DWLBC REPORT

Groundwater Recharge Investigation in the Tookayerta Creek Catchment, South Australia

2007/14

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

Groundwater Recharge Investigation in the Tookayerta Creek Catchment, South Australia

Eddie Banks, Dragana Zulfic and Andrew Love

Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

June 2007

Report DWLBC 2007/14

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

Knowledge and Information Division

Department of Water, Land and Biodiversity Conservation

25 Grenfell Street, Adelaide

GPO Box 2834, Adelaide SA 5001

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

ISBN 978-1-921218-50-7

Preferred way to cite this publication

Banks, EW, Zulfic, D & Love, AJ 2006, *Groundwater recharge investigation in the Tookayerta Creek Catchment, South Australia,* DWLBC Report 2007/14, Government of South Australia, through Department of Water, Land and Biodiversity Conservation, Adelaide.

FOREWORD

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

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

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

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

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Mount Lofty Ranges provide important surface water and groundwater resources for domestic, industrial and agricultural purposes. The development and implementation of the Water Allocation Plan for the Eastern Mount Lofty Ranges will ensure that current and future development of these resources are sustainable and that the environment is also recognised as a user of the resource.

Technical investigations are being conducted to determine the various components of the water balance, which are essential to the development of the Water Allocation Plan. Estimating recharge rates is difficult using standard hydrogeological techniques due to the complex and varied hydraulic properties of the aquifer materials. Hydrochemical, isotopic and anthropogenic tracers have been used widely in groundwater studies to determine the apparent age, depth of circulation, vertical flow and sources of groundwater.

This report describes the methodology and outcomes of the recharge investigation using a variety of different hydrogeological and tracer techniques to estimate the recharge rate to the Permian sands aquifer system in the Tookayerta Creek Catchment. It will provide sound knowledge to estimate recharge rates at a catchment scale and assist in the development of a conceptual model of the sedimentary aquifer systems in the catchment.

Groundwater elevations in the Permian sands aquifer generally reflect changes in the topography. The regional movement of groundwater in the aquifer is from west to east. The direction of groundwater flow is influenced by the surface of the underlying basement rocks, which crop out in the middle of the catchment and along the margin of the catchment boundary. Hence, the regional groundwater flow from the Mount Compass area is eastwards and diverges around a basement high in the middle of the catchment, following the valleys of Nangkita and Cleland Gully Creeks.

The Permian sands aquifer is dominantly an unconfined system and therefore groundwater recharge is diffuse. Recharge is assumed to be greater near the topographic highs corresponding to areas of higher rainfall, particularly in the western region of the catchment. Chlorofluorocarbon data provide evidence for rapid recharge processes to the aquifer occurring in areas where the Permian sands crop out. Hydrochemistry and the stable isotope data provide further evidence for rapid recharge processes as the isotopic signature of the groundwater samples is similar to rainfall events in winter and, therefore, the majority of recharge would occur at this time.

Chlorofluorocarbons have been used successfully to estimate the recharge rate to the unconfined Permian sands aquifer, with average recharge estimated to be between 100 and 150 mm/y. Estimates using the chloride mass balance method were typically lower than the chlorofluorocarbon technique, with groundwater recharge calculations averaging 64 mm/y.

1. INTRODUCTION

The Mount Lofty Ranges (MLR) provide important surface water and groundwater resources for local domestic, industrial and agricultural purposes, as well as metropolitan Adelaide's reticulated water supply. Development and implementation of the Water Allocation Plan (WAP) for the Eastern Mount Lofty Ranges (EMLR) will ensure that current and future use of these resources are sustainable and that the environment is also recognised as a user of the resource.

Currently, technical investigations are being conducted to determine the various components of the water balance, which are essential to the development of the WAP. The long-term sustainability of the groundwater resource requires careful estimates of the magnitude of all components of the groundwater budget. Variability in the amount of water recharging an aquifer system depends on rainfall, evaporation, land use, topography, geology and the physiochemical properties of the water and the rock formation that the water moves through.

Estimating recharge rates is difficult using standard hydrogeological techniques due to the complex and varied hydraulic properties of the aquifer materials. Hydrochemical, isotopic and anthropogenic tracers have been used widely in groundwater studies to determine the apparent groundwater age, depth of circulation, vertical flow, and sources and evolution of groundwater. This report describes the methodology and outcomes of the recharge investigation using a variety of different hydrogeological and tracer techniques.

1.1 AIMS AND OBJECTIVES

The following investigation aims to provide technical information to support the successful implementation of the WAP for the EMLR. Specifically, this investigation aims to:

- estimate the recharge rate to the Permian sands aquifer and hence the sustainable yield for groundwater extraction in the Tookayerta Creek Catchment (TCC)
- provide sound knowledge to estimate recharge rates at a catchment scale
- assist in the development of a conceptual model of the sedimentary system in the TCC.

2. TOOKAYERTA CREEK CATCHMENT

2.1 STUDY SITE

The TCC, with an area of ~100 km^2, is in the southeastern MLR ~60 km south of Adelaide and has three major sub-catchments — the Nangkita Creek, Lower Tookayerta and Cleland Gully sub-catchments. Surface drainage is eastwards from the higher western boundary of the catchment (Fig. 2.1). Nangkita Creek, in the north of the catchment, joins Tookayerta Creek in the south of the catchment near the township of Tooperang. From the confluence, the creek flows in a southeasterly direction through Black Swamp into the lower reaches of the Finniss River and then into Lake Alexandrina and the lower River Murray near Goolwa.

The TCC is unique amongst the catchments of the EMLR as the major tributaries are perennial and have low salinity. The good quality water not only provides an excellent supply for domestic, stock and irrigation purposes but also supports a unique flora and fauna environment not found elsewhere in South Australia (Suter 1987; Hammer 2004).

2.1.1 CLIMATE AND PHYSIOGRAPHY

The climate in the region is characterised by hot dry summers and cool wet winters. The average annual rainfall decreases eastwards across the catchment, from 850 mm/y at the township of Mount Compass, near the western boundary, to 550 mm/y in the east (catchment average 770 mm/y). Eighty percent of the rainfall occurs between the months of May and November.

Land use in the TCC is predominantly livestock grazing (60%) followed by dairy cattle and irrigated pasture (18%), and forestry plantation or protected area (14%). The remaining land use is comprised of vineyards, sand mining and horticulture (Barnett & Zulfic 1999). In the last decade there has been a general decline in the use of irrigated pasture due to the current state of the dairy industry and expansion of other agricultural developments (i.e. vines).

2.1.2 GEOLOGY AND HYDROGEOLOGY

The basement rocks of the TCC consist of Palaeoproterozoic gneisses of the Myponga Inlier (Barossa Complex), Adelaidean sequences and Cambrian sedimentary rocks of the Kanmantoo Group. The catchment is dominated by two ancient glacial valleys that have been infilled by the Cape Jervis Formation (Fig. 2.2). These sediments were deposited by glacial meltwaters towards the end of the Permian glaciation and consist mainly of fine to medium quartz sand with intermittent silty clay layers. They are widespread across the Fleurieu Peninsula and have been found up to depths of 200 m in the Mount Compass area. During the Tertiary Period, the Permian sands underwent some reworking and, as a result, the Tertiary sands typically have higher clay and iron contents than the relatively clean Permian deposits. A recent sand resource investigation included the drilling of 64 holes near

Mount Compass and reported that the dominant lithology intersected was sub-rounded to rounded, fine to medium-grained Permian fluvioglacial sand, with reworked Tertiary sand intersected at the top of many holes (Pain et al. 1999).

There are two major aquifer units in the TCC — the fractured basement rock (Barossa Complex) and the unconfined Cape Jervis Formation (Permian sands) aquifers. The majority of bores in the TCC are located within the unconfined aquifer because its high permeability and porosity provide excellent yields. In addition, salinity in the unconfined aquifer is much lower than the fractured rock aquifer and provides good quality water for domestic use, town water supply, stock and irrigation.

Figure 2.3, a hydrogeological cross-section (transect A-A'-A'') from west to east through the TCC, shows the basement cropping out in the middle of the catchment between bores 6627-9821 and 6627-10913, intersected by a major north–south-orientated fault. The Permian sands are of considerable thickness, up to several hundred metres, in the western and eastern extents of the catchment. Overlying the Permian sands are more recent Quaternary deposits comprised of clay and silt.

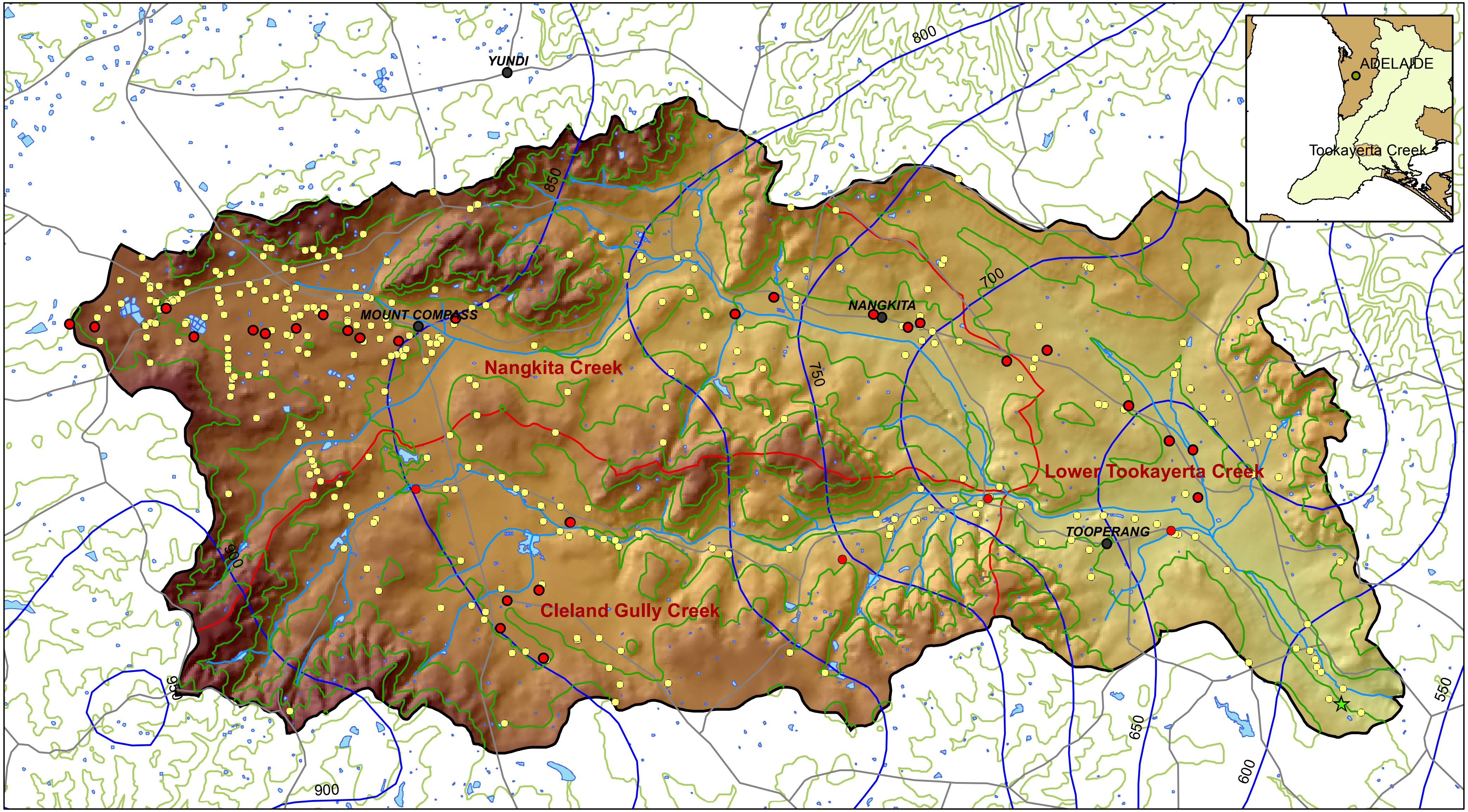


Figure 2.1 Tookayerta Creek Catchment location map

0 1 2 3 Km

Disclaimer: data is for information purposes only and accuracy of the data is not guaranteed and cannot be reproduced

- Major towns
- Bores in the TCC
- Sampled bores
- Tookayerta Creek Catchment boundary
- Sub-catchment boundary
- Dams
- Gauge station
- Major streams
- Annual rainfall (50 mm intervals)
- Major roads
- Contours (40 m intervals)

Elevation m ASL

400 metres

0 metres

Produced By: Mount Lofty Ranges Team
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

Datum: Geocentric Datum of Australia 1994 (GDA94)

Date: 1st November 2006

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

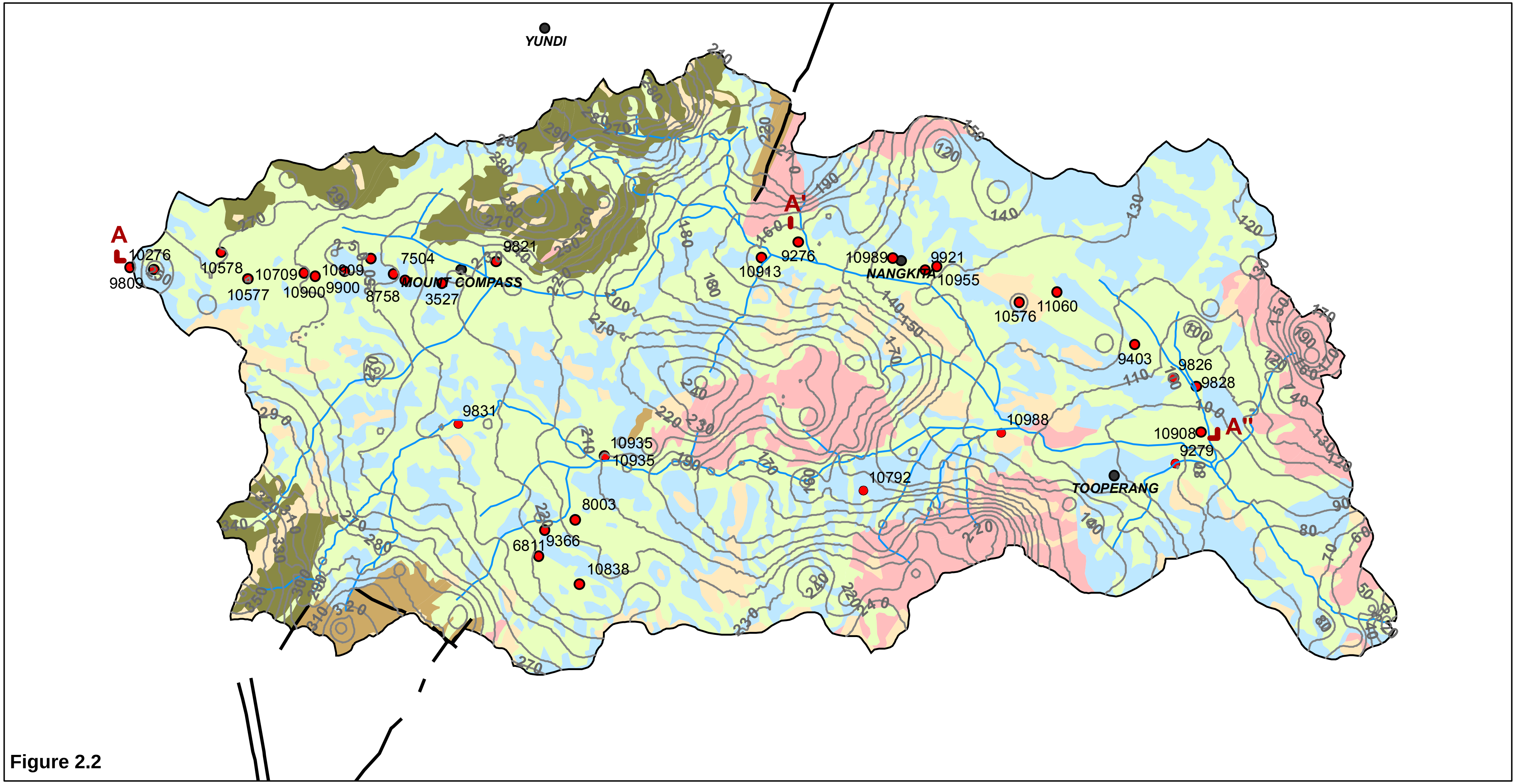


Figure 2.2

Tookayerta Creek Catchment Geology

- Major towns
- Sampled bores
- Tookayerta Creek Catchment boundary
- Major streams
- 180 Water table surface contour m AHD
- Major faults
- A Cross section

Geology

- Quaternary deposits
- Tertiary deposits
- Cape Jarvis Formation
- Kanmantoo Group
- Adelaidean Sediments
- Barosa Complex

0 1 2 3 4 Km

N

Produced By: Mount Lofty Ranges Team Knowledge and Information Division Department of Water, Land and Biodiversity Conservation
Datum: Geocentric Datum of Australia 1994 (GDA94)
Date: 1st November 2006

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

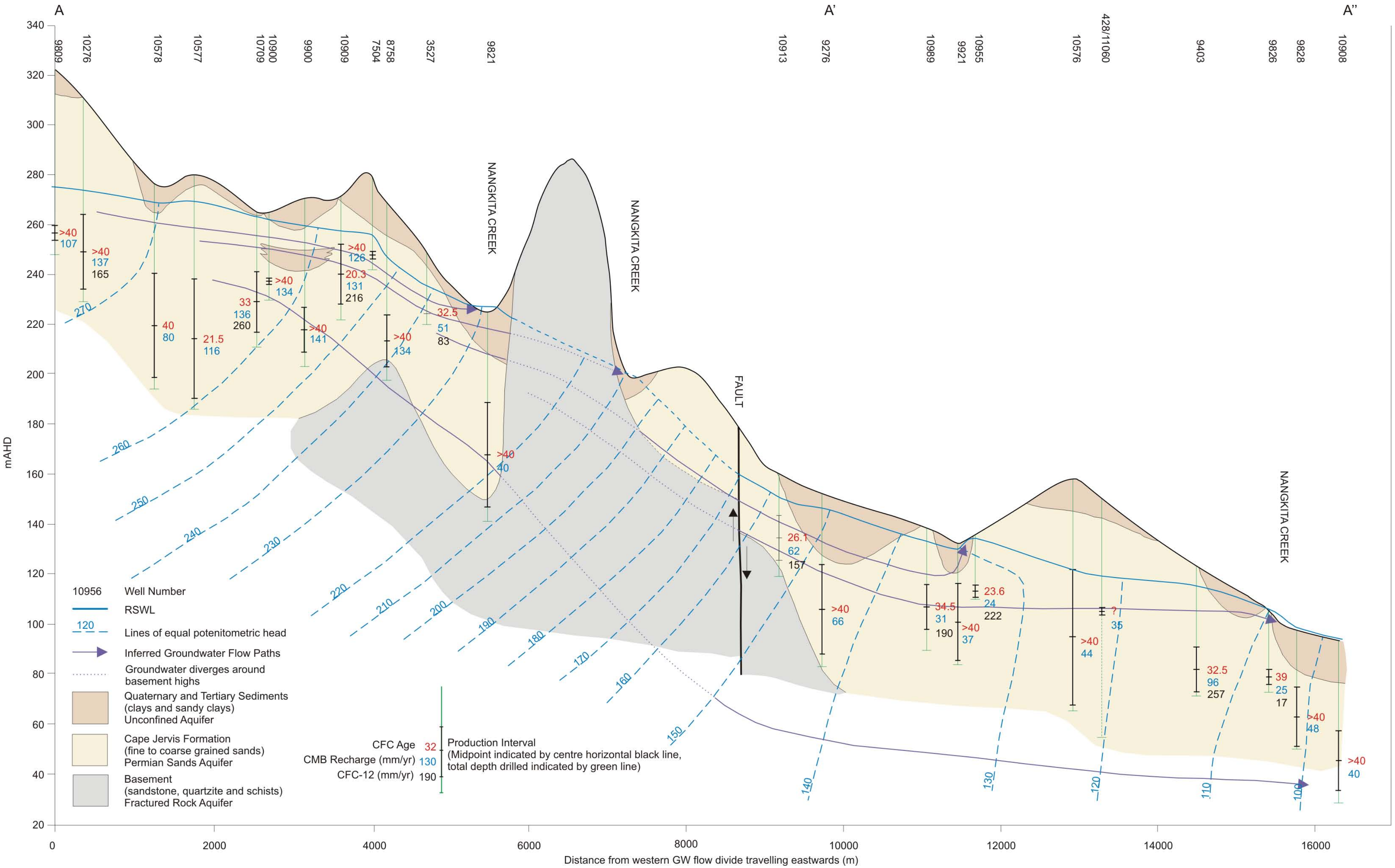


Figure 2.3 **Tookayerta Creek Catchment — schematic hydrogeological cross-section along transect A-A'-A'' (from west to east), showing average CFC age, and the estimated groundwater recharge using the CFC and CMB techniques.**

3. METHODOLOGY

The following section describes the methodology used to understand the groundwater recharge mechanisms and flow processes in the Permian sands aquifer in the TCC.

There are ~360 bores in the TCC, with some being constructed as early as the mid 1940s. A preliminary desktop study and field trip were conducted to select suitable bores to measure watertable elevations and collect water samples for this investigation. Thirty-two bores completed in the Permian sands aquifer were selected, according to their location, current completion depth, relative short production zone interval, and accessibility to measure depth to the watertable and to collect water samples. The elevation of these selected bores was accurately surveyed and transects were drawn between them along potential groundwater flow paths from groundwater divide to discharge zone.

Prior to sampling the bores, the static water level was measured from top of casing (TOC) using an electric water level indicator. The equipped bores were then purged using the existing pump (with unequipped bores a Grundfos-MP1 submersible pump was used) until the parameters (pH, electrical conductivity, dissolved oxygen and temperature) had stabilised, indicating that the sample was representative of the section of the aquifer sampled. This was done using an FL90mv meter and flow-thru cell. The meter was calibrated with known standards prior to use in the field. The total alkalinity (as HCO_3^-) was also measured in the field using a HACH titration kit. Sampling for chlorofluorocarbons (CFCs) using a stainless steel bailer could not be used in all bores due to the construction of the bore headwork. However, due to the high volume of water removed from the bores with the equipped pumps, contamination was considered to be minor.

3.1 HYDROCHEMISTRY AND ISOTOPES

Major ion analysis was conducted on the groundwater samples that had been filtered through a 0.45μ membrane filter. Cations (Na^+, Mg^{2+}, K^+, Ca^{2+}) and trace elements were acidified with nitric acid (1% v/v HNO_3) to keep the ions in solution and analysed by Inductively Coupled Plasma Emission Spectrometry (ICP-ES). Anions (Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-) were analysed by ion chromatography.

Samples were also collected and analysed for stable isotopes of the water molecule — deuterium (δ^2H) and oxygen-18 ($\delta^{18}O$). Adelaide is the closest station to TCC with rainfall isotopic data provided by the International Atomic Energy Agency (IAEA) Global Network of Isotopes in Precipitation (GNIP) service (IAEA/WMO 2005). For this investigation, only complete annual data sets from the GNIP database were used to derive the weighted average rainfall and the local meteoric water line (LMWL) for Adelaide ($\delta^2H = 7.66\ \delta^{18}O + 9.56$).

The stable isotopes of the water molecule are conservative tracers and provide information on physical processes of the hydrological system over time, as opposed to a point in time such as the potentiometric surface. They are also not removed from water by exchange processes in most low temperature aquifer systems (Coplen et al. 1999). In particular, they can be used for the delineation of groundwater flow systems, extent of the discharge zone beneath a water body, recharge processes, and quantification of mass balance relationships.

3.2 CHLOROFLUOROCARBONS

Groundwater samples were collected for chlorofluorocarbon (CFCs) analysis to determine the apparent age of the water and provide information on the groundwater flow processes, including depth of circulation and vertical connectivity. CFCs are stable organic compounds that were first manufactured in the 1930s and are solely from anthropogenic sources. Concentrations of CFCs in water vary as a function of the atmospheric partial pressures of CFCs and their solubility, which is a function of salinity and temperature and can be used to determine apparent groundwater age. An increase in the temperature of the recharged groundwater will decrease the ages calculated from the CFC concentrations. CFCs can be measured in groundwater that has been recharged since about 1940 or in a mixture of 1940 water and older waters. CFCs have been used as age indicators for groundwater studies since about 1979 (Szabo et al. 1996).

Processes that affect the CFC age include sorption, contamination, microbial degradation, hydrodynamic dispersion and diffusion from air in the unsaturated zone (Szabo et al. 1996). Vertical profiles of apparent groundwater age have been used successfully to estimate rates of vertical groundwater flow in sedimentary aquifers (Cook & Bohlke 1999). Assuming that sampling takes place near the watertable, then the vertical water velocity will be constant with depth and the horizontal component of groundwater flow will be relatively small, such that the recharge rate (*R*) may be approximated by:

$$R = \frac{z\theta}{t} \qquad \text{(Equation 1)}$$

where *z* is the depth below the watertable, θ is the porosity of the aquifer medium and *t* is the groundwater age.

3.3 CHLORIDE MASS BALANCE

The chloride mass balance (CMB) method can be used to estimate recharge and has been applied in many different countries and environments (Eriksson & Khunakasem 1969). The method assumes that the only source of chloride in groundwater is via deposition in rainfall, that the rate of chloride accession to the landscape is constant, and there are no sources or sinks of chloride in the subsurface. The following steady state mass balance equation can be used to estimate recharge (*R*) by:

$$R = \frac{(P - RO)}{Cr} Cp \qquad \text{(Equation 2)}$$

where *P* is the mean annual precipitation rate, *RO* is the annual surface runoff rate, *Cp* is the chloride concentration in the precipitation, and *Cr* is the chloride concentration in recharge water (groundwater).

4. RESULTS AND DISCUSSION

4.1 HYDRAULICS

Groundwater elevations in the Permian sands aquifer generally reflect changes in the topography. The observed potentiometric surface determined from measured watertable elevations in groundwater bores in the TCC and surrounding area shows that the regional movement of groundwater in the aquifer is from west (~260 m AHD) to east (~40 m AHD; Fig 2.2). The direction of groundwater flow tends to be influenced by the surface of the underlying basement rocks, which crop out in the middle of the catchment and along the margin of the catchment boundary. Hence, the regional groundwater flow from the Mount Compass area is eastwards and diverges around the basement high in the middle of the catchment, following the valleys of Nangkita and Cleland Gully Creeks.

Groundwater recharge is assumed to be greater near the topographic highs corresponding to areas of higher rainfall, particularly in the western region of the catchment. Figure 2.2 shows many areas in the TCC where Permian sands material is at the surface, and would be areas of greater and more rapid recharge to the aquifer. The Permian sands aquifer is dominantly an unconfined system and, therefore, groundwater recharge is diffuse. The watertable is near ground surface in many areas across the catchment indicated by the presence of swamp vegetation.

Figure 2.3 is a hydrogeological cross-section along transect A-A'-A'' from the western boundary divide of the TCC to the east (see Fig 2.2 for plan view of transect). The light blue dashed lines are lines of estimated equipotential (equal hydraulic head) determined from the potentiometric head measured at the middle of the bore screen. Groundwater flow is perpendicular to lines of equal potential and moves from high to low potential. According to transect A-A'-A", groundwater travels from the western boundary and discharges along the eastern boundary of the catchment near Black Swamp. The outcrop of basement rock in the middle of the catchment is likely to influence groundwater flow, directing it towards the middle of the valley bottom of the Nangkita and Cleland Gully Creeks. In these areas it is likely that groundwater discharge will occur to the surface water features (i.e. near bore 6627-9821). The major fault that divides the catchment in two (just west of bore 6627-10913) is also likely to have some influence on groundwater flow in the Permian sands and fractured rock aquifers (basement). The Permian sands aquifer is ~100 m thick and tends to be thicker in the western and eastern extents of the catchment.

4.2 GROUNDWATER AGE AND VERTICAL FLOW

Figure 4.1(a) shows CFC-11 versus CFC-12 concentrations for the groundwater samples collected between May and June 2005, compared to the air-equilibration curve in pg/kg for recharge at a temperature of 16°C using atmospheric concentrations measured at Cape Grimm, Australia. Atmospheric concentrations of CFC-11 and CFC-12 increased between 1950 and 1995 (Fig. 4.1(b)), and from 1995 onwards the concentrations have started to decrease due to the ceased production of CFCs. The air-equilibration curve describes the

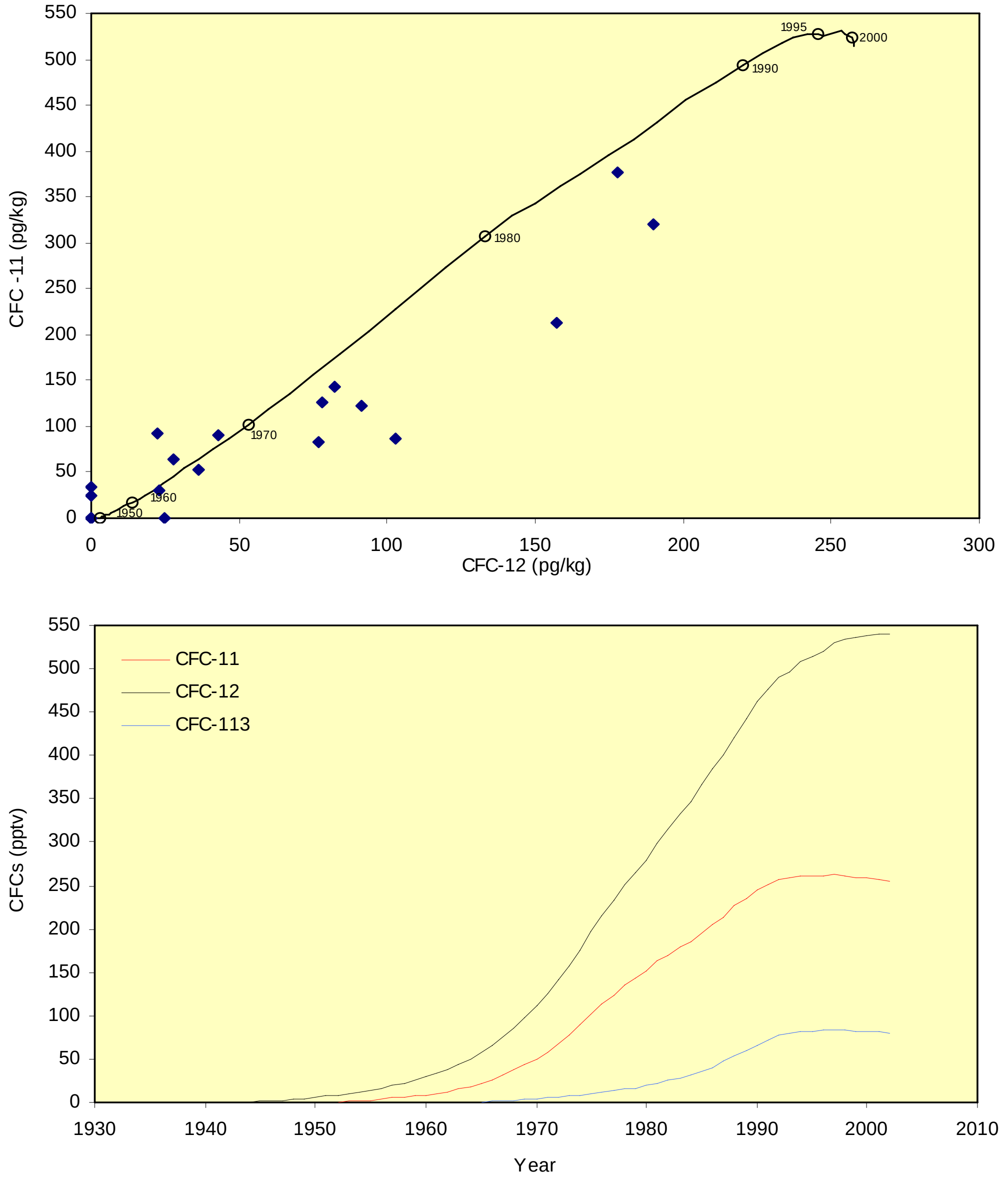


Figure 4.1 (a) CFC-11 versus CFC-12 concentrations for groundwater collected May–June 2005. The solid line indicates the relationship between CFC-11 and CFC-12 concentrations that should occur for samples in equilibrium with the atmosphere at a temperature of 16°C. (b) Atmospheric concentrations of CFC-11, CFC-12 and CFC-113 from 1940 until present, measured at Cape Grimm, Tasmania.

evolution of CFC-11 and CFC-12 concentrations in water in equilibrium with the atmosphere over this period. An average recharge temperature of 16±0.8°C was assumed for the TCC according to measurements of shallow groundwater in the Permian sands aquifer.

The majority of the groundwater samples fall slightly to the right of the air-equilibration curve indicating some loss of CFC-11 and/or addition of CFC-12. Many of the samples had concentrations at or close to background concentrations (CFC-12 <20 pg/kg and CFC-11 <25 pg/kg) and therefore the apparent age of these samples is greater than 1965. The groundwater sample (T15) from bore 6627-10955 has a much higher CFC-12 concentration than present-day atmospheric concentrations indicating that the sample is contaminated by a

CFC-12 source. However, the CFC-11 concentration for the same sample shows no signs of contamination and has an apparent age of 1981, or 24 years.

Table 4.1 shows the sampled groundwater bores for CFCs in the TCC and the estimated apparent CFC groundwater age. It is important to recognise that all of the bores sampled are used for irrigation and domestic purposes, and hence the CFC apparent age is of a mixed groundwater sample over the length of the screened interval or production zone.

Table 4.1 CFC concentrations and apparent groundwater ages for sampled groundwater bores in the TCC.

Unit number	**Ground elevation** (m ASL)	**TOC** (m)	**Bore depth below ground** (m)	**Screen length** (m)	**SWL from TOC** (m)	**Sample depth below watertable** (m)	**CFC11** (pg/kg)	**CFC12** (pg/kg)	**CFC11** (years)	**CFC12** (years)	**Average CFC age** (years)
6627 3527	253.0	0.3	29	1.0	18.0	10.8	123	92	1971.0	1974.0	32.5
6627 6811	232.0	0.39	38	4.0	5.9	30.5	126	78	1971.0	1973.0	33.0
6627 7504	281.0	0.15	34.6	3.0	25.2	8.1	<25	<20	<1965	<1965	>40
6627 8003	226.8	0.28	129.4	27.6	12.2	103.7	<25	<20	<1965	<1965	>40
6627 8758	272.0	0.28	69	21.0	24.9	33.9	<25	<20	<1965	<1965	>40
6627 9276	153.7	0.08	65	36.0	6.5	40.6	<25	<20	<1965	<1965	>40
6627 9279	91.6	0.06	39	18.0	1.7	28.3	25	<20	<1965	<1965	>40
6627 9366	234.9	0.2	72	24.0	6.6	53.6	<25	<20	<1965	<1965	>40
6627 9403	122.2	0.1	48	18.0	5.7	33.4	143	82	1972.0	1973.0	32.5
6627 9809	322.7	0.11	69	6.0	47.5	18.6	31	23	<1965	<1965	>40
6627 9821	225.0	0.17	78	42.0	2.3	54.9	<25	<20	<1965	<1965	>40
6627 9826	109.4	0.07	32	6.0	2.0	27.1	64	28	1967.0	1965.0	39.0
6627 9828	100.3	0.3	48	24.0	0.4	35.9	<25	<20	<1965	<1965	>40
6627 9831	239.8	0.15	42	24.0	4.1	26.1	52	36	1965.0	1966.0	39.5
6627 9900	271.0	0.75	62	18.0	12.0	41.8	<25	<20	<1965	<1965	>40
6627 9921	133.4	0.6	47	31.0	2.9	29.2	<25	<20	<1965	<1965	>40
6627 10276	313.0	0.15	79	30.0	39.1	25.1	92	23	1969.0	<1965	38.0
6627 10576	158.9	0.47	90	54.0	36.4	27.1	33	<20	<1965	<1965	>40
6627 10577	280.0	0.2	90	48.0	11.0	55.2	320	190	1980.4	1986.5	21.5
6627 10578	276.3	0.3	78	42.0	7.5	49.8	<25	25	<1965	1965.0	40.0
6627 10709	265.0	0.06	48	24.0	1.8	34.3	87	103	1968.0	1976.0	33.0
6627 10792	190.6	0.37	60	24.0	24.2	24.2	91	43	1969.0	1968.0	36.5
6627 10900	265.1	0.6	29	2.5	3.6	24.8	<25	<20	<1965	<1965	>40
6627 10908	95.0	0.4	60	24.0	0.0	48.4	<25	<20	<1965	<1965	>40
6627 10909	270.0	0.2	42	24.0	12.6	17.6	376	178	1984.0	1985.3	20.3
6627 10913	162.2	0.26	36	18.0	10.8	16.4	212	157	1975.0	1982.7	26.1
6627 10955	135.2	0	23.5	5.0	0.0	21.0	336	674	1981.4	NA	23.6
6627 10988	116.1	0.68	26	9.0	1.1	21.1	<25	<20	<1965	<1965	>40
6627 10989	140.8	0.5	42	18.0	7.3	26.2	83	77	1968.0	1973.0	34.5

Numerical modelling of multi-phase flow in the unsaturated zone by Cook and Solomon (1995) found that the time lag of transportation of CFCs through thick unsaturated zone material would overestimate the apparent groundwater age. For an unsaturated zone greater than 10 m in thickness the apparent groundwater age may be overestimated by more than several years, and is largely dependent on the gas solubility in water, gas diffusion coefficient and soil water content. The unsaturated zone thickness at the majority of the bore locations in the TCC is less than 10 m; however, at some locations the unsaturated zone thickness is greater than 20 m and the time lag of CFC transportation should be considered. Where this is the case, many of the apparent groundwater ages are greater than 1965.

Figure 4.2 shows the average apparent groundwater age versus depth below the watertable using CFC-11 and CFC-12 concentrations for the sampled bores in the TCC. Samples collected from greater than 40 m depth below the watertable are older than 40 years (1965 being the limit of the CFC age-dating technique) and are not shown. Several samples taken at depths less than 40 m are also older than 40 years and have not been shown, however, these samples do represent a minimum groundwater age. Modern groundwater (>1965) samples tended to correspond to areas in the catchment where the Permian sand crops out (Fig. 2.3). Examples include bores 6627-10909, 6627-3527, 6627-10913, 6627-10989 and 6627-9403. The sample from bore 6627-10577 also had a modern age and is adjacent to an outcrop of Permian sand, whilst bore 6627-10709 is located in a quarry. The sample from bore 6627-9826 in the east of the catchment has an apparent age older than 40 years, although its screen interval is relatively close to the watertable which suggests that this may be a zone of groundwater discharge.

4.3 AQUIFER RECHARGE

4.3.1 CHLOROFLUOROCARBONS

Figure 4.3 shows the measured CFC-12 concentrations of the groundwater samples versus depth below the watertable where they are also compared to two CFC recharge models showing annual recharge rates of 50, 100, 150, 200, 300 and 400 mm. A relationship between sample depth, porosity and time (CFC apparent age) was used to determine an annual recharge rate (Equation 1). Measured CFC-12 values above background concentrations were plotted and used in the model as it behaves more conservatively and is not subject to significant biodegradation like CFC-11. The two different models assume steady state conditions, a constant recharge rate, a recharge temperature of 16°C and a porosity of 0.25 (typical of a well-sorted sand) and 0.35 (silt). These values represent the porosities of fine to medium-grained sands of the Permian sands as reported by Pain et al. (1999).

In the model, using a porosity of 25%, the majority of the groundwater samples between 15–30 m depth below the watertable indicate a recharge rate of between 100–150 mm/y. This is ~13–19% of the average annual rainfall (assuming 770 mm/y average rainfall across the TCC). Using 35% porosity for the same depth interval, the groundwater samples indicate a recharge rate of between 100–300 mm/y, which is ~13–39% of the average annual rainfall to TCC.

Considering that hydrodynamic dispersion is small in unconsolidated unconfined aquifers, groundwater ages determined using these tracers closely approximate hydraulic ages (subsurface residence times) of the water.

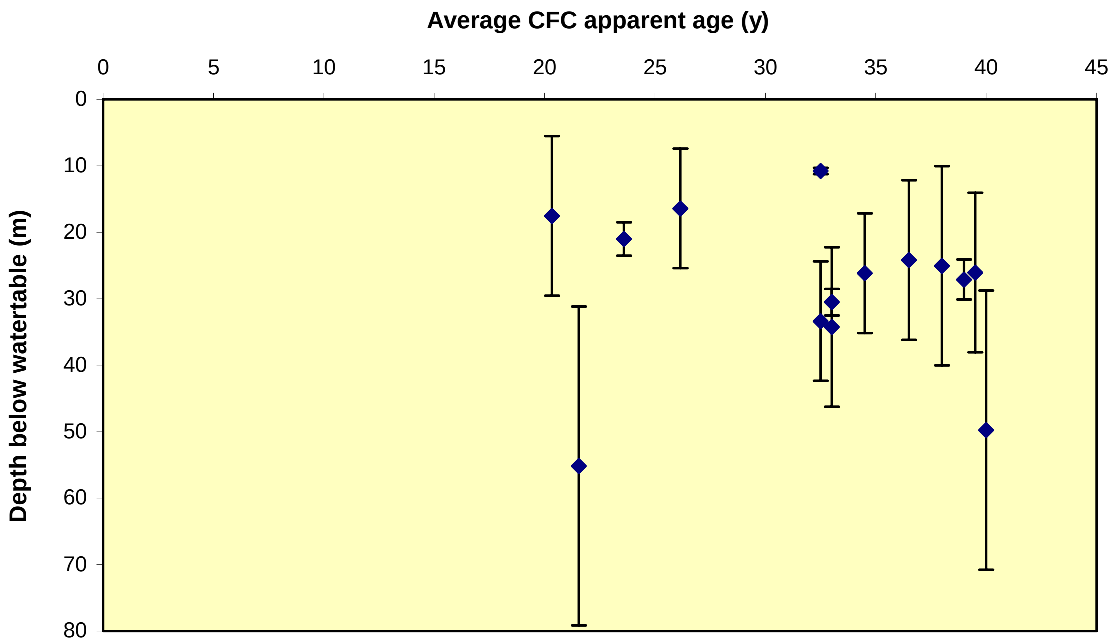
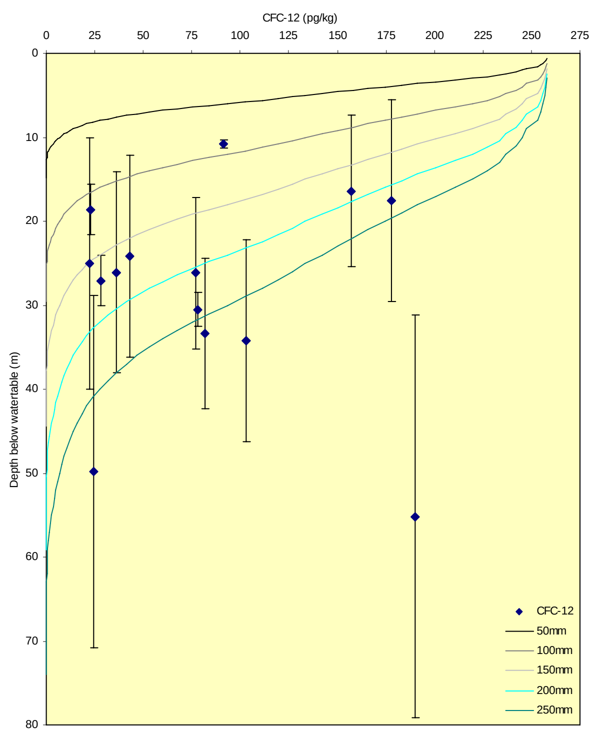


Figure 4.2 Average CFC apparent groundwater age versus depth below watertable measured at individual bores for samples collected between May and June 2005. The vertical bar represents the length of the screen interval for individual bores.



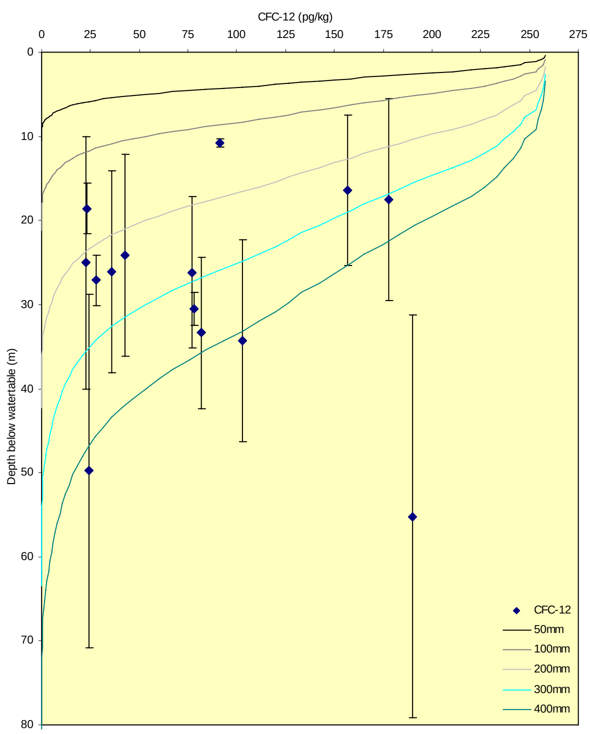


Figure 4.3 CFC-12 versus depth below the watertable measured at individual bores. The vertical bar represents the length of the screen interval for individual bores. Samples with concentrations at or below background (<20 pg/kg) are not shown. Coloured lines represent different CFC recharge models for recharge rates of 50, 100 150, 200, 250 and 400 mm/y.

4.3.2 CHLORIDE MASS BALANCE

Chloride data from bores constructed in the Permian sands aquifer in the TCC and nearby region were used in the CMB calculation to estimate annual rates of groundwater recharge (Table 4.2). A minimum (2.7 mg/L), maximum (11.6 mg/L) and average (7.2 mg/L) chloride concentration in rainfall was used based on measurements from the nearby Myponga and Finniss Catchments. Average annual rainfall data were determined for point locations next to the sampled bores using the rainfall isohyets developed from BoM stations in the area. The surface runoff coefficient for the TCC is estimated to be 0.25 (i.e. 25% of rainfall runs off), which is greater than the calculated 10% for most of the other catchments already assessed in the EMLR (Savadamuthu 2004). The average annual recharge rate to the Permian sands aquifer is 64 mm/y, which is ~8% of annual rainfall to the TCC (assuming 25% runoff), compared to 76 mm/y when a surface runoff of 10% is used. The maximum recharge in the TCC, assuming average chloride concentration in rainfall of 7.2 mg/L and a runoff of 25%, is ~190 mm/y.

4.4 ORIGIN OF GROUNDWATER

Field measurements and laboratory results of groundwater sampling in the TCC between March and June 2005 are shown in Table 4.3, including surface water sampling in the TCC between July 2002 and March 2003 (Harrington 2004), and March 2005 (Fass & Cook 2005). The sampled groundwater bores located in the Permian sands aquifer are named according to the sub-catchment in which the bore is located. Rainfall samples from surrounding gauge stations and pluviometers in the Finniss and Myponga Catchments are also shown.

The surface water and groundwater samples collected from the TCC are shown on a PIPER plot in Figure 4.4. The majority of the surface water and groundwater samples are all of Na–Cl type (similar to the composition of seawater). Some groundwater samples from the Lower Tookayerta Creek (T28) and Nangkita Creek (T1, T4, T6, T15, T16, T26) sub-catchments are Na–Mg–Cl type. Groundwater samples from Nangkita Creek (T20) and Gully (T10) sub-catchments are Na–Ca–HCO_3–Cl type. The water types that differ from Na–Cl (seawater) suggest that there has been some water–rock interaction.

Figure 4.5 shows the major ion/Cl ratios relative to chloride in mmol/L. The surface water samples (Tookayerta, Nangkita and Cleland Gully Creeks) have a higher chloride concentration than most of the groundwater samples from Lower Tookayerta, Nangkita and Cleland Gully sub-catchments. This suggests that solutes in the surface water bodies have been exposed to processes of evapotranspiration or that there is another source that has not been identified.

Table 4.2 Groundwater recharge estimates using chloride mass balance method.

Unit number	Aquifer		**Runoff** (% rainfall)		**Average**		**Minimum**		**Maximum**		**Average**		**Minimum**		**Maximum**	
			Chloride conc. (mg/L) **rainfall**		**0.1**		**0.1**		**0.1**		**0.25**		**0.25**		**0.25**	
					7.2		**2.7**		**11.6**		**7.2**		**2.7**		**11.6**	
		Date collected	**Chloride GW** (mg/L)	**Annual rainfall** (mm/y)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)
6627 427	Cp-j ?	11/11/1976	56	693	80	11.6	30	4.3	129	18.6	67	9.6	25	3.6	108	15.5
6627 428	PS-Lower Tookayerta Creek sub-catchment	31/05/2005	106	682	42	6.1	16	2.3	67	9.9	35	5.1	13	1.9	56	8.2
6627 437	Cp-j ?	25/09/1975	70	818	76	9.3	28	3.5	122	14.9	63	7.7	24	2.9	102	12.4
6627 448	Cp-j ?	25/01/1977	87	866	65	7.4	24	2.8	104	12.0	54	6.2	20	2.3	87	10.0
6627 449	Cp-j ?	25/01/1977	99	865	57	6.5	21	2.5	91	10.5	47	5.5	18	2.0	76	8.8
6627 450	Cp-j ?	25/01/1977	112	859	50	5.8	19	2.2	80	9.3	41	4.8	16	1.8	67	7.8
6627 451	Cp-j ?	25/01/1977	52	837	104	12.5	39	4.7	168	20.1	87	10.4	33	3.9	140	16.7
6627 461	Cp-j ?	08/01/1980	75	861	74	8.6	28	3.2	120	13.9	62	7.2	23	2.7	100	11.6
6627 631	Cp-j	04/07/2005	3210	570	1	0.2	0	0.1	2	0.3	1	0.2	0	0.1	2	0.3
6627 637	Cp-j	23/05/2005	693	570	5	0.9	2	0.4	9	1.5	4	0.8	2	0.3	7	1.3
6627 1355	Cp-j ?	13/12/1961	110	882	52	5.9	20	2.2	84	9.5	43	4.9	16	1.8	70	7.9
6627 1357	Cp-j ?	19/02/1958	49	881	118	13.4	44	5.0	190	21.5	98	11.1	37	4.2	158	17.9
6627 1375	Cp-j ?	14/12/1978	696	882	8	0.9	3	0.3	13	1.5	7	0.8	3	0.3	11	1.3
6627 3527	PS-Cleland Gully Creek sub-catchment	06/06/2005	91	857	61	7.1	23	2.7	98	11.5	51	5.9	19	2.2	82	9.5
6627 6811	PS-Cleland Gully Creek sub-catchment	07/06/2005	31	839	178	21.2	67	8.0	287	34.2	148	17.7	56	6.6	239	28.5
6627 6983	Cp-j ?	06/04/2004	54	885	106	12.0	40	4.5	171	19.3	88	10.0	33	3.8	143	16.1
6627 7070	Cp-j	04/07/2005	925	570	4	0.7	1	0.3	6	1.1	3	0.6	1	0.2	5	0.9
6627 7504	PS-Nangkita Creek sub-catchment	15/06/2005	37	861	151	17.6	57	6.6	244	28.3	126	14.6	47	5.5	203	23.6
6627 7663	Cp-j	23/05/2005	387	570	10	1.7	4	0.6	15	2.7	8	1.4	3	0.5	13	2.2
6627 7671	Cp-j ?	06/04/2004	41	884	140	15.8	52	5.9	225	25.5	116	13.2	44	4.9	188	21.2

Unit number	Aquifer	Date collected	Chloride GW (mg/L)	Annual rainfall (mm/y)												
		Runoff (% rainfall)			**Average**		**Minimum**		**Maximum**		**Average**		**Minimum**		**Maximum**	
		Chloride conc. (mg/L) **rainfall**			**0.1**		**0.1**		**0.1**		**0.25**		**0.25**		**0.25**	
					7.2		**2.7**		**11.6**		**7.2**		**2.7**		**11.6**	
					R (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)
6627 8003	PS-Cleland Gully Creek sub-catchment	07/06/2005	63	831	86	10.3	32	3.9	138	16.7	72	8.6	27	3.2	115	13.9
6627 8758	PS-Nangkita Creek sub-catchment	06/06/2005	34	858	161	18.8	60	7.1	260	30.3	134	15.7	50	5.9	217	25.2
6627 9276	PS-Nangkita Creek sub-catchment	07/06/2005	62	756	79	10.4	29	3.9	127	16.7	66	8.7	25	3.2	106	14.0
6627 9279	PS-Cleland Gully Creek sub-catchment	16/06/2005	87	635	47	7.5	18	2.8	76	12.0	40	6.2	15	2.3	64	10.0
6627 9319	Cp-j ?	06/04/2004	38	883	151	17.1	56	6.4	243	27.5	126	14.2	47	5.3	202	22.9
6627 9320	Cp-j ?	06/04/2004	25	886	230	25.9	86	9.7	370	41.8	191	21.6	72	8.1	308	34.8
6627 9365	Cp-j	23/05/2005	836	615	5	0.8	2	0.3	8	1.2	4	0.6	1	0.2	6	1.0
6627 9366	PS-Cleland Gully Creek sub-catchment	16/06/2005	82	849	67	7.9	25	3.0	109	12.8	56	6.6	21	2.5	91	10.7
6627 9403	PS-Lower Tookayerta Creek sub-catchment	16/06/2005	37	651	116	17.8	43	6.7	186	28.6	96	14.8	36	5.5	155	23.8
6627 9498	Cp-j	23/05/2005	270	600	14	2.4	5	0.9	23	3.9	12	2.0	5	0.8	19	3.2
6627 9809	PS-Nangkita Creek sub-catchment	02/06/2005	44	880	128	14.6	48	5.5	207	23.5	107	12.2	40	4.6	172	19.6
6627 9821	PS-Nangkita Creek sub-catchment	06/06/2005	116	853	48	5.6	18	2.1	77	9.0	40	4.7	15	1.8	64	7.5
6627 9826	PS-Lower Tookayerta Creek sub-catchment	15/06/2005	137	640	30	4.7	11	1.8	49	7.6	25	3.9	9	1.5	41	6.4
6627 9828	PS-Lower Tookayerta Creek sub-catchment	02/06/2005	72	642	58	9.0	22	3.4	93	14.6	48	7.5	18	2.8	78	12.1
6627 9831	PS-Cleland Gully Creek sub-catchment	08/06/2005	55	847	101	11.9	38	4.4	162	19.1	84	9.9	31	3.7	135	15.9
6627 9866	Cp-j	23/05/2005	351	600	11	1.8	4	0.7	18	3.0	9	1.5	3	0.6	15	2.5
6627 9900	PS-Nangkita Creek sub-catchment	31/05/2005	33	871	169	19.4	63	7.3	273	31.3	141	16.2	53	6.1	227	26.1
6627 9921	PS-Nangkita Creek sub-catchment	07/06/2005	104	716	45	6.2	17	2.3	72	10.1	37	5.2	14	2.0	60	8.4
6627 9972	Cp-j	21/07/2005	278	600	14	2.3	5	0.9	23	3.8	12	1.9	4	0.7	19	3.1
6627 10276	PS-Nangkita Creek sub-catchment	02/06/2005	35	880	165	18.7	62	7.0	265	30.2	137	15.6	51	5.9	221	25.1

Unit number	Aquifer	**Runoff** (% rainfall)			**Average**		**Minimum**		**Maximum**		**Average**		**Minimum**		**Maximum**	
		Chloride conc. (mg/L) **rainfall**			**0.1**		**0.1**		**0.1**		**0.25**		**0.25**		**0.25**	
					7.2		**2.7**		**11.6**		**7.2**		**2.7**		**11.6**	
		Date collected	**Chloride GW** (mg/L)	**Annual rainfall** (mm/y)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)	**R** (mm/y)	**R** (% rain)
6627 10301	Cp-j	23/05/2005	369	590	10	1.8	4	0.7	17	2.8	9	1.5	3	0.5	14	2.4
6627 10576	PS-Lower Tookayerta Creek sub-catchment	08/06/2005	84	685	53	7.7	20	2.9	85	12.5	44	6.4	17	2.4	71	10.4
6627 10577	PS-Nangkita Creek sub-catchment	07/06/2005	41	884	140	15.8	52	5.9	225	25.5	116	13.2	44	4.9	188	21.2
6627 10578	PS-Nangkita Creek sub-catchment	02/06/2005	60	884	96	10.9	36	4.1	155	17.5	80	9.1	30	3.4	129	14.6
6627 10709	PS-Nangkita Creek sub-catchment	03/06/2005	35	880	163	18.5	61	6.9	263	29.8	136	15.4	51	5.8	219	24.9
6627 10792	PS-Cleland Gully Creek sub-catchment	16/06/2005	88	759	56	7.4	21	2.8	90	11.9	47	6.2	18	2.3	75	9.9
6627 10838	PS-Cleland Gully Creek sub-catchment	31/05/2005	45	847	121	14.3	45	5.3	195	23.0	101	11.9	38	4.5	162	19.1
6627 10855	Cp-j	04/07/2005	742	603	5	0.9	2	0.3	8	1.4	4	0.7	2	0.3	7	1.2
6627 10898	Cp-j	21/07/2005	502	590	8	1.3	3	0.5	12	2.1	6	1.1	2	0.4	10	1.7
6627 10900	PS-Nangkita Creek sub-catchment	06/06/2005	35	878	161	18.3	60	6.9	259	29.5	134	15.2	50	5.7	216	24.5
6627 10908	PS-Lower Tookayerta Creek sub-catchment	08/06/2005	86	635	48	7.6	18	2.8	77	12.2	40	6.3	15	2.4	64	10.1
6627 10909	PS-Nangkita Creek sub-catchment	06/06/2005	36	867	157	18.1	59	6.8	253	29.2	131	15.1	49	5.7	211	24.3
6627 10913	PS-Nangkita Creek sub-catchment	15/06/2005	67	773	74	9.6	28	3.6	120	15.5	62	8.0	23	3.0	100	12.9
6627 10935	PS-Cleland Gully Creek sub-catchment	03/06/2005	40	822	132	16.0	49	6.0	212	25.9	110	13.4	41	5.0	177	21.5
6627 10955	PS-Nangkita Creek sub-catchment	06/06/2005	163	709	28	4.0	11	1.5	46	6.4	24	3.3	9	1.2	38	5.3
6627 10988	PS-Cleland Gully Creek sub-catchment	16/06/2005	318	692	14	2.0	5	0.8	23	3.3	12	1.7	4	0.6	19	2.7
6627 10989	PS-Nangkita Creek sub-catchment	08/06/2005	127	730	37	5.1	14	1.9	60	8.2	31	4.2	12	1.6	50	6.8
6627 11138	Cp-j	23/05/2005	268	600	15	2.4	5	0.9	23	3.9	12	2.0	5	0.8	19	3.2
		Average	221	763	76	9	29	3	123	15	64	8	24	3	102	13
		Minimum	25.0	570.0	1.2	0.2	0.4	0.1	1.9	0.3	1.0	0.2	0.4	0.1	1.5	0.3
		Maximum	3210	886	230	26	86	10	370	42	191	22	72	8	308	35

Table 4.3 Field measurements and laboratory results of surface water (July 2002 – March 2005) and groundwater (May and June 2005) in the TCC, and rainfall samples from Finniss and Myponga Catchments.

Unit number	Sample type	Sample number	Collection date	EC (mS/cm)	Temp (°C)	pH	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Br (mg/L)	HCO_3 (mg/L)	NO_x-N (mg/L)	$\delta^{18}O$ ‰rel SMOW	δ^2H ‰ rel SMOW
6627 428	PS-Lower Tookayerta Creek sub-catchment	T3	31/05/2005	397	17.2	4.75	193	4.5	6.8	62.3	0.6	7.5	105.8	0.4	4.9	1.216	-5.32	-28.00
6627 3527	PS-Nangkita Creek sub-catchment	T10	06/06/2005	683	17.3	7.06	421	52.4	11.5	78.6	4.7	69.8	91.1	0.4	112.5	<0.005	-5.51	-29.90
6627 6811	PS-Cleland Gully Creek sub-catchment	T18	07/06/2005	142	17.2	4.92	63	0.6	2.3	20.6	1.1	3.0	30.5	0.3	5.0	2.381	-5.32	-27.20
6627 7504	PS- Nangkita Creek sub-catchment	T26	15/06/2005	129	16.4	5	72	1.5	3.0	19.3	0.5	2.5	36.9	0.3	8.0	0.092	-5.69	-31.00
6627 8003	PS-Cleland Gully Creek sub-catchment	T17	07/06/2005	251	18.0	5.2	118	1.8	4.5	34.2	1.2	4.7	62.6	0.3	9.0	0.537	-5.43	-28.70
6627 8758	PS- Nangkita Creek sub-catchment	T11	06/06/2005	133	16.6	5.29	76	3.6	2.6	18.3	1.4	3.0	34.5	0.3	12.2	0.040	-5.74	-29.60
6627 9276	PS- Nangkita Creek sub-catchment	T19	07/06/2005	281	16.2	5.35	140	4.6	4.9	34.1	1.7	10.4	62.4	0.4	22.0	0.059	-5.34	-28.60
6627 9279	PS-Lower Tookayerta Creek sub-catchment	T29	16/06/2005	316	19.0	5.08	169	3.8	5.1	50.6	1.2	6.7	86.8	0.4	14.0	0.099	-5.20	-30.70
6627 9366	PS-Cleland Gully Creek sub-catchment	T31	16/06/2005	139	17.7	4.73	150	5.5	4.8	42.5	0.9	7.1	81.6	0.4	7.0	0.050	-5.37	-28.30
6627 9403	PS-Lower Tookayerta Creek sub-catchment	T28	16/06/2005	530	17.1	4.89	74	0.7	3.1	21.6	0.6	3.2	36.5	0.3	8.0	1.424	-4.78	-25.70
6627 9809	PS- Nangkita Creek sub-catchment	T6	02/06/2005	164	16.1	4.52	81	0.7	3.7	26.6	0.3	3.1	44.4	0.3	1.8	1.511	-5.43	-26.10
6627 9821	PS- Nangkita Creek sub-catchment	T14	06/06/2005	475	16.9	5.63	250	15.1	8.8	63.2	3.1	12.3	115.5	0.4	32.0	0.059	-5.56	-29.00
6627 9826	PS-Lower Tookayerta Creek sub-catchment	T27	15/06/2005	332	17.3	4.97	266	3.9	9.1	84.5	1.3	17.9	136.9	0.4	12.0	1.544	-4.99	-26.00
6627 9828	PS-Lower Tookayerta Creek sub-catchment	T5	02/06/2005	264	18.0	4.9	132	3.4	4.2	40.1	0.8	6.2	71.7	0.4	5.5	0.183	-5.85	-29.00
6627 9831	PS-Cleland Gully Creek sub-catchment	T25	08/06/2005	239	16.4	5.08	106	1.7	3.9	33.1	0.6	5.5	54.6	0.3	6.5	1.535	-5.22	-26.90

Unit number	Sample type	Sample number	Collection date	EC (mS/cm)	Temp (°C)	pH	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Br (mg/L)	HCO_3 (mg/L)	NO_x-N (mg/L)	$\delta^{18}0$ ‰rel SMOW	$\delta^{2}H$ ‰ rel SMOW
6627 9900	PS- Nangkita Creek sub-catchment	T1	31/05/2005	133	16.9	4.95	62	1.1	2.6	18.5	0.4	2.7	33.3	0.3	3.0	0.042	-5.77	-30.70
6627 9921	PS- Nangkita Creek sub-catchment	T20	07/06/2005	693	17.2	6.42	433	51.2	15.2	65.8	1.5	15.7	103.7	0.3	180.0	0.005	-5.05	-26.90
6627 10276	PS- Nangkita Creek sub-catchment	T7	02/06/2005	132	16.1	4.23	62	0.4	2.3	20.3	0.4	3.4	34.6	0.3	0.8	0.768	-5.32	-27.50
6627 10576	PS-Lower Tookayerta Creek sub-catchment	T21	08/06/2005	354	17.5	4.91	177	2.4	6.4	59.5	0.6	15.0	83.8	0.4	8.5	2.138	-4.97	-25.10
6627 10577	PS- Nangkita Creek sub-catchment	T16	07/06/2005	167	16.6	4.45	73	1.0	3.4	21.8	0.6	3.0	41.0	0.3	2.0	1.494	-5.20	-26.20
6627 10578	PS- Nangkita Creek sub-catchment	T4	02/06/2005	293	15.7	4.54	133	2.7	11.8	35.1	1.2	17.6	59.5	0.4	4.2	6.540	-5.15	-26.30
6627 10709	PS- Nangkita Creek sub-catchment	T8	03/06/2005	136	16.7	4.65	66	1.4	2.8	20.4	0.6	3.8	35.0	0.3	2.2	0.935	-5.23	-27.40
6627 10792	PS-Cleland Gully Creek sub-catchment	T30	16/06/2005	345	17.1	4.99	171	3.8	5.6	54.0	1.7	8.1	87.6	0.4	9.5	1.635	-4.92	-27.30
6627 10838	PS-Cleland Gully Creek sub-catchment	T2	31/05/2005	194	16.7	5.14	90	1.8	3.1	29.0	1.6	4.3	45.4	0.3	4.2	1.079	-4.89	-23.90
6627 10900	PS- Nangkita Creek sub-catchment	T13	06/06/2005	133	16.1	4.81	65	1.0	2.6	19.5	0.4	2.3	35.4	0.3	3.0	1.326	-5.48	-29.40
6627 10908	PS-Lower Tookayerta Creek sub-catchment	T22	08/06/2005	339	18.4	5.3	174	7.3	5.5	51.3	2.2	7.1	85.8	0.4	15.0	0.006	-5.18	-27.50
6627 10909	PS- Nangkita Creek sub-catchment	T12	06/06/2005	135	16.0	4.56	68	0.5	2.6	20.6	0.4	2.5	35.8	0.3	5.2	1.042	-5.30	-26.50
6627 10913	PS- Nangkita Creek sub-catchment	T24	15/06/2005	340	16.4	5.89	177	4.9	4.4	54.3	2.0	13.0	67.4	0.3	31.0	1.483	-4.99	-26.10
6627 10935	PS-Cleland Gully Creek sub-catchment	T9	03/06/2005	203	16.3	5.36	99	5.9	3.8	25.9	2.1	6.3	40.4	0.3	13.8	2.260	-5.36	-26.40
6627 10955	PS- Nangkita Creek sub-catchment	T15	06/06/2005	725	16.7	5.67	344	20.0	18.3	93.6	1.4	7.4	162.6	0.4	40.0	9.212	-4.78	-25.50
6627 10988	PS-Cleland Gully Creek sub-catchment	T32	16/06/2005	1437	17.9	6.2	765	27.5	23.3	223.0	4.8	32.6	317.8	0.6	135.0	0.081	-5.25	-31.00
6627 10989	PS- Nangkita Creek sub-catchment	T23	08/06/2005	529	16.8	4.88	254	4.4	9.0	85.4	1.4	19.2	127.1	0.4	7.0	5.044	-4.69	-25.40

Unit number	Sample type	Sample number	Collection date	EC (mS/cm)	Temp (^oC)	pH	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Br (mg/L)	HCO_3 (mg/L)	NO_x-N (mg/L)	$\delta^{18}0$ ‰rel SMOW	$\delta^{2}H$ ‰ rel SMOW
	Cleland Gully Creek	17	2002–03	413			221	7.8	8.1	54.9	4.1	9.8	100.0		36.0			
	Cleland Gully Creek	12	2002–03	364			186	6.2	7.2	46.8	2.6	8.1	89.0		26.0			
	Cleland Gully Creek	11	2002–03	331			182	4.5	5.1	48.0	2.8	8.2	82.0		31.0			
	Lower Tookayerta Creek	14	2002–03	606			288	8.9	10.6	79.6	1.0	12.1	164.0		12.0			
	Nangkita Creek	16	2002–03	418			227	9.4	8.1	57.1	3.6	16.3	101.0		31.0			
	Nangkita Creek	15	2002–03	401			218	9.6	8.2	50.0	4.5	20.1	96.0		30.0			
	Nangkita Creek	10	2002–03	260			215	11.2	7.9	48.4	3.2	25.3	90.0		29.0			
	Tookayerta Creek	BS1	01/03/2005	548	15	6.7	337	15.4	11.4	95.9	2.6	11.6	160.0	0.4	40.0	0.71	-4.96	-26.00
	Tookayerta Creek	BS3	01/03/2005	712	16	6.9	376	15.8	12.6	105.1	2.4	12.2	180.0	0.4	47.2	0.43	-4.83	-24.00
	Tookayerta Creek	BS5	01/03/2005	803	15	6.9	403	16.8	14.5	121.1	2.3	5.8	210.0	0.6	32.0	0.03	-4.47	-22.00
	Rainfall, Myponga	42820	05/03/2003										7.0				-4.84	-28.40
	Rainfall, Myponga	42821	29/05/2003										2.7				-5.26	-30.30
	Myponga pluviometer	42822	03/12/2003										10.2				-2.37	-4.80
	Finniss pluviometer	42824	10/12/2002										11.6				-2.39	-5.60
	Finniss pluviometer	42831	07/03/2003										6.9				-4.95	-27.40
	Rainfall, Finniss Catchment	42832	29/05/2003										5.3				-5.42	-29.90
	Rainfall, Finniss Catchment	46309	06/07/2005										6.9				-5.28	-23.40

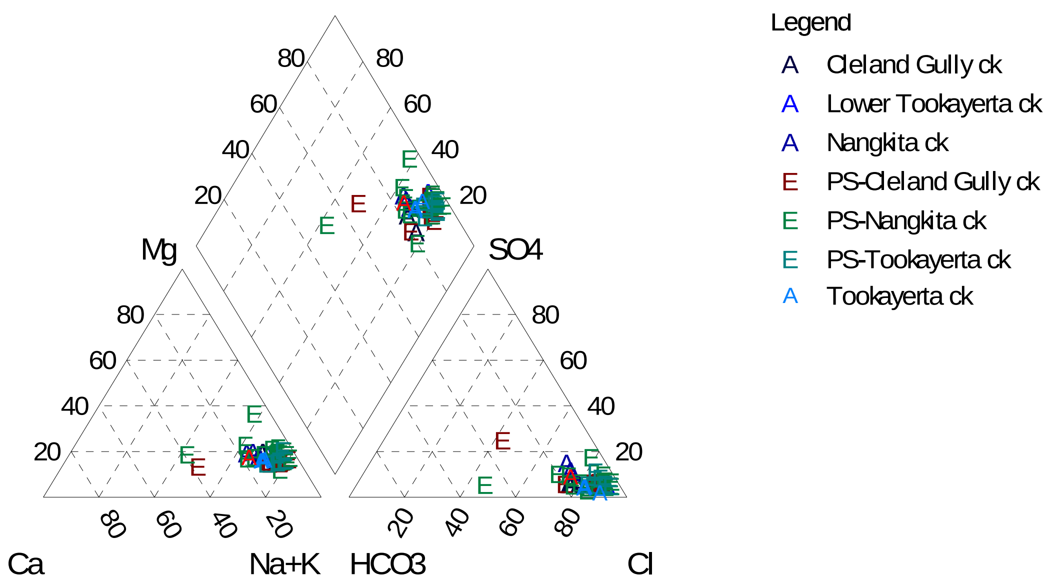


Figure 4.4 PIPER plot showing the relative proportions of major solutes of surface water and groundwater in the TCC.

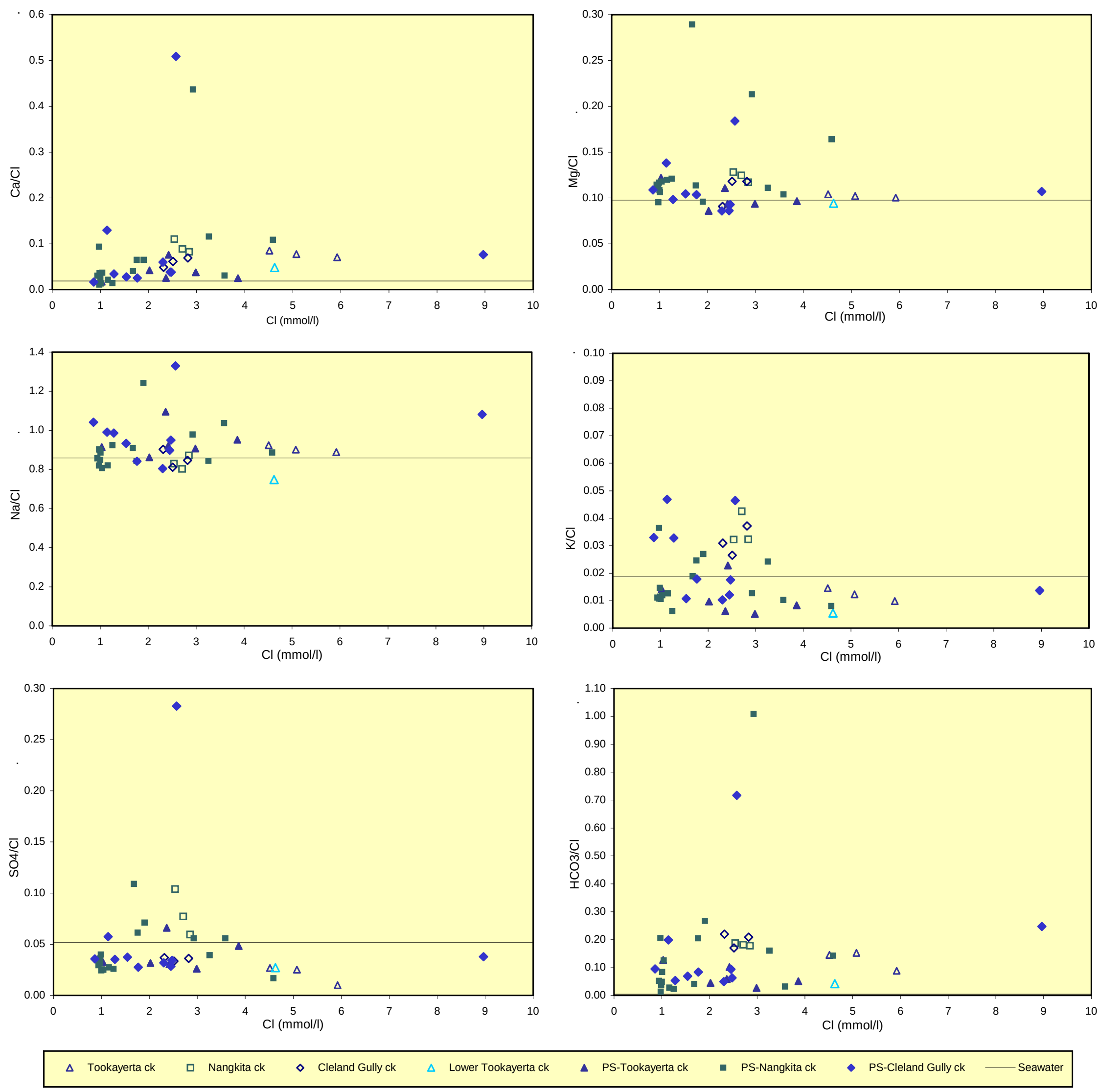


Figure 4.5 Major ion/Cl ratios versus chloride for surface water and groundwater samples in the TCC.

Variations in soil type and geology across the catchment contribute to the degree of evaporation prior to recharge and the type of mineral dissolution reactions. The enrichment of major cations Na^+, Ca^{2+},and Mg^{2+} and HCO_3^- ions in the groundwater samples from the Permian sands aquifer points to weathering of primary silicate minerals and cation exchange reactions on clay minerals. This may be attributed to intermittent beds of clay fines in the dominantly fine quartz sand of the Permian sands aquifer. Major ion/Cl ratios higher than the seawater ratio may also be due to acquisition of major ions in rainfall by partial dissolution of atmospheric dust prior to recharge.

The isotopic compositions (δ^2H and $\delta^{18}O$) of rainfall, surface water and groundwater samples from the TCC are plotted in Figure 4.6, relative to the meteoric line of Adelaide precipitation, to investigate the probable source of the waters. Compositions of the groundwater samples from the Permian sands aquifer range between -31 and -23.9‰ for δ^2H and between -5.85 and -4.69‰ for $\delta^{18}O$. The majority of these groundwater samples plot slightly above the LMWL ($\delta^2H = 7.66\ \delta^{18}O + 9.56$) and have more depleted isotopic compositions than the weighted average rainfall for Adelaide (δ^2H = -26.3‰ and $\delta^{18}O$= -4.7‰). Waters plotting along the LMWL and below the weighted average rainfall (more depleted signature) are indicative of seasonal recharge of autumn and winter rainfall events, and/or altitude effects. Altitude is a temperature-related effect and results in reducing both $\delta^{18}O$ (~0.15–0.5‰ per 100 m) and δ^2H (~1–4‰ per 100 m) values (Clark & Fritz 1997). The elevation difference between Adelaide and the TCC is 200–300 m and therefore the depleted groundwater isotopic values can be attributed to altitude effects. However, observations of higher rainfall and increased watertable elevations during autumn and winter in the TCC provide evidence of seasonal recharge effects. Cooler rainfall would result in lower groundwater isotopic values compared to the values of average rainfall in Adelaide.

No significant deviation of the groundwater samples from the LMWL suggests that recharge has occurred fairly rapidly with minimal isotopic fractionation by evaporative process prior to rainfall infiltration. Similarly, the majority of water samples from Tookayerta Creek have a signature close to mean precipitation and show no significant signs of isotopic enrichment by evaporation. Rainfall samples from the Finniss and Myponga Catchments show seasonal isotopic variations. Between March–May 2003 and July 2005, the isotopic values plot along the LMWL and below the weighted average rainfall, whilst the samples taken during December 2002 and 2003 are significantly more enriched, and characteristic of a summer rainfall event.

Deuterium is particularly sensitive to evaporation, whilst the chloride concentration is influenced to a greater extent by transpiration processes (Fig. 4.7). The rainfall samples from Finniss and Myponga Catchments have a low chloride concentration and plot close to the δ^2H axis. The samples collected in December (2002, 2003) show a more enriched signature than those collected in March–May 2003 and July 2005, which is a result of warmer temperatures and greater evaporation during summer rainfall events. The groundwater samples have similar deuterium values to the March, May and July rainfall signatures and higher chloride concentrations. This provides further evidence that the bulk of groundwater recharge to the Permian sands aquifer occurs during the cooler wet months of the year. The higher chloride concentrations are likely to be a result of transpiration processes by vegetation, i.e. no fractionation of stable isotopes of the water molecule. The samples

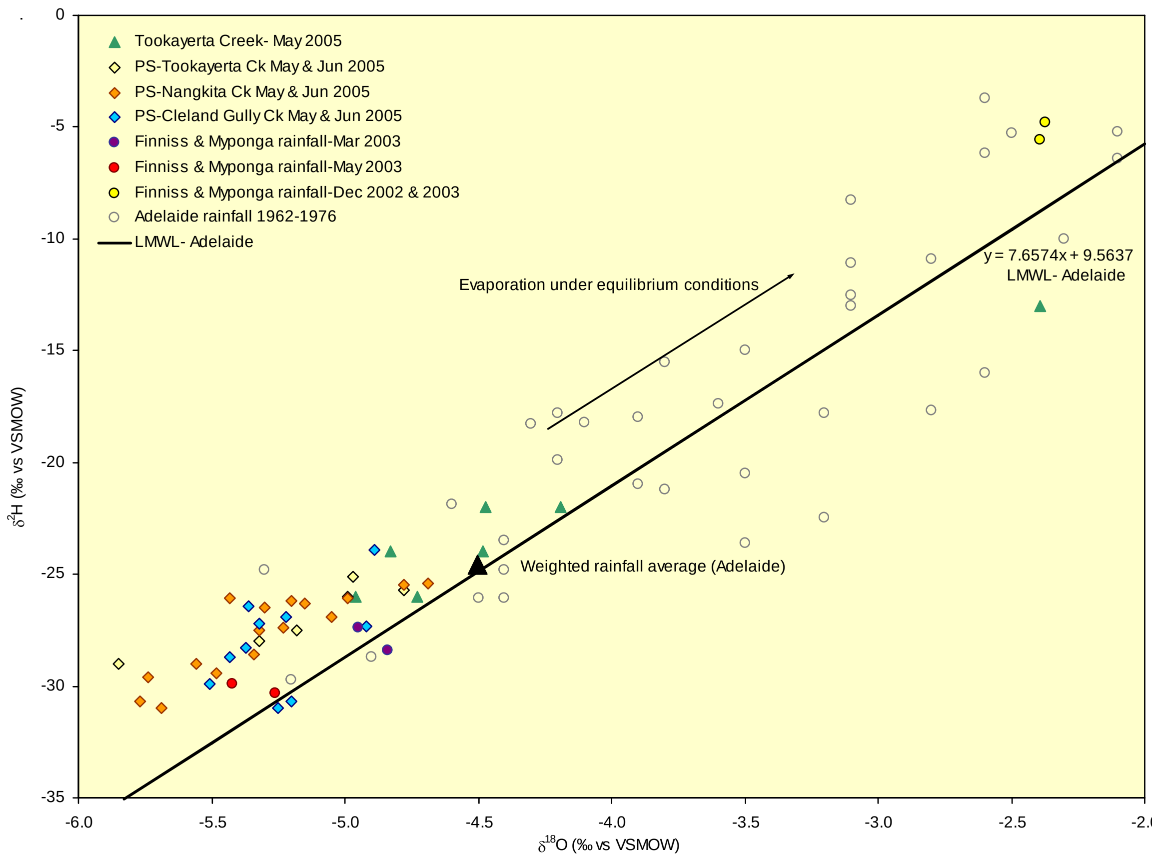


Figure 4.6 Deuterium versus oxygen-18 for Tookayerta Creek, rainfall samples collected in the nearby Finniss and Myponga Catchments, groundwater in the TCC and Adelaide rainfall 1962–76 (IAEA/WHO 2005). Adelaide LMWL is $\delta^2H = 7.66\ \delta^{18}O + 9.56$ and weighted average rainfall is $\delta^2H = -26.3$ and $\delta^{18}O = -4.7$.

collected from Tookayerta Creek plot along a linear trendline ($\delta^2H = 0.14Cl - 50$, $R^2 = 0.85$) and indicates that the creek samples have evolved from a composition similar to groundwater of the Permian sands aquifer and become more enriched as a result of evaporative processes.

4.5 CONCEPTUAL MODEL

The application of CFC age dating techniques used in this investigation supports previous investigations (Barnett & Zulfic 1999; Harrington 2004), which reported that TCC has a high recharge rate because of the high rainfall to the catchment and that the main unconfined aquifer unit is Permian sand (Cape Jervis Formation). The physical properties of sand deliver rapid and effective recharge to the aquifer with minimal evaporation. Many of the sampled bores located in areas where the Permian sands crop out had a modern groundwater age (>1965) at considerable depths below the watertable. This indicates that there are localised areas of rapid recharge, and older waters (<1965) at shallow depths are likely to be related to Tertiary deposits associated with the reworked Permian sands or are zones of groundwater discharge.

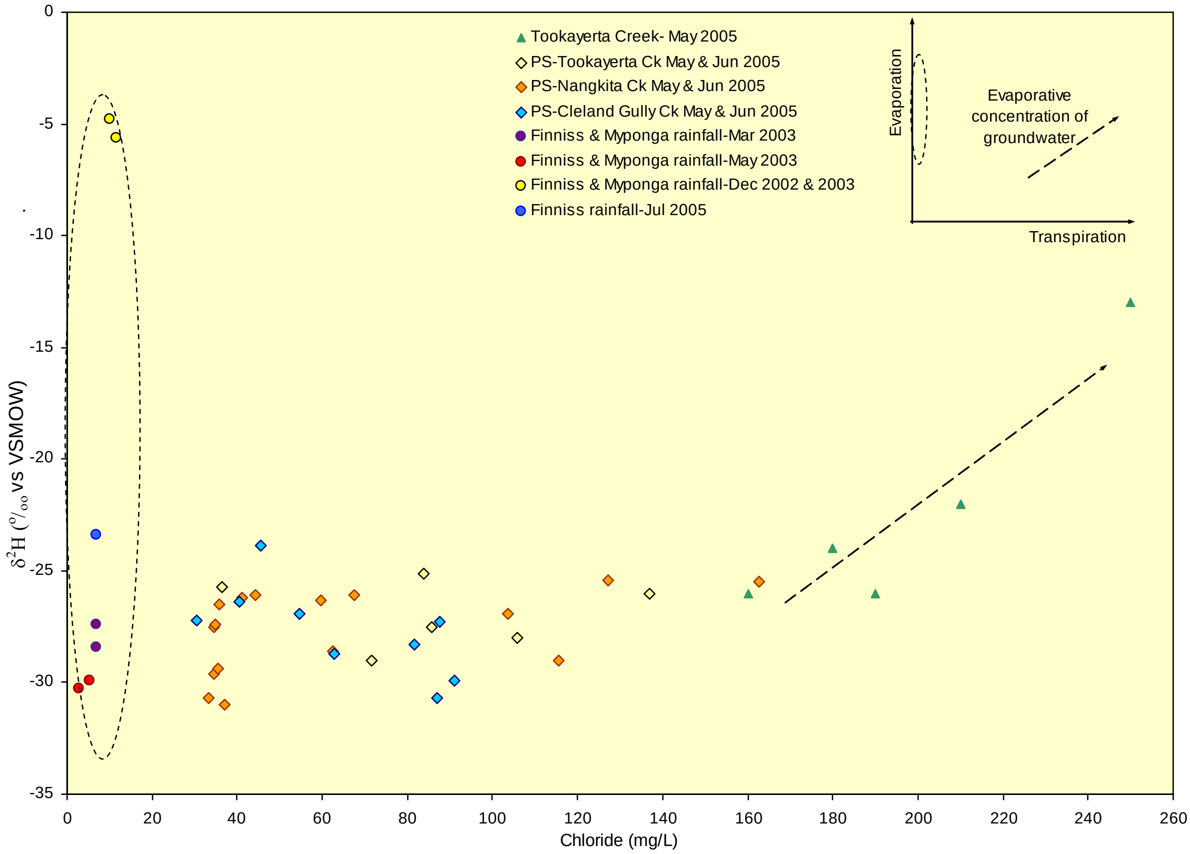


Figure 4.7 Deuterium versus chloride for rainfall samples collected in nearby Finniss and Myponga Catchments during 2002 and 2003, Tookayerta Creek and groundwater in the TCC sampled between March and June 2005.

Long-term (1922–2002) streamflow data generated from rainfall-runoff modelling for the TCC provide an estimated median annual runoff of 17 973 ML and mean annual runoff of 19 107 ML (Savadamuthu 2004). The surface runoff coefficient for the TCC is estimated to be 0.25, which is greater than the calculated 10% for most of the other catchments already assessed in the EMLR. Using only the mean annual streamflow, a simple catchment water balance provides an estimated annual recharge rate of 190 mm/y. Estimates of groundwater recharge to the Permian sands aquifer using CFC age dating techniques were similar, whilst the estimates using CMB were typically lower. There was no significant correlation between the CFC and CMB estimates of recharge. However, it is evident that recharge to the Permian sands aquifer in the TCC is high and is a considerable percentage of annual rainfall to the catchment. As a result of the high recharge, groundwater discharge to the Tookayerta, Nangkita and Cleland Gully Creeks is likely to be high and maintain baseflow during the drier summer months.

5. CONCLUSIONS AND RECOMMENDATIONS

CFCs have been used successfully to estimate the recharge rate to the unconfined Permian sands aquifer in the TCC. Average recharge to the aquifer is 100–150 mm/y and may be higher in areas of the catchment where the porosity of the aquifer material is >25%. Estimates using the CMB method were typically lower than CFC technique, where groundwater recharge was on average 64 mm/y.

CFC data provided evidence for rapid recharge processes to the Permian sands aquifer and that recharge tends to be related to outcrops of the Permian sands. Hydrochemistry and the stable isotope data provided further evidence for rapid recharge processes and that there is minimal evaporation of rainfall prior to groundwater recharge. The isotopic signature of the groundwater samples is similar to rainfall events in winter and therefore the majority of recharge would occur at this time.

The vertical flux could be measured more accurately with a nested piezometer constructed in the unconfined Permian sands aquifer at discrete intervals to at least 40 m depth below the watertable at several locations across the TCC. Additional information from bores constructed in the basement rock aquifer would provide valuable information to understanding the role of the basement in contributing or receiving groundwater from the overlying Permian sands aquifer.

It is suggested that an average of the two techniques be used to determine a Permissible Annual Volume (PAV) as both have advantages and disadvantages for estimating groundwater recharge. The average CFC-12 recharge estimate determined from the 12 samples, using a porosity of 25%, is 190 mm/y^{-1}. The average CMB recharge estimate, based on 58 samples and a rainfall chloride concentration of 7.2 mgL^{-1}, is 64 mm/y^{-1}. Therefore, the average recharge rate calculated from the two methods is 122 mm/y^{-1}. It is recommended that two thirds of the total recharge be used to determine the PAV, which is about 80 mm/y^{-1}.

APPENDICES

A. BORE CONSTRUCTION DETAILS

Transect	Unit number	Easting	Northing	Ground elevation (m AHD)	TOC (m)	Screen interval	Screen length (m)	SWL (m)	RSWL (m)
Nangkita Creek	6627 9809	279224	6085858	322.7	0.11	63-69	6.0	47.52	275.29
	6627 10276	279588	6085873	313.0	0.15	49-79	30.0	39.1	274.06
	6627 10578	280434	6086143	276.3	0.3	36-78	42.0	7.52	269.10
	6627 10577	280786	6085772	280.0	0.2	42-90	48.0	11	269.23
	6627 10709	281583	6085850	265.0	0.06	24-48	24.0	1.8	263.22
	6627 10900	281728	6085795	265.1	0.6	26.5-29	2.5	3.56	262.18
	6627 9900	282171	6085888	271.0	0.75	44-62	18.0	11.95	259.83
	6627 10909	282550	6086139	270.0	0.2	18-42	24.0	12.64	257.60
	6627 7504	282821	6085834	281.0	0.15	31.6-34.6	3.0	25.18	255.97
	6627 8758	282982	6085743	272.0	0.28	48-69	21.0	24.9	247.38
	6627 3527	283489	6085702	253.0	0.3	28-29	1.0	18	235.30
	6627 9821	284192	6086020	225.0	0.17	36-78	42.0	2.32	222.85
	6627 10913	287901	6086059	162.2	0.26	18-36	18.0	10.84	151.66
	6627 9276	288410	6086272	153.7	0.08	29-65	36.0	6.5	147.30
	6627 10989	289715	6086033	140.8	0.5	24-42	18.0	7.32	133.94
	6627 9921	290094	6085903	133.4	0.6	16-47	31.0	2.92	131.07
	6627 10955	290313	6085923	135.2	0	18.5-23.5	5.0	0	135.20
	6627 10576	291462	6085443	158.9	0.47	36-90	54.0	36.42	122.97
	6627 428	291830	6085478	153.0	0.14	45-48	3.0	32.75	120.39
	6627 9403	292907	6084938	122.2	0.1	30-48	18.0	5.72	116.62
	6627 9826	293623	6084366	109.4	0.07	26-32	6.0	1.96	107.48
	6627 9828	293937	6084188	100.3	0.3	24-48	24.0	0.42	100.22
	6627 10908	293974	6083658	95.0	0.4	36-60	24.0	0	95.42
Cleland Gully_1	6627 10838	285382	6081542	237.0	0.21	78-132	54.0	19.49	217.68
	6627 9366	284828	6081937	234.9	0.2	48-72	24.0	6.6	228.53
	6627 6811	284913	6082297	232.0	0.39	34-38	4.0	5.87	226.52
	6627 8003	285327	6082439	226.8	0.28	101.8-129.4	27.6	12.21	214.85
	6627 10935	285688	6083282	206.2	0.6	12-18	6.0	1.29	205.54
Cleland Gully_2	6627 9831	283510	6083750	239.8	0.15	18-42	24.0	4.06	235.94
	6627 10935	285688	6083282	206.2	0.6	12-18	6.0	1.29	205.54
	6627 10792	289293	6082873	190.6	0.37	36-60	24.0	24.2	166.73
	6627 10988	291189	6083656	116.1	0.68	17-26	9.0	1.1	115.71
	6627 9279	293610	6083216	91.6	0.06	21-39	18.0	1.74	89.94

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
degree Celsius	°C		temperature
gram	g	10^{-3} kg	mass
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilometre	km	10^{3} m	length
litre	L	10^{-3} m^{3}	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^{3}	volume
micro-Siemens/centimetre	µS/cm	10^{-3} mS/cm	electrical conductivity
milligram	mg	10^{-3} g	mass
milligram/litre	mg/L		concentration
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
year	y	365 or 366 days	time interval

GLOSSARY

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

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

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.*

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

CMB — chloride mass balance.

CWMB — Catchment Water Management Board.

Domestic purpose — The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

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

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

EMLR — Eastern Mount Lofty Ranges.

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

Groundwater — *See underground water.*

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

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

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

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, asses — sing the impacts of dams or predicting ecological response to environmental change.

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

Natural Resources Management (NRM) — All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Pasture — Grassland used for the production of grazing animals such as sheep and cattle.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard.

PIRSA — (Department of) Primary Industries and Resources South Australia (Government of South Australia).

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

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

PWRA — Prescribed Water Resources Area.

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

Reticulated water — Water supplied through a piped distribution system.

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

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

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.

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

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

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; 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 which gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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

REFERENCES

Barnett, SR & Zulfic, D 1999, *Mount Lofty Ranges groundwater assessment — Tookayerta Catchment*, PIRSA Report 99/00018, Primary Industries and Resources South Australia, Adelaide.

Clark, I & Fritz, P 1997, *Environmental isotopes in hydrogeology*, Lewis, New York.

Cook PG & Bohlke, J-K 1999, 'Determining timescales for groundwater flow and solute transport', in PG Cook & AL Herczeg (eds), *Environmental tracers in subsurface hydrology*, Kluwer Academic, Boston, pp.1-30.

Cook, PG & Solomon, DK 1995, 'Transport of atmospheric gases to the watertable: Implications for groundwater dating with chlorofluorocarbons and Krypton 85', *Water Resources Research*, 31(2), pp.263-270.

Coplen, TB, Herczeg, AL & Barnes, CJ 1999, 'Isotope engineering using stable isotopes of the water molecule to solve practical problems', in PG Cook & AL Herczeg (eds), *Environmental tracers in subsurface hydrology*, Kluwer Academic, Boston, pp.79-110.

Eriksson, E & Khunakasem, V 1969, 'Chloride concentration in groundwater, recharge rate and rate of deposition of chloride in the Israel Coastal Plain'. *Journal of Hydrogeology*, 7, pp.178-197.

Fass, T & Cook, PG 2005, Sources of groundwater discharging to Black Swamp, south-eastern Mount Lofty Ranges, South Australia, CSIRO Land and Water Client Final Report for River Murray Catchment Water Management Board, Adelaide.

Hammer, M 2004, The Eastern Mount Lofty Ranges fish inventory: Distribution and conservation of freshwater fishes of tributaries to the Lower River Murray, South Australia, Native Fish Australia (SA) Inc and River Murray Catchment Water Management Board, Adelaide.

Harrington, G 2004, Hydrogeological investigation of the Mount Lofty Ranges, Progress Report 4: Groundwater — surface water interactions in the Scott Creek, Marne River and Tookayerta Creek Catchments, DWLBC Report 2004/11, Department of Water, Land and Biodiversity Conservation, Adelaide.

IAEA/WMO 2005, Global Network of Isotopes in Precipitation (GNIP) Database, International Atomic Energy Agency and World Meteorological Organisation, viewed August 2006, <http://isohis.iaea.org>.

Pain, AM, Shaw, RA & Valentine, JT 1999, *Sand resources of the Mount Compass area — Reconnaissance drilling and testing*, PIRSA Report 99/00028, Primary Industries and Resources South Australia, Adelaide.

Savadamuthu, K 2004, *Surface water assessment of the Tookayerta Catchment, South Australia*, DWLBC Report 2004/23, Department of Water, Land and Biodiversity Conservation, Adelaide.

Suter, PJ 1987, *Water quality of Tookayerta Creek with particular reference to the aquatic macro-invertebrate fauna*, Report 5651/84, Engineering and Water Supply Department, Adelaide.

Szabo, Z, Rice, DE, Plummer, LN, Busenberg, E, Drenkard, S & Schlosser, P 1996, 'Age dating of shallow groundwater with chlorofluorocarbons, tritium/helium 3, and flow path analysis, southern New Jersey coastal plain', *Water Resources Research*, 32(4), pp.1023-1038.