DWLBC REPORT

Hydrogeochemistry of surface waters and groundwaters, Kangaroo Island

2007/18

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

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FOREWORD

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

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

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

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

ACKNOWLEDGEMENTS

We are grateful to Rivers of Life Project, Kangaroo Island Natural Resource Management Board and the Catchment Management Subsidy Scheme for part funding this project and to the Land Owners for allowing access to borehole and river sites. We would also like to thank the staff of the Flinders Chase National Park for their interest in this work.

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EXECUTIVE SUMMARY

The surface waters of Kangaroo Island display an extremely wide range of salinities (specific electrical conductance varied from 221–63 500 mS cm^{-1}), in general being less saline in the western part of the island. The surface waters display large variations in chemistry, both spatially and with time reflecting the complex sources, pathways and residence time of the waters within individual catchments. Evaporation of river waters is important during the summer months, giving rise to more saline waters at this time. However, the salinity increase is considered too high to be caused by evaporation alone and variable groundwater inputs are likely to be responsible. A number of sample sites were dry during late summer. This was the case for the middle part of the Cygnet River, however flow continued in the upper and lower reaches, indicating distinct areas of gaining and losing reaches.

Natural tracers were measured in river waters and provided evidence that groundwater discharge does form an important control of river flow. The Platypus Pools in Rocky River may, for example, be sustained by groundwater discharge. Only limited groundwater sampling was possible due to the lack of accessible bores, hence the groundwater systems cannot be fully characterised. Nevertheless, the data show that large variations in the salinity of groundwaters also exist in fractured aquifers on the island. Some of the fresh groundwaters are shown to be derived from adjacent dams, highlighting the possibility of conjunctive water management options such as artificial recharge and recovery. Further work is recommended to characterise the hydrogeology of Kangaroo Island.

A comparison of river waters across the island suggests there is a link between land clearance and the flow paths of water through the soil and regolith. Preliminary data in the Rocky River show there are large stores of salt present at a shallow depth. Despite this, the river water is remarkably fresh and, in places, continues to flow throughout the year. It is suggested that flow via macropores, effectively by-passing the salt store and lateral flow in deeper regolith or bedrock, is an important pathway for flow to the river. However, further more focussed research is necessary to establish precise mechanisms of stream flow generation, the importance of surface water – groundwater interactions and impacts on surface ecosystems.

1. INTRODUCTION

This report presents a summary of work completed for the Kangaroo Island Surface Water Groundwater Interaction study, completed between November 2004 and September 2005. The project represents a co-funded project between the Department of Water, Land and Biodiversity Conservation (DWLBC) and the Kangaroo Island Natural Resources Management Board (KI NRM BOARD).

Kangaroo Island is ~140 km long, 55 km wide and ~16 km from Cape Jervis, on the Fleurieu Peninsula of South Australia; separated from the mainland by the Backstairs Passage. It has a Mediterranean type climate, with hot dry summers and mild winters.

Large areas in the west and south of Kangaroo Island still retain native vegetation (Fig. 1.1). However, much of the Island has been cleared of native vegetation since the 1940s (Fig. 1.2), which is likely to have had a significant effect on groundwater recharge. These regions, dominantly in Wilderness Protection Areas and Conservation Parks, provide a baseline with which to assess changes imposed by land-use modification and practices. Several catchments on the island have been impacted by dryland salinity (Henschke et al., 2003), related to land clearance practices in the past. However, evidence of naturally saline lagoons and creeks exists (T Nilsen, pers. comm.). The presence of significantly large areas of pristine vegetation, as well as cleared areas, makes Kangaroo Island ideal to study the baseline water quality and the effects of vegetation clearance. Such comparisons in similar geological terrains (e.g. Mt Lofty Ranges on the mainland) are often difficult, due to the lack of large areas unaffected by land-use change.

Figure 1.1 Native vegetation in the Rocky River area

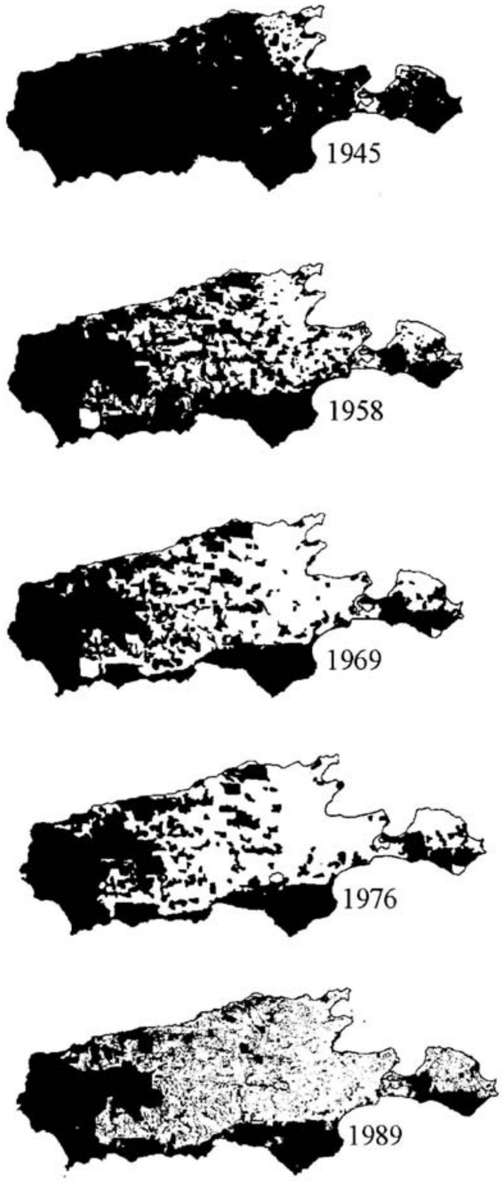

Figure 1.2 Map showing the clearance of native vegetation from 1945–89 on Kangaroo Island (from Harris, 1976; Robinson and Armstrong, 1999)

1.1 PROJECT AIMS AND OUTCOMES

The aim of this study was to assess the quality of surface waters and groundwaters in selected catchments, with an emphasis on the relationships between groundwater and surface water. The report presents recently acquired hydrochemical analyses of samples from several catchments sampled during the study.

The outcomes of this study will contribute to an understanding of the mechanisms of catchment scale processes, in particular the linkages between groundwater and surface water. This will enable more informed decisions to be made regarding allocation of water resources and will contribute to the knowledge base for future management options. This study will also identify areas of limited knowledge and suggest areas for further study.

2. GEOLOGY OF KANGAROO ISLAND

Kangaroo Island has had a long and complex geological history, with the oldest rocks being of NeoProterozoic age. The geology has been described by James and Clark (2002) and the island has been recently remapped (Fairclough, 2002). The area, along with the Fleurieu Peninsula and eastern Mt Lofty Ranges on the mainland, forms an extension of the Adelaide Geosyncline and Delamerian fold belt (Mancktelow, 1990; Flottmann et al., 1995). Kangaroo Island has been described as a dissected high plain or plateau which has been incised by rivers on its northern and southern flanks (Twidale and Bourne, 2002).

The basement geology of the island is dominated by immature clastic metamorphosed sediments of Cambrian (495–545 Ma.) age, belonging to the Cambrian Kanmantoo and Stansbury Basins. The oldest rocks on the island are found on the Dudley Peninsula, around Cuttlefish Bay belonging to the underlying Adelaidean succession of Proterozoic age.

The Cambrian rocks form two distinctive lithological and metamorphic groups, comprising the Kangaroo Island Group in the north and the Kanmantoo Group in the central and southern parts of the Island (Belpeiro and Flint, 1993). These broadly coeval sequences are separated by the Cygnet and Snelling Faults, a complex tectonised shear zone up to 7.5 km wide. The stratigraphy of the Kangaroo Island and Kanmantoo Groups is shown on Figure 2.1.

The geology can thus be considered to form three distinct geological domains (James and Clark, 2002):

1. In the southern-central part of the island, moderately metamorphosed Cambrian Kanmantoo Group comprises simply deformed strata, with NE–SW trending folds and thrusts. These comprise a thick sequence of deep water siliclastic sediments which are highly deformed and regionally metamorphosed to upper greenschist and amphibolite metamorphic facies.

2. The Kangaroo Island Shear Zone, which forms a broad E–W trending sheared and folded zone between Snelling Beach and Point Morrison. Along the shear zone, Kanmantoo sediments have been metamorphosed, compressed and displaced towards the northwest. Lithologies include mylonites and phylolonites.

3. A northern thrust belt of Cambrian rocks, ~15 km wide, known as the Kangaroo Island Group, which is absent on the mainland Fleurieu Peninsula. These comprise weakly metamorphosed (up to chlorite and biotite metamorphic grade) and deformed peritidal to shallow shelf clastic and carbonate rocks (Belpeiro and Flint, 1993).

The lithologies of the Kangaroo Island Group are variable, including deltaic coarse- to fine-grained clastic rocks, mudstones, shales and minor carbonates. The Kanmantoo Group, in the central and southern parts of the island, are composed almost exclusively of uniform grey, impure, massively-bedded metasandstones and metapelites. However, thin calcareous units (Talisker Calc-Siltstone) and conglomerates also occur. The Kanmantoo Formation occurs over most of the southern and western parts of Kangaroo Island, occurring as medium- to fine-grained grey feldspathic sandstones with thin biotite laminations (James and Clark, 2002). Thick bedding and tabular cross beds are typical of this formation, which is characterised by an orange weathering crust (Fig. 2.2).

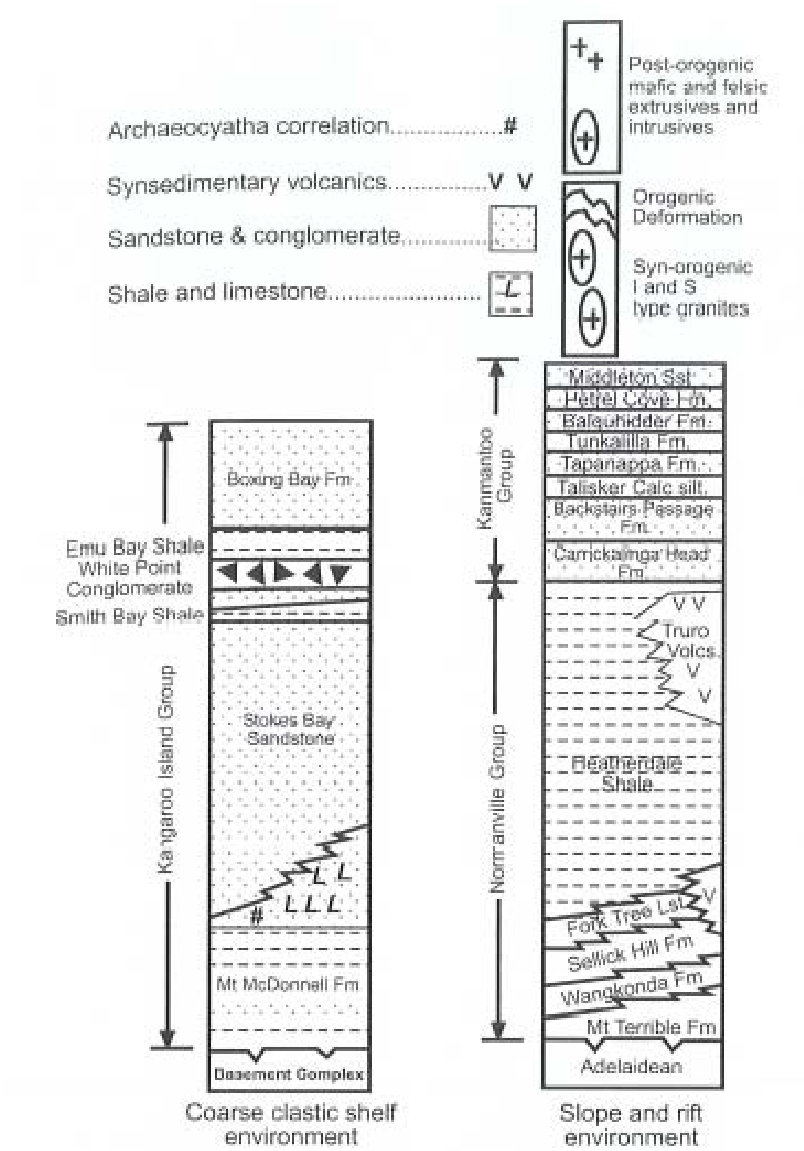

Figure 2.1 **Stratigraphic columns and correlations of the Kangaroo Island Group and Kanmantoo Group sediments from the north coast of Kangaroo Island (from James and Clark, 2002 after Belperio et al. 1998)**

Towards the end of the Cambrian, sedimentation in the Adelaide Geosyncline was terminated by a succession of major tectonic events termed the Delamerian Orogeny (Drexel and Preiss, 1995). Syntectonic granites are present over much of southern Kangaroo Island and are of Late Cambrian to Ordovician age.

The northern zone consists of a series of folds and thrusts with deformation intensity decreasing northwards. The general direction of thrusting is northwest. The structure of the southern zone appears dominated by 10’s m- to km-scale ENE–WSW trending folds separated by thrust faults. The Kangaroo Island Shear Zone, comprising up to 2 km of deformed tectonites is considered to represent an ancient plate margin separating a northern platform from a southern basinal part of the island.

Figure 2.2 Tabular cross bedding (top left), massive cross bedding (top right) and convolute bedding (bottom left) in sandstones, Rocky River

Permian glaciation is evidenced by glacially striated boulders (e.g. at Christmas Cove, Penneshaw) and glaciogenic sediments of the Cape Jervis Formation. These rocks crop out in the north-east of the island but are partly covered by younger Jurassic and Tertiary rocks. Following deposition of the Permian sediments, prolonged weathering and erosion produced a ferruginised capping that forms the main feature of the main plateau of Kangaroo Island (Daily et al., 1974). The lateritic plateau comprises a sandy A-horizon overlying a ferruginous zone up to 2 m thick. The ferruginous zone comprises irregular pisolites of hydrated iron oxide, cemented with goethite sand and silt (Daily et al., 1975; Twidale and Bourne, 2002, see Fig. 2.3). This is underlain by a kaolinised zone, a few tens of metres thick (Fig. 2.3).

Volcanic rocks of Jurassic age outcrop in the Wisanger Hills, east of Kingscote. The development Tertiary rocks are represented by the Kingscote Limestone (of Eocene age) and fluviatile calcareous sediments near Kingscote and in the Cygnet River catchment. On the southern part of the island, calcareous sandstone and sandy limestone occur at several localities, correlating with the basal Loxton Sand. During the Late Tertiary (Pliocene), a widespread transgression occurred, producing calcareous sandstones and limestones e.g. Hallet Bay Sandstone. Limestones occur as high as 120 m above present sea-level at Kelly Hill. Unconsolidated and consolidated Quaternary sediments form a veneer over much of the solid geology, particularly in the south and along the western and eastern coastlines.

Figure 2.3 Soil above pisolitic ironstone and kaolinised bedrock on the Kangaroo Island plateau (left) and a sample of pisolitic ferruginous zone beneath the soil (right), Shackle Road, Rocky River catchment

During the Quaternary, sea-level varied due to glacial and inter-glacial periods, and Kangaroo Island was intermittently connected to the mainland. Raised beaches at 3–5 m and 6–8 m above present are indicative of higher relative sea-levels. During lower sea-levels, sands were blown onshore and formed large fields of beach and backshore sediments. Many of these became cemented by percolating calcium-rich waters and are termed calcarenite (Fig. 2.4).

The spread of calcarenite dunes affected the previous drainage from the plateau and led to the development of shallow lakes or lagoons (Twidale and Bourne, 2002).

Figure 2.4 Calcarenite deposits overlying dipping Kanmantoo Group sediments, Rocky River catchment (left) and Stokes Bay Sandstone (right), Stokes Bay

3. FIELD SAMPLING AND ANALYTICAL METHODS

3.1 SAMPLING CAMPAIGNS

Several field campaigns were undertaken to sample waters from different catchments, covering a range of land-use types and vegetation types. Four catchments were sampled initially during late October and early November 2004: the Cygnet River, Rocky River, Timber Creek and Willson River catchments.

Following the first sampling trip, it was decided to focus on the Cygnet and Rocky River catchments. The Rocky River catchment represents a relatively pristine catchment, totally enclosed within the Ravine des Casoars Wilderness Protection Area and Flinders Chase National Park. In contrast, the Cygnet River catchment has been largely impacted by anthropogenic activities and the area largely cleared of native vegetation.

The second phase of sampling on Kangaroo Island took place from 27–31 January 2005. The work involved the sampling of both rivers and groundwaters (Fig. 3.1).

A third sampling campaign was undertaken during April 2005 to sample for Radon (Rn) and specific electrical conductance (SEC: a measure of salinity). This was followed by a major campaign (fourth campaign) in June 2005, where river samples were collected from the Cygnet River and Rocky River catchments. During the January 2005 and June 2005 field campaigns, a number of the rivers were not flowing and sampling was therefore not possible. Heavy rain occurred during sampling in June 2005 (Fig. 3.2) and a number of rivers began to flow (Fig. 3.3). A reconnaissance of rivers sampled during the initial period showed significant changes in SEC and, where possible, these were re-sampled following the rainfall. A final rapid sampling for Rn in the Rocky River catchment took place in late June, in an attempt to assess groundwater inputs to the rivers once the catchments had ‘wetted up’.

Flow in the upper part of the Cygnet started about three days earlier than further downstream, with the initial rainfall not producing flow at Koala Lodge (Fig. 3.2). Peak stormflow was lagged in comparison with peak rainfall, more so at the downstream site. Flow in the Rocky River did not begin until several days later than the Cygnet.

3.2 SAMPLING TECHNIQUES

The parameters temperature (T °C), SEC, pH, dissolved oxygen (DO), redox potential (Eh) and alkalinity (by titration, Fig. 3.4) were measured on-site. Grab samples were collected from rivers and streams only where flow was visible. A number of borehole sites in the Cygnet catchment were visited prior to sampling (TW). Most were either not found, or the sites had been flooded, with the outflow being used in the construction of farm dams. A total of five boreholes (Fig. 3.5) were sampled from across the catchment (Fig. 3.1) and several were found unsuitable for sampling due to low water levels. The parameters pH and DO were measured, where possible, in a flow-through cell. The boreholes were initially purged of two well bore volumes prior to sampling.

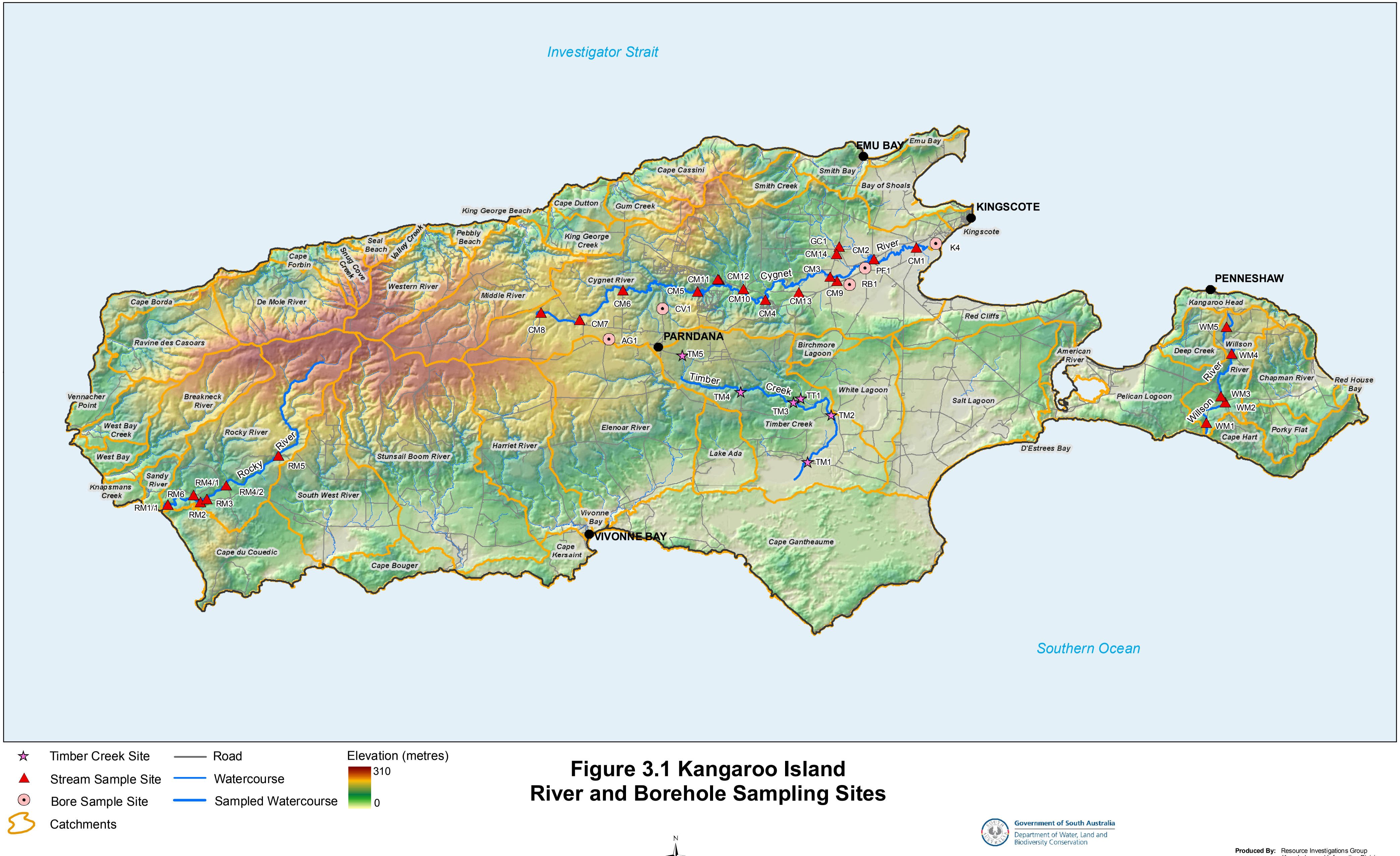

Figure 3.1 Kangaroo Island River and Borehole Sampling Sites

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Datum: Geocentric Datum of Australia 1994
Date: 23 August 2007

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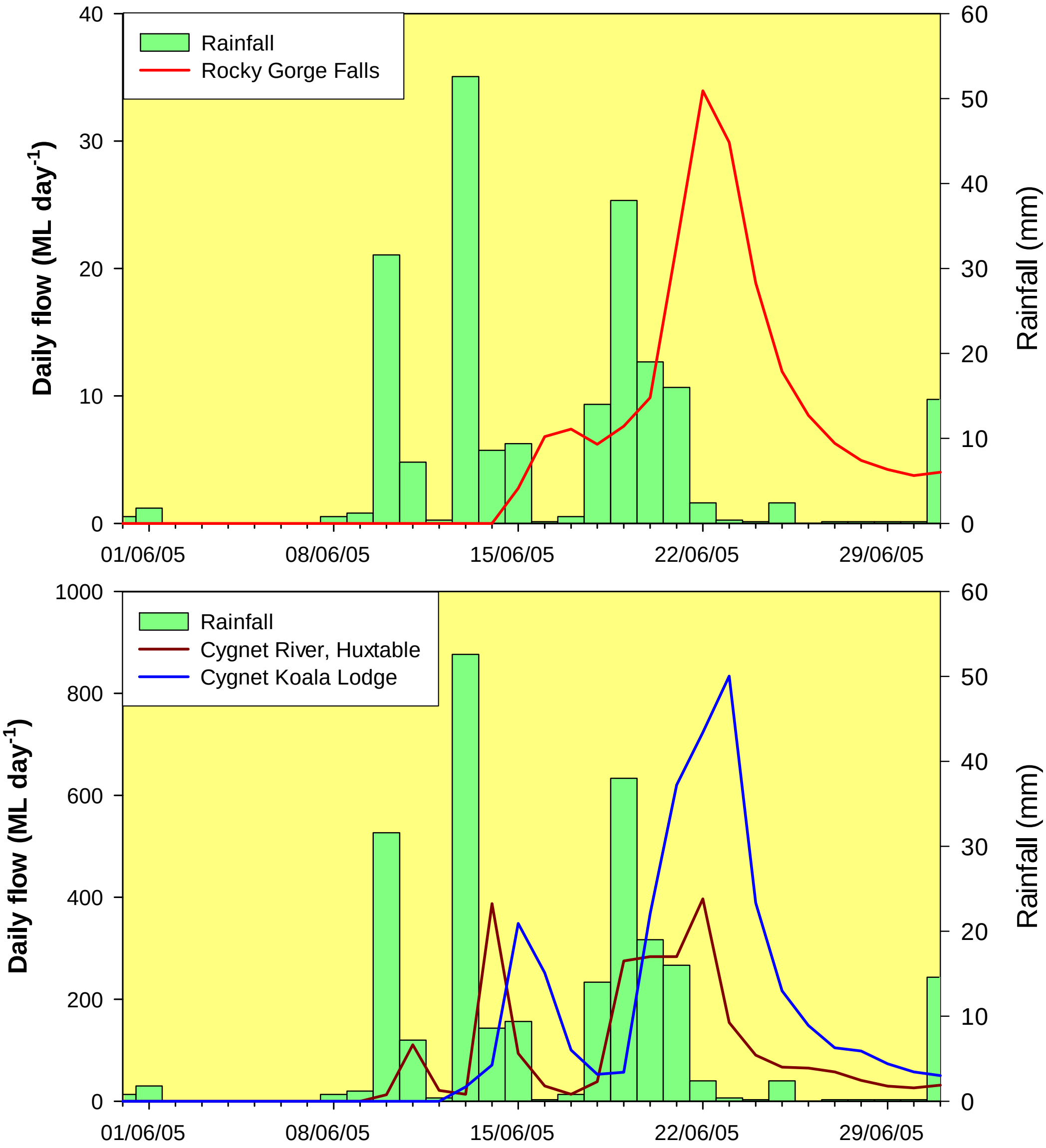

Figure 3.2 **Rainfall and stream flow in the Rocky River and Cygnet catchments during June 2005. Rainfall data from the Rocky River catchment at Shackle Road**

Figure 3.3 **Gum Creek. Left: dry riverbed on 10 June 2005 and right: flowing on 16 June 2005 after heavy rainfall**

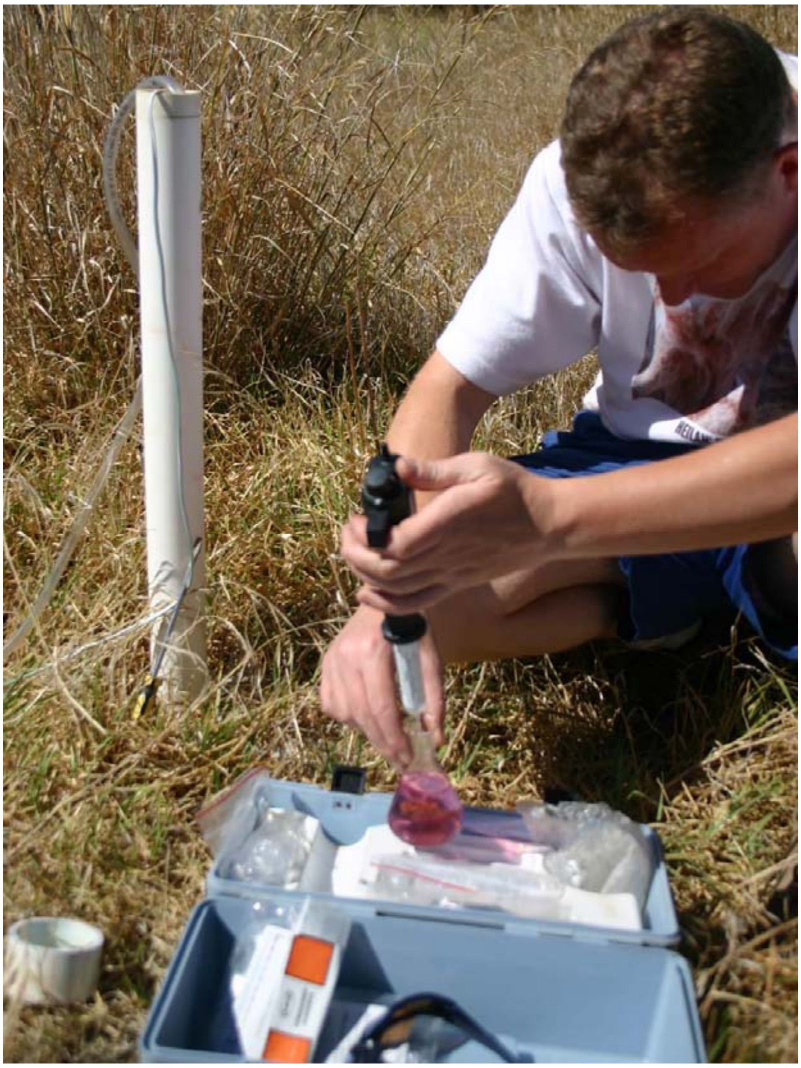

Figure 3.4 Measuring alkalinity in the field by acid titration

Figure 3.5 Sampling a borehole (PF1) in the Cygnet catchment

Samples were collected for major and trace chemical analysis in polyethylene bottles. Those for major and trace elements were filtered through 0.45 µm filters and the aliquot for cation and trace elements was acidified with HNO_3, to minimise adsorption onto container walls. Major cations and sulphate were analysed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP AES) and a wide range of trace elements by Inductively Coupled Plasma Mass Spectrometry (ICP MS). Nitrate was determined by reduction to nitrite using sulphanilamide/NEDD; method 4500-NO_3-F in Std Methods. Samples were also collected in glass bottles for stable isotopes (δ^2H, $\delta^{18}O$). Analyses were completed by mass spectrometry and the results reported relative to VSMOW. Rn samples were collected in 1.25 litre plastic bottles, to which a scintillant (mineral oil) was added to extract the dissolved Rn gas. Samples were shaken for four minutes and then left to settle for two minutes. The supernatant (mineral oil) containing the Rn was then decanted into vials, using a glass nozzle (Fig. 3.6), and sent to the laboratory as soon as possible after sampling (the half life of ^{222}Rn is 3.8 days) for counting and was analysed using a LKB Wallac 1220 quantalus liquid scintillation counter. Strontium isotope samples were collected during the January and June sampling campaigns. The samples were filtered through 0.45 µm membrane filters and left unacidified to minimise contamination.

Rn was collected at the start and end of pumping in boreholes PF1, AG1 and CV1 to estimate groundwater flow velocity. Samples were collected in a syringe which pierced the sample tubing to avoid contact with the atmosphere. In addition, a YSI 600XL multi parameter water quality sonde was lowered to the base of each borehole measuring pH, T, SEC and depth (pressure transducer) prior to, and following pumping.

One ‘spring’ was sampled in the south west of the catchment, relatively close to borehole CV1 (Fig. 3.7). Although classified as a spring, the local farmer thought that it was originally a borehole, consistent with DWLBC records, which show a 21.48 m deep borehole at the site (SWL 0.61 m). The site was sampled on 7 February 2005 after the main sampling, for major and trace elements and isotopes. It is possible that the borehole was discarded and bacterial growth and precipitation of ferric hydroxides have caused the mound shape to develop above the borehole which is artesian. This would be consistent with the low discharge and wet, spongy mound at the surface.

Figure 3.6 Decanting scintillant containing dissolved Rn from sample

Figure 3.7 Sampling from the spring mound

4. HYDROCHEMICAL RESULTS

This section presents the hydrochemical data from the sampling campaigns. The data from the preliminary regional study (Cygnet River, Rocky River, Willson River, Timber Creek) is presented in section 4.1 to highlight the spatial variations across the island. Temporal variations for the Cygnet and Rocky Rivers, which were sampled during the four sampling campaigns, are presented in section 4.2, isotope variations in section 4.3, and groundwater data in section 4.4.

4.1 PHASE 1 RIVER DATA (CYGNET, ROCKY AND WILLSON RIVERS, TIMBER CREEK)

Phase 1 sampling, during late September/early October, where most of the rivers on the island were flowing. The stream waters from all catchments are shown on a PIPER plot in Figure 4.1, which shows the relative proportions of major cations and anions in the water samples. The streams are dominated by Na and Cl and of Na-Cl type, although there is a tendency for higher relative concentrations of Ca+Mg in the Willson and Timber Creek samples.

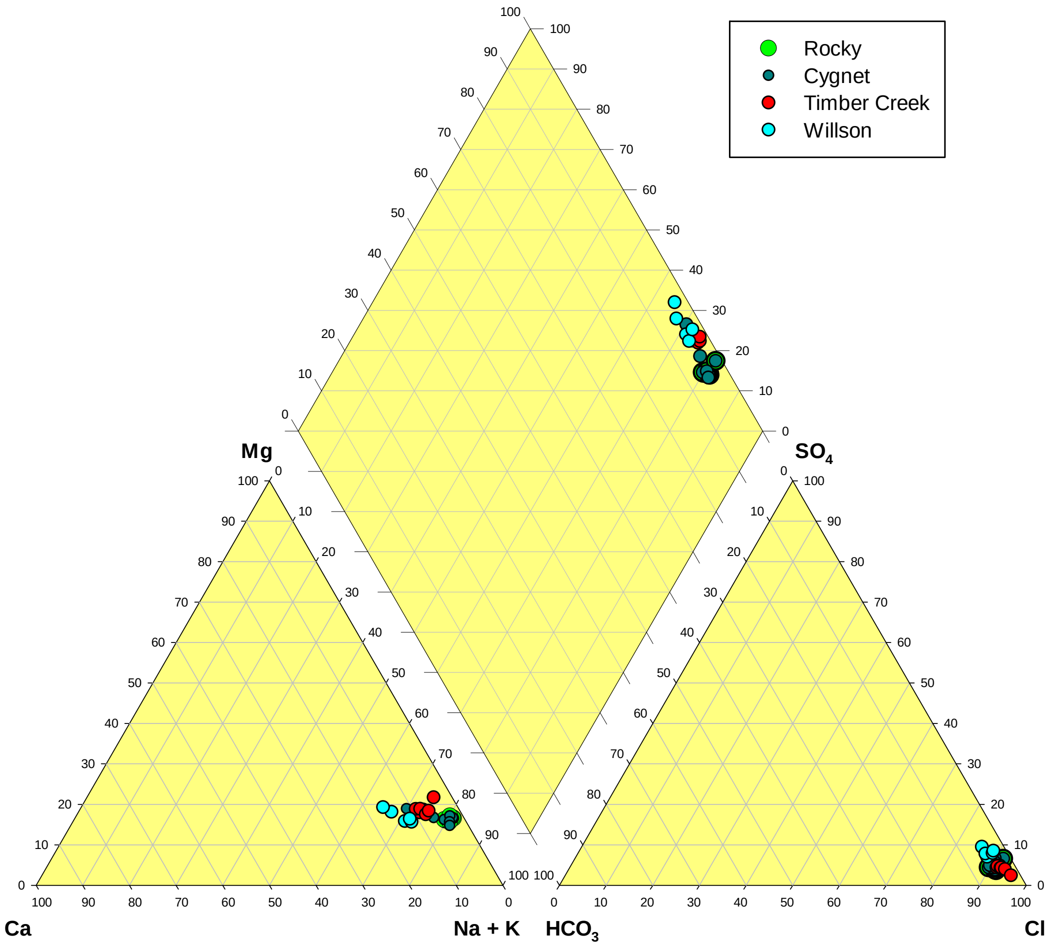

Figure 4.1 PIPER plot showing the relative proportions of major solutes in the Kangaroo Island catchments

The stream data, for selected parameters, are plotted against k-point (distance in km downstream of source) in Figure 4.2 a–d. All of the rivers showed significant spatial differences downstream from the headwater.

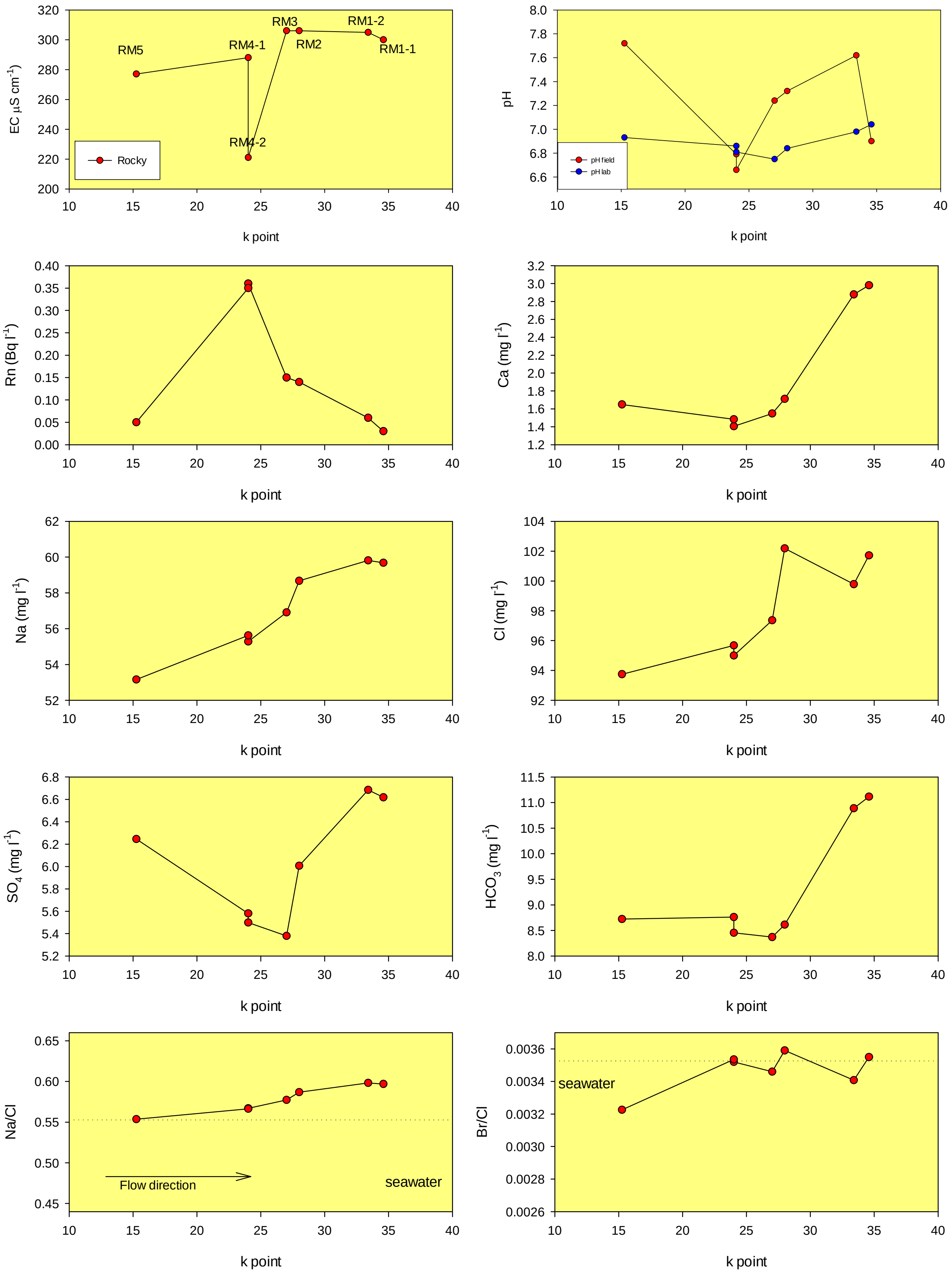

Figure 4.2a Changes in hydrochemical parameters in the Rocky River downstream from source

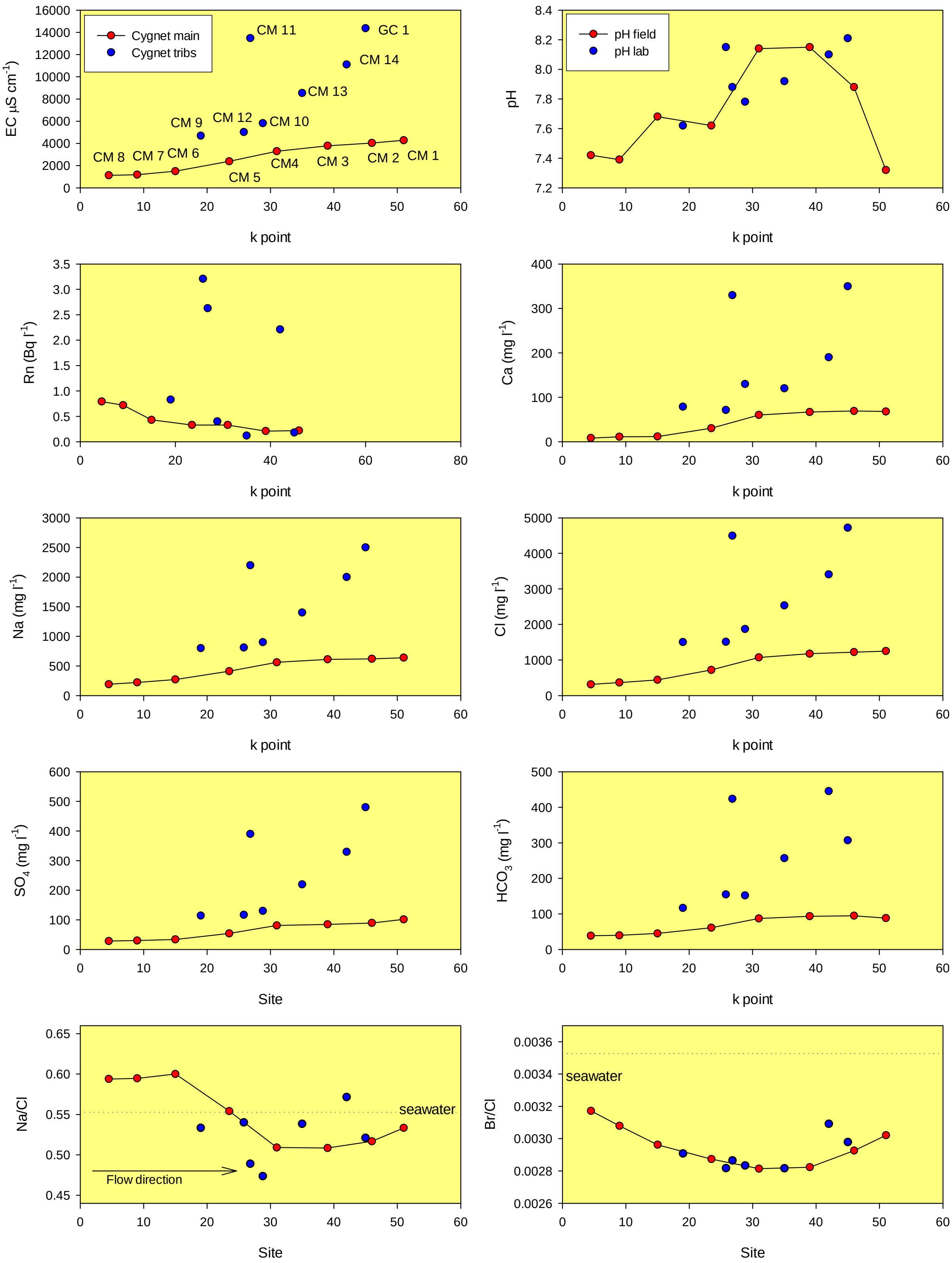

Figure 4.2b **Changes in hydrochemical parameters in the Cygnet River downstream from source**

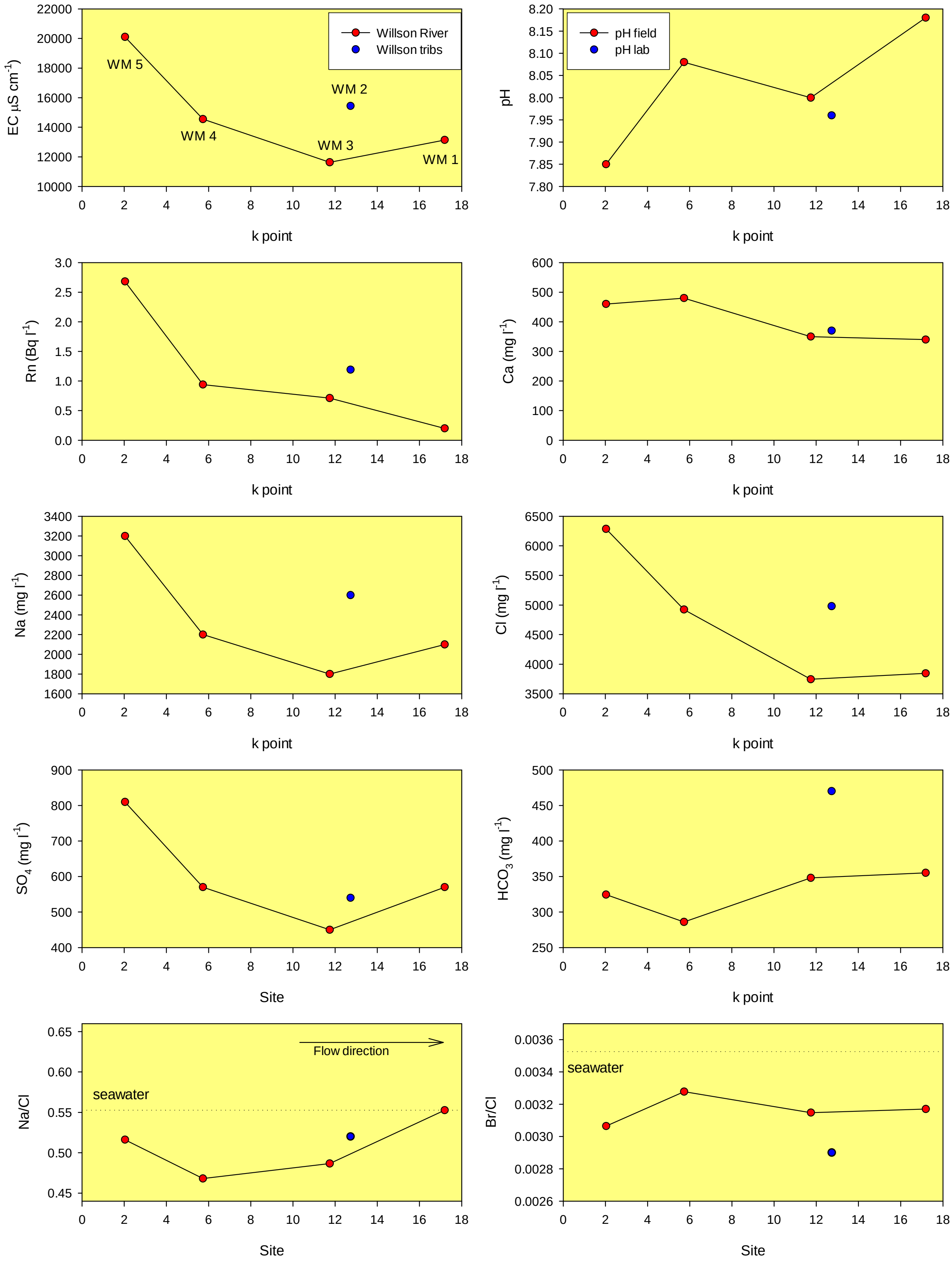

Figure 4.2c Changes in hydrochemical parameters in the Willson River downstream from source

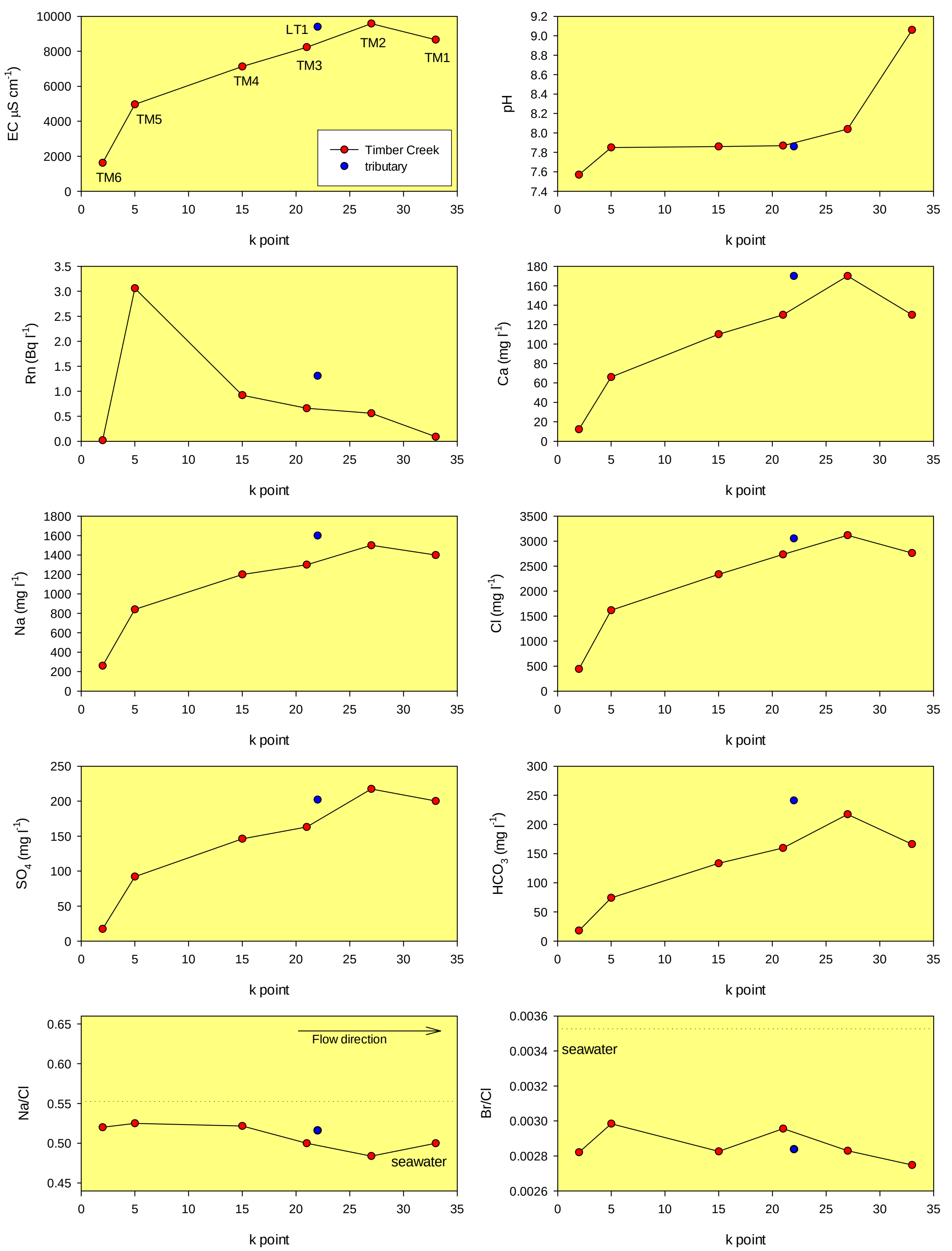

Figure 4.2d Changes in hydrochemical parameters in Timber Creek downstream from source

4.1.1 ROCKY RIVER

The Rocky River samples were very fresh and there is a slight increase in electrical conductivity (SEC) along the river reach. This increase is largely related to an increase in the dominant solutes Na and Cl, and may be related to proximity to the coast (rainfall and sea-spray derived sources being the dominant source of these ions). However, the Na/Cl ratio increases from values close to seawater (0.55) in the headwaters up to 0.6 implying an internal source for some of the Na. The excess Na amounts to ~4.4 mg l^{-1} representing a maximum of 7% of the total Na in samples furthest downstream. The major elements Ca, Mg and HCO_3 are significantly higher in the samples furthest downstream (RM1-1 and RM1-2), coinciding with outcrops of calcarenite (carbonate-rich sandstone) close to the river.

The chemistry of the river waters is dominated by atmospheric sources (as indicated by the similarity of Br/Cl ratios to seawater), modified by minor weathering reactions with soil and/or rock. Silicate weathering dominates in most of the catchment, and carbonate reactions become important close to the coast where carbonate rocks occur. The low mineralization implies either a short residence time or flow through rocks and/or soils containing very unreactive minerals. Rn can be used as an indicator of groundwater inputs to the stream. The amount of Rn present in a river is dependent on:

a. The source and variability of Rn.
b. The amount of groundwater component in the river.
c. The residence time of this component in the river.

It was not possible to estimate the concentrations or variation of Rn in groundwater within the catchment, since no boreholes are present. Although it is not possible to quantify the amount of groundwater component in a stream, due degassing of Rn to the atmosphere, high concentrations are taken to imply groundwater discharge close to the sampling point. Both samples from close to Platypus Walk (RM4-1 and RM4-2, Fig. 5.2) indicate that this part of the catchment may represent an important area of discharging groundwater.

4.1.2 CYGNET RIVER

The Cygnet River (Fig. 4.2b) showed a significant increase in SEC (1120–4280 $\mu S\ cm^{-1}$) from the headwaters downstream. The tributaries sampled all had high SEC, generally increasing downstream to a maximum value of 14 360 $\mu S\ cm^{-1}$. The major elements showed similar patterns to the SEC. The Na/Cl ratios vary from slightly higher than seawater to slightly less than seawater (Fig. 4.2b) along the reach of the main channel. Br/Cl ratios were less than seawater in both the main channel and tributaries. The ratio varied along the catchment reaching a minimum in the lower parts of the catchment. The variation in ratios indicates different sources of water within the catchment, and the low Br/Cl ratios imply that simple evaporation of rainfall cannot explain the source of salinity. Rn concentrations were highest in the upper reaches of the main river and in some of the tributaries.

4.1.3 WILLSON RIVER

The Willson River samples (Fig. 4.2c) showed a general decrease in salinity from the headwaters downstream. The salinity in the headwater was higher than in the other rivers sampled, reaching 20 110 $\mu S\ cm^{-1}$. This was reflected in a decrease in the major elements except for HCO_3, which showed a slight increase. Rn concentrations were highest in the upper reaches and decreased in a similar manner to salinity. This implies that the saline component is groundwater-derived and the decrease in Rn related to dilution or longer residence in the stream channel. Br/Cl ratios were lower than seawater (similar to the Cygnet River), but showed little variation along the river reach.

4.1.4 TIMBER CREEK

The Timber Creek samples showed an increase in salinity and all major elements downstream. Rn concentrations were highest at site TM 5 (Fig. 4.2d) and decreased downstream. Br/Cl ratios were less than seawater, and slightly lower than the Willson and Cygnet Rivers.

4.1.5 COMPARISONS OF PHASE 1 RIVER CHEMISTRY

A comparison of selected parameters is shown in Figure 4.3. This highlights the low salinity and less alkaline pH of the Rocky River.

The highest SEC values were present in the Willson River and Timber Creek catchments, although some of the Cygnet tributaries (Fig. 4.2b) in the lower part of the catchment had relatively high SEC. The Rocky River, representing the most pristine catchment studied, had a remarkably low salt content.

Rn concentrations were variable, but tended to be slightly higher in the upstream reaches of the Cygnet River, Willson River and Timber Creek, but some of the tributaries of the Cygnet River also had high concentrations. The decreases downstream are likely to reflect, at least in part, the longer residence time in the river channel. Rn concentrations in the Rocky River were, by comparison, relatively low. The upper reaches of the river continued to flow all summer, implying a dominance of groundwater inputs despite the very low Rn concentrations. This is likely to reflect degassing of Rn in the steeper gradients and the more dynamic nature of the river in this part of the catchment.

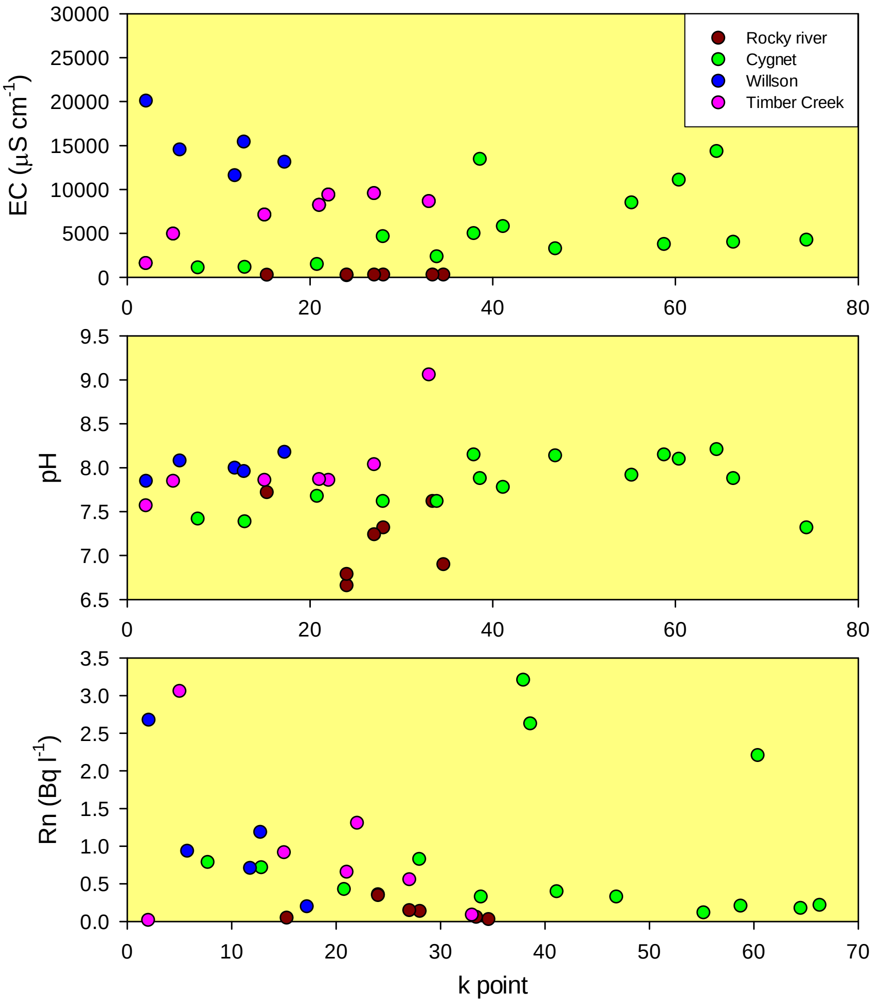

Figure 4.3 **Comparison of EC, pH and Rn for the Rocky, Cygnet and Willson Rivers and Timber Creek**

4.2 TEMPORAL VARIATIONS IN THE CYGNET AND ROCKY RIVER CATCHMENTS

4.2.1 CYGNET RIVER

The Cygnet River sample CM1, from close to the coast, was collected from the tidal zone of the river and is not shown. Many of the rivers visited during the January and April campaigns were dry, and where water was present, flows were typically low. The SEC was higher during the summer periods of low flow (Fig. 4.4).

The central part of the Cygnet River was typically dry, but upstream flows of approximately 0.5 l s^{-1} were present (CM7 and CM 8). This indicates that recharge from the river to the aquifer occurs along the middle reaches of the catchment during low flow. The surface water samples in the lower parts of the catchment showed a dramatic decrease in SEC following heavy rainfall in June (Fig. 4.4), but a much smaller decrease was noted in the upper reaches (CM 8) of the river.

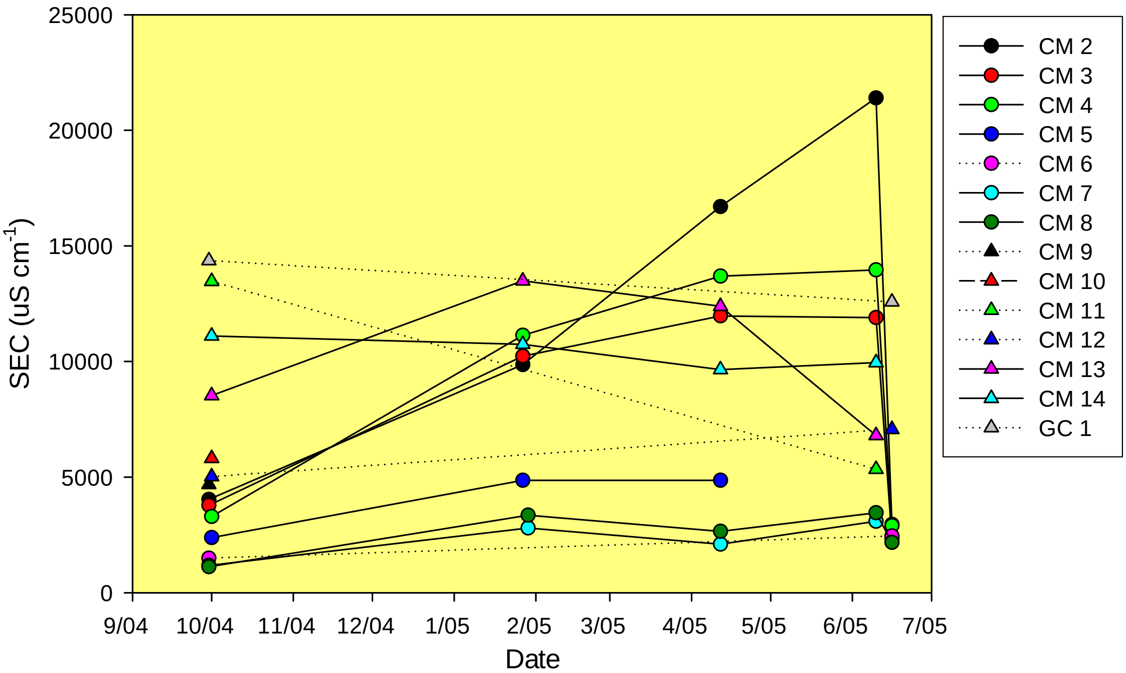

Figure 4.4 SEC in samples from the Cygnet River and tributaries. Sites which were dry during the January and April sampling campaigns are highlighted by dotted lines

Rn concentrations were often higher under baseflow conditions, especially in the upper reaches of the Cygnet catchment (Fig. 4.5). The lower concentrations in the Cygnet River baseflow samples, from the downstream part of the catchment, may simply be due to degassing of Rn to the atmosphere, under conditions of very low flow. Nevertheless, the data indicate an important contribution from groundwater to the river.

Unfortunately, it was not possible to sample for Rn immediately prior to the June rainfall event, but concentrations were elevated above that expected for surface waters in equilibrium with the atmosphere. For the sites where hydrochemical analyses were completed before and after the rainfall event, it was noted that pH and the major elements decreased, whereas Al, NO_3 and Si increased.

4.2.2 ROCKY RIVER

The SEC for samples from the Rocky River is shown in Figure 4.6, which shows an increase in SEC during the summer months. Most of the river was dry during in the April sampling campaign, the exception being the uppermost site (RM 5), which flows all year. Site RM 1-1 was a large pooled part of the river, dammed above a steep rocky descent towards the sea (Fig. 4.7), which showed no evidence of flow. Where possible (where flow occurred), samples were measured for SEC prior to and following the heavy rainfall event of June, and again in July.

In contrast to the Cygnet River, the Rocky River at sites 4-1 and 4-2 (Platypus Pools) and RM 5 showed a slight increase in SEC after rainfall, although these decreased again in July (Fig. 4.6).

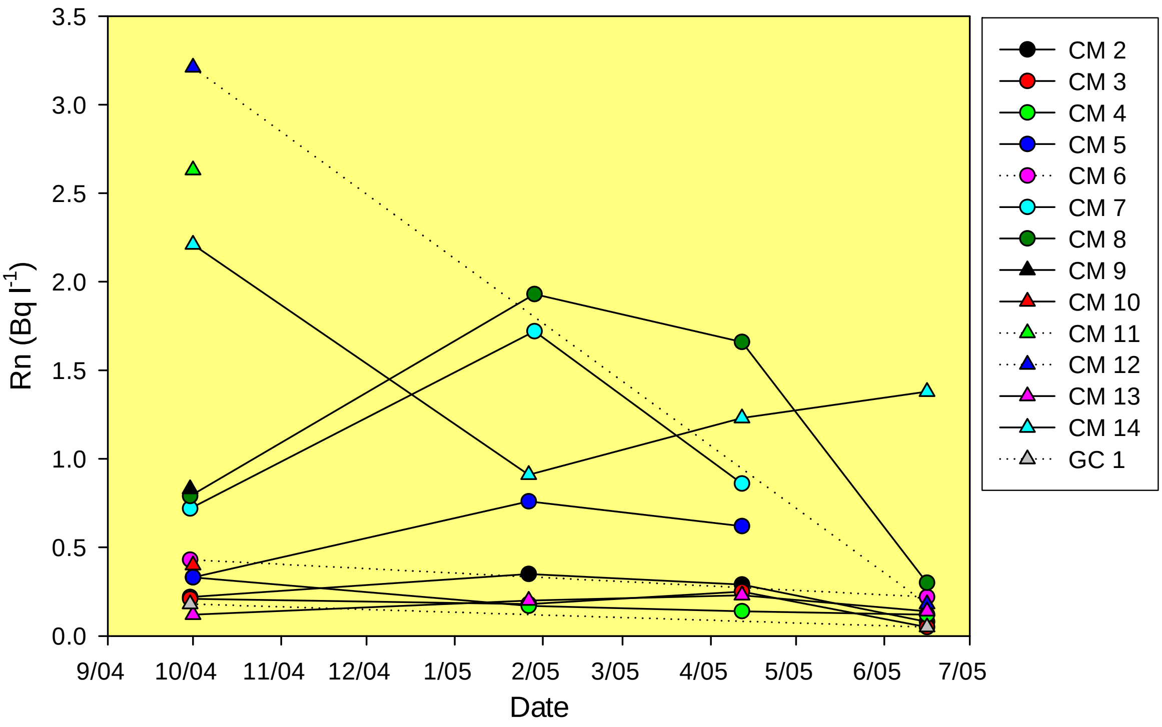

Figure 4.5 **Rn concentrations in samples from the Cygnet River and tributaries. Sites which were dry during the January and April sampling campaigns are highlighted by dotted lines**

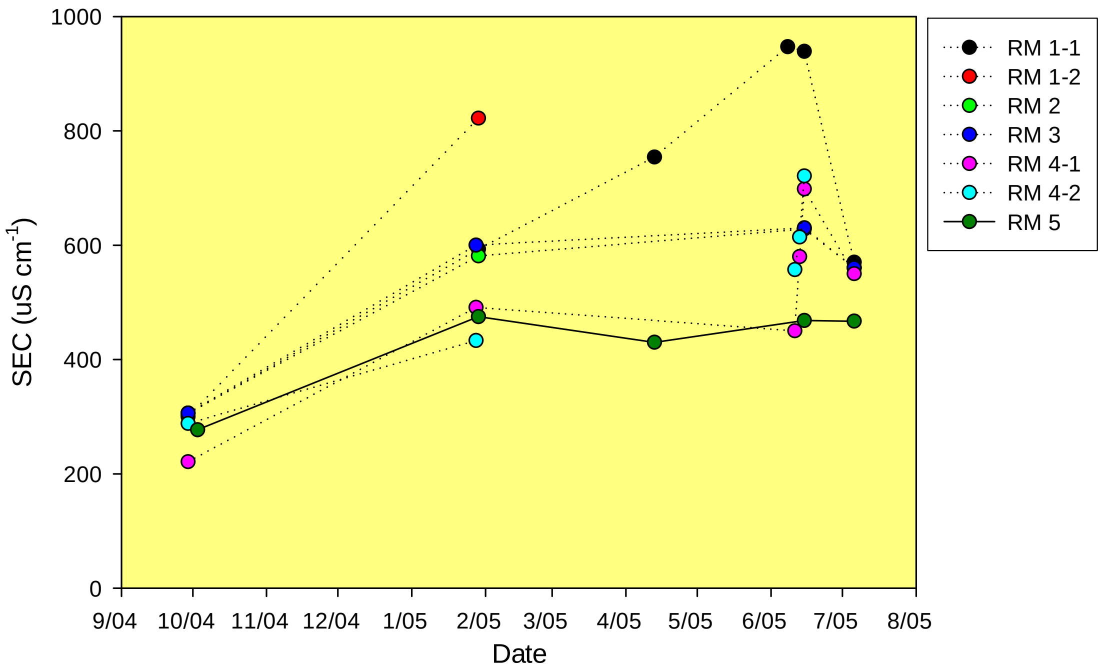

Figure 4.6 **SEC in samples from the Rocky River. Sites which were dry or not flowing (RM1-1) during the April sampling campaign are highlighted by dotted lines**

Figure 4.7 Sampling from a large pool on the Rocky River above a steep descent toward the sea (RM 1-1)

Rn concentrations were slightly higher during the drier summer months (Fig. 4.8), particularly in the middle reaches of the catchment at the Platypus Pool (RM 4-1). Concentrations of Rn showed no consistent behaviour during the rainfall event in June (Fig. 4.8).

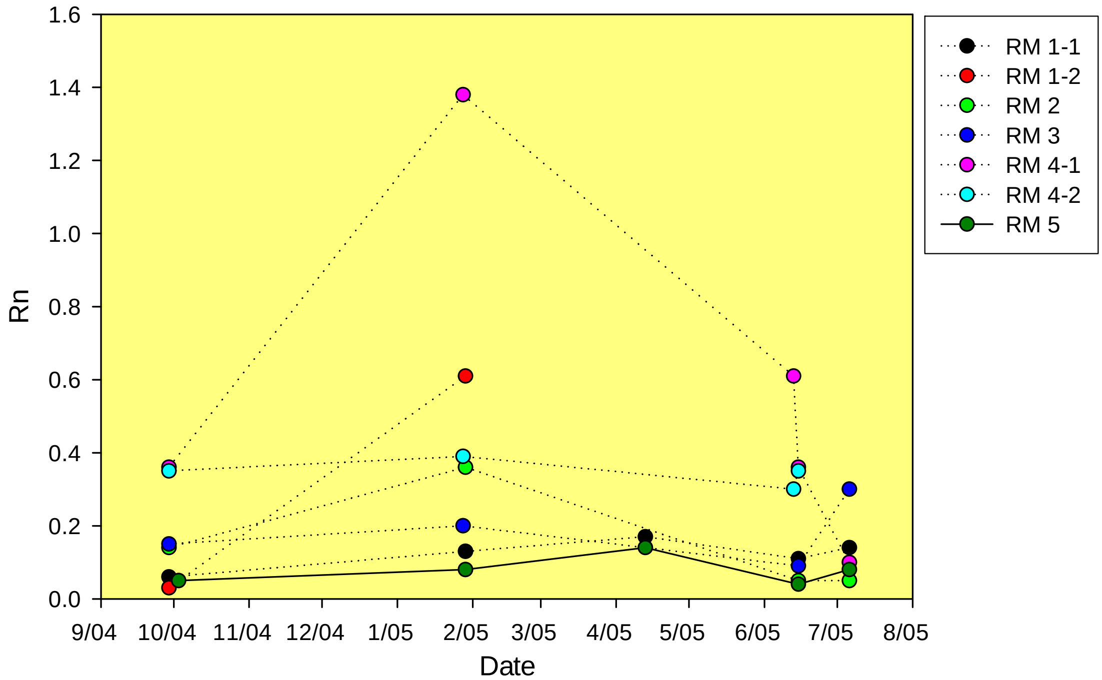

Figure 4.8 Rn concentrations in samples from the Rocky River. Sites which were dry or not flowing (RM1-1) during the April sampling campaign are highlighted by dotted lines

4.3 ISOTOPE VARIATIONS IN THE CYGNET AND ROCKY RIVER CATCHMENTS

Stable isotope data for δ^2H and $\delta^{18}O$ are displayed in Figures 4.9 and 4.10, for the Cygnet and Rocky Rivers respectively. The data for Cygnet River shows a very large variation, deviating away from the local Adelaide Meteoric Line (AML) along a slope characteristic of evaporation (slope of ~4.4). The largest variations were seen for the lower parts of the Cygnet River catchment, with heavier (more positive) signatures correlating with higher salinity. The less saline surface waters in the uppermost part of the catchment tended to show less variability. Following the heavy June rains, the isotopic characteristics returned to values close to the AML for all waters sampled.

A similar pattern was also seen in the Rocky River catchment for samples RM 1-3 (Figure 4.10), but with original compositions falling slightly left of the AML. The river at RM 4 and RM 5 showed much less variation during the summer.

The stable isotopes are plotted against date in Figures 4.11 and 4.12, highlighting the strong evaporation signal and return to light (more negative) values following rainfall.

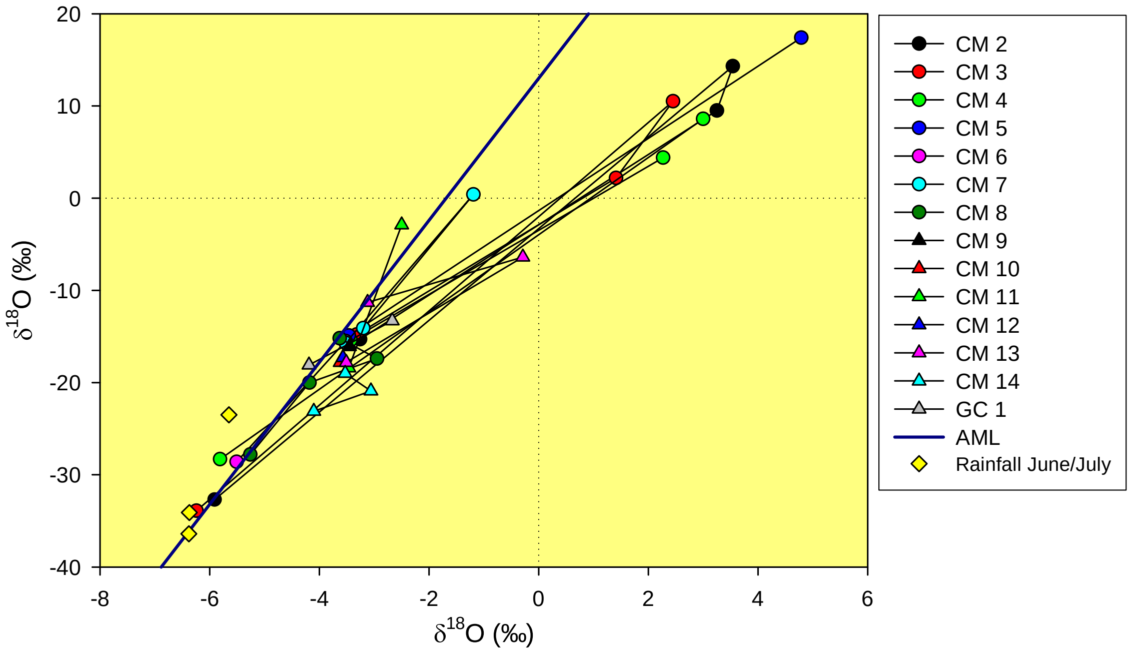

Figure 4.9 **δ^2H and $\delta^{18}O$ in samples from the Cygnet River sampled between September 2004 and July 2005. AML is the Adelaide Meteoric Line; rainfall samples were collected from Kangaroo Island Airport and Rocky River for July 2005 (the two lightest points) and Rocky River during June 2005**

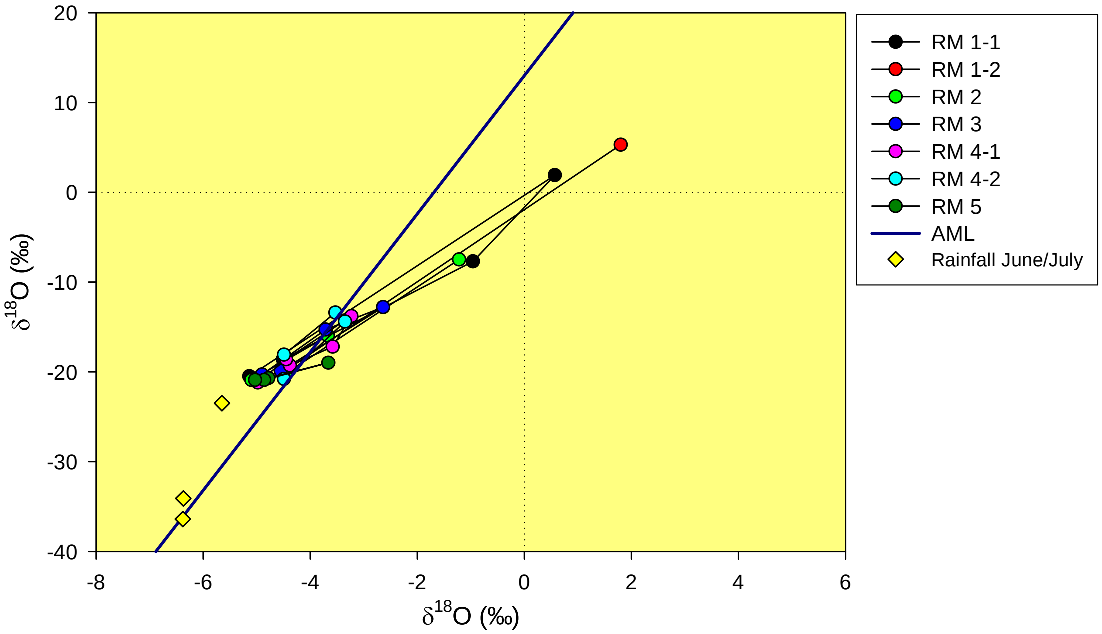

Figure 4.10 δ^2H and δ^{18}O in samples from the Rocky River, sampled between September 2004 and July 2005

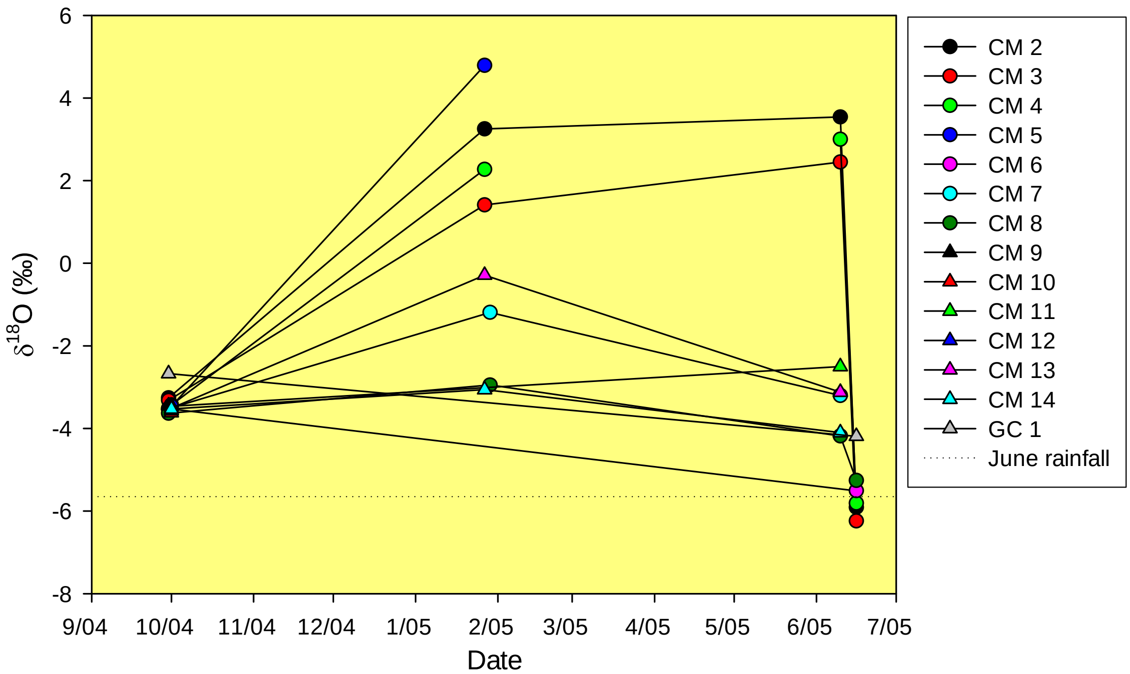

Figure 4.11 Time-series data for δ^{18}O in samples from the Cygnet River

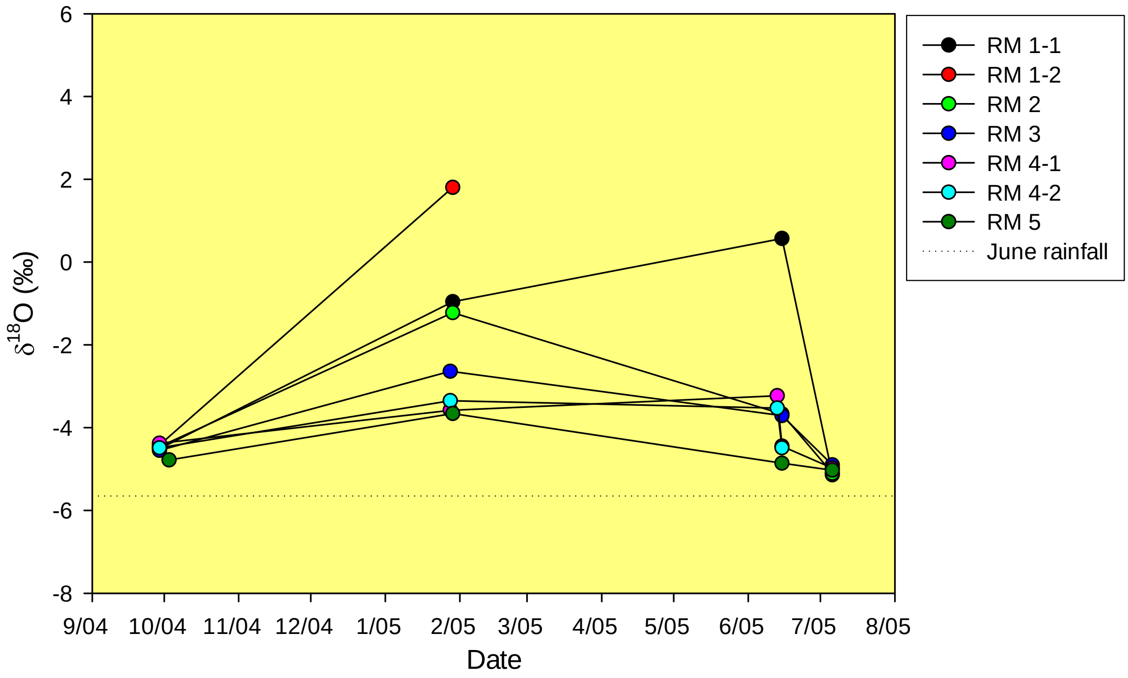

Figure 4.12 Time-series data for $\delta^{18}O$ in samples from the Rocky River

The waters were analysed for Sr isotopes to assist in determining likely weathering sources and inputs, in particular the role of bedrock weathering versus atmospheric inputs. The data are plotted against k point in Figure 4.13. Both catchments displayed a decrease in Sr isotope ratio downstream, changing towards rainfall and calcarenite signatures, the latter sources being very similar in isotope ratio. Higher ratios in the water samples indicate an important contribution of Sr from non-marine sources. The effect of rainfall inputs in June 2006 had little impact on ratios in the Rocky River, but decreased those in the Cygnet River.

4.4 GROUNDWATER

Only limited groundwater sampling was possible on Kangaroo Island, all in the Cygnet River catchment, due mainly to the scarcity of boreholes. It would appear that many boreholes have been backfilled due to salinity problems; hence the present sampling may form a biased view of groundwater chemistry in the catchment. No boreholes are present in the Rocky River catchment.

The borehole K4 (Fig. 3.1) close to the estuary was very saline (EC 107 700 $\mu S\ cm^{-1}$) and atypical of groundwater upstream in the catchment. The other four samples showed a range in EC from 443–6510 $\mu S\ cm^{-1}$. Although there was a tendency for lower SEC in the headwaters, this is based on very limited sampling and further data are required to assess spatial variations.

The pH electrode was damaged during transit on the trip, but data (Fig. 5.5) monitored with a downhole sonde in two boreholes (AG1 and CV) indicated moderately acidic, relatively fresh groundwater (Fig. 4.14). The profiles after pumping showed a marked stratification in pH and SEC. Further work is necessary to relate these variations to borehole construction details, logs and stratigraphic descriptions.

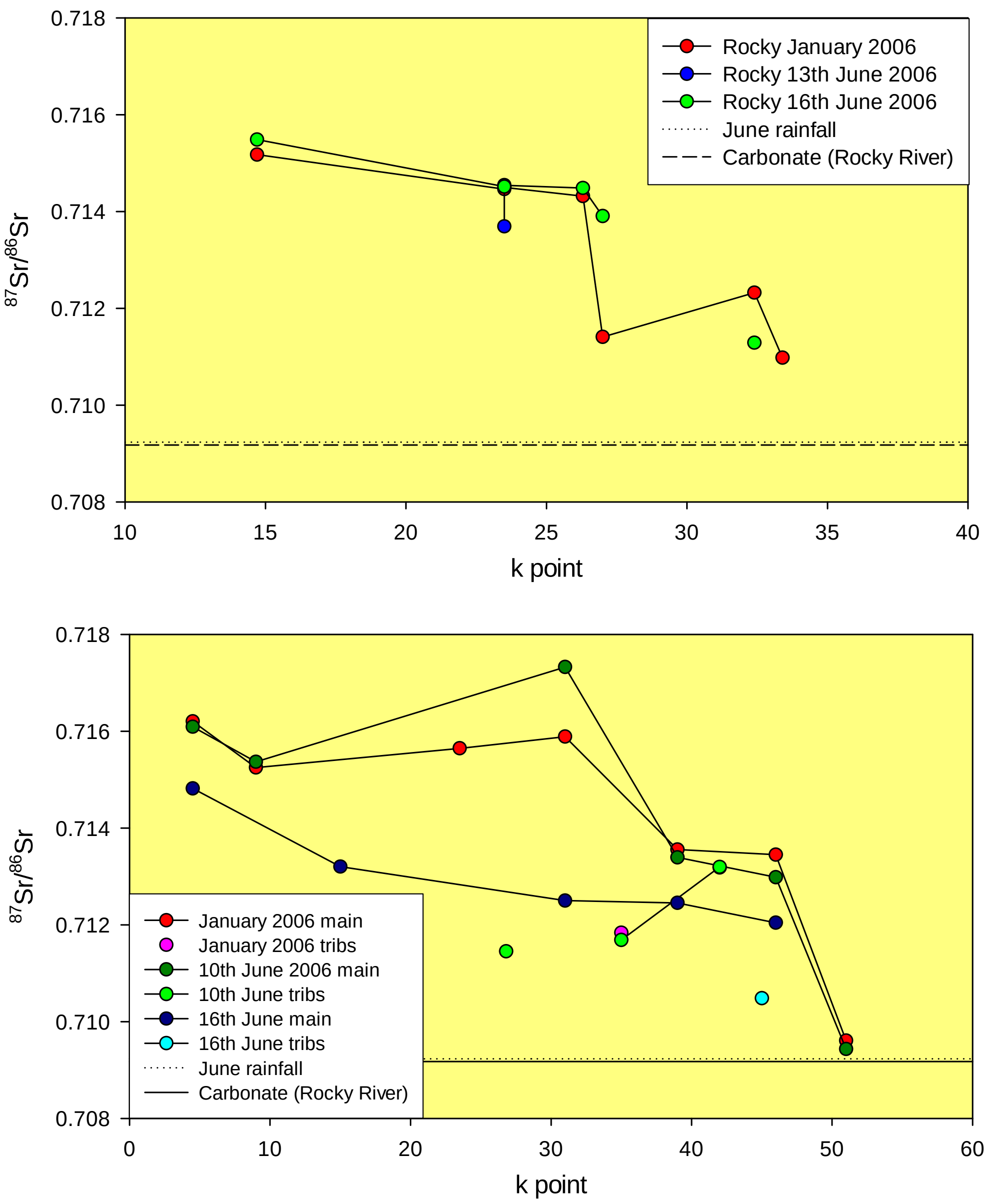

Figure 4.13 $^{87}Sr/^{86}Sr$ **ratios for surface waters in the Rocky River and Cygnet River catchments**

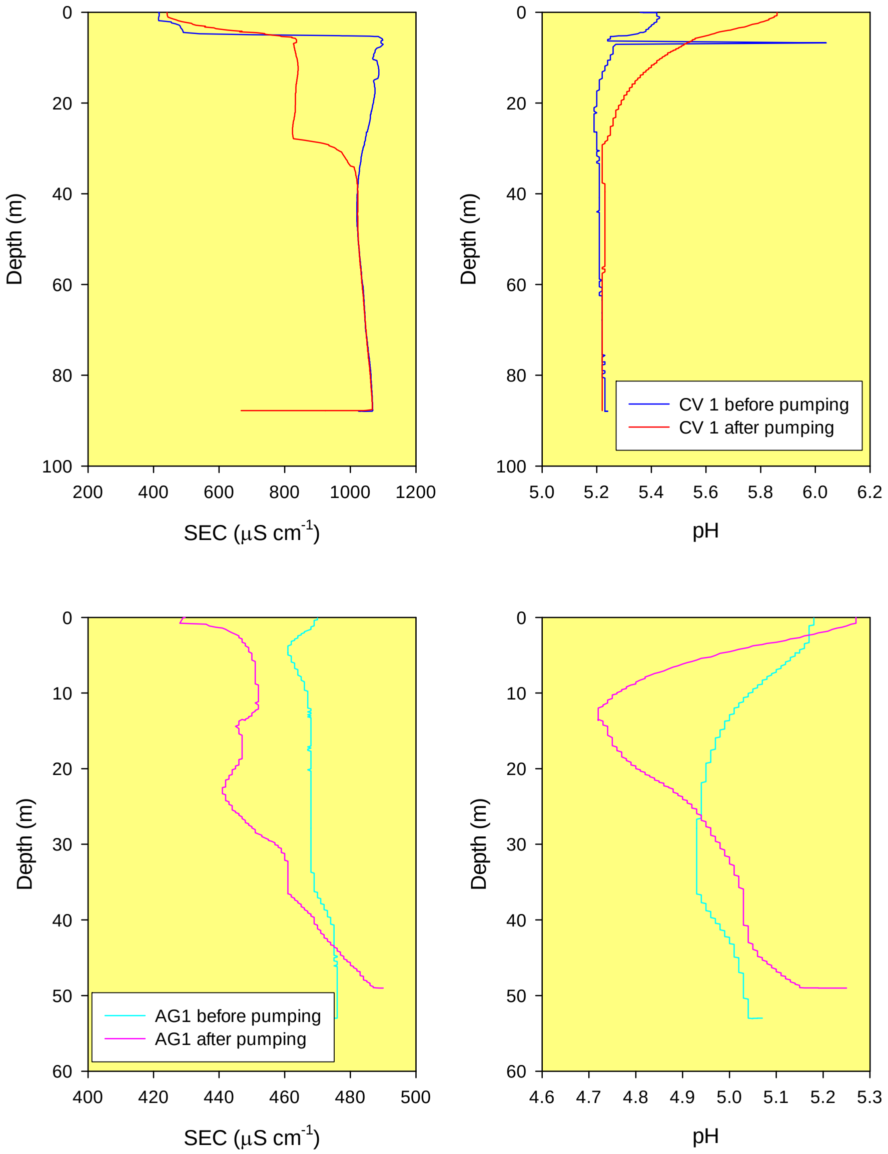

Figure 4.14 **Depth profiles of EC and pH measured by downhole sonde, prior to, and following pumping**

Rn concentrations varied significantly in the groundwaters and were used to estimate flow (q) in the aquifer using the methodology of Cook et al. (1999):

$$q = \frac{c}{c_o - c} \frac{\lambda \pi r}{2}$$

where q is the flow rate into the well, c_o and c and are the Rn concentrations before and after purging, r is the well radius and λ is the decay constant for Rn (0.18 day^{-1}). The results are shown in Table 4.1, indicating relatively low average flow rates for the aquifer.

Table 4.1 Rn data and estimated flow using initial differences in Rn concentrations prior to and following purging

Site		Initial Rn (C)	Final Rn (C_0)	Q m/year
	units	Bq l^{-1}	Bq l^{-1}	
PF1		0.5	18.8	0.18
AG1		22.6	136.4	0.19
RB1		5.5		
CV1			37.1	

The groundwaters are shown on a PIPER plot in Figure 4.15. The saline estuarine sample is identical to seawater (although Cl is ~3.4 times that of seawater), whilst the others show some deviation away from a seawater composition. However, they are still strongly of Na-Cl type, with some plotting to slightly higher HCO_3 than in the river samples (Fig. 4.14).

The stable isotope signatures for some of the groundwaters display a strong evaporation signature (Fig. 4.16a). Although the saline groundwater close to the estuary could be interpreted in terms of mixing with seawater, the heaviest signature was present in one of the freshest groundwaters (CV1, SEC of 805 µS cm^{-1}), where the low Cl concentrations preclude an origin by mixing with seawater. This groundwater was present at the edge of a dammed lake (Fig. 4.16b) and indicates recharge from fresh water which has undergone significant evaporation.

The Sr isotope ratio in the saline groundwater (0.7092) was only slightly higher than seawater (0.7091) and rainfall, indicating a dominance of a marine-derived component. In the other groundwaters, isotope ratios varied between 0.711 and 0.714 indicating an additional non-marine source of Sr.

Porewater samples were collected from soils, by hand augering down to 1.8 m depth, at a site close to the Rocky River in order to determine if storage of salts occurred in the unsaturated zone. Chloride concentrations were relatively high throughout the profile, increasing at depth where concentrations were over 6000 mg l^{-1} at 1.8 m (Fig. 4.17). Concentrations were typically in the order of magnitude higher than found in the river samples. The implications of this are discussed in the following chapter.

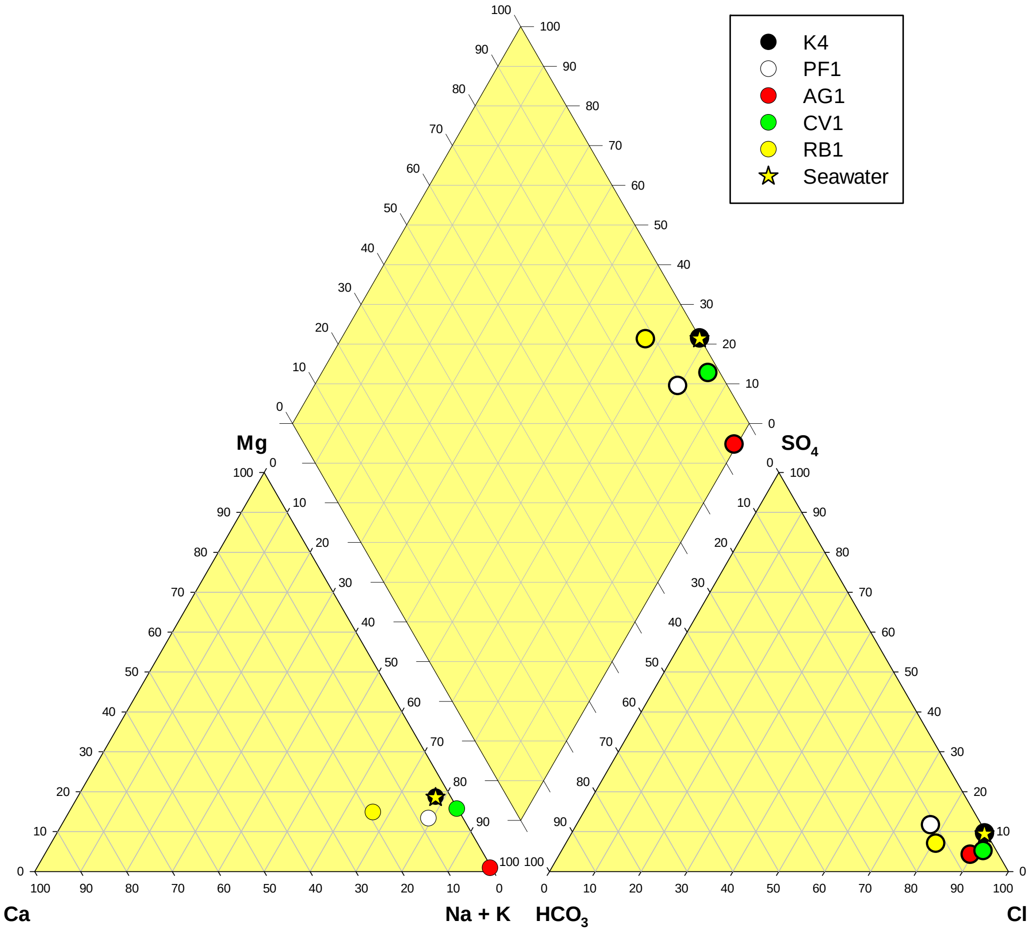

Figure 4.15 PIPER plot showing the relative proportions of major solutes in groundwater

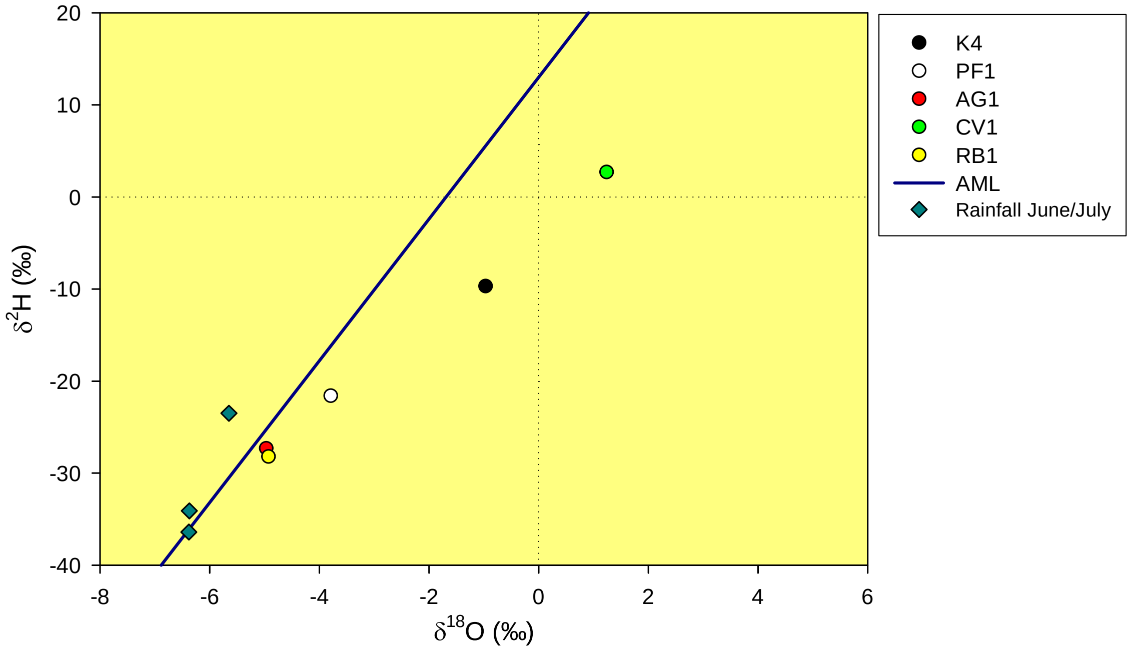

Figure 4.16a δ^2H and $\delta^{18}O$ in groundwater samples

Figure 4.16b Borehole site CV1, where stable isotope signatures and salinity indicate an origin from evaporated fresh water, probably the dam shown

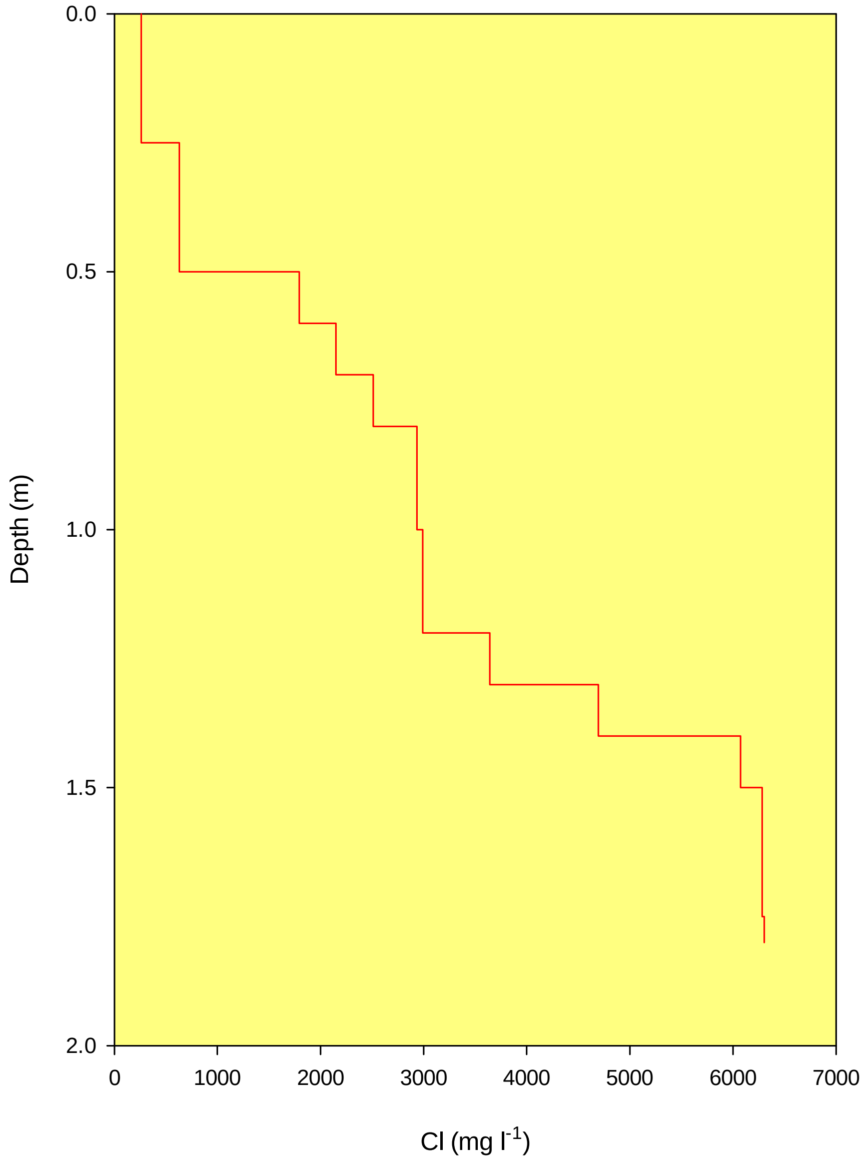

Figure 4.17 Porewater profile for Cl concentration at a site close to the Rocky River

5. DISCUSSION

The surface waters on Kangaroo Island displayed a wide range of chemical compositions. Although they were all of Na-Cl type, they varied in the total concentration (SEC varied from 221–63 500 µS cm^{-1}). Salinities were highest in the Willson River, Timber Creek and Cygnet River catchments, although SEC was relatively low in the upper parts of the Cygnet River. In contrast to these, the river waters of the Rocky River catchment were all very low. There appears, therefore, to be a correlation between land-use and salinity, with the pristine Rocky River catchment having much fresher waters and the catchments cleared of native vegetation have higher salinities. All catchments except for Timber Creek showed an increase in SEC downstream from the headwaters (Fig. 4.3). A reconnaissance survey of rivers in the south-west of the island, outside Flinders Chase National Park indicated moderate salinities in the rivers (SEC from 2625–6730) with 31 700 µS cm^{-1} in the tidal reaches of the Harriet River.

As well as spatial variations in salinity, the Cygnet and Rocky Rivers also displayed a marked temporal variability. Salinity increased dramatically during the summer months, with many streams drying up completely. The stable isotope data (Figs 4.9 and 4.10) displayed a strong concomitant evaporation signature, showing that much of this increase in SEC is due to evaporation during summer baseflow. The impact was most obvious in the lower reaches of the rivers, where stream flows were very low, with much less impact in the upper parts of both catchments, where significant flows were maintained throughout the year. The presence of flowing water in the upper parts of the catchments indicates an important role of groundwater in maintaining surface waters, and hence the stability of surface water ecosystems. The large rainfall events of June 2005 seriously interrupted sampling, but provided the opportunity to sample some streams before and after the events. In the Cygnet River catchment, the summer samples were very variable in the summer for δ^2H and Cl (Fig. 5.1), despite being relatively similar the previous spring (October 2004). The differences in the slope on Figure 5.1 are unlikely to be produced by evaporation alone: hence, groundwater inputs are likely to form an important contribution to the varying Cl/ δ^2H ratios. Following the rainfall events of June 2005, the rivers showed a strong trend towards the rainfall collected in June and July. This indicates a relatively rapid pathway for rainfall to the rivers. The intensity of the rainfall was such that the rainfall was greater than the infiltration capacity of the soils and overland flow was observed over fields in the lower part of the catchment during this period. The changes in δ^{18}O in relation to rainfall and flow is shown in Figure 5.2, the two groups prior to rainfall representing the lower and upper parts of the catchment.

Similar plots are shown for the Rocky River in Figures 5.3 and 5.4. The pattern is similar for the changes in composition at the Rocky River sites in the lower part of the catchment (RM 1 and 2), but the variations were very small for the sites upstream, particularly RM 5.

The lack of variability in the upper section of the Rocky River is consistent with a dominance of groundwater as indicated by flow all year. The lack of significant change at sites RM4-1 and 4-2 is also taken as evidence of an important contribution from groundwater, as suggested by relatively high Rn concentrations at these sites. Overall, the data from both catchments indicate the importance of evaporation and subsequent dilution at the onset of rainfall, but groundwater is also likely to be an important contributor.

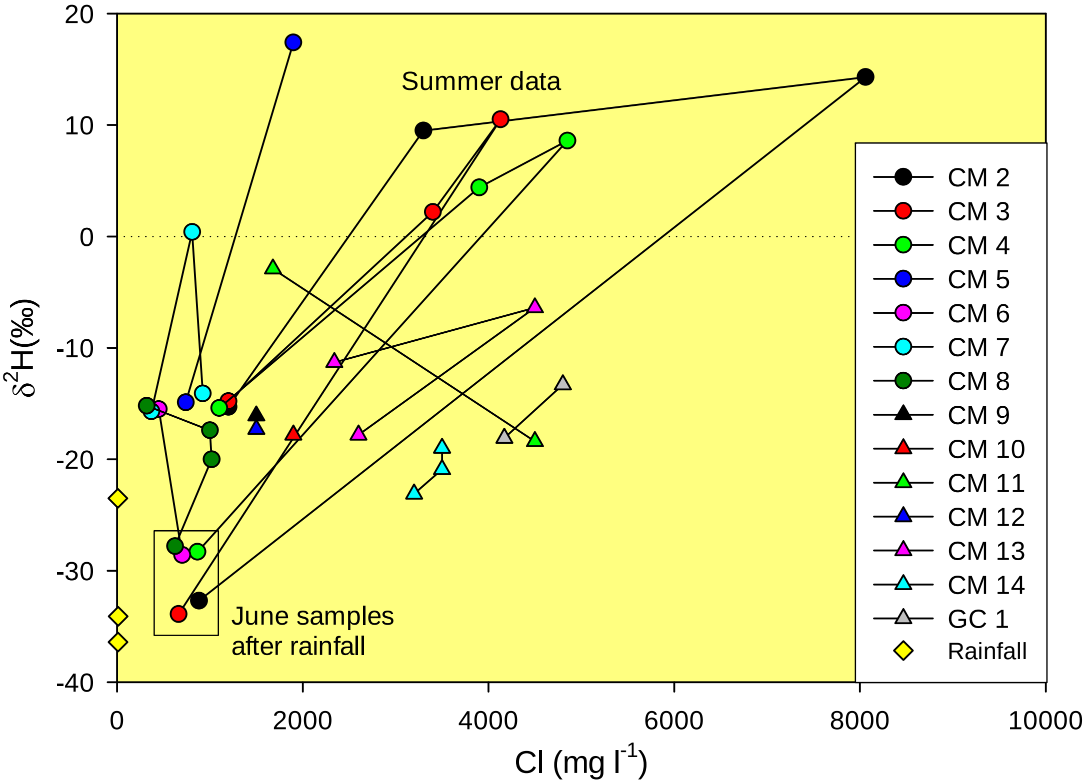

Figure 5.1 Variations in δ^2H and Cl for the Cygnet River, sampled at different times of the year (see text for explanation)

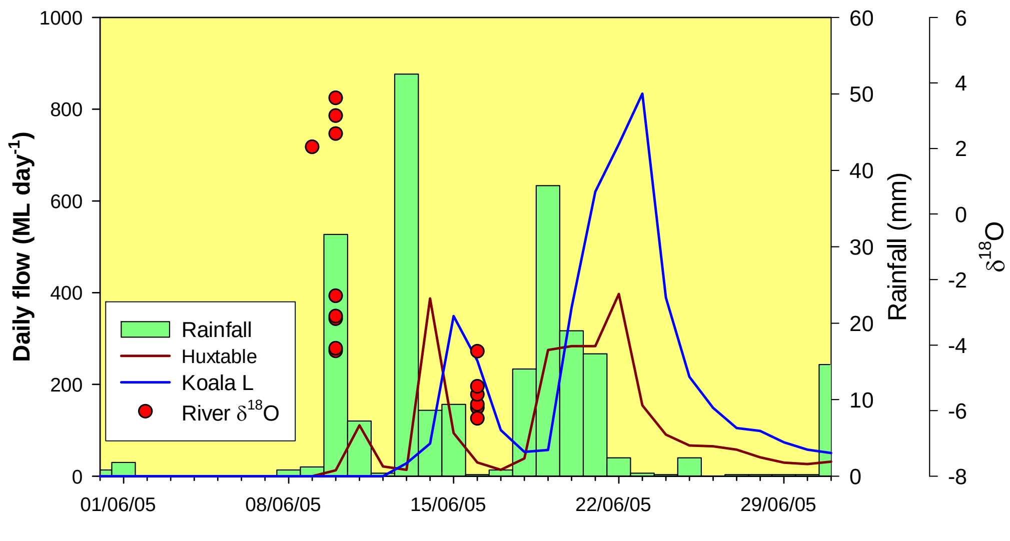

Figure 5.2 Variations in $\delta^{18}O$ with rainfall and flow for the Cygnet River

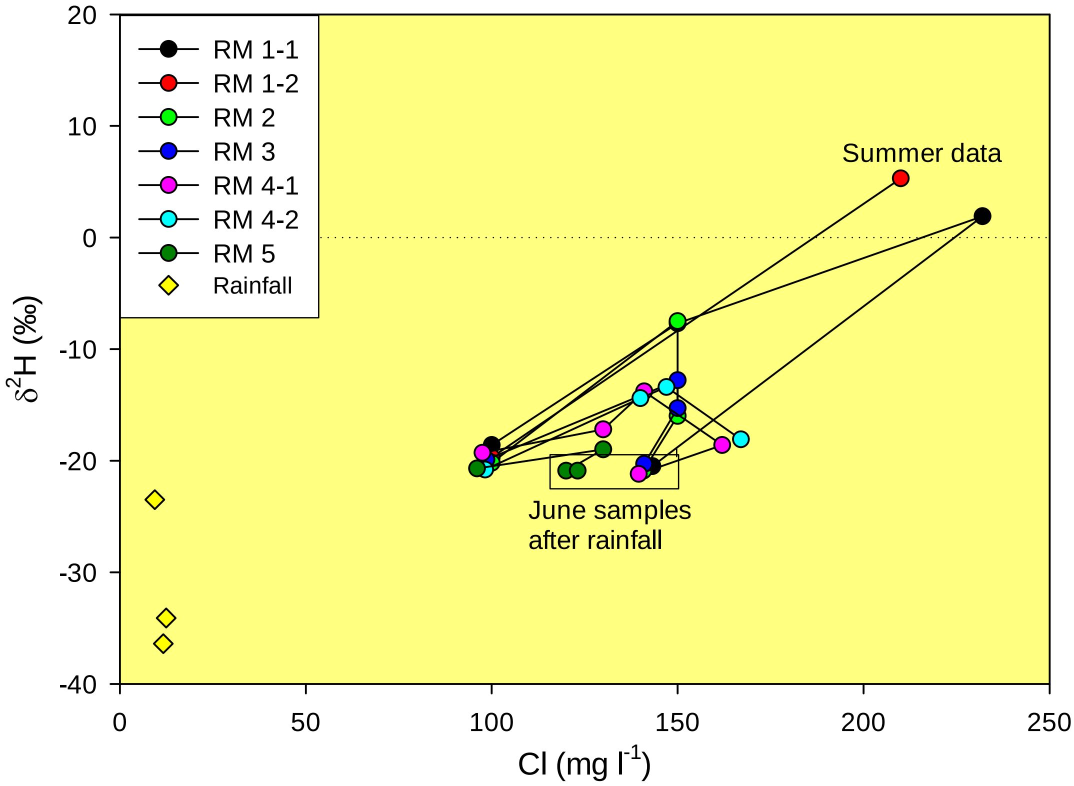

Figure 5.3 **Variations in δ^2H and Cl for the Rocky River, sampled at different times of the year**

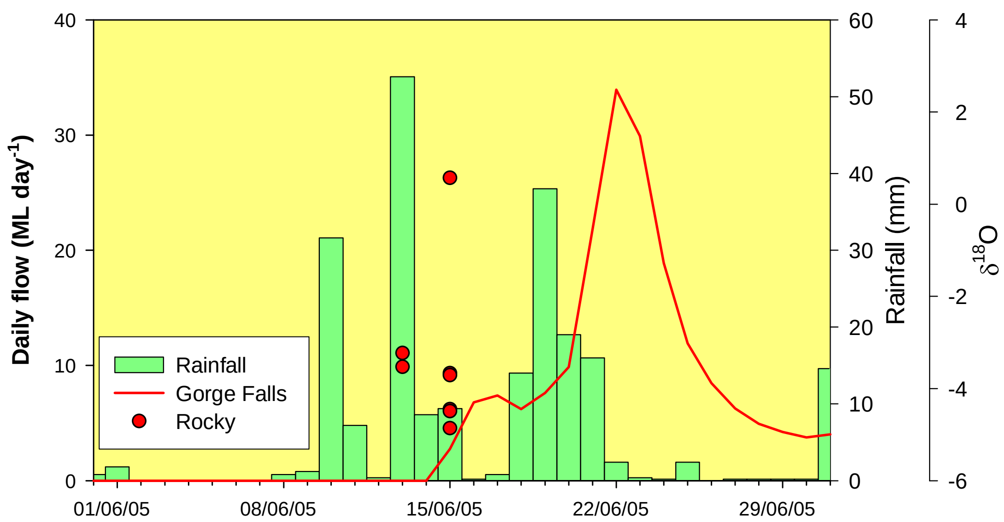

Figure 5.4 **Variations in δ^{18}O with rainfall and flow for the Rocky River**

Nevertheless, it is surprising that there are such significant differences in salinity between the catchments on Kangaroo Island. It is well established that the clearance from land of native vegetation leads to higher salinity, either through increased recharge (and higher water tables), leading to mobilisation of salt, or to changes in flow pathways related to changes in soil structure. What is surprising is the low SEC of the rivers in the pristine Rocky River catchment. Significant storage of salt occurs in the soils of the catchment as shown by the Cl porewater samples (Fig. 4.17). Diffuse flow through such salt-enriched soils should lead to high salt contents in the river. It is, therefore, postulated that much of the source of water in the Rocky River by-passes this salt store e.g. along fractures, root channels etc. The loss of vegetation and deep rooting systems, as well as compaction of soils, may therefore be important contributors to the salinisation of cleared catchments, and furthermore may decrease groundwater recharge. Further, more detailed work is required to assess this and the role of groundwater in stream flow generation in such catchments. The lack of groundwater samples from the Rocky River catchment makes such an assessment difficult at present. The Sr isotope data (Fig. 4.13) are consistent with a greater dominance of groundwater in the Rocky River catchment, the lack of change implying limited overland flow (such flow was not observed beneath the vegetation canopy).

The increased salinity in the Kangaroo Island catchments is undoubtedly derived from salts stored within the catchments, however there are few studies which have assessed how, when and where the salt is mobilised and transported to the rivers. As discussed previously, the evaporation of rivers during the summer months contributes to increased salinity, but evaporation alone cannot explain the high salt content of the rivers. In addition, the samples from the Rocky River confirm that a strong evaporation signal only increases concentrations slightly. Mixing with connate or formation water is commonly assumed to be responsible for increased salinity. Selected solutes have been plotted against Cl in Figure 5.5, where a simple mixing hypothesis is not consistent with the δ^2H-Cl plot. A precise analysis of the relative contributions of salt mobilisation, groundwater flow and evaporation would require a more detailed study at different scales.

Strontium isotopes are useful indicators of sources and mixing. The $^{87}Sr/^{86}Sr$ isotope ratios are plotted against the reciprocal of Sr (Fig. 5.6). Such a plot is useful since mixing between any two components must lie on a straight line. The trend of increasing salinity downstream in the river occurs with a decrease in $^{87}Sr/^{86}Sr$, with a change in slope occurring where carbonate rocks (calcarenite) crop out. These data agree with increasing Ca, Sr and alkalinity concentrations, indicating a major influence of carbonate dissolution.

Although rainfall has a similar signature to the calcarenite, rainfall would decrease both the Sr concentration and isotope ratio. Following the rainfall events of June and the increase in flow of the river, the Sr concentration increased whilst the isotope ratio remained constant. This is inconsistent with a dominant rainfall input to streamflow generation during the sampling period, with the implication that groundwater or interflow formed the source for the bulk of river discharge.

The Cygnet River samples showed more variation (Fig. 5.6). Strontium concentrations and isotope ratios for individual sites (Figs 4.13 and 5.6) decreased, highlighting the importance of event water reaching the stream (at least partly by overland flow). Nevertheless, the stream waters are not dominated by rainfall, being higher in Sr and with a much higher Sr isotope ratio (average rainfall would probably plot with a 1000/Sr value of ~>100, Fig. 5.6).

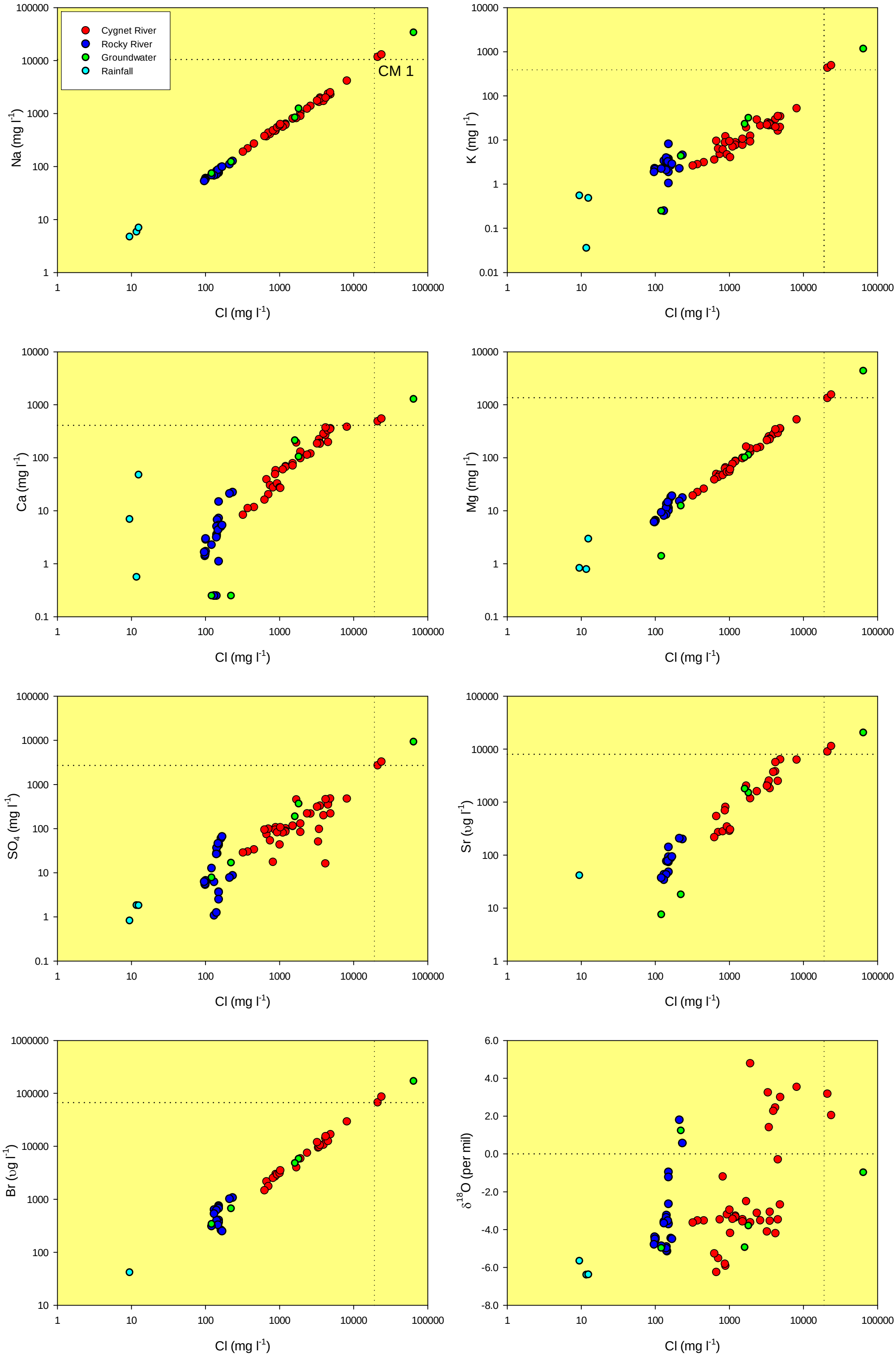

Figure 5.5 **Solute concentrations and δ^2H plotted against Cl concentration for the Cygnet and Rocky River catchments. CM1 is in the tidal zone of the Cygnet River, close to the coast. Dotted lines represent seawater composition**

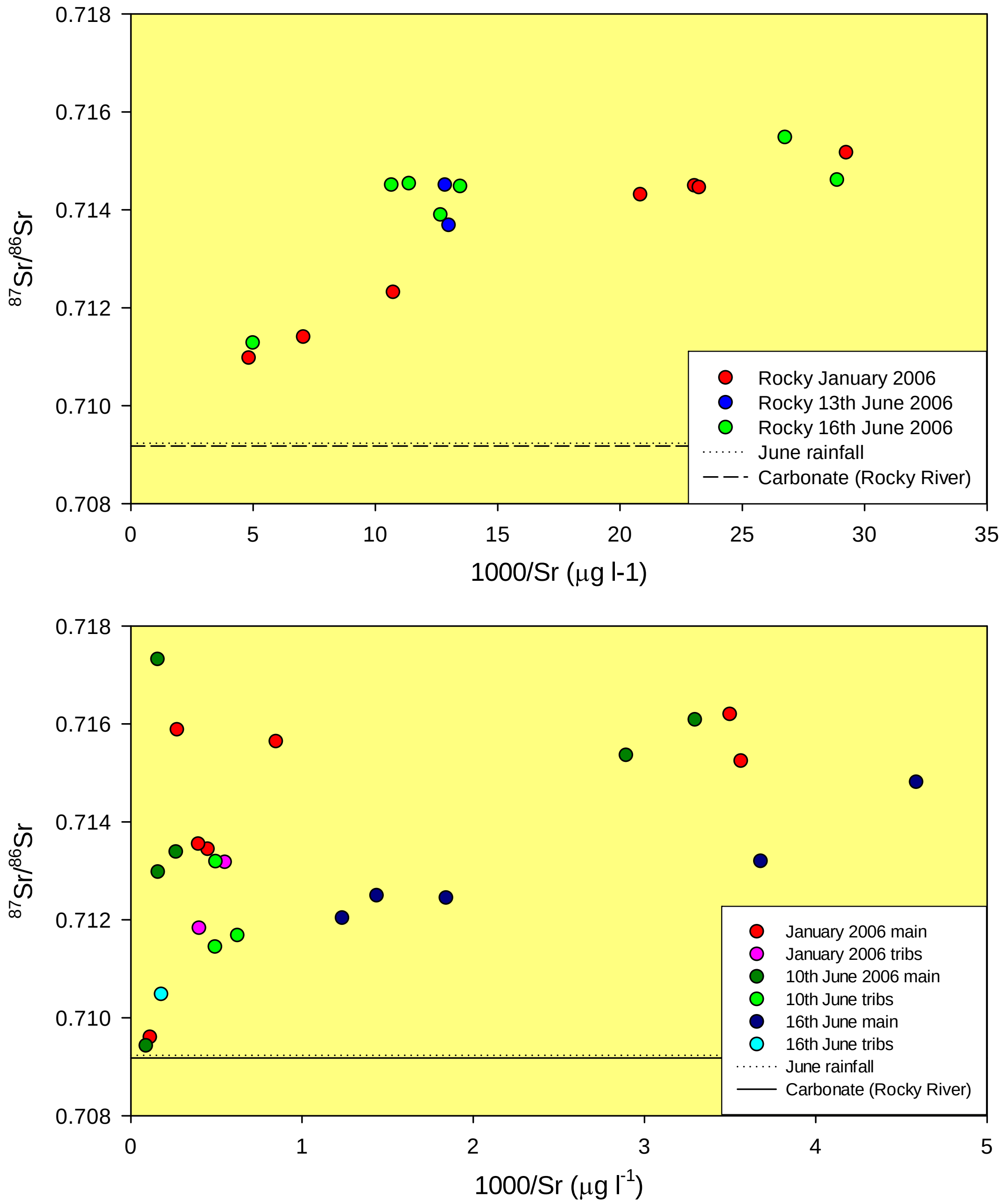

Figure 5.6 Sr isotope variations in the Rocky River (top) and Cygnet River (bottom) catchments

The groundwaters sampled on Kangaroo Island, although limited, also show a wide range of compositions (Fig. 5.5). Although no boreholes are currently present in the pristine Rocky River catchment, it is likely that it will be fresh, similar to the river. The freshest groundwaters in the Cygnet River catchment were present in the upper reaches. One of these, borehole CV1 (Figs 4.15 and 4.16a–b) showed a strong evaporated signature similar to surface waters, and is probably recharged from the overlying dammed lake. Such a low salinity groundwater may be of value in times of drought and similar situations, if present elsewhere on Kangaroo Island; indicating opportunities for artificial recharge and recovery management options. The other fresh groundwater, AG1 was similar to rainfall and may represent rapid recharge through the unsaturated zone. Samples RB1 and PF1 (slightly evaporated isotope signature) were close to the Adelaide Meteoric Line, but were more saline (SEC of 5560 and 6510 µS cm^{-1} respectively). The groundwaters had a wide range of Sr isotope compositions (Fig. 5.7). The sample from close to the estuary (K4) had a ratio identical to that of seawater. The other samples had much higher ratios, indicating that evaporation of marine-derived salt alone cannot explain the origin of dissolved components in the water, and an important contribution from silicate minerals is required. Although the Sr isotope data are limited, they do highlight the usefulness of this natural tracer in helping determine sources of salinity and mechanisms of streamflow generation.

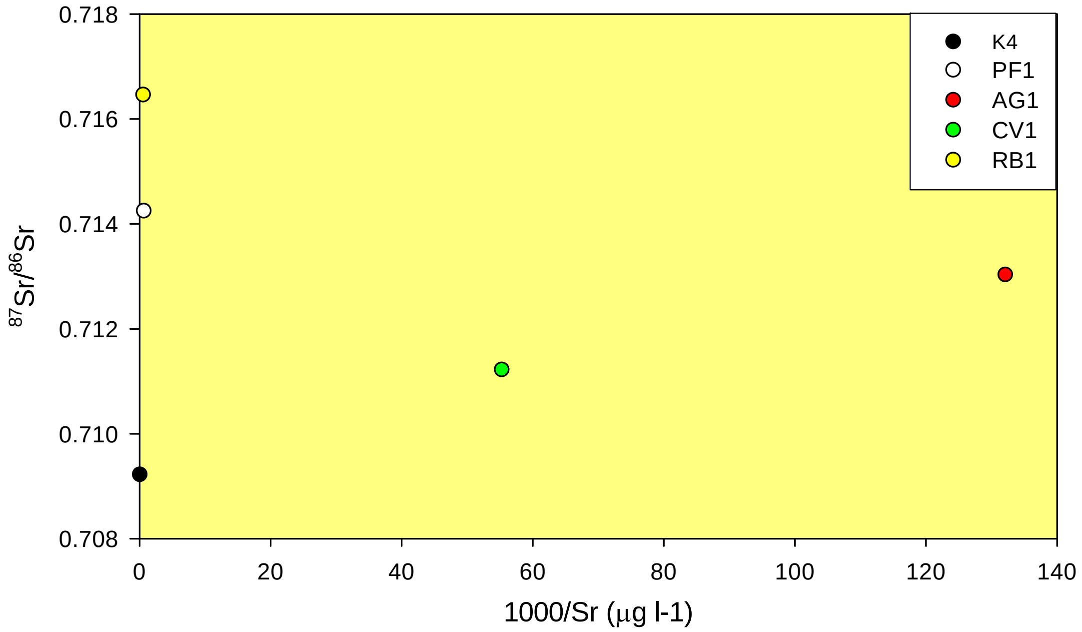

Figure 5.7 Sr isotope variations in groundwater in the Cygnet River (bottom)

6. SUMMARY AND FUTURE DIRECTIONS

Although very limited groundwater chemistry data exists for Kangaroo Island, the presence of fresh groundwater indicates potential for a valuable resource, even if at a local scale.

Further work is recommended to assess the groundwater resource potential of the island, both for use and the potential for aquifer storage and recharge management options.

There are significant differences in salinity between the catchments on Kangaroo Island. The important role that groundwater plays in determining such salinity variations and also the role it plays in stream flow generation across the island is poorly understood. Further work is needed to understand the role that groundwater plays in transporting solutes to rivers and their importance in controlling stream water quality and maintaining the integrity of water dependent ecosystems.

Further work is critical to provide an increased understanding of the spatial and hydraulic interconnectivity between surface water and groundwater systems.

To enable sustainable management of the water resources on Kangaroo Island, it is essential to have a thorough understanding of the available resources. This study contributes critical technical input into the water allocation planning process by determining the accuracy of the water resources available for use.

It is critical that the management of water resources uses an integrated natural resource management approach and that all stakeholder roles and responsibilities are clearly defined.

The impact of land clearance on the water quality of the island is not known in detail. Although previous studies indicate that land use change is likely to have had a significant impact on the salinity of surface waters, saline waters are also likely to have exited in some areas prior to such change. However, limited historical data exist and few areas remain which have not been potentially impacted by land use change.

It is strongly recommended that the Rocky River catchment be considered an area of high priority in terms of understanding the hydrogeology and geology. It is the last remaining catchment unimpacted by anthropogenic activities in South Australia and should be protected accordingly. A comparison of the Rocky River catchment with a similar sized adjacent cleared catchment (paired catchment study) would provide knowledge on how land clearance and other activities modify the mechanisms that control how water reaches rivers, their timescales and the effects on water quality.

UNITS OF MEASUREMENT

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

Name of unit	Symbol	Definition in terms of other metric units	Quantity
Day	d	24 h	time interval
Gigalitre	GL	10^6 m^3	volume
Gram	g	10^{-3} kg	mass
Hectare	ha	10^4 m^2	area
Hour	h	60 min	time interval
Kilogram	kg	base unit	mass
Kilolitre	kL	1 m^3	volume
Kilometre	km	10^3 m	length
Litre	L	10^{-3} m^3	volume
Megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
Microgram	µg	10^{-6} g	mass
Microlitre	µL	10^{-9} m^3	volume
Milligram	mg	10^{-3} g	mass
Millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
Minute	min	60 s	time interval
Second	s	base unit	time interval
Tonne	t	1000 kg	mass
Year	y	365 or 366 days	time interval

~	approximately equal to
δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Act (the). In this document, refers to The *Natural Resources Management Act* (South Australia) 2004.

Adaptive management. A management approach, often used in natural resource management, where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Algal bloom. A rapid accumulation of algal biomass (living organic matter) which can result in deterioration in water quality when the algae die and break down consuming the dissolved oxygen and releasing toxins.

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

Anabranch. A branch of a river that leaves the main stream.

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

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

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test. A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

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

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

Arid lands. In South Australia arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broad acre cropping.

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

Artificial recharge. The process of artificially diverting water from the surface to an aquifer. Artificial recharge can reduce evaporation losses and increase aquifer yield. *(See recharge, natural recharge, aquifer.)*

Barrage. Specifically any of the five low weirs at the mouth of the River Murray constructed to exclude seawater from the Lower Lakes.

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.)

Basin. The area drained by a major river and its tributaries.

Benchmark condition. Points of reference from which change can be measured.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Biota. All of the organisms at a particular locality.

Bore. *See well.*

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

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the Water Resources Act 1997.

Codes of practice. Standards of management developed by industry and government, promoting techniques or methods of environmental management by which environmental objectives may be achieved.

Cone of depression. An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction which exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

Conjunctive use. The utilisation of more than one source of water to satisfy a single demand.

Council of Australian Governments (COAG). A council of the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association which exists to set national policy directions for Australia.

CWMB. Catchment Water Management Board.

Dams, off-stream dam. A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted, or pumped, from a watercourse, a drainage path, an aquifer or from another source. Off-stream dams may capture a limited volume of surface water from the catchment above the dam.

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

Dams, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

Diffuse source pollution. Pollution from sources such as an eroding paddock, urban or suburban lands and forests; spread out, and often not easily identified or managed.

District Plan. (District Soil Conservation Plan) An approved soil conservation plan under the repealed *Soil Conservation Act 1989*. These plans are taken to form part of the relevant regional NRM plans under the transitional provisions of the *Natural Resources Management Act 2004* (Schedule 4 – subclause 53[4] until regional NRM plans are prepared under Chapter 4, Part 2 of the Act.

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.

Domestic wastewater. Water used in the disposal of human waste, for personal washing, washing clothes or dishes, and swimming pools.

DSS (decision support system). A system of logic or a set of rules derived from experts, to assist decision making. Typically they are constructed as computer programs.

DSS. Dissolved suspended solids.

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

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

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

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

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

Ecosystem Services. All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities.

Effluent. Domestic wastewater and industrial wastewater.

EIP. Environment improvement program.

EMLR. Eastern Mount Lofty Ranges.

Entitlement flows. Minimum monthly River Murray flows to South Australia agreed in the Murray-Darling Basin Agreement 1992.

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.

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

EP. Eyre Peninsula.

EPA. Environment Protection Agency.

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

Erosion. Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

ESD. Ecologically sustainable development *(see above for definition)*.

Estuaries. Semi-enclosed waterbodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences and experience periodic fluctuations and gradients in salinity.

Eutrophication. Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom).*

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

Fishway. A generic term describing all mechanisms that allow the passage of fish along a waterway. Specific structures include fish ladders (gentle sloping channels with baffles that reduce the velocity of water and provide resting places for fish as they 'climb' over a weir) and fishlifts (chambers, rather like lift-wells, that are flooded and emptied to enable fish to move across a barrier).

Floodplain. Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the Water Resources Act 1997; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the Development Act 1993, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

Flow bands. Flows of different frequency, volume and duration.

GAB. Great Artesian Basin.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GIS (geographic information system). Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL. *See gigalitre.*

Greenhouse effect. The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

Geological features. Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Greywater. Household wastewater excluding sewage effluent. Wastewater from kitchen, laundry and bathroom.

Groundwater. *See underground water.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Heavy metal. Any metal with a high atomic weight (usually, although not exclusively, greater than 100), for example mercury, lead and chromium. Heavy metals have a widespread industrial use, and many are released into the biosphere via air, water and solids pollution. Usually these metals are toxic at low concentrations to most plant and animal life.

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

Hydrography. The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

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.)*

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

Indigenous species. A species that occurs naturally in a region.

Industrial wastewater. Water (not being domestic wastewater) that has been used in the course of carrying on a business (including water used in the watering of irrigation of plants) that has been allowed to run to waste or has been disposed of or has been collected for disposal.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or by mechanical means.

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

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Lake. A natural lake, pond, lagoon, wetland or spring (whether modified or not) and includes: part of a lake; and a body of water declared by regulation to be a lake; a reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

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

Land capability. The ability of the land to accept a type and intensity of use without sustaining long-term damage.

Leaching. Removal of material in solution such as minerals, nutrients and salts through soil.

Licence. A licence to take water in accordance with the Water Resources Act 1997. *(See water licence.)*

Licensee. A person who holds a water licence.

Local water management plan. A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

Macro-invertebrates. Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

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

Mount Lofty Ranges Watershed. The area prescribed by Schedule 1 of the regulations.

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

NHMRC. National Health and Medical Research Council.

NHT. Natural Heritage Trust.

Natural Resources. Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

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.

Occupier of land. A person who has, or is entitled to, possession or control of the land.

Owner of land. In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Palaeochannels. Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

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

Percentile. A way of describing sets of data by ranking the data set and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

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

Personal property. All forms of property other than real property. For example, shares or a water licence.

Phreaphytic vegetation. Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phytoplankton. The plant constituent of organisms inhabiting the surface layer of a lake; mainly single-cell algae.

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

Pollution, diffuse source. Pollution from sources that are spread out and not easily identified or managed (e.g. an eroding paddock, urban or suburban lands and forests).

Pollution, point source. A localised source of pollution.

Potable water. Water suitable for human consumption.

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

Precautionary principle. Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

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

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

Property right. A right of ownership or some other right to property, whether real property or personal property.

Proponent. The person or persons (who may be a body corporate) seeking approval to take water from prescribed water.

PWA. Prescribed Wells Area.

PWCA. Prescribed Watercourse Area.

PWRA. Prescribed Water Resources Area.

Ramsar Convention. This is an international treaty on wetlands titled The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The Convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

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

Reclaimed water. Treated effluent of a quality suitable for the designated purpose.

Rehabilitation (of waterbodies). Actions that improve the ecological health of a waterbody by reinstating important elements of the environment that existed prior to European settlement.

Remediation (of waterbodies). Actions that improve the ecological condition of a waterbody without necessarily reinstating elements of the environment that existed prior to European settlement.

Restoration (of waterbodies). Actions that reinstate the pre-European condition of a waterbody.

Reticulated water. Water supplied through a piped distribution system.

Riffles. Shallow stream section with fast and turbulent flow.

Riparian landholder. A person whose property abuts a watercourse or through whose property a watercourse runs.

Riparian rights. These were old common law rights of access to, and use of water. These common law rights were abolished with the enactment of the Water Resources Act 1997, which now includes similar rights under s. 7. Riparian rights are therefore now statutory rights under the Act. Where the resource is not prescribed (Water Resources Act 1997, s. 8) or subject to restrictions (Water Resources Act 1997, s. 16), riparian landholders may take any amount of water from watercourses, lakes or wells without consideration to downstream landholders, if it is to be used for stock or domestic purposes. If the capture of water from watercourses and groundwater is to be used for any other purpose then the right of downstream landholders must be protected. Landholders may take any amount of surface water for any purpose without regard to other landholders, unless the surface water is prescribed or subject to restrictions.

Riparian zone. That part of the landscape adjacent to a water body, that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses.

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.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

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

Stormwater. Runoff in an urban area.

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.

Taxa. General term for a group identified by taxonomy — which is the science of describing, naming and classifying organisms.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Total kjeldhal nitrogen (TKN). The sum of aqueous ammonia and organic nitrogen. Used as a measure of probable sewage pollution.

Transfer. A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period.

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

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Wastewater. *See domestic wastewater, industrial wastewater.*

Water affecting activities. Activities referred to in Part 4, Division 1, s. 9 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based. An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water use year.

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.

Water licence. A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Water service provider. A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

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; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

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

Water-use year. The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

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

Wetlands. Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic/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.

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