1100
900
700
500
300
100
-100
4
5
6
7
8
9
10
11
12
1970
1975
1980
1985
1990
1995
2000
2005
Frances 26007
Naracoorte 26023
SWL (m)

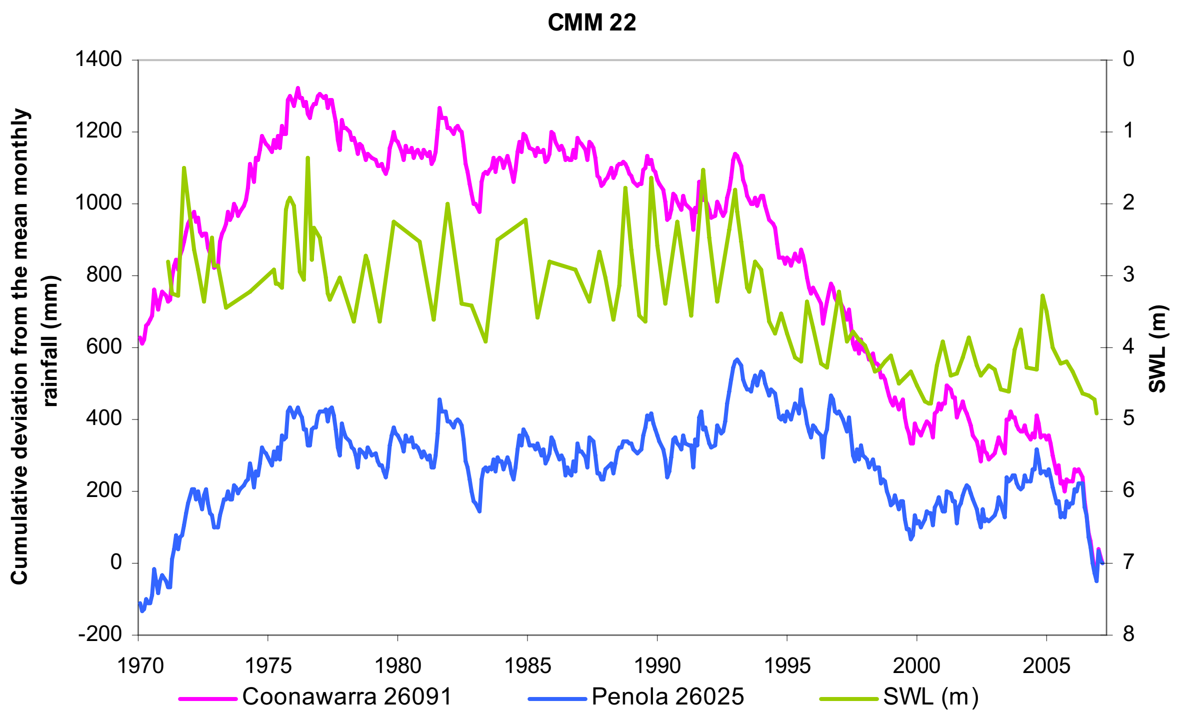

JAO 4
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1500
1300
1100
900
700
500
300
100
-100
20
21
22
23
24
25
26
27
28
1970
1975
1980
1985
1990
1995
2000
2005
Naracoorte 26023
SWL (m)

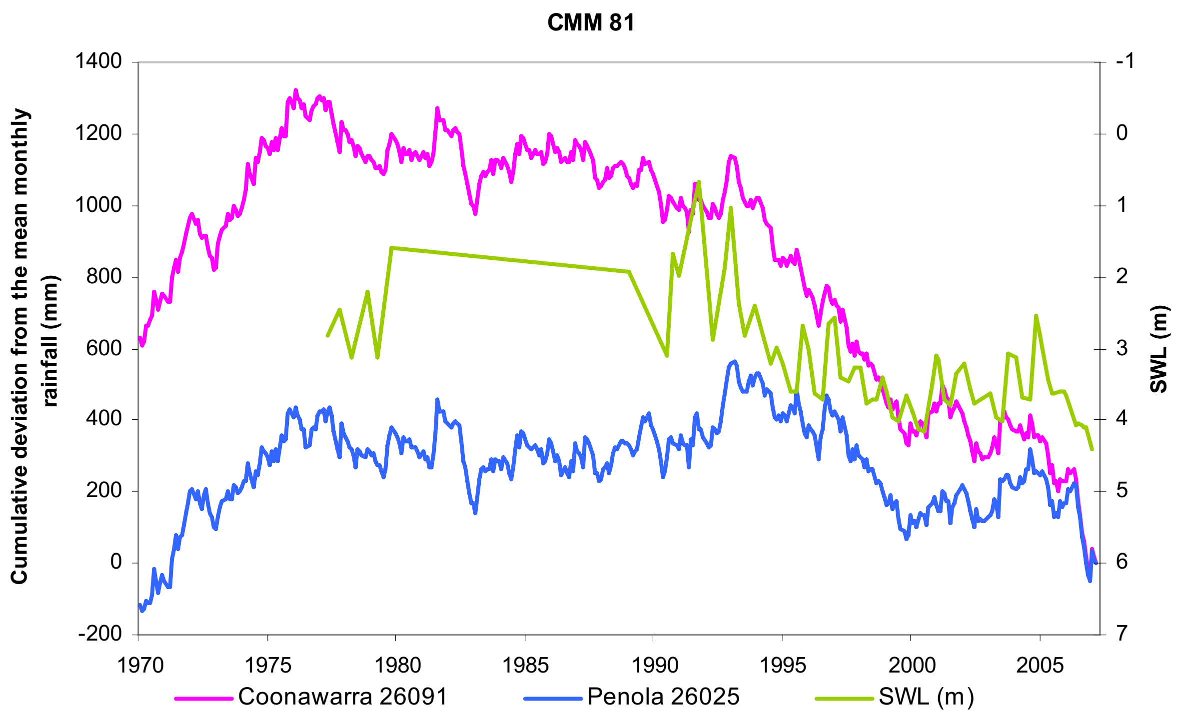

JOA 5
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1500
1300
1100
900
700
500
300
100
-100
6
7
8
9
10
11
12
13
14
1970
1975
1980
1985
1990
1995
2000
2005
Naracoorte 26023
Coonawarra 26091
SWL (m)

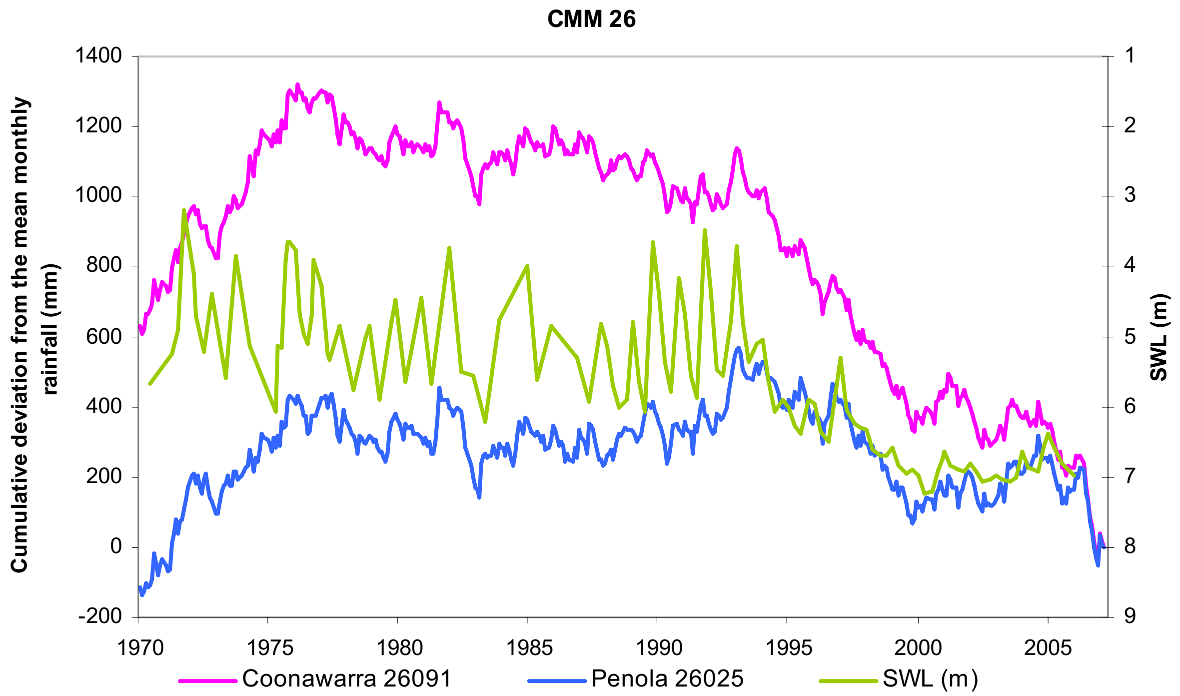

JOA 10
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1400
1200
1000
800
600
400
200
0
-200
19
20
21
22
23
24
25
26
27
1970
1975
1980
1985
1990
1995
2000
2005
Naracoorte 26023
Coonawarra 26091
SWL (m)

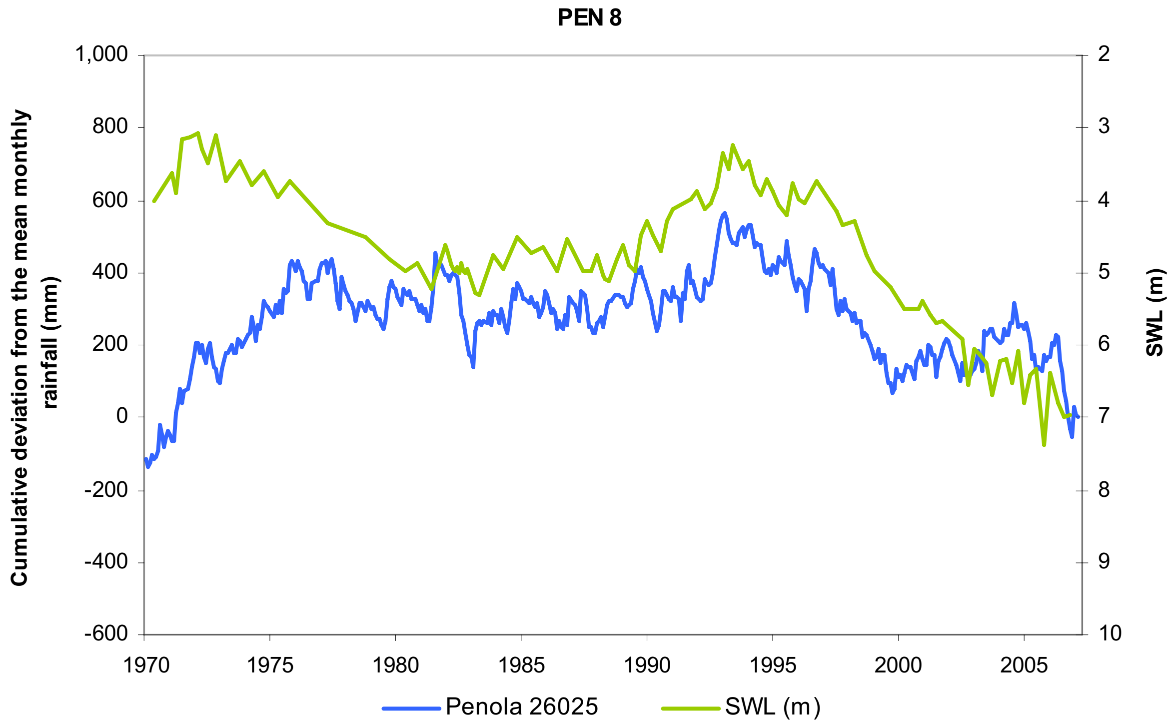

CMM 20
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1400
1200
1000
800
600
400
200
0
-200
11
12
13
14
15
16
17
18
19
1970
1975
1980
1985
1990
1995
2000
2005
Naracoorte 26023
Coonawarra 26091
SWL (m)

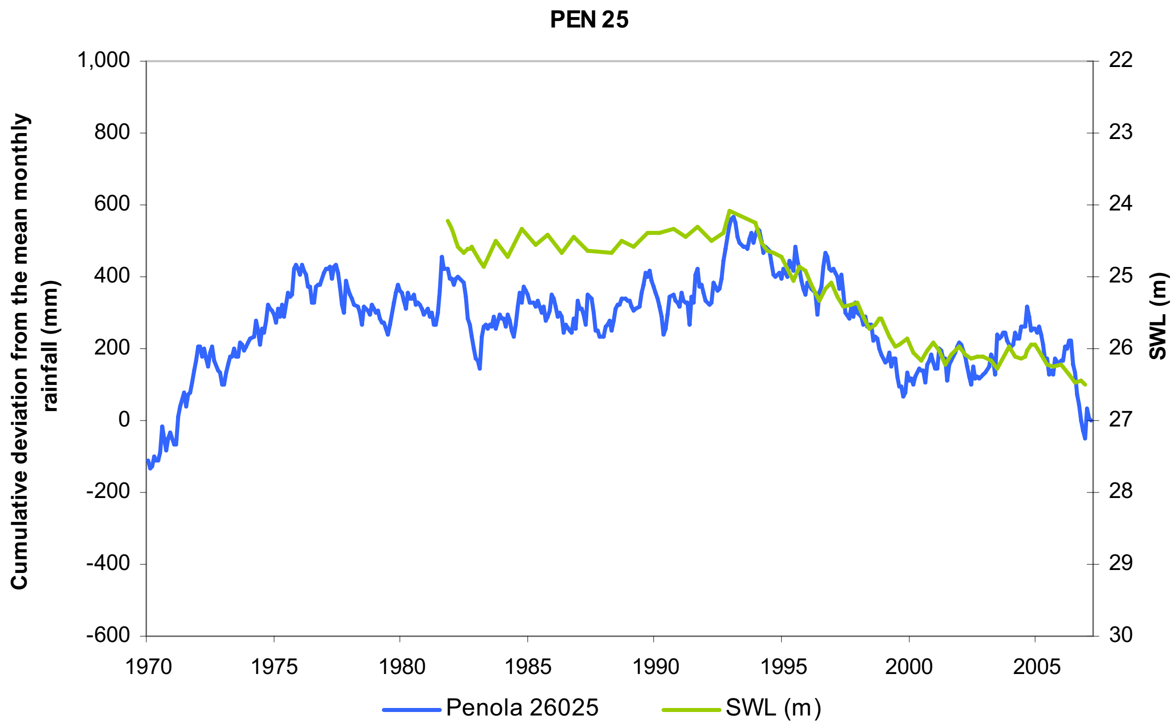

CMM 23
1400
1200
1000
800
600
400
200
0
-200
Cumulative deviation from the mean monthly rainfall (mm)
3
4
5
6
7
8
9
10
11
SWL (m)
1970
1975
1980
1985
1990
1995
2000
2005
Coonawarra 26091
Penola 26025
SWL (m)

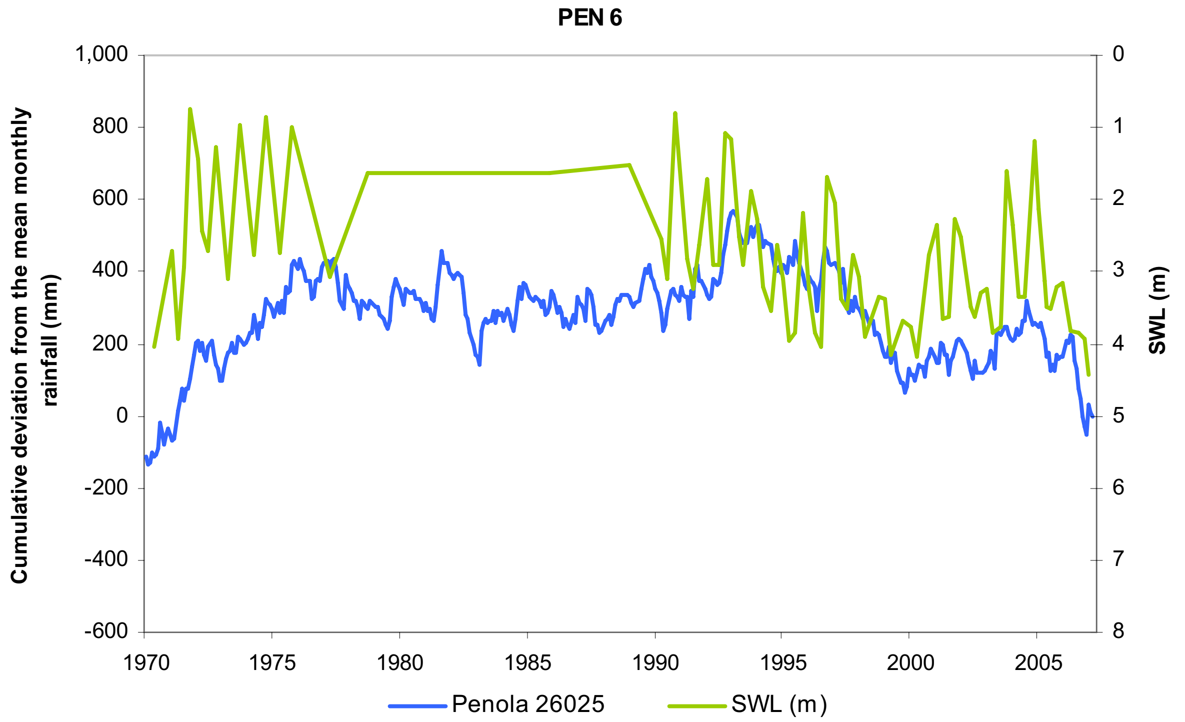

CMM 22
1400
1200
1000
800
600
400
200
0
-200
Cumulative deviation from the mean monthly rainfall (mm)
0
1
2
3
4
5
6
7
8
SWL (m)
1970
1975
1980
1985
1990
1995
2000
2005
Coonawarra 26091
Penola 26025
SWL (m)

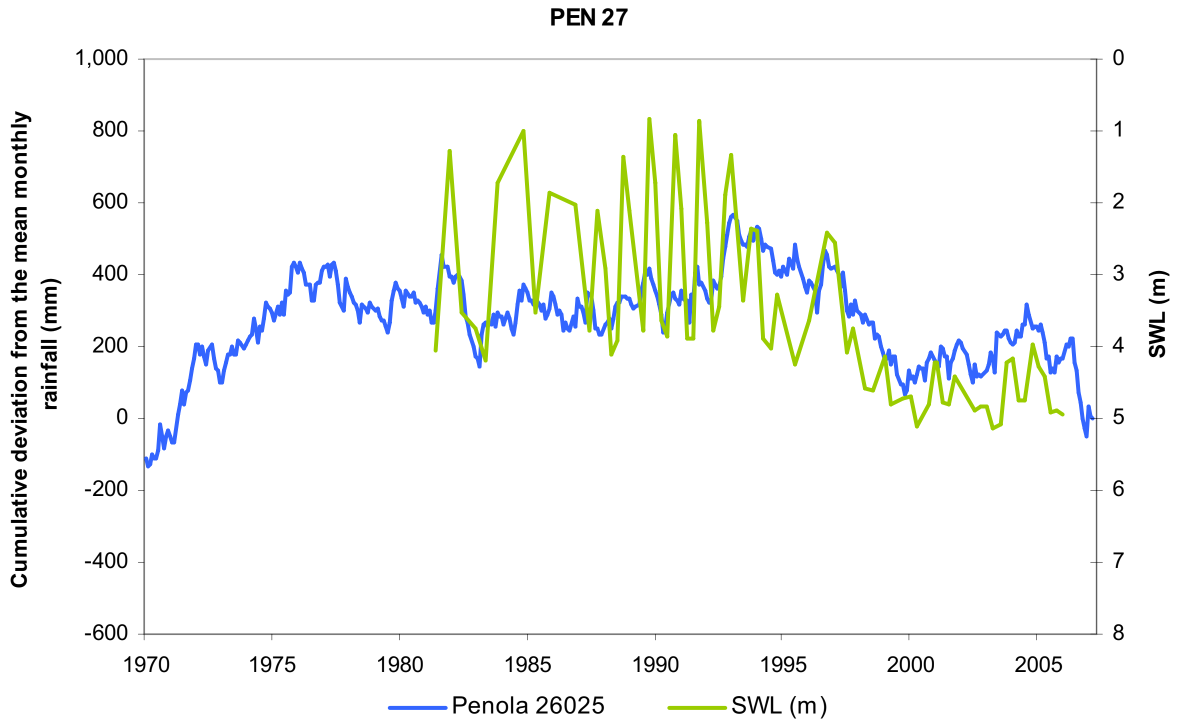

CMM 81
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1400
1200
1000
800
600
400
200
0
-200
-1
0
1
2
3
4
5
6
7
1970
1975
1980
1985
1990
1995
2000
2005
Coonawarra 26091
Penola 26025
SWL (m)

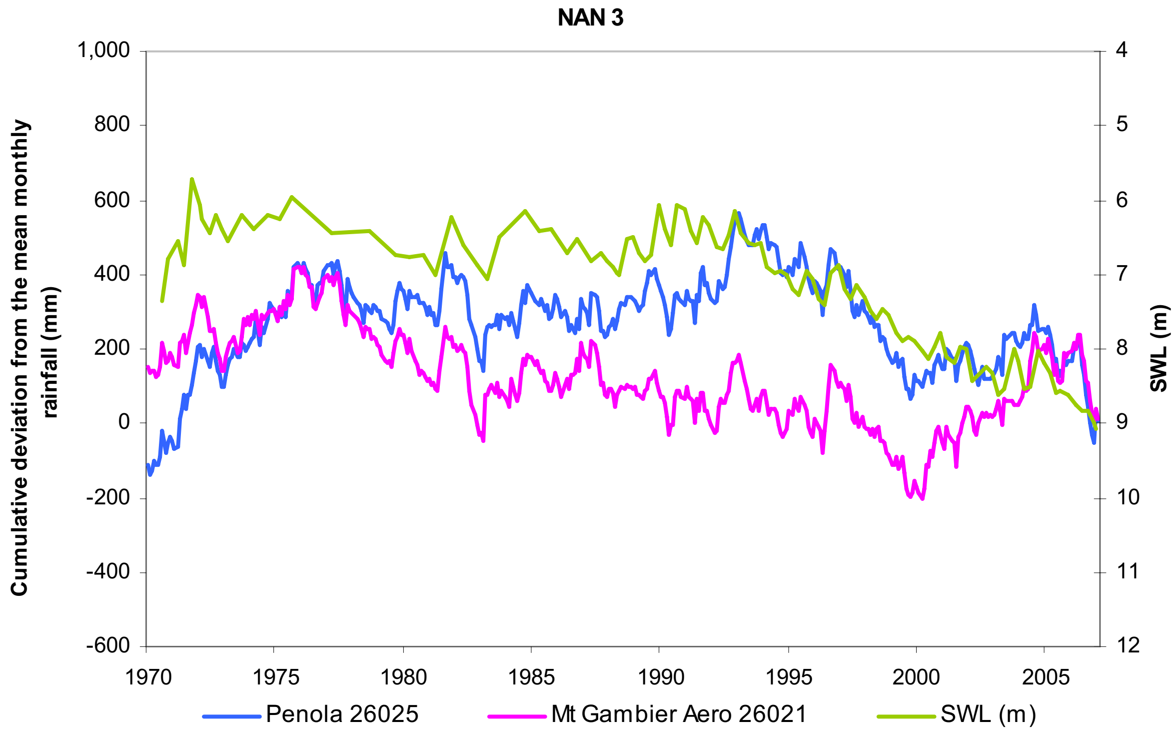

CMM 26
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1400
1200
1000
800
600
400
200
0
-200
1
2
3
4
5
6
7
8
9
1970
1975
1980
1985
1990
1995
2000
2005
Coonawarra 26091
Penola 26025
SWL (m)

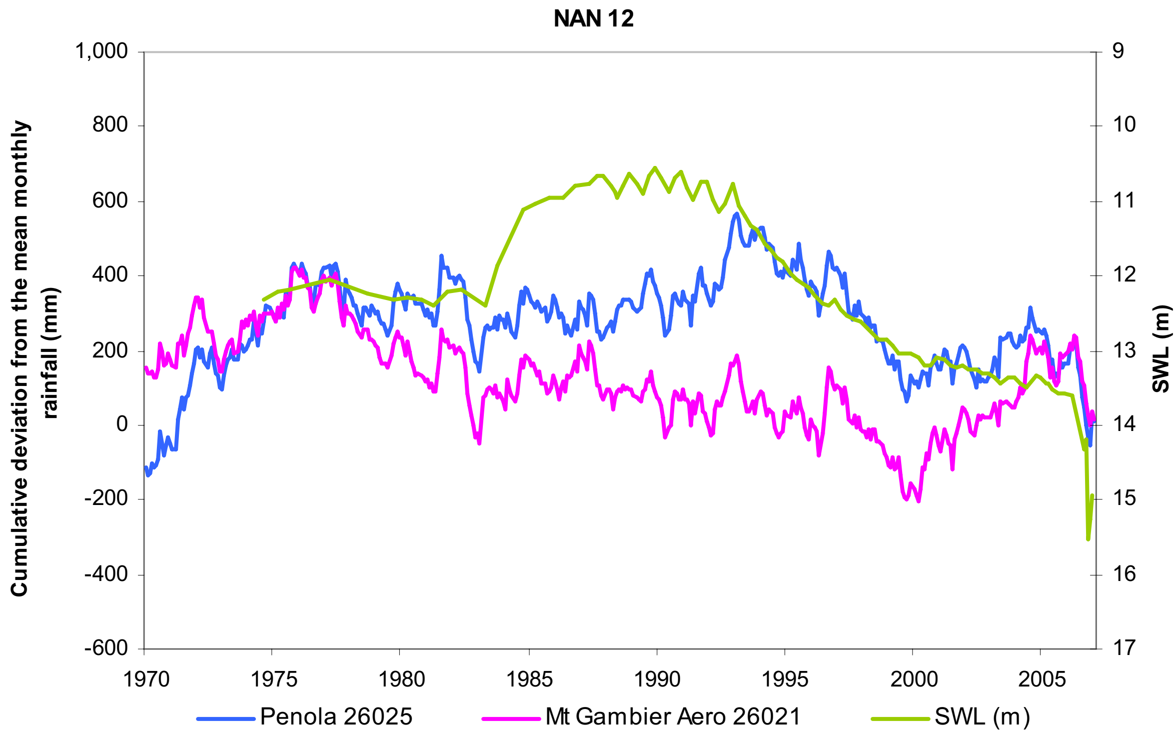

PEN 8
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
2
3
4
5
6
7
8
9
10
SWL (m)
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
SWL (m)

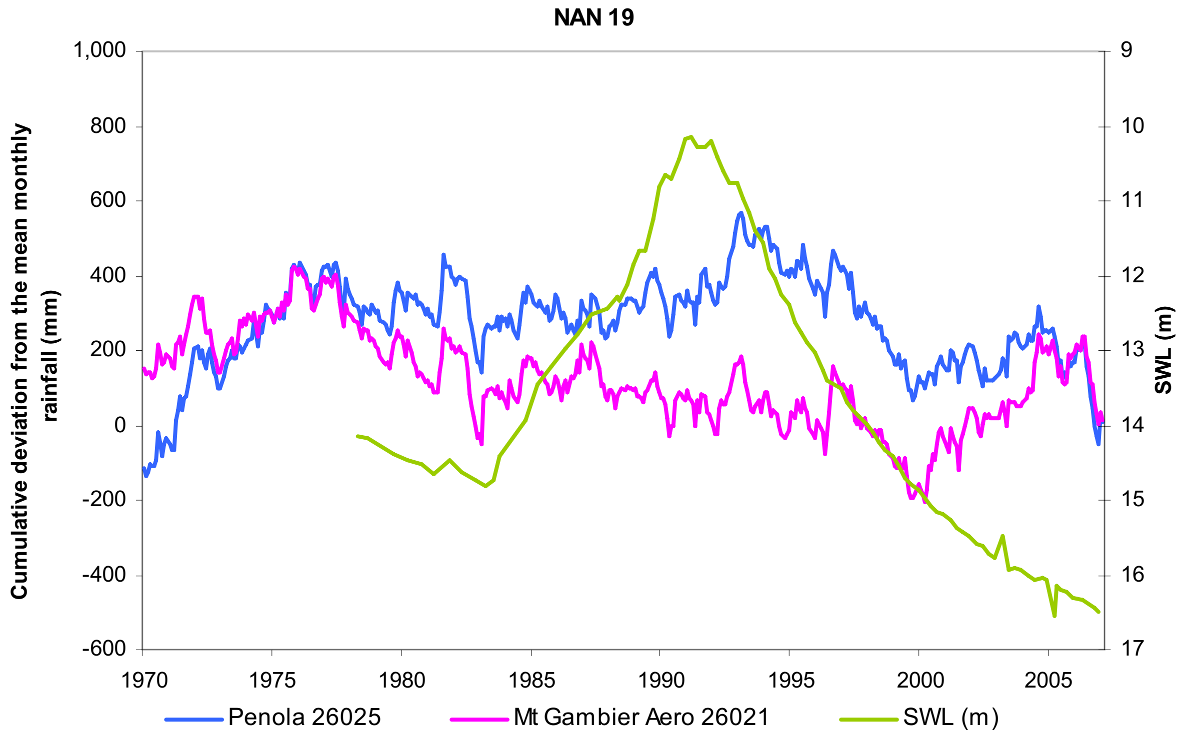

PEN 25
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
22
23
24
25
26
27
28
29
30
SWL (m)
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
SWL (m)

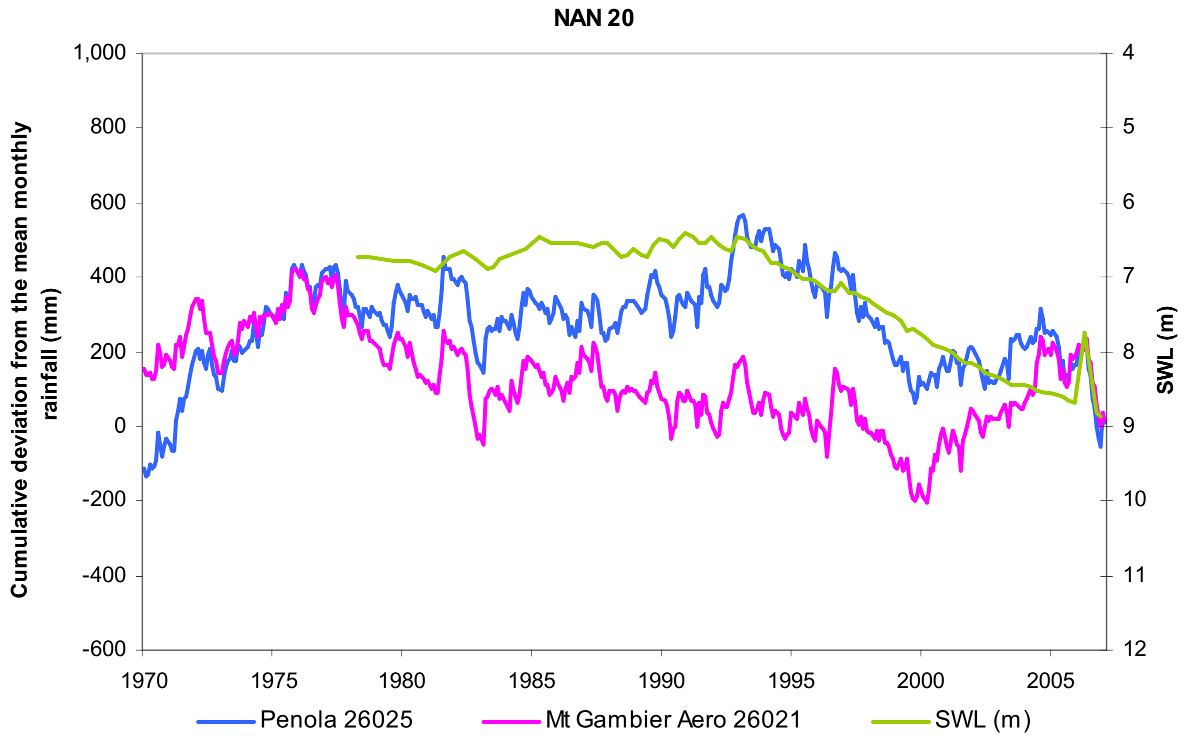

PEN 6
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
SWL (m)

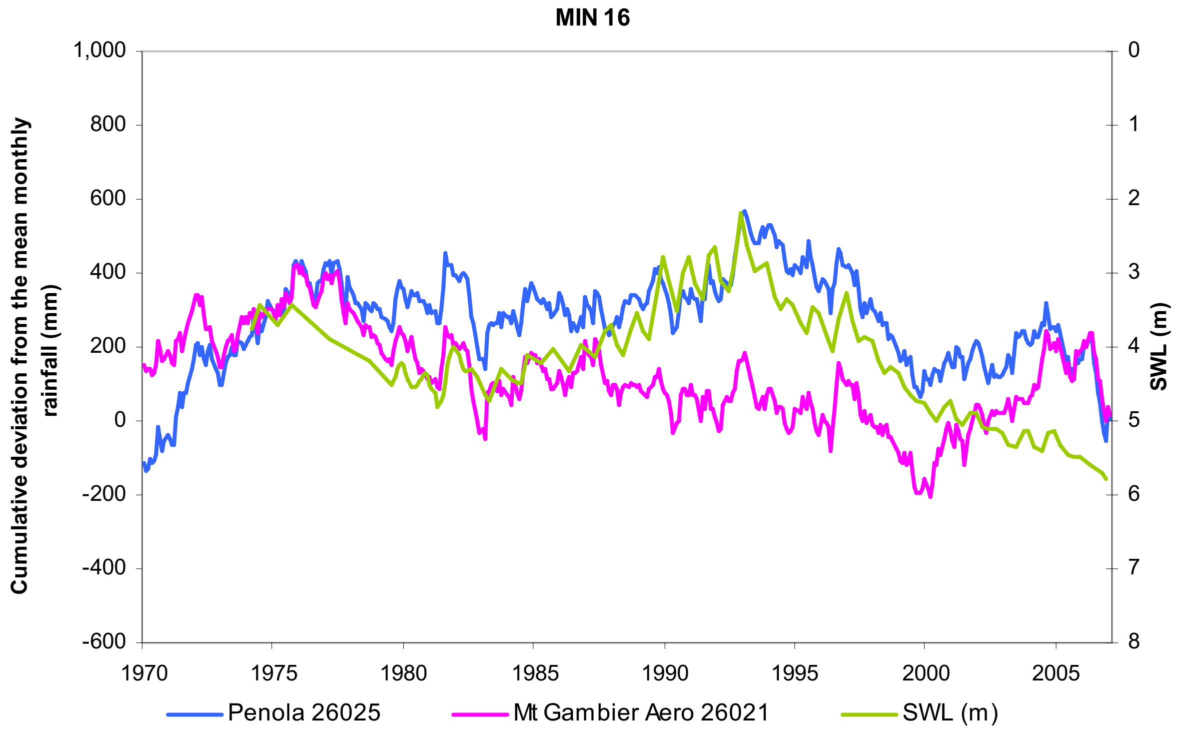

PEN 27
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
SWL (m)

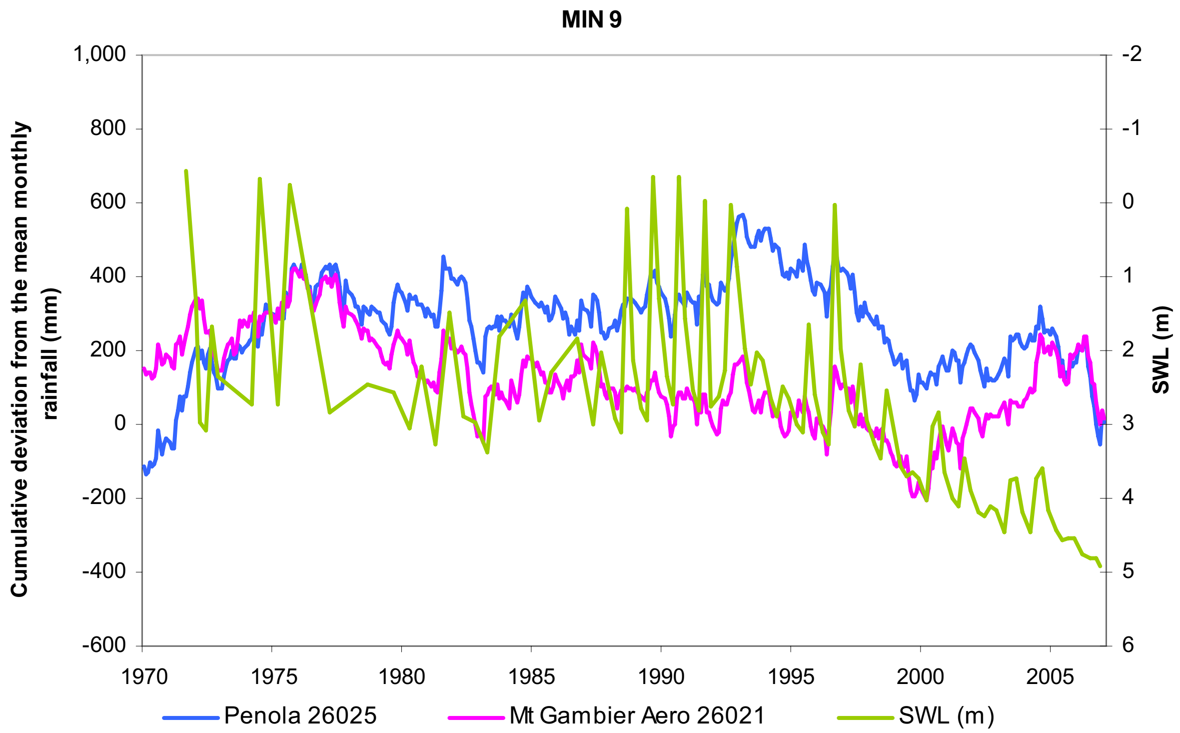

NAN 3
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
4
5
6
7
8
9
10
11
12
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

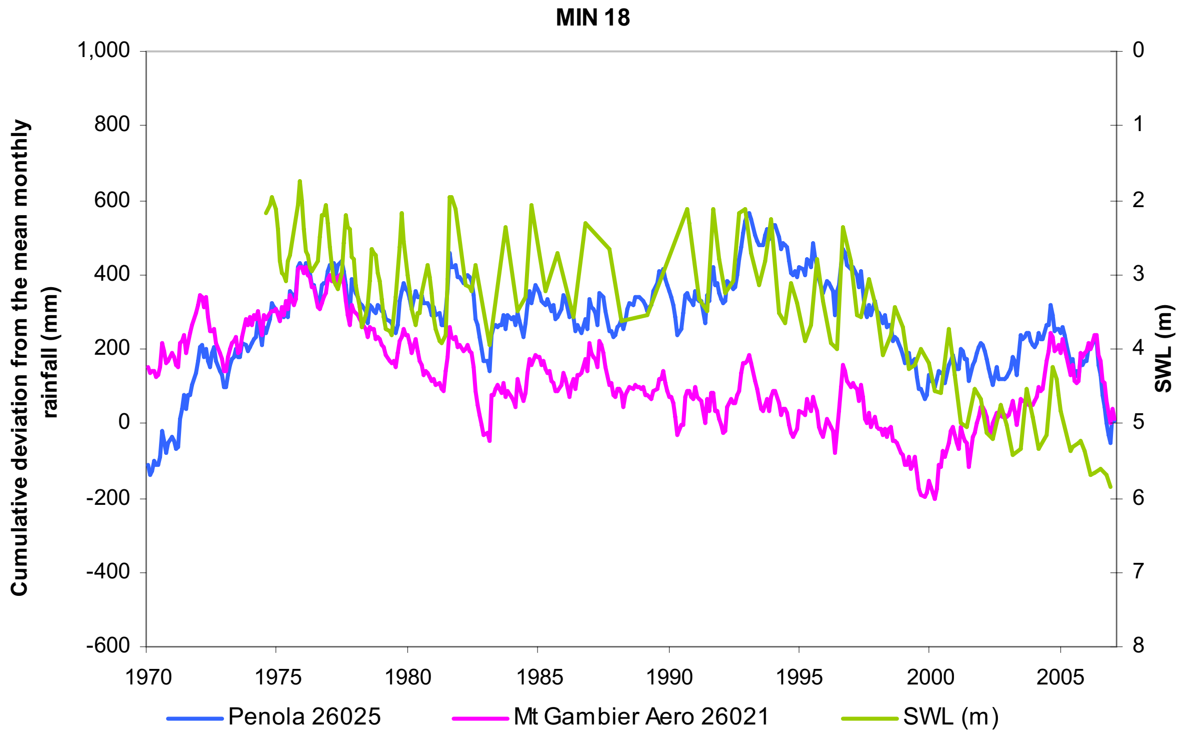

NAN 12
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
9
10
11
12
13
14
15
16
17
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

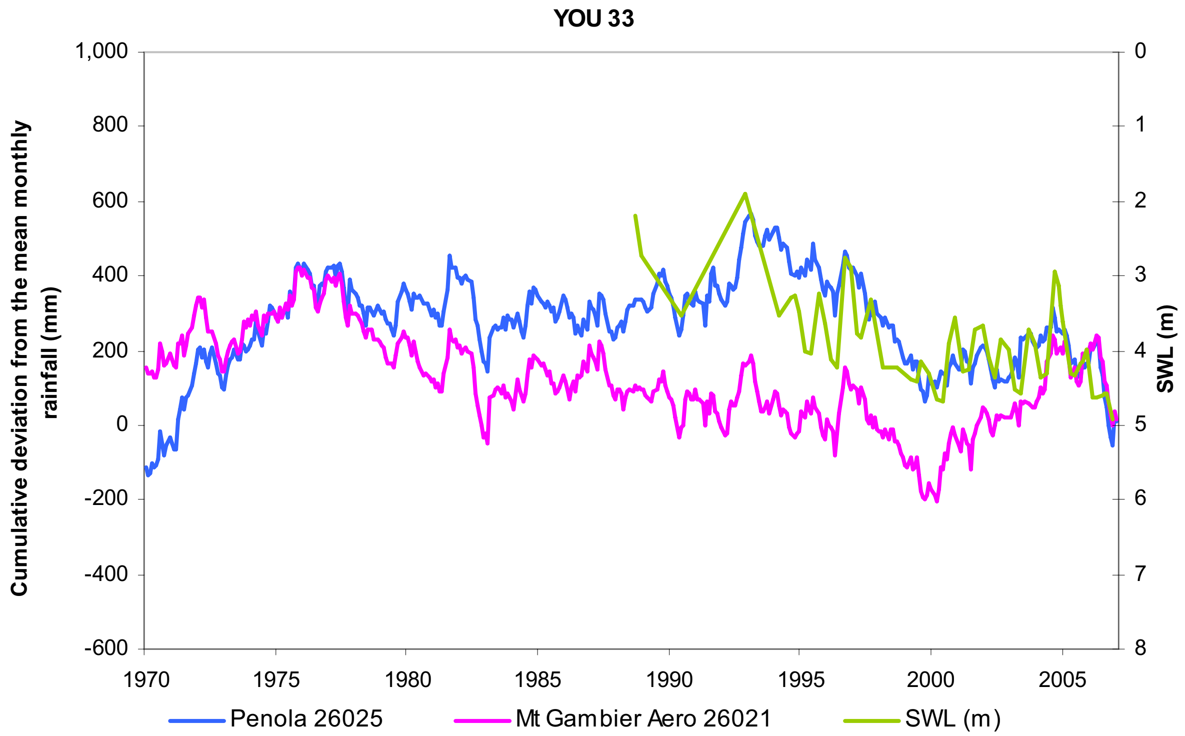

NAN 19
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
SWL (m)
9
10
11
12
13
14
15
16
17
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)


NAN 20
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
SWL (m)
4
5
6
7
8
9
10
11
12
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

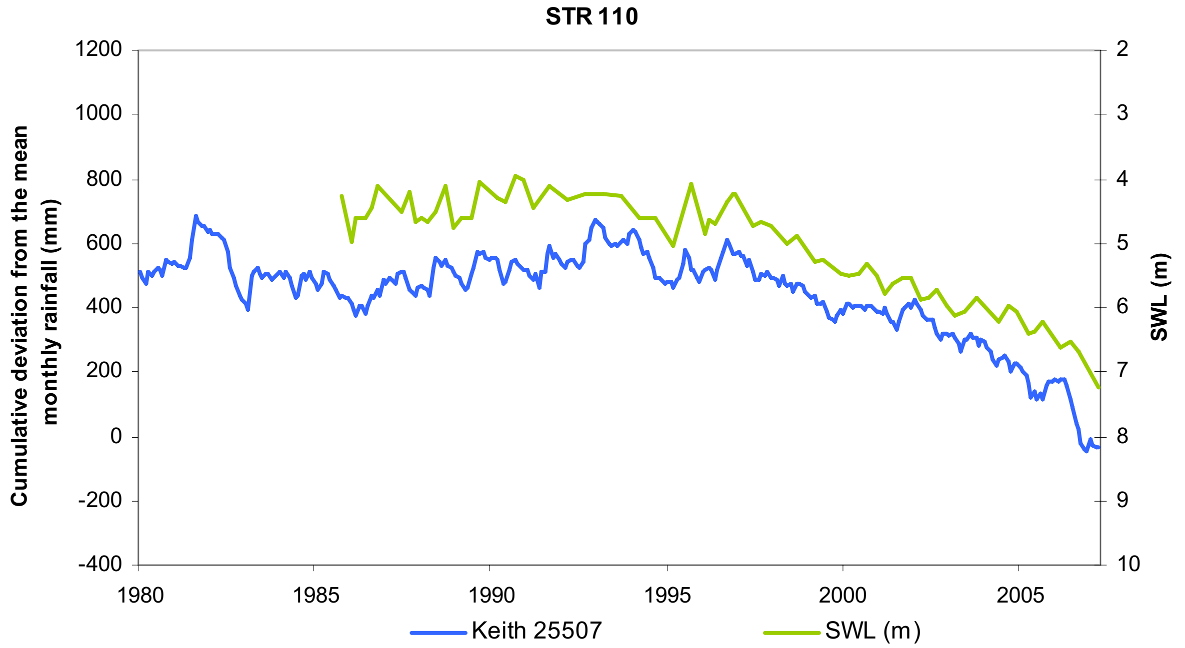

MIN 16
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
SWL (m)
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

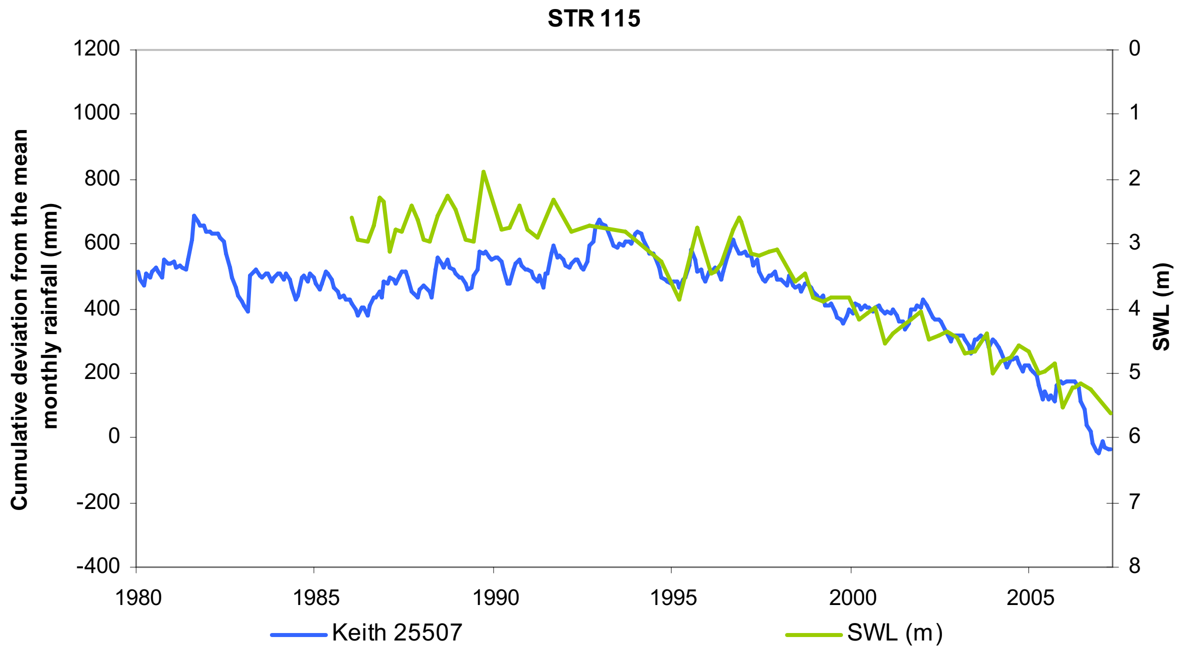

MIN 9
Cumulative deviation from the mean monthly rainfall (mm)
1,000
800
600
400
200
0
-200
-400
-600
SWL (m)
-2
-1
0
1
2
3
4
5
6
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

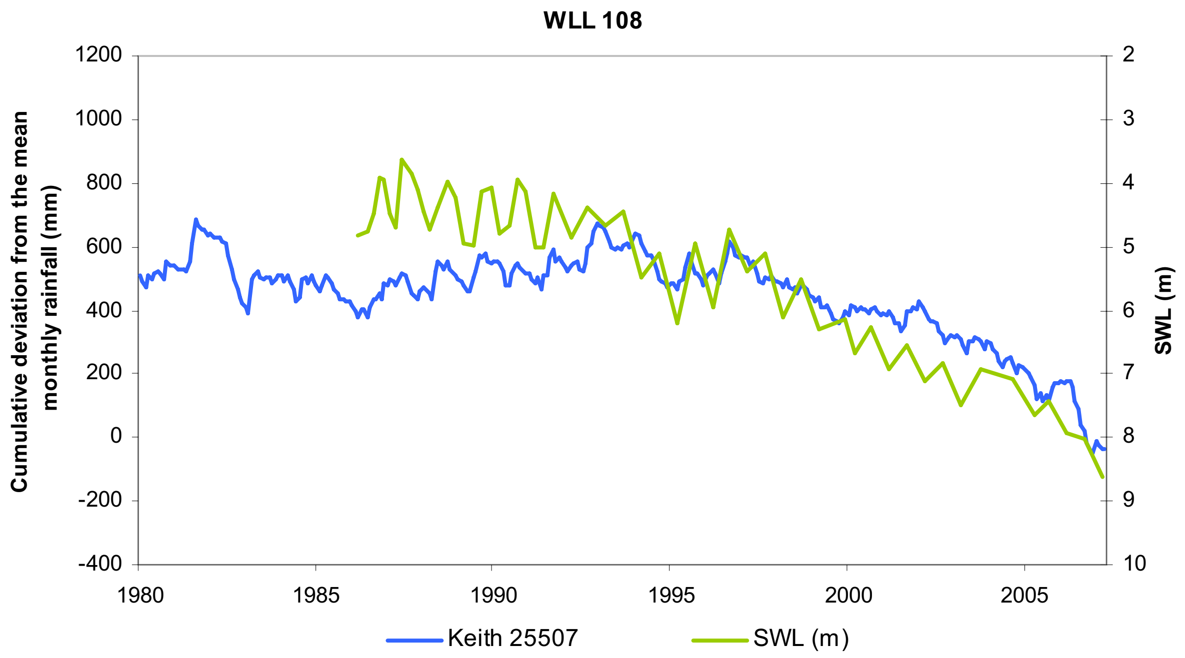

MIN 18
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)


YOU 33
Cumulative deviation from the mean monthly rainfall (mm)
SWL (m)
1,000
800
600
400
200
0
-200
-400
-600
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005
Penola 26025
Mt Gambier Aero 26021
SWL (m)

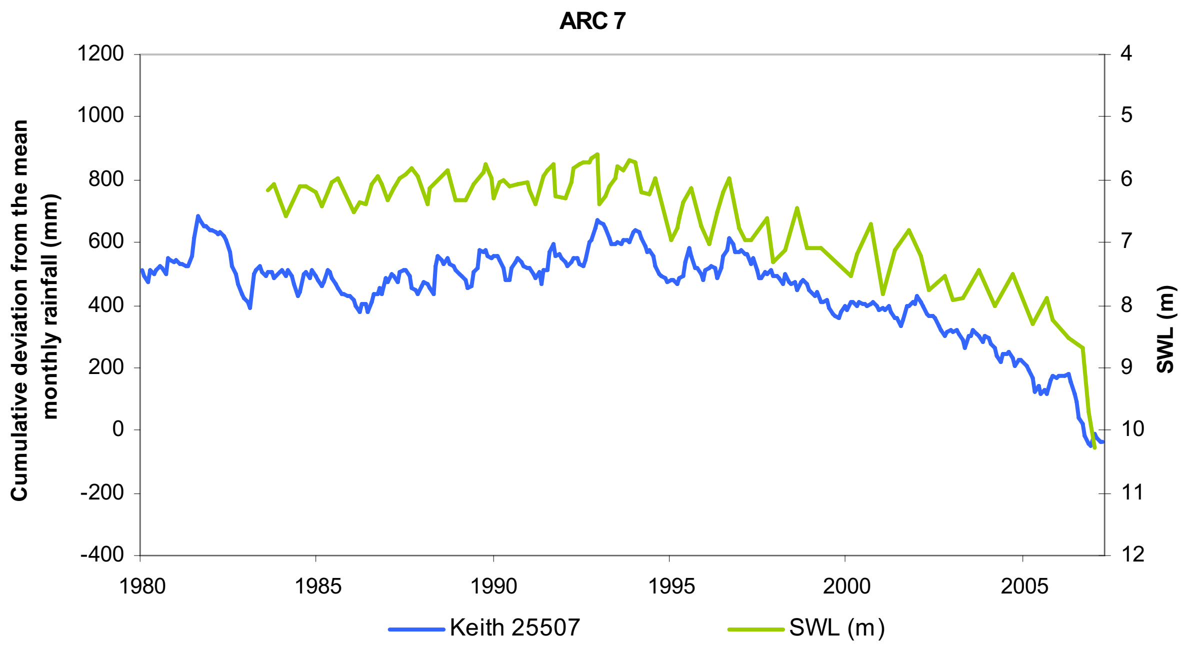
# E.2. CUMULATIVE DEVIATION FROM THE MEAN MONTHLY RAINFALL VS. MONITORING WELL HYDROGRAPHS, HUNDRED OF STIRLING





WLL 108
Cumulative deviation from the mean monthly rainfall (mm)
1200
1000
800
600
400
200
0
-200
-400
1980
1985
1990
1995
2000
2005
2
3
4
5
6
7
8
9
10
SWL (m)
Keith 25507
SWL (m)

ARC 7
Cumulative deviation from the mean monthly rainfall (mm)
1200
1000
800
600
400
200
0
-200
-400
1980
1985
1990
1995
2000
2005
4
5
6
7
8
9
10
11
12
SWL (m)
Keith 25507
SWL (m)

# F. ESTIMATED CLAY CONTENT (0–2 M) AND DRAINAGE FOR SOIL LANDSCAPE UNITS

| LANSLU | % Clay (0–2 m) | Drainage (mm/y) | LANSLU | % Clay (0–2 m) | Drainage (mm/y) |
|---|---|---|---|---|---|
| APSHaA1 | 51.75 | 3.7 | GEEOQF1 | 10.20 | 44.1 |
| APSHaB1 | 26.88 | 16.3 | GEEOQG1 | 10.20 | 44.1 |
| APSHeA1 | 44.00 | 5.8 | GEEOQI1 | 10.20 | 44.1 |
| APSHiB1 | 44.00 | 5.8 | GEEOQJ1 | 10.20 | 44.1 |
| APSHkA1 | 44.00 | 5.8 | GEEOQq1 | 51.75 | 3.7 |
| APSHkB1 | 10.50 | 43.4 | GEEOQt1 | 51.75 | 3.7 |
| APSHmA1 | 51.75 | 3.7 | GEEPCA1 | 38.25 | 8.2 |
| APSHmE1 | 51.75 | 3.7 | GEEPCB1 | 10.20 | 44.1 |
| APSHxA1 | 51.75 | 3.7 | GEEPCb2 | 10.20 | 44.1 |
| APSHxE1 | 51.75 | 3.7 | GEEPQi1 | 54.13 | 3.2 |
| APSHyA1 | 44.00 | 5.8 | GEEPRA1 | 38.25 | 8.2 |
| APSXaK1 | 25.28 | 17.9 | GEEPRa2 | 10.20 | 44.1 |
| APSXq-1 | 47.25 | 4.8 | GEEPXA1 | 54.13 | 3.2 |
| APSXuC1 | 47.25 | 4.8 | GEEPXa2 | 54.13 | 3.2 |
| APSXXB1 | 51.75 | 3.7 | GEEPXB1 | 51.75 | 3.7 |
| APSXXT1 | 51.75 | 3.7 | GEEPXb2 | 51.75 | 3.7 |
| BINONI1 | 12.75 | 37.9 | GEEPYA1 | 56.50 | 2.8 |
| BINONJ1 | 12.75 | 37.9 | GEEPYa2 | 56.50 | 2.8 |
| BINOQF1 | 10.20 | 44.1 | GEEPYB1 | 54.13 | 3.2 |
| BINOQG1 | 10.20 | 44.1 | GEEPYb2 | 26.88 | 16.3 |
| BINOQJ1 | 10.20 | 44.1 | GEETLA1 | 51.75 | 3.7 |
| BINOQt1 | 51.75 | 3.7 | GEETMA1 | 56.50 | 2.8 |
| BINPCA1 | 25.28 | 17.9 | GEETNA1 | 56.50 | 2.8 |
| BINPCB1 | 10.20 | 44.1 | JESMAB1 | 10.50 | 43.4 |
| BINPCb2 | 10.20 | 44.1 | JESM-B1 | 10.50 | 43.4 |
| BINPCi1 | 25.28 | 17.9 | JESMHB1 | 10.50 | 43.4 |
| BINPRA1 | 43.63 | 6.0 | JESMHC1 | 10.50 | 43.4 |
| BINPRa2 | 43.63 | 6.0 | JESMRB1 | 10.50 | 43.4 |
| BINPRB1 | 43.63 | 6.0 | JESMRC1 | 10.50 | 43.4 |
| BINPRi1 | 43.63 | 6.0 | JESMWB1 | 12.75 | 37.9 |
| BINPRi1 | 43.63 | 6.0 | JESMYB1 | 10.50 | 43.4 |
| BINPWA1 | 51.75 | 3.7 | KBLHaA1 | 51.75 | 3.7 |
| BINPYA1 | 54.13 | 3.2 | KBLHaB1 | 26.88 | 16.3 |
| BINPYaa1 | 54.13 | 3.2 | KBLHbA1 | 44.00 | 5.8 |
| BINPYB1 | 54.13 | 3.2 | KBLHbB1 | 37.13 | 8.8 |
| KBLHcA1 | 44.00 | 5.8 | KBLHeA1 | 44.00 | 5.8 |

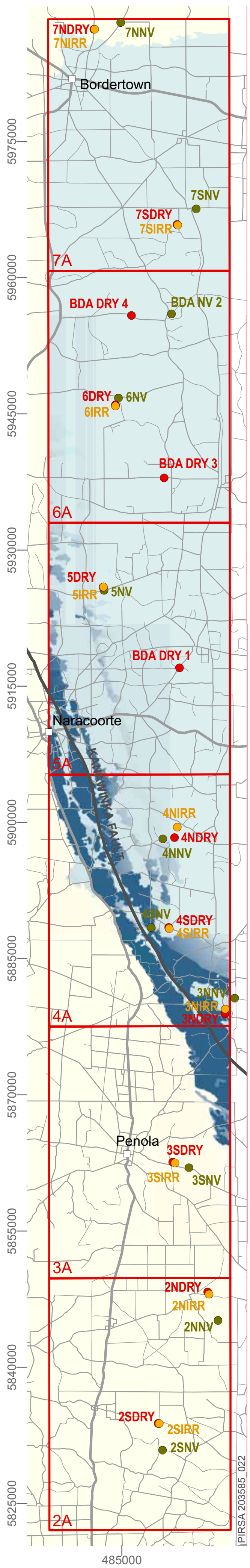
| LANSLU | % Clay (0–2 m) | Drainage (mm/y) |
|---|---|---|
| KBLHeA1 | 44.00 | 5.8 |
| KBLHeB1 | 44.00 | 5.8 |
| KBLHhA1 | 44.00 | 5.8 |
| KBLHiB1 | 44.00 | 5.8 |
| KBLHkA1 | 44.00 | 5.8 |
| KBLHkB1 | 10.50 | 43.4 |
| KBLHmE1 | 51.75 | 3.7 |
| KBLHoB1 | 10.50 | 43.4 |
| KBLHwA1 | 44.00 | 5.8 |
| KBLHwB1 | 44.00 | 5.8 |
| KBLHxA1 | 51.75 | 3.7 |
| KBLHxA1 | 51.75 | 3.7 |
| KBLHxE1 | 51.75 | 3.7 |
| KBLHyA1 | 44.00 | 5.8 |
| KBLHyA1 | 44.00 | 5.8 |
| KBLHyE1 | 51.75 | 3.7 |
| KBLHzA1 | 44.00 | 5.8 |
| KBLHzA1 | 44.00 | 5.8 |
| KBLHzE1 | 42.25 | 6.5 |
| KBLMYA1 | 10.50 | 43.4 |
| KBLOQG1 | 10.20 | 44.1 |
| KBLOQJ1 | 10.20 | 44.1 |
| KBLTIE1 | 54.13 | 3.2 |
| KBLTMA1 | 56.50 | 2.8 |
| KBLTME1 | 54.13 | 3.2 |
| KBLTNA1 | 56.50 | 2.8 |
| KBLTNA1 | 56.50 | 2.8 |
| KBLTNE1 | 54.13 | 3.2 |
| KBLXaC1 | 47.25 | 4.8 |
| KBLXaJ1 | 51.75 | 3.7 |
| KBLXaK1 | 51.75 | 3.7 |
| KBLXaT1 | 51.75 | 3.7 |
| KBLXe-1 | 26.88 | 16.3 |
| KBLXq-1 | 47.25 | 4.8 |
| KBLXqV1 | 44.63 | 5.6 |
| KBLXRC1 | 42.25 | 6.5 |
| KBLXRe1 | 26.88 | 16.3 |
| KBLXRT1 | 44.00 | 5.8 |
| KBLXu-1 | 47.25 | 4.8 |
| KBLXuC1 | 51.75 | 3.7 |

| LANSLU | % Clay (0–2 m) | Drainage (mm/y) |
|---|---|---|
| KBLXXB1 | 51.75 | 3.7 |
| KBLXXT1 | 51.75 | 3.7 |
| KBLZOF1 | 44.00 | 5.8 |
| MIMMHC1 | 10.50 | 43.4 |
| MIMMHI1 | 10.50 | 43.4 |
| MIMOQF1 | 10.20 | 44.1 |
| MIMOQJ1 | 10.20 | 44.1 |
| MIMPCB1 | 10.20 | 44.1 |
| MIMPCb2 | 10.20 | 44.1 |
| MIMPYA1 | 10.20 | 44.1 |
| MIMPYB1 | 10.20 | 44.1 |
| MIMPYb2 | 26.88 | 16.3 |
| NEUHeA1 | 44.00 | 5.8 |
| NEUTMA1 | 56.50 | 2.8 |
| NEUTNA1 | 56.50 | 2.8 |
| NEUTNE1 | 56.50 | 2.8 |
| NEUXaK1 | 54.13 | 3.2 |
| NEUXl-1 | 54.13 | 3.2 |
| NEUXRA1 | 54.13 | 3.2 |
| NRCM-B1 | 10.50 | 43.4 |
| NRCM-C1 | 10.50 | 43.4 |
| NRCMcB1 | 15.35 | 32.4 |
| NRCMcE1 | 10.98 | 42.1 |
| NRCMDB1 | 10.50 | 43.4 |
| NRCMHC1 | 10.50 | 43.4 |
| NRCMHE1 | 43.75 | 5.9 |
| NRCMHP1 | 10.50 | 43.4 |
| NRCMRB1 | 10.50 | 43.4 |
| NRCMRC1 | 10.50 | 43.4 |
| NRCMSB1 | 10.98 | 42.1 |
| NRCMSC1 | 9.00 | 47.4 |
| NRCMWK1 | 29.25 | 14.1 |
| NRCMYB1 | 10.50 | 43.4 |
| NRCMYC1 | 10.50 | 43.4 |
| NRCNTA1 | 10.98 | 42.1 |
| NRCNTG1 | 10.98 | 42.1 |
| NRCOFD1 | 24.68 | 18.5 |
| NRCOQI1 | 10.20 | 44.1 |
| NRCPBa1 | 12.75 | 37.9 |
| NRCXaJ1 | 43.75 | 5.9 |

| LANSLU | % Clay (0–2 m) | Drainage (mm/y) |
|---|---|---|
| NRCXq-1 | 29.25 | 14.1 |
| NRCXqC1 | 29.25 | 14.1 |
| PGCHbA1 | 38.88 | 7.9 |
| PGCHbB1 | 27.13 | 16.0 |
| PGCO-D1 | 4.20 | 63.2 |
| PGCTTA1 | 59.00 | 2.4 |
| PGCTTB1 | 56.50 | 2.8 |
| PGCVZ-1 | 27.25 | 15.9 |
| PGCXq-1 | 0.00 | 81.3 |
| SRNHzA1 | 44.00 | 5.8 |
| SRNM-B1 | 10.50 | 43.4 |
| SRNMHB1 | 10.50 | 43.4 |
| SRNMHC1 | 10.50 | 43.4 |
| SRNMRB1 | 10.50 | 43.4 |
| SRNNCA1 | 42.25 | 6.5 |
| SRNNCF1 | 42.25 | 6.5 |
| SRNNGA1 | 42.25 | 6.5 |
| SRNNlA1 | 30.73 | 12.9 |
| SRNNMF1 | 49.25 | 4.3 |
| SRNNMG1 | 49.25 | 4.3 |
| SRNNnA1 | 49.25 | 4.3 |
| SRNNnF1 | 49.25 | 4.3 |
| SRNNnG1 | 49.25 | 4.3 |
| SRNNSA1 | 30.73 | 12.9 |
| SRNNTA1 | 30.73 | 12.9 |
| SRNNTG1 | 30.73 | 12.9 |
| SRNNTS1 | 18.65 | 26.6 |
| SRNNUA1 | 28.25 | 15.0 |
| SRNNvA1 | 10.50 | 43.4 |
| SRNNzA1 | 43.75 | 5.9 |
| SRNXaJ1 | 43.75 | 5.9 |
| SRNXaK1 | 43.75 | 5.9 |
| SRNXq-1 | 47.25 | 4.8 |
| SRNXuC1 | 47.25 | 4.8 |
| WEFMHB1 | 10.50 | 43.4 |

| LANSLU | % Clay (0–2 m) | Drainage (mm/y) |
|---|---|---|
| WEFMHC1 | 10.50 | 43.4 |
| WEFOQC1 | 10.20 | 44.1 |
| WEFOQI1 | 10.20 | 44.1 |
| WEFPCB1 | 10.20 | 44.1 |
| WEFPRA1 | 25.28 | 17.9 |
| WEFPXA1 | 56.50 | 2.8 |
| WEFPXa2 | 56.50 | 2.8 |
| WEFPYA1 | 10.20 | 44.1 |
| WEFPYb2 | 26.88 | 16.3 |
| WOLGbC1 | 41.40 | 6.8 |
| WOLHdB1 | 27.13 | 16.0 |
| WOLHhA1 | 38.88 | 7.9 |
| WOLO-D1 | 3.30 | 66.7 |
| WOLTUB1 | 38.88 | 7.9 |
| WOLTUC1 | 38.88 | 7.9 |
| WOLTVA1 | 38.88 | 7.9 |
| WOLTWA1 | 49.38 | 4.2 |
| WOLTWE1 | 56.50 | 2.8 |
| WOLXq-1 | 0.00 | 81.3 |
| WRTHaA1 | 51.75 | 3.7 |
| WRTHkB1 | 10.50 | 43.4 |
| WRTHzA1 | 43.63 | 6.0 |
| WRTMWB1 | 10.50 | 43.4 |
| WRTNTD1 | 35.08 | 10.0 |
| WRTOFD1 | 25.28 | 17.9 |
| WRTOQD1 | 25.28 | 17.9 |
| WRTPCB1 | 25.28 | 17.9 |
| WRTPCb2 | 25.28 | 17.9 |
| WRTPRE1 | 51.75 | 3.7 |
| WRTPYA1 | 54.13 | 3.2 |
| WRTPYE1 | 51.75 | 3.7 |
| WRTXq-1 | 47.25 | 4.8 |
| WRTXu-1 | 47.25 | 4.8 |
| WRTXuC1 | 47.25 | 4.8 |
| WRTXXB1 | 51.75 | 3.7 |

# *G. UP SCALING PREDICTED MEAN RECHARGE FOR ZONES 4A–7A OF THE BORDER DESIGNATED AREA*

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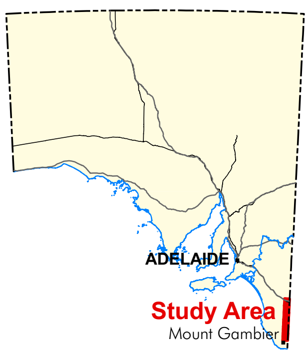



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge
Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

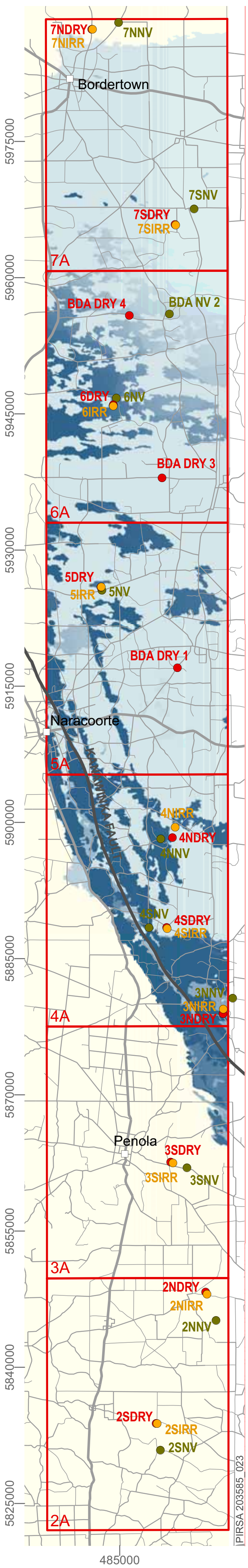
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

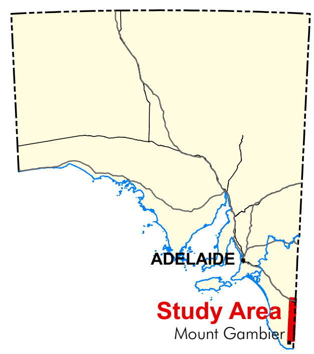
Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 1960 (10 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.1**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge
Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

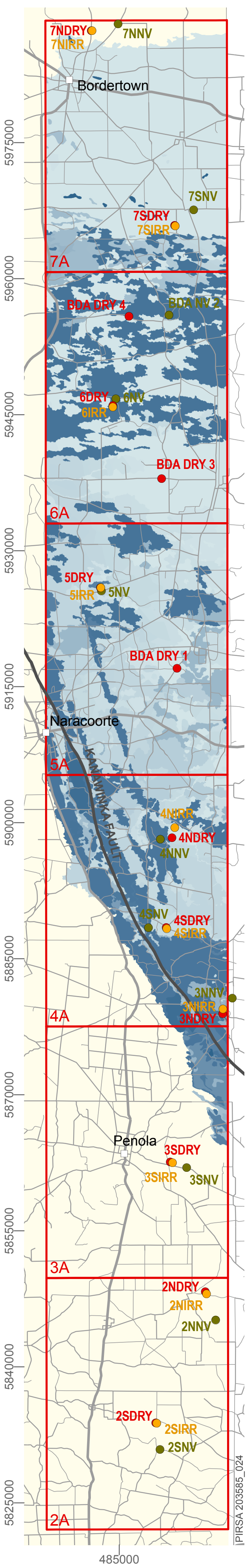
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 1970 (20 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.2**

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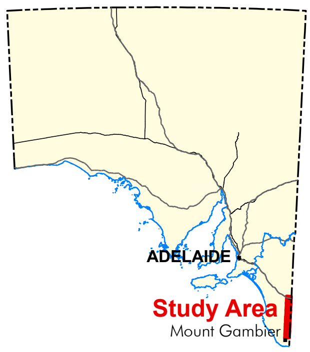



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge
Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

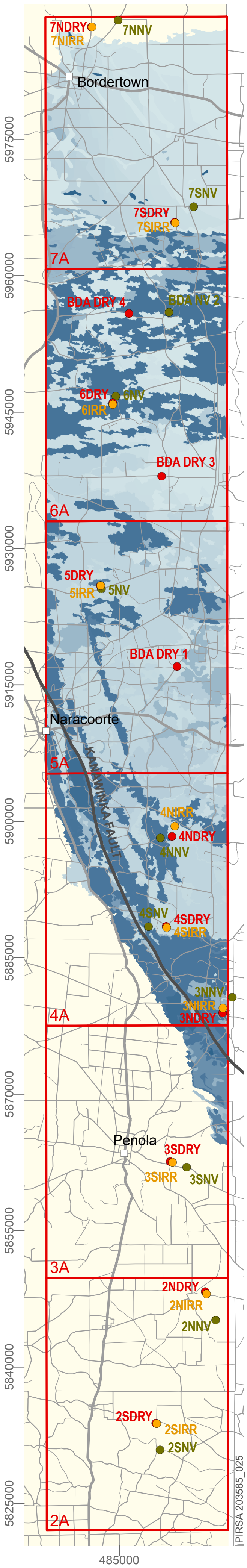
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

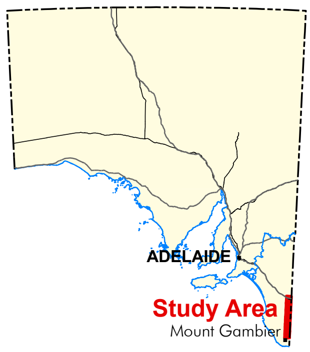
Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 1995 (45 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.3**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

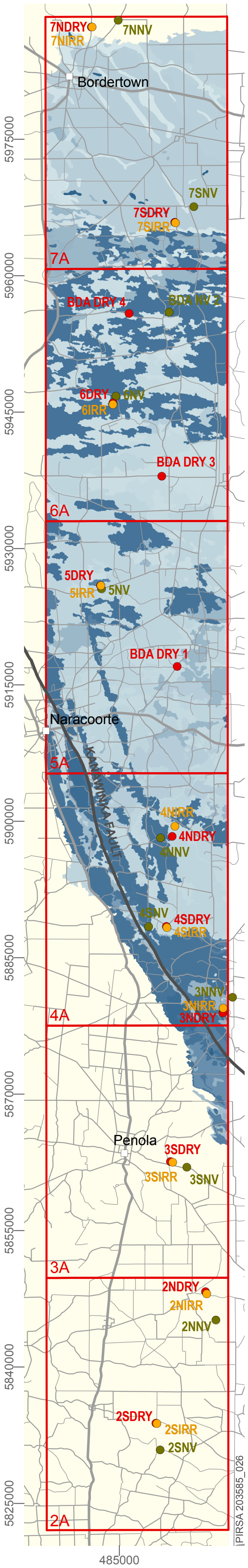
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

## Border Designated Area Salt Accession Project

# UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 2015 (65 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.4**

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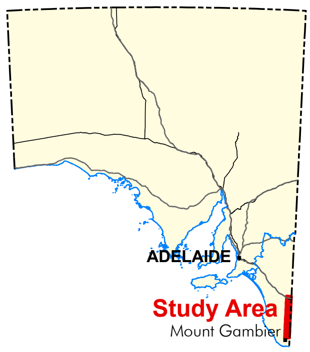



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge
Value (m/y)

High : 0.081

Low : 0.000

Management Zone

0 5 10 15 20 Kilometers

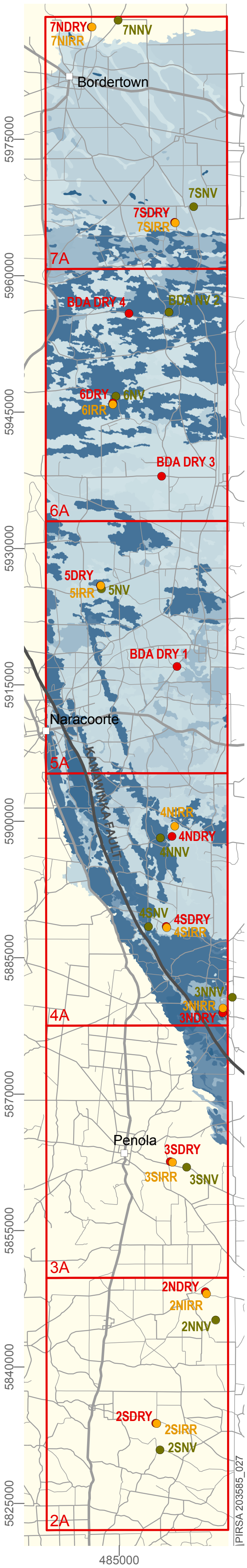
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

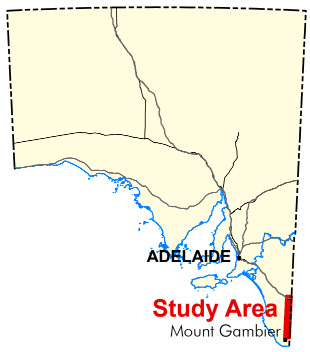
Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 2045 (95 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.5**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Recharge

Value (m/y)

High : 0.081

Low : 0.001

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

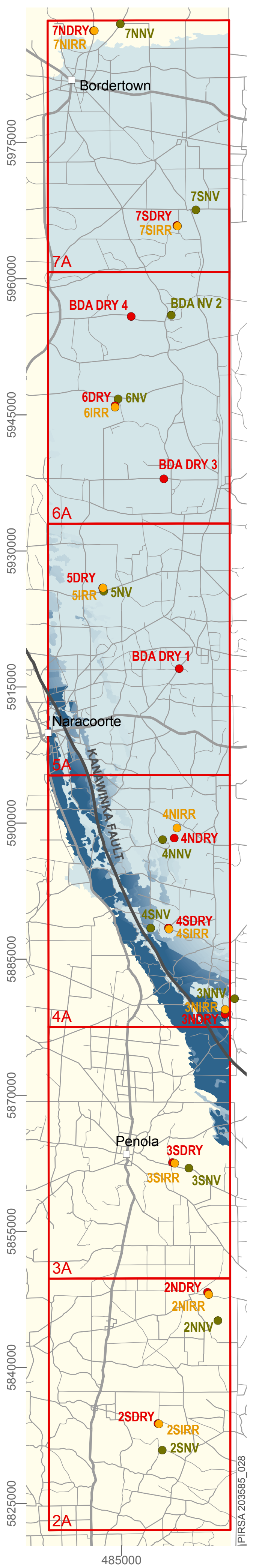
Border Designated Area
Salt Accession Project

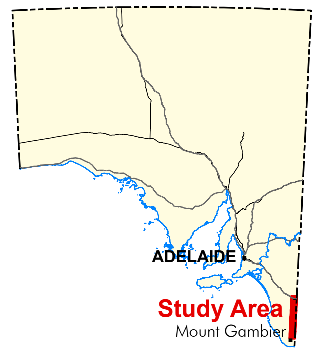
**UP SCALING PREDICTED MEAN RECHARGE RATES, FOR ZONES 4A-7A, 2095 (145 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix G.6**

# H. UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A–7A OF THE BORDER DESIGNATED AREA




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge Value (m)

High : 0.5

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

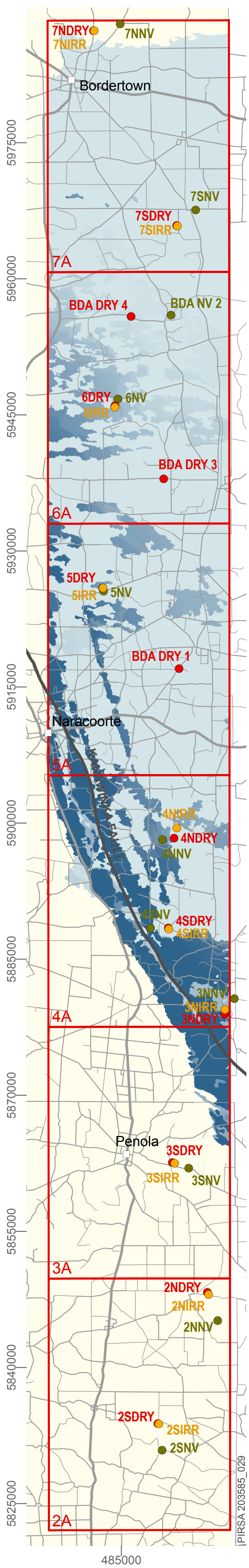
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

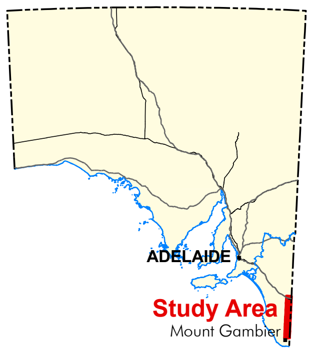
Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 1960 (10 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.1**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge

Value (m)

High : 1.3

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

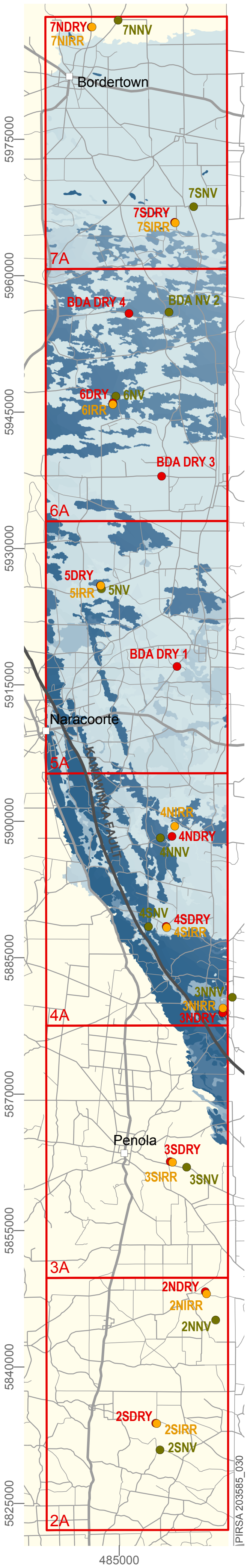
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 1970
# (20 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.2**

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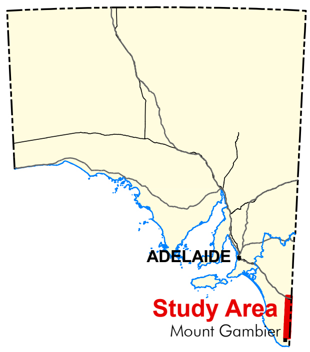



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge
Value (m)

High : 3.3

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

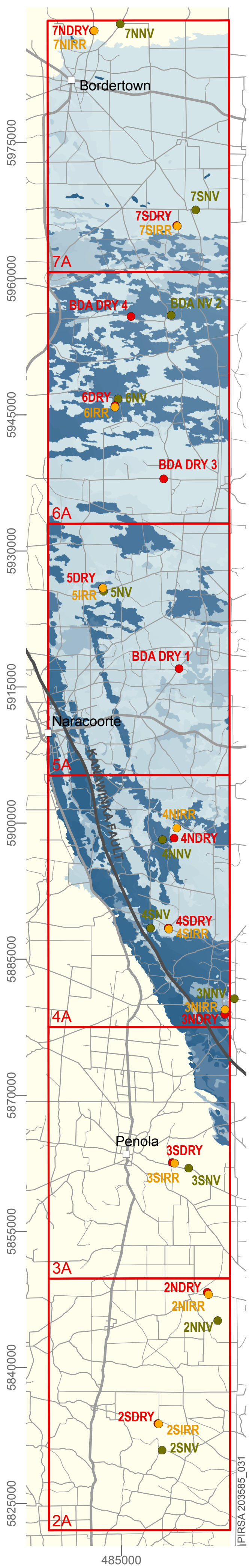
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

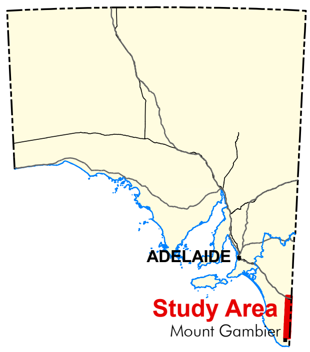
## Border Designated Area Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 1995 (45 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.3**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge

Value (m)

High : 5.0

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

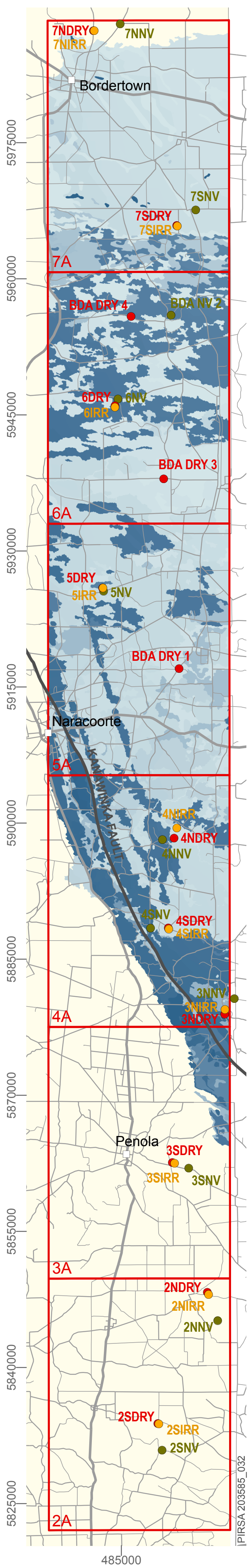
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

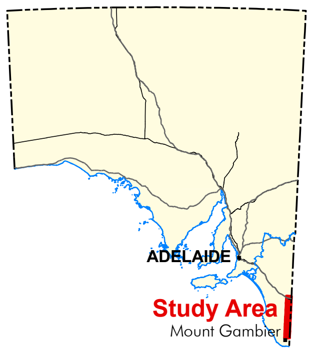
Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 2015 (65 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.4**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge

Value (m)

High : 7.4

Low : 0.0

Management Zone

0 5 10 15 20 Kilometers

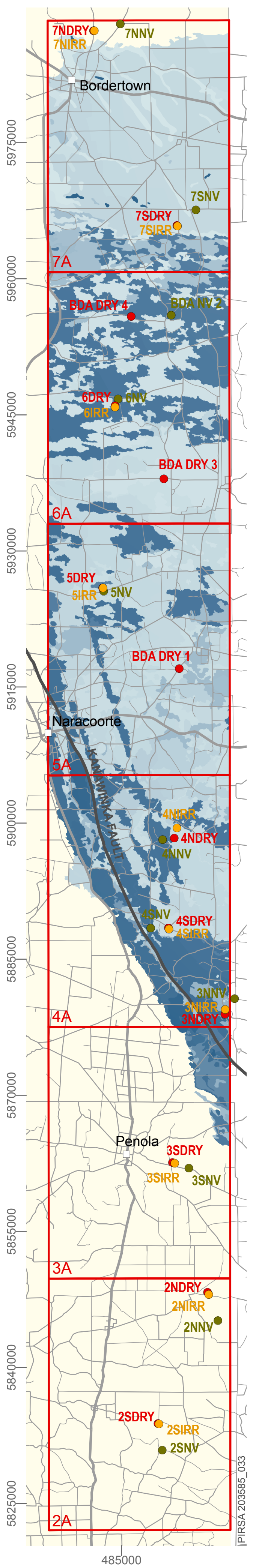
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

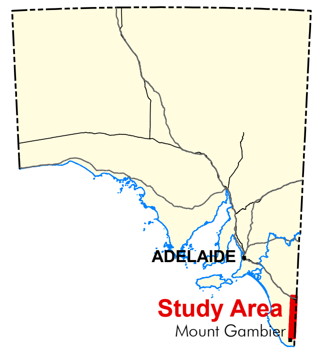
# Border Designated Area
# Salt Accession Project

## UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 2045 (95 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.5**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Recharge

Value (m)

High : 11.5

Low : 0.02

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

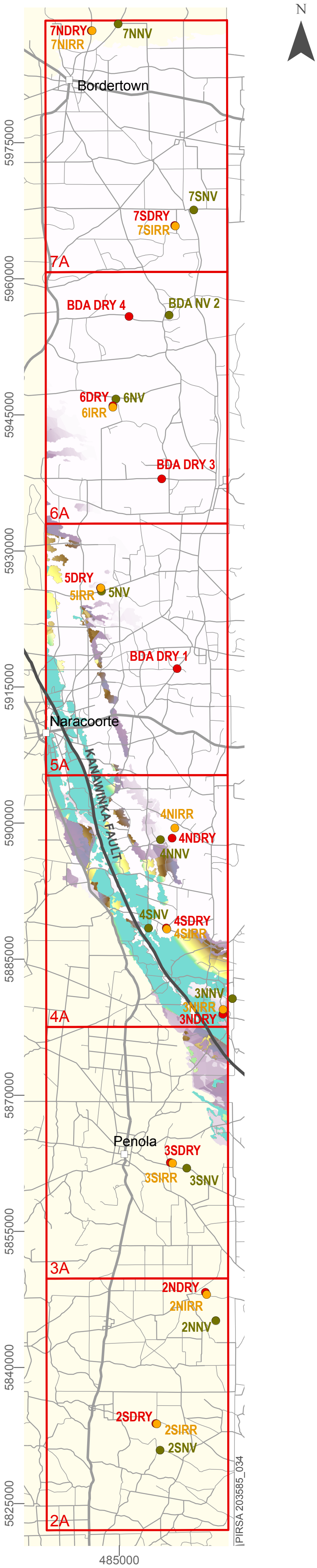
Border Designated Area
Salt Accession Project

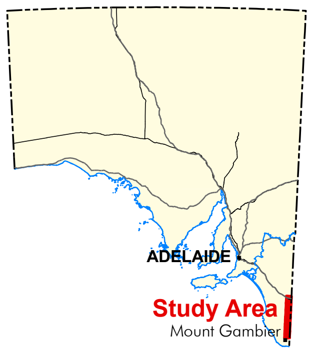
# UP SCALING PREDICTED CUMULATIVE RECHARGE FOR ZONES 4A-7A, 2095 (145 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix H.6**

# *I. UP SCALING PREDICTED SALT FLUX FOR ZONES 4A–7A OF THE BORDER DESIGNATED AREA*




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value (g/m²/y)

High : 200

Low : 0

Management Zone

0 5 10 15 20 Kilometers

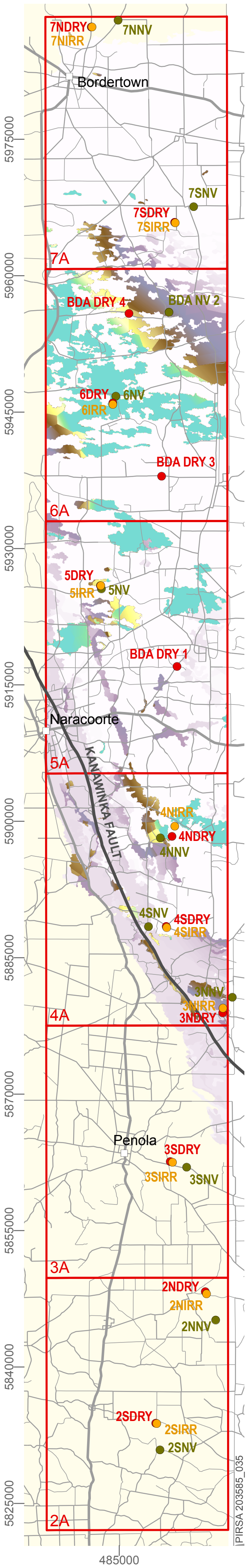
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 1960 (10 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix I.1**

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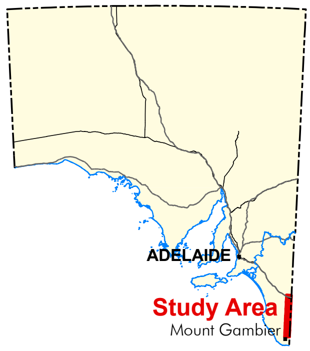



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value (g/m²/y)

High : 222

Low : 0

Management Zone

0 5 10 15 20 Kilometers

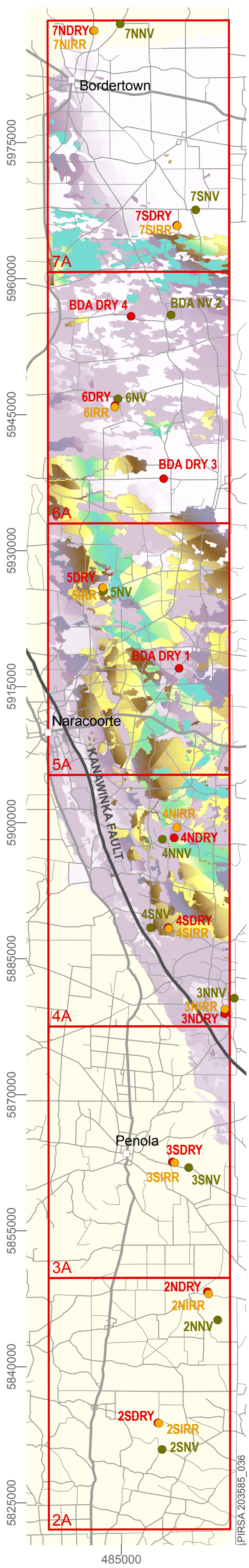
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

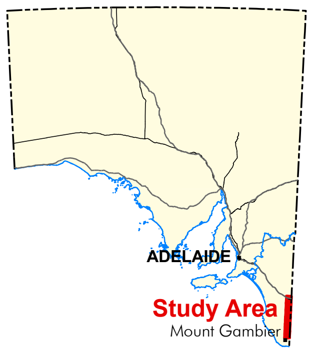
Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 1970 (20 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix I.2**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value (g/m²/y)

High : 117

Low : 0

Management Zone

0 5 10 15 20 Kilometers

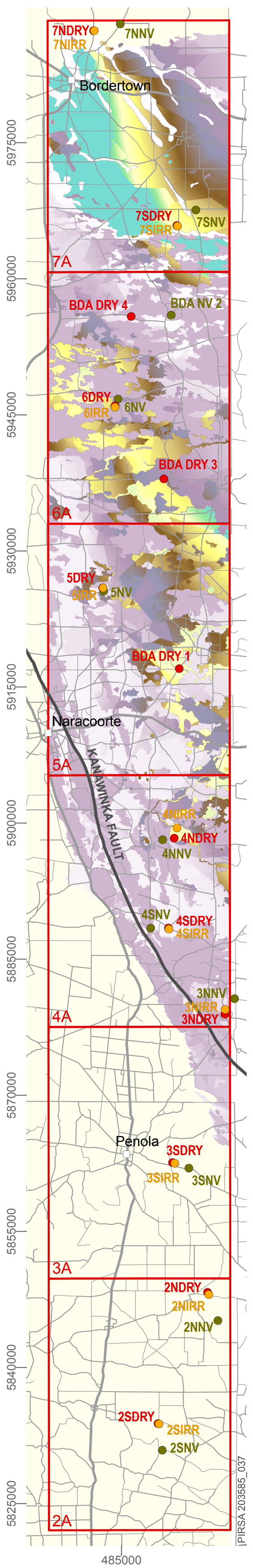
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

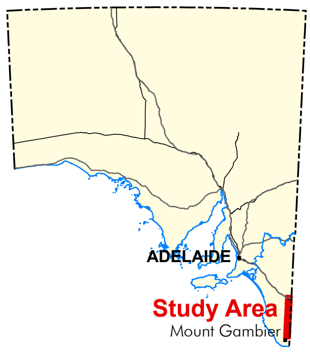
Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 1995 (45 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix I.3**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value ($g/m^2/y$)

High : 90

Low : 0

Management Zone

0 5 10 15 20 Kilometers

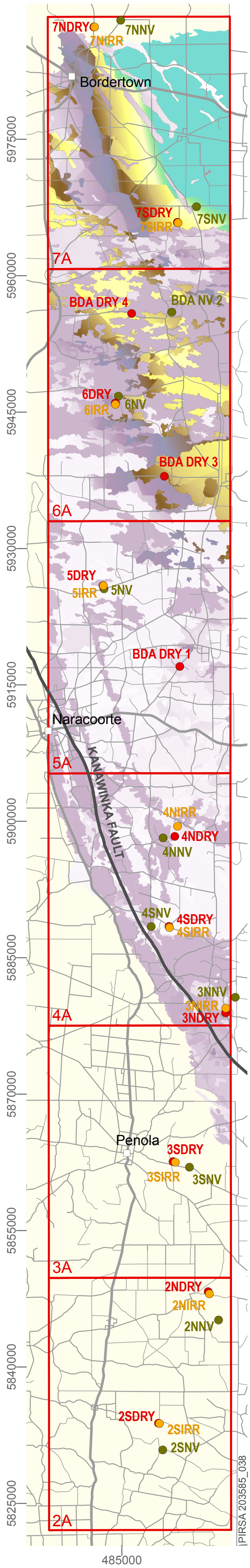
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 2015 (65 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix I.4**

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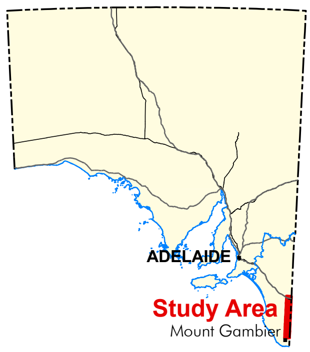



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value (g/m²/y)

High : 73

Low : 0.1

Management Zone

0 5 10 15 20 Kilometers

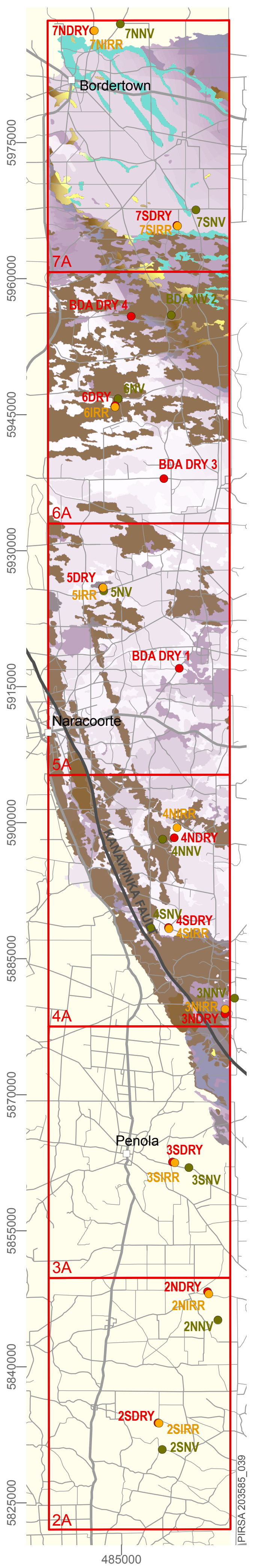
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

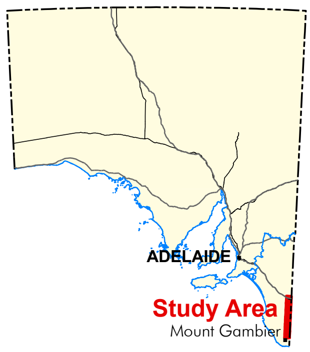
## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 2045 (95 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

# Appendix I.5




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Salt Flux
Value (g/m²/y)

High : 33

Low : 0.2

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

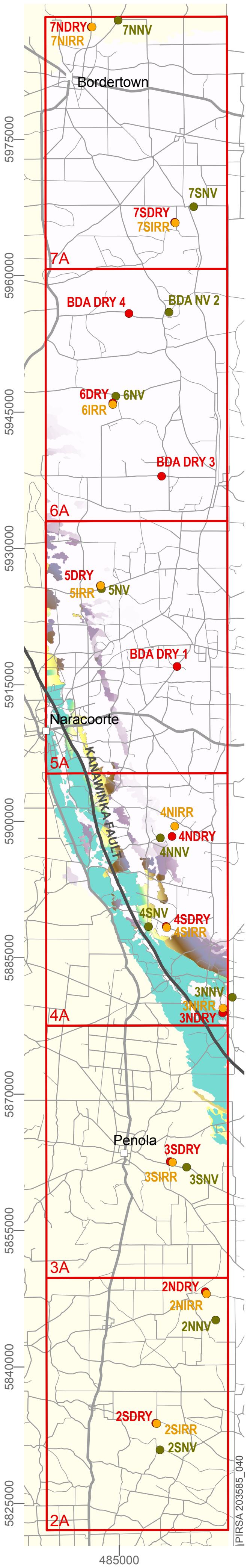
## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED SALT FLUX FOR ZONES 4A-7A, 2095 (145 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix I.6**

# J. UP SCALING PREDICTED CUMULATIVE SALT FOR ZONES 4A–7A OF THE BORDER DESIGNATED AREA

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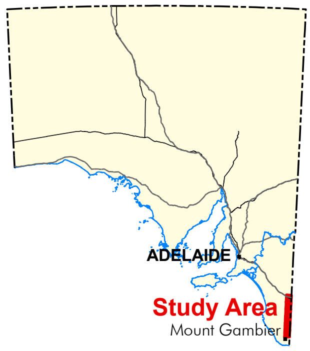



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux
Value (g/m²)

High : 612

Low : 0

Management Zone

0 5 10 15 20 Kilometers

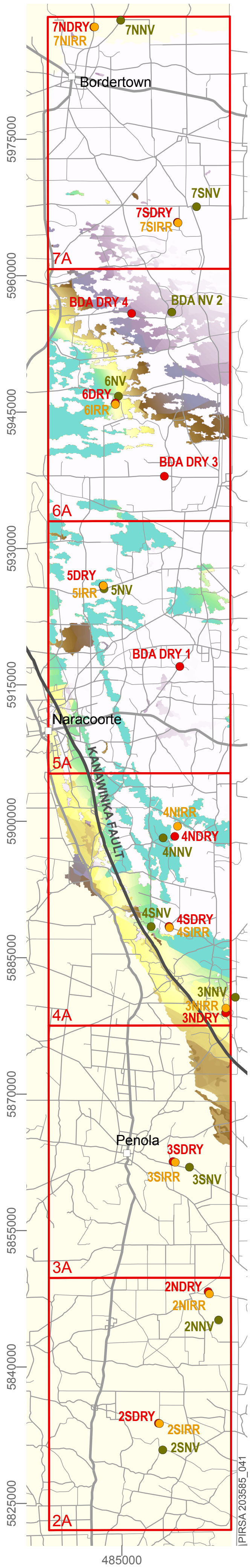
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

**UP SCALING PREDICTED**
**CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 1960**
**(10 years post vegetation clearance)**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.1**

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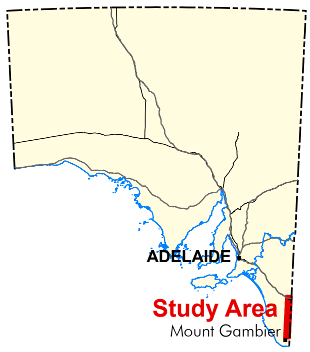



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux

Value (g/m²)

High : 1162

Low : 0

Management Zone

0 5 10 15 20 Kilometers

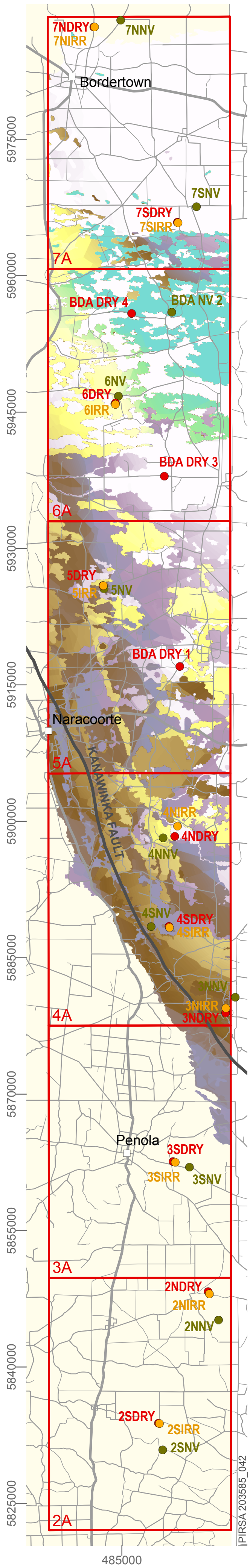
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 1970 (20 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.2**

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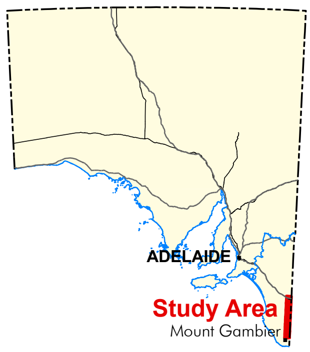



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux

Value (g/m²)

High : 2563

Low : 0

Management Zone

0 5 10 15 20 Kilometers

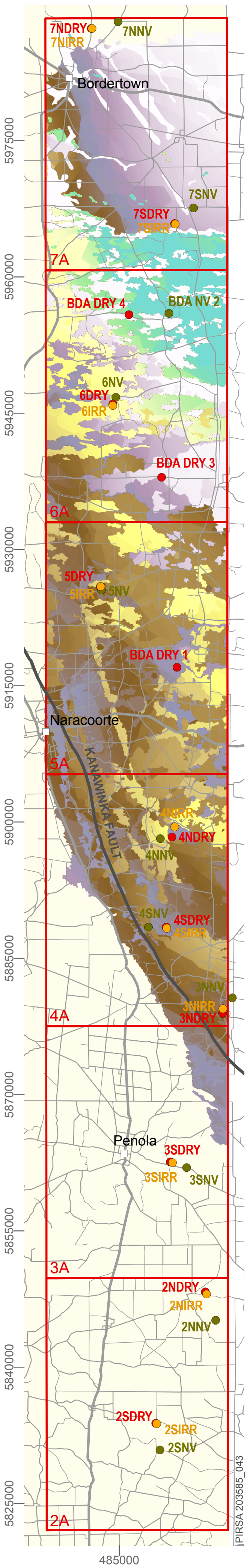
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

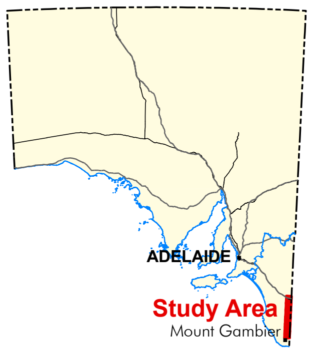
## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 1995
# (45 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.3**




Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux
Value (g/m²)

High : 2769

Low : 0

Management Zone

0 5 10 15 20 Kilometers

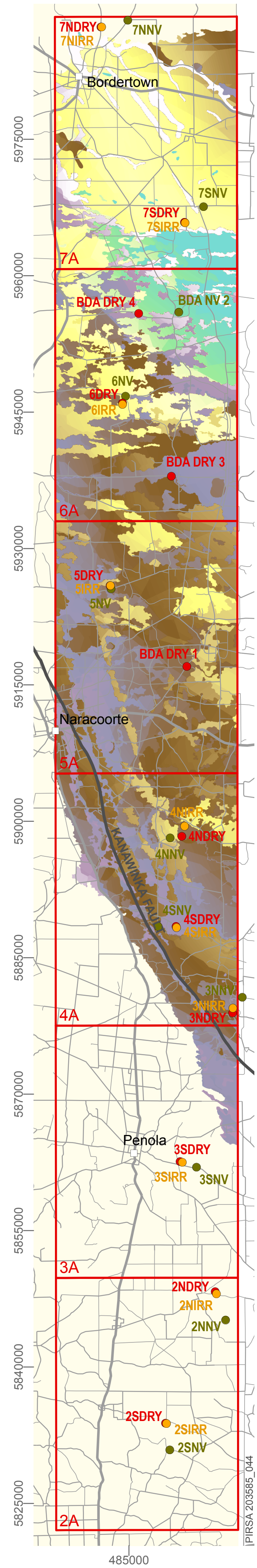
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

## Border Designated Area
## Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 2015
# (65 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.4**

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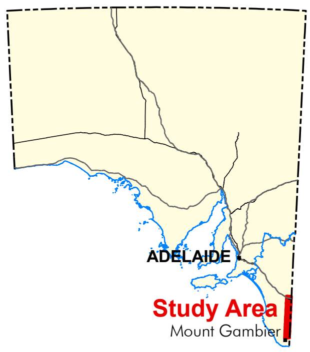



Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux

Value (g/m²)

High : 2901.0

Low : 0.5

Management Zone

0 5 10 15 20 Kilometers

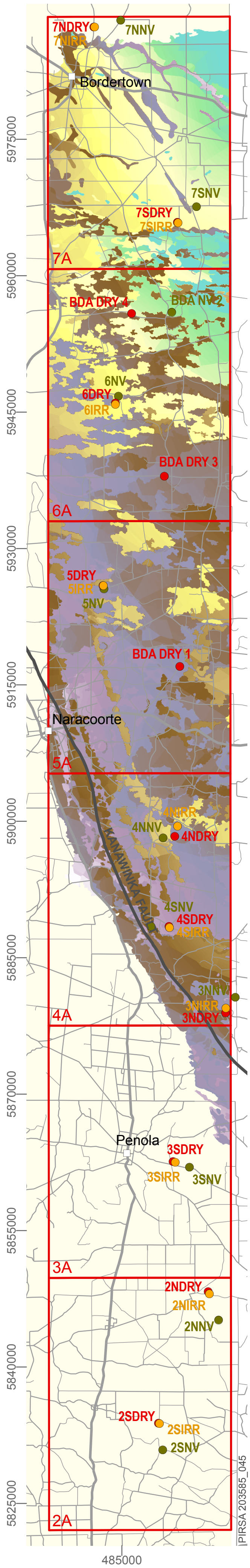
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

Border Designated Area
Salt Accession Project

# UP SCALING PREDICTED CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 2045 (95 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.5**

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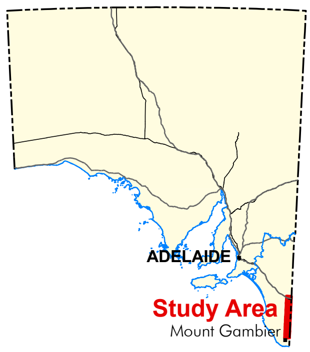


Zone 2A-7A Investigation Sites

- Dry land
- Irrigation
- Native Vegetation

Cumulative Salt Flux

Value (g/m²)

High : 3275

Low : 388

Management Zone

0 5 10 15 20 Kilometers

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
Primary Industries and Resources SA
Date: August 2007

# Border Designated Area Salt Accession Project

## UP SCALING PREDICTED CUMULATIVE SALT FLUX FOR ZONES 4A-7A, 2095 (145 years post vegetation clearance)

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Appendix J.6**

# UNITS OF MEASUREMENT

### Units of measurement commonly used (SI and non-SI Australian legal)

| Name of unit | Symbol | Definition in terms of other metric units | Quantity |
|---|---|---|---|
| day | d | 24 h | time interval |
| gigalitre | GL | $10^6$ m$^3$ | volume |
| gram | g | $10^{-3}$ kg | mass |
| hectare | ha | $10^4$ m$^2$ | area |
| hour | h | 60 min | time interval |
| kilogram | kg | base unit | mass |
| kilolitre | kL | 1 m$^3$ | volume |
| kilometre | km | $10^3$ m | length |
| litre | L | $10^{-3}$ m$^3$ | volume |
| megalitre | ML | $10^3$ m$^3$ | volume |
| metre | m | base unit | length |
| microgram | µg | $10^{-6}$ g | mass |
| microlitre | µL | $10^{-9}$ m$^3$ | volume |
| milligram | mg | $10^{-3}$ g | mass |
| millilitre | mL | $10^{-6}$ m$^3$ | volume |
| millimetre | mm | $10^{-3}$ m | length |
| minute | min | 60 s | time interval |
| second | s | base unit | time interval |
| tonne | t | 1000 kg | mass |
| year | y | 365 or 366 days | time interval |

| | |
|---|---|
| ~ | approximately equal to |
| δD | hydrogen isotope composition |
| $\delta^{18}$O | oxygen isotope composition |
| $^{14}$C | carbon-14 isotope (percent modern carbon) |
| CFC | chlorofluorocarbon |
| EC | electrical conductivity (µS/cm) |
| pH | acidity |
| TDS | total dissolved solids (mg/L) |

# GLOSSARY

**Aquifer** — An underground layer of rock or sediment that holds water and allows water to percolate through.

**Aquifer, confined** — Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

**Aquifer, unconfined** — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

**BoM** — Bureau of Metrology, Australia.

**Bore** — *See well.*

**CFC** — Chlorofluorocarbon; the unit is parts per trillion *(*ppt).

**CMB** — Chloride mass balance.

**δD** — Hydrogen isotope composition ($^{o}/_{oo}$).

**DOC** — Dissolved Organic Carbon.

**Dryland salinity** — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure and the environment.

**DWLBC** — Department of Water, Land and Biodiversity Conservation (Government of South Australia).

**EC** — Electrical conductivity**.** 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

**Evapotranspiration** — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies.

**Geological features** — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

**GIS** — Geographic information system. Computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

**GNIP** — Global Network of Isotopes in Precipitation.

**Groundwater** — *See underground water.*

**Hydrogeology** — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers. *(See hydrology.)*

**Hydrology** — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere. *(See hydrogeology.)*

**Irrigation** — Watering land by any means for the purpose of growing plants.

**Irrigation season** — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

**Leaching** — Removal of material in solution such as minerals, nutrients and salts through soil.

**LMWL** — Local meteoric water line.

**ML** — Megalitre. One million litres (1 000 000).

**Model** — A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

**Monitoring** — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured. (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

**$\delta^{18}O$** — Oxygen isotope composition ($^{o}/_{oo}$).

**Obswell** — Observation Well Network.

**Recharge area** — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

**SA Geodata** — A collection of linked databases storing geological and hydrogeological data, which the public can access at the front counters of PIRSA and its regional offices. Custodianship of data related to minerals–petroleum and groundwater is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater.

**Specific storage ($S_s$)** — Specific storativity. The amount of stored water realised from a unit volume of aquifer per unit decline in head. It is dimensionless.

**Specific yield ($S_y$)** — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless.

**TDS** —Total Dissolved Solids; the unit is milligrams per litre (mg/L).

**Tertiary aquifer** — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago).

**Underground water (groundwater)** — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

**WAP** — Water allocation plan**.** A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

**Well** — (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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