

Hydrogeological Investigation of the Mount Lofty Ranges, Progress Report 4: Groundwater – surface water interactions in the Scott Creek, Marne River and Tookayerta Creek Catchments

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Disclaimer

FOREWORD

South Australia's natural resources are fundamental to the economic and social well-being of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisims and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between, rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of the resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various atresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

Brian Harris

Director, Knowledge and Information Division

Department of Water, Land and Biodiversity Conservation

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SI UNITS COMMONLY USED WITHIN TEXT

Name of unit	Symbol	Definition in terms of other metric units	
Millimetre	mm	10^{-3} m	length
Metre	m		length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^{2}	area
Microlitre	µL	10^{-9} m^{3}	volume
Millilitre	mL	10^{-6} m^{3}	volume
Litre	L	10^{-3} m^{3}	volume
Kilolitre	kL	1 m^{3}	volume
Megalitre	ML	10^{3} m^{3}	volume
Gigalitres	GL	10^{6} m^{3}	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g		mass
Kilogram	kg	10^{3} g	Mass

ABBREVIATIONS COMMONLY USED WITHIN TEXT

Abbreviation		Name	Units of measure
TDS	=	Total Dissolved Solids *(milligrams per litre)*	mg/L
EC	=	Electrical Conductivity *(micro Siemens per centimetre)*	µS/cm
PH	=	Acidity	
δD	=	Hydrogen isotope composition	$^{o}/_{oo}$
CFC	=	Chlorofluorocarbon *(parts per trillion volume)*	pptv
δ^{18}O	=	Oxygen isotope composition	$^{o}/_{oo}$
^{14}C	=	Carbon-14 isotope *(percent modern Carbon)*	pmC
Ppm	=	Parts per million	
Ppb	=	Parts per billion	

ABSTRACT

Groundwater-surface water interactions were investigated in the Scott Creek, Marne River and Tookayerta Creek Catchments of the Mount Lofty Ranges. Historical rainfall, stream flow and salinity data was combined with chemical and isotopic results from a three stage run-of-river sampling program to reveal the timing and location of the most important zones where groundwater discharge occurs. Mean areal groundwater discharge rates for the Scott Creek Catchment were estimated to be between 65–69 mm/yr, which equates to between 45–48% of the annual surface flow out of the catchment. Over three quarters of the estimated annual recharge is lost from the catchment via discharge of interflow water to creeks, probably within several weeks to months of the recharge event. In the Marne River Catchment, surface flow was only observed during the first run-of-river sampling stage due to extended periods of low rainfall and intense damming of most creeks in the catchment. Estimates of groundwater recharge rates for this catchment were much lower than the median annual stream flow out of the catchment (17.6 mm/yr). Historical stream flow and salinity data for Tookayerta Creek Catchment was unavailable for this study, thereby preventing any estimation of the mean annual groundwater discharge flux to streams. Nevertheless, estimates of groundwater recharge rates for this catchment were high (35–124 mm/yr) and discharge to creeks was shown to occur throughout the catchment.

1 INTRODUCTION

The estimation and provision of environmental water requirements (EWR) to maintain biodiversity in aquatic ecosystems is rapidly becoming an integral part of water allocation plans (WAP) for each of the prescribed water resource areas (PWRA) within the State. With this mind, there is a significant lack of understanding with regards to the contribution of groundwater inputs to streams (ie. baseflow) and therefore environmental flows.

Hydrogeological assessment of the Mt Lofty Ranges (MLR) groundwater resources also requires the investigation of groundwater-surface water interactions as these processes can play an important role in catchment-scale water and/or salt balances. For example, recent studies in the Clare Valley have shown that groundwater discharge to streams is an important mechanism for removing salt from the catchments, even though it only accounts for < 10% of the annual recharge flux (Harrington and Love, 2000; Love et al., 2002).

This report identifies three surface water catchments of the MLR for extensive investigations into groundwater-surface water interactions over the next 2 to 3 years. The reasons for choosing each catchment are discussed and methods of investigation presented for future reference. Results from the first three run-of-river sampling programs are presented, providing preliminary insight to the temporal and spatial variability of groundwater discharge in each catchment.

2 STUDY CATCHMENTS

2.1 Scott Creek Catchment

The Scott Creek Catchment (SCC) is a relatively small (27 km^2) sub-catchment for the Onkaparinga River Catchment which is located in the Adelaide Hills (Fig. 1). Land use is dominated by pasture for grazing stock (~65%) and native vegetation (~30%). The area is characterised by steep topography underlain by hard, fractured rocks including Proterozoic meta-siltstone, sandstone and quartzite (James-Smith and Harrington, 2002). Groundwater flow in these formations is potentially very rapid, however the degree of connection between the aquifers and the creek is poorly understood.

Both surface water and groundwater resources are utilised for stock and domestic supplies throughout the catchment but neither are regulated. Approximately 5% of modelled surface runoff is currently being captured in farm dams (McMurray, 2001). Nevertheless, Scott Creek is essentially a permanent stream, with very few recorded occasions when flow has ceased during the last 33 years (Fig. 2). This suggests that groundwater discharge to the creek is extremely important for maintaining flows and thus ecosystem health in the catchment during drier months of the year.

Therefore, the SCC was selected for the current investigation because it:

- is located in the watershed for one of Adelaide's most important water supplies (Mt Bold Reservoir),
- has a long historical record of stream flow at the bottom end of the catchment,
- has permanent flows and therefore important base flow, and
- has fractured rock aquifers that may transmit water to the creeks very rapidly following intense rainfall/recharge events.

2.2 Marne River Catchment

The Marne River Catchment (MRC) covers an area of approximately 270 km^2 stretching from the southern Barossa Highlands across to the eastern edge of the Mount Lofty Ranges and then out onto the flat plains of the Murray Basin (Fig. 1). The upper, fractured rock portion of the MRC is a focus for the current study as it has many differences to the SCC in terms of hydrogeological setting.

The region receives much lower mean annual rainfall than SCC (500-700 mm/yr in the upper MRC cf. 800-1000 mm/yr in SCC) due to the increased distance from the coast and "rain shadow" effect caused by the more-elevated western Mount Lofty Ranges. The topography is also quite dissimilar from SCC; undulating hills and broad alluvial valleys dominate most of upper catchment, except on the eastern side of the study area where the hills become very high and rounded with steep, incised valleys.

Whilst the geology of the MRC is also characterised by hard, fractured rocks, the primary stratigraphic units are more recent, Cambrian-Ordovician rocks of the Kanmantoo Group

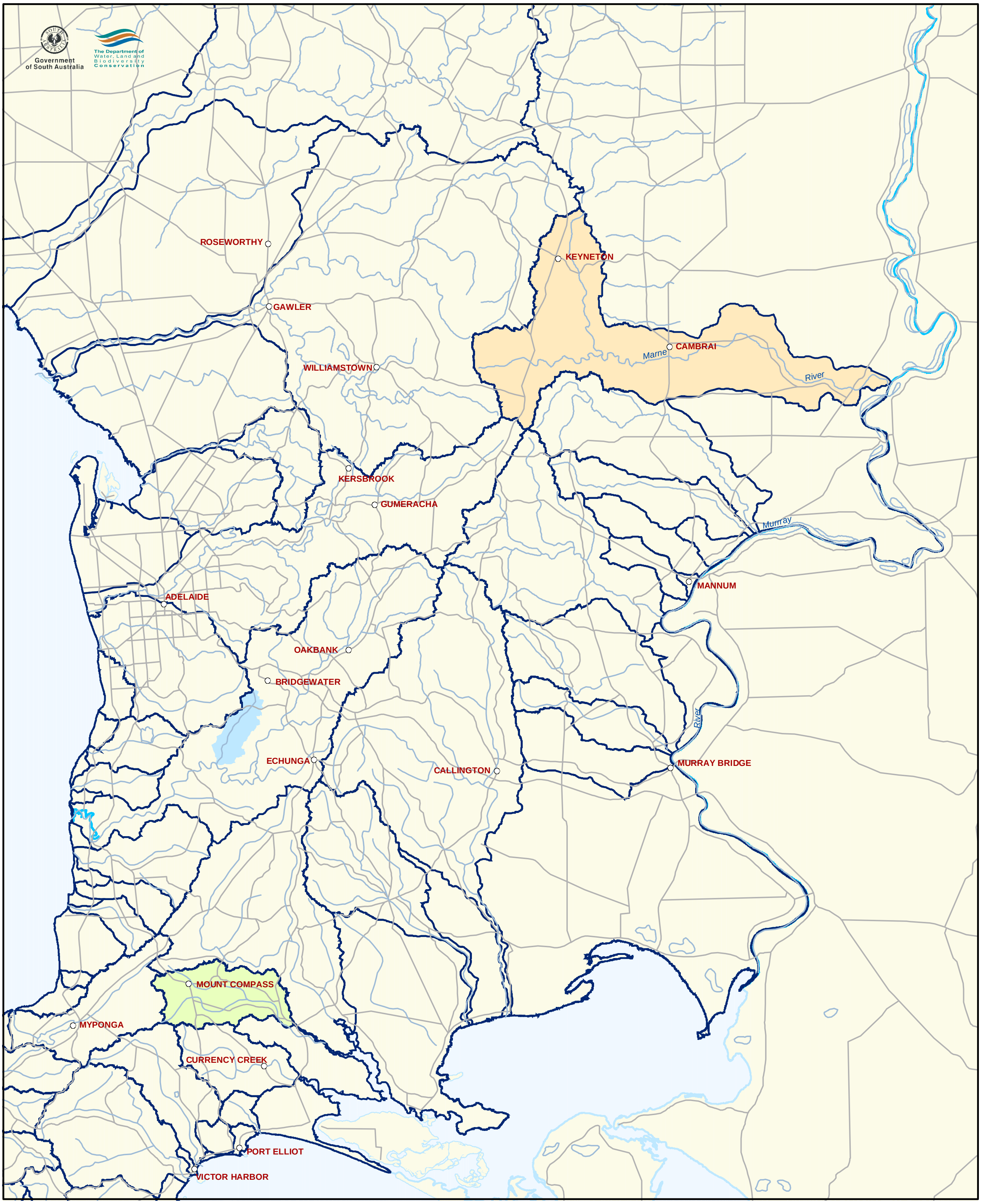
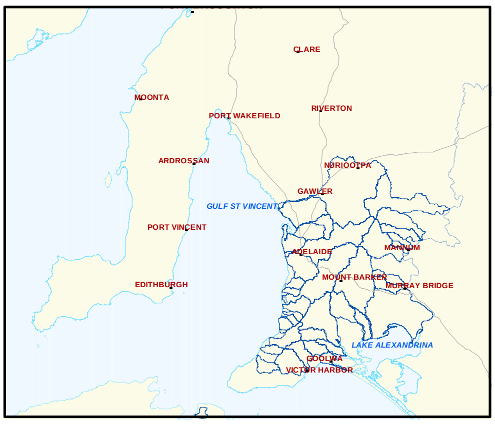


Figure 1
MOUNT LOFTY RANGES CATCHMENTS
Location of Study Catchments and Sub-catchments



Mt Lofty Ranges Catchment boundaries

Study Areas

Marne River Catchment
Scott Creek Sub-catchment
Tookayerta Creek Catchment

0 5 10 20 km

GDA
Datum GDA94
Map projection MGA Zone 54

N

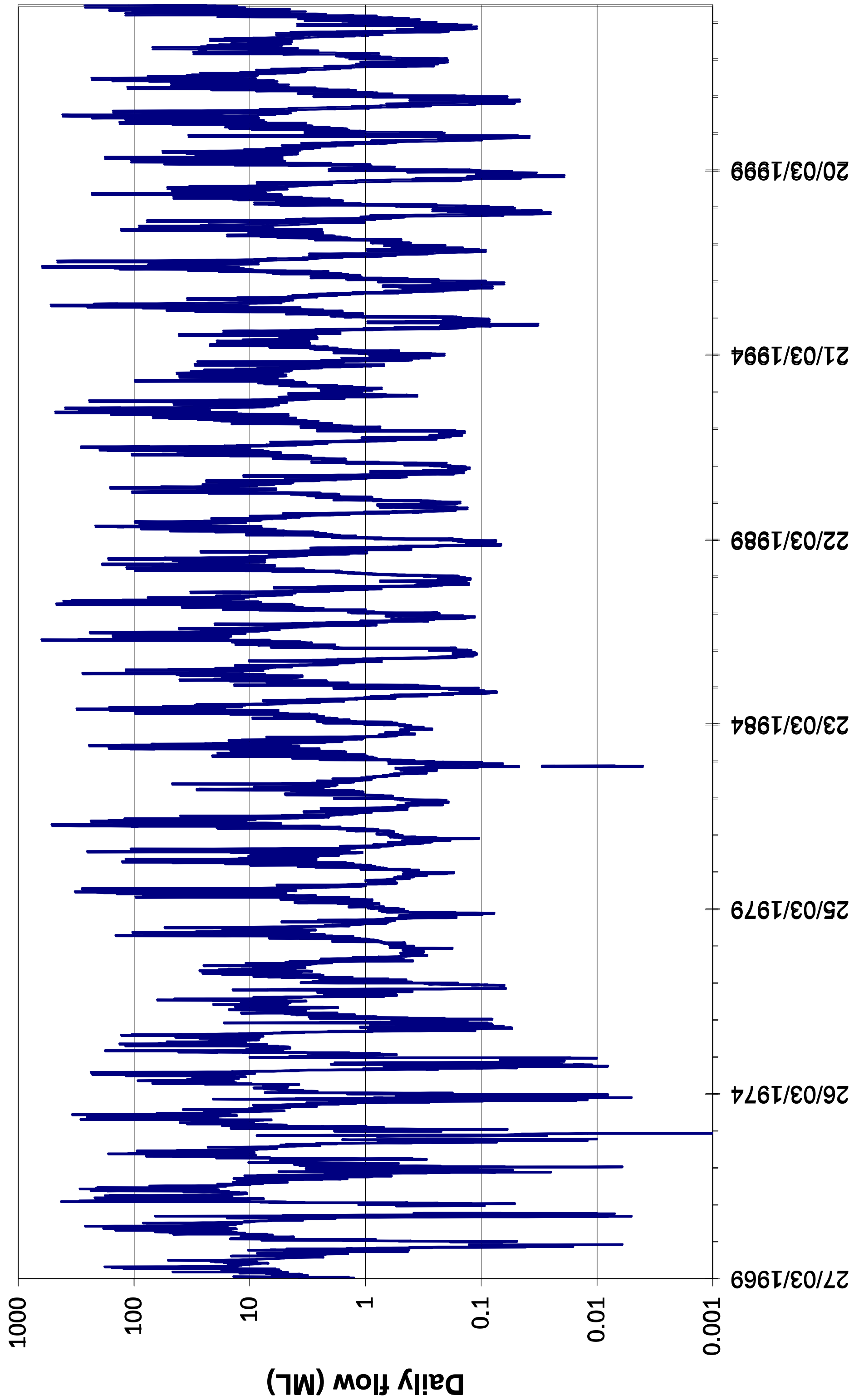


Figure 2. Daily flow record from the Scott Bottom weir located at the discharge point for the Scott Creek Catchment

such as schist, greywacke and acid intrusives. These units are all generally regarded as poor aquifers; groundwater salinity is typically > 1500 mg/L and bore yields < 3 L/s (Barnett et al., 2001).

Flow in the Marne River and the River Somme is highly ephemeral, and surface water only leaves the upper, fractured rock portion of the MRC to transgress the Murray Plains after extended periods of heavy rainfall. This aspect of the hydrology, in combination with the vast difference in topography across the study area (discussed above), suggest that both groundwater recharge from / discharge to the major water courses may occur at different times of the year.

There is growing concern about the possible impacts that recent un-restricted development of farm dams in the upper MRC will have on the surface water hydrology further down the catchment (Barnett et al., 2001). Changes to the surface water flow regime in these ephemeral rivers is also likely to impact upon groundwater recharge via bank infiltration. Therefore, an understanding of surface water-groundwater relationships in this catchment is required to determine likely impacts of dam development on groundwater recharge.

In summary, the reasons for selecting the MRC for this study are:

- semi-arid climate;
- more complex geology/hydrogeology than SCC;
- ephemeral stream flows and potential for both groundwater recharge and discharge throughout the catchment;
- to provide sufficient background understanding of surface water-groundwater relationships to help determine the likely impact of reduced annual surface runoff on groundwater recharge.

2.3 Tookayerta Creek Catchment

Situated in the south-eastern Mount Lofty Ranges, the Tookayerta Creek Catchment (TCC) is the third area selected for the current study (Fig. 1). It has vastly different hydrogeological characteristics to both the SCC and MRC, with perhaps the greatest difference being the predominance (60-70%) of Carboniferous-Permian glaciogenic rocks. These glacio-marine and fluvioglacial deposits mainly consist of undifferentiated sediments with residual erratics sourced from the underlying Proterozoic basement rocks. Therefore interactions between surface water and groundwater in this catchment will occur in essentially porous media, which is far simpler to study than the fractured rock environments common to the SCC and MRC.

Tookayerta Creek is recognised as one of the most ecologically-diverse streams in southern Australia (K. Muller, RMCWMB, pers. comm. 2002). Although mean annual rainfall is relatively high (850 mm/yr at Mt Compass), the potential for surface runoff to contribute to either of the main surface flows (Tookayerta Creek and Nangkita Creek) is extremely low in the summer months. Therefore, groundwater inflow to both creeks is vital for maintaining aquatic ecosystem health during the drier months.

Other reasons for selecting this catchment include an existing network of environmental flow gauging stations (although the maintenance and monitoring of these is somewhat questionable) and increasing pressure on what is an already highly developed groundwater resource (Barnett and Zulfic, 1999). In summary, the TCC was selected for this study because it contains:

- porous media aquifers (cf. fractured rocks in SCC and MRC);
- some records of historical stream flow rates;
- a highly developed, low salinity groundwater resource.

3 METHODS

3.1 Review of Historical Data

Historical rainfall, stream flow and groundwater monitoring data is available for each of the three study catchments, however the number of parameters measured and their respective accuracies are highly variable. Nevertheless, all available hydrological and hydrogeological data was reviewed simultaneously in order to qualitatively establish the relationships between rainfall, stream flow and recharge/discharge.

3.2 Stream and Groundwater Chemical Sampling

Following the desktop review of climatic and hydrogeological data, a stream water sampling program was established in July 2002, with subsequent sampling programs being carried out in November 2002 and March 2003. A total of 57 samples were collected from the three catchments over the course of the project: 22 from SCC, 13 from MRC and 22 from TCC. Sampling stations were sited on the basis of accessibility and representativeness of various parts of the catchment, plus any major tributaries of the main creeks.

A number of field measurements and water samples were taken at each sampling station including GPS coordinates; electrical conductivity (EC), pH and temperature of the stream; and samples for major ion analyses (1 L plastic bottle), stable isotopes (25 ml McCartney bottle) and dissolved radon-222 (mineral scintillant vial). Each of the chemical species may be useful indicators of surface water – groundwater interactions because the EC, major ion concentrations, stable isotope compositions ($^{1}H/^{2}H$ and $^{18}O/^{16}O$ of water) and radon (a radioactive gas with a half life of 3.8 days that is produced in the aquifer by U/Th series decay) concentrations of groundwater are very different to those of surface water derived from rainfall run-off.

Flow rate was also estimated at each sampling station using methods involving propeller gauging, buckets under culverts and various debris floating along a given reach of stream. These techniques were generally very crude. Thus, field estimates of flow rate are not presented in this report.

One or more groundwater bores were chosen from each study catchment for hydrochemical sampling or down-hole water quality logging. Bores were sampled from garden taps after ensuring that several volumes of casing water had been removed from the bore. Down-hole logging was performed with a YSI® 600-XLM sonde fitted with EC, pH and T probes.

3.3 Surface Water – Groundwater Mass Balances

Salt and chloride mass balances were performed to estimate the mean annual groundwater component of stream flow and provide first order approximations of groundwater recharge rates. The respective equations are:

$$Q.C_Q = Q_{RO}.C_{RO} + Q_{GW}.C_{GW} \qquad (1)$$

$$(P\text{-}RO).C_P = R.C_R \qquad (2)$$

where Q is median annual stream flow (rather than the mean which is often biased by very large or small records), C_Q is the mean concentration of salt (EC or Cl) in stream water, Q_{RO} is the median annual stream flow from surface Run-Off, C_{RO} is the concentration of salt in Run-Off water, Q_{GW} is the median annual stream flow from ground water, C_{GW} is the concentration of salt in the groundwater which discharges into the stream, P is the mean annual precipitation rate, RO is the annual runoff rate, C_P is the concentration of salt in precipitation, R is the mean annual recharge rate and C_R is the concentration of salt in recharge water (i.e. groundwater). Thus, we obtained estimates for Q_{GW} and R. Whilst the use of a chloride mass balance to estimate recharge rates in fractured-rock environments has some limitations (Love et al., 2001), careful choice of input parameters for equation (2) minimized the uncertainty in the solutions.

4 RESULTS AND DISCUSSION

4.1 Scott Creek Catchment

4.11 HISTORICAL DATA

The gauging station located at Scott Bottom weir provides a complete record of daily stream flow rates leaving the catchment for the last 34 years (Fig. 2). Seasonal fluctuations in daily flows reflect a strong influence of surface runoff during the wetter months and reliable groundwater contributions throughout the rest of the year, and this trend is also reflected in the stream salinity data. Figure 3 demonstrates how these two primary components of stream flow (i.e. runoff and baseflow) can be distinguished using stream water electrical conductivity (EC); runoff is generally much fresher (<700 µS/cm) than the relatively salty groundwater that contributes to baseflow (>1500 µS/cm).

Daily rainfall records are available for three registered Bureau of Meteorology stations in the catchment (Cherry Gardens since 1899, Longwood since 1949 and Longwood Ridge since 1989) in addition to the relatively short (1991-present) pluviograph record from Scott Bottom (next to the weir). Whilst there are some consistent differences in daily rainfall amount between the measurement stations, all records show similar seasonal trends. Mean annual rainfall for the four stations is 928, 969, 674 and 792 mm/yr respectively.

Given that three stages of chemical sampling of the streams were undertaken (discussed below), it was necessary to review daily rainfall and stream flow records leading up to each of these stages. Figure 4 shows the total daily rainfall and flow for all days of the month leading up to the sampling stage as well as the whole of the previous month. The following observations can be made with reference to Figure 4 about the three stages;

Stage 1:

- measurable rainfall on days of sampling and most of the week leading up to then (1–10 mm/day),
- significant rainfall over previous month (98–126 mm),
- flow is primarily surface runoff or shallow inter-flow, as indicated by the hydrographs.

Stage 2:

- no rain for previous 5 days,
- between 39 and 58 mm of rainfall in the previous month, of which ~40 % occurred over two days,
- hydrograph has gradual recession in flow rate with small events super-imposed, possible baseflow/inter-flow over this time scale (i.e. 6–7 wk)

Stage 3:

- most days in the two month period were dry,
- only 2 days of ~5 mm rainfall in week prior to sampling,
- one large event of 2 days each at 20–25 mm about 5 weeks prior,

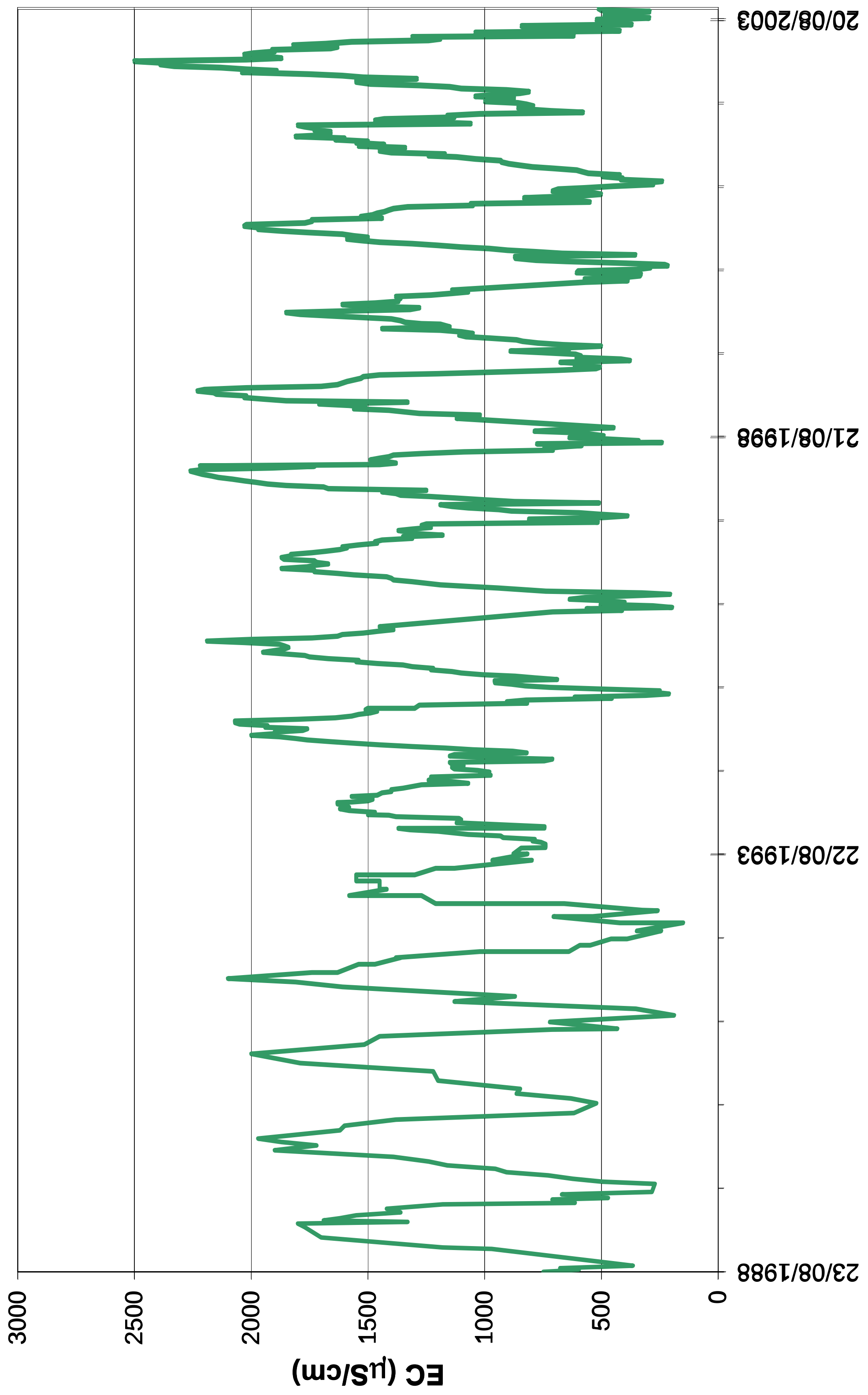


Figure 3. Stream water Electrical Conductivity (EC) record from Scott Bottom weir

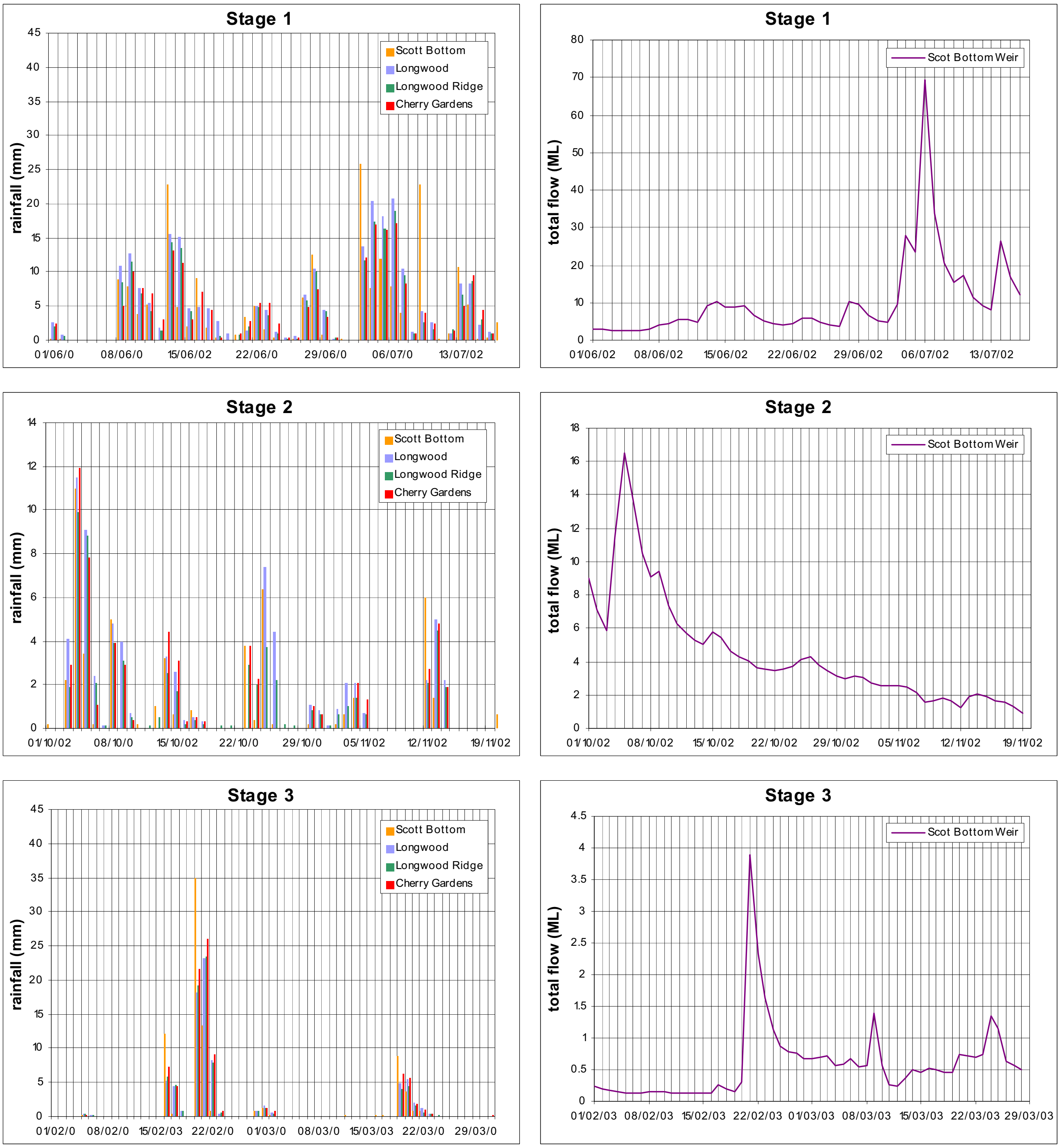


Figure 4. Daily rainfall and stream flow leading up to the three sampling stages for Scott Creek Catchment

- hydrograph recedes rapidly indicating flows >1 ML/day are almost entirely from surface runoff,
- one flow peak of 9/3/2003 does not correspond with (or closely follow) rainfall in any part of the catchment.

4.1.2 RUN-OF-RIVER SAMPLING

Ten different sites were sampled throughout the SCC on some or all occasions of the project, the locations of which are shown in Figure 5. Estimates of flow rate at each of the sampling stations is not presented here due to the problems outlined in section 3.2 and the data are neither indicative on their own nor supportive of any chemical trends. It should be noted however that flow was significantly higher throughout the catchment during Stage 1 (July 2002) compared with the two later stages.

4.1.2.1 Electrical Conductivity

Stream water EC was an extremely useful parameter throughout this study and is presented graphically for each of the sampling stages in the SCC (Fig. 6a). EC measurements at all sampling stations for stage 3 (March 2003) were greater than those at the same stations in stage 2 (November 2002), which were greater than those in stage 1 (July 2002). These consistent rises in stream water EC between sampling stages are related to reductions in both rainfall amount leading up to the time of sampling (Section 4.1.1) and stream flow rates (discussed above). Lower flow rates caused by reduced surface runoff means that a greater proportion of the flow is sourced from more-saline groundwater.

The trends shown in Figure 6(a) reveal the zones of the catchment in which groundwater discharge into the streams is most active. Because there is permanent flow in the main channel of Scott Creek, and the majority of the channel length is covered by various native and introduced plant species, evaporative loss of surface water between the top and bottom of the catchment can be assumed negligible. Therefore increases in stream water EC can only result from inputs of more saline groundwater. The EC trends indicate definite groundwater discharge between 9140–5170 m and 1730–130 m upstream of the weir at Scott Bottom and, for the last two sampling stages, between 5170–3790 m (Fig. 7).

Four groundwater samples were collected in March 2003 from different production wells in the catchment (Unit Nos. 6627-9708, 6627-8356, 6627-9936 and 6627-8729; Fig. 5). The field EC values measured at these wells (Table 1) are typed on Figure 6(a) rather than plotted as data points because they occupy an EC scale that is far greater than that required for the stream water data. Also typed on Figure 6(a) are the ranges of EC values obtained by down-hole logging of two private wells in the catchment (6627-6259 and 6627-7215, see App. 1) and several research wells near the Scott Bottom weir (Harrington, 2004).

The groundwater EC data shows that, for parts of the catchment previously identified as having active groundwater discharge (i.e. where EC rises), the stream water EC is always lower than the EC of the adjacent groundwater. Even in March 2003, when all of the flow

Table 1. Field measurements and laboratory results of surface water and groundwater sampling from each phase of sampling in the Scott Creek, Marne River and Tookayerta Creek Catchments. Ionic concentrations are in mg/L

STREAM SAMPLES	Sample ID No. (GHS#) Phase 1	Phase 2	Phase 3	Distance upstream (m)	Easting	Northing	EC (µS/cm) Phase 1	Phase 2	Phase 3	Flow (l/s) Phase 1	Phase 2	Phase 3	Radon-222 (mBq/l) Phase 1	Phase 2	Phase 3
Scott Creek Catchment	1	50	68	130	287986	6113520	673	1741	1809	62	4.5	7	389	2337	1819.6
	8	51	69	1730	288125	6114909	591.92	1160	1408	81	3.5	4.5	223	625	531.7
	7	52	67	3790	288884	6116416	591.92	1254	1450	51	1.5	4	369	1496	920.7
	6	53	66	5170	289265	6117017	678.16	1173	1294	73	5	4.5	324	1241	442.2
	4	54	64	6615	290144	6117998	531	1047	1208	25	3	4	510	1492	762.0
	2	55		8230	291137	6119044	357	545		35	0.1	dry	430	976	
	3			9140	291176	6119811	284			3	dry	dry	1723		
	9 (tributary)			405	288400	6113800	409.64				dry	dry	778		
		56 (tributary)		1710	288105	6114914		1165			1.5	0.5		497	
	5		65 (tributary)	6550	290220	6117930	726		1003	4	dry	1	777		1984.1
Marne River Catchment	23			0	339296	6161770	4420			0	dry	dry	4216		
	22			1300	338171	6161604	4150				dry	dry	448		
	24			5160	336520	6162216	3200				dry	dry	662		
	25			12540	334016	6162724	2480			17.5	dry	dry	814		
	26			18140	331739	6162210	2730				dry	dry	305		
	19			24370	328985	6162033	2470				dry	dry	337		
	18			30120	325626	6161770	2400			37	dry	dry	123		
	29			33775	322737	6162356	2430			1	dry	dry	297		
	20 (North Rhine)			23180	332115	6168079	8590			< 0.5	dry	dry	2628		
	21 (North Rhine)			29460	331554	6172715	4320			0.5	dry	dry	1345		
	27 (tributary)			27120	326973	6160551	1720			0.25	dry	dry	400		
	(tributary)			10630			2790			< 0.1	dry	dry			
	28 (tributary)			33120	323054	6161903	3310			3	dry	dry	303		
Tookayerta Creek Catchment	13	57	73	0	295402	6081698	500	630	596			high	603	2628	1925.8
	17	59	76	5290	291192	6083701	413	413	369		70		75	142	152.8
	12	58	74	10320	286611	6083201	364	337	338		55	80	694	938	854.5
	11			12820	284501	6083945	331			10	dry	dry	252		
	16	60	75	5325	291196	6083848	418	380	401		17.5		458	1652	1876.6
	15	62	71	9905	287960	6086289	401	330	368	193	40	high	200	345	424.1
	10	63	70	14755	283912	6085917	260	275	349	36	7.5	7	613	411	463.9
	14 (tributary)	61	72	2590	294070	6083692	606	458	534		3	8	57	87	103.2

STREAM SAMPLES	Sample ID No. (GHS#) Phase 1	Phase 2	Phase 3	Na Phase 1	Phase 2	Phase 3	K Phase 1	Phase 2	Phase 3	Ca Phase 1	Phase 2	Phase 3	Mg Phase 1	Phase 2	Phase 3	Cl Phase 1	Phase 2	Phase 3	S as SO_4 Phase 1	Phase 2	Phase 3	HCO_3 Phase 1	Phase 2	Phase 3	CO_3 Phase 1	Phase 2	Phase 3
Scott Creek Catchment	1	50	68	80.1	166.0	191.0	4.1	6.1	7.5	21.6	69.7	71.7	22.5	66.2	71.9	128.0	291.0	362.0	33.1	84.3	99.2	125.0	367.0	397.0	0	18	0
	8	51	69	68.8	126.0	149.0	3.7	5.6	7.3	17.5	46.1	49.8	20.4	51.7	59.4	110.0	203.0	265.0	21.4	26.1	40.5	124.0	344.0	384.0	0	17	0
	7	52	67	62.1	121.0	141.0	3.9	6.4	8.3	19.0	55.4	59.4	21.8	62.1	69.7	108.0	194.0	245.0	21.0	30.7	45.1	135.0	426.0	457.0	0	25	0
	6	53	66	70.4	112.0	121.0	4.5	6.7	7.5	23.8	53.3	53.9	27.2	61.2	66.5	115.0	172.0	201.0	23.0	31.0	39.4	169.0	415.0	440.0	0	24	0
	4	54	64	55.7	87.6	97.3	4.0	6.1	7.2	18.1	50.4	56.6	20.9	56.8	70.1	96.0	141.0	171.0	15.2	16.1	32.0	134.0	412.0	473.0	0	23	0
	2	55		47.3	68.9		2.7	1.9		6.7	13.4		9.5	18.8		84.0	123.0		13.7	1.8		37.0	102.0		0	0	
	3			37.3			2.1			4.8			5.4			67.0			15.7			18.0			0		
	9 (tributary)			53.2			3.5			8.1			10.7			99.0			22.9			25.0			0		
		56 (tributary)			147.0			5.1			36.5			35.8			260.0			34.5			204.0			7	
	5		65 (tributary)	97.8		129.0	4.7		5.2	16.1		24.4	16.8		26.8	157.0		237.0	26.1		21.7	88.0		137.0	0		0
Marne River Catchment	23			588			15.0			121.0			123.0			1200			174.0			253.0			0		
	22			589			13.5			91.8			101.0			1120			136.0			250.0			0		
	24			488			11.3			68.1			74.4			844			93.4			238.0			0		
	25			367			8.0			56.9			60.8			663			82.1			206.0			3		
	26			422			<10.0			48.6			64.3			704			62.4			188.0			0		
	19			389			6.9			44.7			64.8			677			82.9			171.0			0		
	18			380			5.7			39.8			59.1			647			78.4			133.0			0		
	29			348			5.0			36.9			57.0			662			70.8			138.0			0		
	20 (North Rhine)			1320			25.4			148.0			183.0			2470			524.0			384.0			0		
	21 (North Rhine)			703			19.4			55.0			82.9			1190			109.0			264.0			0		
	27 (tributary)			236			14.6			39.2			41.1			359			47.8			260.0			0		
	(tributary)			369			10.5			93.7			56.0			535			69.5			352.0					
	28 (tributary)			529			<10.0			46.4			76.2			909			71.9			146.0			0		
Tookayerta Creek Catchment	13	57	73	67.6	88.4	84.3	3.7	2.6	2.4	10.4	16	14.3	9.5	11.7	11.2	121.0	157	153.0	17.8	14.2	19.4	36.0	61	47.0	0	0	0
	17	59	76	54.9	52.3	50.4	4.1	2.3	2.1	7.8	8.2	7.4	8.1	8	7.5	170.0	93	92.0	9.8	8.1	8.0	36.0	39	37.0	0	0	0
	12	58	74	46.8	46.8	46.0	2.6	1.8	1.6	6.2	7.2	7.0	7.2	7.7	7.3	89.0	83	88.0	8.1	6.4	6.6	26.0	32	33.0	0	0	0
	11			48.0			2.8			4.5			5.1			82.0			8.2			31.0			0		
	16	60	75	57.1	53.7	56.0	3.6	1.7	1.8	9.4	8.5	12.2	8.1	7.8	7.7	101.0	90	102.0	16.3	7.2	10.0	31.0	42	49.0	0	0	0
	15	62	71	50.0	44.4	49.4	4.5	1.6	1.7	9.6	9.4	9.5	8.2	7.3	7.5	96.0	73	88.0	20.1	5.1	9.6	30.0	50	42.0	0	0	0
	10	63	70	48.4	38.3	47.1	3.2	1.9	2.4	11.2	8.3	8.9	7.9	6	6.8	90.0	63	80.0	25.3	9.4	21.4	29.0	35	29.0	0	0	0
	14 (tributary)	61	72	79.6	66.8	76.4	1.0	1	1.0	8.9	7.3	7.8	10.6	9	10.2	164.0	123	151.0	22.1	6.5	8.4	12.0	22	15.0	0	0	0

BORE SAMPLES	Unit No.	Production Zone	Sample Date	EC (µS/cm)	pH	Radon-222 (mBq/l)	Ca (mg/L)	Mg	Na	K	HCO_3	Cl	S as SO_4	TDS	Carbon-14 (pmC)	$\delta^{13}C$ (‰, VSMOW)
Scott Creek Catchment	6627-1-0650	11 - 52.6	15/07/2002	3110	7.05	64900	188.0	99.8	312.0	13.5	474.0	577.0	422.0	2086.3	-	-
	6627-1-0655	11.7 - 52.6	15/07/2002	2830	7.03	34400	152.0	104.0	257.0	10.1	484.0	527.0	338.0	1872.1	-	-
	6627-0-9708	24 - 30	28/03/2003	1187	7.21	-	48.6	58.8	107	7.9	380	192	19.8	814.1	59.2	-12.8
	6627-0-8356	53.7 - 56	28/03/2003	1146	7.39	-	55	66.8	90.1	7.3	456.00	148	30.80	854.0	55.5	-12.5
	6627-0-9936	33.9 - 36.9	28/03/2003	1236	7.72	-	52.5	73.2	100	7.8	478.00	154	52.10	917.6	-	-
	6627-0-8729	24 - 36	28/03/2003	1243	7.1	-	54.4	49.4	134	5.1	370.00	188	67.20	868.1	52.3	-14.2
Tookayerta Creek Catchment	6627 9831		31/03/2003	197	6.7	-	1.4	3.8	28.8	1	9.00	49	5.00	98.0	-	-

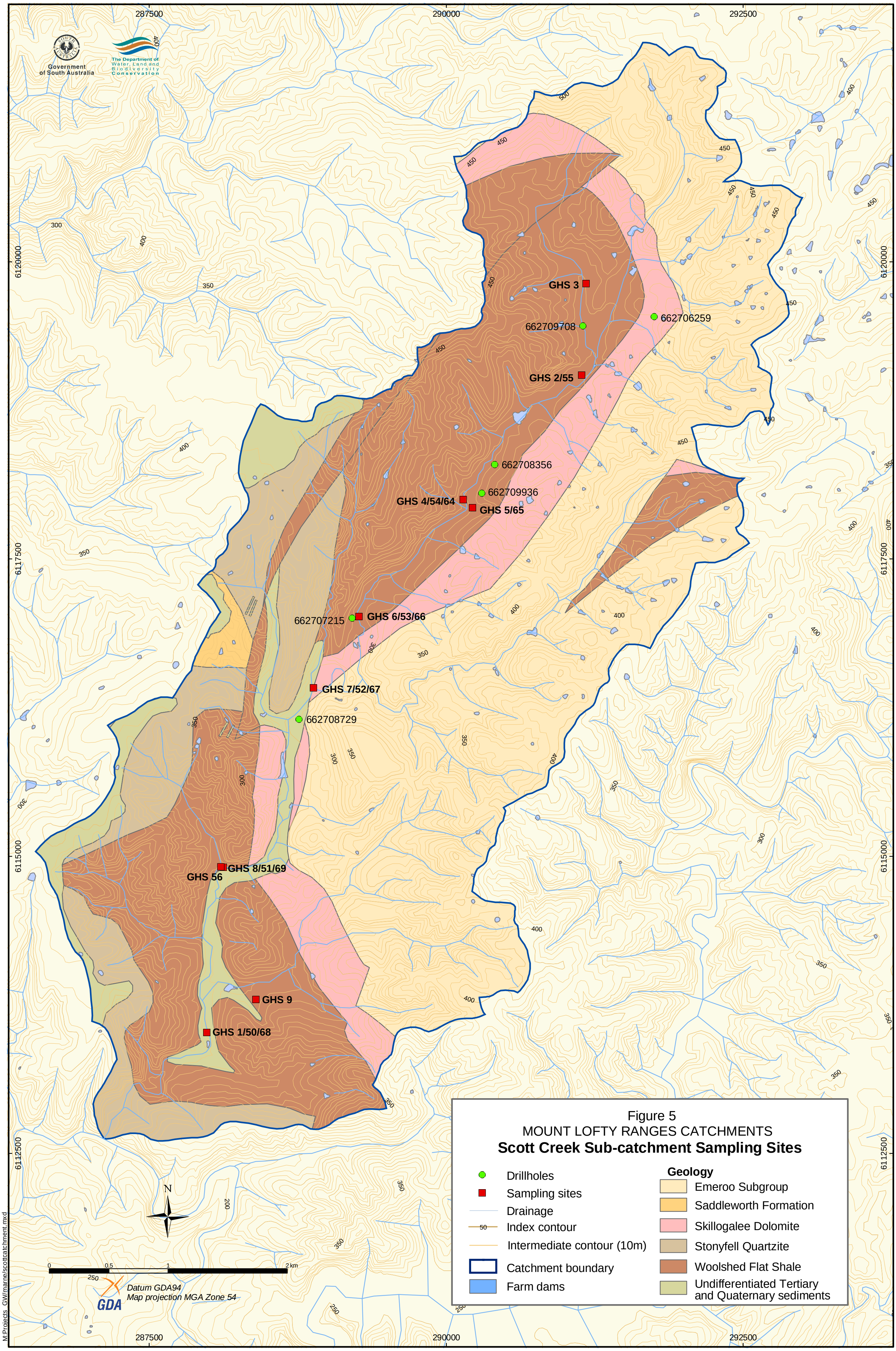


Figure 5
MOUNT LOFTY RANGES CATCHMENTS
Scott Creek Sub-catchment Sampling Sites

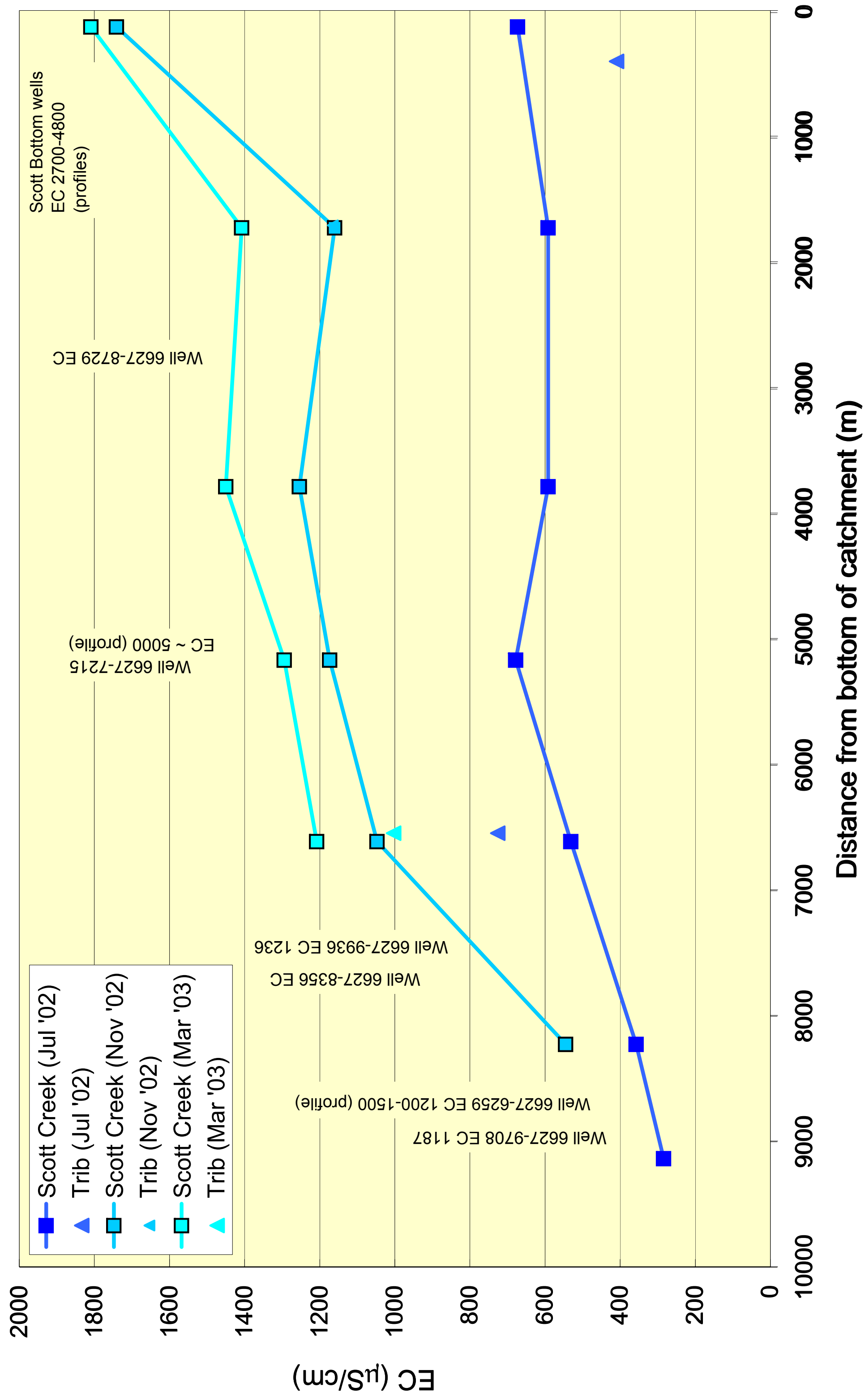


Figure 6. Scott Creek run-of-river sampling results; (a) EC with groundwater values listed in approximate position within the catchment

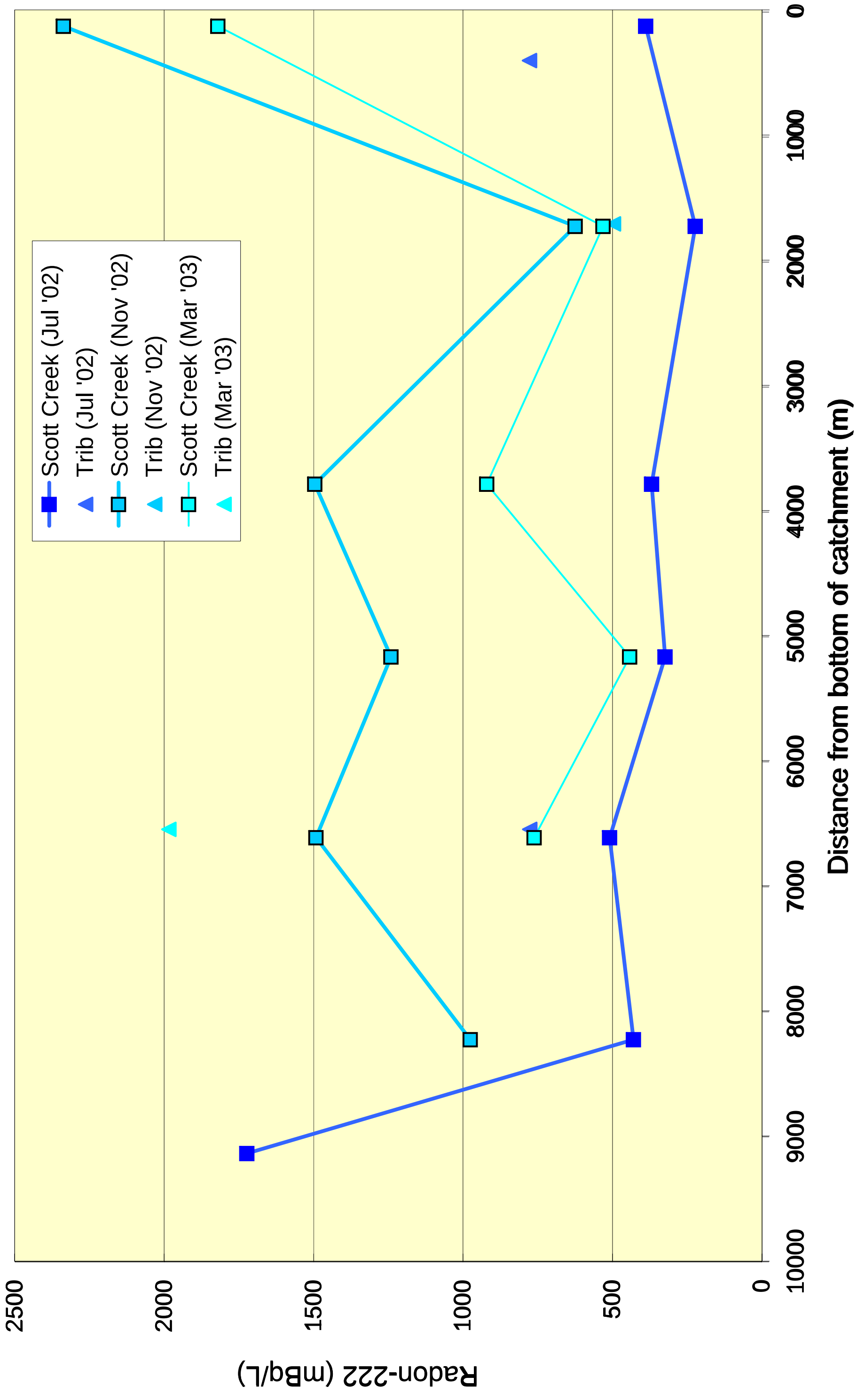


Figure 6. Scott Creek run-of-river sampling results; (b) radon-222 concentrations. Groundwater discharge occurs in reaches where EC increases or decreases between sampling points, and/or where radon concentrations increase

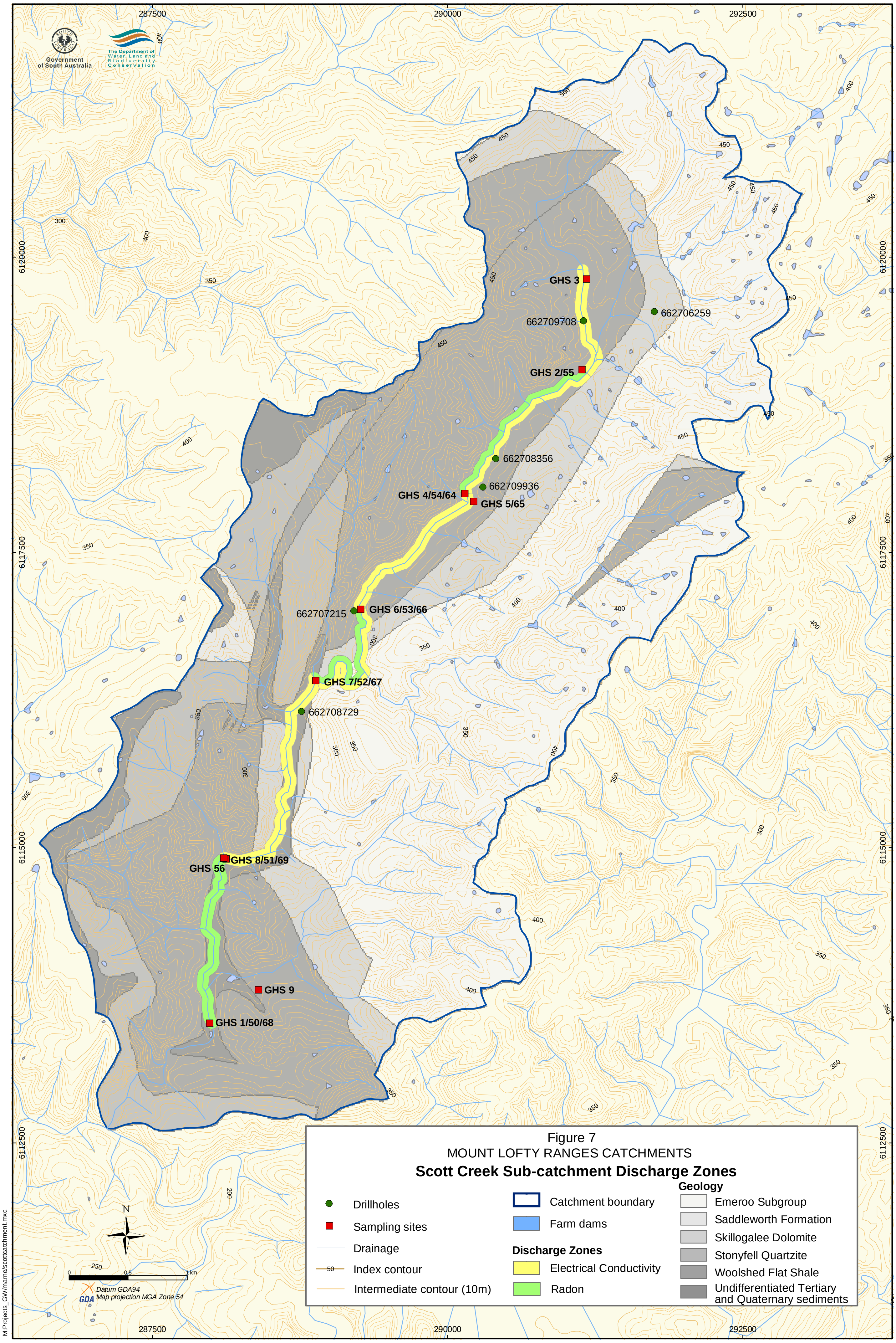


Figure 7
MOUNT LOFTY RANGES CATCHMENTS
Scott Creek Sub-catchment Discharge Zones

was derived from groundwater, the EC of the stream was much lower than the EC values of groundwater in well 6627-7215 and the research wells at Scott Bottom. Therefore, the “groundwater” feeding these streams in March must be less-saline than the groundwater sampled between approximately 10–50 m depth. A possible explanation for this is that the sub-surface water that is discharging into the stream is what is commonly referred to as “inter-flow” rather than baseflow. This water is stored within and moves through the soil and weathered bedrock rather the fractured-rock aquifer. Expected residence times of the interflow water would be on the order of several days to weeks, so extremely long periods of dry weather may result in the loss of this contribution to the stream water balance.

At wetter times of the year (i.e. July and November) it is possible that some of the deeper, more regional groundwater of EC in the range 1000–5000 μS/cm could contribute to stream flows, because higher recharge fluxes would cause both groundwater levels to rise and gradients to steepen. Stream water EC values at these times of the year still don’t reach those of the groundwater because relatively fresh, surface runoff is the main component of the stream flow.

4.1.2.2 Radon

Increases in radon concentration down the stream reveal the zones of most active groundwater discharge, because groundwater radon concentrations are always higher than surface water radon concentrations (Section 3.2). Therefore, the radon data shown in Figure 6(b) suggests significant groundwater discharge into Scott Creek between 8230–6615 m, 5170–3790 m and 1730–130 m above the Scott Bottom weir. The locations of these zones compare very well to the locations of groundwater discharge inferred from the EC data (Fig. 7).

Profiles of dissolved radon concentrations from the stream samples show similar spatial and temporal variability to the EC measurements (Fig. 6(b)). Radon concentrations were generally lowest throughout the catchment during stage 1 (July 2002), which is not surprising given that the flow would have been dominated by surface runoff at this time. One would expect the highest radon concentrations to therefore occur when surface runoff is at a minimum and groundwater discharge is the primary component of flow (i.e. March 2003). However, the highest radon values actually appeared in stage 2 (November 2002) which suggests that groundwater contributions are greatest at this time of the year. The lowest radon values were measured in stage 3 (March 2003) when groundwater discharge was essentially the only component of flow. This may be explained by the lower stream flow rates (i.e. greater residence time in stream) and higher daily temperatures occurring in March relative to the other sampling times, thereby causing the greatest losses of gaseous radon from the stream between sampling stations.

4.1.2.3 Major Ion Compositions

Ionic compositions of samples from Scott Creek and it’s main tributaries for each sampling stage are plotted on Piper diagrams in Figure 8(a–c). Data from both stage 1 and 2 plot along broad linear trends, with stage 1 samples evolving from Na-Mg-Cl-HCO_3 type to Na-

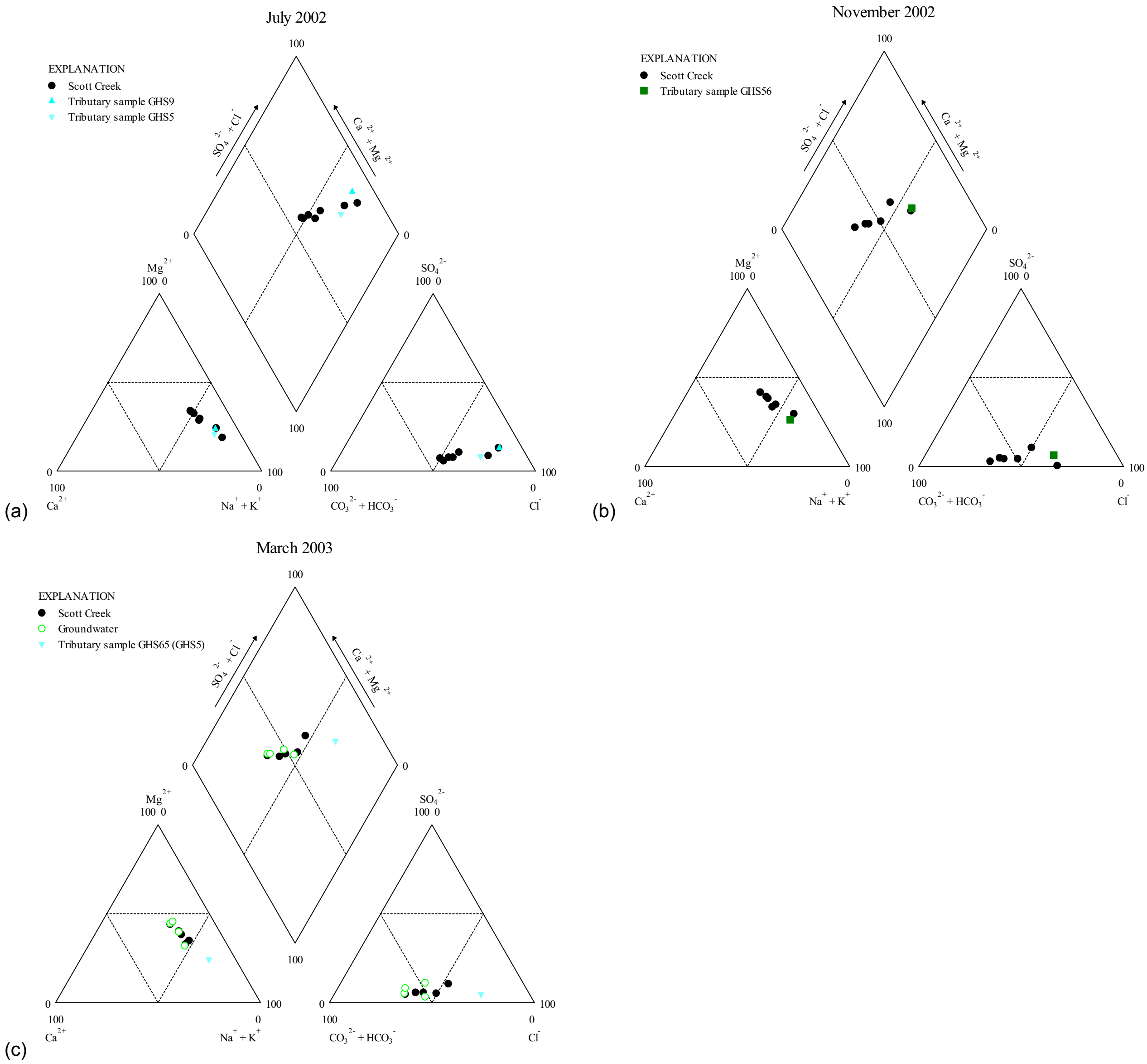


Figure 8. Piper diagrams showing surface water major ion compositions for each of the sampling stages 1 (a) through to 3 (c) in Scott Creek Sub-catchment. Groundwater compositions from several wells are provided in (c).

Cl type, and stage 2 samples evolving from Mg-Na-Ca-HCO_3-Cl type to Na-Mg-Cl-HCO_3 type. These slight differences in major ion compositions and evolutionary trends most likely reflect the different proportions of groundwater and surface water in the stream between the sampling stages. The radon data suggested that groundwater contributions were greatest at Stage 2, and this is supported by the stream water chemical composition being dominated by ions derived from water-rock interactions in the sub-surface (especially Ca, Mg, HCO_3) rather than salts deposited in rainfall (i.e. Na and Cl).

The range of stream water chemical compositions obtained during stage 3 (March 2003, Fig. 8(c)) plot in a similar position to those of stage 2 although they are less variable. Groundwater compositions for the four production wells (discussed above) are also plotted for comparison, and they provide further evidence that the stream flow at this time of the year is dominated by groundwater discharge. However, the salinity (EC) data suggested that it wasn't the deep, regional groundwater (which these samples represent) that was discharging into the creek at this time of the year. Shallower and less-saline inter-flow water was proposed as the source, which means that it must have major ion compositions similar to the deeper groundwater. This implies that the majority of groundwaters must acquire their solutes from rainfall and in the shallow unsaturated/saturated zones before reaching the aquifer.

Major ion/chloride plots of the stream water chemistry may also reveal something about groundwater discharge processes. If there were no groundwater inputs along the entire catchment, the ion/Cl ratio should not change from that at the headwaters (unless evaporative concentration of the stream water caused minerals to precipitate, but this would not occur at the range of salinities observed here). The most striking feature of the Scott Creek data are the rises in Na/Cl, K/Cl, Ca/Cl, Mg/Cl, HCO_3/Cl and (to a lesser degree) SO_4/Cl ratios between 8230–6615 m from the weir (Fig. 9). Of these rises, the most pronounced are for Ca, Mg and HCO_3 which suggests that the groundwater entering the stream along this reach has reacted with some form of Ca-Mg-carbonate mineral. A possible scenario is that this groundwater is recharged into (or has flowed through) the Skillogalee Dolomite which flanks the stream (Fig. 5).

Decreases in Ca/Cl, Mg/Cl and HCO_3/Cl downstream of 6615 m is most likely due to a combination of (i) mixing with surface water and groundwater inputs that have lower ion/Cl values, and (ii) in-stream precipitation of Ca-Mg-carbonates as a result of a pH rise caused by degassing of dissolved CO_2 from the discharged groundwater.

4.1.3 MASS BALANCE CALCULATIONS

Results of the salt and chloride mass balances for the SCC indicate that mean annual groundwater contributions to the stream may be in the range 1740–1850 ML/yr, or 65–69 mm/yr when averaged over the entire catchment area (Table 2). These fluxes comprise over three quarters of the annual recharge rates calculated by salt and chloride mass balances (69–83 mm/yr). For comparison, the mean and median annual stream flow out of the catchment between 1969–2003 was 3654 and 3769 ML/yr respectively (or 135 and 140 mm/yr when averaged over the entire catchment area).

Table 2. Mass balance calculations for Scott Creek Catchment. CAUTION: these approaches can yield large errors in fractured rock environments, so results should be seen as indicative at best

ELECTRICAL CONDUCTIVITY (EC)	CHLORIDE (CL)
Groundwater – surface water mass balance (Equation 1)	
Q (median) = 3840 ML/yr *1 Q_{RO} = 92.5 mm/yr x 27 km^2 = 2498 ML/yr *2 (i.e. water budget: Q_{BF} = 1342 ML/yr)	
C_Q (mean) ~ 1200 µS/cm *1 C_{RO} (assumed) ~ 100 µS/cm C_{BF} (saltiest stream water) ~ 2500 µS/cm THUS, **Q_{BF} ~ 1743 ML/yr = 65 mm/yr**	C_Q (mean/median) ~ 230 mg/L *1 C_{RO} (assumed from EC) ~ 20 mg/L C_{BF} (assumed from EC) ~ 450 mg/L THUS, **Q_{BF} ~ 1852 ML/yr = 69 mm/yr**
Recharge mass balance (Equation 2)	
P (mean) = 925 mm/yr C_P (assumed) ~ 100 µS/cm C_R (freshest groundwater) ~ 1200 µS/cm THUS, ***R ~ 69 mm/yr***	C_P (assumed from EC) ~ 20 mg/L C_R (assumed from EC) ~ 200 mg/L THUS, ***R ~ 83 mm/yr***

*1 Data sourced from historical records at Scott Bottom Weir.

*2 Mean annual runoff estimated to be 10% of mean annual rainfall (P).

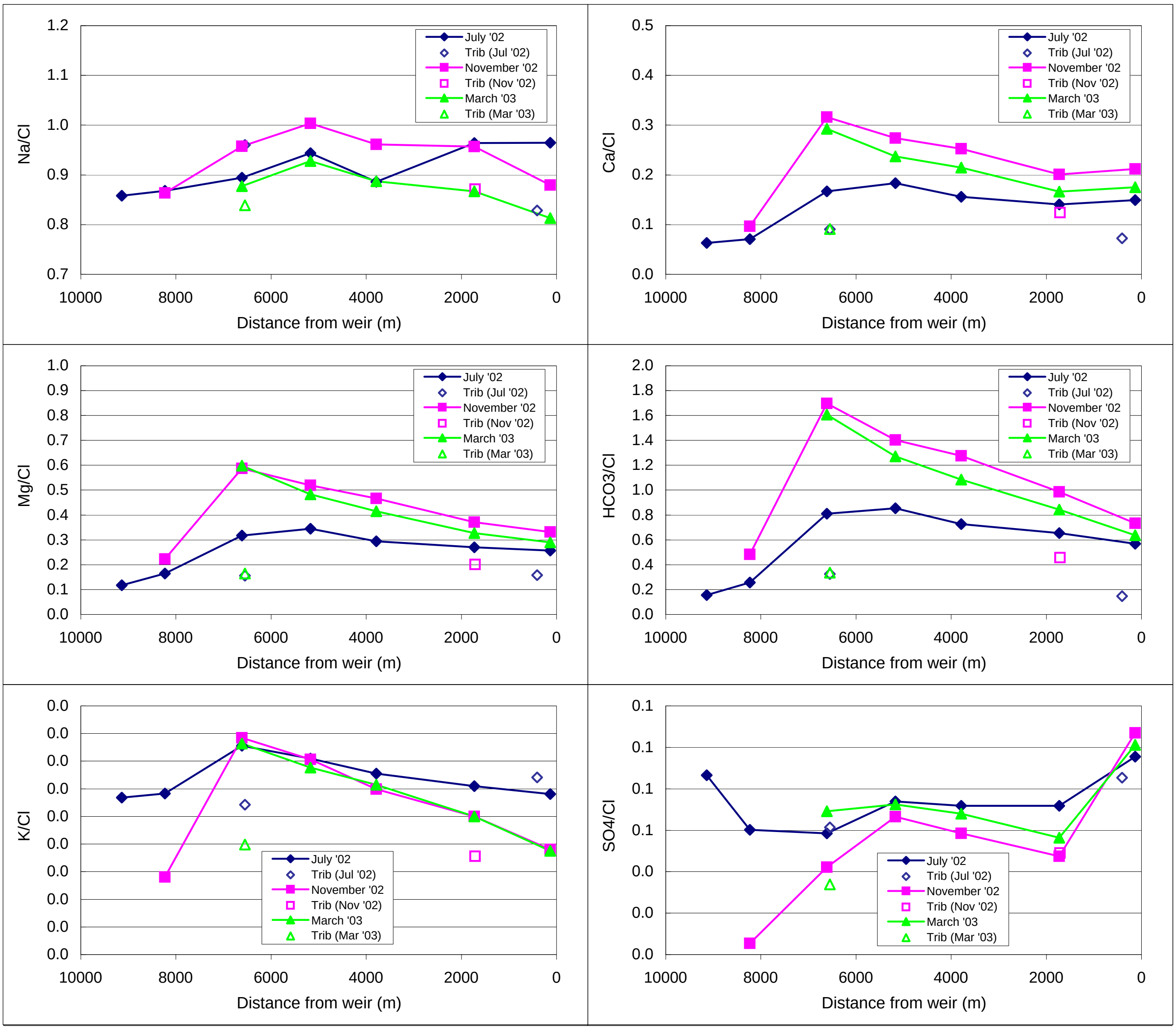


Figure 9. Surface water ion/Cl ratios obtained during each run-of-river sampling stage in the Scott Creek Sub-catchment. Most significant variations along the creek are for Ca/Cl, Mg/Cl and HCO_3/Cl, probably reflecting groundwater discharge from or via the Skillogalee Dolomite

4.1.4 CONCEPTUAL MODEL

From the three sampling stages, stream water EC, radon and major ion concentrations indicated that groundwater discharge to Scott Creek occurs throughout most of the catchment. The greatest contributions appear to occur around November (stage 2) after the main rain-recharge season. While some parts of the catchment appear to contribute more groundwater than others, there is no direct correlation between geology or topography and discharge zone (Fig. 7).

The relatively low EC of the stream water throughout the year suggests that groundwater from between 10–50 m depth is not the source of discharge to the stream. Instead it is proposed that the main sub-surface contribution to the streams is via inter-flow of much fresher, younger water from the shallow soil and weathered bedrock layers. This hypothesis is further supported by three carbon-14 analyses of the groundwater samples (Table 1). All three samples returned values of 50–60 pmC which, even after accounting for some dilution of the total dissolved inorganic carbon with dead carbon by carbonate dissolution, equates to groundwater ages of more than 1000 years. In such a small catchment it is unlikely that groundwater of this age would discharge locally to the streams.

4.1.5 IMPLICATIONS FOR MANAGEMENT

The best quality and most dynamic groundwater resource in the SCC appears to be that which is stored in the deeper soils and weathered bedrock. Whilst this resource is usually replenished on an annual basis, more than two thirds of the total recharge flux is lost to the streams via inter-flow (discussed above). Therefore future development of groundwater in the catchment should be managed in such a way that it does not reduce groundwater contributions to the stream, particularly in those areas identified as having significant groundwater inputs (Fig. 7).

4.1.6 RECOMMENDATIONS

This preliminary investigation of groundwater – surface water interactions in Scott Creek Catchment has shown that the permanent stream flow during the direr months of each year is controlled by discharge of interflow water and not the deeper groundwater. The lateral and vertical extents of this interflow water away from the streams are unknown, as are it’s flow processes and residence times. Therefore, it is suggested that further investigations be undertaken in this (and other similar) catchments to address these knowledge gaps.

4.2 Marne River Catchment

4.2.1 HISTORICAL DATA

Daily flow data for the Marne River Hydrometric Station, which is situated in the Marne Gorge west of Cambrai (Fig. 1), is presented in Figure 10. The original station (AW426529) was upgraded in 2001 with a completely new concrete weir constructed 100 metres downstream (AW426605). The original control was a slightly modified natural rock bar which proved most insensitive for small to medium flows and, during low flow periods, water was observed flowing upstream and downstream but not over the control.

The flow record for the old station (AW426529) has been intermittent since 1997 with many periods of missing data. Total annual flow has been determined for all years that have continuous and reliable daily flow records (Fig. 11). This plot demonstrates a high degree of variability in annual flow albeit the data series is discontinuous. Mean annual flow calculated from the data presented in Figure 11 is approximately 7220 ML/yr, however the standard deviation is around 8440 ML/yr. A more representative value of long-term annual flow at this station is the median value of 4742 ML/yr. It is not possible from this limited dataset to identify any persistent reduction in annual flow rate caused by recent dam development in the upper parts of the catchment (Section 2.2).

Daily rainfall records exist for Keyneton (Fig. 1) between September 1908 and present day. Although the data are not shown in this report, seasonal trends in rainfall amount reflect May through to September being the wettest months with each having at least double the rainfall of other months in the year. The mean annual rainfall for this station is 534 mm/yr.

Figure 12 presents daily rainfall at Keyneton and flow at Marne Gorge (the discharge point for surface water leaving the upper Marne River catchment) for the two months prior to each of the sampling stages. Surface flow in the Marne River only occurs after significant rainfall has caused overland flow and/or groundwater recharge with subsequent discharge into the channel. Therefore, the absence of surface flow out of the MRC during Stages 2 and 3 can be related to the very low rainfall and thus runoff from the catchment, but also no groundwater discharge into the creeks at these times of the year.

4.2.2 RUN-OF-RIVER SAMPLING

Stream water samples were obtained from 12 different sites throughout the upper MRC during Stage 1 (Fig. 13). Flow at site GHS22 immediately downstream of the Marne Gorge weir was in the range 0.075 to 0.296 ML/day when sampling took place between 18-24 July 2002 (AW426529). No samples were taken during the two subsequent stages because all of the sites were dry on these occasions (discussed previously).

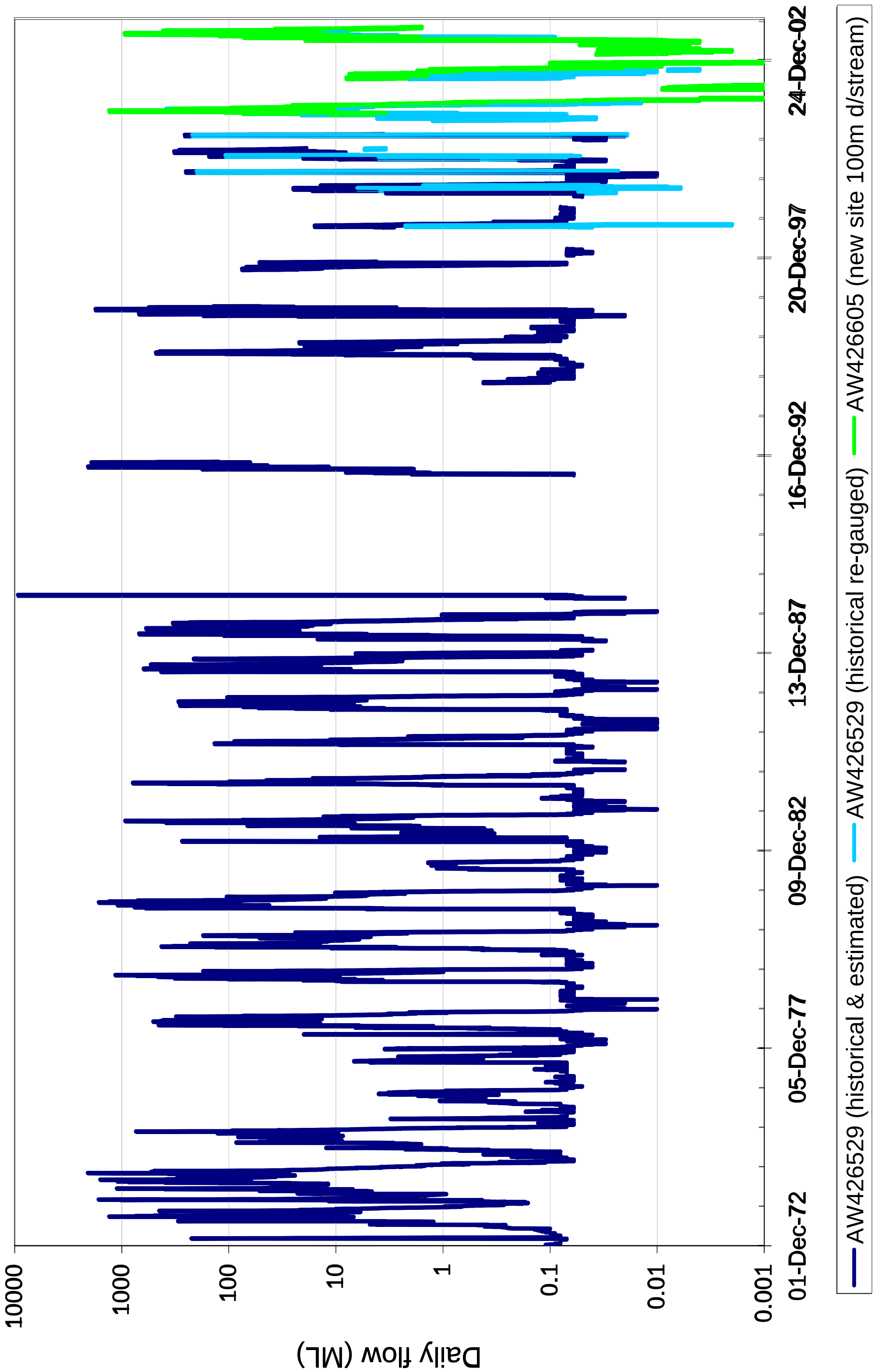


Figure 10. Daily flow record from the Cambrai weirs located at the discharge point for the upper Marne River Catchment

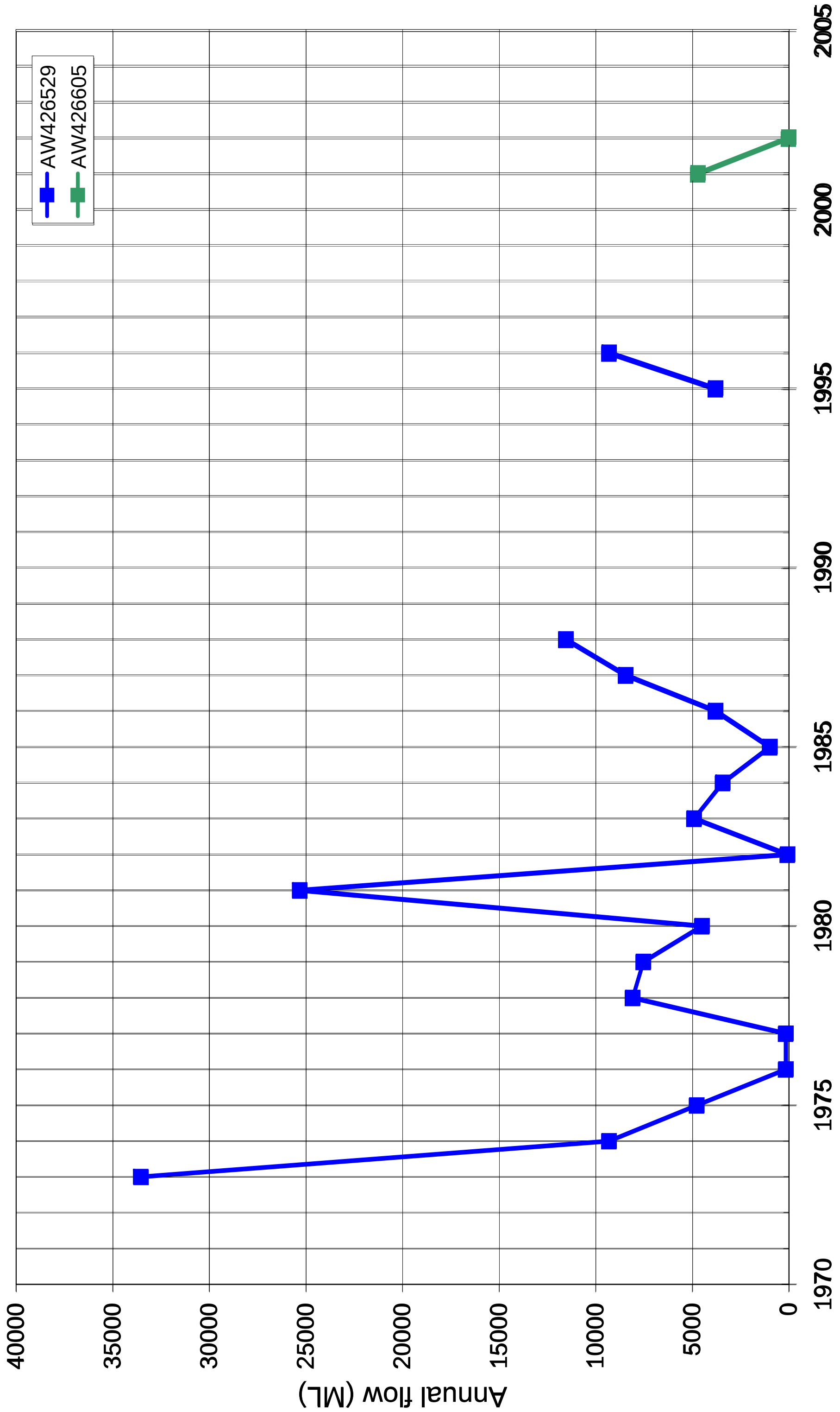


Figure 11. Annual flow record from the Cambrai weir located at the discharge point for the upper Marne River Catchment. Mean and median annual flows are 7220 ML/yr and 4742 ML/yr respectively

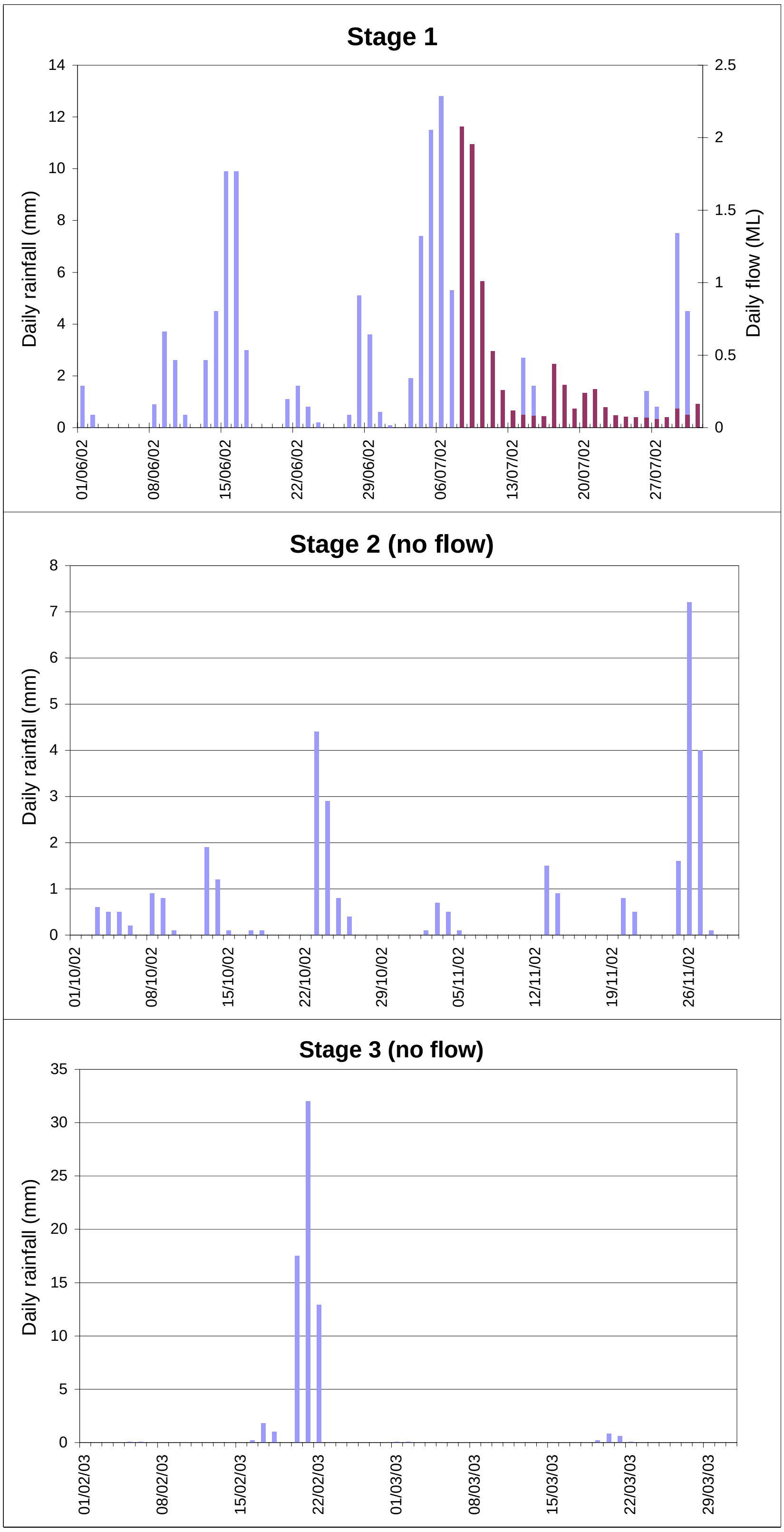
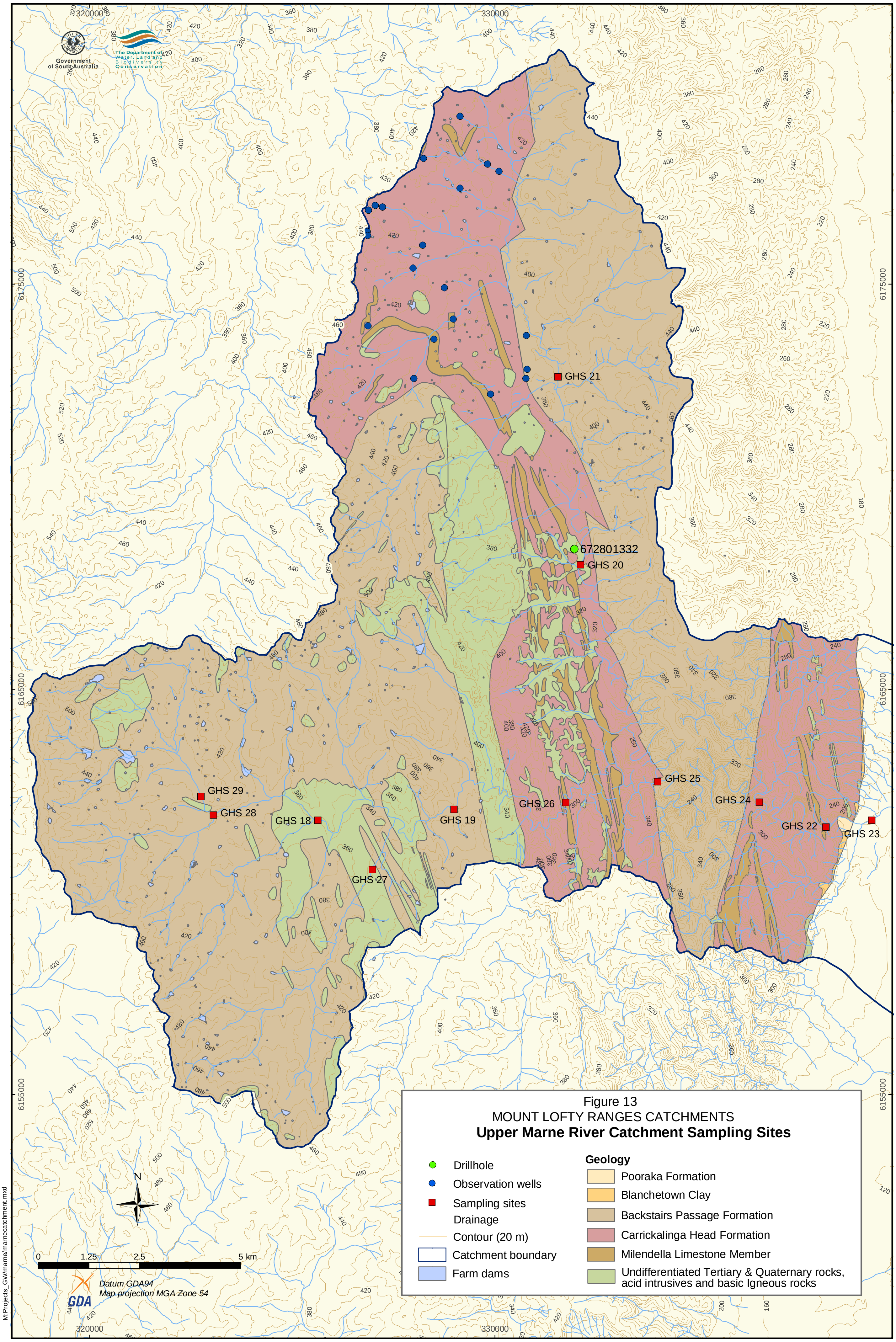


Figure 12. Daily rainfall and stream flow leading up to the three sampling stages for Marne River Catchment. No flow occurred throughout the catchment during the last two stages, and hence no samples were taken at these times



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The Department of Water, Land and Biodiversity Conservation
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GHS 27
GHS 28
GHS 29
GHS 18
GHS 19
Figure 13
MOUNT LOFTY RANGES CATCHMENTS
Upper Marne River Catchment Sampling Sites
Drillhole
Observation wells
Sampling sites
Drainage
Contour (20 m)
Catchment boundary
Farm dams
Geology
Pooraka Formation
Blanchetown Clay
Backstairs Passage Formation
Carrickalinga Head Formation
Milendella Limestone Member
Undifferentiated Tertiary & Quaternary rocks, acid intrusives and basic Igneous rocks
N
0
1.25
2.5
5 km
GDA
Datum GDA94
Map projection MGA Zone 54
M:Projects_GW/marne/marnecatchment.mxd

4.2.2.1 Electrical Conductivity

Surface water EC in the Marne River proper was generally constant throughout most of the catchment (Fig. 14(a)). In the Marne River Gorge, between GHS25 and GHS22 (between 12540 and 1300 m from GHS23), the EC did increase by over 1500 μS/cm indicating significant inputs of relatively saline groundwater in this zone. A noticeable rise in EC was also measured between GHS22 at the end of the gorge and GHS23 where the entire surface flow disappeared underground into the Tertiary sedimentary aquifers. Why the EC should rise in an apparently losing reach of the river is unknown. The only plausible explanation is that some additional discharge of relatively saline groundwater from the fractured-rock hills occurs between GHS22 and the subsurface boundary between the fractured-rock and sedimentary aquifers.

EC rose dramatically between the only two sampling sites on the North Rhine River (GHS21 and GHS22) but this trend could have arisen by saline groundwater inputs and/or concentration by evaporation, as the flow rate was very sluggish at both sites (<0.5 L/s). Support for the latter of these two processes is provided in the results of down-hole logging a deep groundwater bore (6728-1332) near GHS20 which returned EC values of ~1960 μS/cm (i.e. much fresher than the surface flow of ~8590 μS/cm).

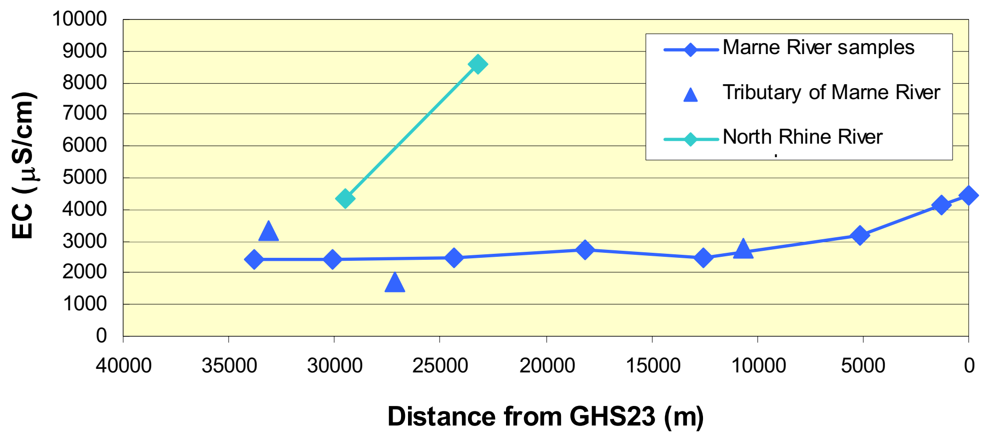
4.2.2.2 Radon

Three separate reaches of the Marne River returned downstream increases in radon concentrations between sampling sites (Fig. 14(b)). The only one of these zones that coincides with increases in EC is the last, between GHS22 and GHS23. This is further support for the process proposed above, whereby active groundwater discharge is occurring from the fractured-rocks into the Marne River in the short reach between GHS22 and the subsurface boundary of the fractured-rock/sedimentary aquifers.

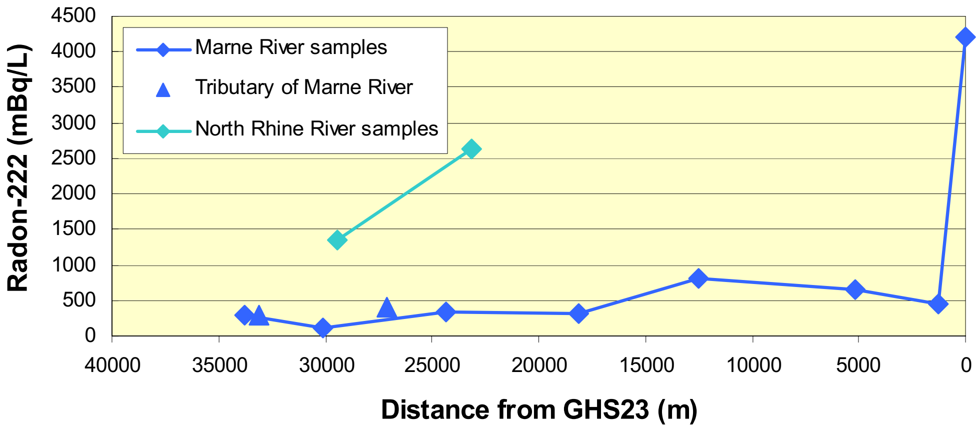
The locations of the other radon increases (between GHS18 and GHS19 and between GHS26 and GHS25) reveal zones where groundwater discharges into the river which were not evident from the EC data. This suggests that the EC of the groundwater discharging into the river must be equal to (in the first reach) or lower than (evident in the second reach) that of the surface water upstream of those reaches. The zone in which an EC increase was not matched by a radon increase (between GHS25 and GHS22) may not be such a significant groundwater discharge zone.

4.2.2.3 Major Ion Compositions

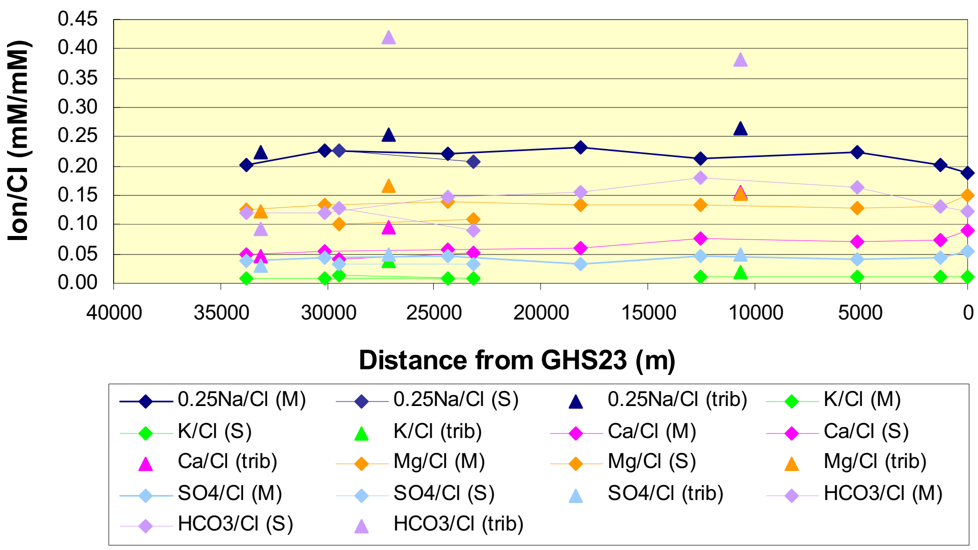
With the exception of HCO_3/Cl and possibly Ca/Cl, surface water major ion/Cl ratios barely differ throughout the catchment (Fig. 14(c)). Ca and HCO_3 ions are perhaps the best major ion indicators of mineral weathering reactions in the subsurface as they are the primary products of carbonate dissolution and silicate weathering reactions. Therefore, changes in the Ca/Cl and HCO_3/Cl ratios in surface waters of the MRC most likely reflect different amounts and/or sources of groundwater discharge into the river. Ca/Cl ratios virtually double between the first (GHS29) and last (GHS23) sample points on the Marne River, whereas HCO_3/Cl ratios increase to site GHS25 (12540 m from GHS23) then



(a)



(b)



(c)

Figure 14. Marne River Catchment run-of-river sampling results from stage 1; (a) EC values, (b) radon-222 concentrations, and (c) major ion/Cl ratios. Groundwater discharge occurs in reaches where EC increases or decreases between sampling points, and/or where radon concentrations increase. Ion Cl ratios vary only slightly throughout the catchment, with the most pronounced changes being for Ca/Cl and HCO_3/Cl, possibly reflecting groundwater discharge from or via a carbonate dominated aquifer

decrease to site GHS23. How these exact trends relate to their surrounding geologies cannot be determined without further investigation into the groundwater chemistry within these areas.

Samples from the Marne and North Rhine Rivers plot as distinct groups but close together on a Piper diagram (Fig. 15), possibly reflecting the slightly different geologies of the source water. All waters are Na-Cl dominated with no particular evolutionary trend downstream.

4.2.3 MASS BALANCE CALCULATIONS

A paucity of groundwater chloride and surface water salinity data for this catchment meant that many of the chloride and salt mass balances either had a high uncertainty or could not be calculated. The most useful calculation was that of a mean recharge rate by chloride mass balance (Equation 2). Using the mean annual rainfall at Keyneton of 534 mm/yr, the mean and median chloride concentrations of 18 regional groundwater samples collected between 1950–1980 (896 mg/L and 511 mg/L respectively) and a range of 5–10 mg/L for the chloride concentration of rainfall in the area (estimated from Blackburn and McLeod, 1983), a range of recharge rates from 3.0–10.5 mm/yr were derived. These values are significantly lower than the spatially-averaged median annual stream flow out of the catchment (4742 ML/yr/270 km^2 = 17.6 mm/yr).

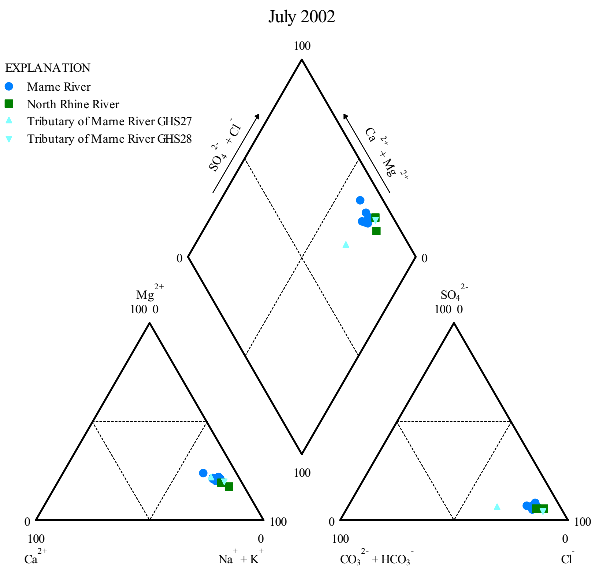


Figure 15. Piper diagram showing surface water major ion compositions for sampling stage 1 in Marne River Catchment

4.2.4 CONCEPTUAL MODEL

Each of the tracers used in this study highlight where groundwater discharge is significant in the catchment. EC and radon were most useful in the MRC, and the discharge zones inferred from these tracers are shown on Figure 16. EC data indicated that discharge of relatively saline groundwater occurs in both the middle section of the North Rhine River and the steep, gorge section of the Marne River. A slight reduction in EC between sites GHS26 and GHS25 indicated that discharge of relatively fresher groundwater occurred in this reach, which is possibly related to the occurrence of Milendella Limestone in this zone (Fig. 13). The radon data provided further support for discharge occurring here. Other zones in which the radon data indicated active groundwater discharge were further up the catchment between sites GHS18 and GHS19, along the North Rhine River and, most significantly, in the last part of the Marne Gorge between the GHS22 and the boundary of the fractured-rock/sedimentary aquifers.

4.2.5 IMPLICATIONS FOR MANAGEMENT

Anecdotal evidence from many sources within the local community and government organisations indicate that surface water flow dynamics in the upper reaches of the MRC have changed dramatically over the last 5 years, and the cause is generally attributed to unregulated farm dam development. Neither the gauging station record for Marne Gorge nor the results of this study can provide support for this hypothesis. Nevertheless, any impoundment of surface water within the catchment will have detrimental impacts on the surface hydrology, particularly on the low to medium flows downstream.

The past six or seven years have been drier than average for most parts of South Australia and the semi-arid Marne River catchment is no exception (Keyneton rainfall data not available for several months between years 2000-2003). This is likely to be another cause of the observed decline in River flows. Lower rainfall rates not only reduces surface runoff into creeks, but also reduces recharge to groundwater and thereby decreases groundwater discharge to the River during times of low rainfall, when contributions from groundwater are vital for maintaining aquatic ecosystems.

4.2.6 RECOMMENDATIONS

The upper Marne River Catchment has received below average rainfall and seen unprecedented levels of dam development over recent years. Therefore, ongoing monitoring of the surface water and groundwater resources will be essential to determine the relative importance of these two mechanisms for changing the stream flow dynamics in this catchment.

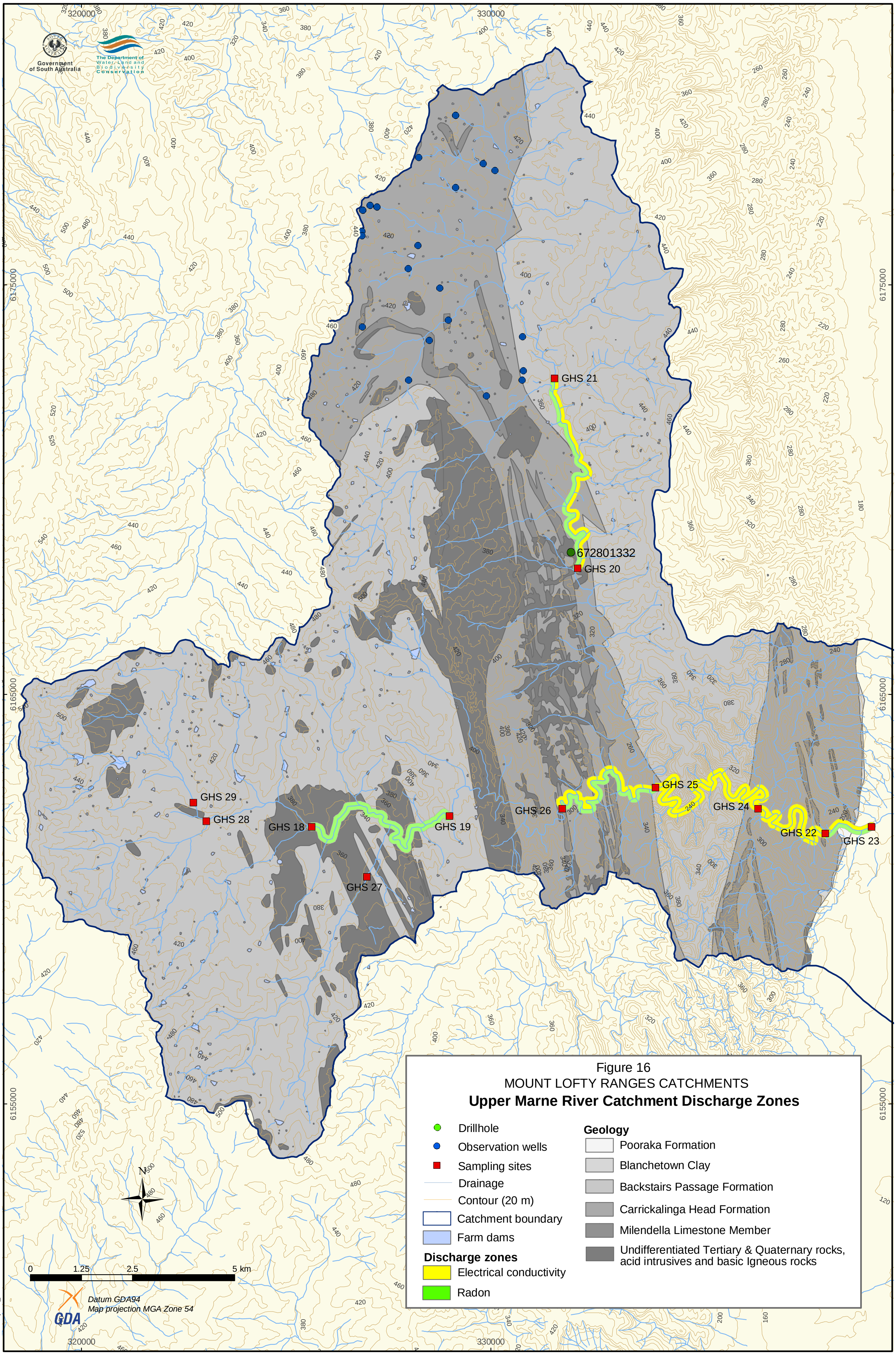


Figure 16
MOUNT LOFTY RANGES CATCHMENTS
Upper Marne River Catchment Discharge Zones

4.3 Tookayerta Creek Catchment

4.3.1 HISTORICAL DATA

A network of eight environmental flow gauging stations has provided indicative stream flow rates for various parts of the TCC over the last 5 to 10 years (Farrow, 1996, 1997, 1999, 2001). The recording devices at several of these stations have occasionally malfunctioned for up to 6 months at a time, thereby returning discontinuous data. The greatest loss of data however, has been since April 2002 when the consulting firm that was hired to download the loggers and supply data has failed to deliver the results, despite numerous verbal and written requests by staff at DWLBC and the River Murray Catchment Water Management Board.

Hence the daily stream flow data presented for station F8 at the bottom of the catchment (below the confluence of the Tookayerta and Nangkita Creeks; Fig. 17) is both discontinuous for the early years of record and absent for the duration of the current study. The four years of almost complete record (1997–2000) yield a mean annual flow of around 15,292 ML/yr. When averaged over the entire area of the catchment (103 km^2) this annual discharge equates to ~ 148 mm/yr, which is slightly higher than that in the Scott Creek Catchment (135–140 mm/yr) and an order of magnitude higher than that in the Marne River Catchment (17.5 mm/yr).

Given the slightly higher annual discharge and lower annual rainfall (845 mm/yr at Mt Compass) in this catchment compared with the Scott Creek Catchment, the groundwater component of annual flow in TCC should be equal to or greater than that estimated for the SCC (45–49% groundwater).

4.3.2 RUN-OF-RIVER SAMPLING

Eight different sites along the Tookayerta and Nangkita Creeks yielded 22 surface water samples for the 3 stage sampling program (Fig. 18). All sites had clear, fast flowing water during each of the sampling stages, except GHS8 which was only flowing at Stage 1.

4.3.2.1 Electrical Conductivity

EC increased downstream between every site in the catchment, indicating that groundwater is discharging along the entire reach of creeks under investigation (Fig. 19). A down-hole sonde of borehole 6627-0-9124 near site GHS 15/62/71 returned EC values of 300–400 μS/cm for a profile between the water table and 100 m depth (App. 1). These groundwater EC values correspond very favourably with the stream water EC in this part of the catchment. Therefore, groundwater from a range of depths (and hence flow paths) may be contributing discharge to the creeks (cf. SCC where it was proposed that only the freshest, shallow inter-flow water discharged into the creek).

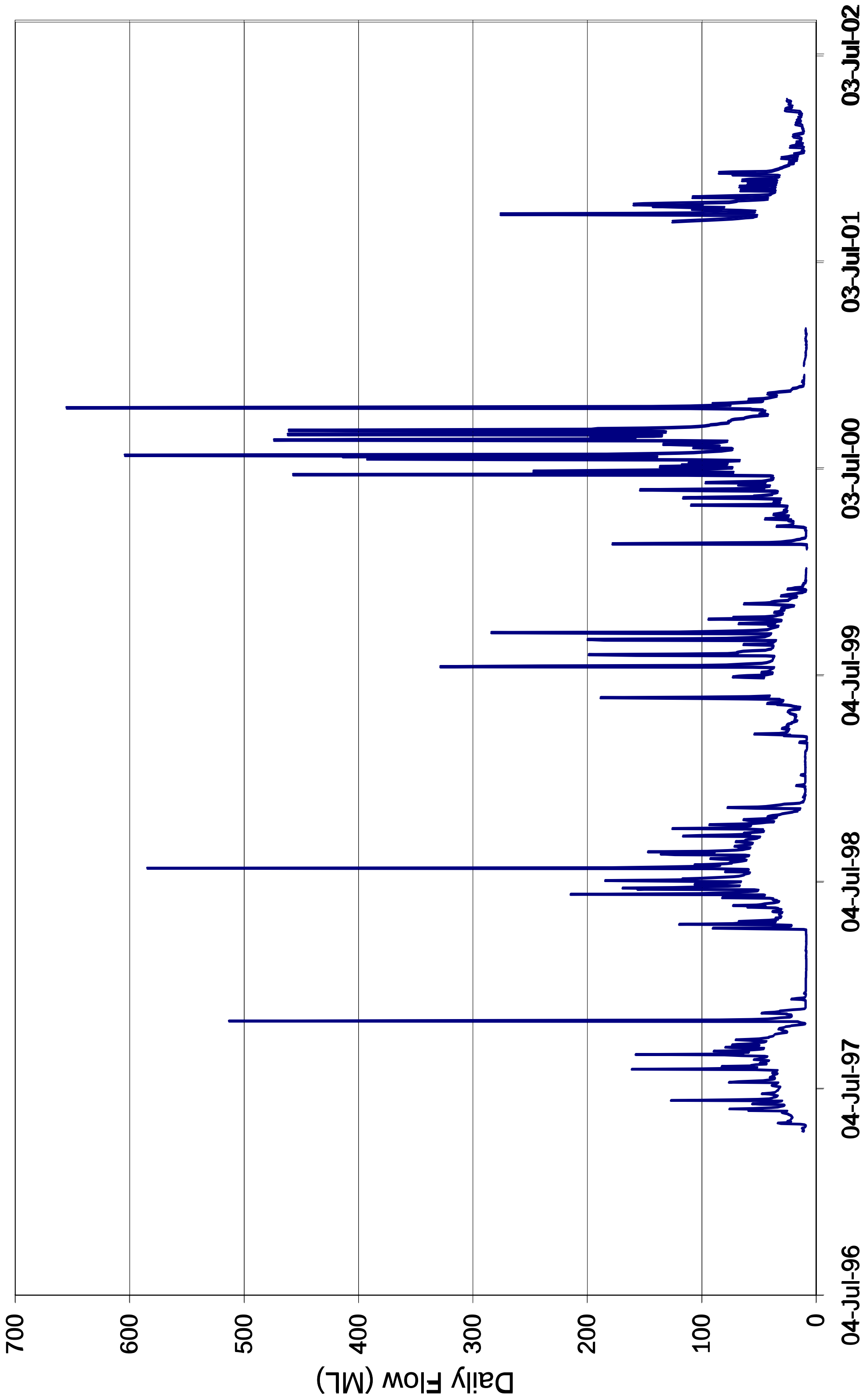


Figure 17. Daily flow record from recorder gauge F8 located near the discharge point for the Tookayerta Creek Catchment

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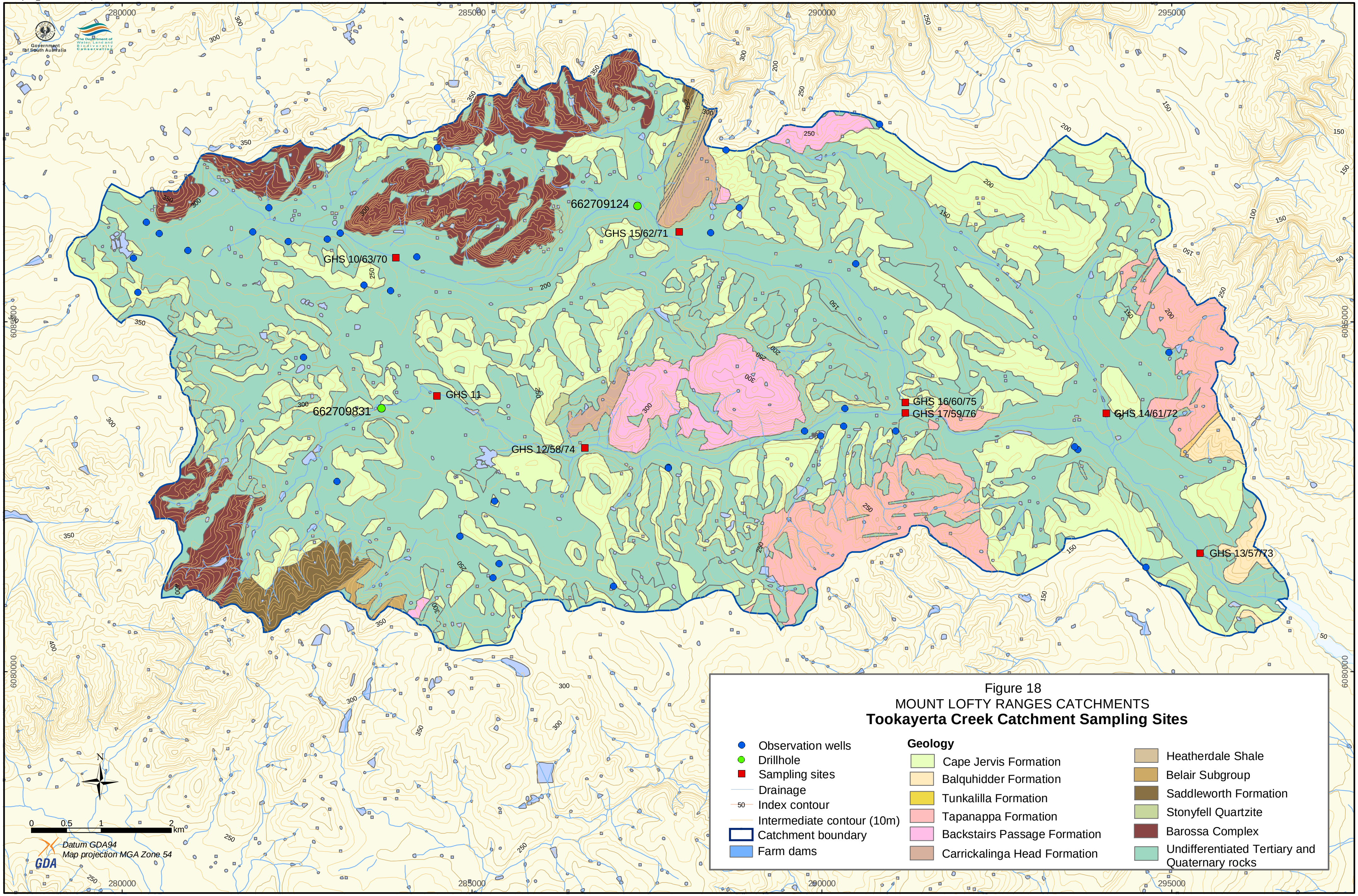
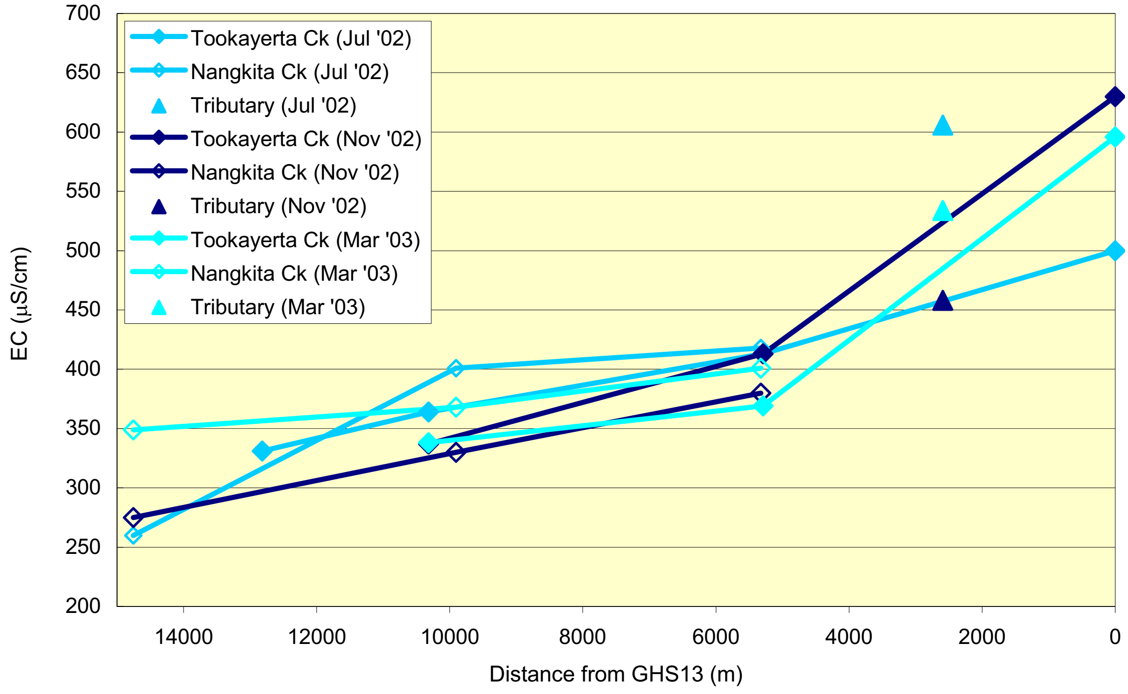
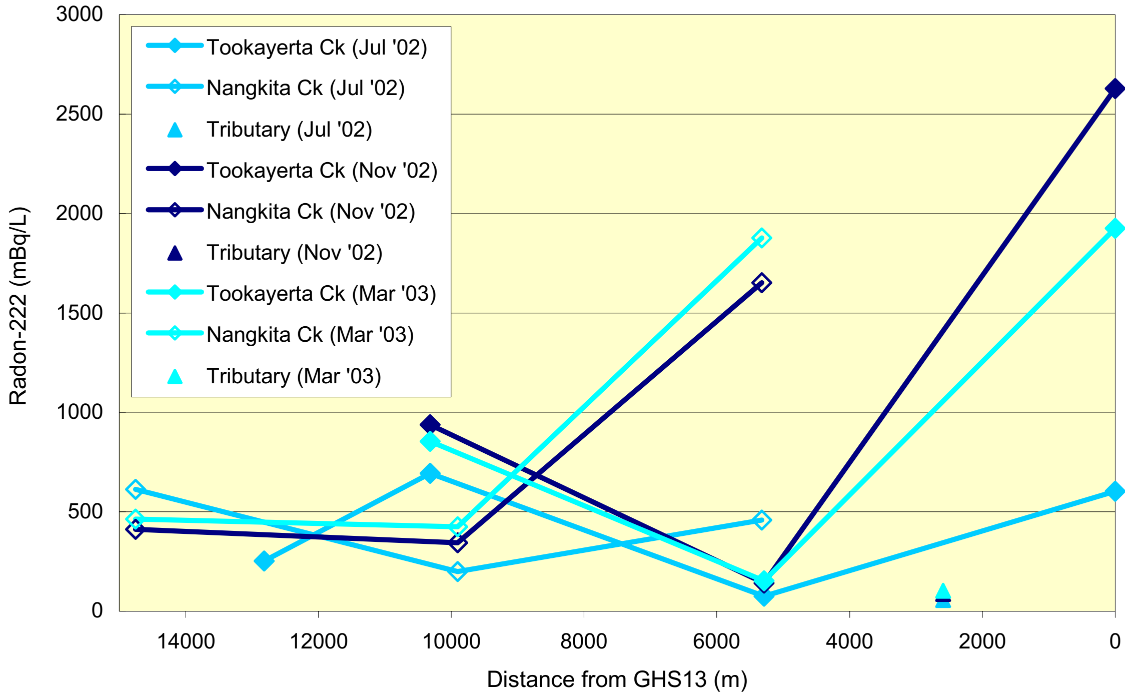


Figure 18
MOUNT LOFTY RANGES CATCHMENTS
Tookayerta Creek Catchment Sampling Sites



(a)



(b)

Figure 19. Tookayerta Creek Catchment run-of-river sampling results; (a) EC values, and (b) radon-222 concentrations. Groundwater discharge occurs in reaches where EC increases or decreases between sampling points, and/or where radon concentrations increase

Similar evidence for deeper groundwater discharging into the creeks of the TCC is provided in a groundwater sample from bore 6627-0-9831 that has a production zone from 18–42 m depth. The sample had an EC of 197 μS/cm which is lower than the EC measured in the stream in this area during winter 2002 (Fig. 19).

4.3.2.2 Radon

Stream water radon concentrations were far more variable than the EC values (Fig. 19(b)) and indicated significant groundwater inputs between the two uppermost stations on Tookayerta Creek during Stage 1, and between the two lowermost stations on both Tookayerta and Nangkita Creeks during all three stages. The locations of these zones are shown, together with those inferred from the EC data, in Figure 20. This map suggests that the most active areas of groundwater discharge are where the geology is dominated by glacial and fluvial deposits, rather than near the basement rock highs in the central-lower portion of the catchment.

4.3.2.3 Major Ion Compositions

Ionic compositions of the TCC samples are plotted on Piper diagrams for each sampling stage in Fig. 21(a–c). Samples from the Tookayerta Creek, Nangkita Creek and a tributary (GHS 14/61/72) plot close together but as distinct groups. The tributary sample has a cation composition which is similar to that of both the Tookayerta Creek and Nangkita Creek samples, but an anion composition that is more dominated by Cl compared with the other samples. The reason for this difference in anion composition, and the slight distinction between the Tookayerta and Nangkita Creek samples, is attributed to variations in the soil type and geology across the catchment as these characteristics ultimately control the degree of evaporation prior to recharge and the type of mineral dissolution reactions.

The samples appear to become more similar in ionic composition (i.e. plot in tighter clusters in Fig. 21) as the sampling proceeds from Stage 1 through to 3. This trend most likely reflects the increasing contribution of one particular source of water (i.e. groundwater) in the creeks from July through to March. The deep groundwater sample obtained from well 6627-0-9831 during stage 3 has a similar composition to surface water samples from Tookayerta Creek.

Major ion/Cl ratios did not show any significant variations nor consistent trends along the creeks (Fig. 22) because the extremely fresh groundwater in the catchment has not been subjected to the extensive mineral dissolution and/or precipitation reactions that are required to alter ion/Cl ratios.

4.3.3 MASS BALANCE CALCULATIONS

Chloride mass balance calculations were performed to estimate the mean annual recharge rate using Equation (1) and the following input parameters: mean annual rainfall, P is 845 mm/yr (Mt Compass); annual runoff, RO is assumed to be 10% of rainfall (i.e. 84.5 mm/yr); chloride concentration in rainfall, C_P is in the range 4 to 8 mg/L (Barnett and

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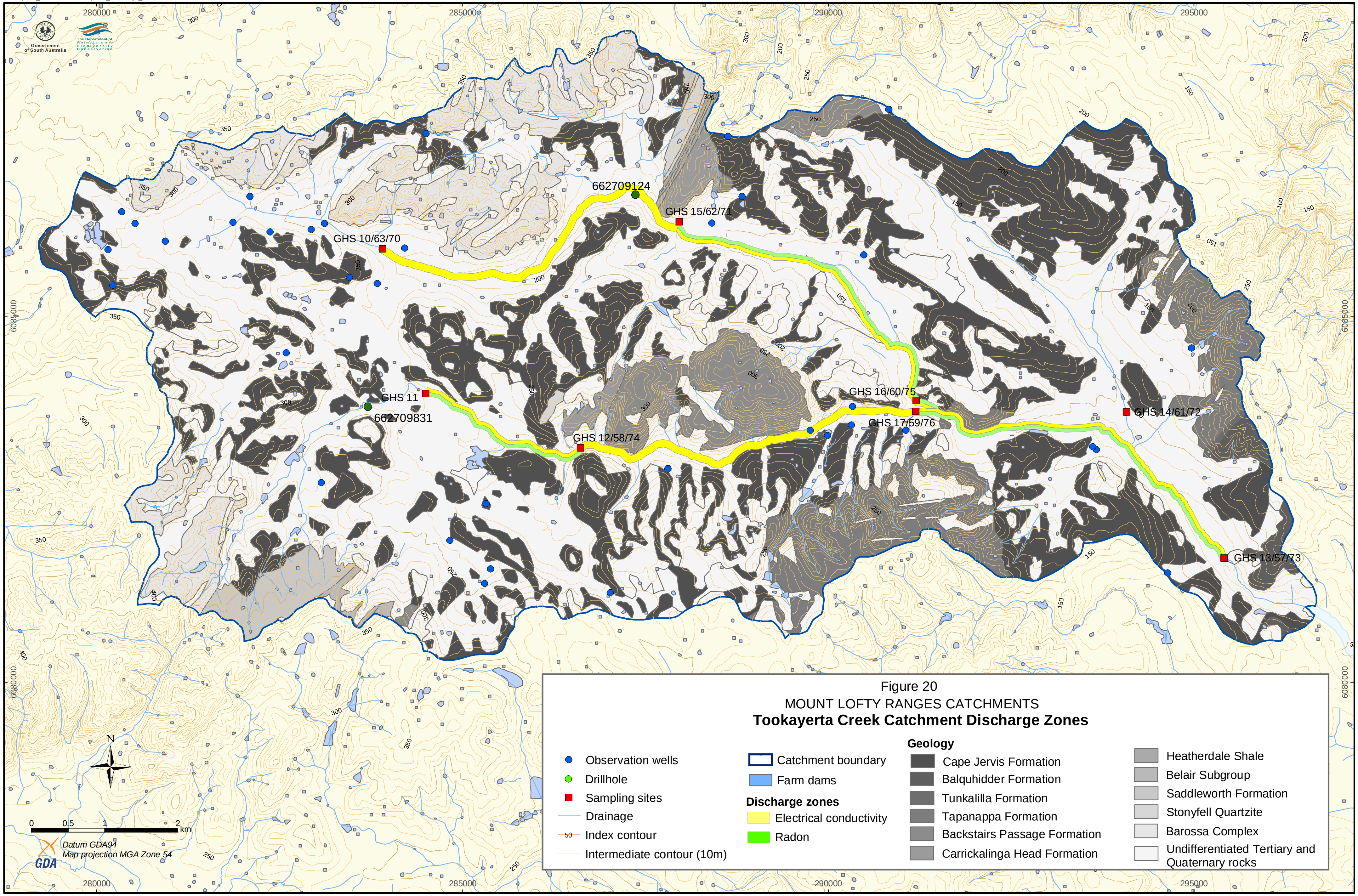

Figure 20
MOUNT LOFTY RANGES CATCHMENTS
Tookayerta Creek Catchment Discharge Zones

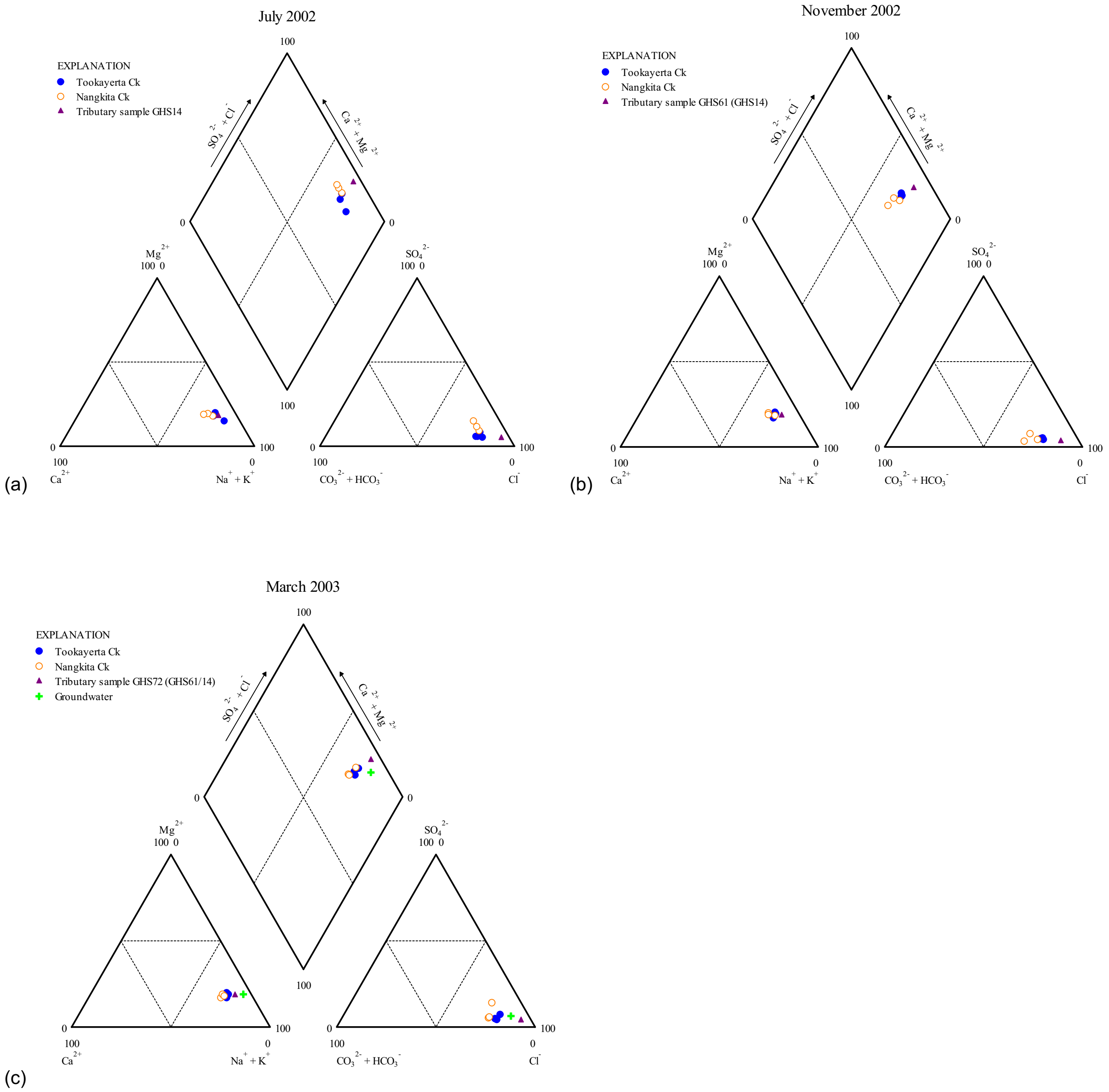

Figure 21. Piper diagrams showing surface water major ion compositions for each of the sampling stages 1 (a) through to 3 (c) in Tookayerta Creek Catchment. The composition of one groundwater sample is also provided in (c)

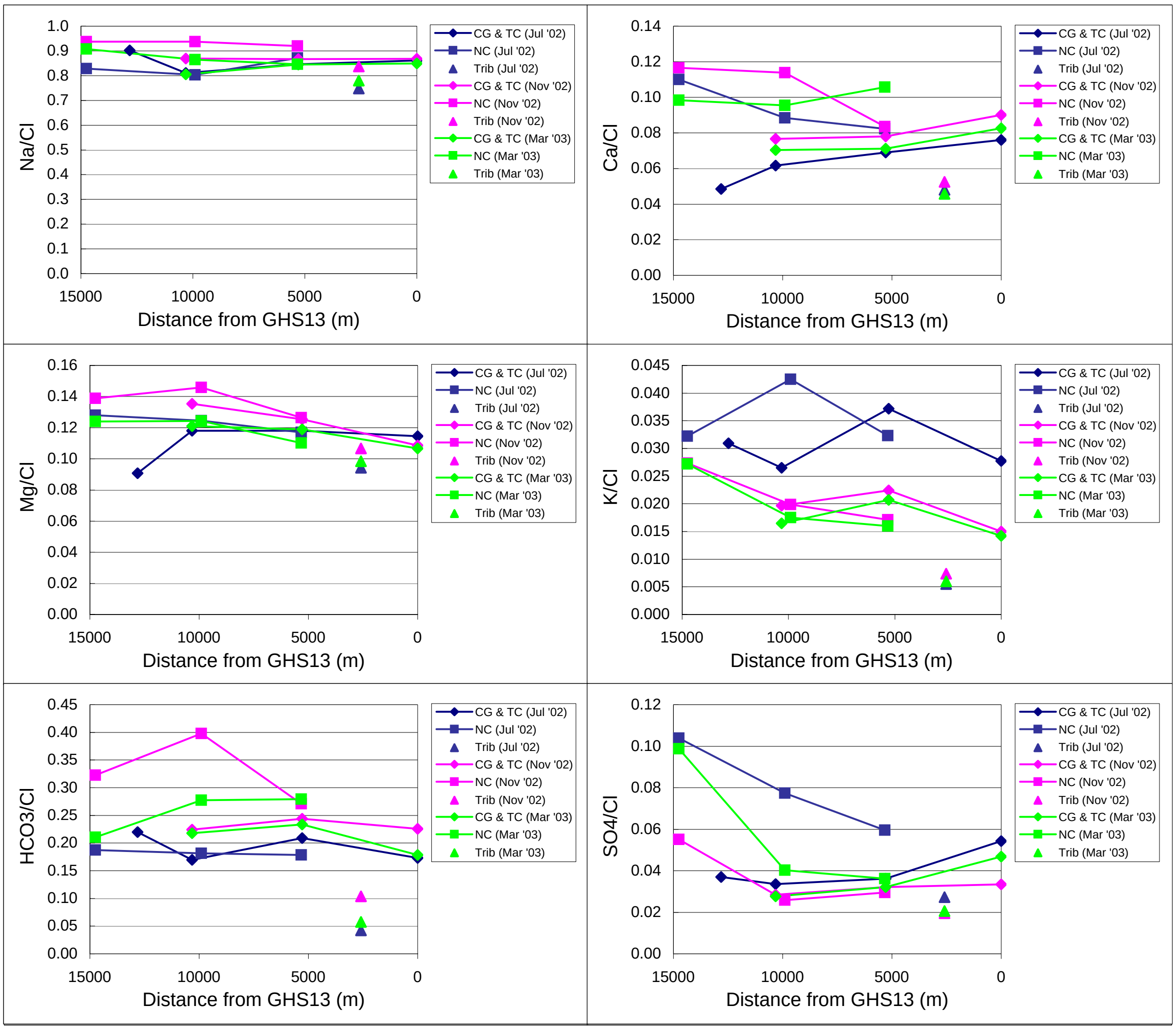

Figure 22. Surface water ion/Cl ratios obtained during each run-of-river sampling stage in the Tookayerta Creek Catchment. No consistent trends are evident in the data, except perhaps for SO_4/Cl

Zulfic, 1999 after Hutton, 1976 and Kayaalp, 1998); chloride concentration in recharge water (i.e. groundwater) ranges from 49 mg/L (well 6627-0-9831, Table 1) to 87 mg/L (Barnett and Zulfic, 1999). This approach provided a wide range of recharge rates from 35–124 mm/yr which inherently accounts for different locations and soil types within the catchment.

Stream salinity and/or chemical data have not been collected from any part of the TCC on a routine basis, although the local community group Compass Creek Care Inc. have initiated occasional sampling for these parameters by school students. Without the historical salinity information, it was not possible to calculate any groundwater-surface water mass balance for estimating annual groundwater contributions to the creeks in this catchment.

4.3.4 CONCEPTUAL MODEL

The Tookayerta Creek Catchment is characterised hydrologically by fresh, permanently flowing streams that are maintained in the drier months by unusually fresh (TDS < 500 mg/L) groundwater from Permian sand aquifers. The marginal and deeper fractured-rock aquifers are generally low yielding and higher salinity (Barnett and Zulfic, 1999). The combination of deep, sandy soils and high amounts of winter rainfall across the catchment means that evaporative loss of rainfall is minimal and recharge rates are high.

4.3.5 IMPLICATIONS FOR MANAGEMENT

Due to the extremely dynamic relationship between groundwater and surface flow in these creeks, no further development of the groundwater resource should be allowed within several hundred metres of the water courses. Groundwater use away from the creeks should also be managed in such a way that extractions do not meet or exceed the mean annual recharge flux in that part of the catchment. (DWLBC is currently undertaking a thorough investigation to estimate recharge fluxes in the Tookayerta Creek catchment and elsewhere in the Eastern Mount Lofty Ranges). These measures will ensure the long-term sustainability of the aquatic biodiversity that currently exists in the catchment.

4.3.6 RECOMMENDATIONS

Historical stream flow data has been collected by Thatch Environmental Consulting in recent years however, despite numerous requests, this data has not be made available to DWLBC staff. Further investigations of water resource issues in this catchment would significantly benefit from the flow data, as it will allow the calibration of surface water flow models and enable calculations of surface water – groundwater flow and salt mass balances.

5 SUMMARY AND CONCLUSIONS

Groundwater – surface water interactions are an important component of catchment-scale water and salt balances in the Mount Lofty Ranges (MLR) and therefore must be recognized and evaluated to ensure both the sustainable development of water resources and future maintenance of groundwater dependent ecosystems.

This report has presented the results of detailed investigations into groundwater-surface water interactions in three different catchments across the MLR, namely Scott Creek, Marne River and Tookayerta Creek. Scott Creek catchment is a small, fractured-rock sub-catchment for the much larger Onkaparinga River catchment, one of the main watersheds for metropolitan Adelaide. A review of historical rainfall, flow and salinity data combined with chemical and isotopic results of a three stage run-of-river sampling program has revealed the timing and location of the most important zones where groundwater discharge to the creeks is occurring. Whilst they have some limitations in fractured-rock aquifers, chloride and salt mass balances were used to estimate mean annual recharge rates in the range 69–83 mm/yr and mean areal groundwater discharge rates between 65–69 mm/yr. These discharge rates equate to between 45–49% of the annual surface flow out of the catchment. Over three quarters of the annual recharge is lost from the catchment, probably within several weeks to months of the recharge event, via groundwater discharge to creeks. Any significant development of the groundwater resources in the catchment (beyond current use) will therefore cause measurable reductions in groundwater contributions to the stream flow, thereby putting aquatic ecosystems at risk.

The upper Marne River catchment also has predominantly fractured-rock aquifers, but is approximately four times the area of Scott Creek catchment, has generally lower topographic relief (with the exception of Marne Gorge) and receives much lower annual rainfall. The run-of-river sampling program was only carried out for stage 1 because the creeks were all dry for the following two stages. Nevertheless, the chemical and isotopic results from stage 1 did provide insight as to where groundwater discharge was most active in the catchment at that time. Recharge to shallow groundwater from creeks may occur in the uppermost parts of the catchment following intense rainfall events in the summer, when water tables are at their lowest. A paucity of historical stream flow and salinity data prevented calculations of mean annual groundwater contributions to the streams. However, groundwater recharge rates (3–10.5 mm/yr) were estimated to be much lower than the median annual surface water discharge out of the catchment (17.6 mm/yr).

The Tookayerta Creek catchment is unique, both in the current study and in a State-wide context. The permanently flowing streams and extensive groundwater resources of the Permian sand aquifers are very good quality resources. Again, historical stream flow and salinity data for this catchment is limited. Estimates of groundwater recharge rates were high (35–124 mm/yr) but discharge to creeks was shown to occur throughout the catchment, especially in areas away from the basement highs in the central-lower region. Careful management of these interactions will be essential if the thriving aquatic species currently residing in the creeks are to be maintained.

ACKNOWLEDGEMENTS

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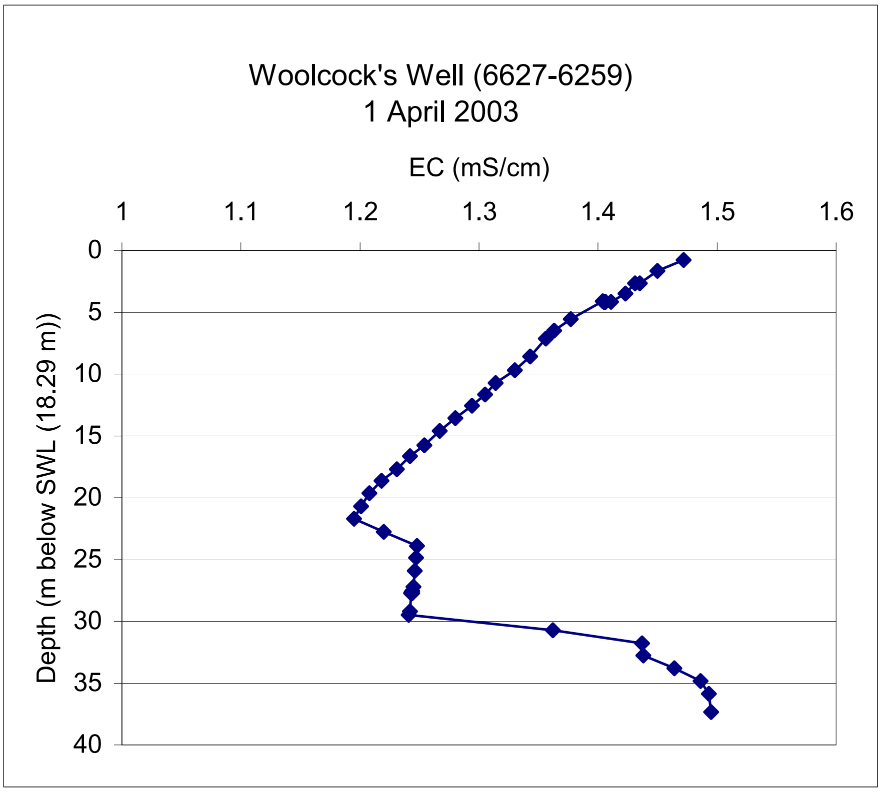
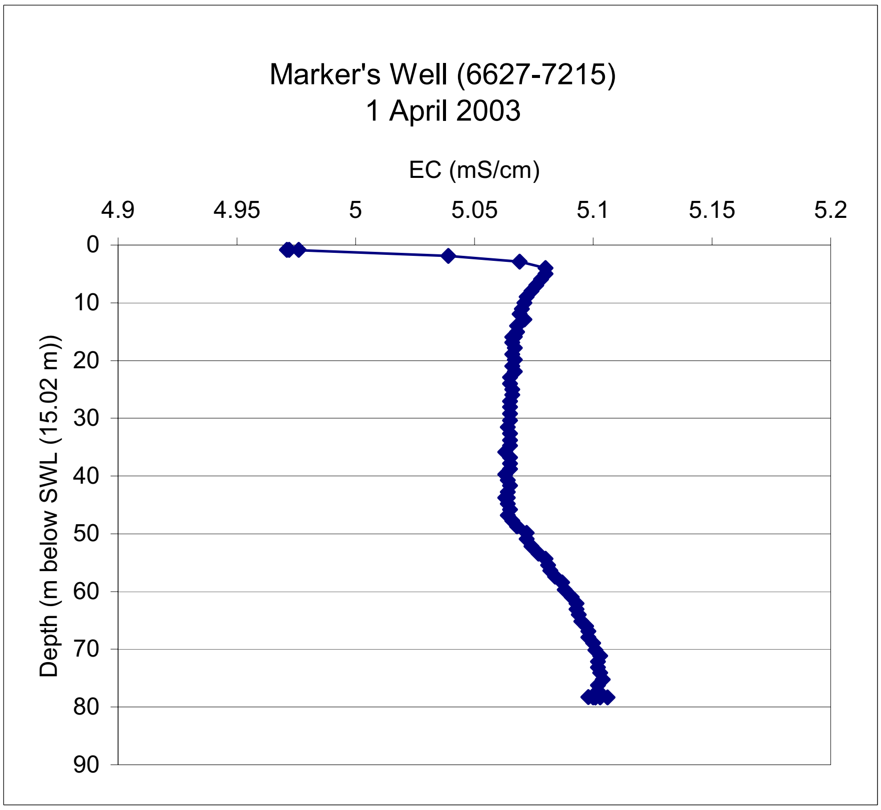
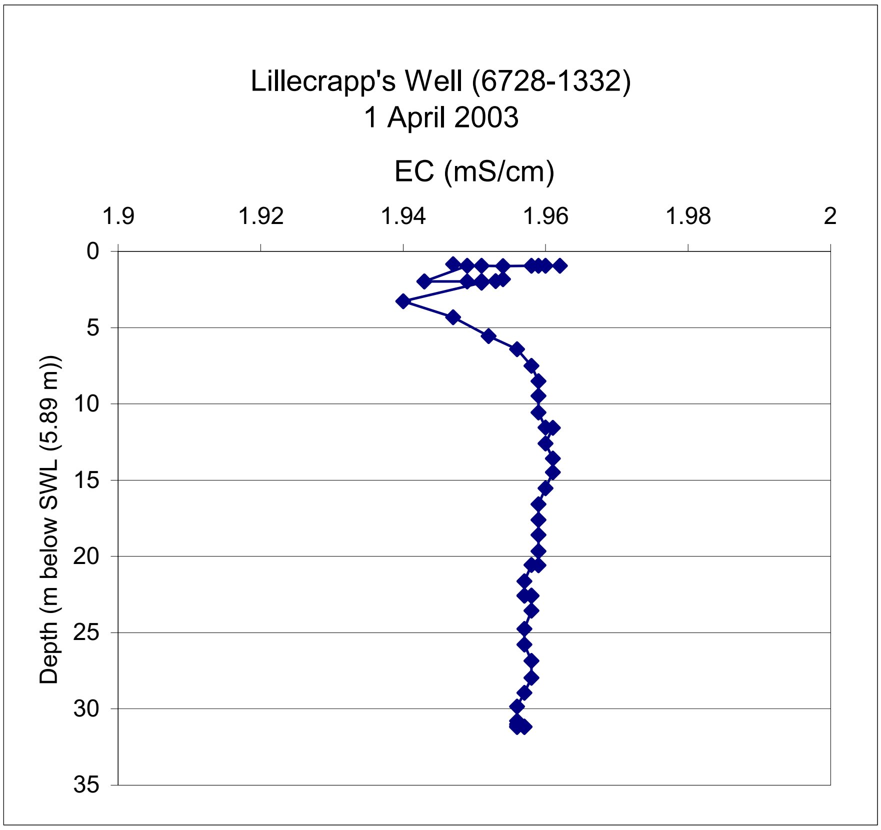
APPENDIX 1

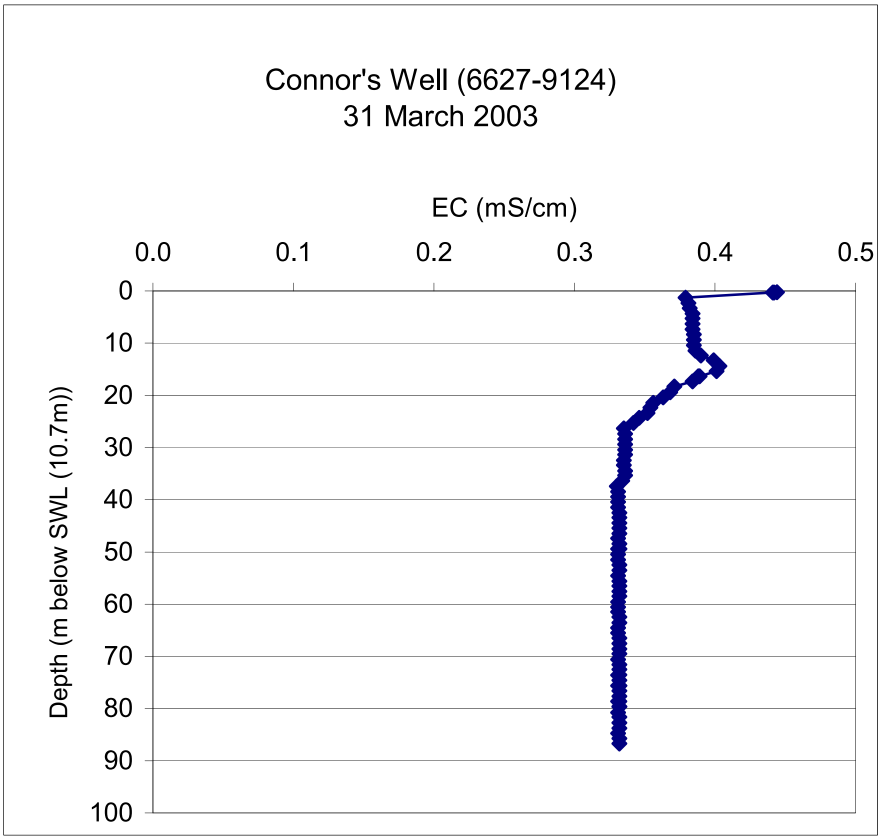


ELECTRICAL CONDUCTIVITY PROFILES FOR WELLS IN SCOTT CREEK, MARNE RIVER AND TOOKAYERTA CREEK CATCHMENTS


Woolcock's Well (6627-6259)
1 April 2003
EC (mS/cm)
1
1.1
1.2
1.3
1.4
1.5
1.6
Depth (m below SWL (18.29 m))
0
5
10
15
20
25
30
35
40


Marker's Well (6627-7215)
1 April 2003
EC (mS/cm)
4.9
4.95
5
5.05
5.1
5.15
5.2
Depth (m below SWL (15.02 m))
0
10
20
30
40
50
60
70
80
90


Lillecrapp's Well (6728-1332)
1 April 2003
EC (mS/cm)
1.9
1.92
1.94
1.96
1.98
2
Depth (m below SWL (5.89 m))
0
5
10
15
20
25
30
35


Connor's Well (6627-9124)
31 March 2003
EC (mS/cm)
0.0
0.1
0.2
0.3
0.4
0.5
Depth (m below SWL (10.7m))
0
10
20
30
40
50
60
70
80
90
100