TECHNICAL REPORT

PRELIMINARY INVESTIGATION OF SEAWATER INTRUSION INTO A FRESH WATER COASTAL AQUIFER – LOWER SOUTH EAST

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Government of South Australia
Department of Environment, Water and Natural Resources

PRELIMINARY INVESTIGATION OF SEAWATER INTRUSION INTO A FRESHWATER COASTAL AQUIFER – LOWER SOUTH EAST

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FOREWORD

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector and that the best skills and expertise are used to inform decision making.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The Tertiary unconfined aquifer (TLA) is the main source of freshwater for human consumption, irrigation, industrial and environmental users in the coastal aquifer of the Lower Limestone Coast (LLC) of South Australia. The TLA is also the main source of freshwater for many groundwater dependent ecosystems (GDEs) found in the LLC, many of which support extremely high biodiversity and provide habitat for many regionally and nationally threatened species.

This fresh groundwater aquifer is vulnerable to salinisation by seawater intrusion due to over exploitation of the resource and climatic changes, which may respectively cause the lowering of the groundwater hydraulic head, and reduced recharge into the unconfined aquifer.

Previous work indicated that the freshwater–saltwater interface in the freshwater coastal aquifer has been detected in the Hundreds of MacDonnell, Caroline and Kongorong. The risk of seawater intrusion into the coastal aquifer in the region has not been previously studied in detail.

This report documents the work undertaken during the investigation of seawater intrusion into the coastal aquifer in the coastal area of the Lower Limestone Coast Prescribed Wells Area (LLC PWA) in Hundreds of Caroline, MacDonnell and Kongorong.

Due to lack of monitoring wells in the deeper part of the unconfined aquifer, the investigation included drilling new observation wells into deeper units of the TLA. Groundwater and surface water samples were taken from observation wells and surface water bodies respectively between August 2008 and March 2011 and tested for general chemical constituent and stable isotopes. Surface water samples were targeted at key groundwater depend ecosystems (GDEs), particularly karst rising spring systems.

The interpretation of drilling cuttings along with existing information obtained from the State database (SA Geodata) was used to construct a 3-D hydrostratigraphic model. The analysis of water chemistry indicates the presence of seawater in some units of the TLA up to 1.5 km from the coast.

The hydrochemical processes that have been detected in the study area include simple mixing between seawater and fresh aquifer water and cation exchange reactions.

The detection of a freshwater-saltwater interface does not automatically mean that active seawater intrusion is occurring, in response to groundwater extraction. At most of the sites where the interface was intersected, there is no historical information available on the ‘pre-development’ location of the interface and hence it is not possible to determine if any intrusion has occurred.

The only evidence of a dynamic freshwater-saltwater interface occurs in the Eight Mile Creek area, where groundwater salinities are slowly increasing and salinity profiles show seasonal changes.

Long-term monitoring is necessary to determine if seawater intrusion is actively occurring in the Eight Mile Creek area and the other areas where the interface between freshwater and seawater has been intersected.

1. INTRODUCTION

1.1. BACKGROUND

The coastal area south of Mount Gambier is underlain by two regional aquifers; the unconfined Tertiary Limestone Aquifer (TLA) and the Tertiary Confined Sand Aquifer (TCSA). There is no major natural surface drainage in the area except coastal creeks and springs and the Glenelg River, where a short reach of the river crosses the Victorian Border into South Australia (Fig. 1).

The unconfined aquifer is the major water source for intensive agriculture and nationally significant groundwater dependent ecosystems (GDEs) in the coastal zone of the Lower South East of South Australia.

Fresh groundwater in coastal aquifers is vulnerable to salinisation by seawater intrusion due to increasing extraction of the resource and climatic changes, which causes the lowering of the groundwater hydraulic head and reduced recharge into the unconfined aquifer. The threat of sea level rise, which could increase the risk of inland salt water migration into the aquifer, is a potential threat to coastal groundwater resources.

Saline groundwater intrusion has the potential to result in significant economic and environmental impacts. It is estimated that approximately 2527 ha of agriculture may be at risk, equating to a potential current regional economic impact of $31 million (DPLG, 2011). Groundwater dependent ecosystems such as nationally important karst wetland systems, Piccaninnie Ponds and Ewens Ponds, may also be at risk.

Freshwater ecosystems of the Lower South East support extremely high biodiversity and provide habitat for many regionally and nationally threatened species (Harding, 2012). The study region is home to a diverse range of aquatic dependent ecological assets including the only South Australian populations of Variegated Pygmy Perch (*Nannoperca variegata*) and Glenelg Spiny Crayfish (*Euastacus bispinosus*), both listed under the Environment Protection and Biodiversity Conservation Act 1999.

The advent of large scale irrigation using centre pivots in the 1990s, resulted in increasing extractions in near coastal areas, meaning that the risk of seawater intrusion into the regional unconfined aquifer became greater. Investigation into this possibility was listed as a high priority by the South East Natural Resources Management (NRM) Board.

Initial studies indicate that the freshwater-saltwater interface in the freshwater coastal aquifer has been detected in the Hundreds of MacDonnell, Caroline and Kongorong. Coastal monitoring wells reveal salinity levels exceeding 25 000 mg/L. The highest risk for seawater intrusion is due to irrigation extraction which could cause a reversal of groundwater movement which is currently toward the coast. Reduced recharge due to climate change may further exacerbate this process. Recent years with below-average annual rainfall has resulted in reduced recharge to the unconfined aquifer and also increased extraction.

The risk of seawater intrusion into the coastal aquifer in the region had not been studied in detail and there was insufficient monitoring infrastructure available to adequately determine the risk posed to GDEs and agriculture in the coastal zone of the Lower South East.

1.2. PREVIOUS WORK

During the drilling of a production well for the Carpenter Rocks town water supply, salt water was intercepted at depth of about 25 m below ground level at a distance of 350 m inland from the coast (Barnett, 1976). The well was abandoned and a second production well was further drilled at 500 m inland to the depth of 25 m and obtained sufficient fresh water.

Following the drilling of the second Carpenter Rocks town water supply well, a resistivity survey was conducted using a series of Schlumberger vertical electrical sounding near Carpenter Rock township to determine the depth to the seawater interface. The result of the geophysical survey indicates that close to the shore, the natural freshwater-saltwater interface dips steeply inland and then levels off at a depth of 40-45 m (Roberts, 1976). The result of the geophysical survey was used to calculate the safe yield for the second production well (Barnett, 1976).

Numerical groundwater modelling undertaken in the area south of Mount Gambier (Stadter and Yan, 2000) highlighted the need to examine in more detail the position of the freshwater-saltwater interface in the unconfined aquifer adjacent to the coast and to determine the likelihood of any adverse impacts to existing and potential groundwater users. If the freshwater–saltwater interface is located beneath the land surface, the potential exists for saline groundwater to be extracted if over-extraction of the groundwater is to occur. The encroachment of saline groundwater may also have an adverse effect on the ecologically-sensitive groundwater springs that are located in the area.

Based on the recommendations of the modelling report (Stadter and Yan, 2000), DEWNR (formerly DWLBC) initiated a geophysical survey along the coastal area in 2002, using the transient electromagnetic method (TEM) over five traverses (Fig. 1) to determine the presence and depth to the freshwater-saltwater interface (King and Dodds, 2002).

The results from the TEM survey did not conclusively determined the position of the freshwater–saltwater interface that is located along the coast, but it has indicated the presence of a strong conductor below the watertable, which may represent the saline interface (King and Dodds, 2002). Also, salinity profiling in conjunction with the TEM survey has established that the freshwater–saltwater interface is present in the vicinity of observation wells CAR 10 and CAR 11.

King and Dodds (2002), also suggested that when present, the depth to the saltwater interface increases rapidly close to the coast but apparently flattens at a depth of ~200 m, and that additional drilling is required to confirm the relationship between geology and geophysics, and to verify that the presence of strong conductors at a depth of ~200 m is due to the saltwater interface.

The department commenced a drilling program in 2002 to further the understanding of the hydrostratigraphy of the TLA. A site near Eight Mile Creek about 1.5 km inland from the coast, was selected to drill a number of observation wells targeting different units within the TLA and the TCSA. The location of the drilling sites coincided with TEM traverse 2 (Fig. 1) in order to ground truth the location of freshwater–saltwater interface estimated by King and Dodds (2002).

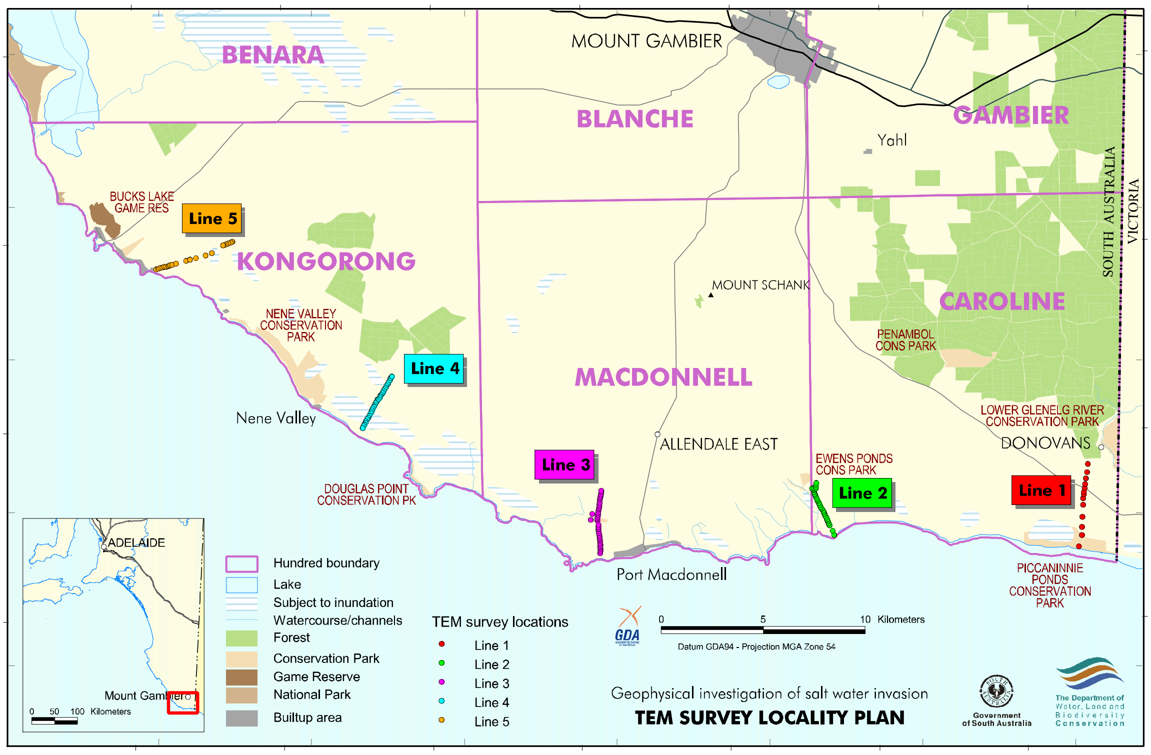


Figure 1. Location of geophysical traverses (source: King and Dodds, 2002)

Saline groundwater (~ 45 000 EC) was intercepted at about 150 m depth in the Camelback Member of the TLA at a distance of about 1.3 km inland from the coast and was in reasonable agreement with the depth of 140 m estimated by the King and Dodds (2002) at 1.6 km from the coast, considering the constraints and limitation of the geophysical survey.

Previous investigations of the hydrochemistry and isotopic tracers of groundwater discharge into aquatic ecosystems within the study area undertaken by REM (2007) and Wood (2011) have determined high levels of groundwater dependence for several high value aquatic ecosystems including Piccaninnie Ponds, Pick Swamp, Crescent Pond, Jerusalem Creek, Cress Creek and Ewens Ponds.

Wood (2011) concluded that the shallow systems (such as Cress Creek and Jerusalem Creek) have a strong dependence on seasonal groundwater discharge from the upper units of the regional TLA and are most vulnerable to fluctuations in groundwater level. The deeper perennial systems (Ewens Ponds and Piccaninnie Ponds) also have a strong dependence on groundwater discharge from the upper units of the TLA; however hydrochemical data suggests there is a small component of discharge from the deeper sub-units of the TLA.

1.3. HYDROGEOLOGY

The study area includes the coastal areas of the Lower South East of South Australia (Fig. 2). The region is typified by a Mediterranean climate with hot, dry summers and cool, wet winters. Annual rainfall ranges from more than 750 mm in the south to about 450 mm in the north. The annual evapotranspiration increases northward from 1400 mm to about 1800 mm. Rainfall recharge occurs to the unconfined aquifer when winter precipitation exceeds evapotranspiration, generally between May and September.

The geology of the study area is characterised by the Gambier Limestone Formation, which is an extensive shallow-water shelf carbonate of Eocene to Miocene age (James and Bone 1989) deposited approximately 30 to 90 million years ago.

During the Pleistocene Period about 1.6 million years ago, a number of marine transgressions and regressions deposited the sandstone of the Bridgewater Formation (Drexel and Preiss, 1995), which forms remnant shore lines on the current regional landscape. Extensive faulting has occurred over time.

The Gambier Limestone formation comprises most of the regional unconfined TLA, which also consists of the Bridgewater Formation and the Padthaway Formation. The Gambier Limestone formation is divided into seven distinct units which are currently mapped throughout the region (Li, *et al.*, 2000). Three of the seven units are recognized as distinct sub-aquifers in the study area (Table 1). These are Unit 1 and Unit 3 of the Green Point Member, and the deeper Camelback Member. South of the Tartwaup Fault and within the study area, the Camelback Member consists of a pale orange dolomite, partly recrystallised with abundant carbonate rhombs (Drexel and Preiss, 1995).

Table 1. General description of the Gambier Limestone Formation sub-units

Stratigraphic Unit	Stratigraphic Name	Hydrostrat Unit	Description
Thgr	Green Point Member	U1 U2 U3 U4 U5	Off white to cream bryzoal limestone, with or without chert Grey marl with abundant chert Cream to light grey bryzoal limestone, with or without chert Grey limestone with abundant marl Cream to off white limestone
Thgc	Camelback Member		Grey to pink dolomite
Thgg	Greenways Member		Grey marl with coarse bioclastic with frequent chert band, often glauconitic near base

1.4. LAND USE

Dairy farming and pasture irrigation are the main land use types in the area, with the main irrigation method by centre pivot. Other land uses include pasture grazing, plantation forestry (Hundred of Kongorong and Caroline), conservation, remanent vegetation and wetlands. The extent of the areas of pasture, plantation forestry and irrigation can be seen in Figure 2.

Harding (2012) generated an irrigation intensity layer from the 2008 licensed allocation data within the SE NRM region. The layer depicts an estimation of the total annual allocations (ML/km^2/y) as at June 2008, and although it may not reflect current annual usage, it does present the potential for groundwater development (Fig. 3). A large portion of high irrigation intensity occurs in the eastern half of the study region which has the potential to be a “hotspot” for abstractive use from the TLA. It should be noted that metered extraction data has only been available since 2008 and before this date, only estimates based on irrigated area have been used.

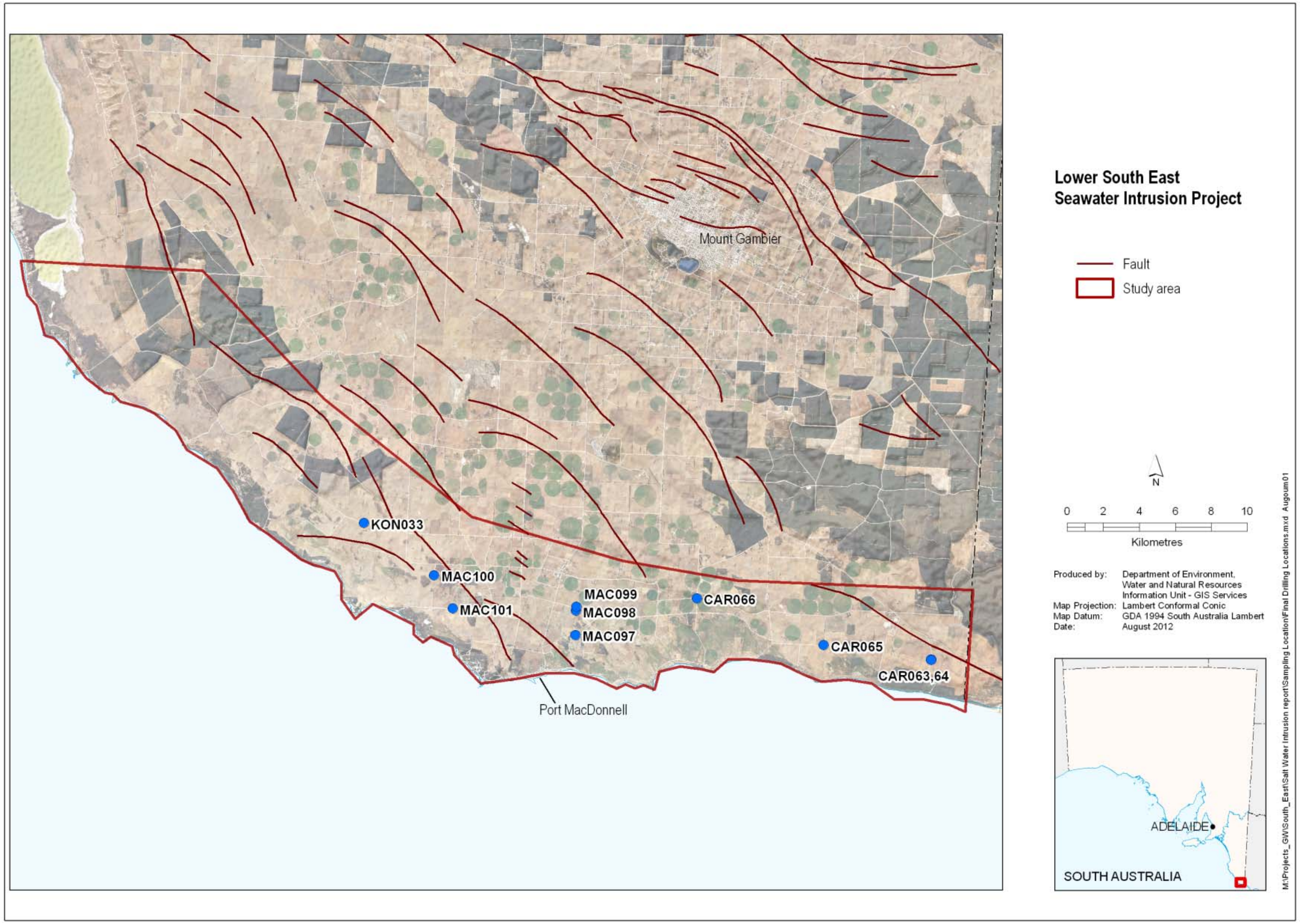


Figure 2. Map of the study area and final location of the drilling sites

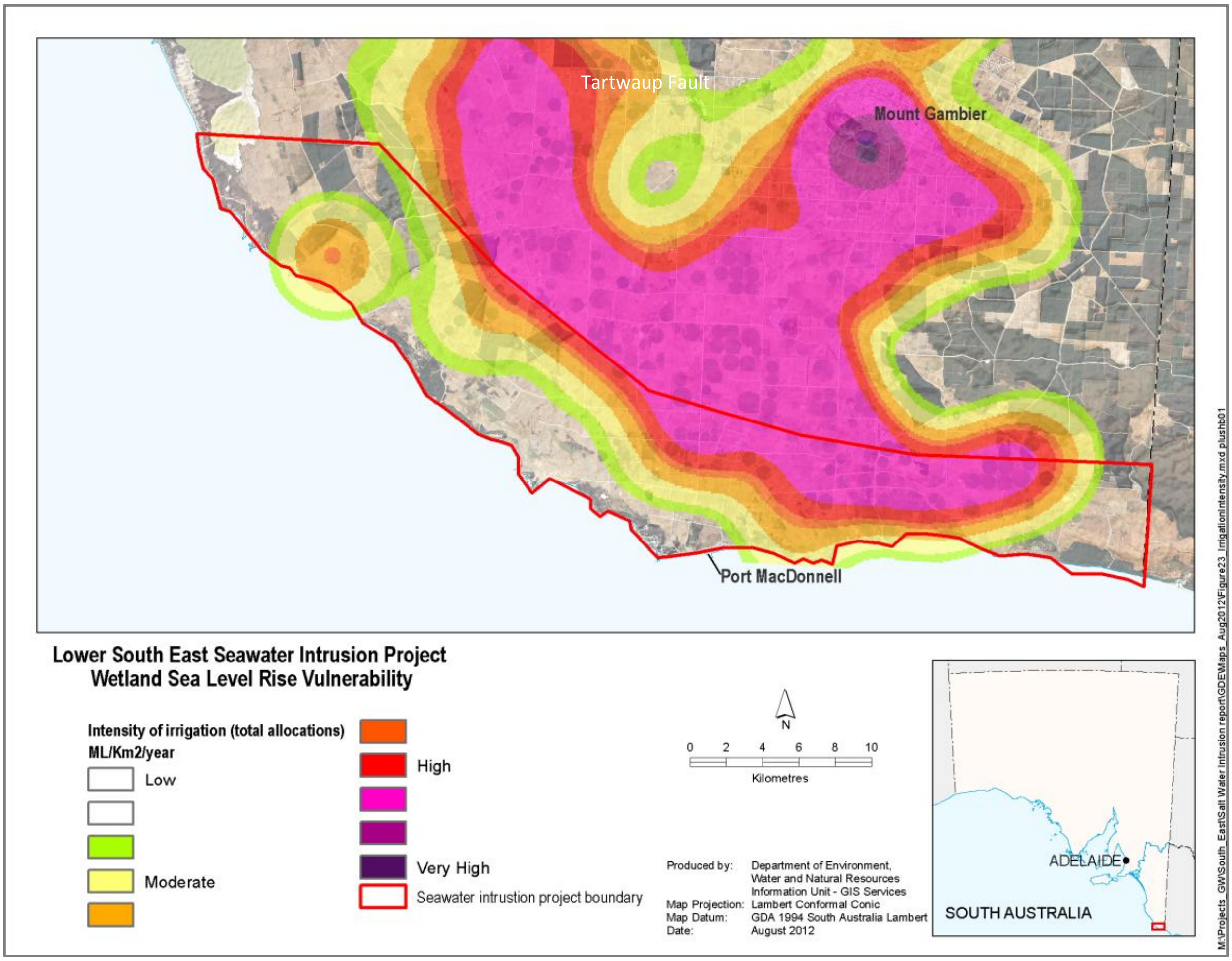


Figure 3. Intensity of groundwater extraction for irrigation within and up hydraulic gradient of the study region

1.5. GROUNDWATER DEPENDENT ECOSYSTEMS

A number of groundwater dependent ecosystems (GDEs) exist in the study area, with a number of karst rising springs including the nationally recognised Piccaninnie Pond, which is a complex karst wetland. These GDEs include:

- Ewens Ponds and Eight Mile Creek
- Piccaninnie Ponds/Pick Swamp complex
- Crescent Pond
- Jerusalem Creek
- Cress Creek
- Deep Creek.

GDEs can be described as any ecosystem that requires access to groundwater for some or all of its environmental water requirements (SKM, 2009). GDEs differ in the nature and degree to which they are reliant on groundwater, which complicates the process of determining how they will respond to changes in hydrogeological conditions, in this case seawater intrusion.

Flow discharge has been recorded from existing coastal creeks in the study. Figure 4 represent the hydrographs of creek discharges (ML/day) correlated to the cumulative rainfall. There is good correlation between the rainfall and discharge from these creeks. Land use change, such as increase in the intensity of abstraction, along with below average rainfall, is likely to further contribute to declines in discharge.

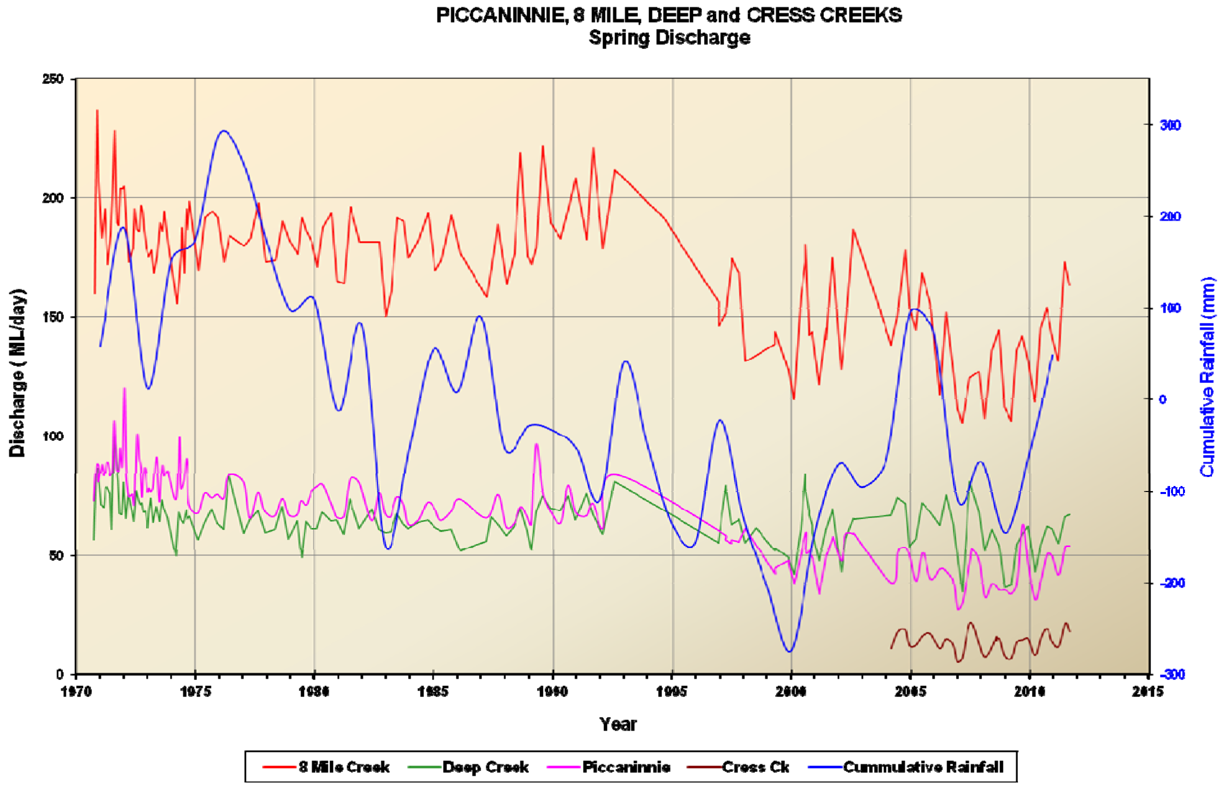


Figure 4. **Coastal spring discharge data for 8 Eight Mile Creek, Deep Creek, Piccaninnie Ponds, Cress Creek. The blue graph represents the cumulative rainfall for Mount Gambier at the Aerodrome weather station (BoM).**

1.6. AIM AND OBJECTIVES

The aim of this work is to investigate and assess the potential threat of seawater intrusion to the unconfined aquifer in the coastal areas of the Lower South East of South Australia (particularly in the Hundreds of Caroline, MacDonnell and Kongorong) to irrigation, industrial and environmental users of the groundwater resources in the study area.

The objectives of the current study, which was funded by Australian Government *Caring for Our Country Program*, are:

- to install investigation wells into the TLA at a depth of 150 m, near the Camelback Member of the TLA
- to sample groundwater and GDE sites in the coastal area for general chemical constituents, environmental isotopes, ^{14}C and radon
- to establish a monitoring program for the GDEs
- to develop a stratigraphic 3-D model of the TLA
- to develop a conceptual model for the process of seawater intrusion in the coastal aquifer
- to assess the threat of seawater intrusion into the unconfined aquifer.

2. METHODOLOGY

2.1. *REGIONAL GROUNDWATER LEVEL AND SALINITY MONITORING*

The department maintains a number of observation wells installed into the unconfined TLA, which are monitored quarterly for water level and groundwater salinity. Data loggers are also installed into some of these wells, which records water level and salinity at approximately 4 to 6 hourly intervals. The measured water levels are used to construct groundwater-level elevation maps with reference to the Australian Height Datum (AHD), to define the groundwater flow direction. The new wells drilled during the current project were added to the monitoring network and some were equipped with data loggers.

A number of irrigation wells have been drilled in near-coastal locations in recent years and as a first step to investigating seawater intrusion, the Department has commenced an ongoing sampling program of these wells to detect if any increase in salinity was occurring.

2.2. *DRILLING*

Seven sites were selected within the study area (Fig. 2) for the installation of new monitoring wells. The selection of the sites was associated with the previous geophysical investigation (Lines 1, 2 and 3 in King and Dodds, 2002) and areas where observation wells indicated high groundwater salinity, such as Eight Mile Creek and observation wells CAR010 and CAR011.

King and Dodds (2002) recommended further drilling to about 150–200 m deep below ground surface to validate the results of the geophysical survey. The aim of the drilling program was to target the Camelback Unit of the TLA as the 2002 drilling program indicated the presence of saline water in this unit at Eight Mile Creek.

During the drilling program, some difficulties including total loss of drilling circulation were encountered at two sites (MAC099 and MAC100). These wells were subsequently completed at depths of 116 m and 72 m below ground surface respectively. Alternate sites were selected and new wells (MAC098 and MAC101) were completed successfully at the desired depth of 162 m (Fig. 2).

The observation wells were constructed by installing 150 mm diameter class 18 PVC casing to the top of the Camelback Member of the TLA and/or about 150 m deep below ground surface. A 15 m long cement plug at the bottom of the casing was used to prevent any leakage/connection between the upper units of the TLA and the Camelback Member. At ground level, the casing was covered with a GATIC® cover. Details of the well construction are presented in Appendix A.

2.3. GEOPHYSICAL INVESTIGATION

Downhole geophysical logging was carried out in the new observation wells. The measured parameters included Gamma, Neutron, Spontaneous Potential (SP), Point Resistivity (PR) and Density. In the cased sections of the observation wells, the only meaningful parameters observed were the Gamma and the Neutron logs, as the SP, PR and Density measurements are valid only in the open hole section of the well.

The Neutron log data can be useful to estimate the porosity of the sedimentary unit if the neuron log is calibrated in the standard American Petroleum Institute (API) units. The tools used for this well-logging exercise were scaled in standard counts per seconds (CPS). An attempt was therefore made to convert the CPS units to API units using the following formula (Schlumberger, 1972):

$$\text{Porosity} = 2.7 * \text{Neutron (CPS)}/ (19*1000) \qquad (1)$$

In the above formula, the following values and assumption were used:

- a 2.7 API units per standard CPS was used as a conversion factor from CPS into API units (Schlumberger, 1972)
- using the 1000 API units equivalent to 19% porosity (Schlumberger, 1972).

2.4. HYDROCHEMISTRY

Groundwater and surface water samples were collected during November–December 2008, August 2009 and June 2010. In March 2011, groundwater samples for ^{14}C and SF_6 analysis were collected from the monitoring wells at the Eight Mile Creek site (CAR059, CAR060 and CAR061) and observation well CAR066 located about two kilometres north of the site.

During November and December 2008, water samples were collected from the State observation wells, private irrigation wells and surface water from the coastal creeks, drains, karst springs and wetlands. The samples were analysed for Cl, Br and SO_4 to establish an understanding of the background composition of the regional groundwater. The results of the analyses are presented in Appendix B.

The newly constructed observation wells were sampled in addition to existing wells in the study area for general chemistry in August 2009 and June 2010. A number of wells (CAR059, CAR060, CAR061 and CAR066), which were completed in different units of the TLA, were also sampled for ^{14}C, CFC, SF_6, radon and noble gases. Environmental isotope sampling was carried out during the August 2009 sampling round. Surface water samples were collected from Pick Swamp and Ewens Pond and several locations were sampled for ^{222}Ra. In addition, rainwater from Mount Gambier and seawater samples were also analysed. Details of the water composition are listed in Appendix B and the sample locations are shown in Figure 5.

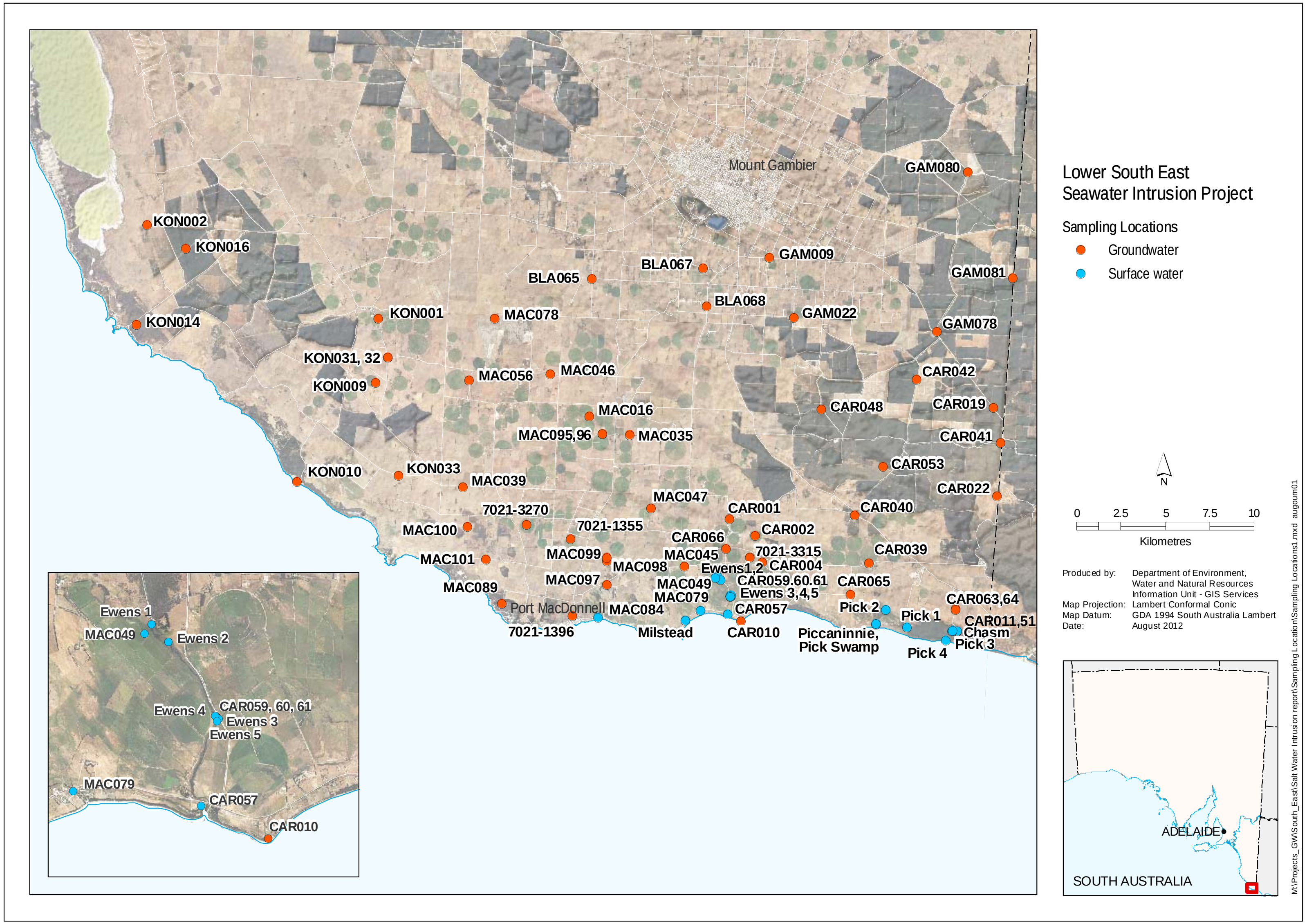


Figure 5. Map showing the sampling locations of groundwater and surface water

2.5. INTEGRATED GROUNDWATER AND SURFACE WATER MONITORING PROGRAM

The newly constructed wells were added to the network and are being monitored for water level and salinity (EC). Data loggers were installed on a number of the wells for continuous water level and salinity records.

As part of the South East GDEs monitoring project initiated by DEWNR, hydrogeological monitoring infrastructure was installed on the following sites within the project area (Fig. 6):

- Ewens Ponds
- Cress Creek
- Middle Point Swamp
- Pick Swamp/Piccaninnie Ponds.

Data collected from these sites were used by SKM (2010) to develop conceptual models for Ewens Ponds, Cress Creek and Middle Point Swamp (Appendix D). Pick Swamp was excluded from SKMs scope of work following development of a numerical model for this site by Aquaterra (2009).

Monitoring wells were installed at the above sites and equipped with loggers to monitor groundwater levels and in some cases, the salinity of the groundwater.

Groundwater salinity profiles were monitored by running a YSI-600XLM multi-parameter Sonde into a number of observations wells to investigate the salinity changes with depth and also to locate the presence of the freshwater–saltwater interface.

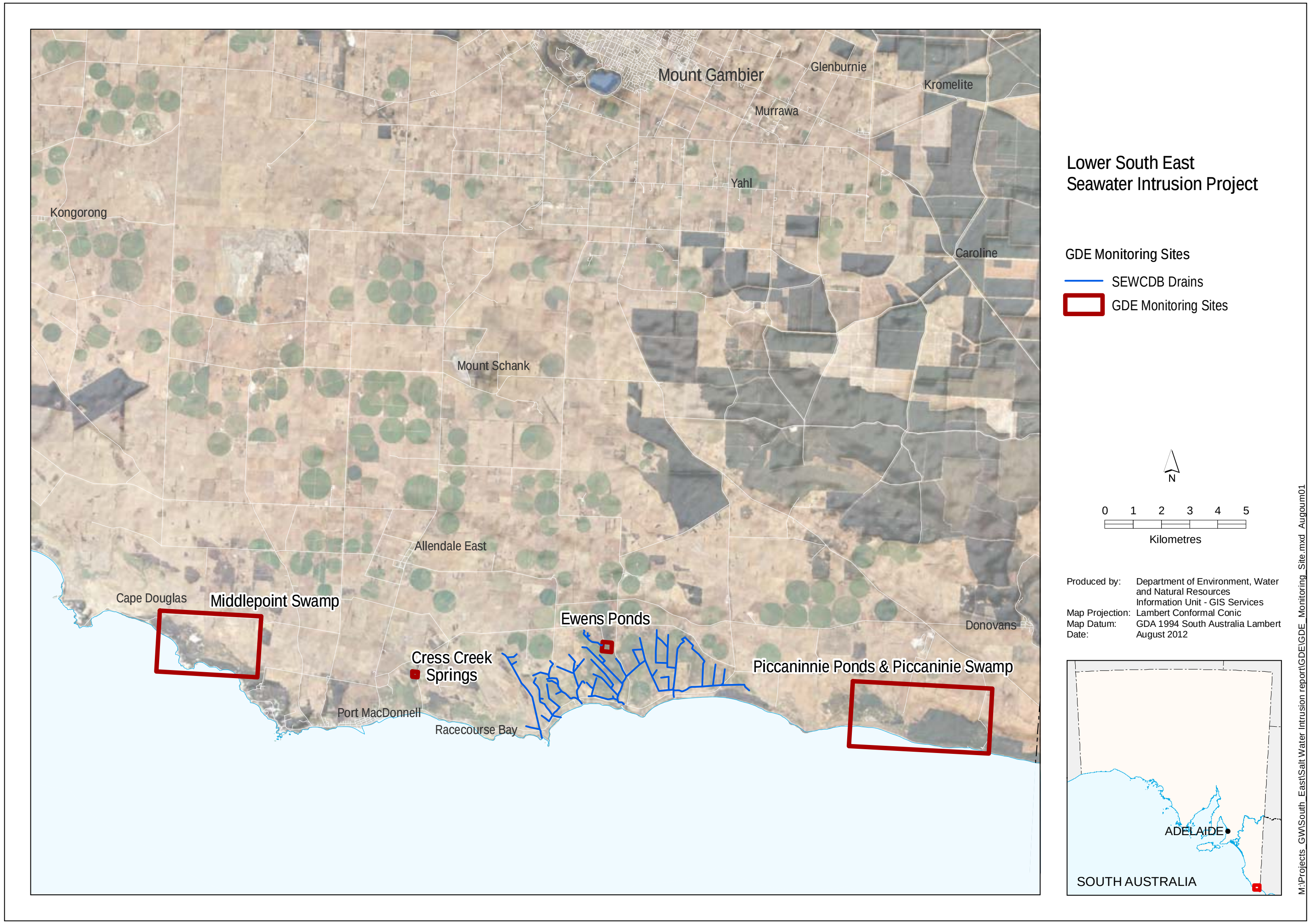


Figure 6. **Location of the monitoring sites for the case study GDEs within the project area**

3. RESULTS

3.1. DRILLING PROGRAM

Drilling cuttings were examined to construct the lithology logs for the wells drilled during this project. Drilling was carried at seven sites with a total of nine wells completed. The majority of the wells encountered the various units of the Gambier Limestone formation.

Two sites (KON033 and MAC101) encountered some variations to the general geological description of the Gambier Limestone as presented in Table 1. The lithology at these two sites is dominated by fossiliferous grey marl and marly limestone which contains abundant chert nodules and some pyritic minerals/marcasites grains. The lithology of these two wells may suggest that the depositional environment is different from the rest of the sites, possibly because they are located to the south of a major fault which trends in SE–NW direction (Fig. 2).

The lithological data from the wells drilled during the current investigation was used, in addition to existing lithology and the stratigraphy data in the SA Geodata, to construct a 3-D stratigraphic model of the study area (Fig. 7).

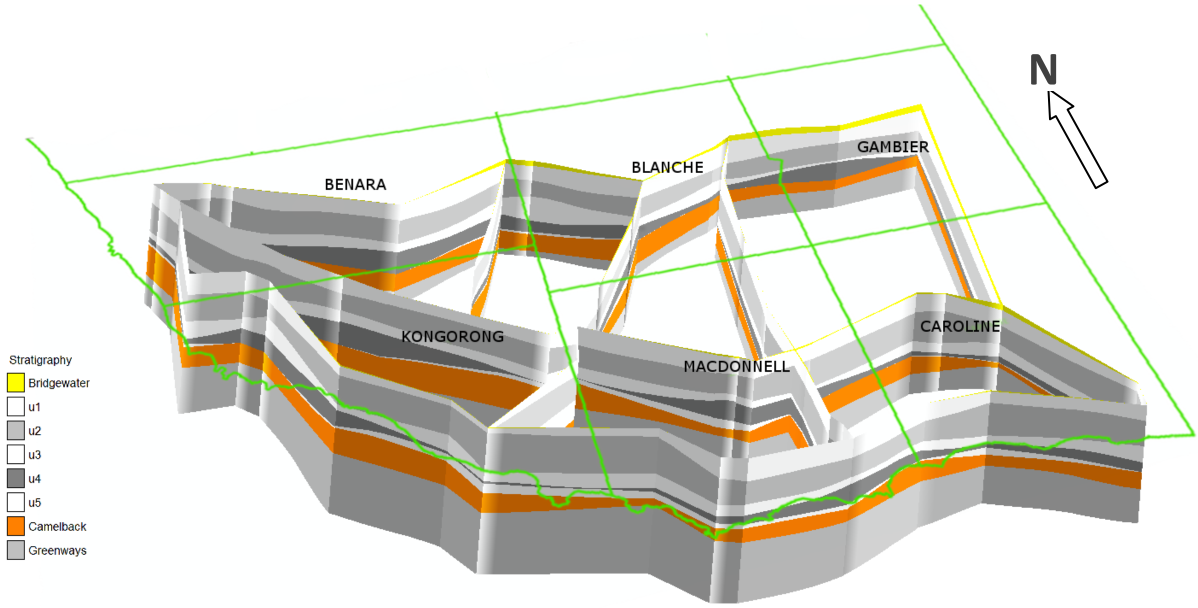


Figure 7. 3-D fence diagram of the study area compiled from stratigraphic information

3.2. GEOPHYSICAL INVESTIGATION

Equation 1 was used to calculate the porosity for the different units of the Gambier Limestone, using data from the Neutron logs. The estimated porosity values were in the range of 6–20% for the Camelback Member and between 4 and 13% for the other units of the TLA.

3.3. REGIONAL WATER LEVEL MONITORING

The results of groundwater level monitoring are presented in Figure 8, which presents the water level elevation contours (m AHD) constructed from June 2000 and June 2010 water-level records. The June 2000 period was used, because at that time the coastal area (particularly the Donovan Management Area) was fully allocated, but was not fully developed for irrigation. The regional groundwater-flow direction is generally in a south to south-east direction.

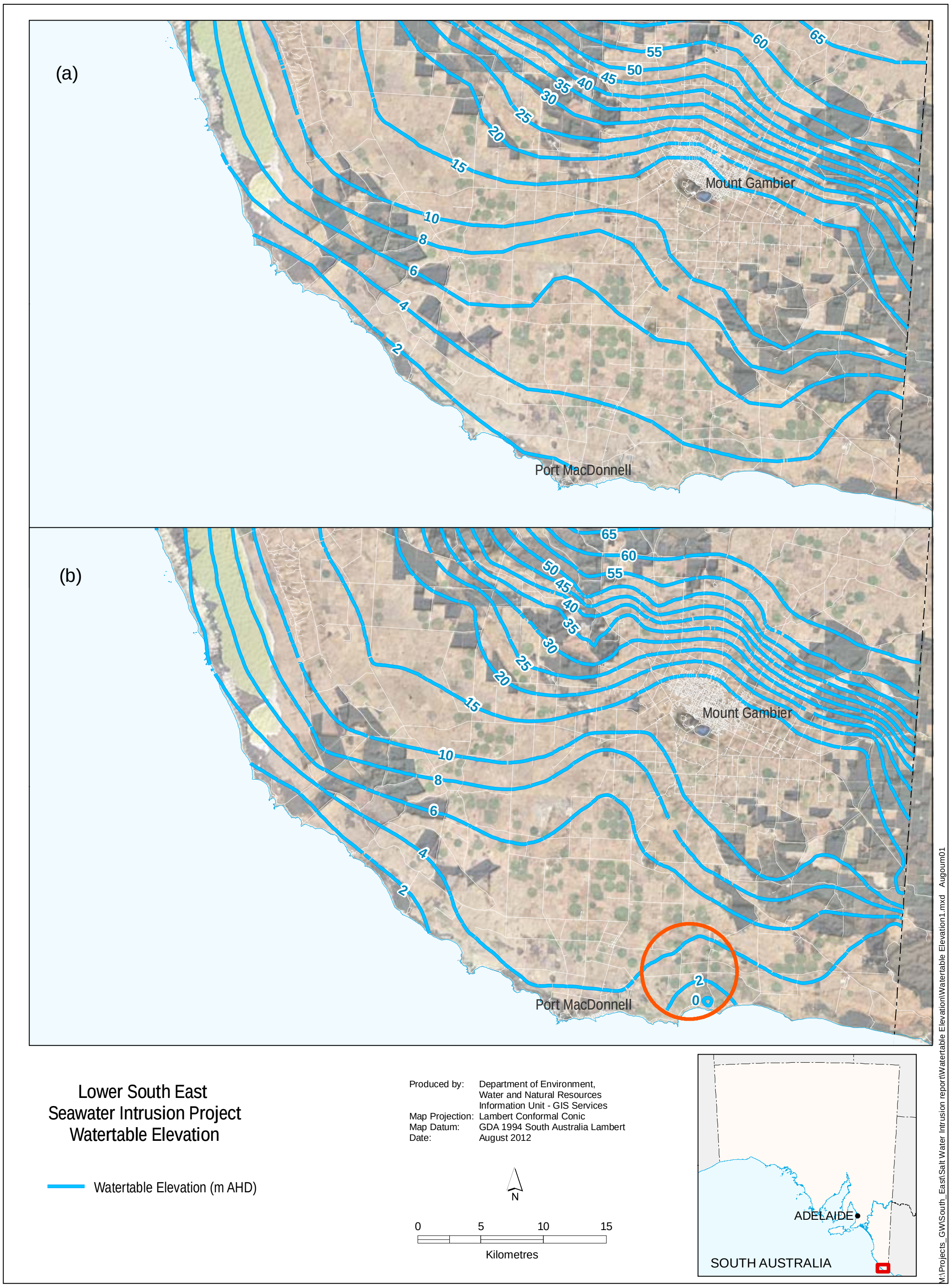


Figure 8. Groundwater level contours (m AHD) for (a) June 2000 and (b) June2010

The water level contours for June 2010 show a decrease in the groundwater elevation at the Eight Mile Creek site (circled area in Fig. 8) since June 2000. This change could be attributed to below average rainfall from 2005 to 2008, which would lead to higher extraction for irrigation (Fig. 9). Also, the area was highly developed for irrigation with many pivots established since 2000. Another factor could be the addition of new observation wells in the area (CAR059, CAR060 and CAR061) which refined the groundwater level contours.

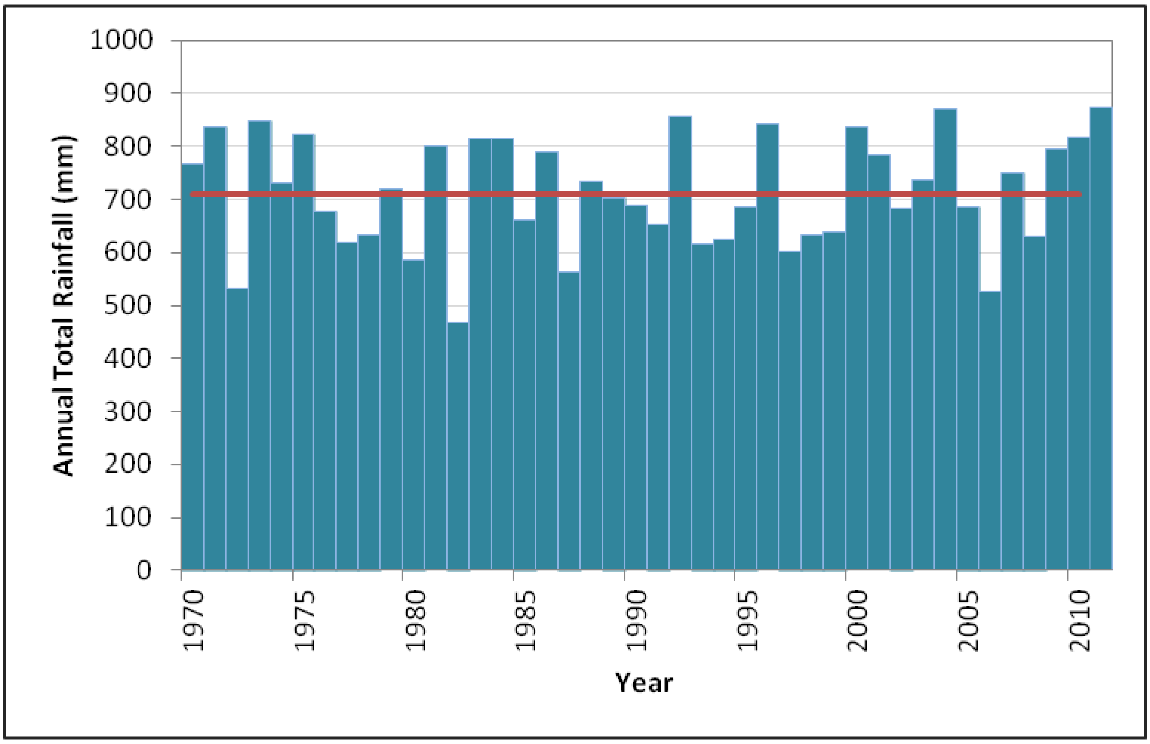


Figure 9. Annual total rainfall for Mount Gambier Aerodrome weather station. The red line represents the annual average rainfall. (source: BoM)

Figure 10 shows the change in groundwater level between the June 2000 and June 2010. The map indicates a decrease in water level of about 0.8 m at Eight Mile Creek site and no significant changes at Pick Swamp and Piccaninnie Ponds.

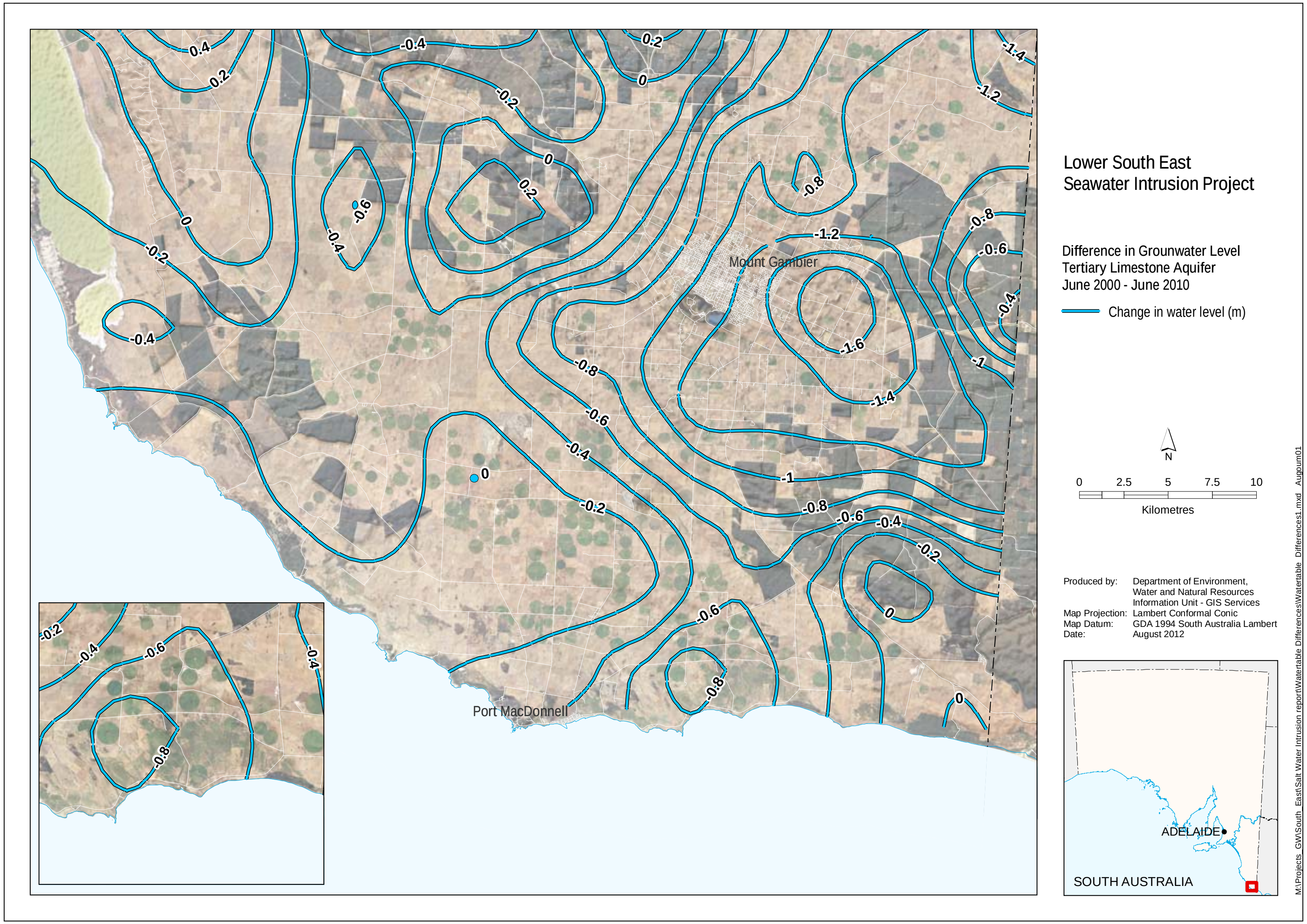


Figure 10 Change in groundwater levels (June 2000 – June 2010)

3.4. REGIONAL SALINITY MONITORING

The regional salinity monitoring has generally not detected widespread rising trends. There may be several causes of rising salinity trends apart from seawater intrusion, including land-use change and irrigation recycling. Figure 11 presents the only observation wells within three kilometres of the coast that are displaying rising trends.

Wells CAR059 and CAR061 are located together about 1 km inland from the coast. CAR059 is a shallow well 12 m deep, while CAR061 was completed at a depth of 180 m.

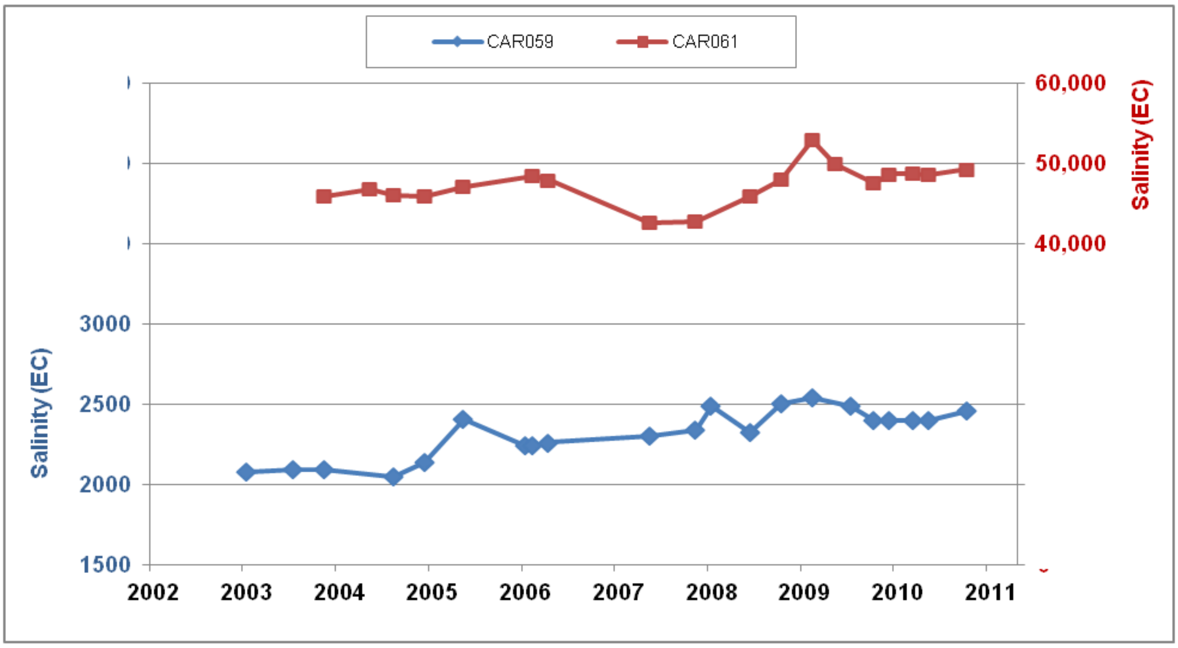


Figure 11. Groundwater salinity trends for observation wells CAR059 and CAR061

3.5. GROUNDWATER SALINITY PROFILES

A multi-parameter YSI-600XLM Sonde was run in observation wells CAR010, CAR011, CAR059, CAR060 and CAR061 to monitor the groundwater salinity change with depth. Salinity profiles were carried out monthly for observation wells CAR010 and CAR011. The results of the salinity profiles are presented in Figures 12 and 13.

Observation wells CAR059, CAR060 and CAR061 were drilled in 2002 during the hydrostratigraphic investigation program for the Lower South East region. Wells CAR059 and CAR060 were completed in Unit 1 and Unit 2 of the Green Point Member respectively and CAR061 was completed in the Camelback Member.

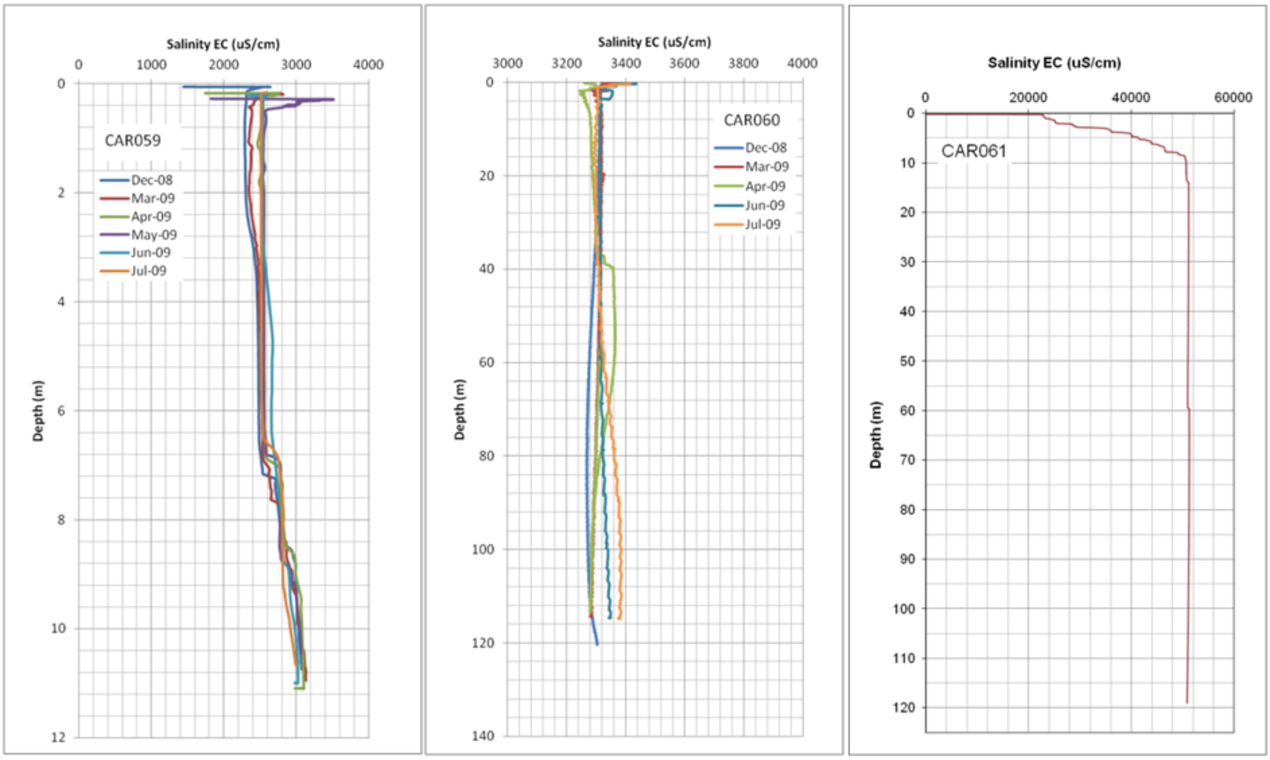


Figure 12. Groundwater salinity profiles for observation wells CAR059, CAR060 and CAR061

Observation well CAR059 is a shallow well 12 m deep completed with 4 m of PVC surface casing and an open hole completion for the remainder of the well. Groundwater salinities increase with depth from 2500 to 3000 EC with a slight change in water salinity at 7 m to 8.5 m deep. The shift in the water salinity also seasonally fluctuates upward and downward.

Well CAR060 was drilled to depth of 124 m. The well was constructed with PVC casing to depth of 116 m with the remainder open hole. The CAR060 salinity is about 3300 EC and does not show any significant change in water salinity with depth.

High salinities up to 50 000 EC are observed in CAR061 which is completed in the Camelback Member at a depth of 180 m. The well is cased to a depth of 154 m and left open hole for the rest of the well.

Observation wells CAR010 and CAR011 were drilled in 1972 as stratigraphic wells which fully penetrated the TLA. Both wells were constructed with open holes through the TLA with only 6 m of surface casing. CAR010 is situated right on the coast line, while CAR011 is located about two kilometres further inland from the shore.

During the drilling operation, water samples were collected from both CAR010 and CAR011 at various depths with the progression of the drilling. In November 2000, salinity profiles for both wells were investigated using the Hydrolab tool by the geophysical unit of DEWNR.

During the current investigation, salinity profiles were run in CAR010 and CAR011, using a multi-parameter YSI-XML600 instrument by DEWNR for several months during 2008–10. Figure 13 is a compilation of all the above profiles

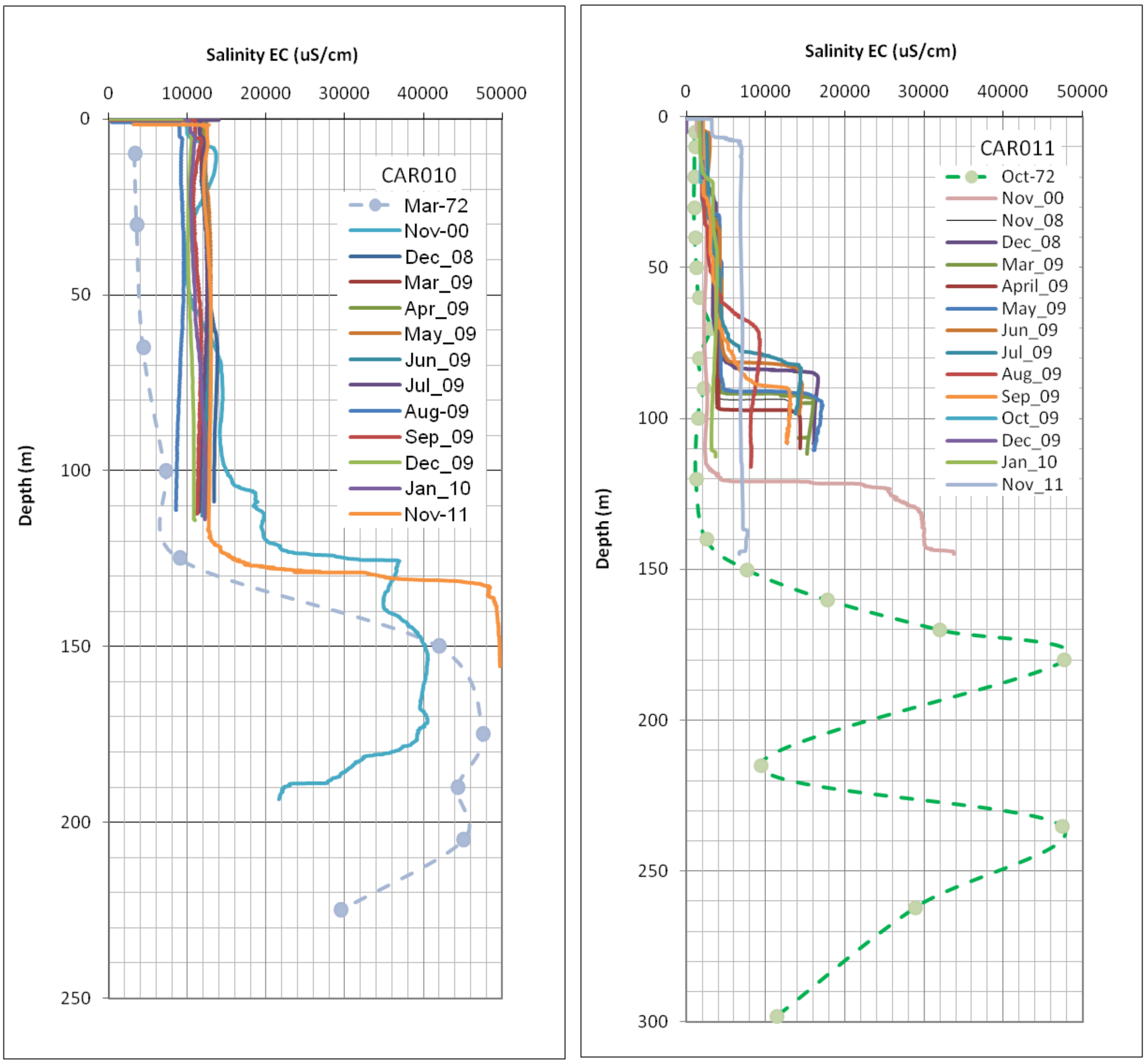


Figure 13. Groundwater salinity profiles for observation wells CAR010 and CAR011

The salinity profile for CAR010 shows that the seasonal variation in groundwater salinity is in the range of 10 000–13 000 EC down to a depth of about 110 m. An increase in salinity is obvious at about 120 m for both the November 2000 and November 2011 readings, although the salinity reaches higher values about 50 000 EC in the November 2011 profile. Discrete water samples from the 1972 water sampling during drilling shows a similar trend. The main body of high salinity is located between 150 m and 200 m, which correspond with the depth of the Camelback Member which lies between 154 and 180 m.

The salinity profile for CAR011 shows that groundwater salinities range between 2000 and 4000 EC to a depth of 80 m. At 80 m depth, the graph shows a sharp increase in salinity to reach about 18 000 EC. Figure 13 also indicates seasonal fluctuations in the depth of this sharp change in salinity and was at its shallowest position at about 60–70 m in August 2009. This change could be due to a reduction in the groundwater hydraulic head due to an increase in the up gradient extraction regime and/or reduced recharge, given the annual rainfall for the previous year was below average (Fig. 9).

The November 2000 salinity profile positions the increase in salinity at a depth of 120 m and reaches about 34 000 EC at a depth of 150 m. The discrete water chemistry sampling in 1972 during the drilling operation, indicates an increase in salinity at a depth of 150 m which reaches a peak of about 48 000 EC at 170 m depth. This depth corresponds with the Camelback Member at 146 – 182 m. Another salinity increase is observed in the Greenways Member at a depth of 182 – 256 m.

Salinity profiles were carried out in CAR010 and CAR011 in November 2011 by the department using Hydrolab water-quality instruments. The CAR010 profile indicates an increase in the salinity at 120 m depth and a mixing zone extending to 130 m, with the salinity level reaching 50 000 EC. Well CAR011 however, indicated no sharp change in salinity profile and showed a consistent salinity profile of about 8000 EC to the depth of 144 m reached by the instrument.

The Hydrolab instrument could not penetrate deeper due to the depth constraints of the tool, and therefore could not confirm the exact depth where the sharp increase in salinity occurs. However from the interpretation of previous salinity profile and sampling, it is expected that the interface will be at depth greater than 150 m.

The reason for this lower salinity profile for CAR011 may be due to the impact of the average annual rainfall experienced during 2010 and 2011. This could increase the recharge of freshwater into the aquifer which consequently diluted the saline water in the well.

Figure 13 also shows changes in the depth of the increase in groundwater salinity and the mixing zone between the freshwater and salt water, which has risen from a depth of 150 m to 120 m; a rise of 30 m since 1972 sampling.

Wood (2011) investigated the groundwater–surface water interaction of key groundwater dependent ecosystems. During this investigation, salinity profiles for CAR011 were carried out before and after pumping. The water salinity against volume pumped was also recorded. The results are presented in Figure 14, which shows that the salinity interface has moved upward after pumping. Figure 14 also indicates a positive correlation between the volume extracted and the increase in water salinity.

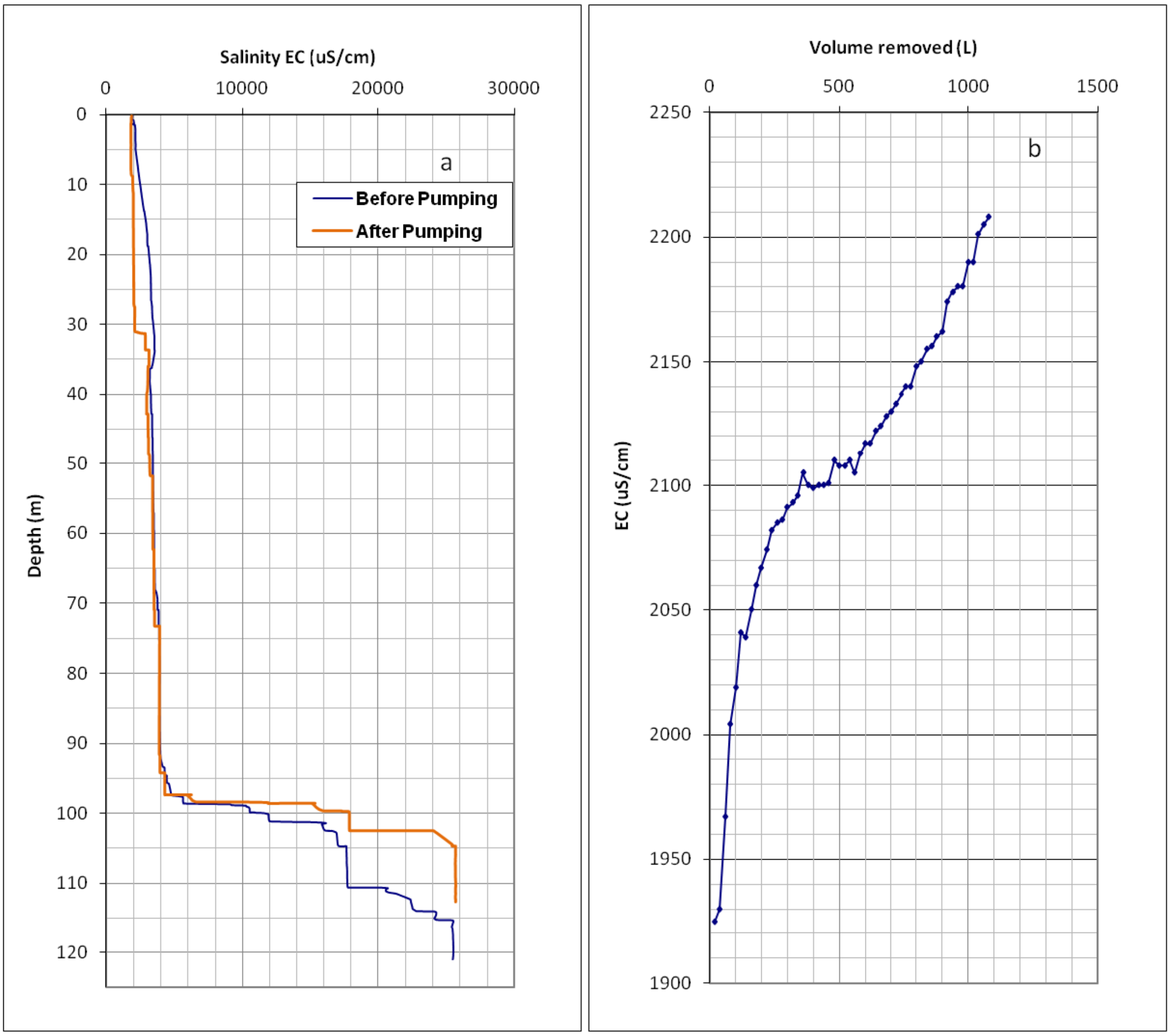


Figure 14. **Observation well CAR011 salinity profile (a) before and after pumping and (b) volume pumped versus water salinity**

3.6. WATER CHEMISTRY

3.6.1. CHEMICAL CHARACTERISTICS

The hydrochemical characteristics of groundwater has been used widely in the investigation of seawater intrusion into shallow and deep coastal aquifers (Capaccioni *et al.*, 2007; Alcalá and Custodio, 2008; Panteleit *et al.*, 2010; Terzić, *et al.*, 2010; Trabelsi *et al.*, 2011 and Bakri, *et al.*, 2011).

Groundwater samples were collected from the new wells, existing wells and surface water from key GDEs within the project area including the Ewens Pond and Piccaninnie Ponds/Pick Swamp complex. The groundwater samples were collected in August 2008 and January 2010, except for samples from the Port MacDonnell area which were collected in October 2009. The surface water samples were collected during October–November 2009.

The results of the chemical analyses are presented in Figure 15, which presents a Piper plot of the chemical constituents and shows that there are no significant differences in the plots of the two sampling events.

The majority of the samples fall on the simple mixing line between freshwater and seawater, grading from a Ca(Mg)-HCO_3 and Ca-Na-HCO_3-Cl water type to a Na-Cl water type. The increase in the Na-Cl water type toward the seawater-end member could be related to seawater intrusion and is evident at CAR061 and 7021-1396 samples, which plot close to the seawater sample on the Piper diagram (Fig. 15).

The Ca(Mg)-HCO_3 type water is related to water-rock interaction and the dissolution of the carbonate rocks of the aquifer. Water samples from KON033 and MAC101 show different trends from the majority of the samples and plot closer to the right side of central field. The geology of these two sites is dominated by marl and marly limestone with abundant chert and also the presence or pyritic mineral as explained in the drilling section.

The water samples from KON033 and MAC101 are characterised with high concentrations of sodium, chloride and low concentrations of calcium ion. The water type for these samples is Na-HCO_3 and Na-HCO_3-Cl for MAC101 and KON033 respectively. The water type may be influenced by water–rock interaction including carbonate dissolution/precipitation and ion exchange (by the release of the Na ion and the take up of the Ca and Mg ions at the exchange surface).

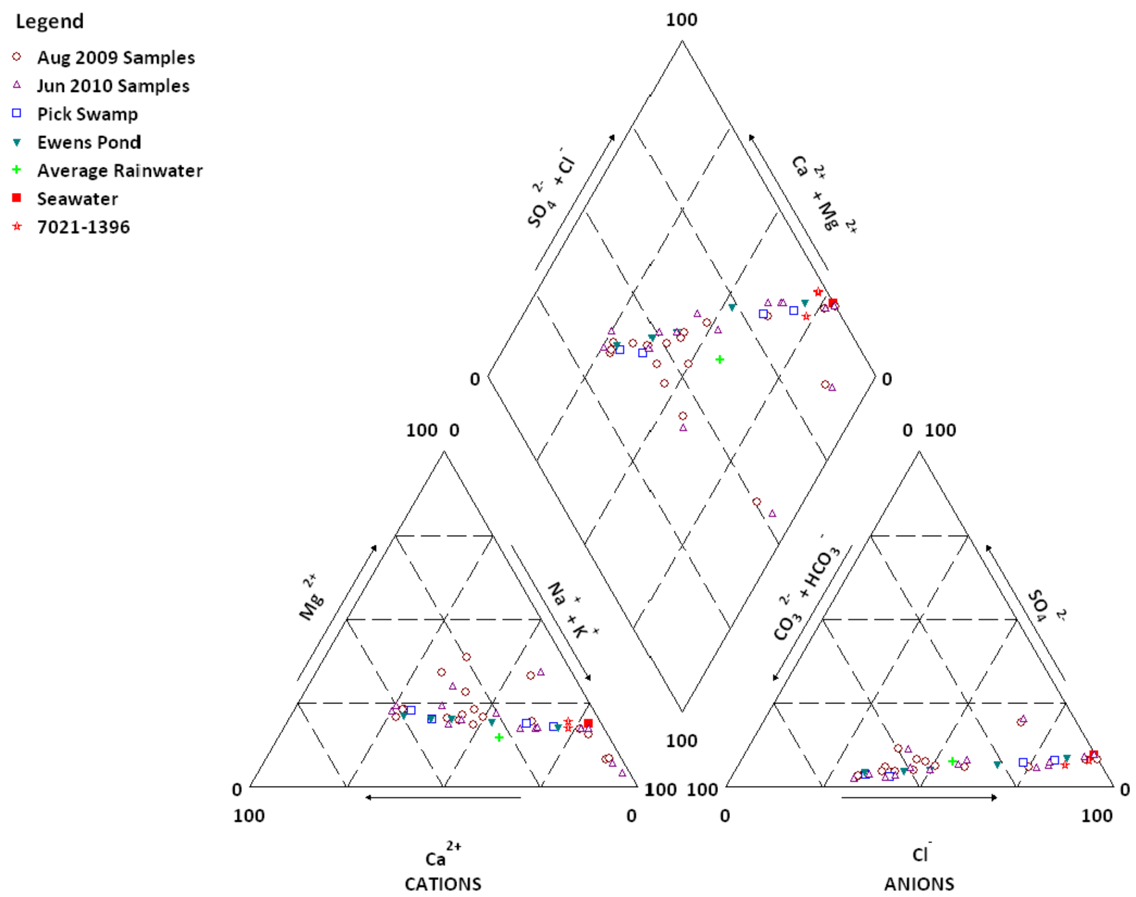


Figure 15. **Piper diagram of groundwater, surface water and rainwater**

The scatter plots of the major ionic constituents of the water samples against the chloride species are presented in Figure 16. There is good correlation between most of the ions (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Br^{-} and SO_4^{-2}) and Cl^{-}. Knowing that the main source of salt in the aquifer is from the infiltration of rainwater and water–rock interaction in the unconfined aquifer; the high correlation between these ion species and Cl^{-} could indicate that these waters are most likely derived from the same source of saline water (Trabelsi, *et al.*, 2011).

The Na/Cl molar ratio in a seawater sample collected south of Port MacDonnell is 0.75. Most of the water samples collected from the unconfined aquifer and the surface water in the study area has Na/Cl ratio in the range between 0.75 and the theoretical seawater ratio of 0.86, which indicates the marine influence on the water salinity. The Na^{+} versus Cl^{-} plot (Fig. 16) shows that the majority of the samples are falling on a theoretical seawater-dilution line.

Water samples from CAR065, MAC100 and MAC101 are showing Na/Cl ratios exceeding unity with the sample from MAC101 having the highest Na/Cl ratio of about 2.3. The geology at MAC100 and MAC101 is dominated by grey marl and marly limestone. Observation well CAR065 is also completed within the Greenways Member of the TLA, which is dominated by marl.

The process of simple mixing of seawater and freshwater cannot alone explain the increase in Na species behaviour in these samples and therefore other processes such as cation exchange between the solution and the aquifer materials could have influenced the increased ratio of the Na species. In areas where seawater intrudes a fresh coastal aquifer, cation exchange reaction will influence the composition of the groundwater and Na ions will be taken up by the aquifer materials and the Ca ions released into the solution resulting in a $CaCl_2$ water type; the reverse will take place when freshwater displaces salt water and the resultant water quality will be of a $NaHCO_3$ water type (Appelo and Postma, 1994).

Bromide (Br) is used to identify the origin of water salinity and is an indicator of seawater intrusion in coastal aquifers (Alcalá and Custodio, 2008; Trabelsi *et al.*, 2011). The Br values correlate well with the Cl values, indicating that the Br/Cl ratio is similar to the seawater ratio and supporting the suggestion that these waters were most likely derived from the same source of saline water (Fig. 16)

Figure 17 shows the Stiff water-chemistry diagrams of the coastal groundwater and surface waters in the study area. Stiff diagrams plot the major-ion composition of a water to produce a figure with a shape representative of the relative proportions of the different ions and a size indicative of total ion concentration. There are at least three areas that show clear indications of the presence of the freshwater–saltwater interface and the potential for seawater intrusion to occur into the coastal aquifer. These are Eight Mile Creek, the Port MacDonnell area, the Piccaninnie Ponds/ Pick Swamp complex to the east and in the vicinity of wells KON033 and MAC101 located to the west. The remaining samples were the least mineralised and dominated by the $Ca\text{-}HCO_3$ water type.

In the Eight Mile Creek area, wells CAR010, CAR061 (groundwater samples) and Ewens3 (surface water sample collected from Spencers drain before it connects with Eight Mile Creek), clearly indicate the presence of the freshwater–saltwater interface and the potential influence of seawater intrusion because of the resemblance with the seawater plot. CAR061 is the most affected by the interface, which is indicated from the scale and the shape of the plot compared to seawater plot. These samples are dominated by the NaCl water type.

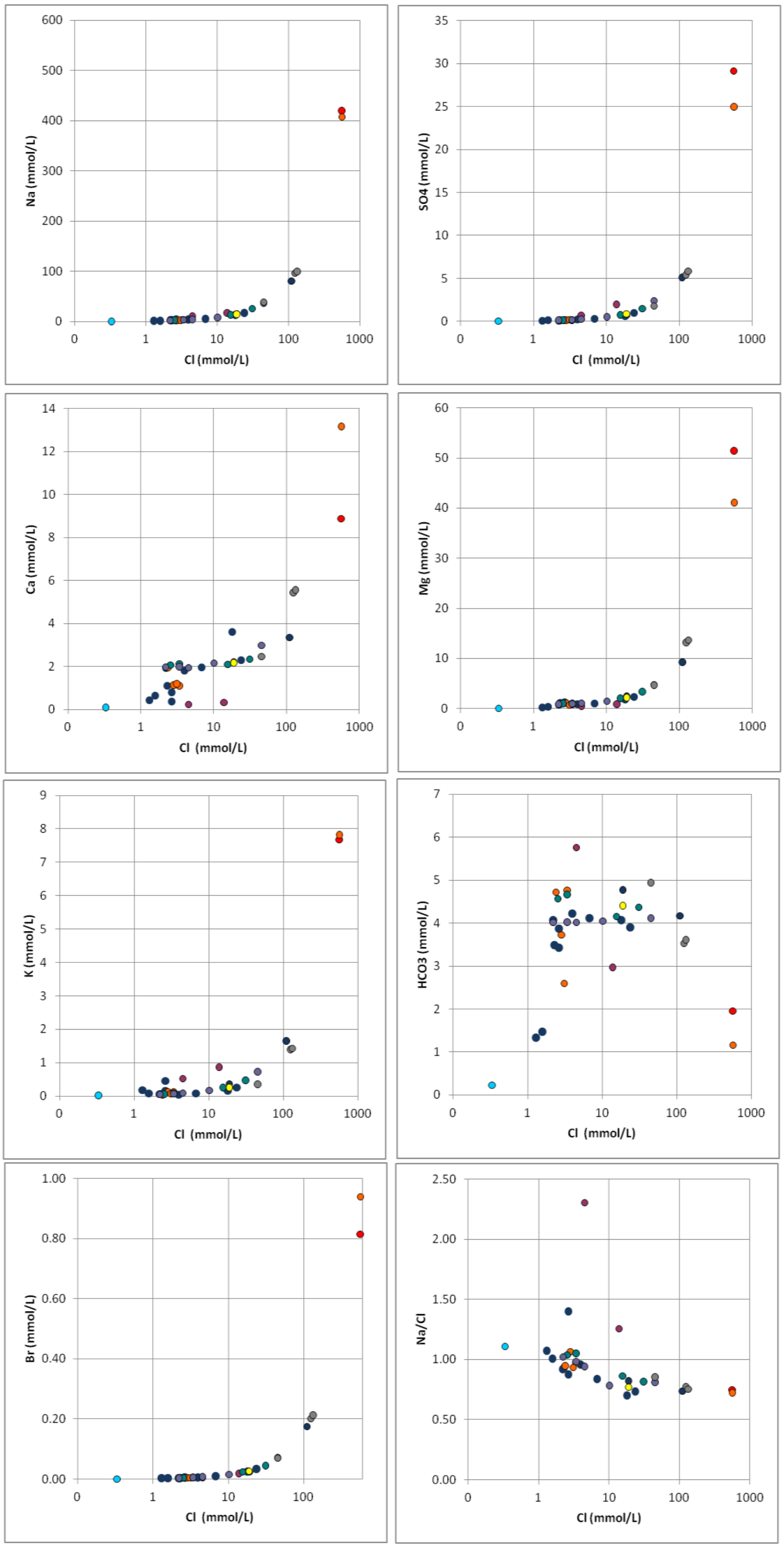


Figure 16. **Scatter plots of the chemical constituent in groundwater, surface water and rainwater. The rainwater (light blue) is an average value, Camelback well (orange), Seawater (red) Piccaninnie Ponds (yellow), Pick Swamp (green), Ewens Ponds (purple)**

Water flows out of Spencers Pond into the Eight Mile Creek via Spencers Drain, which has always carried waters with a higher salt concentration than Eight Mile Creek. It is not clear what is causing this high salinity in Spencers Pond; a potential cause for this high salinity may be due to mixing with seawater at this site at depth.

In 1984, a well (7021-1396) was constructed at the Port MacDonnell Football Club ground to a depth of 64 m. The routine sample collected from the well at the time of drilling showed a high salinity of 7000 EC, which was exceeding the recommended limits for irrigation of the turf area. In September 2009 before the abandonment of the well, three samples were collected at depths of 2.5, 25 and 40 m, and all samples showed a high level of salinity. The Stiff diagram of the sample from 40 m is similar to the seawater plot, but with a lower salinity of 12 100 EC.

The water samples from well CAR011 and the Pick Swamp complex represent a Na-Ca-Cl water type. The plot of these samples shows an increase in the Ca species from the seawater plot (Fig. 17). These samples may indicate a transitional zone between the seawater and freshwater front, or alternatively the area at this site could be subject to a seasonal intrusion and regression of seawater which results in this water type through mixing and cation exchange processes. The results from the salinity profiles (Fig. 13), the karst nature of the area (allowing for rapid recharge of low salinity rainfall) and the groundwater level (Fig. 8) could support this latter interpretation.

The samples from KON033 and MAC101 represent the third area that shows high groundwater salinity. The Stiff diagram of KON033 shows a resemblance to the seawater plot but with a higher concentration of Na, which could be due to cation exchange between the solution and the aquifer material that results in releasing of Na from the rock matrix in favour of Ca.

The MAC101 sample is characterised by a Na-HCO_3 water type and as explained earlier; the processes that influence the water quality at this site could be due to the replacement of salt water by freshwater and cation exchange by removing Ca from the solution and adding the Na species to the solution.

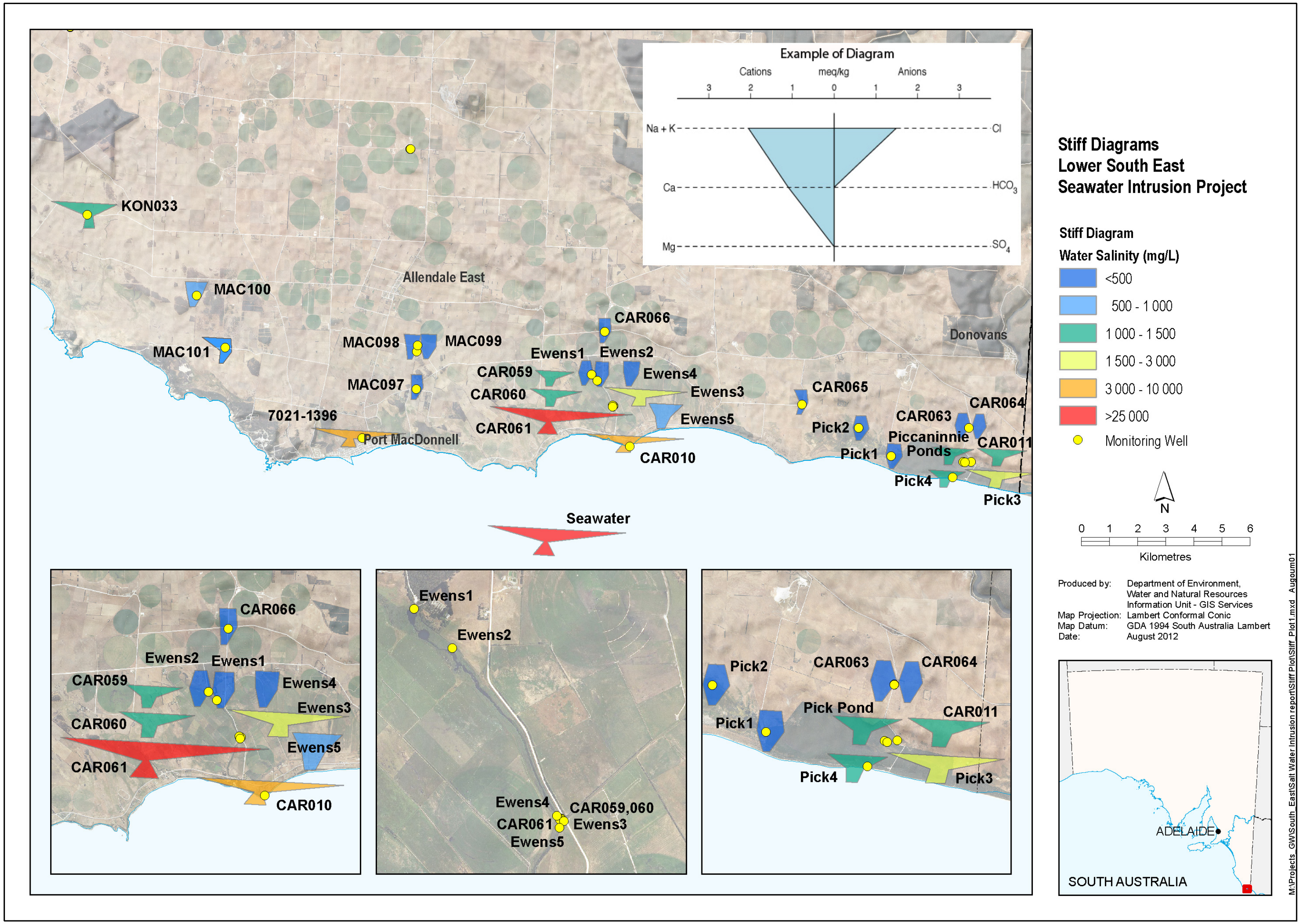


Figure 17. **Stiff diagrams of the coastal groundwater and surface water chemistry**

3.6.2. OXYGEN AND HYDROGEN ISOTOPES

The range of the stable isotope composition of the groundwater and surface water samples is from 0.3 to -5.23 ‰ for Oxygen-18, and from 1.5 to -30.2 ‰ for Deuterium. The sample from CAR061 has positive values (less depleted) of Oxygen-18 and Deuterium close to the seawater values of 0.69‰ and 4.9‰ respectively and has the most mineralised water. Figure 18 shows the isotopic composition of the groundwater and surface waters in the study area.

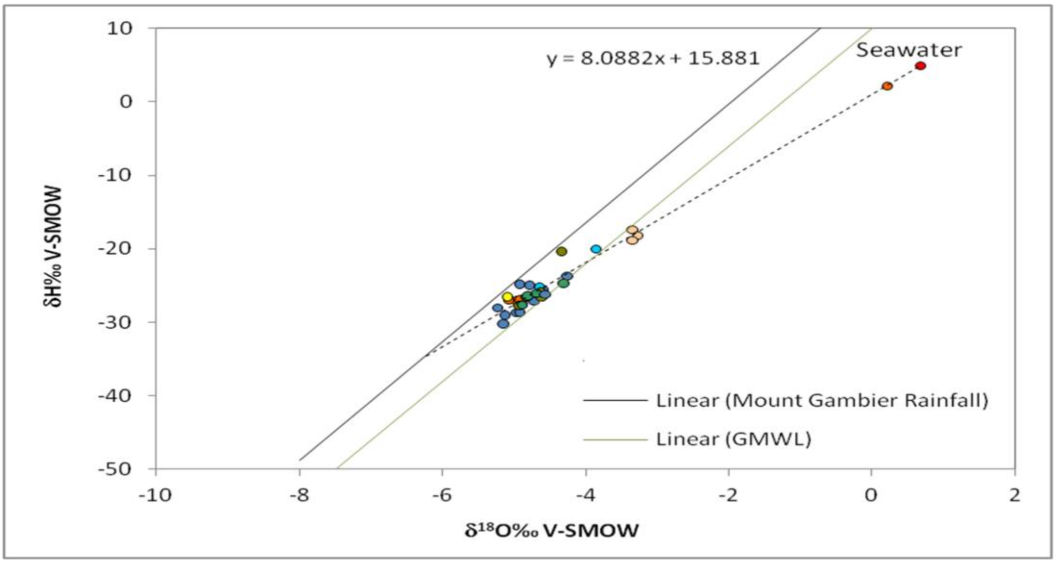


Figure 18. The relationship between Deuterium-Oxygen-18 for groundwater and surface water samples. Seawater (red), 7021-1396(light orange), CAR010, CAR011 (light blue) and Piccaninnie Ponds (yellow)

The water samples plot between the global meteoric water line (GMWL) and the Mount Gambier local meteoric water line (LMWL). The fact that the samples lie to the right of the LMWL may suggest that these waters were subject to evaporation before reaching the watertable. The samples from CAR010, CAR011, CAR061 and 7021-1396 and some samples from Pick Swamp and Eight Mile Creek (Ewens3), lie on a mixing trend line with the seawater samples.

3.6.3. SEAWATER MIXING RATIO

Assuming chloride is a conservative ion, it is possible to calculate the percentage of seawater in a sample using the chloride mass balance by using a conservative mixing approach of seawater and fresh water described by the following formula (Appelo and Postma, 1994; Terzić, *et al.*, 2010; Trabelsi *et al.*, 2011):

$$F_{sea} = [Cl_{sample}^{-} - Cl_{fresh}^{-}] / [Cl_{sea}^{-} - Cl_{fresh}^{-}] \times 100 \qquad (2)$$

Where F_{sea} = mixing ratio expressed as a percentage of seawater

Cl_{sample} = chloride concentrations of the sample

Cl_{fresh} = chloride concentrations of the freshwater component (water sample from CAR064 which is a shallow unaffected fresh water sample)

Cl_{sea} = chloride concentrations of seawater (seawater sample collected from the sea south of Port MacDonnell).

The computed fraction of seawater mixing ratio varied between less than 2 to 98% (Fig. 19). The highest ratios were in CAR061 (98%) and CAR010 (20%) at Eight Mile Creek, also the sample from 7021-1396 (24%). The seawater mixing ratio in the Piccaninnie Pond/Pick Swamp complex ranges from 3 to 6%.

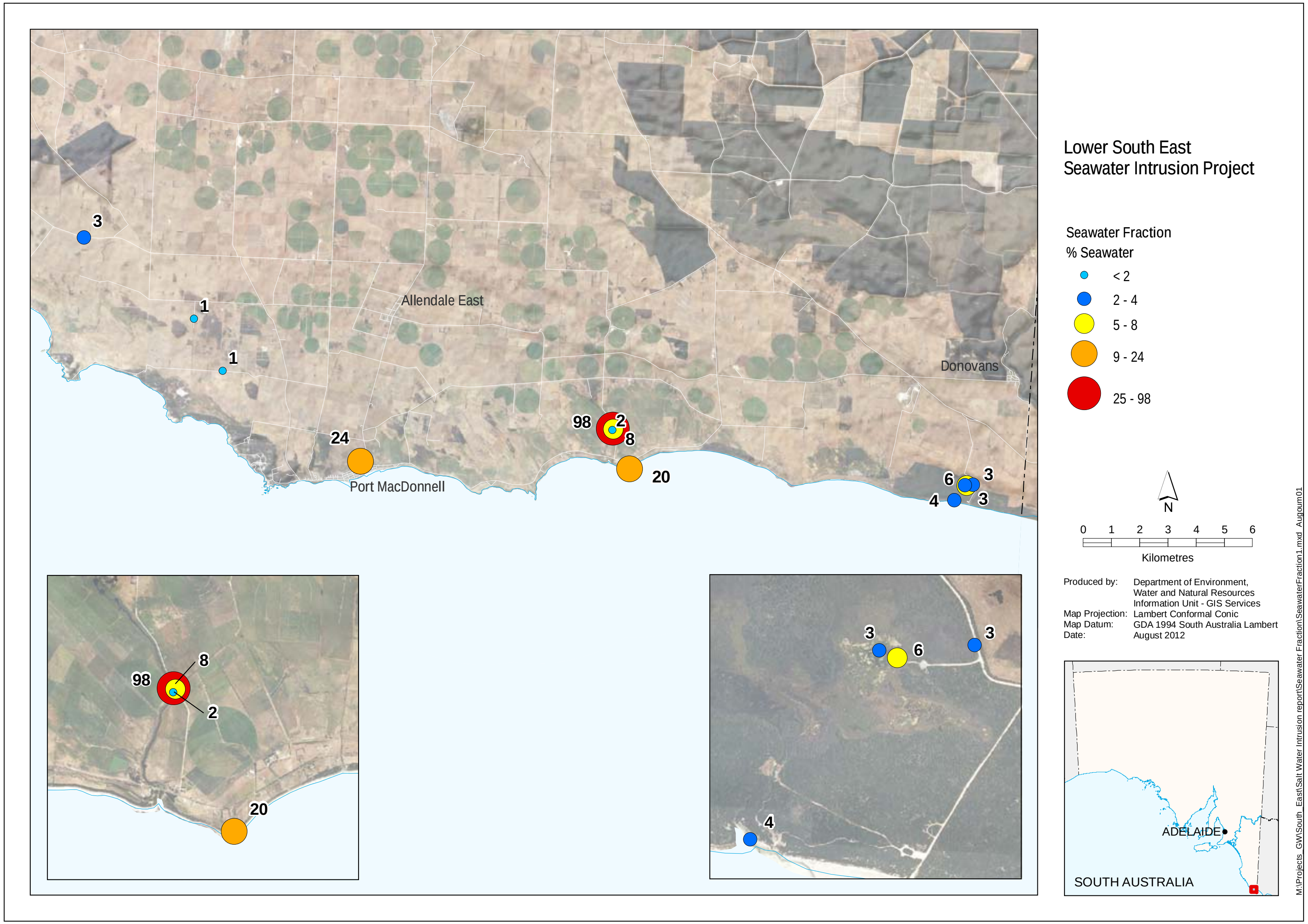


Figure 19. The spatial distribution of seawater mixing fraction as a percentage into the coastal aquifer

3.7. CONCEPTUAL MODEL

Figure 20 presents a conceptual model of the current understanding of the position of the freshwater–saltwater interface in the coastal aquifer at Eight Mile Creek (CAR059, CAR060 and CAR061) site. The results of general water chemistry and stable isotopes indicate the presence of a component of seawater in Unit 1 and Unit 3 of the Green Point Member and the Camelback Member. The most affected unit is the Camelback Member with seawater replacing freshwater at this site (consisting of 98% seawater by composition).

The lack of wells constructed in Unit 2 and Unit 4 of the Green Point Member limits the estimation of the position of the freshwater–seawater interface. However, given that these units consist mainly of marl with low permeability, the interface position will be closer to the sea than in the permeable limestone and dolomite units. More investigations may be required to gain a better understanding of the risk of seawater intrusion into these units.

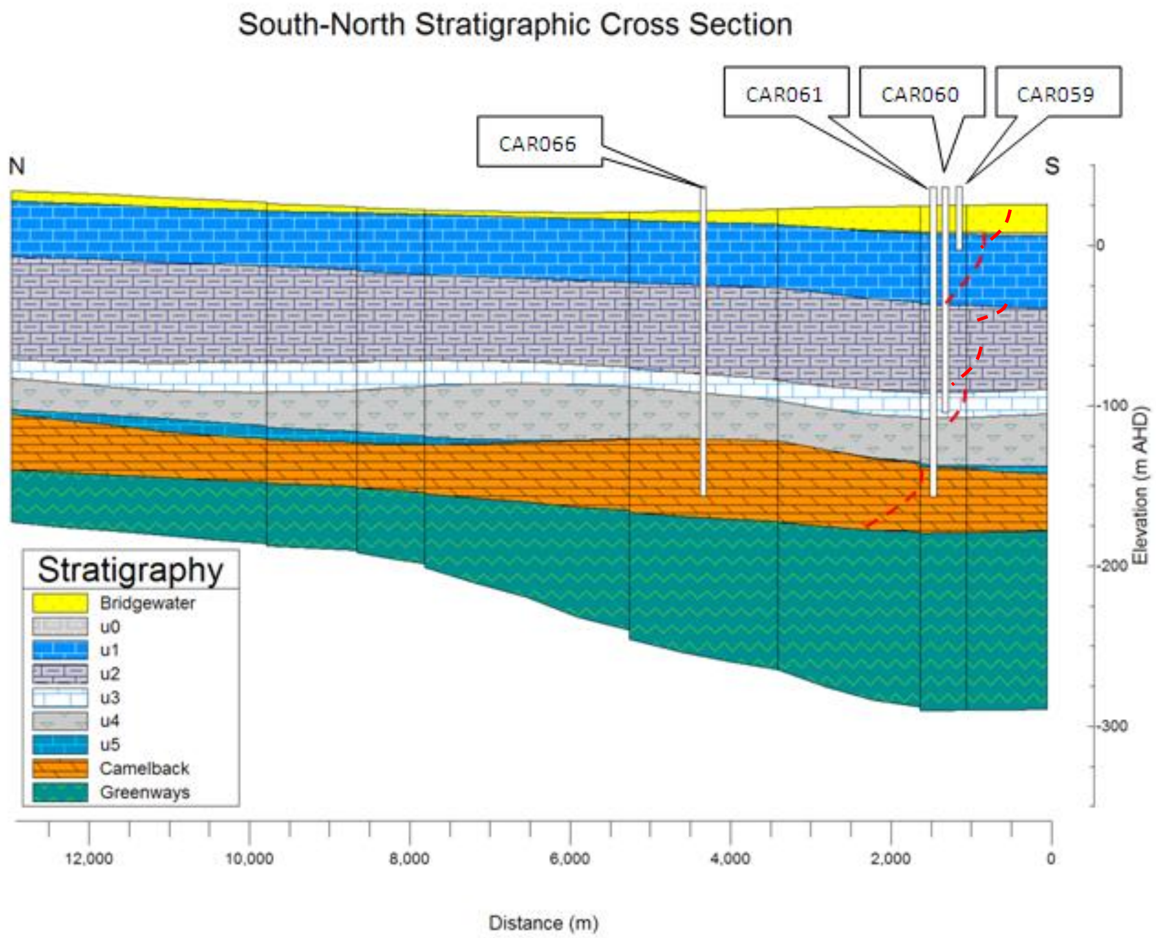


Figure 20. Conceptual model of the seawater intrusion into the coastal aquifer at Eight Mile Creek site

3.8. GROUNDWATER DEPENDENT ECOSYSTEMS

Interrogation of the Wetlands Polygon Layer using ESRI ArcGIS 9.3.1 identified 181 wetland polygons within the study region (Appendix C) including six recognised as having very high ecological value and 21 recognised as having high ecological value (Figure 21).

Based on work undertaken by SKM (2009), 26 of the wetlands in the study region have very high, and 58 have high potential of being groundwater dependent (Fig. 22). Furthermore, wetland types are dominated by Grass Sedge Swamps (84), Karst Systems (76) and Peat Swamps (34), as shown in Figure 23. All the dominant wetland types have varying degrees of dependence on groundwater to meet their environmental water requirements (EWRs) and hence have the potential to be impacted by processes effecting groundwater levels and salinity i.e. seawater intrusion.

Strong groundwater dependence of several ecosystems in the study region was confirmed by field investigations carried out in February 2008 (Wood, 2011). A follow-up round of hydrochemical sampling was carried out by the department in August 2009 to complement some of the investigations undertaken by Wood (2011). The sites that were re-sampled were Pick1, Pick2, Ewens1 and Ewens2 (Appendix B).

Radon-222 has a relatively short half-life of approximately 3.8 days and therefore, decays quickly. It may also be readily lost from surface water by gas exchange with the atmosphere. Its presence show strong evidence of groundwater discharge at the investigation sites within the study region. The later sampling results were consistent with the findings of the earlier sampling as shown in Table 2.

Table 2. Comparison of the Rn-222 results from February 2008 and August 2009

Sample	Easting	Northing	Rn-222 (Bq/L) February 2008	Rn-222 (Bq/L) August 2009
PICK1	492409	5788977	2.3 - 7.4	1.14
PICK2	491195	5789917	3.5 - 3.7	3.77
EWENS1	481615	5791263	2.0	1.40
EWENS2	481824	5791070	3.4	1.82

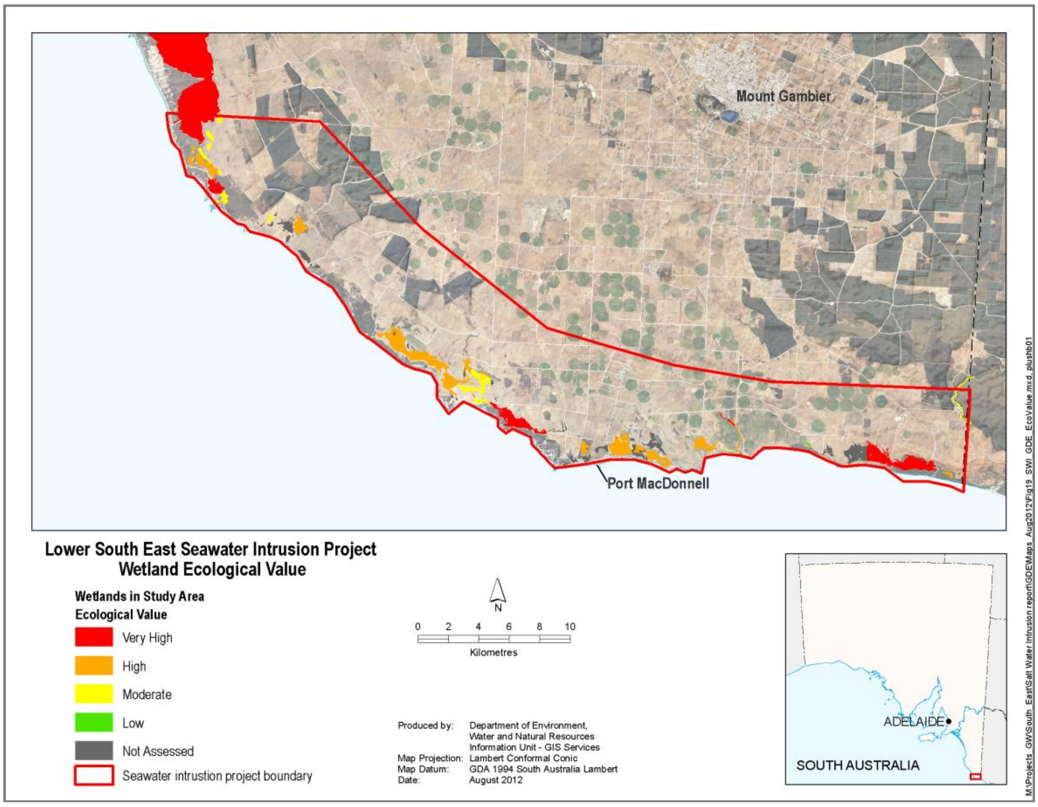


Figure 21. Wetlands in the study area and corresponding ecological value

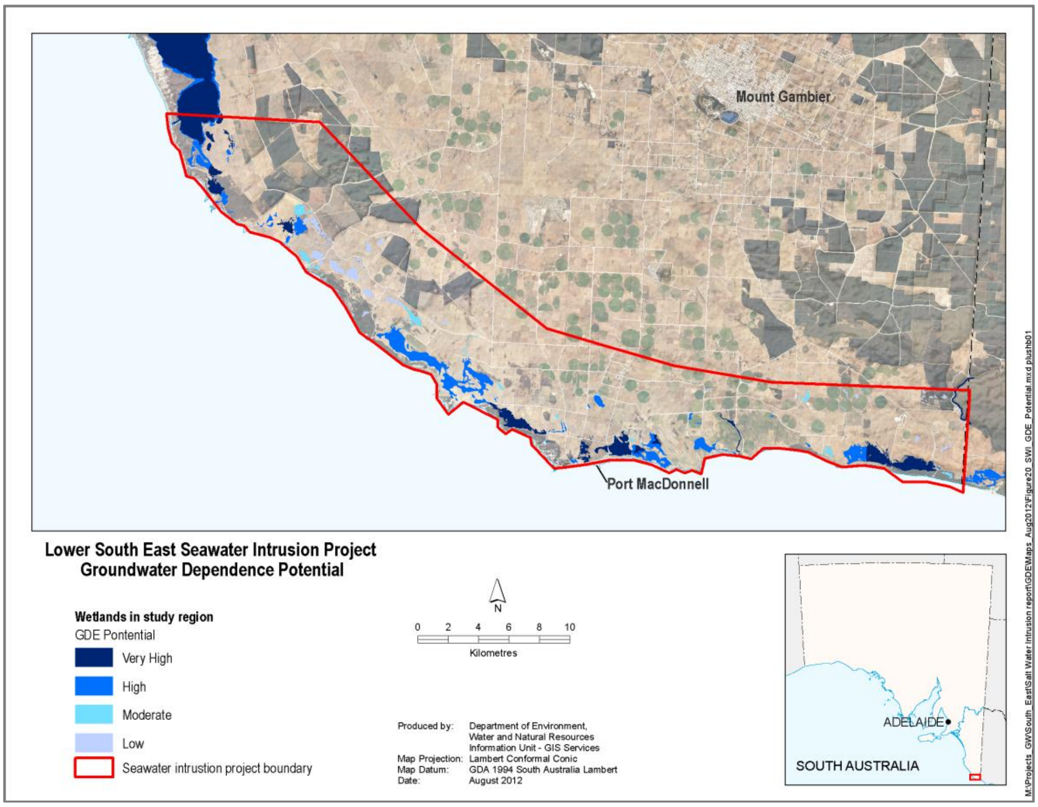


Figure 22. Wetlands in the study area and corresponding groundwater dependence potential

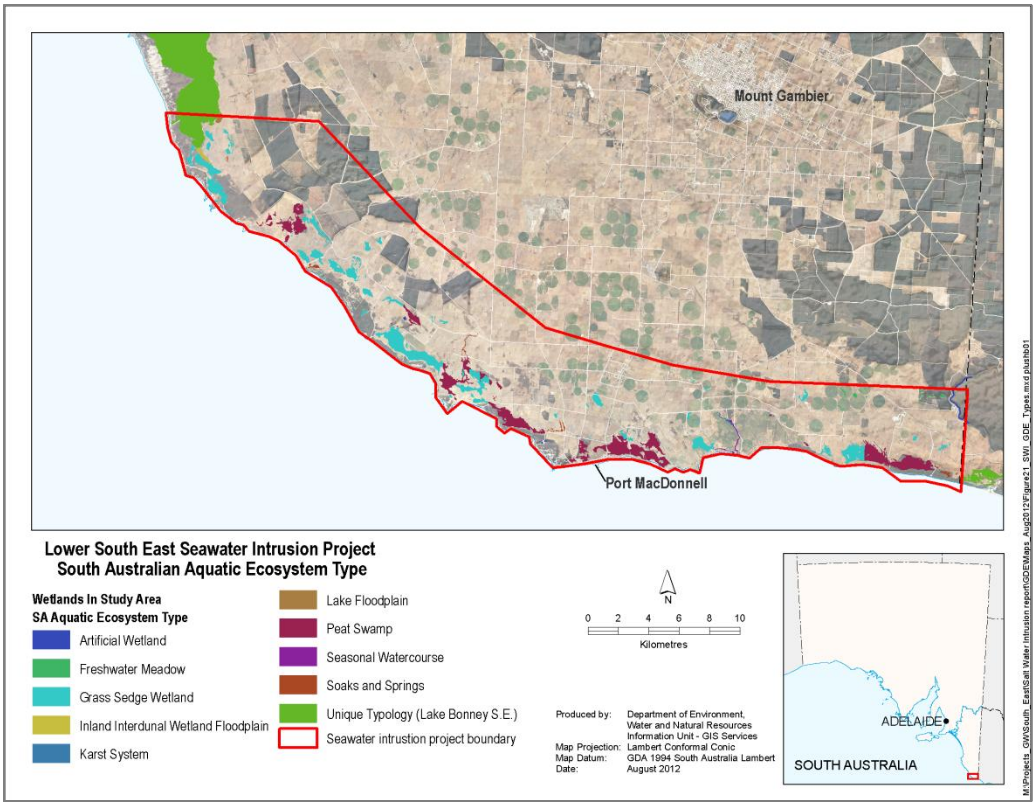


Figure 23. South Australian Aquatic Ecosystem (SAAE) types for the study area based on information provided by DENR (unpublished 2011)

3.8.1. SEAWATER INTRUSION AND SEA LEVEL RISE

The previous studies into the groundwater dependence of ecosystems show a strong reliance on groundwater to meet the environmental water requirements of many wetlands in the study region. Consequently seawater intrusion into the TLA has the potential to impact on water regimes and quality within these systems in particular Karst features that receive groundwater from deeper units within the TLA e.g. Piccaninnie Ponds.

Different GDE types across the study region are likely to have differing vulnerabilities to seawater intrusion based on:

- proximity to the coast
- basin elevation
- soil/aquifer properties
- hydrogeological drivers of the system
- origin of groundwater discharge (shallow or deep units of the TLA).

As part of this study a preliminary assessment of the potential vulnerability of coastal wetlands to the impacts of sea-level rise (SLR) and seawater intrusion (SWI) arising from climate change in the LLC PWA area has been undertaken. The approach adopted 3.5 m AHD as a nominal cut-off height for areas that may be impacted. This height was based on:

- The Climate Commission's (2010) maximum projected sea-level rise of 1 m by 2100
- The maximum high tide observation of 1.535 m (based on 1981 record for Victor Harbor taken from the National Tidal Facility)
- Applying an additional safety buffer of 1 m to account for storm surges/waves and erroneously high elevations in the Digital Elevation Model (resulting from vegetation interference with the LiDAR).

A wetlands layer was produced for the LLC PWA that contained all polygons with elevations equal to or less than 3.5 m AHD in elevation (including drains). Wetlands from this layer that were located within the SWI project area boundary were selected using ESRI ArcGIS 9.3.1 to give an indication of the GDEs within the study area that could potentially be impacted by SWI and or SLR resulting from Climate Change (Fig. 24). Of the 181 wetland polygons mapped in the study region, 87 of them have elevations of ≤3.5 m AHD (refer Appendix C).

The assessment did not differentiate between wetlands with varying basin depths below the cut off height (≤3.5 m AHD), or groundwater discharge sources or types present within the study. However work by Wood (2011) and the evidence of seawater intrusion into deeper units of the TLA detailed in other sections of this report suggest that karst rising springs near the coast are among the most vulnerable GDEs to seawater intrusion resulting from reductions in hydraulic head in deeper units of the TLA (from over abstraction and/or reduced recharge).

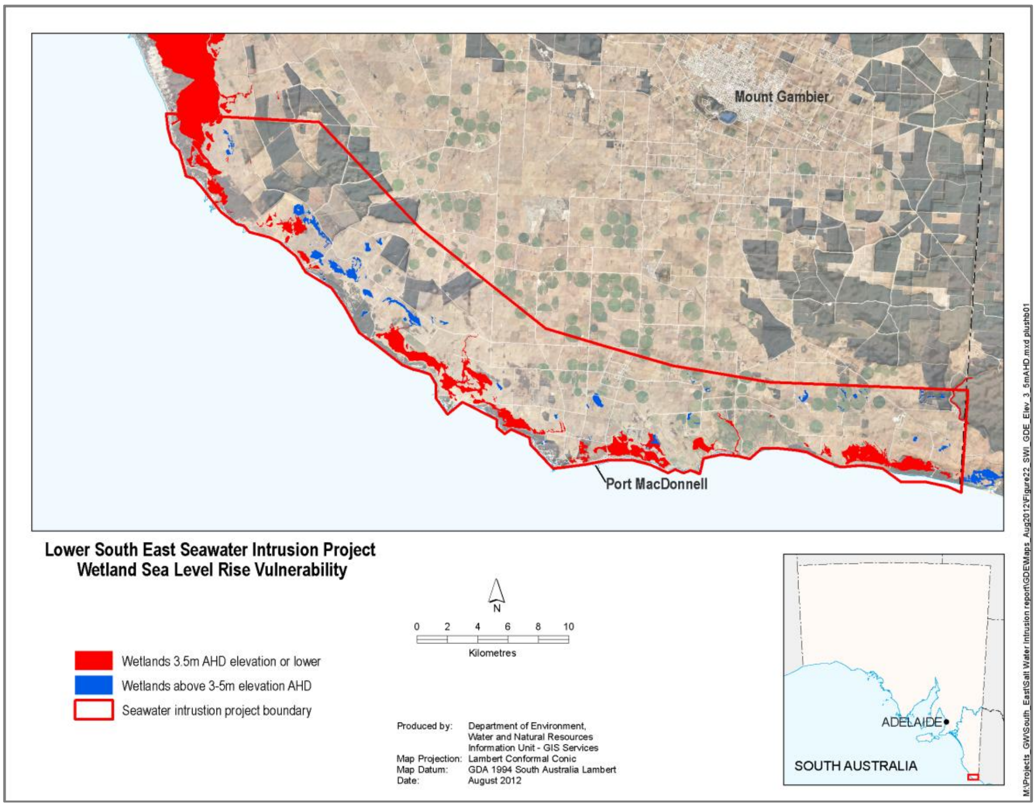


Figure 24. Wetlands in the study area and differentiation between areas below and above 3.5 m AHD showing potential seawater intrusion and sea level rise vulnerability

4. DISCUSSION

Seawater intrusion into freshwater coastal aquifers has been recognised as a major risk to water supply for coastal communities worldwide. Many factors can contribute to the threat of seawater encroachment, which may include extraction from the coastal aquifers, reducing recharge due to climatic changes, seawater rise and seawater tidal effects.

The investigations described in this report have provided a number of lines of evidence establishing the presence of the freshwater–saltwater interface in the karstified Gambier Limestone aquifer. The nature of this interface within Australia's coastal aquifers can vary depending on the geology, coastal geomorphology, the hydrological balance, tidal effects, and the nature of the topographic-bathymetry relationship (Dixon-Jain *et al.*, 2010). While this interface can be geometrically complex, it is generally in a quasi-equilibrium state, unless significantly disturbed through extraction or climate effects as described previously.

Therefore, the detection of a freshwater–saltwater interface does not automatically mean that active seawater intrusion is occurring, in response to groundwater extraction. At most of the sites where the interface was intersected, there is no historical information available on the 'pre-development' location of the interface and hence it is not possible to determine if any intrusion has occurred.

The only evidence of a dynamic interface between freshwater and seawater occurs in the Eight Mile Creek area:

- Observation well CAR061 is completed in the highly fractured Camelback Member of the Gambier Limestone Member at a depth of 180 m. Its already high salinity (50 000 EC) is gradually increasing (Fig. 11).
- Observation well CAR059 (12 m deep at the same location as CAR061) is also slowly increasing in salinity (Fig. 11) and the shift in the water salinity from ~2500 to 3000 EC at about 7 m deep also seasonally fluctuates upward and downward (Fig. 12). This may indicate some movement of the transitional zone of the interface, however the cause of the salinity increase may be related to nearby irrigation.
- Observation wells CAR010 and CAR011 both show an apparent rise in the interface level compared to that observed in 1972 (Fig. 13). However, the fact that the interface between freshwater and seawater moved upward after pumping from CAR011 (Fig. 14) does not prove that active intrusion is taking place.

On-going monitoring is necessary to determine if actual intrusion is occurring in the Eight Mile Creek area and the other areas where the interface has been intersected.

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the investigation results show that:

- Factors that are contributing to the risk of seawater intrusion likely to be climate and groundwater extraction (within and up-gradient of the study area) which both result in the lowering of the groundwater hydraulic head and facilitate the incursion of seawater further inland:
  - the region has shown a decline in the annual rainfall since 1993, with the most recent dry years during 2005–08. The below average rainfall has reduced recharge to the aquifer.
  - there has been a significant increase in groundwater extraction in the study area through the use of centre pivots since 2000.
- The freshwater–saltwater interface in the coastal aquifer has been detected at four locations; Eight Mile Creek and Port MacDonnell, Piccaninnie Ponds/Pick Swamp complex and the area west of the township of Port MacDonnell at the MAC101 site (Cape Douglas Road).
- Mixing between freshwater and seawater and cation exchange reaction are processes that have been observed in the study area.
- The groundwater and surface water hydrochemistry in the study area varies from a Ca(Mg)-HCO_3, Ca-Na-HCO_3-Cl water type to a Na-Cl water type. The Ca(Mg)-HCO_3 water type represents the fresh unaffected end member, while the Na-Cl water type represents the samples with higher salinity contents and area affected by seawater intrusion. The Ca-Na-HCO_3-Cl type is a mixture of the different water types.
- The detection of a freshwater–saltwater interface does not automatically mean that active seawater intrusion is occurring in response to groundwater extraction.
- Important groundwater dependent ecosystems (GDEs) are present in the study area. Seawater intrusion may seriously threaten the viability of inhabitant biota and ecosystems. Piccaninnie Pond/Pick Swamp complex and Spencers Pond are showing evidence of high water salinity, but there is insufficient evidence as yet to conclude that this high salinity is due to active seawater intrusion, or a stable freshwater–saltwater interface.
- The only evidence of a dynamic freshwater-saltwater interface occurs in the Eight Mile Creek area where groundwater salinities are slowly increasing and salinity profiles show seasonal changes.

The current study has shown the use of hydrochemistry is a useful tool in the investigation of the origin of the water salinity and the extent of the freshwater–saltwater interface in the study area. It also recognises however that additional work is required to improve the understanding on the seawater intrusion dynamic in the coastal area, particularly in relation to the GDEs.

CONCLUSIONS AND RECOMMENDATIONS

It is recommended that:

- The current regular monitoring of the seasonal water level and salinity trends from the coastal-area observation wells, as well as irrigation extraction wells, be continued in the long term. Similarly, salinity profiles in suitable wells should be carried out at regular intervals.
- Water chemistry sampling be expanded to include the bromide and chloride ions so that the Br/Cl ratio can been used to differentiate between different origins of water salinity. A database should be established to regularly record the concentration of these ions in the groundwater and surface water in the coastal aquifer.
- Consideration be given to further investigations to improve the understanding of the hydrostratigraphic complexity of the aquifer in the region, in particular the aquifer properties for the Gambier Limestone Formation. Options are further geophysical logging and to calibrate the Neutron unit to read in API, or using packers and conduct discrete slug/short term pumping tests to measure the hydraulic properties of these sub-units.
- Consideration be given to develop a numerical groundwater-flow and solute-transport model to study seawater intrusion in the study area. Any numerical model should consider the TLA as a multi layered aquifer due to different hydraulic properties for the various sub-units. Treating the TLA as one layer will over simplified the conditions in the aquifer and hence limit the usefulness any modelling exercise.
- Consideration be given to the monitoring of observation wells in the vicinity of GDEs within the study area including groundwater and surface water salinity. Additional monitoring should be targeted at Spencers Pond to determine if the observed elevated salinity at this GDE is a consequence of seawater intrusion.
- Options be considered for identifying ecosystem salinity thresholds for important Karst Wetland ecosystems and high risk flora and fauna.

APPENDICES

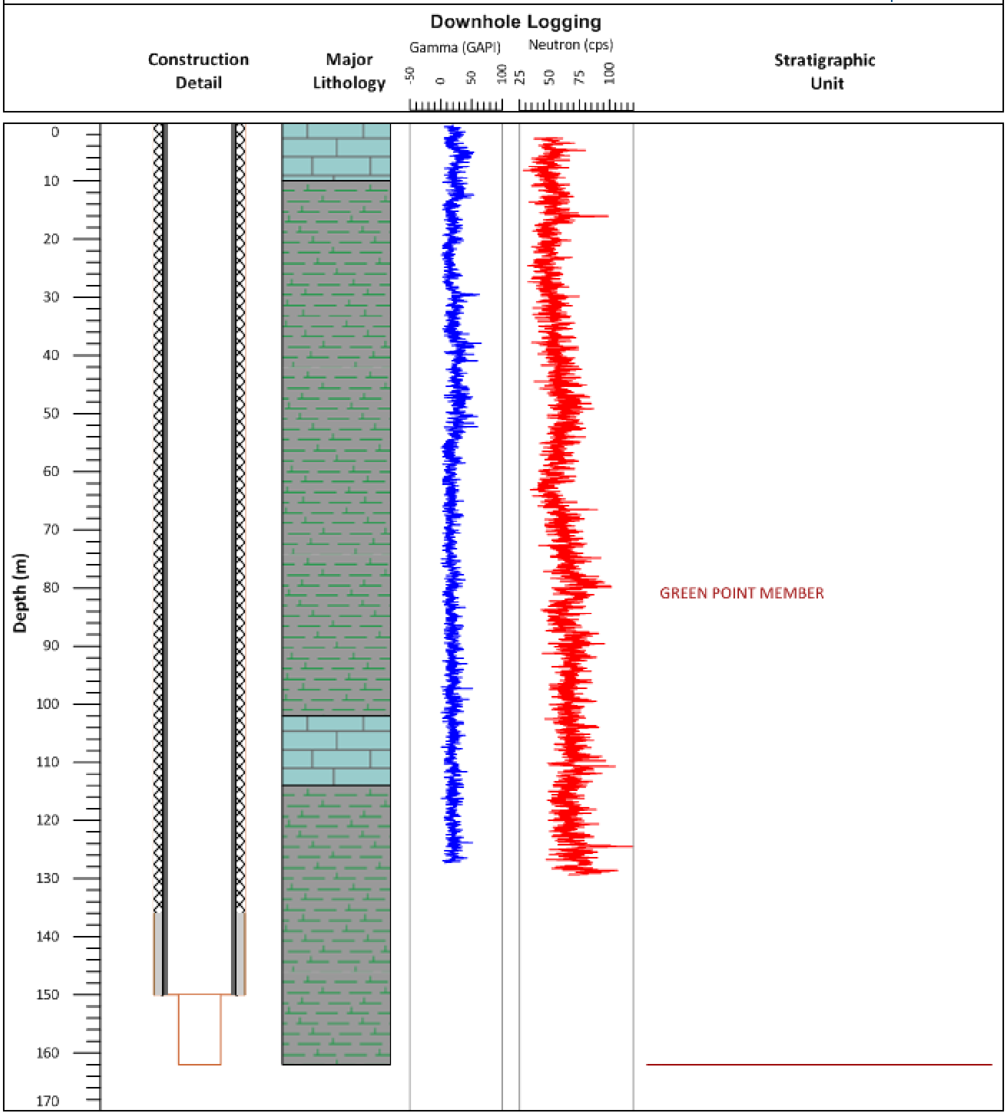
A. HYDROSTRATIGRAPHIC LOGS

Seawater Intrusion Investigation

Unit No: **7021-03532** Drillhole Name: **MAC101** Final Depth (m): **162**

Permit No: Easting: **468564** Northing: **5791487** Zone: **54**

Government of South Australia
Department for Water



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 150 m	136 - 150 m

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		150 - 162 m

Lithological/Construction Symbology

Marl — Drillhole — Limestone — Open Hole — Dolomite — Casing — Backfill — Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

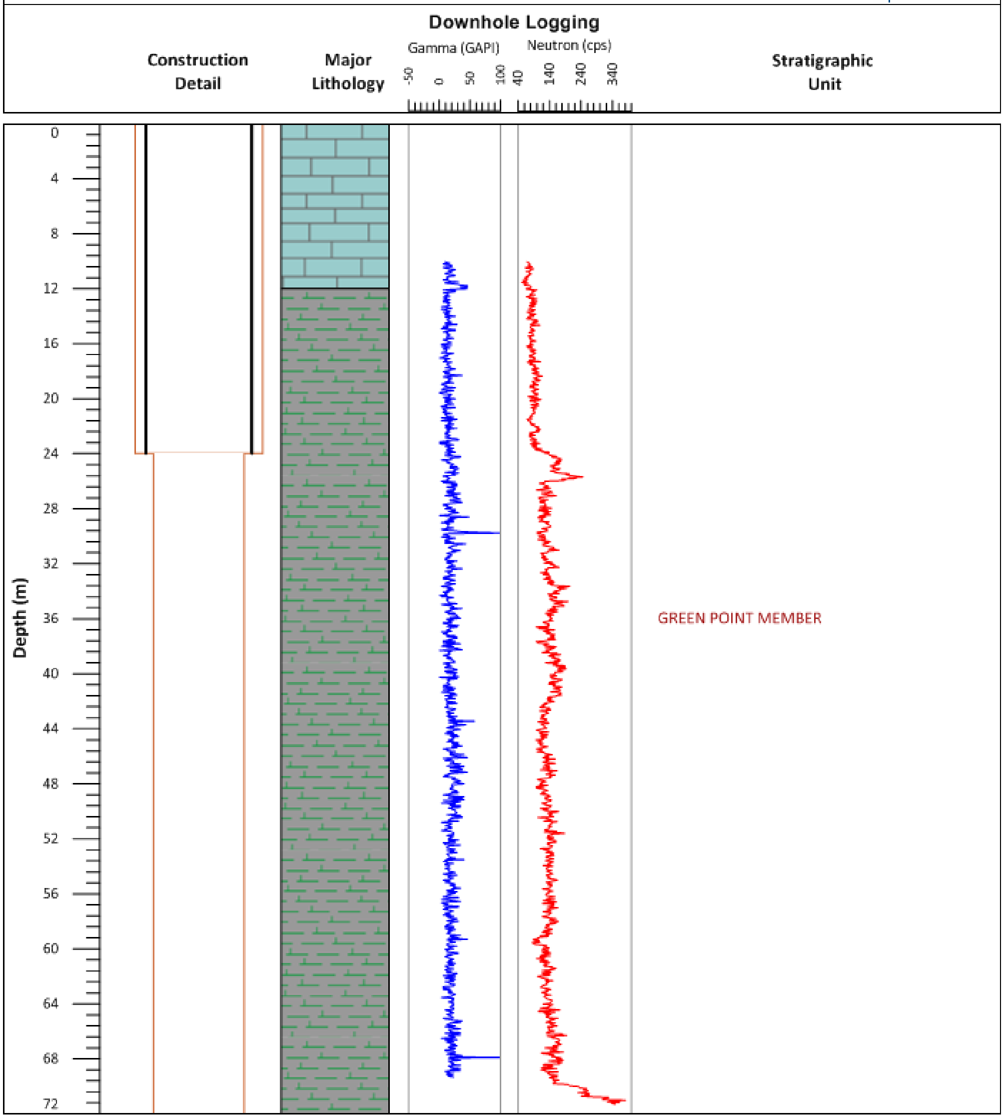
Current as at:

Seawater Intrusion Investigation

Unit No: **7021-03531** Drillhole Name: **MAC100** Final Depth (m): **72**

Permit No: Easting: **467447** Northing: **5793270** Zone: **54**

Government of South Australia
Department for Water



Casing Details

Diameter	Details	Interval	Pressure Cement
	Steel	0 - 24 m	

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
217 mm ID	Open Hole	Open Hole		24 - 72 m

Lithological/Construction Symbology

Marl | Drillhole | Limestone | Open Hole | Dolomite | Casing | Backfill | Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

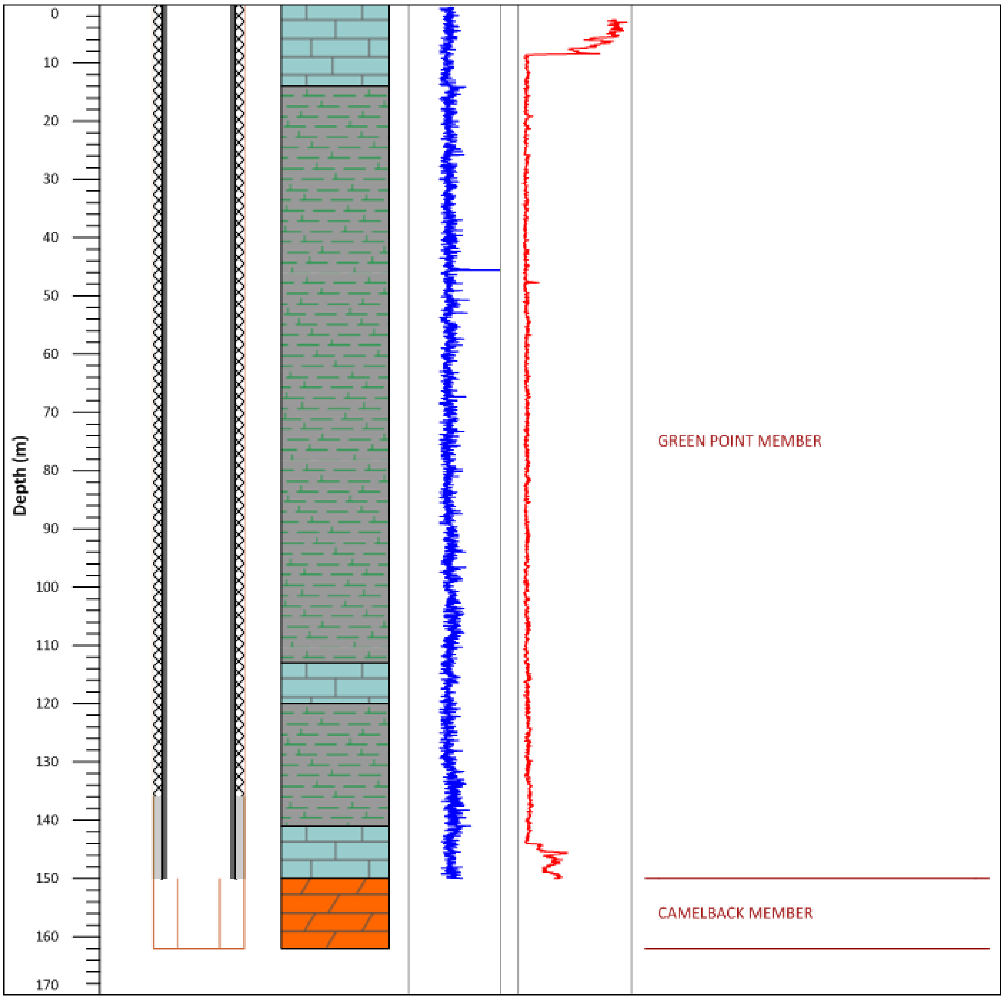
Current as at:

Seawater Intrusion Investigation

Government of South Australia
Department for Water

Unit No:	**7021-03530**	Drillhole Name:	**CAR066**			Final Depth (m):	**162**
Permit No:		Easting:	**482004**	Northing:	**5792811**	Zone:	**54**

Construction Detail | **Major Lithology** | **Downhole Logging** (Gamma (GAPI), Neutron (cps)) | **Stratigraphic Unit**



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 150 m	136 - 150 m

Production Zone Details

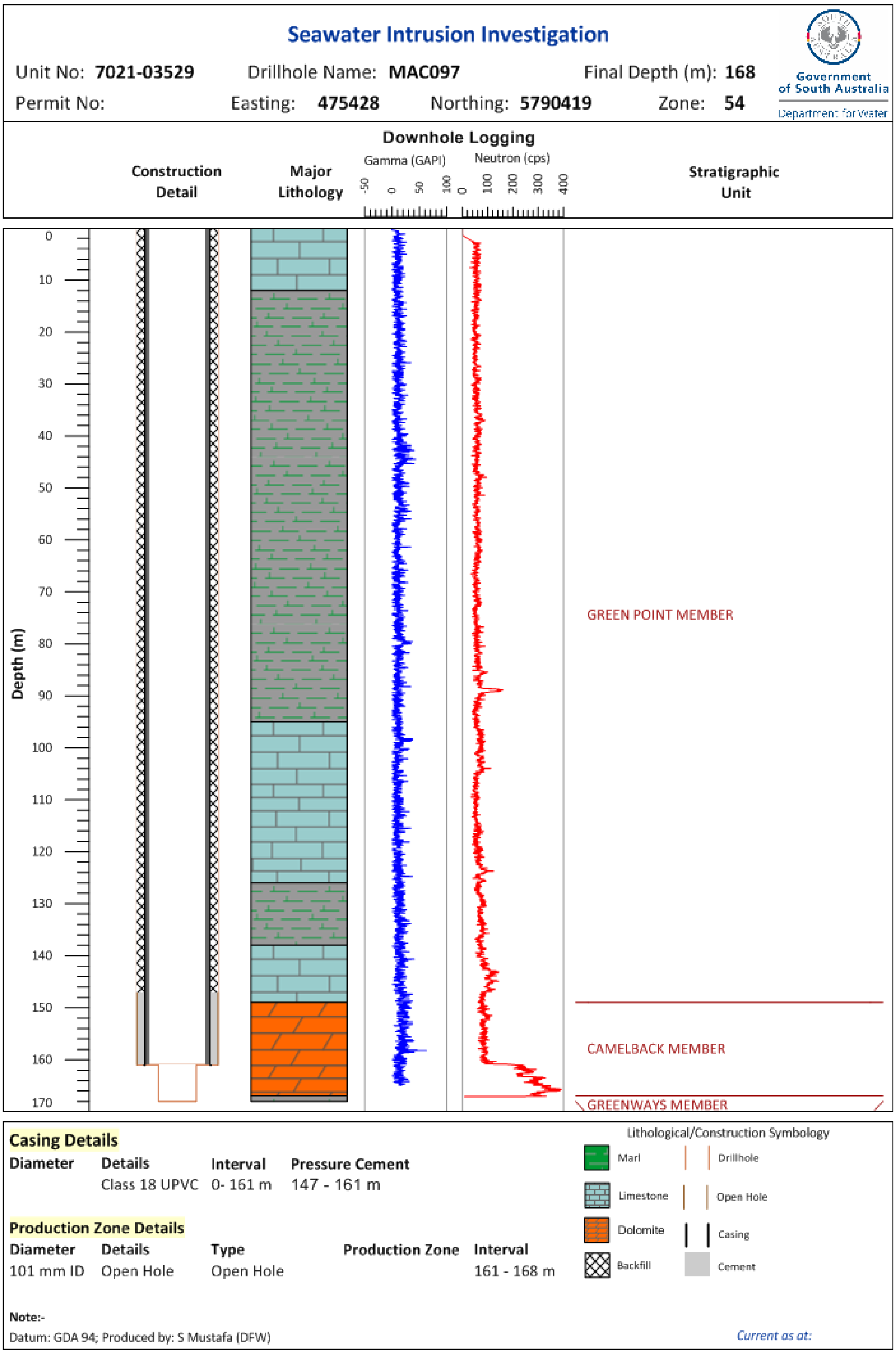
Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		150 - 162 m

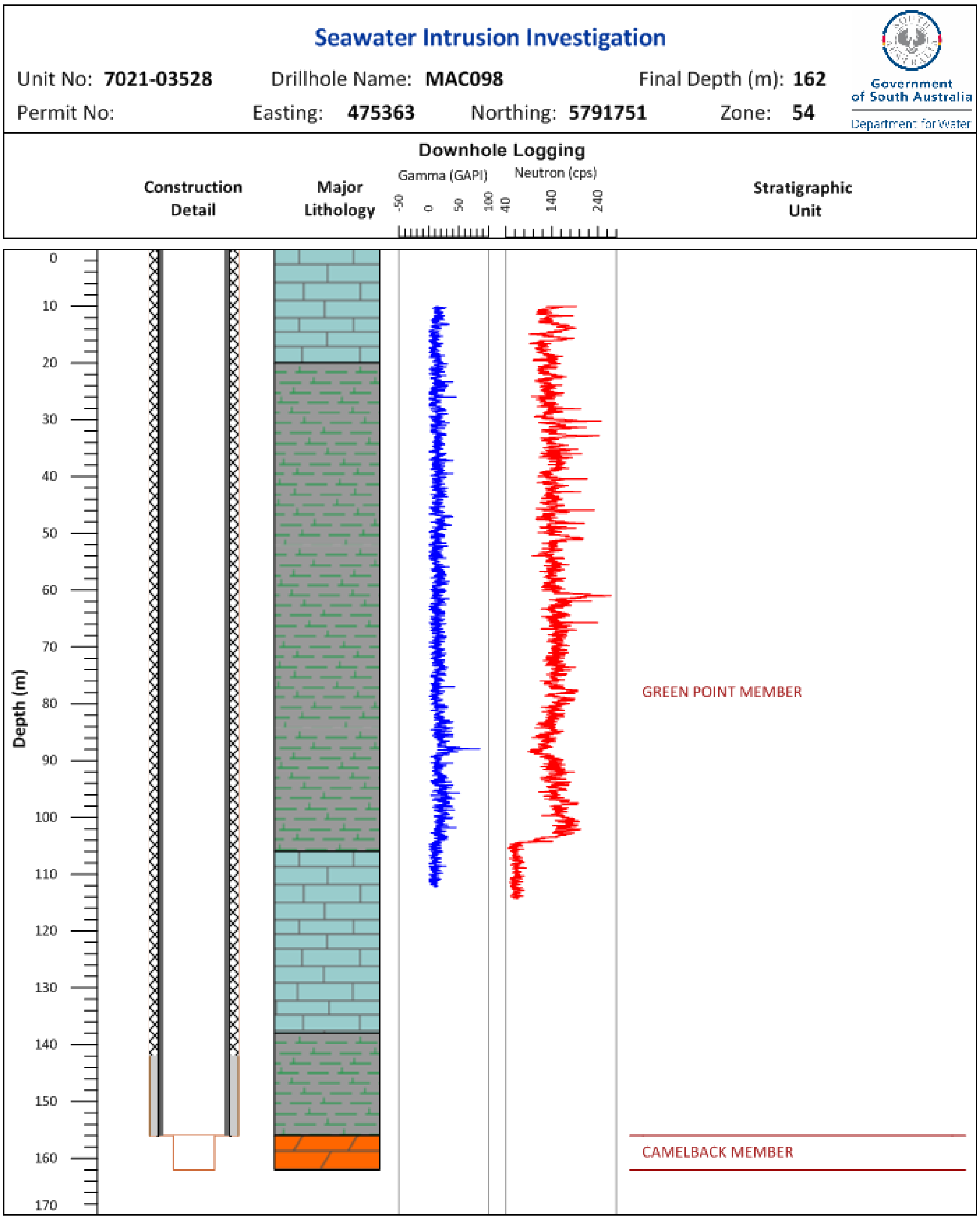
Lithological/Construction Symbology

Marl, Limestone, Dolomite, Backfill, Drillhole, Open Hole, Casing, Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

Current as at:


Seawater Intrusion Investigation
Unit No: 7021-03529
Drillhole Name: MAC097
Final Depth (m): 168
Permit No:
Easting: 475428
Northing: 5790419
Zone: 54
Government of South Australia
Department for Water
Construction Detail
Major Lithology
Downhole Logging
Gamma (GAPI)
-50 0 50 100
Neutron (cps)
0 100 200 300 400
Stratigraphic Unit
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
GREEN POINT MEMBER
CAMELBACK MEMBER
GREENWAYS MEMBER
Casing Details
Diameter
Details
Interval
Pressure Cement
Class 18 UPVC
0- 161 m
147 - 161 m
Production Zone Details
Diameter
Details
Type
Production Zone
Interval
101 mm ID
Open Hole
Open Hole
161 - 168 m
Lithological/Construction Symbology
Marl
Drillhole
Limestone
Open Hole
Dolomite
Casing
Backfill
Cement
Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)
Current as at:



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 156 m	142 - 156 m

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		156 - 162 m

Lithological/Construction Symbology

Marl; Limestone; Dolomite; Backfill; Drillhole; Open Hole; Casing; Cement

Note:-

Datum: GDA 94; Produced by: S Mustafa (DFW)

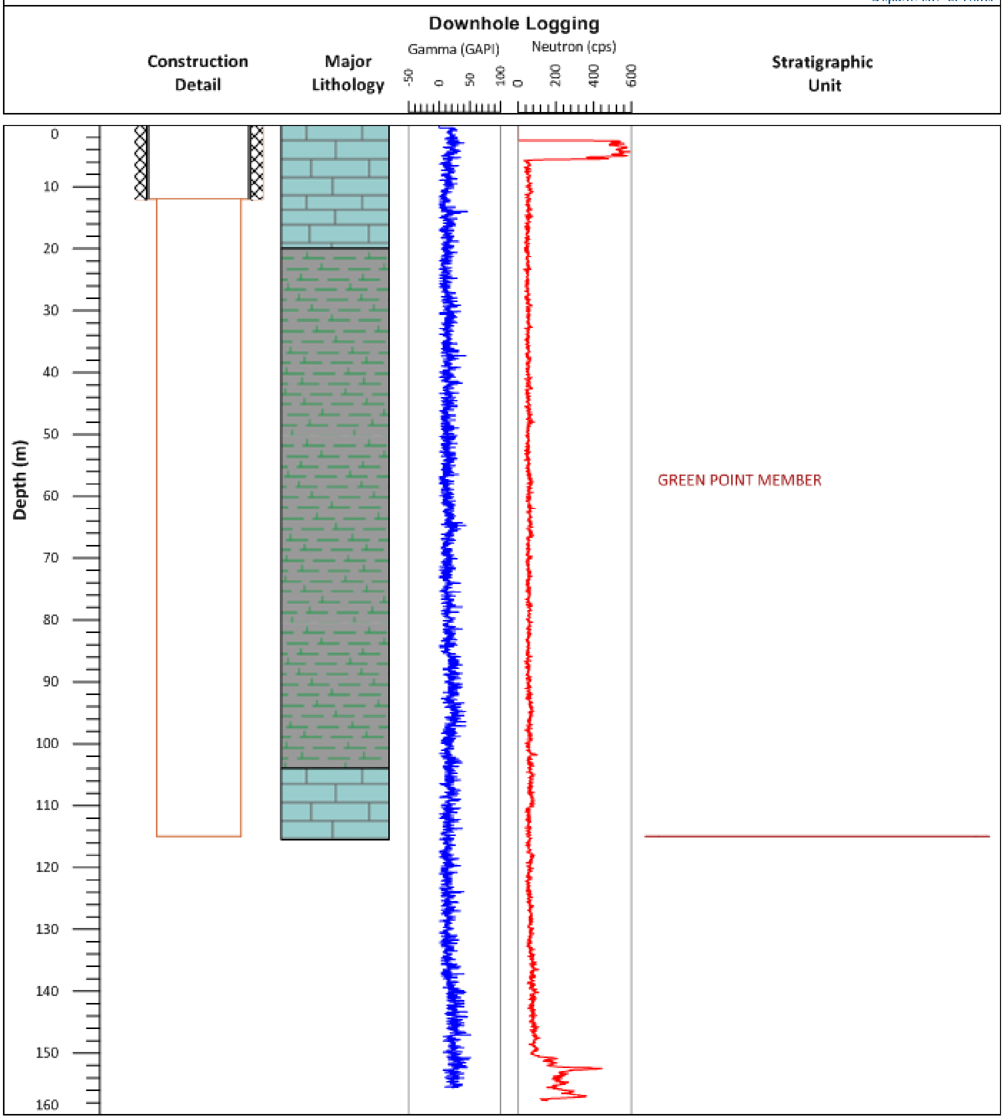
Current as at:

Seawater Intrusion Investigation

Unit No: **7021-03527** Drillhole Name: **MAC099** Final Depth (m): **115**

Permit No: Easting: **475387** Northing: **5791971** Zone: **54**

Government of South Australia
Department for Water



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 12 m	

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
217 mm ID	Open Hole	Open Hole		12 - 115 m

Lithological/Construction Symbology

Marl, Limestone, Dolomite, Backfill, Drillhole, Open Hole, Casing, Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

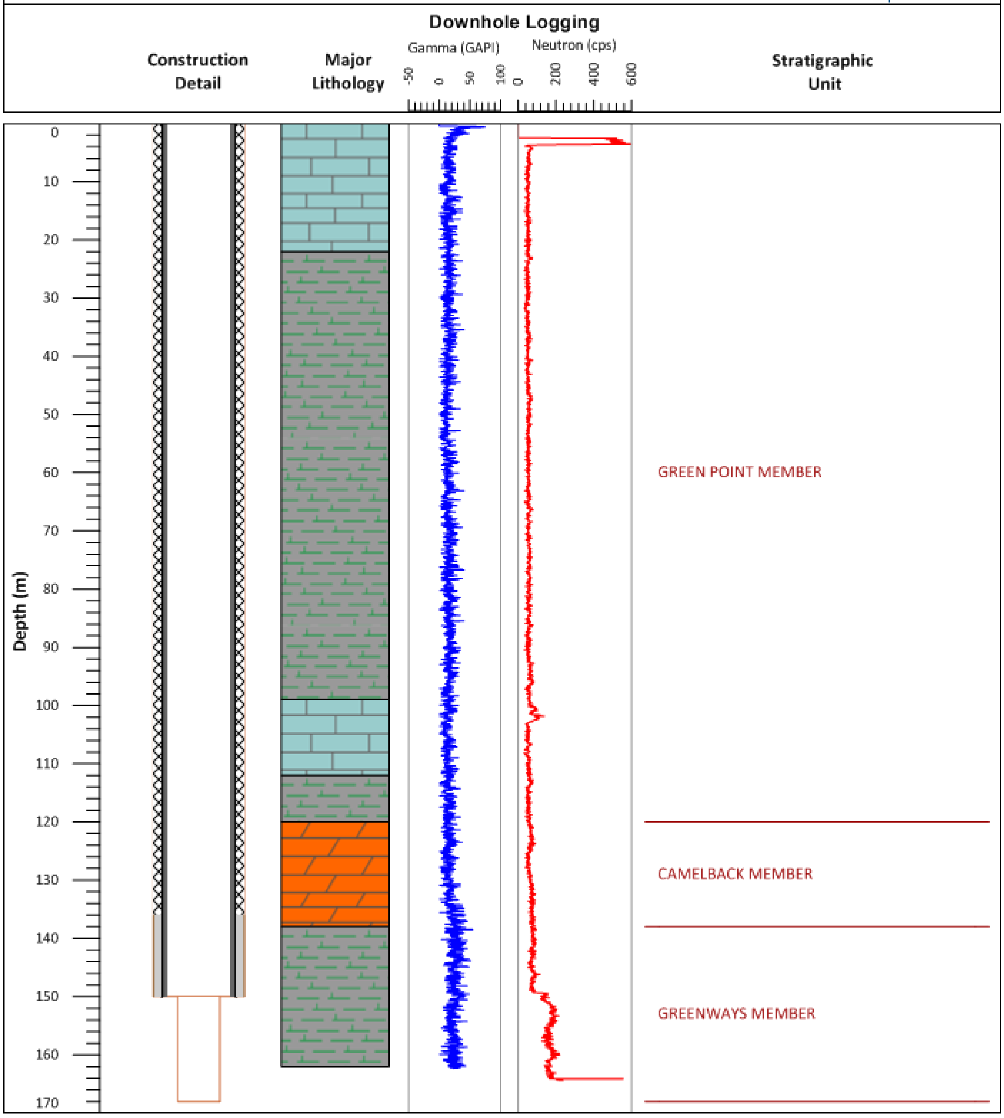
Current as at:

Seawater Intrusion Investigation

Unit No: **7021-03526** Drillhole Name: **CAR065** Final Depth (m): **168**

Permit No: Easting: **489139** Northing: **5790625** Zone: **54**

Government of South Australia
Department for Water



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 150 m	136 - 150 m

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		150 - 168 m

Lithological/Construction Symbology

Marl, Limestone, Dolomite, Backfill, Drillhole, Open Hole, Casing, Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

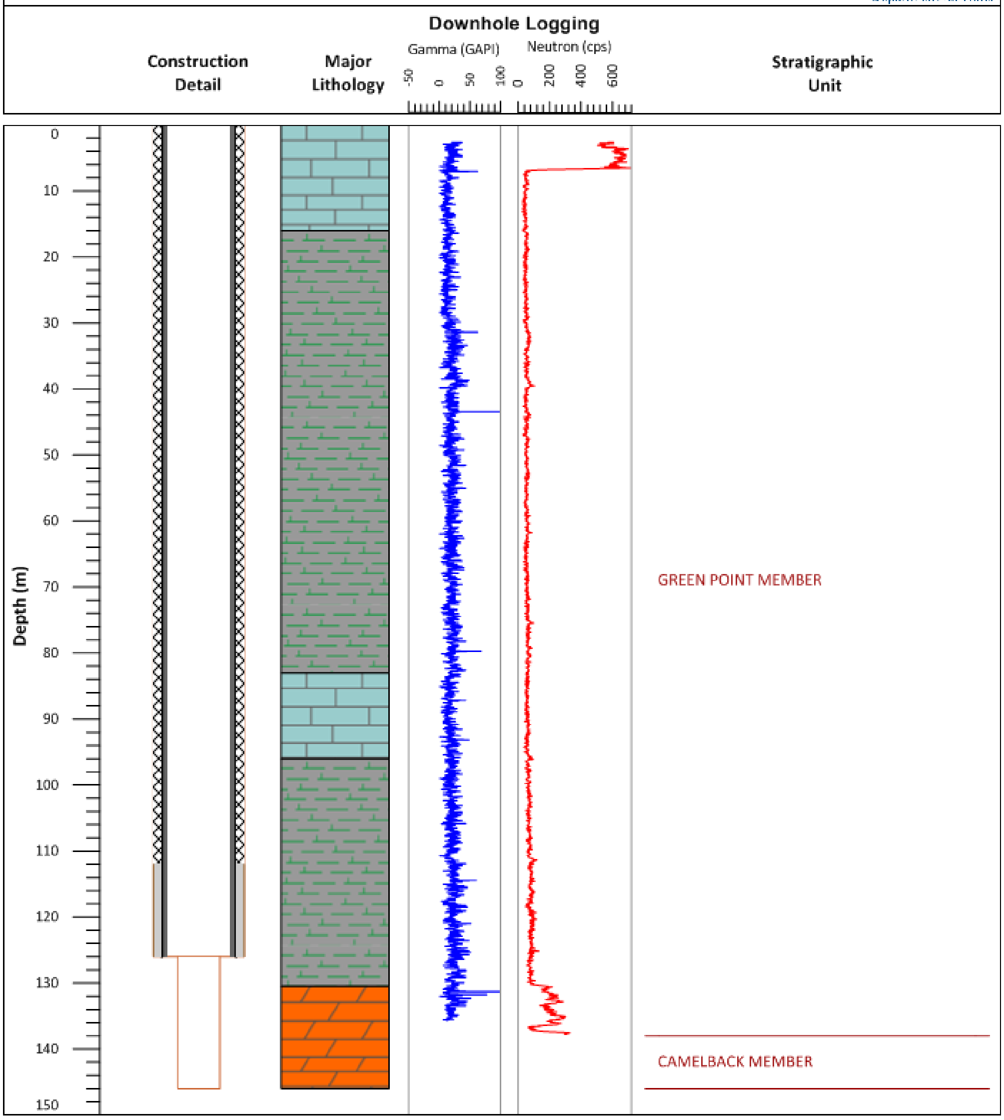
Current as at:

Seawater Intrusion Investigation

Government of South Australia
Department for Water

Unit No: **7021-03524** Drillhole Name: **CAR063** Final Depth (m): **146**

Permit No: Easting: **495111** Northing: **5790152** Zone: **54**



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 126 m	112 - 126 m

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		126 - 146 m

Lithological/Construction Symbology

Marl, Drillhole, Limestone, Open Hole, Dolomite, Casing, Backfill, Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

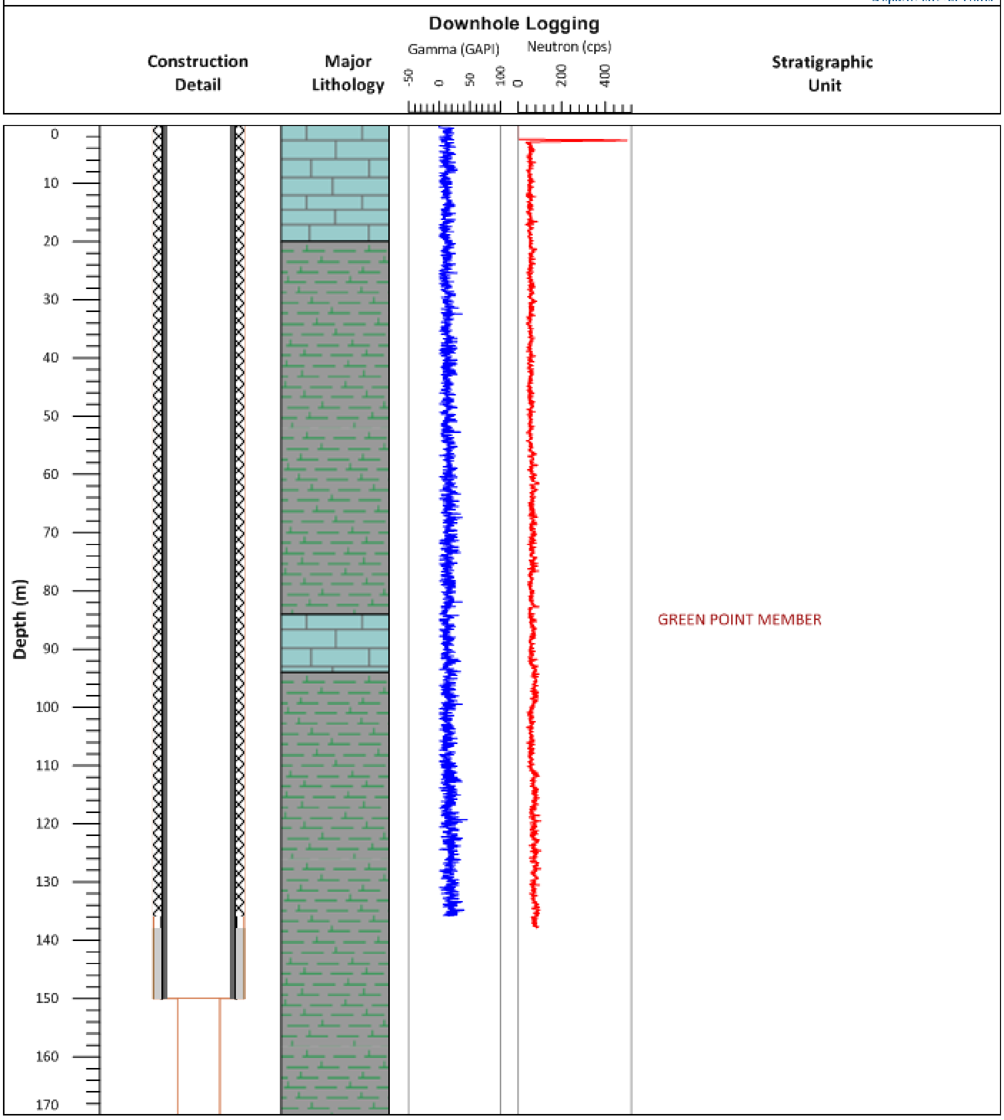
Current as at:

Seawater Intrusion Investigation

Unit No: **7022-10652** Drillhole Name: **KON033** Final Depth (m): **170**

Permit No: Easting: **463415** Northing: **5795924** Zone: **54**

Government of South Australia
Department for Water



Casing Details

Diameter	Details	Interval	Pressure Cement
	Class 18 UPVC	0 - 152 m	138 - 152 m

Production Zone Details

Diameter	Details	Type	Production Zone	Interval
101 mm ID	Open Hole	Open Hole		150 - 170 m

Lithological/Construction Symbology

Marl, Drillhole, Limestone, Open Hole, Dolomite, Casing, Backfill, Cement

Note:-
Datum: GDA 94; Produced by: S Mustafa (DFW)

Current as at:

B. GROUNDWATER AND SURFACE WATER CHEMISTRY

Sample ID	Easting	Northing	Date	Field Parameters			Stable Isotopes		Rn-222 (Bq/L)	Major Ions (mg/L)										
				EC (uS/cm)	Tempe (°C)	pH	δ O18 ‰ VSMOW	δD ‰ VSMOW		Ca	Mg	Na	K	HCO3	CL	SO4	Br	NO3	S	F
CAR 010	483118	5788829	19/08/2009	11570	18.8	7.9	-3.85	-19.90	0.89	134.00	225.00	1860.00	64.50	254.26	3900.00	490.00	14.00	2.00	158.00	0.62
CAR 011	495402	5789082	19/08/2009	2680	15.4	7.9	-4.64	-25.20	1.27	88.20	59.00	357.00	14.30	291.42	670.00	70.00	1.90	2.70	22.80	0.36
CAR 061	482437	5790211	19/08/2009	49390	16.3	9.0	0.14	2.80	0.66	528.00	999.00	9370.00	306.00	70.83	20000.00	2400.00	75.00	20.00	775.00	<2
CAR063	495111	5790152	19/08/2009	805	16	7.7	-4.89	-27.00	0.49	78.70	22.40	52.10	1.13	288.06	84.00	9.80	0.31	4.30	3.26	0.22
CAR064	495111	5790146	19/08/2009	755	15.6	7.9	-4.75	-26.80	3.42	78.00	19.10	46.30	2.31	248.16	78.00	11.00	0.26	23.00	3.63	0.15
CAR065	489139	5790625	18/08/2009	760	16.6	9.3	-4.92	-24.80	0.27	15.90	29.80	85.30	17.50	236.02	94.00	19.00	0.29	11.00	6.28	0.78
CAR066	482004	5792811	18/08/2009	775	16.2	9.6	-4.96	-27.60	0.21	44.20	20.40	75.50	4.61	291.05	120.00	19.00	0.41	20.00	6.26	0.24
MAC095	474740	5798890	19/08/2009	340	15.1	9.6	-5.01	-28.70	0.60	18.30	7.91	31.90	6.82	80.97	46.00	11.00	0.15	4.70	3.54	0.70
MAC096	474750	5798890	19/08/2009	410	14.8	9.2	-5.33	-29.70	0.26	26.10	9.88	36.60	3.21	90.12	56.00	12.00	0.20	20.00	3.56	0.27
MAC097	475428	5790419	17/08/2009	775	16.8	8.7	-4.91	-26.90	0.14	45.50	25.70	69.10	5.23	227.47	100.00	13.00	0.36	1.30	4.50	0.33
MAC098	475363	5791751	18/08/2009	715	16.3	9.4	-5.07	-27.30	0.11	48.20	16.20	66.60	2.75	158.22	110.00	18.00	0.38	13.00	6.03	0.33
MAC099	475387	5791971	18/08/2009	960	15.6	7.9	-4.59	-25.50	1.69	72.40	23.00	87.00	1.79	257.25	140.00	20.00	0.42	4.40	6.84	0.63
Mac100	467447	5793270	17/08/2009	1250	16.0	7.9	-4.78	-25.10	4.92	78.50	26.30	130.00	3.12	250.72	240.00	32.00	0.68	0.35	10.90	0.45
MAC101	468564	5791487	17/08/2009	1295	16.7	9.6	-5.13	-29.00	0.14	9.83	12.10	239.00	20.50	351.46	160.00	64.00	0.45	0.56	20.80	5.30
KON 031	462430	5802500	19/08/2009	660	17.2	9.3	-5.23	-28.00	0.19	32.80	31.00	52.70	6.04	209.29	93.00	14.00	0.30	0.91	4.01	1.10
KON 032	462425	5802510	19/08/2009	660	16.8	8.1	-5.15	-29.70	0.27	44.50	27.50	48.70	2.58	212.71	81.00	13.00	0.24	0.97	4.00	0.70
KON033	463415	5795924	17/08/2009	2240	17.6	10.6	-4.28	-23.70	0.14	13.20	21.30	399.00	33.90	181.34	490.00	190.00	1.50	10.00	62.50	3.10
Pick 1	492409	5788977	25/08/2009				-4.32	-20.5	1.14	85.3	24.3	81.8	3.51	284.65	120	11	0.33	10	3.72	0.30
Pick 2	491195	5789917	25/08/2009				-4.93	-27.7	3.77	82.8	24.4	60.6	2.24	278.54	90	13	0.31	23	4.71	0.28
Pick 3	495027	5788905	25/08/2009				-4.62	-26.6	2.60	94.2	81.1	582	18.5	266.65	1100	140	3.6	12	47	0.25
Pick 4	494633	5788360	25/08/2009				-4.63	-25.9	0.62	83.9	50	307	9.91	253.71	550	73	1.9	8.1	24.6	0.22
Ewens 1	481615	5791263	25/08/2009				-4.89	-27.6	1.40	79.1	20.7	51.6	2.02	245.11	78	14	0.28	26	4.24	0.21
Ewens 2	481824	5791070	25/08/2009				-4.89	-26.6	1.82	80.1	23	76.5	2.75	245.47	120	18	0.45	26	6.19	0.21
Ewens 3	482457	5790204	25/08/2009				-4.31	-24.7	2.81	120	115	841	28.6	251.03	1600	230	5.7	26	78.4	0.34
Ewens 4	482420	5790229	25/08/2009				-4.81	-26.7	1.16	78	25.5	97.7	3.47	245.11	160	23	0.59	27	7.98	0.22
Ewens 5	482436	5790169	25/08/2009				-4.69	-26.3	1.74	86.4	36.4	183	6.37	246.94	360	49	1.2	11	16.2	0.22
Footy club 2.5m				5510	14.1	8.4	-3.35	-17.4		98.7	114	886	14	301.67	1600	170	5.6	0.6	59.3	0.72
Footy Club 25m	473605	5788570	26/08/2009	13325	16.6	7.7	-3.27	-18.2		218	320	2210	54.5	215.45	4400	520	16	2.6	176	2.7
Footy club 40m				13900	16.7	7.7	-3.31	-18.5		223	331	2290	55.7	220.46	4700	560	17	1.2	186	2.8
chasm 10m			30/10/2009	2524	15.84	7.77	-4.95		4.55	88.00	52.80	336.00	10.20	271.59	650.00	83.00	2.00	14.00	25.80	0.23
chasm 20m			30/10/2009	2546	15.84	7.7	-4.74		5.33	86.60	52.80	335.00	10.20	268.35	670.00	86.00	2.20	14.00	26.00	0.27
chasm 25m	494974	5788924	30/10/2009	2551	15.83	7.68	-4.84		5.21	87.50	53.30	332.00	10.20	270.19	670.00	86.00	2.10	14.00	25.90	0.22
bathtub 38.4m			30/10/2009	2552	15.81	7.64	-4.80		5.52	86.90	52.80	332.00	10.20	268.23	670.00	84.00	2.10	14.00	26.00	0.22
chasm 65m			30/10/2009	2561	15.84	7.6	-4.76		5.80	86.80	52.80	332.00	10.20	266.83	680.00	86.00	2.20	14.00	25.90	0.27
CAR010	483118	5788829	29/05/2010	12060	18.8	7.0				134.00	241.00	1990.00	68.70	247.12	4200.00	570.00	14.00	2.30	169.00	0.52
CAR011	495402	5789082	27/05/2010	3275	16.0	7.0				103.00	60.50	424.00	9.77	265.36	910.00	93.00	3.00	10.00	27.70	0.29
CAR059	482442	5790218	29/05/2010	2400	15.1	7.0				90.80	43.90	290.00	6.23	247.85	640.00	62.00	2.00	17.00	19.00	0.20
CAR060	482440	5790216	29/05/2010	3050	17.2	7.0				92.00	57.50	398.00	9.90	238.15	840.00	100.00	2.70	23.00	32.10	0.23
CAR061	482437	5790211	29/05/2010	48610	18.1	7.1				412.00	1070.00	9190.00	304.00	112.52	19000.00	2700.00	67.00	1.50	782.00	0.79
CAR063	495111	5790152	27/05/2010	745	15.6	7.0				74.70	21.60	43.50	0.99	288.31	82.00	7.70	0.27	0.35	2.92	0.22
CAR064	495111	5790146	27/05/2010	700	15.4	7.0				73.30	19.20	39.80	2.18	241.32	80.00	11.00	0.26	24.00	3.75	0.13
CAR065	489139	5790625	27/05/2010	690	15.6	7.7				10.70	27.00	76.90	18.20	227.78	93.00	8.70	0.28	0.18	5.04	0.73
CAR066	482004	5792811	29/05/2010	640	15.8	8.5				53.30	20.30	57.50	4.27	189.40	100.00	17.00	0.33	21.00	5.10	0.20
MAC097	475428	5790419	28/05/2010	750	15.8	7.2				47.30	26.20	60.10	4.66	244.68	110.00	12.00	0.32	<0.05	4.21	0.31
MAC098	475363	5791751	28/05/2010	570	15.4	7.7				26.10	13.40	58.60	4.58	110.01	110.00	20.00	0.35	4.40	6.42	0.32
MAC099	475387	5791971	27/05/2010	990	15.5	7.0				74.70	21.00	91.10	1.02	262.07	170.00	22.00	0.46	6.90	7.05	0.39
MAC100	467447	5793270	28/05/2010	1170	16.0	6.8				77.10	25.90	109.00	2.87	258.04	230.00	36.00	0.63	0.18	11.60	0.42
MAC101	468564	5791487	28/05/2010	1195	16.3	8.0				4.77	5.07	219.00	20.40	300.39	180.00	65.00	0.47	0.18	20.30	5.20
KON033	463415	5795924	28/05/2010	2630	16.0	7.6				12.80	18.70	453.00	34.40	188.54	610.00	250.00	1.80	0.53	76.70	3.80
Seawater	472642	5770398	9/11/2010				0.69	4.90		356.00	1250.00	9650.00	300.00	119.23	19900.00	2800.00	65.00	1.00	809.00	0.44
CAR059	482442	5790218	28/03/2011	2466	17.1	6.72			6.19											
CAR060	482440	5790216	28/03/2011	3030	17.9	6.65	-4.59	-4.6	2.36											
CAR061	482437	5790211	28/03/2011	49200	18.7	7.42	0.31	0.3	2.63											
CAR066	482004	5792811	28/03/2011	744	15.9	7.6	-4.79	-4.8	1.48											

C. WETLANDS WITHIN THE PROJECT BOUNDARY

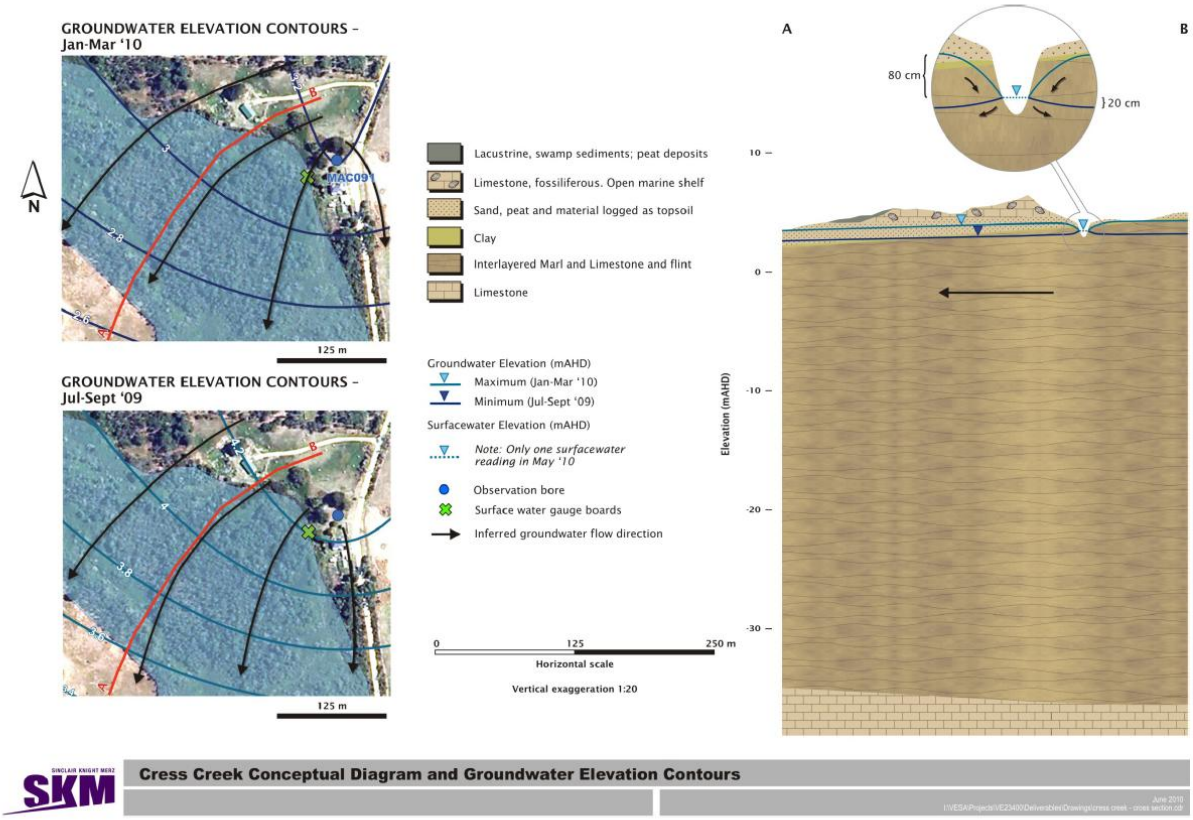
Wetland ID#	NAME*	COMPLEX	GDE Potential	GDE Confidence	Ecological Value	SAAE Type	Potential for SWI/SLR impacts
S0107035	GERMEIN RESERVE	NENE VALLEY	VH	H	High	Peat Swamp	Yes
S0107034		NENE VALLEY	VH	H	Not Assessed	Peat Swamp	Yes
S0106949		SOUTH EAST COASTAL LAKES	VH	H	Moderate	Grass Sedge Wetland	Yes
S0121515	DEAD POND		VH	H	Not Assessed	Karst System	Yes
S0106944		SOUTH EAST COASTAL LAKES	VH	H	Moderate	Grass Sedge Wetland	Yes
S0120717		NENE VALLEY	VH	H	Not Assessed	Peat Swamp	Yes
S0107021	LIONS PARK	NENE VALLEY	VH	H	Not Assessed	Peat Swamp	Yes
S0107050		SOUTH EAST COASTAL LAKES	VH	H	Moderate	Grass Sedge Wetland	Yes
S0106962		SOUTH EAST COASTAL LAKES	VH	H	Moderate	Lake Floodplain	Yes
S0121513	SPENCERS POND		VH	VH	Not Assessed	Karst System	Yes
S0110343	PICK SWAMP	NENE VALLEY	VH	VH	Very High	Peat Swamp	Yes
S0107036		NENE VALLEY	VH	H	High	Peat Swamp	Yes
S0101060	PICCANINNIE PONDS	NENE VALLEY	VH	VH	Very High	Peat Swamp	Yes
S0120253	GLENELG RIVER	CAROLINE	VH	VH	Moderate	Artificial Wetland	Yes
S0120854	EWENS PONDS	EIGHT MILE CREEK	VH	VH	Very High	Karst System	Yes
S0114986	JERUSALEM CREEK WETLAND	NENE VALLEY	VH	H	High	Peat Swamp	Yes
S0121483	LAKE BONNEY S.E.		VH	M	Very High	Unique Typology	Yes
S0107023	EIGHT MILE CREEK	EIGHT MILE CREEK	VH	VH	High	Seasonal Watercourse	Yes
S0107060	BUCKS LAKE	SOUTH EAST COASTAL LAKES	VH	H	Very High	Grass Sedge Wetland	Yes
S0107052		SOUTH EAST COASTAL LAKES	VH	H	High	Grass Sedge Wetland	Yes
S0114982	CRESS CREEK SPRING	NENE VALLEY	VH	VH	High	Grass Sedge Wetland	Yes
S0107004	MIDDLE POINT WETLAND	NENE VALLEY	VH	VH	Very High	Peat Swamp	Yes
S0107062		SOUTH EAST COASTAL LAKES	H	H	High	Grass Sedge Wetland	Yes
S0107037	SMITH POND	NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0107057		SOUTH EAST COASTAL LAKES	H	H	Not Assessed	Soaks and Springs	Yes
S0107038		NENE VALLEY	H	H	Not Assessed	Soaks and Springs	Yes
S0107077		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114971		NENE VALLEY	H	M	High	Peat Swamp	Yes
S0107079	BLACKFELLOWS CAVE WETLAND	NENE VALLEY	H	H	High	Peat Swamp	Yes
S0107027		NENE VALLEY	H	M	Not Assessed	Soaks and Springs	Yes
S0114968		NENE VALLEY	H	M	High	Peat Swamp	Yes
S0114964		NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0114983		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	Yes
S0107058		SOUTH EAST COASTAL LAKES	H	H	Moderate	Inland Interdunal Wetland Floo	Yes
S0108706	STRATMAN POND	NENE VALLEY	H	H	High	Grass Sedge Wetland	Yes
S0120718	BROWNS BEACH	NENE VALLEY	H	H	Low	Peat Swamp	Yes
S0114970		NENE VALLEY	H	M	Not Assessed	Peat Swamp	Yes
S0107061		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	Yes
S0121512	WILKES POND		H	H	Not Assessed	Karst System	Yes
S0114959	WINTERFIELD CREEK	NENE VALLEY	H	M	High	Peat Swamp	Yes
S0107028		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114965		NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0114944		SOUTH EAST COASTAL LAKES	H	H	Moderate	Grass Sedge Wetland	Yes
S0107075		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0107040		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114945		SOUTH EAST COASTAL LAKES	H	H	Moderate	Grass Sedge Wetland	Yes
S0107070		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114975		NENE VALLEY	H	M	Moderate	Grass Sedge Wetland	Yes
S0114974		NENE VALLEY	H	M	High	Grass Sedge Wetland	Yes
S0114987	JERUSALEM CREEK WETLAND	NENE VALLEY	H	H	High	Peat Swamp	Yes
S0120177	JERUSALEM CREEK WETLAND	NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114963	NENE VALLEY	NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0107043		SOUTH EAST COASTAL LAKES	H	H	Not Assessed	Grass Sedge Wetland	Yes
S0114973		NENE VALLEY	H	M	Moderate	Peat Swamp	Yes
S0107024	RIDDOCH BAY	NENE VALLEY	H	H	Moderate	Seasonal Watercourse	Yes
S0114962	NENE VALLEY	NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0114972		NENE VALLEY	H	M	Moderate	Grass Sedge Wetland	Yes
S0114979		NENE VALLEY	H	M	Not Assessed	Soaks and Springs	Yes
S0107069		NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0121514	BONES POND		H	H	Not Assessed	Peat Swamp	Yes
S0107076		NENE VALLEY	H	H	Not Assessed	Soaks and Springs	Yes
S0114969	WINTERFIELD CREEK	NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0114967		NENE VALLEY	H	M	Not Assessed	Peat Swamp	Yes
ERR			H	M			Yes
S0107033	GREEN POINT	NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	Yes
S0110856	MOUNT RUSKIN AND DISCOVERY BA	LONG SWAMP	H	M	Not Assessed		Yes
S0107011	NENE VALLEY	NENE VALLEY	H	M	High	Grass Sedge Wetland	Yes
S0107056		SOUTH EAST COASTAL LAKES	H	H	High	Grass Sedge Wetland	Yes
S0114984	JERUSALEM CREEK WETLAND	NENE VALLEY	H	H	Not Assessed	Peat Swamp	Yes
S0114966		NENE VALLEY	H	M	Not Assessed	Grass Sedge Wetland	Yes
S0107049		NENE VALLEY	H	H	Moderate	Peat Swamp	Yes
S0114950		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	Yes
S0114949		SOUTH EAST COASTAL LAKES	M	H	Not Assessed	Artificial Wetland	Yes
S0114985		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	Yes
S0107055		WOAKWINE RANGE	M	H	Not Assessed	Soaks and Springs	Yes
S0107032	GREEN POINT	NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	Yes
S0114943		SOUTH EAST COASTAL LAKES	M	H	Moderate	Grass Sedge Wetland	Yes
S0114961		NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0107019		NENE VALLEY	M	H	Not Assessed	Soaks and Springs	Yes
S0114976		NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0106943		WOAKWINE RANGE	M	H	Not Assessed	Soaks and Springs	Yes
S0107064		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	Yes
S0107025	PIC PONDS EXTENSION	NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0114958		NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0107026	PICCANINNIE PONDS EASTERN WET	NENE VALLEY	M	M	High	Soaks and Springs	Yes
S0107022	PIC PONDS EXTENSION	NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0114960		NENE VALLEY	M	M	Not Assessed	Soaks and Springs	Yes
S0106947		SOUTH EAST COASTAL LAKES	VH	H	Not Assessed	Grass Sedge Wetland	No
S0107010		SOUTH EAST COASTAL LAKES	VH	H	Not Assessed	Grass Sedge Wetland	No
S0120283	NGARANGA	NENE VALLEY	VH	H	Not Assessed	Grass Sedge Wetland	No
S0114989	JERUSALEM CREEK SPRING	NENE VALLEY	VH	VH	High	Peat Swamp	No
S0114948		SOUTH EAST COASTAL LAKES	H	H	Not Assessed	Grass Sedge Wetland	No
S0107003		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	No

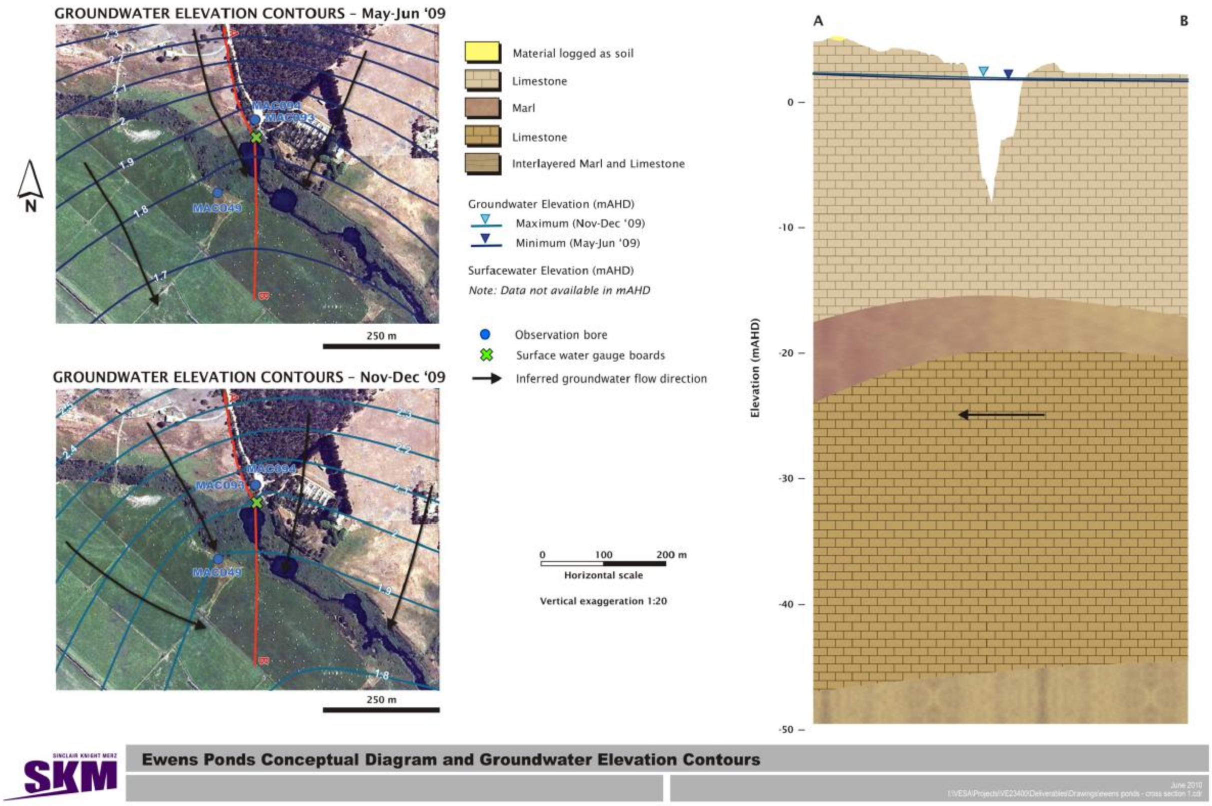
Appendix C - continue

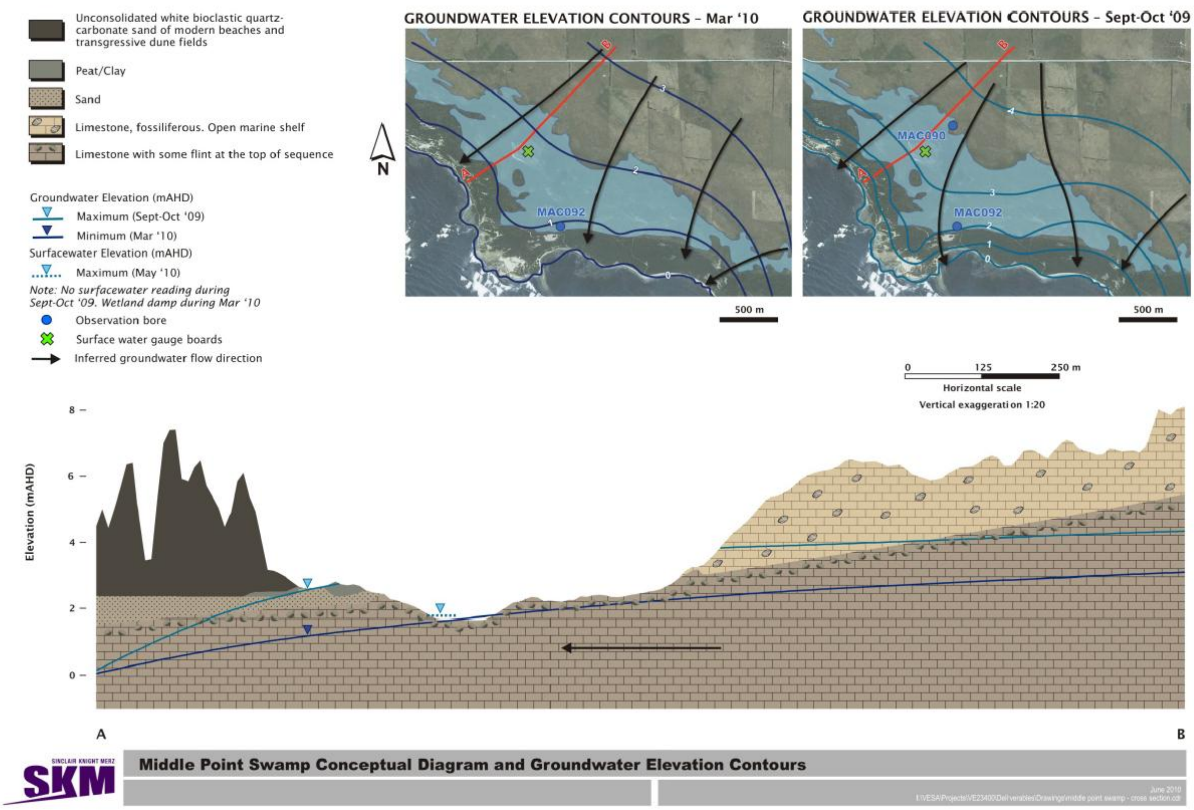
Wetland ID#	NAME*	COMPLEX	GDE Potential	GDE Confidence	Ecological Value	SAAE Type	Potential for SWI/SLR impacts
S0107029	BORONGA	NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	No
S0120756		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	No
S0107073		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	No
S0114981	FINGER POINT SEWAGE TREATMENT	NENE VALLEY	H	H	Not Assessed	Artificial Wetland	No
S0107005		NENE VALLEY	H	H	Not Assessed	Grass Sedge Wetland	No
S0114946		WOAKWINE RANGE	H	H	Not Assessed	Grass Sedge Wetland	No
S0114947		WOAKWINE RANGE	H	H	Not Assessed	Grass Sedge Wetland	No
S0114990		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0107006		NENE VALLEY	M	M	Not Assessed	Peat Swamp	No
S0119767		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0120572	GREEN POINT RD	NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0107015		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0110115	PIC SWAMP	NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0114980	FINGER POINT SEWAGE TREATMENT	NENE VALLEY	M	H	Not Assessed	Artificial Wetland	No
S0107031		NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0107045	BLACKFELLOWS CAVE WETLAND	NENE VALLEY	M	H	High	Peat Swamp	No
S0107044	BLACKFELLOWS CAVE WETLAND	NENE VALLEY	M	H	Not Assessed	Grass Sedge Wetland	No
S0114956		NENE VALLEY	M	M	Not Assessed	Peat Swamp	No
S0114988	JERUSALEM CREEK WETLAND	NENE VALLEY	M	H	High	Peat Swamp	No
S0107018		NENE VALLEY	M	M	Not Assessed	Grass Sedge Wetland	No
S0110106	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0114953		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0114955		WOAKWINE RANGE	L	M	Not Assessed	Grass Sedge Wetland	No
S0120579	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110362	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110349	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110127	PIC PONDS AREA	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0120577	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0114954		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0114978		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0110359	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120581	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110110	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0107068		WOAKWINE RANGE	L	M	Not Assessed	Grass Sedge Wetland	No
S0110130	BIMBADEEN	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0107071		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0120565	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0107016		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0120255		NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0110111	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0120267	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0114952		WOAKWINE RANGE	L	M	Not Assessed	Grass Sedge Wetland	No
S0110363	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0107067		NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0107080		WOAKWINE RANGE	L	H	Not Assessed	Grass Sedge Wetland	No
S0110368	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120257	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110109	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0120274	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0107014		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0110104	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0114957		NENE VALLEY	L	M	Not Assessed	Artificial Wetland	No
S0120564	BIMBADEEN	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120568	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0110120	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0120569	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110356	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120266	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110354	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110119	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0120583	WARREANGA	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0107063		WOAKWINE RANGE	L	M	Not Assessed	Grass Sedge Wetland	No
S0114977		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0107002		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0107013		NENE VALLEY	L	M	High	Grass Sedge Wetland	No
S0110102	WARREANGA	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0120571	STEWARTS RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110131	BIMBADEEN	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110364	DONOVANS	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0110350	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110535		NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110361	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110360	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0119985	BLACKFELLOWS CAVE WETLAND	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0107078		WOAKWINE RANGE	L	H	Not Assessed	Grass Sedge Wetland	No
S0110117	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0107042		NENE VALLEY	L	M	Not Assessed	Grass Sedge Wetland	No
S0110365	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0110132	BIMBADEEN	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120573	FEAST RD	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0120584	WATTLE RD	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110118	BIMADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0110114	BIMBADEEN	NENE VALLEY	L	H	Not Assessed	Freshwater Meadow	No
S0114951		NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0120271	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120273	DONOVANS	CAROLINE	L	H	Not Assessed	Freshwater Meadow	No
S0120561	PIC PONDS AREA	NENE VALLEY	L	H	Not Assessed	Grass Sedge Wetland	No
S0110125	SINKHOLE	NENE VALLEY	L	H	Not Assessed	Karst System	No

* Wetland is unnamed if NAME field is blank

D. CONCEPTUAL FLOW MODELS OF CRESS CREEK, EWENS PONDS AND MIDDLEPOINT SWAMP (SKM, 2010)




GROUNDWATER ELEVATION CONTOURS – May-Jun '09
GROUNDWATER ELEVATION CONTOURS – Nov-Dec '09
N
250 m
Material logged as soil
Limestone
Marl
Limestone
Interlayered Marl and Limestone
Groundwater Elevation (mAHD)
Maximum (Nov-Dec '09)
Minimum (May-Jun '09)
Surfacewater Elevation (mAHD)
Note: Data not available in mAHD
Observation bore
Surface water gauge boards
Inferred groundwater flow direction
0 100 200 m
Horizontal scale
Vertical exaggeration 1:20
A
B
Elevation (mAHD)
0
-10
-20
-30
-40
-50
SKM
Ewens Ponds Conceptual Diagram and Groundwater Elevation Contours


Unconsolidated white bioclastic quartz-carbonate sand of modern beaches and transgressive dune fields
Peat/Clay
Sand
Limestone, fossiliferous. Open marine shelf
Limestone with some flint at the top of sequence
Groundwater Elevation (mAHD)
Maximum (Sept-Oct '09)
Minimum (Mar '10)
Surfacewater Elevation (mAHD)
Maximum (May '10)
Note: No surfacewater reading during Sept-Oct '09. Wetland damp during Mar '10
Observation bore
Surface water gauge boards
Inferred groundwater flow direction
GROUNDWATER ELEVATION CONTOURS – Mar '10
GROUNDWATER ELEVATION CONTOURS – Sept-Oct '09
N
MAC092
MAC090
500 m
0 125 250 m
Horizontal scale
Vertical exaggeration 1:20
Elevation (mAHD)
8
6
4
2
0
A
B
SKM
Middle Point Swamp Conceptual Diagram and Groundwater Elevation Contours

UNITS OF MEASUREMENT

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

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

Shortened forms

~	approximately equal to
bgs	below ground surface
EC	electrical conductivity (µS/cm)
K	hydraulic conductivity (m/d)
pH	acidity
pMC	percent of modern carbon
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
w/v	weight in volume
w/w	weight in weight

GLOSSARY

Aquatic community — An association of interacting populations of aquatic organisms in a given water body or habitat

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

Aquatic habitat — Environments characterised by the presence of standing or flowing water

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

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

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 resources 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

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

BoM — Bureau of Meteorology, Australia

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

CFC — Chlorofluorocarbon; measured in parts per trillion (ppt)

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

Critical habitat — Those areas designated as critical for the survival and recovery of threatened or endangered species

CSIRO — Commonwealth Scientific and Industrial Research Organisation

δD — Hydrogen isotope composition, measured in parts per thousand ($^{o}/_{oo}$)

DENR — Department of Environment and Natural Resources (Government of South Australia)

DFW — Department for Water (Government of South Australia)

Diversity — The distribution and abundance of different kinds of plant and animal species and communities in a specified area

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

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecological indicators — Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance; for example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit

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

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

Endangered species — (1) Any species in danger of extinction throughout all or a significant portion of its range

Environmental values — The uses of the environment that are recognised as being 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 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

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

Flow regime — The character of the timing and amount of flow in a stream

Fully-penetrating well — In theory this is a wellhole that is screened throughout the full thickness of the target aquifer; in practice, any screen that is open to at least the mid 80% of a confined aquifer is regarded as fully-penetrating

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

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

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

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) that 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

Licence — A licence to take water in accordance with the Act; see also 'water licence'

LMWL — Local meteoric water line

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

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

Molar (M) — A term describing the concentration of chemical solutions in moles per litre (mol/L)

GLOSSARY

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

Native species — Any animal and plant species originally in Australia; see also 'indigenous species'

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

$\delta^{18}O$ — Oxygen isotope composition, measured in parts per thousand ($^o/_{oo}$)

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

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

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

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

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

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

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 also artificial recharge, natural recharge

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater

SA Water — South Australian Water Corporation (Government of South Australia)

Seasonal watercourses or wetlands — Those watercourses or 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

Sensitive species — Those plant and animal species for which population viability is a concern

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; it is dimensionless

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

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

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

T — Transmissivity; a parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

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

Threatened species — Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range

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

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) 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

WAP — Water Allocation Plan; a plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Water column — a section of water extending from the surface of a body of water to its bottom. In the sea or ocean, it is referred to as 'pelagic zone'

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

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

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 quality data — Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and wastewater, and of the immediate environment in which the water exists

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Water resource monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

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

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