
TECHNICAL REPORT

GROUNDWATER–SURFACE WATER INTERACTIONS IN THE COX, LENSWOOD AND KERSBROOK CREEK CATCHMENTS, WESTERN MOUNT LOFTY RANGES, SOUTH AUSTRALIA

2010/19

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GROUNDWATER–SURFACE WATER INTERACTIONS IN THE COX, LENSWOOD AND KERSBROOK CREEK CATCHMENTS, WESTERN MOUNT LOFTY RANGES, SOUTH AUSTRALIA

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FOREWORD

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

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

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

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

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

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SUMMARY

This report describes an investigation of groundwater–surface water interactions in the Cox, Lenswood and Kersbrook Creek Catchments of the Western Mount Lofty Ranges (WMLR). The objective of the investigation was to provide technical information to inform the water allocation planning process and ongoing management WMLR Prescribed Water Resources Area (PWRA). Specifically, information was sought with a view to:

- identifying the locations of wetlands and permanent pools whose permanency depends on groundwater inflows,
- identifying stream reaches where there is evidence of exchange between groundwater and surface water systems and whether it is gaining, losing, or losing and disconnected,
- assessing the seasonal temporal variability in the connectivity between groundwater and surface water systems,
- preventing double allocation of water in groundwater and surface water systems in the WMLR Water Allocation Plan.

The investigation involved the analysis of hydrochemical indicators in a large number of groundwater and surface water samples from the Cox, Lenswood and Kersbrook Creek Catchments. The hydrochemical indicators were used in conjunction with streamflow measurements and water level data from existing databases to determine where surface water and groundwater resources are connected.

The outcomes of the investigation show that there are strong hydraulic connections between the surface water and groundwater systems in these catchments. The high spatial density of sample points used allowed a ‘run of river’ analytical approach, providing the detail necessary to assess the state of connectivity between the surface water and groundwater systems and the areas of greater and lesser groundwater discharge into streams. In the three catchments studied, there were dominantly gaining surface water systems, where groundwater discharges through the creek bed to contribute to streamflow. The comparison between different hydrological events and times of the year also highlighted that groundwater input is a significant component of streamflow at all times of the year.

Locations where there appeared to be higher groundwater input to the creeks appeared to be correlated to the changes in the creek’s underlying geology, structure and presence of major fault zones. Other key findings were the presence of groundwater-fed permanent pools along some creek reaches, which provide important refuges for aquatic habitat. Also of significance was the identification of groundwater discharge occurring in the upper reaches of the catchments, providing small but, in some cases, continuous flow to the tributaries of the main creeks.

The three catchments studied have mainly gaining type stream systems with strong hydraulic connections between the surface water and groundwater. This implies that further groundwater development in these catchments is likely to have an impact on both the surface water and groundwater resources.

1. INTRODUCTION

Groundwater and surface water technical investigations have been conducted in the WMLR to provide knowledge of catchment hydrological processes. This understanding is essential to the development and implementation of a water allocation plan, which aims to ensure an integrated and sustainable approach to managing the surface water and groundwater resources in the WMLR. Traditionally, surface water and groundwater have been managed as separate resources. Improved understanding has revealed that in some cases there is strong hydraulic connection between these two resources, and that the connection is spatially and temporally variable. It is necessary to understand this connectivity so that informed decisions can be made.

Interactions between groundwater and surface water form one component of the hydrological cycle and are largely controlled by the effects of physiography (topography and geology) and climate. To understand these interactions it is necessary to understand the hydrogeologic environment that influences groundwater flow systems (Winter 1999). Within a groundwater basin there are multiple flow systems of different orders of magnitude, which can be considered according to their relative position in space. Tóth (1963) suggests that there are three main types of groundwater flow systems - local, intermediate and regional. A local flow system is where the water flows a short distance to a nearby discharge area such as a dam or a stream. Water in an intermediate flow system flows beneath one or more topographic highs and lows located in between the recharge and discharge areas. Water in a regional flow system travels the greatest distance from the major topographic high to the bottom of the basin and often discharges to major rivers, lakes or to oceans. In complex environments, surface water features may receive water from one or more flow systems. Therefore, the long-term sustainability of the surface water resources requires knowledge of the hydrogeology and its flow systems to ensure reliable estimates of the location, volume and timing of fluxes between groundwater and surface water features can be made.

In an undeveloped catchment, under steady state conditions, the outputs of stream discharge and discharge to wetlands and lakes balance the inputs of rainfall and stream loss (aquifer recharge). Groundwater bores introduce a new output and the system must shift to a new state of equilibrium. The groundwater losses from pumping will first draw on the storage of the aquifer, resulting in a decline in the watertable. Depending on the proximity of the bore to the stream and the hydraulic connection, further pumping will either decrease groundwater discharge or induce additional recharge to balance the fluxes from pumping.

The lag time between groundwater extraction and changes in the hydraulic connection with the stream has important ramifications to the timing and volume of stream depletion, critical to managing the resource to sustain dependent aquatic ecosystems. The lag time depends upon a variety of factors, including distance between bore and stream, length and location of hydraulic connection, the physical characteristics of the aquifer and stream bed, and alternative discharge paths (DEH 2004).

2. AIM AND OBJECTIVES

This report describes an investigation of groundwater–surface water interactions in the Cox, Lenswood and Kersbrook Creek Catchments, intended to provide technical information to inform the water allocation planning process and ongoing management of the WMLR PWRA.

The investigation involved the analysis of hydrochemical indicators in a large number of groundwater and surface water samples in three catchments in the WMLR. The hydrochemical indicators were used in conjunction with streamflow and water level data, from existing databases, to determine 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 water allocation plan for the WMLR, 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.
- Identifying stream reaches where there is evidence of exchange between groundwater and surface water systems and whether it is gaining, losing, or losing and disconnected.
- Draw comparisons between four sampling rounds to assess the seasonal temporal variability in the connectivity between groundwater and surface water systems.

3. METHODOLOGY

3.1. STUDY SITES

The Mount Lofty Ranges (MLR) form the central portion of the Adelaide Geosyncline and include a range of metasedimentary and igneous rocks that range in age from Palaeoproterozoic (> 1600 Ma) through to Permian (250–300 Ma) (Drexel, Preiss & Parker 1993; Drexel & Preiss 1995). The hydrogeology of the MLR is dominated by fractured rock aquifer (FRA) systems with shallow alluvial aquifers in the valley bottoms. The pronounced topographic relief results in dominant local flow systems compared to the flatter relief of the plains, which tend to have more dominant intermediate and regional flow systems. Due to the dry temperate climate and steep topographic relief, the contribution of groundwater discharge to surface water features is a significant component of the catchment water cycle, particularly during the summer months and drought conditions. Many of the surface water features in the MLR are permanent and support a diverse range of flora and fauna. The provision of environmental water requirements is an important consideration in the management of the water resources.

The Cox and Lenswood Creek Catchments are smaller catchments that contribute to the Onkaparinga River Catchment, an important water supply for Metropolitan Adelaide. The Kersbrook Creek Catchment lies in the greater Torrens River Catchment and drains into Millbrook Reservoir, one of nine reservoirs in the Mount Lofty Ranges (Figure 1).

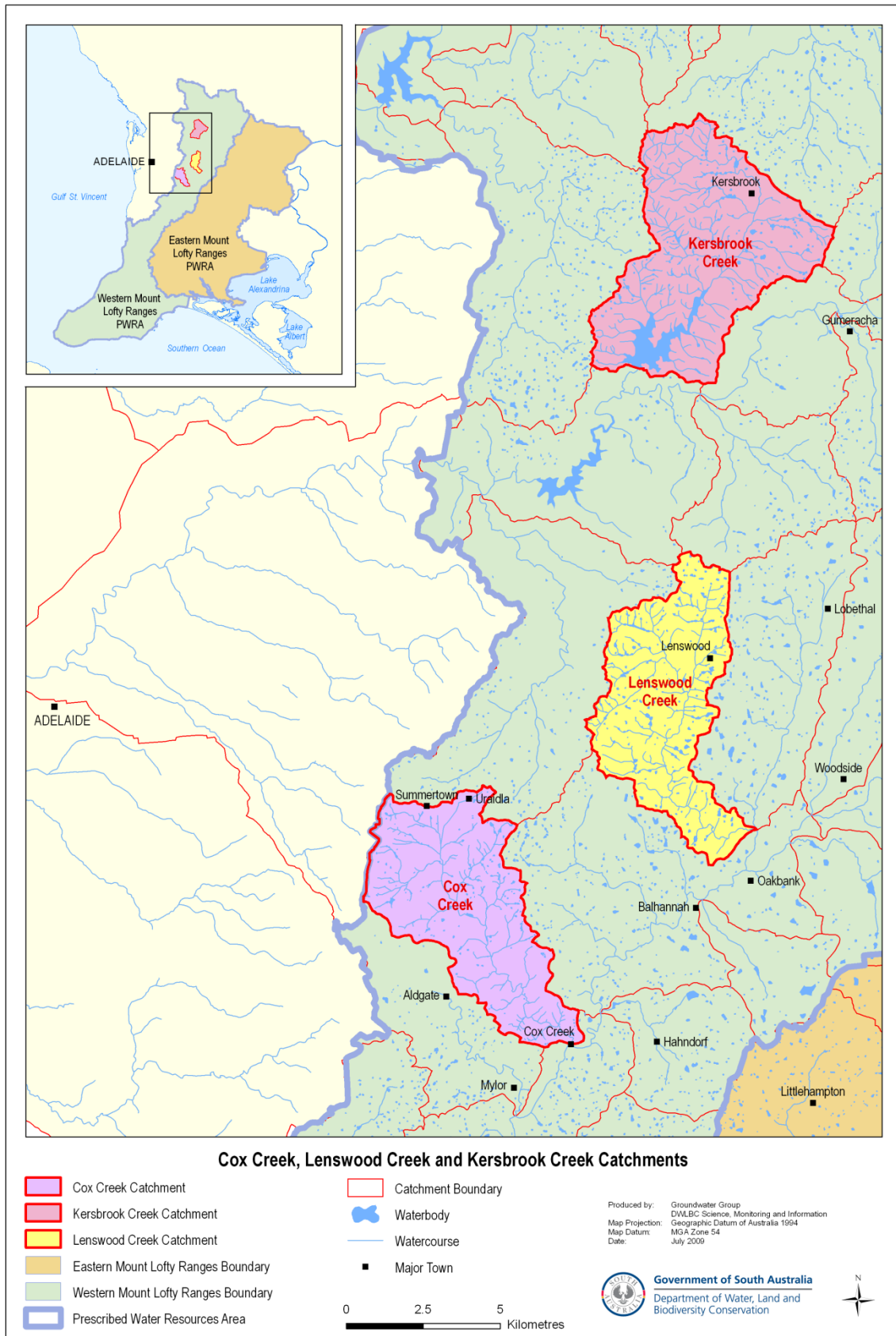


Figure 1 Location of the Cox, Lenswood and Kersbrook Creek Catchments

3.2. COX CREEK CATCHMENT

The Cox Creek Catchment (CCC) is situated approximately 20 km east of Adelaide in the WMLR (Figure 1) and has a catchment area of 29.8 km². Surface drainage is from the higher northern boundary of the catchment—approximately 630 mAHD (metres Australian Height Datum = mean sea level)—through steep topography to the south-east where it discharges into the Onkaparinga River at approximately 320 mAHD (Figure 2). The depth of Cox Creek is typically less than 0.75 m, but does increase to depths greater than 1.5 m during storm flow periods. The width of Cox Creek varies between 1–6 m depending on the location within the catchment and the physical geology and topographic controls. The headwater tributaries of Cox Creek converge less than a kilometre upstream of a streamflow gauging station (A5030526), which measures flow from only the upper 4.3 km² of the catchment. Cox Creek is perennial, and the average annual flow measured at the gauging station (located at the top of the catchment) is 1180 ML. During the summer months, average baseflow is 460 m³/day. Continuous water level data has been recorded at the gauging station since 1976 and water quality data since 1994.

The CCC is characterised by warm summers and cold, wet winters. Daily maximum temperatures in Stirling average about 24°C in summer and 11°C in winter. Average annual rainfall for the last 20 years (gauge station A5040552) is 1189 mm/year, the majority of which falls between May and October (BOM 2007). Land use in the upper region of the catchment is extensively developed for market gardens, however, since the 1970s the market gardens have been progressively replaced by vines and fruit trees (Barnett & Zulfic 1999). Land use in the lower, larger region of the catchment is dominantly urban, small hobby farms and nature reserves.

The geology of the CCC includes several of the stratigraphic sequences associated with the Adelaide Geosyncline. The north and south of the CCC are dominated by the Neoproterozoic Burra Group—including the Emeroo Subgroup (Aldgate Sandstone), Bungarider Subgroup (Woolshed Flat Shale and Stonyfell Quartzite), Saddleworth Formation and Mundallio Subgroup (Basket Range Sandstone and Skillogalee Dolomite)—and are separated by the Archean Barossa Complex, which lies in the centre of the catchment (Figure 8). The Burra Group consists of quartzite, sandstone and dolomite. Minor areas of the Basket Range Sandstone, Skillogalee Dolomite and Stonyfell Quartzite (quartzite with shale interbeds and silty sandstone) are present in the western corner of the catchment. The Barossa Complex is characterised by metamorphic rocks with retrograde metamorphism: metasediments, strongly banded parallel to gneissic banding, and minor intrusive granitic dykes. Throughout the catchment along the valley bottoms and depressions in the landscape, are deposits of undifferentiated quaternary rocks/sediment of Pliocene/Holocene age. Major fault lines are present along the margins of the different geological units, traversing in a north-east–south-west direction (Drexel, Preiss & Parker 1993; Drexel & Preiss 1995).

The aquifers of the CCC are dominantly FRAs with some shallow perched aquifer systems in the valley fill Quaternary deposits. The majority of groundwater bores are completed in the Burra Group, which typically have higher yields and suitable water quality for domestic and agricultural purposes. Fracture spacings in the Burra Group tend to be widely spaced with large apertures and decrease in frequency and permeability with increasing depth due to surface loading. The density of fractures is also greater around major fault zones. In comparison, the Barossa Complex is generally considered a poor aquifer with low obtainable yields and higher salinity. Permeability is greatly reduced in this aquifer and there are fewer conductive fractures compared to the Burra Group aquifers. The regional groundwater flow direction in the FRAs within the CCC is from the edges of the catchment towards the topographically lower, central area where it discharges into Cox Creek (Ivkovic et al. 1998). The direction of groundwater flow is controlled largely by the hydraulic gradient and the orientation of the higher permeability fracture zones relative to the gradient.

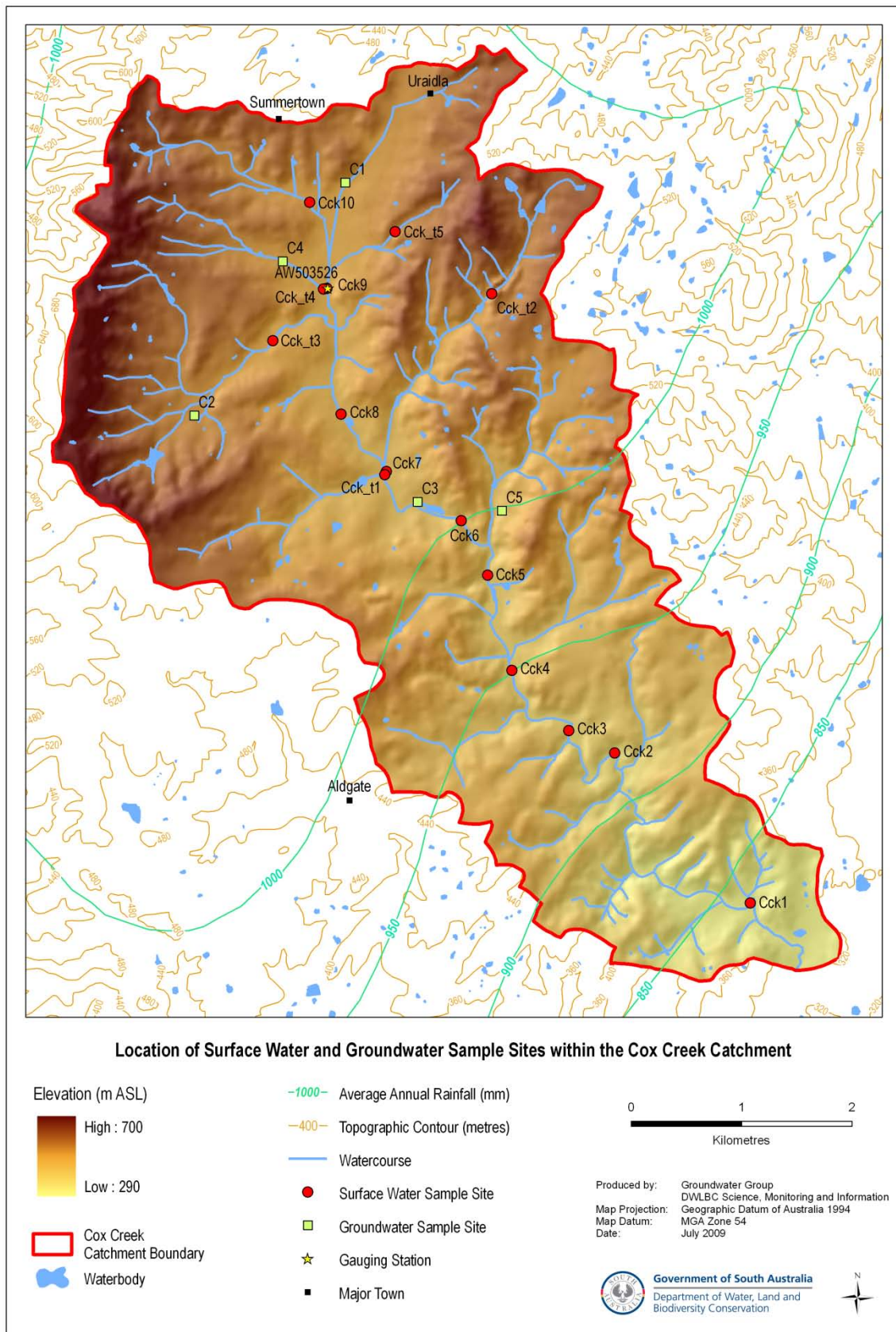


Figure 2. Location of surface water and groundwater sample sites in the CCC

3.3. *LENSWOOD CREEK CATCHMENT*

The Lenswood Creek Catchment (LCC) is situated approximately 5 km to the north-east of the CCC in the WMLR and has a catchment area of 28.3 km² (Figure 1). The surface drainage is from the higher northern boundary of the catchment (580 m AHD) where headwaters of Lenswood Creek begin from two major tributaries in the north and north-east, joining near the junction of Leslie Creek and Swamp Road in the middle of catchment. The creek then flows south, where it joins Western Branch Creek at the bottom of the catchment (350 m AHD) and shortly after discharges into the Onkaparinga River (Figure 3). The depth of Lenswood Creek is typically less than 0.75 m, but does increase to depths greater than 1.5 m during storm flow periods. The width of Lenswood Creek varies between 1–5 m within the catchment. Lenswood Creek is perennial and the average annual flow of the creek, measured at the Lenswood gauge station (A5030507—catchment area of 16.5 km²) located in the middle of the catchment, is 2700 ML. Continuous water level data has been recorded at the gauging station since 1976, continuous rainfall data since 1997 and water quality data since 1994. During the summer months the average baseflow is 230 m³/day.

The climate of LCC is characterised by warm summers and cold, wet/moist winters. Daily maximum temperatures in Lenswood average 24°C in summer and 12°C in winter. The average annual rainfall is 1032 mm, the majority falling between May and September (BOM 2007). Land use in the catchment is dominated by horticulture, primarily stone fruit trees. The other major land use activities are livestock farming and nature reserves.

The geology of the LCC is dominated by the Neoproterozoic Woolshed Flat Shale, comprising black shale, dolomitic siltstone, blue-grey dolomite and grey laminated siltstone (Figure 16). A large area in the north-western corner of the catchment is characterised by the Saddleworth Formation, composed of mudstone, siltstone and shale. In the west of the catchment, there are minor areas of the Basket Range Sandstone, Skillogalee Dolomite and the Barossa Complex. Stonyfell Quartzite also occurs at the bottom of the catchment and forms a narrow band near the western boundary. A large fault system, separating the Woolshed Flat Shale and the Saddleworth Formation, runs from the northern boundary of the catchment to the centre of the western boundary. Bedding and cleavage of the Woolshed Flat Shale and the Saddleworth Formation are steeply dipping with angles of 70–80 degrees. Major faults are also likely to have similar dip angles.

The hydrogeology of the LCC, like the CCC, is characterised by FRA with shallow alluvial aquifers in the valley bottoms. The majority of groundwater bores are located near the valley bottoms due to the steepness of the terrain and close proximity to the watertable. The quality and yields are generally high in the Woolshed Flat Shale and Saddleworth Formation aquifers and have been extensively developed for domestic and agricultural purposes. The regional groundwater flow in the FRA within the LCC is from the topographically high areas towards the valley bottom. The direction of groundwater flow is controlled largely by the hydraulic gradient and the orientation of the higher permeability fracture zones relative to the gradient.

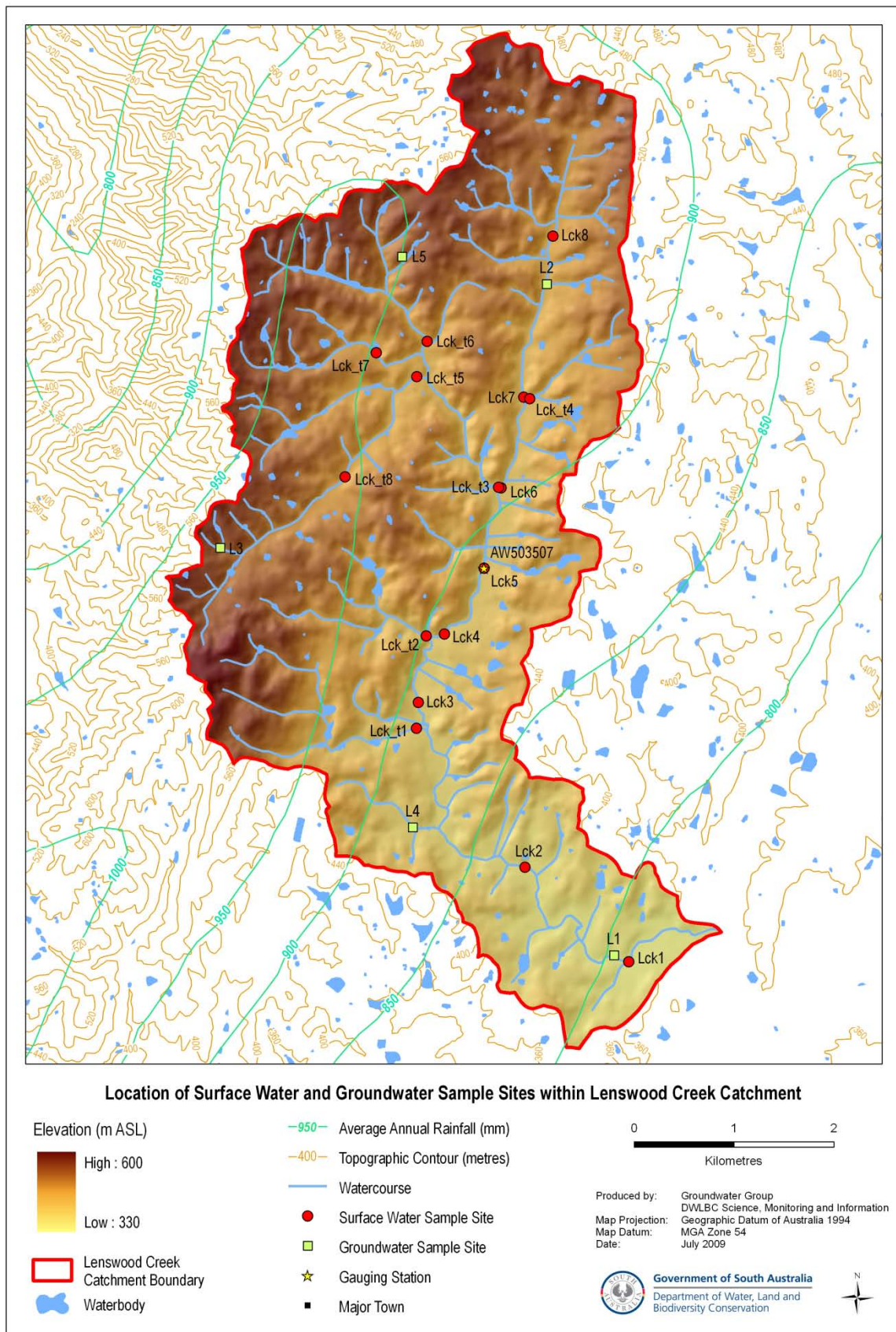


Figure 3. Location of surface water and groundwater sample sites in the LCC

3.4. KERSBROOK CREEK CATCHMENT

The KCC is located approximately 10 km to the north of the LCC and has a catchment area of 36.8 km² (Figure 1). A wide north-east–south-west valley runs through the middle of the catchment with surface drainage from the higher boundary in the north of the catchment (540 m AHD) to the south (300 m AHD) where it discharges into the Millbrook Reservoir and eventually into the Torrens River (Figure 4). The Kersbrook Creek is a semi-permanent watercourse, forming a series of permanent pools during the dry summer months. The depth of Kersbrook Creek is typically less than 0.75 m, but does increase to depths greater than 1 metre during storm flow periods. The width of Kersbrook Creek varies between 1–3 m depending on the location within the catchment. Average annual flow measured at the gauge station (A5040525—catchment area of 23 km²) located above the Millbrook Reservoir is 2390 ML. Continuous water level data has been recorded at the gauging station since 1989 and water quality data since 1992. When there is flow during the summer months the average baseflow is 49 m³/day.

The climate of the KCC is slightly different to the CCC and LCC, receiving an average annual rainfall of 830 mm (measured at gauge station A5040902 in the northern area of the catchment). Continuous rainfall data has been collected from this gauge station since 2001. Daily maximum temperatures in Kersbrook average 25°C in summer and 12°C in winter (BOM 2007). Land use in the catchment is dominantly dryland farming of sheep and cattle grazing, some horticultural development of fruit and nut trees, nature reserves and forestry plantations.

The geology of the KCC is characterised by the Barossa Complex, which extends over the majority of the catchment. There are minor areas of the Stonyfell Quartzite, Saddleworth Formation, Basket Range Sandstone and Skillogalee Dolomite along the fringes of the eastern boundary. Unlike the other two catchments, significant alluvial/colluvial material has been deposited on top of the Barossa Complex across the wide valley floor of the KCC. A north-east–south-west fault runs along the eastern boundary coinciding with the break of slope between the valley and the hills.

The hydrogeology of the KCC is dominantly FRA with minor shallow sedimentary aquifers in the wide valley bottoms. There are fewer groundwater bores in the KCC due to poorer quality groundwater and yields from the Barossa Complex. The regional groundwater flow in the FRA within the KCC tends to mimic the topography, moving from the catchment boundary towards the valley bottom.

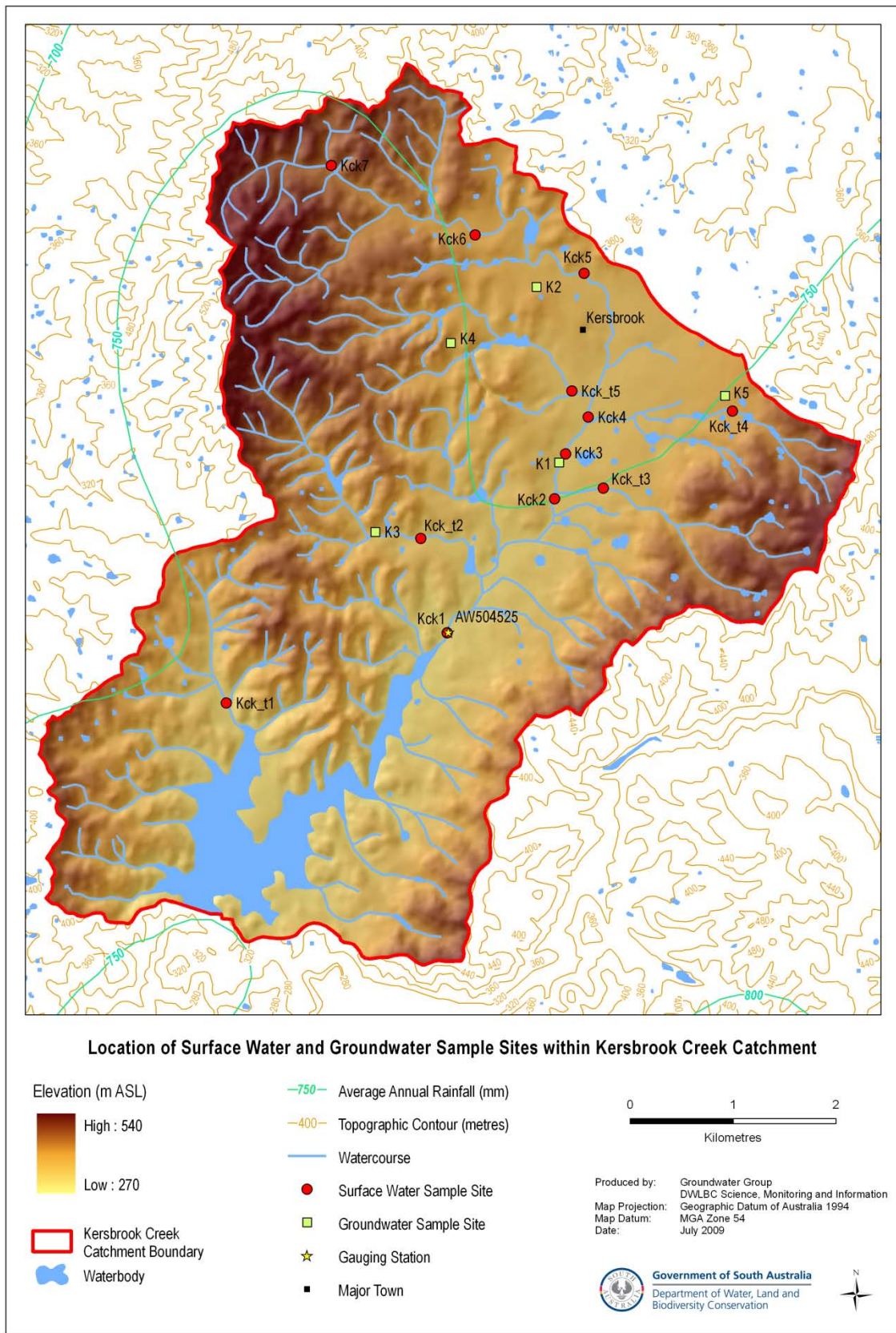


Figure 4. Location of surface water and groundwater sample sites in the KCC

3.5. GROUNDWATER AND SURFACE WATER SAMPLING

Interactions between groundwater and surface water in fractured rock environments are difficult to characterise at a catchment scale, particularly when the hydraulic connection is strongly related to the complex interconnections between the underlying fracture network and streambed. Hydrochemical methods, including the stable isotopes of water ($\delta^2\text{H}$, $\delta^{18}\text{O}$), major and trace ions, radon and strontium isotopes have been successfully used to characterise the spatial and temporal variations in groundwater and surface waters and their interconnection (Ellins, Roman-Mas & Lee 1990; Oxtobee & Navakowski 2002; Cook et al. 2003; Cook et al. 2006; Shand et al. 2005). The following approach was used in the investigation of the interactions between groundwater and surface water in the Cox, Lenswood and Kersbrook Creek Catchments.

Surface water sampling in each catchment was conducted during four sampling rounds to monitor hydrochemical characteristics during different hydrological conditions or events:

- Round 1 (7–9 December 2005)—early summer
- Round 2 (6–7 March 2006)—mid autumn (generally baseflow conditions)
- Round 3 (26–27 July 2006)—winter
- Round 4 (31 October–1 November 2006)—spring.

There were 15 sampling sites in the CCC, 16 in the LCC and 12 in the KCC. Each sampling site is referenced according to its distance from the lowest sampling site at or near the bottom of the respective catchment (refer to Figure 2, Figure 3 and Figure 4). All of the analytical data for the surface water samples are described in Appendix C: tables C1 and C2.

The locations of surface water sampling sites along each of the creeks in the three catchments were selected according to the following criteria:

- confluence of tributaries with the main creek, i.e. above and below key stream junctions on main stream or major tributaries
- adjacent to significant geological outcrops along the creek
- within the range of influence of groundwater sample sites
- at points where permanent pools are located, i.e. (a) permanency of water may indicate these pools are fed by groundwater, and (b) water may be available to sample during all four sampling rounds
- creek access

Groundwater samples were collected twice in each catchment: in round 1 (December 2005–January 2006) and round 3 (26–27 July 2006). Location of the groundwater bores in each of the catchments is shown in Figure 2, Figure 3 and Figure 4). Five groundwater bores were selected in each catchment according to the following criteria:

- operational groundwater well or observation well
- known production zone or screen interval
- short production zone/screen length (ideally <10 m) and maximum bore depth ideally <50 m
- proximity to creek selected for sampling (<300 m)
- in close proximity to surface water sampling locations
- constructed in a range of geological units
- accessible by road or track.

Details on the aquifers that were monitored as well as the construction details of the sampled bores are shown in Appendix A: table A1. All of the analytical data of the groundwater samples are described in Appendix B: tables B1, B2 and B3.

3.5.1. SAMPLING AND ANALYTICAL TECHNIQUES

A YSI® multi-parameter meter was used to measure the pH, specific electrical conductance (conductivity) (SEC), dissolved oxygen (DO), redox potential (Eh), and temperature in the creek and also during purging of the groundwater bores. The meter was calibrated with appropriate standards prior to use in the field. The total alkalinity (as HCO_3^-) was also measured in the field using a HACH titration kit.

Prior to sampling the groundwater bores, the static water level was measured from the top of casing (TOC) using an electronic water level indicator. Samples were collected once the physicochemical parameters had stabilised, indicating that the sample was representative of the aquifer sampled.

Major element analyses were conducted on the surface water and groundwater samples that had been filtered through a 0.45 μm membrane filter in the field. Cation (Na^+ , Mg^{2+} , K^+ , Ca^{2+} , NH_4^+) and trace element samples were acidified with nitric acid (1% v/v HNO_3) to keep the ions in solution and analysed by a Spectro CIROS Radial Inductively Coupled Plasma Optical Emission Spectrometer at CSIRO Land and Water Analytical Services, Adelaide, South Australia. Anions (Cl^- , Br^- , SO_4^{2-} , HCO_3^- and NO_3^-) were analysed by a Dionex ICS-2500 Ion Chromatograph. All ion balances were typically better than $\pm 3\%$.

All isotopic concentrations were measured by isotope ratio mass spectrometry using a Europa Geo 20-20 at the CSIRO Land and Water Isotope Analysis Service in Adelaide, South Australia. $\delta^2\text{H}$ and $\delta^{18}\text{O}$ were analysed by H_2O reduction to H_2 (for $\delta^2\text{H}$) by hot uranium (Dighton et al. 1997) and CO_2 equilibrium for $\delta^{18}\text{O}$ (Socki, Karlsson & Gibson 1992). The results are reported as a deviation from Vienna Standard Mean Ocean Water (vs. VSMOW) in per mil (‰) difference using delta (δ) notation. The analytical precision for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ is $\pm 0.15\text{‰}$ and $\pm 1.5\text{‰}$, respectively. Adelaide is the closest rainfall station to the Cox, Lenswood and Kersbrook Creek Catchments with rainfall isotopic data provided by the International Atomic Energy Agency (IAEA) Global Network of Isotopes in Precipitation (GNIP) service. For this study, only complete annual data sets from the GNIP database were used to derive the weighted average precipitation and the local meteoric water line (LMWL) for Adelaide.

Groundwater and surface water samples were collected for analysis of radon-222 (^{222}Rn) activity: ^{222}Rn is a radioactive, inert gas that is generated from the decay of uranium and thorium series isotopes in the aquifer. It has a half-life of approximately 3.82 days, is highly soluble in water and its concentration will depend on the mineralogy of the aquifer (Love et al. 2002). Groundwater radon concentrations, downstream of groundwater influx to a stream, declines rapidly due to the short half-life of ^{222}Rn and loss to the atmosphere by gas exchange. ^{222}Rn loss across the air–water interface is rapid due to the low concentration of ^{222}Rn in air. Hence, the rate of gas loss is controlled by the gradient of the stream, as well as volume of discharge, stream profile and streambed roughness (Ellins, Roman-Mas & Lee 1990). 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 vial with 6 mL Packard NEN mineral oil scintillant, gently shaken for 30 seconds, sealed and the time recorded.

Surface water samples for the measurement of ^{222}Rn activity were collected using a rapid field extraction method developed by Leaney and Herczeg (2006). 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 shaken for four minutes so that the radon equilibrates between the water-air-scintillant phases. The bottle was left to stand for one minute, to allow the scintillant to settle to the top of the water. The scintillant was returned to the vial using a glass nozzle, sealed, and the date and time recorded. The samples were submitted to the Adelaide Isotope Laboratory within three days of sample collection and counted by liquid scintillation on a LKB Wallac Quantulus counter using a technique developed by

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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 and surface water samples were collected for the analysis of the radiogenic isotopes of strontium. Strontium isotope ($^{87/86}\text{Sr}$) ratios were analysed at the University of Adelaide using a Finnegan Mat 262 thermal ionisation mass spectrometer. Strontium was extracted from filtered 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 . Analysis of the surface water samples was only completed on two samples from round three and all samples collected during round four. Analyses of the groundwater samples were only completed for the samples taken during December 2005–January 2006.

In addition, groundwater samples were collected for chlorofluorocarbons (CFCs), carbon-14 (^{14}C) and carbon-13 ($\delta^{13}\text{C}$) analysis to determine the apparent age of the water. These were analysed by the CSIRO Land and Water Isotope Analysis Service. Analysis of CFCs was by purge and trap gas chromatography. Carbon-14 activity was analysed by liquid scintillation count, using a Wallac Quantulus Liquid Scintillation Counter. These analyses were only completed for the samples taken during December 2005–January 2006.

The Fontes and Garnier (1979) correction model was used to account for geochemical interactions that modify the initial activity (A_0) of ^{14}C at the time of recharge. The correction model requires input of the chemical and isotopic end members of soil gas $\delta^{13}\text{C}$, ^{14}C and partial pressure of CO_2 ($p\text{CO}_2$) and aquifer carbonate mineral $\delta^{13}\text{C}$ and ^{14}C . The values used in this investigation were: initial activity (A_0) of soil CO_2 $^{14}\text{C} = 85 \text{ pmC}$; soil gas $\delta^{13}\text{C} = -13 \text{ ‰}$; carbonate mineral $\delta^{13}\text{C} = -7.8 \text{ ‰}$; and carbonate mineral $^{14}\text{C} = 0 \text{ pmC}$ (Harrington 1999).

Manual flow gauging was conducted using a pigmy flow meter (OTT) at sampling locations in the three catchments during the four sampling rounds. For flows that were below detection of the flow meter, a modified funnel and bucket and stopwatch were used. The manual measurements were used in combination with the continuously monitored creek flow and water quality data taken from the DWLBC HYDSTRA database for each of the gauge stations located in the catchments. The location of these gauge stations in the Cox, Lenswood and Kersbrook Creek Catchments are shown on Figures 2, 3 and 4.

4. RESULTS

The surface water data collected from the Cox, Lenswood and Kersbrook creeks are presented using a 'run of river' approach with comparisons made between the four sampling rounds (December 2005—round 1, March 2006—round 2, July 2006—round 3 and November 2006—round 4). These sampling rounds will be referred to as, round 1, round 2, round 3 and round 4, respectively. The surface water data are also presented spatially, together with the groundwater data.

The label number attached to the surface water sample location identifier increases upstream, with number 1 representing the sample location at or close to the bottom of the catchment, e.g. Cck1 represents the most downstream sample location in CCC (refer to the appropriate catchment map). To represent the data longitudinally along the catchment, the surface water sample sites are plotted with distance (metres) upstream from the sample site at or close to the bottom of the catchment. During some rounds, samples were not collected because the creek was dry. The sample sites located along tributaries to the main creek are referenced '_t' and also plotted with distance (metres) from the sample site at or close to the bottom of the catchment at the point where the tributary enters the main creek.

References to the groundwater data are based on the analyses of the samples that were collected during December 2005–January 2006 and August 2006.

Interpretation of the surface water data needs to be considered in the context of the streamflow conditions prior to and during the time of sampling. Over the sampling period of this investigation, streamflow and rainfall in December 2005 were above average in response to a wet winter in 2005. This can be observed when comparing the rainfall and streamflow data between December 2005 and November 2006, where 2006 was a considerably dry year due to a milder winter and as a result had below average streamflow conditions. March 2006 was particularly dry and represents baseflow conditions in all three catchments.

4.1. COX CREEK CATCHMENT

4.1.1. HISTORICAL DATA AND CREEK FLOW

Figure 5 shows the flow and SEC measurements of Cox Creek from the gauging station (A5030526) located in the upper region of the catchment from October 2005 to December 2006. Average daily rainfall measurements from First Creek at Mount Lofty rainfall gauge station (A5040552) are also shown for the same period.

Gauged streamflow in CCC for 2006 was approximately 1640 ML (DWLBC 2007). High flows usually occur from May to October with maximum flow observed around July and August. There were two large peak flows at the end of October and early November 2005 shortly before the round 1 sampling period (December 2005). Discharge was very low between January and late April 2006 then increased with the onset of the first winter rains in May 2006. There was low streamflow in June followed by several larger flows in July and early August before tapering off towards December 2006. The flows in winter 2006 were significantly lower than the flows experienced in late 2005, corresponding to the atypical climatic conditions for this period. Manual measurements of streamflow showed that the changes in flow between sample locations were similar during the four rounds. Higher flows occurred during rounds 1 and 3 in response to a series of rainfall events prior to measurement. The flow at sites Cck7 and Cck3 were consistently higher than at other sites, suggesting that the creek may be gaining groundwater at

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these locations, whilst between these and sites Cck6 and Cck2 losing stream conditions are more likely. For example, the manual streamflow measurements during round 4 increased from about 17 m³/day at site Cck10 to 1180 m³/day at Cck7 then decreased to 985 m³/day at Cck6 where it remained fairly constant to Cck5 before increasing again slightly to Cck4. Between site Cck4 and Cck3 the flow increased significantly from 1070 to 1560 m³/day then decreased again to 1030 m³/day before increasing slightly towards Cck1.

The measured SEC from the collected composite samples at the gauge station represents the mean flow-weighted SEC, which decreased during stormflow events. Correspondingly, the SEC increased again after rain and peak flow events.

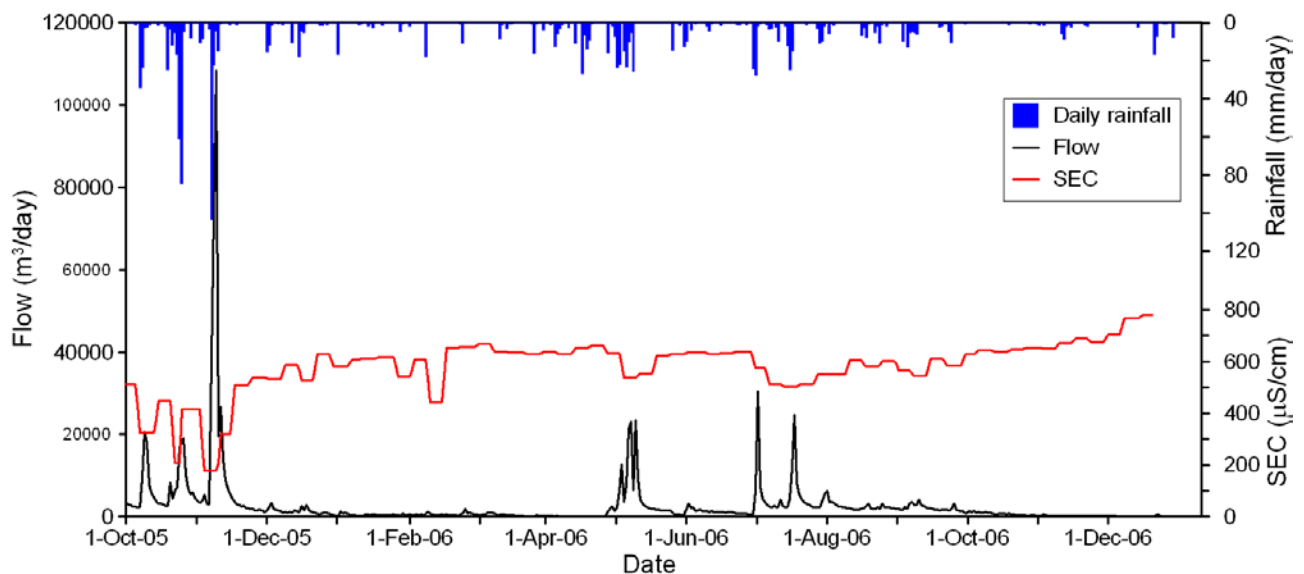


Figure 5. Creek flow, SEC (gauge station A5030526) and rainfall (station A5040552) in the CCC from October 2005 to December 2006 (DWLBC 2007)

4.1.2. PHYSICAL, HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN COX CREEK

The variation in the water chemistry along Cox Creek is a result of mixing of different waters from different flow pathways, geochemical reactions and residence times along the flowpaths. Significant changes in major and trace element concentrations along the length of the creek may indicate changes in water sources resulting from changes in the underlying geology or the influence of fault zones traversed by the creek.

The SEC during rounds 1 and 3 along Cox Creek rapidly increased between sites Cck10 and Cck9 then steadily decrease to Cck7 before gradually decreasing to site Cck1 (

Figure 6). The trends were similar at rounds 2 and 4, except that there was a slight increase in SEC between Cck8 and Cck7, and a sudden drop in SEC at site Cck4 at round 2. The measured SEC was considerably lower at round 3 (winter) compared to the other 3 rounds.

The pH during round 3 along Cox Creek started close to neutral at Cck10 then became more alkaline (pH 8) at Cck9, then gradually decreased downstream to a pH of 7.7 at Cck1 (

Figure 6). The pH trends at the other sampling rounds were more variable than during round 3 and not masked by rainfall and surface runoff. During rounds 1, 2 and 4, a significant increase in pH (8.4)

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occurred between sites Cck7 and Cck6, where Cox Creek travels through the Mount Lofty Golf Course then decreased to about 7.7 at site Cck4. From site Cck4 to Cck1 the pH increased again at rounds 1 and 4 whilst at round 2 it decreased.

The temperature in Cox Creek and its tributaries varied significantly between the different rounds with lowest temperatures during round 3 and highest during round 2 (

Figure 6). The temperature during round 3 increased slightly between sites Cck10 and Cck9 then decreased from about 11°C to 6°C at Cck1. Notable changes in temperature during rounds 1, 2 and 4 were noted between sites Cck7 and Cck6, which also corresponded to changes in the hydrochemistry. Dissolved oxygen was generally greater than 8 mg/L along Cox Creek at rounds 1, 3 and 4 with slightly lower concentrations during baseflow conditions (round 2). There was also greater variability during rounds 2 and 4 as a consequence of the lower flow conditions and reduced mixing in the deeper pools along Cox Creek.

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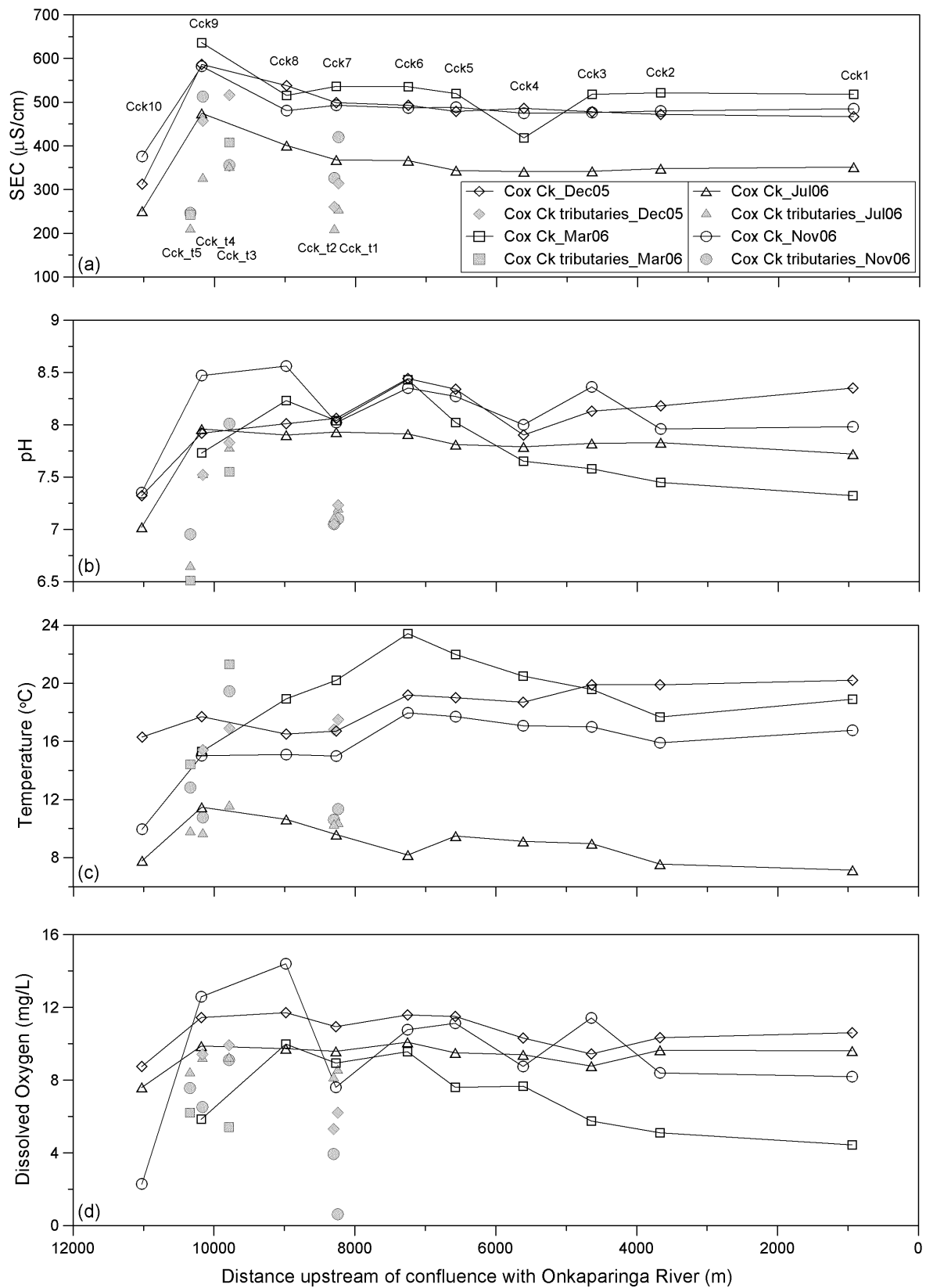


Figure 6. SEC (a), pH (b), temperature (c) and dissolved oxygen (d), in Cox Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of confluence with the Onkaparinga River (m)

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The trends in the ^{222}Rn activity data during the four sample rounds were similar and suggest that the connection between the groundwater system and Cox Creek exists throughout the year. The differences in activity in Cox Creek between seasons are a result of dilution by rainfall and surface water runoff, which have low to zero ^{222}Rn activity (Figure 7a). The locations of high ^{222}Rn activity indicate localised groundwater influx to the stream (in this investigation we assume that the groundwaters have a constant high ^{222}Rn activity and reflect the lithology of the major aquifers sampled). The ^{222}Rn activity downstream of influx declines rapidly due to its short half-life (3.82 days) and loss to the atmosphere by gas exchange. The rate of gas loss is controlled by the gradient of stream, as well as volume of discharge, stream profile and streambed roughness (Ellins, Roman-Mas & Lee 1990). The constant ^{222}Rn activities along some creek reaches suggests a balance between constant groundwater inflow and the de-gassing and radioactive decay of ^{222}Rn in creek water. The ^{222}Rn activities remained fairly constant between sample sites Cck10 and Cck8 followed by a sharp decrease in activity between Cck8 to Cck7. Between sites Cck7 and Cck6, the activity was steady, then gradually increased to Cck2 where it began to decrease again to Cck1. During baseflow conditions (round 2), ^{222}Rn activities varied from 0.6 Bq/L at Cck7 to 3.4 Bq/L at Cck2, compared to winter (round 3) where the activity varied from 0.39 Bq/L and 0.43 Bq/L, respectively. The high ^{222}Rn activities in the two tributaries sampled at Cck_t1 and Cck_t2 (2000 m upstream of confluence with Cox Creek) had minimal influence on the ^{222}Rn activity in Cox Creek, reflecting the small contribution of flow from these tributaries (Figure 8).

The deuterium ratio ($\delta^2\text{H}$) was more negative between Cck10 to Cck9 compared with other sites. This implies a different source, e.g. a result of surface water contribution above Cck9 from one main tributary (Cck_t5) and/or groundwater inflow between these points (Figure 7b). Downstream of Cck9 the $\delta^2\text{H}$ became progressively more positive. Between Cck4 and Cck1, the trends in the $\delta^2\text{H}$ during different rounds highlight the varying degrees of surface evaporation from the creek at different times of the year. This was very clear in round 2 (March 2006), which showed the $\delta^2\text{H}$ significantly more positive, reflecting baseflow conditions, higher evaporation, and minimal rainfall input to Cox Creek at that time of year.

Comparisons between the surface water TDS and chloride concentrations $[\text{Cl}^-]$ from CCC showed that there were additional inputs/losses of some solutes (Figure 7c and Figure 7d). The chloride concentrations ($[\text{Cl}^-]$) in Cox Creek were higher during round 2 (72–98 mg/L) and represent baseflow conditions when there was minimal rainfall. In comparison, $[\text{Cl}^-]$ in round 3 (49–69 mg/L) were lower as a result of dilution by low-chloride winter rainfall and surface runoff. The $[\text{Cl}^-]$ showed a decreasing trend in the downstream direction from sample site Cck9 to Cck7, then gradually increasing from Cck7 to Cck1 in rounds 1, 3 and 4. This trend was similar in round 2 except that the $[\text{Cl}^-]$ were higher and that there was a noticeable increase in $[\text{Cl}^-]$ between Cck8 and Cck4. A small tributary (Cck_t3) provided a low $[\text{Cl}^-]$ inflow, which diluted the concentration in Cox Creek between Cck9 and Cck8 during all four rounds. There was also a low $[\text{Cl}^-]$ contribution from the tributaries Cck_t1 and Cck_t2 in round 3, between locations Cck8 and Cck7, which significantly diluted the $[\text{Cl}^-]$ in Cox Creek downstream to Cck7, after which they increased again.

RESULTS

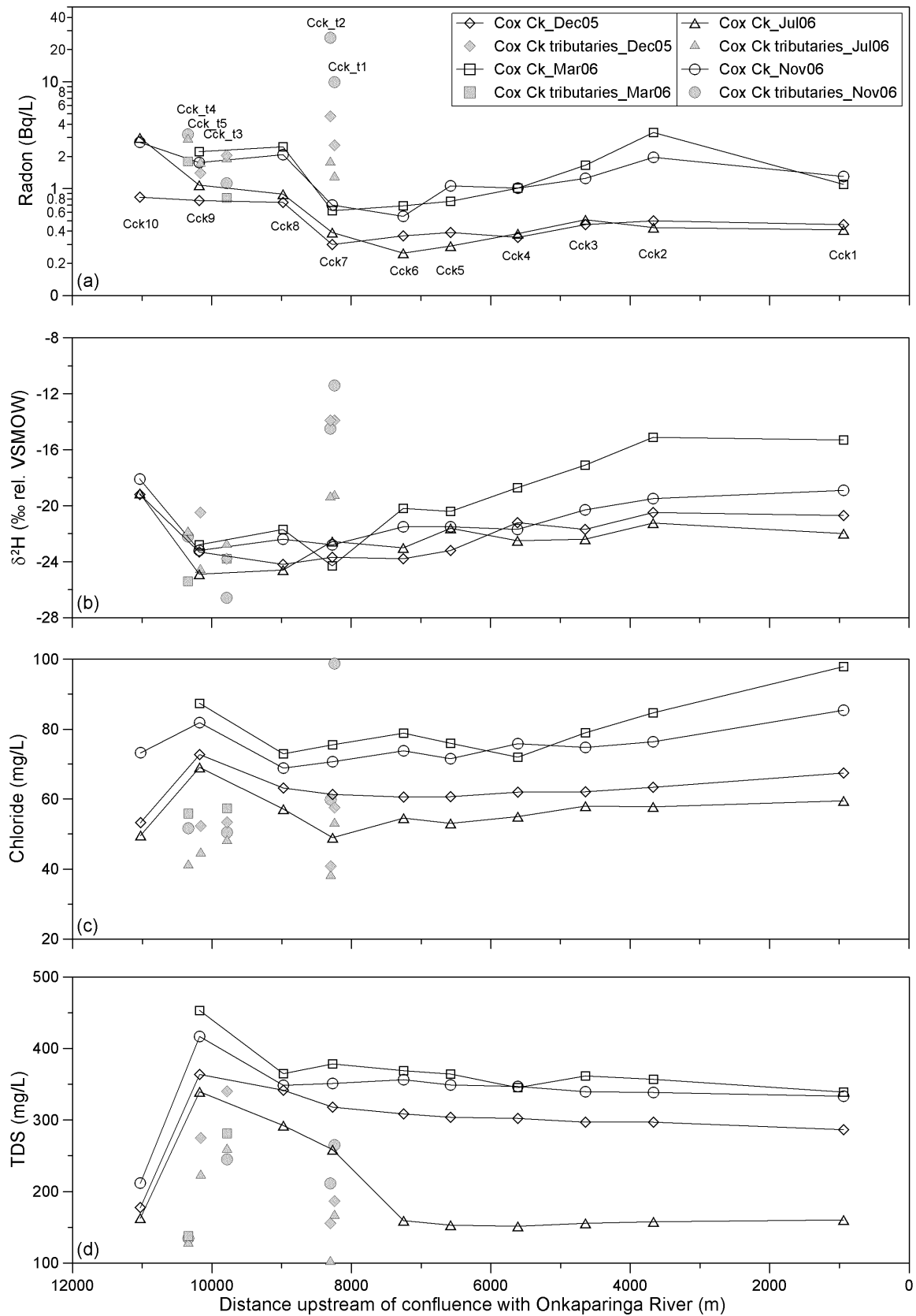


Figure 7. ^{222}Rn (a), deuterium (b), chloride (c) and TDS (d) in Cox Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of confluence with the Onkaparinga River (m)

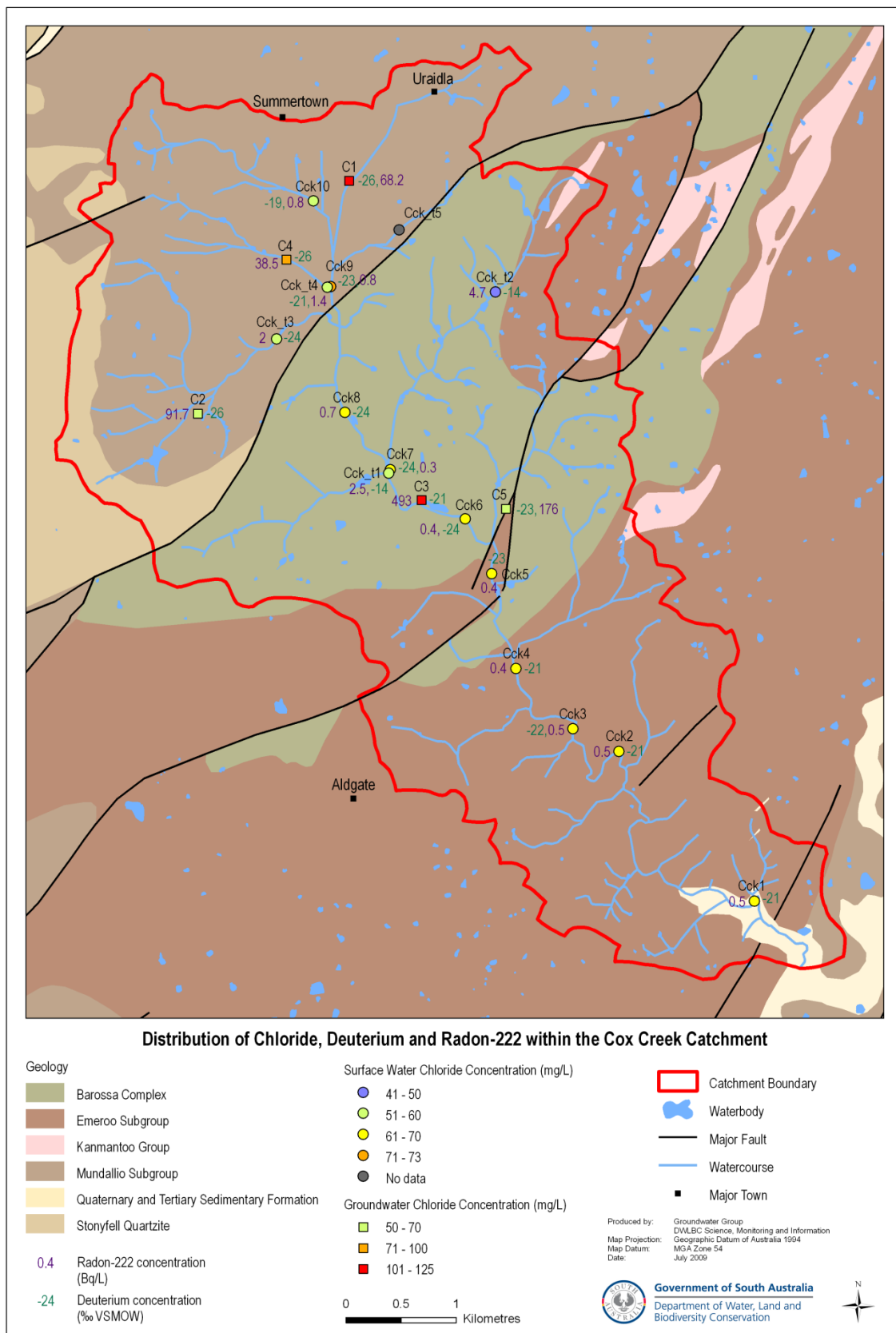


Figure 8. Spatial distribution of ²²²Rn (Bq/L), deuterium (‰VSMOW) and chloride (mg/L) concentrations of surface water and groundwater in the CCC, December 2005

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The strontium concentration in the surface water represents a mixture of precipitation-derived strontium and that derived from weathering. The concentrations at the different rounds were similar at each of the sampling sites along Cox Creek, however, concentrations were higher at round 2 than round 3, which suggests dilution by rainfall during the winter months as confirmed by the other hydrochemical data (Figure 9). In comparison, the $^{87/86}\text{Sr}$ ratio trends along Cox Creek were very similar at each of the four sampling rounds, which indicated that there were similar water sources contributing to creek flow and that the rainfall strontium source has little bearing on the $^{87/86}\text{Sr}$ ratio. It is surmised from these results that surface water $^{87/86}\text{Sr}$ ratio is primarily derived from strontium dissolved from local geology.

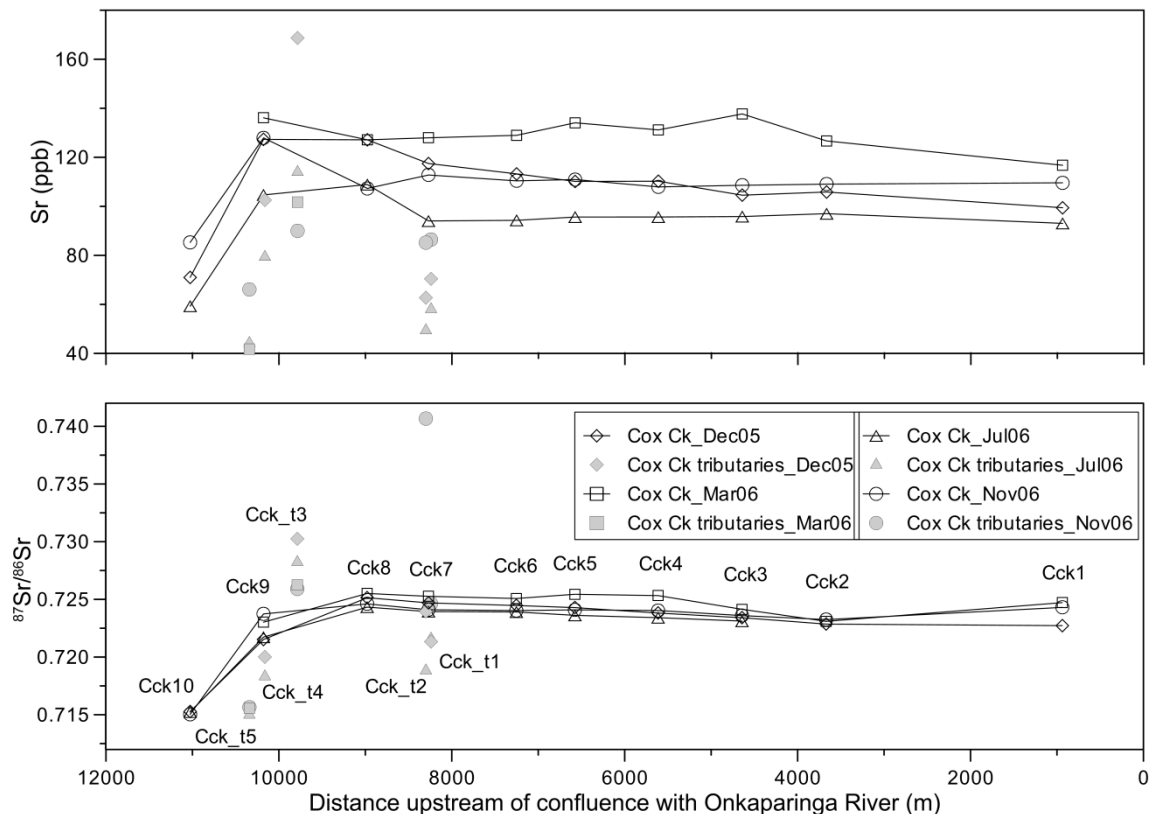


Figure 9. Strontium concentrations and $^{87/86}\text{Sr}$ ratios in Cox Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of confluence with the Onkaparinga River (m)

Figure 10 shows $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ of Cox Creek surface and groundwater samples relative to the Adelaide LMWL. The majority of the surface water samples plot close to and above the LMWL for Adelaide ($\delta^2\text{H} = 7.7\delta^{18}\text{O} + 9.6$), with a composition similar to, or more positive than, the weighted average rainfall for Adelaide ($\delta^2\text{H} = -26\text{‰}$ and $\delta^{18}\text{O} = -4.7\text{‰}$) (IAEA & WMO 2005). The LMWL for Scott Bottom, a rainfall station in the MLR is also shown for comparison. These relatively enriched values of $\delta^2\text{H}$ in the surface water are thought to result from a mixture of seasonal localised recharge events and/or small amounts of evaporation occurring in conditions of high humidity (Coplen, Herczeg & Barnes 1999). Samples from sites Cck4, Cck3 and Cck1 in round 2 fall below the LMWL as a result of isotopic enrichment caused by evaporation. Samples Cck_t1 and Cck_t2, collected from small tributaries to Cox Creek, had a more isotopically enriched composition and suggest evapo-concentration of the water due to longer residence times in a series of pools and in-stream dams before the confluence with the main creek. At round 2 there was only a stagnant pool at these sample locations, which was not sampled.

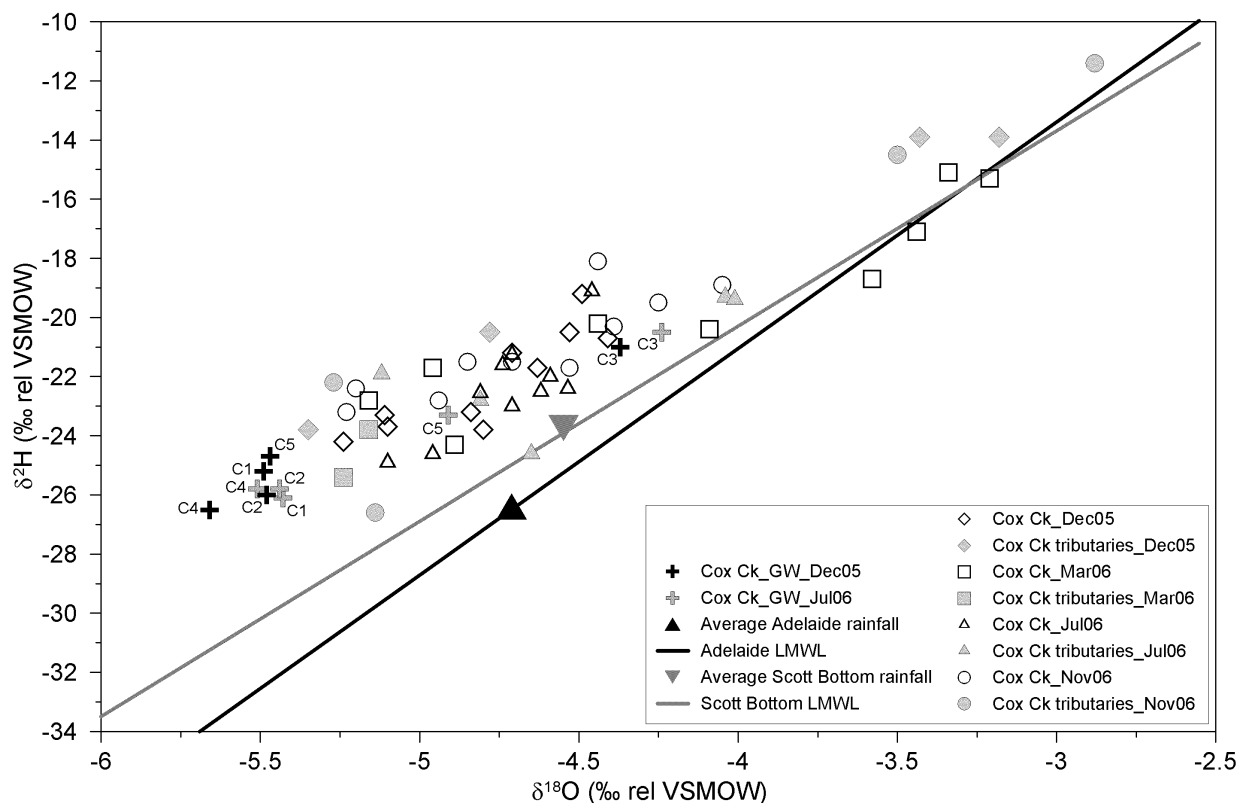


Figure 10. $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ for surface water and groundwater samples, CCC. The MWL for Adelaide is $\delta^2\text{H} = 7.7 \delta^{18}\text{O} + 9.6$. The mean weighted rainfall for Adelaide is $\delta^2\text{H} = -26 \text{‰}_{\text{VSMOW}}$ and $\delta^{18}\text{O} = -4.7 \text{‰}_{\text{VSMOW}}$

4.1.3. HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN GROUNDWATER

The ^{222}Rn activities in the groundwater were an order of magnitude higher than in the surface water samples and reflect the mineralogy of the aquifer (Love et al. 2002). The variation in the groundwater ^{222}Rn activities in the CCC appears to be related to the two major rock types (Figure 8). Groundwater samples C1, C2 and C4 from the FRA in the sandstone, quartzite and dolomite units of the Burra Group had lower ^{222}Rn activities (37.9–87.1 Bq/L) compared to samples C3 and C5 from the FRA in the metamorphosed gneisses and schists of the Barossa Complex which had much higher activities (220–489 Bq/L).

Groundwater samples (C1, C2, C4 and C5) had a more depleted isotopic composition than the weighted average rainfall (Figure 10), which is indicative of (1) diffuse recharge occurring during cooler autumn and winter rainfall events, and (2) altitude effects. The altitude effect results in depletion of both $\delta^{18}\text{O}$ (~ 0.15 to 0.5‰ per 100 m) and $\delta^2\text{H}$ (~ 1 to 4‰ per 100 m) values relative to lower altitude rainfall (Clark & Fritz 1997). The proximity of the groundwater samples to the LMWL suggests that there has been minimal isotopic fractionation by evaporative process prior to rainfall infiltration. All of the groundwater samples (excluding C3) had a $\delta^2\text{H}$ that was more negative than the surface water samples from Cox Creek. The more positive $\delta^2\text{H}$ of sample C3 may be due to the location of the sampled well down-gradient of a leaking dam, which is likely to have an evaporated signature. The samples C1 and C4, sampled from bores located upstream of surface water sample site Cck9, had $\delta^2\text{H} = -25.2$ and -26.5‰ respectively, indicating that groundwater is a likely source of the more negative $\delta^2\text{H}$ end member to Cox Creek in the upper reaches of the catchment. However, the higher $[\text{Cl}^-]$ of sample C1 indicates that the contribution of groundwater from this area would have to be small given that the surface water samples

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have a much lower $[Cl^-]$ (Table B1 and Table C1). Groundwater samples C2, C4 and C5 had similar chloride concentrations to the surface water samples, but are less enriched in deuterium (Table B1). Samples C1 and C3 had higher chloride concentrations and are more representative of water that has been chloride-enriched by transpiration, as there is no indication of evaporative processes in the δ^2H versus $\delta^{18}O$ plot. Hence, the groundwater contribution to the stream from this part of the FRA (C1 and C3) would have to be small given that the stream water samples have a much lower chloride concentration.

4.1.4. APPARENT GROUNDWATER AGES

The CFC–11, CFC–12, and ^{14}C apparent groundwater ages for the five sampled bores in the CCC are listed in Table 1, together with the values of the parameters used in the Fontes and Garnier (1979) correction model for the ^{14}C ages. The uncorrected ^{14}C age is different to the Fontes and Garnier model age because there is no consideration for chemical processes within the soil or groundwater affecting ^{14}C concentrations. The uncorrected age is usually, but not always, an underestimate of the true ^{14}C age and any uncertainty is due to the lack of precise knowledge of the initial ^{14}C at the time of recharge. The Fontes and Garnier model uses geochemical and other isotopic data to reconstruct the initial ^{14}C concentrations (A_0) as well as estimating the $\delta^{13}C$ composition of carbonate material in the aquifer and of the soil gas in the unsaturated zone.

The results indicate that the groundwater is mostly modern or has a considerable modern component. Notwithstanding the apparently large corrected ages indicated by the ^{14}C results, the high (>85 pmC) ^{14}C concentrations in samples C1, C2, C3 and C5 suggest a component of bomb-fallout ^{14}C implying groundwater of less than 50 years old. According to the CFC–12 results, the apparent ages of samples C3, C4 and C5 are about 20–30 years. Samples C1 and C2 appeared to be modern groundwater, however, their spuriously high CFC–12 concentrations suggested they were contaminated in-situ by an organic chemical which distorted to the analytical result. Atmospheric contamination during sampling was ruled out because triplicate samples were taken which showed similar apparent ages. Sample C4 had highly conflicting CFC and ^{14}C data and would require re-sampling to confirm the apparent age. It is notable that the $\delta^{13}C$ of this sample is very different to the other groundwater samples in the CCC.

Table 1. Groundwater age estimates for samples from bores in the CCC. Carbon–14 corrected ages are derived using the Fontes and Garnier (1979) correction model. NA denotes contamination of CFCs

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)
C1	39	86.0	–17.7	79.17	51.53	1249	1495	NA	NA
C2	25	86.8	–18.9	126.08	134.20	1175	1760	1973	NA
C3	30.46	88.1	–16.7	1.58	1.03	1051	113	<1965	1974
C4	36.55	19.0	–13.8	4.01	0.26	13729	12185	1972	1979
C5	29	90.3	–17.0	2.07	0.86	848	1129	1969	1983

4.1.5. SURFACE WATER AND GROUNDWATER END MEMBERS

The graphs in Figure 11 show the surface water and groundwater ion to chloride ratios (Ca/Cl , Mg/Cl , Na/Cl , Br/Cl , SO_4/Cl and HCO_3/Cl) versus chloride concentration and their proximity to the respective seawater dilution lines. The groundwater samples C1 and C3 had higher chloride concentrations than the other groundwater samples and surface water samples, which suggests that groundwater from this part of the catchment contributes a fairly minor input to Cox Creek. Figure 11c of Na/Cl shows the

RESULTS

surface water and most of the groundwater samples plotting along the seawater dilution line, which is indicative of sources of original marine origin, e.g. cyclic salts. However, the graphs of Ca/Cl, Mg/Cl and HCO₃/Cl (Figure 11a, 11b and 11f) show that the surface water and groundwater samples plot above the seawater dilution line and indicate that some water–rock interaction has occurred with the dissolution of, e.g. calcite, dolomite and silicate minerals. Groundwater sample C4 had much higher concentrations of Ca²⁺, Mg²⁺ and HCO₃⁻ relative to chloride compared to the other groundwater samples, which reflects the dolomitic member of the Woolshed Flat Shale unit. Figure 11e of SO₄/Cl shows no obvious trends, and as sulphate is not present as a major mineral in the silicate rocks, the majority of the samples plot close to the seawater dilution line.

The plot of the ^{87/86}Sr ratio versus the reciprocal of the strontium concentration (1/[Sr]) shows that the surface water samples trend between the expected end members of local rainwater and groundwater from the Burra Group and more towards the groundwater end member (Figure 12). The differences in the ^{87/86}Sr ratios of the groundwater samples are controlled by variations in the initial atmospheric inputs, mineralogy of the rock along flowpaths, source of easily weathered strontium and residence time. The groundwater samples C4 (0.7245) and C1 (0.7210) were sampled from bores located upstream of Cck9 in the Basket Range Sandstone and Skillogalee Dolomite, and their ^{87/86}Sr ratios were similar to the average ratio (0.7240) at all four sampling rounds along the length of Cox Creek between sites Cck9 to Cck1 (Figure 9). This suggests that there is a well-mixed and relatively homogeneous source of strontium and that the source of groundwater is dominantly from aquifers located in the Basket Range Sandstone and Skillogalee Dolomite, which dominate the hydrochemical signature in Cox Creek. Evaluation of the ^{87/86}Sr ratio versus δ¹⁸O (plot not shown) provided further evidence, which indicated that the majority of the samples from Cox Creek had an evaporated groundwater signature.

RESULTS

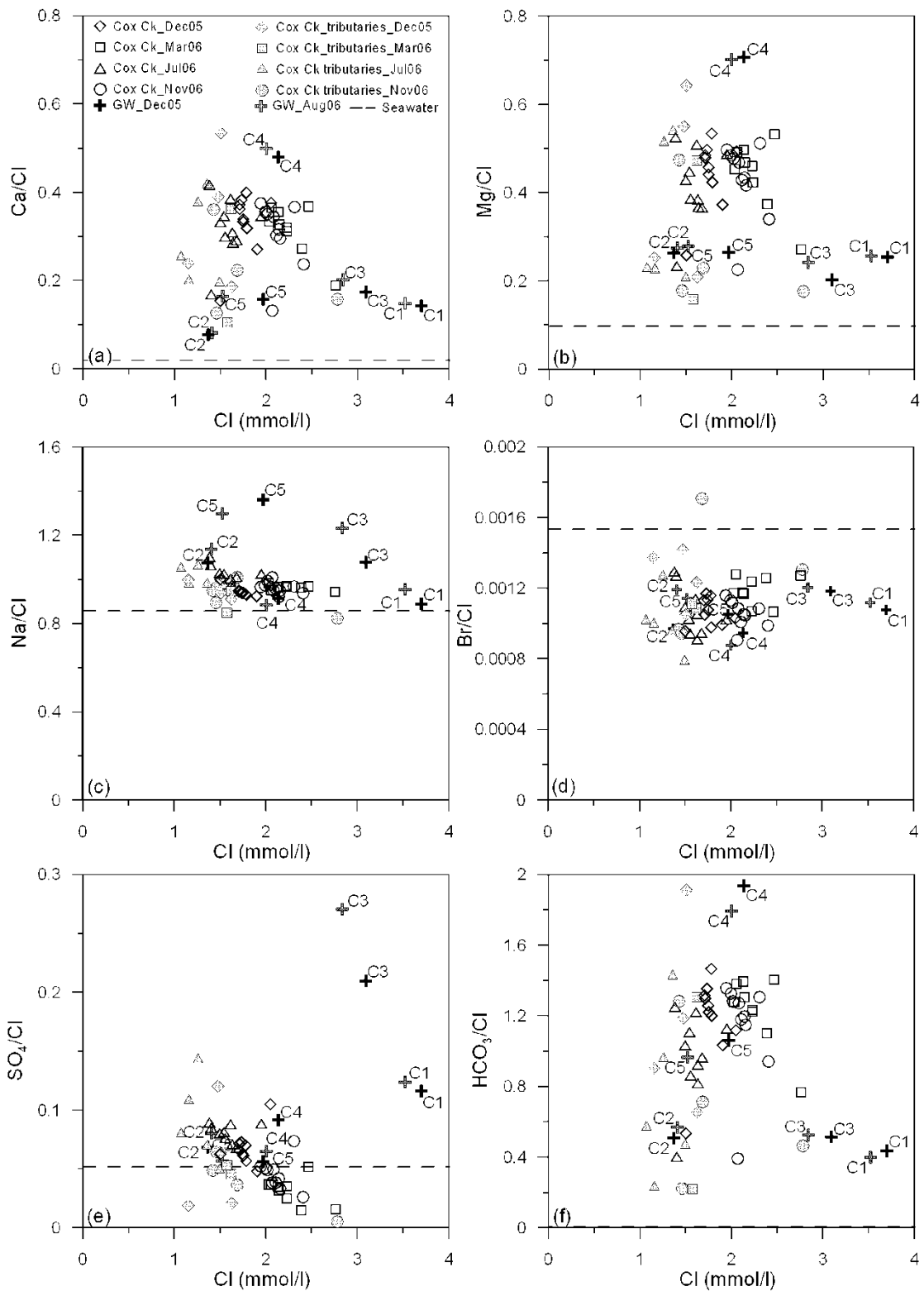


Figure 11. Composition diagrams of ion/chloride ratios Ca/Cl (a), Mg/Cl (b), Na/Cl (c), Br/Cl (d), SO₄/Cl (e) and HCO₃/Cl (f) versus chloride of surface water and groundwater in CCC

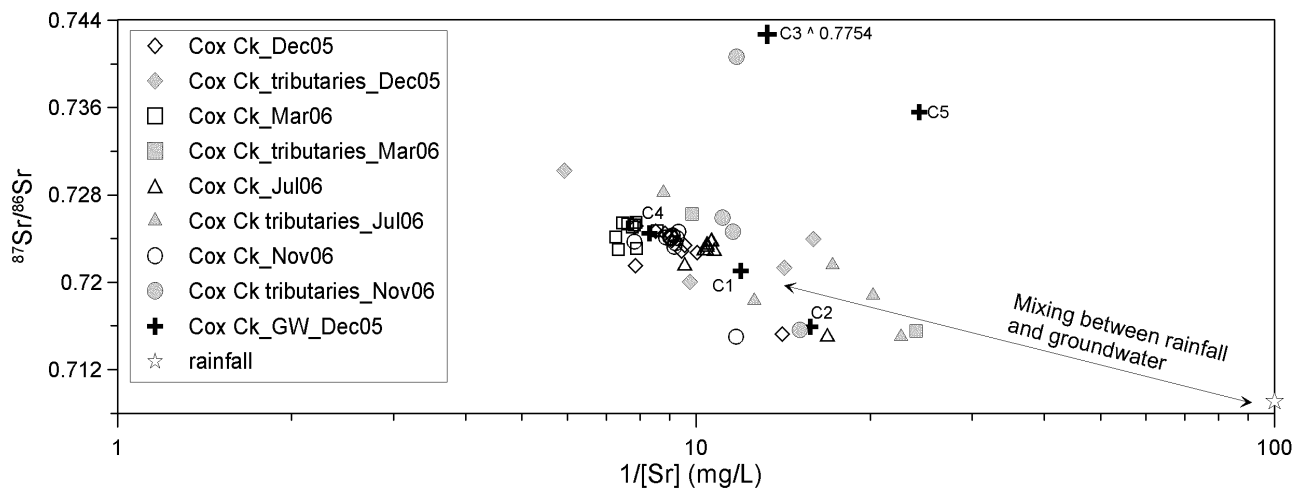


Figure 12. $^{87/86}\text{Sr}$ ratio versus $1/[\text{Sr}]$ in Cox Creek and the sampled groundwater bores

4.2. LENSWOOD CREEK CATCHMENT

4.2.1. HISTORICAL DATA AND CREEK FLOW

Figure 13 shows the flow and SEC of Lenswood Creek and rainfall measurements from the gauging station (A5030507) located in the middle of the catchment from October 2005 to December 2006. In late October–November 2005 there were several rainfall events with daily totals greater than 30 mm, which caused a rapid response in flow down Lenswood Creek just before the first sampling round in December 2005 (round 1). The response of the creek SEC to the rainfall events was fairly rapid, often decreasing prior to the peak in flow. This is most likely caused by the composite sample technique, which represents the mean flow-weighted concentration. The frequency of rainfall events increased in late April, however, there was little influence on creek flow, which did not exceed 100 000 m³/day during the winter months when flow would typically be higher. From early August 2006 until December 2006, the quantity of rainfall and its frequency decreased considerably, with a corresponding decrease in creek flow. The flows during winter 2006 were significantly lower than the flows experienced in late 2005, corresponding to the atypical climatic conditions for this period.

The manual flow measurements during round 4 at the individual sites along Lenswood Creek were low. At some sites flow was too low to measure, the creek forming a series of permanent pools. Between sites Lck7 and Lck4 there was measurable flow, which increased downstream from about 9 m³/day to 130 m³/day.

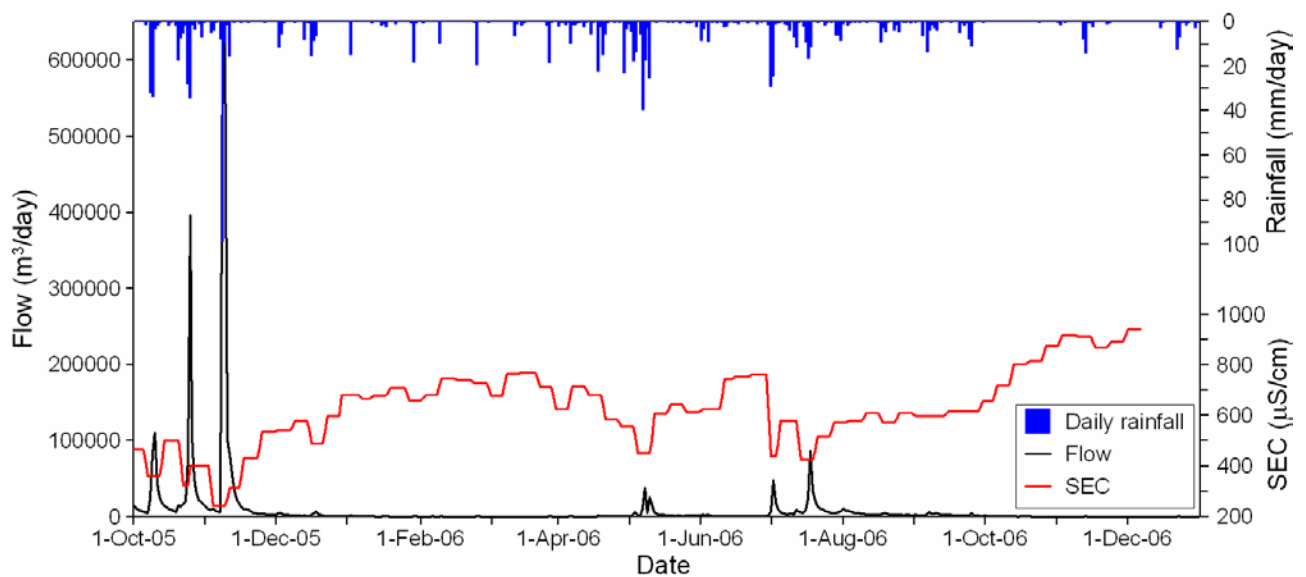


Figure 13. Creek flow, SEC and rainfall (gauge station A5030507) in the LCC from October 2005 to December 2006 (DWLBC 2007)

4.2.2. PHYSICAL, HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN LENSWOOD CREEK

The trends in SEC along Lenswood Creek were similar during rounds 1 and 3. There was a slight increase between sites Lck7 and Lck5, which then gradually increased again from site Lck4 to Lck1 (Figure 14). The SEC was typically below 600 $\mu\text{S}/\text{cm}$ at all the sites during rounds 1 and 3, except for at site Lck1, where it was higher. The measured SEC during rounds 2 and 4 was much higher at each of the sites compared to the other two rounds and also showed a significant increase from below site Lck3. During round 4, there was a pronounced increase in SEC at site Lck5, located at the gauge station. The majority of the sampled sites along the minor tributaries at the four rounds had lower SEC compared to the sites along Lenswood Creek, which may be due to direct groundwater inflow from springs and/or surface runoff from irrigation (which is ultimately groundwater but with a slightly evaporated signature).

The pH along the length of Lenswood Creek was more alkaline during round 3 compared to the measurements from the other three rounds (Figure 14). The higher alkalinities are likely to be a result of surface runoff containing agricultural lime. During round 2 (baseflow conditions), the pH was less than 7.7 and as low as 7.3, and in most cases lower than the pH measured at each of the sites during the other rounds. The major tributary just below Lck6 and its minor feeding tributaries had lower pH values, which caused the pH to decrease in Lenswood Creek below Lck6 during the four rounds. The water temperature in Lenswood Creek between the different rounds varied significantly. During round 3 (winter), the creek temperature was around 8°C, significantly colder than during round 4, which was on average 12°C compared to an average of 16°C during rounds 1 and 2. The water temperature in the minor tributaries followed similar trends, being colder during round 3 and warmer during rounds 1 and 2. The dissolved oxygen concentrations were much lower during rounds 2 and 4 compared to rounds 1 and 3, due to reduced flow activity and water movement in the creek during low flow conditions.

RESULTS

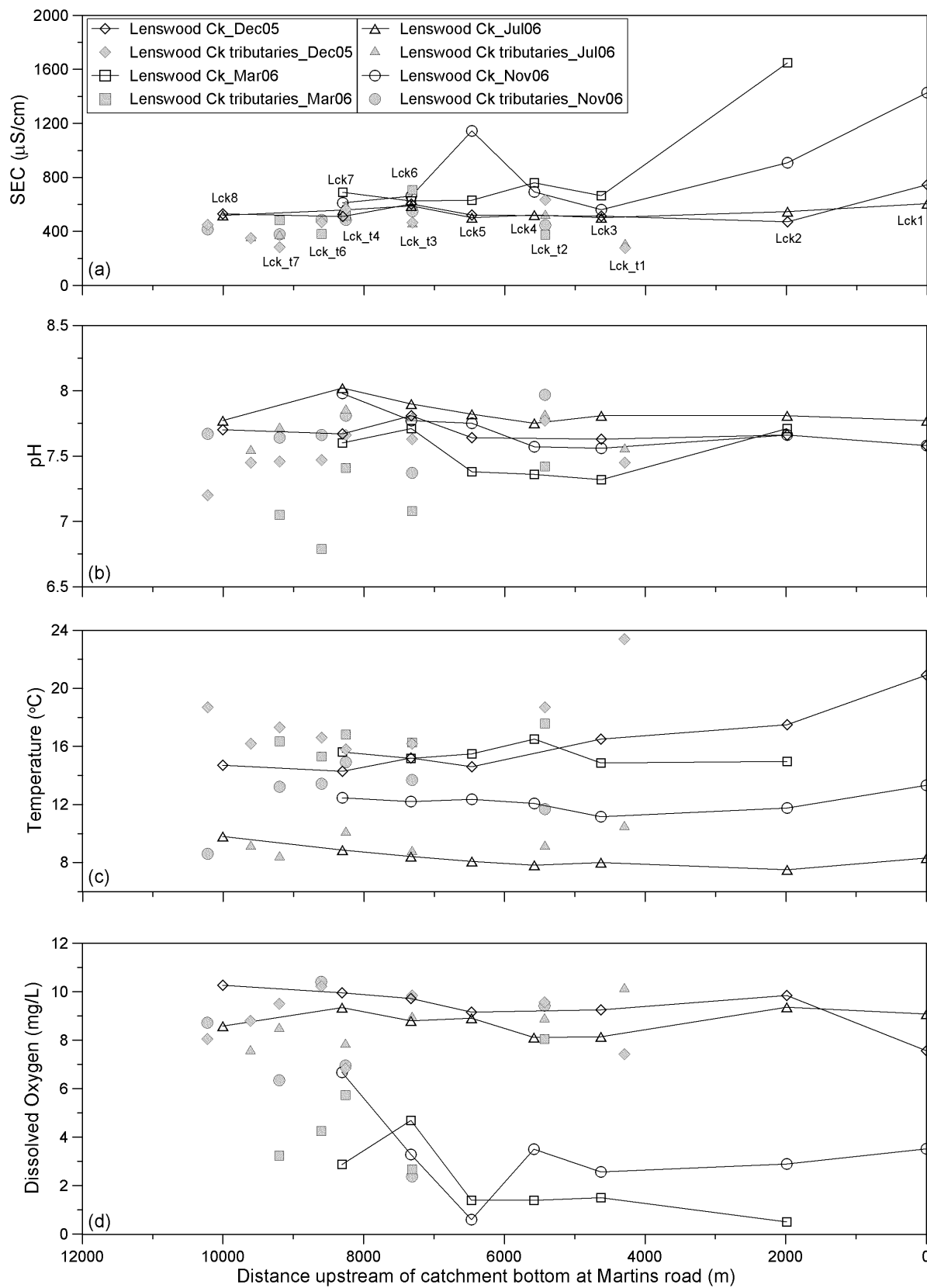


Figure 14. SEC (a), pH (b), temperature (c) and dissolved oxygen (d), in Lenswood Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of catchment bottom at Martins Road (m)

RESULTS

The measured ^{222}Rn activities along Lenswood Creek showed similar trends for the four different rounds (Figure 15). The ^{222}Rn activities were lower during round 1 (December 2005) and round 3 (July 2006) compared to round 2 (March 2006) and round 4 (November 2006), due to dilution by surface runoff and rainfall, which has very low ^{222}Rn . During rounds 1 and 3, there were two prominent increases in ^{222}Rn activities between Lck7 and Lck6 and between Lck2 and Lck1. During rounds 2 and 4 there were similar spikes in activities along Lenswood Creek, but with much higher activities at the same locations. It is worth noting, that at site Lck8, the creek channel is shallow and narrow, and as a result, during rounds 2 and 4 it was dry.

The measured ^{222}Rn activities in the tributary discharging just below Lck6 were ten times higher in rounds 2 and 4 compared to rounds 1 and 3, and were typically higher than in Lenswood Creek. The minor tributary (Lck_t4), that discharges to Lenswood Creek just below Lck7, has its source beneath the Lenswood Coldstores (fruit cold storage and packing warehouse) located on the corner of Coldstore and Lobethal roads, and may represent a mixture of groundwater and surface runoff from the coldstore and adjacent bowling green (Figure 16). This minor tributary had a low ^{222}Rn activity, particularly during rounds 2 and 4. A spring fed dam is the source of the minor tributary (Lck_t2) that discharges to Lenswood Creek just below Lck4. The high ^{222}Rn activity measured at Lck1 was due to direct runoff of groundwater irrigation to the creek. During round 2, the creek at site Lck1 was dry.

The deuterium signature along Lenswood Creek was more enriched during rounds 2 and 4 compared to rounds 1 and 3 (Figure 15). The variation in deuterium was greatly damped in round 3, varying by only 2 ‰, whereas during round 2, the deuterium varied by 7 ‰ between sites. The sample taken at site Lck1 at round 4 showed an evaporation signature as a result of very low flow or stagnant conditions. The minor tributary (Lck_t2) just below site Lck4 had a deuterium signature that was lower than at Lck3 during rounds 1, 2 and 3 and higher during round 4 but did not seem to influence the signature in Lenswood Creek. The less enriched deuterium signature of the major tributary Lck_t3 caused a reduced (more depleted) signature in Lenswood Creek from the point where it entered below site Lck6 and down to point Lck5 (except during round 4). The slight increase in enrichment from Lck6 to Lck5 in round 4 was probably caused by secondary evaporation, due to the creek being reduced to a permanent pool at this location. The minor tributaries feeding the major tributary had a deuterium signature between -14 ‰ and -20 ‰.

There was little variation in the chloride concentration at the individual sample sites along Lenswood Creek in rounds 1 and 3 (Figure 15). The concentration during these two rounds was between 80 and 140 mg/L, being higher in round 3 (winter) compared to round 1. The chloride concentration at each of the sites along the creek during rounds 2 and 4 showed similar trends and was much more variable than during the other two rounds, with significant decreases in concentration between sites Lck7 and Lck5, and sites Lck4 and Lck2. Concentrations in rounds 2 and 4 were generally greater than 103 mg/L, and up to 457 mg/L. The majority of the tributaries sampled during the different rounds had concentrations similar to or less than those along Lenswood Creek.

RESULTS

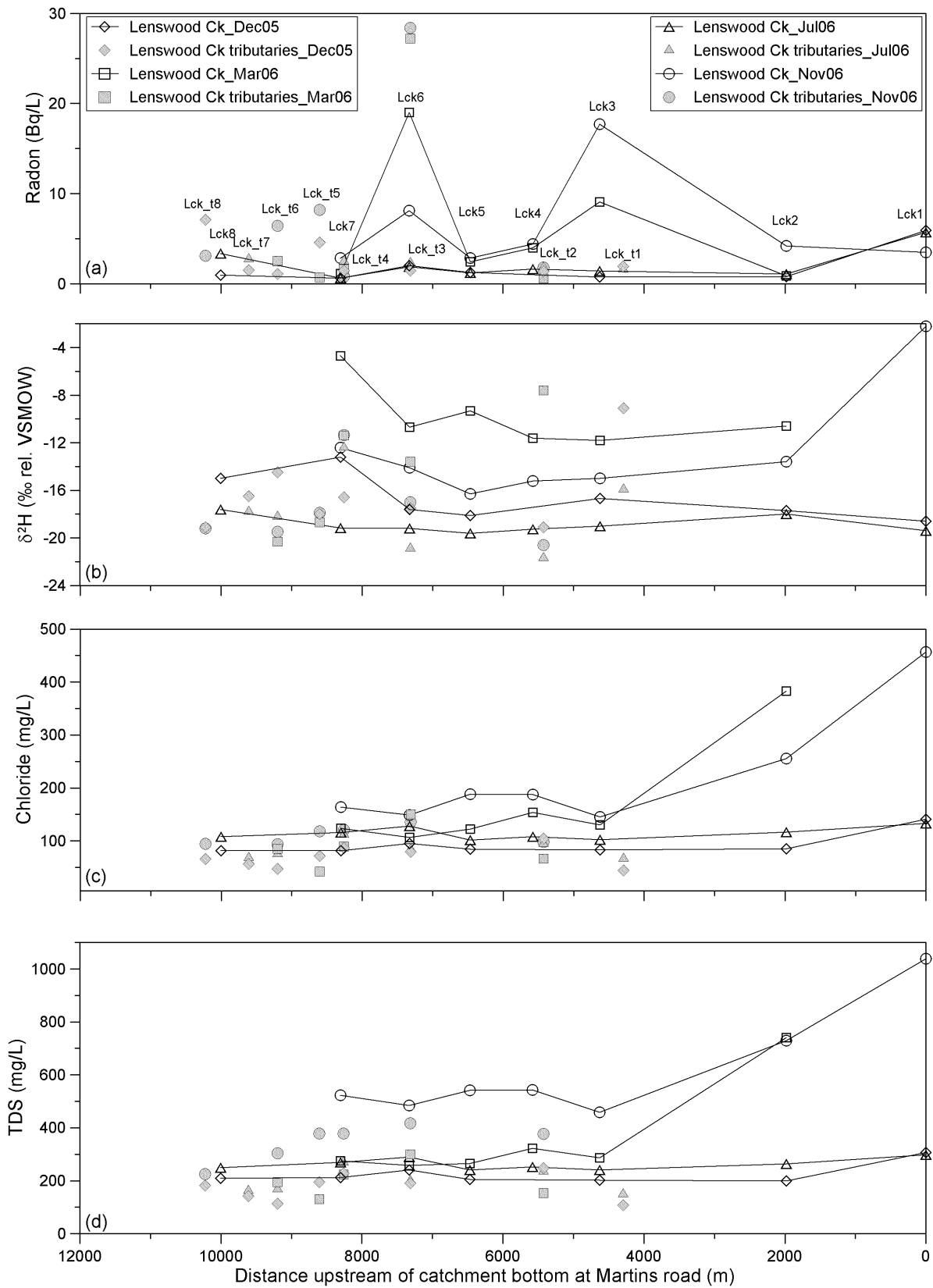


Figure 15. ^{222}Rn (a), deuterium (b), chloride (c) and TDS (d) in Lenswood Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of catchment bottom at Martins Road (m)

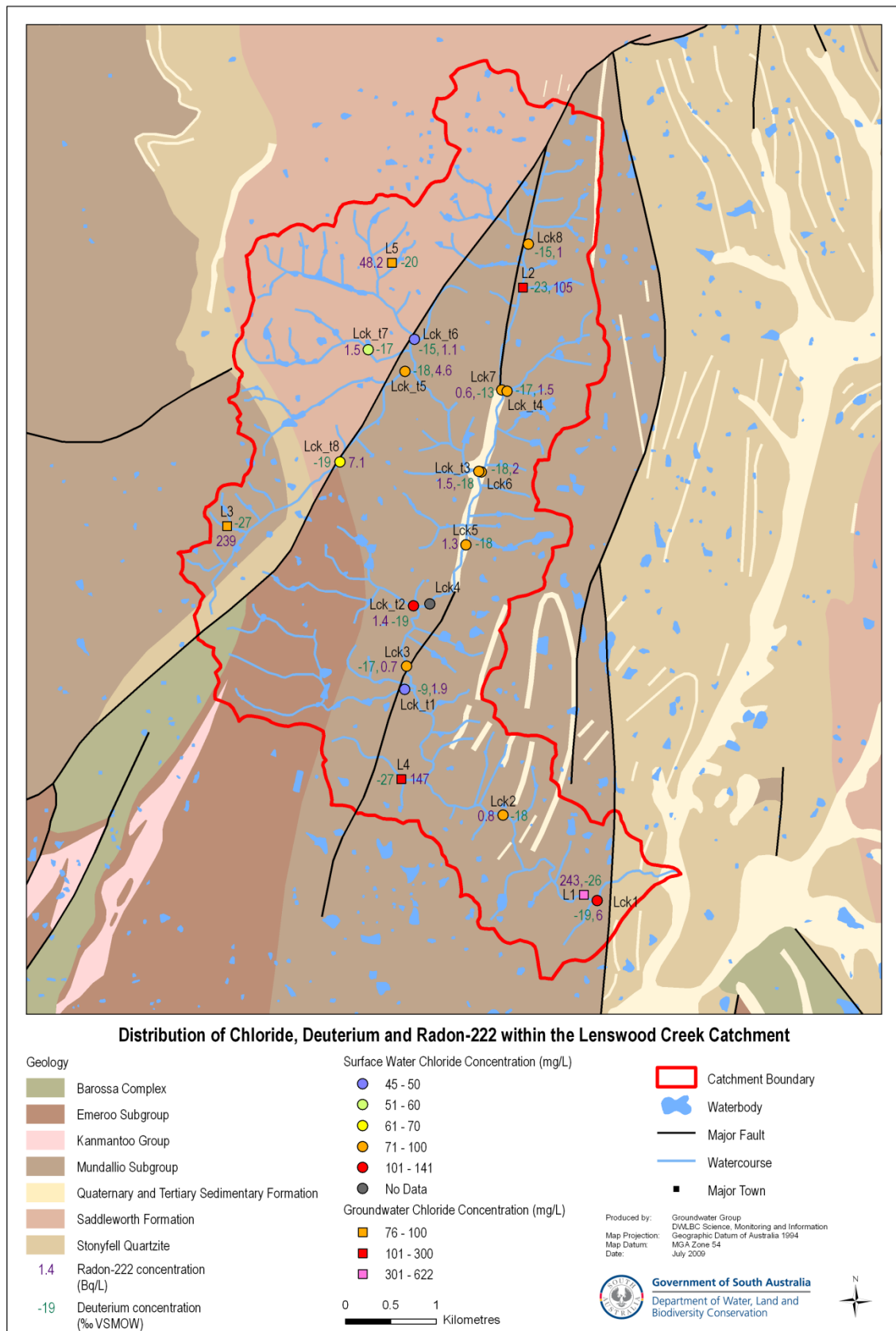


Figure 16. Spatial distribution of ²²²Rn (Bq/L), deuterium (‰_{VSMOW}) and chloride (mg/L) surface water and groundwater concentrations in the LCC, December 2005

RESULTS

The trends in strontium concentration at the sites along Lenswood Creek were similar in rounds 2 and 4 and in rounds 1 and 3. There was far less variability in strontium concentration during rounds 1 and 3 compared to the other rounds. The series of tributaries, that have their confluence just below Lck6, had lower solute strontium concentrations than in Lenswood Creek.

During round 4, the $^{87/86}\text{Sr}$ ratio decreased slightly from site Lck7 to Lck6 then increased from 0.718 at Lck6 to 0.720 at Lck4 where it remained fairly constant to Lck2 before it increased slightly to Lck1. The strontium ratio of the two samples collected at round 4 increased from 0.717 at Lck7 to 0.718 at Lck5. The $^{87/86}\text{Sr}$ ratios of the tributaries sampled at Lck_t2 and Lck_t3 were higher than at the sites located along Lenswood Creek in round 4. The minor tributaries contributing to Lck_t3 had $^{87/86}\text{Sr}$ ratios that were greater than the sample sites at and above Lck6 on Lenswood Creek, whilst the tributary Lck_t4 had a lower $^{87/86}\text{Sr}$ ratio of 0.714.

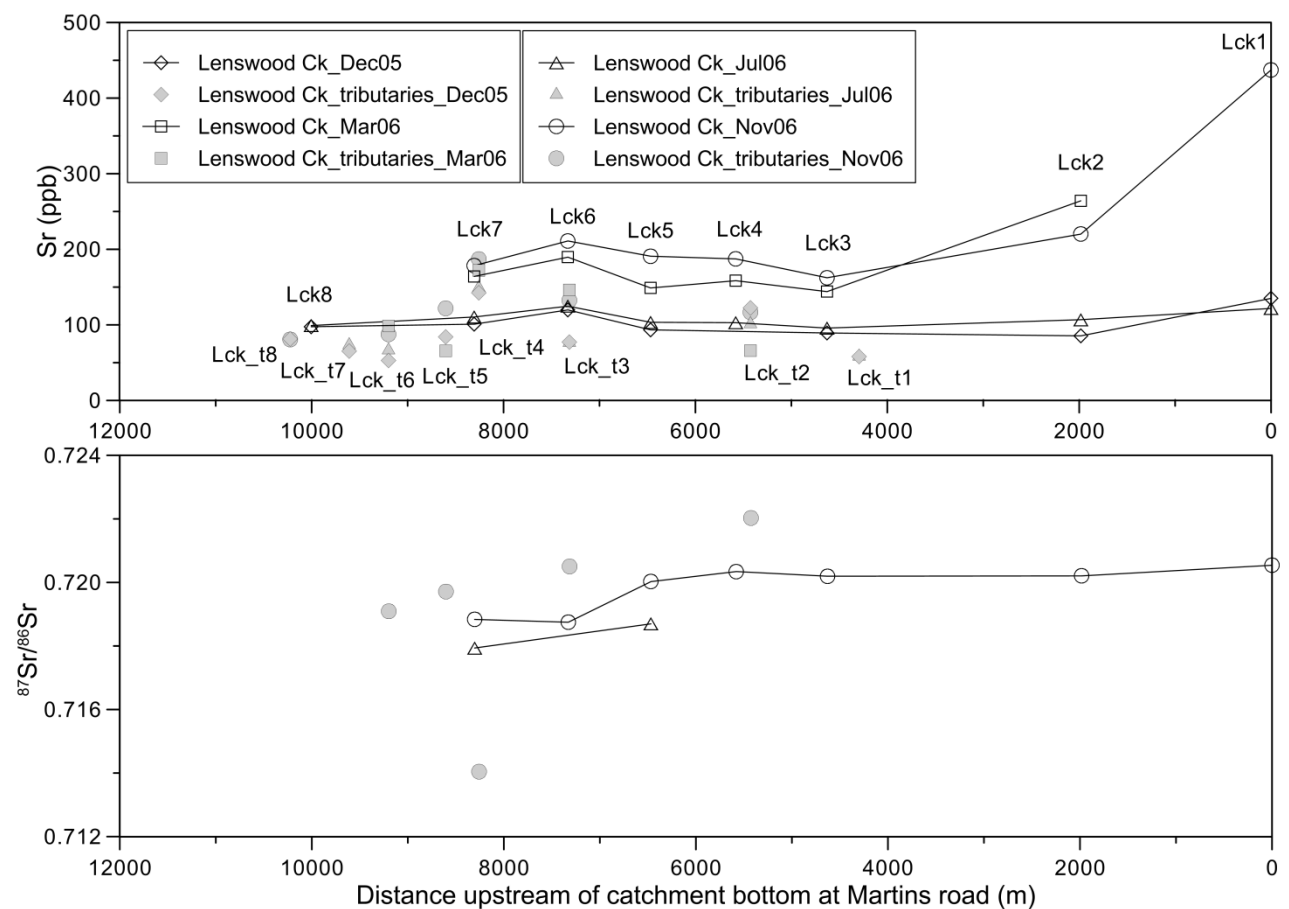


Figure 17. Strontium concentrations in Lenswood Creek in December 2005, March 2006, July 2006 and November 2006. $^{87/86}\text{Sr}$ ratio only for samples collected July 2006 and November 2006. Distances are measured upstream of catchment bottom at Martins Road (m)

The plot of $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ (Figure 18) shows that the majority of surface water samples in Lenswood Creek and its tributaries at the four different rounds had an isotopic signature that was more enriched than the groundwater samples, and represents a mixture of rainfall, surface runoff and groundwater input. Several of the tributaries and samples along Lenswood Creek during rounds 2 and 4 had an evaporative signature, falling to the right of the LMWL. The isotopic composition of Lenswood Creek in rounds 1 and 3 was more uniform than at rounds 2 and 4 and is likely to reflect the seasonal variations in local precipitation. Surface water samples from round 2 were typically more enriched in deuterium than in round 4, the latter being enriched with respect to rounds 1 and 3, but had slightly higher

RESULTS

chloride concentrations (Figure 15). The variation in deuterium and chloride concentrations was much greater in rounds 2 and 4 compared to rounds 1 and 3, as a result of the surface water being subjected to evaporative processes at those times.

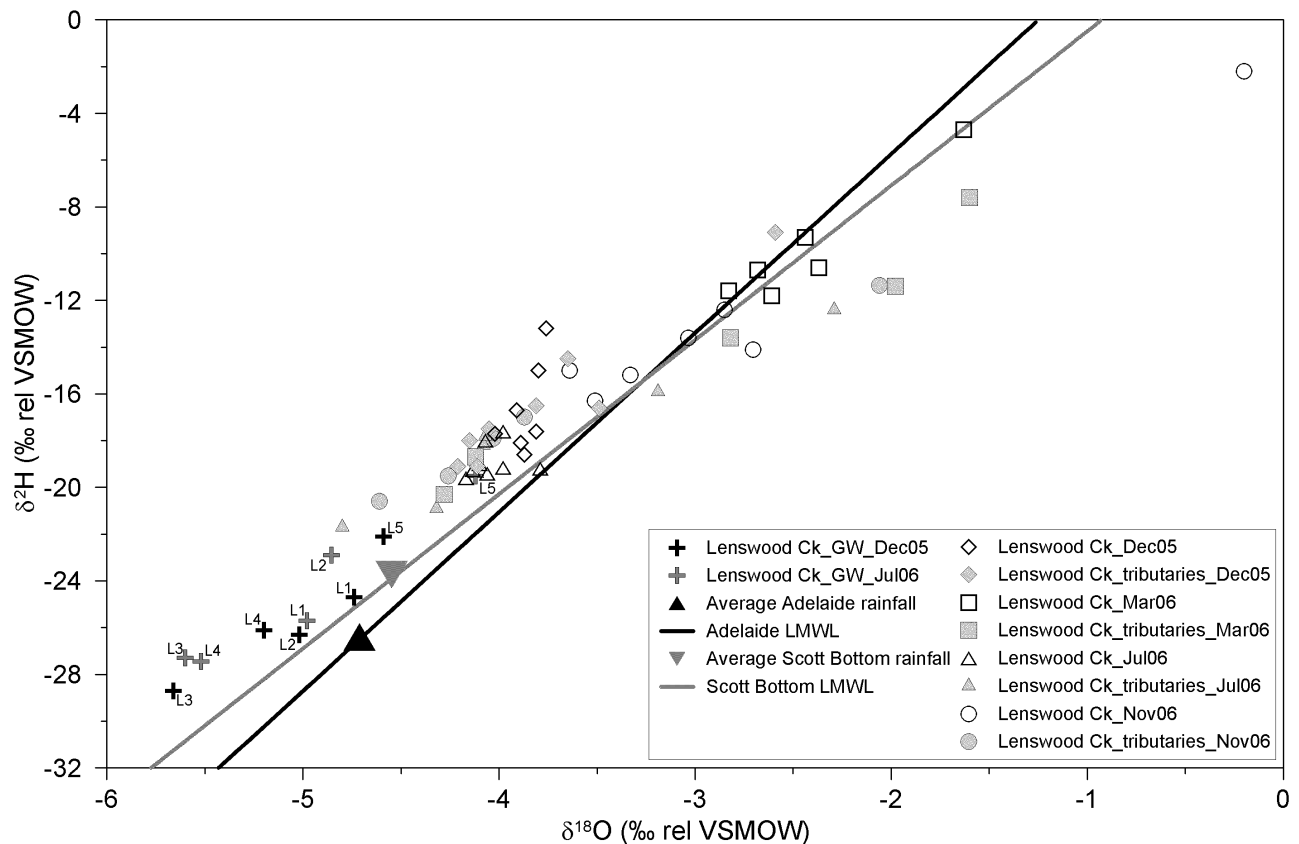


Figure 18. $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ for surface water and groundwater samples, LCC. The MWL for Adelaide is $\delta^2\text{H} = 7.7 \delta^{18}\text{O} + 9.6$. The mean weighted rainfall for Adelaide is $\delta^2\text{H} = -26.4$ ‰_{VSMOW} and $\delta^{18}\text{O} = -4.7$ ‰_{VSMOW}

4.2.3. HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN GROUNDWATER

The ^{222}Rn activities measured in the groundwater samples from the bores located in the LCC ranged from about 80 Bq/L to 500 Bq/L with the lowest concentrations in L5, which was taken from a well located in the Saddleworth Formation in the upper north-west of the catchment (Figure 16). The other samples were taken from bores located in the Woolshed Flat Shale, the dominant geological unit in the catchment. The chloride concentrations of the groundwater samples L2–L4 ranged from 100–200 mg/L and were higher than sample L5, which had a similar concentration to many of the surface water samples in the LCC. Sample L1, taken from a bore located in the lower reaches of the catchment in the Woolshed Flat Shale unit, had the highest chloride concentration (500 mg/L) compared to the other groundwater samples in the catchment.

The isotopic composition of the groundwater samples fall close to the mean Adelaide rainfall composition and above the LMWL (Figure 18). The average $\delta^2\text{H}$ and $\delta^{18}\text{O}$ ratios in the groundwater samples were -5.03 ‰ and -25.08 ‰, respectively. There was some variation in the ratios between the two sampling rounds, which may be due to seasonal variation (if the movement of groundwater is fairly rapid), but more likely because the groundwater sample represents a mixture of water from the aquifer over the entire production interval of the extraction well.

RESULTS

4.2.4. APPARENT GROUNDWATER AGES

The CFC data show that the apparent ages (CFC–12) of the groundwater samples from the five bores were modern, being less than 40 years of age (Table 2). However, the ^{14}C data indicates that samples L2 and L4 may be much older than samples L3 and L5. The conflict between the two age dating methods indicates that there may be either contamination of the CFC sample or that there was a source of ‘dead’ carbon (very low ^{14}C activity) which would make the groundwater appear older than it really is. Sample L1 was misplaced after collection in the field and hence could not be analysed for ^{14}C analysis.

Table 2. Groundwater age estimates for samples from bores in the LCC. Carbon–14 corrected ages are derived using the Fontes and Garnier (1979) correction model. N/S denotes no sample

GW sample ID	Well depth (m)	^{14}C activity (pmC)	$\delta^{13}\text{C}$ (‰)	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)
L1	21.95	N/S	N/S					1970	1980
L2	33.53	19.1	–14.0	5.16	0.26	13686	12531	1975	1990
L3	36	74.0	–18.2	2.95	0.96	2489	4317	<1965	1971
L4	21.34	59.8	–13.1	5.40	0.17	4251	2020	1967	1969
L5	55	71.1	–15.2	2.77	0.14	2820	3083	1970	1976

4.2.5. SURFACE WATER AND GROUNDWATER END MEMBERS

The graphs in Figure 19 show the surface water and groundwater ion to chloride ratios (Ca/Cl, Mg/Cl, Na/Cl, Br/Cl, SO_4/Cl and HCO_3/Cl) versus chloride concentration and their proximity to the respective seawater dilution lines. The plots of Ca/Cl, Mg/Cl, Na/Cl and Br/Cl against chloride shows that the samples from rounds 1 and 3 and the tributary samples from all rounds plot in a relatively tight cluster whilst the samples from rounds 2 and 4 have a much greater variation in concentrations. The high ion/chloride ratios of the groundwater samples compared to the seawater dilution line indicate processes of water-rock interaction. The groundwater sample L1 had much higher chloride concentration than samples L2 and L4 which were also from the same geological unit.

The plot of $^{87}/^{86}\text{Sr}$ ratio versus $1/\text{Sr}$ shows that the groundwater samples had a higher ratio than the surface water samples (Figure 20). There is no clear linear trend between the groundwater and surface water samples, and the typical average rainfall signature (0.709), implying that processes other than simple mixing are taking place. Other processes could include the evaporation of water that is a mix of groundwater and rainwater $^{87}/^{86}\text{Sr}$ ratios.

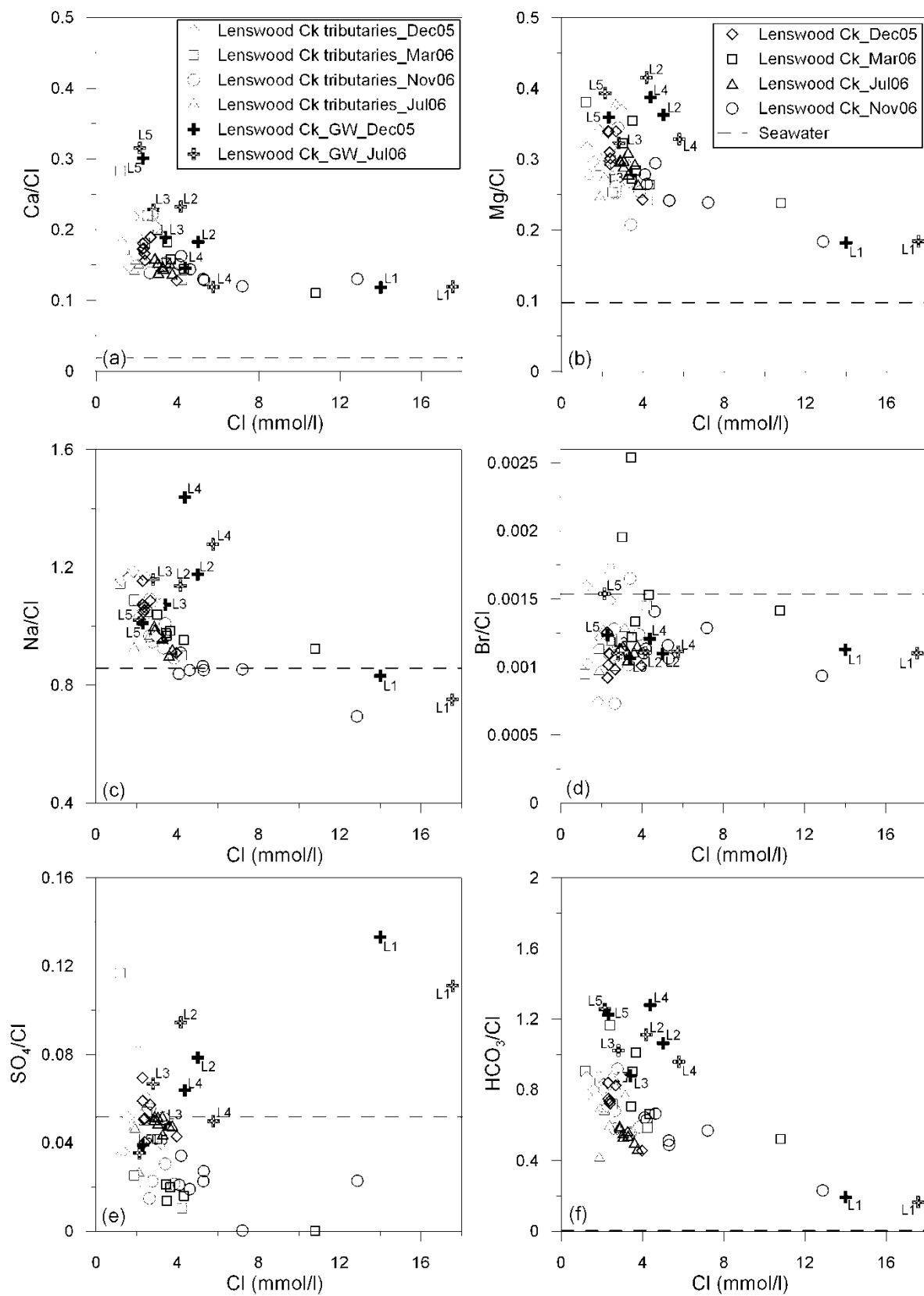


Figure 19. Composition diagrams of ion/chloride ratios Ca/Cl (a), Mg/Cl (b), Na/Cl (c), Cl/Br (d), SO₄/Cl (e) and HCO₃/Cl (f) versus chloride of surface water and groundwater in LCC

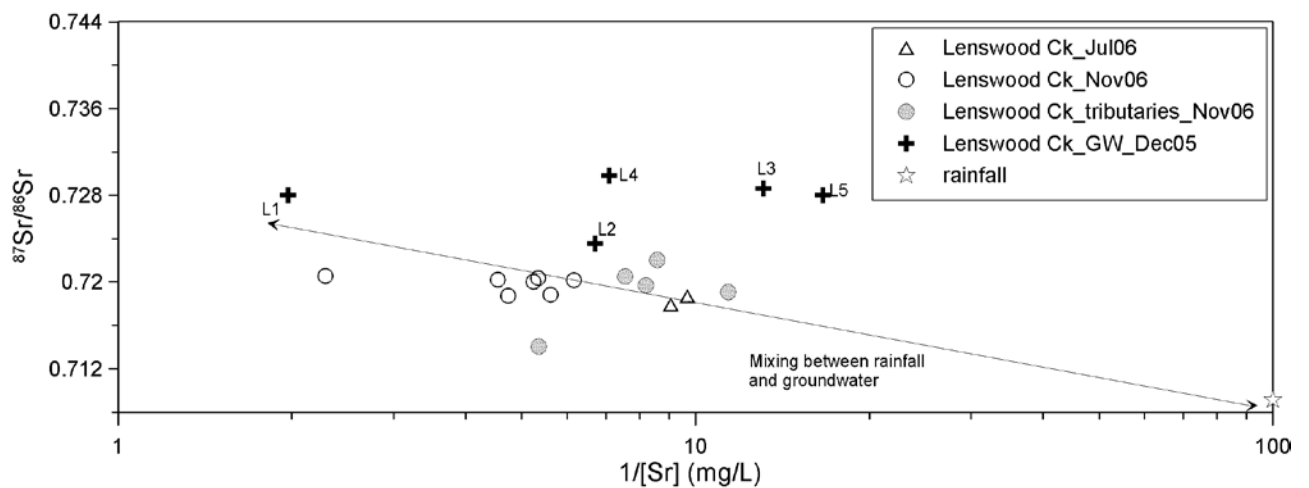


Figure 20. ⁸⁷/₈₆Sr ratios versus 1/[Sr] for surface water samples collected at rounds 3 and 4 and groundwater samples collected during December 2005 in LCC

4.3. KERSBROOK CREEK CATCHMENT

4.3.1. HISTORICAL DATA AND CREEK FLOW

Figure 21 shows the flow measurements and creek SEC from the gauging station (A5040525) in Kersbrook Creek located just above Millbrook Reservoir from October 2005 to December 2006. In late October to mid-November 2005 there were several rainfall events greater than 20 mm causing rapid response in flow and decrease in SEC in Kersbrook Creek just before round 1 in December 2005. The large flow event in early November was in response to a five day rainfall event with a maximum daily rainfall of 66 mm. The frequency of rainfall events increased in late April, however, there was little influence on creek flow, which rarely exceeded 1000 m³/day during the winter months when flow would normally be higher. For the month of May, the gauging station recorder was malfunctioning. From early August 2006 to December 2006, rainfall amount and frequency reduced considerably and corresponded to a decrease in creek flow. The SEC trends over the monitoring period appeared to increase quickly, shortly after the significant hydrological events, suggesting continuous base flow of fairly saline groundwater discharging to the creek.

The manual flow measurements during round 4 were very low at the sampling sites along Kersbrook Creek, with flows less than 8.6 m³/day, and at sites Kck6 and Kck1 (gauging station) there was no flow, just a series of pools. During round 2, sites Kck4 to Kck1 were a series of pools with minimal to no flow. Flow in the sampled tributaries at each of the four rounds was generally low to zero, and during some rounds the sample sites were disconnected from Kersbrook Creek due to in-stream dams.

RESULTS

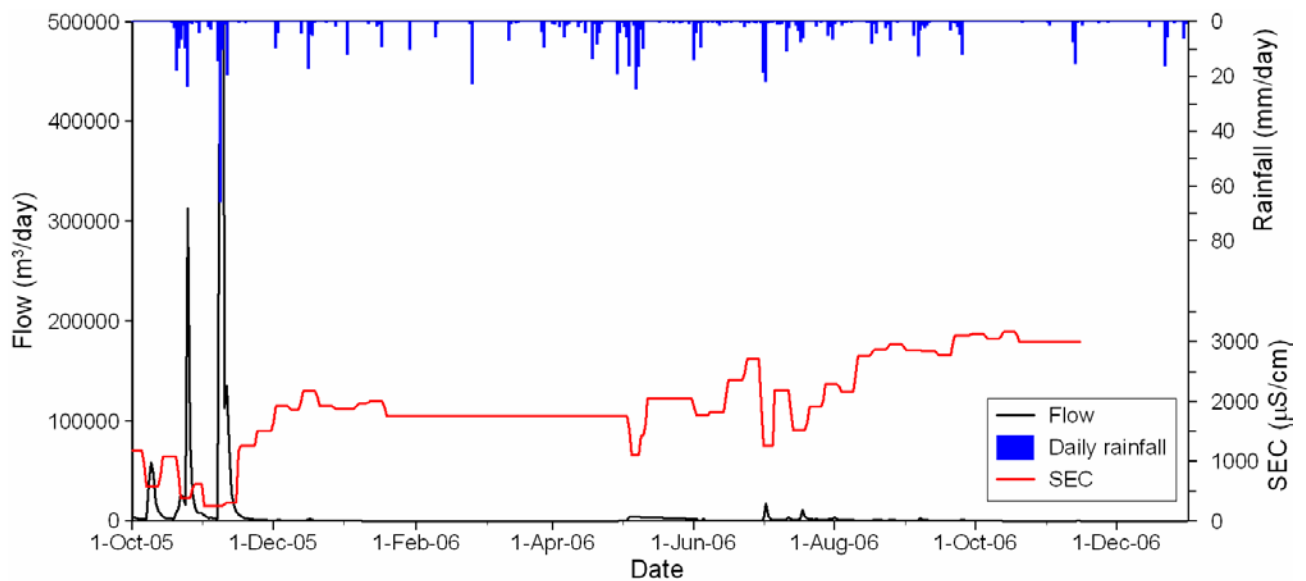


Figure 21. Creek flow, SEC (A5040525) and rainfall (A5040902) in the KCC from October 2005 to December 2006 (DWLBC 2007)

4.3.2. PHYSICAL, HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN KERSBROOK CREEK

The trends in the SEC along Kersbrook Creek were similar to the trends in chloride concentration (described later) showing notable increases in concentration between sites Kck5 and Kck2 (Figure 22). The trends in pH at each of the four rounds increased downstream with a pH of 6.5–7.5 between sites Kck7 and kck5 and a pH above 7.5 at sites Kck4 to Kck1. The measured water temperature at each of the sites along Kersbrook Creek during the four rounds showed a distinct decrease between Kck4 and Kck2. During round 3 (winter), the water temperature in Kersbrook Creek was generally less than 12°C whilst in round 1 (December) the temperature was typically above 18°C. The surface water temperatures in rounds 2 and 4 were similar to the average groundwater temperature (17.5°C) measured in the sampled bores in the KCC. The dissolved oxygen concentrations along Kersbrook Creek varied significantly between the different sampling rounds and also between sample sites. Similar to the other physical parameters, there was a marked decrease in dissolved oxygen concentration between Kck4 and Kck2, except during round 2.

RESULTS

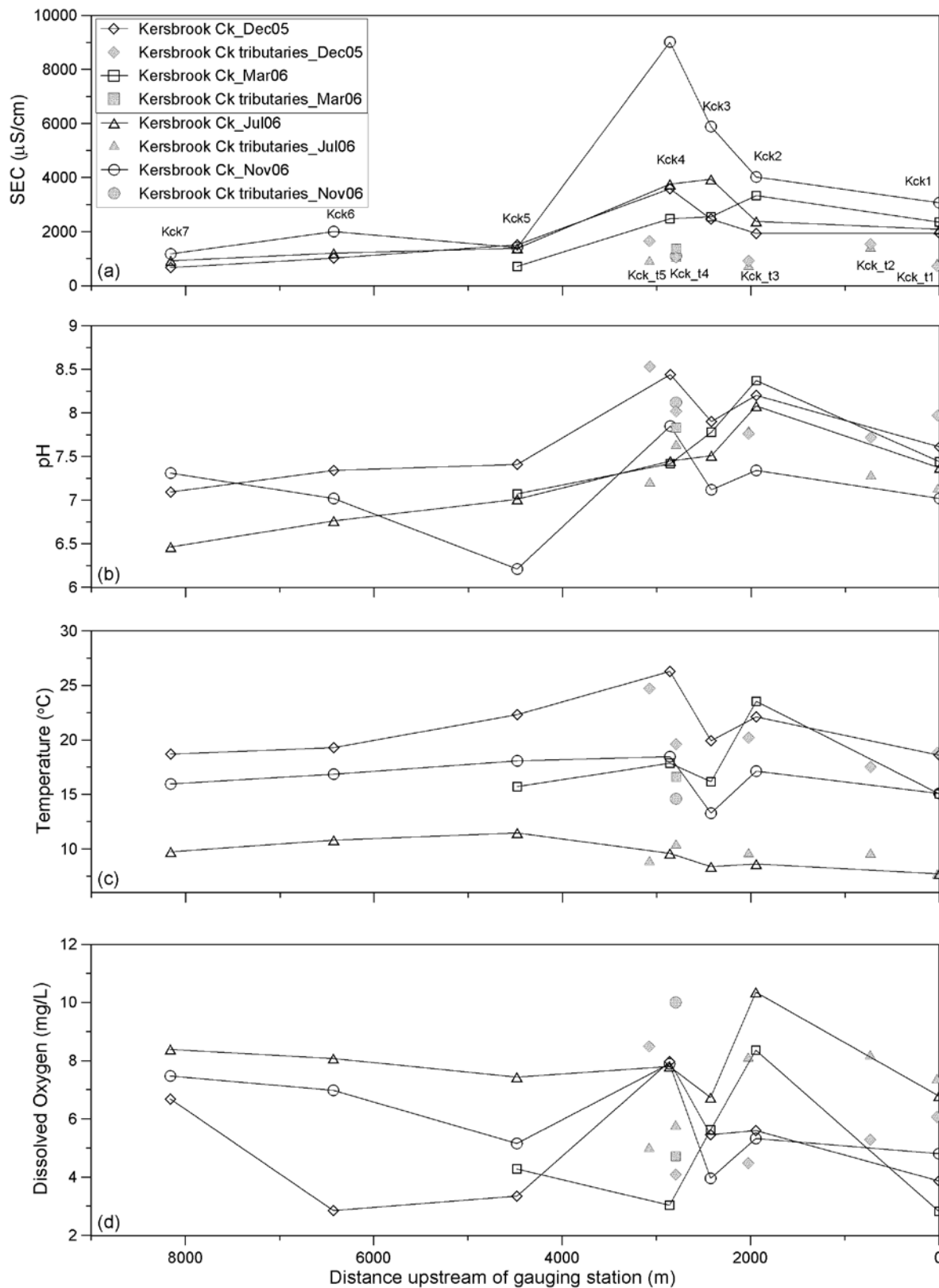


Figure 22. SEC (a), pH (b), temperature (c) and dissolved oxygen (d), in Kersbrook Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of gauging station (m)

RESULTS

The overall trend in ^{222}Rn activities in the four different rounds along Kersbrook Creek decreased from Kck7 to Kck6, then increased towards Kck4 where there was a sharp decrease to Kck3 followed by a sharp increase to Kck2 before decreasing again to Kck1 (Figure 23). The high activity at site Kck5 during round 4 may have been a result of sampling from a permanent pool 15 m further downstream, as the previously sampled site was dry. ^{222}Rn activities between Kck7 and Kck3 were generally lower in rounds 1, 2 and 4 compared to round 3 (winter) due to exchange with the atmosphere and ^{222}Rn decay as a result of much slower flow in the creek. At site Kck2, activities were greater during rounds 1 and 4, than in rounds 2 and 3. Contributions from the minor tributaries (Kck_t2, Kck_t3, Kck_t4 and Kck_t5) to the Kersbrook Creek were relatively small, and in many instances the sample locations were dry and disconnected from Kersbrook Creek by instream dams. Sample site Kck_t1 is located on a tributary with a small catchment area that discharges directly into the Millbrook Reservoir (Figure 24). Kck_t4 was the only site on a tributary that had water at each of the sampling rounds, however, the tributary was not always connected to Kersbrook Creek.

The deuterium composition along Kersbrook Creek varied significantly between the different sampling rounds, particularly rounds 3 and 2 (Figure 23). During rounds 2 and 4 there were similar trends between sample sites Kck5 and Kck1 with a more depleted signature at Kck3. The highly enriched isotopic signature at Kck6 in round 4 is a result of secondary evaporation, as the stream had reduced to a stationary pool at the time of sampling.

The trends in chloride concentration along Kersbrook Creek were similar in rounds 1, 3 and 4, and were close to identical as were the trends in the SEC measurements (Figure 23). The chloride concentration in round 3 increased from sites Kck7 to Kck5 then markedly increased to Kck3 where the concentration was more than double than at Kck5. It decreased sharply at Kck2 as a result of a low chloride contributions from a minor tributary (Kck_t3) with its confluence just above Kck2. A similar trend was seen in rounds 1 and 4, however, in round 4 the minor tributary (Kck_t3) was dry. Below Kck2 the chloride concentration decreased gradually to Kck1. Samples from sites Kck4 to Kck1 had much higher chloride concentrations than samples from sites Kck7 to Kck5, suggesting at least two different groundwater end members to Kersbrook Creek.

RESULTS

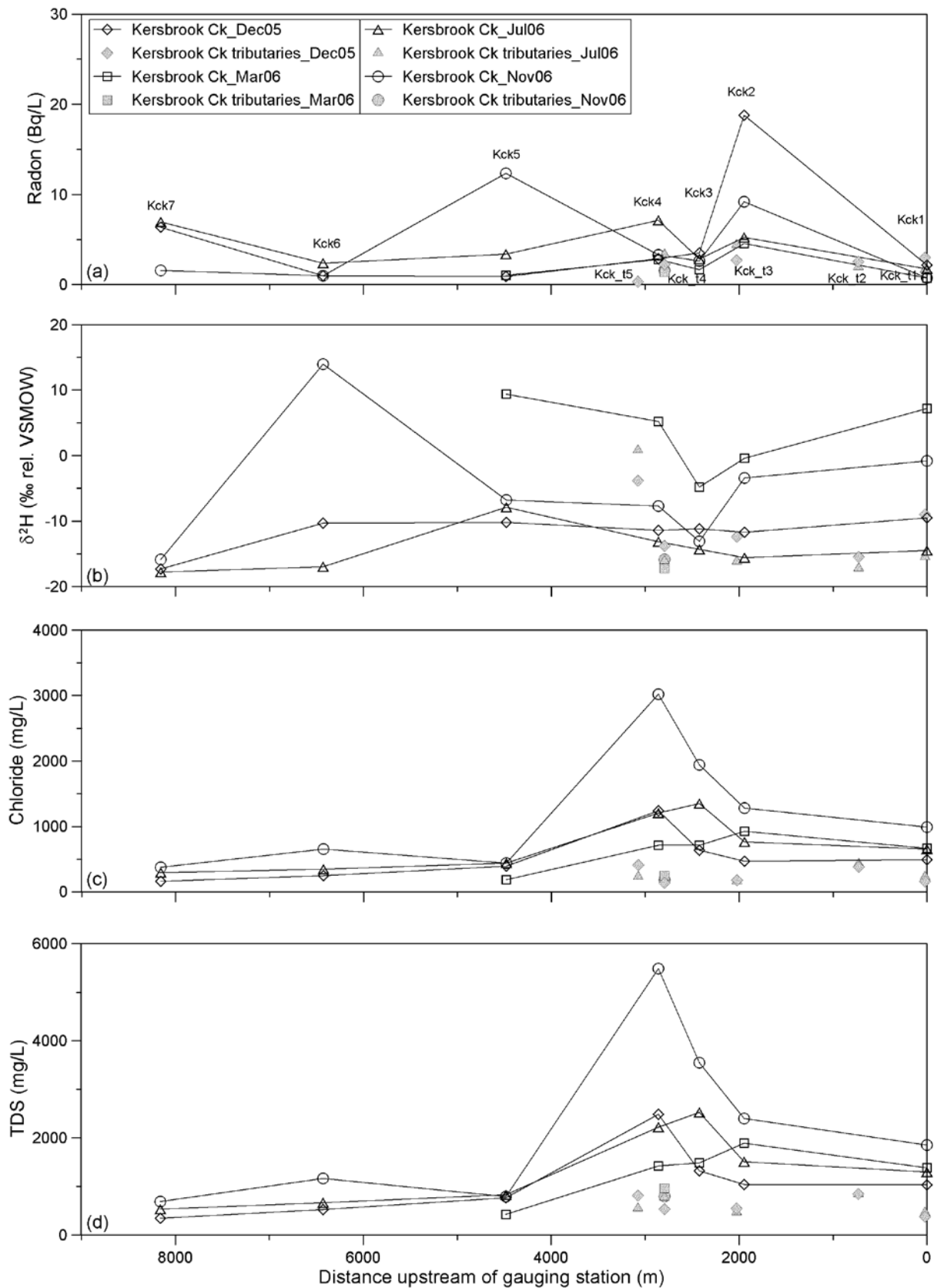


Figure 23. ^{222}Rn (a), deuterium (b), chloride (c) and TDS (d) in Kersbrook Creek in December 2005, March 2006, July 2006 and November 2006. Distances are measured upstream of gauging station (m)

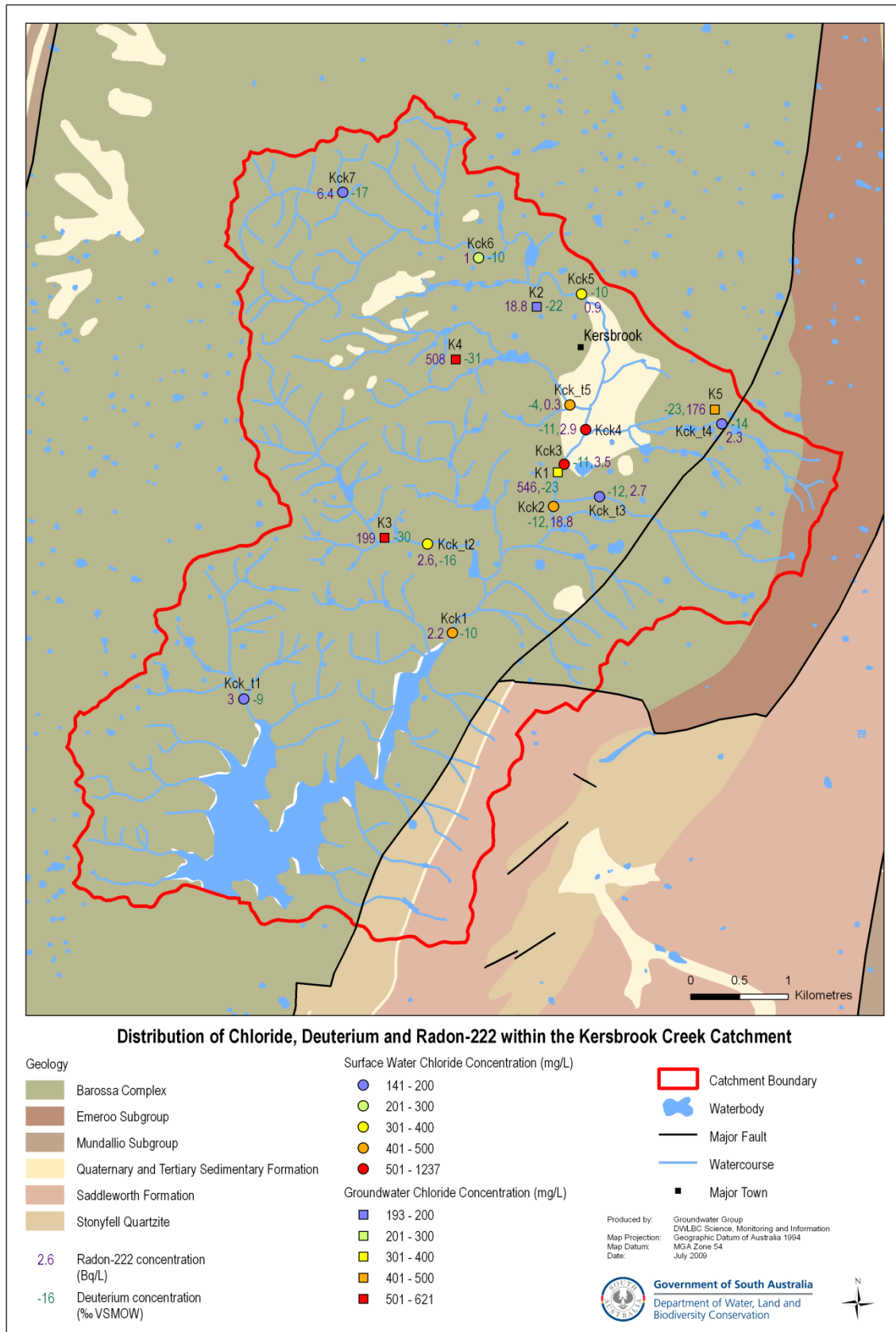


Figure 24. Spatial distribution of ²²²Rn (Bq/L), deuterium (‰_{VSMOW}) and chloride (mg/L) surface water and groundwater concentrations in the KCC, December 2005

RESULTS

The trends in strontium concentration along Kersbrook Creek were similar during each of the sampling rounds (Figure 25). The concentration was fairly similar between Kck7 and Kck5 but higher at Kck4, particularly during round 4. In round 2, the strontium concentrations between sites Kck4 and Kck1 were much more uniform, and do not show the peaks in concentration that were observed during the other rounds. The strontium concentrations in the tributaries were all lower than in Kersbrook Creek in the different rounds. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in round 4 showed an overall decrease from Kck7 to Kck2 then increase to Kck1.

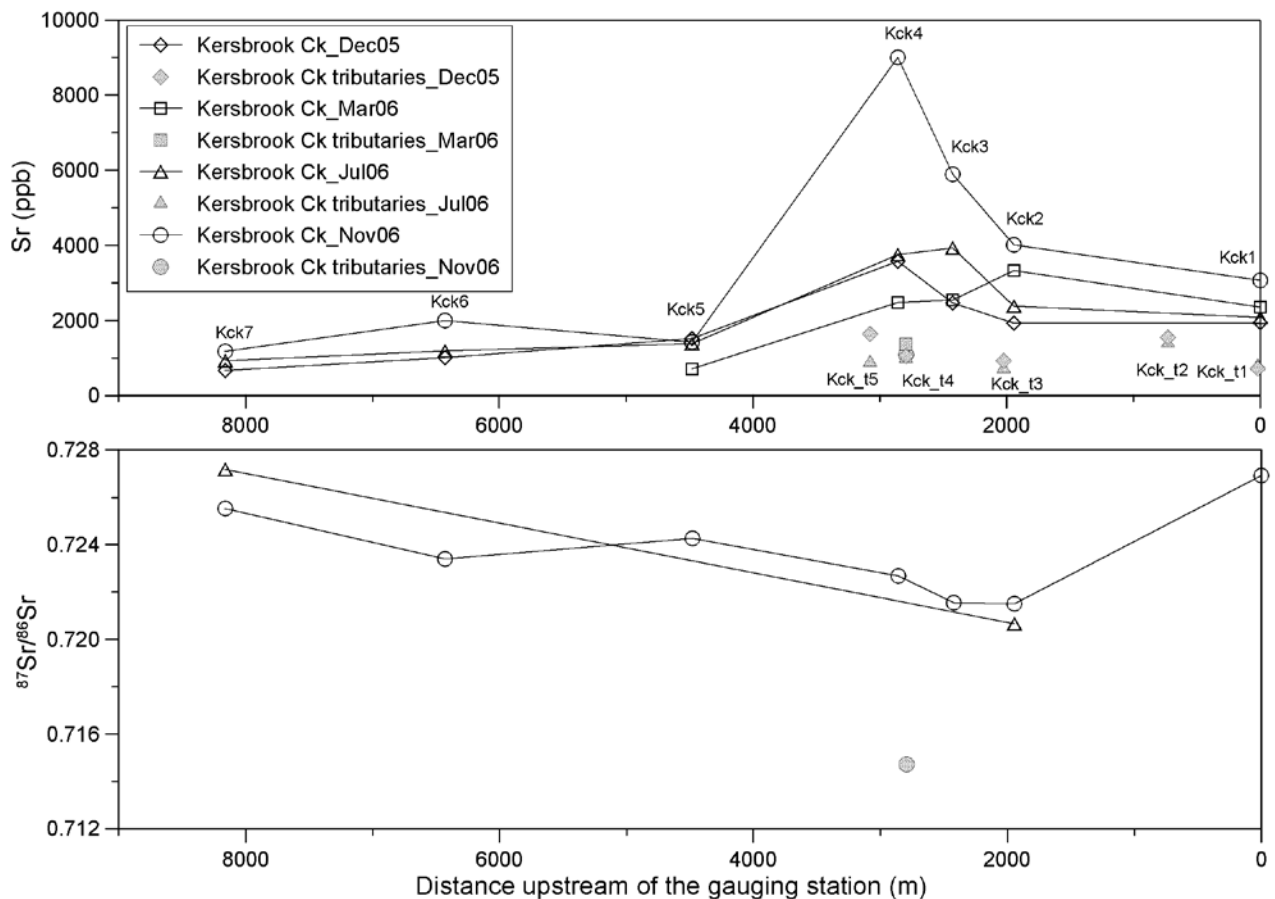


Figure 25. Strontium concentrations in Kersbrook Creek in December 2005, March 2006, July 2006 and November 2006. $^{87}\text{Sr}/^{86}\text{Sr}$ ratio only for samples collected July 2006 and November 2006. Distances are measured upstream of gauging station (m)

The stable isotope ratios of the surface water samples taken along Kersbrook Creek indicate the effects of evaporation in many of the samples, particularly during rounds 2 and 4, falling to the right of the LMWL along an evaporation line with a slope of 3.8–4.5 (Figure 26). In round 4, there was significant variation in the creek water sample compositions, and there was a greater increase in chloride concentration relative to deuterium enrichment at some sites. At site Kck5, the isotopic and chloride compositions were similar in rounds 1, 3, and 4 whilst during round 2 there was greater evaporative enrichment.

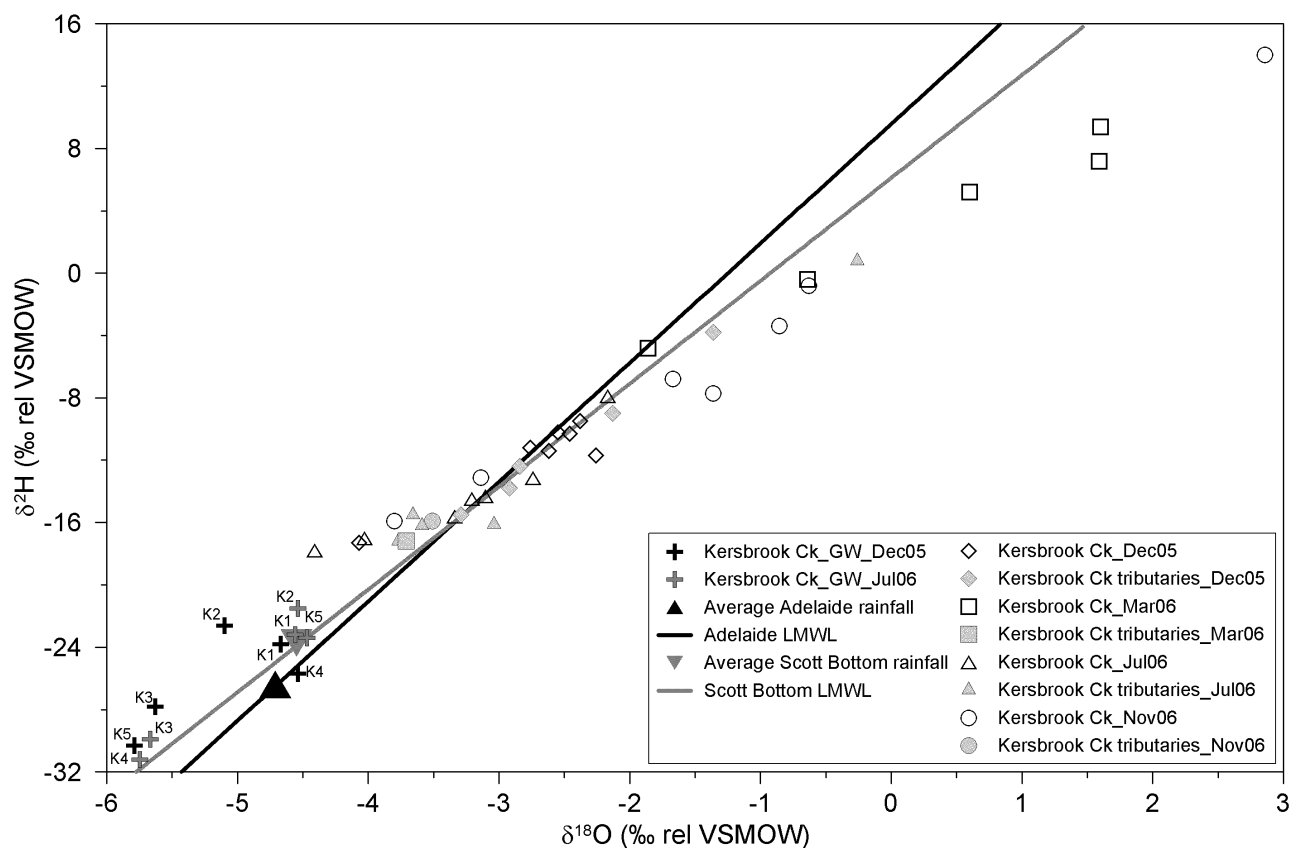


Figure 26. $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ for surface water and groundwater samples, KCC. The MWL for Adelaide is $\delta^2\text{H} = 7.7 \delta^{18}\text{O} + 9.6$. The mean weighted rainfall for Adelaide is $\delta^2\text{H} = -26.4$ ‰_{VSMOW} and $\delta^{18}\text{O} = -4.7$ ‰_{VSMOW}

4.3.3. HYDROCHEMICAL AND ISOTOPIC VARIATIONS IN GROUNDWATER

The ²²²Rn activities of the five sampled bores in the KCC were high, ranging from about 200–650 Bq/L, similar to other groundwater samples taken from bores constructed in the Barossa Complex (Tables B2 and B3). The chloride concentrations from the five sampled bores were also high, ranging from about 200–650 mg/L. Figure 26 shows that the stable isotope compositions of the groundwater samples plot in close proximity to the average Adelaide and Scott Bottom rainfall composition. Some are below the average but close to the LMWL, indicative of winter rainfall and subsequent winter recharge. The isotopic signatures were all less enriched than the surface water samples from Kersbrook Creek, which in many instances showed an evaporation signature. Groundwater samples K4 and K5 showed distinct differences in isotopic composition and solute concentration between the two sample rounds, either due to insufficient purging of the well or seasonal variation in the composition.

4.3.4. APPARENT GROUNDWATER AGES

The CFC and ¹⁴C data show that the apparent ages of the groundwater samples collected in the KCC were both modern and old, and that there was agreement between the two age dating methods (Table 3). The shallower groundwater samples K1, K2 and K4 had an apparent CFC–12 age that was less than about 35 years and ¹⁴C concentrations that were greater than about 75 pmC, which means that they contain some bomb-fallout ¹⁴C making them less than 50 years old. Samples K3 and K5 had no detectable CFCs and had ¹⁴C concentrations that were less than about 70 pmC, indicating that the groundwater is not modern and much older than the other samples.

RESULTS

Table 3. Groundwater age estimates for samples from bores in the KCC. Carbon-14 corrected ages are derived using the Fontes and Garnier (1979) correction model

GW sample ID	Well depth (m)	¹⁴ C activity (pmC)	$\delta^{13}\text{C}$ (‰)	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)
K1	48.64	78.8	-17.1	2.22	0.44	1971	3314	1968	1971
K2	45.6	100.2	-19.5	1.49	0.38	-16	3148	1970	1973
K3	85	53.5	-17.8	3.65	0.18	5171	7900	<1965	<1965
K4	76.8	85.1	-15.7	5.65	0.44	1334	1958	<1965	1979
K5	83.6	70.9	-18.2	2.98	0.46	2840	5374	<1965	<1965

4.3.5. SURFACE WATER AND GROUNDWATER END MEMBERS

The graphs in Figure 27 show the surface water and groundwater ion to chloride ratios (Ca/Cl, Mg/Cl, Na/Cl, Br/Cl, SO₄/Cl and HCO₃/Cl) versus chloride concentration and their proximity to the respective seawater dilution lines. There is a relatively large variation in the ratios of the surface water samples from each of the sites and also during different flow conditions. The tributaries tended to have higher ion/Cl ratios than most of the samples from the main creek which may reflect greater influence of groundwater at these locations. The surface water samples from round 4 had particularly high chloride concentrations and reflect evaporation processes. The groundwater samples had similar ion/Cl ratios to the surface water samples except for SO₄/Cl where the ratio was greater.

The ⁸⁷Sr/⁸⁶Sr ratio versus 1/Sr plot shows that the groundwater samples were quite variable, even though they are all from bores located in the Barossa Complex aquifer, which indicates different sources within the same rock type and preferential weathering of minerals (Figure 28). There is no clear linear mixing trend between groundwater and rainfall, however, the surface water samples tend to plot in two groups which correspond to the sample locations in the catchment. These two groups had similar ⁸⁷Sr/⁸⁶Sr ratios, however, samples from sites Kck5 to Kck7 had much lower strontium concentrations compared to samples from sites Kck1 to Kck4. The higher Sr concentrations of the samples from sites Kck1 to Kck4 suggest another groundwater source that has not been identified with the five sampled bores in the catchment, or that the surface water has undergone evaporation at these locations.

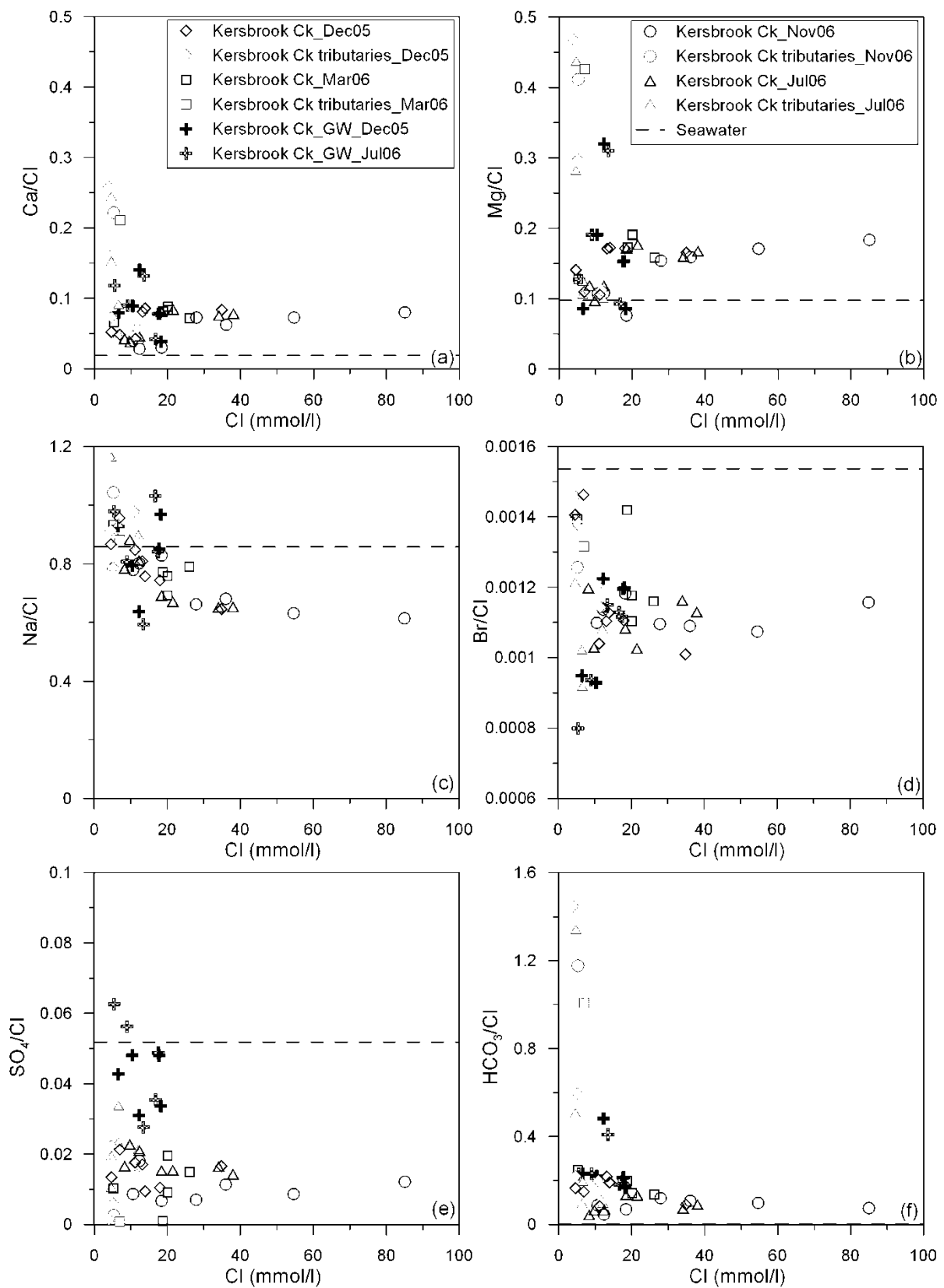


Figure 27. Composition diagrams of ion/chloride ratios Ca/Cl (a), Mg/Cl (b), Na/Cl (c), Br/Cl (d), SO₄/Cl (e) and HCO₃/Cl (f) versus chloride of surface water and groundwater in KCC

RESULTS

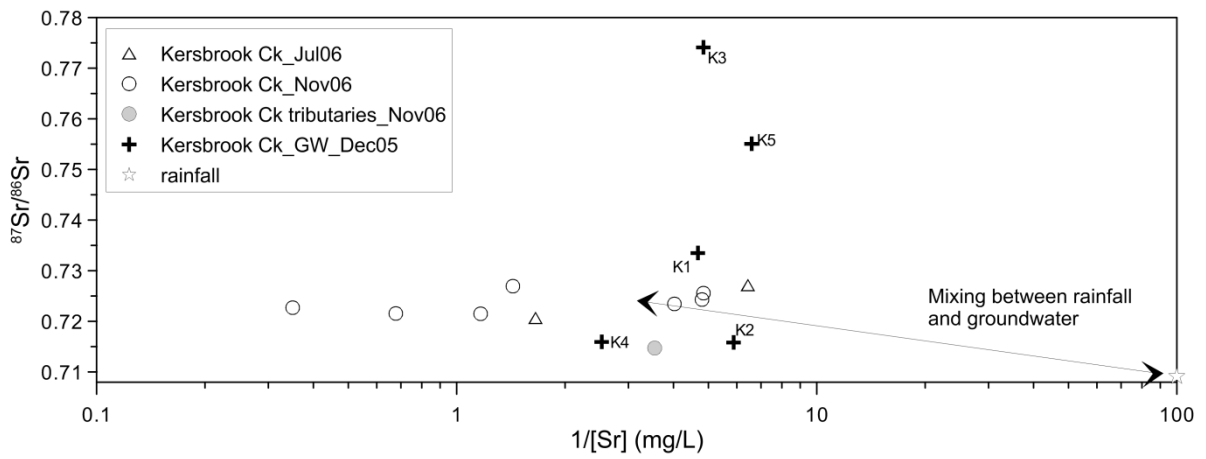


Figure 28. ⁸⁷Sr/⁸⁶Sr ratios versus 1/[Sr] for surface water samples collected at rounds 3 and 4 and groundwater samples collected during December 2005 in KCC

5. DISCUSSION

5.1. COX CREEK CATCHMENT

5.1.1. HYDROCHEMICAL VARIATIONS ALONG COX CREEK

The trends in the hydrochemical, ^{222}Rn and isotope ‘run of river’ tracer data from the four seasonally different sampling rounds show the likely locations of groundwater contributions to Cox Creek along its length at different times of the year. The data also highlighted the importance of flow pathways and residence times of the small ephemeral tributaries to Cox Creek at different times of the year, which were in most instances sustained by groundwater.

The temporal variations in the ^{222}Rn activities, isotopes and ion concentrations are a result of rainfall dilution and evaporative processes and contribution from small ephemeral tributaries to Cox Creek. The contributions of surface water from minor tributaries had some influence on lowering solute concentrations in Cox Creek, particularly during the wetter periods (round 1: December 2005 and round 3: July 2006). During round 2 (March 2006) and round 4 (November 2006), surface water contributions from the minor tributaries were low to non-existent and hence had little influence on the solute concentrations in Cox Creek.

The increase in solute concentration downstream in the main channel is evidence of continuous lateral groundwater inputs to the creek and/or processes of evapotranspiration. The effects of evapotranspiration were minimal according to the stable isotope data. Continuous groundwater inflow was evident, based on the high ^{222}Rn activity along some creek reaches, which indicates a balance between groundwater inflow, gas exchange with the atmosphere, and radioactive decay. The ^{222}Rn activity cannot be used as a stand-alone tool in determining groundwater inflow, as there are several physical and geological processes that affect its concentration. The presence of rapids or turbulent flow is likely to increase the removal of ^{222}Rn through gas exchange (Ellins, Roman-Mas & Lee 1990). Conversely, the hyporheic zone (sediment interface on the creek bed) may contribute a source of ^{222}Rn to the creek (Lamontagne & Cook 2006).

Groundwater flow paths in CCC tend to be towards the creek, and may vary due to heterogeneities in the soil and bedrock. Groundwater discharge in a fractured rock environment primarily occurs through discrete point sources related to open fractures, as compared to the more diffuse, continuous seepage zones typically found in a porous media environment (Oxtobee & Novakowski 2002). These groundwater ‘hotspots’ are present over a scale of 1–2 km along Cox Creek. These would not be easily identified on a potentiometric map constructed from the limited head data measured in the catchment without the use of the tracer data. Downstream of Cck9, Cox Creek traverses a major fault between the Mundallio Subgroup and the Barossa Complex and there is a corresponding increase in ^{222}Rn activity. Cox Creek traverses another fault system near Cck5, possibly another groundwater input zone, before crossing the Barossa Complex/Emeroo Subgroup boundary upstream of Cck4. The ^{222}Rn activities are higher at locations where Cox Creek crosses the Burra Group lithology compared to the Barossa Complex, despite ^{222}Rn activities being much greater in the groundwater sampled from the wells located in the latter. This may be attributed to the reduced permeability of the Barossa Complex and the more developed fracture network and therefore stronger hydraulic connection of the Burra Group with Cox Creek. Comparison of the ^{222}Rn activities, isotope and hydrochemical stream data with the geology across the catchment indicates that the major fault systems, where there is greater fracture density, are

important zones where the contribution of groundwater input to Cox Creek may be greater than at other reaches along the creek.

5.1.2. SOURCES AND EVOLUTION OF GROUNDWATER

Spatial variations in the hydrochemistry of the surface waters and groundwaters are a result of residence time, variation in source, atmospheric inputs and land use. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and strontium concentrations along Cox Creek were quite similar and had a composition similar to the groundwater that is dominantly from aquifers located in the Burra Group. This is supported by the $\delta^2\text{H}$, $\delta^{18}\text{O}$ and hydrochemical data, which shows that the surface waters have become progressively enriched by evaporation from a groundwater end member with a composition similar to the geological units in the Burra Group. The chloride concentrations in groundwater from the Barossa Complex are much greater than those of the Burra Group, implying that this aquifer has a fairly minor contribution to streamflow in Cox Creek. The Barossa Complex covers a large area in the middle of CCC and hence groundwater contribution to Cox Creek in this area would be minimal.

The apparent groundwater ages that were determined in this investigation by CFC and ^{14}C techniques are similar to the tritium and ^{36}Cl age data reported by Ivkovic et al. (1998) and Radke et al. (2000), which showed that the majority of groundwaters in the Piccadilly Valley and Southern MLR were modern or had a modern component (<50 years). The existence of modern water at considerable depth suggests that groundwater movement occurs primarily via preferential flow paths. Therefore, effective recharge would be fairly rapid to the FRAs in the CCC and groundwater discharge to surface drainage should respond accordingly. This implies that the shallow groundwater in the alluvial aquifers would dominantly be modern water with the groundwater flowpaths reflecting the local topography of the surface drainage catchments.

A report by Barnett and Zulfic (1999) concluded that 20% of annual rainfall recharges the FRAs in the Piccadilly Valley area (upper reaches of the CCC) and that the watertable closely matches the seasonal and long-term fluctuations in rainfall. It was reported that the current pumping regime post-1970 was below the determined sustainable yield of the resource, however, the impact of groundwater pumping on baseflows was largely unknown. The results from this investigation suggest that the groundwater contribution to streamflow generation in the CCC is dominantly sourced from the geological units of the Burra Group located in the north and south of the catchment and does not appear to vary during the different seasons. Any development of the aquifers within this geological unit will have impacts on streamflow and it is essential that the level of these impacts be considered for the long-term management of the water resources. The groundwater contribution from the shallow aquifers in the quaternary deposits to Cox Creek are unknown, however, they are likely to provide significant 'bank storage', supplying minimal flows to the creek between storm events.

5.2. LENSWOOD CREEK CATCHMENT

5.2.1. HYDROCHEMICAL VARIATIONS ALONG LENSWOOD CREEK

The hydrochemistry, stable isotopes of water and ^{222}Rn activity data showed that the Lenswood Creek was a gaining creek along much of its length, and groundwater discharge was occurring at each of the four different rounds. Lenswood Creek was also likely to be influenced by the different rock types and presence of major fault zones that it traversed (Figure 16). Between sites Lck8 and Lck3, the Lenswood Creek travels parallel to a major fault zone in the Woolshed Flat Shale unit and bedrock outcrops are frequent along the creek bottom forming a series of interconnected pools. Along the Lenswood Creek valley, between Lck7 and Lck4, quaternary sedimentary deposits overlie the Woolshed Flat Shale and another major fault zone. It appears that the fault zones directly beneath the creek influence the

hydrochemical composition of the surface water samples. This was evident at sites Lck6 and Lck3 where there were high ^{222}Rn activities which indicated likely groundwater input at these locations. The high ^{222}Rn activity measured in the major tributary (Lck_t3) just above its confluence with Lenswood Creek below site Lck6 was also likely to be associated with the fault zone. The high ^{222}Rn activity in the smaller tributaries (Lck_t5, Lck_t6, Lck_t7 and Lck_t8) that fed this major tributary represent a significant groundwater contribution and is likely to be associated with the Saddleworth Formation aquifer in the north-west of the LCC.

The trends in chloride concentration during rounds 1 and 3 were similar and had overall lower concentrations than during rounds 2 and 4 (drier periods) which is indicative of surface runoff events. The higher annual runoff in rounds 1 and 3 should reduce the surface water residence time in the creek and therefore a lesser amount of surface evaporation should occur. In comparison, reduced and slower flows in Lenswood Creek during rounds 2 and 4 resulted in the stable isotopes and solute concentrations increasing along some reaches of the creek. This increase may be a result of surface evaporation and/or contribution of irrigation drainage water, which represents an evaporated groundwater signature.

5.2.2. SOURCES AND EVOLUTION OF GROUNDWATER

The LCC, like the CCC, has been extensively developed for irrigated agriculture and therefore there is an irrigation end member to creek flow, which is likely to be more dominant during the drier months when irrigation is typically used. The irrigation end member represents groundwater which has been exposed to evapotranspiration processes within the soil zone before draining to the aquifer or discharging directly via interflow to surface water features. The water from the minor tributary (Lck_t4) contributing just below site Lck7 was likely to be a source of surface water runoff from the Lenswood Coldstore and bowling green upstream of the sampling site. The groundwater contributing end members to Lenswood Creek are from Woolshed Flat Shale and the Saddleworth Formation, the two main geological units within the catchment. The presence of shallow Quaternary deposits and regolith is also likely to influence the hydrochemical composition of the surface water. The aquifers within these are also likely to contribute to streamflow generation, however, the contribution is not likely to be as significant as that from the FRAs.

5.3. KERSBROOK CREEK CATCHMENT

5.3.1. HYDROCHEMICAL VARIATIONS ALONG KERSBROOK CREEK

The hydrochemical, stable isotope and ^{222}Rn activity data has shown that Kersbrook Creek is a gaining surface water system along many of its reaches. The increases in solute concentrations and isotopic enrichment cannot be explained only by evaporation processes and therefore there must be a contribution from groundwater. Along the creek there are several permanent pools which are sustained by groundwater input throughout the year. Flow in Kersbrook Creek ceases each year and generally commences flowing again later than most streams in surrounding catchments (Water Data Services 2003). During round 2 (March 2006) the creek flow was primarily baseflow and from sites Kck4 to Kck1 the creek was reduced to a series of permanent pools. Similar conditions prevailed in round 4 (November 2006) with a series of permanent pools existing from sites Kck6 to Kck1. It is when the creek starts flowing again that there is a flushing of solutes from the previously dry reaches of the creek as well as the evapo-concentrated water within the permanent pools. Based on a volumetric water balance and measured flow rates at the gauge station, the water residence time in Kersbrook Creek is typically less than a week during winter periods but may be in the order of months during summer when flow is at its lowest. The main tributaries have a fairly insignificant role in generating flow in Kersbrook Creek.

Flow was low to non-existent during the four sampling rounds in the tributaries, and in many cases the sample sites were disconnected from Kersbrook Creek by in-stream dams.

The relatively high ^{222}Rn activities and solute concentrations measured at the sites along Kersbrook Creek suggest that there is groundwater inflow along many of its reaches throughout the year. In particular, the creek was gaining from groundwater between sites Kck6 and Kck4 and sites Kck3 and Kck2. Over a relatively short distance between sites Kck4 and Kck3, the ^{222}Rn activities decreased rapidly (except in round 1: December 2005), which suggests that groundwater input to this part of the creek is minimal. The increases in ^{222}Rn activities between Kck3 and Kck2 indicate continuous groundwater input to Kersbrook Creek along this reach. Decreases in activity from sites Kck2 to Kck1 are a result of ^{222}Rn decay and exchange with the atmosphere over a distance of several kilometres combined with slower flow conditions as the creek meanders through thick sedimentary deposits. The change in ^{222}Rn activity between these two sites is much greater during the drier periods (rounds 2 and 4) due to the low to no flow conditions in the creek. The existence of permanent pools along this reach of the creek and detectable ^{222}Rn activities indicated small but steady groundwater input.

5.3.2. SOURCES AND EVOLUTION OF GROUNDWATER

The hydrochemistry, stable isotopes of water and $^{87}\text{Sr}/^{86}\text{Sr}$ ratio data identified that there were two main groundwater sources contributing to gaining flow conditions in Kersbrook Creek: one source in the upper reaches of the catchment that had a low solute concentration, and the other source with a high solute concentration in the middle of the catchment. The surface water samples collected at the individual sites along Kersbrook Creek indicate that there was significant surface water evaporation occurring along its length, particularly during the drier periods (rounds 2 and 4), as a result of the warmer temperatures and longer residence time in the creek. The higher flows during December 2005 and July 2006 resulted in lower residence time and reduced evaporation. However, the isotopic and chemical compositions of the surface water represented evaporated groundwater.

Whilst the Barossa Complex aquifer typically has high solute concentrations, there are large colluvial/alluvial deposits along the eastern side of Kersbrook Creek that are another likely source of the high solute concentrations measured between sites Kck5 and Kck2. The land in this area has been predominantly cleared of native vegetation for grazing. As a result, there would be increased recharge, and a flushing of solutes from the sedimentary deposits, which would slowly discharge to the surface water features.

The apparent groundwater ages from the Barossa Complex aquifer, determined from the CFC and ^{14}C data, are a combination of modern and older waters suggesting that the movement of groundwater through the aquifer is relatively rapid in some areas of the catchment.

6. CONCLUSIONS AND RECOMMENDATIONS

The groundwater–surface water investigations undertaken in the Cox, Lenswood and Kersbrook Creek Catchments have shown that there are strong hydraulic connections between the surface water and groundwater systems in these catchments. The comparison between different hydrological events and times of the year has highlighted that these hydraulic connections are significant and that groundwater input is a component of surface water flow throughout the year.

The results showed that in the three catchments there are dominantly gaining surface water systems, in which groundwater discharging into watercourses contributes to streamflow. The high spatial density of sample points allowed a ‘run of river’ analytical approach, providing the detail necessary to assess the varying degree of connectivity between the surface water and groundwater systems at different parts of the three catchments. At some locations, higher groundwater discharge to the creeks appears to be correlated with the changes in the creek’s underlying geology and the presence of major fault zones. A lower density of sample locations would not have enabled identification of such influences where the creeks traversed changes in geology.

Other key findings were the presence of groundwater fed permanent pools along some creek reaches, which provide important refuges for aquatic habitat. Also of significance was the discharge of groundwater which occurred in the upper reaches of the catchments, providing small but, in some cases, continuous flow to the tributaries of the main creek.

The strong hydraulic connections between the surface water and groundwater imply that groundwater development in these catchments is likely to have an impact on both the surface water and groundwater resources. In gaining stream systems such as these, increased groundwater extraction may impact on the connectivity state between surface and groundwater systems, potentially causing a reduction in streamflow and duration. Significant reductions in groundwater table elevation may ultimately cause groundwater levels to drop below the elevation of the surface water system such that it becomes a losing type system, eliminating baseflows and posing a threat to the sustenance of permanent pools.

Further work is required to provide quantitative estimates of the groundwater contribution to the surface water systems. This could be carried out using numerical modelling or a solute mass balance approach, supported by the hydrochemistry and isotope data that was collected in this investigation.

APPENDICES

APPENDIX A

Table A1. Construction details of the sampled groundwater bores in the Cox, Lenswood and Kersbrook Creek Catchments

Catchment	Unit number	Easting	Northing	Permit number	Ground elevation (m AHD)	Depth from surface (m)	Diameter (mm)	Casing depth (m)	Production zone from (m)	Production zone to (m)	Mid-production zone (m)	Aquifer monitored	Sample ID
Cox	662821735	293422	6128525	65089		39	203	27.8	27.8	41	34.40		C1
Cox	662806565	292052	6126415	2755	488.3	25	140	20	20	25	22.50	Ndw	C2
Cox	662806696	294077	6125635		417	30.46	152					Lb	C3
Cox	662806815	292853	6127810		474	36.55	203	30.46	30.46	36.55	33.51	Nol	C4
Cox	662806698	294841	6125554		430	29	153					Lb	C5
Lenswood	662809289	302438	6128112			21.95					20.12		L1
Lenswood	662810368	301765	6134816			33.53	102	6.1	6.1	33.53	19.82		L2
Lenswood	662816124	298498	6132181	27962	515	36	152	27	27	36	31.50	Ndw	L3
Lenswood	662809234	300424	6129387			21.34							L4
Lenswood	662816984	300317	6135088	33737		55	205	9.5	9.5	55	32.25	Nds	L5
Kersbrook	662803226	303127	6147623		324	48.64		1.82	1.82	48.64		Lb	K1
Kersbrook	662803220	302907	6149327		356	45.6	152	30.48	30.48	45.6	38.04	Lb	K2
Kersbrook	662808992	301342	6146949	5104	340	85	152	30	30	85	57.50	Lb	K3
Kersbrook	662806884	302074	6148785	1247	364	76.8	150	55	55	76.8	65.90	Lb	K4
Kersbrook	662806075	304741	6148271	2432	361	83.6	152	26.6	26.6	83.6	55.10	Lb	K5

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APPENDIX B

Table B1. Field measurements of collected groundwater samples in the Cox, Lenswood and Kersbrook Creek Catchments

Catchment	Sample ID	Collection date	DO ppm	Field SEC µS/cm	pH	Redox mV	Temp °C	Field Alkalinity (HCO ₃ ⁻) mg/L
Cox	C1	7-Dec-2005	3.4	711	6.4	-228	15.3	84
Cox	C2	8-Dec-2005	0.0	277	5.8	-173	15.2	59
Cox	C3	8-Dec-2005	0.6	672	6.3	-225	16.6	104
Cox	C4	8-Dec-2005	1.2	726	7.5	165	15.8	224
Cox	C5	9-Dec-2005	1.2	470	6.4	-5	16.1	122
Cox	C1	3-Aug-2006	2.2	592	6.2	191	14.9	96
Cox	C2	3-Aug-2006	1.0	250	6.0	144	14.7	36
Cox	C3	3-Aug-2006	1.6	604	6.5	-4	15.1	100
Cox	C4	25-Aug-2006	1.7	675	7.2	63	15.4	200
Cox	C5	3-Aug-2006	2.4	292	6.4	74	15.2	94
Lenswood	L1	19-Jan-2006	2.5	1434	6.6	-27	17.6	132
Lenswood	L2	19-Jan-2006	10.3	1215	7.1	36	16.2	270
Lenswood	L3	19-Jan-2006	0.3	833	6.4	-69	15.2	0
Lenswood	L4	23-Jan-2006	3.1	1260	7.2	14	16.8	294
Lenswood	L5	25-Jan-2006	10.5	657	6.5	40	16.6	130
Lenswood	L1	3-Aug-2006	1.2	2210	6.6	-12	17.3	168
Lenswood	L2	4-Aug-2006	3.2	900	7.5	-96	15.2	264
Lenswood	L3	3-Aug-2006	0.5	568	6.8	-5	15.0	156
Lenswood	L4	3-Aug-2006	2.1	1071	7.5	-44	16.8	316
Lenswood	L5	4-Aug-2006	7.4	458	7.1	12	13.8	162
Kersbrook	K1	24-Jan-2006	1.0	1738	6.7	121	17.6	142

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Kersbrook	K2	24-Jan-2006	0.5	1108	6.1	49	16.3	84
Kersbrook	K3	24-Jan-2006	0.4	2807	6.7	-120	19.6	190
Kersbrook	K4	31-Jan-2006	0.2	2276	6.9	-45	18.7	204
Kersbrook	K5	1-Feb-2006	0.3	2480	6.6	-15	17.5	154
Kersbrook	K1	3-Aug-2006	0.5	1182	6.5	122	17.2	112
Kersbrook	K2	3-Aug-2006	0.3	816	6.3	111	15.2	76
Kersbrook	K3	4-Aug-2006	3.7	2149	7.1	-64	16.7	224
Kersbrook	K4	25-Aug-2006	1.3	2449	6.7	-26	17.5	180
Kersbrook	K5	4-Aug-2006	1.1	1797	7.0	-31	18.7	314

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Table B2. Hydrochemistry of collected groundwater samples in the Cox, Lenswood and Kersbrook Creek Catchments

Catchment	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab Alk (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L
Cox	C1	7-Dec-2005	402	6.5	0.03	4.03	98	0.32	131	41	21	6	23	76
Cox	C2	8-Dec-2005	153	6.3	0.06	4.04	42	0.11	48	9	4	2	9	34
Cox	C3	8-Dec-2005	388	6.5	0.08	<0.02	97	0.29	110	62	22	5	15	77
Cox	C4	8-Dec-2005	477	7.5	0.04	3.14	252	0.16	76	19	41	4	37	45
Cox	C5	9-Dec-2005	297	6.7	0.05	0.03	127	0.17	70	11	12	2	13	62
Cox	C1	3-Aug-2006	383	6.6	0.01	3.8	86	0.32	125	42	21	6	22	77
Cox	C2	3-Aug-2006	167	6.4	0.02	3.98	49	0.13	50	11	5	2	9	37
Cox	C3	3-Aug-2006	391	6.6	0.04	<0.01	91	0.27	101	74	23	5	17	80
Cox	C4	25-Aug-2006	427	7.8	0.02	5.28	219	0.14	71	13	40	4	34	41
Cox	C5	3-Aug-2006	220	6.7	0.02	<0.01	90	0.14	54	8	10	2	10	45
Lenswood	L1	19-Jan-2006	1250	6.9	<0.02	0.12	165	1.26	496	179	67	11	62	268
Lenswood	L2	19-Jan-2006	764	7.6	0.15	<0.02	325	0.44	178	38	37	5	44	136
Lenswood	L3	19-Jan-2006	458	6.8	<0.02	0.07	183	0.29	121	16	26	5	23	84
Lenswood	L4	23-Jan-2006	745	7.8	<0.02	0.32	342	0.42	155	27	26	8	41	145
Lenswood	L5	25-Jan-2006	371	7.6	<0.02	<0.02	173	0.23	82	9	28	4	20	54
Lenswood	L1	3-Aug-2006	1468	6.8	0.06	<0.01	177	1.55	622	187	84	12	79	304
Lenswood	L2	4-Aug-2006	664	7.7	0.02	<0.01	283	0.37	148	38	39	5	42	109
Lenswood	L3	3-Aug-2006	422	7.1	0.03	0.19	176	0.25	100	18				
Lenswood	L4	3-Aug-2006	823	7.7	0.05	<0.01	338	0.51	205	28				
Lenswood	L5	4-Aug-2006	351	7.1	0.04	<0.01	164	0.26	76	7				
Kersbrook	K1	24-Jan-2006	844	7	<0.02	3.85	139	0.77	368	48				
Kersbrook	K2	24-Jan-2006	542	6.9	0.04	0.36	92	0.5	232	27				
Kersbrook	K3	24-Jan-2006	1424	7.6	0.04	<0.02	233	1.7	630	82				
Kersbrook	K4	31-Jan-2006	1192	7.4	<0.02	<0.02	362	1.2	436	37				
Kersbrook	K5	1-Feb-2006	1371	7.1	<0.02	<0.02	186	1.74	645	59				
Kersbrook	K1	3-Aug-2006	750	6.8	0.03	3.62	127	0.68	320	49				

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Kersbrook	K2	3-Aug-2006	494	6.5	0.03	9.22	76	0.35	193	33
Kersbrook	K3	4-Aug-2006	1396	7.3	0.05	<0.01	228	1.56	621	82
Kersbrook	K4	25-Aug-2006	1306	6.9	0.04	<0.01	185	1.51	593	57
Kersbrook	K5	4-Aug-2006	1218	7.2	0.05	<0.01	337	1.24	478	36

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Table B3. Stable isotopes of water, ²²²Rn, strontium isotope ratio, CFCs and carbon-14 data of collected groundwater samples in the Cox, Lenswood and Kersbrook Creek Catchments

Catchment	Sample ID	Collection date	$\delta^{18}\text{O}$ ‰ rel VSMOW	$\delta^2\text{H}$ ‰ rel VSMOW	Radon- 222 Bq/L	Radon-222 error Bq/L	⁸⁷ Sr/ ⁸⁶ Sr ratio	CFC-11 pg/kg	CFC-12 pg/kg	CFC-11 pptv	CFC-12 pptv	CFC-11 app. age (year)	CFC-12 app. age (year)	¹⁴ C pmC	$\delta^{13}\text{C}$ ‰ PDB
Cox	C1	7-Dec-2005	-5.49	-25.2	72.3	1.5	0.721018	1054	388	441	702	NA	NA	86.0	-17.7
Cox	C2	8-Dec-2005	-5.48	-26.0	87.1	1.6	0.715899	191	1693	80	3065	1973	NA	86.8	-18.9
Cox	C3	8-Dec-2005	-4.37	-21.0	489	9	0.775384	26	101	<25	181	<1965	1974	88.1	-16.7
Cox	C4	8-Dec-2005	-5.66	-26.5	37.9	0.8	0.724514	161	142	67	258	1972	1979	19.0	-13.8
Cox	C5	9-Dec-2005	-5.47	-24.7	220	4	0.735573	108	187	45	336	1969	1983	90.3	-17.0
Cox	C1	3-Aug-2006	-5.43	-26.1	68.2	1.5	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Cox	C2	3-Aug-2006	-5.44	-25.8	91.7	1.9	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Cox	C3	3-Aug-2006	-4.24	-20.5	493	9.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Cox	C4	25-Aug-2006	-5.51	-25.8	38.5	0.8	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Cox	C5	3-Aug-2006	-4.91	-23.3	176	3.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lenswood	L1	19-Jan-2006	-4.74	-24.7	263	5	0.728002	116	151	50	284	1970	1980	N/S	N/S
Lenswood	L2	19-Jan-2006	-5.02	-26.3	91.2	1.7	0.723553	238	245	104	460	1975	1990	19.1	-14.0
Lenswood	L3	19-Jan-2006	-5.66	-28.7	122	2	0.728641	45	74	<25	139	<1965	1971	74.0	-18.2
Lenswood	L4	23-Jan-2006	-5.2	-26.1	281	5	0.729842	78	53	34	99	1967	1969	59.8	-13.1
Lenswood	L5	25-Jan-2006	-4.59	-22.1	55.4	1.2	0.728004	117	118	51	220	1970	1976	71.1	-15.2
Lenswood	L1	3-Aug-2006	-4.98	-25.7	243	5.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lenswood	L2	4-Aug-2006	-4.86	-22.9	105	2.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lenswood	L3	3-Aug-2006	-5.60	-27.3	239	4.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lenswood	L4	3-Aug-2006	-5.52	-27.5	147	3.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lenswood	L5	4-Aug-2006	-4.12	-19.5	48.2	1.2	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Kersbrook	K1	24-Jan-2006	-4.67	-23.8	582	10	0.733475	93	73	39	131	1968	1971	78.8	-17.1
Kersbrook	K2	24-Jan-2006	-5.1	-22.6	201	4	0.715794	125	94	52	168	1970	1973	100.2	-19.5
Kersbrook	K3	24-Jan-2006	-5.63	-27.8	222	4	0.774089	28	31	<25	57	<1965	<1965	53.5	-17.8
Kersbrook	K4	31-Jan-2006	-4.54	-25.7	196	4	0.715894	<25	142	<25	258	<1965	1979	85.1	-15.7

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Kersbrook	K5	1-Feb-2006	-5.79	-30.3	666	12	0.755060	<25	<20	<25	<50	<1965	<1965	70.9	-18.2
Kersbrook	K1	3-Aug-2006	-4.56	-23.2	546	10.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Kersbrook	K2	3-Aug-2006	-4.54	-21.5	18.8	0.70	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Kersbrook	K3	4-Aug-2006	-5.67	-29.9	199	4.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Kersbrook	K4	25-Aug-2006	-5.75	-31.2	508	9	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Kersbrook	K5	4-Aug-2006	-4.47	-23.4	176	4.0	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S

APPENDIX C

Table C1. Field measurements of surface water samples collected in the Cox, Lenswood and Kersbrook Creek Catchments

Catchment	Location	Sample	Collection	DO	Field SEC	pH	Redox	Temp	Field Alk
	ID	ID	date	ppm	µS/cm				
Cox	Cck1	CC14	9-Dec-05	10.6	467	8.6	-124	20.2	111
Cox	Cck2	CC13	9-Dec-05	10.3	472	8.5	-151	19.9	120
Cox	Cck3	CC11	9-Dec-05	9.4	478	8.4	177	19.9	120
Cox	Cck4	CC12	9-Dec-05	10.3	486	8	-165	18.7	128
Cox	Cck5	CC6	8-Dec-05	11.5	479	8.8	-71	19	128
Cox	Cck6	CC5	8-Dec-05	11.6	493	9.1	-167	19.2	126
Cox	Cck7	CC4	8-Dec-05	11	499	8.4	-194	16.7	130
Cox	Cck8	CC7	8-Dec-05	11.7	538	8.6	186	16.5	148
Cox	Cck9	CC1	7-Dec-05	11.4	586	8.2	-211	17.7	126
Cox	Cck10	CC9	9-Dec-05	8.8	312	7.2	97	16.3	50
Cox	Cck_t1	CC3	8-Dec-05	6.2	314	7	-387	17.5	62
Cox	Cck_t2	CC10	9-Dec-05	5.3	260	6.8	-7	16.8	58
Cox	Cck_t3	CC8	8-Dec-05	9.9	516	8	106	16.9	158
Cox	Cck_t4	CC2	7-Dec-05	9.4	457	7.8	-355	15.4	102
Cox	Cck_t5	NA	7-Dec-05						
Cox	Cck1	CC15	6-Mar-06	4.4	518	7.5	40	18.9	102
Cox	Cck2	CC16	6-Mar-06	5.1	521	7.4	12	17.7	122
Cox	Cck3	CC17	6-Mar-06	5.8	518	7.7	7	19.6	133
Cox	Cck4	CC18	6-Mar-06	7.7	418	7.7	65	20.5	198
Cox	Cck5	CC19	6-Mar-06	7.6	520	8.2	130	22	160
Cox	Cck6	CC20	6-Mar-06	9.6	535	8.8	119	23.4	208
Cox	Cck7	CC21	6-Mar-06	9	536	8.3	152	20.2	0
Cox	Cck8	CC22	6-Mar-06	10	515	8.5	139	18.9	214
Cox	Cck9	CC24	7-Mar-06	5.9	636	7.4	74	15.3	216
Cox	Cck10	NA	6-Mar-06						
Cox	Cck_t1	NA	6-Mar-06						
Cox	Cck_t2	NA	6-Mar-06						
Cox	Cck_t3	CC23	6-Mar-06	5.4	408	7.8	153	21.3	0
Cox	Cck_t4	NA	6-Mar-06						
Cox	Cck_t5	CC25	7-Mar-06	6.2	242	6.8	81	14.4	20
Cox	Cck1	CC40	27-Jul-06	9.6	351	8.1	280	7.1	68
Cox	Cck2	CC39	27-Jul-06	9.7	348	8.2	297	7.6	88
Cox	Cck3	CC38	26-Jul-06	8.8	342	8.2	252	9	84
Cox	Cck4	CC37	26-Jul-06	9.4	341	8.4	272	9.1	84
Cox	Cck5	CC36	26-Jul-06	9.5	344	8.6	175	9.5	102
Cox	Cck6	CC35	27-Jul-06	10.1	366	8.2	301	8.2	98

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Catchment	Location	Sample	Collection	DO	Field SEC	pH	Redox	Temp	Field Alk
					$\mu\text{S}/\text{cm}$				(HCO_3^-) mg/L
	ID	ID	date	ppm			mV	$^{\circ}\text{C}$	
Cox	Cck7	CC33	26-Jul-06	9.6	367	8.3	112	9.6	96
Cox	Cck8	CC31	26-Jul-06	9.7	401	8.2	198	10.6	108
Cox	Cck9	CC28	26-Jul-06	9.9	475	8.1	66	11.5	121
Cox	Cck10	CC26	26-Jul-06	7.6	251	6.8	171	7.8	36
Cox	Cck_t1	CC32	26-Jul-06	8.5	252	7.5	106	10.3	48
Cox	Cck_t2	CC34	26-Jul-06	8.1	208	7.4	91	10.2	38
Cox	Cck_t3	CC30	26-Jul-06	9.2	349	7.8	176	11.5	119
Cox	Cck_t4	CC29	26-Jul-06	9.2	324	7.6	71	9.6	75
Cox	Cck_t5	CC27	26-Jul-06	8.4	208	6.5	136	9.7	22
Cox	Cck1	CC54	1-Nov-06	8.2	485	7.8	65	16.8	88
Cox	Cck2	CC53	1-Nov-06	8.4	480	7.7	67	15.9	84
Cox	Cck3	CC52	1-Nov-06	11.4	476	8.3	124	17	84
Cox	Cck4	CC51	1-Nov-06	8.8	474	7.6	37	17.1	102
Cox	Cck5	CC50	1-Nov-06	11.1	489	8.2	107	17.7	98
Cox	Cck6	CC49	1-Nov-06	10.8	487	8.3	70	18	38
Cox	Cck7	CC47	1-Nov-06	7.6	493	7.9	-64	15	48
Cox	Cck8	CC45	31-Oct-06	14.4	481	8.4	113	15.1	119
Cox	Cck9	CC42	31-Oct-06	12.6	582	8.4	11	15	21
Cox	Cck10	CC41	31-Oct-06	2.3	375	6.4	88	9.9	36
Cox	Cck_t1	CC46	1-Nov-06	0.6	420	6.2	-82	11.3	108
Cox	Cck_t2	CC48	1-Nov-06	3.9	326	6.3	72	10.6	96
Cox	Cck_t3	CC44	31-Oct-06	9.1	355	7.9	-13	19.5	75
Cox	Cck_t4	NA	31-Oct-06	6.5	512	6.9	-70	10.8	
Cox	Cck_t5	CC43	31-Oct-06	7.6	246	6.8	-95	12.8	121
Lenswood	Lck1	LC15	19-Dec-05	7.6	745	8	-29	20.9	106
Lenswood	Lck2	LC14	19-Dec-05	9.9	471	8.1	269	17.5	245
Lenswood	Lck3	LC13	19-Dec-05	9.3	512	8.5	-72	16.5	98
Lenswood	Lck4	NA	19-Dec-05						
Lenswood	Lck5	LC9	19-Dec-05	9.2	521	8.1	-77	14.6	104
Lenswood	Lck6	LC10	19-Dec-05	9.7	603	8.4	-42	15.2	114
Lenswood	Lck7	LC2	16-Dec-05	10	509	9.2	-151	14.3	96
Lenswood	Lck8	LC1	16-Dec-05	10.3	529	7.9	-290	14.7	0
Lenswood	Lck_t1	LC8	16-Dec-05	7.4	277	8.3	-86	23.4	65
Lenswood	Lck_t2	LC12	19-Dec-05	9.6	634	8.3	230	18.7	149
Lenswood	Lck_t3	LC11	19-Dec-05	9.9	466	8.4	-115	16.2	91
Lenswood	Lck_t4	LC3	16-Dec-05	6.8	564	8.8	-244	15.8	116
Lenswood	Lck_t5	LC4	16-Dec-05	10.2	467	8.1	-216	16.6	98
Lenswood	Lck_t6	LC5	16-Dec-05	9.5	283	8	-173	17.3	64
Lenswood	Lck_t7	LC6	16-Dec-05	8.8	349	7.8	-181	16.2	78
Lenswood	Lck_t8	LC7	16-Dec-05	8.1	448	7.3	-213	18.7	95
Lenswood	Lck1	NA	7-Mar-06						
Lenswood	Lck2	LC16	7-Mar-06	0.5	1649	7.5	11	15	354

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Catchment	Location	Sample	Collection	DO	Field SEC		Redox	Temp	Field Alk
					$\mu\text{S/cm}$	pH			
	ID	ID	date	ppm			mV	$^{\circ}\text{C}$	(HCO_3^-) mg/L
Lenswood	Lck3	LC17	7-Mar-06	1.5	665	7.2	152	14.9	140
Lenswood	Lck4	LC26	7-Mar-06	1.4	759	7.2	81	16.5	186
Lenswood	Lck5	LC19	7-Mar-06	1.4	631	7.2	167	15.5	154
Lenswood	Lck6	LC20	7-Mar-06	4.7	625	7.5	193	15.2	158
Lenswood	Lck7	LC22	7-Mar-06	2.9	689	7.6	112	15.6	254
Lenswood	Lck8	NA	7-Mar-06						
Lenswood	Lck_t1	NA	7-Mar-06						
Lenswood	Lck_t2	LC18	7-Mar-06	8.1	377	8	150	17.6	114
Lenswood	Lck_t3	LC21	7-Mar-06	2.7	707	6.9	-3	16.3	136
Lenswood	Lck_t4	LC23	7-Mar-06	5.7	516	7.7	103	16.8	116
Lenswood	Lck_t5	LC24	7-Mar-06	4.3	380	7.2	58	15.3	94
Lenswood	Lck_t6	LC25	7-Mar-06	3.2	482	6.9	97	16.4	110
Lenswood	Lck_t7	NA	7-Mar-06						
Lenswood	Lck_t8	NA	7-Mar-06						
Lenswood	Lck1	LC27	27-Jul-06	9.1	605	7.7	98	8.3	106
Lenswood	Lck2	LC28	27-Jul-06	9.4	548	7.8	149	7.5	96
Lenswood	Lck3	LC30	27-Jul-06	8.2	502	7.8	189	8	94
Lenswood	Lck4	LC32	27-Jul-06	8.1	521	7.7	65	7.8	104
Lenswood	Lck5	LC33	27-Jul-06	8.9	501	7.9	166	8.1	100
Lenswood	Lck6	LC34	27-Jul-06	8.8	588	8	186	8.4	120
Lenswood	Lck7	LC36	27-Jul-06	9.3	558	8.4	194	8.9	150
Lenswood	Lck8	LC38	27-Jul-06	8.6	518	7.8	169	9.8	102
Lenswood	Lck_t1	LC29	27-Jul-06	10.1	300	7.8	270	10.4	48
Lenswood	Lck_t2	LC31	27-Jul-06	8.9	515	7.8	75	9.1	130
Lenswood	Lck_t3	LC35	27-Jul-06	8.9	450	7.6	91	8.7	78
Lenswood	Lck_t4	LC37	27-Jul-06	7.8	584	7.9	93	10.1	160
Lenswood	Lck_t5	NA	28-Jul-06						
Lenswood	Lck_t6	LC41	28-Jul-06	8.5	364	7.7	191	8.4	90
Lenswood	Lck_t7	LC40	28-Jul-06	7.6	352	7.3	128	9.1	90
Lenswood	Lck_t8	NA	28-Jul-06						
Lenswood	Lck1	LC42	6-Nov-06	3.5	1427	6.9	157	13.3	68
Lenswood	Lck2	LC43	6-Nov-06	2.9	909	7.1	143	11.8	106
Lenswood	Lck3	LC44	6-Nov-06	2.6	561	7.1	60	11.2	96
Lenswood	Lck4	LC46	6-Nov-06	3.5	692	7.1	97	12.1	94
Lenswood	Lck5	LC47	6-Nov-06	0.6	1143	6.7	-83	12.4	130
Lenswood	Lck6	LC48	6-Nov-06	3.3	662	6.9	-95	12.2	104
Lenswood	Lck7	LC52	6-Nov-06	6.7	612	7.6	36	12.5	150
Lenswood	Lck8	NA	6-Nov-06						
Lenswood	Lck_t1	NA	6-Nov-06						
Lenswood	Lck_t2	LC45	6-Nov-06	9.4	447	7.9	87	11.7	48
Lenswood	Lck_t3	LC49	6-Nov-06	2.4	550	6.8	-91	13.7	100
Lenswood	Lck_t4	LC53	6-Nov-06	7	485	7.6	33	14.9	160

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Catchment	Location	Sample	Collection	DO	Field SEC	pH	Redox	Temp	Field Alk
					$\mu\text{S/cm}$				
	ID	ID	date	ppm			mV	$^{\circ}\text{C}$	(HCO_3^-) mg/L
Lenswood	Lck_t5	LC50	6-Nov-06	10.4	486	7.4	16	13.4	120
Lenswood	Lck_t6	LC51	6-Nov-06	6.3	380	7.2	22	13.2	78
Lenswood	Lck_t7	NA	6-Nov-06						
Lenswood	Lck_t8	LC39	6-Nov-06	8.7	415	7.5	206	8.6	110
Kersbrook	Kck1	KC10	21-Dec-05	3.9	1947	7.6	138	18.6	158
Kersbrook	Kck2	KC11	21-Dec-05	5.6	1928	8.2	-77	22.1	166
Kersbrook	Kck3	KC12	21-Dec-05	5.5	2470	7.9	-273	19.9	190
Kersbrook	Kck4	KC8	20-Dec-05	8	3580	8.4	28	26.3	326
Kersbrook	Kck5	KC5	20-Dec-05	3.4	1515	7.4	-11	22.3	53
Kersbrook	Kck6	KC4	20-Dec-05	2.9	1012	7.3	330	19.3	57
Kersbrook	Kck7	KC3	20-Dec-05	6.7	666	7.1	125	18.7	44
Kersbrook	Kck_t1	KC1	20-Dec-05	6.1	720	8	-223	18.8	55
Kersbrook	Kck_t2	KC2	20-Dec-05	5.3	1543	7.7	-37	17.5	128
Kersbrook	Kck_t3	KC9	20-Dec-05	4.5	924	7.8	-263	20.2	217
Kersbrook	Kck_t4	KC7	20-Dec-05	4.1	1043	8	28	19.6	170
Kersbrook	Kck_t5	KC6	20-Dec-05	8.5	1646	8.5	321	24.7	78
Kersbrook	Kck1	KC18	8-Mar-06	2.8	2358	7.4	13	15.1	234
Kersbrook	Kck2	KC17	8-Mar-06	8.4	3332	8.4	140	23.5	208
Kersbrook	Kck3	KC16	8-Mar-06	5.6	2545	7.8	160	16.2	174
Kersbrook	Kck4	KC14	8-Mar-06	3	2481	7.4	198	17.9	166
Kersbrook	Kck5	KC13	8-Mar-06	4.3	710	7.1	170	15.7	108
Kersbrook	Kck6	NA	8-Mar-06						
Kersbrook	Kck7	NA	8-Mar-06						
Kersbrook	Kck_t1	NA	8-Mar-06						
Kersbrook	Kck_t2	NA	8-Mar-06						
Kersbrook	Kck_t3	NA	8-Mar-06						
Kersbrook	Kck_t4	KC15	8-Mar-06	4.7	1367	7.8	173	16.6	372
Kersbrook	Kck_t5	NA	8-Mar-06						
Kersbrook	Kck1	KC20	28-Jul-06	6.8	2086	7.4	230	7.7	40
Kersbrook	Kck2	KC22	28-Jul-06	10.4	2378	8.1	165	8.6	170
Kersbrook	Kck3	KC23	28-Jul-06	6.7	3937	7.5	83	8.4	234
Kersbrook	Kck4	KC25	28-Jul-06	7.8	3751	7.5	144	9.6	140
Kersbrook	Kck5	KC28	28-Jul-06	7.4	1387	7	126	11.5	72
Kersbrook	Kck6	KC29	28-Jul-06	8.1	1195	6.8	139	10.8	41
Kersbrook	Kck7	KC30	28-Jul-06	8.4	921	6.5	165	9.7	23
Kersbrook	Kck_t1	KC19	28-Jul-06	7.3	774	7.1	222	7.6	44
Kersbrook	Kck_t2	KC21	28-Jul-06	8.2	1373	7.3	89	9.5	68
Kersbrook	Kck_t3	KC24	28-Jul-06	8.1	702	7.8	151	9.5	128
Kersbrook	Kck_t4	KC26	28-Jul-06	5.7	985	7.6	-4	10.3	246
Kersbrook	Kck_t5	KC27	28-Jul-06	5	873	7.2	166	8.8	78
Kersbrook	Kck1	KC31	2-Nov-06	4.8	3073	7	154	15.1	102
Kersbrook	Kck2	KC32	2-Nov-06	5.3	4019	7.3	-20	17.1	110

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Catchment	Location	Sample	Collection	DO	Field SEC	pH	Redox	Temp	Field Alk
					$\mu\text{S/cm}$				(HCO_3^-) mg/L
	ID	ID	date	ppm			mV	$^{\circ}\text{C}$	
Kersbrook	Kck3	KC33	2-Nov-06	4	5887	7.1	35	13.3	90
Kersbrook	Kck4	KC34	2-Nov-06	7.9	9015	7.9	54	18.4	90
Kersbrook	Kck5	KC36	2-Nov-06	5.2	1416	6.2	116	18.1	40
Kersbrook	Kck6	KC37	2-Nov-06	7	1997	7	130	16.9	68
Kersbrook	Kck7	KC38	2-Nov-06	7.5	1173	7.3	57	15.9	170
Kersbrook	Kck_t1	NA	2-Nov-06						
Kersbrook	Kck_t2	NA	2-Nov-06						
Kersbrook	Kck_t3	NA	2-Nov-06						
Kersbrook	Kck_t4	KC35	2-Nov-06	10	1099	8.1	158	14.6	44
Kersbrook	Kck_t5	NA	2-Nov-06						

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Table C2. Hydrochemistry, stable isotopes of water, ²²²Rn and strontium isotope ratio data of collected surface water samples in the Cox, Lenswood and Kersbrook Creek Catchments

Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L	δ ¹⁸ O ‰ rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	⁸⁷ / ₈₆ Sr ratio
Cck1	CC14	9-Dec-2005	286	8.4	0.03	<0.02	120	0.15	67	18	21	40	17	2	99	-4.41	-20.7	0.46	0.04	0.7227229
Cck2	CC13	9-Dec-2005	297	8.2	0.04	0.14	131	0.14	63	20	23	38	18	2	106	-4.53	-20.5	0.5	0.04	0.7228584
Cck3	CC11	9-Dec-2005	297	8.1	0.05	0.29	130	0.15	62	21	23	38	19	2	105	-4.63	-21.7	0.46	0.05	0.7234094
Cck4	CC12	9-Dec-2005	302	7.9	0.05	0.52	134	0.16	62	21	24	38	19	2	110	-4.71	-21.2	0.35	0.03	0.7238128
Cck5	CC6	8-Dec-2005	304	8.3	0.03	0.50	135	0.14	61	21	25	37	20	2	110	-4.84	-23.2	0.39	0.03	0.724285
Cck6	CC5	8-Dec-2005	308	8.4	0.03	0.68	137	0.15	60	24	25	37	20	2	113	-4.8	-23.8	0.36	0.03	0.7244684
Cck7	CC4	8-Dec-2005	318	8.1	0.03	0.93	143	0.16	61	24	27	37	21	2	117	-5.1	-23.7	0.3	0.03	0.7246948
Cck8	CC7	8-Dec-2005	341	8.0	0.03	1.10	159	0.16	63	24	29	38	23	2	127	-5.24	-24.2	0.74	0.05	0.7251417
Cck9	CC1	7-Dec-2005	363	7.9	0.04	3.11	140	0.17	73	41	31	46	25	2	127	-5.11	-23.3	0.77	0.05	0.7215212
Cck10	CC9	9-Dec-2005	178	7.3	0.04	1.77	49	0.11	53	18	9	35	9	2	71	-4.49	-19.2	0.83	0.06	0.7152705
Cck_t1	CC3	8-Dec-2005	187	7.2	0.06	0.08	65	0.16	57	7	12	34	8	1	70	-3.43	-13.9	2.54	0.14	0.7213308
Cck_t2	CC10	9-Dec-2005	155	7.1	0.08	0.03	63	0.13	41	4	11	26	7	1	63	-3.18	-13.9	4.74	0.26	0.7239359
Cck_t3	CC8	8-Dec-2005	340	7.8	0.05	0.52	176	0.13	53	18	32	33	24	1	169	-5.35	-23.8	2.04	0.12	0.7302413
Cck_t4	CC2	7-Dec-2005	275	7.5	0.07	2.43	107	0.17	52	34	23	33	20	1	103	-4.78	-20.5	1.4	0.09	0.7200188
Cck_t5	NA	7-Dec-2005																		
Cck1	CC15	6-Mar-2006	339	7.3	0.05	0.00	129	0.28	98	8	21	60	18	3	117	-3.21	-15.30	1.09	0.08	0.7247174
Cck2	CC16	6-Mar-2006	357	7.5	0.04	0.05	160	0.24	85	7	26	53	22	2	127	-3.34	-15.10	3.35	0.23	0.723095
Cck3	CC17	6-Mar-2006	362	7.6	0.05	0.22	167	0.22	79	11	28	50	23	2	138	-3.44	-17.10	1.65	0.12	0.724138
Cck4	CC18	6-Mar-2006	345	7.7	0.05	0.01	158	0.19	72	14	27	46	22	2	131	-3.58	-18.70	1.01	0.07	0.7253272
Cck5	CC19	6-Mar-2006	364	8.0	0.06	0.02	171	0.20	76	13	28	48	24	2	134	-4.09	-20.40	0.76	0.06	0.7254426
Cck6	CC20	6-Mar-2006	369	8.4	0.06	0.03	168	0.19	79	15	29	49	25	2	129	-4.44	-20.20	0.69	0.05	0.7250753
Cck7	CC21	6-Mar-2006	378	8.0	0.05	0.02	181	0.20	75	14	30	47	26	2	128	-4.89	-24.30	0.62	0.05	0.7252641
Cck8	CC22	6-Mar-2006	365	8.2	0.04	0.00	173	0.21	73	14	30	45	25	2	127	-4.96	-21.70	2.46	0.17	0.7255131
Cck9	CC24	7-Mar-2006	453	7.7	0.05	0.52	211	0.21	87	25	36	55	32	2	136	-5.16	-22.80	2.21	0.16	0.7230234
Cck10	NA	6-Mar-2006																		
Cck_t1	NA	6-Mar-2006																		
Cck_t2	NA	6-Mar-2006																		
Cck_t3	CC23	6-Mar-2006	281	7.6	0.06	0.01	129	0.14	57	14	24	35	19	2	102	-5.16	-23.80	0.82	0.06	0.7262537
Cck_t4	NA	6-Mar-2006																		

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Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab										δ ¹⁸ O % rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	^{87/86} Sr ratio
							Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L						
Cck_t5	CC25	7-Mar-2006	138	6.5	0.05	0.58	21	0.14	56	16	7	31	6	1	42	-5.24	-25.40	1.79	0.13	0.7155565	
Cck1	CC40	27-Jul-2006	160	7.7	0.02	0.43	99	0.13	59	22	20	39	15	2	93	-4.59	-22.00	0.41	0.04	0.7230552	
Cck2	CC39	27-Jul-2006	158	7.8	0.02	0.77	92	0.14	58	22	20	37	15	2	97	-4.71	-21.25	0.43	0.04	0.7231114	
Cck3	CC38	26-Jul-2006	155	7.8	0.02	0.79	82	0.12	58	22	19	36	15	2	96	-4.54	-22.40	0.51	0.04	0.7231153	
Cck4	CC37	26-Jul-2006	151	7.8	0.02	0.87	82	0.12	55	23	19	35	15	2	96	-4.62	-22.50	0.38	0.04	0.7234135	
Cck5	CC36	26-Jul-2006	153	7.8	0.03	1.01	94	0.13	53	23	20	35	16	2	96	-4.74	-21.60	0.29	0.03	0.7236137	
Cck6	CC35	27-Jul-2006	159	7.9	0.02	1.07	104	0.13	55	24	21	36	17	2	94	-4.71	-23.00	0.25	0.03	0.7239086	
Cck7	CC33	26-Jul-2006	258	7.9	<0.01	1.04	105	0.14	49	24	23	35	18	2	94	-4.81	-22.55	0.39	0.04	0.72394	
Cck8	CC31	26-Jul-2006	292	7.9	0.02	1.57	120	0.15	57	27	25	37	20	2	109	-4.96	-24.60	0.89	0.07	0.7243269	
Cck9	CC28	26-Jul-2006	340	8.0	0.02	2.52	134	0.16	69	33	27	46	23	2	105	-5.10	-24.90	1.08	0.08	0.7217283	
Cck10	CC26	26-Jul-2006	163	7.0	0.02	1.44	34	0.14	50	23	9	34	8	1	59	-4.46	-19.10	2.99	0.18	0.7152297	
Cck_t1	CC32	26-Jul-2006	166	7.2	0.07	0.42	43	0.09	53	14	12	34	7	1	58	-4.04	-19.30	1.28	0.12	0.7215855	
Cck_t2	CC34	26-Jul-2006	101	7.1	0.02	0.57	37	0.09	38	16	11	26	6	1	49	-4.01	-19.40	1.75	0.12	0.7188206	
Cck_t3	CC30	26-Jul-2006	259	7.8	0.02	0.37	118	0.10	48	18	23	30	18	1	114	-4.81	-22.80	1.88	0.12	0.7282305	
Cck_t4	CC29	26-Jul-2006	222	7.5	0.01	2.26	73	0.13	44	34	19	31	16	1	79	-4.65	-24.60	1.71	0.11	0.7183114	
Cck_t5	CC27	26-Jul-2006	127	6.6	0.15	2.16	16	0.09	41	24	9	26	6	1	44	-5.12	-21.90	2.88	0.17	0.7150006	
Cck1	CC54	1-Nov-2006	333	8.0	<0.01	<0.01	138	0.19	85	12	23	52	20	2	110	-4.05	-18.90	1.3	0.08	0.7243033	
Cck2	CC53	1-Nov-2006	338	8.0	<0.01	<0.01	151	0.18	76	14	26	47	22	2	109	-4.25	-19.50	1.96	0.11	0.723248	
Cck3	CC52	1-Nov-2006	340	8.4	<0.01	<0.01	152	0.17	75	16	26	46	22	2	109	-4.39	-20.30	1.25	0.08	0.7235941	
Cck4	CC51	1-Nov-2006	347	8.0	<0.01	<0.01	156	0.18	76	17	27	45	23	2	108	-4.53	-21.70	1.01	0.06	0.724034	
Cck5	CC50	1-Nov-2006	349	8.3	<0.01	<0.01	158	0.18	71	19	28	46	23	2	111	-4.85	-21.50	1.06	0.07	0.7240909	
Cck6	CC49	1-Nov-2006	356	8.4	<0.01	<0.01	162	0.18	74	20	29	45	24	2	110	-4.71	-21.50	0.55	0.04	0.7240312	
Cck7	CC47	1-Nov-2006	351	8.0	<0.01	0.02	161	0.18	71	19	28	45	24	2	113	-4.94	-22.80	0.7	0.05	0.7240992	
Cck8	CC45	31-Oct-2006	348	8.6	<0.01	0.18	161	0.18	69	20	29	43	24	2	107	-5.2	-22.40	2.07	0.12	0.7246111	
Cck9	CC42	31-Oct-2006	417	8.5	<0.01	0.65	184	0.20	82	33	34	51	29	2	128	-5.23	-23.20	1.75	0.10	0.7237368	
Cck10	CC41	31-Oct-2006	212	7.4	0.02	4.36	50	0.15	73	15	11	48	11	2	85	-4.44	-18.10	2.72	0.15	0.715026	
Cck_t1	CC46	1-Nov-2006	265	7.1	0.02	<0.01	79	0.29	99	3	18	53	12	2	86	-2.88	-11.40	9.86	0.53	0.7246337	
Cck_t2	CC48	1-Nov-2006	211	7.1	0.04	0.01	73	0.23	60	12	15	39	9	2	85	-3.5	-14.50	25.81	1.38	0.7406715	
Cck_t3	CC44	31-Oct-2006	245	8.0	<0.01	<0.01	111	0.11	50	13	21	31	16	1	90	-5.14	-26.60	1.12	0.07	0.725897	
Cck_t4	NA	31-Oct-2006																			
Cck_t5	CC43	31-Oct-2006	135	7.0	0.16	1.41	20	0.11	52	18	7	30	6	1	66	-5.27	-22.20	3.21	0.18	0.7156403	
Lck1	LC15	19-Dec-2005	307	7.6	0.02	0.01	111	0.32	141	33	20	83	23	4	135	-3.87	-18.60	5.95	0.32	N/A	
Lck2	LC14	19-Dec-2005	200	7.7	0.02	0.03	106	0.21	85	19	15	58	17	3	85	-4.02	-17.70	0.78	0.05	N/A	

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Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab										δ ¹⁸ O ‰ rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	⁸⁷ / ₈₆ Sr ratio
							Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L						
Lck3	LC13	19-Dec-2005	202	7.6	0.07	0.11	105	0.19	83	23	16	56	18	2	89	-3.91	-16.70	0.73	0.05	N/A	
Lck4	NA	19-Dec-2005																			
Lck5	LC9	19-Dec-2005	206	7.6	0.02	0.04	108	0.21	85	23	16	59	17	3	93	-3.89	-18.10	1.28	0.08	N/A	
Lck6	LC10	19-Dec-2005	240	7.8	0.01	0.18	135	0.21	95	29	20	67	22	3	120	-3.81	-17.60	2.03	0.12	N/A	
Lck7	LC2	16-Dec-2005	212	7.7	0.02	0.11	106	0.17	82	31	17	57	19	2	101	-3.76	-13.20	0.61	0.05	N/A	
Lck8	LC1	16-Dec-2005	209	7.7	0.01	0.06	118	0.23	81	26	16	61	19	3	98	-3.8	-15.00	0.97	0.07	N/A	
Lck_t1	LC8	16-Dec-2005	108	7.5	0.01	<0.01	67	0.16	44	8	9	33	10	1	58	-2.59	-9.10	1.92	0.12	N/A	
Lck_t2	LC12	19-Dec-2005	248	7.8	0.03	0.15	157	0.26	105	21	24	66	26	3	123	-4.11	-19.10	1.37	0.09	N/A	
Lck_t3	LC11	19-Dec-2005	191	7.6	<0.01	<0.01	96	0.18	79	23	14	55	16	2	77	-4.05	-17.50	1.47	0.09	N/A	
Lck_t4	LC3	16-Dec-2005	229	7.7	0.05	0.71	129	0.29	86	28	22	66	19	3	143	-3.49	-16.60	1.48	0.09	N/A	
Lck_t5	LC4	16-Dec-2005	194	7.5	<0.01	0.08	99	0.17	72	32	16	54	16	2	84	-4.15	-18.00	4.57	0.25	N/A	
Lck_t6	LC5	16-Dec-2005	114	7.5	<0.01	0.05	64	0.11	48	9	8	37	9	2	53	-3.65	-14.50	1.09	0.07	N/A	
Lck_t7	LC6	16-Dec-2005	141	7.5	<0.01	0.07	78	0.15	56	16	10	43	11	2	65	-3.81	-16.50	1.52	0.1	N/A	
Lck_t8	LC7	16-Dec-2005	182	7.2	0.02	0.13	99	0.11	66	29	16	50	15	2	81	-4.21	-19.10	7.11	0.38	N/A	
Lck1	NA	7-Mar-2006																			
Lck2	LC16	7-Mar-2006	740	7.7	0.06	0.01	345	1.22	383	1	48	229	62	10	264	-2.37	-10.60	0.86	0.06	N/A	
Lck3	LC17	7-Mar-2006	286	7.3	0.13	0.05	226	0.39	130	14	23	83	25	4	144	-2.61	-11.80	9.1	1.31	N/A	
Lck4	LC26	7-Mar-2006	323	7.4	0.06	0.04	175	0.53	153	13	25	95	28	4	158	-2.83	-11.60	3.97	0.28	N/A	
Lck5	LC19	7-Mar-2006	265	7.4	0.05	0.01	149	0.70	122	14	21	77	23	3	149	-2.44	-9.30	2.45	0.17	N/A	
Lck6	LC20	7-Mar-2006	258	7.7	0.05	0.05	160	0.47	107	24	24	72	24	3	190	-2.68	-10.70	19	1.30	N/A	
Lck7	LC22	7-Mar-2006	275	7.6	0.05	0.01	193	0.34	124	9	26	78	30	3	164	-1.63	-4.70	1.14	0.08	N/A	
Lck8	NA	7-Mar-2006																			
Lck_t1	NA	7-Mar-2006																			
Lck_t2	LC18	7-Mar-2006	153	7.4	0.05	0.02	96	0.17	67	9	12	47	13	2	66	-1.6	-7.60	0.59	0.05	N/A	
Lck_t3	LC21	7-Mar-2006	299	7.1	0.05	0.01	151	0.49	150	9	22	88	25	4	146	-2.82	-13.60	27.2	1.90	N/A	
Lck_t4	LC23	7-Mar-2006	223	7.4	0.05	0.61	110	0.24	89	26	22	61	16	3	172	-1.98	-11.40	1.64	0.12	N/A	
Lck_t5	LC24	7-Mar-2006	131	6.8	0.05	0.03	66	0.09	42	27	14	31	11	1	65	-4.12	-18.70	0.7	0.05	N/A	
Lck_t6	LC25	7-Mar-2006	196	7.1	0.05	0.02	170	0.33	85	10	17	58	17	3	99	-4.28	-20.30	2.55	0.35	N/A	
Lck_t7	NA	7-Mar-2006																			
Lck_t8	NA	7-Mar-2006																			
Lck1	LC27	27-Jul-2006	298	7.8	0.02	0.17	107	0.35	133	35	21	80	24	3	122	-4.06	-19.40	5.7	0.33	N/A	
Lck2	LC28	27-Jul-2006	264	7.8	0.02	0.20	109	0.28	117	28	19	73	22	3	107	-4.07	-18.00	1.1	0.08	N/A	
Lck3	LC30	27-Jul-2006	242	7.8	0.01	0.19	103	0.26	102	29	19	66	21	3	96	-4.10	-19.00	1.44	0.1	N/A	

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Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab										δ ¹⁸ O % rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	^{87/86} Sr ratio
							Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L						
Lck4	LC32	27-Jul-2006	252	7.8	0.02	0.18	99	0.27	108	30	19	68	21	3	103	-4.14	-19.25	1.62	0.11	N/A	
Lck5	LC33	27-Jul-2006	240	7.8	0.02	0.22	104	0.26	102	28	18	66	21	3	103	-4.17	-19.60	1.23	0.09	0.7186968	
Lck6	LC34	27-Jul-2006	290	7.9	0.02	0.28	110	0.32	128	33	22	75	26	3	125	-3.79	-19.20	1.9	0.12	N/A	
Lck7	LC36	27-Jul-2006	270	8.0	0.02	0.14	113	0.29	116	33	19	72	25	3	110	-3.98	-19.15	0.61	0.05	0.7179362	
Lck8	LC38	27-Jul-2006	249	7.8	0.02	0.26	104	0.28	108	29	17	68	22	3	99	-3.98	-17.60	3.37	0.2	N/A	
Lck_t1	LC29	27-Jul-2006	149	7.6	0.02	0.11	47	0.15	67	17	11	40	11	2	59	-3.19	-15.90	1.58	0.1	N/A	
Lck_t2	LC31	27-Jul-2006	234	7.8	0.02	0.38	133	0.21	95	26	23	59	24	3	101	-4.80	-21.70	1.82	0.11	N/A	
Lck_t3	LC35	27-Jul-2006	199	7.8	0.01	0.22	86	0.22	84	23	15	57	16	2	77	-4.32	-20.90	2.3	0.14	N/A	
Lck_t4	LC37	27-Jul-2006	270	7.9	0.03	0.72	148	0.32	112	24	25	78	23	3	149	-2.29	-12.40	2.47	0.15	N/A	
Lck_t5	NA	28-Jul-2006																			
Lck_t6	LC41	28-Jul-2006	167	7.7	0.01	0.30	87	0.21	75	11	13	51	14	2	67	-4.08	-18.20	2.25	0.13	N/A	
Lck_t7	LC40	28-Jul-2006	162	7.5	0.01	0.34	81	0.19	68	17	12	47	14	2	74	-4.07	-17.80	2.71	0.15	N/A	
Lck_t8	NA	28-Jul-2006																			
Lck1	LC42	6-Nov-2006	1039	7.58	0.05	<0.01	181	0.96	456	57	67	205	57	9	437	-0.20	-2.20	3.5	0.19	0.720541	
Lck2	LC43	6-Nov-2006	729	7.66	0.04	<0.01	251	0.74	255	1	35	141	42	6	220	-3.04	-13.60	4.21	0.23	0.7202064	
Lck3	LC44	6-Nov-2006	458	7.56	0.08	0.02	161	0.36	145	17	25	79	28	3	162	-3.64	-15.00	17.7	0.90	0.7201958	
Lck4	LC46	6-Nov-2006	544	7.57	0.03	0.03	165	0.49	187	23	28	105	31	5	187	-3.33	-15.20	4.39	0.24	0.7203429	
Lck5	LC47	6-Nov-2006	541	7.75	0.02	0.02	158	0.45	188	28	27	104	31	5	191	-3.51	-16.30	2.86	0.16	0.7200262	
Lck6	LC48	6-Nov-2006	485	7.77	0.01	0.20	161	0.38	149	28	27	88	27	4	211	-2.71	-14.10	8.1	0.44	0.7187478	
Lck7	LC52	6-Nov-2006	523	7.98	<0.01	0.03	188	0.52	164	17	27	90	33	4	178	-2.85	-12.40	2.85	0.16	0.7188371	
Lck8	NA	6-Nov-2006																			
Lck_t1	NA	6-Nov-2006																			
Lck_t2	LC45	6-Nov-2006	377	7.97	0.01	0.02	155	0.24	98	12	25	60	23	3	117	-4.61	-20.60	1.79	0.10	0.7220289	
Lck_t3	LC49	6-Nov-2006	416	7.37	0.02	<0.01	138	0.38	136	16	21	79	24	3	133	-3.87	-17.00	28.4	1.50	0.7205015	
Lck_t4	LC53	6-Nov-2006	378	7.81	0.03	0.15	116	0.45	121	20	21	79	17	3	187	-2.06	-11.35	0.8	0.05	0.7140441	
Lck_t5	LC50	6-Nov-2006	379	7.66	0.01	0.05	112	0.27	118	33	20	71	22	3	122	-4.03	-17.90	8.18	0.44	0.719708	
Lck_t6	LC51	6-Nov-2006	304	7.64	<0.01	0.03	110	0.27	94	8	15	59	16	3	88	-4.26	-19.50	6.44	0.35	0.7190923	
Lck_t7	NA	6-Nov-2006																			
Lck_t8	LC39	6-Nov-2006	225	7.7	0.01	0.14	94	0.16	94	28	15	67	17	3	81	-4.55	-19.20	3.11	0.17	N/A	
Kck1	KC10	21-Dec-2005	1037	7.6	0.23	0.17	162	1.25	492	25	48	242	58	11	478	-2.38	-9.50	2.18	0.13	N/A	
Kck2	KC11	21-Dec-2005	1038	7.8	0.02	0.21	176	1.16	467	43	43	245	55	11	438	-2.26	-11.70	18.8	1	N/A	
Kck3	KC12	21-Dec-2005	1324	7.6	0.06	0.25	199	1.59	638	36	57	308	75	13	600	-2.76	-11.20	3.54	0.2	N/A	
Kck4	KC8	20-Dec-2005	2488	7.9	0.05	<0.01	193	2.81	1235	111	116	517	140	22	1203	-2.62	-11.40	2.88	0.13	N/A	

APPENDICES

Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab										δ ¹⁸ O ‰ rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	^{87/86} Sr ratio
							Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L						
Kck5	KC5	20-Dec-2005	765	7.1	0.07	0.05	57	0.93	397	38	19	218	29	9	204	-2.55	-10.20	0.92	0.06	N/A	
Kck6	KC4	20-Dec-2005	528	7.3	0.11	0.04	63	0.81	246	28	13	152	18	7	137	-2.46	-10.30	1	0.07	N/A	
Kck7	KC3	20-Dec-2005	345	7.2	0.19	<0.01	47	0.52	164	12	10	92	16	4	114	-4.07	-17.30	6.39	0.34	N/A	
Kck_t1	KC1	20-Dec-2005	380	7.1	0.10	0.01	62	0.54	164	20	14	97	16	4	137	-2.13	-9.00	3.02	0.17	N/A	
Kck_t2	KC2	20-Dec-2005	847	7.3	0.16	0.09	130	1.04	383	35	21	243	28	11	229	-3.29	-15.50	2.55	0.15	N/A	
Kck_t3	KC9	20-Dec-2005	546	7.8	<0.01	<0.01	187	0.57	182	6	34	93	37	4	194	-2.84	-12.40	2.73	0.16	N/A	
Kck_t4	KC7	20-Dec-2005	533	7.8	0.05	0.03	350	0.43	140	1	41	106	45	5	265	-2.92	-13.80	2.25	0.16	N/A	
Kck_t5	KC6	20-Dec-2005	815	7.2	0.15	1.87	73	1.06	411	32	27	225	32	10	213	-1.36	-3.80	0.32	0.03	N/A	
Kck1	KC18	8-Mar-2006	1385	7.6	0.11	0.03	228	2.13	665	4	62	333	79	14	598	1.59	7.20	0.72	0.05	N/A	
Kck2	KC17	8-Mar-2006	1888	8.1	0.06	0.01	218	2.42	926	75	75	475	101	21	763	-0.64	-0.40	4.56	0.32	N/A	
Kck3	KC16	8-Mar-2006	1487	7.6	0.06	0.14	175	1.77	712	75	67	350	93	15	667	-1.86	-4.80	1.68	0.12	N/A	
Kck4	KC14	8-Mar-2006	1421	7.5	0.06	0.01	174	1.89	713	35	71	320	94	14	711	0.60	5.20	2.82	0.20	N/A	
Kck5	KC13	8-Mar-2006	421	7.1	0.05	0.08	79	0.58	185	10	14	112	16	5	137	1.60	9.40	1.05	0.08	N/A	
Kck6	NA	8-Mar-2006																			
Kck7	NA	8-Mar-2006																			
Kck_t1	NA	8-Mar-2006																			
Kck_t2	NA	8-Mar-2006																			
Kck_t3	NA	8-Mar-2006																			
Kck_t4	KC15	8-Mar-2006	964	7.9	0.08	0.06	432	0.74	250	1	60	142	73	6	385	-3.71	-17.20	1.4	0.10	N/A	
Kck_t5	NA	8-Mar-2006																			
Kck1	KC20	28-Jul-2006	1297	7.6	0.05	0.14	152	1.59	653	54	60	293	77	13	490	-3.21	-14.50	1.75	0.11	N/A	
Kck2	KC22	28-Jul-2006	1510	8.0	0.05	0.33	175	1.77	763	64	72	333	92	14	604	-3.34	-15.60	5.23	0.28	0.7206672	
Kck3	KC23	28-Jul-2006	2523	7.8	0.09	0.31	212	3.43	1347	104	119	572	155	25	941	-3.11	-14.30	2.83	0.21	N/A	
Kck4	KC25	28-Jul-2006	2225	7.6	0.09	0.13	152	3.16	1207	107	103	510	133	22	917	-2.74	-13.15	7.14	0.39	N/A	
Kck5	KC28	28-Jul-2006	830	7.2	0.04	0.26	49	1.13	438	50	23	230	35	10	241	-2.17	-7.90	3.41	0.19	N/A	
Kck6	KC29	28-Jul-2006	669	7.1	0.03	0.04	39	0.80	346	43	15	198	23	9	149	-4.03	-17.00	2.37	0.14	N/A	
Kck7	KC30	28-Jul-2006	534	6.7	0.04	0.02	22	0.79	294	26	14	150	24	7	155	-4.41	-17.80	6.98	0.38	0.7271871	
Kck_t1	KC19	28-Jul-2006	463	7.1	0.02	0.05	35	0.53	231	29	13	132	17	6	127	-3.66	-15.50	1.66	0.1	N/A	
Kck_t2	KC21	28-Jul-2006	847	7.4	0.03	0.01	67	1.04	429	49	20	249	29	11	201	-3.77	-17.20	1.96	0.12	N/A	
Kck_t3	KC24	28-Jul-2006	470	7.9	0.02	0.03	141	0.45	164	17	28	83	31	4	154	-3.59	-16.20	4.42	0.24	N/A	
Kck_t4	KC26	28-Jul-2006	778	7.9	0.06	0.01	379	0.52	165	9	45	124	49	5	258	-3.04	-16.10	3.34	0.19	N/A	
Kck_t5	KC27	28-Jul-2006	547	7.3	0.08	0.12	76	0.48	234	42	24	142	20	6	154	-0.26	0.80	0.38	0.03	N/A	
Kck1	KC31	2-Nov-2006	1852	7.8	0.04	<0.01	205	2.44	988	38	81	424	104	18	698	-0.63	-0.80	0.74	0.05	0.7269147	

APPENDICES

Location ID	Sample ID	Collection date	TDS mg/L	Lab pH	NH ₄ -N mg/L	NO _x -N mg/L	Lab Alkalinity (HCO ₃ ⁻) mg/L	Br ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	K ⁺ mg/L	Mg ²⁺ mg/L	Na ⁺ mg/L	Sr ug/L	δ ¹⁸ O ‰ rel VSMOW	δ ² H‰ rel VSMOW	Radon-222 Bq/L	Radon-222 error Bq/L	⁸⁷ / ₈₆ Sr ratio
Kck2	KC32	2-Nov-2006	2401	7.9	0.20	0.04	235	3.14	1278	79	90	564	139	25	858	-0.86	-3.40	9.17	0.49	0.7215091
Kck3	KC33	2-Nov-2006	3551	7.84	0.11	0.08	328	4.69	1937	90	159	793	227	35	1476	-3.14	-13.10	2.62	0.15	0.7215517
Kck4	KC34	2-Nov-2006	5484	7.91	0.18	<0.01	388	7.86	3016	198	273	1200	379	52	2854	-1.36	-7.70	3.3	0.18	0.7226764
Kck5	KC36	2-Nov-2006	794	6.75	0.01	<0.01	35	1.12	437	43	14	228	32	10	208	-1.67	-6.80	12.36	0.66	0.7242666
Kck6	KC37	2-Nov-2006	1171	7.52	0.01	<0.01	78	1.74	653	24	22	351	34	15	248	2.86	14.00	1.01	0.06	0.7234085
Kck7	KC38	2-Nov-2006	689	7.42	0.03	0.01	57	0.93	375	18	17	190	28	8	206	-3.80	-15.90	1.58	0.09	0.7255431
Kck_t1	NA	2-Nov-2006																		
Kck_t2	NA	2-Nov-2006																		
Kck_t3	NA	2-Nov-2006																		
Kck_t4	KC35	2-Nov-2006	800	7.98	0.01	<0.01	379	0.53	187	3	47	127	53	6	282	-3.51	-15.90	1.58	0.09	0.714719
Kck_t5	NA	2-Nov-2006																		

UNITS OF MEASUREMENT

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

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

Shortened forms

Abbreviations of environmental and isotopic tracers

$\delta^2\text{H}$	hydrogen isotope composition	$\delta^{13}\text{C}$	CFC	chlorofluorocarbon
	carbon-13		CO_2	carbon dioxide
$\delta^{18}\text{O}$	oxygen isotope composition		$[\text{Cl}^-]$	chloride
^{14}C	carbon-14		EC	electrical conductivity ($\mu\text{S}/\text{cm}$)
$^{87/86}\text{Sr}$	ratio of strontium isotopes		pCO_2	pressure of CO_2
	strontium-87 to strontium-86		pMC	percent of modern carbon
^{222}Rn	radon isotope radon-222		pH	acidity
^{14}C	carbon isotope carbon-14		K	hydraulic conductivity (m/d)
A_o	initial activity			
Bq	becquerel			

GLOSSARY

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

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)

Bore — *See well*

¹⁴C — 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 — Cox Creek Catchment

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

Contaminant/Contamination — 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

δ²H — Hydrogen isotope composition (‰)

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

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

FRA — Fractured rock aquifer

GNIP — Global Network of Isotopes in Precipitation

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

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

GLOSSARY

KCC — Kersbrook Creek Catchment

LCC — Lenswood Creek Catchment

LMWL — Local meteoric water line

Ma — Million annum

mAHD — metres Australian Height Datum = mean sea level

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

$\delta^{18}\text{O}$ — Oxygen isotope composition (‰)

ppm — Parts per million

Recharge — rainfall, streamflow, irrigation, etc infiltration to an aquifer

SEC — Specific electrical conductance: electrical conductivity measurement adjusted to the equivalent EC at 25°C. 1 EC unit = 1 micro-Siemen per centimetre ($\mu\text{S}/\text{cm}$); commonly used to indicate the salinity of water

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

TDS — Total dissolved solids: the unit is milligrams per litre (mg/L)

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

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

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

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 *Natural Resources Management (SA) Act 2004* 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

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