DWLBC REPORT

Interactions between groundwater and surface water systems in the Eastern Mount Lofty Ranges

2008/27

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

Interactions between groundwater and surface water systems in the Eastern Mount Lofty Ranges

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FOREWORD

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

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

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

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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SUMMARY

An understanding of the interactions between surface streams and groundwater systems in the catchments of the Eastern Mount Lofty Ranges (EMLR) is important to identify areas of special consideration in the development of the EMLR Water Allocation Plan (WAP). This report describes the methodology and outcomes of field investigations into these interactions and the interpretation of the results achieved.

Field investigations were conducted between September 2006 and June 2007. Water samples were collected from surface streams and groundwater wells at locations distributed across six catchments in the EMLR. Samples were analysed for a number of hydrochemical indicators to characterise water from differing sources. Streamflow measurements were made at the majority of the surface water sample locations in October 2006.

Flows between surface water and groundwater typically vary seasonally and from year to year, in many places diminishing to a zero-flow condition during the summer months. However, the minimal groundwater discharges occurring during summer have great significance for aquatic ecosystems at some locations, as the persistence of water through dry summer conditions is dependent on these flows.

The results of the investigation represent predominantly dry-season conditions due to a relatively low occurrence of rainfall during, and in the months prior to, the period of the field investigations. Analyses of hydrochemical data and the spatial variations of streamflow rates have provided an indication of where water present in surface streams during periods of no rain has been discharged from the adjacent groundwater system. The results confirm that the majority of the permanent pools and wetlands in the EMLR are largely dependent on groundwater inflows during low rainfall periods.

Discharge of groundwater was most commonly found to occur in the upper reaches of the catchments, providing small amounts of flow into the tributaries of the major creeks and rivers. There are a number of locations in the EMLR where surface water–groundwater interactions are observed to be particularly significant. Of these, the most significant are in the upper Angas River Catchment, the south-western Finniss River Catchment and the northern Tookayerta Creek Catchment, where surface water flows are dependent on substantial discharges from the groundwater system; and in the southern Bremer River Catchment, where there is significant loss from the river into the groundwater system.

There may be significant groundwater discharges that occur within the study area that have not been identified in this study because groundwater levels were unusually low during the period of the field investigation. Similarly, at locations where it has been identified that the surface stream is losing water to the groundwater system, the direction of surface water–groundwater exchange may reverse during times of higher groundwater levels.

This study provides a snapshot of interactions occurring during the period of the field investigation and improves the understanding of the prevalence of surface water–groundwater interactions in fractured rock environments. The large hydrochemical data set resulting from the study (provided in Appendix B) also provides a valuable information resource, which can be drawn on in future investigations.

1. INTRODUCTION

Technical investigations have been conducted to determine the various components of the water balance in catchments of the Eastern Mount Lofty Ranges (EMLR), which are essential to the development of the Water Allocation Plan (WAP). Traditionally, surface water and groundwater have been managed as separate resources. Ongoing development of natural resource management science has revealed that in many cases there is a strong hydraulic connection between these two resources, and that the connection is spatially and temporally variable. It is acknowledged that groundwater and surface water resources are intimately connected and that the two resources cannot be managed independently of each other.

Changes in the rate of groundwater extraction for agricultural or industrial uses creates changes in the hydrostatic pressure in groundwater aquifers, which in turn may cause changes in groundwater flows to surface watercourses. Conversely, in areas where surface watercourses naturally lose water to subsurface aquifers, extraction of water from surface watercourses may result in reductions in recharge to those aquifers and a decline in the groundwater resource. This is of particular importance in water allocation planning, where double allocation of the resource can occur when there is insufficient understanding of these systems.

The long-term sustainability of surface water resources requires careful estimates of the location, volume and timing of fluxes between groundwater and surface water systems. Determining these components in fractured rock aquifers (FRA) presents more difficulty than in areas of sedimentary porous media aquifers as the groundwater is stored in, and moves through, fractures and joints in what is essentially impervious rock. Groundwater flow-paths are difficult to determine and the methods commonly applied to determine fluxes in porous media are not applicable. This investigation has involved the analysis of hydrochemical indicators in a large number of groundwater and surface water samples. The data generated by these analyses are used in conjunction with streamflow and water level data from existing databases, to determine the relative proportions of groundwater discharge and surface runoff in surface water systems and the likely source aquifer(s) of the groundwater.

1.1 STUDY AREA

In total, six catchments in the EMLR were investigated (Figure 1). Priority was given to the Finniss, Angas and Bremer River catchments, which contain a large proportion of the total groundwater users in the EMLR. The catchments of Reedy and Currency Creeks were investigated with a lower number of sample locations, reflecting the lower priority given to the understanding of surface water–groundwater (SW–GW) interactions in those catchments because of the relatively low number of groundwater users. The Tookayerta Creek Catchment was investigated with a similar number of sample points to the Reedy and Currency Creek catchments. While there is a high level of groundwater use in the Tookayerta Creek Catchment, earlier investigations (Banks et al. 2007; Fass and Cook 2005) have provided data on groundwater and surface water indicators in that catchment.

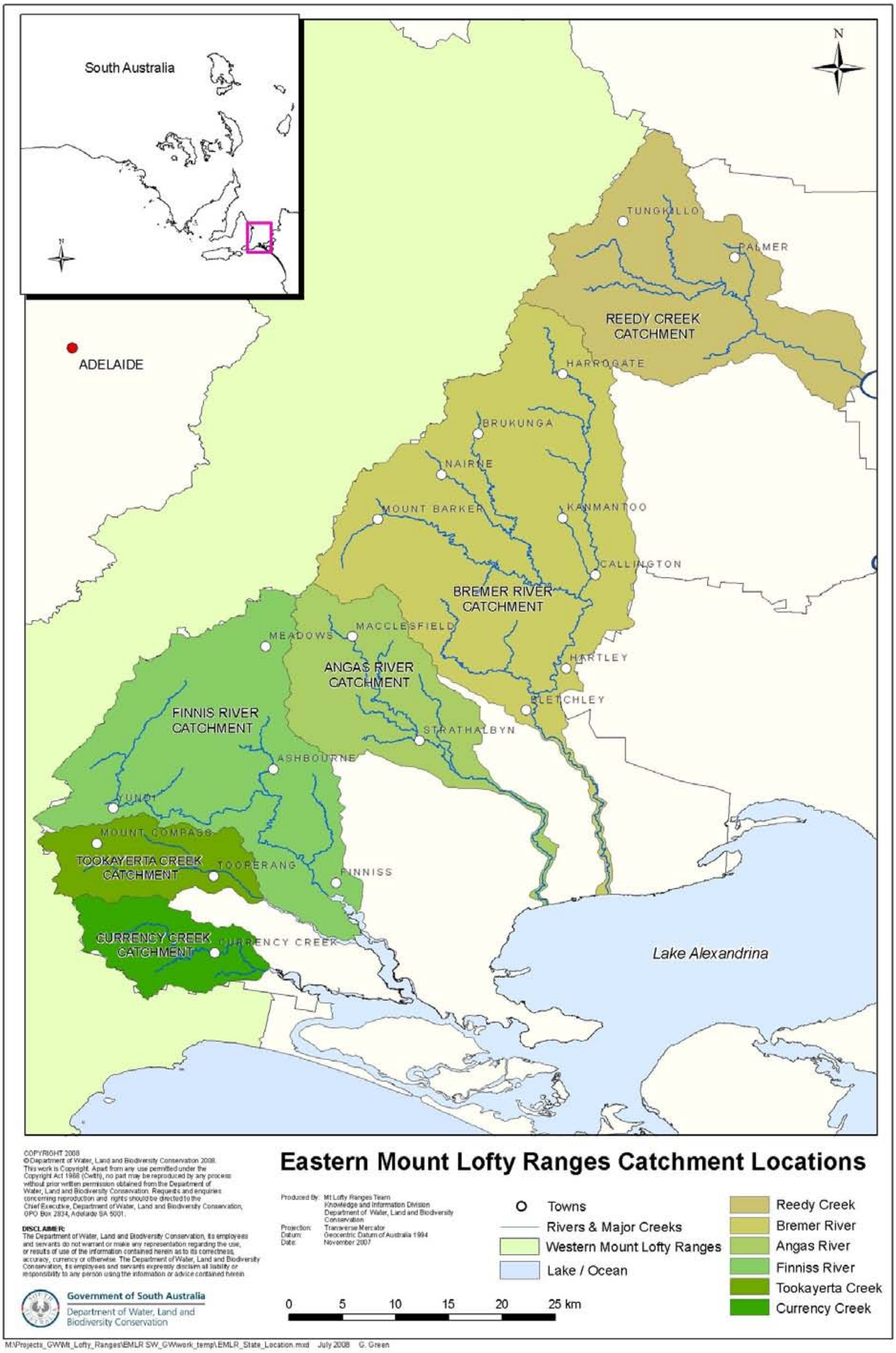
Groundwater in the Angas River, Bremer River and Reedy Creek catchments occurs primarily in FRA of the Adelaidean and the Kanmantoo Group geological formations. The lower, south eastern parts of these catchments are characterised by unconsolidated sediments typical of the Quaternary clay, sand and gravel deposits of the lower Murray Basin.

In the more southerly catchments of the Tookayerta and Currency Creeks and the Finniss River, groundwater occurs within Permian glacial and fluvioglacial deposits of the Cape Jervis Formation as well as in FRA of the Kanmantoo Group and Adelaidean sequence.

The northern and western half of the Finniss River Catchment overlies Adelaidean sequence geology, although much of the Meadows Creek sub-catchment is infilled with Quaternary floodplain deposits. In a distinct contrast, there is a broad band of the Archaean Barossa Complex through the southern half of this sub-catchment, extending into the northern part of the adjacent Tookayerta Creek Catchment. The south-western half of the Finniss River Catchment overlies Kanmantoo Group geology, namely Tapanappa Formation, Backstairs Passage Formation and Balquhidder Formation. There are also large areas of the Permian Cape Jervis Formation sand deposits throughout the lowland parts of this half of the Finniss River Catchment.

1.2 STUDY CONTEXT

The Mount Lofty Ranges (MLR) form the central portion of the Adelaide Geosyncline and include a suite of meta-sedimentary and igneous rocks that range in age from Palaeoproterozoic (> 1600 Ma) through to Permian (250-300 Ma) (Drexel et al. 1993; Drexel and Preiss 1995). The hydrogeology of the MLR is dominated by FRA systems with shallow alluvial aquifers in the valley bottoms. The topographic relief of the ranges results in dominant local groundwater flow systems compared to the flatter relief of the plains, which tend to have dominant intermediate and regional flow systems. The dry temperate climate and areas of pronounced topographic relief lead to relatively high rates of surface evaporation and runoff. As a result, the contribution of groundwater discharge to surface water features is a significant component of the catchment water balance, particularly during the summer months and in drought conditions. The many permanent pools and wetlands that lie within watercourses in the EMLR represent important ecological assets as they provide important dry season refuges for a variety of aquatic organisms. Hence, the provision of environmental water requirements (EWR) is an important consideration in the management of natural water resources in the region. The map in Figure 1 shows the extent of the permanent pools and significant wetlands in the studied catchments.



Eastern Mount Lofty Ranges Catchment Locations

Produced By: Mt Lofty Ranges Team
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
Projection: Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Date: November 2007

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Figure 1. Location of Eastern Mount Lofty Ranges catchments investigated

1.3 AIMS AND OBJECTIVES

This investigation is intended to provide technical information to support the successful implementation of the WAP for the EMLR.

Specifically, this investigation identifies areas where surface water and groundwater resources are connected with a view to:

- Preventing double allocation of water in groundwater and surface water systems. If, in preparing the WAP for the EMLR the total volumes of surface water flow and groundwater recharge were accounted for separately, then the proportion of surface water that is derived from groundwater inflows would be duplicated in the catchment water balance.
- Identifying the locations of wetlands and permanent pools whose permanency depends on groundwater inflows. Furthermore, to evaluate how vulnerable these are to changes in groundwater extraction rates.
- Identifying stream reaches where there is evidence of exchange between groundwater and surface water systems.
- Quantifying the proportion of water that is derived from groundwater inflows in surface water bodies at 60 locations in the selected catchments.
- Identifying a source of groundwater that, together with discharges from the Permian Cape Jervis Formation sand aquifer, provides a large proportion of the water in the lower Tookayerta Creek and Black Swamp.

2. METHODOLOGY

2.1 FIELD WORK PROGRAM

2.1.1 SAMPLE SITE LOCATIONS

The number of possible locations for the sampling of surface and groundwater was governed by financial and logistical constraints. In total, 60 surface water locations and 30 existing groundwater wells were selected according to a number of criteria. These were as follows.

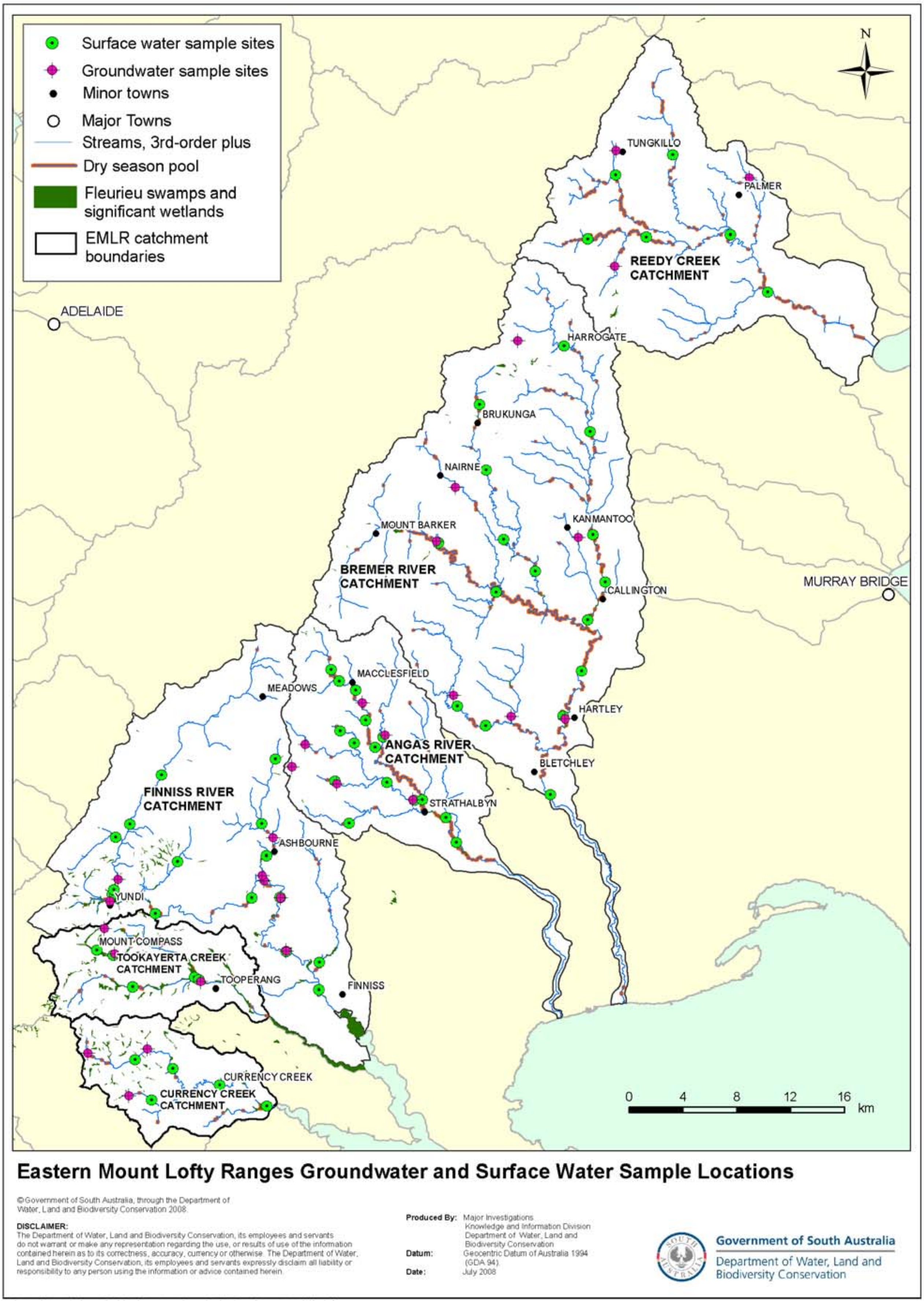
A) Groundwater Sample Site Selection Criteria:

- Operational groundwater well or observation well
- Less than 60 m maximum depth
- Known production zone or screen interval
- Short screen interval / production zone (<5 m)
- Within 400 m of a stream also selected for sampling
- Preferably in close proximity to surface water sample locations
- In topographic locations that enable groundwater interaction with stream
- Sites in each catchment to sample a range of different geological units
- Accessible by road

B) Surface Water Sample Site Selection Criteria:

- In locations where stream-flow is influential on dry season pools and significant ecological assets (such as Fleurieu Swamps), and known locations of listed fish species, according to the EMLR Fish Inventory (Hammer 2004)
- Preferably close to surface water gauging stations
- On higher order streams, above and below key stream junctions on main stream or major tributaries
- Within the range of influence of groundwater sample sites
- Where there is high intensity of groundwater use, or in a stream that may be fed from an area of intense groundwater use
- At points where permanent pools are located. This is for two reasons: (a) permanency of water suggests these pools are fed by groundwater, and (b) water may be available to sample during all three sampling rounds
- Accessible by road

The sample locations shown in Figure 2 were selected in view of these criteria.



Eastern Mount Lofty Ranges Groundwater and Surface Water Sample Locations

Produced By: Major Investigations
Knowledge and Information Division
Department of Water, Land and
Biodiversity Conservation
Datum: Geocentric Datum of Australia 1994
(GDA 94).
Date: July 2008

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

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Figure 2. **Locations of surface water and groundwater sample sites, dry season pools and significant wetlands in the six EMLR study catchments**

2.1.2 SAMPLING TIMES

Three rounds of surface water sampling were conducted, spaced at approximately four–month intervals. These were intended to be at times of the year when: (1) water tables were at their annual maximum (September/October); (2) surface and groundwater inflows were collectively at a minimum (January/February); and (3) surface runoff inflows to river and creeks are expected to exceed groundwater inflows (May).

Surface water sampling round 1	20 Sep 06 – 10 Oct 06	(spring)
Surface water sampling round 2	24 Jan 07 – 2 Feb 07	(summer)
Surface water sampling round 3	21 May 07 – 31 May 07	(autumn)

Hereafter these sampling rounds will be referred to as, round 1, round 2 and round 3, respectively

The rainfall events preceding and during the surface water sampling rounds are an important consideration. There was minimal rain for approximately 12 days prior to round 1, then a significant rainfall event (approximately 33 mm recorded at Mount Barker) occurred between 23 and 25 September. This may have been enough to affect flows in the Bremer and Angas River catchments, when some sites in these catchments were sampled on 27 and 28 September. Prior to round 2, conditions had been exceptionally dry apart from a rainfall event approximately one week prior to the start of sampling in the Reedy Creek Catchment. This rainfall may have affected the amount and composition of water in pools sampled in the Reedy Creek Catchment. The locations sampled in other catchments later in round 2 are not thought to have been affected by this rainfall event. Sample round 3 was conducted after a period of approximately three weeks of significant rain events. Prior to this period, most creeks in the target catchments were not flowing (apart from in the Tookayerta Creek Catchment), but after this period of sustained rain, creeks and rivers in most of the catchments were experiencing some flow. Of the three sampling rounds, the surface water samples taken during round 3 are the most likely to be a mix of groundwater discharge, interflow and surface runoff.

Two rounds of groundwater sampling were conducted approximately six months apart. The rationale of having two rounds of groundwater sampling was to determine whether the hydrochemical characterisation changes seasonally.

Groundwater sampling round 1	15 Nov 06 – 5 Dec 06
Groundwater sampling round 2	7 May 07 – 18 May 07

As groundwater tends to have a high residence time, and represents an integration of water recharging the aquifer over a number of years, it is not expected that weather conditions close to the time of sampling affected the chemical characteristics of the groundwater samples.

2.1.3 PARAMETERS MEASURED

A. Parameters measured for both surface water and groundwater:

i. Measured in-field in surface water and groundwater:
    - Temperature, pH, specific electrical conductivity (SEC), dissolved oxygen (DO), redox potential, alkalinity

ii. Laboratory analyses for samples of surface water and groundwater:
    - Major and trace dissolved ions and total dissolved solids (TDS)

  - Stable isotopes of water, deuterium and oxygen-18 (δ^{2}H and δ^{18}O)
  - Strontium isotope ratio ($^{87/86}$Sr)
  - Radon-222 activity (^{222}Rn)

B. Parameters laboratory analysed in samples of groundwater only:

- Carbon 14 activity (^{14}C)
- Carbon 13/12 isotope ratio (δ^{13}C)
- CFC-12 and CFC-11 concentrations

C. Volumetric flow rates of surface water flows, where flow was apparent and where possible with an in-stream flow meter.

D. Standing water level in groundwater wells, where accessible.

2.1.4 GROUNDWATER SAMPLING METHODS

Groundwater samples were taken from wells during two sampling rounds approximately six months apart. The sampled wells included a mix of production wells used for irrigation and stock watering, as well as a number of domestic wells used for household water supply. Four investigation wells, which were established for an earlier investigation by the Department of Water, Land and Biodiversity Conservation (DWLBC), were also sampled.

Prior to sampling, wells were purged of a volume of water intended to be equivalent to at least three times the volume of the well casing. Where the well casing details were not available, water quality parameters were monitored while the well was purged and a sample was then taken when parameters had stabilised. Water samples for major and trace element and strontium isotope analysis were collected directly from the pump outlet into 6 L plastic pressure packs and immediately pressure-filtered through a 0.45 μ membrane filter into rinsed sample bottles. Samples for analysis of cations (Na^{+}, Mg^{2+}, K^{+}, Ca^{2+}, NH_4^{+}) and trace elements were acidified with nitric acid (1% v/v HNO_3) to a pH of less than 2 in order to keep the ions in solution.

A YSI® multi-parameter meter was used to monitor the chemical and physical parameters, pH, SEC, DO, redox, and temperature during purging. The meter was calibrated with known standards prior to use in the field. Samples were collected and a multi-parameter reading taken when the physical parameters had stabilised. The total alkalinity (assumed to be the concentration of HCO_{3-} within the pH range of the samples) was also measured in the field using a HACH titration kit.

Groundwater samples for ^{222}Rn analysis were collected directly from the pump outlet of the purged well using a syringe. A sample of 14 mL was transferred to a pre-weighed 22 mL Teflon-coated PTFE scintillation vial containing 6 mL of Packard NEN mineral oil. It was then gently agitated for 30 seconds, sealed and the time recorded.

Samples for the analysis of stable isotopes of water were collected directly from the pump outlet and sealed in pre-rinsed glass McCartney bottles.

Samples for CFC analysis were collected in glass bottles, filled directly from the pump outlet where possible, with care taken to ensure exclusion of air from the sample. Carbon-14 samples were prepared by mixing strontium chloride solution into 40–60 litres of sample water prior to adding saturated sodium hydroxide and a flocculating agent to aid the precipitation of carbon from the water sample as strontium carbonate ($SrCO_3$). The $SrCO_3$ precipitate was decanted into a 5 L plastic container for storage prior to laboratory analysis.

2.1.5 SURFACE WATER SAMPLING METHODS

Surface water samples were taken directly from rivers and creeks during three rounds of sampling, four months apart. Water samples for major and trace element and strontium isotope analysis were collected in 6 L plastic pressure packs and immediately pressure-filtered through a 0.45 µ membrane filter into rinsed sample bottles. Samples for analysis of cations (Na^+, Mg^{2+}, K^+, Ca^{2+}, NH_4^+) and trace elements were acidified with nitric acid (1% v/v HNO_3) to a pH of less than 2. The sensor assembly of a YSI® multi-parameter meter was placed directly in the stream/pool to obtain in-situ measurements of pH, SEC, DO, redox, and temperature.

Samples for analysis of stable isotopes of water, deuterium and oxygen-18, were collected in glass McCartney bottles, directly from the stream or pool.

The preparation of samples for analysis of ^{222}Rn activity in surface waters employed a rapid field extraction method developed by Leaney and Herczeg (2006). Surface water samples were collected in 1.25 L polyethylene terephthalate bottles. Using a syringe, 50 mL of sample was removed from the bottle and then 20 mL of mineral oil scintillant was added from a pre-weighed scintillation vial. The bottle was repeatedly inverted for four minutes to equilibrate radon between the water-air-scintillant phases, then left to stand for one minute allowing scintillant to settle to the top of the water. The scintillant was returned to the vial using a glass nozzle, the vial sealed, and the time recorded. The samples were delivered to the laboratory within 72 hours of collection to be analysed for ^{222}Rn activity.

2.1.6 FIELD OBSERVATIONS

In addition to hydrochemical sampling, the field work program enabled a number of other variables to be observed and measured.

The standing water level in the sampled groundwater wells was measured wherever possible. In many cases, the well cap made the water inaccessible to a water level probe.

Manual flow gauging was conducted using an OTT Pigmy flowmeter at most of the surface water sampling locations shortly after the completion of the first round of sampling. Where flow was either not apparent or too low to measure with the flowmeter, a range of methods were used to estimate flow at each sampling location. Where water flowed through culverts, a bucket and stopwatch was used to measure the volumetric flow-rate. At other locations a visual estimate was made. These manual flow measurements and observations are used in combination with flow and water quality data logged at gauge stations located in the studied catchments and recorded in the DWLBC HYDSTRA database.

During the second and third round of surface water sampling, when flow was not apparent at all sampling locations, observations were made of where flow was occurring. In some locations it is clear from visual observations that water emerges from the ground or disappears underground. These observations, taken along the length of a watercourse provide an understanding of where each watercourse changes from being a ‘gaining stream’ — which is receiving inflow from groundwater; to a ‘losing stream’ — which is discharging water into the ground. These are direct observations of groundwater–surface water interactions, providing important information regarding the location and direction of groundwater exchange.

2.2 HYDROCHEMICAL ANALYSIS OF WATER SAMPLES

Major cation and trace ion analysis was conducted by Inductively Coupled Plasma Emission Spectrometry (ICP-ES). Anions (Cl^-, Br^-, SO_4^{2-} and NO_3^-) were analysed by Ion Chromatography (IC).

The stable isotopes of water (δ^2H and $\delta^{18}O$) were analysed by the CSIRO Land and Water Isotope Analysis Service, using gas ratio mass spectrometry.

Strontium isotope ratios ($^{87/86}Sr$) were analysed at the University of Adelaide using a Finnegan Mat 262 thermal ionisation mass spectrometer (TIMS). Strontium was extracted from water samples by evaporating water to leave a solid precipitate, which was then re-dissolved in hydrochloric acid and filtered through columns of Biorad cation exchange resin to isolate $SrCl_2$ from the precipitate.

Radon-222 activities (^{222}Rn) were analysed by liquid scintillation counting on a LKB Wallac Quantulus counter, according to the technique developed by Herczeg et al. (1994). Corrections are made to account for radioactive decay that occurs between the time of sampling and time of analysis in the laboratory.

Groundwater samples were collected for chlorofluorocarbons (CFCs), carbon-14 (^{14}C) and carbon 13/12 ratio ($\delta^{13}C$) analysis to determine the age of the water. These parameters were analysed by the CSIRO Land and Water Isotope Analysis Service. Analysis of CFCs is by purge and trap gas chromatography. Carbon-14 activity is analysed by liquid scintillation count, using a Wallac Quantulus Liquid Scintillation Counter.

The Fontes and Garnier correction model (Fontes and Garnier 1979) was used to account for geochemical interactions that modify the initial activity (A_o) of ^{14}C at the time of recharge. The correction model requires input of the chemical and isotopic end members of soil gas $\delta^{13}C$, ^{14}C and partial pressure of CO_2 (pCO_2) and carbonate mineral $\delta^{13}C$ and ^{14}C. The values used in this investigation were: initial activity (A_o) of soil CO_2 ^{14}C = 85 pmC; soil gas $\delta^{13}C$ = -13 ‰; carbonate mineral $\delta^{13}C$ = -7.8 ‰; and carbonate mineral ^{14}C = 0 pmC (Harrington 1999).

2.3 VIDEOGRAPHY

The locations of dry season pools shown in Figure 2 were determined from extensive aerial videographic surveys of watercourses of the Mount Lofty Ranges undertaken in April and May 2003. Digital video image of watercourses was captured using a helicopter-mounted gyro-stabilised digital video camera. The locations of identifiable pools were transferred from digital video to GIS spatial data coverage. The survey was conducted in autumn before rain, to ensure that only permanent water was recorded.

This coverage provides important data in the determination of groundwater discharge locations as the persistence of these pools through the dry season suggests that water levels are maintained by groundwater discharges.

2.4 HYDROGRAPHS

When interpreting the hydrochemical indicators of surface waters, it is useful to have an understanding of the flow conditions in the stream at the time of sampling and in the period prior to sampling. Flow-rates are affected by the amount of water entering the stream, either via surface runoff, groundwater discharges, or interflow. Variations in the rate of surface runoff and interflow are affected by the occurrence, duration, and intensity of rainfall events. Hence, if sampling of surface water occurs during or shortly after significant rain events, the influence of recent rainfall runoff may be indicated by the surface water hydrochemistry.

The hydrographs in Figures 3 and 4 indicate where river/creek flows were affected by rain events close to the time of sampling. It can be seen that during sampling round 1, recent rain events had affected flow in the Lower Bremer River, Mount Barker Creek, the Angas River and Currency Creek. Other creeks and rivers in the target catchments, for which streamflow data was available, were not affected.

In the particularly dry period during which sampling round 2 took place, much of the water from significant rain events preceding the sampling round was captured, either by infiltration into soils or by agricultural dams, and hence did not result in significant flow in any of the monitored creeks and rivers.

There were a number of significant rain events in the three weeks leading up to sampling round 3. It can be seen in the hydrographs that this rain resulted in the recommencement of flows in all the monitored rivers/creeks (apart from Reedy Creek, for which the data does not extend to that time). However, the initial flows caused by the rain in late April 2007 had diminished to varying degrees by the time sampling round 3 commenced. The result of these short-term peaks in flow prior to round 3 may have been to flush the rivers/creeks of much of the solutes and dry sediments deposited during the prior dry period. It is also seen that significant early winter flow peaks, leading to sustained winter flow-rates in these rivers/creeks, occurred after the completion of sampling round 3.

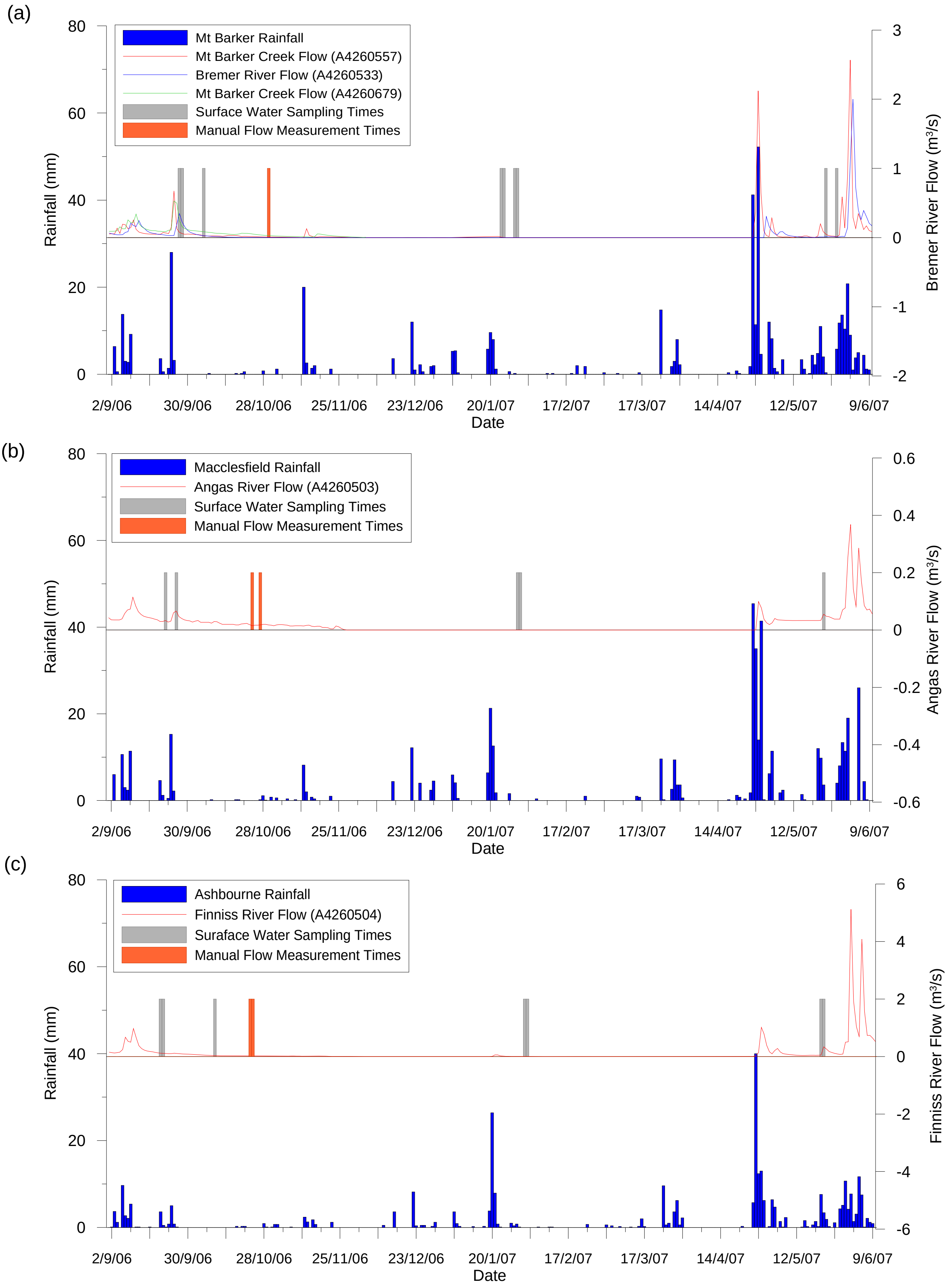


Figure 3. **Hydrographs and rainfall records for the (a) Bremer, (b) Angas and (c) Finniss River catchments, spanning the period of the three sampling rounds**

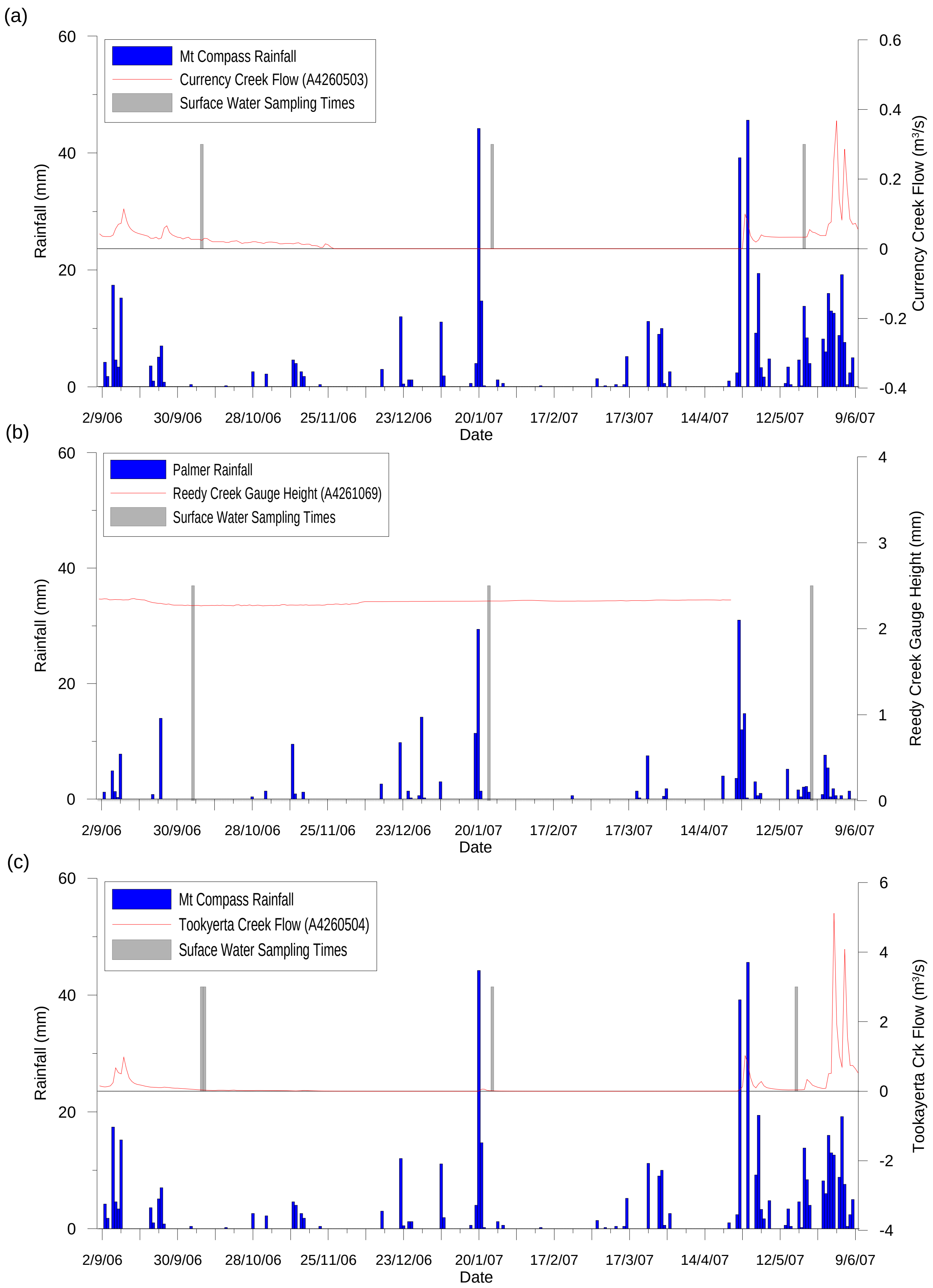


Figure 4. **Hydrographs and rainfall records for the (a) Currency, (b) Reedy and (c) Tookayerta Creek catchments, spanning the period of the three sampling rounds**

3. RESULTS

3.1 PRESENTATION OF HYDROCHEMISTRY RESULTS

The results presented in this chapter focus primarily on the hydrochemical analyses of surface and groundwater samples. The results for each catchment are examined in turn, with a graphical presentation of the key data and a brief discussion of their significance. The interpretation of these data, and the findings in relation to the interaction between surface water and groundwater in each catchment are then discussed in Chapter 5.

Groundwater salinity (expressed as specific electrical conductivity, SEC) and chloride concentrations ([Cl^-]) are presented in tables. Surface water [Cl^-] values are presented as bar graphs with the samples arranged in approximately run-of-river order and with samples from tributaries grouped together to reveal patterns of change in the flow direction of the river, or differing water characteristics in individual sub-catchments. Chloride generally does not participate in common hydrochemical reactions occurring in surface water environments. Variations in the [Cl^-] values of surface water are generally a result of evaporation, which increases [Cl^-]. When surface water is stationary it is subject to evaporation for a longer time than when it is flowing. Hence, pools of stationary water undergo more evaporative concentration than flowing water and tend to have higher [Cl^-] values. Ultimately, the observed [Cl^-] of surface water is a result of the [Cl^-] of the mixture of inflowing water sources, including groundwater and surface runoff, and the degree of evaporation that the surface water has been subject to. Groundwater [Cl^-] values result from a combination of the evaporative enrichment of chloride in water prior to and during groundwater recharge, and the dissolution of chloride-bearing minerals from the matrix of the aquifer over the typically long periods of residence of water in an aquifer system.

The stable isotopes of the water molecule, expressed as the ^{2}H to ^{1}H ratio ($\delta^{2}H$) and the ^{18}O to ^{16}O ratio ($\delta^{18}O$) relative to standard mean ocean water, are presented in scatter graphs of $\delta^{2}H$ versus $\delta^{18}O$, or $\delta^{2}H$ versus [Cl^-], depending on which analysis is more revealing. These provide indications of isotopic characteristics of the groundwater and surface water samples and the degree of evaporation that the water has undergone at the time and location of the sample collection. As well as revealing some of the isotopic similarity of water from different sources, this knowledge provides some constraint on the likely causes of differences in other hydrochemical parameters of interest, such as chloride concentrations and radon activity. Also shown in these graphs are historic stable isotope data for rainfall samples from a number of rainfall collection stations that are located close to the study catchments. A local meteoric water line (LMWL), which is a trend line through the $\delta^{2}H$ and $\delta^{18}O$ data for samples from a particular location, is shown on each graph. In some cases there are insufficient data to construct a LMWL for a nearby rainfall collection station, and hence a LMWL for Adelaide is shown.

The radon-222 (^{222}Rn) activities of surface water samples are presented in scatter graphs, plotted against sample salinities expressed as SEC. Presenting these data in this way allows easy visual identification of which samples have significantly higher ^{222}Rn activities and whether there is any correlation between radon activity and salinity, which may occur if there is an inflow of saline groundwater into the surface water close to the sample location. The ^{222}Rn activity was used as an indicator of groundwater outflows occurring either recently before, or contemporary with, the time of sampling, and occurring fairly close to the sampling point. ^{222}Rn activity values of greater than 1 Bq/L in surface water samples were taken to indicate some degree of nearby and recent groundwater outflow. Activities below 1 Bq/L were not taken to imply that groundwater is not contributing to the water found at any location, but that if it was contributing, then the groundwater outflow rate is low, such that discharged groundwater has had sufficient time to degas its ^{222}Rn or has undergone radioactive decay to the extent that the remaining activity of the ^{222}Rn in the water is low and cannot be distinguished from the activity of ^{222}Rn that may result from emanation of Rn from sediments in the hyporheic zone (Cook et al. 2006). In recognition of this, ^{222}Rn activity values below 1 Bq/L were considered to be ambiguous.

Dissolved strontium is present in small quantities in most natural waters. The ratio of two naturally occurring strontium isotopes, ^{87}Sr and ^{86}Sr, is commonly used as a tracer of the source of environmental strontium and, by implication, the source of the water in which the strontium is dissolved. The strontium isotope ratios of surface water samples are presented in two ways. Firstly, they are shown as points against their sample location identifications, which are arranged in run-of-river order with samples from tributaries grouped together. This form of presentation illustrates the relative change in ratio between each sample round and the differences or similarities of ratios between locations, revealing the degree of variation of water sources at each location. Secondly, the ratios of all surface and groundwater samples are plotted on a scatter graph of $^{87/86}$Sr ratio versus the reciprocal of the strontium concentration (1/[Sr]). This presentation format reveals patterns of mixing between water sources. If the dissolved Sr in a water sample is derived from two sources with distinct $^{87/86}$Sr ratios, the ratio of the sample will fall on a line on the graph between the $^{87/86}$Sr ratio and 1/[Sr] of the two contributing water sources. Its position along this line depends on the proportion of contribution from each source.

The age dating estimates of groundwater samples were achieved using carbon-14 and CFC-11 and CFC-12 dating techniques. These techniques are effective in different age ranges: carbon-14 dating being useful for samples of ages greater than 100–200 years; while CFC dating is effective only for groundwaters that have recharge since 1965. As CFCs are not natural in the environment and did not exist in the atmosphere until approximately 1965, groundwater recharged prior to that year should have CFC concentrations that are zero or below detection levels.

As ^{14}C activities in groundwater are generally diminished by the dissolution of carbonates in the rock matrix and through the recharge zone, groundwater ^{14}C activities of greater than 85 pmC are considered to be indistinguishable from present-day ^{14}C activities, and are therefore discarded in preference of CFC age estimates. Where ^{14}C age estimates are stated in this report, uncorrected ^{14}C ages are stated as well as ages corrected using the Fontes and Garnier (1979) correction model. In some cases the correction model results in a negative age because a large proportion of the dissolved carbon is from aquifer matrix carbonate dissolution. In these cases the CFC age estimate should be used in preference to the ^{14}C age estimate.

The ages of groundwater samples provide an indication of residence times of water within the aquifers. As a general rule, shorter residence times indicate a relatively rapid flow through the aquifer as water is replenished in a timescale of years or decades, rather than over a period of centuries or more. This effect is dependent on the type and extent of the aquifer. In the MLR, where aquifers are largely unconfined and groundwater divides are governed by topography, high replenishments rates and low groundwater residence times are more likely in aquifers from which water is flowing freely through discharge zones within the catchment.

3.2 BREMER RIVER CATCHMENT

3.2.1 CHLORIDE CONCENTRATIONS

Groundwater samples from wells in the Bremer River Catchment (BRC) had [Cl$^-$] ranging from 503 mg/L to 1988 mg/L (Table 1). The variation of these concentrations was in approximate proportion to the salinity of the water, as signified by the specific electrical conductivity (SEC).

Table 1. Chloride concentrations ([Cl$^-$]) and specific electrical conductivity (SEC) for wells sampled in the Bremer River Catchment during two rounds of sampling

Sampled Well ID	Round 1 [Cl$^-$] (mg/L)	Round 2 [Cl$^-$] (mg/L)	Round 1 SEC µS/cm	Round 2 SEC µS/cm
Bg01	672	687	3080	2619
Bg02	1749	n/t	5332	n/t
Bg03	1260	1258	4408	4539
Bg04	1941	1988	5670	5954
Bg05	1060	986	4240	3519
Bg06	695	696	2946	2612
Bg07	n/t	503	n/t	1785

n/t signifies not tested

Significantly, these groundwater [Cl$^-$] values were all higher than the [Cl$^-$] of any of the Mount Barker, Nairne and Dawsley Creek surface water samples (Figure 5), suggesting either that there were lower [Cl$^-$] groundwater sources that were not sampled, or that groundwater outflows were probably not the only source of water to those creeks at the time of sampling. Conversely, many of the surface water samples from the Upper Bremer River and Rodwell Creek had higher [Cl$^-$] than any of the groundwater samples, suggesting that there were higher [Cl$^-$] groundwater sources that were not sampled and/or there has been significant evaporative concentration of many of the surface waters sampled.

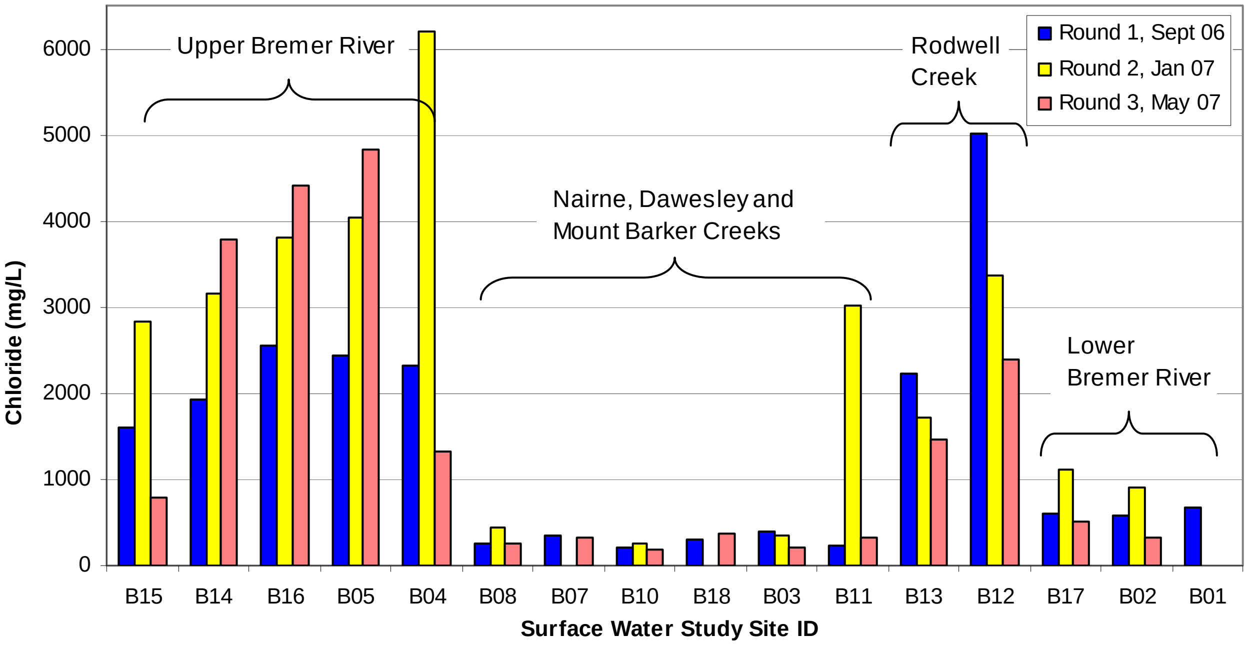


Figure 5. Chloride concentrations of surface water samples from the Bremer River Catchment, arranged in order of the run-of-river and tributaries

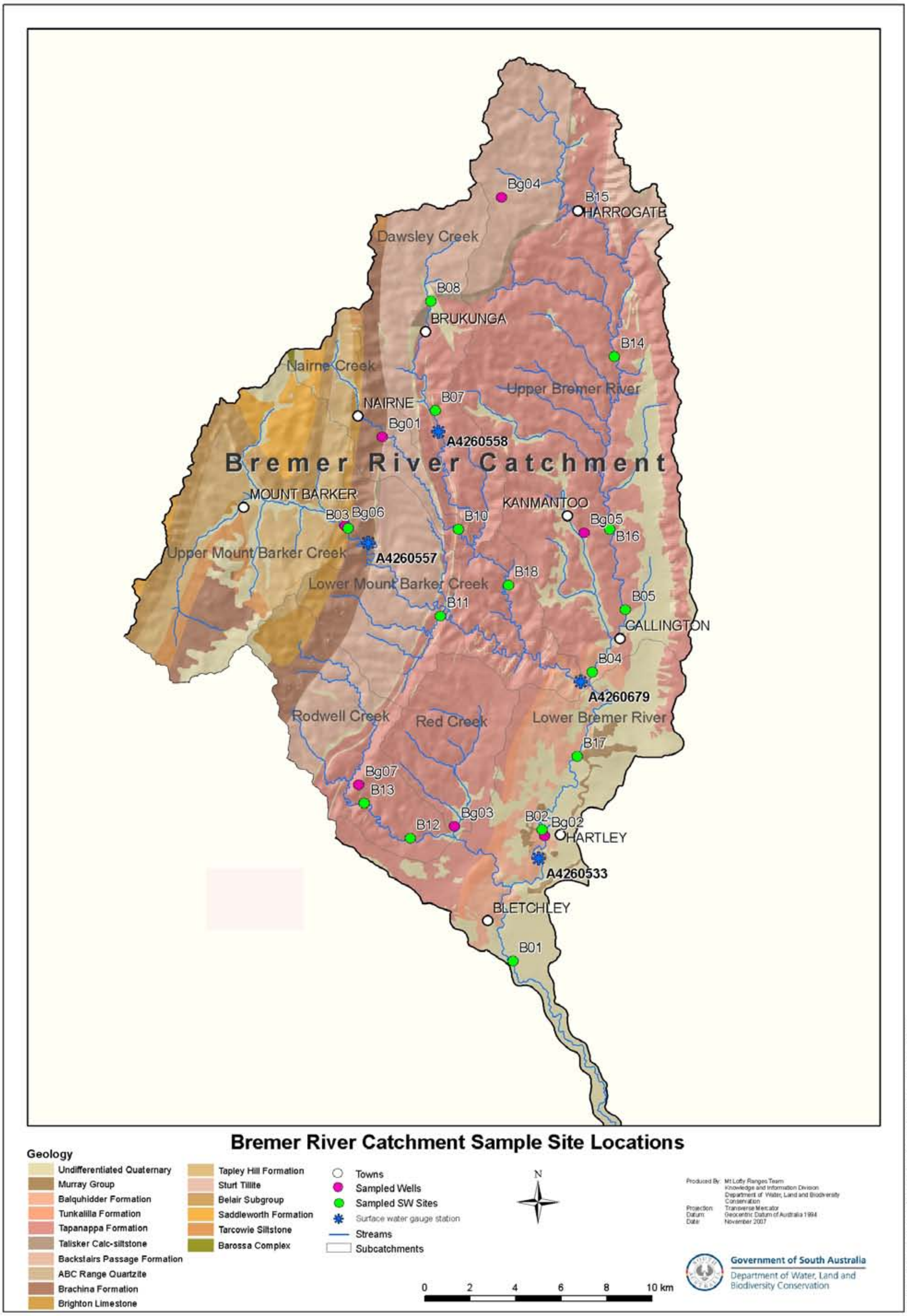


Figure 6. Bremer River Catchment sample site locations

Samples from locations in the upper Bremer River (B15, B14, B16, B05, B04) and Rodwell Creek (B13 and B12) had chloride concentrations that were much higher than samples from the Mount Barker, Nairne and Dawsley Creeks. Samples from the Bremer River below the confluence with Mount Barker Creek (B17, B02 and B01) had [Cl^-] that were higher than those from the Mount Barker, Nairne and Dawsley Creeks but significantly lower than samples from the Upper Bremer River and Rodwell Creek. These probably resulted from a mixture of low salinity water discharging from Mount Barker Creek and high salinity water discharging from the Upper Bremer River, Rodwell Creek and the groundwater systems local to the lower Bremer River.

Samples from the Nairne/Dawsley and Mount Barker Creeks were fairly consistent between the three rounds and all but one of the samples were within a narrow [Cl^-] range between 187 mg/L and 438 mg/L. These are low [Cl^-] values compared to samples from elsewhere in the BRC. The exception in these sub-catchments was the January 2007 sample from location B11, which at that time had reduced to a stationary pool, subject to a high degree of evaporation. Significantly, the [Cl^-] at locations B08, B07, B10, B18 did not vary much between sample rounds 1 and 2 (spring and autumn), suggesting similar sources of water to these creeks in spring and autumn. At location B03, the autumn sample had significantly lower [Cl^-] than in sample round 1 (spring), indicating a higher proportion of low [Cl^-] surface runoff from recent rainfall at the time of sampling.

The large [Cl^-] difference in all three sample rounds between sample locations in the Nairne/Dawsley/Mount Barker Creek sub-catchments and those in the Upper Bremer River in round 1 cannot be ascribed to evaporation alone. There must be a source of high [Cl^-] groundwater that is supplying water to the upper Bremer River. In the autumn round of sampling, three of the five locations were even more evapo-concentrated than in the summer round, suggesting that the rain prior to round 3 did not affect these locations. If the heavy and sustained rain at that time did not create surface inflows at those locations, it can be surmised that the waters present did not arise from earlier summer rainfall events and were therefore solely a result of groundwater inflows. In the other two Upper Bremer River locations, B15 and B04, the [Cl^-] concentration was lower in round 3 than in round 2, indicating that there had been considerable dilution by the recent rainfall.

The [Cl^-] of water sampled at the two Rodwell Creek locations (B12 and B13) were in the same range as the upper Bremer River samples. The high [Cl^-] in the spring sample round suggest inflows of high [Cl^-] groundwater. The [Cl^-] at these locations declined from a maximum in round 1 to a minimum in round 3. The lower [Cl^-] in autumn can be ascribed to inflows of low [Cl^-] surface runoff resulting from the rain at that time.

Samples from the Lower Bremer River at locations (B17, B02 and B01) were very similar to each other in the spring sampling round, suggesting water from a common source flowing through this section of the river at that time.

3.2.2 STABLE ISOTOPES OF WATER

The positions of the BRC groundwater samples on the graph of δ^2H versus δ^{18}O (Figure 7) are distributed above the local meteoric water line (LMWL) based on Adelaide Rainfall. Another LMWL is drawn based on rainfall samples from Mount Pleasant, which is geographically and topographically more characteristic of the BRC. The BRC groundwater samples lie in a region between the two LMWL and within the same region of the graph as the rainfall samples from Mount Pleasant. All of the groundwater samples are therefore isotopically similar to rainfall in the area, indicating that recharge of groundwater is direct and rapid in this area, as water does not undergo much evaporative enrichment between falling as rain and recharging the aquifers. The location on the graph of the groundwater samples, toward the isotopically depleted end of the LMWL, also suggests that the groundwater results primarily from winter rainfall, which is generally more isotopically depleted than summer rainfall.

The round 1 surface water samples (27 Sep to 6 Oct 2006) were enriched in ^{2}H and ^{18}O compared to the groundwater, lying on a trend line of evaporative enrichment of the groundwater and Mount Pleasant rainfall samples. The position of these on the graph indicates that the surface water at that time either resulted from isotopically enriched rainfall, which is more typical of summer rain, or resulted from evaporative enrichment of either groundwater or rainfall with the typical winter isotopic characteristics.

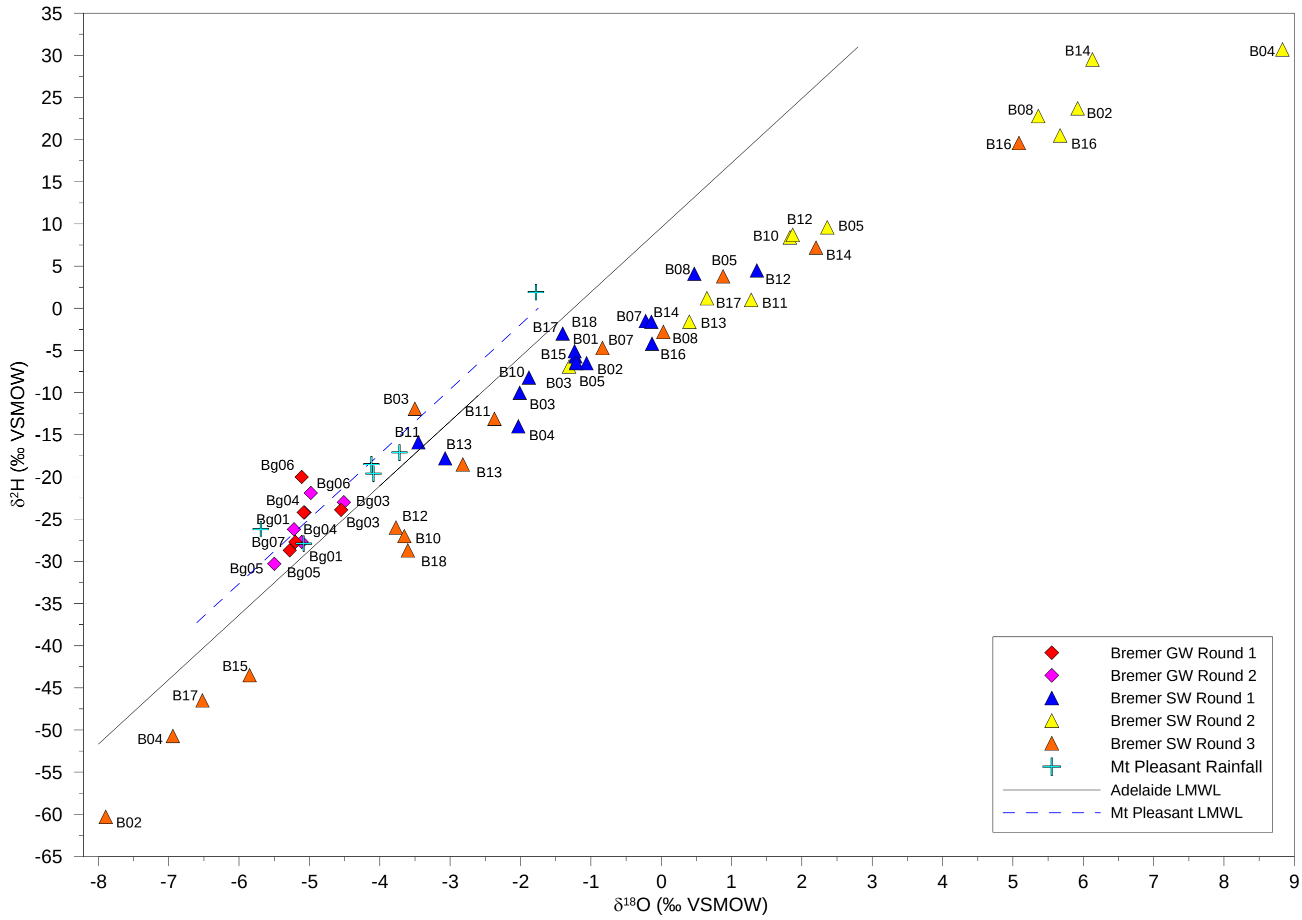


Figure 7. Stable isotopes of water, expressed as δ^{2}H versus δ^{18}O, for samples from the Bremer River Catchment (study site identifiers are shown beside each point)

The round 2 surface water samples, taken between 24 and 30 Jan 2007, fall further along the evaporative enrichment trend than the round 1 surface water samples, reflecting a greater degree of evaporation during the summer. A group of five samples (B02, B04, B08, B14, B16) was significantly more enriched than the other round 2 samples. Of these, four were from the main course of the Bremer River at points where water formed broad pools with very low rates of inflow, resulting in a high residence time of water and large surface area, promoting a high degree of evaporative enrichment.

The round 3 surface water samples, taken between 24 and 28 May 2007, were affected by rain that fell between 26 and 30 April, and also during the first three days of sampling in this catchment. The stable isotope results for these samples are widely distributed on the δ^{2}H/δ^{18}O graph. Many of the samples lie on the same evaporative enrichment trend as the samples from the spring and summer sample rounds, but were generally less enriched than samples from the other two rounds. These results suggest water at those locations was derived from the same water sources as during the earlier rounds, but had been subject to conditions of lower evaporation than during the prior rounds of sampling. Four samples (B02, B04, B15 and B17) lie at the highly depleted end of the meteoric water line. As there are unlikely to be any environmental processes that cause depletion of $\delta^{2}H$ and $\delta^{18}O$ after the water has fallen as rain, these samples must be representative of the rainfall immediately preceding the autumn sample round, suggesting unusually isotopically depleted rain events at that time. These samples are all from points along the main course of the Bremer River. At these points, for the river water to be isotopically similar to recent rainfall, the water present at these points during the sampling round must have been derived almost entirely from recent surface runoff, implying that water previously existing at these points must have been flushed through by the May rainfall. Three points (B12, B10 and B18) lie between the main group of evaporatively enriched water samples and the highly depleted, rainfall dominated samples. These are interpreted as being a result of the dilution of residual evaporatively enriched water by recent rainfall.

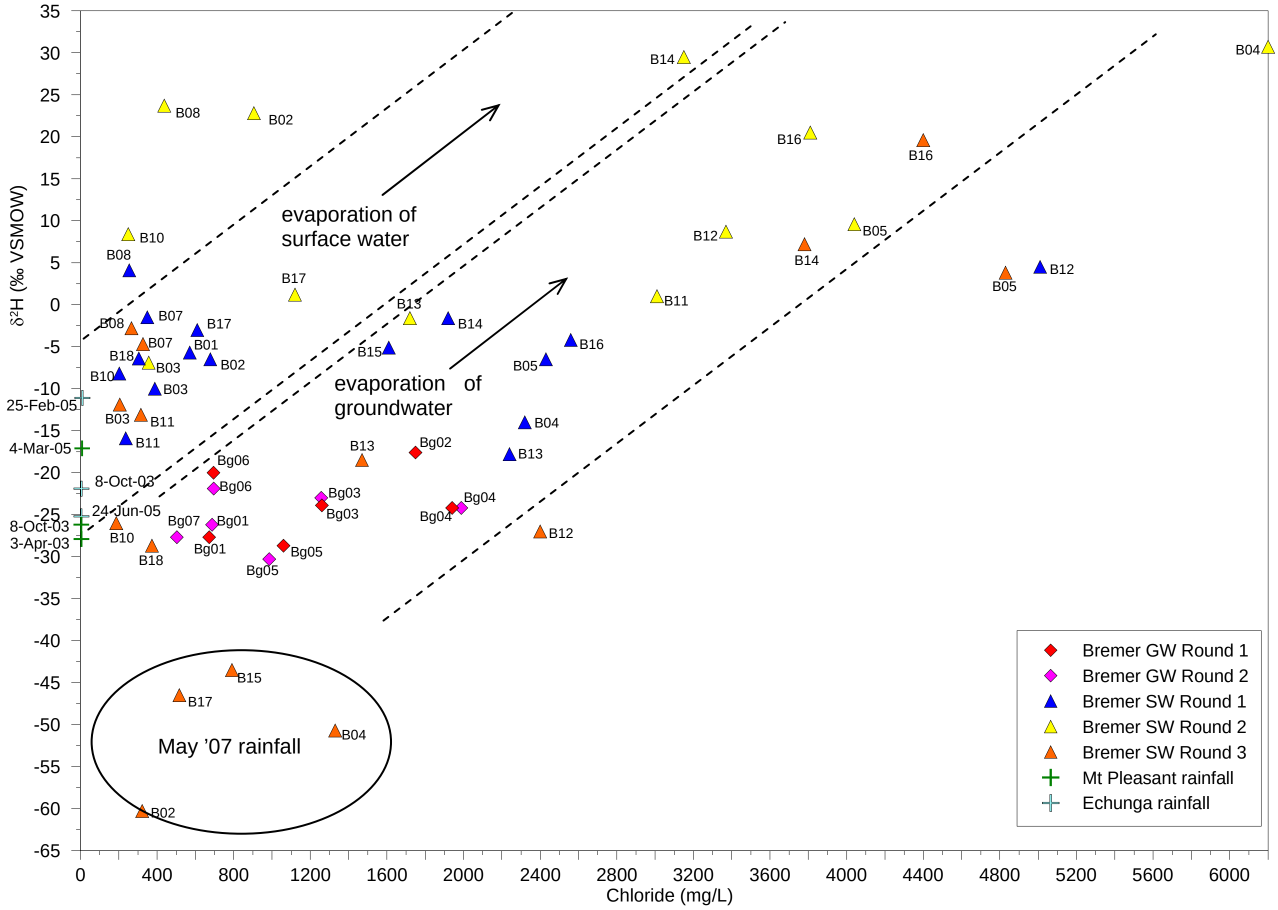


Figure 8. Deuterium isotope ratio ($\delta^{2}H$) versus chloride for groundwater and surface water samples from the Bremer River Catchment (the dashed lines outline areas of the graph occupied by samples resulting from evaporative enrichment of rainfall or surface runoff, and those resulting from evaporative enrichment of groundwater)

The graph of deuterium ($\delta^{2}H$) plotted against the chloride concentration ($[Cl^{-}]$) (Figure 8) was used to identify the degree of evaporation of surface water samples and to indicate whether this was likely to be a result of the evaporation of groundwater or surface runoff. All of the groundwater samples from the Bremer River Catchment lie in a cluster between $\delta^{2}H$ of -17 $^{o}/_{oo}$ and -31 $^{o}/_{oo}$ and $[Cl^{-}]$ of 500 and 2000 mg/L. Evaporation causes enrichment in $\delta^{2}H$ and $[Cl^{-}]$ simultaneously. The direction of evaporative enrichment of groundwater samples shown in Figure 8 is derived from the location on the $\delta^{2}H/[Cl^{-}]$ of surface water samples, such as B05 and B16, that are shown in the $\delta^{2}H/\delta^{18}O$ graph to differ only in their degree of evaporative enrichment. The location of surface water samples on the $\delta^{2}H/[Cl^{-}]$ graph with respect to the evaporative enrichment trend suggests that the δ^2H/[Cl$^-$] characteristics of samples from the Upper Bremer River (B04, B05, B14, B15, B16) and Rodwell Creek (B12, B13) result from the evaporative enrichment of groundwater, whereas the δ^2H/[Cl$^-$] characteristics of samples from the Nairne, Dawsley and Mount Barker Creeks (B03, B11, B07, B10, B18), and water outflowing from Mount Barker Creek at B17, result from evaporation of local rainfall or surface runoff. An exception to the latter group is the round 2 (summer) sample from B11, which had characteristics resulting from the evaporation of groundwater.

3.2.3 RADON-222 ACTIVITY

The western part of the BRC overlies Adelaidean sequence geology, while the majority overlies Kanmantoo group geology, primarily the Tapanappa Formation and Backstairs Passage Formation. Groundwater samples taken from wells in Kanmantoo Group geology had ^{222}Rn concentrations that ranged from 102 to 1139 Bq/L. Only one sample, with a ^{222}Rn activity of 118 Bq/L, was taken from a well in the Adelaidean geology in this catchment. Surface water ^{222}Rn activities were all relatively low, ranging from approximately 0.1 to 3.7 Bq/L (Figure 9). Generally, activities were higher during sample rounds 1 and 2, when there had been little preceding rainfall, and lower during sampling round 3, after significant recent rainfall. In the four locations where surface water ^{222}Rn activities were above 1 Bq/L (B11, B17, B13 and B15), some degree of groundwater inflow was confirmed.

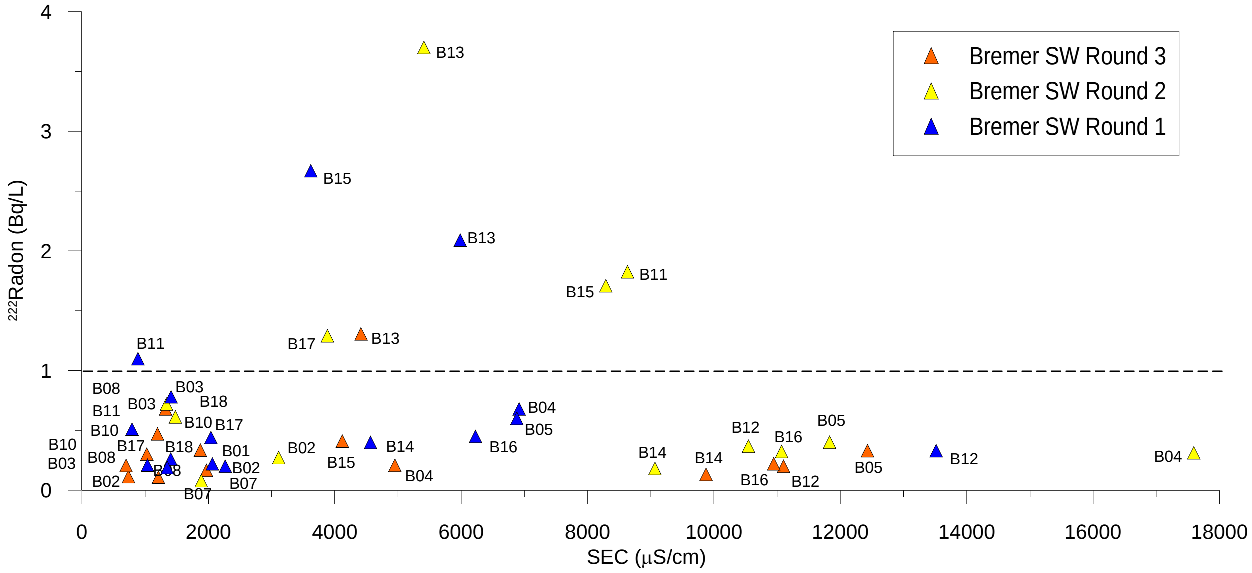


Figure 9. ^{222}Radon activities of surface water samples in the Bremer River Catchment

In a catchment where groundwater ^{222}Rn activities are relatively high, low surface water ^{222}Rn activities may be either a result of minimal interaction between surface and groundwater or reflective of low inflows of groundwater, resulting in high residence time of water in pools and allowing more time for radon to decay or degas. The high degree of evaporative enrichment of dissolved salts in many of these surface water samples suggests a high residence time for water at many of the BRC surface water sample locations.

Salinity measurements of BRC groundwater samples ranged from 1785 to 6284 µS/cm EC, whereas surface water salinity during the summer round of sampling, when ^{222}Rn activities were highest, ranged from 1479 to 17 593 µS/cm. Seven of the thirteen sites with water present at that time had salinities that were greater than the highest groundwater value, including five that were greater than 9000 µS/cm. These results suggest a high degree of evaporation had occurred, indicative of higher residence times of water in the pools in the BRC. Hence, the relatively low ^{222}Rn activities may be due to the decay and degassing of radon rather than due to low groundwater contributions. The salinity results also suggest that water at these locations did not result from rainfall in the week prior to sampling, but that the water had been resident in the pools for some time.

3.2.4 STRONTIUM ISOTOPE RATIOS

Strontium 87/86 isotope ratios ($^{87/86}$Sr ratio) of surface water samples from the BRC were remarkably similar across the three sampling rounds at all but one location (Figure 10). At location B11 the $^{87/86}$Sr ratios suggested the source of dissolved strontium was distinctly different during round 2 (summer) than during the other sample rounds. This supports the finding from the stable isotope results that surface water at B11 was from a groundwater source in the summer but predominantly from surface runoff in the spring and autumn sampling rounds.

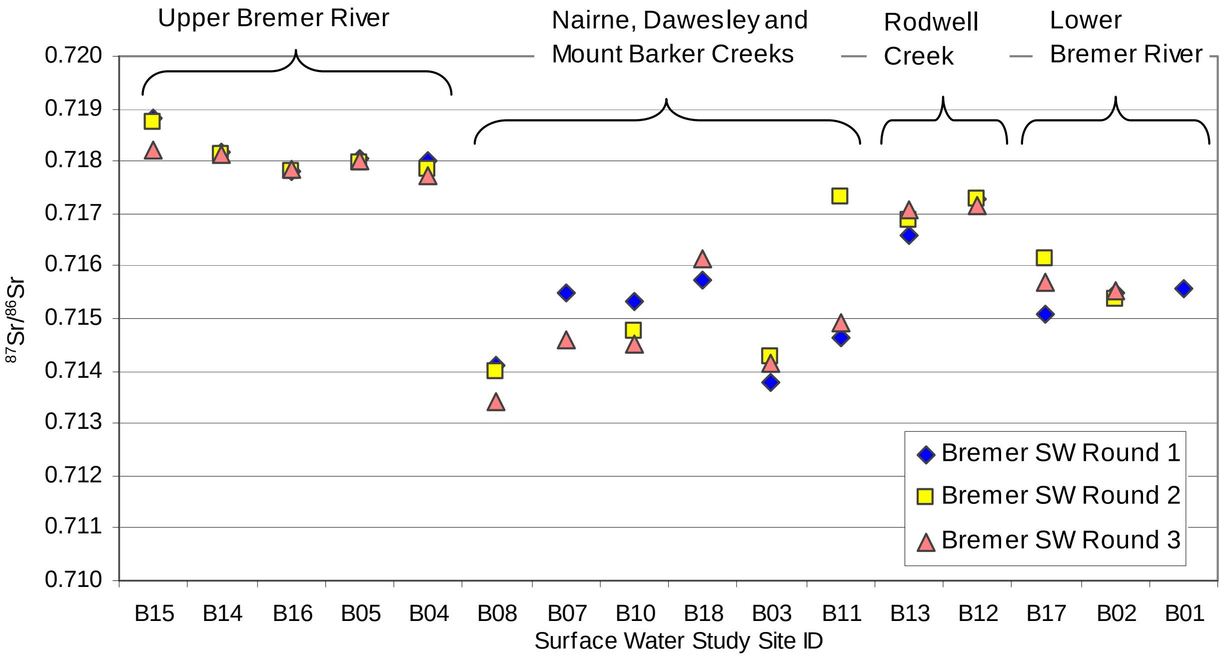


Figure 10. Strontium isotope ratios of surface water samples from the Bremer River Catchment

There were significant variations in $^{87/86}$Sr between sampling points, suggesting that sources of dissolved strontium differed from one location to another, but that those sources did not change from one season to another. The similarity of the $^{87/86}$Sr ratios across seasons at each sample location also suggests a single source for the dissolved strontium at each location. This would result if the water at each location was predominantly from groundwater, or if the solutes in each location were static, and simply diluted each time there was a new input of water from rainfall. The latter explanation is only possible in streams which did not flow during the year of the sampling program and remained a series of connected pools. This was not the case for Mount Barker, Dawsley Creek and the lower parts of Rodwell Creek, and the lower parts of the Bremer River during sampling round 1. The $^{87/86}$Sr ratios of groundwater samples within the catchment were all within a range from 0.716 to 0.7185. Many of the surface water $^{87/86}$Sr ratios fall within this range, and all are significantly different to a modern rainwater $^{87/86}$Sr ratio, which is typically around 0.710.

Although $^{87/86}$Sr ratios were generally constant between sample rounds, strontium concentrations varied in time due to differences in the total solute concentrations of water, resulting from varying degrees of evaporative enrichment of the water at different times. These are illustrated by plotting the $^{87/86}$Sr ratio against the reciprocal of the Sr concentration ([Sr]) (Figure 11).

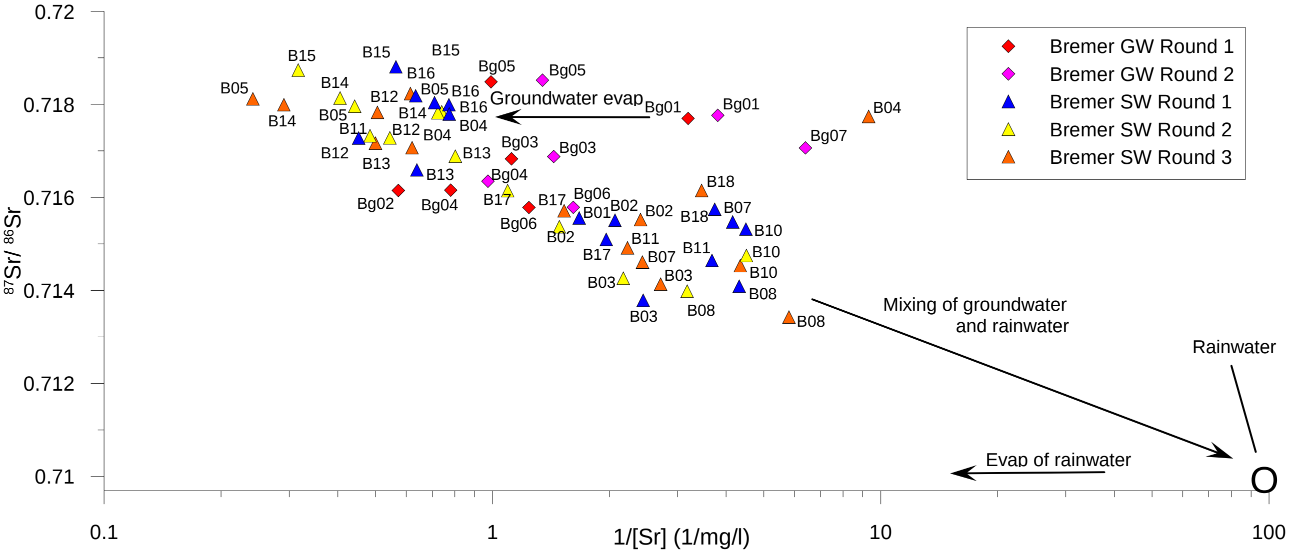


Figure 11. $^{87/86}$**Sr isotope ratios versus reciprocal of Sr concentrations for surface water and groundwater samples from the BRC**

Some more location-specific interpretations can be made from Figure 11 when the results for samples from subsections of the catchment are examined individually.

Samples from location B13 in Rodwell Creek had the same $^{87/86}$Sr ratio of water from well Bg07, but had a higher [Sr] suggesting that this was an evaporative enrichment of water from the same source. There is no indication of any other sources, including rain water, in the B13 surface water Sr characteristics. This is the same for all three sampling rounds. There was a particularly close agreement between surface water at points B12 and B13, and nearby groundwater $^{87/86}$Sr ratios in wells Bg07 and Bg03. Location B12 is at a point where the property owner reports there is water permanently present due to inflows from springs, while B13 is an isolated permanent pool at the base of a steep fractured rock escarpment.

All samples from the Bremer River north of the Mount Barker Creek confluence (B15, B14, B16, B05) had $^{87/86}$Sr signatures that appear to result from evaporative enrichment of the Sr signature of groundwater sampled in well Bg05, possibly with some influence from the groundwater source sampled in well Bg03, also in the Tapanappa formation.

Water in Dawsley Creek and Nairne Creek (at points B18, B10, B07 and B08), lie on a mixing line between rainwater and groundwater samples from wells Bg01, Bg04 and Bg05, which are located to the west, north and east of the Dawsley/Nairne Creek system.

Surface water samples from the lower Bremer River at point B17 had $^{87/86}$Sr values similar to groundwater from wells at Bg06, or Bg02 with some rain-dilution. Well Bg02 is located only a few kilometres downstream of B17, in an area with similar geology.

Samples in the lower reaches of the Bremer River, at B02 lie on a $^{87/86}$Sr mixing line between water from the nearby well Bg02, and rainwater. Bg02 is a shallow well in quaternary sediments. Both the groundwater and the surface water here may have derived their $^{87/86}$Sr signature largely from the near-surface sediments and soil.

The surface water sample from B01 is from a section of the lower Bremer River that was observed to lose water to the groundwater system. We would not expect this water to reflect the characteristics of groundwater in the immediate area, but to have flowed from further upstream. The sample lies on a mixing line between groundwaters from Bg03 and Bg02 and rainwater.

3.2.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years and corrected ^{14}C ages for wells sampled in the BRC are listed in Table 2, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. There is no conflict between the ^{14}C and CFC results for wells Bg02 and Bg03, which suggest groundwater of a low age of around 26–40 years, and wells Bg05 and Bg06, which have older groundwater of approximately 650 years and 1880 years respectively. The ^{14}C and CFC results for wells Bg01 and Bg04 are conflicting, and the age of water from Bg01 cannot be stated with any confidence from these results. However, well Bg04 is completed very deep (193 m) in a Kanmantoo Group rock type and is very unlikely to be as low in age as the CFC results suggest. It is more likely that some CFC contamination of the sample has occurred in this case and the corrected ^{14}C age of approximately 3700 years may be a reliable result.

Table 2. Groundwater age estimates for samples from wells in the BRC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}C$ ($^o/_{oo}$)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
Bg01	37.00	40.8	-12.00	6.04	0.184	7411	4062	1972	1973
Bg02	38.50	87.6	-11.10	4.69	0.054	1092	-4164	1975	1981
Bg03	49.00	76.35	-11.20	8.00	0.233	2231	-2614	1968	1972
Bg04	59.00	66.6	-14.20	3.65	0.520	3357	3697	1971	1971
Bg05	16.5	82.40	-13.70	6.40	0.128	1600	652	<1965	<1965
Bg06	22.5	66.90	-13.30	5.82	0.140	3323	1882	<1965	NA

3.3 FINNISS RIVER CATCHMENT

3.3.1 CHLORIDE CONCENTRATIONS

Groundwater samples from wells in the Finniss River Catchment (FRC) had [Cl^-] values ranging from 58 mg/L to 1199 mg/L (Table 3). The variation of these concentrations was in approximate proportion to the salinity of the water as signified by the SEC. The majority of wells sampled have [Cl^-] values within a narrower range than this, between 282 and 633 uS/cm. The low value of 58 mg/L came from a well at Yundi that draws from the Permian Sand aquifer (PSA), which typically has a low concentration of dissolved solids (Banks et al. 2007). The PSA occurs extensively throughout the south-western and eastern parts of the FRC and adjacent to the main course of the Finniss River, all the other wells sampled in this catchment draw from the fractured rock aquifers (FRA) in areas of Adelaidean, Kanmantoo Group or Barossa Complex (BC) geology. The one well with an unusually high [Cl^-] of 1199 mg/L is located in the Kanmantoo Group FRA near Ashbourne.

Table 3. Chloride concentrations and specific electrical conductivity for wells sampled in the Finniss River Catchment during two rounds of sampling (n/t signifies not tested)

Study Site ID	Round 1 [Cl$^-$] (mg/L)	Round 2 [Cl$^-$] (mg/L)	Round 1 SEC µS/cm	Round 2 SEC µS/cm
Fg01	301	282	1111	1142
Fg02	431	414	1359	1407
Fg03	1199	n/t	4542	n/t
Fg04	414	404	1951	1492
Fg05	279	278	1379	1051
Fg06	447	n/t	1742	n/t
Fg07	58	n/t	225	n/t
Fg08	n/t	633	n/t	2422

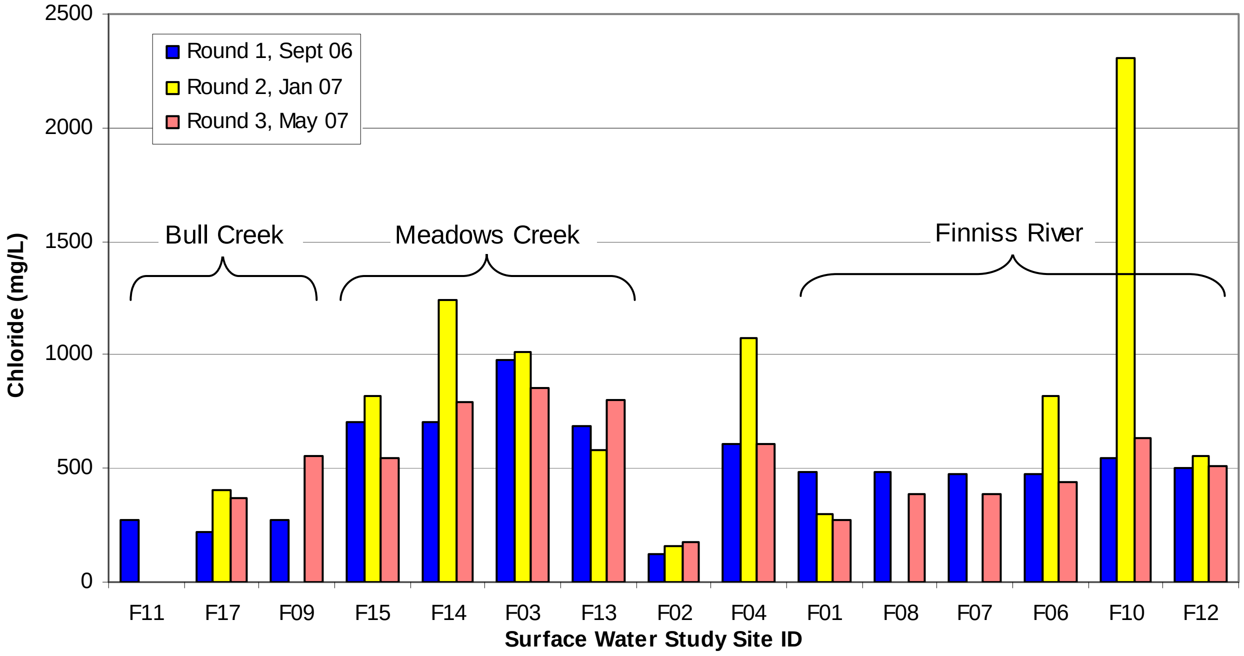


Figure 12. Chloride concentrations of surface water samples from the Finniss River Catchment

Several interpretations can be drawn from the FRC surface water chloride concentrations (Figure 12) when the values for samples from sub-sections of the catchment are examined individually.

Flow was only occurring at all three surface water sample locations in Bull Creek (F11, F17 and F09) during sample round 1. The low [Cl$^-$] at all three points at that time indicates a common water source at all three points that is distinctly lower in [Cl$^-$] than at most other places in the FRC. The higher [Cl$^-$] at F17 and F09 in the summer and autumn rounds are indicative of evapo-concentrated water from the same source.

There are three surface water sample locations on Meadows Creek (F15, F14 and F13). Location F13 is at the end of Meadows Creek, a short distance from the confluence with the Finniss River. A fourth sample location (F03) lies close to Meadows Creek on one of its tributaries. In sample round 1 (spring), the whole length of Meadows Creek was flowing and the flow-rate was successively higher at each sample location in the direction of flow, indicating the creek was gaining water along the whole section from F15 to F13. The [Cl$^-$] did not vary significantly between F15 and F13 from approximately 700 mg/L at that time. This suggests a common source of water with a [Cl$^-$] of approximately 700 mg/L to the creek along its whole length.

During sample round 2 (summer) there was no flow occurring between the Meadows Creek sample locations. The variation in [Cl$^-$] at the four sample points at that time can be attributed to differing degrees of evapo-concentration at the differing locations.

The Finniss River initially rises to the west of Yundi in an area of Permian Sand aquifers (PSA) overlying BC bedrock. Flow from this area converges with flow from the Meadows Creek at Yundi, with the Meadows Creek flow providing the majority of water at this confluence. Water sampled at location F02, just upstream of the confluence at Yundi, had a low TDS concentration and corresponding low [Cl$^-$], particularly in sample round 1. The water here had a TDS and [Cl$^-$] that was lower than elsewhere in the FRC and is very likely to be largely representative of water flowing from the PSA lying upstream of this point.

Samples from location F01 in sample round 1 represent the mixture of water from Meadows Creek, Blackfellows Creek and the upper section of the Finniss, as well as any inflows of groundwater that occur downstream of the Meadows Creek/Finniss River confluence. Equation 1 provides a two-component chloride mass balance equation in which $[Cl^-]_{mix}$ is the chloride concentration of the mixture of components with chloride concentrations $[Cl^-]_1$ and $[Cl^-]_2$, and f is the fraction of component 1 in the mixture.

$$[Cl^-]_{mix} \quad = \quad f[Cl^-]_1 + (1 - f)\,[Cl^-]_2 \qquad \textbf{Equation 1}$$

The [Cl$^-$] at F01 in sample round 1 was 487 mg/L. If Equation 1 is applied to this concentration and those at locations F13 and F02, which had [Cl$^-$] values of 688 mg/L and 126 mg/L respectively, then the proportion of water from Meadows Creek is found to be approximately 64%.

The remaining 36% of the water flowing in the Finniss River at F01 must be from a source of low [Cl$^-$] water flowing into the 6 km stretch of river between locations F02 and F01. Flow measurements at that time showed the flow-rate of low [Cl$^-$] water from the upper Finniss River at location F02 to be only approximately 0.35 L/s, while flow of high [Cl$^-$] water from Meadows Creek was approximately 13–16 L/s, and the flow in the Finniss River at location F01 was approximately 22 L/s, according to data from the river gauging station at that location. If the 13–16 L/s from Meadows Creek is considered to be approximately 64% of the water flowing at location F01, and the 0.35 L/s arriving from the upper Finniss River upstream of Yundi provides only approximately a further 1.5% of the 22 L/s flow, then the remaining 34.5 % must be provided by an inflow of low [Cl$^-$] water between the confluence with Meadows Creek and the Finniss River weir at location F01. The most likely source of this low [Cl$^-$] water is the inflow of water from the PSA into the Finniss along this stretch, implying that at the time of sample round 1, approximately one third of water in the Finniss at F01 derived from inflows from the PSA into the river between Yundi and location F01.

During sample round 2, water at F01 had significantly lower [Cl$^-$] than in round 1. There was no flow from Meadows Creek or the upper Finniss River at that time. However, a small amount of flow from Blackfellows Creek was occurring. The [Cl$^-$] observed at F01 is interpreted as being due to continued inflows of low [Cl$^-$] water from the PSA, with a minimal input from Blackfellows Creek, resulting in water at F01 having a higher [Cl$^-$] than the inflowing PSA water. In sample round 3, when there were significant flows occurring at F01, the [Cl$^-$] was less than half of that of the water flowing from Meadows Creek at F13. The volume of inflow of low [Cl$^-$] water from the upper Finniss River at F02 was not sufficient to cause this degree of dilution, suggesting again that, as during sample round 1, there was a significant inflow of low [Cl$^-$] groundwater occurring between F13 and F01.

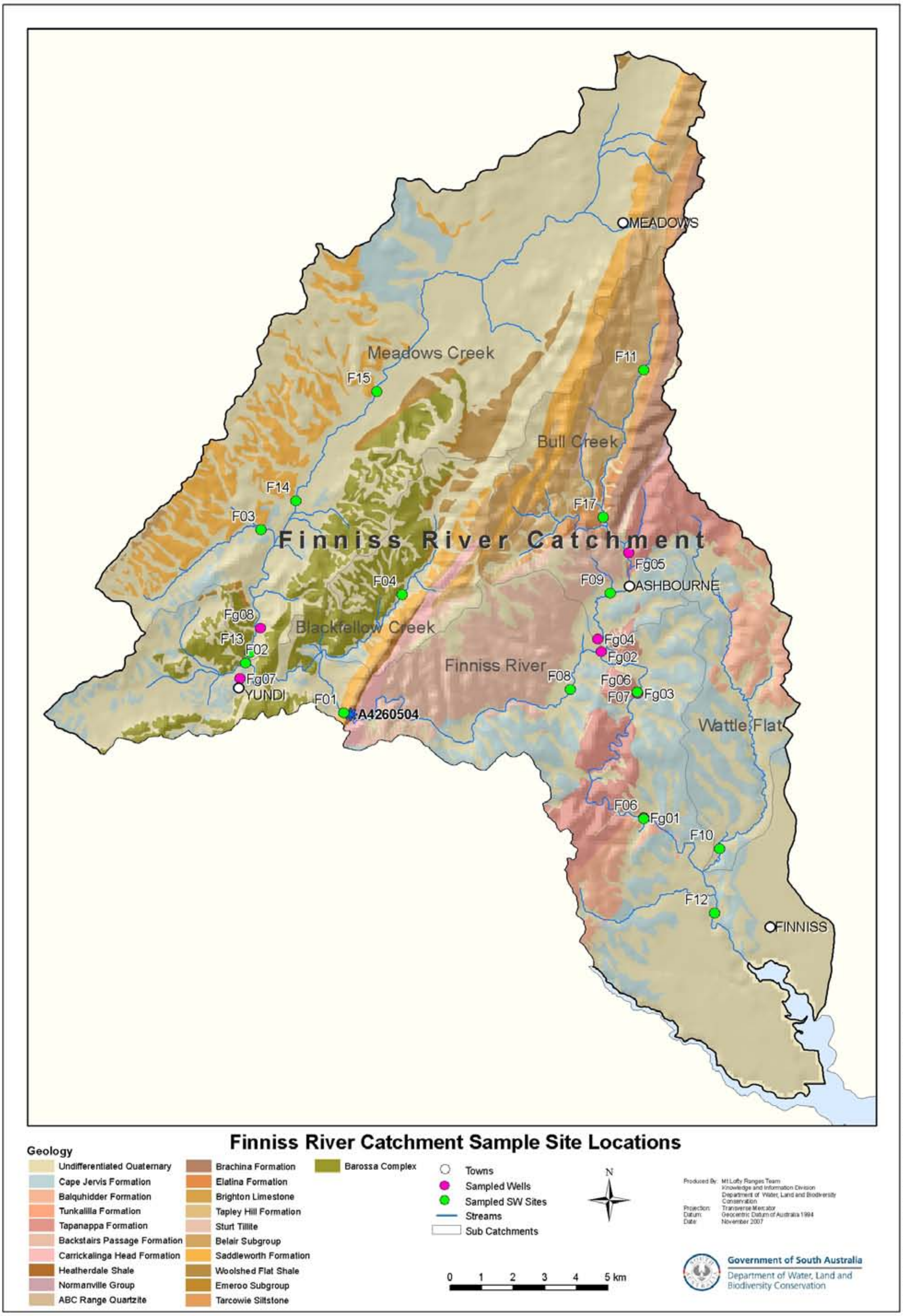


Figure 13. Finniss River Catchment sample site locations

3.3.2 STABLE ISOTOPES OF WATER

The positions of the FRC groundwater samples on the graph of δ^{2}H versus δ^{18}O (Figure 14) are distributed above the Adelaide LMWL. Another LMWL is drawn based on rainfall samples from Echunga and Kyeema, which are both geographically and topographically closer to the FRC. The FRC groundwater samples lie in a region between the two LMWL and within the same region of the graph as nine of the ten rainfall samples from Kyeema and Echunga. All of the groundwater samples are therefore isotopically similar to rainfall in the area, indicating that recharge of groundwater is direct and rapid in this area, as water does not undergo evaporation between falling as rain and recharging the aquifer. The location on the graph of the groundwater samples, toward the isotopically depleted end of the LMWL, also suggests that the groundwater results primarily from winter rainfall, which is generally more isotopically depleted than summer rainfall.

The round 1 surface water samples (20–21 Sep 2006) were enriched in ^{2}H and ^{18}O compared to the groundwater, appearing further along the LMWL than the groundwater samples and most of the MLR rainfall samples. The position of these on the graph indicates that the surface water at that time either resulted from isotopically enriched rainfall, which is more typical of summer rain, or from evaporative enrichment of either groundwater or rainfall with the typical winter isotopic characteristics. Significantly, these surface water samples fall into two groups: one clustered close to the groundwater samples Fg03 and Fg06, and the other close to a sample of rainfall from Echunga, taken in February 2005, with a distinct summer rainfall signature. In the former group, three of the five samples are from Bull Creek, where the geology is similar to that at the location of groundwater samples Fg03 and Fg06. The latter group, clustered around the Echunga summer rainfall sample, includes all of the remaining round 1 surface water samples.

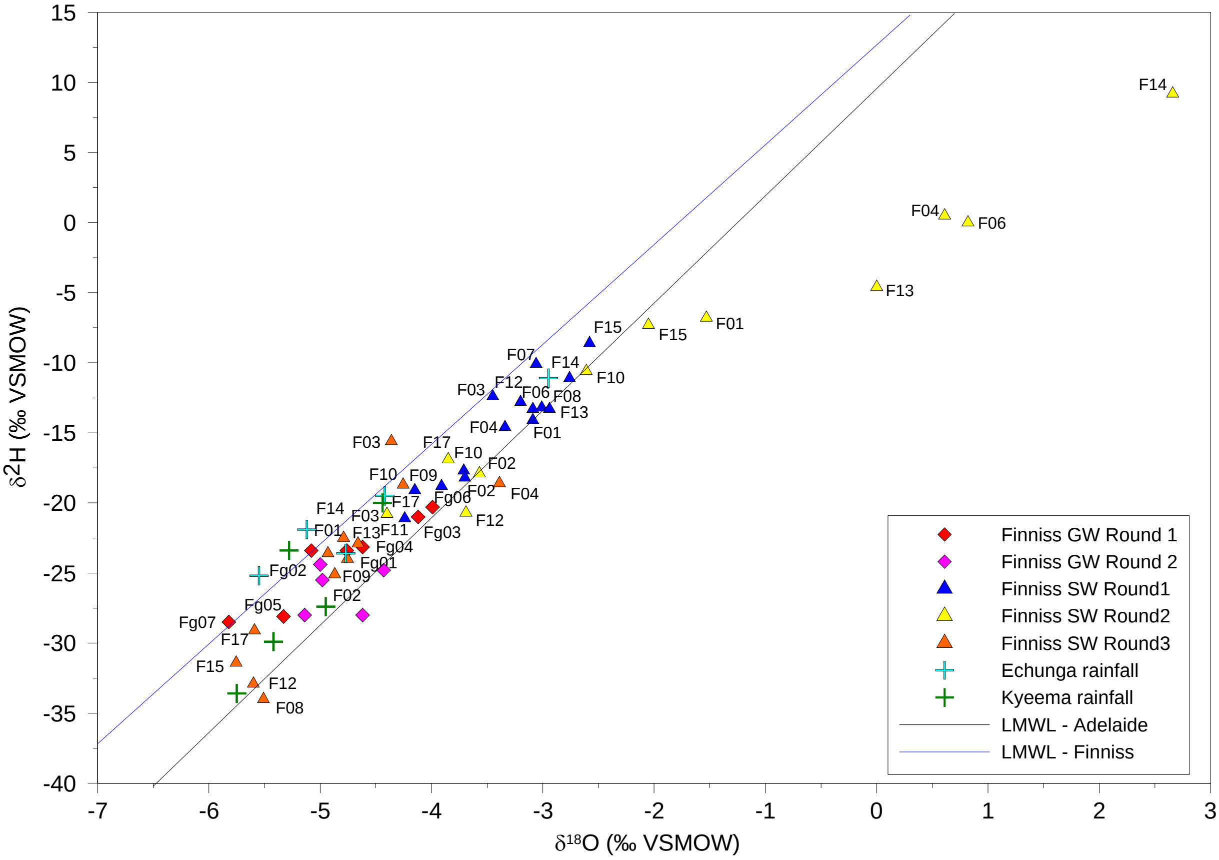


Figure 14. Stable isotopes of water, expressed as δ^{2}H versus δ^{18}O for samples from the Finniss River Catchment (study site identifiers are shown beside each point)

The round 2 surface water samples (1–2 Feb 2007) also fall into two groups. One group of four samples is positioned close to the winter rain/groundwater characteristics, although slightly enriched compared to these. These samples are most likely to be representative of groundwater outflows as they are too isotopically depleted to be a result of evaporative enrichment of summer rainfall. While there was a significant rain event in this catchment approximately eight days prior to sampling, the rain from that event is expected to have a more enriched signature than these samples. That these samples are isotopically very similar to the corresponding samples from the sampling round 1, also implies a common source and similar degree of evaporative enrichment between the spring and summer samples, suggesting that these waters were groundwater-derived and had not undergone more evaporative enrichment in the summer compared to the winter. This also suggests that the samples were collected from close to the point where the groundwater is discharged into the stream.

The other group of round 2 surface water samples appears to follow a characteristic evaporation trend, originating from the same area on the LWML as the more isotopically enriched of the round 1 surface water samples. This implies that these summer surface water samples were probably from the same source as the more enriched of the round 1 samples, and had been evaporatively enriched prior to sampling in round 2. The rainfall event in the week prior to round 2 sampling was a possible source of this water, with evaporative enrichment having occurred during the week between the rainfall event and the sampling round. However, the majority of water from that rainfall event is thought to have been captured by the many agricultural dams in the FRC, as evidenced by a negligible response to this rain event in the Finniss River hydrograph (Figure 3).

The round 3 surface water samples (21–22 May 2007) are thought to be representative of recent rainfall in the FRC. Heavy rain fell in the catchment between 26 and 30 April and also during the days of sampling. These rain events caused short-lived peaks in the Finniss River hydrograph, indicating that water in the system prior to these rain events will have been flushed shortly before this sampling round. The stable isotope results for these samples confirm that winter rainfall in this catchment has a range of $\delta^{2}H/\delta^{18}O$ values that are similar to the groundwater sampled in the catchment. In the graph of $\delta^{2}H$ versus chloride concentration (Figure 15), the round 3 surface water samples are displaced along the chloride axis relative to rainfall and groundwater samples. It is thought that this is due to the dissolution of residual salt on the land surface and in the stream bed by these first heavy rains of the winter of 2007.

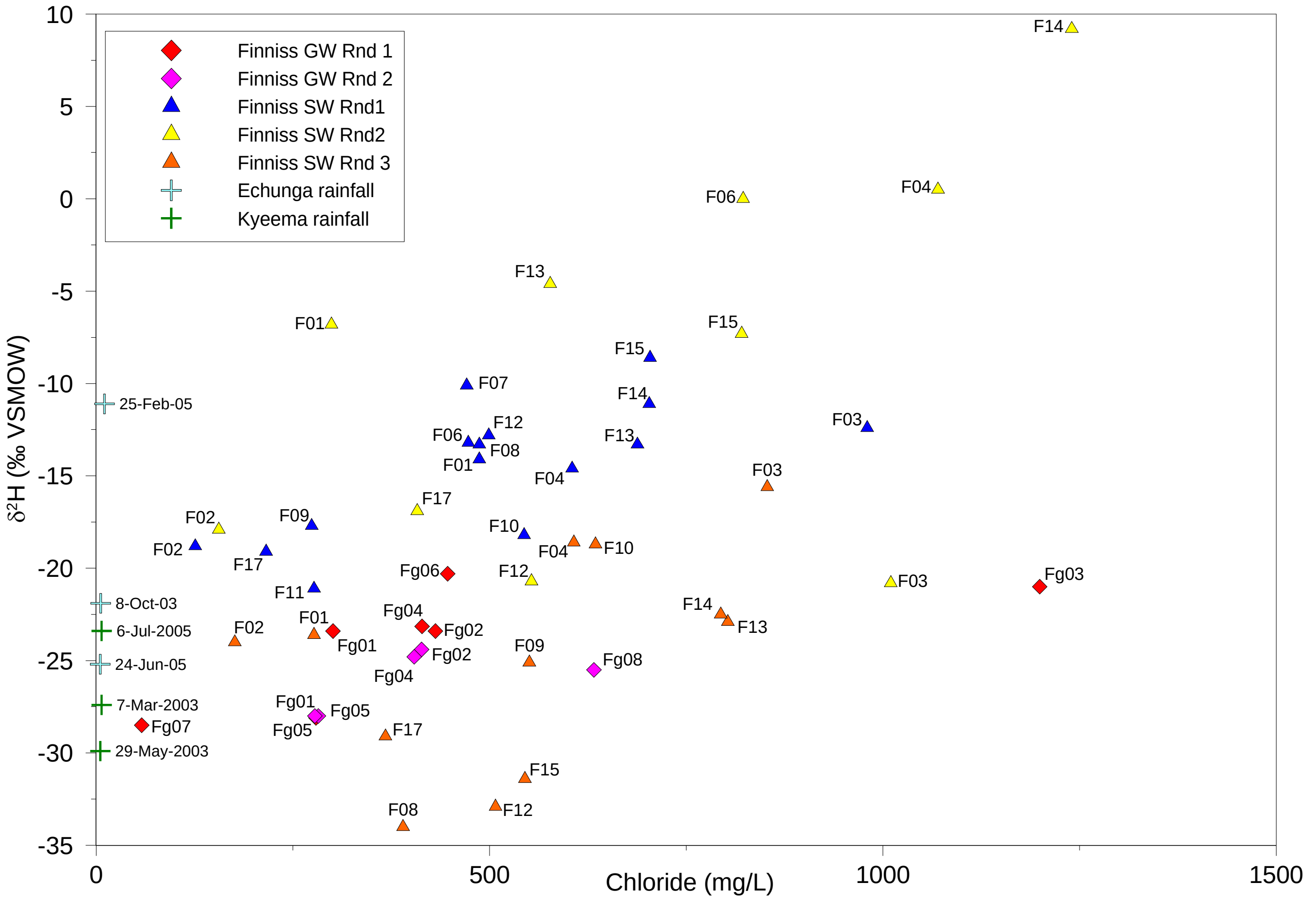


Figure 15. Deuterium isotope ratio (δ^2H) versus chloride for groundwater and surface water samples from the Finniss River Catchment

3.3.3 RADON-222 ACTIVITY

Approximately half of the surface water samples from the FRC had ^{222}Rn activities greater than 1 Bq/L. Samples with activities above 1 Bq/L were taken to be influenced by recently (<7 days) discharged groundwater. ^{222}Rn activities below 1 Bq/L were taken to be inconclusive of groundwater influence as surface water can gain a small amount of ^{222}Rn gas in-situ from the rocks and sediments of the hyporheic zone (Cook et al. 2006). There is no apparent correlation between surface water radon activity and salinity (Figure 16), which may otherwise have indicated the presence of relatively high salinity groundwater with corresponding high radon activities.

There were a small number of sample locations where ^{222}Rn activities were greater than 1 Bq/L during all three sample rounds or whenever water was present. Samples from Bull Creek, at locations F09, F11 and F17 were all between three and seven Bq/L, suggesting active inflows of groundwater close to these locations at all times that water was present. Similarly, samples from location F12, close to the end of the Finniss River, had ^{222}Rn between two and five Bq/L during all three sample rounds.

The round 2 sample from location F13 had the highest ^{222}Rn (8.78 Bq/L) of all the FRC surface water samples, while the round 1 sample from this location also had a relatively high ^{222}Rn of 2.71 Bq/L. The round 3 sample from this site was below 1 Bq/L suggesting that water flowing from further upstream, possibly due to surface runoff from the recent rains, was dominant in Meadows Creek at that time.

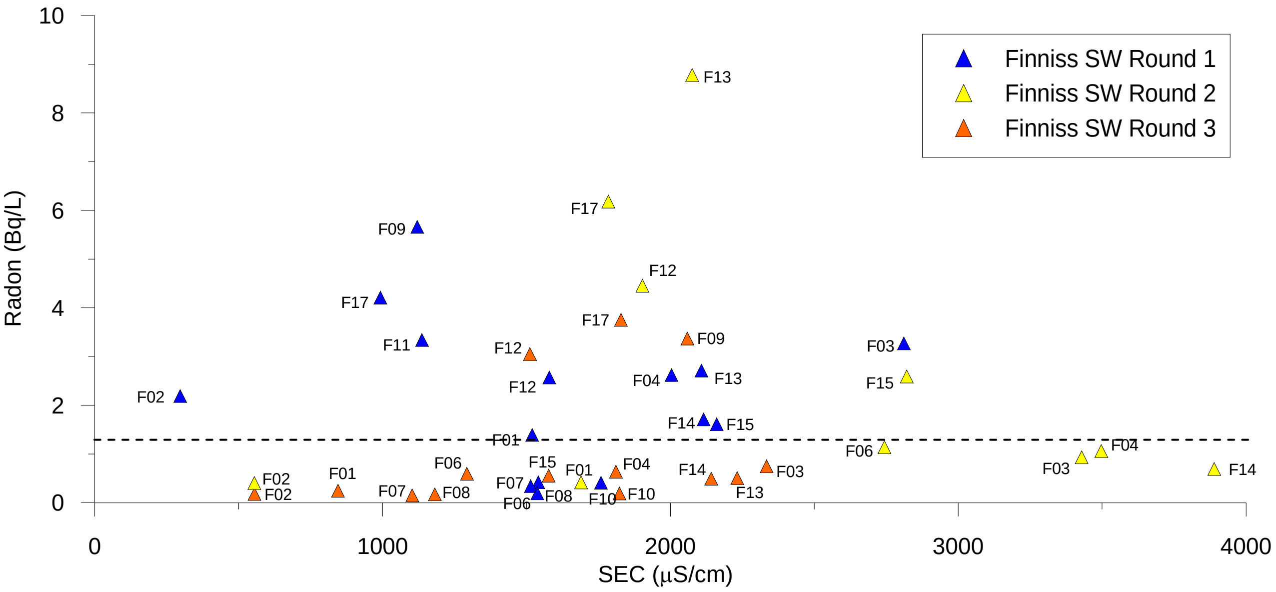


Figure 16. ^{222}Radon activities of surface water samples in the Finniss River Catchment

The remainder of samples with ^{222}Rn above 1 Bq/L were from the Meadows Creek locations (F14, F15, F03), during the spring and summer sample rounds, and in locations close to the start of the Finniss River (F02, F01, F04), during the spring sample round only.

The ^{222}Rn in samples from the main channel of the Finniss River (F01, F06, F07 and F08) may have been low because groundwater input some distance upstream had been in the stream bed for some time before arriving at the sampling point. The reason for their low Rn values in round 1 is that, while there were higher Rn activities in all of the tributaries above these points in the river, the Rn had degassed or expired by the time the water reached these sampling points. This suggests a low or zero inflow of groundwater directly to the main section of the Finniss River between location F01 and F06.

3.3.4 STRONTIUM ISOTOPE RATIOS

The majority of surface water samples from the FRC had $^{87/86}$Sr ratios in a narrow range of between 0.712 and 0.719, and strontium concentrations between 0.33 mg/L and 1.03 mg/L (Figure 17).

The $^{87/86}$Sr ratios of surface water samples were very similar across the three sampling rounds in samples from all locations in the FRC, apart from those close to the start of the Finniss River at Yundi. Samples from locations F13 and F02 had a higher $^{87/86}$Sr ratio in sample round 2, which indicates a greater proportion of water deriving from the adjacent Barossa Complex (BC) FRA during the summer. This is also reflected in the round 2 sample from F01, which is downstream of F02 and F13 and receives water flowing from those points as well as groundwater inflows from the surrounding BC FRA and PSA.

Elsewhere in the FRC, $^{87/86}$Sr ratios were almost unchanged between different sample rounds, suggesting sources of dissolved strontium to the surface water at those locations were the same throughout the period of the sampling program.

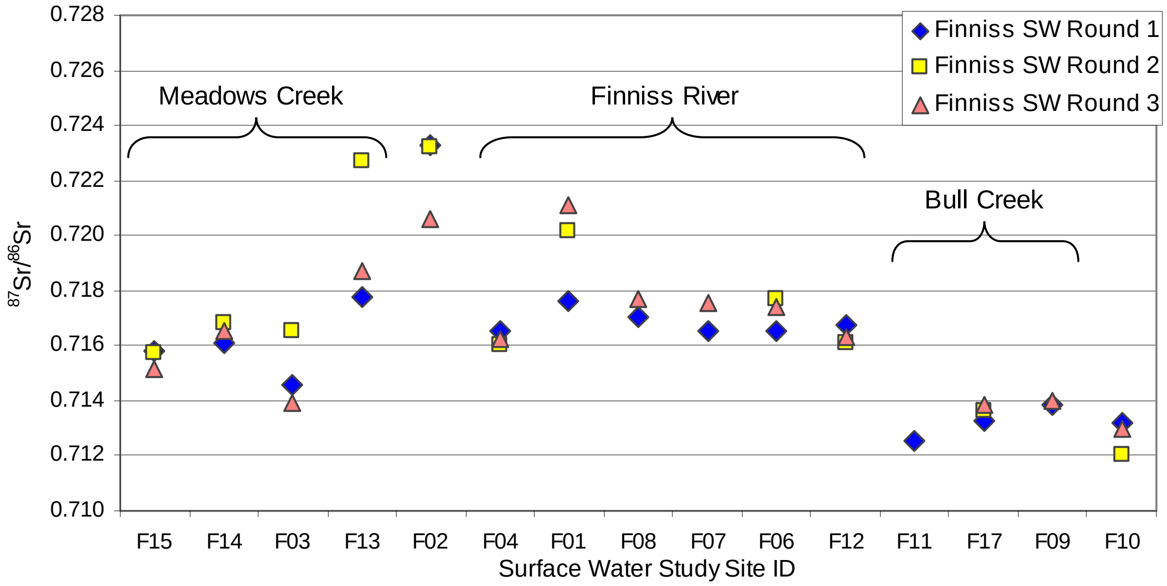


Figure 17. Strontium isotope ratios of surface water samples from the Finniss River Catchment

On the graph of $^{87/86}$Sr ratios plotted against 1/[Sr], two-component mixing relationships are indicated by linear distribution of points on the graph. In Figure 18, the majority of surface water samples lie in a cluster close to the groundwater samples from wells in the PSA and Kanmantoo Group FRA near Ashbourne (Fg02, Fg04, Fg06 and Fg01).

Groundwater sampled from wells near Yundi came from two sources with distinctly different $^{87/86}$Sr ratios and Sr concentrations. Well Fg07 draws from the PSA and had a low $^{87/86}$Sr ratio of 0.713 and [Sr] of 0.059, while well Fg08 is in the BC FRA and had a high $^{87/86}$Sr ratio of 0.753 and high [Sr] of 1.088 mg/L. Surface water sample location F02 is at the start of the Finniss River at Yundi, upstream of the confluence with Meadows Creek. It can be seen in Figure 18 that in all three sample rounds, the water at location F02 lies close to a mixing line between the PSA water represented by Fg07 and the BC FRA represented by Fg08. This suggests the water at this location is a mixture of water from these two aquifers, with the majority from the PSA.

Location F01 is downstream of the confluence of Meadows Creek and the upper Finniss River and receives the downstream flow of water from these sources, as well as local inputs of groundwater that may be expected to be from the same sources as those at locations F02 and F13. The $^{87/86}$Sr ratios seem to confirm this, with samples from F01 in sample rounds 2 and 3 lying between samples from Meadows Creek and samples from F02, representing the mix of groundwater discharges into the Finniss River at Yundi.

The two remaining outlying points among the samples in Figure 17 are the round 2 samples from locations F10 and F13. The major ion analysis of the sample from F10 shows high calcium and sulphate concentrations, suggesting the water was possibly contaminated with runoff of gypsum from adjacent agricultural land at that time. Such contamination would have most likely added Sr with a low $^{87/86}$Sr ratio, which may be reflected in the low ratio for the F10 sample. The sample from F13 lies above the main group, with a higher $^{87/86}$Sr ratio that was most likely due to water at this location in the summer being more dependent on inflows from the BC FRA.

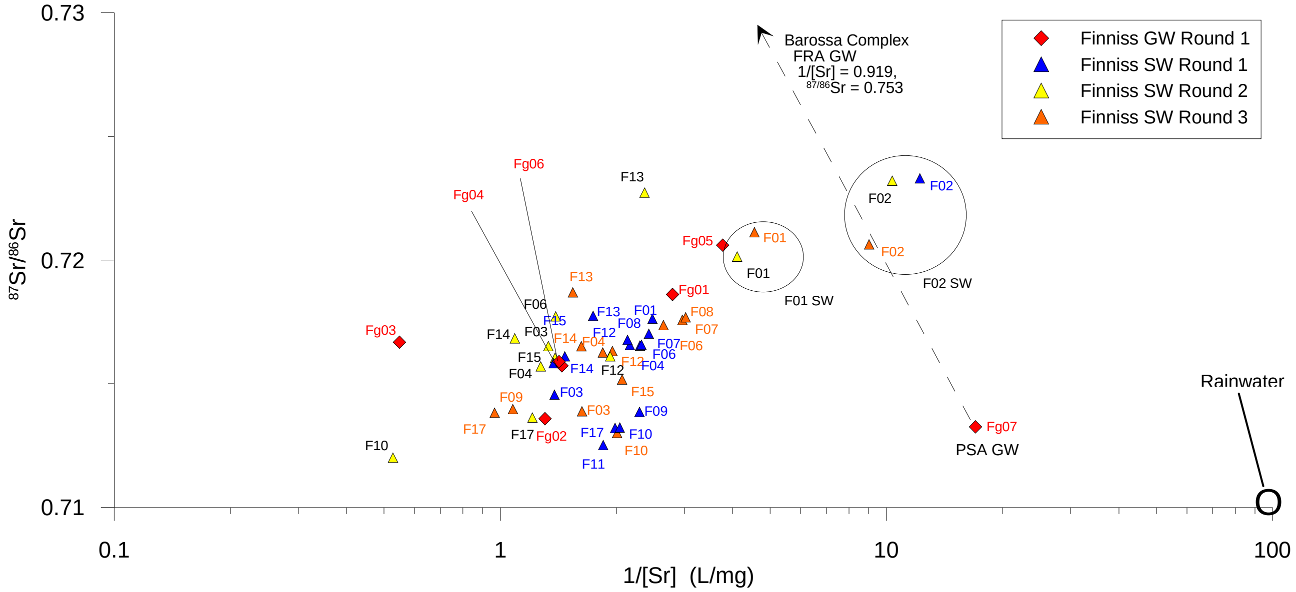


Figure 18. Strontium isotope ratios of surface water and groundwater samples from the Finniss River Catchment

3.3.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years and corrected ^{14}C ages for wells sampled in the FRC are listed in Table 4, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. There is no conflict between the ^{14}C and CFC results for well Fg04, which suggest groundwater of a low age of around 20–32 years. Water from well Fg07 was found to have low CFC concentrations, suggesting it recharged prior to 1965. The ^{14}C activity for this water was too high to provide a reliable age, hence the results are somewhat ambiguous for this well. The CFC samples for well Fg08 were contaminated and only a ^{14}C age estimate is given. The corrected estimate of 622 years for water from well Fg08 is not unreasonable. The CFC and ^{14}C results for wells Fg01, Fg02 and Fg05 are conflicting and a reliable age for the groundwater from these wells cannot be surmised from these results.

Table 4 Groundwater age estimates for samples from wells in the FRC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}C$ ($^{o}/_{oo}$)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
Fg01	54.0	61.20	-15.20	3.88	0.310	4059	5137	1965	1967
Fg02	61.0	85.80	-15.90	3.00	0.591	1266	3471	1967	1973
Fg04	74.0	101.90	-13.70	3.96	0.390	-156	-612	1975	1987
Fg05	13.00	71.2	-19.50	1.96	0.622	2808	7928	1974	1976
Fg07	45.00	87.8	-19.10	0.39	0.420	1072	6877	<1965	<1965
Fg08	158.00	63.3	-12.20	1.73	0.026	3775	622	n/t	n/t

3.4 ANGAS RIVER CATCHMENT

3.4.1 CHLORIDE CONCENTRATIONS

Groundwater samples from wells in the Angas River Catchment (ARC) had [Cl$^-$] values ranging from 266 mg/L to 2085 mg/L (Table 5).

Table 5 Chloride concentrations and specific electrical conductivity for wells sampled in the Angas River Catchment during two rounds of sampling (n/t signifies not tested)

Sampled Well ID	Round 1 [Cl$^-$] (mg/L)	Round 2 [Cl$^-$] (mg/L)	Round 1 SEC µS/cm	Round 2 SEC µS/cm
Ag01	1111	1114	3014	3223
Ag02	2085	1657	5443	5022
Ag03	1117	1126	3244	3511
Ag04	862	875	2581	2739
Ag05	266	337	1551	1197
Ag06	446	n/t	2590	n/t
Ag07	511	n/t	2529	n/t

Several indications of the SW-GW interactions in the ARC can be drawn from the surface water chloride concentrations (Figure 19). These are discussed at some length in sections 3.4.1 to 3.4.4 below, with regard to sets of samples from subsections of the catchment.

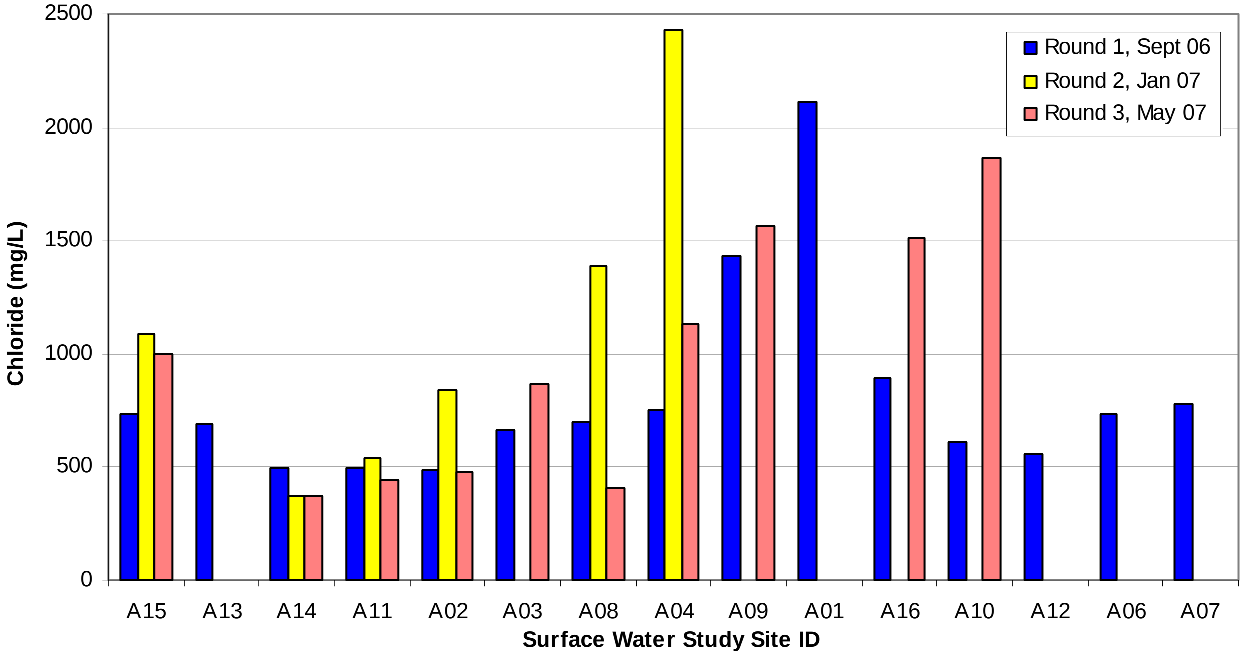


Figure 19. Chloride concentrations of surface water samples from the Angas River Catchment

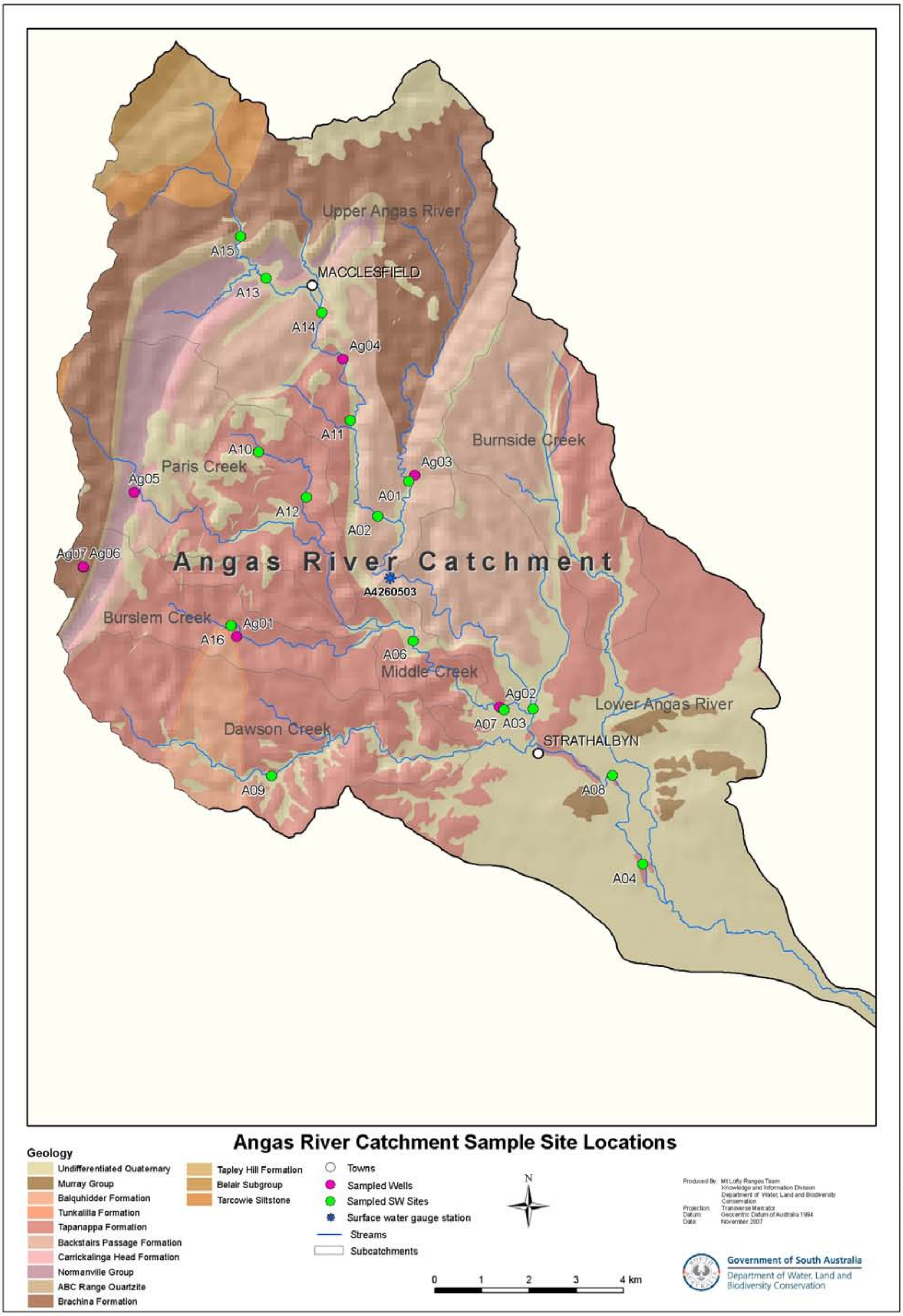


Figure 20. **Angas River Catchment sample site locations**

3.4.1.1 Upper Angas River

At the top of the ARC, at surface water locations A15 and A13, chloride concentrations were very similar to each other in sample round 1, when water was flowing at both points. At the same time, the three surface water locations downstream of these (A14, A11 and A02), had [Cl^-] that were very similar to each other but significantly lower than those at A15 and A13. These results suggest that the sources of water in the uppermost part of the catchment differ from the sources to the section of the river between A14 and A02. As [Cl^-] values were lower at the downstream locations, there must be an inflow of lower [Cl^-] water entering the river between A13 and A14. This is also indicated by the greater flow occurring at A14 during all three sampling rounds. In sample round 2 there was no water present at location A13, while at A15 there was still water flowing and with a significantly higher [Cl^-] than at that point in sample round 1. The latter is probably due to evapo-concentration of water from the same source as at this location during the spring sample round.

Surface water at A14 had identical [Cl^-] values in the summer and autumn sampling rounds and both were lower than in round 1. This is interpreted as being due to the water at A14 in the latter two rounds being a result of only local groundwater inflow occurring close to the sampling location. The [Cl^-] of 374 mg/L at A14 during the summer and autumn sample rounds was therefore taken to be the [Cl^-] of the groundwater discharging to the river at A14. The higher [Cl^-] observed in round 1 was due to the Angas River upstream of this location flowing with higher [Cl^-] water and mixing with the lower [Cl^-] groundwater discharging into the river close to A14. The round 1 A14 sample [Cl^-] of 499 mg/L resulted from the mixture of Upper Angas streamflow with [Cl^-] of 686 mg/L and the groundwater inflow at Macclesfield with [Cl^-] of 374 mg/L.

At the two sample locations downstream of Macclesfield (A11 and A02), the [Cl^-] was successively higher at each location in the direction of streamflow in both the summer and autumn sampling rounds, probably due to evapo-concentration of water flowing downstream from Macclesfield. The increase in [Cl^-] in the direction of flow was greater in summer than in sample round 3, as would be expected in view of the hot and dry conditions prevailing during sample round 2, in contrast to the relatively cool and humid conditions in the autumn. This trend of evaporation downstream of Macclesfield is taken to imply that there is very little additional flow into the river between Macclesfield and location A02, which is approximately 7 km downstream. Streamflow measurements made at locations A14, A11 and A02 in October 2006 (Table 13) showed the rate of flow to be approximately equal at these three locations. As the [Cl^-] measurements at that time indicated that there was negligible evaporation of stream water between these two points, it is surmised that all of the water flowing through this stretch of the river results from inflows of groundwater into the river at Macclesfield, and that there is negligible exchange between surface and groundwater systems in the length of river between Macclesfield and the Blackwood Park property approximately 7 km downstream of Macclesfield.

3.4.1.2 Lower Angas River

The results of the [Cl^-] analysis are not as revealing in the lower section of the Angas River as they are in the upper section. There were three sample locations in this section: A03, which was immediately upstream of Strathalbyn, A08 and A04, which were respectively approximately 2 km and 4 km downstream of Strathalbyn. The river is controlled by a number of weirs within the Strathalbyn township, which may interrupt flows between A03 and A08 during the drier months. Hence, any comparison of water quality parameters between these points should be taken with caution. The river was only flowing at all three locations during the sample round 1. During all three sample rounds the river flow-rate was found to be greater at A04 than at the upstream location A03, indicating the river may be gaining from groundwater inflows through this reach.

The moderate increase in [Cl^-] from 663 mg/L at A03 to 755 mg/L at A04 during sample round 1 may have been due to evapo-concentration of water of the same upstream source at all three locations. This would imply that when the river is flowing though the whole of this section, the majority source of water may be water flowing from the upper Angas River upstream of Strathalbyn, supplemented downstream of Strathalbyn by inflows of groundwater, possibly from the Murray Group limestone aquifer underlying the Angas plains.

3.4.1.3 Paris, Burslem and Middle Creeks

There are five surface water sample locations on these creeks: A10 and A12 on Paris Creek; A16 on Burslem Creek; A06 and A07 are on Middle Creek, downstream of the confluence of Paris and Burslem Creeks. These creeks were only flowing at all five sample locations during sample round 1. Only at that time can it be assumed that water at any sample point was influenced by water flowing from an upstream sample point.

Although locations A10 and A12 are fairly close to each other, they are separated by two large on-stream dams. There is also a large dam upstream of location A10, which may prevent inflows from upstream to that point. The occurrence of flow at A10 in both the spring and autumn rounds suggests there is a local inflow of groundwater to the creek between the two dams. That [Cl^-] at A12 was lower than at A10, also indicates a local groundwater source for the water in the creek at that point. The higher [Cl^-] at locations A06 and A07 during sample round 1 may have been due to evapo-concentration of water from the same groundwater source as at location A12. The very high [Cl^-] at A10 and A16 in sample round 3 suggests that the appearance of water at these locations, which were dry at the time of sample round 2, is most likely due to evapo-concentration of groundwater rather than inflows of surface runoff after the heavy rainfall at that time.

3.4.1.4 Dawson Creek

There was water present at surface water location A09 in the spring and autumn sample rounds. At both times there was a small amount of flow occurring. The high [Cl^-] in this water during both the spring and autumn sample rounds suggests a local groundwater source.

3.4.2 STABLE ISOTOPES OF WATER

In the graph of δ^2H versus δ^{18}O for the ARC samples (Figure 21) the stable isotope ratios of all of the groundwater samples from wells drawing from fractured rock in areas of Kanmantoo Group geology are closely grouped around the Echunga rainfall LMWL. The majority of the Echunga rainfall samples also fall close to this group, indicating that recharge to these aquifers occurs rapidly and directly as the water does not undergo evaporative enrichment during recharge processes. All of the round 1 (spring) and most of the round 2 (summer) surface water samples lie along a trend line of evaporative enrichment of water originating from sources in this group. As the groundwater and rainwater samples are so closely grouped (isotopically similar) it is not discernible from these data whether the surface water isotopic characteristics result from evaporation of surface runoff or discharged groundwater.

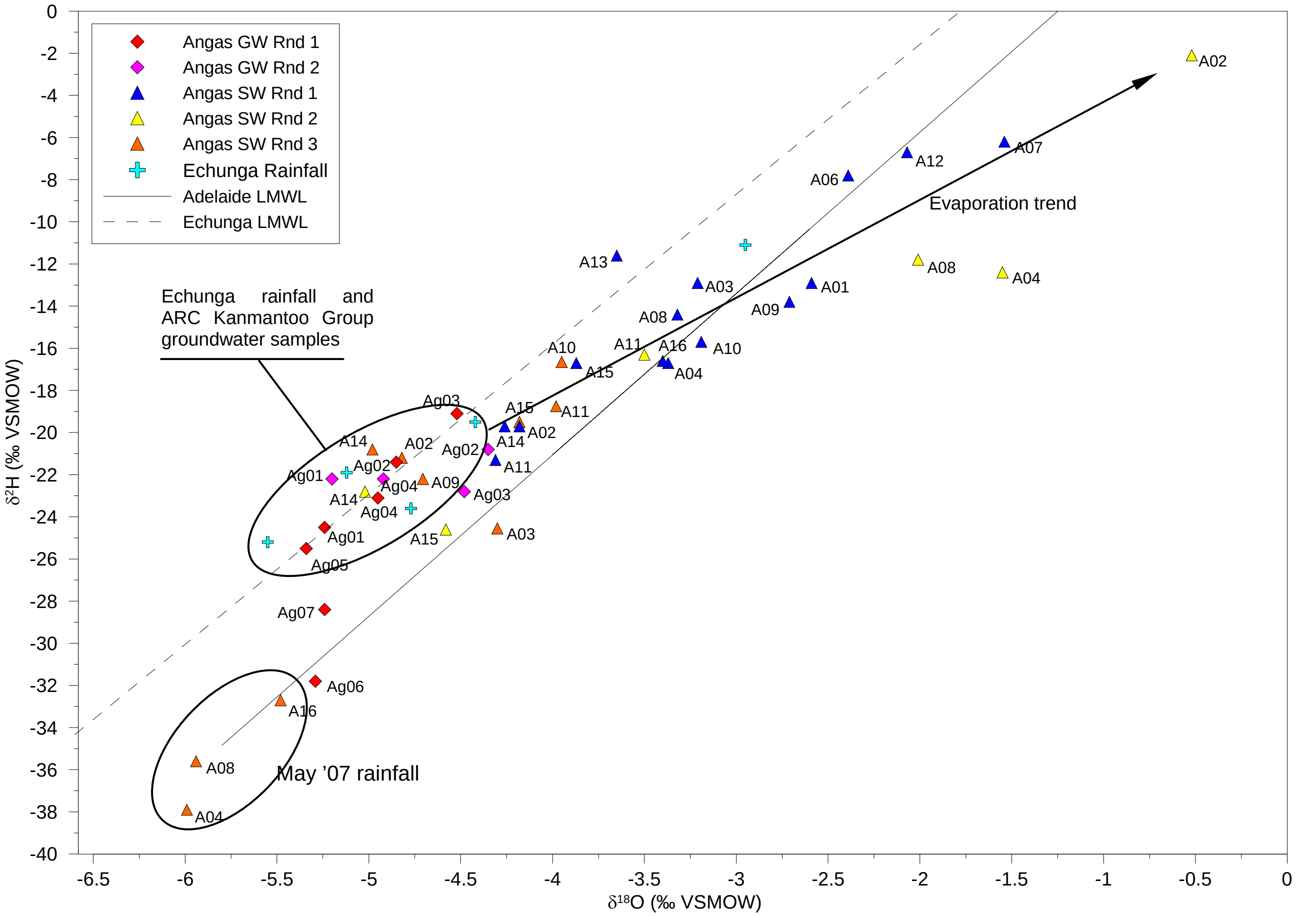


Figure 21. Stable isotopes of water, expressed as δ^2H versus δ^{18}O for samples from the Angas River Catchment (study site identifiers are shown beside each point)

Results for the round 1 surface water samples from location A14 and the two locations immediately downstream, A11 and A02, indicate they are all from a similar source and have undergone a similar degree of evaporative enrichment.

The round 2 sample from A14 lies in the middle of the cluster of groundwater and rainwater samples. Samples from A11 and A02 are isotopically enriched, with greater enrichment with increased distance downstream. This is interpreted as being due to groundwater discharged close to A14 being subject to a high degree of evaporation through this stretch of the river in the summer.

Surface water samples from locations A04, A08 and A16 during sample round 3 are highly depleted, and thought to be indicative of the highly depleted rainfall preceding that sampling round.

3.4.3 RN-222 ACTIVITY

Groundwater samples from the ARC (Figure 22) ranged in ^{222}Rn activity from 27 Bq/L to 666 Bq/L. However, the low activity of 27 Bq/L in water from well Ag05 was anomalous, as all other sampled wells in this catchment had significantly higher activities. Excluding well Ag05, the minimum groundwater ^{222}Rn activity sampled in the ARC was 202 Bq/L.

The majority of surface water samples had ^{222}Rn activities of less than 1 Bq/L. These ^{222}Rn activities below 1 Bq/L are taken to be inconclusive of groundwater influence as surface water can gain a small amount of ^{222}Rn gas from the rocks and sediments of the hyporheic zone (Cook et al.

2006). Samples with activities above 1 Bq/L were taken to be influenced by recently (<7 days) discharged groundwater, in which the ^{222}Rn activity had both decayed and degassed to some extent since discharging.

All but one of the samples with ^{222}Rn activities greater than 1 Bq/L were from the higher elevation parts of the catchment, in areas of Kanmantoo Group and Adelaidean Sequence geology.

Samples from Paris Creek at location A10 were similar in the spring and autumn sampling rounds, suggesting similar rates of groundwater discharge at that location at both times. Samples from Burslem Creek at location A16 had high ^{222}Rn activities of 4.9 and 3.3 Bq/L respectively during the spring and autumn sampling rounds, indicating active discharge of groundwater close to that location at the times that water was present. The sample from A06, approximately 3 km downstream of A16 also had a high ^{222}Rn of 5.6 Bq/L in sample round 1. There was no water at locations A10, A16 or A06 during sampling round 2, indicating that the groundwater source discharging to the creeks in those locations must have ceased to flow to the surface at those locations during the summer.

There is some correlation between surface water ^{222}Rn activity and salinity (expressed as SEC), which may indicate the presence of relatively high salinity groundwater with corresponding high radon activities.

The round 2 sample from location A04 was the only one from the lower ARC with a ^{222}Rn activity greater than 1 Bq/L. The high activity of 3.6 Bq/L at that location corresponds with a high SEC of approximately 7200 µS/cm during sample round 2. An outcrop of Tapanappa Formation rocks occurring at this location indicates that the high ^{222}Rn activity here may be due to water emerging from a fractured rock aquifer beneath the quaternary sediments. The absence of a high Rn activity in the spring and autumn sample rounds may have been due to dilution of the small amount of discharging groundwater by a larger amount of water flowing from upstream at those times when flow in the river was greater.

At location A01 on Doctors Creek, there was only water present during sample round 1. At that time the water had a ^{222}Rn activity of 6.2 Bq/L, indicating active discharge of groundwater occurring at that location. It is surmised that during the summer and autumn sample rounds, the groundwater level at that location must have dropped below the level at which it can discharge to the surface.

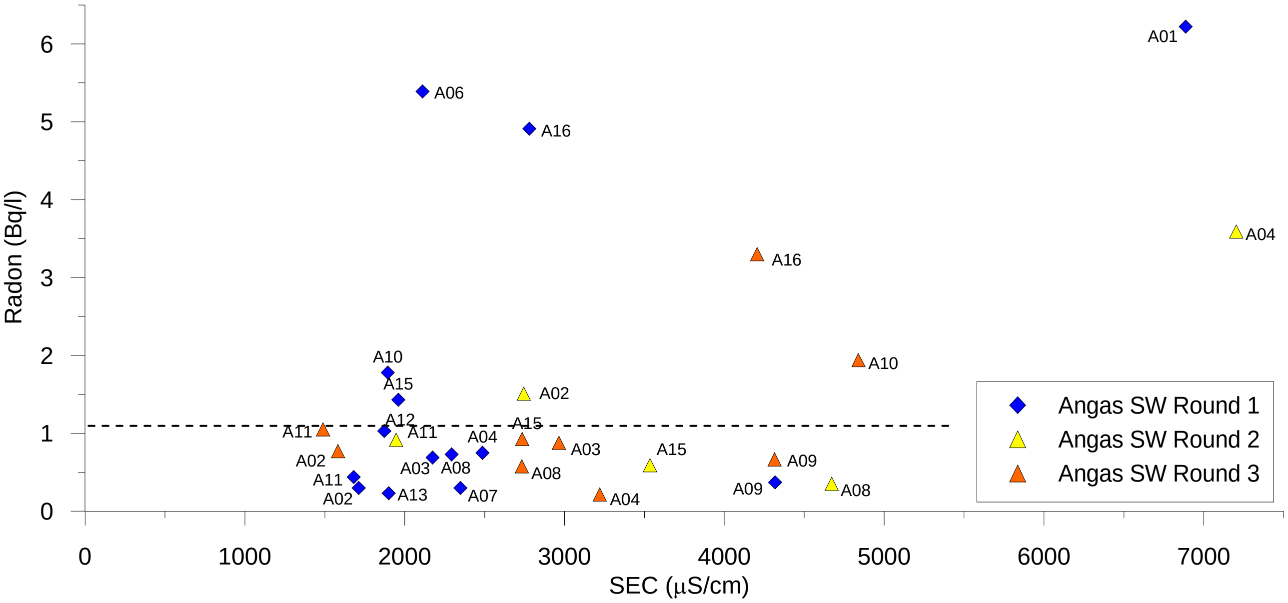


Figure 22. **^{222}Radon activities of surface water samples in the Angas River Catchment**

The graph in Figure 22 excludes the ^{222}Rn activity results for samples from location A14, which is on the Angas River in the centre of Macclesfield. Radon activities at that location were much higher than any other surface water samples analysed in this study, and were excluded from the graph in Figure 22 to prevent all the samples with lower values from being crowded together close to the horizontal axis. Results for location A14 are shown in Figure 23, together with results from the next two sample locations downstream, A11 and A02.

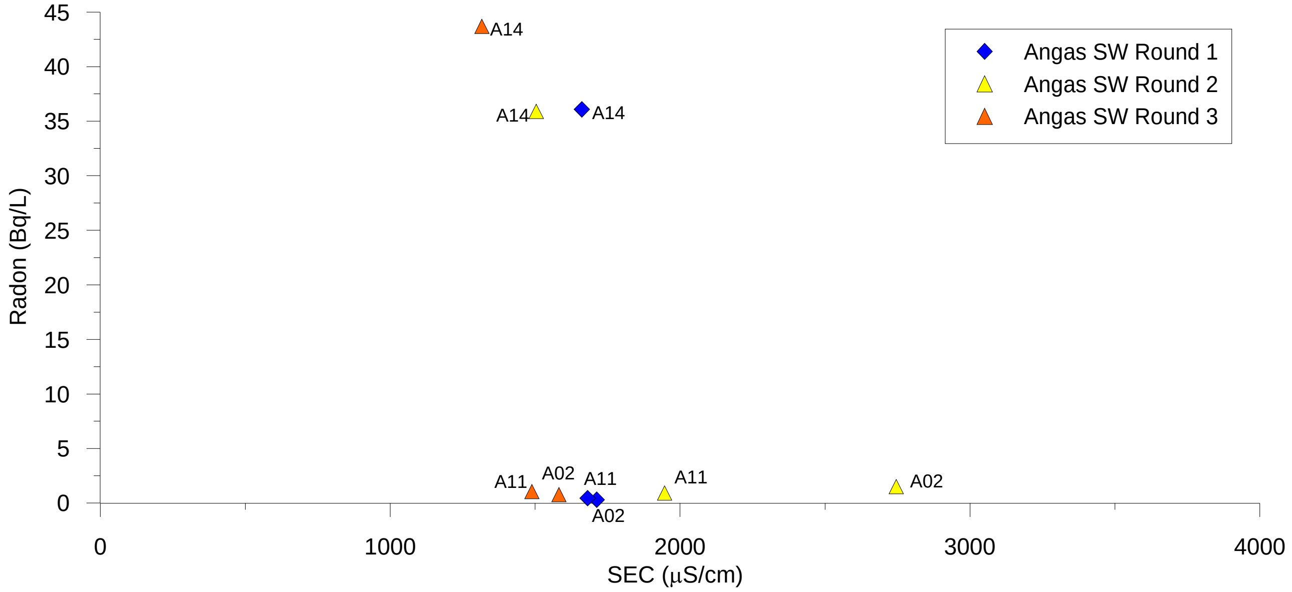


Figure 23. ^{222}**Radon activities of surface water samples in the Angas River locations A14, A11 and A02**

The ^{222}Rn activities in samples from location A14 ranged from 35.9 Bq/L to 43.7 Bq/L. These were exceptionally high radon activities for surface water samples and suggest that the majority of water in the Angas River at that location is sourced from groundwater discharged close to the point of sampling. While the surface water at A14 had a very high ^{222}Rn activity during all three sample rounds, activities at locations A11 and A02 were consistently low, indicating that most of the ^{222}Rn in the water at A14 had expired or degassed while flowing to the downstream sample points, and that there had not been significant further discharge of groundwater into the river between these points.

Significantly, during sample round 3 (autumn), after significant rain in the ARC, the ^{222}Rn activity of the surface water at A14 had increased rather than decreased, as would be expected if the water in the river at that time was a mix of discharged groundwater and surface runoff. This may indicate that minimal runoff into the river occurs upstream of A14 and that the recent rain had increased the rate of discharge of groundwater into the river. This would increase flow-rates while decreasing the residence time of the water in the river, thus increasing ^{222}Rn activity.

These findings strongly support the suggestion from the chloride results (discussed in 3.4.1 above), that water in the Angas River at Macclesfield is derived almost entirely from groundwater discharged into a short reach of the river within the Macclesfield township, but that very little additional groundwater discharges to the river between Macclesfield and sample location A02, approximately 6 km further down the Angas River.

3.4.4 STRONTIUM ISOTOPE RATIOS

All surface water samples from the ARC occupied a narrow range of $^{87/86}$Sr values, between 0.7144 and 0.7179 (Figure 24). Samples from locations A15, A13, A14, A11 and A02 in the upper Angas River occupied a very narrow range of $^{87/86}$Sr ratio values, and in most cases had values that did not vary significantly between sample rounds.

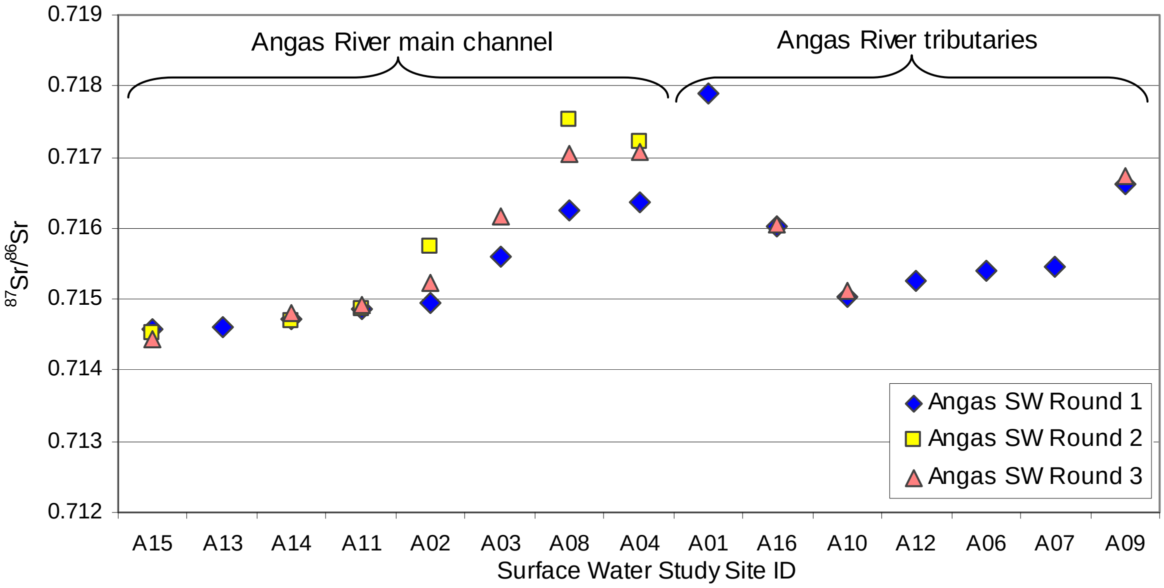


Figure 24. Strontium isotope ratios of surface water samples from the Angas River Catchment

There were significant variations in $^{87/86}$Sr between sampling points, suggesting that sources of dissolved strontium differ from one location to another. The similarity of the $^{87/86}$Sr ratios across seasons at several locations suggests sources did not change from one season to another, implying a single source for the dissolved strontium at those locations. This would result if the water at each location was predominantly from groundwater, or if the solutes were static and simply diluted each time there was a new input of water from rainfall. The latter explanation is only possible in streams which did not flow during the year of the sampling program and remained a series of connected pools. This was not the case for the main course of the Angas River, in which there was flow occurring during the spring and autumn sample rounds. In the upper section of the Angas River there was little variation between sample rounds, whereas in the lower section of the river there was a consistent increase of $^{87/86}$Sr ratio in summer and autumn compared to sample round 1. There were also consistently higher $^{87/86}$Sr ratios in the lower section of the Angas River compared to the upper section.

The surface water sample from location A01 had a distinctly higher $^{87/86}$Sr ratio (0.7179) than any of the other locations in the upper ARC. Location A01 is close to sampled well Ag03, which had a $^{87/86}$Sr ratio of 0.7183, very similar to that of sample A01. Well Ag03 draws from fractured rock in the Backstairs Passage Formation (BPF) and it is surmised from these results that surface water at A01 was sourced from groundwater discharging at a low rate from this formation. Although the upper section of the Angas River runs adjacent to a section of the BPF (Figure 20), the lower $^{87/86}$Sr ratio of water in the river indicates that it does not receive significant inflows from this formation. Only at location A02 in sample round 2 was there an increase in the observed $^{87/86}$Sr ratio, which may indicate some groundwater inflow from the BPF at that time.

On a graph of $^{87/86}$Sr ratios plotted against the reciprocal of the Sr concentration (Figure 25), all of the ARC surface water samples fall in a cluster that is bounded by the ARC groundwater samples. The evidence from the chloride and radon data suggests that surface water samples from the Angas River at Macclesfield can also be considered to be representative of the groundwater in that area. If a line of mixing between groundwater samples is drawn between the surface water from location A14 at Macclesfield and the groundwater sample from well Ag03, all of the surface water samples lie either on this line or to the left of it, indicating evaporative enrichment of the groundwater [Sr] without any change in $^{87/86}$Sr, as would be expected with the evaporation of groundwater after discharging to surface systems. An alternative explanation for the position on the graph of some of these samples is that they lie on a line of dilution by rainwater of some of the higher $^{87/86}$Sr ratio groundwaters such as that from well Ag02.

The close grouping of samples from locations A14, A11 and A02 in Figure 25 provide further evidence that water at these locations is from the same source, that being groundwater discharging into the Angas River at Macclesfield.

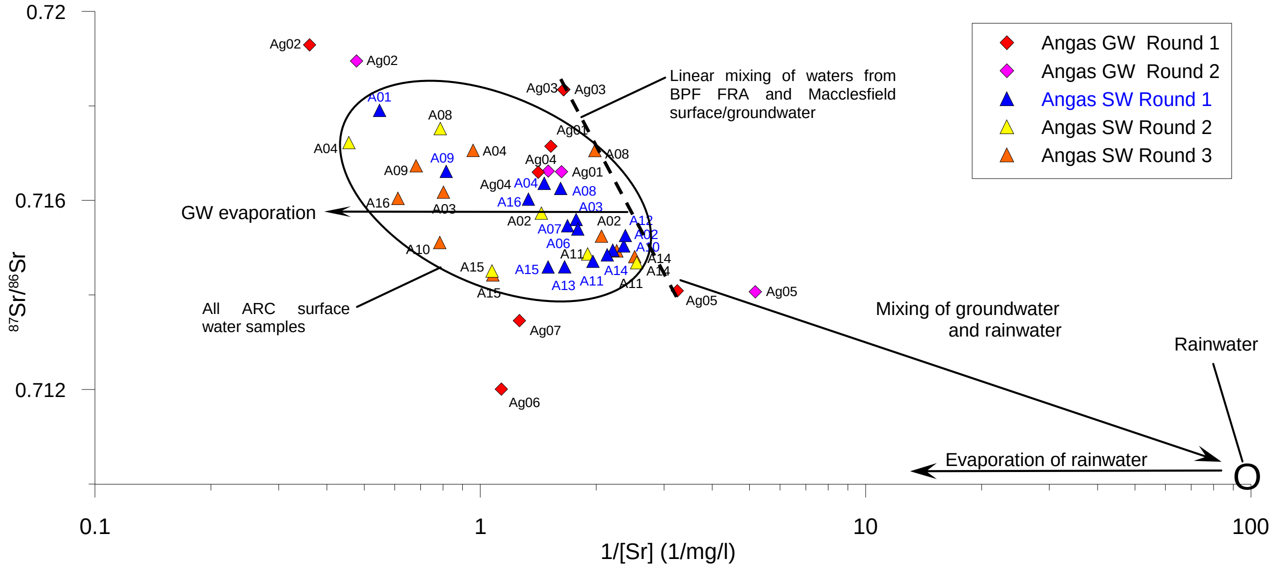


Figure 25. **Strontium isotope ratios plotted against the reciprocal of the strontium concentration of surface water and groundwater samples from the Angas River Catchment**

3.4.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years and corrected ^{14}C ages for wells sampled in the ARC are listed in Table 6, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. There is conflict between the dates suggested by the two methods for all of the wells sampled in this catchment. The ^{14}C result for well Ag04 is considered unreliable as the ^{14}C activity of 89.4 for this sample is too high for reliable ^{14}C dating. This well is shallow (12 m) and completed in Quaternary floodplain sediments. A low groundwater age of around 40 years, as indicated by the CFC results, is reasonable for groundwater from this well.

Table 6 **Groundwater age estimates for samples from wells in the ARC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).**

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}C$ ($^{o}/_{oo}$)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
Ag01	14.60	57.4	-15.90	3.84	0.045	4589	6002	<1965	1967
Ag02	19.50	75.5	-14.50	4.74	0.053	2323	2277	<1965	1967
Ag03	26.50	77	-15.30	5.32	0.198	2161	3121	1969	1975
Ag04	28.50	89.4	-15.40	5.83	0.552	926	2269	1968	1969
Ag05	33.00	60.7	-14.50	5.13	0.051	4127	4073	1973	1979

3.5 REEDY CREEK CATCHMENT

3.5.1 CHLORIDE CONCENTRATIONS

Only three wells were sampled in the Reedy Creek Catchment (RCC), and these had [Cl^-] concentrations ranging from 193 mg/L to 1514 mg/L. The [Cl^-] in each well was approximately consistent between the two sample rounds (Table 7).

Table 7. Chloride concentrations and specific electrical conductivity for wells sampled in the Reedy Creek Catchment during two rounds of sampling

Sampled Well ID	Round 1 [Cl^-] (mg/L)	Round 2 [Cl^-] (mg/L)	Round 1 SEC µS/cm	Round 2 SEC µS/cm
Rg01	193	201	1264	1107
Rg02	741	705	3109	2504
Rg03	1500	1514	5233	4730

The [Cl^-] of surface water samples from the RCC ranged from 471 mg/L to 5500 mg/L (Figure 26). The lowest of these was at location RE03 in sample round 2, however this may have been affected by runoff from irrigation that was occurring nearby at the time of sampling. All other surface water samples had [Cl^-] of more than 1000 mg/L and a majority of samples had [Cl^-] greater than the highest [Cl^-] found in the groundwater samples. Groundwater [Cl^-] in well Rg01, which was close to surface water sampling location RE03, was approximately 200 mg/L, whereas the typical [Cl^-] at location RE03 was over 1000 mg/L. If there is a groundwater contribution to the surface water in that location, then a large amount of evaporation must have occurred upstream of the point of surface water sampling.

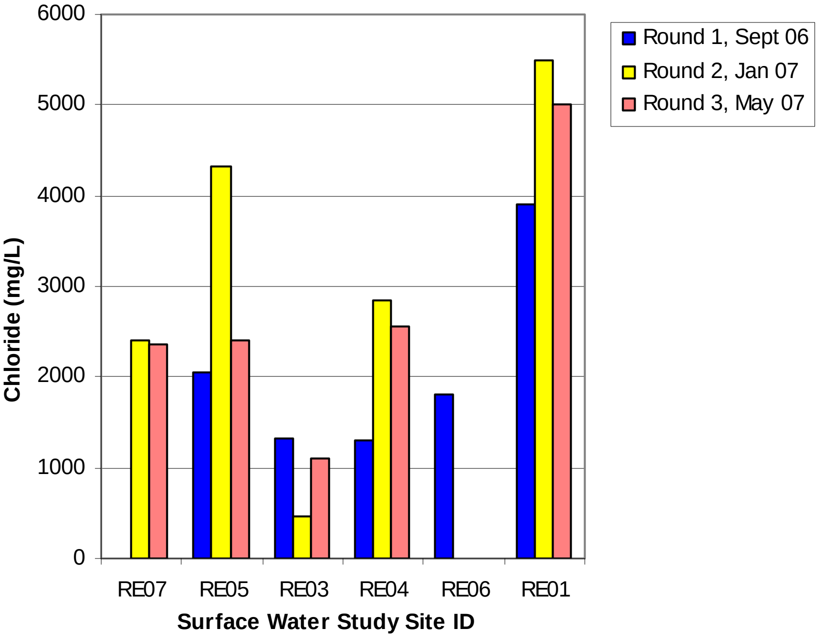


Figure 26. Chloride concentrations of surface water samples from the Reedy Creek Catchment

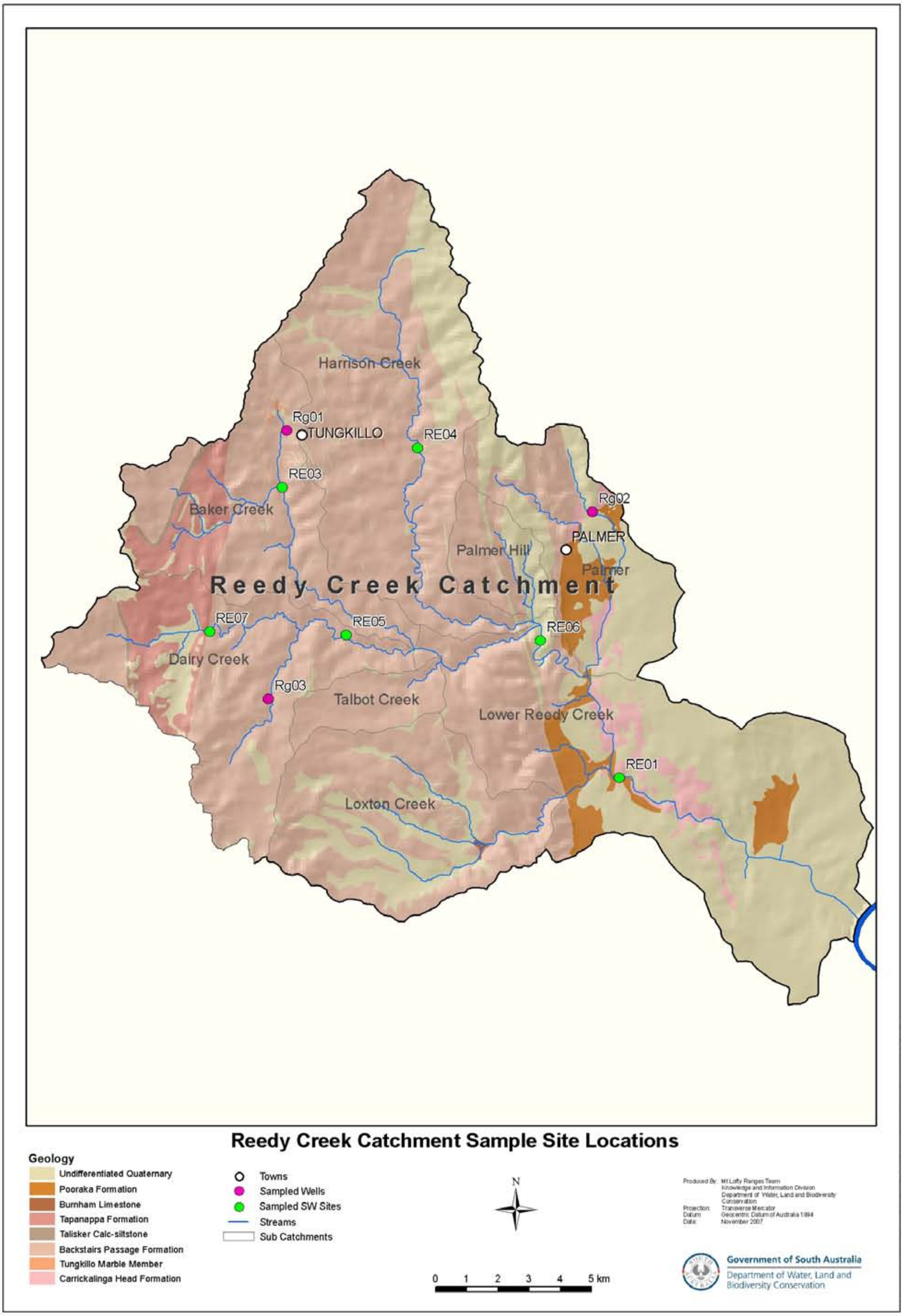


Figure 27. **Reedy Creek Catchment sample site locations**

3.5.2 STABLE ISOTOPES OF WATER

The positions of the RCC groundwater samples on the graph of δ^2H versus $\delta^{18}O$ graph (Figure 28) are distributed above the Adelaide LMWL. Also shown in Figure 28 are rainfall samples from Mount Pleasant, which is a short distance to the south west of the RCC. The RCC groundwater samples lie above the Adelaide LMWL and within the same region of the graph as two of the five rainfall samples from Mount Pleasant. The remaining Mount Pleasant rainfall samples are more isotopically enriched. The isotopic similarity between RCC groundwater samples and local rainfall indicate that recharge of groundwater is direct and rapid as water does not undergo evaporation between falling as rain and recharging the aquifer. The location on the graph of the groundwater samples, toward the isotopically depleted end of the LMWL, also suggests that the groundwater is recharged primarily from winter rainfall, which is generally more isotopically depleted than summer rainfall.

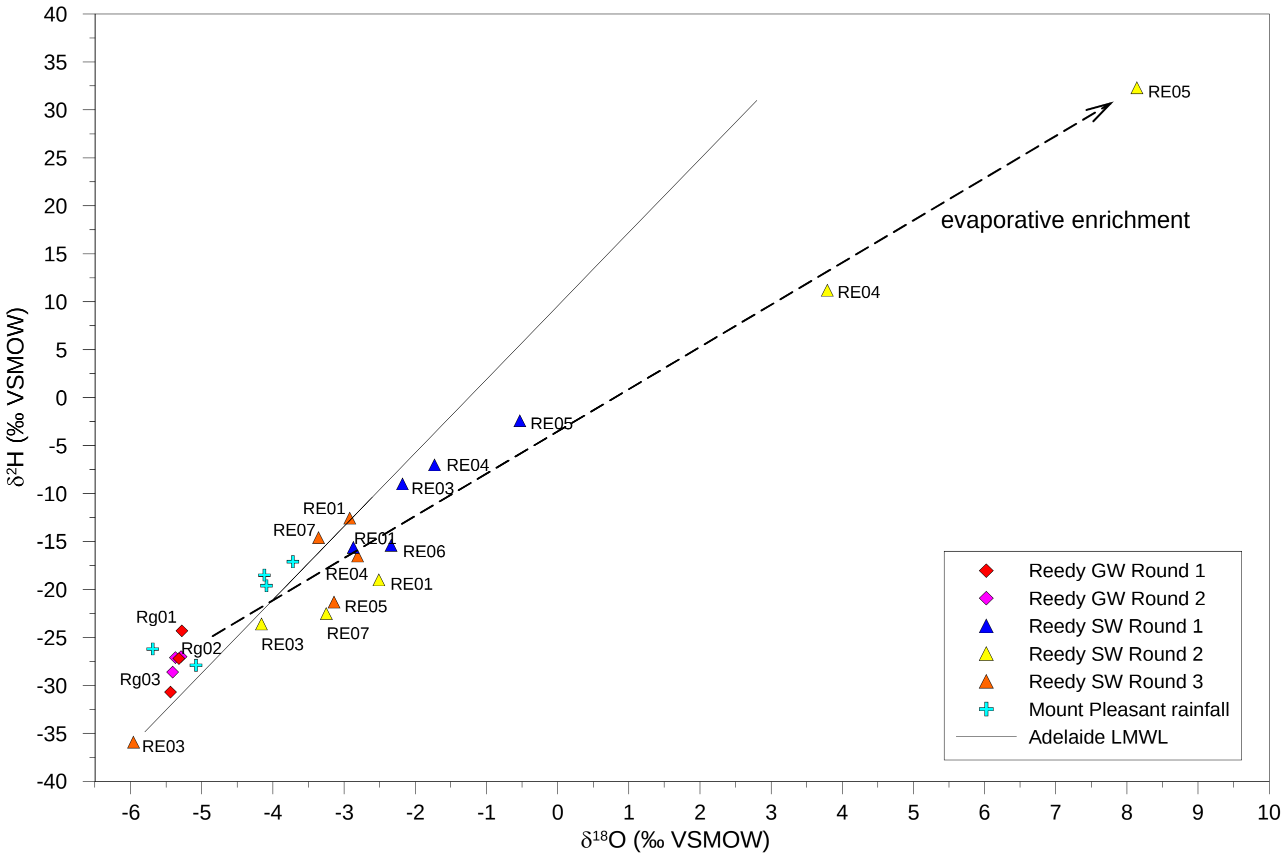


Figure 28. Stable isotopes of water, expressed as δ^2H versus $\delta^{18}O$ for samples from the Reedy Creek Catchment (study site identifiers are shown beside each point)

The majority of RCC surface water samples lie on a line of evaporative enrichment that may originate with either rainwater or groundwater samples. Samples from locations RE04 and RE05 were more isotopically enriched than any of the other SW samples, particularly those taken in sample round 2. The large difference in [Cl^-] observed between round 1 and round 2 samples from these two locations was shown by the stable isotopes to be due to the water here having undergone a greater degree of evaporation prior to the summer sampling round. The isotopic ratios of the round 3 (autumn) samples from RE04 and RE05 resulted from a mixture of evaporatively enriched water and recent isotopically depleted rainwater.

The isotopic ratios of samples from location RE01 were quite similar across the three sample rounds and were not particularly enriched in δ^{2}H and δ^{18}O compared to other surface water samples. These isotopic results suggest that the particularly high [Cl^-] of water from RE01 was due to it deriving from a saline groundwater source, rather than being due to evaporative concentration of solutes.

The round 3 sample from location RE03 was isotopically more depleted than any of the other samples in the catchment, suggesting that water at that location was mostly from recent rainfall at that time. This concurs with the low [Cl^-] and salinity of this sample.

The observed occurrence of flow at location RE07 during the summer and autumn sample rounds (rounds 2 and 3) suggests a perennial groundwater source for the surface water at this location. The isotopic results for these samples, lying toward the depleted end of the LWML, indicates not much evaporative enrichment of the water had occurred, even during the summer sample round, suggesting the groundwater source discharges close to this sample location.

3.5.3 RN-222 ACTIVITY

The radon activities of samples from the RCC (Figure 29) are only taken to be indicative of groundwater input if they were greater than 1 Bq/L. All three of the samples from location RE01 were above this threshold, supporting the finding from the stable isotope and chloride concentrations, that surface water at RE01 is consistently from a fairly saline groundwater source. Water at this location exists in a pool at the lower end of Reedy Creek, which was not flowing during any of the three sample rounds. Water at this location was expected to have relatively low ^{222}Rn activity due to the high residence time of the water there.

At location RE06 there was only water present during sample round 1. This sample had a ^{222}Rn activity of 11.3 Bq/L, which was considerably higher than any other surface water sample in the RCC and a clear indicator of a groundwater source of this water. The absence of water at this location during sample rounds 2 and 3 suggests a lowering of the watertable, preventing discharge of groundwater to the surface, after sampling round 1. The ^{222}Rn activity of 2.1 Bq/L at RE04 indicated a contribution of groundwater at that location. The lower activity during the following two rounds indicated that a longer residence time of the water had allowed the Rn to expire. This is supported by the highly isotopically enriched δ^{2}H and δ^{18}O ratios of the water at this location during sample round 2.

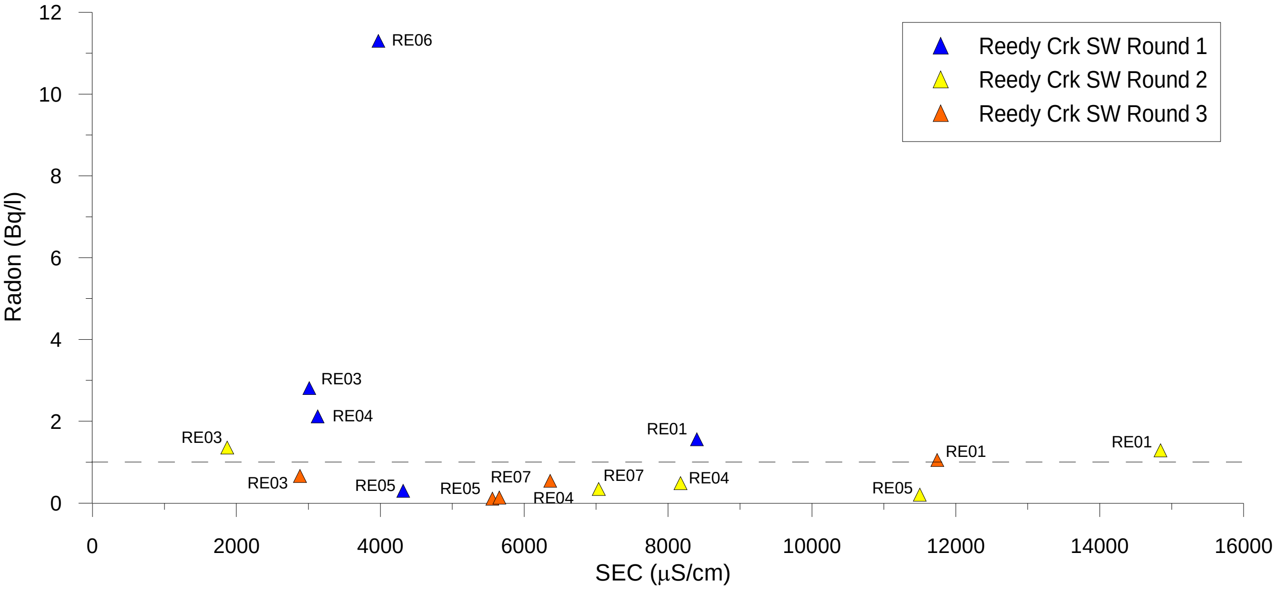


Figure 29. ^{222}**Radon activities of surface water samples in the Reedy Creek Catchment**

3.5.4 STRONTIUM ISOTOPE RATIOS

On a graph of $^{87/86}$Sr ratios plotted against the reciprocal of the Sr concentration (Figure 30), all of the RCC surface water samples fall in a cluster that lies to the left of the RCC groundwater samples, suggesting that these had a source of strontium similar to the groundwater in the catchment and that the surface water may have been derived from groundwater in which the concentration of Sr had been increased by evaporation. An exception was the round 2 sample from location RE03, which had a similar $^{87/86}$Sr ratio but a lower Sr concentration than any of the other surface water samples. This sample may have been affected by irrigation occurring nearby at the time of sampling.

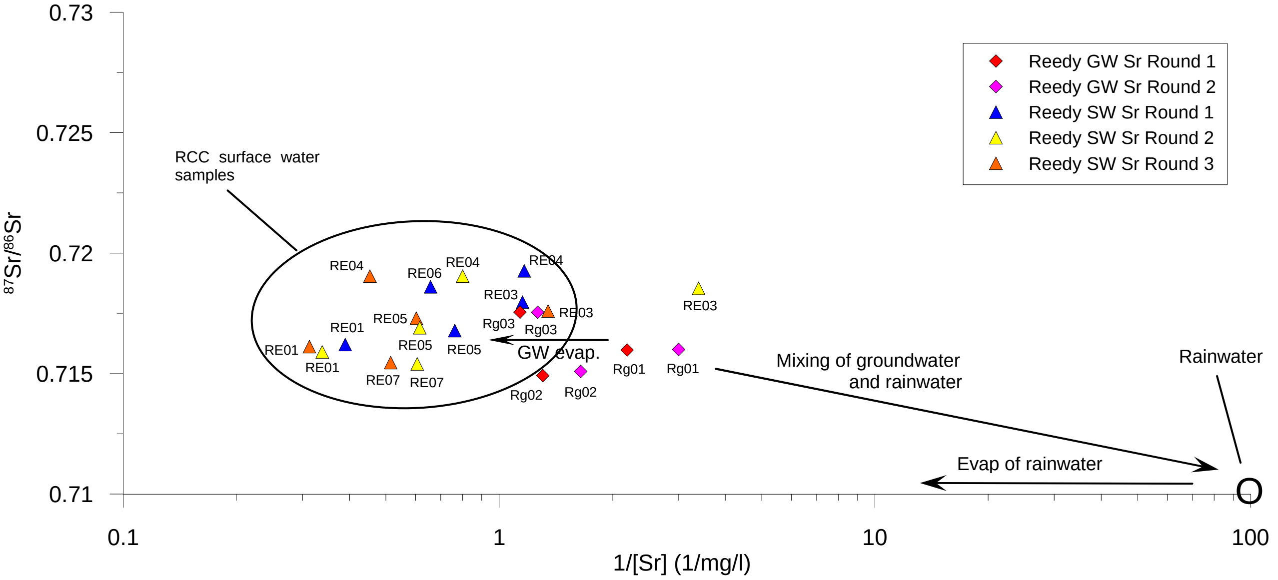


Figure 30. Strontium isotope ratios plotted against the reciprocal of the strontium concentration of surface water and groundwater samples from the Reedy Creek Catchment

As observed in other catchments, the strontium isotope ratios of surface water samples from the RCC varied between locations but were very consistent between sampling rounds, indicating a consistent source of dissolved strontium in the water at each location (Figure 31).

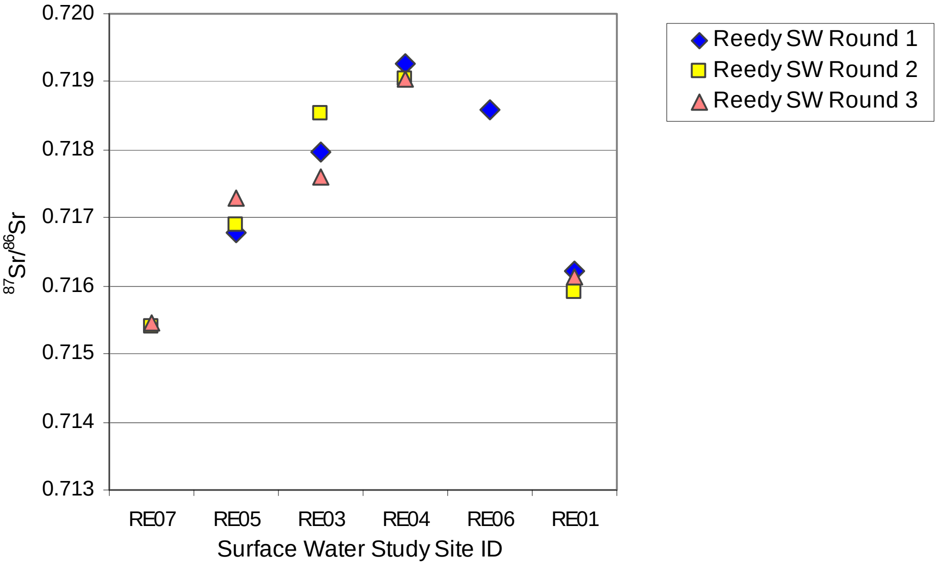


Figure 31. Strontium isotope ratios of surface water samples from the Reedy Creek Catchment

3.5.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years and corrected ^{14}C ages for wells sampled in the RCC are listed in Table 8, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. The ^{14}C activity of groundwater from well Rg01 was too high for reliable ^{14}C age dating and the corrected ^{14}C age for this sample is considered unreliable. The CFC-11 and CFC-12 results, suggesting water of an age of approximately 33 years, provide a more reliable indication of the age of water from this well. Groundwater from well Rg03 is older than can be indicated by CFC methods and the corrected ^{14}C age of approximately 6800 years is not an unreasonable estimate for this water. There is some conflict between the results of the 14C and CFC methods for water from well Rg02. However, the inconsistency between the CFC-11 and CFC-12 results for this sample may indicate the CFC-12 recharge date of 1973 is due to contamination due to sampling. If this is the case, and the corrected ^{14}C age of approximately 1500 years is not an unreasonable estimate for the age of water from Rg02.

Table 8. Groundwater age estimates for samples from wells in the RCC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}C$ ($^{o}/_{oo}$)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
Rg01	62.00	96.3	-16.20	4.13	0.130	312	2104	1967	1974
Rg02	20.00	80.3	-13.90	3.98	0.302	1814	1465	<1965	1973
Rg03	51.00	55.6	-16.40	6.32	0.145	4853	6784	<1965	<1965

3.6 CURRENCY CREEK CATCHMENT

3.6.1 CHLORIDE CONCENTRATIONS

Three wells were sampled in the Currency Creek Catchment (CCC), each completed in a different aquifer type. Well CUg01 is completed in a FRA in the Tapanappa Formation, CUg02 in a Tertiary limestone aquifer, and CUg03 in a PSA. The chloride concentrations of all three sampled wells in the CCC, as shown in Table 9, were not particularly high, although water from the Tertiary limestone aquifer had a significantly greater [Cl-] than the PSA or FRA.

Table 9. Chloride concentrations and specific electrical conductivity of groundwater sampled from wells in the Currency Creek Catchment

Sampled Well ID	Round 1 [Cl$^-$] (mg/L)	Round 2 [Cl$^-$] (mg/L)	Round 1 SEC μS/cm	Round 2 SEC μS/cm
CUg01	93	96	540	641
CUg02	407	462	1439	1851
CUg03	139	174	425	555

The CCC is bisected by a southeast to northwest trending fault, which separates the basement Kanmantoo Group geology between Tapanappa Formation in the northwest and Balquhidder Formation in the southeast. Many valleys in the northwest of the catchment are in-filled with sand sediments of the Permian Cape Jervis Formation, from which water may discharge to streams in the northwest of the catchment. Surface water sample points CU02 and CU05 are both at locations where water flows from streams in the upper, northwest part of the catchment. Water from CU02 and CU05 had markedly lower [Cl$^-$] than the other three surface water sample locations, which are all in the lower, southeast part of the catchment. The almost identical [Cl$^-$] during spring and autumn sampling rounds at CU02 and CU05 suggest a groundwater source with a consistent [Cl$^-$] discharging water to these locations.

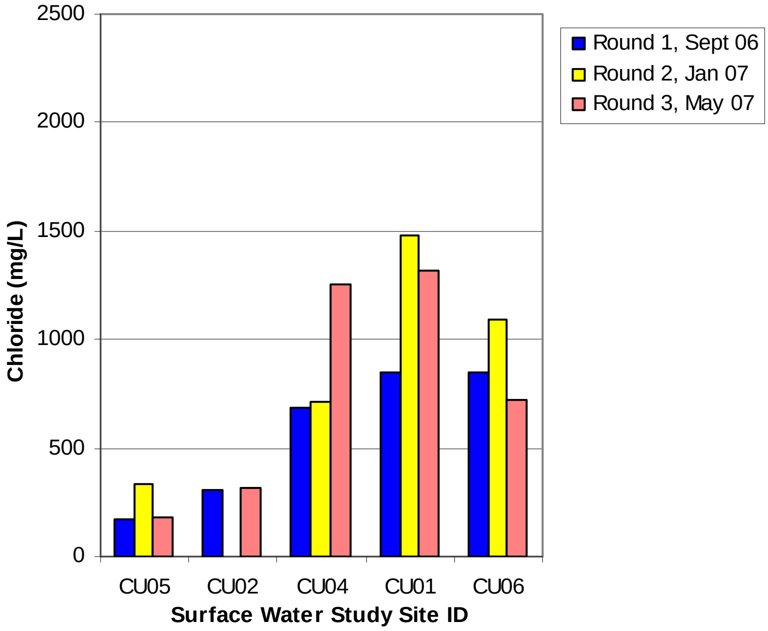


Figure 32. Chloride concentrations of surface water samples from Currency Creek Catchment

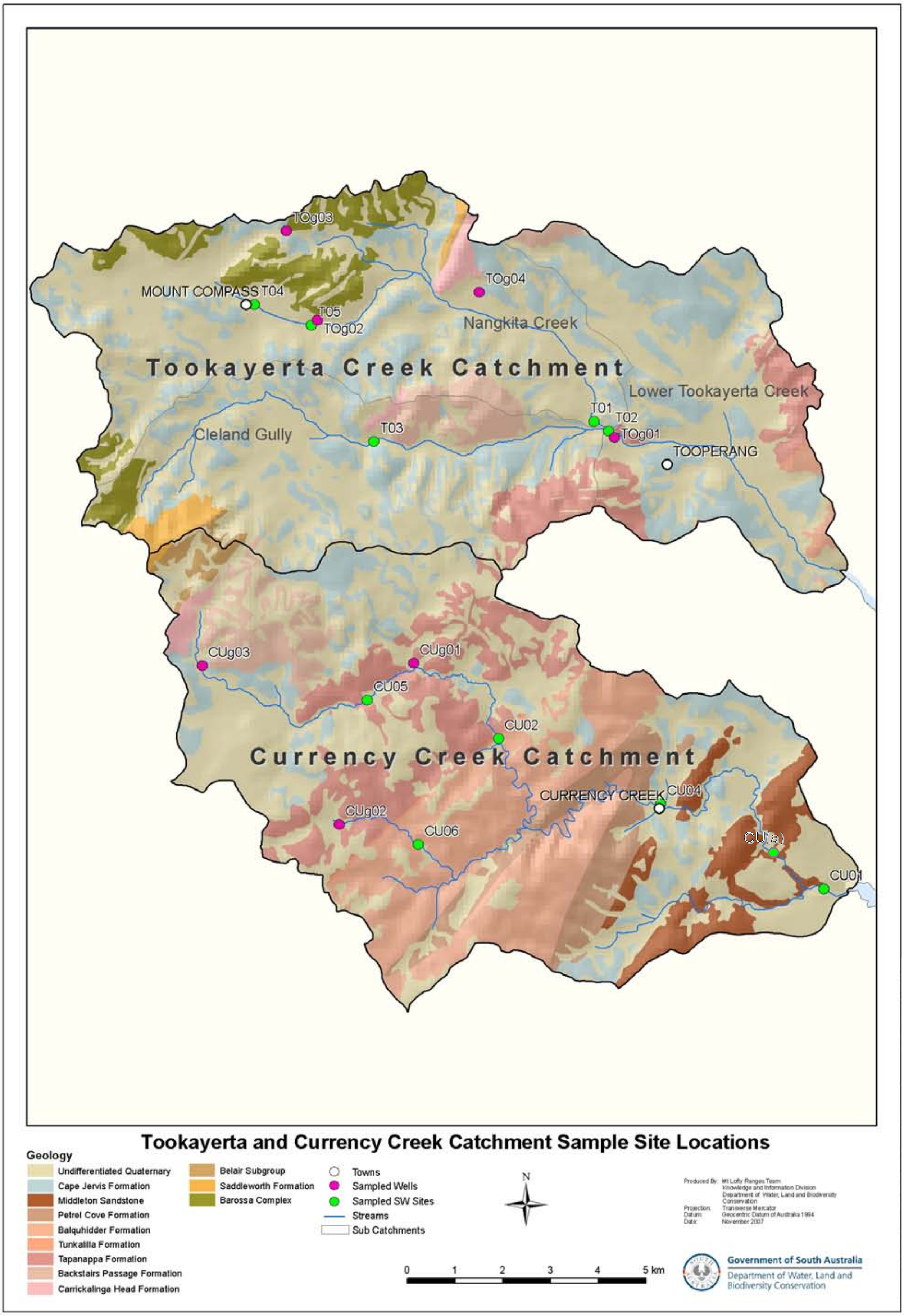


Figure 33. **Tookayerta and Currency Creek catchment sample site locations**

3.6.2 STABLE ISOTOPES OF WATER

The positions of the CCC groundwater samples on the graph of δ^2H versus δ^{18}O graph (Figure 34) are distributed above the Adelaide LMWL, with similar isotopic characteristics to rainfall samples from Echunga and Kyeema. This indicates that recharge of groundwater is direct and rapid in this area as water does not undergo evaporation between falling as rain and recharging the aquifer. The location on the graph of the groundwater samples, toward the isotopically depleted end of the LMWL, also suggests that the groundwater results primarily from winter rainfall, which is generally more isotopically depleted than summer rainfall. As the rainwater and groundwater in this catchment are not particularly isotopically distinct, the stable isotope ratios do not reveal the origin of surface water samples.

The CCC surface water samples lie on a line of evaporative enrichment that may originate with either rainwater or groundwater samples. The samples from locations CU04 and CU01 during both the spring and summer sampling rounds were evaporatively enriched, indicating that the high [Cl-] at those locations was likely to be at least partly due to evaporative concentration of solutes. The round 1 sample from CU02 and round 1 and 2 samples from CU05 were also evaporatively enriched, indicating that even the relatively low [Cl-] at those locations had been increased by evaporative concentration. The samples from CU06 were relatively isotopically depleted during all three sampling rounds, suggesting that the high [Cl$^-$] at that location was not due to evaporative enrichment of solutes, but more likely to be from a saline groundwater source.

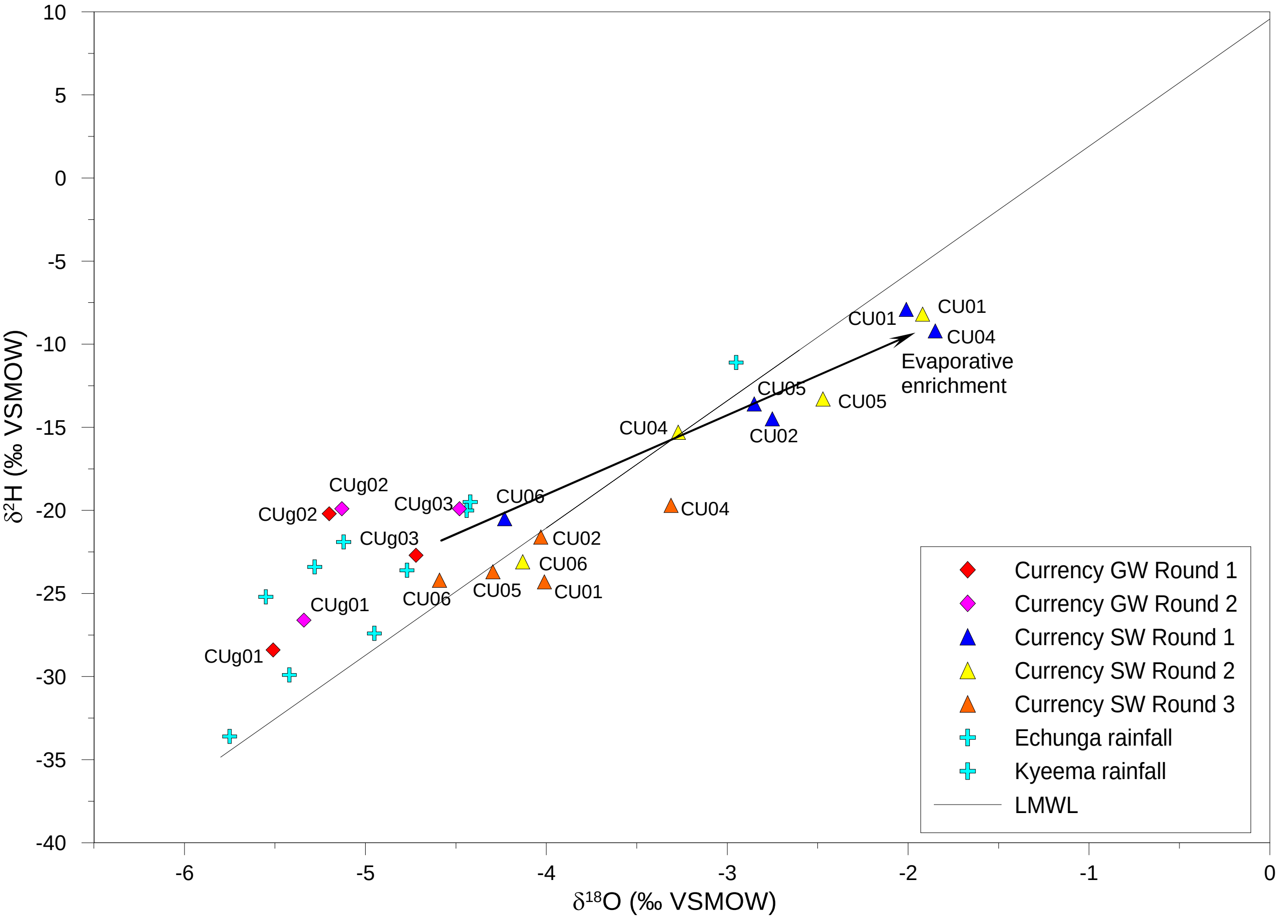


Figure 34. Stable isotopes of water, expressed as δ^2H versus δ^{18}O for samples from the Currency Creek Catchment (study site identifiers are shown beside each point)

3.6.3 RN-222 ACTIVITY

The ^{222}Rn activities of groundwater samples from the CCC were variable with Cug01, Cug02 and Cug03 having average activities over the two sample rounds of 528 Bq/L, 25 Bq/L and 43 Bq/L, respectively. The ^{222}Rn activities of surface waters from the CCC (Figure 35) were relatively high. The activity of samples from CU06 during all three sample rounds seems to confirm that the majority of water at that location derives predominantly from groundwater. The high Rn activity at CU01, particularly during the summer sample round also suggests a groundwater source. This is supported by observations of the creek a short distance upstream of this point, which was dry during all three sample rounds, while water was always present at CU01. The relatively low ^{222}Rn activities at CU05 may be a result of a longer residence time of water in the creek at this point, or due to the water being derived from the PSA, which, as exemplified by the water from well Cug03, has water with a relatively low ^{222}Rn activity, which may decline to low levels within a relatively short time after discharging to the surface system. The year-round presence of water at CU05 suggests a groundwater source for this water. The ^{222}Rn activities of approximately 3 Bq/L at CU04 in both the spring and summer sample rounds suggests a contribution from groundwater at that location, with a similar residence time of this water is the stream during both rounds. During sample round 3, water at CU04 was diluted with water from another source, probably runoff from recent rain. At location CU02, where water was only present in sample rounds 1 and 3, the activities of 4.3 Bq/L in round 1 and 1.8 Bq/L in round 2 indicate a contribution from groundwater at both times.

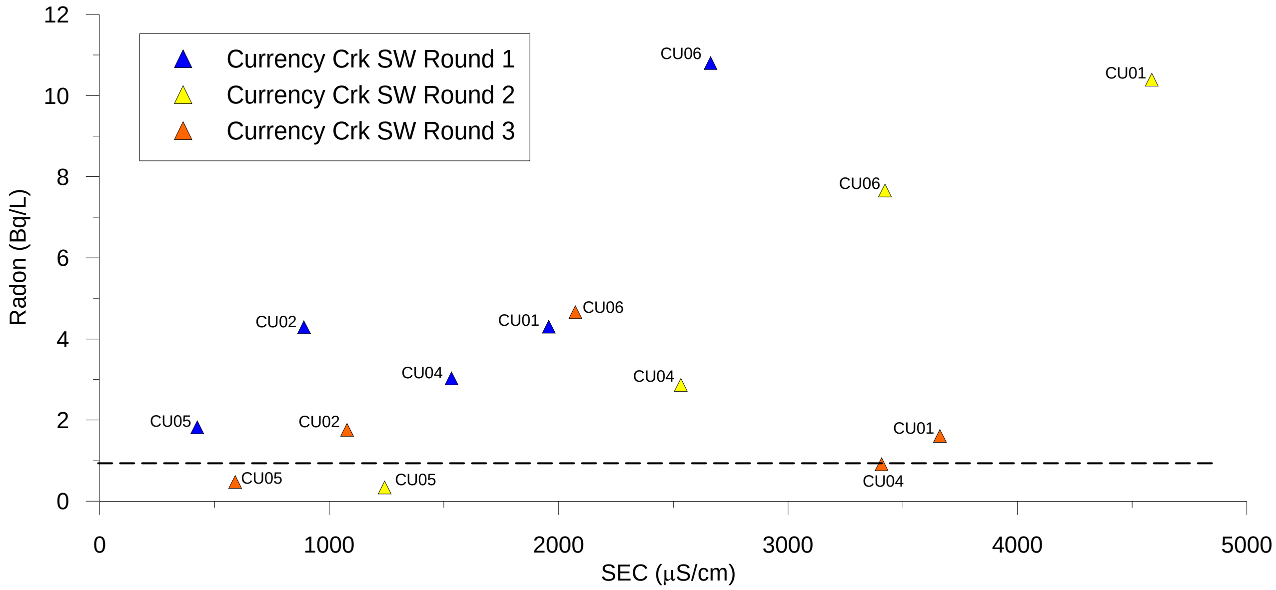


Figure 35. **^{222}Radon activities of surface water samples in the Currency Creek Catchment**

3.6.4 STRONTIUM ISOTOPE RATIOS

Although water at locations CU02 and CU05 had similarly low [Cl$^-$] values, they had distinctly different $^{87/86}$Sr ratios (Figure 36). The water at location CU05 had a $^{87/86}$Sr ratio of approximately 0.7135, similar to that in wells CUg03 (0.7126) and Fg07 (0.7133) in the Finniss River Catchment, both of which draw water from Permian sand aquifers. Sample point CU05 is close to the junction of two streams that emerge from areas of Permian sand aquifers.

Sample point CU02 is on a separate stream system which emerges from an area of Tapanappa Formation geology. The relatively high $^{87/86}$Sr ratio of 0.7170 at CU02 was similar to the $^{87/86}$Sr ratio of 0.7171 in water from well CUg01, which draws from fractured rock in the Tapanappa Formation, at a location close to the stream on which CU02 is located. This was a similar $^{87/86}$Sr ratio to samples from wells completed in the Tapanappa Formation in the Finniss, Angas, and Bremer River catchments (Fg03, Ag01, Bg07, Bg05) and seems to be a typical $^{87/86}$Sr ratio for water in the fractured rock of the Tapanappa Formation, where it occurs in the EMLR.

Samples from surface water sites CU01, CU04 and CU06 all had fairly similar $^{87/86}$Sr ratios of close to 0.715. Well CUg02 had a very low $^{87/86}$Sr ratio of 0.7114. Although CU06 is a short distance downstream of the location of well CUg02, the Sr isotope ratios suggest that the surface water at CU06 is not contributed to by the Tertiary limestone aquifer in which the well CUg02 is completed. However, as the high ^{222}Rn activity of water at CU06 indicates that it does have a groundwater source, it is surmised that the source is probably a FRA in the Kanmantoo Group close to the location of CU06.

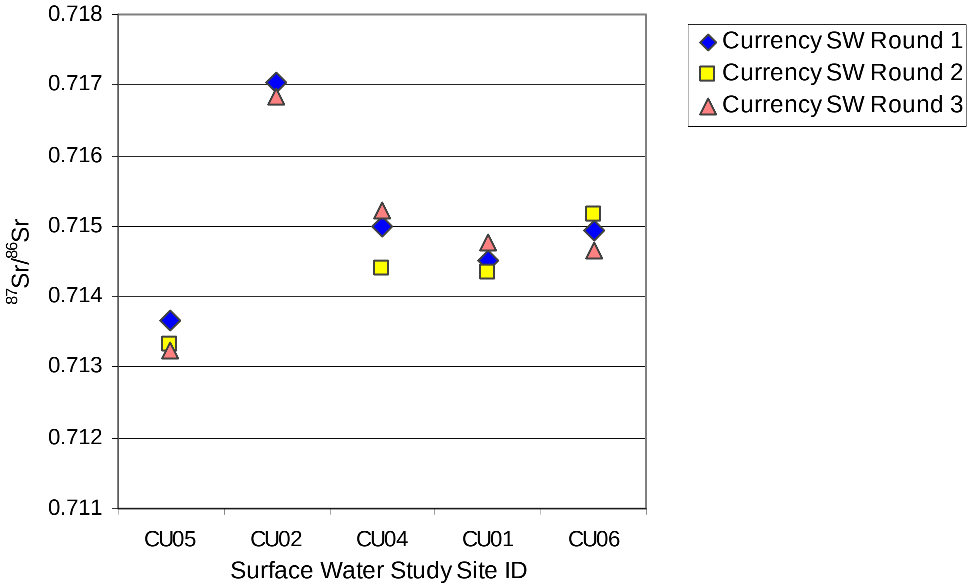


Figure 36. Strontium isotope ratios of surface water samples from the Currency Creek Catchment

On a graph of $^{87/86}$Sr ratios plotted against the reciprocal of the Sr concentration (Figure 37), the position of the surface water samples from CU02 and groundwater samples from CUg01 in this graph clearly suggests that water at CU02 is an evaporated form of the groundwater in CUg01. The position of surface water samples from CU05 also indicates they may be a result of a mixture of groundwater from the PSA and fractured rock in the Tapanappa Formation, with the majority of water coming from the PSA.

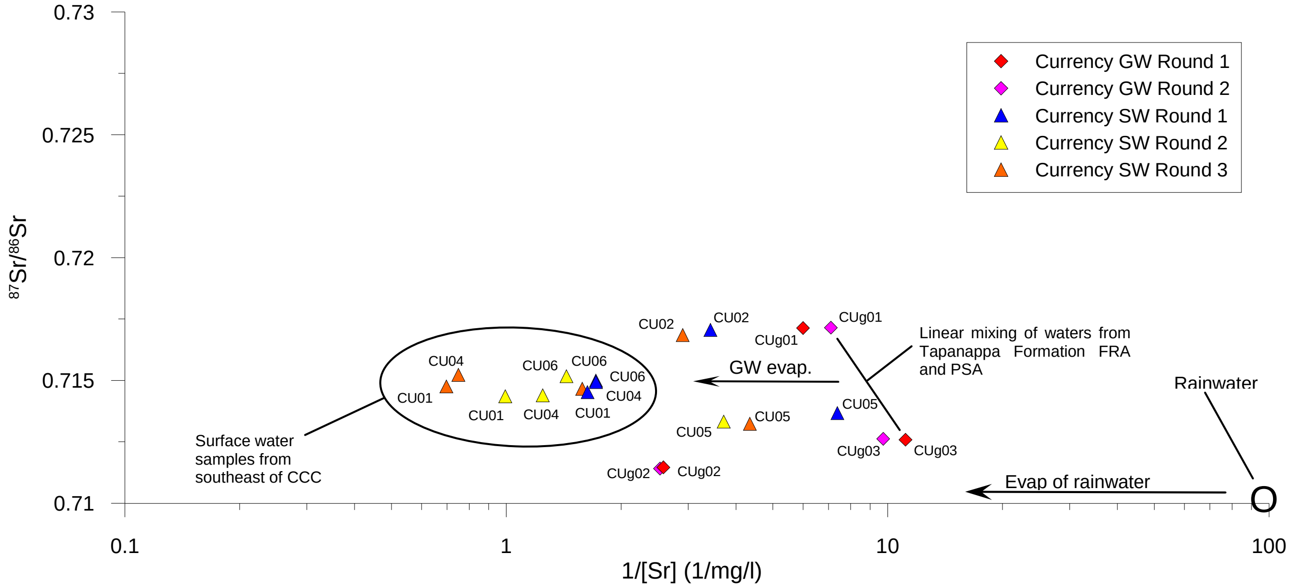


Figure 37. **Strontium isotope ratios plotted against the reciprocal of the strontium concentration of surface water and groundwater samples from the Currency Creek Catchment**

3.6.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years and corrected ^{14}C ages for wells sampled in the CCC are listed in Table 10, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. Water from CUg01 is clearly very old, with an estimated corrected ^{14}C age of approximately 10 700 years. This well is completed in Tapanappa Formation fractured rock at a depth of approximately 42 m. The Results of ^{14}C and CFC methods are conflicting for the sample from well CUg02 and a reliable age cannot be determined from these results. For well CUg03 the ^{14}C activity of 100.33 pmC suggests recently recharged water and is too high for reliable ^{14}C age dating. The CFC-11 result, estimating a recharge date of 1975, provides a reasonable estimate for the age of water from this well.

Table 10. **Groundwater age estimates for samples from wells in the CCC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).**

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}C$ (‰)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
CUg01	25.5	27.48	-14.40	3.71	0.152	10679	10702	<1965	<1965
CUg02	31.5	64.52	-12.60	5.10	0.395	3623	1590	1968	1971
CUg03	36.5	100.33	-18.00	0.30	1.230	-27	6083	1975	NA

3.7 TOOKAYERTA CREEK CATCHMENT

The perennial nature of the creeks and the consistently low salinity and chloride concentrations of the surface water in the Tookayerta Creek Catchment (TCC) suggest that the major creeks are fed by a low-salinity groundwater source. The connection between the extensive PSAs and the surface streams in the TCC has been established by previous studies (Harrington 2004; Banks et al. 2007) and the results presented here further support the findings of these reports.

3.7.1 CHLORIDE CONCENTRATIONS

The [Cl$^-$] results illustrated in Figure 38 are shown with the same vertical axis scale as the [Cl$^-$] results from other catchments (see Figures 5, 12, 19, 26, 32). Surface water [Cl$^-$] values in the TCC were remarkably similar between locations and exceptionally low compared to surface water [Cl$^-$] samples taken in other catchments. Concentrations were slightly higher in sample round 2 than in sample round 1 and this can be attributed to a greater degree of evaporative enrichment during the summer. The low [Cl-] values at these surface water sample locations suggest that the water here may derive from the PSAs in the TCC.

Ground water [Cl-] and salinity values were highly variable in the four wells sampled in the TCC (Table 11). Well TOg01 has distinctly higher [Cl-] and salinity values than the other three wells and is known to be completed in the Adelaidean fractured rock at a depth of approximately 100 m. Well TOg02 is completed in a PSA and had very low [Cl-] and salinity values, similar to those in well Fg07 in the FRC, also known to be completed in a PSA. Well TOg03 is completed in the fractured rock of the Barossa Complex at the northern edge of the catchment.

Table 11. Chloride concentrations and specific electrical conductivity of groundwater sampled from wells in the Tookayerta Creek Catchment

Sampled Well ID	Round 1 [Cl$^-$] (mg/L)	Round 2 [Cl$^-$] (mg/L)	Round 1 SEC µS/cm	Round 2 SEC µS/cm
TOg01	579	591	1817	2164
TOg02	48	50	221	233
TOg03	70	74	352	436
TOg04	146	n/t	520	n/t

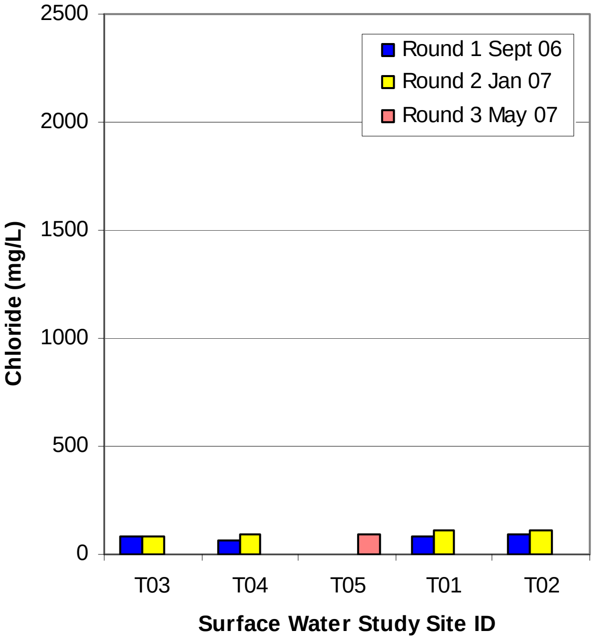


Figure 38. Chloride concentrations of surface water samples from Tookayerta Creek Catchment

3.7.2 STABLE ISOTOPES OF WATER

On the graph of δ^2H versus δ^{18}O (Figure 39), the stable isotope ratios of groundwater samples from the TCC lie close to a trend line through the rainfall samples from the Echunga and Kyeema rainfall collection stations. The groundwater samples were unusually isotopically depleted, suggesting that the majority of recharge of these aquifers is due to winter rainfall, and that not much evaporation of water occurs during the recharge process. The stable isotope ratios of surface water samples were moderately evaporatively enriched compared to the groundwater, however these samples fall into the same region on the graph as a number of rainfall samples. Hence, the stable isotope results suggest the surface water may be either from direct rainfall runoff or evaporatively enriched groundwater, or a mixture of these two sources. All the surface water samples from various points in the catchment were evaporatively enriched by approximately the same degree, indicating that if this water is derived from groundwater, then it is discharged to the surface streams throughout the catchment rather than just at the top of the catchment.

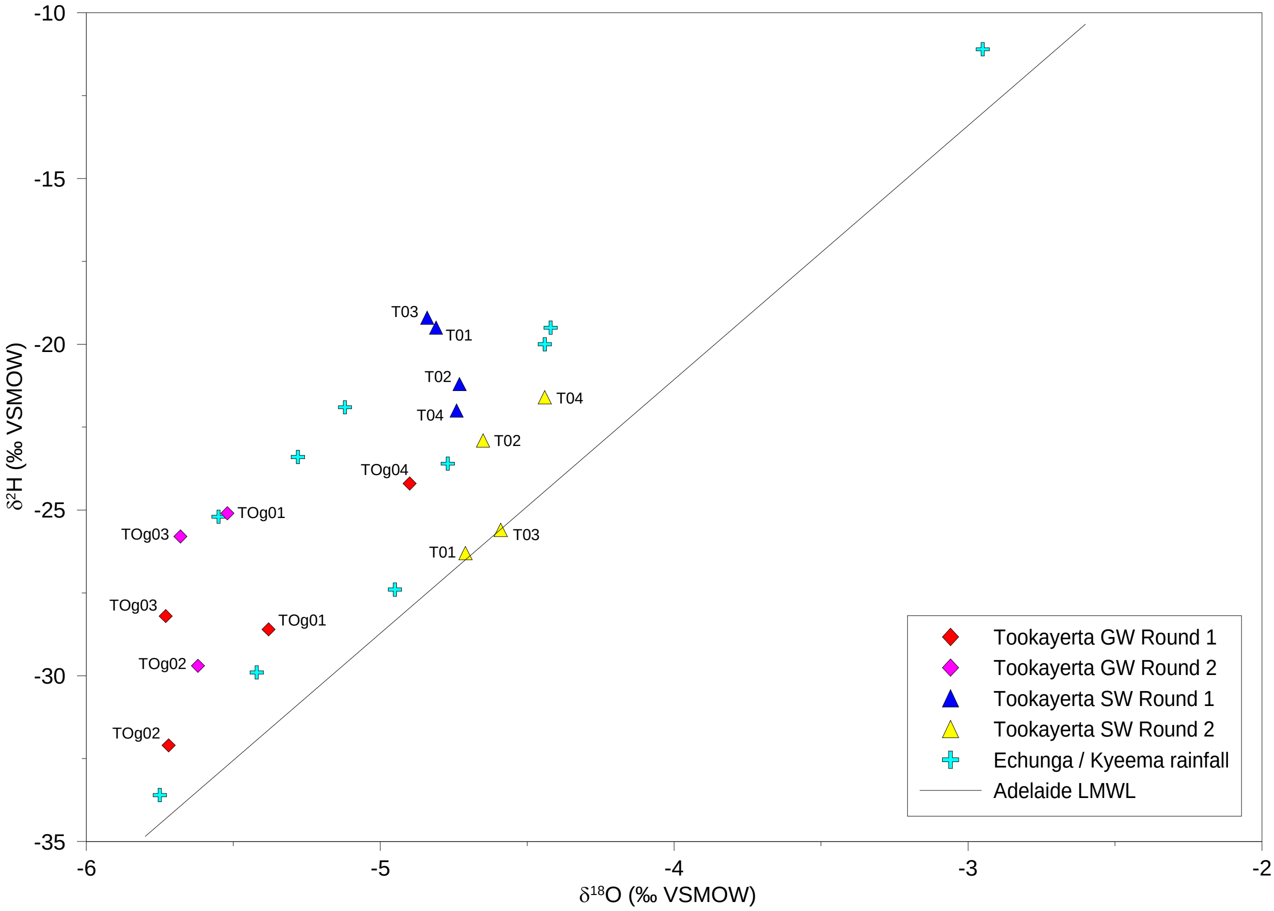


Figure 39. Stable isotopes of water, expressed as δ^2H versus δ^{18}O for samples from the Tookayerta Creek Catchment (study site identifiers are shown beside each point)

3.7.3 RN-222 ACTIVITY

The ^{222}Rn activities of groundwater samples from the TCC were variable, with TOg01, TOg02, TOg03 and TOg04 having average activities over the two sample rounds of 275 Bq/L, 18 Bq/L, 147 Bq/L and 1 Bq/L respectively. This variability is a result of the sampled wells being completed in different aquifer systems: TOg02 and TOg04 in the PSA, TOg01 in the Adelaidean FRA and TOg03 in the BC FRA.

Radon-222 activities in the surface water samples from the TCC were relatively low, although samples from locations T01, T03 and T05 were above 1 Bq/L, suggesting recent discharge from the groundwater system. The radon activity of water in the PSA is typically low (<20 Bq/L), so low ^{222}Rn activities should be expected in water emerging from this aquifer system.

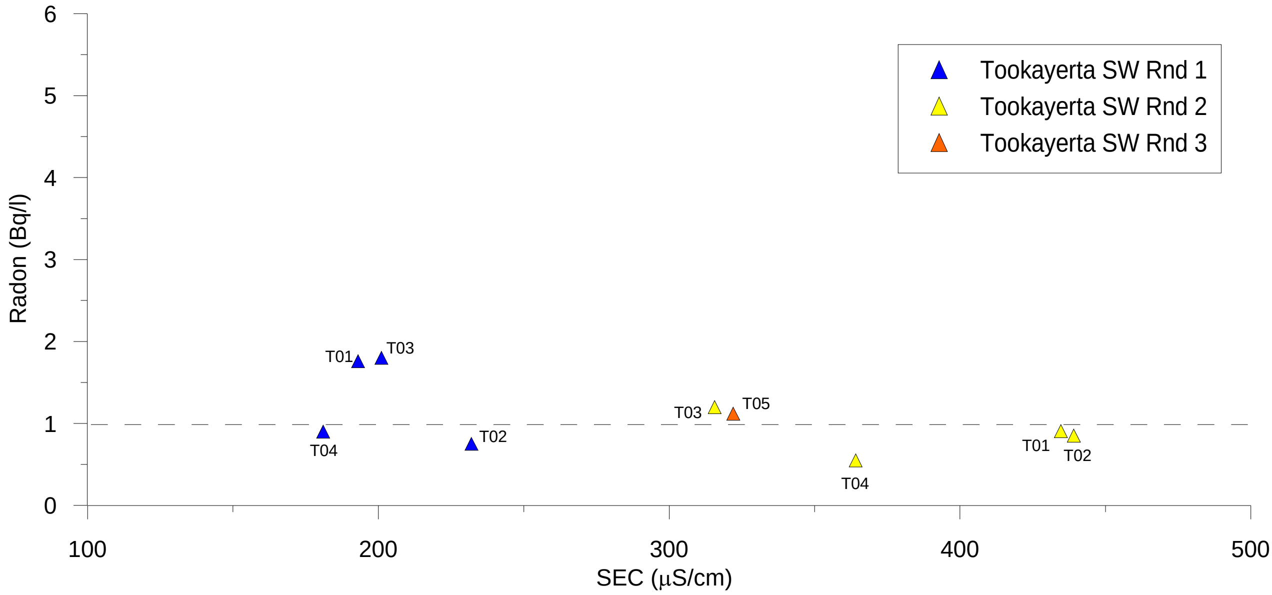


Figure 40. **^{222}Radon activities of surface water samples in the Tookayerta Creek Catchment**

3.7.4 STRONTIUM ISOTOPE RATIOS

The $^{87/86}$Sr ratios of surface water samples in the TCC span a greater range of values than the surface waters in the other EMLR catchments, ranging between 0.7154 and 0.724 (Figure 41). This is due to the influence of strontium from two distinct sources: the BC FRA, which has a high $^{87/86}$Sr ratio; and the PSA, which typically has a relatively low $^{87/86}$Sr ratio. Surface water samples from location T01 had a higher ratio, more influenced by Sr from the BC in the north of the TCC, whereas surface water samples from locations T03 and T04, appeared to have Sr primarily from the PSA. At location T02, just below the confluence of Nangkita Creek and Cleland Gully Creek, the $^{87/86}$Sr ratio reflects the relative contribution of water from the two creeks. In the sample round 1 (spring), when both creeks were flowing strongly, the $^{87/86}$Sr at T02 indicated approximately 60% of the water is from Nangkita Creek, while in sample round 2 (summer), when there was a relatively small flow from the Cleland Gully Creek, the $^{87/86}$Sr ratio at T02 was very similar to that at T01, indicating the majority of water in Tookayerta Creek at that time was from Nangkita Creek, as was observed at the time of sampling.

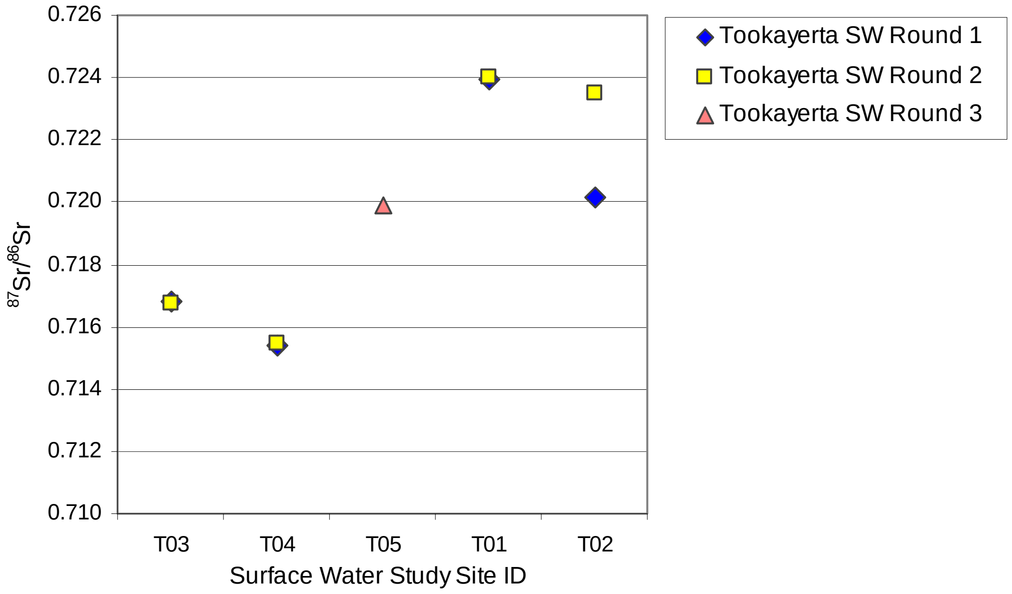


Figure 41. Strontium isotope ratios of surface water samples from the Tookayerta Creek Catchment

On a graph of $^{87/86}Sr$ ratios plotted against the reciprocal of the Sr concentration (Figure 42), all of the TCC surface water samples plot close together in a position on the graph that indicates their Sr characteristics result from a mixture of dissolved Sr from the PSA and BC FRA, combined with some evaporative enrichment. The majority component in the mixture is water from the PSA.

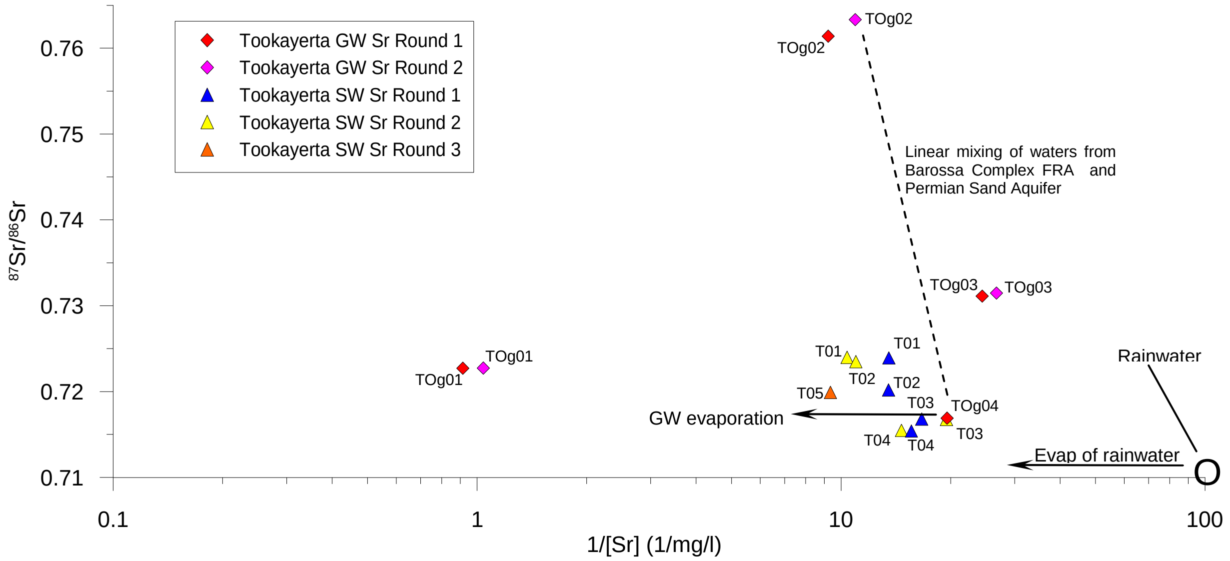


Figure 42. Strontium isotope ratios plotted against the reciprocal of the strontium concentration of surface water and groundwater samples from the Tookayerta Creek Catchment

3.7.5 CARBON-14 AND CHLOROFLUOROCARBONS

The CFC-11 and CFC-12 recharge years for wells sampled in the TCC are listed in Table 12, together with the corrected ^{14}C age of groundwater from well TOg01 and values of the parameters used in the Fontes and Garnier (1979) ^{14}C age correction model. The estimated recharge years of

1971 and 1980 for groundwater from well TOg01 are inconsistent with the much higher corrected ^{14}C age of 8729 years, derived from the particularly low ^{14}C activity of 26.8 pmC. Well TOg01 is a deep well (92 m), completed in a Kanmantoo Group FRA, and is unlikely to contain water with an age of only 30–40 years. The CFC content of these samples may have been a result of atmospheric CFC contamination during sampling. The corrected ^{14}C age of approximately 8700 years is more likely to be a reliable age estimate for water from well TOg01. Water from wells TOg02 and TOg04 contained too little dissolved carbon for ^{14}C dating. These wells are completed in the PSA, which typically has high recharge rates and high rates of flow. The CFC-11/CFC-12 recharge dates for TOg02 and TOg04 of 1969/71 and 1984/86 respectively, are surmised to be reasonable estimates for the ages of water from these wells.

Table 12. Groundwater age estimates for samples from wells in the TCC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model (refer section 2.2).

GW Sample ID	Well depth (m)	^{14}C activity (pmC)	δ^{13}C ($^o/_{oo}$)	HCO_3 (mmol/L)	CO_2 (mmol/L)	^{14}C Uncorrected age (y)	[F & G model] ^{14}C corrected age (y)	CFC-11 age (recharge year)	CFC-12 age (recharge year)
TOg01	92.00	26.8	-12.60	3.84	0.235	10880	8729	1971	1980
TOg02		n/t						1969	1971
TOg04		n/t						1984	1986

3.8 STREAMFLOW MEASUREMENTS

In the catchments of the Bremer, Angas and Finniss rivers, manual streamflow measurements or estimates were made at all surface water sample points during one week in October 2006. Where a measurement of flow with an in-stream flowmeter was not practical, an estimate of flow was made based on visual observations. These measurements and estimates were to provide an indication of the relative flow-rates of the rivers/creeks and their tributaries at a particular point in time, when not affected by runoff of recent rainfall. The dates of these measurements, and the corresponding streamflow rates and rainfall at these times, are indicated in hydrographs in Figures 3 and 4. At the time of these measurements there had been no significant rain in these catchments for over 30 days: water flowing in the streams is derived from groundwater discharges and delayed interflow. Results of these measurements and observations are listed in Table 13. The study site locations are shown on catchment maps in Figures 6, 13, 20, 27 and 33.

Table 13. Streamflow measurements and observations at surface water study sites, October 2006

SW Study Site ID	Catchment	Date of observation	Flow rate estimate method	Flow rate estimate (L/sec)	Flow rate estimate (m^3/day)	Comments
A01	ANGAS	27/10/06	Visual estimate	0.0		Little surface water present, but no flow.
A02	ANGAS	27/10/06	Current meter	16.3	1406.6	
A03	ANGAS	24/10/06	Visual estimate	5.0	432.0	River bed dry (no flow) approx 200m d/s of here.
A04	ANGAS	24/10/06	Bucket volume/time	10.0	864.0	
A06	ANGAS	24/10/06	Visual estimate	0.1	8.6	Lots of water present but very low flow
A07	ANGAS	24/10/06	Visual estimate	0.0	0.0	Some water present, but no flow apparent.
A08	ANGAS	24/10/06				Flow estimate not possible: river too wide.
A09	ANGAS	24/10/06	Visual estimate	0.0	0.0	Water still present, but no flow.
A10	ANGAS	27/10/06	Visual estimate	0.0	0.0	Lots water present, but no flow.
A11	ANGAS	27/10/06	Current meter	15.3	1318.5	Water level appears higher now than sample Round 1.
A12	ANGAS	27/10/06	Visual estimate	0.0	0.0	Surface water present but no flow.
A13	ANGAS	27/10/06	Visual estimate	0.0	0.0	No water present.
A14	ANGAS	27/10/06	Current meter	15.7	1352.2	
A15	ANGAS	27/10/06	Current meter	4.6	396.6	Flow here all g/w at this time. No flow 2km d/s of here.
A16	ANGAS	24/10/06	Visual estimate	0.1	8.6	
F01	FINNISS	24/10/06	Staff gauge: 1.037 m	26.0	2246.4	Gauge station A426 0 504 : Flow from rating table
F02	FINNISS	23/10/06	Bucket volume/time	0.4	30.2	
F03	FINNISS	24/10/06	Visual estimate	0.1	8.6	
F04	FINNISS	24/10/06	Visual estimate	0.2	17.3	
F06	FINNISS	24/10/06	Current meter	5.6	481.2	
F08	FINNISS	24/10/06	Current meter	21.5	1858.5	Flow measurement approx 300 m u/s of sample site.
F09	FINNISS	24/10/06	Current meter	1.7	150.3	
F10	FINNISS	24/10/06	Visual estimate	0.2	17.3	
F12	FINNISS	24/10/06				Flow estimate not possible: river too wide.
F11	FINNISS	24/10/06	Visual estimate	0.0	0.0	Creek bed dry.
F13	FINNISS	23/10/06	Current meter + visual	40.0	3456.0	
F14	FINNISS	24/10/06	Current meter	11.2	964.2	
F15	FINNISS	23/10/06	Current meter	6.4	548.6	
F17	FINNISS	23/10/06	Current meter	6.2	532.2	
B01	BREMER	30/10/06	Visual estimate	0.0	0.0	No water & no flow.
B02	BREMER	30/10/06	Visual estimate	0.0	0.0	Lots S/water, but no flow apparent.
B03	BREMER	27/10/06	Current meter + visual	3.3	288.6	
B04	BREMER	30/10/06	Visual estimate	0.0	0.0	Large pool here, but no flow apparent.
B05	BREMER	30/10/06	Visual estimate	0.0	0.0	No flow apparent. Water too wide here to tell if flowing.
B07	BREMER	30/10/06	Current meter	5.2	446.7	
B08	BREMER	30/10/06	Bucket volume/time	5.1	438.9	Flow rate error est +/- 25%.
B10	BREMER	30/10/06	Current meter	5.6	485.6	
B11	BREMER	30/10/06	Current meter + visual	8.8	762.9	
B12	BREMER	30/10/06	Visual estimate	0.0	0.0	Lots of surface water, but no flow apparent.
B13	BREMER	30/10/06	Visual estimate	0.0	0.0	Lots of surface water, but no flow apparent.
B14	BREMER	30/10/06	Visual estimate	0.0	0.0	Two large pools here , but no flow apparent
B15	BREMER	30/10/06	Visual estimate	0.0	0.0	May be flow of <0.1 L/s. Large pools still present.
B16	BREMER	30/10/06	Visual estimate	0.0	0.0	Large pools here but no surface flow.
B17	BREMER	30/10/06	Visual estimate	0.5	43.2	Large pool, but very low flow.
B18	BREMER	30/10/06	Visual estimate	0.0	0.0	Surface water, but no flow apparent.

4. DISCUSSION

4.1 BREMER RIVER CATCHMENT

There are many permanent pools along the Bremer River and Mount Barker, Dawsley and Rodwell Creeks, as identified by the videography program (Figure 2). The persistence of these pools through the dry season implies that they are likely to be in part supplied from groundwater inflows.

The Bremer River Catchment (BRC) can be divided for the purpose of this analysis into five distinct sections (rather than sub-catchments).

4.1.1 UPPER BREMER RIVER

This section of the BRC includes all of the river and its tributaries to the north of the confluence with Mount Barker Creek. This includes the surface water sampling points B14 (Br02), B15 (Br01), B16 (Br03), B05 (Br04) and B04 (Br05).

In this section of the river system, all of the surface water samples showed similar chemical and isotopic characteristics. During the year of this study, this section of the river did not flow and was reduced to a line of disconnected pools. The permanence of these pools through this exceptionally dry year suggests that there must be an inflow of groundwater that is approximately equal to the evaporation from the pools. The stable isotope ratios of the surface water samples all lie on an evaporation line drawn from the groundwater samples from this catchment in the direction of greater enrichment of ^{2}H and greater Cl^{-} concentration. Some samples from the summer and autumn samplings showed very high levels of enrichment of $\delta^{2}H$ and Cl^{-}, as would be expected after a long period of evaporation, without being flushed by a flowing river.

The strontium isotope ratios of these samples support this interpretation when plotted on a graph of $^{87/86}Sr$ against 1/[Sr]. The $^{87/86}Sr$ ratio of the groundwater samples in this section of the catchment was 0.7185, with a [Sr] of approximately 0.75–1.0 mg/L. All of the surface water samples from the upper Bremer River had a similar $^{87/86}Sr$ ratio, but lie to the left of the groundwater samples, indicating high Sr concentration resulting from evaporation of the water with the same $^{87/86}Sr$ and 1/[Sr] signature as the local groundwater.

If the majority of water in the pools in this section of the catchment is derived from groundwater inflows from the surrounding Tapanappa formation FRA, then a fairly high ^{222}Rn activity might be expected in these surface waters, especially given that the groundwater sampled nearby was found to have a ^{222}Rn activity of between 200 and 400 Bq/L. In fact, the majority of the surface water samples from this area had low Rn activities of less than 0.5 Bq/L. This can be explained by the low rate of inflow of groundwater to these pools. In a stationary pool of, for example, 20 m length by 4 m width and 0.5 m depth, and with a summer evaporation rate of approximately 6 mm/d, with an inflow rate equalling the evaporation rate, the average residence time of the water in the pool would be well over 100 days. If inflowing water had a ^{222}Rn activity of 360 Bq/L, it would be reduced to less than 0.5 Bq/L in less than 35 days by radioactive decay alone, even without any degassing of radon. Hence, we would not expect to find much ^{222}Rn in these stationary pools. In fact there were ^{222}Rn activities of greater than 0.5 Bq/L in three of the pools during the spring sample round only, with a high reading of 2.6 Bq/L in pool B15, indicating a higher rate of groundwater inflow during spring in those locations.

4.1.2 DAWSLEY AND NAIRNE CREEK

The Dawsley and Nairne Creek sub-catchments occupy the northern half of the BRC, to the west of the northern Bremer River section. Nairne Creek converges with Dawsley Creek at a point in the centre of the BRC and then Dawsley Creek converges with Mount Barker Creek approximately 6 km to the southeast.

The most northerly part of Dawsley Creek receives water from the outflow of the Bird-in-Hand wastewater treatment plant (WWTP), which is very likely to affect the quality of water collected at surface water sample point B08, close to the source of this creek. Water sampled at point B07 is affected by acid-attenuation treatment of water draining from the Brukunga pyrite mine, which is a few kilometres upstream of that point.

There are four surface water sample points in these sub-catchments: one on Nairne creek and three on Dawsley Creek, with two of these above the confluence with Nairne Creek and one below the confluence. All of the surface water samples from these points had low ^{222}Rn activities in all three sampling rounds, even when there was significant flow and water residence times were low. These results suggest that there is minimal inflow of groundwater to these creeks. The deuterium isotope ratio to Cl concentration relationship in samples from these points all lie in a zone representing the evaporative enrichment of local rainwater, suggesting that the majority of this water is derived from surface runoff.

These findings are supported by the results of the strontium isotopes analysis. On the graph of $^{87/86}$Sr versus 1/[Sr], these samples all lie on a line of dilution between the samples of groundwater from this catchment and the expected Sr isotopic characteristics of evapo-concentrated local rainwater. Because of the mass balance between the very low concentrations of Sr in rainwater (typically <0.005 mg/L) and the relatively high concentrations in the BRC groundwater (0.4–1.5 mg/L), any movement toward the rainwater end-member in the $^{87/86}$Sr versus 1/[Sr] relationship requires a high degree of dilution of groundwater by rainwater. A mass balance calculation according to Equation 2, using both Sr concentrations and $^{87/86}$Sr isotope ratios, indicates the surface water at these samples to be a mix of 21% or less of evapo-concentrated groundwater, characterised by GW samples Bg03 and Bg05, and 79% or more of evapo-concentrated rainwater.

$$^{87/86}\mathrm{Sr}_M = {}^{87/86}\mathrm{Sr}_A \,.\, f\,\mathrm{Sr}_A/\mathrm{Sr}_M + {}^{87/86}\mathrm{Sr}_B \,.\, (\mathrm{Sr}_B\,(1-f)\,/\,\mathrm{Sr}_M) \qquad \textbf{Equation 2}$$

(Faure 1986)

In Equation 2, $^{87/76}\mathrm{Sr}_{A,}$ $^{87/76}\mathrm{Sr}_B$ and $^{87/76}\mathrm{Sr}_M$ are the Sr isotope ratios of end-members A and B and the mixture M. The terms Sr_A, Sr_B and Sr_M are strontium concentrations in A, B and M, and f is the fraction of the end-member A in the mixture.

Samples from B07 were omitted from this mass balance analysis as they are expected to have been overly affected by addition of Sr from a foreign source in the acid-attenuation process at the Brukunga mine.

4.1.3 MOUNT BARKER CREEK

The Mount Barker Creek sub-catchment has two surface water sample points (B03 and B11). There is also a sampled groundwater well (Bg06), which is close to surface water point B03.

The groundwater sample from well Bg06 had a ^{222}Rn activity of 60–118 Bq/L. The surface water sample at B03 by contrast had a maximum Rn activity of only 0.78, during the spring sampling round. This suggests that either there is a very low rate of groundwater inflow here or that any groundwater inflow occurs some distance upstream of this point. However, the creek flows throughout the year at this location, even through the very dry year of 2006-2007, implying there must be some inflow of groundwater to sustain flows. The $^{87/86}$Sr isotope ratios from the two surface water sample points lie on a dilution line between the Sr isotopic characteristics of the Bg06 groundwater and the expected Sr isotopic characteristics of evapo-concentrated local rainwater. Again, this implies the water here is a mix of discharged groundwater and surface runoff. Application of the mass balance calculation described by Equation 2, using the Sr characteristics of water from well Bg06, indicates a groundwater/surface runoff mix at point B03, with groundwater comprising 43%, 51% and 38% respectively in the spring, summer and autumn sampling rounds.

Application of this mass balance calculation to the Sr characteristics of the spring and autumn surface water samples from location B11 and the groundwater samples from Bg03 and Bg05, indicates the surface water at B11 to be a mix of groundwater and surface runoff with the groundwater proportion being 22–25% in the spring sample and 45–50% in the autumn sample. The same calculation could not be applied to the summer sample from B11 as it had undergone too much evaporative enrichment of the Sr concentration. However, the $^{87/86}$Sr ratio of the summer sample was approximately the same as that of the groundwater from wells Bg03 and Bg05, indicating that the majority of that water probably derives from groundwater discharging from the Tapanappa Formation FRA in this area.

The stable isotope analysis supports these findings, showing the B03 and B11 samples in the plot of δ^2H versus [Cl$^-$] to lie at a point that either represents evaporation of local rainwater, or a mix of local rainwater with a low percentage of local groundwater.

The surface water sample point B11 is at a point where two minor creeks converge with Mount Barker Creek in a steeply-incised valley where a significant inflow of groundwater might be expected. The $^{87/86}$Sr isotope ratio of the surface water sample taken in the summer sampling round is indicative of evapo-concentrated groundwater, with a similar $^{87/86}$Sr ratio to the groundwater samples taken from wells in the Kanmantoo Group FRA in the south of the BRC. This implies that, while the surface flow here in the spring and autumn may be mostly derived from surface runoff, the water that remains here in a stationary pool in the summer is derived predominantly from local groundwater inflows. This is confirmed by the deuterium ratio/[Cl$^-$] signature for this sample, which is strongly indicative of evapo-concentrated groundwater.

When streamflow measurements were made in October 2006 (Table 13), a significant flow of 763 m^3/d was recorded at location B11 in Mount Barker Creek, on the same day as flow of only approximately 43 m^3/d was observed at B17. Hence, approximately 720 m^3/d was lost from the surface water system between these two points. The indication from the summer ^{222}Rn activity at B17 is that small amounts of groundwater discharge occurs some distance upstream of that point in summer. This suggests that the section of the Bremer River between the Mount Barker Creek confluence and B17 is unlikely to have been losing to groundwater in October 2006 when groundwater levels would have been higher. Hence, the loss of water between B11 and B17 is most likely to occur in the lower reaches of Mount Barker Creek.

4.1.4 RODWELL CREEK

The Rodwell Creek sub-catchment occupies the south-eastern section of the BRC, and Rodwell Creek itself converges with the Bremer River close to the southern-most point of the BRC. There are two surface water sample points (B12 and B13) and two sampled groundwater wells (Bg03 and Bg07) in this sub-catchment.

Although the upper part of this sub-catchment has a number of farm dams that prevented flow in the upper part of the creek for the whole period of the sampling program, water was present at both of the surface water sample locations throughout the year, suggesting a groundwater inflow to maintain the permanent pools that exist at both locations.

The groundwater sample from well Bg07 was considerably less saline than the sample from well Bg03, with an EC of 1785 μS/cm compared to 4539 μS/cm, and had lower ^{222}Rn activity of 146 Bq/L compared to 860 Bq/L for well Bg03. However, the $^{87/86}$Sr ratios of the two wells were very similar, with 0.7169 for Bg03 and 0.7171 for Bg07, reflecting the similar chemistry of the Tapanappa Formation FRA that is common to both of these wells.

On the plot of δ^2H versus [Cl-], the surface water samples from B13 in all three sampling rounds lie on a line of evapo-enrichment of groundwater exemplified by the groundwater samples from Bg03 and Bg07. The samples from B12 also lie on this evapo-enrichment line, indicating evaporation of groundwater inflow only, although the autumn sample from B12 is somewhat depleted in ^{2}H, indicating some dilution by the highly ^{2}H-depleted rainfall at that time.

The ^{222}Rn activities of the spring, summer and autumn samples from site B13 had ^{222}Rn activities of 2.1 Bq/L, 3.7 Bq/L and 1.3 Bq/L respectively, indicating some groundwater inflow throughout the year. The activities at B12 were lower than at B13, all being less than 0.5 Bq/L. These results may indicate that if the surface water at point B12 is derived from groundwater inflows, then the residence time of the water here is higher than at point B13. However, the ^{222}Rn activity of the groundwater in well Bg07 close to surface water point B13 was much lower than that in well Bg03, which is close to surface water point B12, indicating a much lower residence time of groundwater in the permanent pool at B13 than at point B12. The pools found at location B13 exist at the base of a sheer rock face where the rock of the Tapanappa Formation FRA is exposed (Figure 43). The position of these pools in the landscape may allow them to receive a through-flow of groundwater from the aquifer, with water in the pool entering from and exiting to the aquifer. This would result in a lower residence time of the water in the pool and result in higher ^{222}Rn activity than at B12.

Figure 43. Permanent pool in Rodwell Creek at the base of an exposure of Tapanappa Formation shale

Surface water at B13 had a very similar $^{87/86}$Sr ratio to the water taken from the nearby well Bg07. The nearest sampled wells to the Rodwell Creek surface water sample points are wells Bg03 and Bg07. These are both in the Tapanappa Formation FRA and, while they had significantly differing salinities, they had $^{87/86}$Sr isotope ratios that were almost identical. The strontium isotope characteristics of samples from B12 and B13 are all indicative of evapo-concentrated groundwater from the Tapanappa Formation FRA, as characterised by the water in wells Bg03 and Bg07. On the plot of $^{87/86}$Sr versus 1/[Sr], all the surface water samples from B12 and B13 lie directly to the left of the Bg03 and Bg07 groundwater samples, indicating that they result solely from evapo-concentration of groundwater discharged from the Tapanappa Formation FRA, without any mixing with other water sources.

Collectively, the hydrochemical and isotopic data for the Rodwell Creek samples strongly suggests that surface water at these locations is derived largely from groundwater discharge. These findings are supported by anecdotal evidence in which the local landholders report the presence of springs at these locations, and surface water present in all seasons.

4.1.5 LOWER BREMER RIVER

For the purpose of this discussion, this section of the Bremer River is considered to start at the confluence with Mount Barker Creek and extend to the sample location point B01 at Bletchley. Rodwell Creek converges with the Bremer River near the southern end of this part of the river. There are three surface water sample points in this section of the river. Two of these (B17 and B02) are between the confluences of the Mount Barker Creek and Rodwell Creek, and one (B01) is approximately 4 km downstream of the Rodwell Creek confluence. There is one sampled groundwater well (Bg02) in this section of the catchment, close to surface water sample point B02.

There were no significant flows from Rodwell Creek into the Bremer River during the period of monitoring for this project. This part of the BRC has significantly lower rainfall than the areas of higher elevation in the west and north of the catchment. At times when flow occurs in this section of the river, it is mostly as a result of flows from further up in the catchment, primarily from Mount Barker Creek.

During the autumn sampling round, the river was observed to have a significant flow of approximately 20 L/s at point B02, which was all lost to groundwater within approximately 1 km south of that point. Further south of this point at B01, water was only flowing during the spring sampling round. It is inferred from these observations that the section between points B02 and B01 is a losing reach of the river and that flow only occurs at point B01 during winter and after rain, when the rate of flow through point B02 is greater than the rate at which water can drain to the groundwater system between B02 and B01.

All but one of the surface water samples from this section of the Bremer River had low ^{222}Rn activities of less than 0.5 Bq/L. The exception was from point B17 during the summer sampling round, which had an activity of 1.3 Bq/L. This may indicate that water flowing in this river section during summer is at least partly derived from groundwater inflows occurring immediately upstream of B17. The low-flow occurring here in the summer makes it unlikely that this ^{222}Rn activity is a residual of groundwater inflows into Mount Barker Creek, which enters the river approximately 4 km upstream of this point, as nearly all ^{222}Rn activity would have expired over the time taken for the water to travel that distance.

The stable isotope analysis for these samples suggests that in the spring and summer, the water at point B17 has the characteristics of evaporatively-enriched rain water. In the autumn sampling round, the water here was all derived from the recent highly deuterium-depleted rainfall. The samples from points B01 and B02 had stable isotope characteristics of evapo-concentrated rainwater at all times that water was present.

Between the Mount Barker Creek/Bremer River confluence and point B17, at least some flow may occur all year due to residual outflows from Mount Barker Creek and small amounts of local groundwater inflow. It appears that water occurring in the lower reaches of the Bremer River south of point B17 are due mostly to surface runoff, and that flow may only occur here after heavy rain, or during the winter when significant amounts of water are flowing from Mount Barker Creek. However, when flows are low, as is typical through the summer, all the flow occurring through this section is lost to groundwater a short distance downstream of point B02.

4.2 FINNISS RIVER CATCHMENT

The videography program identified only a few permanent pools in the Finniss River Catchment (FRC), however there are large numbers of Fleurieu swamps and significant wetlands in the southern half of this catchment. The Finniss River is also a major contributor of flows to Black Swamp.

Meadows Creek appears to gain groundwater along its whole length in spring, when groundwater head levels are high. In summer, there still appears to be significant evidence of groundwater inflow at locations F03 and F15. Location F14 may be receiving inflows from further upstream, evidenced by the highly isotopically enriched state of the water here in summer. The ^{222}Rn activities at F15, F14 and F13 in the summer sample round were 2.6 Bq/L, 0.7 Bq/L and 8.75 Bq/L respectively, suggesting active groundwater inflows are contributing water at F15 and F13. The lower ^{222}Rn activity at F14 does not discount the inflow of groundwater at that location, but may indicate a lower rate of inflow such that the residence time of water here is greater, providing a longer time for degassing and expiration of Rn. The δ^2H and δ^{18}O stable isotope results indicate that water at F15 and F14 in the summer were evapo-enrichment of the same water at these locations in the spring sample round. In the autumn sample round, the stable isotope results indicate that water at these locations was largely from the recent rain prior to sampling. This is further supported by the low radon activities of the Meadows Creek samples in the autumn sample round.

At location F13, the water may be predominantly derived from locally inflowing groundwater in summer, including from the nearby BC FRA, as evidenced by the high strontium isotope ratio. Both the δ^2H stable isotope value and the Sr isotope ratio at location F13 changed significantly between the spring and summer sample round, suggesting a different source of water in the summer. While the summer δ^2H value was not conclusive, the high Rn activity indicates a nearby groundwater source, and the higher Sr isotope ratio indicates that this source is likely to be groundwater discharging from a BC FRA, which surrounds this location and was shown by the groundwater sample from the nearby well Fg08 to have a high $^{87/86}$Sr ratio of 0.7529. Hence, it is surmised that during summer, water at the end of Meadows Creek is a mix of water discharged from two FRAs. The major contributor is water emerging either from the Saddleworth Formation to the west of the creek, or surface sediments in the floodplain of the creek, with a minor contribution from the BC FRA close to the end of the creek near Yundi.

Surface water at location F02 had strontium isotope characteristics that were distinct from the other surface water samples in this catchment. On the graph of $^{87/86}$Sr versus 1/[Sr], the F02 samples lie on a mixing line between groundwater from the PSA (Fg07) and groundwater from the BC aquifer (Fg08). In view of the location of F02, lying at the end of a reach that runs between areas of Permian sand and Barossa Complex geologies, it is reasonable to draw from this that the surface water at F02 is a mixture of groundwater from these two distinct aquifers. The water here had a ^{222}Rn activity of 2.2 Bq/L in the spring sampling round, indicating recent groundwater outflow, and an activity of 0.4 Bq/L in the summer. The lower ^{222}Rn activity in the summer is probably a result of longer residence time after discharging from groundwater, because of the lower discharge rate and lower streamflow rate. In the winter sampling, the Rn activity was very low, probably reflecting a dominance of rain runoff at that time.

Water sampled at location F02 had a [Cl$^-$] and TDS approximately twice as high as that measured in water extracted directly from the PSA in well Fg07, which is close to this surface water location. This may result from some evapo-concentration of the water after discharging into the stream, however the $^{87/86}$Sr isotope ratio of the surface water at F02 suggest that this water is a mix of water from the PSA and the underlying BC FRA. This indicates that [Cl$^-$], TDS and $^{87/86}$Sr ratio of the surface water at F02 are all a result of a small amount of water from the BC FRA mixing with the majority contribution of water from the PSA. The strontium isotope mixing equation derived by Faure (1986) (Equation 2, sec 4.1.2) suggests the proportion from the PSA ranges from 95% in the autumn sampling round to 98% in the spring sample round (Table 14).

In Equation 2, $^{87/76}$Sr$_{A,}$ $^{87/76}$Sr$_B$ and $^{87/76}$Sr$_M$ are the Sr isotope ratios of end-members A and B and the mixture M. The terms Sr$_A$, Sr$_B$ and Sr$_M$ are strontium concentrations in A, B and M, and f is the fraction of the end-member A in the mixture.

Table 14. Fraction of water in Finniss River at location F02 that derives from the Permian Sand aquifer, according to the strontium isotope mixing equation of Faure (1986).

		[Sr]	**Sr** 87/86	***f*** (fraction of component X_A in mix)
Finniss GW Fg07	X_A	0.06	0.71326	
Finniss GW Fg08	X_B	1.09	0.7529	
Finnis River at Yundi SW Spring	F02	0.0819	0.723301	0.98
Finnis River at Yundi SW Summer	F02	0.0966	0.723204	0.96
Finnis River at Yundi SW Autumn	F02	0.11095	0.720629	0.95

Applying a two-component mixing equation to the chloride concentrations (Equation 1, sec 3.3.1) of the BC FRA and PSA groundwaters—which were 633 mg/L and 58 mg/L respectively, and the [Cl$^-$] of the F02 Finniss River water in spring (126 mg/L), summer (156 mg/L) and autumn (176 mg/L)—the proportion of PSA water in the F02 Finniss River water is 88%, 83% and 82.6% in spring, summer and autumn respectively. While these are lower proportions than shown by the Sr isotope model, the results obtained from the two-component [Cl$^-$] mixing equation are more likely to be affected by evapo-concentration of the surface water than results from the strontium isotope model. A reasonable summary of these results is that the river water at location F02 is at least 83% from the PSA and less than 17% from the BC FRA.

The confluence of Meadows Creek and Finniss River lies a short distance downstream of locations F02 and F13. At the confluence, the majority of water flows from Meadows Creek rather than from the upper section of the Finniss. The next surface water sample location downstream of here is F01 at the Finniss weir, approximately 6 km downstream of location F02 at Yundi. Between these two stations, the river is joined by flow from Blackfellows Creek, which was sampled at location F04. Water at F04 had many similar characteristics to that in Meadows Creek at locations F14 and F15. The presence of a small flow here during all three sample rounds suggests a groundwater source. The identical [Cl$^-$] of approximately 605 mg/L in the spring and summer sample rounds indicates the same source at those times, while the high [Cl$^-$] of 1070 mg/L in the summer sample round suggests evapo-concentrated water from the same source. The stable isotope results are also similar to each other in the spring and autumn rounds. In the summer they indicate a high degree of evaporative enrichment of water from the same source.

Blackfellows Creek is on the boundary between Barossa Complex and Adelaidean lithological units. Groundwater discharging into Blackfellows Creek can either come from the Barossa Complex to the western side of the creek, or the Saddleworth Formation to the eastern side. The low Sr isotope ratios of F04 samples rule out the BC FRA as a source, implying that the Saddleworth Formation FRA is the primary groundwater source of water in Blackfellows Creek at location F04. In Blackfellows Creek there is water present all year round, with a small amount of flow even through the very dry summer of 2007. The round 1 (spring) sample from F04 shows significant ^{222}Rn activity from outflowing groundwater. The ^{222}Rn activity here was approximately 1 Bq/L in the summer, even during very low flows when the potential for ^{222}Rn to degas and expire is very high. Strontium isotope ratios at F04 were similar to those in the upper section of Meadows Creek—they indicate that the groundwater feeding this creek is predominantly from the Adelaidean or the Kanmantoo FRAs to the eastern side of the creek, and not from the Barossa Complex FRA to the west, which is characterised by higher Sr isotope ratios.

In Bull Creek, the ^{222}Rn activities during the spring sampling round indicate that a high proportion of the water in the creek is from groundwater outflow. In the upper and lower reaches of the creek, this groundwater outflow appears to be largely seasonal, as the creek is dry in the summer. However, in the middle section of the creek at location F17, water was flowing during all three sampling rounds with a high ^{222}Rn activity each time, suggesting year-round groundwater outflow to this section of the creek. The strontium isotope ratios of this water are low, at around 0.713, similar to those of the PSA wells Fg04 and Fg07. However, there are no Permian Sand sediments in the upper section of Bull Creek. The sample from well Fg05, which is in the Kanmantoo FRA, has a relatively high Sr isotope ratio of ~0.721. It is surmised that the groundwater inflow to the upper section of Bull Creek is from the Adelaidean FRA in that area.

The majority of groundwater rising in surface water streams in the FRC emerges in the tributaries of the upper catchment—Meadows Creek, Bull Creek, and Blackfellows Creek, and possibly also Giles Creek. These are the primary sources of water in these streams during prolonged periods with no rain. There is an extensive section between the Finniss River weir at Yundi, and the intersection of the Finniss River with Braeside Road, where the river does not gain significant groundwater input. The section between locations F01 and F07 appears to lose water, hence there is water at location F01 in summer while the river bed is dry at F08 and F07.

During spring, water at location F06 is a mix of locally inflowing groundwater and water flowing from upstream, in which ^{222}Rn has degassed or expired. The Sr isotopes and ^{222}Rn activity indicate some locally inflowing groundwater at F06 in summer, while the stable isotopes suggest this is mixed with water from the same source as in the spring sampling round (probably surface runoff), but has been evaporatively enriched. The $^{87/86}$Sr isotope ratios of samples from these locations are very close to groundwaters from the same area of the catchment, and occupy the same area of the graphs of $^{87/86}$Sr versus 1/[Sr]. This supports the view that water in these locations is derived from groundwater, but has been in the river for some time, leading to the majority of radon to expire and/or degas.

There is a small amount of flow into the Finniss River from Giles Creek, and this was sampled at location F10. In the summer sampling round, the water at F10 had a fairly high ^{222}Rn activity of 4.4 Bq/L, but in the spring and winter sampling rounds it had low ^{222}Rn activities of 0.4 and 0.2 Bq/L respectively. The strontium isotope ratios of these samples are similar to that of groundwater at Fg04, which draws from the PSA at Ashbourne. The hydrochemistry of the summer sample had high concentrations of Ca^{2+} and SO_4^{2-}, which may indicate the water is contaminated with runoff of agricultural applications of gypsum. If correct, this would make the summer strontium isotope result invalid, as natural Sr would be overwhelmed by Sr in the applied gypsum. This contamination may also have affected the ^{222}Rn activity of this sample, if runoff of irrigation water drawn from a well has transported the gypsum contamination.

Near the end of the Finniss River, at location F12, ^{222}Rn activities were consistently high, ranging from 2.5 Bq/l in round 1 (spring), to 4.5 Bq/l in round 2 (summer). These are higher activities than at the sampling points F06 and F10, 2 km and 4 km upstream respectively. This indicates that water in the river at F12 is not just a result of water flowing from sources upstream, but must derive largely from points of groundwater discharge between F06, F10 and F12. Strontium isotope characteristics of water at F12 were very consistent between sampling rounds, being very similar to groundwater samples Fg01, Fg02 and Fg06, which draw water from the Kanmantoo Group aquifer which underlies the Finniss River upstream of location F12.

4.3 ANGAS RIVER CATCHMENT

The main channel of the Angas River should be considered in two distinct sections. The upper section runs from the head of the river, approximately 4 km NNW of Macclesfield, to the foot of the eastern ranges approximately 4 km NW of Strathalbyn. The lower section runs from downstream of that point, through Strathalbyn and across the Angas Plains to Lake Alexandrina.

The major tributaries to the upper section—Doctors Creek, Paris Creek, Burslem Creek, and Middle Creek—depend primarily on groundwater inflows for continuation of flow during seasonal dry periods. Through the summer of 2006–2007, all tributaries to the Angas River ceased to flow, indicating that groundwater discharges to these creeks are sensitive to seasonal fluctuations in groundwater levels.

At the head of the river north of Macclesfield, a low baseflow of approximately 400 m^3/d is preserved throughout the year by groundwater discharges from a FRA in the Adelaidean Brachina and Saddleworth Formations between Greenhills Road and Whites Road approximately 3 km to the north. However, apart from during winter, when flow here may be supplemented by surface runoff, this baseflow in the river is lost into the groundwater system close to the northern side of Greenhills Road. Hence, the Angas River does not flow between this point and Macclesfield town for the majority of the year. In view of the higher chloride concentration of the water in this northern section of the river, it is unlikely that the water lost to the groundwater system here is the source of water that discharges into the Angas River in the township of Macclesfield.

The groundwater discharge into the Angas River at Macclesfield is clearly a major point of SW–GW interaction in this catchment. The results of the radon, strontium isotope and chloride analyses all indicate that the perennial flow of over 1300 m^3/d in the river at this point is all due to groundwater discharge into a short section of the river within the Macclesfield township. This appears to be the only major inflow into the upper section of the river and is retained in the river channel to at least sample location A02, which is approximately 7 km downstream of this point. Flow in the river through this reach was constant at between 1318 and 1407 m^3/d, when streamflows were measured in the spring of 2006, indicating that the river does not gain or lose any significant amounts of water between Macclesfield and location A02, and probably for some distance further downstream than this. However, the flow had diminished to less than one third of this volume at location A03, the first sample location in the lower section of the river. This indicates that the majority of flow in the Angas River is lost into the groundwater system as the river descends to the Angas Plains. The implications of these findings are that discharge of groundwater into the river at Macclesfield is critical to maintain the majority of the perennial flow in the upper Angas River, and to provide a major source of recharge to groundwater systems in the lower Angas River valley to the north east of Strathalbyn.

In the lower Angas River downstream of Strathalbyn, the increase in flow-rate towards the downstream sample points, even during the summer sample round, suggests some groundwater inflows to this reach of the river. The high ^{222}Rn activity at the furthest downstream sample point (A04) in the summer sample round indicates active groundwater flow into the river close to that point, possibly from the Kanmantoo Group FRA that outcrops in that section of the river. That the ^{222}Rn activity at that point was not similarly high during the other sample rounds is probably due to dilution of groundwater inflows by greater surface water flows from upstream at other times of the year.

As water was only present at the end of Doctors Creek during the first round of sampling, it is difficult to make an assessment of surface water–groundwater interactions in that sub-catchment. However, the high ^{222}Rn activity of the water present in the first sampling round indicates direct groundwater discharge close to sample point A01 at the end of the creek. The distinctly high $^{87/86}$Sr isotope ratio of the creek water at that time, and the similarity of this to the $^{87/86}$Sr ratio of groundwater from the underlying Tapanappa Formation FRA, indicates that the latter is the source of water to at least the lower section of Doctors Creek during late winter and spring, when groundwater levels are relatively high.

In Paris Creek and Burslem Creek, high ^{222}Rn activities were found whenever water was present, suggesting that the limited flows occurring in these creeks during the sampling program were mostly derived from groundwater from the Tapanappa Formation FRA. At the most upstream sample locations (A10 and A16) the creeks were flowing during both the spring and autumn sample rounds, and the high radon activities in those samples indicate the majority of these flows were a result of groundwater discharging in the upper reaches of these sub-catchments. At sample locations downstream of these—including A12 in Paris Creek, and A06 and A07 in Middle Creek below the confluence of Paris and Burslem Creeks—there was only water present during the spring sampling round. While the high ^{222}Rn activity at A06 indicated a nearby groundwater source at that time, the low activity at A07 suggests that the water in the creek at that location results from flow from further upstream. The strontium isotope ratios of the samples from Middle Creek lie approximately half way between those of the samples from upstream locations in Paris and Burslem Creek, suggesting that they are a mixture of water flowing from those two upstream locations. Collectively these results indicate that during extended periods of dry weather, any flows that may occur in Middle Creek are dependent on groundwater discharging into the upper reaches of its two main tributaries, Paris Creek and Burslem Creek.

Water observed at sample location A09 in Dawson Creek was found to have almost identical salinity and $^{87/86}$Sr ratios in the spring and autumn sample rounds, indicating a common source of the water at both times, most likely to be a groundwater source. While the flow was very limited at this location, it was supporting an area of wetland vegetation. The creek bed was dry downstream of location A09 during all three sampling rounds, indicating that the water flowing at A09 is either lost to evaporation or to the groundwater system a short distance downstream of this location.

4.4 REEDY CREEK CATCHMENT

At most of the surface water sample sites in the RCC, the combination of high chloride concentrations and relatively depleted stable isotope ratios suggests that the small amounts of surface water that were present during the period of the monitoring program were in nearly all cases derived from groundwater discharges. These results are perhaps not surprising in view of the dry climate of this catchment and the timing of the monitoring program, occurring during a particularly low-rainfall period. The only exceptions were during the summer and autumn sample rounds at surface water location RE03, where the water had the characteristics of irrigation runoff in the summer sample round, and runoff of recent rainfall in the autumn sample round. Although radon activities were generally relatively low in the RCC surface water samples, this is indicative of low rates of groundwater discharge rather than non-groundwater sources. Most of the small amount of rain that did fall during the monitoring period in this catchment (Figure 4b) is likely to have been captured in farm dams. Groundwater discharges appear to be sustaining permanent surface water bodies in several places in this catchment, although in all observed cases these discharges are fairly high in salinity. At locations RE04, RE05, and RE07, pools of surface water derived from groundwater discharges were present throughout the period of the monitoring program, and were observed to be supporting limited communities of aquatic fauna.

4.5 CURRENCY CREEK CATCHMENT

The results of the various hydrochemical analyses consistently indicate that during the period of the monitoring program, the surface water observed at the five sample locations in the CCC was mostly derived from groundwater discharges from up to three different aquifer types. The low chloride concentrations, low radon activities and low strontium isotope ratios of water from location CU05 all indicate this water has discharged from the PSAs that occur a short distance upstream of this point. Surface water sample location CU02 lies approximately 4 km downstream of CU05, however the results for samples from CU02 indicate the creek gains most of its flow from the part of the sub-catchment between these two points, where the surface geology is dominated by Kanmantoo Group Tapanappa Formation. The chloride concentration at CU02 was higher than that from the well CUg01, which is completed in the Tapanappa Formation FRA between locations CU05 and CU02, however the stable isotope ratios indicate the surface water has undergone some evaporative enrichment. The high radon activity of the surface water here indicates a groundwater source with a greater radon activity than the low activities of 25 Bq/L and 43 Bq/L observed in the Permian Sand and Tertiary Limestone aquifers in the CCC, respectively. The relatively high strontium isotope ratio of 0.717 at CU02, which was distinct among surface water samples in this catchment, is identical to that of water from well Cug01. The combination of these radon and strontium isotope characteristics provides a clear indication that surface water at location Cu02 is from the same Tapanappa Formation FRA that well CUg01 draws from.

Surface water location CU06 is on Mosquito Creek, a short distance downstream of well Cug02, which is located close to this tributary of Currency Creek. Observations at the time of sampling were that flow in this branch of the creek commenced only a short distance upstream of the sampling location. The high radon activities of samples from CU02 were sufficient to indicate that this water derives from groundwater discharging close to the point of sampling. The strontium isotope results indicate that water at CU06 has the characteristics of an evaporatively enriched mixture of water from the Tapanappa Formation FRA and the PSAs, both of which occur in the small sub-catchment drained by this creek.

On a graph of $^{87/86}$Sr ratios plotted against the reciprocal of the Sr concentration (Figure 37), all of the samples from locations CU01 and CU04 plot together in a cluster, suggesting they may have a similar source. The high radon activities and high salinities of these samples indicate the source is likely to be groundwater from fractured rock in the Kanmantoo Group formation, which underlies much of the southeast of the catchment. Observations at the time of sampling were that the main channel of Currency Creek, a short distance upstream of location CU01, was dry for the whole of the period of monitoring, implying that water at the end of Currency Creek at location CU01 emerges from a groundwater source close to that location.

There was strong flow occurring at location CU04 during the spring and autumn sampling rounds. However, at both of those times, there was no flow in the creek at point CU(a) (Figure 33), approximately 4 km downstream. With no on-stream dams between these two points, it must be assumed that this section of Currency Creek loses significant amounts of water to groundwater in this part of the lower CCC. However, the creek reverts to gaining from the groundwater system between point CU(a) and sample location CU01, where discharged groundwater is shown to be present. The high radon activity during the spring sample round confirms a groundwater contribution at that time, while the strontium isotope results for location CU01 suggest the dissolved strontium in this water is most influenced by the Kanmantoo Group formation that underlies this location.

4.6 TOOKAYERTA CREEK CATCHMENT

Groundwater resources and surface water interactions in the TCC have previously been investigated and reported on at some length (Barnett and Zulfic 1999; Fass and Cook 2005; Banks et al. 2007). The objective of the investigations in the TCC during this project was to provide answers to specific questions that remained unanswered by earlier investigations regarding the dependence of surface water in the lower TCC on discharges from aquifers in the upper TCC.

A study of sources of groundwater discharging to Black Swamp in the TCC was conducted in 2005 by Torsten Fass and Peter Cook of CSIRO Land and Water (Fass and Cook 2005). Their report concluded that there are two main sources of groundwater input to the Tookayerta Creek and Black Swamp. One source was found to be the PSA, contributing 18–33% of water, but they were unable to identify the other source. However, they concluded that the unidentified source must lie upstream of their study area, and must have a high $^{87/86}$Sr ratio.

As part of this EMLR surface water/groundwater interaction investigation, four wells and five surface water locations were sampled in the TCC (Figure 44). The results suggest that the source of water with a high $^{87/86}$Sr ratio appears to be groundwater emerging from the BC FRA in the north of the Nangkita Creek sub-catchment. Two wells were sampled in this area—one drawing directly from the BC FRA (TOg03) and one drawing from a part of the PSA lying adjacent to the Barossa Complex (TOg02). The latter had a particularly high $^{87/86}$Sr ratio of 0.7614, which probably results from water discharging from the fractured rock into the sand aquifer. A similarly high $^{87/86}$Sr ratio of 0.7529 was found in water from another well in the BC FRA a few kilometres to the north in the Finniss River Catchment.

Further west in the Nangkita Creek sub-catchment, a well in the PSA (TOg04) had a low $^{87/86}$Sr ratio of 0.7169, similar to the average determined by Fass and Cook (2005) for water from that aquifer. In the middle of the Tookayerta Creek Catchment, water from a well in the Kanmantoo Group basement FRA (TOg01), had a relatively low $^{87/86}$Sr of 0.7227, and had a relatively high Sr concentration of 1.09 mg/L. This combination of high Sr concentration and relatively low $^{87/86}$Sr ratio suggests the Kanmantoo Group FRA is unlikely to be a major source of water to Tookayerta Creek.

In their report, Fass and Cook (2005) suggest a Sr concentration and $^{87/86}$Sr ratio for the unknown water source and use the strontium isotope mixing equation of Faure (1986) (Equation 2, sec 4.1.2) to determine the fraction of water from the unknown source in samples from Black Swamp (Table 15). The fractions of these samples that were from the unknown source were determined to be 0.81, 0.75 and 0.71, suggesting that the majority of water in Black Swamp is from the unknown source.

However, if the Sr concentration and $^{87/86}$Sr ratio of the unknown source are replaced with the values for the groundwater samples from well TOg02, the corresponding fractions from this source in the Black Swamp samples become 0.98, 0.91 and 0.87 (Table 16).

Table 15. Fraction of water in Black Swamp samples that derives from an unknown water source in the upper Tookayerta Creek Catchment, according to Fass and Cook (2005)

		[Sr]	87/86Sr	***f*** (fraction of component XA in mix)
Unknown water source (Fass & Cook)	XA	0.06	0.73	
Permian sand average (Fass & Cook)	XB	0.39	0.7139	
Black Swamp sample location 1	BS1	0.12	0.7201	0.81
Black Swamp sample location 2	BS2	0.14	0.7195	0.75
Black Swamp sample location 6	BS6	0.15	0.7179	0.71

Table 16. Fraction of water in Black Swamp samples that may derive from the BC FRA, characterised by groundwater sampled at TOg02 in the upper TCC, if the [Sr] and $^{87/86}$Sr values of water from the PSA are according to Fass and Cook (2005)

		[Sr]	87/86Sr	***f*** (fraction of component XA in mix)
Groundwater at SW-GW location TOg02	XA	0.11	0.7614	
Permian sand average (Fass & Cook)	XB	0.39	0.7139	
Black Swamp sample location 1	BS1	0.12	0.7201	0.98
Black Swamp sample location 2	BS2	0.14	0.7195	0.91
Black Swamp sample location 6	BS6	0.15	0.7179	0.87

In isolation, this analysis would suggest that the great majority of water in Black Swamp is derived from groundwater discharge from the BC FRA. However, these numbers are strongly influenced by the assumed average PSA Sr concentration of 0.39 mg/L used by Fass and Cook (2005). If water in Nangkita Creek is assumed to be a mix of discharges from the BC FRA, characterised by well TOg02, and water of the quality found in the PSA in well TOg04, then the fraction of water from the BC FRA becomes approximately 0.37 (Table 17).

Table 17. Fraction of water in the lower Nangkita Creek and upper Tookayerta Creek that may derive from the BC FRA in the upper TCC, if the [Sr] and $^{87/86}$Sr values of water from the PSA are according to samples from well TOg04

		[Sr]	87/86Sr	***f*** (fraction of component XA in mix)
Groundwater at SW-GW location TOg02	XA	0.11	0.7614	
Groundwater at SW-GW location TOg04	XB	0.05	0.7169	
Stream water in Nangkita Creek at T01	TO1	0.074	0.7239	0.37
Stream water in Tookayerta Creek at T02	TO2	0.074	0.7201	0.37

The higher $^{87/86}$Sr ratio values in stream water sampled in Nangkita Creek, compared to Cleland Gully Creek (0.7168 at point T03), supports the view that water with a higher $^{87/86}$Sr ratio, discharging from the BC FRA into Nangkita Creek, leads to the combination of Sr concentration and $^{87/86}$Sr ratio observed in Black Swamp by Fass and Cook (2005).

At the very low Sr concentrations found in the upper Tookayerta catchment, the linear mixing equation (Equation 2, sec 4.1.2) is more sensitive to the small differences in Sr concentration than to differences in the $^{87/86}$Sr ratio. As a result, the fraction of water in Nangkita Creek and Tookayerta Creek attributable to the BC FRA is variable depending on which data are used. It is clear that the BC FRA is the unknown source of the high $^{87/86}$Sr ratio water referred to by Fass and

Cook (2005). The results of this investigation indicate that the fraction of water in Black Swamp that is attributable to this source may not be as high as suggested by Fass and Cook (2005), and may be less than 40%.

The BC FRA in the north of the TCC is clearly a significant contributor to the Nangkita Creek, which is a major tributary to Tookayerta Creek. These findings suggest that flows in the Nangkita and Tookayerta Creeks and ultimately, the flow of water into Black Swamp, would be affected by inappropriate increases in groundwater extractions from the BC FRA in that area.

Cleland Gully Creek, which is the minor contributor of the two main tributaries to Tookayerta Creek, was sampled at surface water location T03 and has all the characteristics of water from the PSA. Flow in this creek was observed to commence only a short distance to the west of location T03. However, flow at T03 was observed to be similar to flow close to the confluence with Nangkita Creek, so it is surmised that Cleland Gully Creek gains most of its flow over a distance of only approximately 2 km from the PSA occurring just to the west of T03.

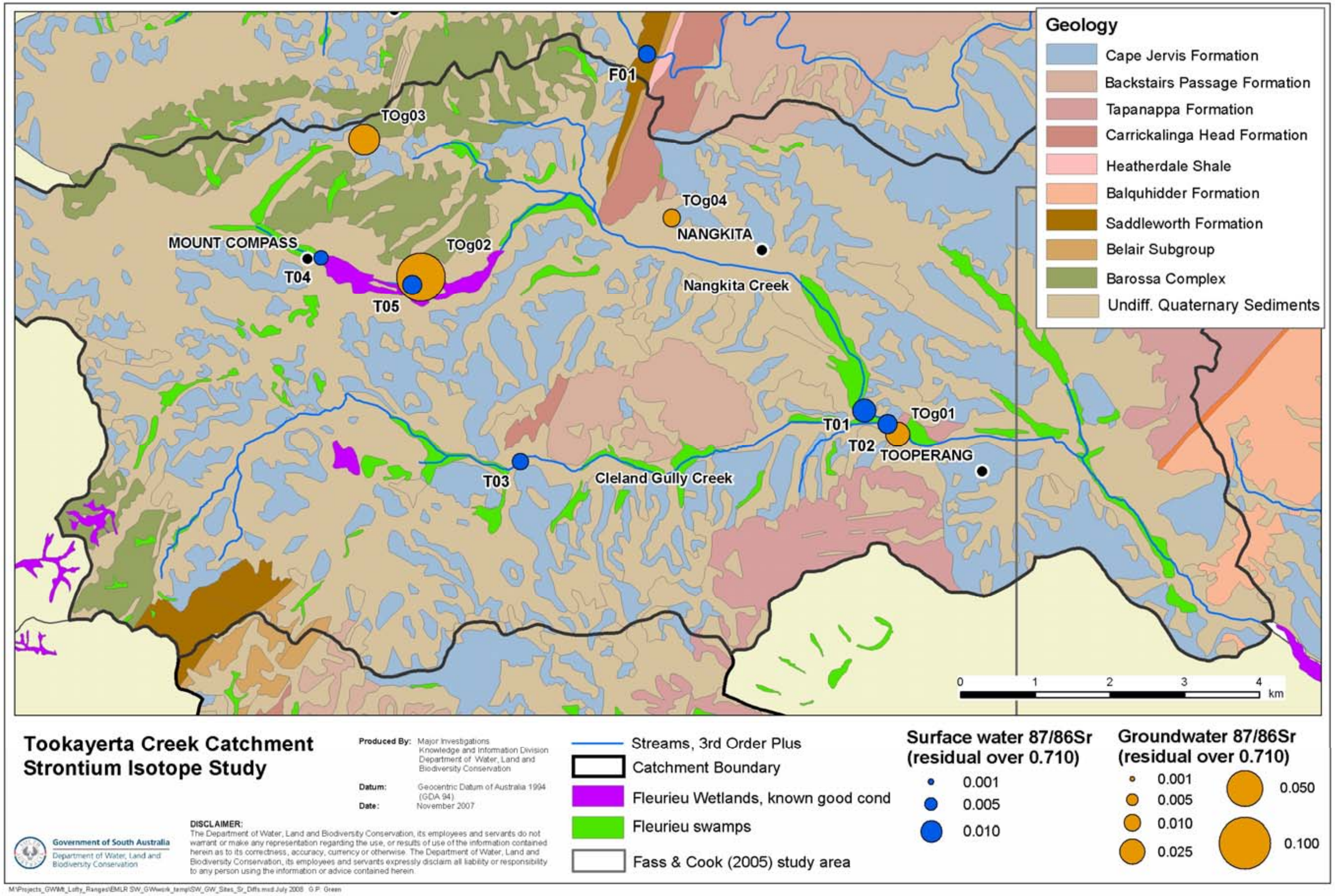


Figure 44. Geology of the Tookayerta Creek Catchment and locations of surface water and groundwater sample points with strontium isotope ratio results

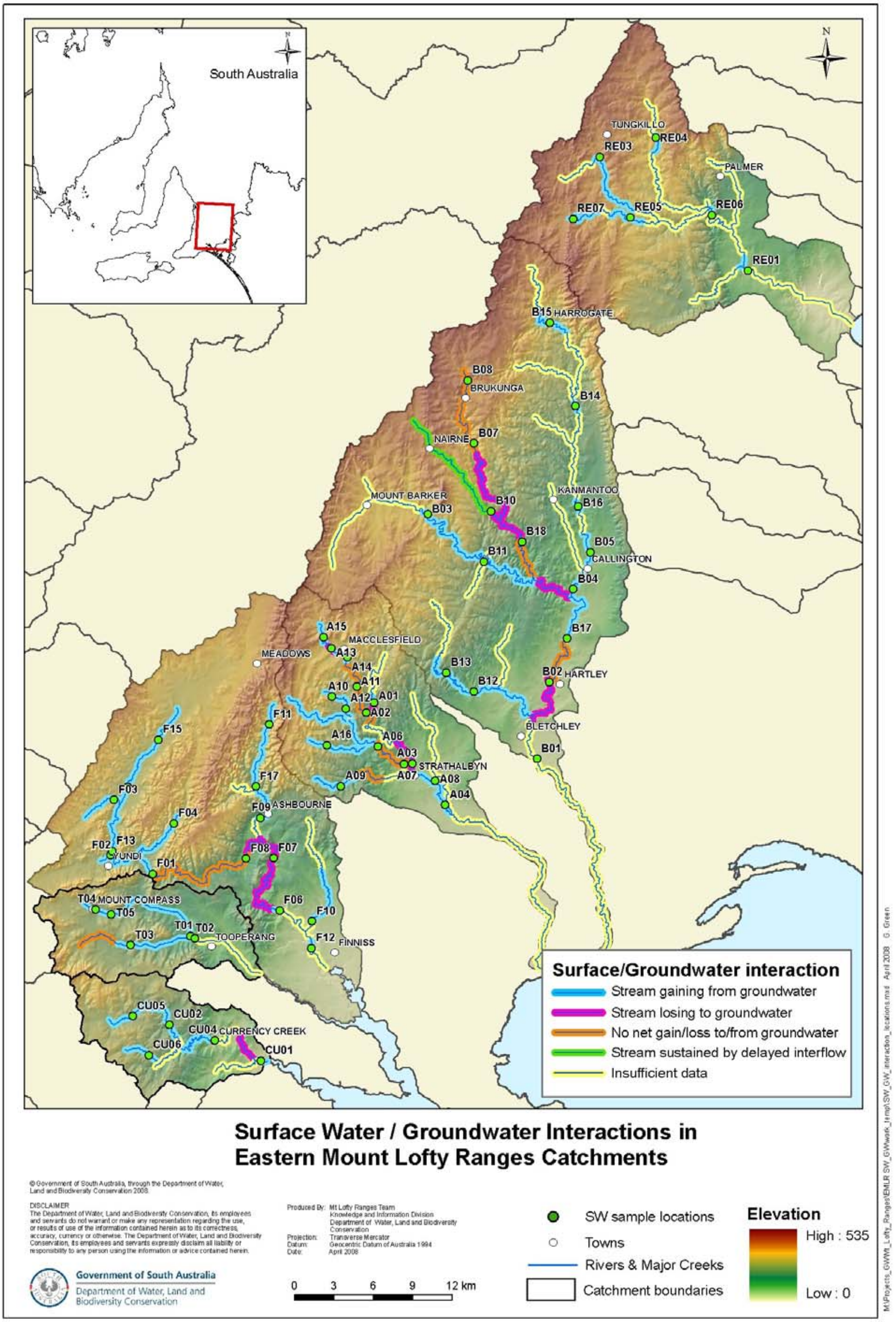
5. SUMMARY AND CONCLUSIONS

Analysis of the hydrogeochemical results for groundwater and surface water samples confirm that the majority of the permanent pools and wetlands in the EMLR are largely dependent on groundwater inflows. This is probably to be expected in a region of low rainfall and high summer evaporation rates, with many areas having very thin soil coverage and minimal surficial sedimentary deposits to store water between rain events.

A general pattern in the EMLR is that discharge of groundwater occurs in the upper reaches of the catchments and provides small amounts of flow into the tributaries of the major creeks and rivers. These flows are at their greatest when groundwater levels are seasonally high, and in many places disappear through the summer as groundwater levels decline. The re-commencement in autumn, and discontinuation in spring, of flows in these watercourses are not wholly correlated with rainfall. This implies that flow commences as watertables rise in early winter, and continue until groundwater levels drop to an extent that groundwater heads are below the level of creek/river beds, or that groundwater discharges to creeks are balanced by evaporation losses.

The map in Figure 45 provides an illustrated summary of the inferred direction of exchange between surface water and groundwater, based on the interpretations discussed in Chapter 4. The map indicates only whether a stream section is gaining or losing, and does not quantify the rate of exchange. All stream sections that were found to be receiving groundwater discharges during any of the three sampling rounds are denoted as gaining. While some of these reaches were receiving large volumes of groundwater throughout the period of the investigation, many were only receiving small flows in the spring or autumn sampling round. Hence, the status of 'gaining from groundwater' may only apply seasonally for many of the reaches denoted in blue on the map. In view of this investigation having been conducted in a period following a particularly dry winter, when groundwater levels may have been unusually low, the findings are representative of a time when the number of stream sections that are gaining from groundwater is at a minimum. Some of the stream reaches denoted on the map as losing, or having no net gain or loss, may become gaining stream reaches at times when groundwater levels are higher.

Stream sections denoted as neither gaining nor losing may contain water derived from groundwater discharges that occur further upstream. This condition is particularly important in the Angas River downstream of Macclesfield, and in the Finniss River between Yundi and Ashbourne. In the Reedy Creek Catchment and the Upper Bremer River, there was no flow occurring between sampling points at any time in the period of the study. In these areas, although the stationary water at the sampling locations was found to be groundwater-sourced, gaining from groundwater between these pools could not be inferred. Hence, the creek/river sections adjacent to the sample locations are shown to be gaining from groundwater, but the sections between these are shown to be indeterminate due to insufficient data.



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Produced By: Mt Lofty Ranges Team
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
Projection: Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Date: April 2008

Figure 45. Inferred surface water–groundwater interaction locations

There is considerable contrast in both rainfall and hydrogeology, between catchments at the northern and southern ends of the study area. In the north, Reedy Creek Catchment has a low annual rainfall and predominantly Kanmantoo Group geology, typically providing fractured rock aquifers with low groundwater flow-rates and high salinity. These conditions are in stark contrast to the Tookayerta Creek Catchment, which has much higher annual rainfall and includes a variety of geology—predominantly Permian Sand, but also including Barossa Complex and Kanmantoo Group siltstones and shales—providing aquifers with very differing properties. These climatic and geologic differences are reflected in the surface water volume and quality in the two catchments. The Tookayerta Creek Catchment has continual, year-round flows of low salinity water discharged from the groundwater system. In contrast, Reedy Creek Catchment has minimal flows of generally high salinity groundwater discharging to the surface water streams, insufficient through much of the year to generate flow in these streams, but sufficient in some locations to sustain small and saline pools through dry summer conditions. The larger catchments that comprise the major part of the study area contain a combination of these conditions. There are some perennially flowing surface streams of low salinity water supplied by groundwater discharge, while in other places, minor discharge of saline groundwater supports stationary pools of water that become increasingly saline through the summer as a result of evaporative concentration, and in some years will dry out completely. In general, the former is typical of the southern and western parts of the EMLR study area, and the latter are more typical of the north and east of the study area.

There are a number of locations in the EMLR where surface water flows are particularly dependent on inflows from groundwater systems or where surface water–groundwater interactions are observed to be particularly significant:

i. In the Angas River Catchment, discharge of groundwater at Macclesfield provides the majority of flow in the upper Angas River. At times when there is no significant surface runoff, surface flows from Macclesfield supply all the flow in the river for at least 7 km downstream. The river then becomes a losing reach as it descends to the Angas River plains towards Strathalbyn. Hence, the river provides a conduit for groundwater from Macclesfield to provide recharge to the groundwater system closer to Strathalbyn. If exploitation of groundwater resources around Macclesfield is permitted to increase, and discharges to the Angas River decrease as a consequence, then groundwater and surface water hydrology will be affected through a large part of the upper Angas River Catchment.

ii. In the Tookayerta Creek Catchment, flows in Tookayerta Creek are reliant on groundwater discharges into its two major tributaries, Nangkita Creek and Cleland Gully Creek. During times when surface runoff of recent rainfall is not significant, the majority of flow in Cleland Gully Creek is derived from the Permian Sand aquifer. Nangkita Creek supplies a greater proportion of the flow to Tookayerta Creek than Cleland Gully Creek. When surface runoff of recent rainfall is not significant, Nangkita Creek gains at least 60% of its flow from the Permian Sand aquifer and up to 40% from the Barossa Complex fractured rock aquifer in the north of the catchment.

iii. In the Finniss River Catchment, groundwater discharge into the Finniss River from both the Permian Sand aquifer and the Barossa Complex fractured rock aquifer close to Yundi, and up to 3 km to the east and west of Yundi, provide a significant proportion of the flow in the Finniss River. The remainder of the flow in the upper Finniss River derives from Meadows Creek, which in turn gains much of its flow during times when rain runoff is insignificant from the Adelaidean fractured rock aquifer to the west.

iv. The disconnected sections of year-round flow in Bull Creek to the north of Ashbourne, are entirely dependent on inflows from groundwater.

v. The extensive Permian Sand aquifers in the south-eastern part of the Finniss River Catchment do not appear to contribute much water to the central section of the river between the Finniss River weir approximately 4 km to the west of Yundi, and Ashbourne. Furthermore, there are only limited flows of groundwater into the subsequent section of the Finniss River between Ashbourne and the Braeside Road ford, and these appear to be from the underlying fractured rock aquifer, rather than from the Permian Sand aquifer. Further south, water in the permanently inundated wetland close to Strathalbyn-Goolwa Road has consistently high Radon-222 activities, indicating that groundwater is a significant contributor to this water body, however there is insufficient data to indicate the type of aquifer supplying this water.

vi. Flow occurring in the lower Bremer River between the Mount Barker Creek confluence and Hartley is dependent on flow from Mount Barker Creek, which, at times when surface runoff of rainfall is not significant, appears to be dependent on flows from the Kanmantoo Group fractured rock aquifer to the southeast of Mount Barker Springs.

vii. In the Bremer River Catchment, there is an important point of surface water–groundwater interaction approximately 1 km to the south of Hartley. During times of relatively low flow, the Bremer River loses all of its flow to the subsurface at this location. This flow does not reappear in the river channel between that point and the most southerly point studied, at Bletchley approximately 5 km to the south. Flow estimated to be nearly 2 ML/d was observed to disappear into the groundwater system at this point in May 2007.

This list is not exhaustive but provides an indication of the location and nature of the most significant areas of groundwater–surface water interaction in the EMLR study area, which may require special consideration when planning and managing the natural water resources of these catchments.

A. CHEMISTRY RESULTS

Table A1. Results of in-field measurements of hydrochemical indices, and laboratory measurements of major ion chemistry, stable isotope ratios, radon-222 activity and strontium isotope ratios, for groundwater sampling round 1, November 2006

						In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																		
Study ID	Sampled Well Unit Number	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (µS/cm)	DO (mg/L)	Redox (mV)	Temp (°C)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ ($^o/_{oo}$ rel SMOW)	$\delta^{2}H$ ($^o/_{oo}$ rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
Ag01	662706471	ANGAS	301753	6098219	15/11/2006 12:04	4.34	6.43	3014	1.58	17.6	17.49	341.00	11.000	-5.24	-24.50	0.716599	8.24	4.33	0.04	0.00	1111	3.4	94.3	91.2	20.4	92.6	542	31.0	0.707
Ag02	662708891	ANGAS	307407	6097053	15/11/2006 14:00	2.85	6.56	5443	0.98	-34.7	18.35	486.00	16.000	-4.85	-21.40	0.719291	8.17	5.58	0.09	0.01	2085	6.4	280.1	229.3	39.9	155.4	973	91.8	2.772
Ag03	662707613	ANGAS	305337	6101852	15/11/2006 16:10	5.74	6.82	3244	3.63	-88.7	17.59	485.00	16.000	-4.52	-19.10	0.718342	7.66	5.64	0.03	0.00	1117	3.3	164.7	63.3	23.7	64.9	699	55.8	0.608
Ag04	662709589	ANGAS	303672	6104228	16/11/2006 13:19	5.80	6.73	2581	0.24	-122.7	16.85	590.00	20.000	-4.95	-23.10	0.717147	7.27	6.08	0.12	0.07	862	2.4	97.2	97.7	13.6	67.6	444	33.0	0.656
Ag05	662706462	ANGAS	299413	6101155	20/11/2006 15:49	5.03	6.97	1551	2.39	22.9	18.59	37.30	1.300	-5.34	-25.50	0.714089	8.27	5.61	0.00	0.79	266	0.8	23.4						0.308
Ag06	662711300	ANGAS	298420	6099511	20/11/2006 17:58	4.56	7.03	2590	1.72	44.3	17.81	202.00	7.000	-5.29	-31.80	0.712007	7.61	4.67	0.00	1.07	446	1.2	320.8	129.9	10.3	35.8	285	112.0	0.882
Ag07	662711304	ANGAS	298420	6099508	20/11/2006 17:34	3.57	6.63	2529	0.58	80.9	16.22	383.00	13.000	-5.24	-28.40	0.713457	7.15	3.70	0.00	1.17	511	1.3	226.6	113.5	9.4	34.1	317	77.1	0.791
Bg01	662709701	BREMER	310582	6120208	22/11/2006 10:13	6.03	7.47	3080	3.51	3.4	21.65	144.00	5.000	-5.20	-27.70	0.717695	7.83	6.31	0.00	0.01	672	1.9	83.6	39.5	17.1	36.5	492	28.7	0.313
Bg02	672702419	BREMER	318722	6103028	23/11/2006 12:17	5.34	7.36	5332	5.07	-28.0	18.86	57.00	1.900	-3.12	-17.60	0.716147	8.15	5.45	0.09	0.36	1749	5.5	158.6	148.2	30.3	125.4	886	54.2	1.747
Bg03	662710374	BREMER	314732	6103221	23/11/2006 10:12	7.70	7.30	4408	3.75	116.1	18.74	887.00	29.000	-4.55	-23.90	0.716830	7.75	8.45	0.01	0.16	1260	4.0	202.3	55.6	45.2	83.7	882	72.2	0.893
Bg04	662812138	BREMER	315213	6131095	23/11/2006 14:28	3.87	6.66	5670	1.59	-47.5	18.75	1139.00	38.000	-5.08	-24.20	0.716156	7.10	3.92	0.09	3.18	1941	5.4	207.2	119.3	24.0	167.0	1012	72.7	1.281
Bg05	662702404	BREMER	319692	6116498	05/12/2006 12:15	6.05	7.08	4240	1.66	-25.0	21.10	386.00	7.000	-5.28	-28.70	0.718483	8.02	6.91	0.03	0.07	1060	3.3	178.0	60.3	43.6	87.6	632	59.2	1.009
Bg06	662706412	BREMER	309178	6116211	05/12/2006 13:59	6.11	7.31	2946	5.70	-149.0	18.51	118.00	3.000	-5.11	-20.00	0.715784	7.91	6.31	0.03	<0.01	695	2.0	77.5	121.0	18.5	75.7	334	26.0	0.805
CUg01	662700385	CURRENCY CRK	287698	6078582	13/11/2006 11:18	3.49	7.23	540	4.56	-31.4	17.18	499.00	17.000	-5.51	-28.40	0.717131	7.71	3.78	0.00	0.00	93	0.3	10.8	28.9	5.4	12.9	106	4.0	0.144
CUg02	662709607	CURRENCY CRK	286332	6075103	13/11/2006 11:41	5.05	6.84	1439	2.14	65.5	16.89	32.90	1.200	-5.20	-20.20	0.711460	7.40	5.31	0.00	0.70	407	1.1	50.3	119.8	5.6	28.3	215	17.4	0.385
CUg03	662708650	CURRENCY CRK	283271	6078265	13/11/2006 12:38	0.41	5.41	425	2.89	171.2	15.33	40.80	1.400	-4.72	-22.70	0.712582	5.74	0.32	0.00	3.45	139	0.3	12.9	5.3	2.3	10.2	84	4.7	0.080
Fg01	662706810	FINNISS	297995	6085855	14/11/2006 10:31	3.87	6.97	1111	2.62	-40.2	20.00	410.00	14.000	-4.76	-23.40	0.718606	7.39	4.00	0.01	0.00	301	1.0	43.4	41.6	15.6	40.2	178	14.9	0.322
Fg02	662701065	FINNISS	295972	6091070	14/11/2006 11:43	3.00	6.40	1359	4.00	22.5	17.42	8.30	0.400	-5.08	-23.40	0.715726	6.97	3.08	0.01	0.49	431	1.3	44.5	72.2	6.6	36.9	216	15.0	0.636
Fg03	662711289	FINNISS	297576	6089786	20/11/2006 14:00	3.93	6.54	4542	0.62	-17.5	18.81	693.00	23.000	-4.12	-21.00	0.716680	7.21	4.13	0.05	0.01	1199	3.1	131.4	270.2	15.6	91.0	419	42.6	1.823
Fg04	662710526	FINNISS	296222	6091742	20/11/2006 10:31	4.15	6.62	1951	8.93	55.2	16.37	25.70	0.900	-4.62	-23.15	0.713586	7.25	4.07	0.00	1.04	414	1.1	59.6	77.0	6.2	39.1	193	19.9	0.766
Fg05	662710843	FINNISS	297034	6094224	20/11/2006 11:16	2.08	6.28	1379	2.88	-45.8	17.52	530.00	18.000	-5.33	-28.10	0.720599	6.82	1.99	0.04	0.00	279	0.9	90.1	33.1	7.2	36.1	156	30.9	0.265
Fg06	662711287	FINNISS	297576	6089786	20/11/2006 14:42	0.79	8.57	1742	7.62	-67.0	25.02	102.00	4.000	-3.99	-20.30	0.715896	9.08	0.58	0.01	0.01	447	1.3	105.9	108.1	15.3	7.1	201	34.6	0.704
Fg07	662707072	FINNISS	284931	6089527	05/12/2006 16:30	0.29	5.86	225	9.79	91.0	16.96	13.20	0.500	-5.82	-28.50	0.713260	6.33	0.40	<0.01	0.11	58	0.2	3.2	3.7	2.2	3.2	32	1.1	0.059
Rg01	672802578	REEDY CRK	322501	6145207	22/11/2006 13:52	4.29	6.92	1264	3.36	101.6	17.18	210.00	7.000	-5.28	-24.30	0.715979	7.78	4.26	0.01	5.73	193	0.7	51.0	54.8	4.7	22.2	155	17.5	0.456
Rg02	672899999	REEDY CRK	332425	6143172	22/11/2006 16:49	4.18	6.81	3109	1.91	-24.0	19.09	972.00	32.000	-5.32	-27.20	0.714915	7.43	4.22	0.06	0.03	741	1.9	108.2	88.4	11.2	82.1	337	35.8	0.765
Rg03	672800904	REEDY CRK	322410	6136594	05/12/2006 10:29	4.83	6.56	5233	1.44	4.0	21.64	418.00	8.000	-5.44	-30.70	0.717547	7.88	7.02	0.08	<0.01	1500	4.3	150.7	75.5	19.9	201.5	631	50.6	0.880
TOg01	662709278	TOOKAYERTA CRK	291642	6083548	13/11/2006 14:33	3.80	6.99	1817	5.46	84.9	18.06	279.00	9.000	-5.38	-28.60	0.722710	7.47	3.98	0.02	0.09	579	1.7	95.9	87.4	10.1	40.9	322	32.5	1.093
TOg02	662709830	TOOKAYERTA CRK	285266	6085649	14/11/2006 13:50	0.57	6.28	221	5.75	66.4	17.65	18.30	0.700	-5.72	-32.10	0.761398	6.70	0.54	0.00	0.04	48	0.1	25.6	14.5	3.8	3.8	30	8.9	0.092
TOg03	662708408	TOOKAYERTA CRK	284505	6087492	15/11/2006 09:48	1.92	6.52	352	2.67	-46.7	17.46	173.00	6.000	-5.73	-28.20	0.731116	7.16	1.92	0.03	0.01	70	0.3	8.9	5.2	3.7	7.3	73	3.2	0.036
TOg04	662709823	TOOKAYERTA CRK	288622	6086438	15/11/2006 11:04	0.92	6.46	520	8.18	15.0	16.19	0.74	0.090	-4.90	-24.20	0.716895	6.77	0.85	0.01	1.17	146	0.4	42.3	2.9	2.2	5.6	120	15.1	0.044

Table A2.Results of in-field measurements of hydrochemical indices, and laboratory measurements of major ion chemistry, stable isotope ratios, radon-222 activity and strontium isotope ratios, for groundwater sampling round 2, May 2007

							In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	**Sampled Well Unit Number**	**Catchment**	**Easting**	**Northing**	**Sampling Date / Time**	**SWL (where accessible) (m)**	**Alkalinity (meq/L HCO_3^-)**	**pH**	**SEC (µS/cm)**	**DO (mg/L)**	**Redox (mV)**	**Temp (^oC)**	**Rn-222 (Bq/L)**	**Rn-222 Error (Bq/L)**	**$\delta^{18}O$ ($^o/_{oo}$ rel SMOW)**	**δ^2H ($^o/_{oo}$ rel SMOW)**	**$^{87}Sr/^{86}Sr$ ratio**	**Lab Sample pH**	**Total Alkalinity (pH 4.5) (meq/L)**	**NH_4-N (mg/L)**	**NO_x-N (mg/L)**	**Cl^- (mg/L)**	**Br^- (mg/L)**	**$SO_4^=$ (mg/L)**	**Ca (mg/L)**	**K (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**S (mg/L)**	**Sr (mg/L)**
Ag01	662706471	ANGAS	301753	6098219	09/05/2007 15:02	Artesian	4.02	6.53	3223	15.86	-39	17.02	691.00	9.000	-5.20	-22.20	0.716621	7.76	4.24	0.04	0.03	1114	3.6	98.5	95.4	21.2	94.8	547	31.8	0.666
Ag02	662708891	ANGAS	307407	6097053	10/05/2007 13:36		5.31	6.72	5022	21.21	-69	18.39	535.00	7.000	-4.35	-20.80	0.718951	7.47	5.61	0.05	0.05	1657	5.3	208.0	225.8	37.3	136.3	841	71.0	2.095
Ag03	662707613	ANGAS	305337	6101852	10/05/2007 12:25	Artesian	5.36	6.79	3511	19.98	-95	18.47	596.00	8.000	-4.48	-22.80	0.718348	7.40	5.39	0.05	0.13	1126	3.7	175.8	78.5	24.7	67.3	714	58.2	0.607
Ag04	662709589	ANGAS	303672	6104228	10/05/2007 11:35	2.39	5.56	6.91	2739	14.97	-99	16.68	492.00	7.000	-4.92	-22.20	0.716609	7.92	5.93	0.12	0.04	875	2.7	94.0	140.7	15.4	75.1	431	30.1	0.615
Ag05	662706462	ANGAS	299413	6101155	10/05/2007 14:17		3.38	7.08	1197	27.52	-61	16.09	27.20	0.600	-1.90	-11.60	0.714067	7.55	3.19	0.11	0.10	337	1.0	7.8	69.7	7.9	36.9	145	2.0	0.193
Bg01	662709701	BREMER	310582	6120208	08/05/2007 16:18	13.90	5.83	7.51	2619	7.85	-12	21.71	125.00	2.000	-5.22	-26.20	0.717762	8.09	6.27	0.03	0.02	687	2.2	89.2	42.2	17.9	38.1	511	29.9	0.263
Bg03	662710374	BREMER	314732	6103221	09/05/2007 11:55	6.90	7.88	7.51	4539	22.12	41	18.19	859.00	11.000	-4.51	-23.00	0.716879	8.33	8.18	0.02	0.33	1258	4.4	208.9	70.5	44.6	81.7	861	69.5	0.695
Bg04	662812138	BREMER	315213	6131095	08/05/2007 10:54	(< 40 m)	4.31	6.37	5954	4.92	-44	15.99	695.00	10.000	-5.07	-24.20	0.716347	8.04	3.82	0.04	1.30	1988	6.1	169.0	110.0	24.2	162.0	996	54.5	1.027
Bg05	662702404	BREMER	319692	6116498	08/05/2007 15:14		5.90	7.01	3519	11.25	-73	19.42	225.00	6.000	-5.50	-30.30	0.718519	7.98	5.98	0.03	0.03	986	3.6	169.1	60.8	43.4	86.2	599	56.7	0.743
Bg06	662706412	BREMER	309178	6116211	09/05/2007 10:21	4.06	6.23	6.74	2612	9.70	-129	17.59	60.40	1.200	-4.98	-21.90	0.715785	7.99	6.10	0.03	0.14	696	2.3	67.7	121.5	18.5	76.0	337	22.2	0.619
Bg07	662709806	BREMER	310427	6104803	09/05/2007 13:16		4.69	6.83	1785	19.97	10	19.78	146.00	3.000	-5.11	-27.70	0.717063	7.51	5.02	0.02	0.03	503	1.7	62.3	15.9	10.4	26.3	396	21.0	0.156
CUg01	662700385	CURRENCY CRK	287698	6078582	07/05/2007 14:30	Artesian	3.11	7.21	641	2.54	-35	17.04	558.00	8.000	-5.34	-26.60	0.717144	7.72	3.68	0.02	0.03	96	0.3	11.2	29.5	4.9	13.1	102	3.8	0.141
CUg02	662709607	CURRENCY CRK	286332	6075103	07/05/2007 12:05	10.68	4.41	6.54	1851	6.70	214	16.98	17.10	0.600	-5.13	-19.90	0.711410	7.53	5.33	0.02	0.68	462	1.2	58.9	145.7	5.1	29.3	228	18.5	0.395
CUg03	662708650	CURRENCY CRK	283271	6078265	07/05/2007 10:48	2.20	0.20	5.00	555	2.96	250	16.81	44.80	1.100	-4.48	-19.90	0.712619	6.71	0.21	0.02	4.52	174	0.4	16.2	4.7	2.0	13.8	100	5.7	0.103
Fg01	662706810	FINNISS	297995	6085855	18/05/2007 14:06		3.74	6.97	1142	18.38	-101	20.47	398.00	6.000	-4.62	-28.00	0.718547	8.01	3.53	0.03	0.03	282	1.0	42.4	40.5	15.2	38.2	172	14.3	0.286
Fg02	662701065	FINNISS	295972	6091070	10/05/2007 16:14		2.75	6.57	1407	31.05	-23	17.14	8.08	0.260	-5.00	-24.40	0.715829	7.66	2.96	0.03	0.47	414	1.4	44.6	71.2	6.4	35.4	209	14.6	0.571
Fg04	662710526	FINNISS	296222	6091742	18/05/2007 12:57			6.65	1492	25.59	33	15.85	16.30	0.600	-4.43	-24.80	0.713635	8.19	4.06	0.02	0.77	404	1.3	63.2	109.0	6.4	41.3	198	21.3	0.632
Fg05	662710843	FINNISS	297034	6094224	10/05/2007 15:09	8.82	2.10	6.34	1051	11.03	-49	16.76	439.00	6.000	-5.14	-28.00	0.720470	7.56	1.94	0.05	0.02	278	1.0	91.1	34.4	7.2	36.1	157	31.2	0.215
Fg07	662707072	FINNISS	284931	6089527	NOT SAMPLED																									
Fg08	662710483	FINNISS	285502	6091160	18/05/2007 11:50	12.20	2.72	6.24	2422	15.78	17	16.49	235.00	4.000	-4.98	-25.50	0.752900	8.11	3.28	0.04	0.04	633	2.0	294.6	122.9	11.1	57.5	384	100.9	1.088
Rg01	672802578	REEDY CRK	322501	6145207	08/05/2007 14:06		3.83	7.08	1107	10.02	28	16.77	124.00	2.000	-5.37	-27.10	0.716002	8.34	4.26	0.02	5.60	201	0.8	52.7	59.9	4.8	24.3	159	18.0	0.333
Rg02	672899999	REEDY CRK	332425	6143172	08/05/2007 12:38		4.08	6.84	2504	2.92	-110	19.28	829.00	11.000	-5.41	-28.60	0.715088	7.50	4.32	0.05	0.07	705	2.3	102.9	91.7	12.5	78.1	345	34.3	0.607
Rg03	672800904	REEDY CRK	322410	6136594	08/05/2007 11:40	3.30	4.59	6.50	4730	4.92	-50	18.38	472.00	7.000	-5.29	-27.00	0.717543	7.89	4.96	0.04	0.02	1514	4.7	158.5	80.6	20.2	207.1	657	52.3	0.788
TOg01	662709278	TOOKAYERTA CRK	291642	6083548	07/05/2007 12:46	Artesian	3.39	6.89	2164	8.44	110	17.85	271.00	5.000	-5.52	-25.10	0.722726	7.58	3.91	0.02	0.06	591	2.0	101.5	90.8	10.4	42.3	327	33.8	0.962
TOg02	662709830	TOOKAYERTA CRK	285266	6085649	18/05/2007 10:24	2.70	0.62	5.79	233	15.40	54	16.78	17.20	0.600	-5.62	-29.70	0.763322	7.19	0.55	0.02	0.05	50	<0.25	27.0	15.2	3.8	4.2	31	9.1	0.091
TOg03	662708408	TOOKAYERTA CRK	284505	6087492	07/05/2007 17:03		1.75	6.38	436	6.45	-56	16.50	121.00	2.000	-5.68	-25.80	0.731465	7.34	1.96	0.09	0.03	74	0.2	7.4	6.3	3.8	8.5	76	2.6	0.037
TOg04	662709823	TOOKAYERTA CRK	288622	6086438	NOT SAMPLED																									

Table A3. Results of in-field measurements of hydrochemical indices, and laboratory measurements of major ion chemistry, stable isotope ratios, radon-222 activity and strontium isotope ratios, for surface water sampling round 1, September/October 2006.

a) Angas, Bremer and Currency Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (μS/cm)	DO (mg/L)	Redox (mV)	Temp (^oC)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ ($^o/_{oo}$ rel SMOW)	$\delta^{2}H$ ($^o/_{oo}$ rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
A01	ANGAS RIVER	305209	6101720	22/09/2006 15:00	4.18	6.88	6887	5.30	108	13.91	6.22	0.340	-2.59	-12.90	0.717905	7.53	4.27	0.04	0.01	2110	5.9	209.0	287.0	44.5	169.2	971	73.7	1.825
A02	ANGAS RIVER	304600	6100946	26/09/2006 16:25	3.88	8.27	1681	12.75	54	16.13	0.44	0.040	-4.26	-19.70	0.714946	8.06	3.99	<0.01	<0.01	486	1.2	34.2	128.0	13.0	41.5	206	11.1	0.453
A03	ANGAS RIVER	308118	6097045	22/09/2006 10:15	3.69	7.76	2174	10.52	137	14.66	0.69	0.050	-3.21	-12.90	0.715596	7.94	4.00	<0.01	<0.01	662	1.7	45.4	120.0	16.7	54.2	302	15.5	0.564
A04	ANGAS RIVER	310637	6093896	22/09/2006 09:28	4.03	7.99	2486	11.93	160	14.88	0.75	0.050	-3.37	-16.70	0.716361	7.96	4.35	0.01	0.02	755	2.0	66.2	126.0	19.4	60.9	360	23.0	0.682
A06	ANGAS RIVER	305501	6098341	26/09/2006 13:31	3.11	7.60	2112	11.99	125	13.20	5.39	0.290	-2.39	-7.80	0.715395	7.95	3.38	<0.01	<0.01	729	1.8	49.4	110.0	17.3	57.0	330	16.8	0.558
A07	ANGAS RIVER	307508	6096993	26/09/2006 15:41	2.88	7.80	2349	10.57	79	15.74	0.30	0.030	-1.54	-6.20	0.715465	8.02	3.20	0.01	0.01	774	2.0	56.2	108.0	17.8	58.7	348	19.0	0.594
A08	ANGAS RIVER	309879	6095741	22/09/2006 09:47	4.15	7.55	2294	8.35	239	14.58	0.73	0.050	-3.32	-14.40	0.716254	8.00	4.46	<0.01	0.08	694	1.8	53.3	121.0	16.8	54.8	326	18.0	0.619
A09	ANGAS RIVER	302667	6095315	22/09/2006 12:35	4.06	7.85	4317	11.27	293	15.96	0.37	0.030	-2.71	-13.80	0.716614	7.99	4.41	0.03	0.02	1430	3.9	106.6	135.0	30.3	113.0	696	37.7	1.226
A10	ANGAS RIVER	301999	6102158	26/09/2006 12:11	3.38	7.74	1894	11.94	181	15.02	1.78	0.110	-3.19	-15.70	0.715039	8.00	3.59	<0.01	<0.01	606	1.5	35.5	98.0	8.5	42.3	299	12.1	0.424
A11	ANGAS RIVER	303900	6102943	22/09/2006 15:46	4.24	8.25	1713	11.70	181	13.85	0.30	0.030	-4.31	-21.30	0.714848	8.18	4.57	<0.01	<0.01	491	1.2	33.0	134.0	9.5	42.1	208	10.7	0.468
A12	ANGAS RIVER	303059	6101255	26/09/2006 13:06	2.52	8.13	1873	10.84	117	19.28	1.03	0.070	-2.07	-6.70	0.715256	8.17	2.80	<0.01	<0.01	553	1.2	38.5	78.7	8.0	38.1	271	13.0	0.420
A13	ANGAS RIVER	301940	6105851	26/09/2006 09:42	2.97	7.69	1899	12.84	168	10.93	0.23	0.020	-3.65	-11.60	0.714595	8.04	3.37	0.01	0.02	686	1.7	39.9	101.0	12.5	58.6	312	13.8	0.604
A14	ANGAS RIVER	303166	6105188	26/09/2006 10:09	4.10	7.29	1661	7.58	142	14.19	36.09	1.920	-4.18	-19.70	0.714713	7.77	4.41	0.01	0.20	499	1.3	35.1	134.0	10.6	43.6	211	11.6	0.510
A15	ANGAS RIVER	301351	6106709	26/09/2006 09:52	3.43	7.75	1960	12.77	168	10.09	1.43	0.090	-3.87	-16.70	0.714593	7.95	3.68	<0.01	0.01	730	1.8	43.3	110.0	13.1	63.8	332	15.1	0.667
A16	ANGAS RIVER	301618	6098446	22/09/2006 13:32	4.36	7.98	2780	11.65	167	14.49	4.91	0.270	-3.40	-16.60	0.716030	7.99	4.36	<0.01	<0.01	889	2.3	50.3	140.0	13.7	68.3	408	17.2	0.750
B01	BREMER RIVER	317648	6097416	28/09/2006 10:58	3.34	7.75	2267	10.21	92	13.97	0.20	0.020	-1.06	-6.50	0.715557	7.99	3.27	0.03	0.26	678	1.6	199.0	92.5	21.4	58.7	381	70.0	0.598
B02	BREMER RIVER	318535	6101974	28/09/2006 13:00	2.65	8.15	2065	11.78	61	15.41	0.22	0.020	-1.22	-5.70	0.715507	8.10	2.90	<0.01	0.23	571	1.3	198.0	83.3	19.8	50.4	333	70.5	0.483
B03	BREMER RIVER	309308	6116101	27/09/2006 11:40	2.21	7.28	1410	7.87	172	14.91	0.78	0.050	-2.01	-10.00	0.713788	7.78	2.25	5.32	6.05	388	0.7	99.8	61.7	15.8	35.5	213	36.0	0.409
B04	BREMER RIVER	320408	6110368	27/09/2006 16:06	9.87	7.65	6918	12.88	259	14.65	0.68	0.050	-2.03	-14.00	0.717992	8.10	10.51	0.02	0.01	2320	7.1	399.0	110.0	74.2	138.0	1450	142.5	1.294
B05	BREMER RIVER	321414	6114041	28/09/2006 15:07	6.87	7.63	6882	11.24	269	13.52	0.60	0.040	-1.21	-6.50	0.718036	7.96	7.05	0.03	0.02	2430	7.3	405.0	132.0	60.3	150.0	1420	144.4	1.410
B07	BREMER RIVER	313039	6120524	27/09/2006 10:39	2.16	7.41	1406	12.83	122	12.17	0.26	0.030	-0.22	-1.50	0.715469	7.73	2.26	0.02	6.20	349	0.7	229.0	69.3	25.2	42.0	234	82.4	0.240
B08	BREMER RIVER	312266	6125128	27/09/2006 10:00	3.59	7.17	1038	5.06	161	12.13	0.21	0.020	0.47	4.10	0.714089	7.79	3.66	8.12	11.47	255	0.4	19.6	31.7	26.7	21.7	186	7.7	0.232
B10	BREMER RIVER	314164	6116341	27/09/2006 11:12	1.77	7.73	793	12.76	189	13.27	0.51	0.040	-1.88	-8.20	0.715320	7.79	1.79	<0.01	7.90	203	0.3	35.9	36.2	10.5	18.1	127	13.1	0.222
B11	BREMER RIVER	313593	6112459	27/09/2006 13:50	1.74	8.32	886	13.10	205	15.72	1.10	0.070	-3.45	-15.90	0.714644	8.13	2.24	<0.01	1.22	237	0.4	41.7	39.9	7.9	22.0	127	14.9	0.272
B12	BREMER RIVER	315240	6102446	28/09/2006 10:34	8.19	8.46	13517	16.78	96	14.17	0.33	0.030	1.36	4.50	0.717275	8.55	8.11	0.07	0.03	5010	15.1	1120.0	202.0	202.0	318.0	3084	369.7	2.212
B13	BREMER RIVER	310720	6103991	28/09/2006 09:34	9.67	7.77	5985	8.53	100	10.98	2.09	0.120	-3.07	-17.80	0.716590	7.97	10.02	0.01	0.03	2240	5.8	341.0	178.0	78.0	168.0	1250	121.5	1.564
B14	BREMER RIVER	320586	6124350	06/10/2006 16:23	5.20	8.16	4566	10.52	268	16.62	0.40	0.030	-0.14	-1.60	0.718186	8.07	5.10	0.03	<0.01	1920	5.2	272.0	146.0	51.8	147.0	990	96.8	1.575
B15	BREMER RIVER	318654	6130716	06/10/2006 15:52	4.26	7.20	3622	4.72	255	14.56	2.67	0.150	-1.23	-5.10	0.718807	7.79	4.09	0.03	<0.01	1610	4.3	188.0	184.0	35.5	133.0	740	66.6	1.772
B16	BREMER RIVER	320677	6117999	06/10/2006 16:49	6.90	8.35	6228	11.38	256	17.60	0.45	0.040	-0.13	-4.20	0.717793	8.34	6.92	0.03	<0.01	2560	7.8	391.0	106.0	68.5	163.0	1440	138.4	1.291
B17	BREMER RIVER	319949	6106603	28/09/2006 13:21	2.57	7.78	2040	12.38	144	15.39	0.44	0.040	-1.40	-3.00	0.715096	8.02	2.67	<0.01	1.06	610	1.4	134.0	79.1	19.2	50.3	324	47.5	0.509
B18	BREMER RIVER	316857	6112349	27/09/2006 15:39	1.72	7.37	1349	11.92	253	14.35	0.19	0.020	-1.21	-6.40	0.715742	7.69	1.61	0.70	4.50	305	0.9	263.0	78.3	17.9	35.1	199	91.5	0.268
CU01	CURRENCY CRK	296566	6074343	09/10/2006 13:10	3.56	7.60	1957	8.71	230	14.53	4.30	0.230	-2.01	-7.90	0.714524	7.89	3.88	0.01	0.07	844	2.1	58.7	77.7	17.9	62.3	451	21.2	0.612
CU02	CURRENCY CRK	295919	6074590	09/10/2006 13:47	2.25	7.65	890	12.07	180	18.73	4.29	0.230	-2.75	-14.50	0.717050	7.84	2.30	0.04	0.12	311	0.7	22.4	34.3	9.2	22.7	184	8.5	0.291
CU04	CURRENCY CRK	292724	6073346	09/10/2006 11:03	3.02	7.29	1533	7.91	185	12.48	3.03	0.170	-1.85	-9.20	0.714989	7.76	3.08	0.02	0.13	689	1.7	39.2	72.4	15.1	56.4	345	14.2	0.582
CU05	CURRENCY CRK	284307	6077747	09/10/2006 09:43	1.47	6.84	425	8.29	159	10.37	1.82	0.110	-2.85	-13.60	0.713668	7.70	1.65	0.04	0.13	169	0.3	7.8	15.2	4.4	12.5	111	3.1	0.136
CU06	CURRENCY CRK	287084	6075299	09/10/2006 10:04	3.49	7.02	2662	6.10	-82	12.59	10.80	0.600	-4.23	-20.50	0.714928	7.82	3.55	0.02	0.01	850	2.2	66.3	84.0	11.2	62.0	442	23.5	0.582

b) Finniss River, Reedy Creek and Tookayerta Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (μS/cm)	DO (mg/L)	Redox (mV)	Temp (°C)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ (°/oo rel SMOW)	$\delta^{2}H$ (°/oo rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
F01	FINNISS RIVER	288292	6088633	20/09/2006 15:17	2.00	7.63	1520	10.17	108	14.47	1.39	0.090	-3.09	-14.10	0.717622	7.80	2.11	0.01	0.03	487	1.1	36.4	55.6	5.6	47.7	222	13.0	0.404
F02	FINNISS RIVER	285085	6090035	10/10/2006 12:34	0.51	6.79	297	8.70	202	11.43	2.19	0.120	-3.91	-18.80	0.723301	7.08	0.64	0.01	0.06	126	0.3	8.0	9.9	1.9	10.0	68	3.0	0.082
F03	FINNISS RIVER	285339	6094277	21/09/2006 11:03	4.02	7.52	2811	10.14	185	12.45	3.27	0.180	-3.45	-12.40	0.714559	7.86	4.06	0.01	0.05	980	2.4	59.9	116.0	6.9	97.5	423	20.6	0.723
F04	FINNISS RIVER	289935	6092489	21/09/2006 12:22	3.61	7.97	2004	12.76	176	15.77	2.62	0.150	-3.34	-14.60	0.716564	7.99	3.37	<0.01	0.02	605	1.6	44.0	64.1	8.4	53.7	300	15.4	0.462
F06	FINNISS RIVER	298001	6085819	21/09/2006 15:18	2.21	8.01	1541	11.63	202	15.03	0.42	0.030	-3.01	-13.20	0.716540	7.95	2.40	0.01	0.01	473	1.2	37.5	60.0	6.5	45.2	216	13.2	0.435
F07	FINNISS RIVER	297557	6089824	20/09/2006 16:17	2.29	7.72	1515	10.75	218	14.03	0.34	0.030	-3.06	-10.10	0.716568	7.85	2.39	<0.01	0.02	471	1.1	39.5	61.7	6.4	46.3	217	14.1	0.431
F08	FINNISS RIVER	295441	6089786	20/09/2006 11:18	1.88	7.69	1538	10.98	168	14.34	0.19	0.020	-3.09	-13.30	0.717018	7.87	2.14	<0.01	0.01	487	1.2	34.2	56.7	6.2	47.6	223	12.2	0.413
F09	FINNISS RIVER	296525	6092912	20/09/2006 10:58	4.00	7.90	1121	11.16	156	13.26	5.66	0.310	-3.71	-17.70	0.713863	8.01	4.33	<0.01	0.01	274	0.7	22.8	79.7	6.6	30.2	149	8.0	0.436
F10	FINNISS RIVER	300460	6085008	21/09/2006 13:20	3.26	7.69	1759	11.05	-16	14.61	0.41	0.030	-3.70	-18.20	0.713211	7.97	3.47	<0.01	<0.01	544	1.5	9.2	50.7	8.2	38.2	287	2.9	0.505
F11	FINNISS RIVER	300422	6082953	21/09/2006 08:56	4.61	7.73	1137	7.94	134	12.22	3.34	0.180	-4.24	-21.10	0.712520	7.96	4.87	0.13	0.67	277	0.6	30.9	101.2	6.6	29.4	136	10.1	0.542
F12	FINNISS RIVER	297185	6100044	21/09/2006 13:02	2.38	7.48	1579	8.65	198	14.84	2.57	0.150	-3.20	-12.80	0.716775	7.79	2.53	<0.01	0.03	499	1.2	40.1	62.0	7.5	44.1	244	14.2	0.468
F13	FINNISS RIVER	285201	6090371	20/09/2006 15:47	2.93	7.71	2108	9.59	184	13.95	2.71	0.150	-2.94	-13.30	0.717745	7.85	3.00	0.01	0.05	688	1.6	54.2	85.6	7.6	67.6	306	18.9	0.575
F14	FINNISS RIVER	286388	6095266	21/09/2006 09:46	3.29	7.46	2115	8.97	165	12.90	1.71	0.100	-2.76	-11.10	0.716107	7.77	3.38	0.01	0.25	703	1.7	54.2	93.3	8.1	72.7	310	19.1	0.680
F15	FINNISS RIVER	288746	6098886	21/09/2006 09:36	3.62	7.38	2161	6.94	121	12.65	1.61	0.100	-2.58	-8.60	0.715829	7.74	3.86	0.01	0.02	704	1.8	46.6	99.1	10.8	73.6	313	16.4	0.728
F17	FINNISS RIVER	296168	6095298	20/09/2006 10:34	4.46	7.78	992	10.15	145	13.23	4.21	0.230	-4.15	-19.10	0.713230	7.98	4.76	<0.01	0.06	216	0.6	18.3	86.1	7.1	25.6	122	5.9	0.490
RE01	REEDY CREEK	333771	6134714	06/10/2006 12:44	10.23	7.87	8401	9.67	191	15.24	1.56	0.100	-2.87	-15.60	0.716206	7.85	10.60	0.03	0.02	3900	11.6	319.0	212.0	79.2	322.0	1760	110.6	2.565
RE03	REEDY CREEK	322468	6143383	06/10/2006 09:21	4.93	7.59	3012	12.92	180	13.35	2.81	0.160	-2.18	-9.00	0.717964	7.82	4.37	0.03	0.02	1330	3.6	152.0	114.0	21.3	106.0	672	53.5	0.866
RE04	REEDY CREEK	325427	6139208	06/10/2006 13:42	6.23	7.92	3129	8.79	101	13.87	2.12	0.120	-1.73	-7.00	0.719259	7.97	6.74	0.02	<0.01	1310	3.6	96.0	102.0	24.1	102.0	715	34.3	0.857
RE05	REEDY CREEK	324773	6138772	06/10/2006 09:47	4.95	8.21	4318	7.73	147	13.57	0.30	0.030	-0.53	-2.40	0.716778	8.02	5.16	0.03	<0.01	2050	5.6	173.0	117.0	30.1	161.0	1020	61.0	1.312
RE06	REEDY CREEK	330999	6138952	06/10/2006 12:20	6.06	8.03	3973	11.24	174	13.76	11.30	0.600	-2.34	-15.40	0.718596	7.85	6.33	0.02	<0.01	1800	4.9	207.0	191.0	32.9	126.0	899	71.7	1.521
T01	TOOKAYERTA CRK	291175	6083693	10/10/2006 09:27	0.74	6.80	201	13.93	82	10.45	1.80	0.100	-4.81	-19.50	0.723923	7.20	0.55	0.01	0.09	85	<0.3	8.1	8.6	2.9	6.8	48	2.8	0.074
T02	TOOKAYERTA CRK	291192	6083864	10/10/2006 10:05	0.72	6.97	232	13.87	100	11.72	0.75	0.050	-4.73	-21.20	0.720183	7.24	0.57	0.02	0.12	95	<0.3	8.8	8.8	2.9	7.7	53	3.1	0.074
T03	TOOKAYERTA CRK	284513	6083976	10/10/2006 08:58	0.49	6.40	193	12.43	53	10.60	1.76	0.100	-4.84	-19.20	0.716788	7.03	0.48	<0.01	0.30	84	<0.3	7.0	7.9	2.4	7.1	44	2.2	0.060
T04	TOOKAYERTA CRK	283930	6085907	09/10/2006 14:38	0.69	6.84	181	12.25	104	13.85	0.90	0.060	-4.74	-22.00	0.715406	7.15	0.43	0.01	0.08	69	<0.3	9.1	8.0	1.6	5.6	38	3.2	0.064

Table A4. Results of in-field measurements of hydrochemical indices, and laboratory measurements of major ion chemistry, stable isotope ratios, radon-222 activity and strontium isotope ratios, for surface water sampling round 2, January/February 2007

a) Angas, Bremer and Currency Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (μS/cm)	DO (mg/L)	Redox (mV)	Temp (°C)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ (°/oo rel SMOW)	$\delta^{2}H$ (°/oo rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
A01	ANGAS	305209	6101720	NO WATER																								
A02	ANGAS	304600	6100946	31/01/2007 11:18	4.10	7.41	2745	14.82	161	20.28	1.51	0.090	-0.46 -0.59	-1.9 -2.3	0.715731	7.98	4.43	0.02	<0.01	840	2.2	42.0	136.0	15.2	61.0	342	12.8	0.694
A03	ANGAS	308118	6097045																									
A04	ANGAS	310637	6093896	31/01/2007 14:07	6.46	8.07	7203	16.46	83	24.79	3.59	1.910	-1.52 -1.57	-12.2 -12.7	0.717225	7.96	5.84	0.07	0.02	2430	7.7	278.4	192.0	38.5	176.0	1160	94.5	2.194
A06	ANGAS	305501	6098341	NO WATER																								
A07	ANGAS	307508	6096993	NO WATER																								
A08	ANGAS	309879	6095741	31/01/2007 13:42	9.08	7.78	4672	10.77	83	22.38	0.35	0.025	-1.99 -2.04	-11.3 -12.3	0.717523	8.10	8.11	0.02	<0.01	1390	4.1	152.2	113.7	27.4	93.1	771	49.9	1.270
A09	ANGAS	302667	6095315	NO WATER																								
A10	ANGAS	301999	6102158	NO WATER																								
A11	ANGAS	303900	6102943	31/01/2007 11:52	4.88	7.61	1947	11.01	123	19.48	0.92	0.056	-3.55 -3.45	-16.3 -16.2	0.714868	7.93	4.98	0.02	<0.01	542	1.5	17.4	131.5	9.1	42.8	205	4.6	0.526
A12	ANGAS	303059	6101255	NO WATER																								
A13	ANGAS	301940	6105851	NO WATER																								
A14	ANGAS	303166	6105188	31/01/2007 10:04	4.46	7.33	1504	11.41	143	17.96	35.90	1.900	-5.02	-23.3 -22.4	0.714685	7.81	4.58	<0.01	0.04	374	1.0	30.6	125.1	7.7	31.6	143	9.2	0.393
A15	ANGAS	301351	6106709	31/01/2007 09:45	5.21	7.56	3535	15.05	150	17.18	0.59	0.038	-4.58	-24.6 -24.7	0.714509	8.11	5.29	0.02	<0.01	1090	2.9	85.5	162.7	15.9	89.6	453	27.4	0.932
A16	ANGAS	301618	6098446	NO WATER																								
B01	BREMER	317648	6097416	NO WATER																								
B02	BREMER	318535	6101974	30/01/2007 13:46	4.82	7.99	3113	6.94	86	22.15	0.27	0.021	5.36	22.5 23.1	0.715368	8.13	4.68	0.02	<0.01	906	2.3	130.9	94.3	24.4	69.4	468	44.2	0.672
B03	BREMER	309308	6116101	30/01/2007 10:46	3.93	7.14	1479	11.07	163	19.71	0.61	0.040	-1.31	-7.2 -6.6	0.714263	7.94	3.86	0.05	0.02	356	0.8	71.8	58.6	15.7	35.8	203	24.8	0.460
B04	BREMER	320408	6110368	29/01/2007 15:49	12.85	8.98	17593	18.28	-21	30.40	0.31	0.024	8.83	30.6 30.8	0.717841	8.95	13.72	0.32	<0.01	6200	19.5	898.2	37.6	119.1	325.6	3720	298.9	1.351
B05	BREMER	321414	6114041	29/01/2007 12:19	10.72	7.98	11830	13.62	76	19.39	0.40	0.028	2.36	9.6	0.717961	8.23	11.11	0.31	<0.01	4040	12.4	514.5	155.0	59.6	253.0	2220	174.7	2.263
B07	BREMER	313039	6120524	NO WATER																								
B08	BREMER	312266	6125128	29/01/2007 09:31	6.52	7.57	1888	8.23	178	16.16	0.08	0.009	5.92	23.7	0.713985	8.08	6.55	0.02	0.95	438	0.9	2.8	34.7	54.5	24.8	327	1.5	0.315
B10	BREMER	314164	6116341	29/01/2007 14:06	3.61	7.78	1337	12.16	109	19.63	0.72	0.047	1.84 1.83	8.4	0.714749	8.06	3.59	0.10	0.10	250	0.6	59.8	30.1	29.7	18.0	196	21.4	0.222
B11	BREMER	313593	6112459	29/01/2007 14:31	5.18	8.04	8633	19.08	-65	22.97	1.83	0.105	1.28	1 1.1	0.717323	8.28	5.26	0.07	0.01	3010	8.9	350.7	182.4	58.8	186.3	1520	118.6	2.066
B12	BREMER	315240	6102446	30/01/2007 12:53	17.21	7.95	10547	12.03	-38	20.54	0.37	0.026	1.96 1.78	8.9 8.4	0.717279	8.16	18.10	0.40	0.01	3370	10.5	378.2	120.0	115.4	228.2	1990	129.1	1.838
B13	BREMER	310720	6103991	30/01/2007 11:58	5.92	7.62	5412	13.97	48	19.56	3.70	0.200	0.40	-2 -1.1	0.716885	8.02	6.06	0.06	<0.01	1720	4.5	196.7	101.4	38.3	126.8	885	64.1	1.246
B14	BREMER	320586	6124350	29/01/2007 11:07	8.44	7.95	9067	15.77	-38	17.45	0.18	0.016	6.13	29.5	0.718136	7.97	8.65	0.31	0.02	3150	8.8	221.9	173.1	52.5	229.3	1530	77.1	2.469
B15	BREMER	318654	6130716	24/01/2007 16:34	7.57	7.60	8290	4.80	-179	21.35	1.71	0.100	0.45 0.46	-5.3	0.718737	7.95	8.14	0.06	<0.01	2830	7.8	336.3	302.5	47.4	206.5	1310	114.9	3.161
B16	BREMER	320677	6117999	29/01/2007 12:01	6.85	8.42	11072	8.22	79	20.93	0.32	0.024	5.67	20.7 20.4	0.717820	8.55	7.03	0.09	<0.01	3810	11.7	519.4	73.9	62.7	239.8	2130	175.0	1.381
B17	BREMER	319949	6106603	29/01/2007 16:02	6.72	8.05	3885	19.40	-47	20.63	1.29	0.080	0.67 0.63	0.9 1.5	0.716145	8.34	6.86	0.07	<0.01	1120	3.1	160.7	97.1	25.7	75.7	633	53.4	0.913
B18	BREMER	316857	6112349	NO WATER																								
CU01	CURRENCY CRK	296566	6074343	25/01/2007 12:22	6.80	7.33	4585	3.64	-197	18.92	10.39	0.550	-1.92	-8.2	0.714349	8.19	7.13	0.05	0.11	1480	4.1	115.8	90.9	29.9	92.6	830	39.1	1.006
CU02	CURRENCY CRK	295919	6074590	NO WATER																								
CU04	CURRENCY CRK	292724	6073346	25/01/2007 11:26	4.92	7.38	2533	5.22	5	17.46	2.87	0.160	-3.27	-15.3	0.714393	8.00	5.04	0.02	0.21	709	1.9	67.0	85.0	16.9	56.8	363	22.3	0.802
CU05	CURRENCY CRK	284307	6077747	25/01/2007 10:25	1.23	7.10	1242	4.22	-29	16.93	0.34	0.027	-2.44 -2.51	-13.4 -13.2	0.713322	7.39	1.25	0.08	0.28	331	0.6	91.6	29.6	13.3	22.2	191	31.7	0.269
CU06	CURRENCY CRK	287084	6075299	25/01/2007 09:49	4.10	7.06	3422	6.22	-98	17.29	7.66	0.410	-4.13	-23 -23.2	0.715166	7.80	4.15	0.02	0.08	1090	2.7	88.4	91.1	11.2	79.0	544	30.0	0.695

b) Finniss River, Reedy Creek and Tookayerta Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (µS/cm)	DO (mg/L)	Redox (mV)	Temp (^oC)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ ($^o/_{oo}$ rel SMOW)	δ^2H ($^o/_{oo}$ rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
F01	FINNISS	288292	6088633	01/02/2007 14:41	1.80	6.61	1690	6.81	-168	17.32	0.42	0.029	-1.56 -1.5	-6.8	0.720137	7.41	1.90	0.06	0.62	299	0.8	14.9	31.0	6.2	27.5	153	5.2	0.243
F02	FINNISS	285085	6090035	01/02/2007 15:13	0.43	7.36	555	11.29	-59	17.97	0.40	0.028	-3.57	-17.5 -18.3	0.723204	6.81	0.41	0.02	0.45	156	0.3	26.1	11.2	2.9	11.6	81	9.1	0.097
F03	FINNISS	285339	6094277	02/02/2007 11:07	4.26	7.34	3429	5.82	5	16.87	0.93	0.057	-4.41 -4.39	-20.6 -21	0.716517	7.67	4.19	0.08	0.62	1010	1.8	168.9	139.3	13.5	118.9	427	58.7	0.751
F04	FINNISS	289935	6092489	01/02/2007 16:50	5.57	7.60	3497	9.35	-25	31.35	1.06	0.640	0.61	0.1 0.8	0.716050	7.98	5.75	0.02	0.01	1070	2.8	14.2	98.0	21.9	80.9	509	4.4	0.721
F06	FINNISS	298001	6085819	01/02/2007 11:30	4.23	7.35	2744	3.99	132	18.80	1.14	0.070	0.82	-0.7 -0.3 -0.7	0.717720	7.78	4.49	0.15	0.06	822	2.1	41.3	96.6	15.9	69.3	391	13.9	0.718
F07	FINNISS	297557	6089824	NO WATER																								
F08	FINNISS	295441	6089786	NO WATER																								
F09	FINNISS	296525	6092912	NO WATER																								
F10	FINNISS	300460	6085008	01/02/2007 12:36	7.74	7.02	7541	14.35	34	19.88	4.35	0.230	-2.53 -2.69	-10.2 -11.1	0.712012	7.62	8.32	0.03	<0.01	2310	6.6	263.7	161.4	18.9	172.2	1190	89.8	1.896
F11	FINNISS	300422	6082953	NO WATER																								
F12	FINNISS	297185	6100044	01/02/2007 14:33	2.95	7.66	1903	12.89	-42	24.44	4.45	0.240	-3.69	-20.6 -20.8	0.716103	7.86	2.76	<0.01	<0.01	553	1.5	39.2	50.7	7.8	35.3	300	13.3	0.519
F13	FINNISS	285201	6090371	01/02/2007 16:10	3.24	7.27	2076	11.54	-32	21.01	8.78	0.460	0.86 -0.85	-4.9 -4.3	0.722722	7.75	3.30	<0.01	0.05	577	1.5	47.3	62.2	7.1	51.0	290	16.1	0.423
F14	FINNISS	286388	6095266	02/02/2007 10:18	4.88	7.32	3889	10.40	-130	20.64	0.69	0.463	2.74 2.58	9 9.3	0.716832	7.92	5.18	0.06	0.29	1240	3.1	56.0	132.6	11.2	124.6	534	19.0	0.917
F15	FINNISS	288746	6098886	02/02/2007 09:52	4.98	6.71	2821	10.86	-1	16.38	2.59	0.140	-2.05	-7 -7.5	0.715700	7.48	5.46	0.05	<0.01	820	2.3	82.7	117.9	9.6	90.3	372	28.2	0.787
F17	FINNISS	296168	6095298	01/02/2007 10:11	6.78	7.14	1784	9.97	18	15.09	6.18	0.330	-3.78 -3.92	-17.2 -16.6	0.713626	7.82	7.32	0.01	<0.01	408	1.0	4.4	142.7	7.5	44.9	175	<1	0.826
RE01	REEDY CRK	333771	6134714	24/01/2007 14:49	11.64	7.89	14846	14.62	-12	23.05	1.29	0.080	-2.51	-19	0.715897	8.13	12.39	0.15	<0.01	5500	15.5	346.4	217.5	78.7	493.2	2530	116.4	2.954
RE03	REEDY CRK	322468	6143383	24/01/2007 10:38	4.02	7.20	1872	5.89	62	20.09	1.36	0.080	-4.05 -4.27	-24 -23.1	0.718537	8.03	4.48	0.05	1.75	471	1.0	56.1	69.5	9.7	46.8	262	19.3	0.294
RE04	REEDY CRK	325427	6139208	24/01/2007 13:14	6.88	8.71	8173	15.88	13	22.69	0.49	0.036	3.76 3.81	11.2	0.719044	8.43	6.77	0.18	0.02	2850	7.9	160.4	105.7	39.3	205.4	1420	53.8	1.250
RE05	REEDY CRK	324773	6138772	24/01/2007 11:54	5.08	8.60	11498	10.79	15	19.88	0.20	0.018	8.14	32.3	0.716901	8.45	5.69	0.23	1.22	4320	11.6	208.0	99.7	43.6	328.0	2080	71.9	1.625
RE06	REEDY CRK	330999	6138952	NO WATER																								
RE07	REEDY CRK	320408	6138650	24/01/2007 15:31	3.44	7.91	7035	7.23	61	22.23	0.34	0.027	-3.25	-22.5	0.715401	7.90	3.90	0.10	<0.01	2400	6.4	331.9	154.7	24.5	169.7	1190	112.7	1.649
T01	TOOKAYERTA CRK	291175	6083693	25/01/2007 15:08	0.41	7.41	435	10.41	112	22.22	0.91	0.059	-4.65 -4.77	-26.7 -25.9	0.723997	7.01	0.46	0.04	<0.01	111	0.2	27.5	12.4	4.4	9.1	59	9.5	0.096
T02	TOOKAYERTA CRK	291192	6083864	25/01/2007 15:16	0.48	7.52	439	11.69	72	22.66	0.85	0.056	-4.65	-23.1 -22.7	0.723479	7.01	0.46	0.02	<0.01	112	0.3	27.9	12.3	4.4	9.2	59	9.6	0.091
T03	TOOKAYERTA CRK	284513	6083976	25/01/2007 14:19	0.48	7.37	316	10.75	47	16.64	1.20	0.080	-4.52 -4.66	-25.8 -25.5	0.716756	6.97	0.44	0.05	0.15	87	0.2	6.3	6.6	3.3	7.1	44	2.1	0.051
T04	TOOKAYERTA CRK	283930	6085907	25/01/2007 12:50	0.46	7.63	364	12.78	-54	19.19	0.55	0.039	-4.44	-21.6	0.715477	7.17	0.46	0.04	0.06	94	0.3	18.0	10.7	4.0	7.4	51	6.6	0.068

Table A5. Results of in-field measurements of hydrochemical indices, and laboratory measurements of major ion chemistry, stable isotope ratios, radon-222 activity and strontium isotope ratios, for surface water sampling round 2, May 2007

a) Angas, Bremer and Currency Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (μS/cm)	DO (mg/L)	Redox (mV)	Temp (^oC)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ ($^o/_{oo}$ rel SMOW)	$\delta^{2}H$ ($^o/_{oo}$ rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
A15	ANGAS	301351	6106709	23/05/2007 10:05	3.18	7.70	2735	28.38	-34	11.93	0.93	0.055	-4.18	-19.50	0.714424	7.99	3.46	0.03	<0.01	1000	2.3	102.2	149.8	15.3	78.3	429	33.5	0.928
A13	ANGAS	301940	6105851	NO WATER																								
A14	ANGAS	303166	6105188	23/05/2007 10:35	4.28	7.29	1316	19.55	-19	15.67	43.70	2.100	-4.98	-20.80	0.714812	7.72	4.54	0.02	0.07	374	1.0	39.9	132.8	7.4	33.1	149	12.4	0.397
A11	ANGAS	303900	6102943	23/05/2007 12:00	4.05	7.76	1489	43.52	-11	12.45	1.05	0.060	-3.98	-18.75	0.714933	7.94	4.38	0.01	<0.01	444	1.1	55.6	133.4	8.5	39.5	184	17.9	0.442
A02	ANGAS	304600	6100946	23/05/2007 13:00	3.59	7.80	1582	32.43	17	12.90	0.77	0.046	-4.82	-21.20	0.715243	7.93	3.78	<0.01	<0.01	477	1.2	102.8	133.7	10.0	43.5	200	32.0	0.485
A03	ANGAS	308118	6097045	23/05/2007 13:23	2.85	7.35	2965	30.80	-18	13.30	0.88	0.051	-4.30	-24.55	0.716174	7.75	2.98	0.02	<0.01	866	2.0	578.5	251.2	25.0	94.8	413	189.5	1.246
A08	ANGAS	309879	6095741	23/05/2007 14:24	2.72	7.35	2733	25.15	12	14.57	0.58	0.036	-5.94	-35.60	0.717059	7.67	2.87	0.01	0.13	407	0.9	104.0	79.0	11.6	34.6	227	37.1	0.504
A04	ANGAS	310637	6093896	23/05/2007 14:45	4.62	7.67	3220	36.83	22	14.36	0.22	0.016	-5.99	-37.90	0.717060	7.99	4.72	0.02	<0.01	1127	3.6	175.1	130.6	22.6	86.1	585	58.3	1.044
A16	ANGAS	301618	6098446	23/05/2007 15:51	2.65	7.52	4205	20.00	11	13.67	3.30	0.170	-5.48	-32.70	0.716044	7.65	2.64	0.07	<0.01	1510	3.6	401.2	251.2	19.9	125.4	667	130.8	1.635
A09	ANGAS	302667	6095315	22/05/2007 16:32	3.77	6.66	4315	21.73	-74	13.10	0.66	0.042	-4.71	-22.20	0.716733	7.26	3.76	0.24	0.03	1562	4.3	336.6	164.6	28.4	127.2	775	110.3	1.468
A01	ANGAS	305209	6101720	NO WATER																								
A10	ANGAS	301999	6102158	23/05/2007 11:15	3.93	7.45	4839	25.98	26	13.06	1.94	0.110	-3.95	-16.65	0.715112	7.74	4.13	0.06	0.03	1868	5.2	168.2	173.3	13.5	110.3	951	55.1	1.273
A12	ANGAS	303059	6101255	NO WATER																								
A06	ANGAS	305501	6098341	NO WATER																								
A07	ANGAS	307508	6096993	NO WATER																								
B15	BREMER	318654	6130716	24/05/2007 14:16	2.64	7.41	4120	7.81	-146	13.00	0.41	0.030	-5.85	-43.50	0.718229	7.58	2.70	0.23	0.03	791	1.5	426.0	175.7	29.4	80.2	389	142.2	1.625
B14	BREMER	320586	6124350	28/05/2007 10:33	4.59	11.38	9875	11.77	-67	11.85	0.13	0.012	2.20	7.20	0.718119	7.86	4.75	1.03	0.01	3780	10.7	1190.0	292.2	72.2	353.0	1950	399.8	4.139
B16	BREMER	320677	6117999	28/05/2007 10:05	8.14	11.25	10948	13.07	-7	13.05	0.22	0.017	5.09	19.60	0.717828	8.45	8.56	0.24	0.06	4400	14.3	639.8	106.7	75.5	288.3	2510	215.1	1.977
B05	BREMER	321414	6114041	28/05/2007 11:29	10.47	7.46	12430	15.02	-31	12.76	0.33	0.023	0.88	3.80	0.717991	7.90	10.68	0.09	<0.01	4830	15.3	931.6	260.9	69.1	332.5	2800	314.3	3.444
B04	BREMER	320408	6110368	28/05/2007 11:51	5.08	7.80	4952	6.52	-207	13.34	0.21	0.016	-6.94	-50.70	0.717737	8.37	5.17	0.04	<0.01	1330	3.8	464.1	83.3	47.6	84.0	931	155.6	0.107
B17	BREMER	319949	6106603	28/05/2007 12:33	2.08	4.74	1874	12.28	5	12.83	0.34	0.024	-6.52	-46.50	0.715711	7.67	2.06	0.12	0.01	517	1.2	318.6	97.0	21.1	53.9	297	106.7	0.653
B02	BREMER	318535	6101974	28/05/2007 13:04	1.84	8.96	1209	13.25	-21	13.35	0.11	0.010	-3.50	-11.90	0.715523	7.68	1.98	0.08	0.11	322	0.7	166.0	63.7	16.1	33.6	188	56.7	0.416
B01	BREMER	317648	6097416	NO WATER									-7.90	-60.30														
B08	BREMER	312266	6125128	24/05/2007 12:46	3.97	8.21	1027	8.83	13	11.67	0.30	0.024	0.03	-2.80	0.713425	7.72	3.84	6.57	8.99	266	0.5	24.1	26.3	40.0	15.8	212	8.9	0.172
B07	BREMER	313039	6120524	24/05/2007 13:04	0.64	8.24	1971	14.53	-10	11.75	0.17	0.016	-0.84	-4.70	0.714609	6.99	0.76	0.46	3.38	327	0.8	983.4	203.0	34.4	91.5	244	314.5	0.411
B10	BREMER	314164	6116341	24/05/2007 11:47	2.57	9.07	697	20.09	-9	11.05	0.21	0.018	-3.77	-26.00	0.714531	7.82	2.72	<0.01	1.63	187	0.5	48.6	35.3	15.2	18.6	136	17.3	0.230
B18	BREMER	316857	6112349	24/05/2007 11:29	1.47	8.89	1323	14.76	17	12.96	0.68	0.045	-3.60	-28.70	0.716147	7.54	1.44	<0.01	0.54	374	0.8	254.2	62.1	24.2	33.0	245	86.7	0.289
B03	BREMER	309308	6116101	24/05/2007 10:14	2.10	9.70	735	27.81	0	10.78	0.11	0.012			0.714135	7.84	2.20	0.01	0.07	206	0.5	59.6	51.9	8.2	23.7	110	20.8	0.369
B11	BREMER	313593	6112459	24/05/2007 10:53	2.52	8.90	1196	31.66	11	11.78	0.47	0.034	-2.37	-13.10	0.714915	7.88	2.57	<0.01	0.06	316	0.7	84.4	61.7	11.8	32.4	169	29.1	0.449
B13	BREMER	310720	6103991	28/05/2007 15:24	3.70	8.28	4416	16.75	-128	11.45	1.31	0.076	-2.82	-18.50	0.717067	7.71	3.74	0.15	0.06	1470	3.8	545.4	150.9	45.6	128.5	816	177.3	1.611
B12	BREMER	315240	6102446	28/05/2007 14:27	11.80	7.68	11102	5.19	-379	15.69	0.20	0.016	-3.65	-27.00	0.717166	7.92	12.37	0.17	0.01	2400	7.1	394.2	140.2	98.7	179.4	1450	136.9	1.999
CU05	CURRENCY CRK	284307	6077747	21/05/2007 10:43	0.98	6.26	590	35.84	102	11.98	0.47	0.036	-4.30	-23.70	0.713235	7.62	1.02	0.01	0.04	183	0.4	25.4	15.5	5.0	11.7	113	9.2	0.230
CU02	CURRENCY CRK	295919	6074590	21/05/2007 12:05	1.02	7.14	1078	53.53	-10	12.28	1.76	0.110	-4.03	-21.60	0.716849	7.61	1.08	0.21	0.10	320	0.7	130.8	40.6	9.6	24.8	192	44.8	0.345
CU04	CURRENCY CRK	292724	6073346	21/05/2007 12:27	2.03	6.78	3408	47.36	-22	13.28	0.91	0.058	-3.31	-19.70	0.715222	7.44	2.03	0.17	0.05	1255	3.2	251.3	128.3	19.8	105.5	586	83.8	1.336
CU01	CURRENCY CRK	296566	6074343	21/05/2007 13:27	3.36	7.25	3662	25.09	7	13.45	1.61	0.100	-4.01	-24.30	0.714756	7.95	3.37	0.04	0.11	1317	3.4	287.8	130.5	22.8	104.4	670	95.1	1.436
CU06	CURRENCY CRK	287084	6075299	21/05/2007 11:24	2.72	6.71	2073	41.30	-56	12.22	4.66	0.250	-4.59	-24.20	0.714655	7.87	2.88	0.06	0.05	722	1.8	90.0	70.5	7.1	53.1	382	30.8	0.632

b) Finniss River, Reedy Creek and Tookayerta Creek catchments

					In-field measurements						Laboratory analysis - Isotopes and major ion chemistry																	
Study ID	Catchment	Easting	Northing	Sampling Date / Time	Alkalinity (meq/L HCO_3^-)	pH	SEC (µS/cm)	DO (mg/L)	Redox (mV)	Temp (°C)	Rn-222 (Bq/L)	Rn-222 Error (Bq/L)	$\delta^{18}O$ ($^{o}/_{oo}$ rel SMOW)	$\delta^{2}H$ ($^{o}/_{oo}$ rel SMOW)	$^{87}Sr/^{86}Sr$ ratio	Lab Sample pH	Total Alkalinity (pH 4.5) (meq/L)	NH_4-N (mg/L)	NO_x-N (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$SO_4^=$ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)	Sr (mg/L)
F11	FINNISS	300422	6082953	NO WATER																								
F17	FINNISS	296168	6095298	22/05/2007 15:57	4.34	7.09	1828	16.00	-47	12.81	3.75	0.200	-5.59	-29.10	0.713826	7.71	4.66	0.04	0.03	368	0.9	506.0	225.2	9.8	64.2	197	163.4	1.034
F09	FINNISS	296525	6092912	21/05/2007 17:06	3.08	7.07	2059	10.44	37	13.69	3.37	0.190	-4.87	-25.10	0.713972	7.74	3.25	0.01	0.04	551	1.3	413.0	181.4	11.4	67.6	257	133.5	0.928
F04	FINNISS	289935	6092489	22/05/2007 12:17	2.44	7.46	1811	21.31	19	12.00	0.63	0.043	-3.39	-18.60	0.716263	7.84	2.56	<0.01	0.09	607	1.4	110.7	68.1	10.9	57.3	301	37.5	0.543
F01	FINNISS	288292	6088633	22/05/2007 11:55	0.80	7.69	845	31.84	13	11.67	0.25	0.021	-4.93	-23.60	0.721126	7.37	0.85	<0.01	0.09	277	0.6	55.4	29.4	6.2	25.3	137	19.0	0.220
F08	FINNISS	295441	6089786	21/05/2007 16:32	1.31	7.17	1103	11.98	20	13.29	0.15	0.015	-5.51	-34.00	0.717684	7.82	1.39	<0.01	0.03	390	0.8	93.9	50.2	8.0	39.8	188	31.7	0.331
F07	FINNISS	297557	6089824	21/05/2007 16:15	1.03	7.26	1182	15.94	16	13.89	0.17	0.017	-6.14	-41.00	0.717576	7.55	1.16	0.09	<0.01	383	0.7	106.7	50.0	8.0	39.7	181	36.3	0.338
F06	FINNISS	298001	6085819	21/05/2007 14:51	1.41	7.16	1293	51.48	-26	13.82	0.60	0.041	-6.41	-43.30	0.717370	7.59	1.41	<0.01	<0.01	441	0.9	117.9	58.1	8.3	44.4	207	39.7	0.378
F12	FINNISS	297185	6100044	21/05/2007 14:20	1.61	7.45	1512	45.56	-3	14.17	3.05	0.170	-5.60	-32.90	0.716322	7.38	1.69	0.11	0.04	508	1.2	116.0	57.5	8.6	43.5	255	39.2	0.512
F10	FINNISS	300460	6085008	21/05/2007 14:36	2.69	7.01	1823	52.60	-96	13.23	0.19	0.018	-4.26	-18.70	0.713009	7.84	2.82	0.07	0.01	635	1.8	22.8	51.0	11.2	40.3	338	7.7	0.498
F15	FINNISS	288746	6098886	22/05/2007 14:46	1.56	7.01	1577	10.91	28	11.47	0.55	0.039	-5.76	-31.40	0.715170	7.24	1.69	0.07	0.48	545	1.2	92.6	64.4	9.5	54.9	237	31.2	0.484
F14	FINNISS	286388	6095266	22/05/2007 13:56	1.97	7.41	2142	15.53	21	11.65	0.49	0.035	-4.79	-22.50	0.716511	7.50	2.02	0.04	0.02	794	1.8	77.2	85.9	8.2	79.8	317	25.7	0.616
F03	FINNISS	285339	6094277	22/05/2007 13:40	2.61	7.57	2334	29.60	16	11.60	0.75	0.049	-4.36	-15.60	0.713885	7.74	2.61	0.09	0.25	853	1.8	80.1	87.0	11.8	79.3	374	27.0	0.615
F13	FINNISS	285201	6090371	22/05/2007 10:59	2.34	7.38	2232	39.42	13	11.60	0.50	0.036	-4.66	-22.90	0.718693	7.75	2.41	0.02	0.04	803	1.8	111.4	91.7	9.7	77.4	350	37.4	0.649
F02	FINNISS	285085	6090035	22/05/2007 10:40	0.38	7.68	555	19.01	-25	11.38	0.18	0.016	-4.76	-24.00	0.720629	6.92	0.37	0.10	0.63	176	0.3	41.0	14.0	7.8	13.3	96	14.5	0.111
RE07	REEDY CRK	320408	6138650	24/05/2007 14:40	5.47	7.76	5655	15.72	-19	11.88	0.13	0.014	-3.36	-14.60	0.715452	8.18	5.59	0.05	<0.01	2368	7.1	310.4	168.5	14.3	176.9	1190	102.8	1.944
RE05	REEDY CRK	324773	6138772	24/05/2007 15:58	4.13	8.06	5557	29.69	34	13.14	0.11	0.012	-3.14	-21.30	0.717299	8.02	4.24	0.07	<0.01	2394	6.5	396.9	149.3	32.8	215.6	1180	134.5	1.660
RE03	REEDY CRK	322468	6143383	24/05/2007 15:22	2.49	8.40	2883	23.18	-25	11.54	0.66	0.045	-5.96	-35.90	0.717597	7.75	2.39	0.09	<0.01	1096	2.7	245.0	107.9	18.1	89.6	546	81.2	0.741
RE04	REEDY CRK	325427	6139208	24/05/2007 16:41	3.59	7.57	6362	35.39	4	13.11	0.54	0.041	-2.81	-16.50	0.719040	7.78	3.70	0.14	<0.01	2569	6.5	1039.1	251.5	48.7	274.3	1330	350.4	2.205
RE06	REEDY CRK	330999	6138952	NO WATER																								
RE01	REEDY CRK	333771	6134714	24/05/2007 17:23	12.34	7.13	11741	22.85	-104	14.28	1.05	0.070	-2.92	-12.55	0.716119	7.89	12.79	0.08	<0.01	5005	15.5	351.0	214.7	66.7	441.7	2410	116.4	3.196
T03	TOOKAYERTA CRK	284513	6083976	NOT SAMPLED																								
T04	TOOKAYERTA CRK	283930	6085907	NOT SAMPLED																								
T05	TOOKAYERTA CRK	285266	6085649	18/05/2007 10:36	0.31	5.74	322	19.86	63	12.09	1.12	0.070			0.719892	6.64	0.40	0.03	0.11	91	<0.25	28.3	11.1	3.0	8.3	50	9.8	0.107
T01	TOOKAYERTA CRK	291175	6083693	NOT SAMPLED																								
T02	TOOKAYERTA CRK	291192	6083864	NOT SAMPLED																								

B. DETAILS OF SAMPLED WELLS

Sample Code	Unit number	Depth (m)	Aquifer (where known)	Surface Geology *	Status	Purpose	Drill Date	Casing Details
Reedy Creek								
Rg01	6728-2578	30.6		Ekb		Stock	26/08/1985	Unknown.
Rg03	6728-904	51		Ekb		Unused	06/08/1976	Unknown.
Rg02	6728-99999	19 *		EO-d-04				
Bremer River								
Bg01	6627-9701	35		Nsb		IRR	20/01/1998	Cased from -0.30 to 18m with welded steel (min diameter 152mm); open hole production zone
Bg02	6727-2419	13.5		Q over Eka	OPR	STK/DOM	22/03/1992	Cased from -0.30 to 11.7m with unknown material (min diameter 155mm); unknown screened production zone
Bg03	6627-10374	27		Ekt		STK/DOM	06/09/2000	Cased from 0 to 6m with PVC (min diameter 150mm); open hole production zone
Bg04	6628-12138	192.6		Ekb	OPR	STK/DOM	16/11/1982	Cased 0 to 97 m, dia 152 mm WST, Prod zone 30 m to 36.6 m and 97 m to 103 m
Bg05	6727-2404	59.4		Q over Ekt	OPR	DOM	28/12/1991	Cased from -0.30 to 53.70, dia 152 mm. Prod zone 53.70 to 59.40
Bg06	6627-6412	26.5		Nfi	OPR	DOM	09/12/1981	Cased from 0.50 m, dia 150 mm
Bg07	6627-9806	118		Ekt	OPR	DOM	23/04/4998	Prod'n zone from 100 - 118 m
Angas River								
Ag01	6627-6471	11.9		Ekt	OPR	STK/DOM	10/02/1982	Cased from 0.50 to unknown depth with unknown material (min diameter 152mm); unknown production zone
Ag02	6627-8891	40		Q over Ekt		IRR	30/03/1994	Cased from -0.3 to 5.7m with welded steel (min diameter 152mm); open hole production
Ag03	6627-7613	56		Ekb	OPR	STK/DOM	27/05/1986	Cased from 0.30 to 45.70m with unknown material (min diameter 152mm); unknown production zone from 45.70 to 56m
Ag04	6627-9589	12		Ek1, Ekt or Ekb		IRR	11/07/1997	Cased from 0 to 12m with PVC (min diameter 150mm); PVC slotted casing production zone from 8 to 12m (min diameter 150mm) aperture 3mm
Ag05	6627-6462	20.73		En	OPR	DOM/IRR	01/01/1982	Unknown
Ag06	6627-11300	47		Nsb		MON	24/06/2005	Cased from 0 to 41m with PVC (min diameter 50mm); PVC slotted casing production zone from 41 to 47m (min diameter 50mm) aperture 1mm, pressure cemented from 0 to 40.30m
Ag07	6627-11304	25		Nsb		MON	24/06/2005	Cased from 0 to 20m with PVC (min diameter 50mm); PVC slotted casing production zone from 20 to 25m (min diameter 50mm) aperture 1mm, pressure cemented from 0 to 19.30m
Finniss River								
Fg01	6627-6810	97	Ebb	Eka	OPR		01/06/1983	Cased from -0.35 to 18.2 m. Open hole below 18.5 m.
Fg02	6627-10083	58	CP-j	Q over CPj over Ekt	OPR	IRR	27/07/1999	
Fg03	6627-11289	27		Q over CPj over Ekt		MON	19/11/2005	Cased from 0 to 22m with PVC (min diameter 50mm); PVC slotted casing production zone from 22 to 27m (min diameter 50mm) aperture 1mm; pressure cemented from 15 to 19.50m
Fg04	6627-9119	68.5	CP-j	Q over CPj over Ekt	OPR	STK	16/11/1994	
Fg05	6627-10843	24		Ekt		DOM	12/02/2003	Cased from 0 to 24m with PVC (min diameter 145mm); PVC slotted casing production zone from 12 to 21m (min diameter 145mm) aperture 2mm
Fg06	6627-11287	46.6		Q over CPj over Ekt		MON	16/11/2005	Cased from 0 to 41.60m with PVC (min diameter 50mm); PVC slotted casing production zone from 41.60 to 46.60m (min diameter 50mm) aperture 1mm; pressure cemented from 39.50 to 40.70m
Fg07	6627-7072	45	CP-j	CPj	OPR	DOM	11/04/1984	Cased from 0 to 31 m, dia 150 mm PVC. OH production zone from 31 to 45 m.
Fg08	6627-10483	158	Lb	Q over Lb	OPR	IRR	20/10/1998	
Tookayerta Creek								
TOg01	6627-9278	92		Q over Ekt	OPR	STK	28/02/1995	Cased 0 to 27 m, dia 155 mm PVC. Prod zone 27 to 92 m - OH + PVC screen, 4mm aperture
TOg02	6627-9830	60		Q over Lb	OPR	IND	24/02/1998	Production zone: 24 - 60m (min diameter 155mm) apperture 4 slotting PVC casing
TOg03	6627-8408	117		Q over Lb	OPR		15/03/1991	Cased 0 to 79.5 m, dia 155 mm WST. Prod zone 79.5 to 117 m OH.
TOg04	6627-9823	42		Q over CPj	OPR	STK/DOM	26/02/1998	Cased 0 to 42 m, dia 155 mm PVC. Screened prod zone 24 to 42 m, 4 mm aperture.
Currency Creek								
CUg01	6627-385	42.67	Ek	Q over Ekt	OPR	STK	01/05/1967	Casing dia 153 mm to 30.17 m. Unknown from 30.17 to 42.67 m
CUg02	6627-9607	30	Tow	Q over Ekt	OPR	IRR	11/12/1996	Production zone: 12 - 30m (min diameter 155mm) apperture 4 slotting PVC casing
CUg03	6627-8650	42	CP-j	Q over CP-j	OPR	IRR	24/02/1992	Production zone: 24 - 42m (min diameter 148mm) apperture 4 slotting PVC casing

*** Surface Geology** derived from 'Map Unit' field at location of well on DWLBC shapefile of Geology in Mt Lofty Ranges.

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

Abbreviations of environmental and isotopic tracers

$\delta^{2}H$	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
$^{87/86}Sr$	ratio of strontium isotopes strontium-87 to strontium-86
^{222}Rn	radon isotope radon-222
CFC	chlorofluorocarbon
^{14}C	carbon isotope carbon-14

GLOSSARY

Ambient — The background level of an environmental parameter (e.g. a background water quality such as salinity)

Aquatic ecosystem — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

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

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

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

ARC — Angas River Catchment

Artesian — Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping

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

BC — Barossa Complex

Bore — *See well*

BPF — Backstairs Passage Formation

BRC — Bremer River Catchment

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

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

CCC — Currency Creek Catchment

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

Contaminant — A material added by humans or natural activities that may, in sufficient concentrations, render the environment unacceptable for biota. The mere presence of these materials is not necessarily harmful

δ**D** — Hydrogen isotope composition ($^{o}/_{oo}$)

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

DO — Dissolved Oxygen

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

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

EMLR — Eastern Mount Lofty Ranges

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

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

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

EWR – Environmental Water Requirement

FRA — Fractured Rock aquifer

FRC — Finniss River Catchment

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 or released into a well for storage underground

GW – Groundwater

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

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

HYDSTRA — A time series data management system that stores continuously recorded water-related data such as water level, salinity and temperature. It provides a powerful data analysis, modelling and simulation system; Contains details of site locations, setup and other supporting information

Hyporheic zone — The wetted zone among sediments below and alongside rivers. It is a refuge for some aquatic fauna

IAEA — International Atomic Energy Agency

IC — Ion chromatography

ICP-ES — Inductively Coupled Plasma Emission Spectrometry

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

LMWL — Local meteoric water line

MLR — Mount Lofty Ranges

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

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

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge)*

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

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

Pluviometer — An automated rain gauge consisting of an instrument to measure the quantity of precipitation over a set period of time

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer; the unit is metres (m)

ppm — Parts per million

ppb — Parts per billion

PSA — Permian Sands aquifer

RCC — Reedy Creek Catchment

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

Seasonal watercourses or wetlands — Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times

SEC — Specific Electrical Conductivity**;** electrical conductivity measurement adjusted to the equivalent EC at 25°C. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm); commonly used to indicate the salinity of water

SMOW — Standard Mean Ocean Water: international standard for isotopic abundance ratios of the stable isotopes of the water molecule

Subcatchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

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

SW — Surface water

SW–GW — Surface water–groundwater (usually refers to interaction between the two)

TCC — Tookayerta Creek Catchment

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

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

TIMS — Thermal ionisation mass spectrometer

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

WAP — Water allocation Plan

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

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

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

WMLR — Western Mount Lofty Ranges

WWTP — Waste water treatment plant

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