# TECHNICAL REPORT

# MEASUREMENT AND EVALUATION OF KEY GROUNDWATER DISCHARGE SITES IN THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

## 2011/14

Government of South Australia
Department for Water

# MEASUREMENT AND EVALUATION OF KEY GROUNDWATER DISCHARGE SITES IN THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

Cameron Wood

Science, Monitoring and Information Division
Department for Water

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**Science, Monitoring and Information Division**
Department for Water
25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone National (08) 8463 6946
International +61 8 8463 6946
Fax National (08) 8463 6999
International +61 8 8463 6999
Website www.waterforgood.sa.gov.au

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# PREFACE

On 1 July 2010, the Department for Water replaced the former Department of Water, Land and Biodiversity Conservation. The Department of Water, Land and Biodiversity Conservation and the abbreviation 'DWLBC' are referred to in several instances in this report. The reader is advised that these terms are retained in certain contexts within this document in order to provide a correct historical account of the investigation and the production of the technical report document.

# FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

**Scott Ashby**
**CHIEF EXECUTIVE**
**DEPARTMENT FOR WATER**

# ACKNOWLEDGEMENTS

The work detailed in this report would not have been possible without the help of the following people:

Dr Glenn Harrington (CSIRO) for help with commencing the project, and ongoing assistance with interpretation of geochemical data. Also Greg Jones and Claire Harding (DFW) for helping greatly with field work and data collection, and shaking countless bottles for radon samples. DFW would also like to thank the Department for Environment and Heritage for granting permission to conduct research in Ewens Ponds Conservation Park and Piccaninnie Ponds Conservation Park.

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# EXECUTIVE SUMMARY

This report documents work undertaken as part of the Resource Sustainability component of the South East National Water Initiative project 'Integrated Water Resource Management.' In this part of the project, groundwater–surface water interactions have been investigated at six groundwater-dependent ecosystem (GDE) sites in the Lower South East of South Australia. A hydrochemical approach was used to gain a better understanding of hydrogeological controls on groundwater discharge and flow at the following sites:

- Ewens Ponds and Eight Mile Creek (spring-fed pond and creek system)
- Piccaninnie Ponds (karst wetland complex)
- Pick Swamp (rehabilitated wetland site)
- Crescent Pond (perennial spring)
- Jerusalem Creek (spring-fed creek)
- Cress Creek (spring-fed creek).

Surface water samples were taken periodically between August 2007 and June 2009 and analysed for major ion and isotope chemistry. Stream flow in creeks was also measured where possible. Analysis of these results has led to a new appreciation of groundwater discharge and flow dynamics at these sites and conceptual models of the hydrogeology of each system have been developed. The sites vary from shallow, ephemerally spring-fed creeks to deeper perennial systems. The shallow systems (Cress Creek and Jerusalem Creek) have a strong dependence on seasonal groundwater discharge from the upper units of the regional Tertiary Limestone Aquifer (TLA) and are most vulnerable to fluctuations in groundwater level (Jerusalem Creek was nearly dry in summer 2008). The deeper perennial systems (Ewens Ponds and Piccaninnie Ponds) also have a strong dependence on groundwater discharge from the upper units of the TLA; however, hydrochemical data suggests there is a small component of discharge from the deeper sub-units of the TLA. Pick Swamp was found to be fed by both perennial spring discharge (from Crescent Pond) and ephemeral discharge from the western part of Piccaninnie Ponds.

Using this new information, a monitoring strategy has been developed to assess changes in system dynamics in the future. The monitoring strategy relies on regular sampling and analysis of ion and isotope concentrations in surface water at each site, combined with stream gauging measurements to assess future changes in groundwater discharge and system behaviour.

# SUMMARY

# 1. INTRODUCTION

## 1.1. BACKGROUND

The groundwater resources of the South East are important for South Australia. These resources support a wide array of industry—predominantly wine; wool; meat; dairy; forestry and timber; fishing and aquaculture; vegetables; and seed production. Furthermore, groundwater is the primary source of water for town supply throughout the region. There are signs of groundwater resource stress in the region.,

Groundwater-dependent ecosystems (GDEs) present a challenge for groundwater management in the region. Some of the recognised GDEs in the Lower South East of South Australia are considered of great importance for biodiversity conservation, as well as being popular tourist attractions. It is therefore important to manage groundwater flows into these systems to ensure their ongoing health.

Currently in the region, a nominal 10% of the total volume of water available for allocation in each management area is set aside as allocation for Environmental Water Requirements (EWRs) of GDEs. This allocation also allows for lateral through-flow in the aquifer (Brown et al. 2006). Whether this allocation is adequate is unknown, as quantification of the rates of groundwater discharge to individual GDEs in the region has not yet been achieved. Furthermore, whilst the groundwater resource is monitored quarterly through the state's observation well network (Obswell) and resource condition reported on, there is currently no formal monitoring done on the condition of significant GDEs in the region.

## 1.2. DEFINITIONS

Much literature has been published on GDEs in Australia in recent years. This highlights the increased awareness of the importance of these systems, as well as the increasing need to take them into consideration when managing groundwater resources. The term 'groundwater-dependent ecosystem' encompasses a variety of ecosystems, although a general definition would be an ecosystem that *'must have access to groundwater to maintain its ecological structure and function'* (Murray et al. 2006), and may include:

1. vegetation that may rely on shallow groundwater to sustain transpiration and growth, where a surface expression of groundwater is not necessary
2. ecosystems that do require a surface expression of groundwater (i.e. groundwater discharge), including base-flow to streams and rivers, wetlands and springs
3. aquifer and cave ecosystems (which may occur in karst, fractured rock and alluvial aquifers), which support stygofauna.

Some of these systems, particularly those that rely on a surface expression of groundwater, may also rely on a certain component of surface water (precipitation, run-off). Therefore, different GDEs may have different levels of 'reliance' on groundwater. For practical purposes, the degree of groundwater dependence of a given GDE may be defined as the fraction of the ecosystem's annual water budget that is derived from groundwater (Eamus et al. 2006). For the purposes of this study, the focus will only be on those GDEs in the second category listed above.

## *1.3. AIM*

The aim of this study is to:

- improve understanding of the hydrogeological flow regime to significant GDEs in the Lower South East of South Australia
- develop an ongoing monitoring strategy for these sites based on findings.

The improved understanding will include a better conceptual understanding of groundwater discharge to key GDEs, including estimation of rates of discharge, location of discharge points, and source aquifer units for groundwater discharge. Sites have been selected based on their significance to regional ecology and cultural value. The monitoring strategy developed will then help managers assess changes in system behaviour (i.e. changes in groundwater discharge patterns), which may inform future decision-making regarding management of surface water–groundwater interactions.

## *1.4. APPROACH*

The increase in study of surface water–groundwater interactions in recent years has meant a number of methods for assessing connectivity have been developed and described in the literature. Brodie et al. (2007) present a summary of the various techniques and methodologies available. These include:

- direct seepage measurement with seepage meters, instruments designed to capture groundwater discharge into surface water at the sediment–water interface
- hydrometric analysis, which uses Darcy's Law and changes in hydraulic head to estimate groundwater discharge
- geophysical and remote sensing surveying, which looks at variations in subsurface water chemistry (particularly salinity) and water content
- water budgets, which look at the various volumetric inflow and outflow components of the hydrologic cycle in a certain area (for example, in a lake, rainfall = inflow, and evaporation = outflow) and solve for unknown components (e.g. groundwater inflow or outflow)
- hydrochemistry and environmental tracer techniques, which look at the ionic and isotopic constituents of surface water and groundwater in order to build conceptual models of surface water–groundwater interactions and estimate rates of discharge. Tracer concentrations can also be used in combination with water balance calculations to better constrain estimates of groundwater discharge.

Each of these approaches has its advantages and disadvantages. For example, seepage meters can only measure seepage across a small surface area; hence, problems can be associated with up-scaling. Also, some of the field sites in this study (e.g. Ewens Ponds, Piccaninnie Ponds) are relatively deep (>10 m), making seepage meter deployment and measurement logistically difficult. Hydrometric techniques are also not particularly useful in the Lower South East of South Australia, where hydraulic gradients are typically quite low ($\sim 10^{-3}$), and the development of secondary porosity in the karst limestone makes estimating hydraulic conductivity difficult. Geophysical methods can be quite expensive and require expert technical input, and estimates of groundwater discharge from water balances can be adversely affected by uncertainties in estimates of various other components of the water balance. For these reasons, a hydrochemistry approach was adopted in order to obtain a better understanding of these sites.

### 1.4.1. HYDROCHEMISTRY

Major cations and anions are among the most commonly used hydrochemical tracers. Rainfall carries with it low-level concentrations of water-soluble salts from oceanic evaporation (e.g. seawater salinity is ~35 000 mg/L, rainfall salinity is ~23 mg/L in Mount Gambier), which brings dissolved cations and anions into the terrestrial hydrological cycle (Blackburn & McLeod 1983). Once deposited through rainfall, the concentrations of cations and anions are influenced by evaporation and evapotranspiration prior to infiltrating into the groundwater system. Once in the groundwater system, the relative chemical composition of meteorically derived water may be further influenced by water–rock interactions such as mineral dissolution and precipitation, cation exchange and redox reactions (reactions may also occur in the unsaturated zone prior to recharging groundwater). Typically, groundwater increases in salinity along a regional flow path and this evolution is usually accompanied by the following changes in anion dominance (Chebotarev 1955 in Freeze & Cherry 1979):

Travel along flow path ⟶

$HCO_3^-$ → $HCO_3^- + SO_4^{2-}$ $SO_4^{2-} + HCO_3^-$ ⟶

$SO_4^{2-} + Cl^-$ ⟶ $Cl^- + SO_4^{2-}$ ⟶ $Cl^-$

Increasing age ⟶

The ratios of various cation and anion concentrations can be used to infer hydrogeochemical processes. For example, Vengosh and Rosenthal (1994) give a review of some useful ion ratios in hydrogeological studies in coastal aquifers. These include magnesium to calcium (Mg/Ca) ratios, which are typically in the range 0.5–0.7 (molar ratios) in limestone aquifers, but will be higher (0.7–1.1) in dolomite aquifers because of the higher levels of Mg in dolomitic limestone. Seawater intrusion is a potential issue in coastal aquifers and hydrochemistry can be used to assess this process. If seawater intrusion is thought to be occurring in a coastal aquifer, then the fraction of seawater intrusion may be estimated from a mass balance equation that describes the mixing of two water bodies:

$$C_m V_m = C_1 V_1 + C_2 V_2 \qquad \text{Equation (1)}$$

where $C$ and $V$ are the concentrations and volumes (respectively) of the mixed solution ($_m$) comprised of seawater ($_1$) and 'freshwater' or regional groundwater ($_2$). Given that ($V_m = V_1 + V_2$), $V_m$ may be cancelled out to give:

$$F_{sea} = \frac{V_1}{V_2} = \frac{(C_m - C_2)}{(C_1 - C_2)} \qquad \text{Equation (2)}$$

where $F_{sea}$ is the fraction of seawater in the mixture (Langmuir 1997). The tracer to be used in this approach, however, needs to be chemically conservative (i.e. not removed or added from another source during the mixing process). Chloride (Cl) is generally considered the most appropriate ionic tracer for this approach, due to its inert and unreactive nature (Langmuir 1997).

Major ion chemistry data can also be used in conjunction with stream flow data to assess the proportions of contribution to stream flow where multiple sources are present. The approach is largely the same as that used in Equations (1) and (2). For example, Hem (1985) outlines a method for calculating spring inflow into a stream where direct spring flow cannot be measured. It is based on the principle that stream flow rate at a point downstream ($Q_3$) results from discharge upstream ($Q_1$), with additional discharge from another source further along the stream path ($Q_2$):

$$Q_1 + Q_2 = Q_3 \qquad \text{Equation (3)}$$

Combining Equation (1) with measurements of a conservative tracer such as chloride ($C$) at all these points gives:

$$Q_1 C_1 + Q_2 C_2 = Q_3 C_3 \qquad \text{Equation (4)}$$

If flow is gauged at the downstream location ($Q_3$), and ($C_1$), ($C_2$) and ($C_3$) are all measured, these two equations may be solved to give the amount of flow from ($Q_1$) and ($Q_2$). If these two sources are both springs, then the volume of discharge from each of the two springs can be determined. It should be noted that this method assumes that ($Q_1$) and ($Q_2$) are the only sources of stream flow at ($Q_3$).

Radon-222 (Rn-222), a radioactive noble gas, has found increasing use in studies of surface water–groundwater interactions in recent years. Rn-222 is an isotopic daughter product of radium-226 (Ra-226), present in the mineral grains of rocks and soils. The decay of Ra-226 to Rn-222 produces a recoil energy capable of ejecting the Rn-222 molecule out of the mineral grain. If the Rn-222 molecule comes to rest in pore space, it may move freely through the porous media by either advection or diffusion. If the porous medium is saturated, Rn-222 will move with groundwater and if that groundwater discharges to surface water, Rn-222 will discharge with it. Rn-222 has a relatively short half-life of approximately 3.8 days; therefore, it decays quickly. It may also be lost from surface water by gas exchange with the atmosphere (atmospheric Rn-222 concentrations being negligible). Therefore, due to the fact that its primary source is groundwater, and it has a relatively short residence time in surface water, Rn-222 is an ideal tracer for these types of studies (Cecil & Green 2000), and concentrations in surface water can be a good qualitative indicator of areas of enhanced groundwater discharge.

Stable isotopes of components of the water molecule, oxygen-18 ($^{18}O/^{16}O$) and deuterium ($^{2}H/^{1}H$) have long been used in hydrogeologic studies. Both heavier isotopes ($^{18}O$ and $^{2}H$) make up a relatively small proportion of the abundance of hydrogen and oxygen on Earth ($^{18}O$ being ~0.205% of total oxygen and $^{2}H$ being 0.015% of total hydrogen [Coplen et al. 2000]). When water is evaporated, and water molecules move from the liquid to the vapour phase, isotopically ‘lighter’ water evaporates more efficiently than ‘heavier’ water. Therefore, a partially evaporated body of water will be more enriched in the heavier isotopes $^{18}O$ and $^{2}H$ than a water body that has not undergone any evaporation. This process is called isotopic fractionation (Mazor 2004). Under low temperatures, the only other physical processes that may alter the isotopic composition of a water body are diffusion, dispersion and mixing. Therefore, the stable isotopes of water may act as tracers and can be used to infer different hydrogeological processes or mixing of different water bodies, where the difference in isotope concentrations is greater than the degree of analytical error. The stable isotope composition of $^{18}O$ and $^{2}H$ in water is reported here in delta ($\delta$) notation relative to Vienna standard mean ocean water (VSMOW) in parts per thousand, so that:

$$\delta(^{18}O,^{2}H)_{SMOW}=\left(\frac{R_{sample}-R_{s\tan dard}}{R_{s\tan dard}}\right)\times 1000 \qquad \text{Equation (5)}$$

where *R* is the ratio of either $^{18}O/^{16}O$ or $^{2}H/H$.

Chlorofluorocarbons (CFCs) CFC-11 and CFC-12 are derived from the atmosphere and may enter the groundwater system via infiltrating rainfall recharge (Cook & Herczeg 1998). The atmospheric concentration of CFCs has been measured over the past 50 years; hence, the concentration of CFCs in groundwater may yield useful information on the approximate age of 'young' groundwater (i.e. the time since recharge if recharge occurred in the past 50 years).

Carbon-14, a radioactive isotope of carbon, is useful in determining the age of older groundwater samples. Produced in the atmosphere, it may enter the groundwater system in dissolved $CO_2$ in recharge water, then decays radioactively, with a half-life of 5730 years. The age of a groundwater sample may be calculated from the $^{14}C$ concentration of dissolved inorganic carbon (DIC); however, this may be complicated where the $^{14}C$ concentration measured may have been diluted by carbon derived from organic carbon degradation or carbonate dissolution (Appelo & Postma 2005), and appropriate corrections need to be applied.

# INTRODUCTION

# 2. STUDY AREA

## 2.1. *REGIONAL SITE DESCRIPTION*

The six key groundwater discharge sites studied in this project are located within 3 km of the coastline in the Lower South East of South Australia, between Port MacDonnell and the South Australian – Victorian border, ~30 km south of Mount Gambier (Figure 1). The climate can be characterised as Mediterranean with hot, dry summers and cool, wet winters. Mean annual rainfall at Mount Gambier is 708 mm/y and potential evapotranspiration is approximately 1400 mm/y (BoM 2008). The dominant land use types in the Lower South East are dryland grazing of modified pastures; softwood and hardwood plantation; and irrigated sown grasses.

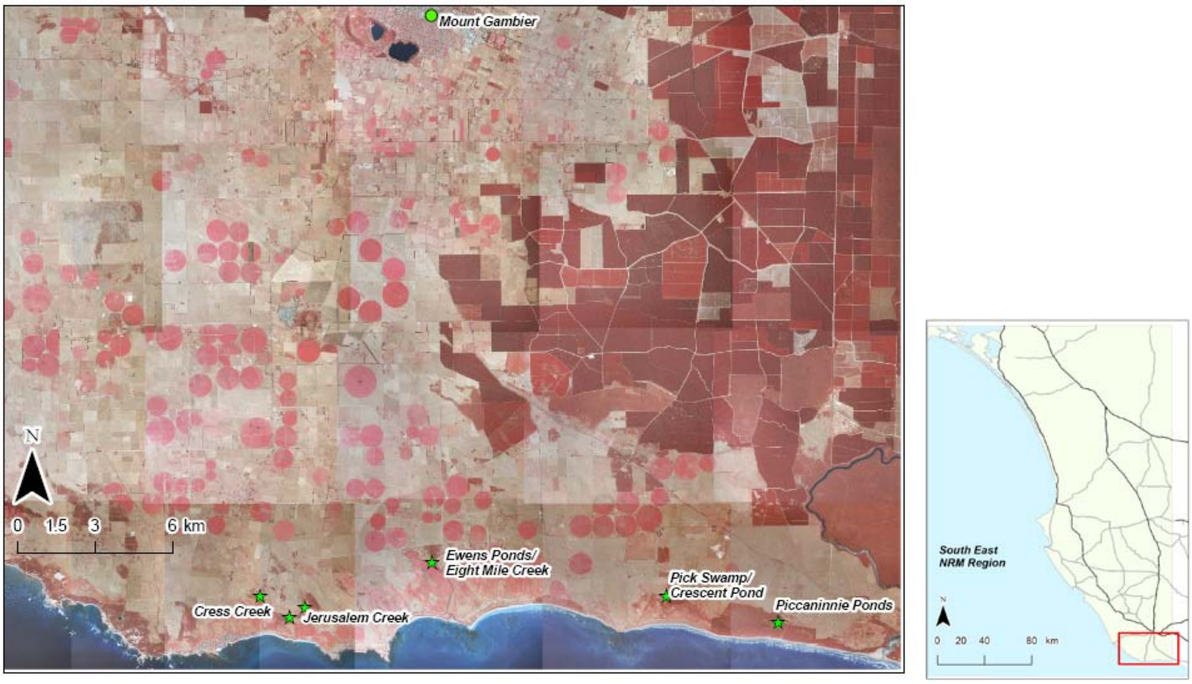


**Figure 1. Six key groundwater discharge sites in the Lower South East SA**

With the exception of the Glenelg River (which straddles the SA–Vic border for ~10 km), there are no natural river systems in the Lower South East. Geographically, the region is characterised by a series of stranded beach dune ridges that run sub-parallel to the coastline, which have prevented the development of rivers and streams. Historically, this meant that much of the South East, given the shallow depth to groundwater and relatively high rainfall, was at least seasonally inundated with surface water in the form of wetlands, swamps, and groundwater-fed springs. Artificial drainage, which commenced in the 1860s, has greatly reduced the number of surface water ecosystems in the South East, which has had a detrimental effect on regional biodiversity (Harding 2009). Therefore, understanding and managing the hydrogeology of GDEs in the South East is a crucial step in maintaining biodiversity.

### 2.1.1. GEOLOGY

The study sites are located in the Gambier Embayment of the Otway Basin. In the Lower South East, this structure is characterised by an upper Tertiary Limestone Aquifer (the TLA or Gambier Limestone) and a lower Tertiary Confined Sand Aquifer (the Dilwyn Formation), separated by a Tertiary Aquitard (Narrawaturk Marl, Mepunga Formation and upper carbonaceous clays of the Dilwyn Formation). The Dilwyn Formation is a Late Palaeocene to Middle Miocene sequence of sand, gravel and clay, deposited in a fluvial, deltaic environment. The Gambier Limestone is a Late Eocene to Middle Miocene formation of marine origin, which is up to 300 m thick at the coast. It consists of three main sub-aquifer units (Lawson & Hill, in prep), which are (from top to bottom):

1. The Green Point Member – Consists of up to three separate units (Unit 1, 3, 5) of off-white to cream bryozoan limestone, separated by layers of grey marl with abundant flint (Units 2 and 4).
2. The Camelback Member – May occur as grey to cream bryozoan limestone and marl with little flint, or grey to pink dolomite (recrystallised and saccharoidal), especially in the region south of Mount Gambier.
3. The Greenways Member – Consists of grey coarse bioclastic (bryozoan) limestone, abundant sponge spicules in upper part or marl with frequent flint bands, and is often glauconitic near its base.

### 2.1.2. HYDROGEOLOGY

In the Lower South East, groundwater flows in a south to south-westerly direction towards the coast in both the Gambier Limestone Formation (Figure 2) and the Dilwyn Formation. The Gambier Limestone is sub-karstic with dual porosity; primary porosity is present as a mixture of framework porosity in cemented sections of limestone, and inter-particle porosity within the unconsolidated carbonate sands. Secondary porosity is present as fracture porosity along structurally weak zones, developed by dissolution of the rock matrix by meteoric water (Love 1991). Further rock dissolution in some regions has created sinkholes and other karst features, some of which (e.g. Ewens Ponds and Piccaninnie Ponds) are connected to (and fed by) the regional water table of the TLA. Reported transmissivities range from 20 $m^2$/day in the less permeable parts of the aquifer to more than 25 000 $m^2$/day. The higher reported transmissivities are likely due to the development of solution features which act as conduits to groundwater flow (Mustafa & Lawson 2002).

Recharge to the Gambier Limestone occurs throughout the study area via infiltration of rainfall, and local-scale groundwater flow systems occur in the upper sequences. Discharge occurs at a number of locations close to the coast through natural springs (including those featured in this study) as well as submarine groundwater discharge off the coast (Allison 1975). Groundwater may also discharge inland to swamps and wetlands.

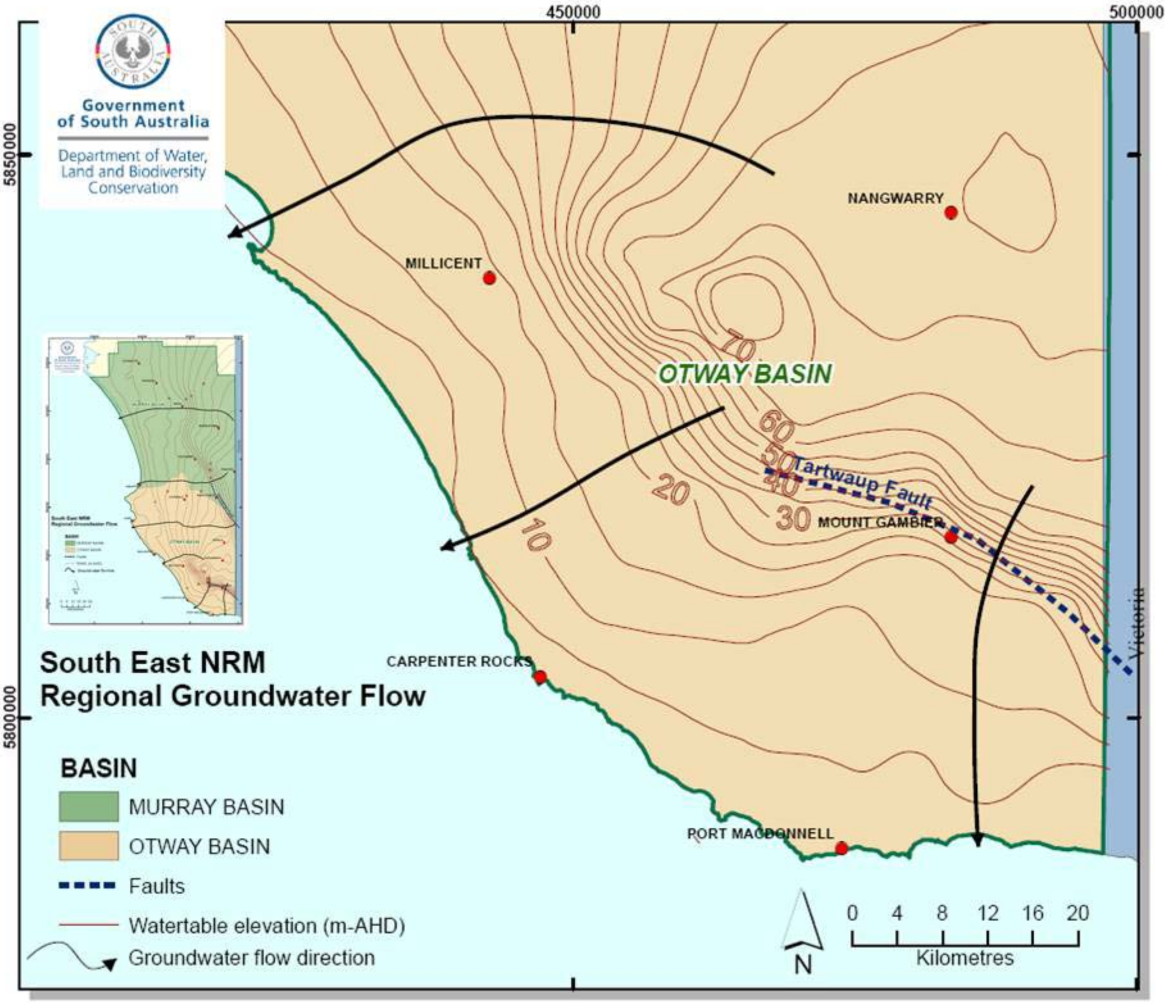


**Figure 2. Regional groundwater flow in the unconfined Tertiary Limestone Aquifer in the Lower South East of South Australia**

## 2.1.3. STUDY SITES

### 2.1.3.1. Piccaninnie Ponds

Piccaninnie Ponds Conservation Park is a large groundwater-fed spring and wetland complex within 1 km of the coast just west of the South Australian–Victorian border. It consists of shallow wetland areas and three deeper karst spring features referred to as the Main Ponds (First Pond, Turtle Pond and the Chasm, Figure 3). The First Pond is approximately 10 m deep, and Turtle Pond is approximately 4–6 m deep. The total depth of the Chasm is not known with any certainty; however, values given in the literature range from 65 m to more than 90 m (Scholz 1990; Hallam & Thurgate 1992). A submerged chamber known as 'the Cathedral' is connected to the Chasm. Further minor ponds that are fed by groundwater discharge are also reported to be present west of the abovementioned area (Clisby 1972). Surface run-off into the ponds is thought to be insignificant in comparison to groundwater discharge, given the small surface catchment area (Clisby 1972). However, it may significantly influence the seasonal flux in physical and chemical parameters (Scholz 1990).

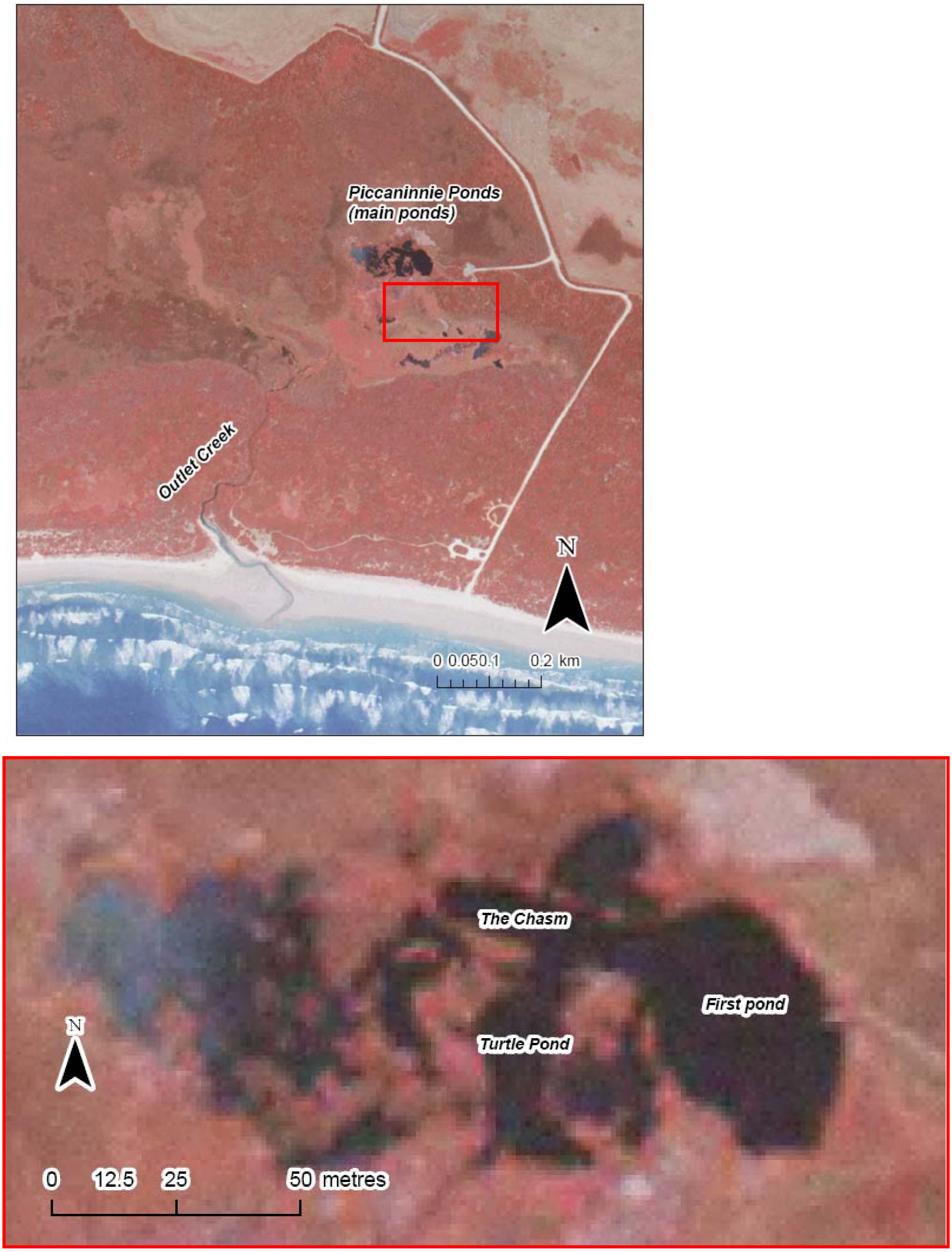


Figure 3. Piccaninnie Ponds and close-up of the Main Ponds

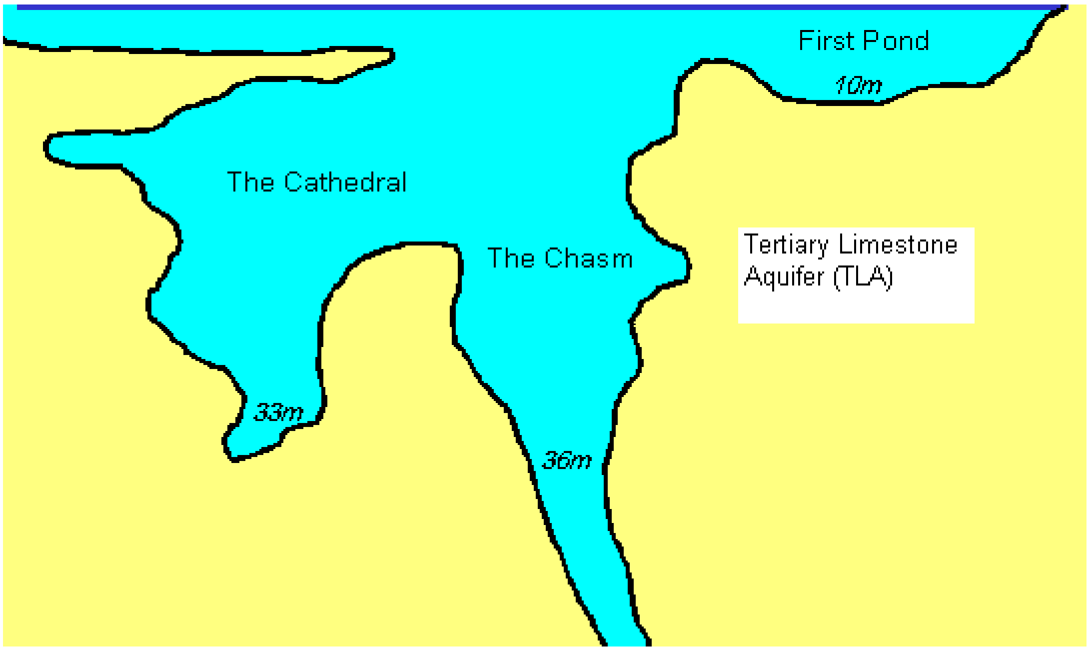


**Figure 4. Conceptual east-to-west cross section of Piccaninnie Ponds (after Hallam & Thurgate 1992)**

The chemistry of the water in the ponds is dominated by Na-Cl, whereas the regional groundwater chemistry is dominated by Ca-$HCO_3$. This apparent difference in surface water and groundwater chemistry is often attributed to the presence of a saline–freshwater interface within the aquifer, which is at such a depth that saline water may be entering the ponds via the Chasm (Clisby 1972). While groundwater observation wells adjacent to the ponds show a sharp increase in salinity at approximately 100 m depth (King & Dodds 2002), the nature and influence of saline groundwater intrusion in the region is not well-understood. Reported electrical conductivities (EC) in Piccaninnie Ponds range from 2700 µS/cm to 3400 µS/cm (total dissolved solids (TDS) ~1755–2210 mg/L), with a seasonal fluctuation of higher salinity in winter, and lower salinity in summer (Scholz 1990; Hallam & Thurgate 1992; Fass & Cook 2005). The increase in salinity in winter has been attributed to the flushing of the surrounding shallow, evaporated wetland waters into the main ponds with increased rainfall. There is no significant variation in salinity with depth (the maximum depth of sampling is 37 m in the Chasm [Clisby 1972]). There is little information on the exact location of obvious spring discharge sites (i.e. sites where water can be seen discharging from the aquifer) in the ponds; however, the Chasm is believed to be the source of much of the water discharging into the ponds.

Allison and Holmes (1973) measured tritium concentrations in Piccaninnie Ponds from July 1970 to October 1971. Tritium is a radioactive isotope of hydrogen with a half-life of ~12 years. Its presence in the hydrological cycle is largely a result of fallout from nuclear weapons testing up to the 1960s. Estimated tritium concentrations in precipitation for the Lower South East range from ~5 TU (tritium units) in 1956 up to ~40 TU in 1967. Concentrations in Piccaninnie Ponds ranged from 0.6 TU to 1.1 TU. Such low concentrations suggest that the water discharging at Piccaninnie Ponds is only 15 or more years old (i.e. the water present in the Ponds in the early 1970s was recharged prior to 1956).

The Ponds discharge to the coast via a drain 300 m south-west of the Main Ponds complex. Water that discharges at this point is generally fresher than that in the Ponds (EC ~1950 µS/cm), suggesting further input from fresher springs in the western portion of the Conservation Park. Discharge at this point has been measured periodically since 1970 and flow rates range from 27 ML/day to 120 ML/day. There has been a trend of declining flows since the early 1990s (Figure 5).

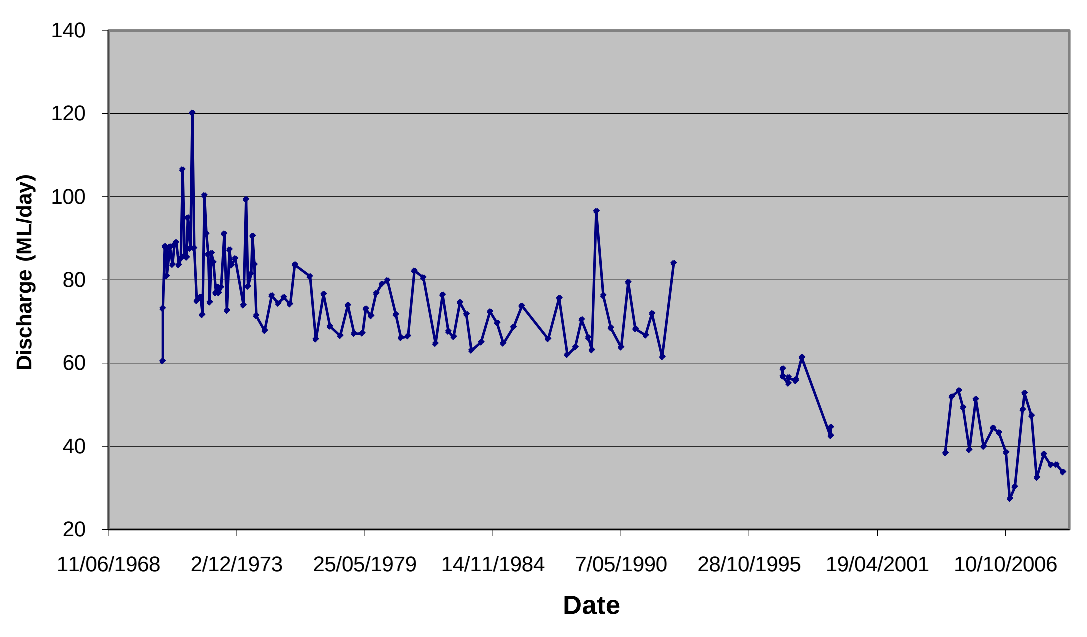


**Figure 5. Piccaninnie Ponds discharge**

### 2.1.3.2. Pick Swamp and Crescent Pond

Pick Swamp is a wetland site on the western side of Piccaninnie Ponds Conservation Park. It is fed by discharge from Crescent Pond, a small spring ~4–6 m deep, as well as seasonal flow out of Piccaninnie Ponds Conservation Park (~1–5 ML/day), and precipitation. Until recently, surface water was drained from the site and it was used as grazing land for livestock. However, the Department of Environment and Heritage acquired the land and wetland rehabilitation work began in early 2007. The site consists of two open wetland basins, separated by a levee (Figure 6). The eastern basin receives water from Piccaninnie Ponds, Crescent Pond and rainfall. The western basin is thought to be fed by both Crescent Pond and rainfall. Crescent Pond is located within a dense, semi-inundated stand of silky tea-tree vegetation, which makes delineating the exact northern boundary of the western basin difficult. A second levee marks the western extent of the site, along which runs a drain that discharges water from the silky tea-tree area to the sea. The western basin is also semi-connected to this drain, via a fish-ladder and a sluice gate.

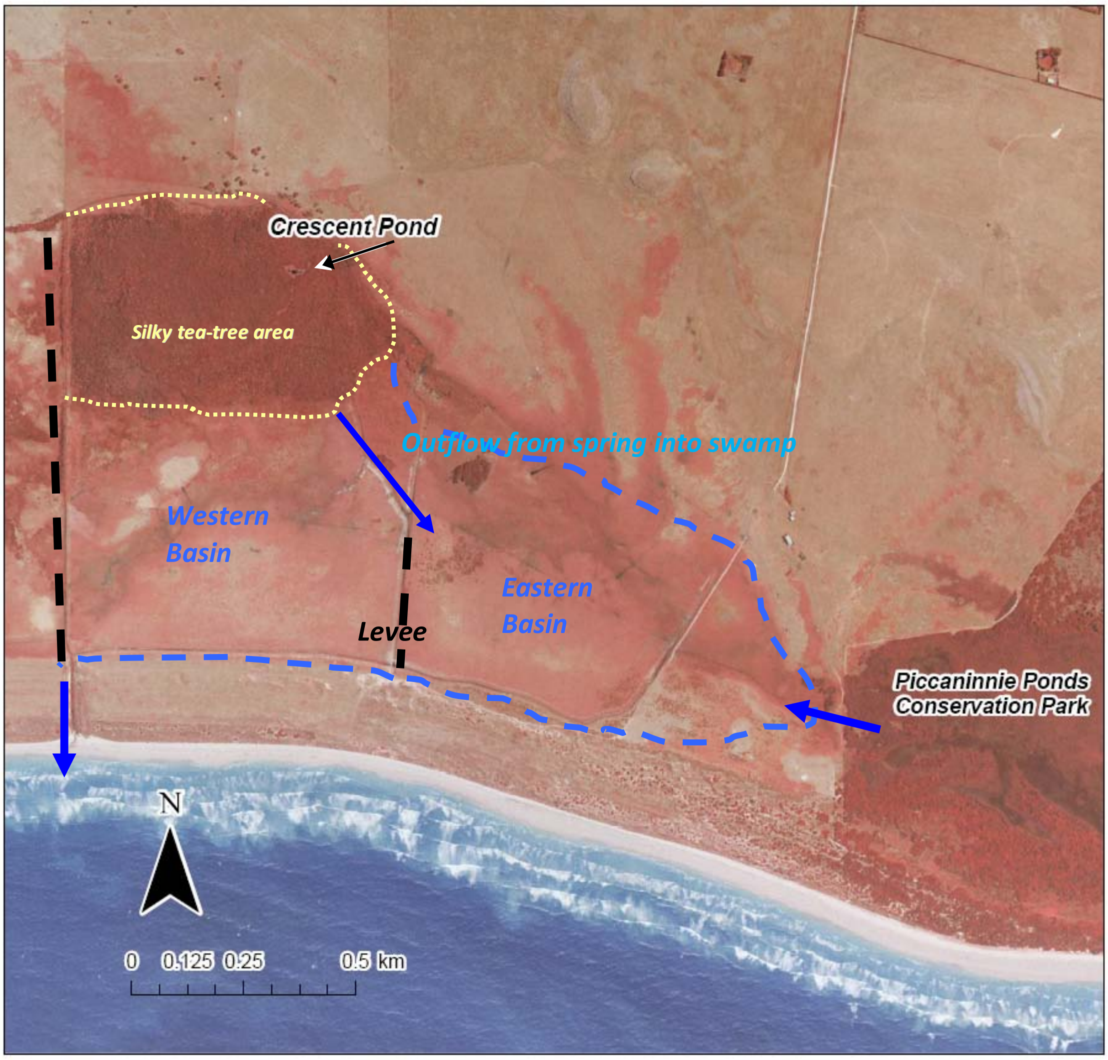


**Figure 6. Pick Swamp and Crescent Pond**

### 2.1.3.3. Ewens Ponds

Ewens Ponds (~8 km north-east of Port Macdonnell) consists of a series of three spring-fed ponds which flow into Eight Mile Creek, which in turn discharges to the sea ~2.5 km downstream (Figure 7). The Ponds range in depth from ~8 m to 10 m. Groundwater discharge into the Ponds can be seen at numerous points where sediments appear to 'bubble' as spring discharge occurs. A submerged cave is present in the third Pond, which provides a likely conduit for discharge from the regional aquifer. Surface run-off into the Ponds is thought to account for less than 5% of flow out of Eight Mile Creek, making them almost entirely groundwater-dependent (Grandfield & Ashman 1984). Further input into Eight Mile Creek occurs ~1.5 km downstream, where Spencers Pond drains into the Creek. There are other minor tributaries that flow into Eight Mile Creek; however, they do not contribute as much of the total flow as Ewens Ponds and Spencers Pond (Clisby 1972).

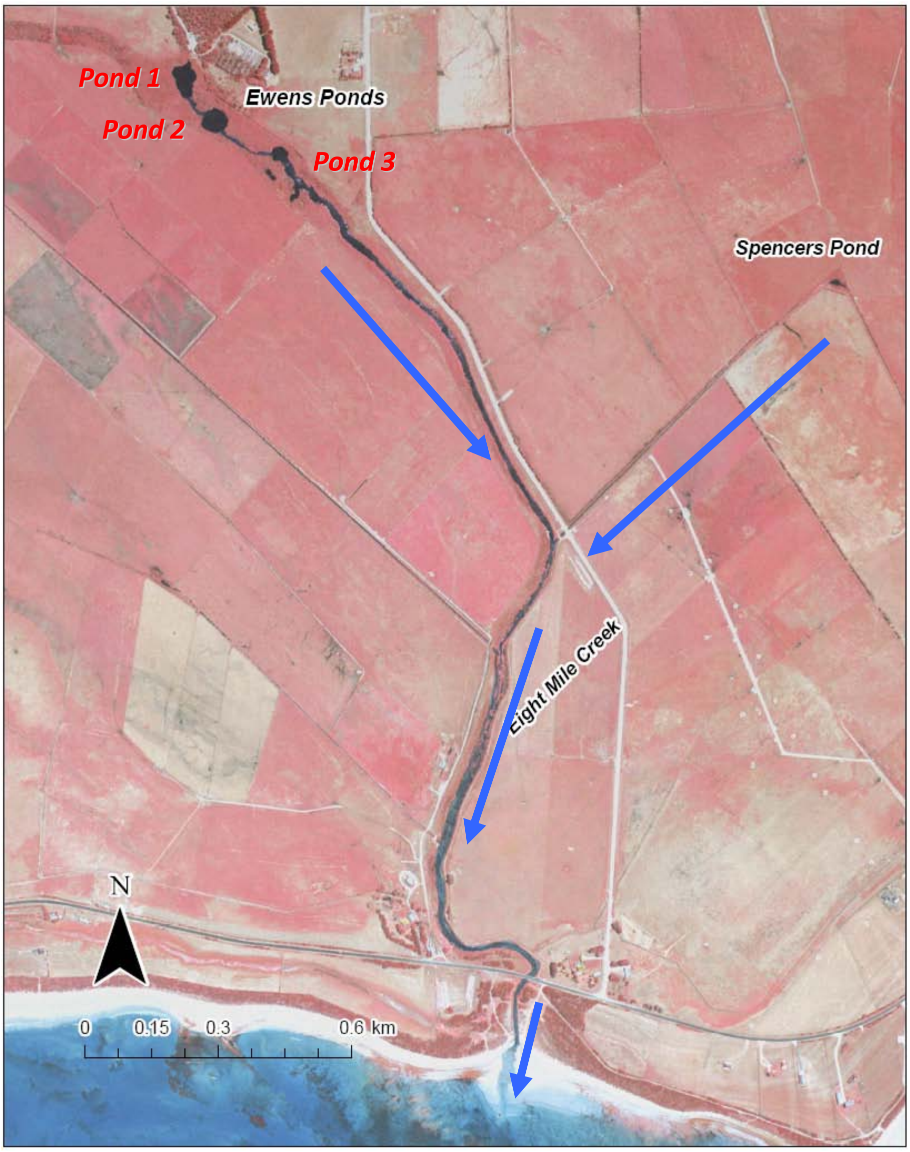


**Figure 7. Ewens Ponds and Eight Mile Creek**

The water in Ewens Ponds is dominated by Ca-$HCO_3$, reflecting the regional groundwater chemistry. Reported EC ranges from 720 µS/cm to 744 µS/cm and there is little variation between Ponds (Hallam & Thurgate 1992; Fass & Cook 2005). EC at the Eight Mile Creek outlet is generally higher (~900–1500 µS/cm) and fluctuates in response to seasonal changes in discharge (Figure 8). As part of a resistivity survey, King and Dodds (2002) identified a potential zone of higher salinity groundwater around the Spencers Pond inlet to Eight Mile Creek, which could be the source of higher salinity water in Eight Mile Creek.

Allison and Holmes (1973) measured tritium concentrations in Ewens Ponds from December 1969 to October 1971. Concentrations in Ewens Ponds ranged from 0.5 TU to 0.9 TU. Such low concentrations, as in Piccaninnie Ponds, suggest that the groundwater discharging at Ewens Ponds in the early 1970s recharged prior to 1956 (i.e. is more than 15 years old).

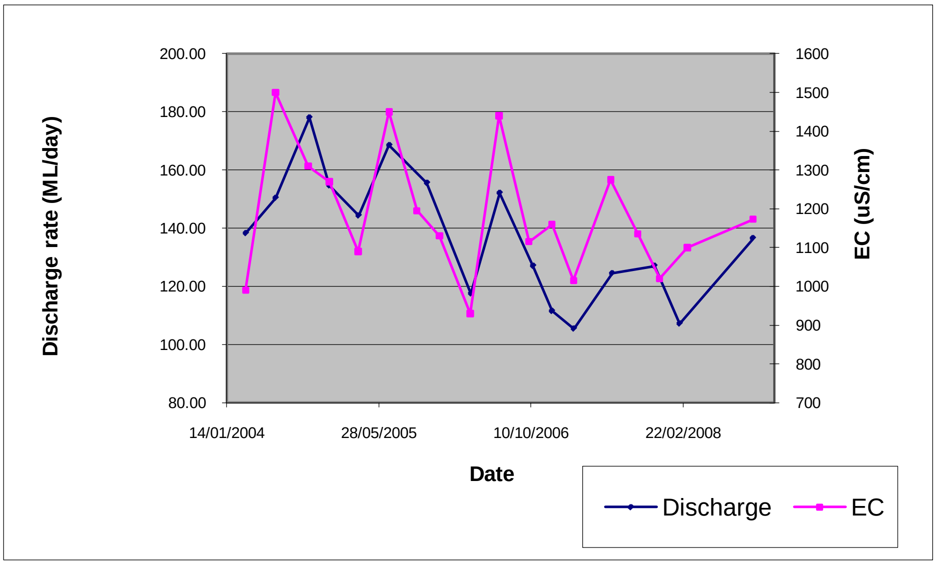


**Figure 8. Eight Mile Creek electrical conductivity (EC, µS/cm) and discharge (ML/day)**

Discharge from Eight Mile Creek has been measured periodically since 1970 and flow rates range from 105 ML/day to 236 ML/day. As with Piccaninnie Ponds, a decline in measured flow has been observed since 1990 (Figure 9).

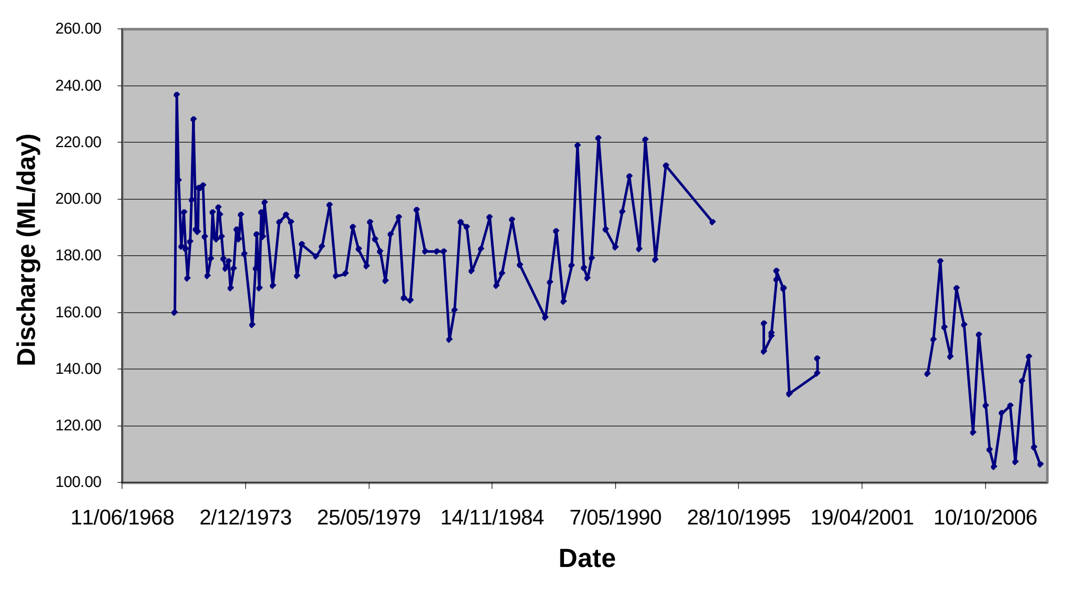


**Figure 9. Eight Mile Creek discharge**

### 2.1.3.4. Cress Creek and Jerusalem Creek

Cress Creek and Jerusalem Creek are both spring-fed creeks located 1–2 km east of Port Macdonnell. Cress Creek originates from one spring source (Figure 10) and drains along a constructed flow path approximately 1.2 km before discharging to the sea. Jerusalem Creek is an ephemerally spring-fed creek, traditionally fed by two spring sources (J1 and J2 on Figure 10). However, at the time of sampling, only J1 was feeding the creek. Not a great deal is known about Cress Creek or Jerusalem Creek, as very little data has been collected at either location in the past. Discharge data collected from Cress Creek since 2004 shows flow rates of ~5–20 ML/day, with a noticeable relationship between flow and monthly rainfall.

**Figure 10. Cress Creek and Jerusalem Creek**

Lithco (2003) measured major ion chemistry at Cress Creek outlet (point where the creek discharges to the sea) monthly from August 1998 to July 1999 and reported ion ratios akin to that of seawater, suggesting that seawater intrusion was influencing the chemistry of discharging groundwater. It should be noted, however, that EC ranged from 1469 µS/cm to 1711 µS/cm; hence, the amount of seawater intrusion would be minimal.

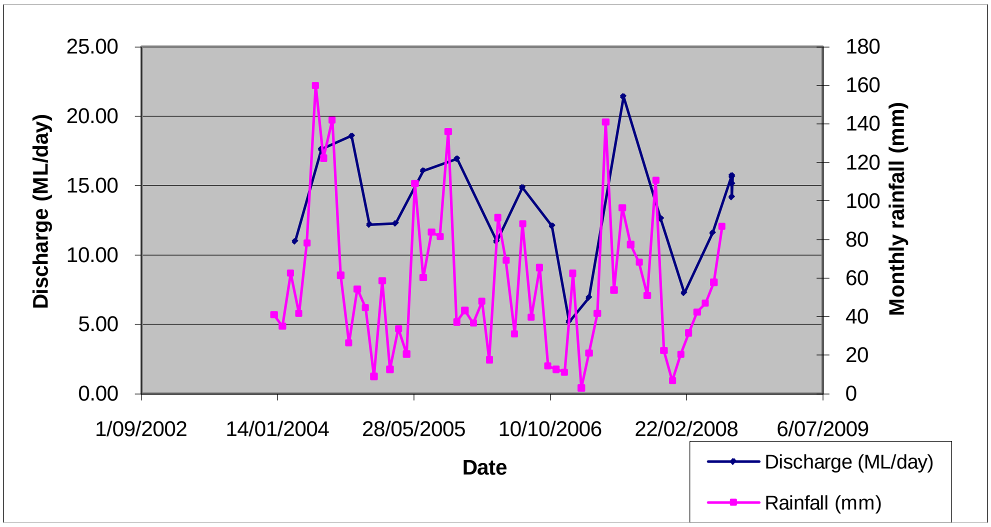


Figure 11. Cress Creek discharge and monthly rainfall measured at Mount Gambier

# 3. METHODOLOGY

Surface water and groundwater samples were collected at three separate times of the year over an 18-month period (August 2007, February 2008, October 2008). Piccaninnie Ponds was not sampled in October 2008, as sampling took place at this site in June 2008 to coincide with diving activities being conducted there. During each sampling round, a submersible Whale pump (approximately 10–15 m length) was used to pump water into specific sample bottles. At Piccaninnie Ponds, a 50 m extension was attached to the pump to aid sampling from the Chasm. At shallow sites, samples were collected from the edge of the water body or by wading through it. At the deeper sites (Ewens Ponds and Piccaninnie Ponds), a small boat was used to achieve better spatial coverage.

Samples for major ion analysis were pumped into 1 L bottles before being refrigerated. Samples for nitrate analysis were delivered to the laboratory within 1–2 days; however, this was not always possible. Samples for Rn-222 analysis were pumped into a 1.25 L PET bottle, sealed immediately, and the time recorded. Within 24 hours, radon was extracted from the PET bottles into a mineral oil, using the method described by Leaney and Herczeg (2006), and couriered to the CSIRO (Urrbrae) laboratory within 1–2 days. Samples for stable isotope analysis were collected in glass McArtney bottles and attempts were made to avoid getting any air bubbles in the bottles. Where bubbles were present, the bottles were stored upside down prior to being sent to the laboratory, to prevent any potential evaporation. Samples for chlorofluorocarbon analysis were collected by connecting nylon tubing to the discharge end of the submersible pump. Water was then pumped into a glass container, allowed to over-fill into a larger container, and the smaller glass container sealed under water. Samples were checked immediately for air bubbles, and discarded if bubbles were present. Where possible, field parameters (EC, pH, temperature, EH, DO) were measured in-situ, using a TPS multimeter that had been calibrated prior to commencing field work. A YSI multi-parameter Sonde was also used to assess vertical mixing in the deeper springs in this study (Ewens Ponds and Piccaninnie Ponds). This instrument was calibrated prior to use.

Measurements of stream discharge were also made at suitable points during sampling activities. These were made with either a propeller-type current meter or an acoustic Doppler-type meter. All laboratory and field measurement results are given in Appendix A.

# 4. RESULTS

## 4.1. PICCANINNIE PONDS

Sampling of surface water at Piccaninnie Ponds took place in February 2008 and June 2008. Figure 12 displays surface water chemistry in a Piper plot. As can be seen, the surface water at Piccaninnie Ponds is of Na-Cl type. A seasonal fluctuation in salinity similar to that observed by Scholz (1990) was observed, with higher total dissolved solids (TDS) in June (1730–2400 mg/L) than in February (1240–1510 mg/L). Rn-222 concentrations were higher in February (2.46–4.57 Bq/L) than in June (1.52–4.14 Bq/L, Figure 13).

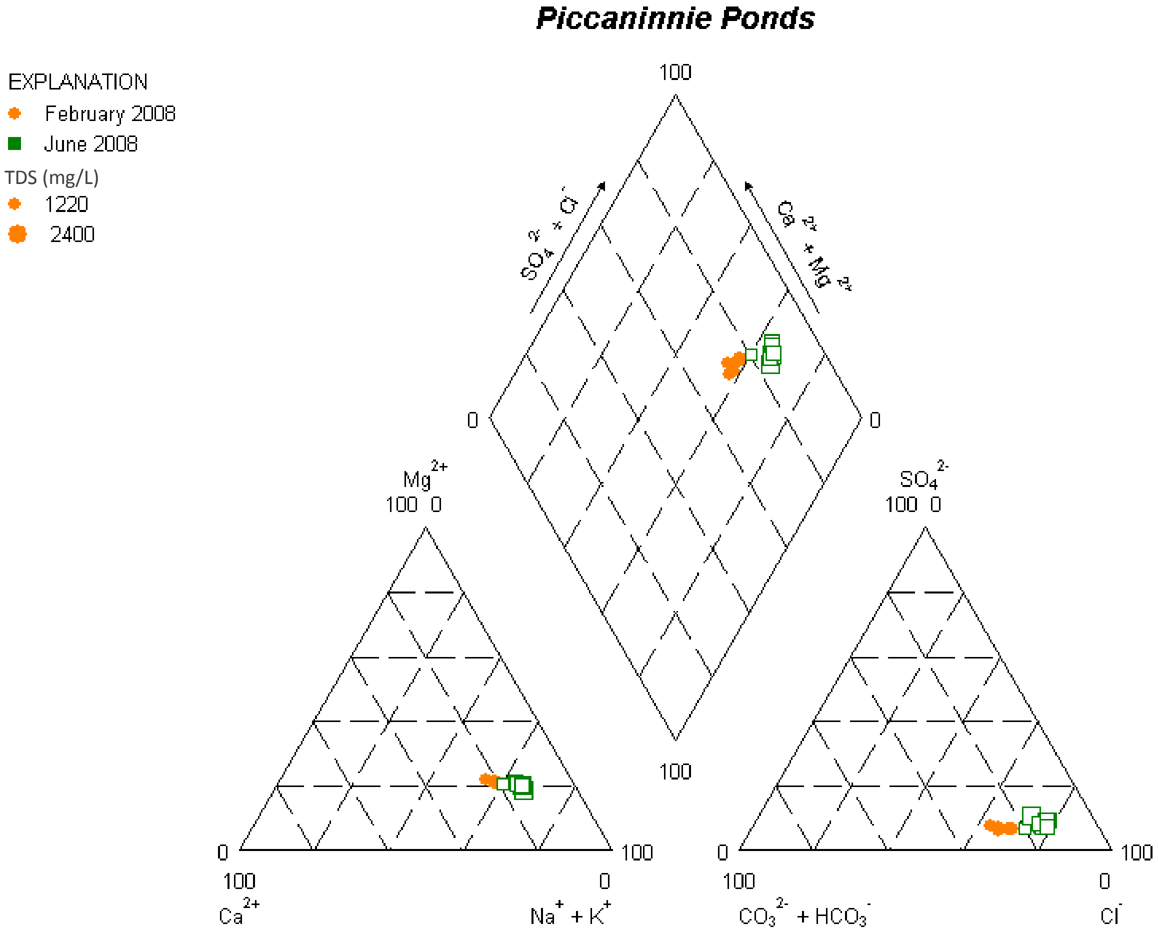


Figure 12. Piper plot of surface water chemistry at Piccaninnie Ponds

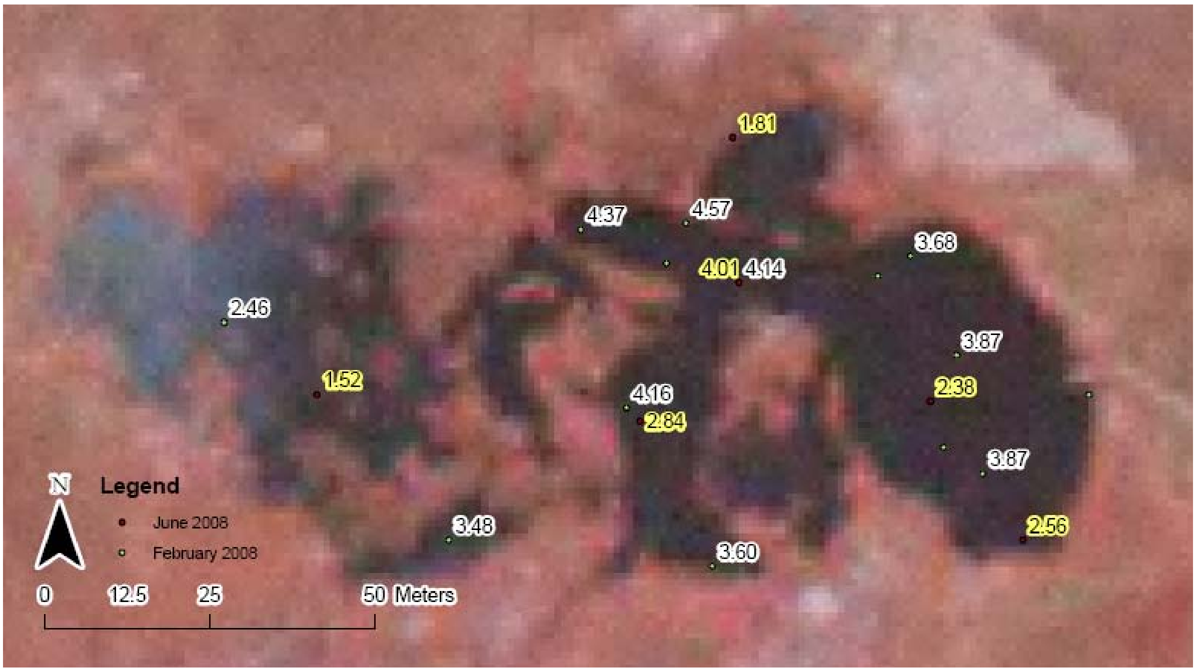


**Figure 13. Radon-222 (Bq/L) in surface water at Piccaninnie Ponds, white halo indicates February 2008 sampling and yellow halo indicates June 2008 sampling**

Radon-222 concentrations were highest in the surface water directly above the Chasm, suggesting that this is the location of most groundwater discharge into the Ponds. The processes of groundwater discharge in the Chasm were investigated in June 2008, when samples were collected using a pump down to 50 m in the Chasm. A further 'grab' sample was taken by divers at 110 m; however, given the small sample volume, only major ions could be analysed from this sample. Figure 14 shows the TDS (mg/L) from these samples in the Chasm, along with a Sonde profile from CAR011, an observation bore ~250 m east of the Ponds (note: the Sonde profile measured specific conductivity and has been converted to TDS for the sake of comparison using a conversion factor of 0.65). As can be seen, there is an increase in salinity in CAR011 at ~36 m, which corresponds with a change in hydrostratigraphy in the TLA (transition from a limestone unit to a marl unit, see Appendix B for geological log of CAR011). A similar increase can be seen in the Chasm; however, the change in salinity is not as abrupt as in CAR011. These types of profiles are similar to those observed in wells in fractured rock aquifers (Love et al. 2001) and are thought to be associated with zones where groundwater flow enters the well via fractures. Geophysical data from the Obswell CAR011—in particular, the neutron data—suggests that this transitional zone is more fractured than surrounding rock (J Lawson, pers. comm.) and is likely to be a zone of induced discharge (see Appendix B for neutron log of CAR011).

A further, more dramatic, increase in TDS is seen in the Obswell CAR011 between 80 m and 100 m depth, corresponding with a change from marl back to limestone. The sample collected at 110 m in the Chasm, however, does not show any great increase in salinity. This either means that there is no discharge from the lower units of the TLA into Piccaninnie Ponds or that results from the grab samples are incorrect. This is a possibility as sample containers had to be pre-filled before sampling at depth, due to pressure effects in deeper sections of the pond.

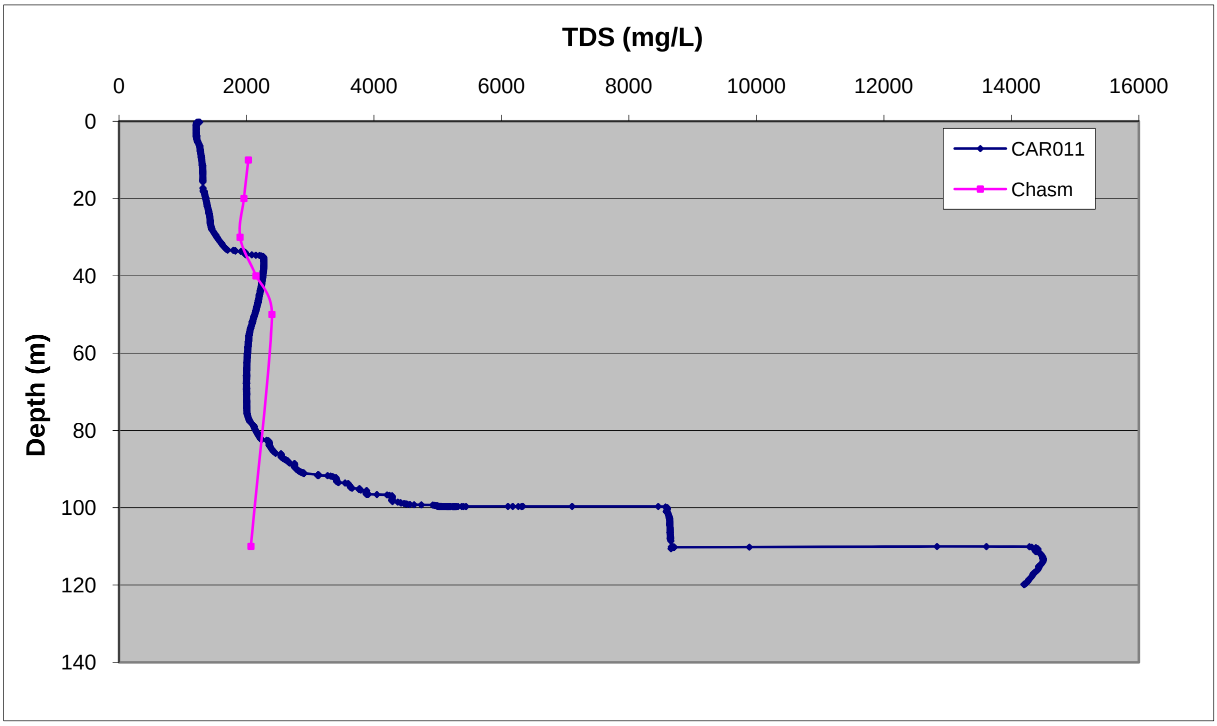


Figure 14. Total dissolved solids (mg/L) in the Chasm and in CAR011

Radon sampled with depth shows higher concentrations at 10 m depth and also at 40 m. This confirms that the transitional zone between 35 m and 40 m depth is a zone of greater groundwater discharge. However, the high concentrations at 10 m depth suggest high discharge at that location, as well.

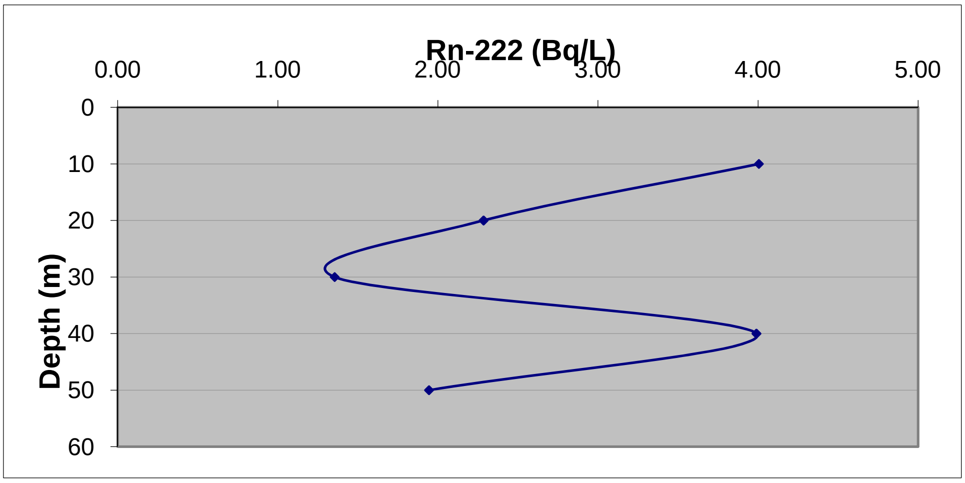


Figure 15. Radon-222 concentrations with depth in Piccaninnie Ponds

Judging from these results, it is most likely that groundwater discharge into Piccaninnie Ponds comes from the entire sequence of the open limestone in the Ponds; however, the presence of fracture zones means there are locations of higher discharge, as conceptualised in Figure 16.

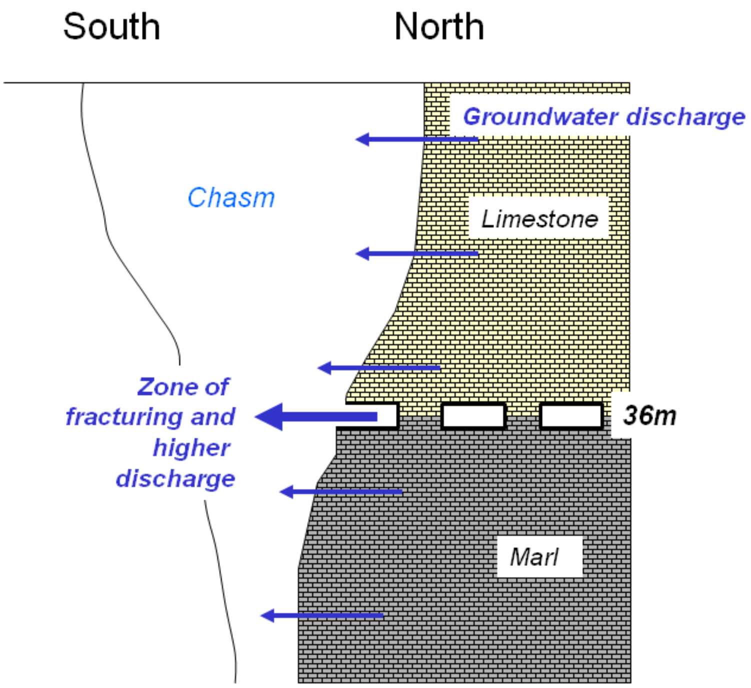


Figure 16. Conceptual model of groundwater discharge into the Chasm

Chlorofluorocarbons were sampled for at 10 m depth in the Chasm and results gave an age of 36 years. In other words, the groundwater discharging into Piccaninnie Ponds (at 10 m depth at least) in June 2008 was recharged around 1972. This correlates well with Allison and Holmes' (1973) data which suggested the groundwater discharging into Piccaninnie Ponds was more than 15 years old. Carbon-14 was also sampled for at this location and the concentration, when compared with other regional samples from previous studies, also shows the water to be 'relatively young.'

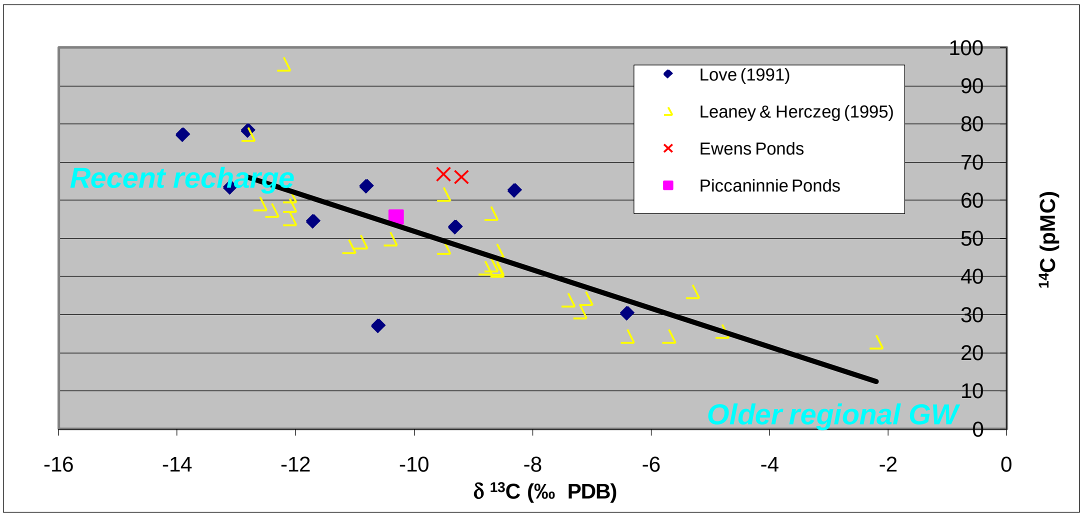


Figure 17. Carbon-14 isotope data from Piccaninnie Ponds and Ewens Ponds, compared with other regional TLA samples from previous studies (Leaney and Herczeg, 1995, and Love, 1991)

The seasonal relationship between higher salinity and lower Rn-222 (and vice versa) could be explained with Scholz's (1990) hypothesis of seasonal changes in chemistry in the Ponds. That is, in winter months, excess rainfall flushes stagnant surface water from the surrounding swamps into Piccaninnie Ponds. This inflow of more evaporated surface water increases the salinity in the Ponds. The inflow of surface water would also act to decrease Rn-222 concentrations in the Ponds (via dilution). In summer months, when surface water is not being flushed into the Ponds, there is no dilution of Rn-222; therefore, concentrations are higher. However, the inflow of more evaporated surface water into the Ponds would, in theory, also influence the stable isotope composition of surface water. That is, surface water in winter would become more enriched in stable isotopes, and start to plot away from the Mount Gambier Meteoric Water Line. As can be seen in Figure 18, however, there is very little seasonal variation in the stable isotope composition of surface water in Piccaninnie Ponds. This suggests that there may be another explanation for the seasonal change in salinity in Piccaninnie Ponds.

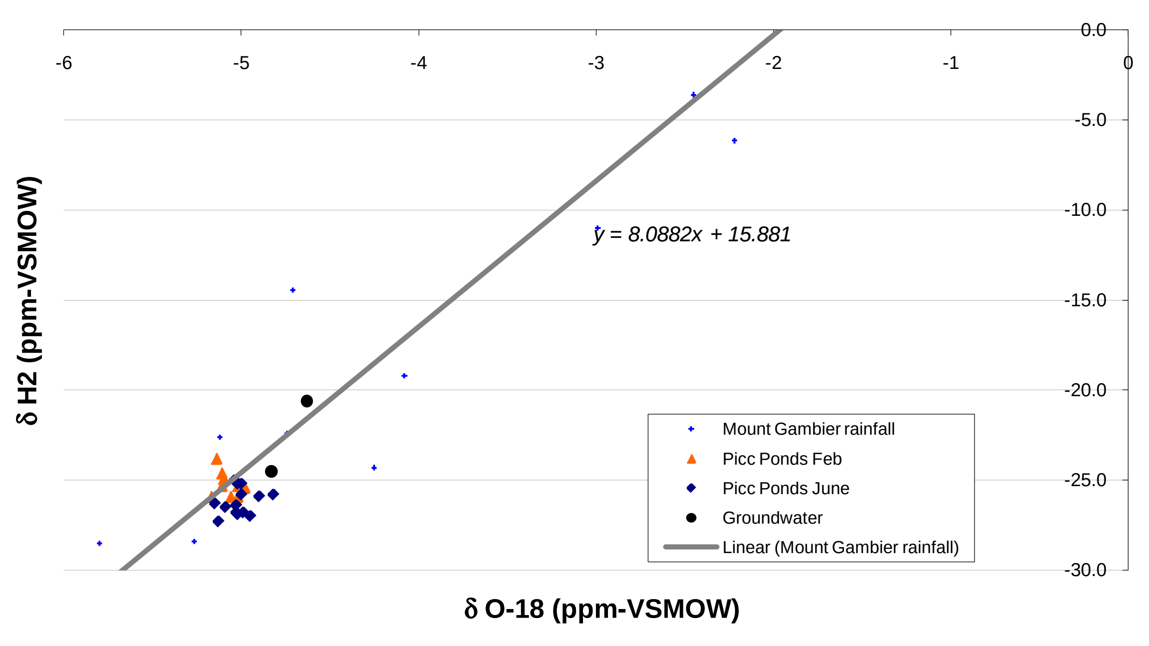


**Figure 18. Stable isotope composition of water in Piccaninnie Ponds**

Samples at the Piccaninnie Ponds Outlet creek ranged from 1220 mg/L in February to 1330 mg/L in June, which was generally fresher than the water in the Main Ponds. Clisby (1972) observed the same pattern and hypothesised that 'fresher', shallower springs exist in the western part of the Conservation Park, which also contribute to discharge at the Outlet. Indeed, lower salinity water, with $HCO_3$ as the dominant anion over Cl, was found to be flowing out of the western extent of the Conservation Park into Pick Swamp (TDS ~600–736 mg/L). Assuming the water at the Outlet is a mixture of water from the main ponds and water similar in composition to that flowing into Pick Swamp, Equations (1) and (2) can be used to estimate the proportion of discharge from the main ponds at the Outlet. Using Cl as the tracer, discharge at the Outlet was estimated to consist of 82% Main Ponds water and 18% fresher water in February, when discharge was lower. In June, flow from the Main Ponds was estimated to be 63% of discharge at the Outlet and 37% discharge from a fresher source. Discharge at the Outlet was not gauged in June; however, based on historical, seasonal trends, it can be assumed to be greater than that measured in February. A likely explanation for this pattern is that during wetter periods when there is more discharge, there is a greater proportion of flow from the shallower, fresher springs in response to seasonal water table rise in the shallower sub-units of the aquifer. This also correlates with discharge from the western extent of the Conservation Park into Pick Swamp, with higher discharge rates in winter months and low to no flow in summer months.

In summary, discharge into the Main Ponds of Piccaninnie Ponds is likely to be dominated by groundwater discharge from the Chasm, with discharge also occurring in the other Main Ponds. Based on vertical profiling of surface water and groundwater salinity, discharge seems to occur via lateral seepage out of the entire open section of limestone, rather than from a discrete spring source; however, there is likely to be more discharge at depths where there is a transition between hydrostratigraphic units, and associated fracturing in the aquifer. As a result of the apparent lack of a saline–freshwater interface in the Chasm, discharge is assumed to come primarily from the top two units of the Green Point Member. However, seasonal changes in surface water chemistry suggest a possible influence of seawater intrusion, which needs to be investigated further. Discharge also comes from unsurveyed springs or wetlands in the western portion of the Conservation Park. Based on changes in chemistry at the Piccaninnie Ponds Outlet, these groundwater discharge sites can be assumed to be fed by shallower, local groundwater and are strongly influenced by seasonal changes in the water table.

## *4.2. PICK SWAMP AND CRESCENT POND*

Pick Swamp and Crescent Pond were sampled in August 2007, February 2008 and October 2008. Figure 19 displays surface water ion chemistry on a Piper plot. It shows water dominated by Ca-$HCO_3$, with some samples trending towards Na-Cl type. The Ca-$HCO_3$ type water comes from the Crescent Pond spring and also the inlet from Piccaninnie Ponds Conservation Park. Given the Ca-$HCO_3$ signature, both sources are assumed to be fed by discharge from the TLA. The waters lying towards the centre and the right of the plot are from the more open surface water bodies. The two highest salinity data points that plot furthest to the right were from fringing areas of the eastern basin in February 2008 and reflect the influence of evaporation during summer.

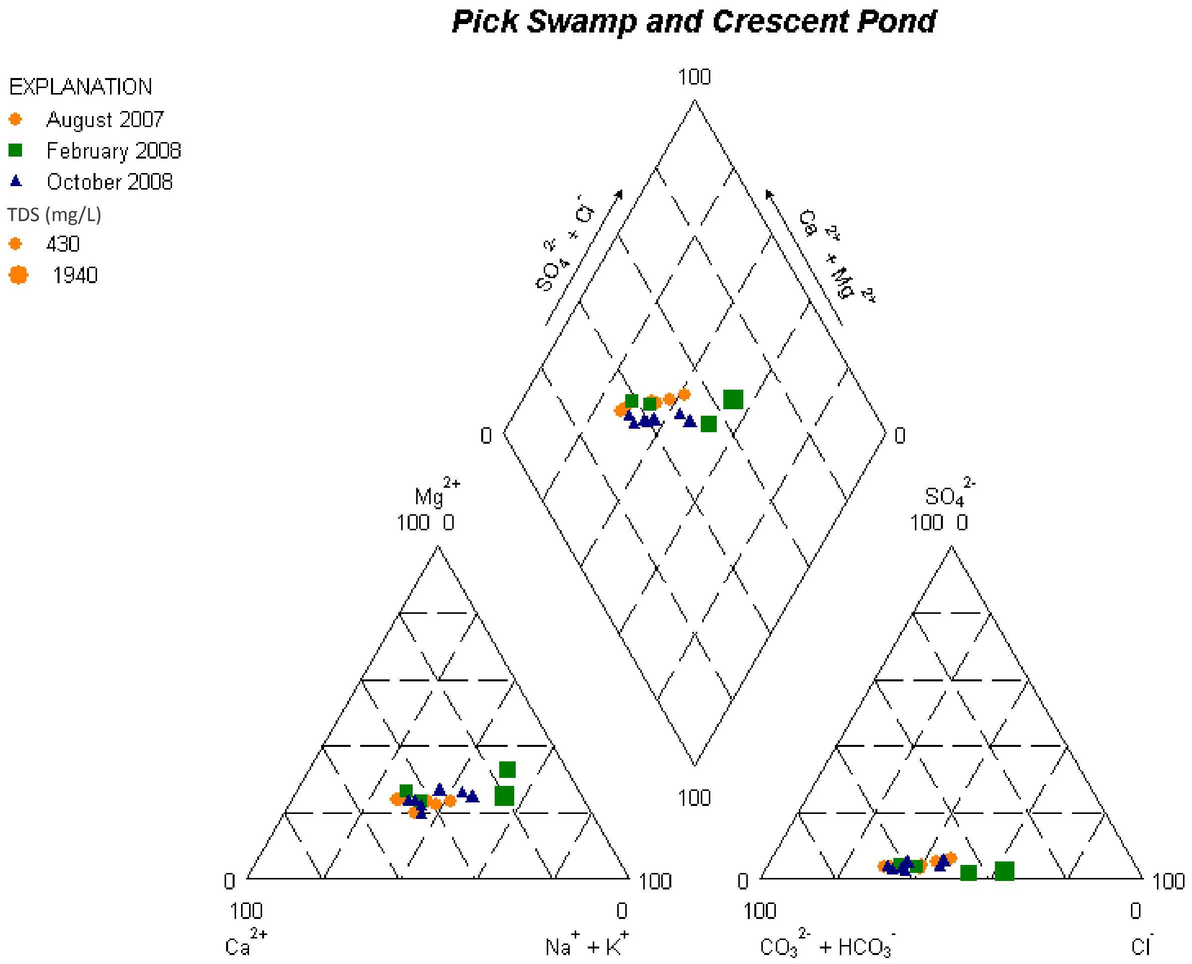


Figure 19. Piper plot of surface water chemistry at Pick Swamp and Crescent Pond

Figure 20 shows the spatial pattern of surface water Rn-222 (Bq/L) and Cl (mg/L). As can be seen, high Rn-222 and low Cl is observed in Crescent Pond. There is no significant seasonal variation in either tracer in Crescent Pond, suggesting a relatively constant rate of groundwater discharge (whereas variation in Rn-222 with variation in discharge is observed in Ewens Pond, see Section 4.3). A channel flowing out of the silky tea-tree area and into the basins had similar Cl concentrations to those of Crescent Pond but lower Rn-222, likely due to loss via gas exchange. Flow from Piccaninnie Ponds has high Rn-222 and higher Cl than that from Crescent Ponds. However, it is fresher than the water from the main ponds of Piccaninnie Ponds, and likely sourced from shallower springs in the western portion of Piccaninnie Ponds Conservation Park (see Section 4.1 for further discussion). Surface water in the eastern and western basins is characterised by higher Cl and lower Rn-222 than that found elsewhere, indicating that there is little or no groundwater discharge from the bottom or edges of the basins, and evaporation influences major ion concentrations. The influence of evaporation on water in the open basins can also be observed in Figure 21, which plots stable isotope composition of Pick Swamp and Crescent Pond water.

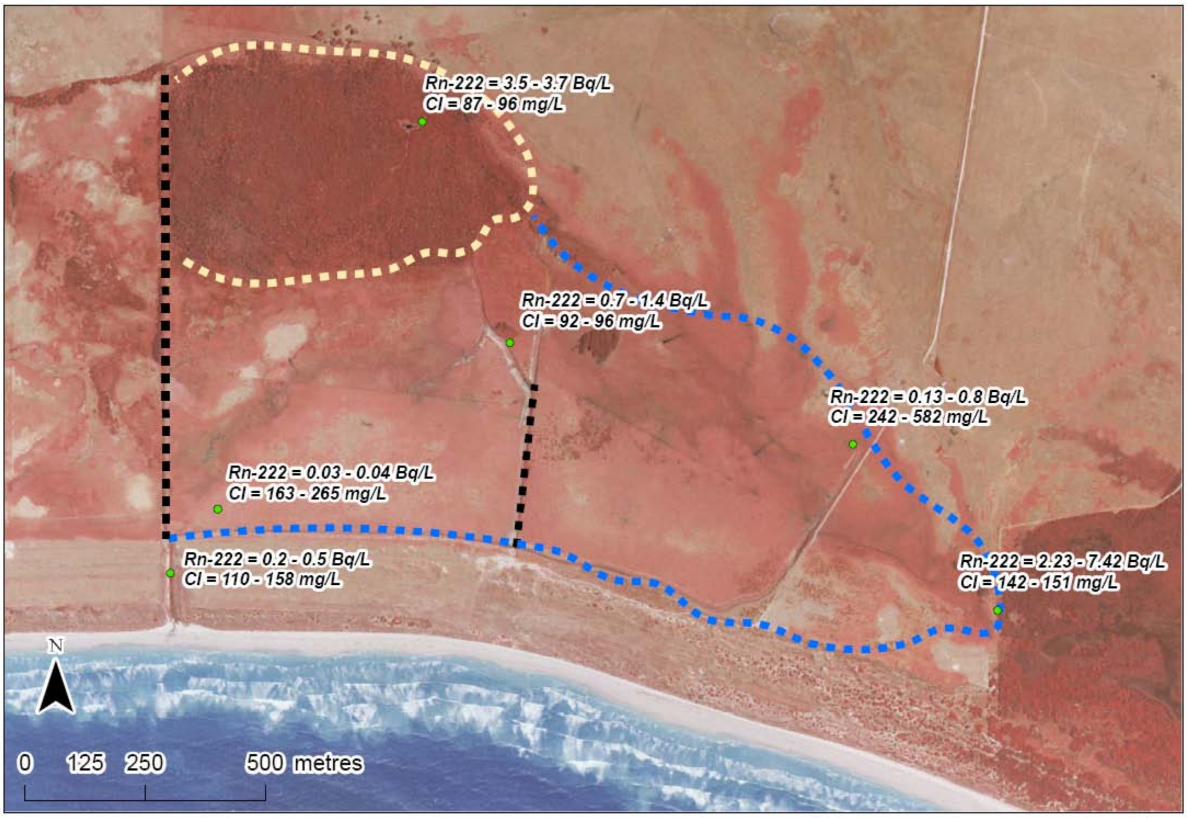


Figure 20. Spatial distribution of Rn-222 and chloride concentrations in Pick Swamp and Crescent Pond

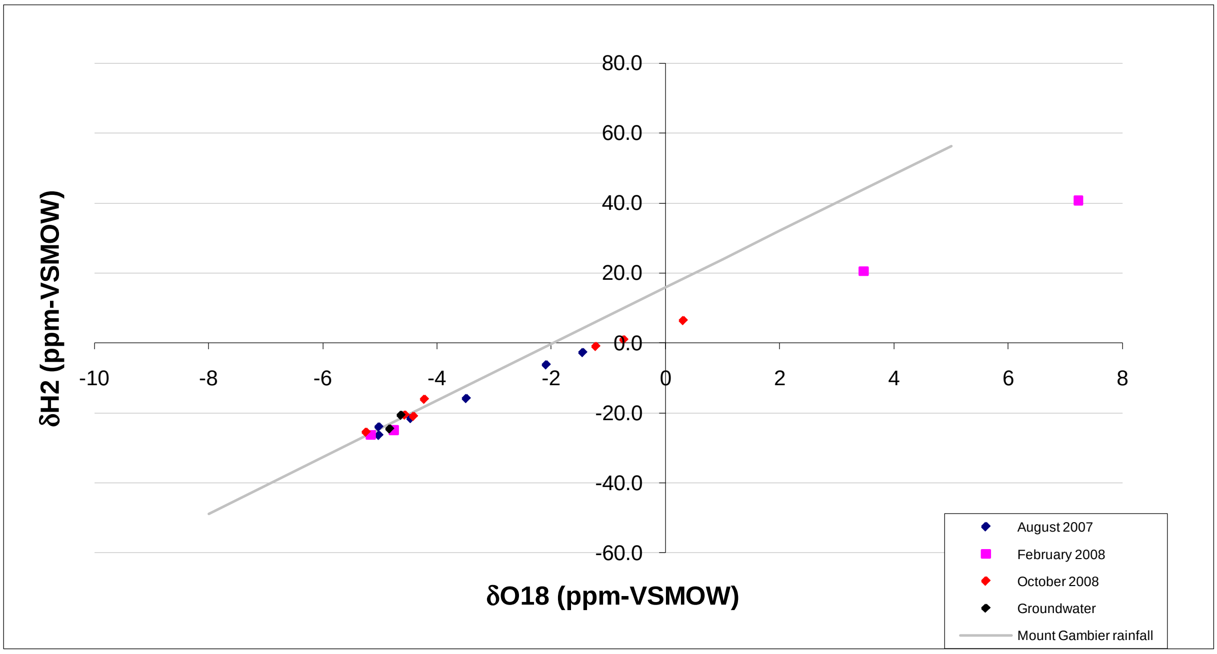


Figure 21. Stable isotope composition of surface water in Pick Swamp and Crescent Pond

In summary, the Pick Swamp wetland complex appears to be fed by continuous groundwater discharge from Crescent Pond and seasonal discharge from Piccaninnie Ponds Conservation Park. Given the difference in the size of the open basins in winter and summer, rainfall must also play a significant part in contributing water (and evaporation a large part in removing water from the system). Given that the system has only been in its current 'restored' condition since early 2007, further monitoring into the future will provide a better understanding of the controlling factors.

## *4.3. EWENS PONDS AND EIGHT MILE CREEK*

Ewens Ponds and Eight Mile Creek were sampled in August 2007, March 2008 and October 2008. Figure 22 shows a Piper plot from the August 2007 sampling. A pattern of progressive mixing from Ca-$HCO_3$ water towards Na-Cl is observed over the length of the system (this trend was observed on all occasions). The water in Ponds 1 and 2 shows Ca-$HCO_3$ dominance (reflecting regional groundwater); however, water in Pond 3 has a higher Na and Cl concentration, which gives the water flowing out in Eight Mile Creek a mixed signature. Spencers Pond has a strong Na-Cl signature, which makes the water downstream of the Spencers Pond inlet plot further away from the initial Ca-$HCO_3$ signature.

The difference in chemistry in the first two Ponds and Pond 3 was an unexpected find given the previous reports on water chemistry in Ewens Ponds (e.g. Hallam & Thurgate 1992; Lithco 2003). However, the pattern of higher salinity in Pond 3 was observed on all sampling occasions, as summarised in Table 1. Sonding was performed in Pond 1 and Pond 3 in February 2008 and revealed that while Pond 1 appeared well-mixed with regards to salinity (Figure 23), Pond 3 showed some stratification (Figure 24). The explanation for this is that the lower salinity water in the top metre of Pond 3 is the discharge from Ponds 1 and 2 flowing through, while the higher salinity water beneath is reflective of the discharge from Pond 3. The samples from Pond 3 were pumped from ~5 m to 6 m depth, over the top of the submerged cave. Given the similarity in water chemistry at depth, it is assumed that Pond 2 is as well-mixed as is Pond 1.

| **Location** | **Date** | **TDS (mg/L)** | **Cl (mg/L)** | **Rn-222 (Bq/L)** |
|---|---|---|---|---|
| Pond 1 | 29/08/2007 | 478* | 81 | 1.59 |
| Pond 2 | 29/08/2007 | 478* | 80 | 1.76 |
| Pond 3 | 29/08/2007 | 631* | 168 | 4.29 |
| | | | | |
| Pond 1 | 11/02/2008 | 510 | 72 | 2 |
| Pond 2 | 11/02/2008 | 496 | 77 | 2 |
| Pond 3 | 11/02/2008 | 730 | 193 | 3.4 |
| | | | | |
| Pond 1 | 09/10/2008 | 456 | 65 | 1.76 |
| Pond 2 | 09/10/2008 | 456 | 65 | 1.57 |
| Pond 3 | 09/10/2008 | 794 | 173 | 2.03 |

**Table 1. Measured total dissolved solids (TDS), Cl and Rn-222 in Ewens Ponds over the three sampling periods (* indicates TDS not measured but calculated from laboratory EC)**

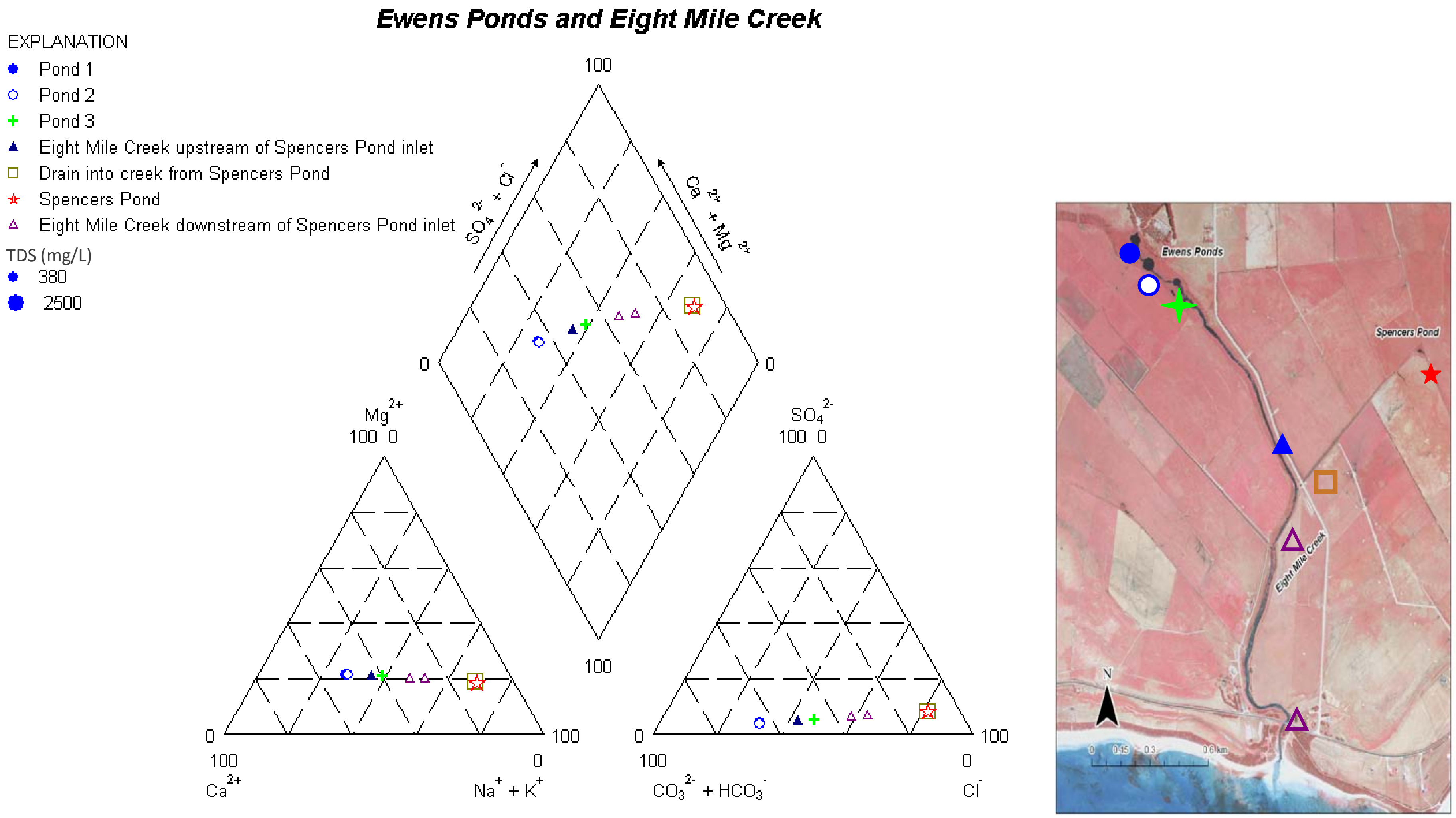


Figure 22. Piper plot of water chemistry in Ewens Ponds and Eight Mile Creek (locations shown on adjacent map)

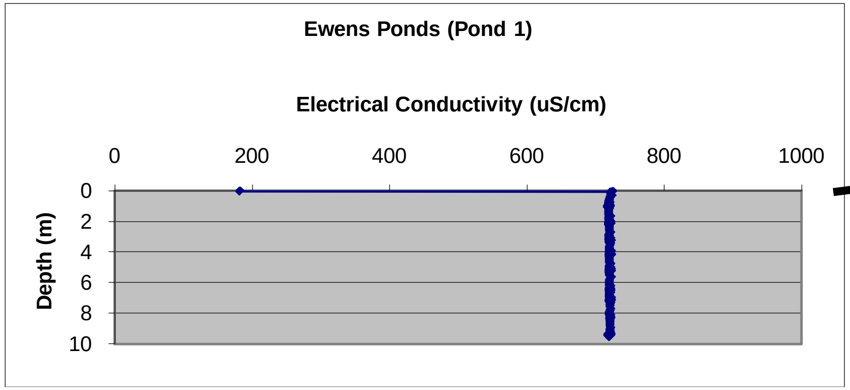


Figure 23. Sonde profile from Pond 1 of Ewens Ponds (February 2008)

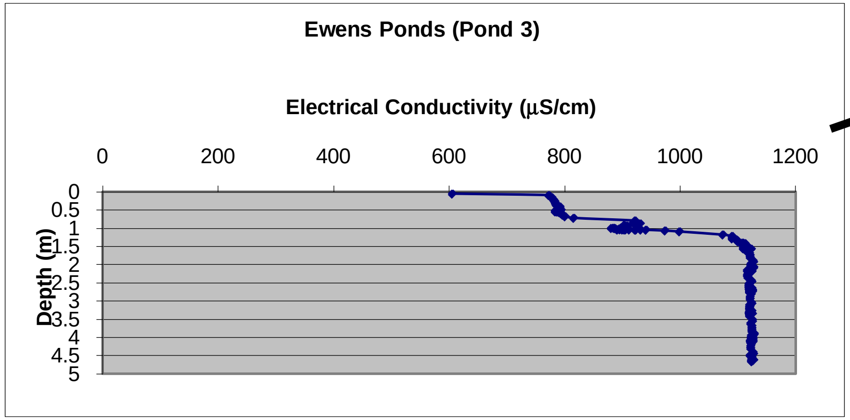


Figure 24. Sonde profile from Pond 3 of Ewens Ponds (February 2008)

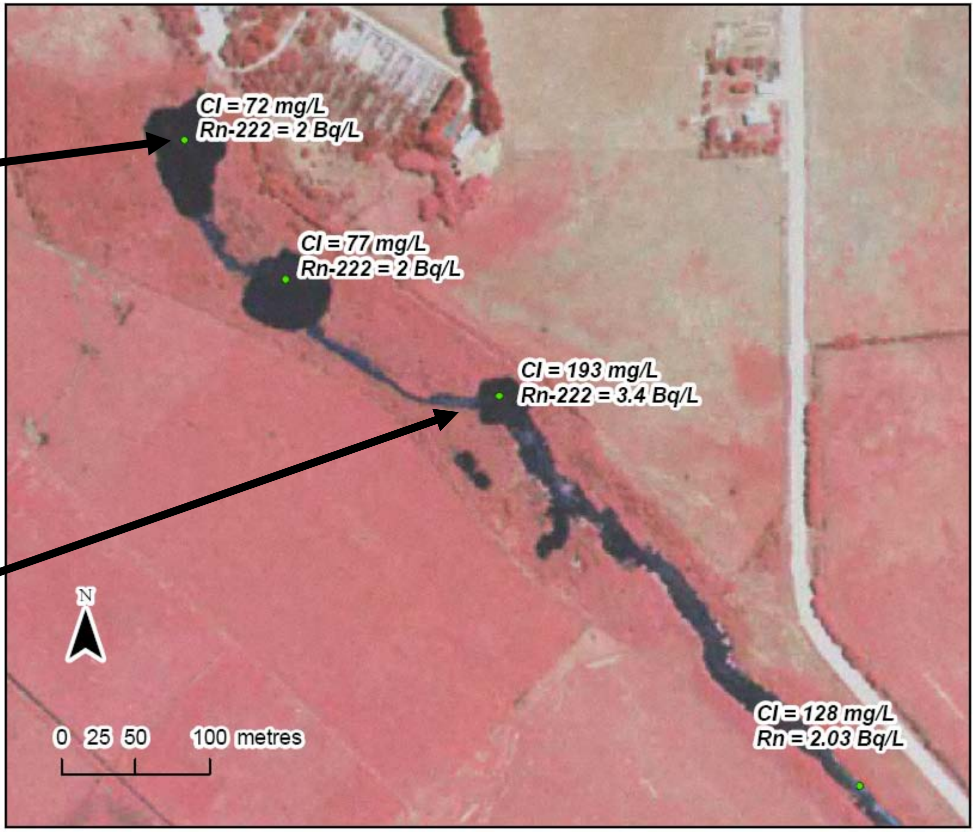
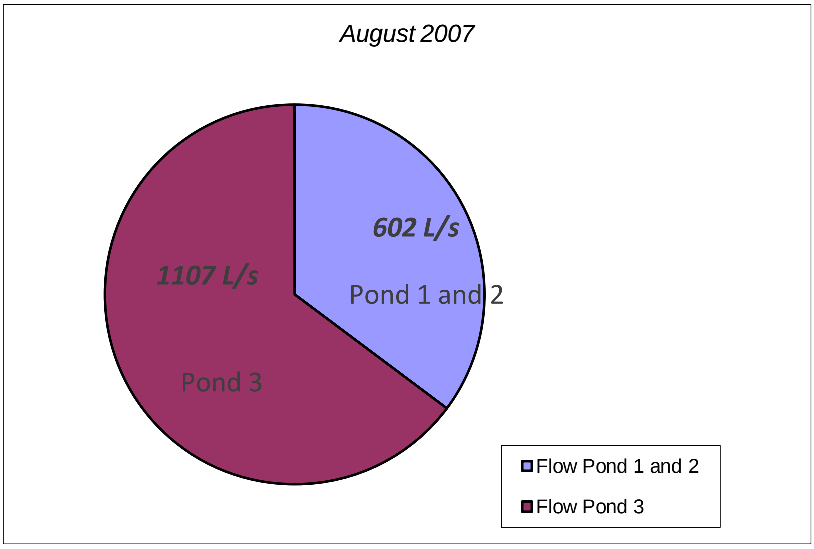
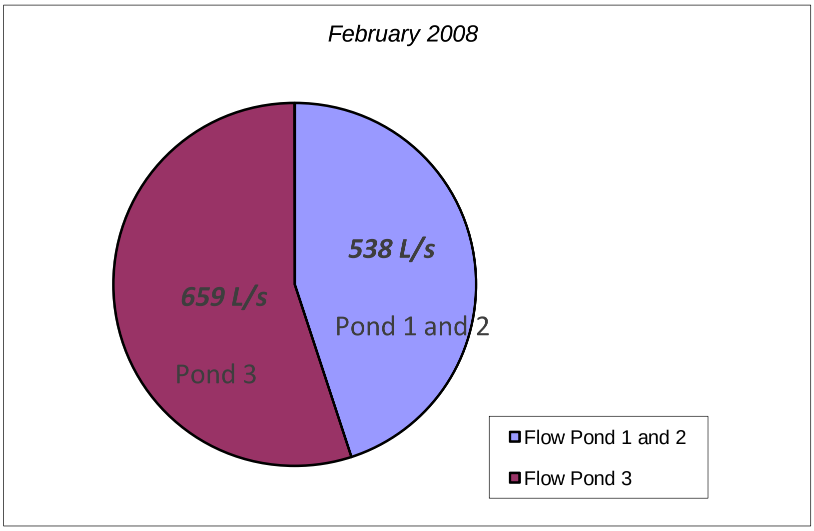


Figure 25. Chloride and radon-222 concentrations in Ewens Ponds (February 2008)

Rn-222 concentrations were also higher in Pond 3, suggesting that this is the location of most significant groundwater discharge (Figure 25). In order to determine the proportion of flow out of the Ponds, Ponds 1 and 2 were grouped together as one source of flow into Eight Mile Creek (given their similar chemistry) and Pond 3 as the second source. Using measured chloride concentrations in Equations 3 and 4, and stream gauging data upstream of the Spencers Pond inlet, it was estimated that ~65% of the flow in Eight Mile Creek in August 2007 came from Pond 3. For February and October 2008, flow from Pond 3 was estimated to be 55% and 51%, respectively (for these two occasions, stream flow was taken at the Eight Mile Creek outlet and flow from Spencers Pond inlet was gauged or estimated and subtracted from the total). This is summarised in Figure 26 and Table 2.





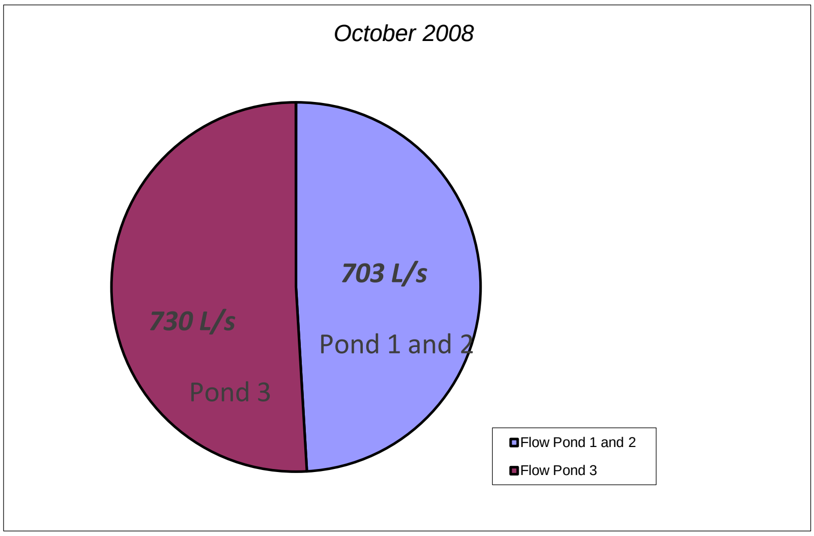


**Figure 26. Seasonal variation in discharge from the Ponds in Ewens Ponds**

| | *Aug-07* | *Feb-08* | *Oct-08* |
|---|---|---|---|
| **Flow Pond 1 and 2 (L/s)** | 602 | 538 | 703 |
| **Flow Pond 3 (L/s)** | 1107 | 659 | 730 |
| **Total from Ponds (L/s)** | 1709 | 1197* | 1433* |

**Table 2. Summary of discharge data from Ewens Ponds (*estimated by subtracting flow out of Spencers Pond inlet from total flow at Eight Mile Creek outlet)**

The difference in chemistry in Pond 3, given that all ponds are likely to be maintained pre-dominantly by groundwater, suggests there is a different source of groundwater for Pond 3, or at least some mixing with a groundwater body of different chemical composition. The Mg/Ca ratios for the three Ponds show consistently higher ratios in Pond 3, a function of increasing Mg concentrations rather than decreasing Ca concentrations (Table 3). This suggests a possible component of groundwater from the lower dolomite unit of the TLA (the Camelback Member) mixing with shallower groundwater and discharging into Pond 3.

| | *Ca (meq/L)* | | | *Mg (meq/L)* | | | *Mg/Ca* | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Aug '07** | **Feb '08** | **Oct '08** | **Aug '07** | **Feb '08** | **Oct '08** | **Aug '07** | **Feb '08** | **Oct '08** |
| **Pond 1** | 4.1 | 3.4 | 3.8 | 1.7 | 1.7 | 1.6 | 0.41 | 0.50 | 0.43 |
| **Pond 2** | 4.0 | 3.3 | 3.8 | 1.7 | 1.6 | 1.6 | 0.42 | 0.49 | 0.43 |
| **Pond 3** | 4.1 | 3.5 | 3.9 | 2.1 | 2.5 | 2.2 | 0.51 | 0.70 | 0.57 |

**Table 3. Mg/Ca ratios in Ewens Ponds**

The pattern of higher Rn-222, higher chloride, and higher estimated discharge in Pond 3 was observed on all sampling occasions (Figure 27). In August 2007, when flow was highest, Rn-222 was higher coming out of Pond 3 and chloride was slightly lower than in February and October 2008. A spike in chloride concentration is also observed where higher salinity water from Spencers Pond (TDS of 1790–2500 mg/L) drains in. This is most pronounced in August 2007 and October 2008. In February 2008, there was minimal flow out of Spencers Pond drain; hence, only a slight increase in chloride. The high salinity water in Spencers Pond is likely to be caused by groundwater discharge from the zone of higher salinity in this area identified by King and Dodds (2002). This also explains the correlation between seasonal variation in discharge and salinity shown in Figure 9. That is, when there is high discharge, and more water coming out of Spencers Pond drain, salinity increases in Eight Mile Creek. When there is less discharge, and less water coming from the drain into Eight Mile Creek, salinity is lower.

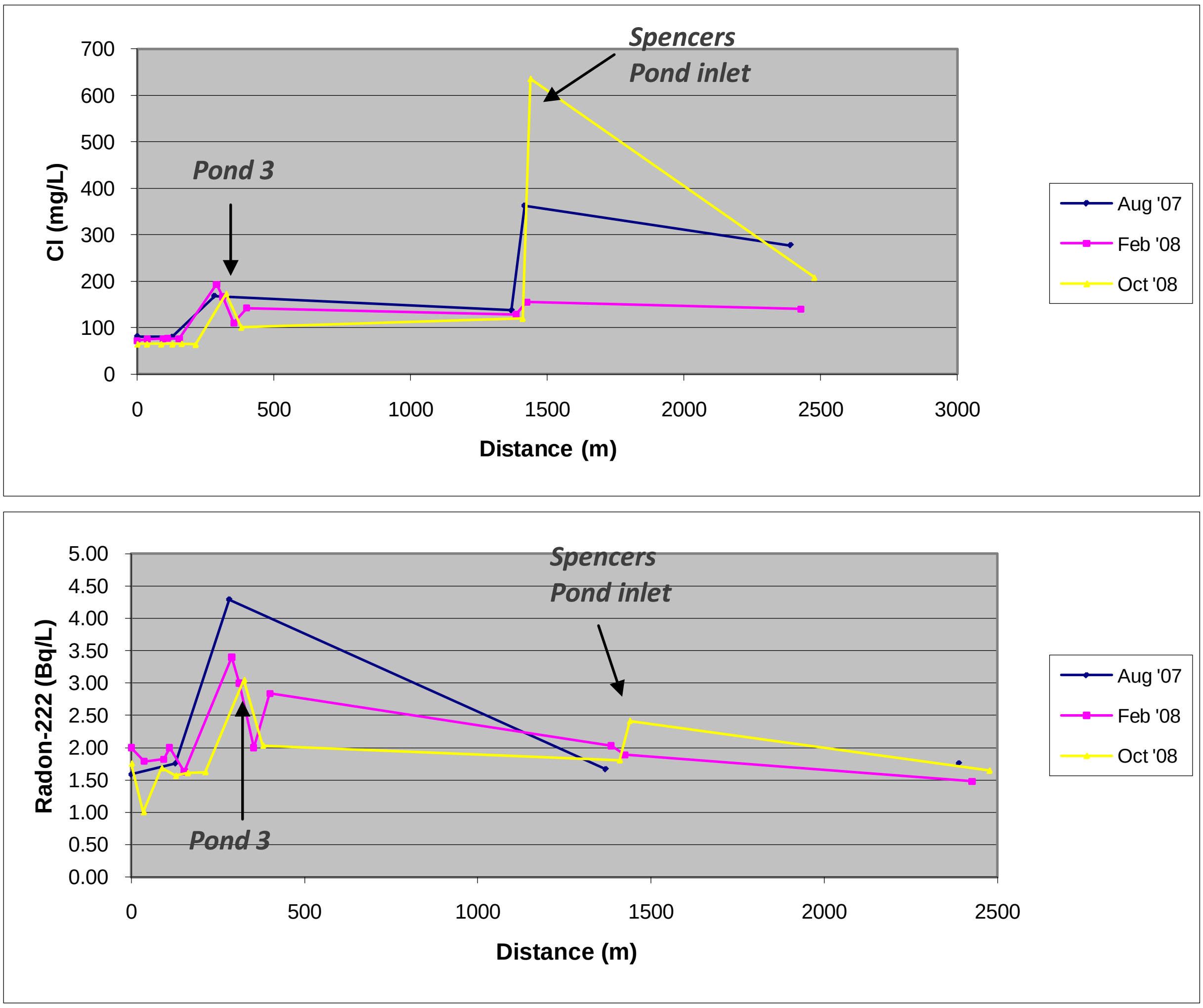


**Figure 27. Seasonal variation in chloride and radon-222 concentrations with distance along Ewens Ponds and Eight Mile Creek**

Figure 28 shows stable isotope data for Ewens Ponds and Eight Mile Creek. Samples from February and October 2008 plot close together and lie mostly on the LMWL for Mount Gambier. Samples from August 2007, however, tend to lie to the right of the LMWL, suggesting this water has undergone fractionation. A possible explanation for this is that the discharge into Ewens Ponds and Eight Mile Creek during the August sampling included a component of groundwater that had undergone some degree of evaporation prior to infiltration. Lakey and Krothe (1996) observed an enrichment in isotopic composition of spring discharge following a storm event in springs in Indiana and hypothesised that this could be due to enhanced discharge from the vadose zone (where, presumably, stored water had undergone some evaporation) or another source not identified. While the resolution of sampling and stream gauging is not detailed enough to draw any such conclusions in this case, this seems a likely explanation for Ewens Ponds, as groundwater levels up-gradient of the site tend to peak in between June and October, and flushing of shallow, slightly evaporated soil water is likely to occur.

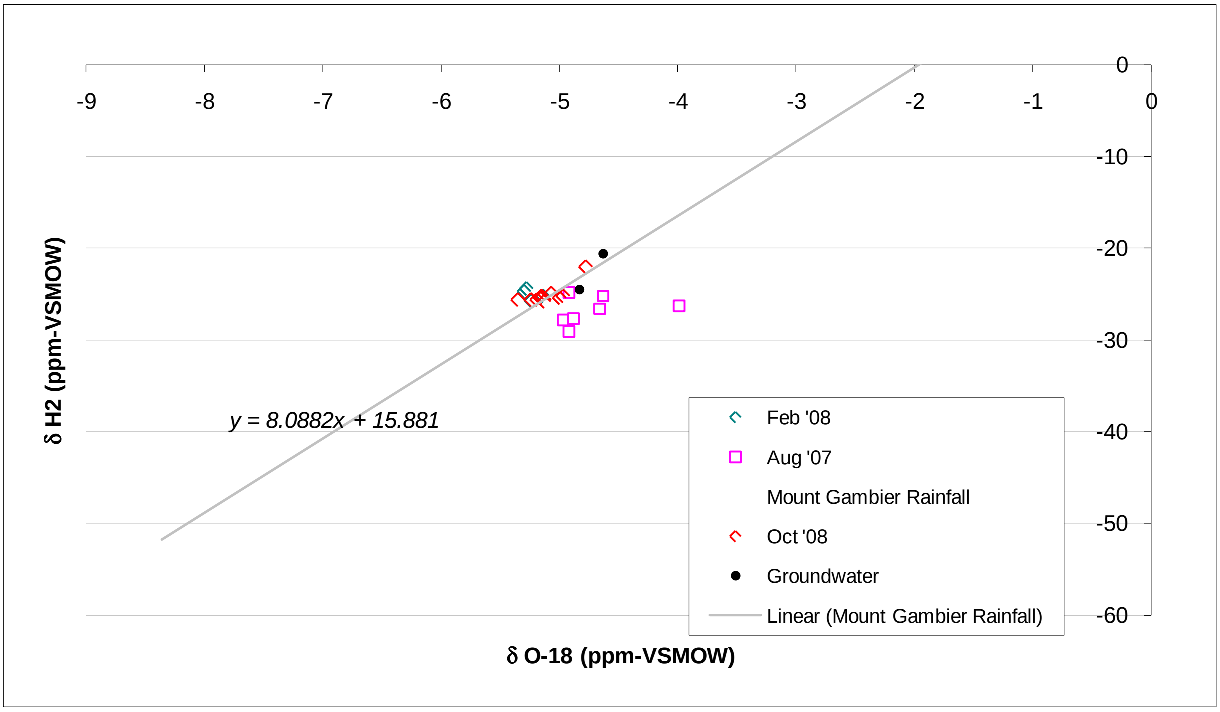


**Figure 28. Stable isotope data for Ewens Ponds and Eight Mile Creek**

Chlorofluorocarbons were sampled for in Pond 1 and Pond 3 in February 2008. CFC-12 analysis gave an age of 23 years. In other words, the groundwater discharging in both ponds in February 2008 was recharged around 1985. Carbon-14 results also show the groundwater discharge to be relatively 'young' groundwater (see Figure 18). As with Piccaninnie Ponds, this correlates with Allison and Holmes' (1973) data, which showed the groundwater discharge at Ewens Ponds to be at least 15 years old.

In summary, flow out of Ewens Ponds and into Eight Mile Creek appears to be dominated by flow out of Pond 3. During winter, when flow in Eight Mile Creek is highest, approximately 65% of the total discharge from Ewens Ponds comes from Pond 3. During drier periods, it is closer to a 50:50 mixture of discharge from Pond 3 and combined discharge from Ponds 1 and 2. Hydrochemical data indicates that this discharge from Pond 3 contains a component of water from the deeper dolomite sub-unit of the TLA—the Camelback Member. Judging from Mg/Ca ratios, the component of Camelback-derived groundwater in Pond 3 is greatest during low flow periods (i.e. during summer). In wetter periods, there seems to be less of a Camelback signature in Pond 3, which could be explained by the flushing of shallow TLA groundwater and soil water into the Ponds, diluting the higher Mg/Ca signature and enriching the stable isotope concentration. Further downstream, a drain from Spencers Pond contributes flow to Eight Mile Creek. Flow from this drain is ephemeral, with more flow during winter and less flow during summer. The water coming from Spencers Pond is also much higher in salinity than from Ewens Ponds, likely due to discharge from a previously identified saline pocket of groundwater in the area. This results in a seasonal flux in salinity at the Eight Mile Creek outlet that follows the seasonal flux in discharge (i.e. higher flow and higher discharge from Spencers Pond correlates with higher salinity at the Eight Mile Creek outlet).

## 4.4. CRESS CREEK AND JERUSALEM CREEK

### 4.4.1. CRESS CREEK

Samples were collected at Cress Creek in August 2007 and March 2008. Figure 29 shows a Piper plot of surface water chemistry in both Cress and Jerusalem Creeks. As can be seen, most surface water in Cress Creek is of a mixed Ca-Na-$HCO_3$-Cl type. The higher salinity, Na-Cl-type samples were collected close to the outlet and are likely influenced by seawater ingress into the Creek (at the time of the August sampling, there was a high tide, significant reverse flow, and a discharge rate could not be measured).

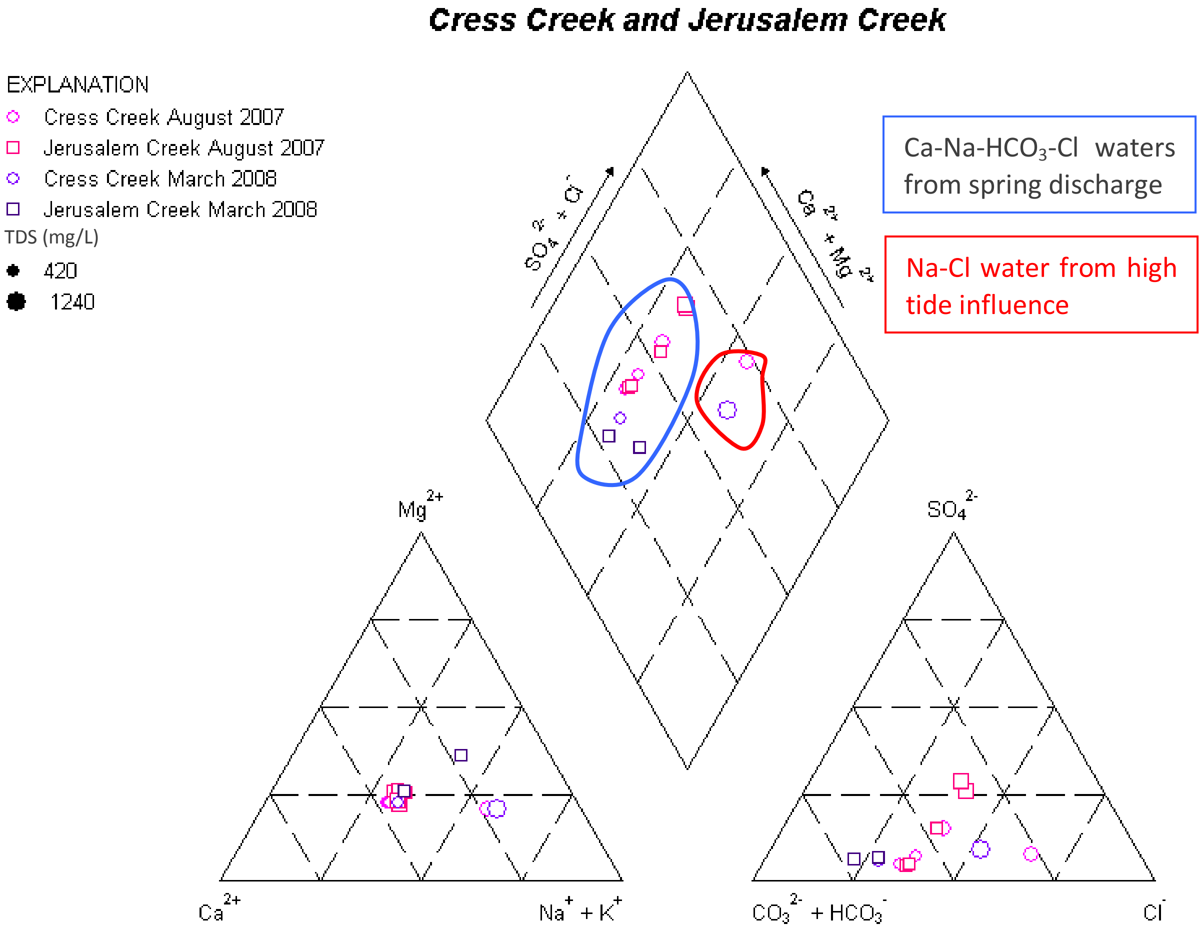


**Figure 29. Piper plot of surface water chemistry in Cress Creek and Jerusalem Creek**

Total dissolved solids (TDS) range from 430 mg/L to 1240 mg/L in Cress Creek. Table 4 gives the average ion ratios of Cress Creek water compared to that of seawater. As can be seen, the Na/Cl is similar to that of seawater, as one would expect given the proximity to the coast and subsequent rainfall chemistry. However, both the Mg/Cl and Ca/Cl ratios are far higher in Cress Creek than in seawater, reflecting the influence of water–rock interactions on the chemistry of the discharging groundwater (dissolution of carbonates).

| | Seawater* | Rainfall** | Cress Creek | Cress Creek outlet | Jerusalem Creek |
|---|---|---|---|---|---|
| **TDS (mg/L)** | ~35000 | 23 | 502 | 1000 | 600 |
| **Na/Cl** | 0.86 | 1.01 | 0.85 | 0.88 | 0.84 |
| **Mg/Cl** | 0.21 | 0.20 | 0.62 | 0.32 | 0.64 |
| **Ca/Cl** | 0.04 | 0.09 | 1.29 | 0.37 | 1.14 |
| **Ca/Mg** | 0.18 | 0.43 | 2.09 | 1.16 | 1.79 |
| **Cl/(HCO3+CO3)** | | | 0.68 | 2.40 | 0.87 |

**Table 4. Total dissolved solids (mg/L) and ion ratios (using meq/L) of Cress Creek and Jerusalem Creek compared to that of seawater and rainwater (* taken from Langmuir 1997 and ** Mount Gambier rainfall taken from Blackburn & McLeod 1983)**

Rn-222 concentrations in Cress Creek ranged from 1.86 Bq/L to 17.8 Bq/L in August 2007. Samples at the source spring were 5.88–6.06 Bq/L and decreased further downstream due to radioactive decay and gas exchange with the atmosphere (see Figure 32). Higher concentrations (17.8 Bq/L) occur upstream of the outlet, and are likely due to further spring input (Figure 32). High Rn-222 (22.3 Bq/L) was also observed at this location in March 2008. These Rn-222 concentrations are higher than those expected of groundwater discharge from a limestone aquifer. Herczeg et al. (1994) reported a mean concentration of 3.2 ± 3.2 Bq/L (maximum 15 Bq/L) for the Gambier Limestone, and samples collected as part of this study range from 1 Bq/L to 7 Bq/L. A peat/soil layer lining the creek (see Figure 30) may explain this apparent anomaly. Soils developed on top of carbonate rocks can be enriched in uranium, as the dissolution of $CaCO_3$ leaves behind such impurities (Gundersen et al. 1992). For example, Cook et al. (2008) reported Rn-222 concentrations in perched groundwater in sand, clay and peat soils overlying the Gambier Limestone of 8–38 Bq/L.

**Figure 30. Peat soil lining creek bed, a possible geological source for higher Rn-222 concentrations**

Figure 31 shows the stable isotope composition of Cress and Jerusalem Creek water in August 2007 and March 2008. As can be seen, all samples lie on or just to the right of the Mount Gambier Meteoric Water Line (MWL) and are relatively depleted with respect to seawater (where $\delta^2$H and $\delta^{18}$O are both zero).

This signature is typical of regional unconfined aquifer groundwater (Love 1991) and suggests very little evaporation prior to recharge.

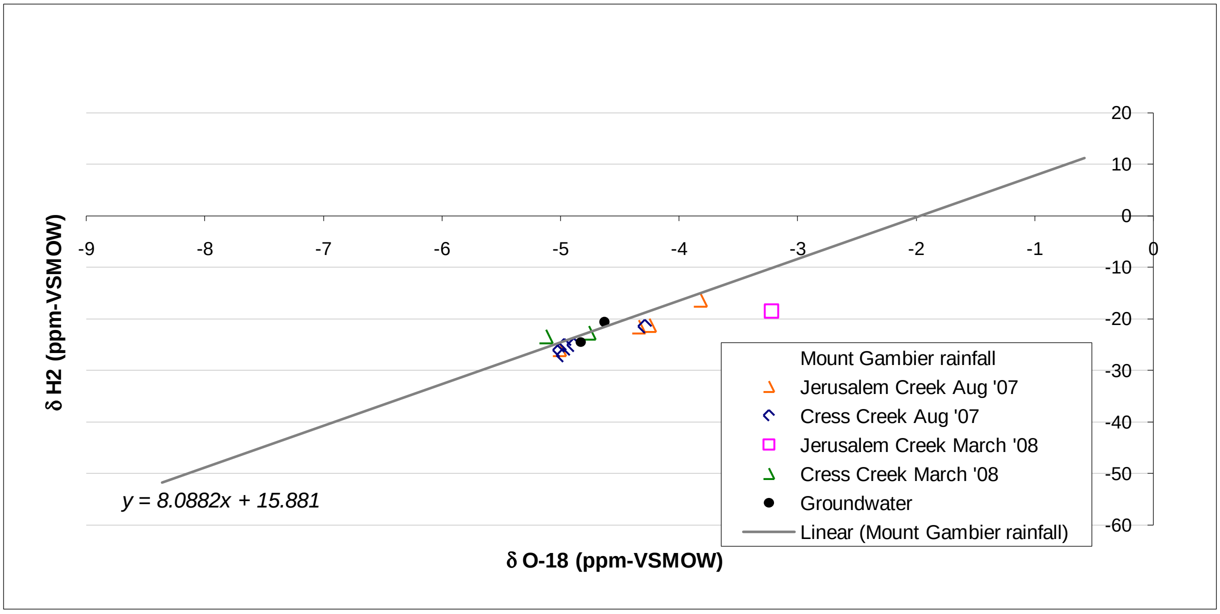


Figure 31. Stable isotope samples from Cress Creek and Jerusalem Creek

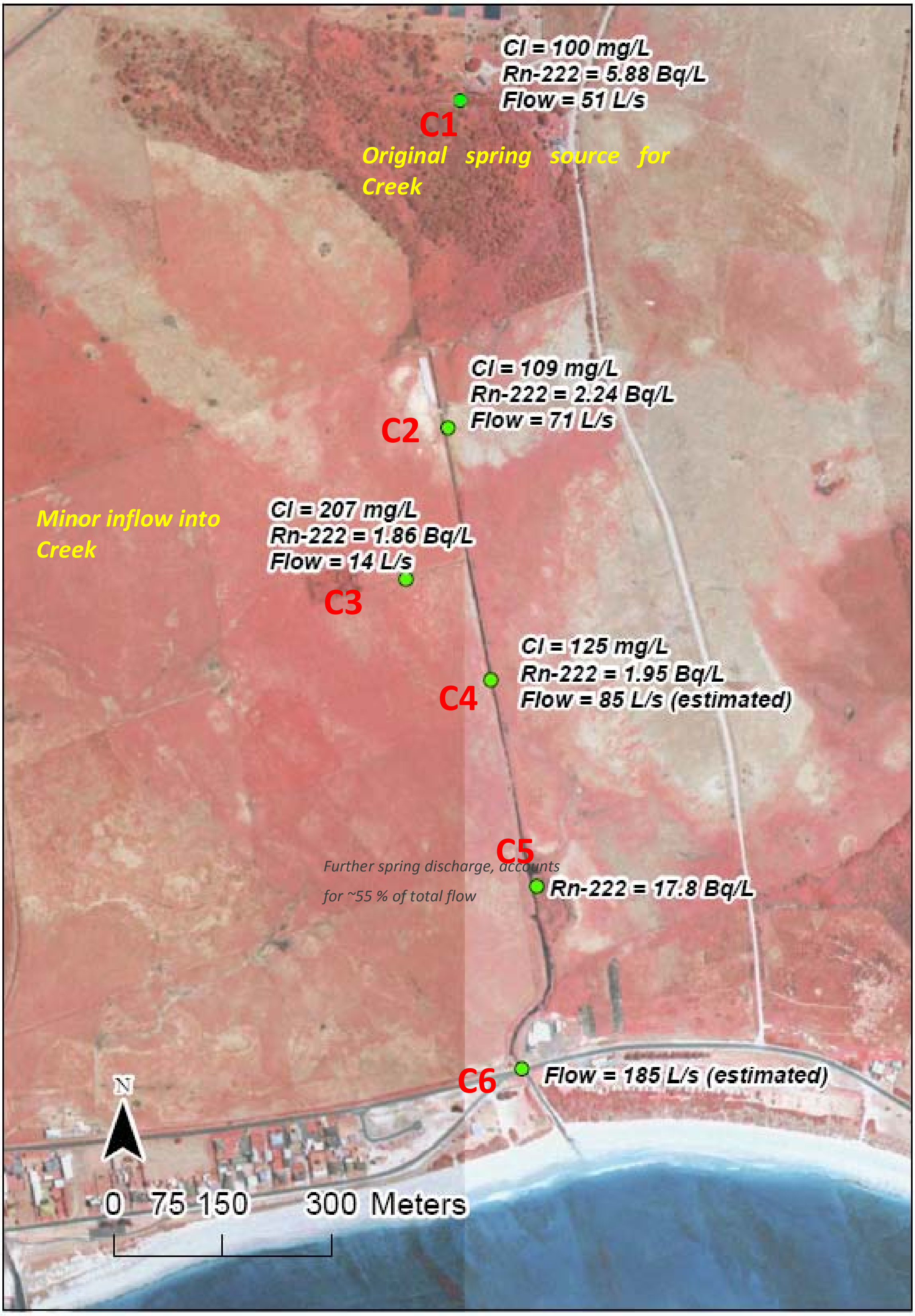


**Figure 32. Conceptual model of flow and tracer concentrations (from August 2007 sampling) in Cress Creek**

Figure 32 presents a conceptual model for flow in Cress Creek and associated tracer concentrations during the August 2007 sampling. Flow originates from the springs at point C1 and continues through a patch of native vegetation where further spring input is likely to occur. It then flows into the constructed drain, with Rn-222 concentration decreasing via gas exchange and decay. Further flow comes in at point C3 so that at point C4, the flow rate is increased to 85 L/s (estimated from chloride-mixing using Equations 3 and 4). Flow could not be measured at the outlet point C6 due to tidal influences; however, flow was measured at this point in July and November 2007. Assuming a linear decrease in flow rate between these months (following the observed seasonal trend), and interpolating between these points, flow at the time of sampling is estimated to be 185 L/s. Although this is a broad assumption to make, it means that groundwater discharge in between points C4 and C6 would need to be ~100 L/s, which helps explain the high Rn-222 concentration at point C5. Therefore, while Cress Creek is sourced from springs 1.5 km upstream, it is estimated that approximately 55% of the water that discharges to the coast comes from a spring relatively close to the outlet.

### 4.4.2. JERUSALEM CREEK

Jerusalem Creek was sampled at the same times as Cress Creek, August 2007 and March 2008. As can be seen from Figure 29, the ionic composition of the water in Jerusalem Creek is similar to that of Cress Creek. The stable isotope composition is similar, as well, except for one sample from March 2008, taken at the creek outlet, which shows isotopic enrichment, likely due to evaporation (at the time of sampling, the Creek outlet was almost dry and not flowing).

The ion ratios are somewhat different to Cress Creek (Table 4), Jerusalem Creek having, on average, a lower Ca/Mg ratio and higher $Cl/(HCO_3 + CO_3)$ ratio than Cress Creek. Given the ephemeral nature of the springs in Jerusalem Creek, a likely explanation for this is that Jerusalem Creek is fed by very shallow, local groundwater flow systems, which respond to seasonal fluctuations in the water table. As a result of this, the groundwater feeding Jerusalem Creek will have had a shorter residence time in the Tertiary Limestone Aquifer, and therefore less dissolved Ca and $HCO_3$, resulting in lower Ca/Mg and higher $Cl/(HCO_3 + CO_3)$ ratios.

Radon concentrations ranged from 1.7 Bq/L to 3.76 Bq/L in the Jerusalem Creek system. The highest concentration came from a small tributary 300 m upstream of the outlet (Figure 33). Although it had a high Rn-222 concentration, it was estimated (using chloride concentrations in Equations 3 and 4) that this tributary contributed only 3 L/s to Jerusalem Creek at the time of sampling (August 2007).

Figure 33 conceptualises the Jerusalem Creek system. As can be seen, most of the flow discharging to the sea originates from the spring at location J1. As mentioned earlier, the springs at J2 were not contributing to flow in Jerusalem Creek at the time of sampling. Further minor flow comes from a small tributary to the east of the Creek. Given the ephemeral nature of Jerusalem Creek and its ionic characteristics compared to Cress Creek, it can be characterised as a seasonally influenced creek fed by shallow, local groundwater.

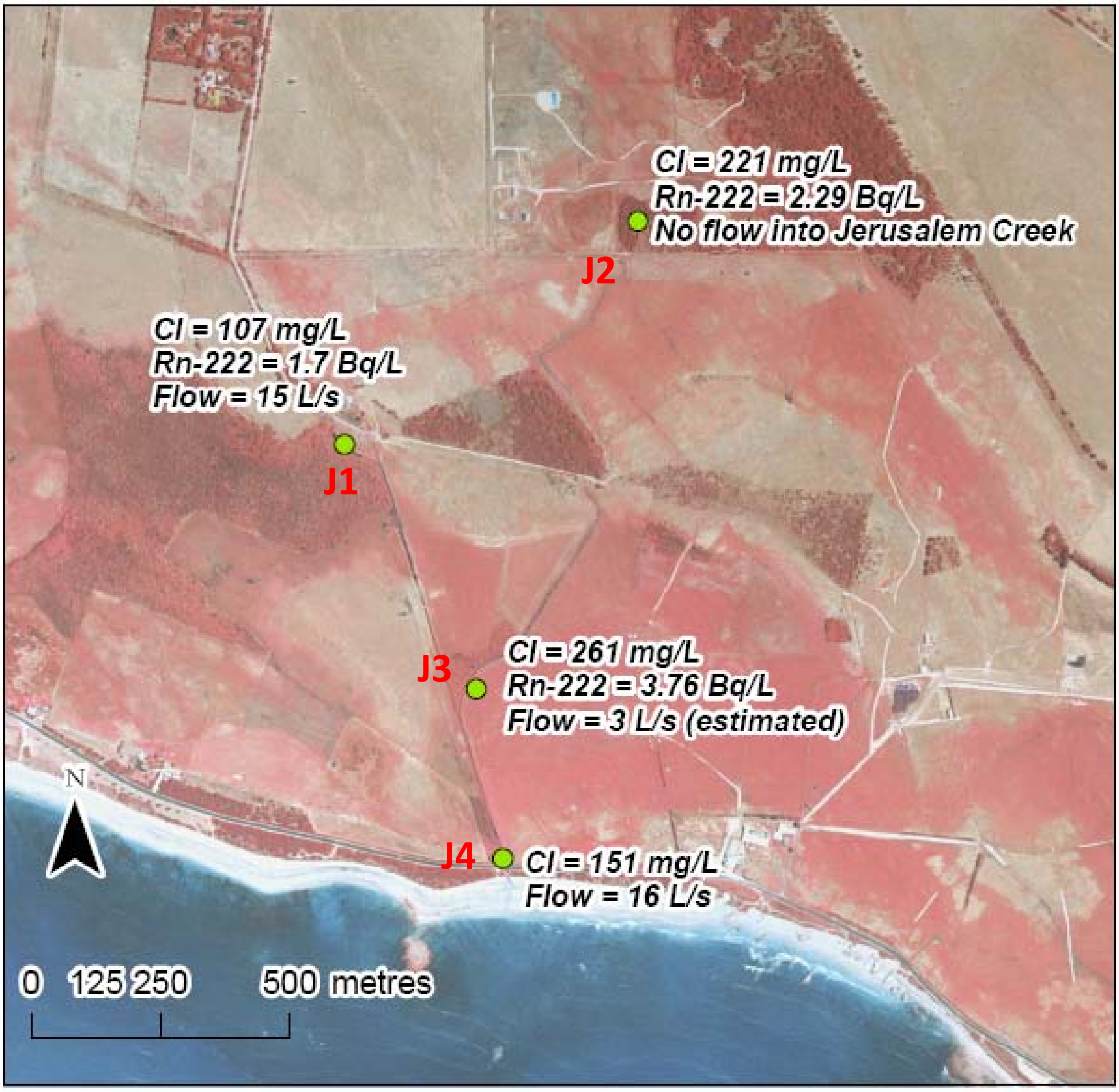


Figure 33. Conceptual model of flow and tracer concentrations (from August 2007 sampling) in Jerusalem Creek

# 5. MONITORING STRATEGY

## *5.1. SAMPLING ROUTINE*

The following section of the report outlines a strategy for ongoing monitoring of each site, including suggested sampling locations, analytes to sample for, and changes to look for into the future, summarised in Table 5. The sampling routine is intended to provide a basis on which to monitor these systems using chemistry and flow data, and may be used in the future to set target levels for management.

### 5.1.1. PICCANINNIE PONDS

Detailed sampling at Piccaninnie Ponds involves taking a small boat onto the water. As this is logistically difficult, time-consuming and involves numerous staff members, it is recommended that a simpler approach to monitoring the Ponds be adopted. As the relative seasonal changes in water chemistry in the First Pond are representative of those in the whole Main Ponds area, sampling from the First Pond will suffice. Sampling can be conducted from the pontoon and should be done using a submersible pump. The pump should be deployed at a depth of at least 2 m in the First Pond. Table 5 outlines all analytes that should be sampled. Sampling should be done at least quarterly. At the same time, Sonding of Obswell CAR011 should be conducted. Comparison of changes in the seawater/freshwater interface in CAR011, along with seasonal changes in salinity in the Main Ponds, may provide useful information on potential seawater intrusion. A sample should also be collected from the Outlet Creek. The difference in chemistry (particularly Cl concentration) between the First Pond and Outlet Creek, if analysed in conjunction with gauging data from Outlet Creek, will give useful information on the proportion of flow from the Main Ponds and the shallow western wetlands. Decline in water table and flow from the western wetlands may thereby be monitored. A sample should also be collected from the outlet into Pick Swamp, which can be considered representative of the western wetland water.

### 5.1.2. PICK SWAMP AND CRESCENT POND

Sampling at Pick Swamp should include assessing flow out of Crescent Pond, as well as monitoring the quality of water collecting in the basins. Based on this study, there is no seasonal change observed in the chemistry of Crescent Pond, particularly Rn-222 concentrations, suggesting continual groundwater discharge. Sampling into the future will provide information on changes in discharge from Crescent Pond (e.g. decreased Rn-222 concentrations will suggest a decrease in groundwater discharge). A high degree of evaporation over summer was observed in the basins; therefore, sampling in the future should focus on stable isotopes and ion chemistry to assess any long-term increases in salinity. Sampling should be conducted quarterly to capture seasonal changes.

### 5.1.3. EWENS PONDS AND EIGHT MILE CREEK

Like Piccaninnie Ponds, detailed sampling at Ewens Ponds requires the use of a boat. Ongoing monitoring, however, does not require this. Quarterly sampling should include a pumped sample from the pontoons in Ponds 1 and 3. The pump should be deployed at a depth of at least 2 m, to ensure a representative sample is obtained. Samples should also be collected upstream and downstream of the Spencers Pond inlet, from the Spencers Pond inlet itself, and at the Eight Mile Creek outlet where flow is gauged. If flow is gauged, and samples collected from the abovementioned locations, it will be possible to assess the proportion of discharge from Ponds 1 and 2 (combined) and Pond 3 using the chloride-mixing equation outlined in Section 1.4.1. Ongoing monitoring of this discharge will provide useful information on how the system responds to changes in groundwater availability in the future and may support management intervention to ensure flows are maintained in Ewens Ponds.

### 5.1.4. CRESS CREEK

Quarterly monitoring at Cress Creek should involve sampling of the springs at the beginning of the Creek, sampling of the downstream spring with high radon concentrations that feeds ~55% of discharge, and sampling at the outlet (where gauging takes place). While scant sampling was done at Cress Creek as part of this study, it is believed that ongoing monitoring of radon and ion concentrations, in conjunction with stream-gauging, will yield important information on the change in flow in this shallow, ephemeral system over time.

### 5.1.5. JERUSALEM CREEK

Since most of the flow in Jerusalem Creek seems to originate from one spring, sampling should be conducted at the origin spring and at the creek outlet. Monitoring should also involve sampling of the springs that no longer feed Jerusalem Creek. Like Cress Creek, not a great deal of data was collected at Jerusalem Creek as part of this study; however, it is important to monitor this site into the future. Given their shallow, ephemeral nature, both creeks have a higher risk of receiving reduced flow or potentially going dry for longer periods of the year as a result of water table decline in the future.

## *5.2. TESTING OF MONITORING STRATEGY*

In March 2009, sampling took place at Ewens Ponds and Eight Mile Creek to test the adequacy of the proposed monitoring strategy. This site was targeted for testing to see if sampling off the pontoons at the Ponds, as opposed to sampling from a boat, would give meaningful results. Sampling took place at the locations specified in Section 5.1.3. Figure 34 shows the results of Cl and Rn-222 analysis from these samples, compared with results from the more detailed sampling in October 2008. While the values are not identical (not that they are expected to be), the trends are the same. That is, Rn-222 and Cl concentrations increase in Pond 3 and also at the point into which Spencers Pond drains. These results show that the monitoring strategy proposed for Ewens Ponds and Eight Mile Creek adequately captures the trends in water chemistry that are required to make assessments on the hydrogeological behaviour of the system.

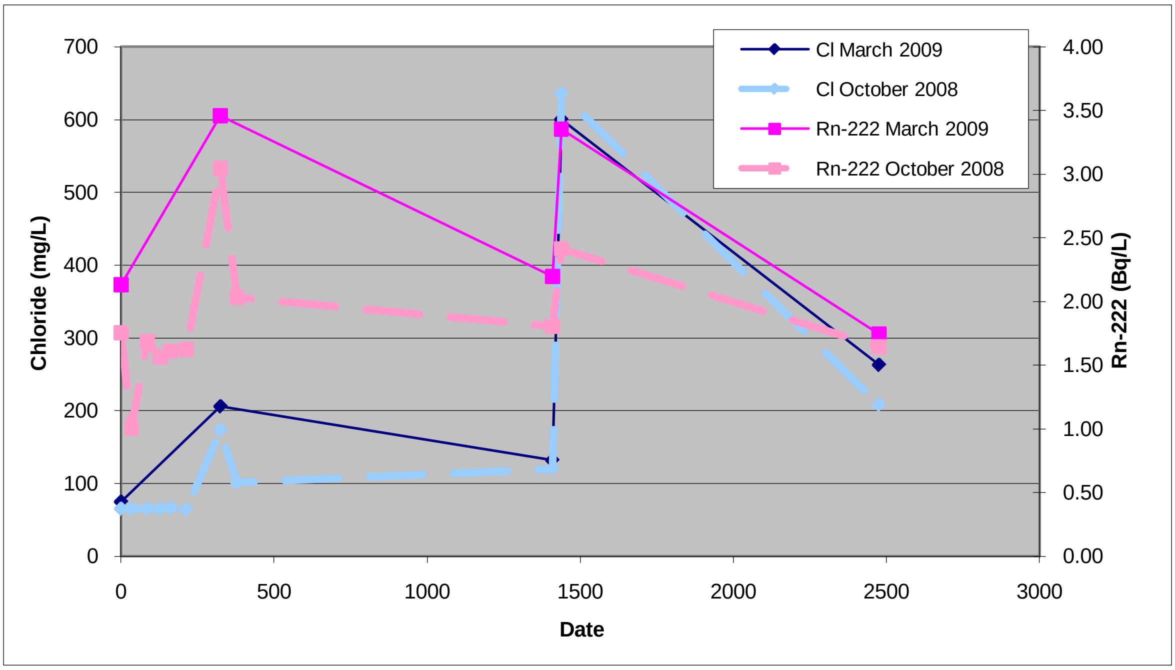


**Figure 34. Comparison of March 2009 'monitoring strategy' results (solid lines) with October 2008 'detailed sampling' results (dashed line)**

| **Piccaninnie Ponds** | | |
|---|---|---|
| **Analyte** | **Trends to observe** | **Location** |
| Major cations (Ca, Na, Mg, K) | Increased concentration in winter | First Pond, Outlet Creek, outlet to Pick Swamp |
| Major anions (Cl, HCO3, SO4, NO3) | Increased concentration in winter | First Pond, Outlet Creek, outlet to Pick Swamp |
| Total dissolved solids (ideally logged EC) | Increased concentration in winter | First Pond, Outlet Creek, outlet to Pick Swamp |
| Radon-222 | Decreased concentration in winter | First Pond, Outlet Creek, outlet to Pick Swamp |
| Oxygen-18 and deuterium | Possible enrichment in winter | First Pond, Outlet Creek, outlet to Pick Swamp |
| | | |
| **Ewens Ponds/Eight Mile Creek** | | |
| **Analyte** | **Trends to observe** | **Location** |
| Major cations (Ca, Na, Mg, K) | Increases in 3rd pond and Spencers | Ponds 1 and 3, Eight Mile Creek |
| Major anions (Cl, HCO3, SO4, NO3) | Increases in 3rd pond and Spencers, Cl used to assess proportion of flows | Ponds 1 and 3, Eight Mile Creek |
| Total dissolved solids (ideally logged EC) | Increases in 3rd pond and Spencers | Ponds 1 and 3, Eight Mile Creek |
| Radon-222 | Increases in 3rd pond and Spencers | Ponds 1 and 3, Eight Mile Creek |
| Oxygen-18 and deuterium | Possibly more enrichment in higher flow periods | Ponds 1 and 3, Eight Mile Creek |
| | | |
| **Pick Swamp** | | |
| **Analyte** | **Trends to observe** | **Location** |
| Major cations (Ca, Na, Mg, K) | Increase in basins (rising salinity), no change in Crescent Pond (constant discharge) | Crescent Pond, basins |
| Major anions (Cl, HCO3, SO4, NO3) | Increase in basins (rising salinity), no change in Crescent Pond (constant discharge) | Crescent Pond, basins |
| Total dissolved solids (ideally logged EC) | Increase in basins (rising salinity), no change in Crescent Pond (constant discharge) | Crescent Pond, basins |
| Radon-222 | Any decrease in concentration, indicating reduced discharge | Crescent Pond |
| Oxygen-18 and deuterium | Enrichment in basins (evaporation), no change in Crescent Pond | Crescent Pond, basins |
| | | |
| **Cress Creek** | | |
| **Analyte** | **Trends to observe** | **Location** |
| Major cations (Ca, Na, Mg, K) | Changes in concentration (potential influence of shallow recharge) | Springs at creek origin, spring upstream of outlet |
| Major anions (Cl, HCO3, SO4, NO3) | Changes in concentration (potential influence of shallow recharge) | Springs at creek origin, spring upstream of outlet |
| Total dissolved solids (ideally logged EC) | Changes in concentration (potential influence of shallow recharge) | Springs at creek origin, spring upstream of outlet |
| Radon-222 | Reduced concentrations indicating reduced flow | Springs at creek origin, spring upstream of outlet |
| | | |
| **Jerusalem Creek** | | |
| **Analyte** | **Trends to observe** | **Location** |
| Major cations (Ca, Na, Mg, K) | Changes in concentration (potential influence of shallow recharge) | Origin spring, outlet, and disconnected wetlands |
| Major anions (Cl, HCO3, SO4, NO3) | Changes in concentration (potential influence of shallow recharge) | Origin spring, outlet, and disconnected wetlands |
| Total dissolved solids (ideally logged EC) | Changes in concentration (potential influence of shallow recharge) | Origin spring, outlet, and disconnected wetlands |
| Radon-222 | Reduced concentrations indicating reduced flow | Origin spring, outlet, and disconnected wetlands |

**Table 5. Details of monitoring strategy**

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1. CONCLUSIONS

Six groundwater-dependent ecosystems in the Lower South East of South Australia were sampled for major ion and isotope concentrations between August 2007 and March 2009. Analysis of these results showed the systems to be a mixture of ephemeral streams fed by shallow spring discharge sourced from groundwater with an apparently low residence time in the unconfined Tertiary Limestone Aquifer (e.g. Jerusalem Creek and Cress Creek) and perennial spring systems with higher discharge rates and potential connection to the deeper sub-units of the Tertiary Limestone Aquifer (e.g. Ewens Ponds and Piccaninnie Ponds). These results confirm some previous studies and also provide a new insight into the hydrogeological behaviour of sites such as Ewens Ponds and Piccaninnie Ponds. Based on this new information, a monitoring strategy has been proposed that will assess changes in the hydrogeological behaviour of these systems into the future. It is hoped that this information will inform future decision-making with regards to management and maintenance of these ecologically and culturally significant sites (for example, setting management targets based on water chemistry and flow rate indicators).

## 6.2. RECOMMENDATIONS

While this study has shed new light on the hydrogeology of groundwater-dependant ecosystems in the Lower South East of SA, it has also identified areas for further research. Some of these are discussed in the monitoring strategy; however, the following are some of the key points that require further investigation in the future:

- Groundwater chemistry—very little groundwater sampling was conducted in this study. This was largely due to the fact that groundwater observation wells with suitable ‘end-member’ concentrations could not be found. As discussed earlier, the hydrostratigraphy of the Lower South East is complex and changes in groundwater chemistry can be observed over small distances. The inclusion of new monitoring wells in the regional observation network as part of recent drilling will hopefully help fill this gap. Future sampling should be conducted to investigate the relative contribution to groundwater discharge from different sub-units of the TLA. For example, the proportion and seasonality of discharge from the Camelback unit to Ewens Ponds could be further investigated.

- Investigation of seawater/freshwater dynamics in and around Piccaninnie Ponds.

- Further geochemical modelling using programs such as PHREEQC to assess degrees of mixing of different water bodies—for example, modelling of the degree of influence of groundwater from the Camelback sub-unit on discharge in Ewens Ponds.

- Identify further research needs in the future as more data is collected and a better understanding of these systems is obtained.

# APPENDICES

## A. SURFACE WATER AND GROUNDWATER CHEMISTRY AND FLOW RATES

| | | | | | Stable isotopes (ppm-VSMOW) | | Major ions (mg/L) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^2$ | Ca | Mg | Na | K | $HCO_3$ | Cl | $SO_4$ | TDS | $NO_3$ | $SiO_2$ | Flow (L/s) | Notes |
| GD005_A01_SW01 | 495013 | 5788912 | 12/02/2008 | 3.87 | -5.1 | -24.9 | 81 | 49 | 251 | 10 | 261 | 453 | 55 | 1330 | 3.58 | 14.3 | | First pond ~10 m |
| GD005_A02_SW01 | 495006 | 5788927 | 12/02/2008 | 3.68 | | | 78 | 48 | 244 | 9 | 262 | 450 | 54 | 1250 | 3.64 | 13.7 | | First pond ~5 m |
| GD005_A03_SW01 | 495017 | 5788894 | 12/02/2008 | 3.87 | -5.03 | -26.1 | 80 | 48 | 248 | 10 | 266 | 456 | 55 | 1250 | 3.23 | 12.9 | | First pond ~5 m |
| GD005_A04_SW01 | 494980 | 5788923 | 12/02/2008 | 4.14 | -5.11 | -24.6 | 79 | 48 | 247 | 10 | 263 | 340 | 54 | 1510 | 3.90 | 14.0 | | Start of Chasm 5–6 m |
| GD005_A05_SW01 | 494972 | 5788932 | 12/02/2008 | 4.57 | -5.06 | -25.9 | 78 | 49 | 250 | 10 | 264 | 376 | 55 | 1480 | 3.83 | 14.0 | | 12–13 m in Chasm, CFC sample as well |
| GD005_A06_SW01 | 494956 | 5788931 | 12/02/2008 | 4.37 | -5.17 | -25.9 | 80 | 50 | 256 | 10 | 262 | 455 | 57 | 1290 | 3.79 | 14.6 | | Western edge of chasm ~7 m |
| GD005_A08_SW01 | 494963 | 5788904 | 12/02/2008 | 4.16 | -5.02 | -25.9 | 80 | 48 | 248 | 10 | 265 | 430 | 54 | 1260 | 3.62 | 12.5 | | |
| GD005_A08_SW02 | 494976 | 5788880 | 12/02/2008 | 3.60 | | | 79 | | | | | 434 | | 1280 | | | | Turtle Pond |
| GD005_A09_SW01 | 494936 | 5788884 | 12/02/2008 | 3.48 | | | 78 | | | | | 435 | | 1310 | | | | Shallow western part |
| GD005_A09_SW02 | 494902 | 5788917 | 12/02/2008 | 2.46 | -5.14 | -23.8 | 78 | 48 | 247 | 10 | 263 | 448 | 54 | 1310 | 3.01 | 10.7 | | Shallow western part |
| GD005_A10_SW01 | 494795 | 5788695 | 12/02/2008 | 0.951 | -4.98 | -25.4 | 82 | 50 | 254 | 10 | 266 | 456 | 55 | 1310 | 2.81 | 14.0 | | Outflow from main Picc Ponds area (Chasm etc.) |
| GD005_A10_SW02 | 494776 | 5788698 | 12/02/2008 | 0.586 | -5.11 | -25.3 | 79 | 48 | 245 | 9 | 263 | 434 | 54 | 1240 | 2.68 | 12.7 | | Fresher outflow from west? |
| GD005_A12_SW01 | 494612 | 5788381 | 12/02/2008 | 0.483 | -5.02 | -25.3 | 76 | 43 | 205 | 8 | 265 | 379 | 44 | 1220 | 2.72 | 13.5 | 375 | Terminal discharge point on beach |
| | | | | | | | | | | | | | | | | | | |
| GD005_A01_SW01 | 495009 | 5788905 | 27/06/2008 | 2.38 | -5.15 | -26.3 | 98 | 83 | 521 | 18 | 293 | 957 | 122 | 2080 | | 16.10 | | Middle of Pond 1, temp = 15.7 |
| GD005_A02_SW01 | 495010 | 5788929 | 27/06/2008 | 3.42 | -5.03 | -26.4 | 100 | 83 | 522 | 19 | 296 | 949 | 121 | 1960 | | 15.70 | | North Pond 1 |
| GD005_A03_SW01 | 495023 | 5788884 | 27/06/2008 | 2.56 | -4.90 | -25.9 | 99 | 83 | 520 | 19 | 298 | 999 | 121 | 2060 | | 15.90 | | South Pond 1 |
| GD005_A05_SW01 | 494980 | 5788923 | 27/06/2008 | 4.01 | -5.04 | -26.7 | 99 | 80 | 519 | 19 | 298 | 865 | 122 | 2030 | | 16.10 | | Chasm 10 m |
| GD005_A05_SW02 | 494980 | 5788923 | 27/06/2008 | 2.29 | -4.99 | -26.8 | 96 | 79 | 465 | 20 | 230 | 799 | 124 | 1960 | | 16.30 | | Chasm 20 m |
| GD005_A05_SW03 | 494980 | 5788923 | 27/06/2008 | 1.36 | -5.00 | -25.2 | 110 | 88 | 423 | 20 | 220 | 786 | <1 | 1900 | | <0.1 | | Chasm 30 m |
| GD005_A05_SW04 | 494980 | 5788923 | 27/06/2008 | 3.99 | -5.09 | -26.5 | 102 | 85 | 537 | 19 | 300 | 961 | 125 | 2150 | | 16.60 | | Chasm 40 m |
| GD005_A05_SW05 | 494980 | 5788923 | 27/06/2008 | 1.95 | -5.13 | -27.3 | 120 | 93 | 632 | 24 | 300 | 790 | 154 | 2400 | | 20.80 | | Chasm 50 m |
| GD005_A05_SW06 | 494980 | 5788923 | 27/06/2008 | 3.75 | -5.03 | -26.4 | 95 | 77 | 446 | 19 | 210 | 797 | 122 | 1950 | | 16.10 | | Cathedral entrance—grab sample divers |
| GD005_A05_SW07 | 494980 | 5788923 | 27/06/2008 | 4.14 | -5.03 | -26.8 | 97 | 79 | 469 | 20 | 218 | 790 | 124 | 1970 | | 16.70 | | Cathedral bottom—grab sample divers |
| GD005_A05_SW08 | 494980 | 5788923 | 27/06/2008 | 3.78 | -5.00 | -25.8 | 98 | 82 | 518 | 18 | 300 | 1020 | 119 | 2090 | | 15.50 | | Cathedral temp—grab sample divers |
| GD005_A05_SW09 | 494980 | 5788923 | 27/06/2008 | | | | 96 | 80 | 508 | | 297 | 1270 | | 2070 | | | | Chasm 110 m—grab sample divers |
| GD005_A07_SW01 | 494979 | 5788945 | 27/06/2008 | 1.81 | -4.82 | -19.3 | 97 | 78 | 511 | 18 | 299 | 897 | 118 | 1730 | | 15.70 | | |
| GD005_A08_SW01 | 494965 | 5788902 | 27/06/2008 | 2.84 | -5.02 | -25.2 | 112 | 86 | 566 | 21 | 311 | 968 | 134 | 1990 | | 14.30 | | |
| GD005_A09_SW01 | 494916 | 5788906 | 27/06/2008 | 1.52 | -5.02 | -26.9 | 99 | 83 | 521 | 18 | 301 | 963 | 119 | 1910 | | 15.10 | | |
| GD005_A11_SW01 | 494697 | 5788549 | 27/06/2008 | 0.532 | -4.95 | -27.0 | 93 | 61 | 337 | 12 | 304 | 658 | 77 | 1330 | | 16.40 | | |
| | | | | | | | | | | | | | | | | | | |
| GD005_A01_SW01 | 495033 | 5788906 | 26/03/2009 | 5.07 | -5.37 | -25.9 | 84 | 59 | 353 | 14 | 283 | 600 | 87 | 1600 | 3.16 | 14.6 | | First pond, off pontoon |
| GD005_A12_SW01 | 494612 | 5788381 | 26/03/2009 | 0.578 | -4.92 | -27.2 | 83 | 48 | 269 | 10 | 294 | 428 | 63 | 1210 | 2.28 | 15.8 | 390 | Discharge on beach, flow measured 23/03/09 |

Table 6. Piccaninnie Ponds data

| | | | | Field parameters | | | | | | Stable isotopes (ppm-VSMOW) | | Major ions (mg/L) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | EC (µS/cm) | pH | Temp (C) | DO (ppm) | EH (mv) | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^{2}$ | Ca | Mg | Na | K | HCO3 | Cl | SO4 | TDS | NO3 | SiO2 | Flow (L/s) |
| GD004_A01_SW01 | 491186 | 5789928 | 30/08/2007 | 834 | 7.11 | 16.7 | 5.65 | 138 | 3.50 | -5.02 | -26.4 | 85.5 | 25.4 | 57.1 | 1.8 | 328 | 96 | 14.7 | 430 | | 13 | |
| GD004_A01_SW02 | 491186 | 5789928 | 30/08/2007 | 834 | 7.11 | 16.7 | 5.65 | 138 | 3.68 | | | | | | | | | | | | | |
| GD004_A02_SW01 | 492212 | 5789289 | 30/08/2007 | 1300 | 8.56 | 15.8 | 9.06 | 132 | 0.048 | | | | | | | | | | | | | |
| GD004_A02_SW02 | 492021 | 5789465 | 30/08/2007 | 1310 | 8.52 | 17.5 | 11.85 | -18 | 0.032 | | | | | | | | | | | | | |
| GD004_A03_SW01 | 492420 | 5788981 | 30/08/2007 | 870 | 7.26 | 12.5 | 5.98 | 99 | 2.23 | -4.46 | -21.6 | 98.9 | 25.8 | 82.1 | 2.9 | 363 | 151 | 15.9 | 510 | | 13 | 22 |
| GD004_A04_SW01 | 491798 | 5788916 | 30/08/2007 | 1220 | 8.47 | 16.4 | 11.38 | 10 | 0.004 | | | | | | | | | | | | | |
| GD004_A05_SW01 | 490714 | 5789068 | 30/08/2007 | 1220 | 8.51 | 15.2 | 11.47 | 57 | 0.023 | -1.45 | -2.8 | 95.5 | 38 | 122 | 11.2 | 384 | 221 | 37.8 | 640 | | 3 | |
| GD004_A06_SW01 | 490703 | 5788911 | 30/08/2007 | 990 | 8.08 | 15.4 | 9.56 | 84 | 0.243 | -3.49 | -15.9 | 91.9 | 31.2 | 88.1 | 4.7 | 372 | 158 | 21.6 | 530 | | 7 | 77 |
| GD004_A07_SW01 | 491438 | 5789308 | 30/08/2007 | 1650 | 8.5 | 18.3 | 12.5 | 99 | | -2.09 | -6.3 | | | | | | | | | | | |
| GD004_A07_SW02 | 491438 | 5789308 | 30/08/2007 | 1164 | 8.05 | 15 | 8.26 | -77 | | | | 109 | 37.6 | 115 | 11.4 | 426 | 214 | 32.7 | 650 | | 4 | |
| GD004_A08_SW01 | 491375 | 5789486 | 30/08/2007 | 828 | 7.47 | 15.4 | 9.83 | 90 | 0.793 | -5.02 | -24.0 | 91.4 | 26.8 | 58.7 | 1.5 | 360 | 96 | 14.7 | 440 | | 14 | |
| | | | | | | | | | | | | | | | | | | | | | | |
| GD004_A01_SW01 | 491186 | 5789928 | 14/02/2008 | 800 | 6.86 | 16 | 4.45 | | 3.64 | -5.16 | -26.3 | 74 | 26 | 53 | 2 | 272 | 90 | 13 | 566 | 4.11 | | |
| GD004_A06_SW01 | 490703 | 5788911 | 14/02/2008 | 904 | 6.98 | 15.4 | 7.48 | | 0.362 | -4.76 | -24.9 | 75 | 25 | 68 | 2 | 281 | 112 | 14 | 564 | 1.61 | | 10 |
| GD004_A05_SW01 | 490745 | 5789064 | 14/02/2008 | 1756 | 8.18 | 16.7 | 8.19 | | 0.040 | 3.47 | 20.5 | 54 | 69 | 207 | 8 | 352 | 265 | 9 | 1150 | <0.010 | | |
| GD004_A08_SW01 | 491421 | 5789410 | 14/02/2008 | 848 | 7.89 | 16.2 | 9.28 | | 1.44 | | | | | | | | 92 | | 566 | | | |
| GD004_A02_SW01 | 492202 | 5789270 | 14/02/2008 | 2830 | 8.58 | 20 | 13.78 | | 0.125 | 7.23 | 40.7 | 124 | 91 | 374 | 25 | 505 | 582 | 24 | 1940 | <0.010 | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| GD004_A01_SW01 | 491186 | 5789928 | 16/10/2008 | 825 | 6.44 | 16.31 | | | 3.72 | -5.24 | -25.5 | 80 | 24 | 59 | 2 | 270 | 87 | 13 | 594 | 4.26 | 16 | |
| GD004_A06_SW01 | 490707 | 5789058 | 16/10/2008 | 911 | 6.76 | 14.68 | | | 0.513 | -4.56 | -20.6 | 85 | 26 | 77 | 2 | 302 | 110 | 12 | 552 | 1.36 | 16.6 | 40 |
| GD004_A05_SW01 | 490727 | 5789084 | 16/10/2008 | 1002 | 7.45 | 14.4 | | | 0.039 | -1.22 | -1.0 | 65 | 33 | 106 | 2 | 262 | 163 | 17 | 606 | <0.01 | 11.6 | |
| GD004_A07_SW01 | 491448 | 5789349 | 16/10/2008 | 1024 | 6.86 | 15.2 | | | 0.239 | -4.41 | -21.0 | 89 | 28 | 74 | 2 | 338 | 109 | 11 | 620 | 0.41 | 17.9 | |
| GD004_A07_SW02 | 491448 | 5789349 | 16/10/2008 | 2051 | 7.17 | 14.55 | | | 0.107 | -0.73 | 0.9 | 163 | 70 | 181 | 17 | 678 | 268 | 46 | 1440 | <0.01 | 35 | |
| GD004_A03_SW01 | 492409 | 5788978 | 16/10/2008 | 1101 | 7.12 | 11.67 | | | 7.42 | -4.22 | -16.1 | 99 | 26 | 89 | 3 | 350 | 142 | 10 | 736 | <0.01 | 19.4 | 1 |
| GD004_A02_SW01 | 492186 | 5789341 | 16/10/2008 | 1619 | 7.47 | 14.97 | | | 0.841 | 0.31 | 6.4 | 93 | 47 | 172 | 6 | 369 | 242 | 36 | 1180 | <0.01 | 9.4 | |

**Table 7. Pick Swamp data**

| Site ID | Notes |
|---|---|
| GD004_A01_SW01 | Crescent Pond, western edge |
| GD004_A01_SW02 | Crescent Pond |
| GD004_A02_SW01 | Edge of Pick Swamp, northern side of eastern portion of swamp |
| GD004_A02_SW02 | Northern side of eastern portion of swamp |
| GD004_A03_SW01 | Point where Piccaninnie Ponds flows into Pick Swamp |
| GD004_A04_SW01 | Southern end of eastern portion of swamp |
| GD004_A05_SW01 | South-western edge of Pick Swamp (near outflow drain) |
| GD004_A06_SW01 | Drain that discharges Pick Swamp to sea, not connected to two big ponds? Outflow direct from springs? |
| GD004_A07_SW01 | Just off western side of levee, all values rough averages, meter would not settle on values (DO continuously ranged between 11 and 14) |
| GD004_A07_SW02 | Just off eastern side of levee, ORP reading negative number? |
| GD004_A08_SW01 | Pond/stream (spring?) that feeds eastern portion of Pick Swamp, depth unknown, at least 1–2 m |
| | |
| GD004_A01_SW01 | Crescent Pond, western edge |
| GD004_A06_SW01 | Discharge to sea from ponds/springs |
| GD004_A05_SW01 | Southern edge of western pond |
| GD004_A08_SW01 | Drain out of springs (including Crescent Pond?) |
| GD004_A02_SW01 | Northern edge of eastern pond |
| | |
| GD004_A01_SW01 | Crescent Pond |
| GD004_A06_SW01 | Drain outflow to beach |
| GD004_A05_SW01 | Weir before outflow (weir closed at time, water banked up in swamp) |
| GD004_A07_SW01 | Eastern side of levee bank |
| GD004_A07_SW02 | Western side of levee bank |
| GD004_A03_SW01 | Picc Pond to Pick Swamp inlet |
| GD004_A02_SW01 | Just down from shearing shed |

**Table 8. Pick Swamp notes from data collection points**

|  |  |  |  | Field parameters |  |  |  |  |  | Stable isotopes (ppm-VSMOW) |  | Major ions (mg/L) |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | EC (µS/cm) | pH | Temp (C) | DO (ppm) | EH (mv) | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^2$ | Ca | Mg | Na | K | HCO3 | Cl | SO4 | TDS | NO3 | SiO2 | Flow (L/s) |
| GD003_A01_SW01 | 481608 | 5791230 | 29/08/2007 |  |  |  |  |  | 1.59 | -4.92 | -24.8 | 82.1 | 20.6 | 49.7 | 1.9 | 286 | 81 | 12.9 | 380 |  | 11 |  |
| GD003_A02_SW01 | 481608 | 5791196 | 29/08/2007 |  |  |  |  |  | 1.61 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A04_SW01 | 481665 | 5791147 | 29/08/2007 |  |  |  |  |  | 1.76 | -4.97 | -27.8 | 80.7 | 20.5 | 49.7 | 1.9 | 287 | 80 | 12.6 | 390 |  | 11 |  |
| GD003_A05_SW01 | 481684 | 5791117 | 29/08/2007 |  |  |  |  |  | 1.20 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A07_SW01 | 481817 | 5791066 | 29/08/2007 |  |  |  |  |  | 4.29 | -4.92 | -29.1 | 82.2 | 25.3 | 89.3 | 3.4 | 286 | 168 | 23.1 | 520 |  | 11 |  |
| GD003_A09_SW02 | 481864 | 5790997 | 29/08/2007 |  |  |  |  |  | 1.94 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A08_SW02 | 481850 | 5791023 | 29/08/2007 |  |  |  |  |  | 1.79 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A09_SW01 | 481858 | 5790968 | 29/08/2007 |  |  |  |  |  | 3.53 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A10_SW01 | 482455 | 5790210 | 29/08/2007 | 900 | 7.53 | 16.4 | 9 | 118 | 1.67 | -4.88 | -27.7 | 81.5 | 23.7 | 75.1 | 2.9 | 288 | 137 | 19.2 | 470 |  | 11 | 1709 |
| GD003_A11_SW01 | 482452 | 5790196 | 29/08/2007 | 4320 | 7.78 | 17 | 11.04 | 90 | 2.98 | -4.66 | -26.6 | 101 | 95.8 | 653 | 24.9 | 285 | 1340 | 175 | 2300 |  | 11 | 242 |
| GD003_A12_SW01 | 482438 | 5790144 | 29/08/2007 | 1700 | 7.54 | 16.4 | 9.81 | 103 |  |  |  | 86.1 | 37.1 | 185 | 6.9 | 290 | 362 | 48.9 | 800 |  | 11 |  |
| GD003_A13_SW01 | 483057 | 5790765 | 29/08/2007 | 4400 | 7.45 | 16.3 | 6.37 | 71 | 4.96 | -4.63 | -25.2 | 100 | 96 | 675 | 25.1 | 286 | 1330 | 174 | 2500 |  | 12 |  |
| GD003_A14_SW01 | 482266 | 5789284 | 29/08/2007 | 1320 | 7.9 | 17.3 | 10.5 | 111 | 1.76 | -3.99 | -26.3 | 84.5 | 32 | 143 | 5.4 | 288 | 277 | 37.5 | 680 |  | 11 | 1780 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A01_SW01 | 481607 | 5791235 | 11/02/2008 |  |  |  |  |  | 2.01 | -5.16 | -25.3 | 69 | 21 | 46 | 2 | 236 | 72 | 11 | 510 | 7.15 | 13.7 |  |
| GD003_A02_SW01 | 481613 | 5791198 | 11/02/2008 |  |  |  |  |  | 1.79 | -5.24 | -25.7 | 67 |  |  |  |  | 75 |  | 530 |  |  |  |
| GD003_A03_SW01 | 481637 | 5791147 | 11/02/2008 |  |  |  |  |  | 1.82 |  |  | 68 |  |  |  |  | 76 |  | 530 |  |  |  |
| GD003_A04_SW01 | 481660 | 5791152 | 11/02/2008 |  |  |  |  |  | 2.00 | -5.14 | -25.2 | 67 | 20 | 47 | 2 | 236 | 77 | 11 | 496 | 6.87 | 13.1 |  |
| GD003_A05_SW01 | 481689 | 5791116 | 11/02/2008 |  |  |  |  |  | 1.63 |  |  | 69 |  |  |  |  | 76 |  | 596 |  |  |  |
| GD003_A07_SW01 | 481818 | 5791069 | 11/02/2008 |  |  |  |  |  | 3.40 | -5.28 | -24.4 | 71 | 30 | 112 | 5 | 236 | 193 | 27 | 730 | 7.38 | 13.8 |  |
| GD003_A08_SW01 | 481835 | 5791056 | 11/02/2008 |  |  |  |  |  | 3.00 |  |  | 72 |  |  |  |  | 166 |  | 742 |  |  |  |
| GD003_A08_SW02 | 481845 | 5791016 | 11/02/2008 |  |  |  |  |  | 2.06 |  |  | 69 |  |  |  |  | 110 |  | 526 |  |  |  |
| GD003_A09_SW01 | 481860 | 5790973 | 11/02/2008 |  |  |  |  |  | 2.84 |  |  | 72 |  |  |  |  | 142 |  | 606 |  |  |  |
| GD003_A10_SW01 | 482442 | 5790195 | 11/02/2008 | 860 | 7.48 | 18 | 7.58 |  | 2.03 |  |  | 72 |  |  |  |  | 128 |  | 566 |  |  |  |
| GD003_A11_SW01 | 482448 | 5790201 | 11/02/2008 | 2210 | 8 | 19.4 | 11.5 |  | 1.80 |  |  | 76 |  |  |  |  | 478 |  | 1380 |  |  |  |
| GD003_A12_SW01 | 482442 | 5790154 | 11/02/2008 | 1025 | 7.92 | 17.2 | 9.6 |  | 1.89 |  |  | 72 |  |  |  |  | 155 |  | 616 |  |  |  |
| GD003_A13_SW01 | 483059 | 5790758 | 11/02/2008 | 2840 | 7.82 | 14.7 | 6.77 |  | 4.82 | -4.96 | -23.6 | 81 | 62 | 382 | 16 | 245 | 619 | 106 | 1790 | 6.90 | 15.7 |  |
| GD003_A14_SW01 | 482280 | 5789285 | 11/02/2008 | 918 | 7.94 | 19.4 | 13.16 |  | 1.48 | -5.3 | -24.7 | 71 |  |  |  |  | 140 |  | 598 |  |  | 1197 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A01_SW01 | 481618 | 5791237 | 09/10/2008 | 865 | 6.18 | 13.8 | 8.56 | 170 | 1.76 | -5.35 | -25.6 | 77 | 20 | 53 | 2 | 106 | 65 | 12 | 456 | 5.76 | 14.7 |  |
| GD003_A02_SW01 | 481609 | 5791203 | 09/10/2008 | 731 | 7.01 | 14.3 | 8 | 111 | 1.01 | -5.24 | -25.6 | 75 | 20 | 52 | 2 | 170 | 65 | 12 | 488 | 5.75 | 14.3 |  |
| GD003_A03_SW01 | 481630 | 5791155 | 09/10/2008 | 675 | 7.45 | 13.9 | 8.57 | 117 | 1.68 | -5.19 | -25.6 | 76 | 20 | 50 | 2 | 135 | 65 | 12 | 427 | 5.72 | 14.5 |  |
| GD003_A04_SW01 | 481663 | 5791136 | 09/10/2008 | 700 | 7.48 | 14 | 8.94 | 110 | 1.57 | -5.15 | -25.4 | 76 | 20 | 54 | 2 | 115 | 65 | 12 | 456 | 5.64 | 14.3 |  |
| GD003_A05_SW01 | 481690 | 5791116 | 09/10/2008 | 458 | 7.63 | 13.9 | 8.83 | 111 | 1.61 | -5.13 | -25.8 | 76 | 20 | 53 | 2 | 145 | 66 | 12 | 458 | 5.64 | 14.7 |  |
| GD003_A06_SW01 | 481720 | 5791083 | 09/10/2008 | 712 | 7.7 | 13.7 | 8.8 | 110 | 1.62 | -5.16 | -25.4 | 74 | 19 | 52 | 2 | 145 | 64 | 11 | 493 | 5.65 | 6.5 |  |
| GD003_A07_SW01 | 481817 | 5791065 | 09/10/2008 | 1030 | 7.63 | 14.4 | 8.5 | 110 | 3.05 | -5.00 | -25.4 | 78 | 27 | 117 | 5 | 160 | 173 | 27 | 794 | 6.16 | 6.88 |  |
| GD003_A08_SW01 | 481847 | 5791019 | 09/10/2008 | 825 | 7.71 | 13.7 | 9.7 | 102 | 2.03 | -5.07 | -24.9 | 76 | 22 | 75 | 4 | 167 | 101 | 17 | 580 | 5.59 | 6.83 |  |
| GD003_A10_SW01 | 482438 | 5790200 | 09/10/2008 | 879 | 7.74 | 13.7 | 12.41 | 102 | 1.81 | -5.16 | -25.4 | 75 | 23 | 86 | 4 | 116 | 120 | 19 | 658 | 5.75 | 6.64 |  |
| GD003_A11_SW01 | 482451 | 5790196 | 09/10/2008 | 3850 | 7.81 | 15.6 | 11.82 | 84 | 2.97 | -4.78 | -22.0 | 97 | 96 | 695 | 29 | 222 | 1240 | 174 | 2470 | 5.98 | 14.8 |  |
| GD003_A12_SW01 | 482442 | 5790172 | 09/10/2008 | 2170 | 7.97 | 14.9 | 10.85 | 89 | 2.42 | -4.97 | -25.2 | 86 | 58 | 374 | 16 | 168 | 636 | 91 | 1640 | 5.76 | 13.9 |  |

|  |  |  |  | Field parameters |  |  |  |  |  | Stable isotopes (ppm-VSMOW) |  | Major ions (mg/L) |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | EC (µS/cm) | pH | Temp (C) | DO (ppm) | EH (mv) | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^{2}$ | Ca | Mg | Na | K | HCO3 | Cl | SO4 | TDS | NO3 | SiO2 | Flow (L/s) |
| GD003_A14_SW01 | 482283 | 5789265 | 9/10/2008 | 1173 | 8.12 | 15.4 | 11.23 | 78 | 1.65 | -5.15 | -25.2 | 75 | 28 | 133 | 6 | 145 | 208 | 31 | 814 | 5.66 | 6.29 | 1433 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GD003_A01_SW01 | 481616 | 5791267 | 25/03/2009 | 736 | 7.23 | 14.8 | 6.5 | 111 | 2.13 | -4.67 | -26.6 | 70 | 19 | 52 | 2 | 254 | 75 | 12 | 480 | 6.6 | 14 |  |
| GD003_A07_SW01 | 481810 | 5791078 | 25/03/2009 | 1102 | 7.82 | 14.7 | 6.4 | 89 | 3.46 | -4.94 | -25.9 | 72 | 27 | 118 | 5 | 253 | 206 | 28 | 677 | 6.7 | 14 |  |
| GD003_A10_SW01 | 482442 | 5790195 | 26/03/2009 | 957 | 7.95 | 14.4 | 5.68 | 91 | 2.2 | -4.64 | -24.5 | 73 | 23 | 85 | 4 | 257 | 132 | 19 | 593 | 6.6 | 15 |  |
| GD003_A11_SW01 | 482448 | 5790201 | 26/03/2009 | 3710 | 7.76 | 14.2 | 7.26 | 77 | 4.34 | -5.13 | -26.4 | 91 | 80 | 564 | 24 | 252 | 951 | 143 | 2270 | 7.4 | 15 |  |
| GD003_A12_SW01 | 482442 | 5790154 | 26/03/2009 | 2440 | 7.72 | 14.4 | 6.74 | 95 | 3.35 | -4.75 | -25.2 | 82 | 57 | 351 | 15 | 256 | 600 | 88 | 1560 | 7 | 14 |  |
| GD003_A14_SW01 | 482280 | 5789285 | 26/03/2009 | 1346 | 7.89 | 14.5 | 6.09 | 94 | 1.74 | -4.91 | -26 | 73 | 31 | 156 | 6 | 256 | 263 | 38 | 942 | 6.8 | 14 | 1230 |

**Table 9. Ewens Ponds and Eight Mile Creek data**

| Site ID | Date | Notes |
|---|---|---|
| GD003_A01_SW01 | 29/08/2007 | Sampled approx 10.5 m deep |
| GD003_A02_SW01 | 29/08/2007 | Outlet from Pond 1 |
| GD003_A04_SW01 | 29/08/2007 | Sampled over sands, approx 8 m |
| GD003_A05_SW01 | 29/08/2007 | Approx 2 m deep, outlet of Pond 2 |
| GD003_A07_SW01 | 29/08/2007 | Approx 8 m, Pond 3 with pump off ledge into sands |
| GD003_A09_SW02 | 29/08/2007 | Approx 2 m deep |
| GD003_A08_SW02 | 29/08/2007 | Approx 2 m deep |
| GD003_A09_SW01 | 29/08/2007 | Approx 3 m deep |
| GD003_A10_SW01 | 29/08/2007 | Eight Mile Creek before GD003_A11 drains in, gauged at this point, accuracy +30% (weedy), EC 730 on GJ's meter |
| GD003_A11_SW01 | 29/08/2007 | Spencers drain, EC 3600 on GJ's meter |
| GD003_A12_SW01 | 29/08/2007 | Eight Mile Creek down from where GD003_A11 drains in, EC jumped around between 1400 and 1900 uS, wouldn't settle (EC=1300 on GJ's meter) |
| GD003_A13_SW01 | 29/08/2007 | Spencers Pond, high conductivity considering 'fresh water' vegetation (CH), gauge board on it gives 1.92 (m-AHD?) at surface |
| GD003_A14_SW01 | 29/08/2007 | Outlet of Eight Mile before coast |
| | | |
| GD003_A01_SW01 | 11/02/2008 | First pond, over spring in slight little ‘cave’ ~10 m |
| GD003_A02_SW01 | 11/02/2008 | End of first pond, 2–3 m depth |
| GD003_A03_SW01 | 11/02/2008 | Pond 1–2 channel |
| GD003_A04_SW01 | 11/02/2008 | Second pond, over spring depth 6.2 m, temp 16 |
| GD003_A05_SW01 | 11/02/2008 | Second pond south |
| GD003_A07_SW01 | 11/02/2008 | Third pond over cave |
| GD003_A08_SW01 | 11/02/2008 | Third pond (south) |
| GD003_A08_SW02 | 11/02/2008 | Third pond south 2 |
| GD003_A09_SW01 | 11/02/2008 | Third pond outlet |
| GD003_A10_SW01 | 11/02/2008 | Eight Mile Creek, upstream of Spencers drain |
| GD003_A11_SW01 | 11/02/2008 | Spencers drain inlet to Eight Mile creek, not much flow, 0.25m^2x0.1 velocity GJ’s best guess |
| GD003_A12_SW01 | 11/02/2008 | Downstream of Spencers drain inlet |
| GD003_A13_SW01 | 11/02/2008 | |
| GD003_A14_SW01 | 11/02/2008 | Eight Mile Creek outflow at gauge site |
| | | |
| GD003_A01_SW01 | 09/10/2008 | Pond 1, over sands |
| GD003_A02_SW01 | 09/10/2008 | Pond 1 outlet |
| GD003_A03_SW01 | 09/10/2008 | Channel 1–2 |
| GD003_A04_SW01 | 09/10/2008 | Pond 2, over sands |
| GD003_A05_SW01 | 09/10/2008 | Pond 2 outlet |
| GD003_A06_SW01 | 09/10/2008 | Channel 2–3 |
| GD003_A07_SW01 | 09/10/2008 | Pond 3 cave |
| GD003_A08_SW01 | 09/10/2008 | Pond 3 outlet |
| GD003_A10_SW01 | 09/10/2008 | Upstream of Spencers |
| GD003_A11_SW01 | 09/10/2008 | Spencers drain |
| GD003_A12_SW01 | 09/10/2008 | Downstream of Spencers |
| **Site ID** | **Date** | **Notes** |
| GD003_A14_SW01 | 09/10/2008 | Outlet |
| | | |

| | | |
|---|---|---|
| GD003_A01_SW01 | 25/03/2009 | Pond 1—off pontoon |
| GD003_A07_SW01 | 25/03/2009 | Pond 3—off pontoon |
| GD003_A10_SW01 | 26/03/2009 | Upstream of Spencers drain |
| GD003_A11_SW01 | 26/03/2009 | Spencers drain |
| GD003_A12_SW01 | 26/03/2009 | Downstream of Spencers drain |
| GD003_A14_SW01 | 26/03/2009 | EMC outlet, flow gauged on 23/03/09 |

**Table 10. Ewens Ponds and Eight Mile Creek notes from data collection points**

| | | | | Field parameters | | | | | | Stable isotopes (ppm-VSMOW) | | Major ions (mg/L) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | EC (µS/cm) | pH | Temp (C) | DO (ppm) | EH (mv) | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^{2}$ | Ca | Mg | Na | K | HCO3 | Cl | SO4 | TDS | NO3 | SiO2 | Flow (L/s) |
| GD001_A01_SW01 | 474922 | 5789909 | 27/08/2007 | 780 | 7.28 | 17.1 | 5.6 | 252 | 5.88 | -4.98 | -27.0 | 83.9 | 24 | 60.6 | 1.7 | 305 | 100 | 17.4 | 430 | | 12 | 51 |
| GD001_A02_SW01 | 474942 | 5789921 | 27/08/2007 | 789 | 7.4 | 16.6 | 5.9 | 228 | 6.06 | | | | | | | | | | | | | |
| GD001_A03_SW01 | 474905 | 5789517 | 27/08/2007 | | | | | | 4.53 | | | | | | | | | | | | | 3 |
| GD001_A04_SW01 | 474893 | 5789505 | 27/08/2007 | | | | | | 3.31 | | | | | | | | | | | | | |
| GD001_A05_SW01 | 474895 | 5789484 | 27/08/2007 | 768 | 7.74 | 17.1 | 10.54 | 190 | 2.24 | -5.01 | -26.0 | 83.5 | 24.1 | 61.4 | 1.6 | 310 | 109 | 18 | 430 | | 12 | 71 |
| GD001_A06_SW01 | 474855 | 5789261 | 27/08/2007 | 1340 | 7.53 | 17.4 | 12.18 | 128 | 1.86 | -4.29 | -21.4 | 122 | 36.3 | 101 | <1.0 | 394 | 207 | 102 | 680 | | 3 | |
| GD001_A07_SW01 | 474925 | 5789277 | 27/08/2007 | 866 | 7.84 | 17.2 | 10.3 | 141 | 1.95 | -4.89 | -25.0 | 90.4 | 26.4 | 69 | 1.4 | 320 | 125 | 30.9 | 470 | | 10 | 14 |
| GD001_A08_SW01 | 475008 | 5788586 | 27/08/2007 | 2000 | 7.8 | 18.1 | 12.8 | 133 | | | | | | | | | | | | | | |
| GD001_A09_SW01 | 475029 | 5788656 | 27/08/2007 | 2067 | 7.81 | 18.1 | 12.45 | 113 | 12.1 | | | | | | | | | | | | | |
| GD001_A10_SW01 | 475056 | 5788749 | 27/08/2007 | 1909 | 7.65 | 17.6 | 7.57 | 121 | 5.32 | -4.97 | -25.1 | 90.2 | 47.4 | 245 | 7.6 | 305 | 429 | 67.5 | 1000 | | 13 | |
| GD001_A11_SW01 | 475032 | 5788753 | 27/08/2007 | 1900 | 7.9 | 17.8 | 10.8 | 98 | 17.8 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| GD001_A01_SW01 | 474945 | 5789926 | 12/03/2008 | 795 | 8.15 | 14.2 | 3.78 | | 0.503 | -4.76 | -22.7 | 69 | 21 | 58 | 3 | 265 | 67 | 17 | 560 | 1.40 | | |
| GD001_A08_SW01 | 474991 | 5788626 | 12/03/2008 | 1905 | 7.64 | 14.6 | 4.56 | | 22.3 | -5.12 | -23.4 | 73 | 44 | 231 | 8 | 350 | 277 | 62 | 1240 | 2.96 | | |

**Table 11. Cress Creek data**

| | | | | Field parameters | | | | | | Stable isotopes (ppm-VSMOW) | | Major ions (mg/L) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | E | N | Date | EC (µS/cm) | pH | Temp (C) | DO (ppm) | EH (mv) | Rn-222 (Bq/L) | $\delta O^{18}$ | $\delta H^{2}$ | Ca | Mg | Na | K | HCO3 | Cl | SO4 | TDS | NO3 | SiO2 | Flow (L/s) |
| GD002_A01_SW01 | 476663 | 5789515 | 28/08/2007 | 1391 | 7.17 | 14 | 5.15 | 126 | 2.29 | -4.25 | -21.3 | 131 | 39.5 | 113 | 2.4 | 316 | 221 | 189 | 720 | | 9 | |
| GD002_A02_SW01 | 476661 | 5789536 | 28/08/2007 | 1274 | 7.47 | 12.3 | 6.66 | 115 | 2.13 | | | | | | | | | | | | | |
| GD002_A03_SW01 | 477031 | 5789507 | 28/08/2007 | 2114 | 7.14 | 14.4 | 7.92 | 74 | | | | | | | | | | | | | | |
| GD002_A04_SW01 | 476093 | 5789107 | 28/08/2007 | 811 | 7.01 | 16.9 | 6.74 | 112 | 1.7 | -5.01 | -26.0 | 76.5 | 26.9 | 59.7 | 1.9 | 305 | 107 | 16.5 | 420 | | 12 | |
| GD002_A05_SW01 | 476174 | 5789054 | 28/08/2007 | 819 | 7.57 | 17.7 | 16.4 | 106 | | | | | | | | | | | | | | 15 |
| GD002_A06_SW01 | 476262 | 5788687 | 28/08/2007 | 810 | 7.5 | 16.2 | 7.75 | 103 | | | | 74.1 | 27.1 | 61 | 2.2 | 296 | 109 | 18 | 420 | | 11 | |
| GD002_A07_SW01 | 476406 | 5788283 | 28/08/2007 | 1000 | 8.04 | 16.3 | 13.8 | 62 | 0.930 | -4.34 | -21.6 | 91.4 | 33.9 | 85 | 2.4 | 312 | 151 | 77.4 | 550 | | 5 | 16 |
| GD002_A08_SW01 | 476326 | 5788570 | 28/08/2007 | 1703 | 7.33 | 14.9 | 8.87 | 83 | 3.76 | -3.82 | -16.4 | 166 | 52.5 | 140 | 3 | 400 | 261 | 262 | 890 | | 10 | |
| | | | | | | | | | | | | | | | | | | | | | | |
| GD002_A07_SW01 | 476398 | 5788308 | 12/03/2008 | 647 | 8.64 | 14.1 | 7.7 | | 0.048 | -3.22 | -18.5 | 26 | 26 | 57 | <1 | 190 | 47 | 15 | 478 | <0.010 | | |
| GD002_A04_SW01 | 476085 | 5789117 | 12/03/2008 | 828 | 7.57 | 15.4 | 0.62 | | 2.34 | | | 61 | 23 | 54 | 2 | 250 | 45 | 16 | 542 | 2.78 | | |

**Table 12. Jerusalem Creek data**

| Site ID | Notes |
|---|---|
| GD001_A01_SW01 | Cress Creek spring |
| GD001_A02_SW01 | |
| GD001_A03_SW01 | Pooling in paddock, feeds into CC slowly, approx 2–3 L/s |
| GD001_A04_SW01 | Main flow of Creek |
| GD001_A05_SW01 | Continuation of Creek after GD001_A03 and A04 have joined |
| GD001_A06_SW01 | Drain dug west of creek that drains paddock and potential spring |
| GD001_A07_SW01 | Gauging on side drain, samples taken downstream of inlet of side drain |
| GD001_A08_SW01 | Bridge to Woolwash. High tide, some seawater inflow, didn't seem to affect EC greatly, though |
| GD001_A09_SW01 | |
| GD001_A10_SW01 | |
| GD001_A11_SW01 | Est. 0.7 m deep, 2–3 m wide |
| | |
| GD001_A01_SW01 | Cress Creek spring |
| GD001_A08_SW01 | Cress Creek outlet |

**Table 13. Notes from Cress Creek data points**

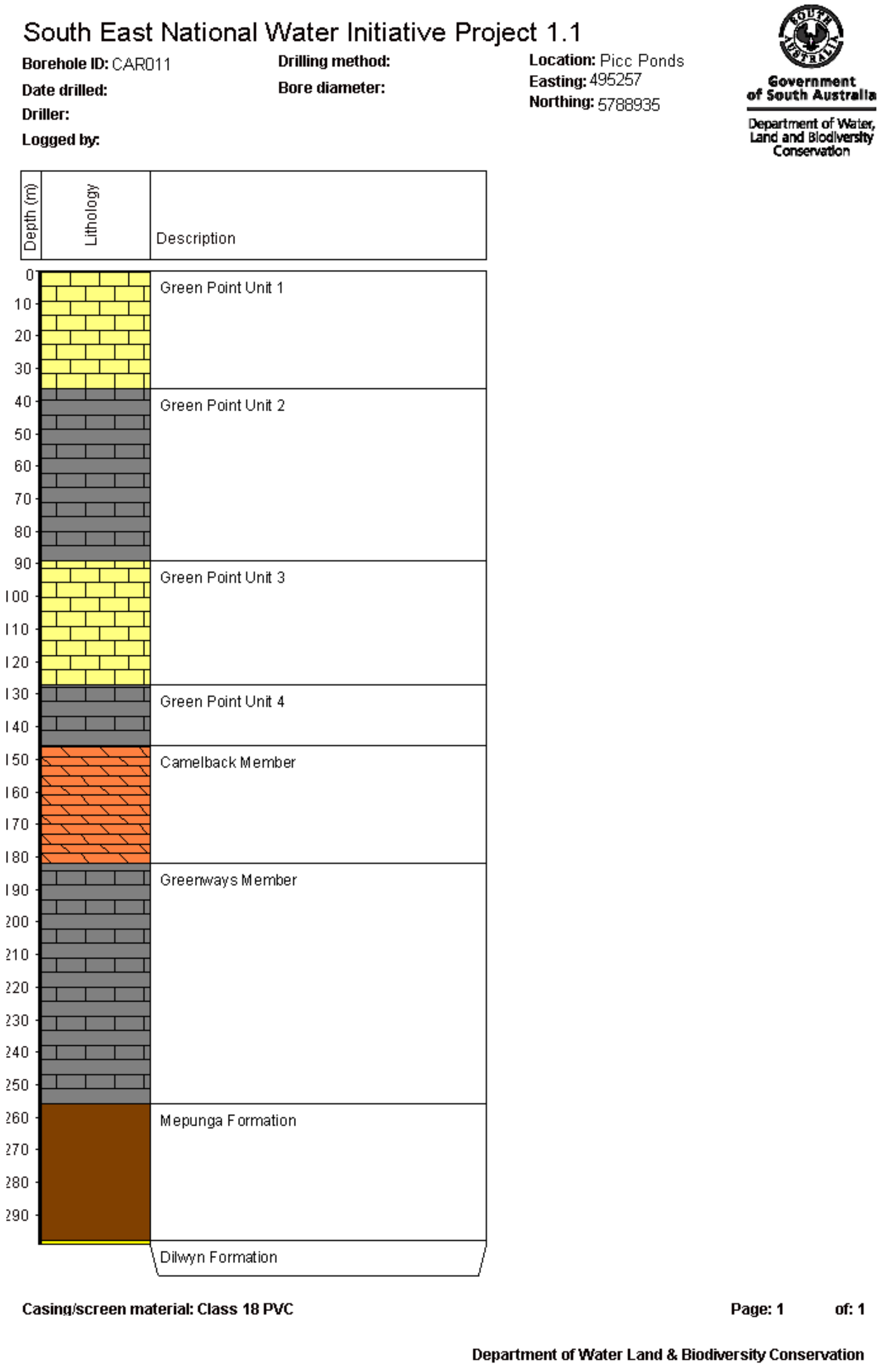
| Site ID | Notes |
|---|---|
| GD002_A01_SW01 | No bubbling seen, peat lining in small stream |
| GD002_A02_SW01 | 'Hidden Spring', no sign of bubbling, peat-lined pond |
| GD002_A03_SW01 | Wetland, no radon taken, open shallow surface water |
| GD002_A04_SW01 | 'Little Piccaninnie' sample taken in algal clearing 0.5 m beneath surface, base of pond very muddy, silts up pump, very loose peat/silt, gauge stick sinks down easily through it |
| GD002_A05_SW01 | Creek outflow from Little Piccaninnie |
| GD002_A06_SW01 | Continuation of creek from A05 |
| GD002_A07_SW01 | At bridge just before outflow to sea, gauged on southern side of bridge, sampled north side |
| GD002_A08_SW01 | Fork in drain, separate inflow from Little Piccaninnie, flow rate 3–5 L/s? |
| | |
| GD002_A07_SW01 | Jerusalem Creek outlet, no flow/almost dry |
| GD002_A04_SW01 | 'Little Piccaninnie', lots of algae, fish gulping at surface |

**Table 14. Notes from Jerusalem Creek data points**

| Site ID | E | N | Date | CFC-11 (pg/kg) | CFC-12 (pg/kg) | CFC-11 (yrs) | CFC-12 (yrs) | d$^{13}$C (‰ PDB) | $^{14}$C pMC±1s |
|---|---|---|---|---|---|---|---|---|---|
| CAR059 | 482442 | 5790218 | 04/09/2007 | 10.5 | 81 | <1965 | 1972 | | |
| MAC045 | 479734 | 5791715 | 05/09/2007 | 495.5 | 270 | 1987 | 1992 | | |
| GD003_A01_SW01 | 481608 | 5791230 | 29/08/2007 | 418 | 189 | 1983 | 1984 | | |
| GD003_A01_SW01 | 481608 | 5791230 | 11/02/2008 | 253.0 | 175.5 | 1980 | 1985 | | |
| GD003_A07_SW01 | 481818 | 5791069 | 11/02/2008 | 294.3 | 178.9 | 1983 | 1985 | | |
| GD005_A05_SW01 | 494972 | 5788932 | 12/02/2008 | 365.2 | 203.3 | 1972 | 1972 | | |
| GD004_A01_SW01 | 491186 | 5789928 | 14/02/2008 | 304.1 | 185.9 | 1971 | 1975 | | |
| GD003_A01_SW01 | 481608 | 5791230 | 09/10/2008 | | | | | -9.2 | 66.1 |
| GD003_A07_SW01 | 481818 | 5791069 | 09/10/2008 | | | | | -9.5 | 66.9 |
| GD005_A05_SW05 | 494980 | 5788923 | 27/06/2008 | | | | | -10.3 | 55.6 |

**Table 15. Age data**

# B. HYDROSTRATIGRAPHY OF CAR011



South East National Water Initiative Project 1.1

**Borehole ID:** CAR011
**Date drilled:**
**Driller:**
**Logged by:**
**Drilling method:**
**Bore diameter:**
**Location:** Picc Ponds
**Easting:** 495257
**Northing:** 5788935

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

**Casing/screen material: Class 18 PVC**

**Page: 1** **of: 1**

**Department of Water Land & Biodiversity Conservation**

**Figure 35. Hydrostratigraphy of CAR011**

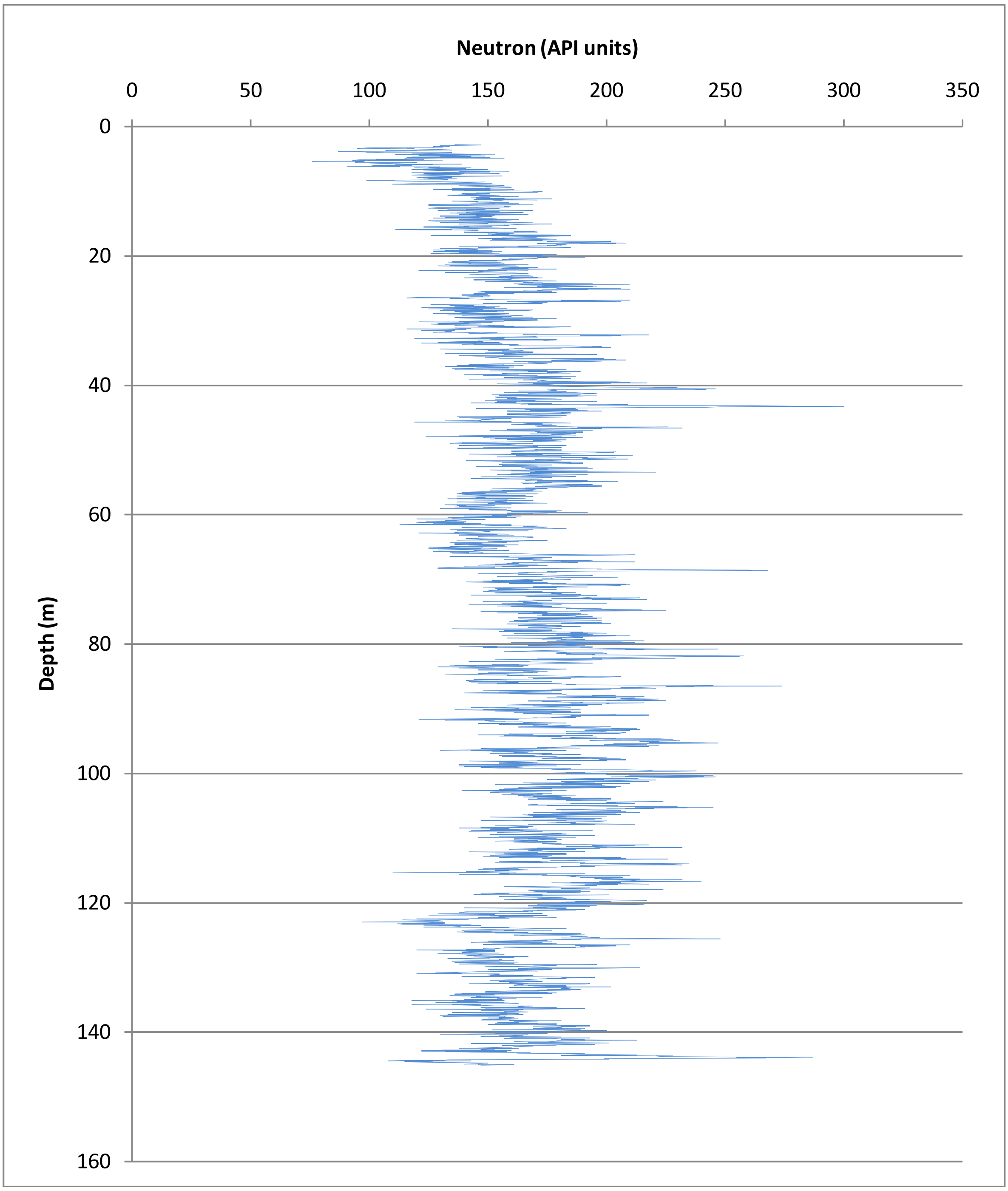


Figure 36. Neutron reading from geophysical log of Obswell CAR011

# 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 |

## Shortened forms

| | |
|---|---|
| ~ | approximately equal to |
| bgs | below ground surface |
| EC | electrical conductivity (µS/cm) |
| K | hydraulic conductivity (m/d) |
| pH | acidity |
| pMC | percent of modern carbon |
| ppb | parts per billion |
| ppm | parts per million |
| ppt | parts per trillion |
| w/v | weight in volume |
| w/w | weight in weight |

# 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 (see ‘confining layer’) 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

**Aquitard** — A layer in the geological profile that separates two aquifers and restricts the flow between them

**Baseflow** — The water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

**Basin** — The area drained by a major river and its tributaries

**Biodiversity** — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

**BoM** — Bureau of Meteorology, Australia

**Buffer zone** — A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (eg. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses)

**$^{14}$C** — Carbon-14 isotope (percent modern Carbon; pmC)

**Catchment** — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

**CFC** — Chlorofluorocarbon; measured in parts per trillion (ppt)

**Confining layer** — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also ‘aquifer, confined’

**CSIRO** — Commonwealth Scientific and Industrial Research Organisation

**δD** — Hydrogen isotope composition, measured in parts per thousand ($^{o}/_{oo}$)

**DEH** — Department for Environment and Heritage (Government of South Australia)

**DES** — Drillhole Enquiry System; a database of groundwater wells in South Australia, compiled by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC)

**Diversity** — The distribution and abundance of different kinds of plant and animal species and communities in a specified area

**DO** — Dissolved Oxygen

**DOC** — Dissolved Organic Carbon

**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 as a measure of water salinity as it is quicker and easier than measurement by TDS

**Ecology** — The study of the relationships between living organisms and their environment

**Ecosystem** — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

**Ephemeral streams or wetlands** — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

# GLOSSARY

**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

**Groundwater** — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also ‘underground water’

**Hydraulic conductivity (K)** — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

**Hydrogeology** — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also ‘hydrology’

**Hydrometric** — Literally relating to water measurement, from the Greek words ‘hydro’ (water) and metrikos (measurement); see also DWLBC fact sheet FS1 <http://www.dwlbc.sa.gov.au/assets/files/fs0001_hydrometric_surface_water_monitoring.pdf>

**Hyporheic zone** — The wetted zone among sediments below and alongside rivers; it is a refuge for some aquatic fauna

**IAEA** — International Atomic Energy Agency

**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

**Land** — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

**LMWL** — Local meteoric water line

**m AHD** — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

**Model** — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, 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

**NRM** — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

**$\delta^{18}$O** — Oxygen isotope composition, measured in parts per thousand (‰)

**Observation well** — A narrow well or piezometer whose sole function is to permit water level measurements

**Obswell** — Observation Well Network

**Perennial streams** — Permanently inundated surface stream courses. Surface water flows throughout the year except in years of infrequent drought.

**Piezometer** — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

**Potentiometric head** — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

**Prescribed water resource** — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

**Rehabilitation (of water bodies)** — Actions that improve the ecological health of a water body by reinstating important elements of the environment that existed prior to European settlement

**Restoration (of water bodies)** — Actions that reinstate the pre-European condition of a water body

**Surface water** — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

**TDS** — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

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

**Tributary** — A river or creek that flows into a larger river

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

**Water body** — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

**Water-dependent ecosystems** — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

**Well** — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

**Wetlands** — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

# GLOSSARY

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