MURRAY**FUTURES**
Lower Lakes & Coorong Recovery

Acid Sulfate Soils Research Program

Quantification of Acidity Flux Rates to the Lower Murray Lakes

Report 2: Supplementary Report
Part 1 of 2: Main Report | June 2010

Australian Government

Government of South Australia

WATER FOR GOOD

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Cover image

Currency Creek, June 2009 (DENR 2009)

Quantification of Acidity Flux Rates to the Lower Murray Lakes: Supplementary Report

Prepared by Earth Systems Consulting Pty. Ltd. for the SA Department of Environment and Natural Resources, as part of the South Australian Government's $610 million Murray Futures program funded by the Australian Government's Water for the Future initiative.

June 2010

Government of South Australia
Department of Environment
and Natural Resources

EARTH SYSTEMS
Environment - Water - Sustainability

Executive Summary

The Department of Environment and Natural Resources (DENR), South Australia, commissioned Earth Systems Consulting Pty. Ltd. (Earth Systems) to quantify acidity flux rates from acid sulfate soils into the surface waters of Lake Alexandrina and Lake Albert (Lower Murray Lakes). A detailed report on the project was prepared by Earth Systems (2010), including laboratory and field monitoring results over 3 months (August-November 2009), acidity generation estimates, acidity flux rate estimates and management recommendations. This Supplementary Report incorporates more recent field monitoring data, collected in February and April 2010, and discusses the implications of new data for the quantification of acidity flux rates and development of ASS management strategies for the Lower Murray Lakes.

As of late April 2010, the surface water level in both lakes was around -0.5 m AHD, based on Department for Water lake level data. There remain some apparent inconsistencies between piezometric level data proximal to the lakes. From January 2010, the recorded surface water levels at Currency Creek were also inconsistent with data from all (3) piezometers on the creek margins. In all cases the surface water level data appear to be overestimates, potentially due to subsidence of monitoring equipment in soft lake/creek bed sediments.

The additional sediment moisture data obtained in early 2010 has provided further insight into the nature of desaturation processes in sandy lake sediments. Sediment moisture results from January-April 2010 indicate that, despite surface water levels decreasing in both lakes (and corresponding decreases in piezometric levels in the lake sediments), a reasonably consistent moisture profile is maintained in the upper 0.3-0.4 m of sediments, with effectively saturated conditions (moisture contents of around 40-50 vol% H_2O) at greater depths.

Recent surface water quality data provided by EPA (2010) indicates that:

- The surface water pH in both lakes has generally been maintained 8.5, with a recent trend towards pH 9 at all sites from January-April 2010.
- The surface water alkalinity at most sites in Lake Alexandrina remained around 180 mg/L $CaCO_3$, and increased in Lake Albert from around 250 mg/L $CaCO_3$ to 300 mg/L $CaCO_3$, from January-April 2010.
- The chloride to sulfate ratio did not noticeably decrease in Lake Alexandrina, and progressively increased in Lake Albert (indicating net sulfate reduction) from January-April 2010.

The lack of evidence of major acidity flux to the lakes from January-April 2010 is attributed to the following key factors:

- Surface water level data indicates that Lake Alexandrina generally remained above -1.0 m AHD, significantly higher than the predicted level of -1.4 m AHD in February 2010. (The minimum of less than -2.0 m AHD was predicted to occur around April 2011). Lake Albert reached a minimum level of around -0.7 m AHD, significantly higher than the predicted minimum of -1.0 m AHD.
- Moisture data collected at Point Sturt, Campbell Park and the Windmill location, indicate that sediments remained effectively saturated at depths below 0.3-0.4 m throughout the 2009-2010 summer.

Furthermore, the elevated surface water pH and significant increases in alkalinity provide evidence of sulfate reduction processes occurring within both lake water bodies.

Nevertheless, recent trends in groundwater quality at Point Sturt, Campbell Park and the Windmill location, indicate that there remains a risk of localised acidity fluxes around the margins of both lakes, such as that observed at Boggy Lake (Lake Alexandrina) and Reedy Point (Lake Albert).

The future risk of lake acidification will primarily depend on long term surface water level predictions.

A number of ASS risk factors have been developed to assist in the identification of localised high risk ASS areas or “hot spots” around the lakes.

Estimates of future acidity generation rates in unsaturated sediments can be improved by updating assumptions regarding sediment moisture profiles in existing models, and utilising revised predictions of lake water levels (when available).

The estimated rates of acidity flux for each scenario documented by Earth Systems (2010) remain valid. However, the duration of acidity flux events is likely to have been overestimated for the following reasons:

- Lake water levels have remained significantly higher than predicted, and therefore acidity generation rates are likely to have been overestimated (see above).
- Surface runoff and acid salt dissolution associated with high intensity rainfall events (where rainfall intensity exceeds infiltration rate) was not taken into account as an acidity flux mechanism. This mechanism is likely to have been an important component of the rapid acidity flux event observed at Currency Creek in 2009.

Recommendations

The following recommendations supplement those provided in Earth Systems (2010).

Acidity flux quantification

- Conduct geological mapping of the margins of both lakes as a priority to better characterise the ASS risk at various locations around both lakes.
- Use the geological information (generated above) as well as other key risk factors to generate a risk-based map of ASS hot spots.
- Update acidity generation rate estimates based on new sediment moisture data and new predictions of surface water levels (when available).
- Incorporate surface runoff and acid salt dissolution associated with high intensity rainfall events as a key component (flux mechanism) in future acidity flux modelling.
- Conduct further investigation to resolve the discrepancy between surface water levels and piezometric levels, particularly in Lake Albert and Currency Creek.
- Consider utilising low-cost level loggers in shallow piezometers to replace the heavy and apparently problematic level sensors currently used to monitor lake levels.
- Continue long term monitoring of sediment moisture and piezometric levels at existing sites (download data at least every 2 months) to:
    - Confirm or update the findings presented in this report.
    - Investigate the implications of further rises in lake levels on surface water quality (eg. throughout the 2010 wet season).
    - Provide early warning of localised acidity generation and fluxes to the lakes.
- Consider establishing a more extensive groundwater monitoring network (levels and chemistry) throughout the lake system. Prioritise future monitoring sites according to key ASS risk criteria.
- Conduct periodic mapping of the nature and distribution of secondary salts around both lakes. Use this information to create more accurate deterministic models for the formations of these materials, in conjunction with the geological mapping (recommended above) to better characterise the ASS risk at various locations around both lakes.
- Utilise ASS risk criteria to identify localised high risk ASS sites or “hot spots” that may require management intervention.

Acidity flux management

- All efforts should be directed at keeping sulfidic lake sediments saturated to prevent acidity generation.
- In the event that the inundation of sandy sediments cannot be guaranteed, consider the benefits of subsurface barriers.
- In the event that significant areas of clay-rich sediment become exposed to atmospheric oxygen, consider strategic installation of shallow terraces constructed from ultra-fine grained limestone along contours on top of exposed clays to maintain saturation (not inundation) during dry periods.
- Consider treatment of lake water and exposed sediment banks with limestone at high risk locations. This could involve either pre-emptive or post acidification limestone addition, and could potentially be done from the lake surface (eg. barges), from the shoreline (eg. mixing and dosing equipment), or from the air (eg. air tractors).

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1 Introduction

The Department of Environment and Natural Resources (DENR), South Australia, commissioned Earth Systems Consulting Pty. Ltd. (Earth Systems) to quantify acidity flux rates from acid sulfate soils into the surface waters of Lake Alexandrina and Lake Albert (Lower Murray Lakes).

A detailed report on the project was prepared by Earth Systems (2010), included laboratory and field monitoring results over 3 months (August-November 2009), modelling outputs, acidity flux rate estimates and management recommendations.

This Supplementary Report incorporates more recent field monitoring data, collected in February and April 2010, and discusses the implications of new data for quantification of acidity flux rates and development of ASS management strategies for the Lower Murray Lakes.

2 Objectives

The objectives of this study are to:

- Quantify acidity flux rates to proximal water bodies during wetting events based on the current understanding of the hydrogeology and hydrogeochemistry of lake sediments via new and existing field and laboratory data analysis.
- Provide recommendations for future management of the Lower Murray Lakes.

3 Scope of Works

The scope of works required for the acidity flux project included:

1. Design, establishment and implementation of a laboratory testwork program to measure sulfide oxidation rates of Lower Murray Lakes ASS as a function of sediment moisture content.
2. Design and establishment of a field monitoring program to collect geological, geophysical, hydrogeological and hydrogeochemical data at selected high risk locations in the Lower Murray Lakes including:
    - Currency Creek (tributary of Lake Alexandrina).
    - Point Sturt (Lake Alexandrina).
    - Campbell Park (Lake Albert).
    - “Windmill” location (Lake Albert, north-eastern shoreline).
3. Implementation of a field monitoring program at the four sites listed above over a period of 8 months.
4. Laboratory and field data analysis, including modelling, to estimate acidity flux rates to the Lower Murray Lakes based on available data.
5. Preparation of a final report incorporating laboratory and field monitoring results over 3 months (August-November 2009), modelling outputs, acidity flux rate estimates and management recommendations (prepared in April 2010).
6. Preparation of a Supplementary Report (this document) incorporating field monitoring results over 8 months (August 2009 to April 2010), and discussion of implications for modelling outputs, acidity flux rate estimates and management recommendations.

4 Methodology

The methodology for quantifying acidity flux rates to the Lower Murray Lakes, described in detail in Earth Systems (2010), included the following key steps:

- Design, establish and implement a laboratory testwork program.
- Design, establish and implement a field monitoring program.
- Conduct an assessment of laboratory and field data in order to develop acidity generation and acidity flux models for the lakes.
- Determine the management implications of acidity flux modelling for the Lower Murray Lakes.

Supplementary field monitoring was conducted in February and April 2010 in accordance with the methodology described in Section 4.2.7 of Earth Systems (2010). A map of the field monitoring locations is shown in Figure 1.

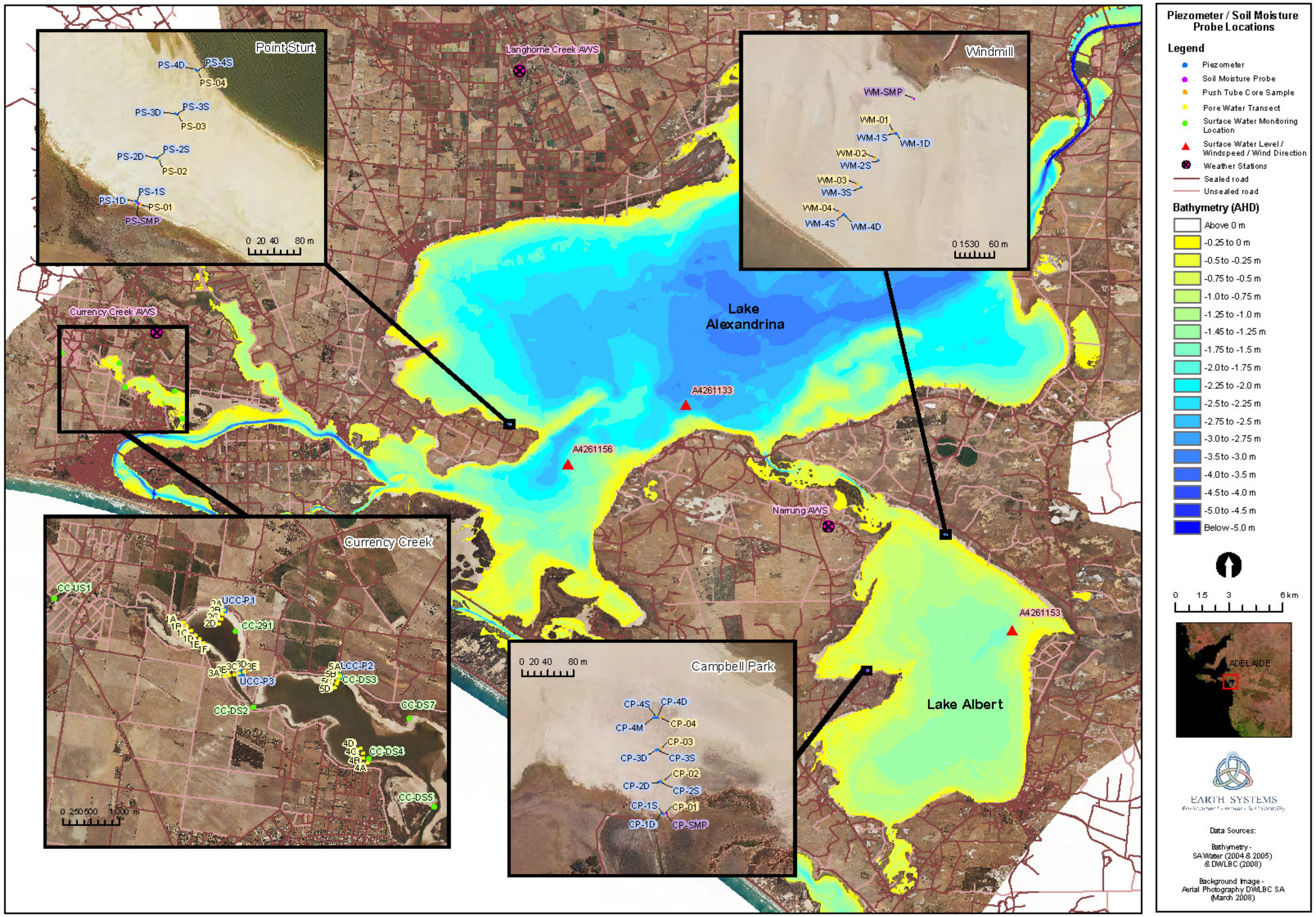

Figure 1. Location of piezometers and moisture sensors installed in the Lower Murray Lakes.

5 Results

5.1 *Field monitoring program*

5.1.1 Sediment moisture

Raw data collected from the moisture sensors installed at Point Sturt, Campbell Park and the Windmill location are provided in Attachment A. The hourly moisture content data are graphed alongside 15 minute rainfall data in Figures 2, 3 and 4, respectively. Figures 5-7 provide a summary of average, minimum and maximum moisture profile data for the Point Sturt, Campbell Park and Windmill locations.

The key results are summarised below:

- At all three locations, the moisture content progressively increases with depth below ground, approaching saturation at a depth of 30-40 cm.
- The data across all three locations are generally consistent (given local lithological variations) suggesting that the results are broadly representative of moisture conditions throughout the sandy sediments around the periphery of both lakes.
- Saturated conditions are indicated by moisture contents of around 40-50 vol% H_2O, assuming a sediment porosity of 40-50 vol%. This is consistent with the relatively constant moisture content of 46-47 vol% measured at a depth of 40 cm at Point Sturt and 30 cm at Campbell Park.
- In general, there has been a progressive decrease in moisture content over time at all three sites, from late August to late March 2010. This trend is most evident at shallower depths in the sediment profile (10-20 cm below ground).
- Hourly moisture content data are responsive to some but not all rainfall events. This applies to all depths monitored from late August to late April 2010.
- The effect of rainfall on moisture content is most evident at shallower depths in the sediment profile and during higher intensity and/or longer duration rainfall events.
- Where the rainfall intensity or duration is sufficient to affect sediment moisture content, peak moisture values generally occur within a few hours of the onset of rainfall. Moisture contents can increase by up to 30 vol% following a significant rainfall event, particularly in the upper 10-20 cm of the sediment profile. After significant rainfall events, moisture contents can take several days to recover to pre-event values.
- Where the rainfall intensity or duration is sufficient to affect sediment moisture content, peak moisture values in the upper sediments are achieved more rapidly at the Windmill location (eg. within 5 hours) than the Point Sturt (eg. 10 hours) and Campbell Park (eg. 15 hours) locations. This trend is consistent with the relatively high hydraulic conductivity values (coarser grained sediments) at Windmill and low hydraulic conductivity values (finer grained sediments) at Campbell Park. A delay of around 20-30 hours was generally observed between the initial rise in moisture content in the upper 10 cm layer, and the peak moisture content at a depth of 40-50 cm below ground, at all locations. This suggests that vertical migration of infiltrating rainwater through the upper 40-50 cm occurs within approximately 1 day of the onset of a significant rainfall event.
- A strong correlation exists between moisture content (Figures 2-4) and piezometric levels (Figures 9-11) at all three sites. This is particularly evident in the moisture content data for the upper (unsaturated) sediment layers.
- Low magnitude diurnal oscillations in moisture content at Windmill and Campbell Park are interpreted to be associated with the effects of Earth tides[1]. This observation is also consistent with fluctuations in piezometric levels. The magnitude of diurnal oscillations in moisture content is around 1-2 vol% at the Windmill location and less than 0.5 vol% at Campbell Park. The significantly higher hydraulic conductivity of Windmill sediments (K >30 m/day at Site 1) may be associated with the greater response to Earth tides (c.f. K = 0.22 m/day at Campbell Park, Site 1). In comparison, Earth tides were barely evident in the Point Sturt moisture data, corresponding to the lowest K value of the three sites (K = 0.09 m/day).

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[1] Earth tides (distinct from ocean tides) refer to the sub-metre motion of the Earth associated with gravitational forces of the moon and, to a lesser extent, the sun. Earth tides comprise diurnal constituents, with a typical cycle length of around 24 hours (one high tide or 'bulge' and one low tide or 'depression' per day) and semi-diurnal constituents, with a typical cycle length of around 12 hours, among other longer term constituents associated with the Earth's axial tilt, etc. Earth tides encompass the entire body of the Earth, including the outer crustal layers, surficial sediments / rocks, groundwater, etc.

- The average moisture profile data in Figures 5-7 demonstrate the progressive increase in moisture content with depth below ground surface at all sites. Much of the variation in moisture content with depth occurs over an interval of around 0.3 m at all sites. The lowest moisture contents observed in the upper 0.1 m were around 2 vol%, 4 vol% and 2 vol% at Point Sturt, Campbell Park and Windmill, respectively. Minimum and maximum moisture contents for each depth interval, as shown in Figures 5-7, indicate that the upper sediment layers (upper 0.1-0.2 m) have experienced significant variation over 7 months. This is attributed to the increased response to incident rainfall as well as greater evapotranspiration within the upper layers.
- The moisture profile data for Point Sturt (Figure 5) indicate that, while the piezometric level in the adjacent piezometer reached a minimum of 1.38 m below ground between 28 August and 5 April 2010, the sediments remained near-saturated (average moisture content 42 vol%) at a depth of 0.4 m throughout this period. Thus, approximately 1 m of sediment was effectively saturated above the minimum piezometric level.

  At Point Sturt, the moisture profile in the upper 0.4 m did not change significantly from late November 2009 to early April 2010, despite the minimum piezometric level decreasing from 0.87 m to 1.38 m below ground. Therefore, the zone of effectively saturated sediments observed at Point Sturt increased in thickness by approximately 0.5 m from late November 2009 to early April 2010.
- The moisture profile data for Campbell Park (Figure 6) indicate that, while the piezometric level in the adjacent piezometer reached a minimum of 0.84 m below ground (piezometer effectively dry) between 27 August and 5 April 2010, the sediments remained saturated (average moisture content 39-45 vol%) at a depth of 0.3-0.5 m throughout this period. Thus, approximately 0.5 m of sediment was effectively saturated above the minimum piezometric level.

  The apparent anomaly (decrease) in moisture content observed at a depth of 0.4 m (Figure 6) is attributed to lower sediment porosity in this layer, which limits the moisture holding capacity of the sediment.

  At Campbell Park, the moisture profile in the upper 0.4 m did not change significantly from late November 2009 to early April 2010, despite the piezometric level data at Site 1 indicating a minimum of 0.84 m below ground (effectively dry).
- The moisture profile data for the Windmill location (Figure 7) indicate that, while the piezometric level in the adjacent piezometer reached a minimum of 0.60 m below ground between 20 October and 5 April 2010, the sediments remained saturated (average moisture content around 50 vol%) at a depth of 0.3 m throughout this period. Thus, approximately 0.2-0.3 m of sediment was effectively saturated above the minimum piezometric level.

  The relatively high moisture contents measured at the Windmill location may be attributed to higher porosity in these sediments. Furthermore, the effects of seiching at the Windmill location could contribute to the higher moisture contents. This is apparent from a rapid rise in piezometric level around 25 October 2009 at the Windmill location (Site 1) and subsequent rise in moisture content at multiple depths, despite the lack of rainfall prior to this event (Figure 7). Further evidence of seiching is discussed in Section 5.1.2.

  At the Windmill location, the moisture profile in the upper 0.4 m did not change significantly from late November 2009 to early April 2010, despite a slight decrease in the minimum piezometric level, from 0.56 m to 0.60 m below ground.
- The above results indicate that effectively saturated sediments were maintained within 0.3-0.4 m of the ground surface from late August 2009 to early April 2010, prior to the onset of autumnal rains in April 2010. This is despite a significant decrease in the minimum piezometric level at Point Sturt, and minor decreases at the Campbell Park and Windmill locations, over the same monitoring period.

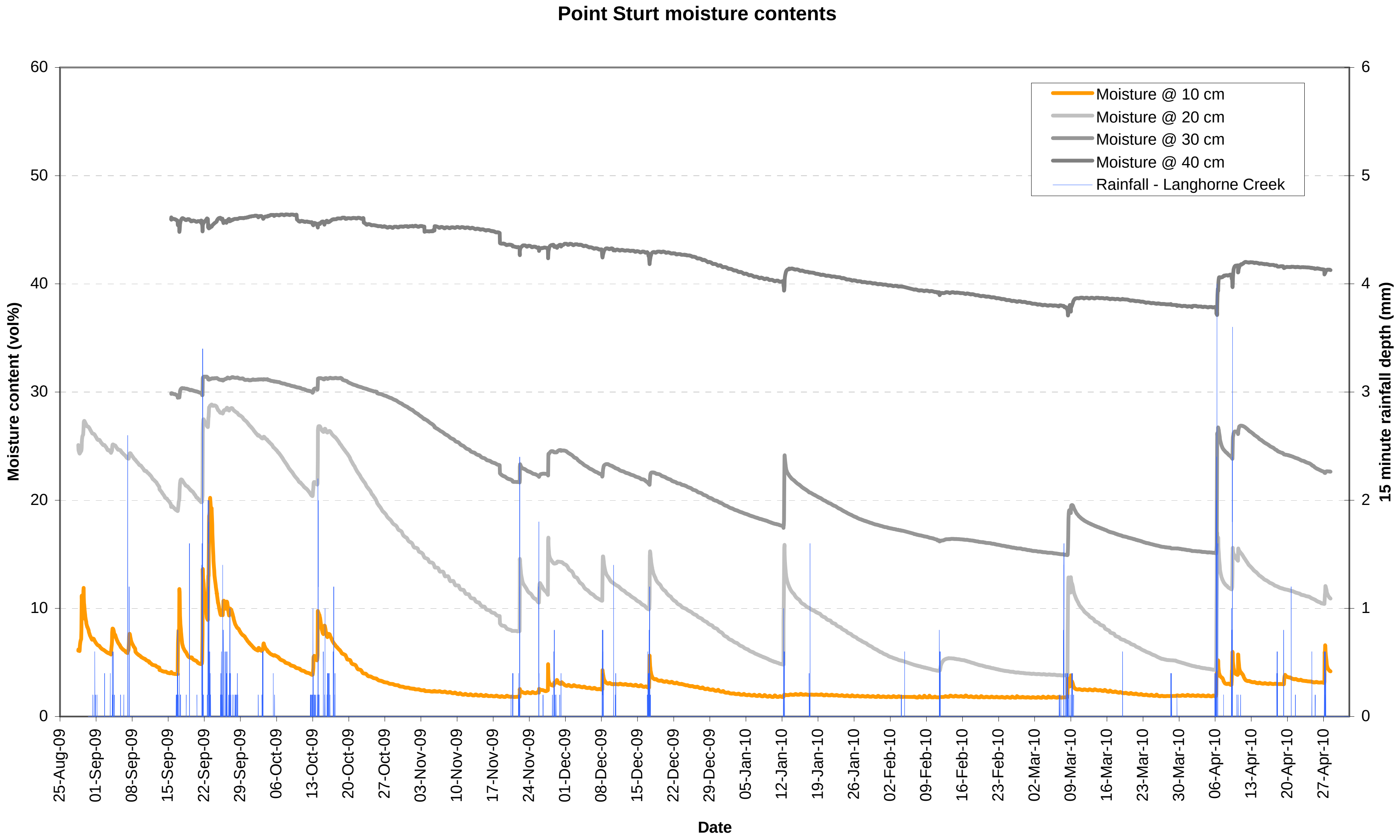

Figure 2. Temporal variation in sediment moisture contents at Point Sturt from 28 August to 28 April 2010.

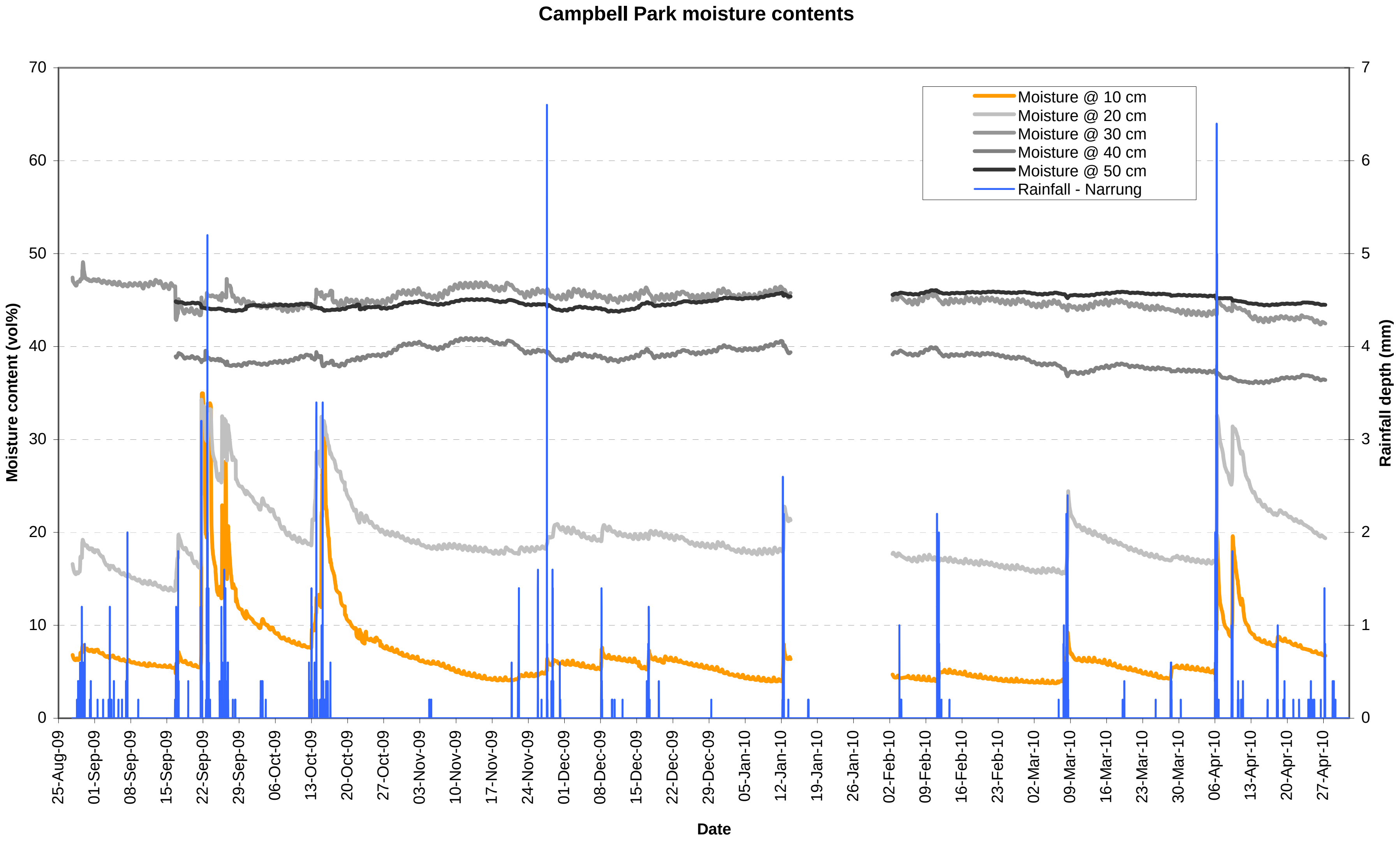

Figure 3. Temporal variation in sediment moisture contents at Campbell Park from 27 August to 27 April 2010. No data available from 13 January – 4 February 2010 due to battery exhaustion.

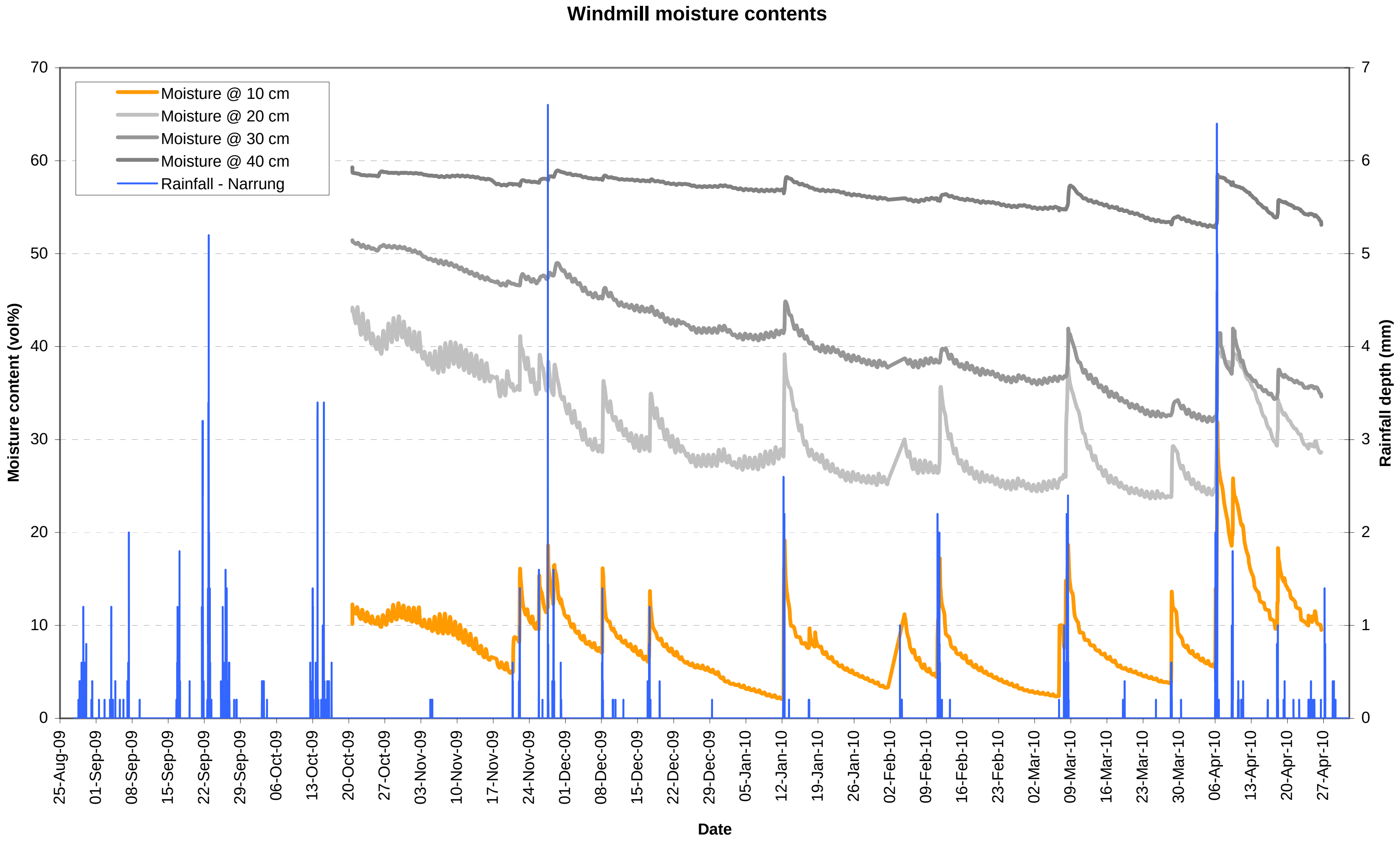

Figure 4. Temporal variation in sediment moisture contents at the Windmill location from 20 October to 26 April 2010.

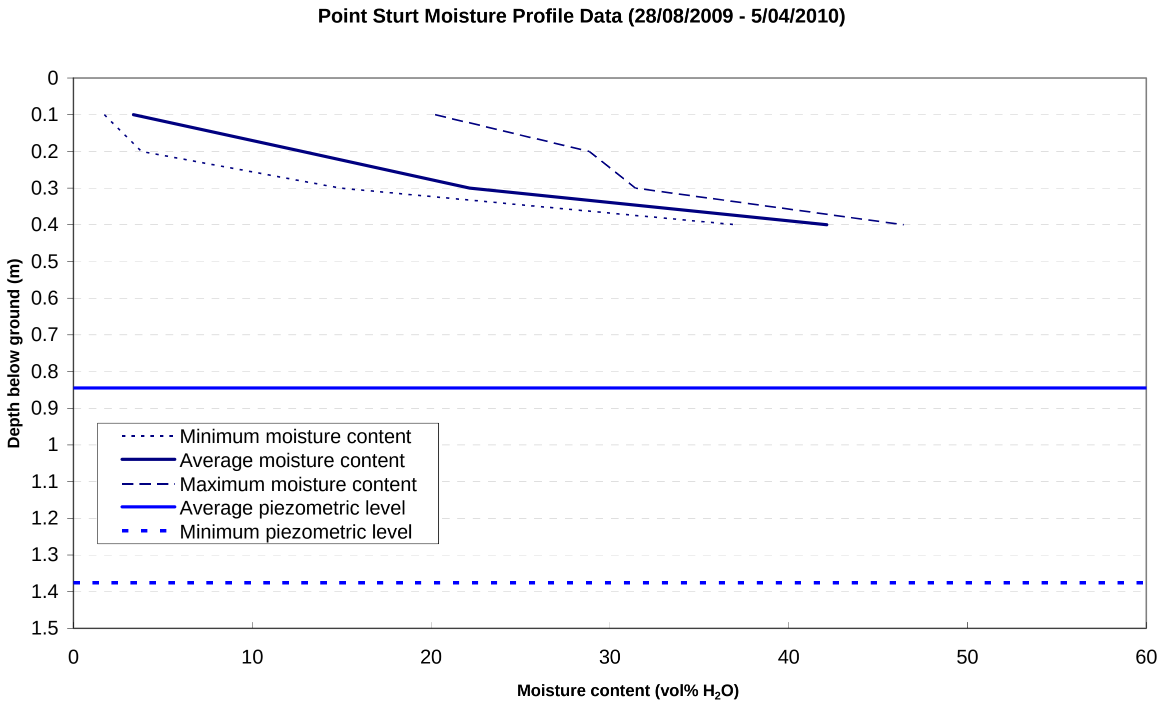

Figure 5. Average, minimum and maximum moisture content profiles at the Point Sturt location, from 28 August to 5 April 2010. Average and minimum piezometric levels at Piezometer Site 1 (nearest the moisture sensors) are shown for comparison.

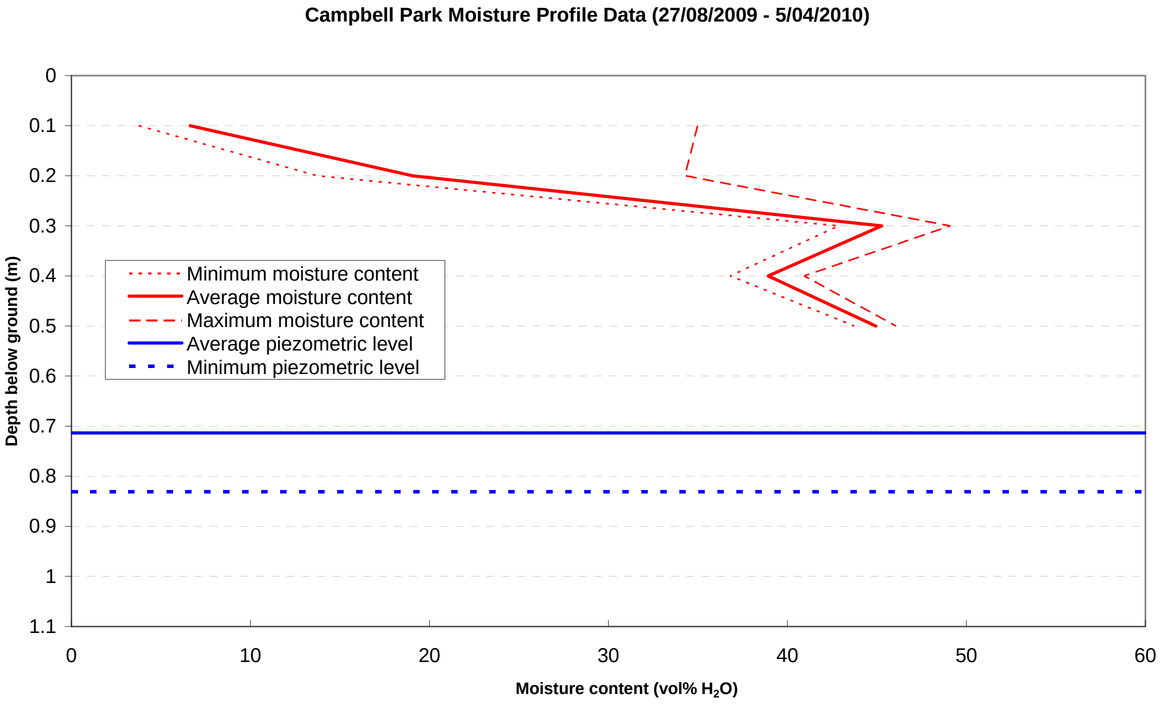

Figure 6. Average, minimum and maximum moisture content profiles at the Campbell Park location, from 27 August to 5 April 2010. Average and minimum piezometric levels at Piezometer Site 1 (nearest the moisture sensors) are shown for comparison.

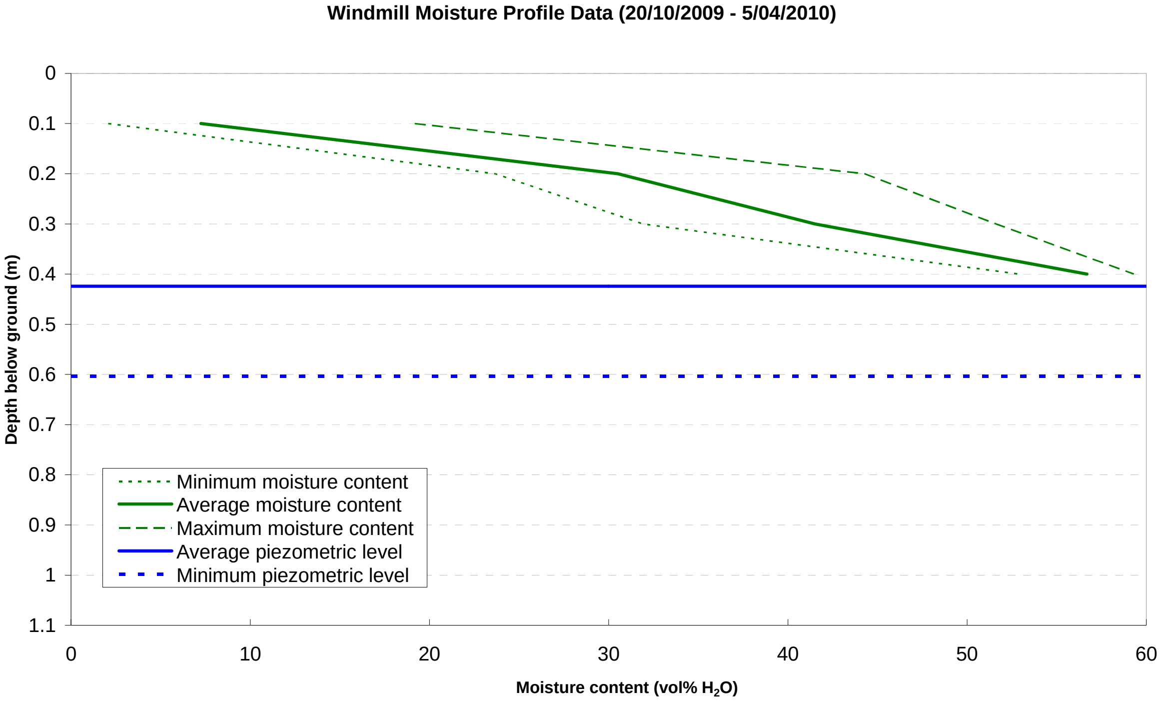

Figure 7. Average, minimum and maximum moisture content profiles at the Windmill location, from 20 October to 5 April 2010. Average and minimum piezometric levels at Piezometer Site 1 (nearest the moisture sensors) are shown for comparison.

5.1.2 Groundwater (piezometric) levels

Currency Creek

Piezometric level results for Currency Creek are graphed alongside rainfall data and surface water level data in Figure 8. The key results are summarised below:

- Piezometric levels decrease with proximity to the Goolwa Channel, from UCC-P1 to UCC-P3 to LCC-P2 (as expected). From mid-May to mid-September 2009, levels in UCC-P3 were approximately 0.2 m lower than in UCC-P1, while the levels at LCC-P2 were approximately 0.2-0.3 m below UCC-P1. For the remainder of 2009, piezometric levels and creek water levels were approximately the same (within 0.05 m), coinciding with peak water levels in (and connectivity between) the upper and lower sections of Currency Creek. A gradient of around 0.2 m between UCC-P1 and LCC-P2 was subsequently re-established from January-April 2010.
- Piezometric levels increased by around 1.0-1.2 m from mid-May to mid-November 2009 at UCC-P1 and LCC-P2. Levels peaked at around 0.7 m AHD at both sites. Piezometric levels subsequently decreased to nearly -0.4 m AHD in UCC-P1 and -0.6 m AHD in LCC-P2 by late March 2010, comparable to the levels observed when monitoring commenced in May 2009. The data indicate that creek water levels exceeded piezometric levels from January-April 2010. The cause of this discrepancy requires investigation, but is believed to be associated with errors in surface level data, possibly associated with settlement of the DLWBC monitoring station.
- Piezometric levels at UCC-P1 and LCC-P2 show a clear response to some but not all rainfall events. The effect of rainfall on piezometric levels is most evident during higher intensity and/or longer duration rainfall events.
- If the rainfall intensity or duration is sufficient to affect piezometric levels, there is a lag of around 1 day between the onset of rainfall and peak groundwater levels. Piezometric levels generally take several days to recover to pre-event values.
- The rapid rise in surface water levels commencing in late August corresponded to the pumping of water from Lake Alexandrina into the Goolwa Channel / Currency Creek / Finniss River region. Surface water levels had risen by around 1.3 m by 7 November 2009. Throughout October to December 2009, there was a close correlation between surface and piezometric levels. The surface water level was at or above the ground level at each piezometer site for much of this period.
- The above results demonstrate that rainfall was the key influence on changing piezometric levels in Currency Creek from May to September 2009 and from January to April 2010. Between October and

December 2009, as the creek was refilling, surface water levels became the key influence on piezometric levels. Thus, the rewetting of previously exposed ASS in Currency Creek was initially dominated by rainfall, until the point at which surface water levels began to recover via pumping from Lake Alexandrina. With creek levels declining in early 2010, rainfall patterns have recently become the key factor affecting groundwater levels.

- The sharp rise in piezometric levels at both UCC-P1 and LCC-P2 on 21 September 2009 may be attributed to the effects of seiching, although it is unclear why a comparable rise in surface water levels was not observed on this date.
- Low magnitude daily oscillations in piezometric levels are interpreted to be associated with the effects of Earth tides. This observation is also consistent with fluctuations in moisture content, as described in Section 5.1.1.

Point Sturt, Campbell Park and Windmill locations

Piezometric level results for the Point Sturt, Campbell Park and Windmill locations are graphed alongside rainfall data and surface water level data in Figures 9, 10 and 11, respectively. The key results are summarised below:

- Piezometric levels at Point Sturt generally decrease with proximity to the lake surface water, indicating groundwater gradients towards the lake (as expected). In some cases, however, piezometric levels at Site 4 exceed those at Site 3, indicating the potential for flow in the reverse direction. Such short duration events are interpreted to be related to periods of seiching.
- From late August 2009 to late February 2010, piezometric levels decreased in all Point Sturt piezometers, with the magnitude of the change decreasing with proximity to the lake water (from Site 1 to 4). For example, levels decreased by around 0.8 m at Site 1, 0.5 m at Site 2, and 0.3 m at Sites 3 and 4.
- In the lower layer of sandy sediments at Point Sturt, piezometric levels were generally slightly higher (by around 0.05-0.10 m) than those measured in the upper sand layer. The only exception was at Site 1 (nearest the shore) where the piezometric levels in the deeper sediments were 0.15-0.25 m lower than in the upper sediments. Piezometric levels in the deeper sand layer at Site 1 were nevertheless only 0.6-0.7 m below ground. The discrepancies in piezometric levels at all sites indicate locally disconnected aquifers throughout the Point Sturt transect.
- At Point Sturt, the hydraulic gradient from Site 2 to 4 varied considerably during the wetter months of August to October 2009 but tended to stabilise in the range 0.0004-0.0006 by mid-November 2009. In comparison, the ground surface gradient from Site 2 to 4 was 0.0023. Thus, the hydraulic gradient in mid-November 2009 represented approximately 15-25% of the beach slope. Refer to Earth Systems (2010) for further detail.
- Piezometric levels at the Point Sturt nearest the lake water (Site 4) generally exceeded surface water levels measured in Lake Alexandrina at Beacon 97 by less than 0.1-0.2 m in August and September 2009 (as expected). However, the reverse was apparent from October 2009 to April 2010, with surface water levels at Pt McLeay exceeding piezometric levels at Site 4 by 0.1-0.2 m. As there is no clear evidence of seiching at Site 4 during this period, the surface water level data for Pt McLeay (from DLWBC) is assumed to overestimate actual surface water levels at the Point Sturt transect.
- Overall, piezometric levels at Point Sturt have generally remained below the ground surface, with the exception of Site 4 (nearest the lake water) in late September 2009, mid-October 2009 and early April 2010. These occasions coincided with significant rainfall events, indicating that rainwater ponding and infiltration through the sediments, rather than lake water seiching, was responsible for the elevated piezometric levels.
- Piezometric levels at Campbell Park (Sites 1-4) decreased by around 0.5-1.0 m from late August to late February 2010.
- As with Point Sturt, piezometric levels at Campbell Park generally decrease with proximity to the lake surface water, indicating groundwater gradients towards the lake (as expected).
- At Campbell Park, the hydraulic gradient from Site 2 to 4 varied considerably during the wetter months of August to October 2009 but tended to stabilise around 0.0019 by mid-November 2009. In comparison, the ground surface gradient from Site 2 to 4 was 0.0015. Thus, the hydraulic gradient in mid-November 2009 was approximately parallel with the beach slope. Refer to Earth Systems (2010) for further detail.
- The variability in hydraulic gradients at Campbell Park was higher than observed at Point Sturt, particularly during the wetter months of August to October. Much of the variability occurred during rainfall events, while the clearest trends in piezometric levels at Campbell Park were observed during low/no rainfall periods such as 5-13 October and 20 October-17 November 2009. Refer to Earth Systems (2010) for further detail.

- In the lower layer of sediments at Campbell Park, piezometric levels were generally inconsistent with those measured in the upper layer. This suggests that the upper and lower aquifers are poorly connected, which is consistent with the thick clay layer observed between the two sandy horizons (Earth Systems, 2010; Figure 10).
- Overall, piezometric levels at Campbell Park have generally remained below the ground surface, with the exception of Sites 2 and 4 in late September 2009, mid-October 2009 and early April 2010. These occasions coincided with significant rainfall events, indicating that rainwater ponding and infiltration through the sediments, rather than lake water seiching, was responsible for the elevated piezometric levels. This is consistent with observations in the Point Sturt piezometric level data.
- Piezometric levels at Campbell Park (Site 4) were up to 0.3-0.4 m lower than surface water levels measured in Lake Albert near Waltowa Swamp and Warringee Point from mid-November 2009 to late April 2010. The cause of this discrepancy requires further investigation, but is believed to be associated with survey errors in DLWBC lake level monitoring sites.
- Recent data on piezometric levels in the upper sand layer at Campbell Park indicates that this layer was effectively dry at Site 1 from 16-24 November 2009, 2-12 January 2010, 30 January - 8 March 2010 and 27 March - 6 April 2010
- Piezometric levels at the Windmill location (Sites 1-3) decreased by around 0.5-0.7 m from late August to mid-January 2010.
- As with Point Sturt and Campbell Park, piezometric levels at the Windmill location generally decrease with proximity to the lake surface water, indicating groundwater gradients towards the lake (as expected).
- At the Windmill location, the hydraulic gradient from Site 2 to 4 varied considerably throughout the monitoring period, approaching 0.0006 by mid-November 2009. In comparison, the ground surface gradient from Site 2 to 4 was 0.0009. Thus, the hydraulic gradient in mid-November 2009 was approximately two-thirds that of the beach slope. Refer to Earth Systems (2010) for further detail.
- In late April 2010, in the lower layer of sandy sediments at the Windmill location, piezometric levels were similar to those measured in the upper layer at Site 1 (within 0.02-0.03 m). At Site 4, however, piezometric levels in the lower sand layer were 0.1 m higher than in the upper sand, indicating locally disconnected aquifers.
- As observed at Campbell Park, piezometric levels at the Windmill location (all sites) were around 0.3 m lower than surface water levels measured in Lake Albert near Waltowa Swamp until early January 2010. The cause of this discrepancy requires further investigation, but is believed to be associated with survey errors in DLWBC lake level monitoring sites.
- Piezometric levels at the Windmill location have generally remained below the ground surface, however, there appears to be evidence of one significant seiching event (affecting two or more piezometers) around 25 October 2009, as indicated in Figure 11. During this event, piezometric levels increased rapidly by around 0.5-0.6 m at all sites, despite no corresponding rainfall event. Other occasions where piezometric levels exceeded the ground surface elevation (eg. late September 2009, mid-October 2009 and early April 2010) coincided with significant rainfall events, indicating that rainwater ponding and infiltration through the sediments, rather than lake water seiching, was more likely to be responsible for the elevated piezometric levels. This is consistent with observations in the Point Sturt and Campbell Park piezometric level data.
- At all locations, piezometric levels show a clear response to some but not all rainfall events. The effect of rainfall on piezometric levels is most evident during higher intensity and/or longer duration rainfall events.
- If the rainfall intensity or duration is sufficient to affect piezometric levels, there is a lag of around 1-2 hours between the onset of rainfall and peak water levels. Piezometric levels generally take several hours to recover to pre-event values. This was more rapid than the response observed at Currency Creek, and is considered to be more realistic due to the method of piezometer installation. The rapid recovery of piezometric levels could be attributed to discharge of groundwater through the sediments to the lake water and/or increased evapotranspiration rates near the ground surface. The latter is considered more likely on the basis of groundwater quality results, as discussed in Section 5.1.3.
- Daily oscillations in piezometric levels are interpreted to be associated with the effects of Earth tides. This observation is also consistent with fluctuations in piezometric levels at Currency Creek and moisture content values, as described in Section 5.1.1.

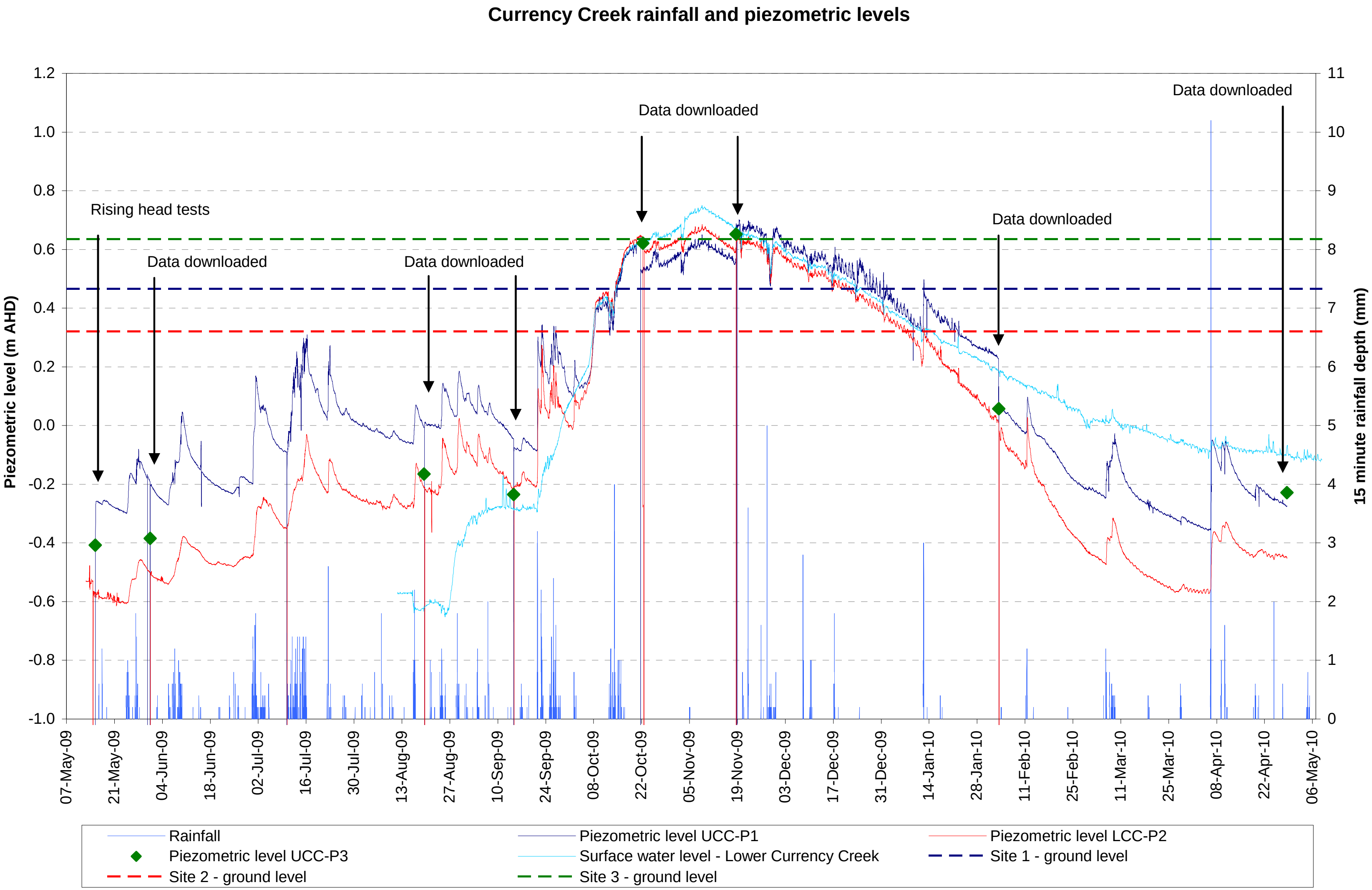

Figure 8. Temporal variation in piezometric levels at Currency Creek from 15 May to 28 April 2010. Note that surface water level data from January-April 2010 are believed to be inaccurate.

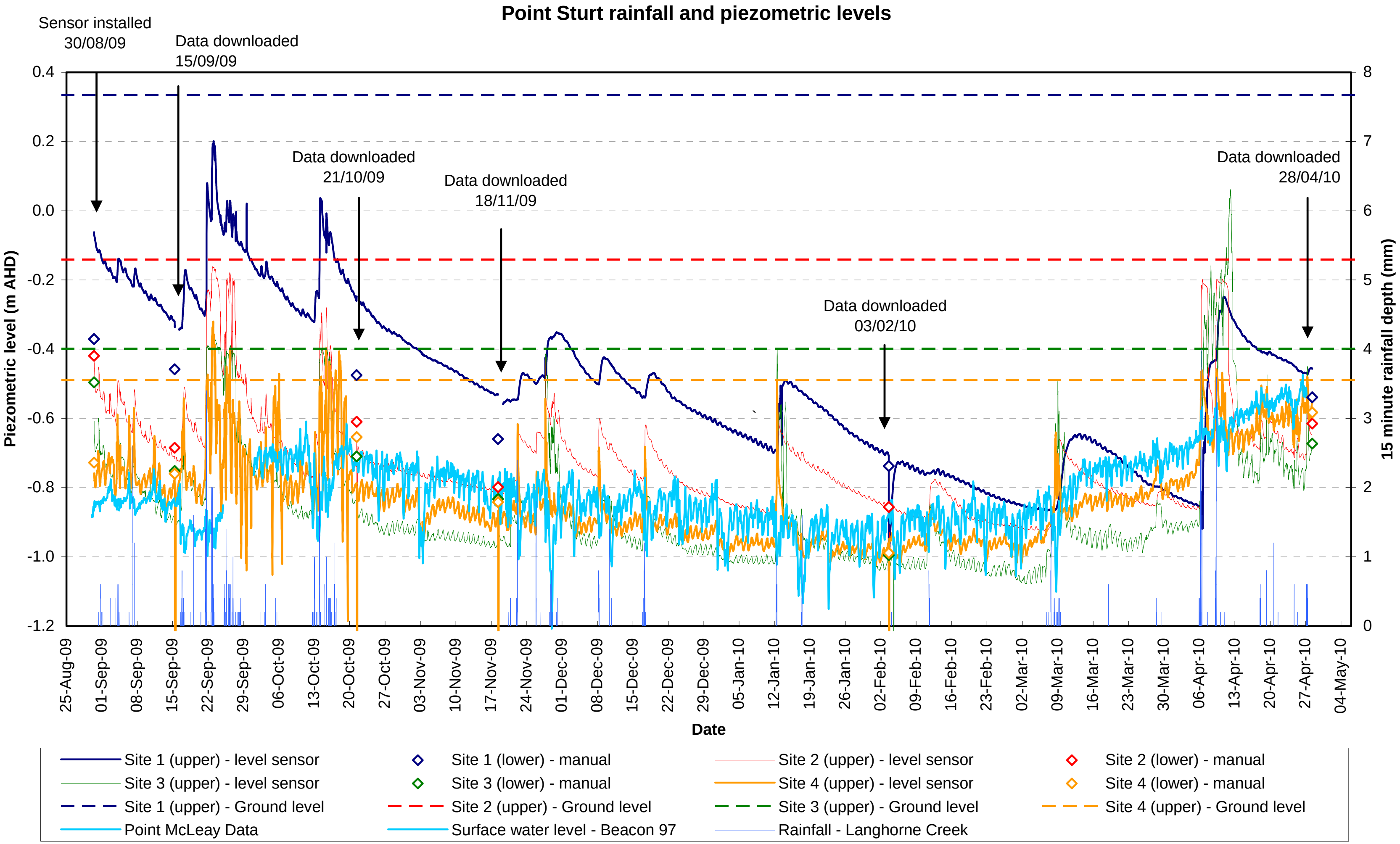

Figure 9. Temporal variation in piezometric levels at Point Sturt from 30 August to 28 April 2010. Piezometric levels at Site 4 were generally around 0.1 m lower than surface water levels measured in Lake Alexandrina near Point McLeay. The cause of this discrepancy is currently under investigation, but is believed to be associated with survey errors in DLWBC lake level monitoring sites.

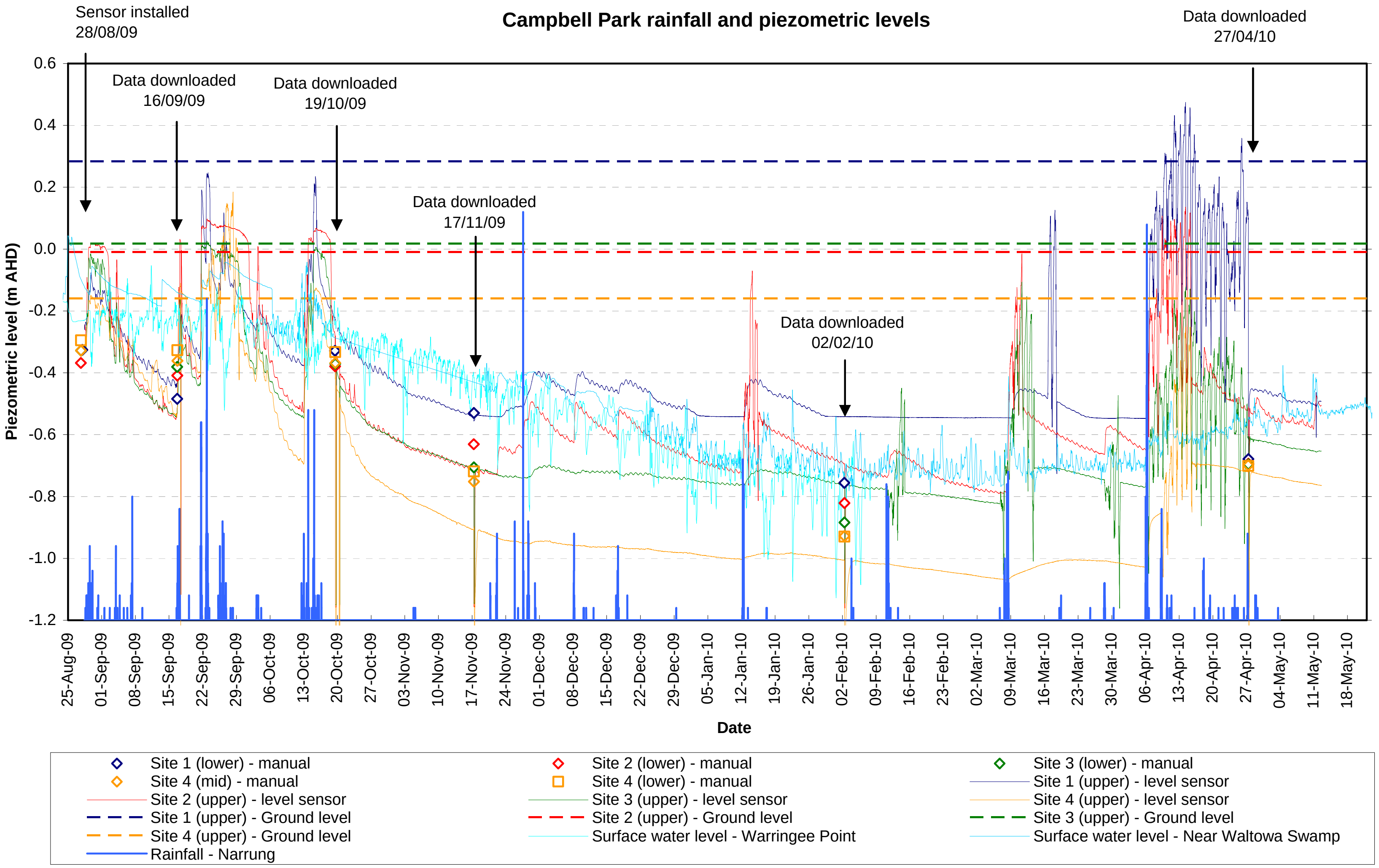

Figure 10. Temporal variation in piezometric levels at Campbell Park from 28 August to 27 April 2010. Piezometric levels at Site 4 were generally around 0.3 m lower than surface water levels measured in Lake Albert near Waltowa Swamp. The cause of this discrepancy is currently under investigation, but is believed to be associated with survey errors in DLWBC lake level monitoring sites. The upper piezometer at Site 1 was effectively dry from 16-24 November 2009, 2-12 January 2010, 30 January - 8 March 2010 and 27 March - 6 April 2010. Unreliable data from 6-27 April 2010 attributed to exhaustion of dessicants in LevelTroll cable (dessicants replaced on 12 May 2010).

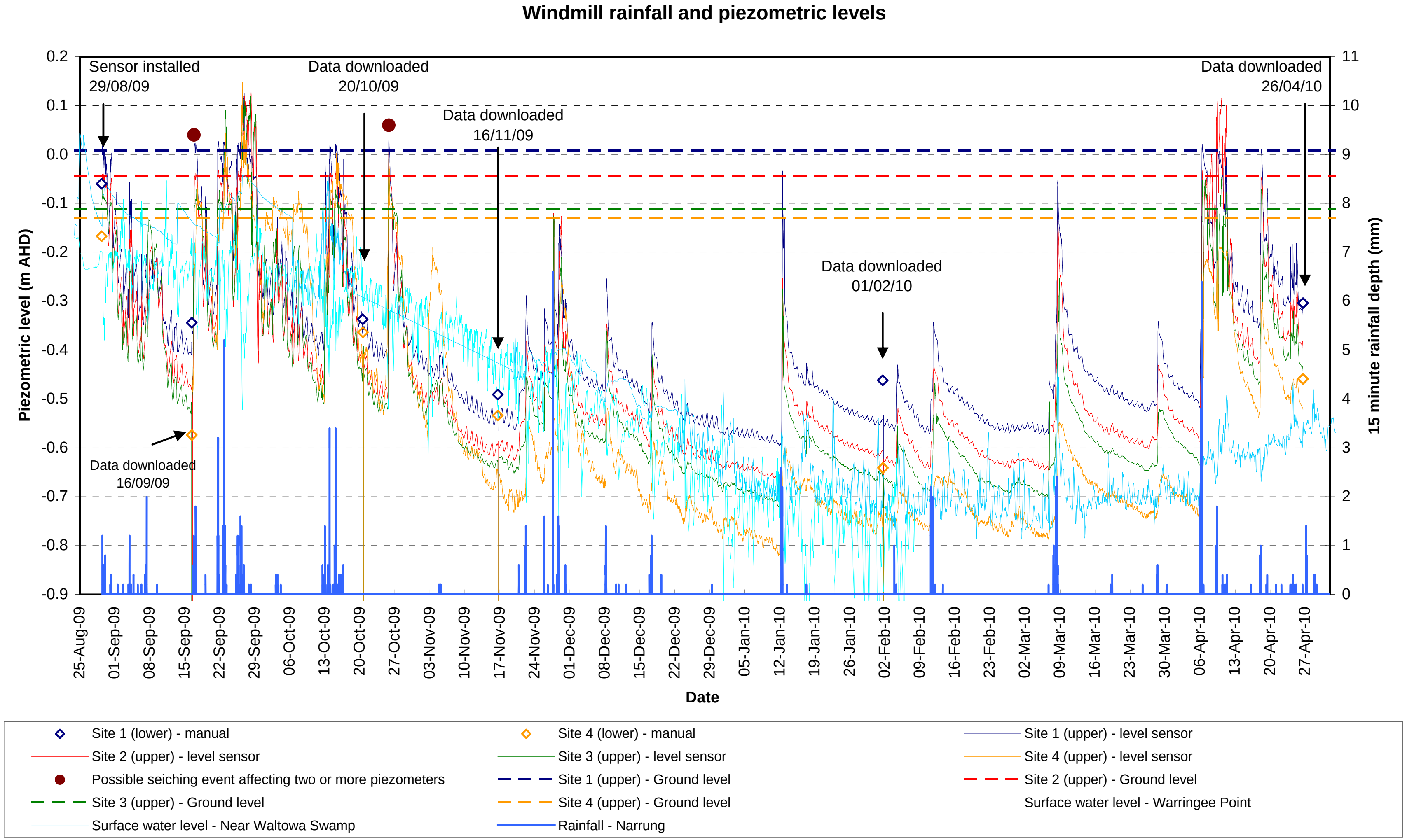

Figure 11. Temporal variation in piezometric levels at Windmill location from 29 August to 26 April 2010. Piezometric levels at Site 4 were around 0.2-0.3 m lower than surface water levels measured in Lake Albert near Waltowa Swamp prior to February 2010. The cause of this discrepancy is currently under investigation, but is believed to be associated with survey errors in DLWBC lake level monitoring sites.

5.1.3 Groundwater quality

Currency Creek

Bulk water quality results for the Currency Creek piezometers are summarised in Table 1 and temporal trends in pH, EC and ORP, are shown in Figures 12-14. Refer to Attachment B for laboratory data. Graphs showing variations in pH, EC and ORP with depth at each location are provided in Attachment C. The key results are summarised below:

- In UCC-P1, groundwater quality is characterised by near-neutral to slightly acidic pH, decreasing from pH 6.9 to 6.1 (marginally below the trigger value of 6.5) from early May to mid-November 2009, but rebounding to 6.6 in February and 6.8 in April 2010.

  EC peaked at 15 mS/cm in May and again in April 2010.

  ORP values indicate the groundwater was moderately to strongly reduced throughout the monitoring period. However, the rise in ORP from around -500 mV in June to around -50 mV in November suggests that progressive oxidation occurred during this time, which is consistent with the observed pH decline.

  Significant alkalinity was present in UCC-P1 (only). Field/laboratory data indicate a decreasing trend in alkalinity, from 420 mg/L $CaCO_3$ to less than 50 mg/L $CaCO_3$ from mid-July to mid-November 2009, rebounding to >200 mg/L $CaCO_3$ in February and >400 mg/L $CaCO_3$ in April 2010. These alkalinity trends are consistent with the declining then increasing pH observed at this site.

- In LCC-P2, the pH decreased from 5.3 in early May 2009 to 2.5-3.5 (well below the trigger value of 6.5) between mid-May and mid-November 2009, then increased to around 4.0 by April 2010. The lowest pH value of 2.5 corresponded to a groundwater acidity of 1800 mg/L $CaCO_3$.

  EC was in the range 7-11 mS/cm.

  ORP values from May to November 2009 were generally around +300-400 mV, indicating oxidising conditions, and consistent with the low pH values observed during this time. Decreasing ORP in 2010 correspond to increasing pH values.

  The groundwater in LCC-P2 had an acidity of around 1300 mg/L $CaCO_3$ from May to mid-September 2009, decreasing to around 700-1000 mg/L $CaCO_3$ from mid-November 2009.

  A significant chemical gradient clearly remains between groundwater at LCC-P2 and overlying surface water at CC-DS3, which had an alkalinity of 50-100 mg/L $CaCO_3$ throughout January-April 2010. This indicates that acidic groundwater is unlikely to rapidly affect the creek water via diffusional exchange.

- In UCC-P3 (in between UCC-P1 and LCC-P2) the groundwater was slightly acidic with a pH around 5-6 from mid-May to mid-September 2009 (below the trigger value of 6.5), falling to around 4.0-4.5 in October-November 2009 and April 2010. The lowest pH value of 4.2 corresponded to an acidity of around 300 mg/L $CaCO_3$.

  Relatively high EC values (up to 23 mS/cm) were observed in this piezometer, although the EC dropped to below 10 mS/cm in April 2010.

- The key contributors to high salinities in all piezometers, in order of significance, are chloride (800-7500 mg/L), sulfate (750-5700 mg/L), sodium (700-4000 mg/L), magnesium (120-1100 mg/L), calcium (140-660 mg/L) and potassium (50-200 mg/L).
- Dissolved concentrations of Al, As, Cd, Cu, Mn, Ni, Pb and Zn exceeded trigger values for 95% protection of aquatic ecosystems on one or more occasions in all piezometers.
- The highest dissolved metal concentrations were observed in LCC-P2, consistent with low pH and high acidity values. Dissolved Al, Cd, Cu, Mn, Ni, Pb and Zn, exceeded trigger values for both 80% and 95% protection of aquatic ecosystems on one or more occasions in LCC-P2 and UCC-P3. Dissolved Fe and Al were elevated in LCC-P2 (up to 476 mg/L Fe and 111 mg/L Al) and UCC-P3 (up to 120 mg/L Fe and 17 mg/L Al).
- Dissolved Al, Cu, Ni, Pb and Zn exceeded trigger values for both 80% and 95% protection of aquatic ecosystems on one or more occasions in UCC-P1 (dissolved As and Cd also exceeded the 95% trigger value).
- The elevated Ca, Mg and Mn concentrations observed in LCC-P2 (average 290 mg/L Ca, 224 mg/L Mg and 3.1 mg/L Mn) and UCC-P3 (average 535 mg/L Ca, 804 mg/L Mg and 6.4 mg/L Mn) indicate that some degree of in-situ carbonate dissolution (ANC consumption) has occurred in response to acidity generation at these sites. The higher Ca, Mg and Mn concentrations at UCC-P3 relative to LCC-P2 are consistent with relatively high ANC values at UCC-P3.
- Nutrient concentrations (total N, NO_x and total P) exceeded trigger values in all piezometers on one or more occasions.

Plots showing the variation in groundwater quality with depth at UCC-P1, LCC-P2 and UCC-P3 (prior to purging) for each monitoring event are provided in Attachment C. These plots indicate that:

- Overall, few variations in groundwater quality with depth were observed at all Currency Creek piezometers on all monitoring events.
- Significant pH variations with depth were observed on 22 October 2009 at UCC-P1 (ranging from 3.5 at 3.05 m below ground level to 6.8 at 1.90 m below ground level); at LCC-P2 (ranging from 2.2 at 0.30 m below ground level to 3.6 at 1.80 m below ground level); and at UCC-P3 (ranging from 3.7 at 2.13 m below ground level to 1.9 at 1.63 m below ground level).
- pH was generally lower and ORP generally higher when measured in piezometers prior to purging and bulk sampling. This is due to (localised) oxidising conditions within the piezometer. As such the groundwater quality measured in this manner cannot be considered indicative of the surrounding formation.
- At all piezometers and for all monitoring events, EC generally increased with depth. This was most noticeable at UCC-P1 for all monitoring events with EC ranging from 3.79 mS/cm at 0.5 m below ground level to 16.60 mS/cm at 3.05 m below ground level on 2 May 2009 and 5.05 mS/cm at 0.55 m below ground level to 14.10 mS/cm at 2.25 m below ground level on 19 August 2009.

However, the above results need to be considered in the context that groundwater quality profiles were obtained prior to purging of the piezometers. Thus, the plots are not necessarily representative of actual trends in groundwater quality with depth in the surrounding sediments.

Low-flow discrete interval sampling was carried out at LCC-P2 on 22 October 2009 to assess the reliability of the pH, EC and ORP data obtained without purging, and the bulk sample pH, EC and ORP data obtained after purging of the piezometer.

Results from low-flow discrete interval sampling at LCC-P2 are provided in Earth Systems (2010) and summarised below.

The field data obtained within the upper sandy horizon prior to purging LCC-P2 on 22 October 2009 indicated pH values of 2.2-2.3, EC of 9.1 mS/cm and highly oxidised water (ORP +470 mV). In comparison, the stabilised low-flow samples had significantly higher pH (ranging from 2.8 to 3.0), lower EC (ranging from 7.84-8.43 mS/cm) and were less oxidised (+350-400 mV).

The bulk sample pH (2.7) and EC (7.21 mS/cm) were more consistent with stabilised low-flow sample pH (ranging from 2.8 to 3.0) and EC (ranging from 7.84-8.43 mS/cm). Similarly, ORP values for the bulk sample and stabilised low-flow samples were comparable. This suggests that bulk sample water chemistry is largely representative of the water in the upper sandy horizon (as expected).

There is evidence that little stratification exists within the upper sandy horizon, despite alkaline surface water being present at the time of sampling, suggesting that diffusional exchange at the sediment-water interface is occurring at a slow rate (Earth Systems, 2010).

Table 1. Groundwater quality data for Currency Creek piezometers.

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
General parameters							
pH (field)	-	2/5/09	6.5-9.0	6.5-9.0	6.93	5.33	-
		19/8/09			6.48	2.50	5.15
		14/9/09			6.39	3.06	5.26
		22/10/09			6.62	2.70	4.26
		18/11/09			6.13	2.72	4.57
		3/2/10			6.55	3.31	5.48
		28/4/10			6.82	4.02	4.20
pH (lab)	-	2/5/09	6.5-9.0	6.5-9.0	6.61	3.07	7.05
		19/8/09			6.70	2.91	5.60
		14/9/09			6.88	2.99	3.18
		22/10/09			6.35	2.95	3.76
		18/11/09			5.86	3.14	3.47
		3/2/10			6.70	3.03	6.25
		28/4/10			6.51	3.04	3.19
EC (field)	mS/cm	2/5/09	0.3-1	0.3-1	3.79	7.03	-
		19/8/09			10.48	9.49	21.02
		14/9/09			10.82	8.73	22.51
		22/10/09			6.10	7.21	15.71
		18/11/09			7.07	7.00	17.95
		3/2/10			9.02	10.84	17.58
		28/4/10			15.32	8.50	7.71
EC (lab)	mS/cm	2/5/09	0.3-1	0.3-1	11.10	8.84	23.30
		19/8/09			10.80	9.50	21.90
		14/9/09			11.70	23.90	9.00
		22/10/09			6.50	7.50	17.80
		18/11/09			6.26	6.68	18.70
		3/2/10			12.20	11.40	20.20
		28/4/10			15.80	8.80	24.80
ORP (field)	mV	2/5/09	n/a	n/a	+74	+109	-
		19/8/09			-40	+359	+145
		14/9/09			-19	+172	+332
		22/10/09			-150	+382	+300
		18/11/09			-52	+318	+139
		3/2/10			-66	+210	+63
		28/4/10			-47	+241	-
DO (field)	mg/L	2/5/09	n/a	n/a	-	-	-
		19/8/09			3.34	5.22	6.02
		14/9/09			4.33	10.27	7.13
		22/10/09			3.65	3.16	4.78
		18/11/09			2.87	2.42	5.53
		3/2/10			-	-	-
		28/4/10			-	-	-

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
Alkalinity / acidity							
Alkalinity (field)	mg/L $CaCO_3$	2/5/09	n/a	n/a	-	-	-
		19/8/09			-	-	-
		14/9/09			200	-	-
		22/10/09			51	-	-
		18/11/09			246	-	-
		3/2/10			266	-	-
		28/4/10			436	-	-
Alkalinity (lab)	mg/L $CaCO_3$	2/5/09	n/a	n/a	-	-	-
		19/8/09			165	-	-
		14/9/09			297	<1	<1
		22/10/09			48	<1	<1
		18/11/09			52	<1	<1
		3/2/10			205	<1	43
		28/4/10			418	-	-
Acidity (field)	mg/L $CaCO_3$	2/5/09	n/a	n/a	-	-	-
		19/8/09			65	1790	275
		14/9/09			-	1380	395
		22/10/09			30	800	200
		18/11/09			-	1220	500
		3/2/10			-	1586	284
		28/4/10			-	1085	404
Acidity (lab)	mg/L $CaCO_3$	2/5/09	n/a	n/a	50	1470	55
		19/8/09			10	1800	176
		14/9/09			-	1160	-
		22/10/09			27	912	165
		18/11/09			81	746	366
		3/2/10			-	1050	81
		28/4/10			-	911	306
Acidity (calculated)	mg/L $CaCO_3$	2/5/09	n/a	n/a	54	1341	3
		19/8/09			12	1315	227
		14/9/09			19	1225	451
		22/10/09			67	708	161
		18/11/09			102	819	400
		3/2/10			34	1351	149
		28/4/10			3	985	319
Major ions							
Ca	mg/L	2/5/09	n/a	n/a	292	374	263
		19/8/09			265	412	606
		14/9/09			252	415	664
		22/10/09			136	213	567
		18/11/09			146	163	528
		3/2/10			254	182	483
		28/4/10			325	270	634

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
Mg	mg/L	2/5/09	n/a	n/a	248	271	503
		19/8/09			236	302	928
		14/9/09			276	332	1100
		22/10/09			122	154	519
		18/11/09			161	137	772
		3/2/10			285	180	804
		28/4/10			368	195	1000
Na	mg/L	2/5/09	n/a	n/a	1830	740	3780
		19/8/09			1600	774	3600
		14/9/09			2180	809	3970
		22/10/09			909	784	2530
		18/11/09			1100	981	3460
		3/2/10			2230	1580	3580
		28/4/10			3200	1160	4010
K	mg/L	2/5/09	n/a	n/a	99	73	151
		19/8/09			111	48	162
		14/9/09			118	51	205
		22/10/09			46	30	117
		18/11/09			50	38	150
		3/2/10			107	68	169
		28/4/10			138	76	209
Cl	mg/L	2/5/09	n/a	n/a	2490	1380	5290
		19/8/09			2010	805	5130
		14/9/09			3410	1300	6320
		22/10/09			1270	851	3360
		18/11/09			1740	1560	5070
		3/2/10			3310	3170	4690
		28/4/10			5330	2000	7500
SO_4	mg/L	2/5/09	n/a	n/a	1840	3240	2500
		19/8/09			1900	3760	5570
		14/9/09			1830	3660	5670
		22/10/09			750	1910	3550
		18/11/09			765	1350	4110
		3/2/10			1590	1270	5340
		28/4/10			1980	2100	5150
Cl:SO_4 ratio	-	2/5/09	n/a	n/a	1.4	0.4	2.1
		19/8/09			1.1	0.2	0.9
		14/9/09			1.9	0.4	1.1
		22/10/09			1.7	0.4	0.9
		18/11/09			2.3	1.2	1.2
		3/2/10			2.1	2.5	0.9
		28/4/10			2.7	1.0	1.5

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
Dissolved metals							
Al	mg/L	2/5/09	0.055	0.15	1.87	111	0.01
		19/8/09			0.37	84.1	1.26
		14/9/09			1.45	69.0	14.4
		22/10/09			7.34	41.4	11.3
		18/11/09			0.20	15.8	11.8
		3/2/10			0.12	7.84	0.14
		28/4/10			0.01	13.1	17.3
As	mg/L	2/5/09	0.013 (AsV)	0.140 (AsV)	0.007	0.024	0.003
		19/8/09			0.007	0.019	0.007
		14/9/09			0.005	0.020	0.009
		22/10/09			0.004	0.013	0.004
		18/11/09			0.023	0.028	0.014
		3/2/10			0.009	0.061	0.006
		28/4/10			0.007	0.021	0.004
Cd	mg/L	2/5/09	0.0002	0.0008	-	-	-
		19/8/09			0.0003	0.0027	0.0006
		14/9/09			<0.0001	0.0016	0.0009
		22/10/09			0.0004	0.0012	0.0026
		18/11/09			0.0005	0.0016	0.0020
		3/2/10			0.0002	0.0003	0.0002
		28/4/10			0.0001	0.0005	0.0020
Cu	mg/L	2/5/09	0.0014	0.0025	0.011	0.101	0.008
		19/8/09			0.005	0.075	0.001
		14/9/09			0.005	0.066	0.016
		22/10/09			0.013	0.095	0.016
		18/11/09			0.003	0.033	0.013
		3/2/10			0.005	0.007	0.014
		28/4/10			0.004	0.006	0.017
Fe	mg/L	2/5/09	n/a	n/a	15.8	249	0.10
		19/8/09			3.35	288	77.6
		14/9/09			3.87	290	120
		22/10/09			9.51	139	30.9
		18/11/09			36.8	235	118
		3/2/10			11.9	476	51.9
		28/4/10			1.09	336	75.1
Mn	mg/L	2/5/09	1.9	3.6	0.330	5.580	1.480
		19/8/09			0.264	5.080	5.920
		14/9/09			0.245	4.770	8.420
		22/10/09			0.505	1.690	6.480
		18/11/09			0.900	1.290	8.200
		3/2/10			0.471	1.340	4.590
		28/4/10			0.185	1.820	9.450

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
Ni	mg/L	2/5/09	0.011	0.017	-	-	-
		19/8/09			0.016	0.494	0.033
		14/9/09			0.012	0.368	0.071
		22/10/09			0.021	0.230	0.117
		18/11/09			0.011	0.134	0.136
		3/2/10			0.043	0.136	0.066
		28/4/10			0.008	0.065	0.110
Pb	mg/L	2/5/09	0.0034	0.0094	0.177	0.142	0.001
		19/8/09			0.003	0.011	0.005
		14/9/09			0.003	0.023	0.021
		22/10/09			0.015	0.015	0.015
		18/11/09			0.001	0.009	0.007
		3/2/10			<0.001	0.008	<0.001
		28/4/10			<0.001	0.019	0.019
Se	mg/L	2/5/09	0.011	0.034	-	-	-
		19/8/09			<0.01	0.01	<0.01
		14/9/09			<0.01	0.01	<0.01
		22/10/09			<0.01	<0.01	<0.01
		18/11/09			<0.01	<0.01	<0.01
		3/2/10			<0.01	<0.01	<0.01
		28/4/10			<0.01	<0.01	<0.01
Zn	mg/L	2/5/09	0.008	0.031	0.078	0.857	0.005
		19/8/09			0.037	0.562	0.045
		14/9/09			0.010	0.541	0.038
		22/10/09			0.039	0.337	0.127
		18/11/09			0.115	0.507	0.144
		3/2/10			0.039	0.404	0.129
		28/4/10			0.006	0.340	0.049
Nutrients							
NO_2 + NO_3	mg/L N	2/5/09	0.1	0.1	1.87	0.07	0.19
		19/8/09			2.82	0.33	0.15
		14/9/09			1.46	0.17	0.35
		22/10/09			1.85	0.23	3.54
		18/11/09			0.79	0.10	0.31
		3/2/10			0.07	0.06	0.02
		28/4/10			0.57	0.11	-
TKN	mg/L N	2/5/09	n/a	n/a	4.2	0.8	8.3
		19/8/09			0.8	3.0	7.2
		14/9/09			1.4	3.9	12.1
		22/10/09			2.0	7.1	26.8
		18/11/09			7.3	7.8	23.6
		3/2/10			3.0	12.4	14.1
		28/4/10			5.7	9.3	-

Parameter	Unit	Date	Trigger values*		UCC-P1	LCC-P2	UCC-P3
			95%	80%			
Total N	mg/L N	2/5/09	1	1	6.1	0.9	8.5
		19/8/09			3.7	3.3	7.4
		14/9/09			2.8	4.0	12.5
		22/10/09			3.8	7.3	30.4
		18/11/09			8.1	7.9	23.9
		3/2/10			3.1	12.4	14.1
		28/4/10			6.3	9.4	-
Total P	mg/L P	2/5/09	0.025	0.025	0.48	1.34	0.64
		19/8/09			0.19	1.42	0.05
		14/9/09			0.38	0.9	0.22
		22/10/09			0.09	0.37	<0.01
		18/11/09			3.54	1.17	0.18
		3/2/10			0.63	2.19	0.03
		28/4/10			0.68	0.81	-

* ANZECC/ARMCANZ (2000) trigger values for 80% and 95% protection of freshwater ecosystems. Values exceeding ANZECC/ARMCANZ (2000) trigger values for **95%** protection of freshwater ecosystems are shaded in orange. Values exceeding trigger values for **95%** and **80%** protection of freshwater ecosystems are shaded in red.

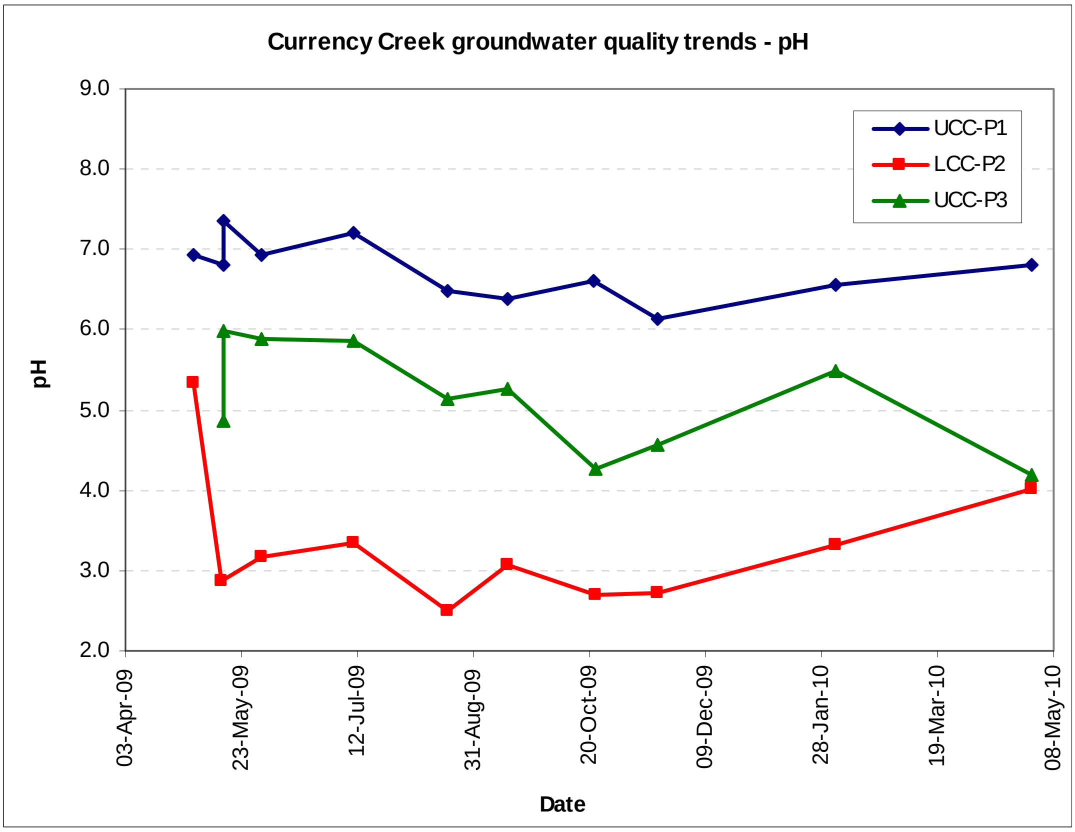

Figure 12. Groundwater pH at Currency Creek (after purging), 2 May – 28 April 2010.

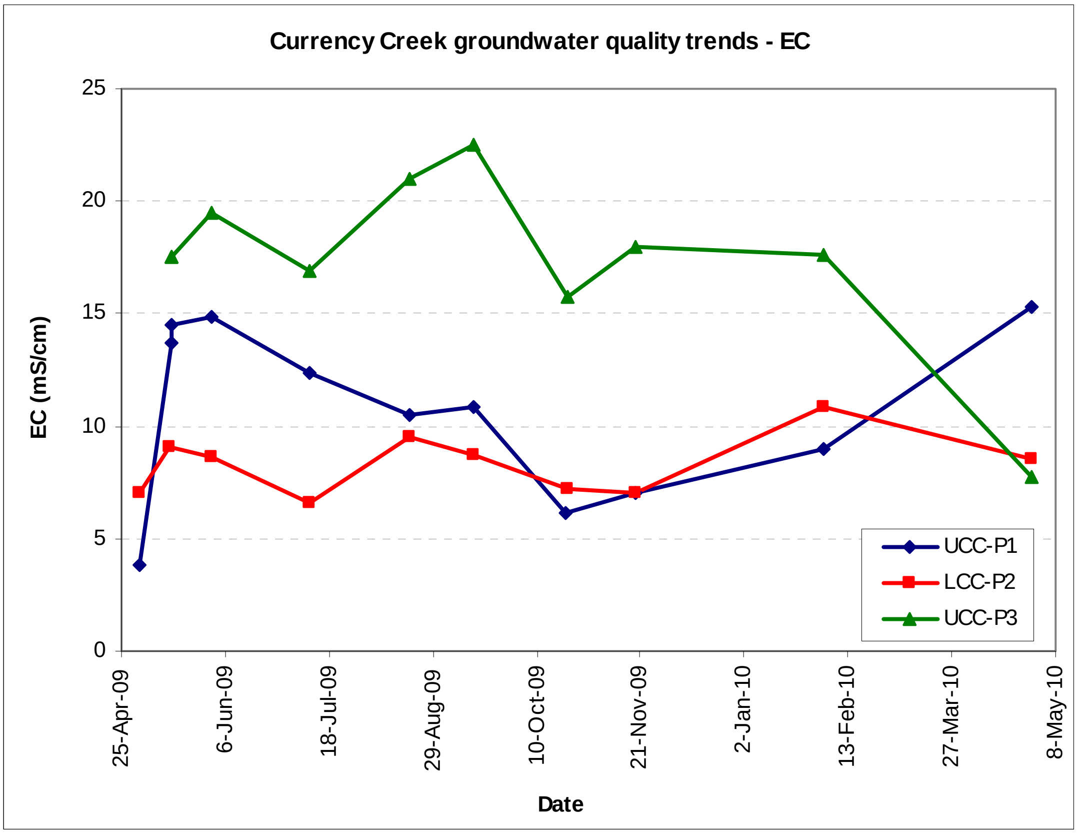

Figure 13. Groundwater EC at Currency Creek (after purging), 2 May – 28 April 2010.

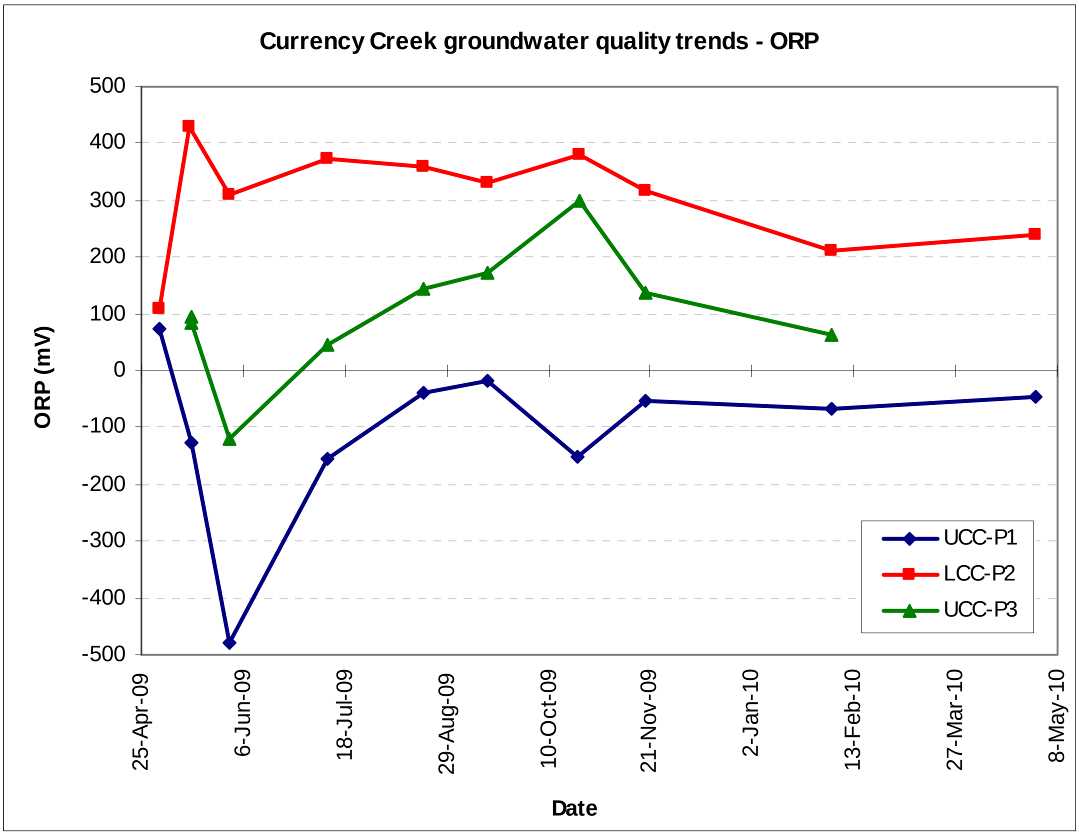

Figure 14. Groundwater ORP at Currency Creek (after purging), 2 May – 28 April 2010.

Point Sturt, Campbell Park and Windmill locations

Bulk water quality results for the Point Sturt, Campbell Park and Windmill piezometers are summarised in Tables 2-4. Trends in pH, EC, ORP, alkalinity/acidity and Cl:SO_4 ratio, with distance along each transect, are shown in Figures 15-44. Refer to Attachment B for laboratory data. Graphs showing variations in pH, EC and ORP with depth at each location are provided in Attachment C. Graphs showing temporal trends in these parameters at each location are also provided in Attachment D. The key results are summarised below:

- In the upper sediments at Point Sturt, groundwater was acidic at Site 2 (pH 4-5; acidity 300-700 mg/L $CaCO_3$) from late August to mid-November 2009. The pH at Site 2 decreased to 3.6 by April 2010. Slightly acidic pH was measured at the original shore (Site 1) in late August 2009 (pH 6.0; acidity 50 mg/L $CaCO_3$). All other sites at Point Sturt (upper and lower sediments) were characterised by near-neutral pH with alkalinities in the range 200-700 mg/L $CaCO_3$. Relatively oxidised groundwater (ORP up to +334 mV) in the upper sediments at Point Sturt (Sites 1 and 2) corresponded to the lowest pH values. In 2010 there has been a general decline in pH in the upper and lower sediments throughout the transect. This is consistent with the more oxidised conditions observed in the upper sediments at Sites 1, 2 and 4.
- EC values at Point Sturt ranged from 4 mS/cm to 22 mS/cm, with the lowest salinities associated with the upper sandy aquifer (generally <10 mS/cm). The higher salinities at depth are dominated by Na and Cl, rather than sulfate, indicating they are not related to acidity generation. EC progressively increased over the 8 month monitoring period at Site 2 (lower sediments 7.1-17.6 mS/cm), Site 3 (upper sediments 4.2-9.2 mS/cm; lower sediments 12.8-21.9 mS/cm) and Site 4 (upper sediments 6.1-8.8 mS/cm; lower sediments 5.7-7.8 mS/cm), but was relatively constant at Site 1 and the upper sediments of Site 2.
- The trends in pH and EC observed at Point Sturt over the 8 month monitoring period suggest that:
  - Some localised acidity generation occurred in the more exposed near shore sediments (eg. Site 2) prior to commencement of the monitoring program;
  - Some additional acid generation occurred at Site 2 between mid-November 2009 and late April 2010;
  - Localised acidity generation in the near shore sediments (eg. Site 2) is limited to the upper sandy horizon;
  - The acidity has been transported vertically from sandy layers in the unsaturated zone to the groundwater via rainwater infiltration;
  - There has been no vertical transport of acidity from the upper sandy layer (aquifer) to the lower aquifer, indicating that the aquifers are hydraulically disconnected by the intervening clay layer and/or diffusional mixing of groundwater within the sediments is limited; and
  - Where acidity generation has occurred, groundwater flow has been insufficient to transport the acidity from one site to the next (75 metres). This is attributed to the small hydraulic gradients at Point Sturt (Earth Systems, 2010).
- The key contributors to high salinities at Point Sturt, in order of significance, are chloride (250-8200 mg/L), sulfate (150-4100 mg/L), sodium (500-4500 mg/L), magnesium (50-550 mg/L), calcium (30-380 mg/L) and potassium (30-110 mg/L). Sulfate concentrations in the upper sandy aquifer exceeded those in the underlying sediments at all sites (with the exception of Site 3 post November 2009). This was particularly evident at Site 2 (upper sediment aquifer contained 3200-4100 mg/L SO_4, lower sediments 300-840 mg/L SO_4) and Site 1 (upper sediments 2360-2980 mg/L SO_4, lower sediments 690-1010 mg/L SO_4). The Cl:SO_4 ratio was also lowest in the upper sediments at Site 1 (0.1-0.2) and Site 2 (0.2-0.4).
- Dissolved concentrations of Al, As, Cd Cu, Mn, Ni, Pb and Zn exceeded trigger values for 95% protection of aquatic ecosystems on one or more occasions in most piezometers at Point Sturt. These metals, excluding As and Cd, also generally exceeded the 80% trigger value.
- Dissolved Fe was generally elevated in all piezometers at Point Sturt, particularly in the upper sandy sediments (up to 107 mg/L at Site 2).
- Dissolved Mn was also considerably higher in the upper sandy sediments (up to 30 mg/L at Site 2) at Point Sturt.
- Unlike Fe and Mn, dissolved As was generally higher in the lower sandy sediments (up to 0.144 mg/L at Site 2) at Point Sturt.
- The elevated Ca, Mg and Mn concentrations observed in the upper sandy horizon at Point Sturt (Site 1 - average 180 mg/L Ca, 180 mg/L Mg and 4.7 mg/L Mn; Site 2 – average 280 mg/L Ca, 430 mg/L Mg and 24 mg/L Mn) indicate that some degree of in-situ carbonate dissolution has occurred, probably in response to previous acidity generation at these sites.
- There is no clear evidence of sulfide precipitation (bacterial sulfate reduction) within the upper sandy sediments affected by acidity generation at Site 2 at Point Sturt, based on the consistent Cl:SO_4 ratios

observed throughout the 8 month monitoring period. At Site 2, the process of sulfate reduction is likely to have been inhibited by the low pH values observed.

- In the upper sandy sediments at Campbell Park, groundwater was acidic at Sites 2-4 (pH 2.4-5.9; acidity 140-1600 mg/L $CaCO_3$) from late August 2009 to late April 2010. There was some improvement at these sites from late August to mid-November 2009 (with pH increasing from 2.4 to 4.7 at Site 2, from 4.3 to 5.4 at Site 3, and from 3.0 to 4.2 at Site 4) although pH levels declined again by April 2010. Relatively oxidising groundwater (ORP up to+400 mV) in the upper sediments at Campbell Park (Sites 2-4) corresponded to the lowest pH values. The deeper sandy sediments at all Campbell Park sites (and upper sediments at Site 1) were characterised by near-neutral pH with alkalinities generally in the range 500-800 mg/L $CaCO_3$. In 2010 there has been a general decline in pH in the upper and lower sediments throughout the transect. (The upper piezometer at Site 1 has been dry since mid-November 2009).
- EC values at Campbell Park generally ranged from 8.9 mS/cm to 48.3 mS/cm. The highest salinities are associated with the deeper sandy sediments (18.6-48.3 mS/cm), particularly those nearest the shore at Sites 1 and 2 (>35 mS/cm). The higher salinities at depth are dominated by Na and Cl, rather than sulfate, indicating they are not related to acidity generation. EC values in the upper and lower sandy layers at Campbell Park were highly variable (spatially) relative to the other locations and there were no consistent trends over time within each piezometer site.
- The trends in pH and EC observed at Campbell Park over the 8 month monitoring period suggest that:
    - Acidity generation occurred within the upper sandy horizon sediments (with the exception of Site 1, near the shore) prior to commencement of the monitoring program;
    - Some additional acidity generation occurred at Sites 2, 3 and 4 between mid-November 2009 and late April 2010 (acidity generation also likely at Site 1 where the piezometer in the upper sediments was dry);
    - The acidity has been transported vertically from sandy layers in the unsaturated zone to the groundwater table via rainwater infiltration;
    - There has been no vertical transport of acidity from the upper sandy layer (aquifer) to the lower sandy aquifer, indicating that the aquifers are effectively hydraulically disconnected by the intervening clay layer; and
    - Where acidity generation has occurred, groundwater flow has been insufficient to transport the acidity from one (piezometer) site to the next (50 metres), as indicated by the discrepancy in pH values between sites. This is attributed to the relatively small hydraulic gradients at Campbell Park (Earth Systems, 2010).
- The key contributors to high salinities at Campbell Park, in order of significance, are chloride (2300-18900 mg/L), sodium (1800-11000 mg/L), sulfate (500-8000 mg/L) and magnesium (300-1300 mg/L), calcium (220-880 mg/L) and potassium (70-370 mg/L). Sulfate concentrations in the upper piezometers at Sites 2-4 exceeded those in the underlying sediments. The $Cl:SO_4$ ratio was also lower in the upper sediments at Site 2-4 (0.4-1.9) than the lower sediments (4.0-11.6).
- Dissolved concentrations of Al, As, Cd Cu, Mn, Ni, Pb and Zn exceeded trigger values for 95% protection of aquatic ecosystems on one or more occasions in most piezometers at Campbell Park.
- Dissolved Fe was generally elevated in all piezometers at Campbell Park, particularly in the upper sediments (up to 287 mg/L at Site 2). This is consistent with observations at Point Sturt.
- Dissolved Mn was considerably higher in the upper sandy sediments (up to 16 mg/L at Sites 2 and 4) at Campbell Park. This is consistent with observations at Point Sturt.
- Other dissolved metals that were generally higher in the upper sandy sediments at Campbell Park included Cd (up to 0.006 mg/L), Cu (up to 0.172 mg/L), Ni (up to 1.48 mg/L), Pb (up to 0.186 mg/L) and Zn (up to 0.678 mg/L).
- Unlike most other metals, dissolved As was generally higher in the deeper sandy sediments at Campbell Park. This is consistent with observations at Point Sturt, and is presumably related to the more reducing conditions in these sediments.
- The elevated Ca, Mg and Mn concentrations observed in the upper sandy horizons at Campbell Park nearest the lake water (Site 4 - average 520 mg/L Ca, 760 mg/L Mg and 12.1 mg/L Mn) indicates that some degree of localised in-situ carbonate dissolution (ANC consumption) has occurred in response to acidity generation at this site.
- There is some evidence of sulfide precipitation (bacterial sulfate reduction) within the upper sandy sediments affected by acidity generation at Campbell Park (Sites 2-4), based on the progressive increase in pH and $Cl:SO_4$ ratios observed from late August to mid-November 2009. Subsequent decreases in pH and $Cl:SO_4$ ratios suggest this process was partially reversed in April 2010.

- In contrast to Point Sturt and Campbell Park, groundwater at the Windmill location was near-neutral to slightly alkaline in all piezometers (pH 6.2-7.9; alkalinity 340-1050 mg/L $CaCO_3$). Relatively reduced groundwater (ORP ranging from -55 to -250 mV) was observed in all Windmill piezometers, consistent with near-neutral to slightly alkaline pH values. The maintenance of near-neutral pH over time suggests that no significant acidity generation occurred at the Windmill location from late August 2009 to late April 2010, or prior to the commencement of monitoring. In 2010, however, there has been a general decline in alkalinity in the upper sediments at Sites 3 and 4.
- EC values at the Windmill location ranged from 13.1 mS/cm to 32.6 mS/cm, with the highest salinities (23.9-32.6 mS/cm) associated with the deeper sandy sediments at Sites 1 and 4, and the upper sandy sediments at Sites 1-2. The higher salinities are dominated by Na and Cl, rather than sulfate, indicating they are not related to acidity generation. In 2010 there has been a general increase in EC in the upper and lower sediments throughout the transect. The variations in EC with depth and distance along the transect indicate that:
  - There is some hydraulic connectivity between the upper and lower sediments nearest the original shore (Site 1), consistent with the lack of significant clay barrier between the sandy lake sediments and underlying sands of the Bridgewater Formation at this site;
  - In the upper sandy sediments, the EC ranged from around 30 mS/cm nearest the original shore (Sites 1 and 2) to around 15 mS/cm nearest the lake water (Site 4);
  - The significant contrast in EC in between the sandy lake sediments and underlying sands of the Bridgewater Formation nearest the lake water (Site 4) is attributed to hydraulic disconnection associated with a clay horizon;
  - While some dilution of groundwater by relatively lower salinity lake water may be responsible for the salinity contrast in the upper sand sediments between sites 1 and 4, the significant salinity gradient has been maintained throughout the 8 month monitoring period, indicating that groundwater flow has been insufficient to transport the saline water from one site to the next (50 metres). This is attributed to the relatively small hydraulic gradients at the Windmill location (Earth Systems, 2010).
- The key contributors to high salinities at the Windmill location, in order of significance, are chloride (3000-12800 mg/L), sodium (1450-7930 mg/L), sulfate (90-2620 mg/L), magnesium (440-1200 mg/L), calcium (290-980 mg/L) and potassium (50-240 mg/L). Sulfate concentrations in the upper piezometer exceeded those in the underlying sediments at Site 1, although the reverse was observed at Site 4.
- Dissolved concentrations of Al, As, Cd Cu, Mn, Ni, Pb and Zn exceeded trigger values for 95% protection of aquatic ecosystems on one or more occasions in most piezometers at the Windmill location. These metals, excluding As and Cd, also exceeded the 80% trigger value.
- Dissolved Fe was generally elevated in all piezometers at the Windmill location. This is consistent with observations at Point Sturt.
- Dissolved Mn was considerably higher in the upper sandy sediments nearest the lake water (up to 6.3 mg/L at Site 4) at the Windmill location from late August to mid-November 2009. This is consistent with observations at Point Sturt and Campbell Park.
- There is evidence that sulfide precipitation (bacterial sulfate reduction) has occurred within the upper sandy sediments nearest the lake water at the Windmill location (Sites 3-4) prior to the commencement of monitoring, based on the high $Cl:SO_4$ ratios observed in late August 2009. The $Cl:SO_4$ ratios at these sites have subsequently decreased over time throughout the 8 month monitoring period. Recent decreases in $Cl:SO_4$ ratios in the upper sediments at Sites 3 and 4 may be associated with observed alkalinity decreases (due to sulfide oxidation and acidity generation).
- Nutrient concentrations (total N and total P) exceeded trigger values in all Point Sturt, Campbell Park and Windmill piezometers on one or more occasions.

Plots of variation in groundwater quality with depth at piezometers at Point Sturt, Campbell Park and Windmill for each monitoring event are provided in Attachment C. These plots indicate that:

- Few variations in pH with depth were observed for all piezometers for all monitoring events, with the exception of:
  - PS-2S on 29 August 2009 (ranging from 5.6 at 0.168 m BGL to 4.1 at 1.018 m BGL);
  - CP-3S on 26 August 2009 (ranging from 7.3 at 0.320 m BGL to 3.6 at 1.07 m BGL); and
  - PS-1S on 15 September 2009 (ranging from 7.5 at 0.75 m BGL to 4.4 at 1.30 m BGL).
- At all piezometers for all monitoring events, EC increased with depth. The highest variation in EC with depth occurred at CP-2S, CP-3S, WM-1S and WM-2S for all monitoring events.

However, the above results need to be considered in the context that groundwater quality profiles were obtained prior to purging of the piezometers. Thus, the plots are not necessarily representative of actual trends in groundwater quality with depth in the surrounding sediments.

Results for low-flow sampling undertaken at Point Sturt (PS-2S) at 0.8 m below ground level (~0.25 m below groundwater level) on 21 October 2009 are provided in Earth Systems (2010) and summarised below.

The stabilised pH of the low-flow sample at 0.8 m below ground level (4.1 at 16.7°C) was noticeably lower than the pH of the bulk sample after purging (4.8 at 15.7°C). Similarly, EC was slightly elevated in the low-flow sample (8.46 mS/cm) compared with the bulk sample after purging (8.03 mS/cm). This indicates that the water in the upper sand horizon is stratified. The thickness or extent of stratification is unknown. Deeper intervals were unable to be sampled due to the equipment dimensions (position of pump inlet relative to base of the pump).

When comparing the bulk sample water quality and the discrete interval sample water quality with the water quality profile measured prior to purging, pH is noticeably lower in the profile (3.6 to 3.7) than in the bulk sample (4.8). ORP is also noticeably higher in the profile (321 to 362 mV) than the bulk sample (248 mV). This is presumably explained by oxidation of relatively stagnant water in the piezometer.

Table 2. Groundwater quality data for Point Sturt piezometers.

Parameter	**Trigger values***		**Date**	**Site 1**		**Site 2**		**Site 3**		**Site 4**	
	95%	**80%**		**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
General parameters											
pH – field	6.5-9.0	6.5-9.0	29/8/09	5.97	7.44	4.42	7.40	7.32	7.35	7.16	7.31
			15/9/09	7.12	7.86	4.97	7.94	7.77	7.57	7.31	7.66
			21/10/09	7.07	7.60	4.78	7.48	7.27	7.26	6.56	7.45
			18/11/09	7.08	7.48	4.13	7.34	7.44	7.20	7.19	7.22
			3/2/10	7.22	7.38	3.79	7.12	6.44	6.91	7.93	7.04
			28/4/10	6.72	7.31	3.63	7.10	7.08	6.85	6.83	6.95
pH – laboratory	6.5-9.0	6.5-9.0	29/8/09	6.00	7.66	3.54	7.48	7.18	7.25	6.95	7.16
			15/9/09	6.80	7.64	3.18	7.50	7.42	7.37	6.98	7.31
			21/10/09	6.60	7.60	3.30	7.30	7.24	7.22	6.84	7.34
			18/11/09	6.95	7.56	3.20	7.40	7.30	7.20	6.85	7.27
			3/2/10	7.45	7.38	3.65	7.28	7.50	6.98	6.73	7.20
			28/4/10	6.90	7.30	3.50	6.57	6.78	6.88	6.90	7.00
EC – field (mS/cm)	0.3-1	0.3-1	29/8/09	5.32	11.01	7.74	7.18	4.22	12.83	6.05	5.74
			15/9/09	5.35	10.22	7.99	9.31	5.88	14.43	7.81	5.60
			21/10/09	5.30	10.60	8.03	11.15	5.19	14.69	7.77	5.67
			18/11/09	4.94	9.95	7.59	11.06	7.01	17.67	7.67	6.09
			3/2/10	4.83	10.53	6.63	10.61	8.07	20.33	7.93	6.12
			28/4/10	5.29	11.14	7.59	17.60	9.24	21.91	8.81	7.80
EC – laboratory (mS/cm)	0.3-1	0.3-1	29/8/09	5.65	11.40	8.30	7.76	4.00	13.70	6.10	6.06
			15/9/09	5.51	10.70	8.69	10.50	6.10	15.10	8.05	5.73
			21/10/09	5.54	11.80	9.30	12.60	5.75	16.20	8.26	6.00
			18/11/09	4.95	10.40	8.04	11.20	6.82	18.20	7.15	5.93
			3/2/10	4.88	10.80	7.80	11.20	8.16	21.10	7.86	6.20
			28/4/10	5.30	11.30	7.90	12.60	10.30	21.50	8.40	7.60
ORP – field (mV)	n/a	n/a	29/8/09	+75	-16	-	-94	-118	-73	-94	-106
			15/9/09	+19	-62	+204	-82	-50	-70	-94	-106
			21/10/09	-17	-79	+248	-79	-89	-39	-75	-100
			18/11/09	-40	-62	+209	-83	-95	-72	-90	-101
			3/2/10	-137	-119	+246	-109	+4	-117	-158	-108
			28/4/10	-32	-95	+334	-101	-150	-89	-89	-92

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4	
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
DO – field (mg/L)	n/a	n/a	15/9/09	6.08	3.56	5.84	3.92	4.76	4.13	4.54	4.46
			21/10/09	5.23	3.57	4.98	3.23	-	-	5.78	5.36
			18/11/09	5.16	6.78	3.87	3.60	4.87	3.81	5.18	3.15
			3/2/10	-	-	-	-	-	-	-	-
			28/4/10	-	-	-	-	-	-	-	-
Alkalinity / acidity											
Alkalinity – field	n/a	n/a	29/8/09	-	-	-	-	-	1305	-	765
			15/9/09	120	630	-	1275	420	570	378	636
			21/10/09	165	756	-	1080	360	708	453	816
			18/11/09	258	708	-	2400	480	696	516	882
			3/2/10	223	736	-	518	508	440	469	668
			28/4/10	184	649	-	455	-	411	436	605
Alkalinity – laboratory	n/a	n/a	29/8/09	76	715	-	552	216	501	272	626
			15/9/09	126	696	<1	459	384	481	343	663
			21/10/09	161	714	<1	463	332	494	357	688
			18/11/09	224	727	<1	503	470	459	397	704
			3/2/10	296	675	<1	468	434	395	391	616
			28/4/10	201	682	<1	471	414	414	392	600
Acidity – field	n/a	n/a	29/8/09	-	-	290	-	-	-	-	-
			15/9/09	93	-	410	-	-	-	-	-
			21/10/09	-	-	761	-	-	-	-	-
			18/11/09	-	-	420	-	-	-	-	-
			3/2/10	-	-	284	-	-	-	-	-
			28/4/10	-	-	524	-	-	-	-	-
Acidity – laboratory	n/a	n/a	29/8/09	50	35	396	25	20	50	35	60
			15/9/09	33	-	404	-	-	-	-	-
			21/10/09	-	-	684	-	-	-	-	-
			18/11/09	-	-	309	-	-	-	-	-
			3/2/10	-	-	190	-	-	-	-	-
			28/4/10	-	-	402	-	-	-	-	-
Acidity – calculated	n/a	n/a	29/8/09	35	2	307	10	5	1	33	9
			15/9/09	77	105	513	211	109	255	187	367
			21/10/09	53	60	554	125	52	247	129	105
			18/11/09	9	12	340	4	3	6	57	8
			3/2/10	8	4	192	6	3	21	99	21
			28/4/10	7	2	339	12	4	14	50	25
Major ions											
Ca	n/a	n/a	29/8/09	230	54	269	80	139	216	140	110
			15/9/09	235	53	305	123	125	254	166	105
			21/10/09	195	40	314	137	146	246	146	98
			18/11/09	168	47	294	158	132	347	143	114
			3/2/10	87	34	215	125	133	311	139	92
			28/4/10	158	52	266	178	205	378	177	146

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4	
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Mg	n/a	n/a	29/8/09	238	55	391	101	86	262	100	114
			15/9/09	234	64	461	178	130	316	130	126
			21/10/09	184	57	446	194	114	293	116	117
			18/11/09	182	69	484	239	162	487	134	159
			3/2/10	98	62	374	206	214	503	135	137
			28/4/10	152	80	402	258	244	556	168	200
Na	n/a	n/a	29/8/09	713	2040	873	1240	497	2090	939	921
			15/9/09	788	2220	951	1810	930	2560	1260	887
			21/10/09	724	2220	891	2020	772	2510	1100	814
			18/11/09	871	2310	1040	2160	1230	2990	1040	1030
			3/2/10	916	2330	953	2050	1970	3690	1240	887
			28/4/10	1020	3020	990	2600	1880	4540	1490	1300
K	n/a	n/a	29/8/09	64	52	71	43	28	59	34	32
			15/9/09	65	54	82	56	34	54	32	33
			21/10/09	60	50	89	53	33	53	30	30
			18/11/09	62	52	110	58	42	65	33	36
			3/2/10	53	52	78	59	70	73	43	36
			28/4/10	75	75	98	72	59	92	71	48
Cl	n/a	n/a	29/8/09	268	2440	1080	2060	772	4220	988	877
			15/9/09	360	2780	1090	3050	1540	4550	2290	1440
			21/10/09	246	2450	850	3280	1200	4380	1770	1080
			18/11/09	285	2550	1080	3260	1790	5340	1750	1420
			3/2/10	304	2810	1100	2960	2950	7000	2210	1500
			28/4/10	318	4000	766	4200	3500	8160	2250	1930
SO_4	n/a	n/a	29/8/09	2600	775	3210	294	609	384	480	339
			15/9/09	2650	776	3660	423	486	465	400	242
			21/10/09	2360	693	3780	468	553	432	302	149
			18/11/09	2390	847	3810	603	372	628	321	214
			3/2/10	2020	699	2990	518	530	621	280	145
			28/4/10	2980	1010	4120	838	324	922	615	358
Cl:SO_4 ratio	n/a	n/a	29/8/09	0.1	3.1	0.3	7.0	1.3	11.0	2.1	2.6
			15/9/09	0.1	3.6	0.3	7.2	3.2	9.8	5.7	6.0
			21/10/09	0.1	3.5	0.2	7.0	2.2	10.1	5.9	7.2
			18/11/09	0.1	3.0	0.3	5.4	4.8	8.5	5.5	6.6
			3/2/10	0.2	4.0	0.4	5.7	5.6	11.3	7.9	10.3
			28/4/10	0.1	4.0	0.2	5.0	10.8	8.9	3.7	5.4
Dissolved metals											
Al	0.055	0.15	29/8/09	0.28	0.08	23.6	0.75	0.10	0.03	0.06	0.05
			15/9/09	6.10	13.7	32.0	22.2	12.5	32.3	10.8	42.50
			21/10/09	2.47	7.59	42.1	12.8	5.57	29.9	3.33	9.95
			18/11/09	0.04	1.39	16.9	0.19	0.13	0.09	0.10	0.12
			3/2/10	0.02	0.01	14.1	0.01	0.01	0.01	<0.01	0.01
			28/4/10	0.02	<0.01	41.6	<0.01	<0.01	<0.01	0.01	<0.01

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4	
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
As	0.013 (AsV)	0.140 (AsV)	29/8/09	0.001	0.046	0.004	0.020	0.004	0.007	0.009	0.030
			15/9/09	0.005	0.074	0.006	0.144	0.024	0.048	0.058	0.106
			21/10/09	0.002	0.072	0.003	0.107	0.011	0.052	0.045	0.071
			18/11/09	<0.001	0.067	0.003	0.042	0.006	0.029	0.040	0.044
			3/2/10	0.002	0.113	0.002	0.082	0.005	0.099	0.109	0.074
			28/4/10	0.002	0.112	0.002	0.067	0.003	0.085	0.059	0.066
Cd	0.0002	0.0008	29/8/09	0.0002	0.0004	0.0002	0.0017	0.0001	0.0004	0.0001	0.0001
			15/9/09	0.0004	<0.0001	0.0003	0.0003	0.0002	0.0002	0.0002	0.0005
			21/10/09	0.0002	<0.0001	0.0001	0.0001	<0.0001	0.0002	<0.0001	<0.0001
			18/11/09	<0.0001	<0.0001	0.0004	<0.0001	0.0003	0.0001	0.0003	<0.0001
			3/2/10	0.0002	<0.0001	0.0001	0.0003	<0.0001	0.0003	<0.0001	0.0003
			28/4/10	0.0001	0.0001	0.0002	0.0001	<0.0001	0.0004	0.0004	0.0001
Cu	0.0014	0.0025	29/8/09	0.006	0.002	0.010	0.002	0.002	0.002	0.005	0.007
			15/9/09	0.011	0.027	0.019	0.024	0.110	0.036	0.012	0.016
			21/10/09	0.006	0.016	0.012	0.015	0.005	0.038	0.005	0.005
			18/11/09	0.006	0.006	0.008	0.001	0.001	0.002	0.001	<0.001
			3/2/10	0.005	0.004	0.009	0.002	0.001	0.003	0.002	0.002
			28/4/10	0.005	0.003	0.006	0.003	0.002	0.003	0.002	0.001
Fe	n/a	n/a	29/8/09	6.17	0.13	50.2	1.39	0.32	<0.05	10.3	2.33
			15/9/09	10.9	10.6	107	31.8	13.4	27.5	43.8	47.5
			21/10/09	10.9	6.51	98.1	19.7	6.84	29.5	38.0	17.7
			18/11/09	1.30	1.27	72.7	0.90	0.19	1.69	18.2	2.03
			3/2/10	2.43	1.04	25.3	2.05	0.28	7.30	33.9	6.84
			28/4/10	0.98	0.61	20.5	4.15	0.24	4.62	16.3	8.45
Mn	1.9	3.6	29/8/09	9.03	0.287	20.9	0.838	2.10	0.458	2.76	1.29
			15/9/09	7.16	0.104	25.4	0.612	1.68	0.636	4.89	1.41
			21/10/09	5.32	0.085	29.9	0.467	1.52	0.617	4.65	1.06
			18/11/09	3.01	0.161	25.4	0.410	1.06	0.583	3.96	0.97
			3/2/10	0.934	0.058	20.2	0.223	1.19	0.535	3.88	1.05
			28/4/10	2.44	0.047	21.9	21.9	1.80	0.539	3.16	1.18
Ni	0.011	0.017	29/8/09	0.222	0.013	0.185	0.008	0.002	0.004	0.003	0.002
			15/9/09	0.136	0.019	0.165	0.031	0.010	0.042	0.011	0.048
			21/10/09	0.096	0.015	0.215	0.020	0.005	0.052	0.004	0.011
			18/11/09	0.030	0.010	0.092	0.004	0.001	0.002	0.001	0.002
			3/2/10	0.005	0.026	0.084	0.006	0.009	0.012	0.007	0.004
			28/4/10	0.023	0.007	0.159	0.003	<0.001	0.002	0.001	<0.001
Pb	0.0034	0.0094	29/8/09	0.002	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001
			15/9/09	0.010	0.013	0.029	0.024	0.013	0.030	0.014	0.031
			21/10/09	0.005	0.008	0.015	0.015	0.010	0.032	0.005	0.013
			18/11/09	<0.001	0.002	0.009	<0.001	<0.001	<0.001	<0.001	<0.001
			3/2/10	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001
			28/4/10	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4	
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Se	0.011	0.034	29/8/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			15/9/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			21/10/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			18/11/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			3/2/10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			28/4/10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	0.008	0.031	29/8/09	0.116	0.008	0.287	0.010	<0.005	0.006	0.008	0.008
			15/9/09	0.084	0.033	0.219	0.035	0.034	0.050	0.035	0.049
			21/10/09	0.069	0.027	0.253	0.026	0.016	0.050	0.021	0.025
			18/11/09	0.018	0.017	0.218	0.015	0.020	0.018	0.024	0.020
			3/2/10	0.008	0.114	0.134	0.014	<0.005	0.010	0.007	0.038
			28/4/10	0.010	<0.005	0.182	<0.005	0.005	0.006	<0.005	<0.005
Nutrients											
Nitrite + nitrate as N	0.1	0.1	29/8/09	0.02	<0.01	0.04	<0.01	0.13	0.02	<0.01	<0.01
			15/9/09	0.02	0.02	0.05	0.02	1.04	0.03	0.29	0.02
			21/10/09	<0.01	0.02	0.05	0.17	1.14	0.04	0.28	0.01
			18/11/09	0.02	0.02	0.01	0.22	1.04	0.41	0.76	0.10
			3/2/10	<0.01	0.01	0.05	0.03	0.48	0.02	0.20	0.11
			28/4/10	0.01	<0.01	0.07	0.06	1.16	0.29	0.53	0.10
Total Kjeldahl Nitrogen as N	n/a	n/a	29/8/09	<0.1	1.0	2.4	2.2	4.6	7.1	17.7	14.5
			15/9/09	<0.1	<0.1	3.3	2.5	6.8	4.9	36.7	19.2
			21/10/09	3.4	0.7	2.9	2.2	4.7	4.6	26.0	14.0
			18/11/09	0.6	1.0	2.8	1.9	5.8	5.1	31.0	13.5
			3/2/10	0.6	0.7	3.9	2.1	8.6	5.7	40.3	16.0
			28/4/10	0.4	1.2	3.9	2.4	9.4	7.4	28.9	17.7
Total Nitrogen as N	1	1	29/8/09	<0.1	<1.0	2.4	2.2	4.7	7.2	17.7	14.5
			15/9/09	<0.1	<0.1	3.4	2.5	7.9	4.9	36.9	19.3
			21/10/09	3.4	0.7	3.0	2.4	5.8	4.6	26.2	14.0
			18/11/09	0.6	1.0	2.8	2.1	6.8	5.5	31.7	13.6
			3/2/10	0.6	0.8	3.9	2.2	9.1	5.7	40.5	16.1
			28/4/10	0.4	1.2	4.0	2.5	10.6	7.7	29.4	17.8
Total Phosphorus as P	0.025	0.025	29/8/09	0.15	0.18	0.23	0.49	0.53	1.83	1.02	0.60
			15/9/09	0.08	0.11	0.12	0.22	0.67	0.33	0.64	0.43
			21/10/09	<0.01	<0.01	<0.01	0.11	0.42	0.24	0.42	0.04
			18/11/09	0.13	0.12	0.11	0.15	1.36	0.33	0.97	0.38
			3/2/10	0.76	1.14	0.18	0.08	0.60	0.23	0.85	0.23
			28/4/10	<0.01	0.04	<0.01	<0.01	1.34	0.18	1.03	0.11

* ANZECC/ARMCANZ (2000) trigger values for 80% and 95% protection of freshwater ecosystems. Values exceeding ANZECC/ARMCANZ (2000) trigger values for **95%** protection of freshwater ecosystems are shaded in orange. Values exceeding trigger values for **95%** and **80%** protection of freshwater ecosystems are shaded in red.

Table 3. Groundwater quality data for Campbell Park piezometers.

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4		
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Mid	Lower
General parameters												
pH – field	6.5-9.0	6.5-9.0	26/8/09	7.21	6.81	3.65	6.86	4.24	6.82	2.99	7.03	7.05
			17/9/09	6.75	6.34	2.43	6.38	4.30	6.32	3.01	6.63	6.87
			19/10/09	7.70	6.99	3.87	6.89	4.68	6.89	3.35	6.91	6.97
			17/11/09	-	7.12	4.69	7.16	5.44	7.04	4.18	7.60	7.65
			2/2/10	-	6.82	4.16	6.72	5.89	6.80	4.14	7.98	6.86
			27/4/10	-	6.89	3.94	6.73	4.62	6.71	3.47	6.84	6.79
pH – laboratory	6.5-9.0	6.5-9.0	26/8/09	6.41	6.89	3.29	6.93	3.26	7.06	3.14	7.07	6.94
			17/9/09	6.32	6.99	3.12	7.01	3.30	7.12	3.19	7.15	7.08
			19/10/09	6.70	7.03	3.33	7.00	3.34	7.03	3.30	7.05	7.10
			17/11/09	-	7.27	3.37	6.99	3.25	6.97	3.23	7.11	6.90
			2/2/10	-	7.06	3.27	6.65	6.00	6.89	3.29	7.00	6.80
			27/4/10	-	6.65	3.16	6.50	3.55	6.65	3.38	6.75	6.55
EC – field (mS/cm)	0.3-1	0.3-1	26/8/09	16.43	40.45	26.51	48.26	16.09	30.35	14.38	14.13	20.83
			17/9/09	15.95	41.50	28.80	42.20	11.07	18.61	8.92	14.83	20.50
			19/10/09	2.47	38.80	29.30	39.80	17.07	29.50	13.54	14.05	19.08
			17/11/09	-	39.70	29.70	45.60	19.74	30.20	12.76	14.34	18.89
			2/2/10	-	39.60	27.90	42.20	19.60	30.20	12.33	13.37	20.45
			27/4/10	-	39.90	28.70	37.20	19.94	30.60	13.06	14.69	20.86
EC – laboratory (mS/cm)	0.3-1	0.3-1	26/8/09	16.10	43.80	30.50	51.50	17.60	32.10	15.30	15.40	22.30
			17/9/09	16.40	43.40	29.00	48.50	18.10	31.90	14.60	15.00	20.60
			19/10/09	2.46	43.10	3200	46.70	20.20	34.20	15.20	16.40	22.40
			17/11/09	-	40.70	31.20	46.20	20.10	30.40	13.60	14.60	19.10
			2/2/10	-	42.50	30.20	46.70	20.40	31.20	12.80	14.40	21.00
			27/4/10	-	42.90	31.10	40.00	20.40	32.30	13.70	15.00	21.70
ORP – field (mV)	n/a	n/a	26/8/09	-120	-236	+32.3	-226	+291	-264	+397	-258	-179
			17/9/09	-27	-113	+402	-205	+158	-208	+387	-244	-146
			19/10/09	+1	-157	+301	-176	+177	-200	+342	-208	-62
			17/11/09	-	-206	+82	-244	-9	-225	+327	-248	-176
			2/2/10	-	-283	+186	-282	-93	-313	-	-284	-235
			27/4/10	-	-254	-31	-264	-132	-311	+360	-274	+60
DO – field (mg/L)	n/a	n/a	17/9/09	7.65	3.39	6.37	2.52	5.54	2.83	4.60	3.48	2.96
			19/10/09	5.13	2.32	-	1.46	3.03	3.64	2.99	3.87	3.78
			17/11/09	-	-	5.87	3.43	3.21	2.57	3.95	1.68	2.89
			2/2/10	-	-	-	-	-	-	-	-	-
			27/4/10	-	-	-	-	-	-	-	-	-
Alkalinity / acidity												
Alkalinity – field	n/a	n/a	26/8/09	-	-	-	-	-	-	-	690	735
			17/9/09	153	585	-	630	-	960	-	720	1800
			19/10/09	285	435	-	720	-	1095	-	840	1038
			17/11/09	-	630	-	642	-	1008	-	972	1002
			2/2/10	-	615	-	702	-	779	-	702	707
			27/4/10	-	532	-	629	-	750	-	726	992

Parameter	**Trigger values***		**Date**	**Site 1**		**Site 2**		**Site 3**		**Site 4**		
	95%	**80%**		**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Mid**	**Lower**
Alkalinity – laboratory	n/a	n/a	26/8/09	118	515	-	495	-	-	-	746	674
			17/9/09	82	485	<1	488	<1	657	<1	626	627
			19/10/09	99	523	<1	670	<1	739	<1	691	693
			17/11/09	-	587	<1	625	<1	761	<1	792	239
			2/2/10	-	535	<1	590	40	692	<1	727	630
			27/4/10	-	508	<1	719	<1	696	<1	696	648
Acidity – field	n/a	n/a	26/8/09	75	-	1650	-	375	-	625	-	-
			17/9/09	130	-	1950	-	575	-	1725	-	-
			19/10/09	-	-	1100	-	550	-	1250	-	-
			17/11/09	-	-	985	-	400	-	890	-	-
			2/2/10	-	-	1242	-	299	-	359	-	-
			27/4/10	-	-	1870	-	381	-	464	-	-
Acidity – laboratory	n/a	n/a	26/8/09	88	85	1580	85	502	120	1080	-	100
			17/9/09	57	-	1470	-	480	-	1360	-	-
			19/10/09	40	-	1260	-	519	-	1380	-	-
			17/11/09	-	-	708	-	295	-	698	-	-
			2/2/10	-	-	703	-	142	-	195	-	-
			27/4/10	-	-	1360	-	402	-	402	-	-
Acidity – calculated	n/a	n/a	26/8/09	54	2	1311	42	413	15	510	3	13
			17/9/09	173	92	1521	146	443	171	1240	18	233
			19/10/09	1617	28	995	52	364	58	985	36	83
			17/11/09	-	4	741	8	293	4	688	11	11
			2/2/10	-	3	787	4	186	8	197	1	12
			27/4/10	-	2	1099	3	264	5	281	1	16
Major ions												
Ca	n/a	n/a	26/8/09	306	592	494	677	346	512	603	233	407
			17/9/09	333	654	491	686	366	546	596	289	398
			19/10/09	33	576	488	474	359	537	544	268	369
			17/11/09	-	704	549	875	423	591	494	272	384
			2/2/10	-	600	568	631	360	518	339	224	387
			27/4/10	-	720	659	638	546	725	536	313	506
Mg	n/a	n/a	26/8/09	409	992	920	821	598	790	839	296	549
			17/9/09	489	1110	913	1080	649	760	846	338	546
			19/10/09	27	944	920	507	614	686	751	299	490
			17/11/09	-	1280	1120	1260	803	871	775	349	546
			2/2/10	-	1110	1200	1110	726	774	543	294	557
			27/4/10	-	1270	1260	1050	992	982	821	423	686
Na	n/a	n/a	26/8/09	2570	8540	4970	11000	2670	6050	1840	2590	3660
			17/9/09	2940	9080	4990	9810	2930	6150	1760	2950	3660
			19/10/09	384	7510	5100	8700	2870	5690	1790	2700	3510
			17/11/09	-	8620	6330	10000	3590	5600	2090	2860	3810
			2/2/10	-	8200	6660	9220	3520	6060	1900	2370	3580
			27/4/10	-	9980	7100	10400	4440	8560	2710	3700	4820

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4		
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Mid	Lower
K	n/a	n/a	26/8/09	84	214	186	209	133	189	145	70	76
			17/9/09	100	230	177	258	143	177	140	76	78
			19/10/09	20	195	187	145	141	161	121	69	74
			17/11/09	-	233	216	366	159	172	119	68	74
			2/2/10	-	230	259	253	175	181	106	67	82
			27/4/10	-	289	242	264	222	244	145	110	104
Cl	n/a	n/a	26/8/09	3520	10700	8440	17400	2970	10500	2580	4550	7140
			17/9/09	4670	16600	8120	18900	4750	10200	2360	4600	6950
			19/10/09	500	11900	8160	12100	4620	9000	2520	4250	6180
			17/11/09	-	13900	9780	16500	5140	10500	2770	4540	6930
			2/2/10	-	14700	9410	16400	5850	11100	2830	4540	6830
			27/4/10	-	16900	10200	15500	5980	13500	2830	6200	8500
SO_4	n/a	n/a	26/8/09	1830	2810	5410	3650	3420	1700	5840	510	655
			17/9/09	2120	2930	5320	3200	3500	1850	6400	702	685
			19/10/09	202	2640	4660	2830	3280	1720	5500	613	599
			17/11/09	-	3340	5210	4150	3830	1800	5140	537	634
			2/2/10	-	2770	5730	2860	3330	1600	3090	408	603
			27/4/10	-	3810	7970	3820	5940	2670	6030	535	913
$Cl:SO_4$ ratio	n/a	n/a	26/8/09	1.9	3.8	1.6	4.8	0.9	6.2	0.4	8.9	10.9
			17/9/09	2.2	5.7	1.5	5.9	1.4	5.5	0.4	6.6	10.1
			19/10/09	2.5	4.5	1.8	4.3	1.4	5.2	0.5	6.9	10.3
			17/11/09	-	4.2	1.9	4.0	1.3	5.8	0.5	8.5	10.9
			2/2/10	-	5.3	1.6	5.7	1.8	6.9	0.9	11.1	11.3
			27/4/10	-	4.4	1.3	4.1	1.0	5.1	0.5	11.6	9.3
Dissolved metals												
Al	0.055	0.15	26/8/09	0.37	0.07	90.0	2.36	23.7	1.40	52.9	0.20	0.09
			17/9/09	13.8	11.4	99.7	17.0	29.2	19.5	105	1.90	16.8
			19/10/09	185	3.52	53.2	6.28	20.0	6.97	75.6	4.09	5.52
			17/11/09	-	0.05	28.1	0.16	3.78	0.12	38.2	0.57	0.05
			2/2/10	-	<0.01	35.0	<0.01	0.57	<0.01	6.14	0.02	<0.01
			27/4/10	-	0.01	105	<0.01	23.0	0.01	29.8	<0.01	<0.01
As	0.013 (AsV)	0.140 (AsV)	26/8/09	0.001	0.001	0.007	0.001	0.003	0.005	0.003	0.011	0.012
			17/9/09	0.014	0.017	0.012	0.035	0.007	0.030	0.011	0.009	0.134
			19/10/09	0.200	0.005	0.002	0.021	0.001	0.006	0.004	0.007	0.046
			17/11/09	-	0.013	0.008	0.008	0.005	0.008	0.007	0.004	0.016
			2/2/10	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.020
			27/4/10	-	0.003	0.006	0.001	0.004	0.001	0.002	<0.001	0.032
Cd	0.0002	0.0008	26/8/09	0.0001	0.0002	0.0032	0.0002	0.0008	0.0002	0.0046	0.0002	0.0003
			17/9/09	0.0002	<0.0001	0.0022	0.0001	0.0004	0.0001	0.0060	0.0001	0.0002
			19/10/09	<0.0001	0.0001	0.0007	<0.0001	0.0004	0.0001	0.0022	<0.0001	<0.0001
			17/11/09	-	0.0002	0.0007	0.0004	0.0003	0.0002	0.0007	<0.0001	0.0003
			2/2/10	-	0.0001	0.0002	0.0001	<0.0001	0.0010	0.0001	<0.0001	<0.0001
			27/4/10	-	<0.0001	0.0007	<0.0001	0.0001	0.0001	0.0006	0.0001	<0.0001

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4		
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Mid	Lower
Cu	0.0014	0.0025	26/8/09	0.005	0.007	0.059	0.008	0.013	0.006	0.104	0.002	0.003
			17/9/09	0.021	0.011	0.055	0.015	0.018	0.016	0.172	0.003	0.014
			19/10/09	0.143	0.008	0.024	0.009	0.013	0.009	0.065	0.006	0.007
			17/11/09	-	0.009	0.015	0.009	0.011	0.005	0.019	0.003	0.002
			2/2/10	-	0.009	0.018	0.010	0.011	0.008	0.012	0.005	0.003
			27/4/10	-	0.010	0.016	0.008	0.012	0.006	0.014	0.004	0.004
Fe	n/a	n/a	26/8/09	15.8	<0.05	287	9.27	99.7	1.69	53.6	0.13	4.38
			17/9/09	31.4	10.1	279	18.0	99.4	21.8	214	2.44	50.7
			19/10/09	217	2.44	249	5.78	89.8	6.11	191	4.46	19.1
			17/11/09	-	0.74	209	1.67	97.3	0.47	166	2.40	3.67
			2/2/10	-	0.59	210	0.48	64.0	2.09	53.3	0.09	4.40
			27/4/10	-	<0.05	178	<0.05	45.6	1.15	29.3	<0.05	5.86
Mn	1.9	3.6	26/8/09	5.17	0.779	13.0	1.84	4.77	1.53	10.2	0.721	0.176
			17/9/09	6.20	0.941	14.4	1.68	5.29	1.80	15.7	0.677	1.30
			19/10/09	1.45	0.736	11.7	0.992	5.03	1.25	14.4	0.724	0.454
			17/11/09	-	0.870	11.1	1.52	5.43	0.999	13.4	0.842	0.164
			2/2/10	-	0.863	12.9	1.48	5.41	1.10	8.73	0.519	0.120
			27/4/10	-	0.737	15.9	1.28	6.25	0.961	10.4	0.569	0.104
Ni	0.011	0.017	26/8/09	0.058	0.005	1.480	0.049	0.446	0.025	0.721	0.002	<0.001
			17/9/09	0.111	0.018	1.450	0.027	0.431	0.037	1.140	0.006	0.028
			19/10/09	0.133	0.003	0.831	0.008	0.328	0.009	0.902	0.008	0.008
			17/11/09	-	<0.001	0.444	0.001	0.208	0.002	0.500	0.007	0.001
			2/2/10	-	0.009	0.377	0.009	0.104	0.005	0.090	0.008	0.010
			27/4/10	-	0.001	0.741	0.002	0.148	0.003	0.278	0.002	<0.001
Pb	0.0034	0.0094	26/8/09	<0.001	<0.001	0.038	<0.001	0.017	0.001	0.047	<0.001	<0.001
			17/9/09	0.024	0.009	0.043	0.017	0.020	0.019	0.039	0.004	0.029
			19/10/09	0.186	0.006	0.019	0.007	0.013	0.008	0.015	0.006	0.009
			17/11/09	-	<0.001	0.013	<0.001	0.005	<0.001	0.010	<0.001	<0.001
			2/2/10	-	<0.001	0.012	<0.001	0.001	<0.001	0.002	<0.001	<0.001
			27/4/10	-	<0.001	0.004	<0.001	0.005	<0.001	0.002	<0.001	<0.001
Se	0.011	0.034	26/8/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
			17/9/09	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.02	<0.01	0.01
			19/10/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
			17/11/09	-	0.02	0.02	0.01	0.01	0.01	0.01	<0.01	<0.01
			2/2/10	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			27/4/10	-	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	0.008	0.031	26/8/09	0.046	0.009	0.678	0.025	0.385	0.022	0.339	0.008	0.009
			17/9/09	0.110	0.023	0.638	0.050	0.366	0.091	0.634	0.014	0.036
			19/10/09	0.517	0.018	0.328	0.013	0.318	0.028	0.482	0.017	0.018
			17/11/09	-	0.014	0.243	0.020	0.266	0.014	0.307	0.022	0.009
			2/2/10	-	0.013	0.195	0.010	0.120	0.013	0.093	0.017	0.008
			27/4/10	-	<0.005	0.275	<0.005	0.134	0.012	0.146	0.006	<0.005

Parameter	Trigger values*		Date	Site 1		Site 2		Site 3		Site 4		
	95%	80%		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Mid	Lower
Nutrients												
Nitrite + Nitrate as N	0.1	0.1	26/8/09	0.02	0.03	0.18	0.02	0.10	0.03	0.10	0.02	0.03
			17/9/09	0.03	0.02	0.16	0.02	0.06	0.03	0.21	0.02	0.02
			19/10/09	4.03	0.03	0.16	0.02	0.09	0.02	0.16	0.01	0.02
			17/11/09	-	0.01	0.09	<0.01	0.03	0.02	0.09	<0.01	<0.01
			2/2/10	-	<0.01	0.12	0.01	0.07	0.01	0.07	<0.01	0.09
			27/4/10	-	0.03	0.10	0.09	0.08	<0.01	0.02	0.02	0.08
Total Kjeldahl Nitrogen as N	n/a	n/a	26/8/09	2.3	9.1	4.5	8.9	3.1	9.9	3.2	5.1	5.5
			17/9/09	3.0	10.4	6.0	13.2	2.3	11.0	3.9	4.0	7.7
			19/10/09	3.0	5.9	5.4	5.6	2.2	5.9	3.5	3.6	4.6
			17/11/09	-	7.0	4.6	8.3	3.9	6.5	3.6	4.2	4.2
			2/2/10	-	6.9	6.0	8.0	4.2	6.3	4.0	4.6	5.7
			27/4/10	-	9.3	7.6	11.0	4.7	7.5	4.9	5.2	5.9
Total Nitrogen as N	1	1	26/8/09	2.4	9.1	4.6	8.9	3.2	10.0	3.3	5.2	5.5
			17/9/09	3.1	10.4	6.1	13.3	2.4	11.0	4.1	4.0	7.7
			19/10/09	7.0	5.9	5.6	5.6	2.2	5.9	3.7	3.6	4.6
			17/11/09	-	7.0	4.7	8.3	4.0	6.5	3.7	4.2	4.2
			2/2/10	-	6.9	6.1	8.0	4.3	6.3	4.1	4.6	5.8
			27/4/10	-	9.3	7.7	11.1	4.8	7.5	4.9	5.2	6.0
Total Phosphorus as P	0.025	0.025	26/8/09	0.18	1.15	0.17	0.65	0.67	1.60	0.13	0.76	0.20
			17/9/09	0.32	0.67	0.18	0.77	0.09	1.15	0.12	0.44	0.52
			19/10/09	1.06	0.34	0.01	0.15	<0.01	0.46	<0.01	0.21	<0.01
			17/11/09	-	1.05	0.25	1.00	0.12	1.43	0.14	0.66	0.18
			2/2/10	-	1.63	0.29	0.77	0.04	1.02	0.28	0.56	0.33
			27/4/10	-	1.13	0.01	0.62	<0.01	0.98	<0.01	0.61	0.06

* ANZECC/ARMCANZ (2000) trigger values for 80% and 95% protection of freshwater ecosystems. Values exceeding ANZECC/ARMCANZ (2000) trigger values for **95%** protection of freshwater ecosystems are shaded in orange. Values exceeding trigger values for **95%** and **80%** protection of freshwater ecosystems are shaded in red.

Table 4. Groundwater quality data for Windmill piezometers.

Parameter	Trigger values*		Date	Site 1		Site 2	Site 3	Site 4	
	95%	80%		Upper	Lower	Upper	Upper	Upper	Lower
General parameters									
pH – field	6.5-9.0	6.5-9.0	28/8/09	7.03	7.00	7.13	7.19	6.95	6.86
			16/9/09	7.91	7.65	7.70	7.59	7.35	7.29
			20/10/09	6.82	6.81	7.05	6.96	6.87	6.17
			16/11/09	7.20	6.86	6.98	6.89	6.69	6.55
			1/2/10	7.29	7.00	7.11	7.06	6.90	6.88
			26/4/10	7.21	7.23	7.25	7.23	7.00	6.90
pH – laboratory	6.5-9.0	6.5-9.0	28/8/09	7.08	6.97	7.02	7.33	6.98	6.65
			16/9/09	7.38	7.22	7.34	7.28	7.18	6.89
			20/10/09	7.20	7.10	7.13	7.13	7.07	6.72
			16/11/09	7.28	6.85	7.20	7.15	6.99	6.65
			1/2/10	7.20	6.99	6.98	6.98	6.95	6.62
			26/4/10	6.30	6.55	6.52	6.68	6.6	6.43
EC – field (mS/cm)	0.3-1	0.3-1	28/8/09	30.30	31.70	30.70	20.76	13.06	30.30
			16/9/09	27.70	26.60	28.10	19.38	13.57	26.30
			20/10/09	30.60	26.20	29.80	21.18	13.68	27.20
			16/11/09	29.00	26.10	29.60	21.74	14.63	27.30
			1/2/10	31.10	23.90	31.30	23.10	16.73	29.70
			26/4/10	30.40	25.80	32.60	24.60	19.91	31.10
EC – laboratory (mS/cm)	0.3-1	0.3-1	28/8/09	31.50	31.40	30.10	18.10	12.90	30.50
			16/9/09	29.50	27.90	29.60	20.90	14.50	28.20
			20/10/09	33.60	28.70	33.90	24.10	15.50	31.80
			16/11/09	29.20	25.90	29.80	21.60	14.70	27.30
			1/2/10	32.20	26.00	32.50	24.00	17.40	31.30
			26/4/10	31.80	26.20	34.00	24.50	20.20	32.30
ORP – field (mV)	n/a	n/a	28/8/09	-160	-55	-107	-115	-139	-81
			16/9/09	-96	-80	-107	-119	-82	-105
			20/10/09	-126	-42	-77	-96	-81	-80
			16/11/09	-77	-37	-69	-95	-102	-68
			1/2/10	-241	-184	-177	-128	-244	-178
			26/4/10	-176	-99	-76	-92	-149	-102
DO – field (mg/L)	n/a	n/a	16/9/09	9.40	8.39	7.71	7.52	12.15	8.80
			20/10/09	2.44	4.02	3.68	3.59	3.39	1.89
			16/11/09	3.69	5.04	3.32	3.30	4.41	3.66
			1/2/10	-	-	-	-	-	-
			26/4/10	3.02	3.54	3.60	-	3.72	2.98
Alkalinity / acidity									
Alkalinity – field	n/a	n/a	28/8/09	-	390	-	-	-	-
			16/9/09	510	450	660	870	660	651
			20/10/09	588	447	834	933	1059	648
			16/11/09	510	354	600	780	876	540
			1/2/10	518	445	581	895	920	450
			26/4/10	411	399	523	852	745	460

Parameter	Trigger values*		Date	Site 1		Site 2	Site 3	Site 4	
	95%	80%		Upper	Lower	Upper	Upper	Upper	Lower
Alkalinity – laboratory	n/a	n/a	28/8/09	494	441	582	1050	-	392
			16/9/09	504	421	593	926	1040	449
			20/10/09	502	423	574	890	1020	436
			16/11/09	512	349	598	872	1030	443
			1/2/10	471	396	507	778	843	342
			26/4/10	436	405	500	754	738	363
Acidity – field	n/a	n/a	28/8/09	-	-	-	-	-	-
			16/9/09	-	-	-	-	-	-
			20/10/09	-	-	-	-	-	-
			16/11/09	-	-	-	-	-	-
			1/2/10	-	-	-	-	-	-
			26/4/10	-	-	-	-	-	-
Acidity – laboratory	n/a	n/a	28/8/09	55	55	60	95	130	100
			16/9/09	-	-	-	-	-	-
			20/10/09	-	-	-	-	-	-
			16/11/09	-	-	-	-	-	-
			1/2/10	-	-	-	-	-	-
			26/4/10	-	-	-	-	-	-
Acidity – calculated	n/a	n/a	28/8/09	6	16	4	10	13	50
			16/9/09	232	3	183	336	176	128
			20/10/09	140	39	247	211	78	158
			16/11/09	4	8	11	36	9	76
			1/2/10	10	10	32	54	6	116
			26/4/10	9	9	28	38	5	90
Major ions									
Ca	n/a	n/a	28/8/09	390	420	413	417	311	756
			16/9/09	381	346	415	456	384	789
			20/10/09	403	342	433	499	384	823
			16/11/09	391	338	448	541	335	794
			1/2/10	382	293	403	542	502	825
			26/4/10	461	384	564	715	627	977
Mg	n/a	n/a	28/8/09	707	655	754	553	444	963
			16/9/09	709	564	762	653	542	940
			20/10/09	712	545	779	701	526	972
			16/11/09	764	576	854	822	545	1120
			1/2/10	851	529	739	841	808	1120
			26/4/10	835	613	1000	1060	874	1200
Na	n/a	n/a	28/8/09	5840	6200	5860	2710	1450	4400
			16/9/09	5800	5430	5770	3220	1800	4400
			20/10/09	5880	5310	5820	3530	1880	4250
			16/11/09	6350	5600	6200	3540	2080	4500
			1/2/10	7480	5150	5820	4190	2530	4750
			26/4/10	7530	6330	7930	5250	3020	5470

Parameter	Trigger values*		Date	Site 1		Site 2	Site 3	Site 4	
	95%	80%		Upper	Lower	Upper	Upper	Upper	Lower
K	n/a	n/a	28/8/09	169	126	119	55	50	88
			16/9/09	167	118	116	67	53	83
			20/10/09	175	119	125	75	55	86
			16/11/09	174	114	122	77	57	83
			1/2/10	222	122	127	96	74	101
			26/4/10	240	150	175	118	83	119
Cl	n/a	n/a	28/8/09	9430	10400	9340	5850	3000	10000
			16/9/09	9440	9110	9600	6880	4360	9150
			20/10/09	9520	8580	9740	7210	3850	8750
			16/11/09	11900	8850	10100	7350	4020	10400
			1/2/10	11400	8300	10600	8060	5610	9850
			26/4/10	11700	9800	12800	10200	7340	12500
SO_4	n/a	n/a	28/8/09	1750	1660	1600	216	90	1300
			16/9/09	1710	1240	1590	417	185	1420
			20/10/09	1710	1160	1680	536	202	1230
			16/11/09	1850	1200	1820	674	266	1250
			1/2/10	2320	1060	1640	817	401	1260
			26/4/10	2620	1510	2580	1260	670	1650
Cl:SO_4 ratio	n/a	n/a	28/8/09	5.4	6.3	5.8	27.1	33.3	7.7
			16/9/09	5.5	7.3	6.0	16.5	23.6	6.4
			20/10/09	5.6	7.4	5.8	13.5	19.1	7.1
			16/11/09	6.4	7.4	5.5	10.9	15.1	8.3
			1/2/10	4.9	7.8	6.5	9.9	14.0	7.8
			26/4/10	4.5	6.5	5.0	8.1	11.0	7.6
Dissolved metals									
Al	0.055	0.15	28/8/09	0.11	0.20	0.11	0.23	0.05	0.01
			16/9/09	23.2	<0.01	19.4	32.4	14.7	5.70
			20/10/09	14.2	3.29	25.0	16.4	7.13	8.70
			16/11/09	0.02	0.03	0.12	0.13	0.02	0.02
			1/2/10	0.02	<0.01	0.01	<0.01	<0.01	<0.01
			26/4/10	0.02	<0.01	<0.01	<0.01	<0.01	0.02
As	0.013 (AsV)	0.140 (AsV)	28/8/09	0.001	0.020	0.001	<0.001	0.002	0.012
			16/9/09	0.050	0.009	0.032	0.048	0.037	0.036
			20/10/09	0.018	0.027	0.034	0.015	0.011	0.037
			16/11/09	0.005	0.022	0.004	0.005	0.004	0.032
			1/2/10	<0.001	0.016	<0.001	<0.001	<0.001	0.048
			26/4/10	0.003	0.026	0.004	0.002	0.002	0.038
Cd	0.0002	0.0008	28/8/09	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
			16/9/09	0.0001	<0.0001	0.0002	0.0002	<0.0001	<0.0001
			20/10/09	0.0003	0.0002	0.0005	0.0002	0.0006	0.0001
			16/11/09	0.0006	0.0001	0.0003	0.0002	0.0006	0.0003
			1/2/10	0.0003	0.0002	0.0003	0.0002	0.0001	0.0002
			26/4/10	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0004

Parameter	Trigger values*		Date	Site 1		Site 2	Site 3	Site 4	
	95%	80%		Upper	Lower	Upper	Upper	Upper	Lower
Cu	0.0014	0.0025	28/8/09	0.005	0.005	0.004	0.002	0.002	0.004
			16/9/09	0.018	0.004	0.013	0.017	0.019	0.012
			20/10/09	0.013	0.006	0.021	0.011	0.010	0.018
			16/11/09	0.005	0.003	0.005	0.005	0.001	0.005
			1/2/10	0.006	0.004	0.007	0.004	0.003	0.007
			26/4/10	0.007	0.005	0.007	0.004	0.004	0.007
Fe	n/a	n/a	28/8/09	1.58	4.26	0.54	2.62	0.41	17.1
			16/9/09	37.6	-	27.0	57.0	31.9	34.3
			20/10/09	21.9	6.55	38.9	43.6	11.3	39.0
			16/11/09	0.91	1.91	3.07	12.4	1.06	26.6
			1/2/10	3.21	2.42	11.0	19.3	0.44	41.1
			26/4/10	2.70	2.31	9.4	13.4	<0.05	31.4
Mn	1.9	3.6	28/8/09	0.628	1.89	0.898	1.16	6.32	2.41
			16/9/09	0.958	1.59	1.15	1.25	4.50	2.36
			20/10/09	0.860	1.72	1.40	1.12	4.23	2.44
			16/11/09	0.511	1.66	1.11	1.17	3.24	2.53
			1/2/10	0.702	1.78	1.30	1.33	2.84	2.90
			26/4/10	1.14	1.60	1.22	1.24	2.82	2.80
Ni	0.011	0.017	28/8/09	0.004	0.007	0.004	0.001	0.006	0.002
			16/9/09	0.018	0.006	0.014	0.029	0.020	0.006
			20/10/09	0.012	0.009	0.020	0.013	0.009	0.012
			16/11/09	0.002	0.006	0.003	0.002	0.003	0.003
			1/2/10	0.002	0.007	0.002	0.002	0.008	0.002
			26/4/10	0.002	0.005	<0.001	<0.001	0.002	<0.001
Pb	0.0034	0.0094	28/8/09	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
			16/9/09	0.034	<0.001	0.026	0.036	0.025	0.007
			20/10/09	0.022	0.005	0.056	0.024	0.012	0.019
			16/11/09	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
			1/2/10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
			26/4/10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	0.011	0.034	28/8/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			16/9/09	0.01	0.02	0.01	<0.01	<0.01	0.02
			20/10/09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			16/11/09	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			1/2/10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			26/4/10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	0.008	0.031	28/8/09	0.012	0.011	0.016	0.006	0.006	0.010
			16/9/09	0.045	-	0.028	0.040	0.030	0.017
			20/10/09	0.046	0.045	0.056	0.033	0.038	0.036
			16/11/09	0.012	0.018	0.017	0.054	<0.005	0.017
			1/2/10	0.011	0.007	0.036	0.009	0.022	0.029
			26/4/10	0.007	<0.005	0.012	0.006	0.008	0.012

Parameter	**Trigger values***		**Date**	**Site 1**		**Site 2**	**Site 3**	**Site 4**	
	95%	**80%**		**Upper**	**Lower**	**Upper**	**Upper**	**Upper**	**Lower**
Nutrients									
Nitrite + Nitrate as N	0.1	0.1	28/8/09	0.02	0.02	0.02	0.02	0.02	0.01
			16/9/09	0.02	0.03	0.02	0.05	0.06	0.03
			20/10/09	0.01	0.01	0.19	0.26	0.04	0.01
			16/11/09	<0.01	0.04	0.56	1.60	0.99	<0.01
			1/2/10	0.08	0.03	0.18	0.12	0.37	<0.01
			26/4/10	0.25	0.23	0.62	1.06	2.13	0.17
Total Kjeldahl Nitrogen as N	n/a	n/a	28/8/09	3.0	3.7	6.6	14.6	47.0	13.0
			16/9/09	3.0	4.7	8.9	17.9	49.9	16.7
			20/10/09	2.0	2.2	5.0	9.0	33.0	10.7
			16/11/09	1.8	2.1	5.9	11.7	32.1	12.4
			1/2/10	2.6	2.9	6.0	14.8	39.2	13.1
			26/4/10	3.8	3.5	6.3	15.8	36.9	16.3
Total Nitrogen as N	1	1	28/8/09	3.0	3.7	6.6	14.6	47.0	13.0
			16/9/09	3.0	4.7	8.9	17.9	50.0	16.7
			20/10/09	2.0	2.2	5.2	9.2	33.0	10.8
			16/11/09	1.8	2.2	6.4	13.3	33.1	12.4
			1/2/10	2.7	3.0	6.1	14.9	39.5	13.1
			26/4/10	4.0	3.7	6.9	16.9	39.0	16.5
Total Phosphorus as P	0.025	0.025	28/8/09	0.68	0.16	1.09	2.30	1.54	0.23
			16/9/09	0.64	0.38	1.00	1.52	1.66	0.07
			20/10/09	0.36	<0.01	0.94	2.09	1.26	<0.01
			16/11/09	0.74	0.06	1.29	1.13	1.62	0.03
			1/2/10	0.98	0.02	1.54	1.03	1.79	0.01
			26/4/10	1.16	0.02	1.51	1.51	1.32	<0.01

* ANZECC/ARMCANZ (2000) trigger values for 80% and 95% protection of freshwater ecosystems. Values exceeding ANZECC/ARMCANZ (2000) trigger values for **95%** protection of freshwater ecosystems are shaded in orange. Values exceeding trigger values for **95%** and **80%** protection of freshwater ecosystems are shaded in red.

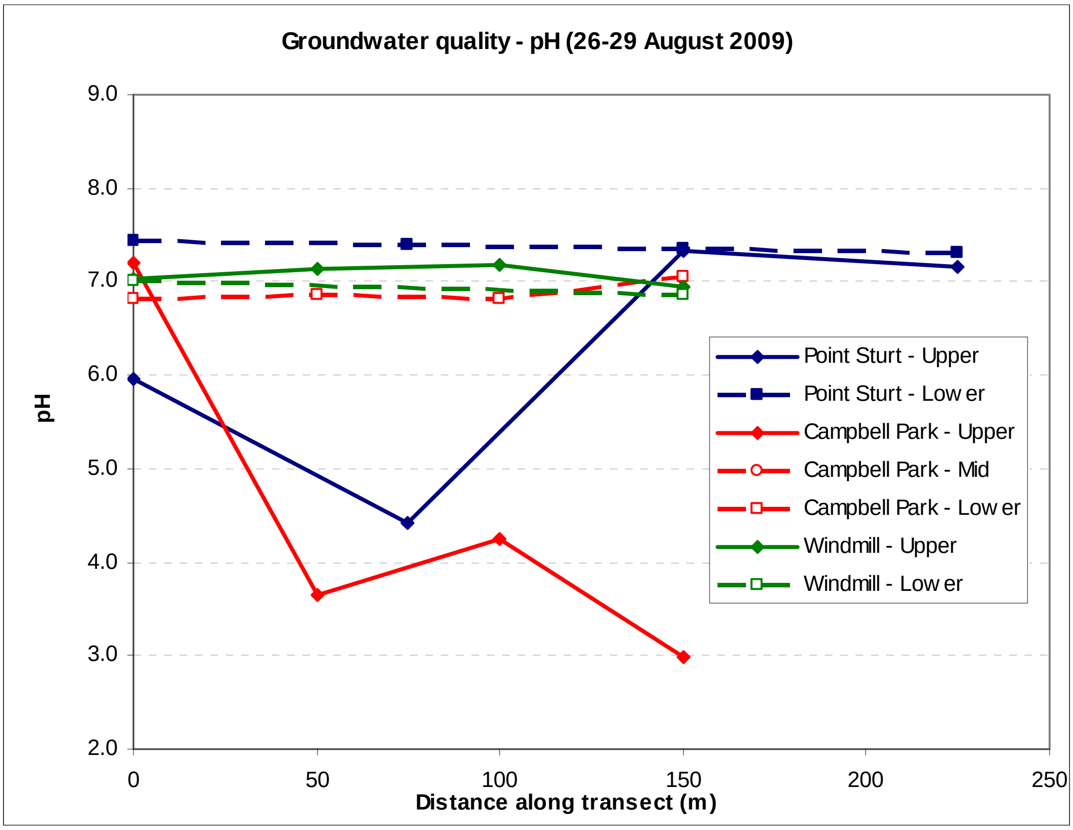

Figure 15. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 26-29 August 2009 (baseline).

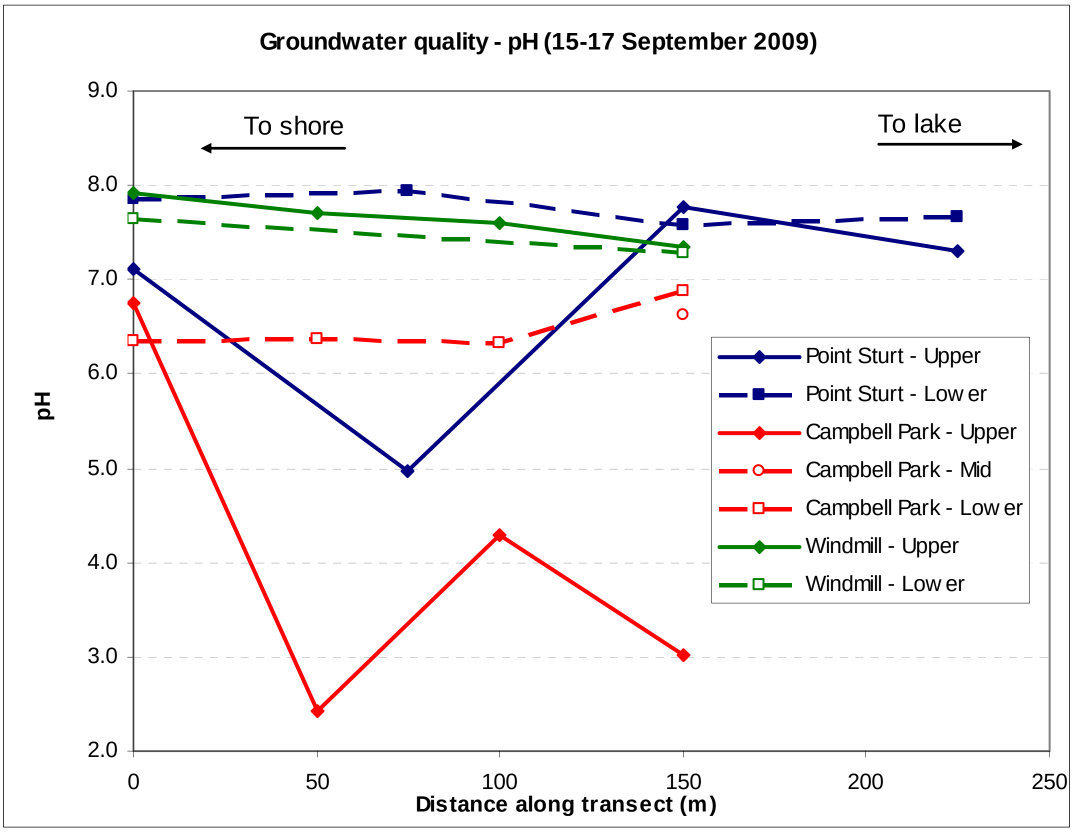

Figure 16. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 15-17 September 2009.

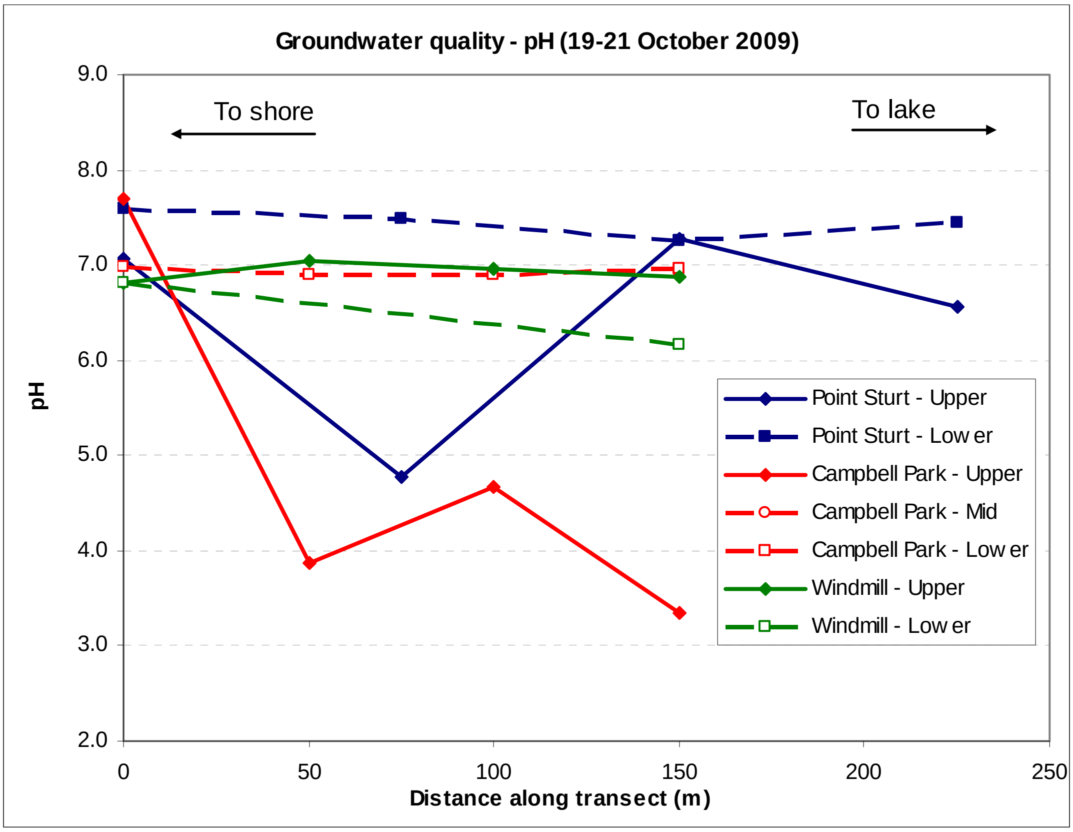

Figure 17. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 19-21 October 2009.

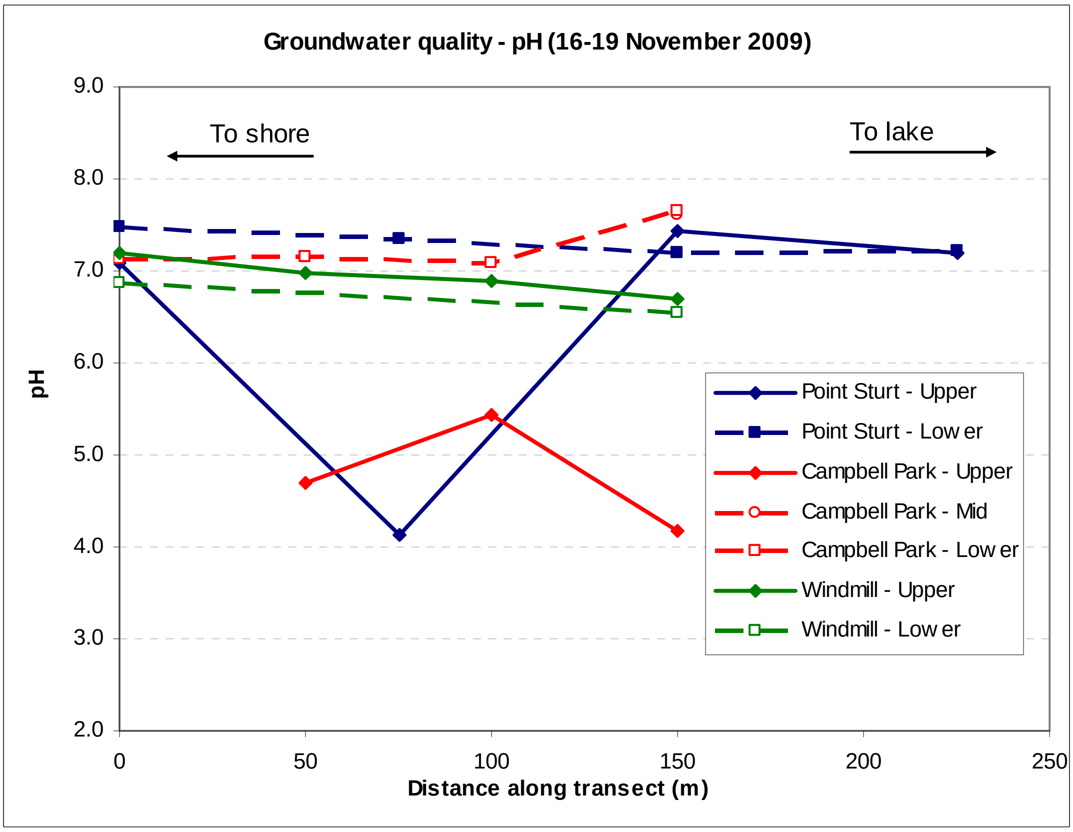

Figure 18. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 16-19 November 2009.

Figure 19. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 1-4 February 2010.

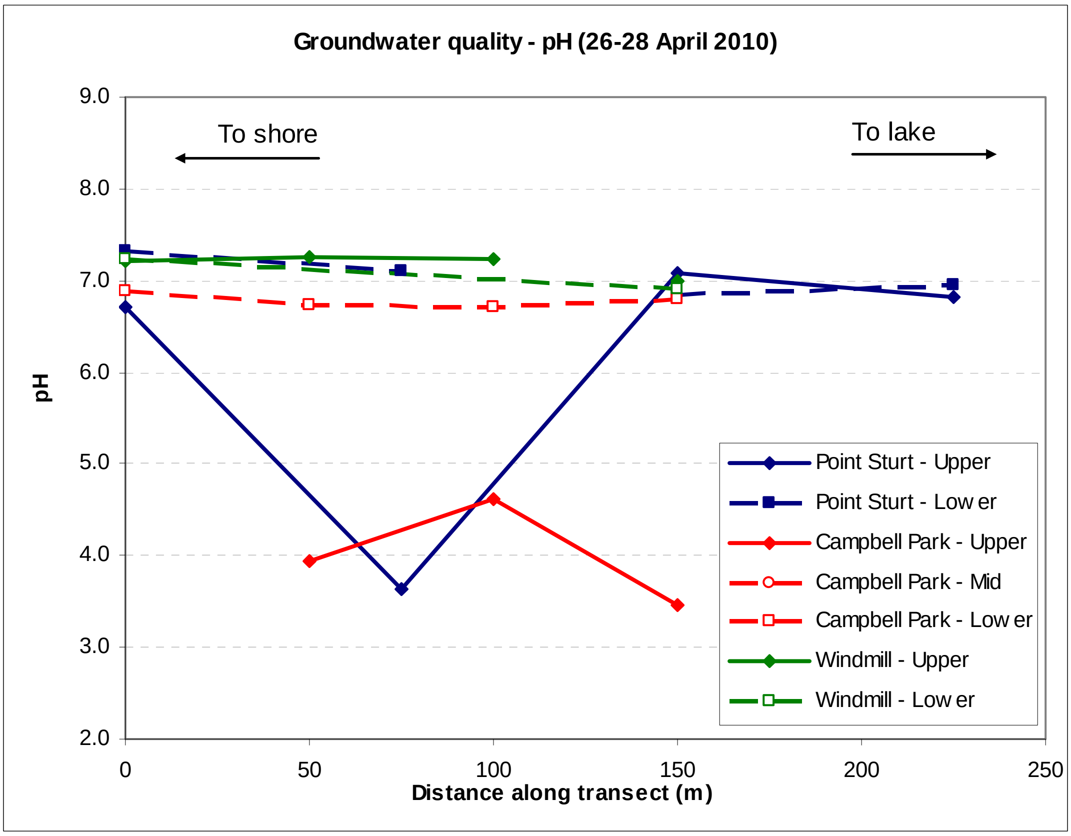

Figure 20. Groundwater pH at Point Sturt, Campbell Park and Windmill locations (after purging), 26-28 April 2010.

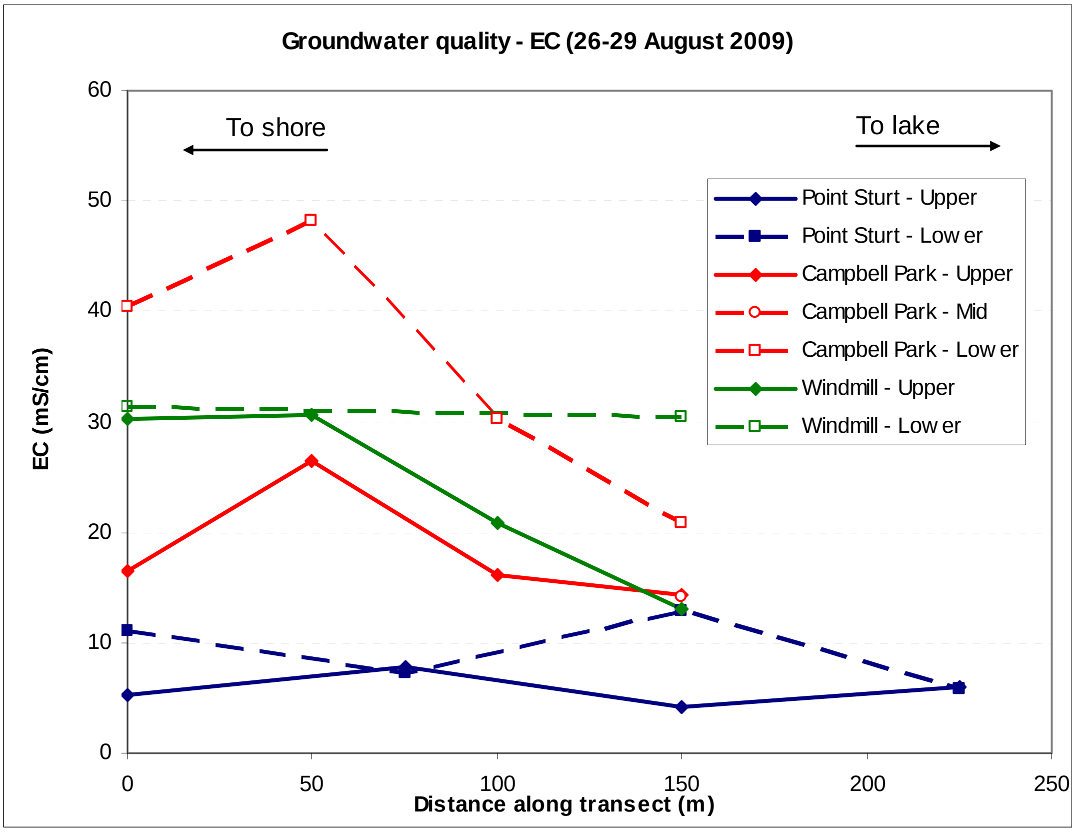

Figure 21. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 26-29 August 2009 (baseline).

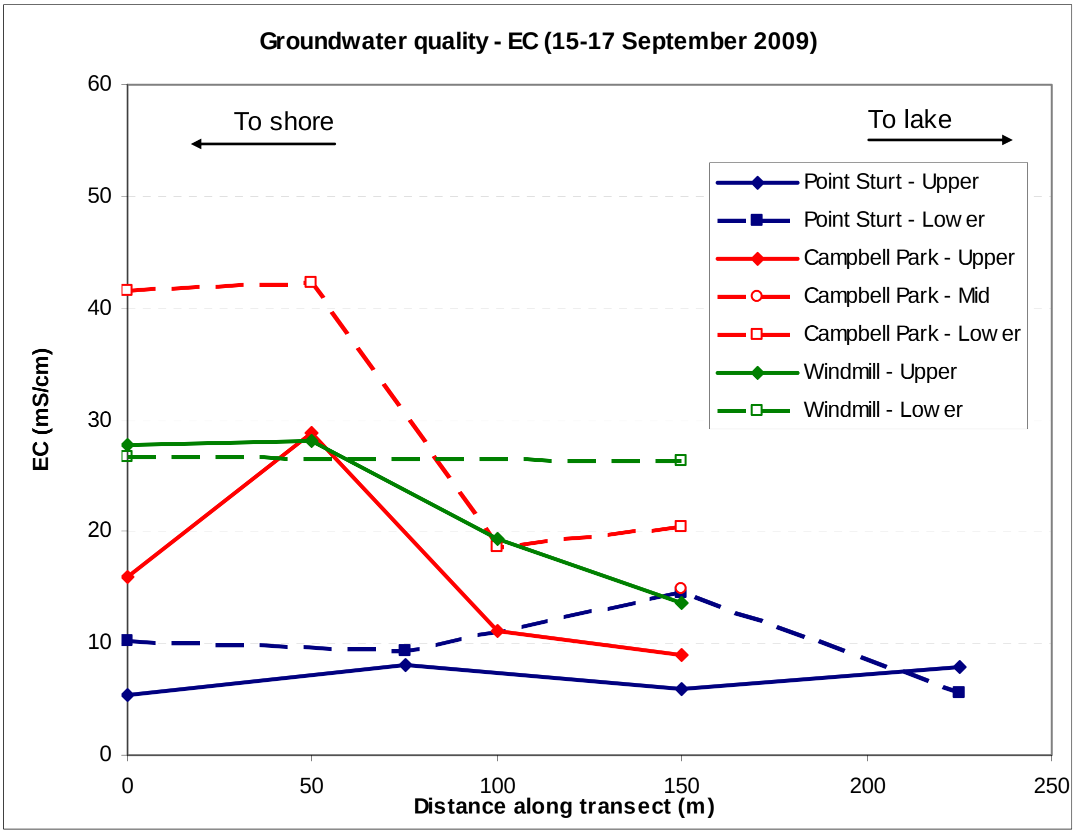

Figure 22. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 15-17 September 2009.

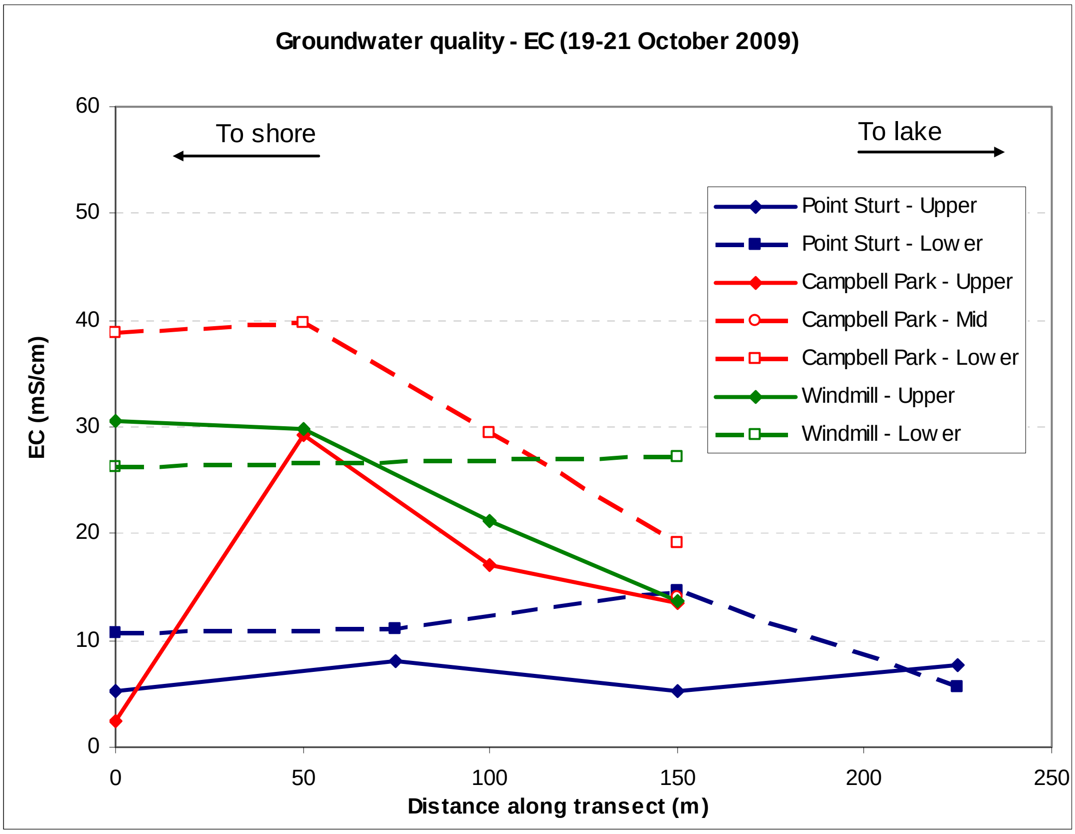

Figure 23. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 19-21 October 2009.

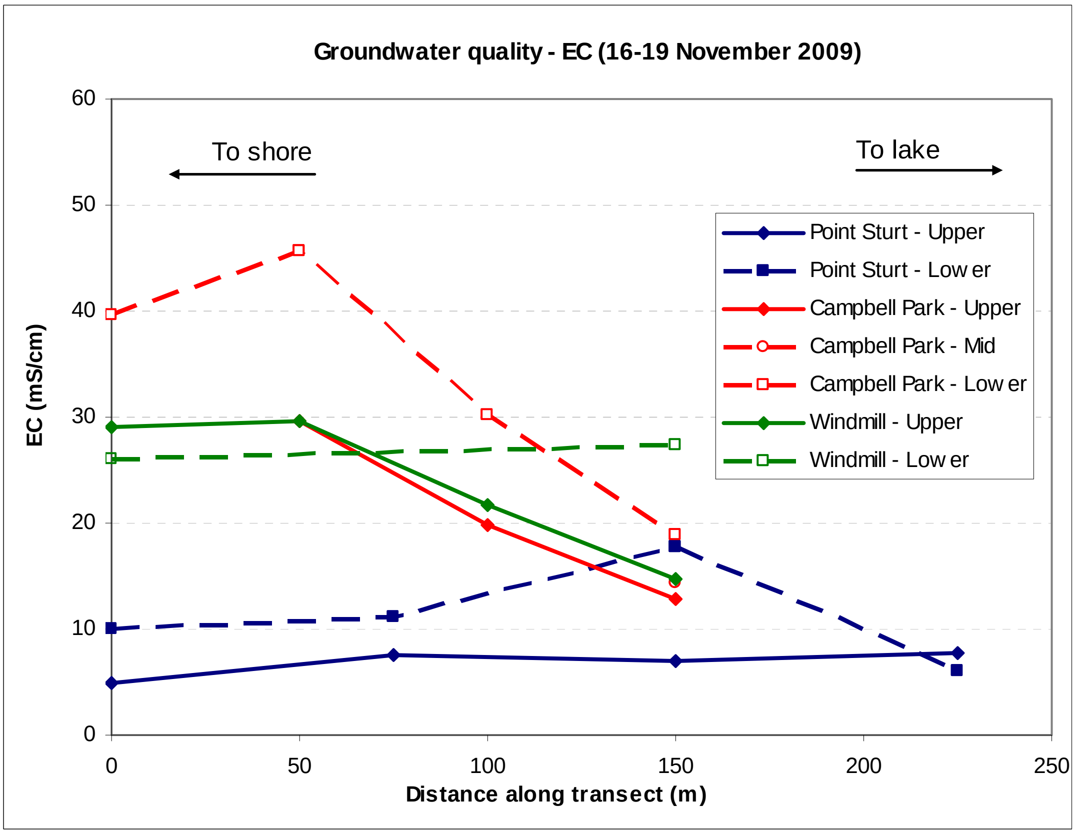

Figure 24. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 16-19 November 2009.

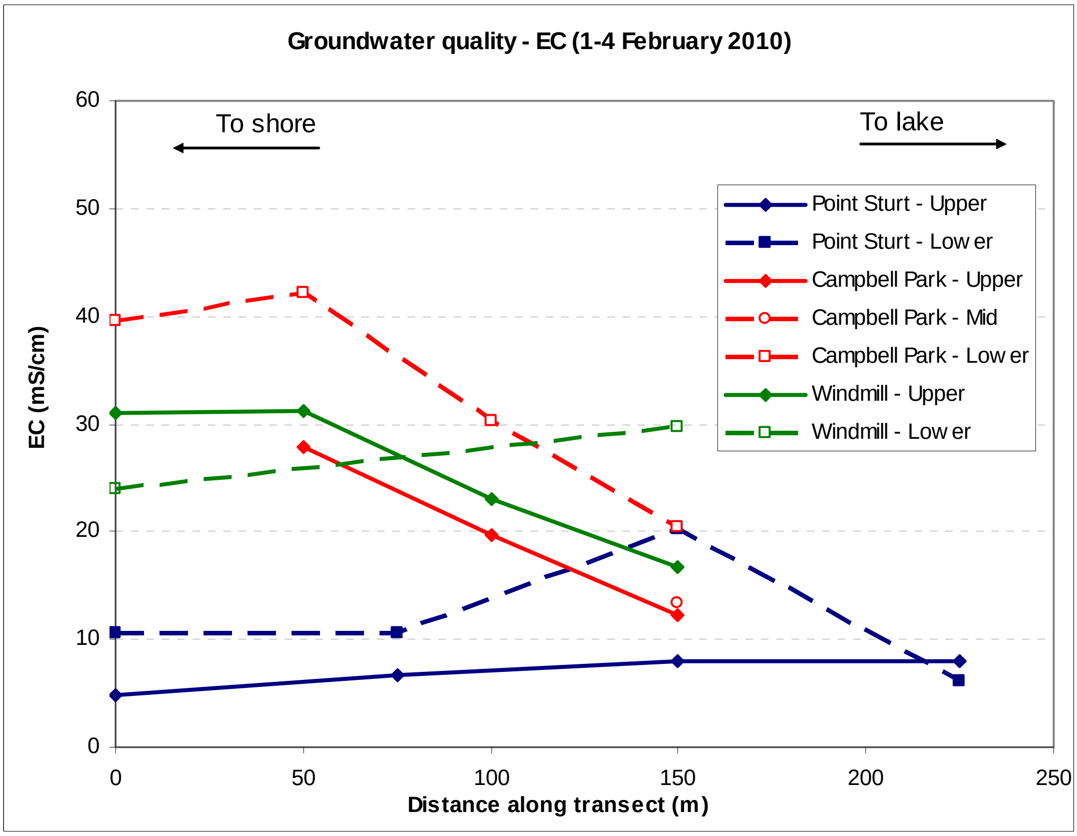

Figure 25. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 1-4 February 2010.

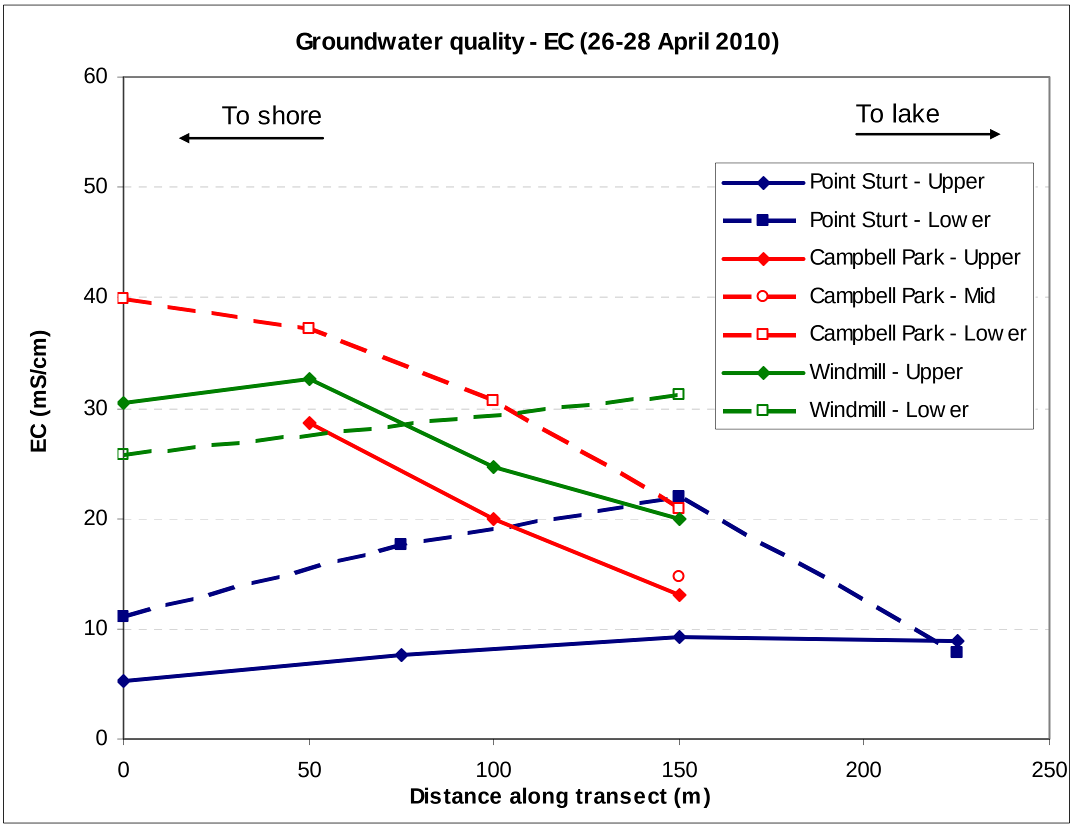

Figure 26. Groundwater EC at Point Sturt, Campbell Park and Windmill locations (after purging), 26-28 April 2010.

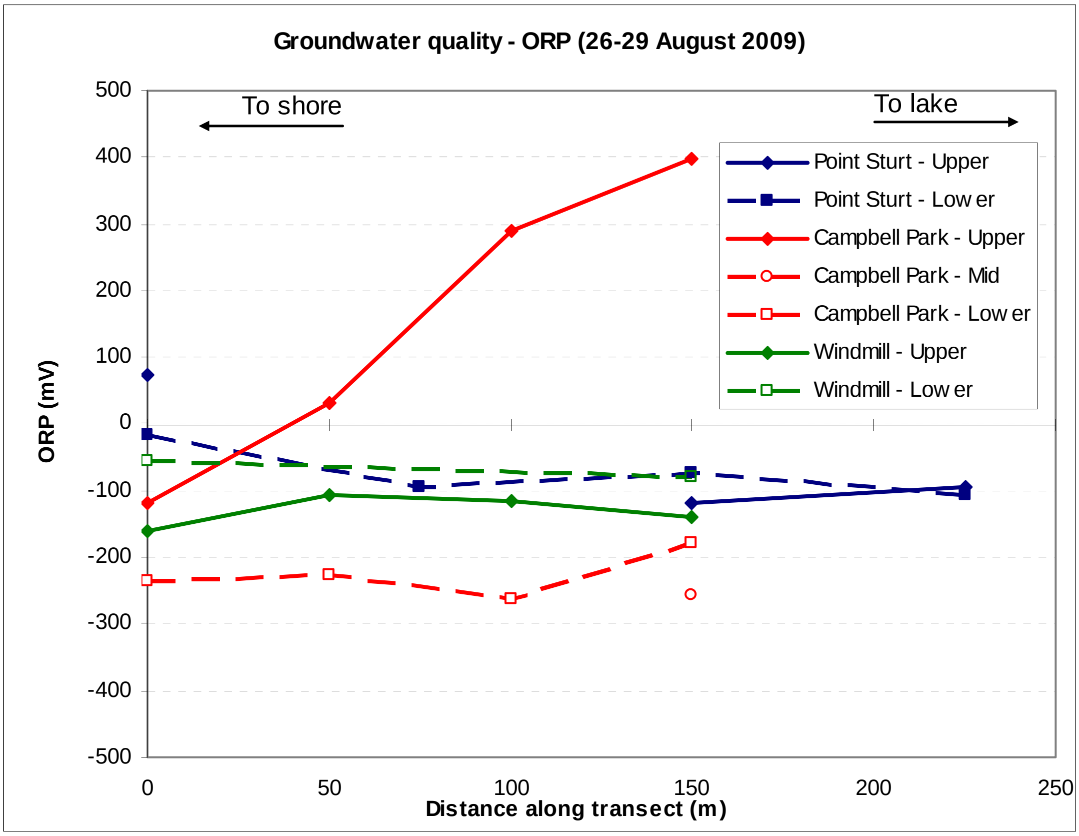

Figure 27. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 26-29 August 2009 (baseline).

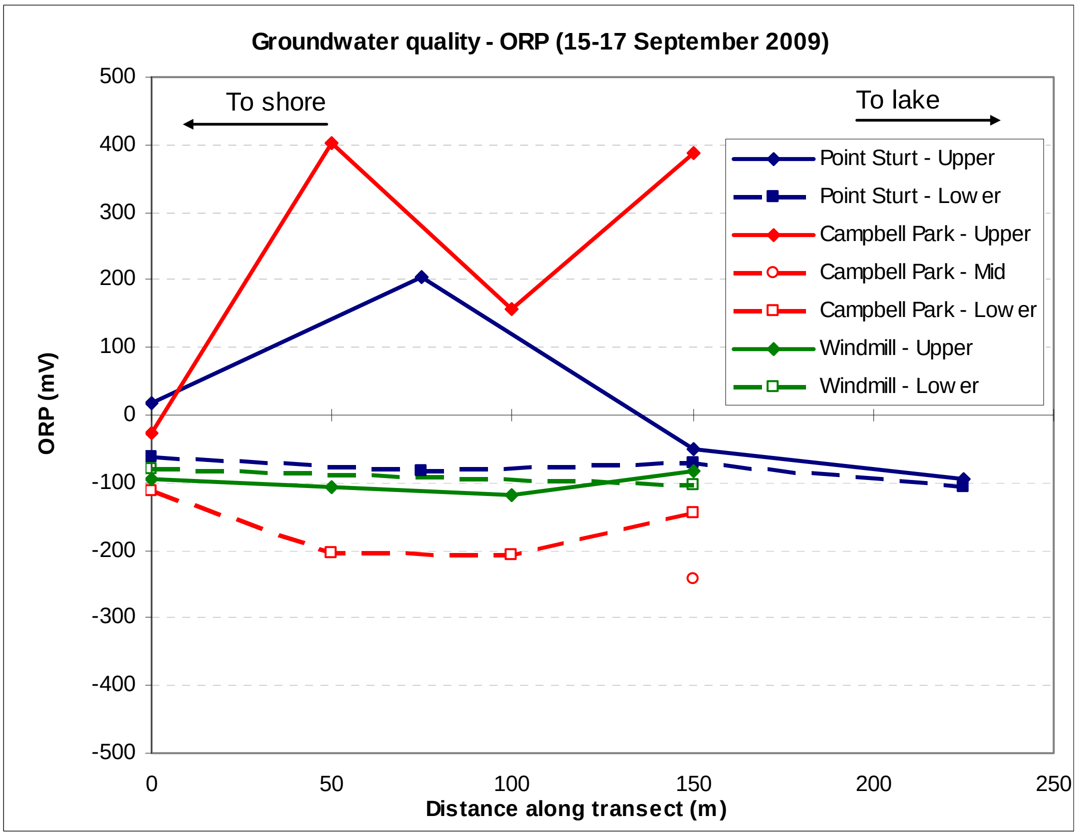

Figure 28. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 15-17 September 2009.

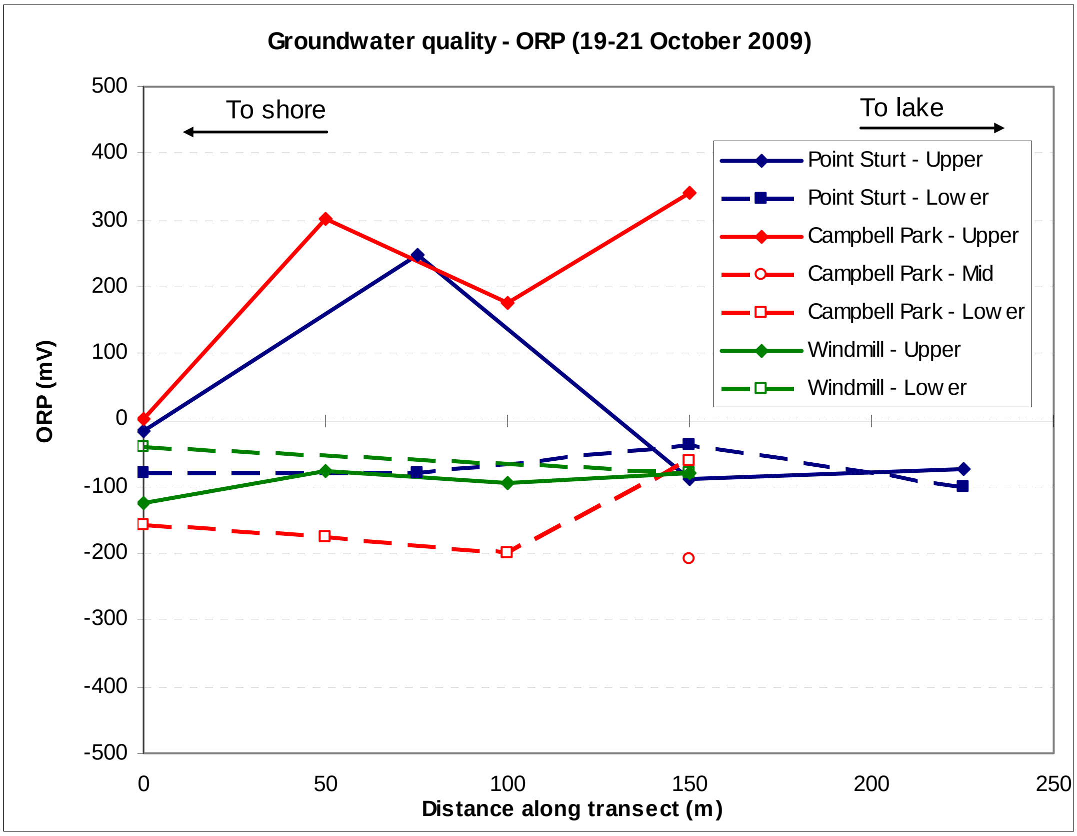

Figure 29. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 19-21 October 2009.

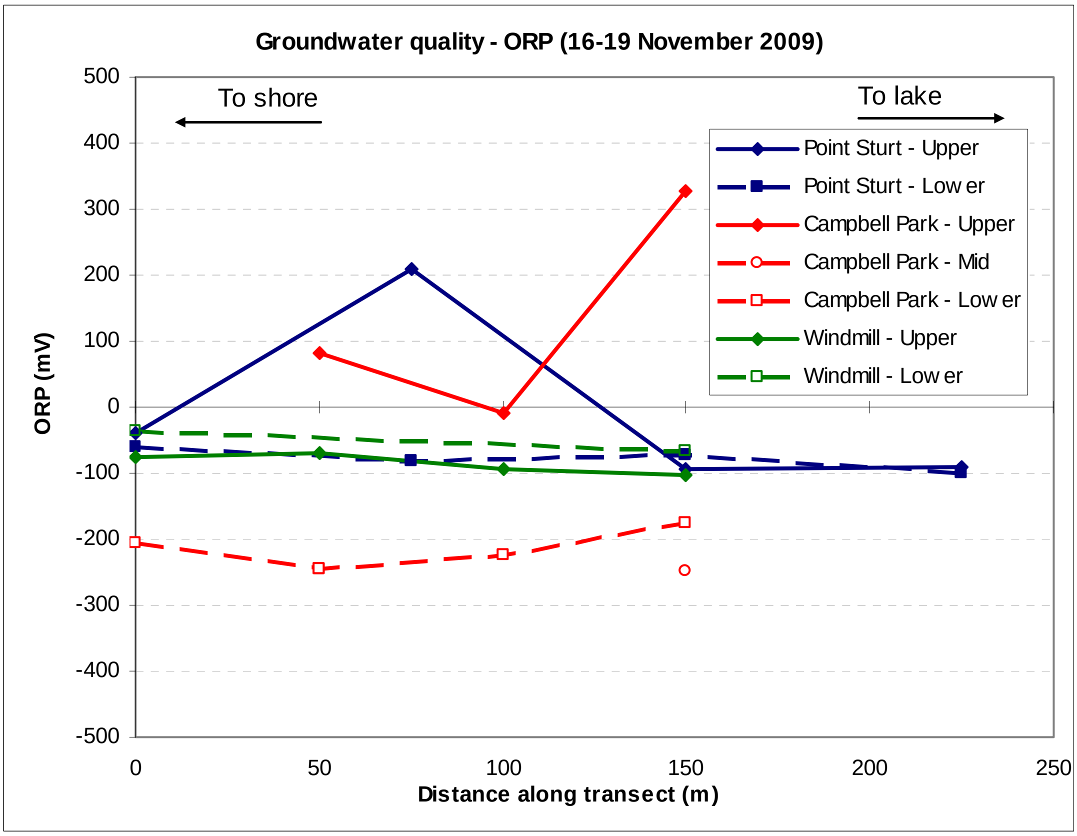

Figure 30. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 16-19 November 2009.

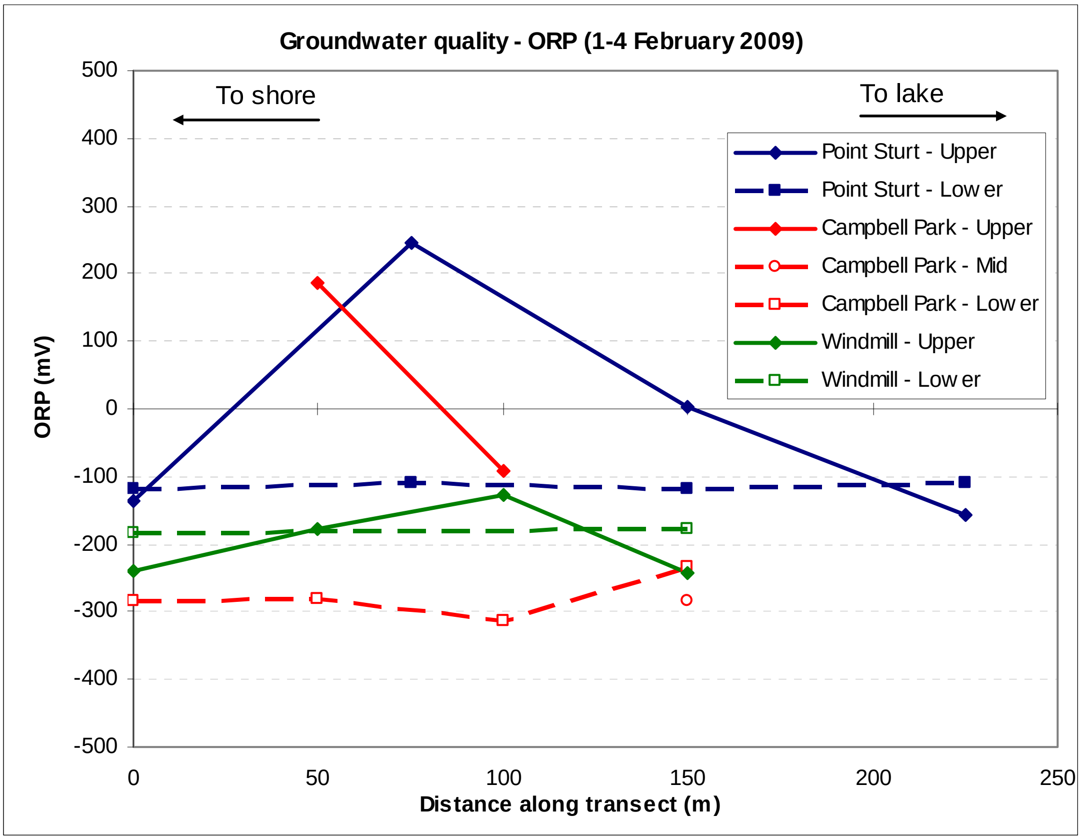

Figure 31. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 1-4 February 2010.

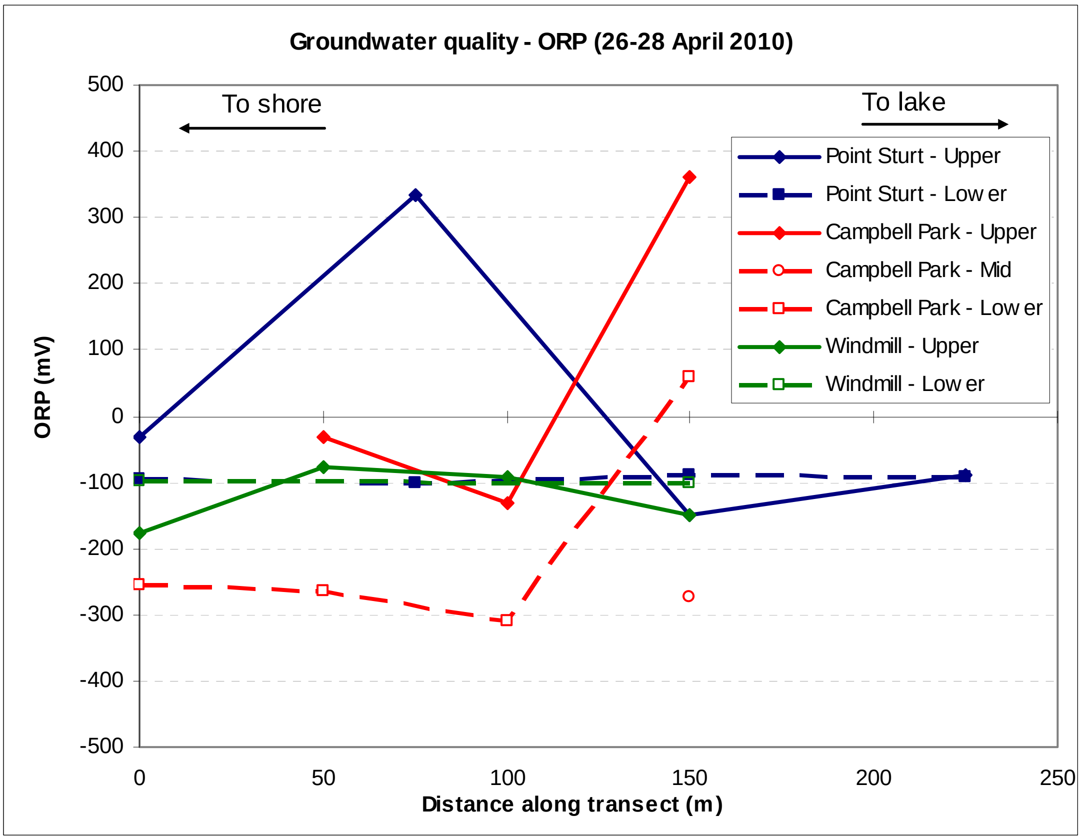

Figure 32. Groundwater ORP at Point Sturt, Campbell Park and Windmill locations (after purging), 26-28 April 2010.

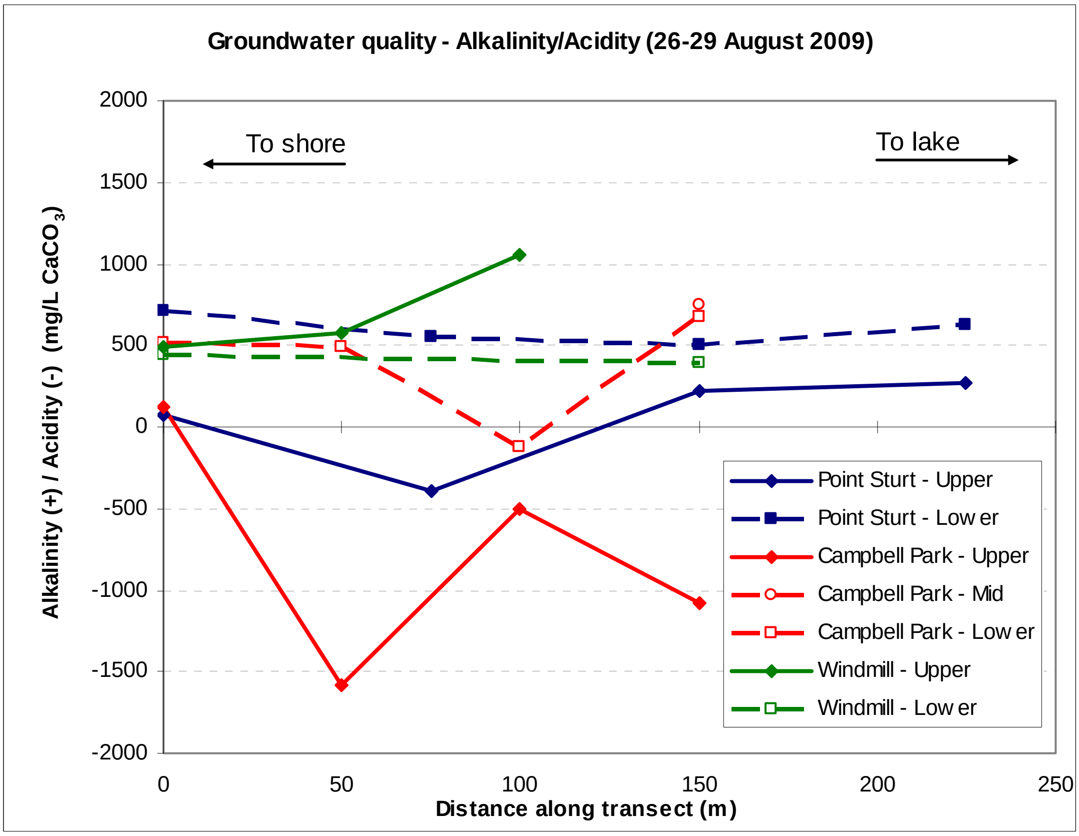

Figure 33. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 26-29 August 2009 (baseline).

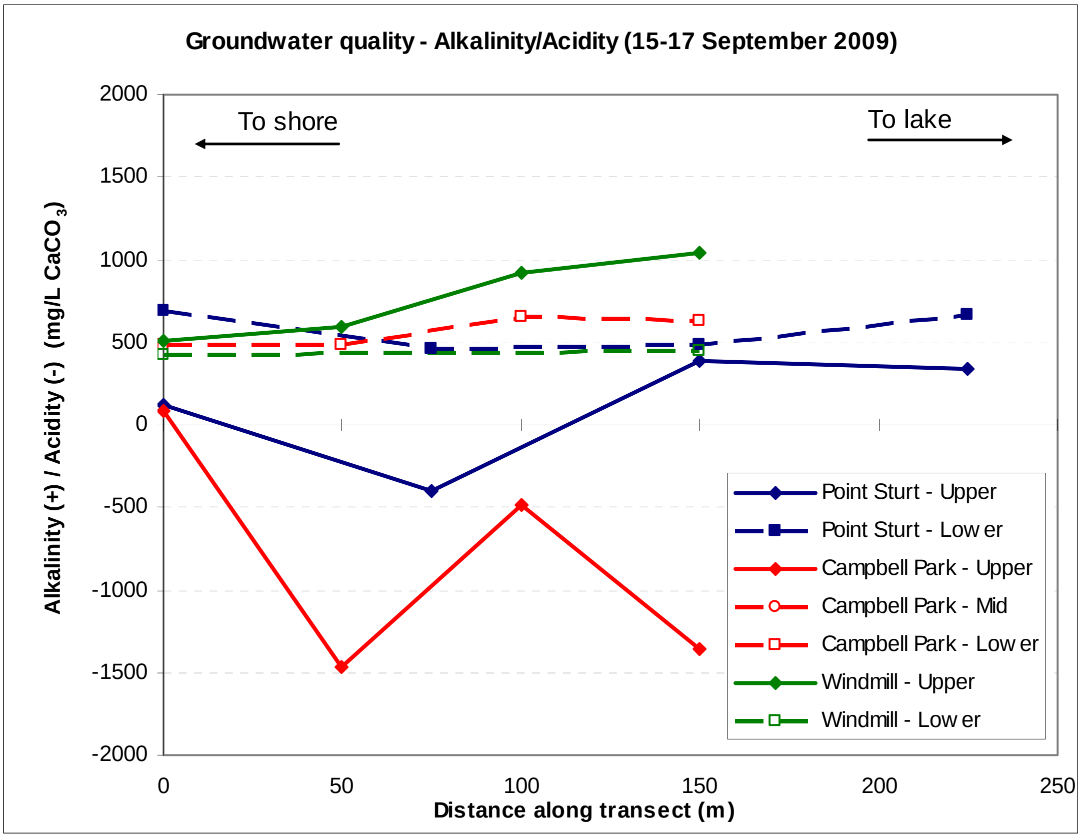

Figure 34. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 15-17 September 2009.

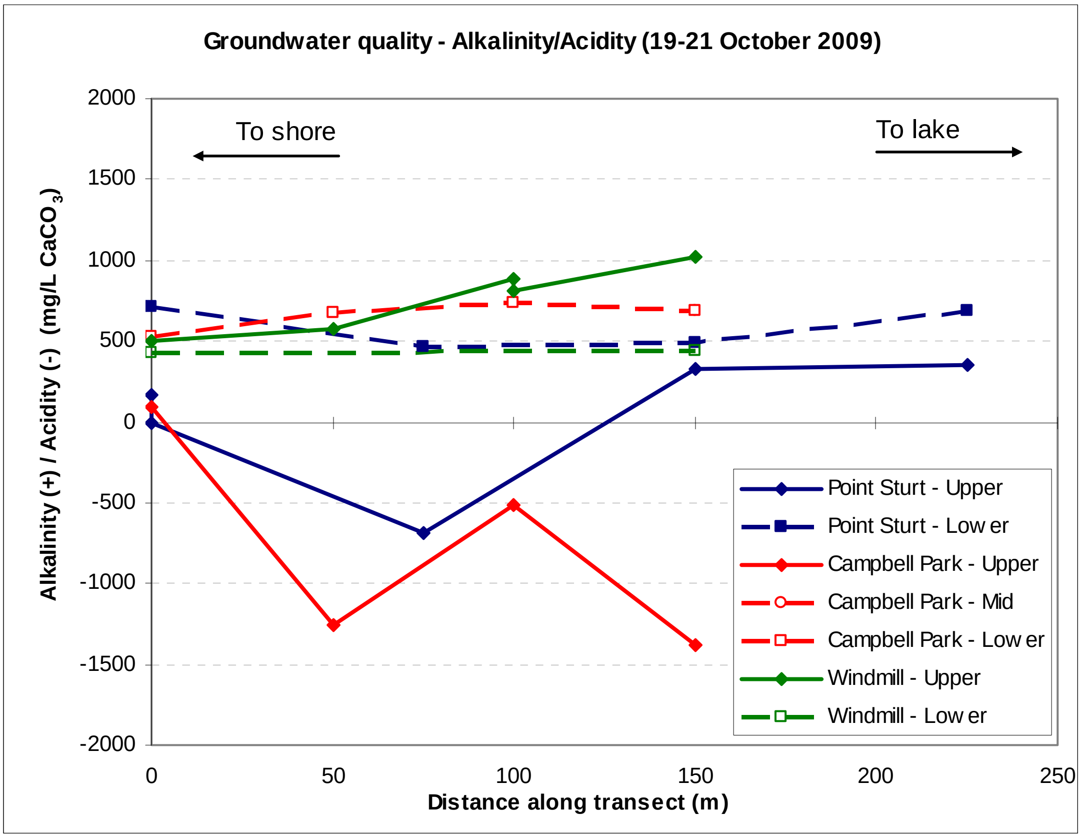

Figure 35. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 19-21 October 2009.

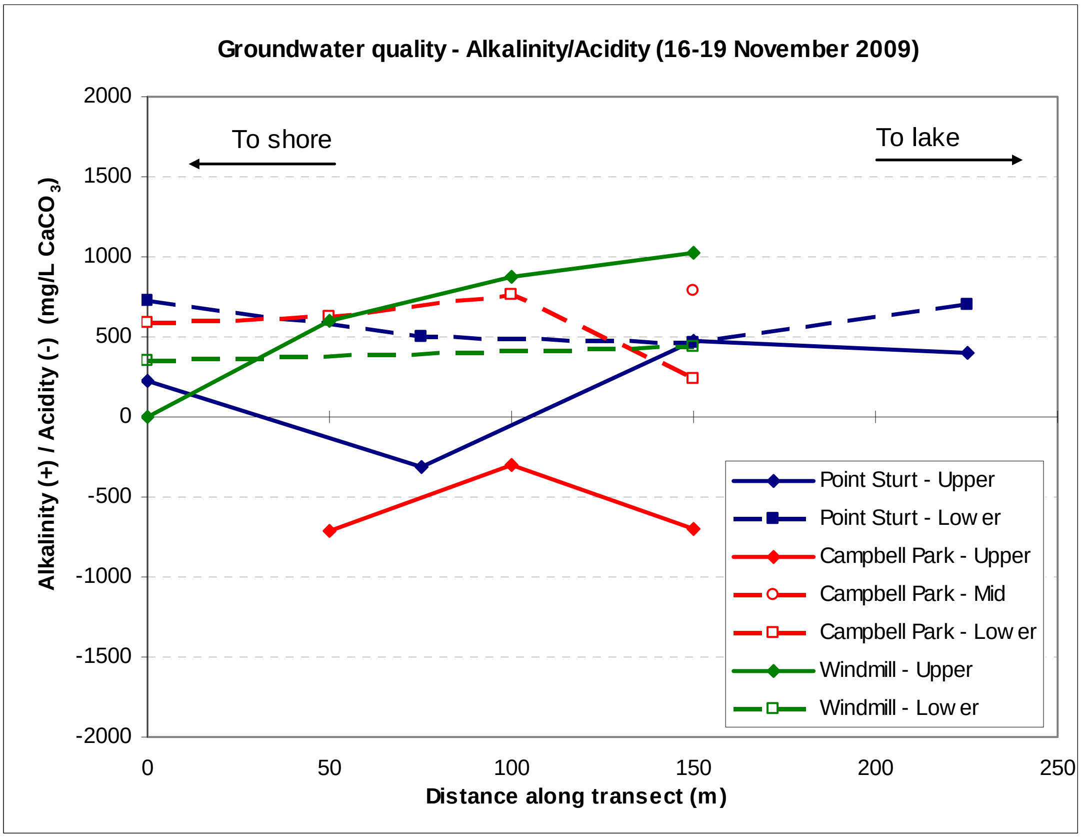

Figure 36. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 16-19 November 2009.

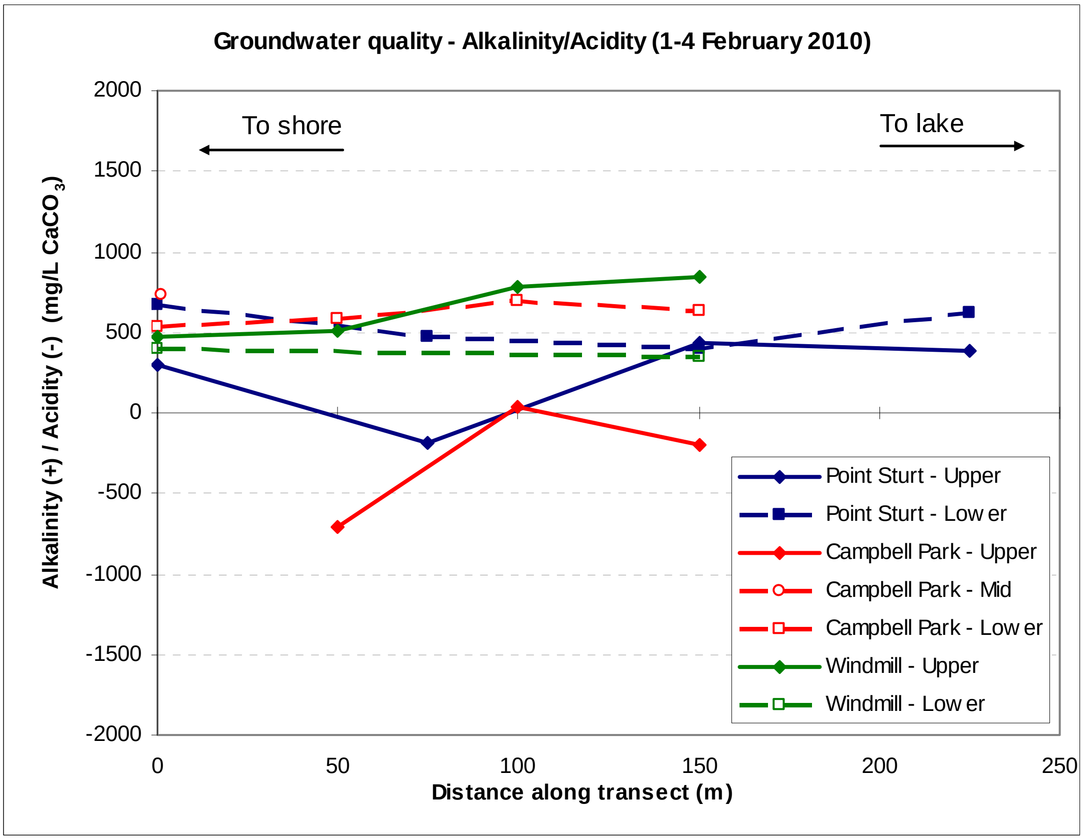

Figure 37. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 1-4 February 2010.

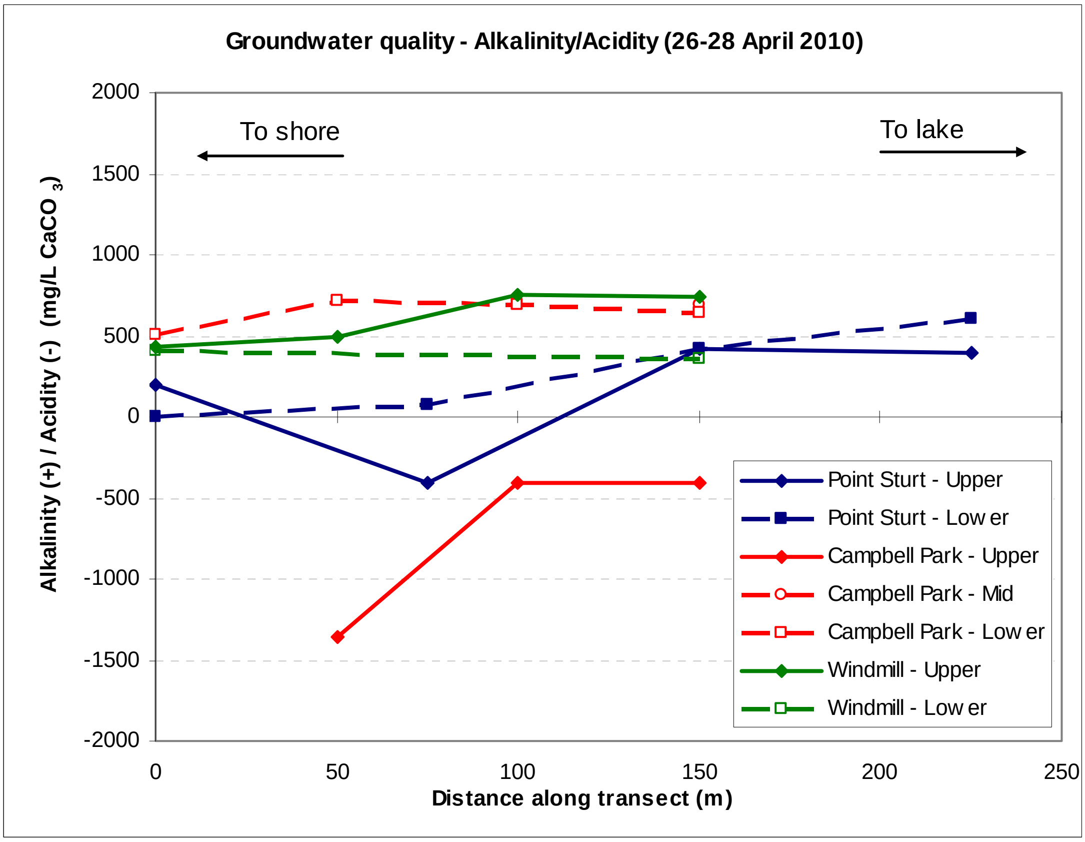

Figure 38. Groundwater alkalinity (positive values) and acidity (negative values) at Point Sturt, Campbell Park and Windmill locations (after purging), 26-28 April 2010.

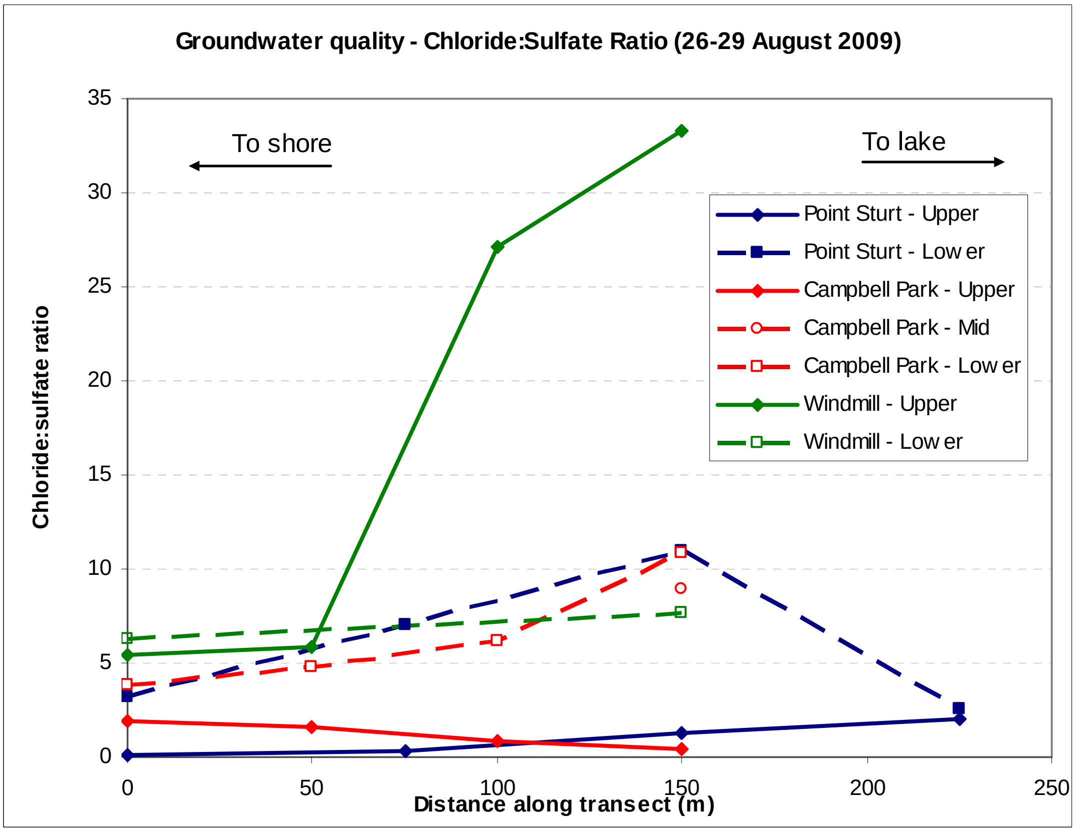

Figure 39. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 26-29 August 2009 (baseline).

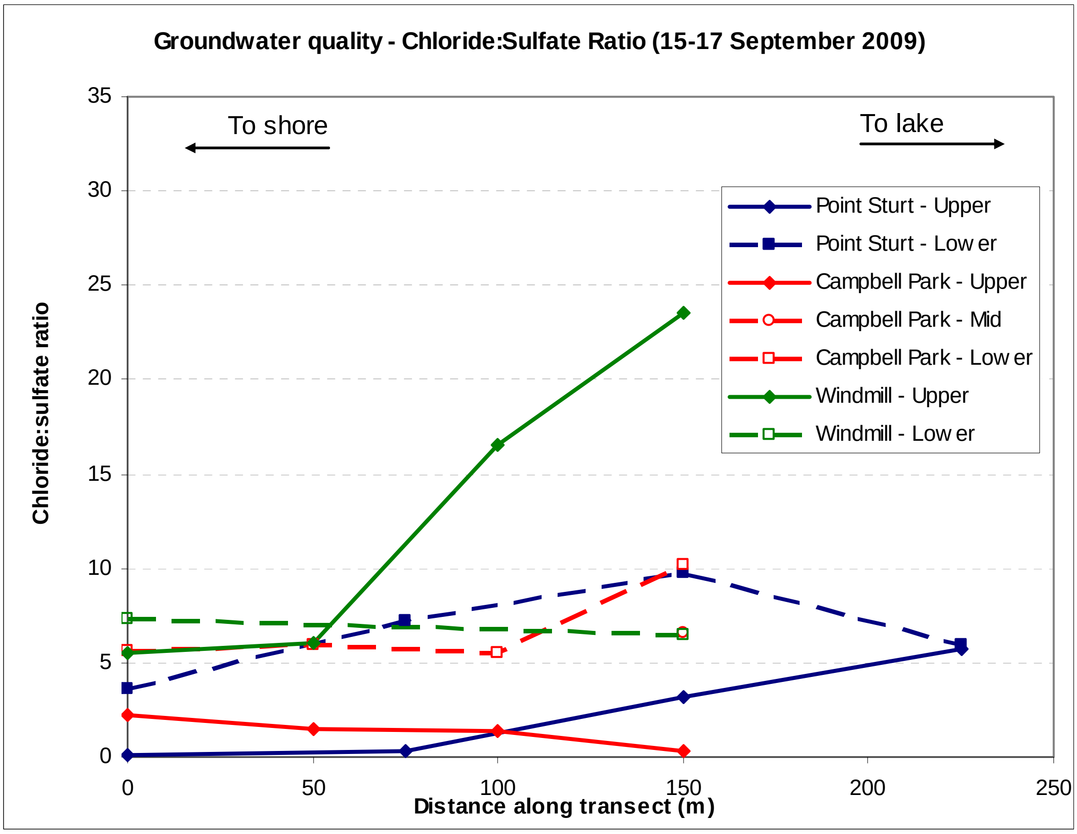

Figure 40. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 15-17 September 2009.

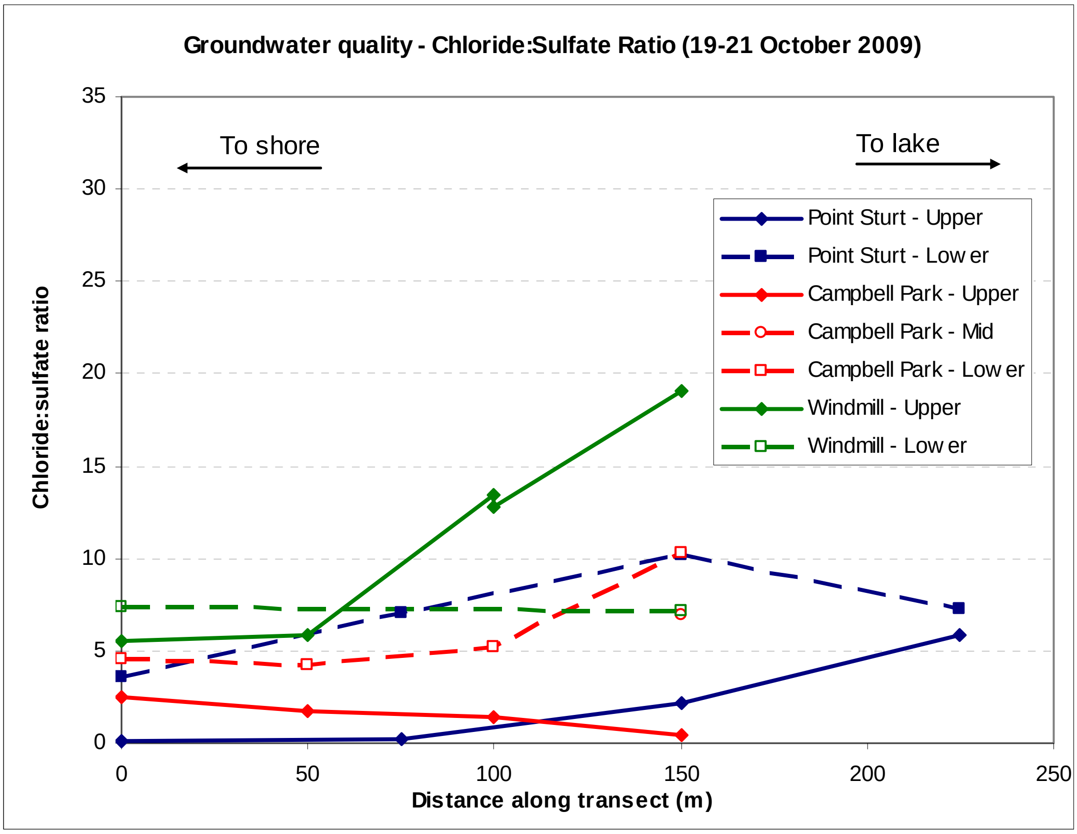

Figure 41. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 19-21 October 2009.

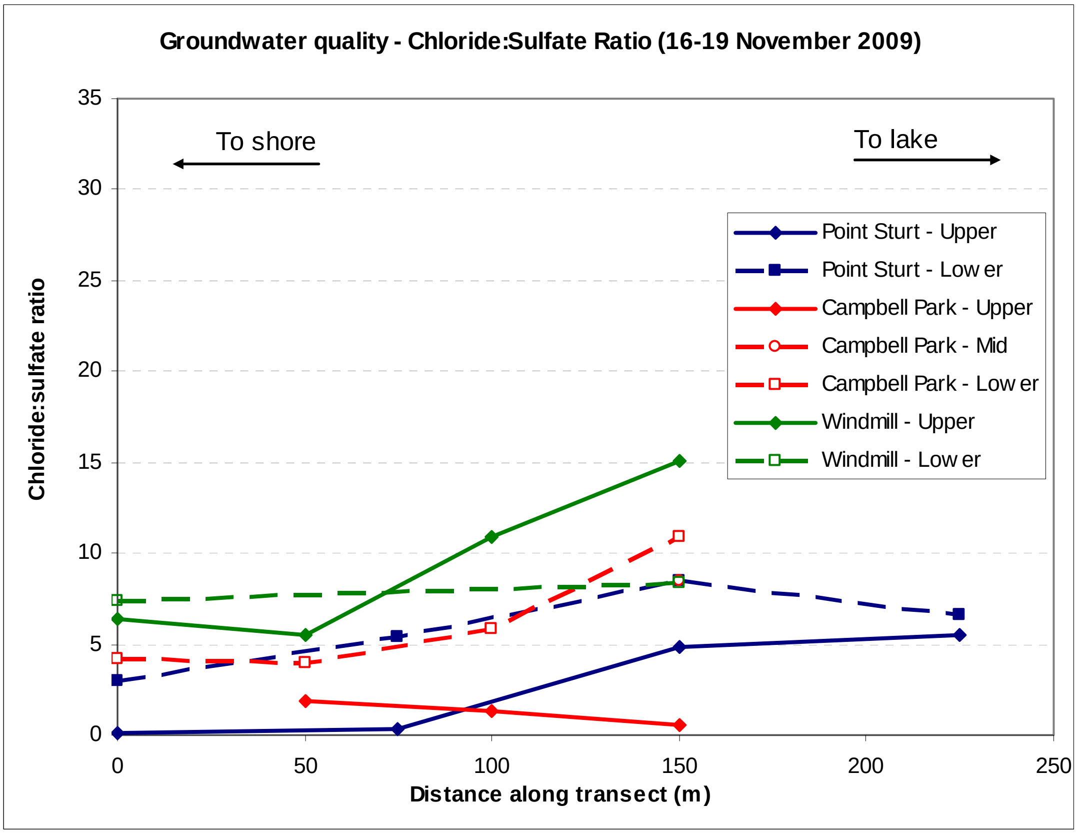

Figure 42. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 16-19 November 2009.

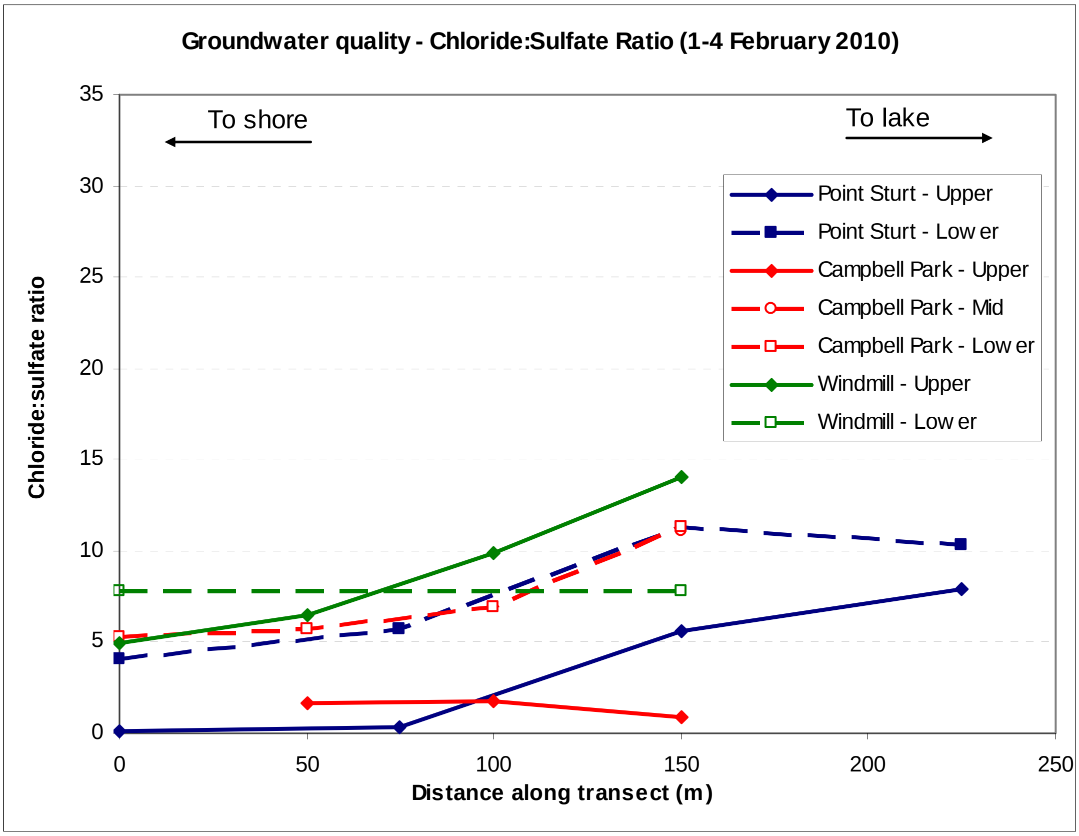

Figure 43. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 1-4 February 2010.

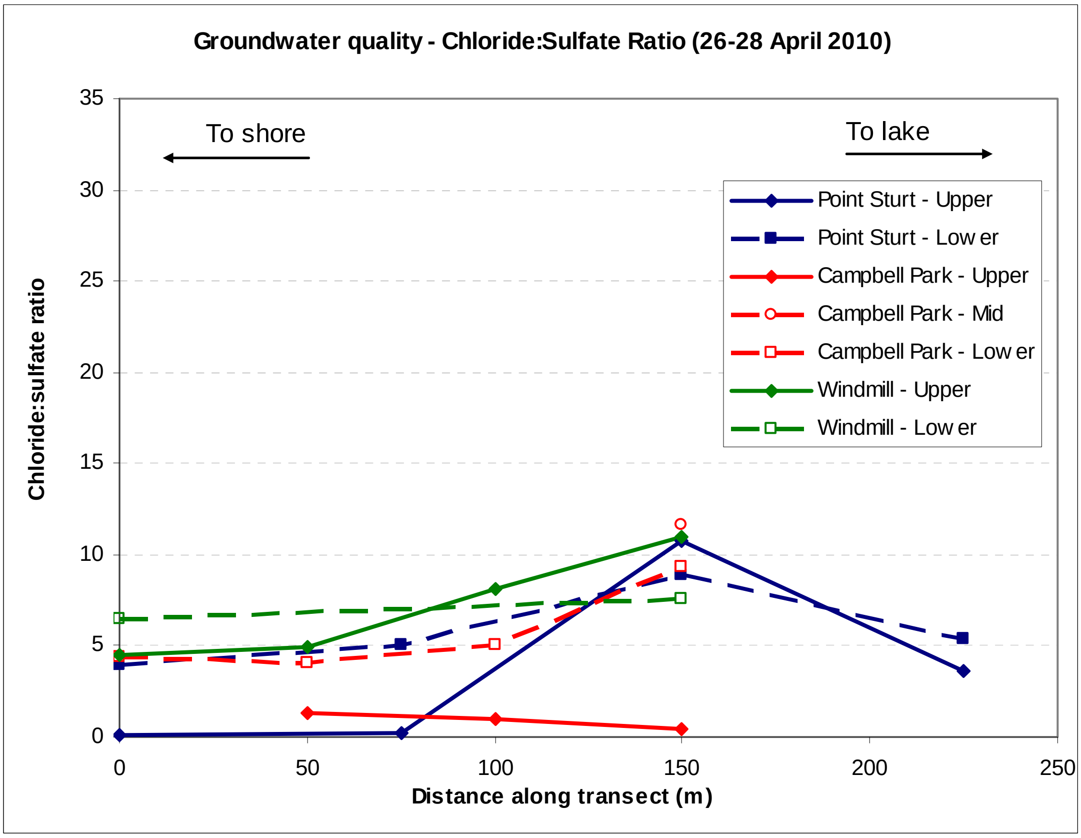

Figure 44. Groundwater chloride:sulfate ratio at Point Sturt, Campbell Park and Windmill locations (after purging), 26-28 April 2010.

6 Discussion and Conclusions

This section discusses the implications of supplementary field data obtained in February and April 2010 in terms of the potential for acidity generation and flux to Currency Creek, Lake Albert and Lake Alexandrina.

6.1 *Sediment moisture profiles*

The additional sediment moisture data obtained in early 2010 has provided further insight into the nature of desaturation processes in sandy lake sediments. This section supercedes the discussion provided in Earth Systems (2010; Section 6.5).

Sediment moisture results from January-April 2010 indicate that, despite surface water levels decreasing in both lakes (and corresponding decreases in piezometric levels in the lake sediments), a reasonably consistent moisture profile is maintained in the upper 0.3-0.4 m of sediments, with effectively saturated conditions (ie. sediment moisture contents of around 40-50 vol% H_2O) at greater depths. This was particularly evident at the Point Sturt location, where sediments were found to be effectively saturated over a depth of approximately 1 metre above the minimum piezometric level. Similarly, at Campbell Park, the unsaturated zone was limited to the upper 0.3-0.4 m of lake sediments, despite the unsaturated state of the adjacent piezometer on several occasions in early 2010. The sediment moisture profile measured at the Windmill location is consistent with observations at Point Sturt and Campbell Park, although piezometric levels were maintained relatively close to the ground surface (within 0.6 m). Therefore, ongoing monitoring data (particularly at the Windmill location) will further assist in understanding the rate of sediment desaturation and rewetting in response to climatic changes and seiching events.

The above findings have important implications for assumptions used to estimate acidity generation rates (and hence acidity flux rates) from the lake sediments.

6.2 *Lake Levels*

As of late April 2010, the surface water level in both lakes was around -0.5 m AHD, based on Department for Water lake level data. There remain some apparent inconsistencies between piezometric level data proximal to the lakes and DLWBC lake level data. From January 2010, the recorded surface water levels at Currency Creek were also inconsistent with data from all (3) piezometers on the creek margins. In all cases the surface water level data appear to be overestimates, potentially due to subsidence of monitoring equipment in soft lake/creek bed sediments. The DLWBC surface water level data documented in this study need to be assessed in more detail.

6.3 *Water quality in Lake Albert*

The groundwater monitoring data collected from August 2009 to April 2010 suggests that:

- Prior to the commencement of monitoring, some localised acidity generation had occurred within the upper lake sediments, as indicated by acidic groundwater observed in some piezometers (3 sites at Campbell Park).
- There has been some evidence of additional acidity generation within the lake sediments from mid-November 2009 to late April 2010.
- Acidity generated within the upper lake sediments has migrated vertically from sandy layers in the unsaturated zone to the groundwater via rainwater infiltration. However, there has been only limited vertical mixing / diffusion within the groundwater profile.
- There has been no significant lateral migration of acidity from the sediments towards the lake water, based on reasonably consistent water quality over time (at each site), despite significant chemical variations relative to other sites on the same transect. This is consistent with the low hydraulic gradients, as well as the significant near-surface evapotranspiration water losses.
- Groundwater chemistry data shows that some degree of in-situ carbonate dissolution (ANC consumption) has occurred at both sites in Lake Albert. At Campbell Park this has clearly been related to acidity generation. However, ANC consumption has been insufficient to counter the acidity in groundwater at Campbell Park. This is despite indications that sandy lake sediments are generally NAPP negative.
- There is some evidence of sulfide precipitation (bacterial sulfate reduction) within the upper sandy sediments following acidity generation at Campbell Park (Sites 2-4), based on the progressive increase in pH and $Cl:SO_4$ ratios observed from late August to mid-November 2009. Subsequent decreases in pH and $Cl:SO_4$ ratios suggest this process was partially reversed in April 2010.

The risk to surface water quality in Lake Albert was predicted to increase significantly as lake levels were expected to decrease to unprecedented levels (-1.0 m AHD) in early 2010 (Earth Systems, 2010). As discussed in Earth Systems (2010), the increased acidity generation risk was expected to result from:

- Exposure of larger volumes of ASS.
- Increased sulfide-sulfur content with depth in exposed sediments.
- Increased rate of groundwater flow through sandy sediments due to greater hydraulic gradients to lake water.

Water quality predictions by Hipsey et al. (2010) and Earth Systems (2010) were used to inform management measures, and additional water allocations for Lake Albert were identified as vital for avoiding substantial acidification.

Recent surface water quality data for Lake Albert, provided by EPA (2010) indicates that:

- The surface water pH has generally been maintained at 8.5, with a recent trend towards pH 9 at all sites from January-April 2010.
- The surface water alkalinity at most sites has increased from around 250 mg/L $CaCO_3$ to 300 mg/L $CaCO_3$ from January-April 2010.
- The chloride to sulfate ratio has been progressively increasing, indicating net sulfate reduction, from January-April 2010.

The lack of evidence of major acidity flux to the lake from January-April 2010, contrary to the predicted risk in Earth Systems (2010) is attributed to the following key factors:

- Surface water level data indicates that the lake only reached a minimum level of around -0.7 m AHD, significantly higher than the predicted minimum of -1.0 m AHD.
- Sediments remained effectively saturated at depths below 0.3-0.4 m throughout the 2009-2010 summer (see Section 6.1).

Furthermore, there is strong evidence for significant sulfate reduction processes occurring within the lake water body (elevated pH and significant increases in alkalinity and chloride to sulfate ratios in lake water).

Nevertheless, recent trends in groundwater quality at the Campbell Park and Windmill locations indicate that there remains a risk of localised acidity fluxes around the lake perimeter, such as that observed on the western margin of Lake Albert at Reedy Point (EPA, 2010).

The future risk of acidification in Lake Albert will primarily depend on long term surface water level predictions.

Key factors that may be used to identify localised zones of high ASS risk are documented in Section 6.7.

6.4 Water quality in Lake Alexandrina

The groundwater monitoring data collected from August 2009 to April 2010 suggests that:

- Prior to the commencement of monitoring, some localised acidity generation had occurred within the upper lake sediments, as indicated by acidic groundwater observed at Point Sturt (Site 2).
- Some additional acid generation occurred at Site 2 between mid-November 2009 and late April 2010;
- Acidity generated within the upper lake sediments (Site 2) has migrated vertically from sandy layers in the unsaturated zone to the groundwater via rainwater infiltration. However, there has been limited vertical mixing / diffusion within the groundwater profile.
- There has been no significant lateral migration of acidity from the sediments towards the lake water, based on reasonably consistent water quality over time (at each site), despite significant chemical variations relative to other sites on the same transect. This is attributed to low hydraulic gradients, as well as the significant near-surface evapotranspiration water losses.
- Groundwater chemistry data shows that some degree of in-situ carbonate dissolution has occurred at Point Sturt. This has clearly been related to acidity generation. However, ANC consumption has been insufficient to counter the acidity in groundwater at Point Sturt. This is despite indications that sandy lake sediments are generally NAPP negative.
- There is no clear evidence of sulfide precipitation (bacterial sulfate reduction) within the upper sandy sediments affected by acidity generation at Point Sturt.

The risk to surface water quality in Lake Alexandrina was predicted to increase significantly as lake levels were expected to decrease to unprecedented levels (below -2.0 m AHD) during 2010-2011(Earth Systems, 2010). As discussed in Earth Systems (2010), the increased risk was expected to result from:

- Exposure of larger volumes of ASS.
- Increased sulfide-sulfur content with depth in exposed sediments.
- Increased rate of groundwater flow through sandy sediments due to greater hydraulic gradients to lake water.

Recent surface water quality data for Lake Alexandrina, provided by EPA (2010) indicates that:

- The surface water pH has generally been maintained 8.5, with a recent trend towards pH 9 at all sites from January-April 2010.
- The surface water alkalinity at most sites has been maintained around 180 mg/L $CaCO_3$ throughout January-April 2010.
- The chloride to sulfate ratio did not noticeably decrease from January-April 2010.

The lack of evidence of major acidity flux to the lake from January-April 2010 is attributed to the following key factors:

- Surface water level data indicates that the lake generally remained above -1.0 m AHD, significantly higher than the predicted level of -1.4 m AHD in February 2010. (The minimum of less than -2.0 m AHD was predicted to occur around April 2011).
- Sediments remained effectively saturated at depths below 0.3-0.4 m throughout the 2009-2010 summer (see Section 6.1).

Furthermore, there is some evidence to support the possibility of sulfate reduction processes occurring within the lake water body (elevated pH and significant increases in alkalinity in lake water).

Nevertheless, recent trends in groundwater quality at Point Sturt indicate that there remains a risk of localised acidity fluxes around the lake perimeter, such as that observed on the northern margin of Lake Alexandrina at Boggy Lake (EPA, 2010).

The future risk of acidification in Lake Alexandrina will primarily depend on long term surface water level predictions.

Key factors that may be used to identify localised zones of high ASS risk are documented in Section 6.7.

6.5 Acidity generation rate modelling

As noted in Section 6.1, the recent sediment moisture results from January-April 2010 have important implications for assumptions used to estimate acidity generation rates from the lake sediments.

If the unsaturated zone is limited to the upper 0.3-0.4 m of sandy sediments at the lake margin (and presumably a progressively narrower zone with proximity to the lake water) the rate of acidity generation will be considerably lower than that modelled previously (Earth Systems, 2010) given that:

- Significantly smaller volumes of ASS would be exposed.
- Sediments in the upper 0.3-0.4 m are associated with relatively low sulfide-sulfur contents.

To further improve estimates of future acidity generation rates in unsaturated sediments, updated predictions of lake water levels would also be required.

6.6 Acidity flux rate modelling

The likely rate and duration of acidity release (flux) events in Lake Albert and Lake Alexandrina was estimated by Earth Systems (2010) for a range of lake water level, hydraulic conductivity and acidity concentration scenarios, based on hydrogeological modelling conducted by Coletti and Hipsey (2010).

While the estimated rates of acidity flux for each scenario documented by Earth Systems (2010) remain valid, the duration of acidity flux events is likely to have been overestimated for the following reasons:

- Lake water levels have remained significantly higher than predicted, and therefore acidity generation rates are likely to have been overestimated (see Section 6.4).
- Surface runoff and acid salt dissolution associated with high intensity rainfall events (where rainfall intensity exceeds infiltration rate) was not taken into account as an acidity flux mechanism. This mechanism is likely to have been an important component of the rapid acidity flux event observed at Currency Creek in 2009.

6.7 Key ASS risk factors

Based on the results collected to date, the following ASS risk factors have been developed to assist in the identification of localised high risk ASS areas or “hot spots” around the lakes that may require management intervention. Management options are discussed in Section 6.8.

Primary risk factors

1. Elevation of outer lake margin sediments (bathymetry).
2. Sulfide content.
3. Desaturation rate:
    a. Low moisture retention capacity (high sand content relative to clays);
    b. Low potential for inundation during seich events;
    c. Presence of vegetation.
4. Potential for groundwater flux from sediments to lake:
    a. High hydraulic conductivity / permeability (high sand content relative to clays);
    b. High hydraulic gradient:
        i. Low relief upgradient of lake sediments;
        ii. High gradient of sediment bank (bathymetry);
        iii. High gradient of sand/clay contacts;
        iv. Low lake water level (current and predicted levels, relative to previous minimum lake levels).
5. Volume of unsaturated lake sediments:
    a. Depth to groundwater / saturated zone at outer lake margin;
    b. Surface area (length and width) of exposed lake sediments.
6. Geological distribution of Bridgewater Formation.

Secondary risk factors

7. Availability of organic matter / iron for bacterial pyrite precipitation.
8. ANC content in near-surface lake sediments (unsaturated zone and upper saturated zone).
9. Visible evidence of acid formation (metal precipitates and acid efflorescences).
10. Potential for acid ponds to develop on lake margins.
11. Potential to impact on populated areas (proximity).

6.8 Management Options

All efforts should be directed at keeping sulfidic lake sediments saturated to prevent acidity generation.

In the event that the inundation of sandy sediments cannot be guaranteed, the benefits of subsurface barriers need to be considered. Subsurface barrier installation within the uppermost sandy sediments around the unsaturated margins of both lakes can be expected to assist with retarding sulfide oxidation by maintaining the sulfidic material in a saturated, or largely saturated state. The barriers are expected to have the added benefit of enhancing ANC consumption and preventing acidity discharge.

In the event that significant areas of clay-rich sediment become exposed to atmospheric oxygen, shallow terraces constructed from ultra-fine grained limestone could be strategically installed along contours on top of exposed clays to maintain saturation (not inundation) during dry periods. The water required for surface application above the terraces could potentially be obtained from the Tertiary Limestone aquifer.

Treatment of lake water and exposed sediment banks could be conducted with limestone. This could involve either pre-emptive or post acidification limestone addition, and could potentially be done from the lake surface (eg. barges), from the shoreline (eg. mixing and dosing equipment), or from the air (eg. air tractors).

7 Recommendations

The following recommendations supplement those provided in Earth Systems (2010).

Acidity flux quantification

- Conduct geological mapping of the margins of both lakes as a priority to better characterise the ASS risk at various locations around both lakes.
- Use the geological information (generated above) as well as other key risk factors to generate a risk-based map of ASS hot spots.
- Update acidity generation rate estimates based on new sediment moisture data and new predictions of surface water levels (when available).
- Incorporate surface runoff and acid salt dissolution associated with high intensity rainfall events as a key component (flux mechanism) in future acidity flux modelling.
- Conduct further investigation to resolve the discrepancy between surface water levels and piezometric levels, particularly in Lake Albert and Currency Creek.
- Consider utilising low-cost level loggers in shallow piezometers to replace the heavy and apparently problematic level sensors currently used to monitor lake levels.
- Continue long term monitoring of sediment moisture and piezometric levels at existing sites (download data at least every 2 months) to:
    - Confirm or update the findings presented in this report.
    - Investigate the implications of further rises in lake levels on surface water quality (eg. throughout the 2010 wet season).
    - Provide early warning of localised acidity generation and fluxes to the lakes.
- Consider establishing a more extensive groundwater monitoring network (levels and chemistry) throughout the lake system. Prioritise future monitoring sites according to key ASS risk criteria.
- Conduct periodic mapping of the nature and distribution of secondary salts around both lakes. Use this information to create more accurate deterministic models for the formations of these materials, in conjunction with the geological mapping (recommended above) to better characterise the ASS risk at various locations around both lakes.

Acidity flux management

- All efforts should be directed at keeping sulfidic lake sediments saturated to prevent acidity generation.
- In the event that the inundation of sandy sediments cannot be guaranteed, consider the benefits of subsurface barriers.
- In the event that significant areas of clay-rich sediment become exposed to atmospheric oxygen, consider strategic installation of shallow terraces constructed from ultra-fine grained limestone along contours on top of exposed clays to maintain saturation (not inundation) during dry periods.
- Consider treatment of lake water and exposed sediment banks with limestone at high risk locations. This could involve either pre-emptive or post acidification limestone addition, and could potentially be done from the lake surface (eg. barges), from the shoreline (eg. mixing and dosing equipment), or from the air (eg. air tractors).

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