Centre for ecosystem management

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

June 2008

LIEGE STREET WETLAND AERATION TRIAL EVALUATION: SUMMER AND AUTUMN 2008

By, **Dr. Clint McCullough**
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Centre for Ecosystem Management Report No. 2008-11

Prepared for,

Swan River Trust

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1 Executive Summary

1. The Liege Street Wetland is the first major project to be undertaken through the Swan River Trust's Drainage Nutrient Intervention Program (DNIP) which funds on-ground drainage intervention works to reduce nutrients being delivered to the Swan and Canning rivers.

2. In August 2007, GHD Pty Ltd consultants reviewed monitoring data collected from the wetland between late 2004 and early 2007. This review identified that phosphorus mobilisation was likely and suggested this was caused by low wetland pond dissolved oxygen (DO) concentrations.

3. GHD Pty Ltd recommended management strategies to increase Liege Street Wetland pond oxygen levels. Specifically, GHD Pty Ltd (2007) recommended that aerators be incorporated into open ponds and that a monitoring program with a higher density of DO sites and frequency of sampling than under normal wetland monitoring be implemented to assess effectiveness of aerators.

4. Under a separate contract, Waterbeetle aerators were run in three Wetland ponds over summer–autumn 2008. This study assessed the performance of aeration of three of the Liege Street Constructed Wetland ponds by Waterbeetles from January to May 2008.

5. Continuous monitoring for temperature, pH, electrical conductivity (EC), DO and oxidation-reduction potential (ORP) was undertaken near the sediment surface of three wetland ponds over a four-week period. These data was supplemented by general observations and weekly profiling along a transect from the wetland pond bank to a Waterbeetle.

6. By mid-Summer, *Potamogeton* and *Azolla* (aquatic macrophytes) appeared to reach very high biomass levels in the wetland ponds, reducing both natural and Waterbeetle water mixing. *Potamogeton* biomass was greatly reduced by shading as *Azolla* wetland pond coverage became complete. *Azolla* biomass was almost wholly removed by an unseasonal early-autumn rain event.

7. Because the Waterbeetles are solar powered, operation only occurred during daylight hours. The Waterbeetles were also run at 100 RPM rather than their full rate on solar power of 140 RPM to limit sediment re-suspension in the wetland.

8. Wetland ORP was extremely low in all ponds indicating sediment oxygen demand was extremely high. This observation suggests either historic or ongoing contamination from the wetland catchment to these pond sediments.

9. Waterbeetle aeration produced little change to measured wetland pond water quality. Limited thermocline destabilisation lead to a slight increase in near-sediment water temperature, however ORP remained extremely low across all wetland ponds.

10. Recommendations from this study are that:

    a. aeration by Waterbeetles is not continued;

    b. a separate study examines the water quality entering the wetland that may be contributing to the very high sediment oxygen demand; and

    c. sediment nutrient release mechanisms be investigated to better understand how they then may be managed.

Frontispiece

Figure 1. Waterbeetle in Liege Street Wetland Pond 6. The surface of the Wetland pond has become covered with *Azolla pinnata* by the end of February 2008.

This document should be referenced as follows.

McCullough, C. D. & Lund, M. A. (2008). *Liege Street Wetland aeration trial evaluation: Summer and Autumn 2008*. Centre for Ecosystem Management Report No. 2008-11, Edith Cowan University, Perth, Australia. 36pp. Unpublished report to Swan River Trust.

2 Contents

3 Background

The Swan River Trust's Drainage Nutrient Intervention Program (DNIP) funds on-ground drainage intervention works to reduce nutrients being delivered to the Swan and Canning rivers. The Liege Street Wetland was the first major project to be undertaken through this program. Located in a 3.2 ha area of the Canning River Regional Park between Carden Drive and the Canning River in Cannington (Figure 1), the wetland was designed by Syrinx Environmental PL and developed through a partnership between the Swan River Trust, City of Canning, South East Regional Centre for Urban Landcare, Department of Environment and Conservation, Water Corporation and Two Rivers Catchment Group.

The wetland's design was intended as a best management practice example of a constructed stormwater treatment wetland specifically designed for the site conditions (Syrinx Environmental Pl, 2004) and was built in April 2004. Planting of the wetland, commenced in June 2004 and continued until June 2006. The wetland receives stormwater input from a 532 ha catchment, principally draining through the Liege Street main drain but also from the Cockram Street Drain and two small local drains.

The main objective of the constructed wetland is to improve water quality of the Liege and Cockram Street main drains prior to discharge to the Canning River, upstream of the Kent Street Weir. Specifically it sought:

- to improve water quality and reduce the delivery of nutrients to the Swan-Canning river system in low flows during summer and autumn when the risk of algal blooms is high;
- to restore and enhance the habitat and amenity values of the area including: protection of existing remnant vegetation; weed control and revegetation; and provision of habitat diversity to attract fauna; and

- to create an educational and recreational asset for the residents of surrounding suburbs, as well as visitors to the area which is achieved with an interactive landscape design strategy that integrates into the greater landscape.

Design features of the wetland include (see Figure 1):

- gross pollutant traps at each major drain outfall;
- a sediment forebay for collecting and removing sediment;
- a series of shallow (~ 1.2m deep) naturally clay lined ponds and shallow (~0.5m deep) densely vegetated sumplands;
- a raised adjustable weir at the outlet to create a floodplain;
- two internal adjustable weirs for water level manipulation to assist with maintenance and planting;
- a vertical flow filter bed; and
- a small “bypass” drain near the sediment forebay to allow for draining of the wetland if required.

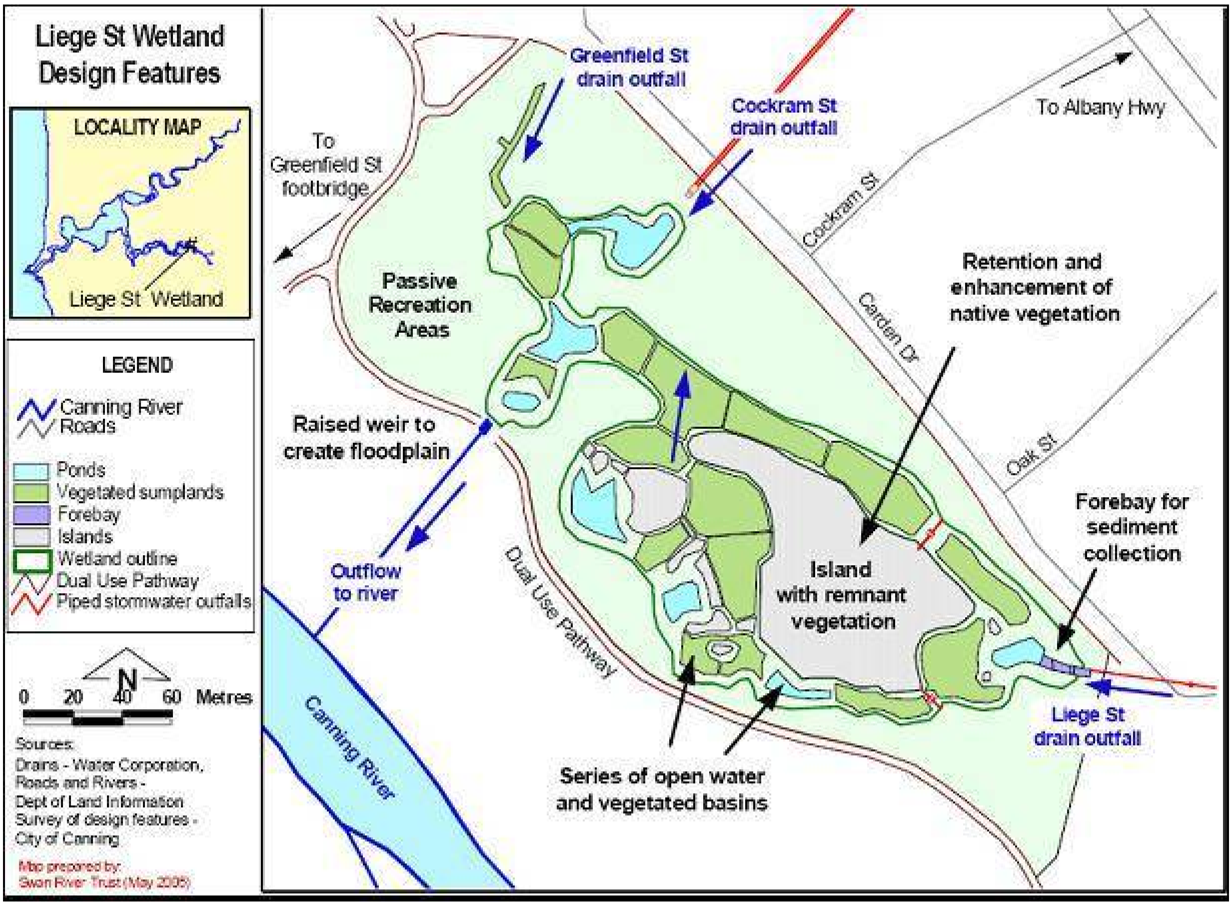

Figure 2. Plan of the Liege Street Constructed Wetland in the City of Canning, Perth (From GHD Pty Ltd, 2007).

From November 2004 to date, the Department of Water (DoW), with funding from the Trust, has undertaken a comprehensive monitoring program to assess the wetland's health and performance. In August 2007, GHD Pty Ltd reviewed the monitoring data from late 2004 to early 2007. This preliminary analysis indicated that the wetland was successfully reducing concentrations of nutrients in low flows. However there were persistent low dissolved oxygen (DO) levels in the wetland that did not generally meet 80% ANZECC and ARMCANZ (2000) (disturbed ecosystem) guidelines for percentage DO saturation. GHD considered these low DO concentrations likely to place extra stress of the wetland's fauna and well as to negatively impact the wetland's performance at improving water quality, particularly nutrient concentrations.

In summary, GHD Pty Ltd (GHD Pty Ltd, 2007) reported that:

"Seasonally dissolved oxygen (DO) concentrations had much greater variability during 2005 than 2006. In general the wetland had elevated DO from August to November and much lower levels for the remainder of the year. Only the Liege Street Main Drain inlet maintained a relatively consistent DO level near the ANZECC and ARMCANZ (2000) guideline [note: actual guideline undefined so south-west Australia general physico-chemical guideline assumed]. *The much lower DO levels during the summer are highlighted by a comparison of the summer and annual medians over the period of monitoring. In general, DO at the outlet and in sumpland 6 remained elevated for a greater proportion of 2005 (April to December) than 2006. Presumably, higher discharge during 2005 than 2006 led to a lower residence time, greater flushing, and less oxygen consumption within the wetland. Non-compliance with the guideline occurred at a greater frequency during 2006 than during 2005. The DO guideline was met for nearly half of the year during 2005 at the outlet, but only on one occasion during 2006. The low DO over the past two summers (<2 mg/L) provide conditions conducive for the release of dissolved nutrients and metals from the sediments."*

As part of its review of the wetland's performance GHD Pty Ltd (2007) recommended management strategies to increase oxygen levels, specifically:

a) aerators be incorporated into open ponds, namely:

- the sedimentation forebay to promote sequestration of particulate forms of nutrients and to help prevent remobilisation of pollutants under low DO conditions;
- the outlet pond (Pond 6) to improve (or 'polish') water prior to discharge, which will be particularly effective for reduced dissolved forms of metals; and

b) a monitoring program with a higher density of DO sites and frequency of sampling be implemented to ascertain the effectiveness of the aerators and identification of ‘low DO hot spots’.

In response to the GHD report (2007) recommendations, the Swan River Trust, commissioned two separate contracts. The first contract was a trial of aerators in key ponds of the wetland and the second was this study of the effectiveness of the aerators on improving water quality. However, these aerators were only operated at 100 RPM instead of their usual speed of 140 RPM (Peter Adkins, Swan River Trust, *pers. Comm*.). The latter contract was for a study of the efficacy of this aeration method in remediating low DO in wetland ponds and how this may influence nutrient mobility. Dr. Clint McCullough and Assoc. Prof. Mark Lund of Edith Cowan University were appointed to undertake this latter study. The aeration trial was undertaken directly by the equipment manufacturer and is reported elsewhere. This document reports on the results of the monitoring program evaluating the aeration trial in the wetland.

The key aims of this study were:

- to determine the effectiveness of the aerators in maintaining dissolved oxygen concentrations at levels that meet ANZECC/ARNCANZ (2000) guidelines;
- to determine the effectiveness of the aerators in maintaining conditions at the sediment/water interface that would minimise the chances of phosphorous release from the sediments; and
- to determine the spatial extent of the effects of the aerators within each pond.

4 Methods

4.1 Data collection

Five of the Wetland ponds had solar-powered ‘Watermill Waterbeetles’ installed in January 2008 to aerate the waters of the pond. From 30th January to 27th February 2008 six YSI 600XLM multiparameter sondes were deployed within three of the five Wetland cells that were aerated. The focus of the placement of this large number of loggers was to ensure a monitoring program with a high density of DO sites and frequency of sampling in order to ascertain the effectiveness of the aerators and identification of any ‘low DO hot spots’ that are not aerated adequately. These sondes simultaneously logged DO (as both % saturation and mg L^{-1}), electrical conductivity (specific conductance as an indicator of nutrient and metals mobilisation), oxidation-reduction-potential (as actual relevant indicator of nutrient forcing conditions rather than dissolved oxygen alone), temperature (as an indicator of ambient physical characteristics defining dissolved percentage oxygen concentrations and also of nutrient forcing conditions) and pH (as another potential stressor variable and indicator of photosynthetic drive and wetland pond aeration coefficients by aquatic macrophytes).

Sondes were placed in pairs within wetland ponds 4, 5 and 6 as shown in Figure 2. Each sonde was placed 2 m away and the other sonde 10–20 m away downstream from each Water beetle aerator centre within each pond. Sondes were placed on ceramic tiles immediately above the sediment surface to assess the effectiveness of aerators at increasing dissolved oxygen and ORP at the near the sediment/water interface.

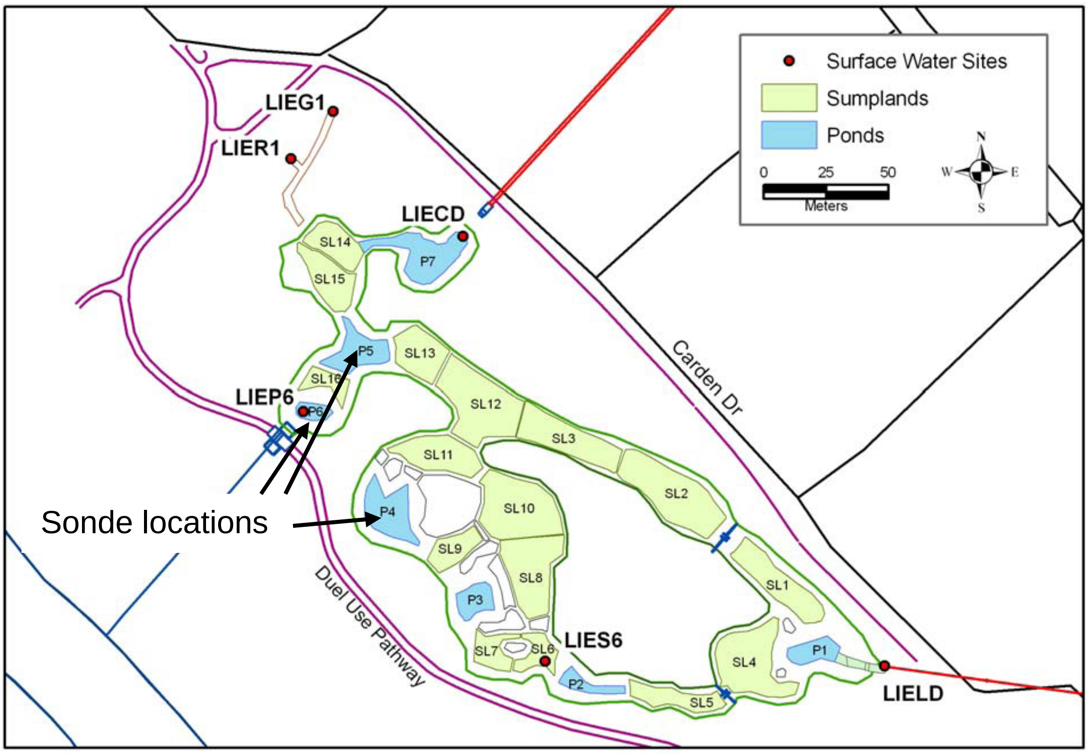

Figure 3. Locations of Liege Wetland aeration monitoring for this study (after GHD 2007).

At weekly intervals sondes were removed, checked and calibrated before re-deployment to the same site. All sonde parameters were logged every 10 minutes during deployment. Initial deployment of sondes was for a week-long unaerated baseline period (when Waterbeetles were turned off) between January 30th and February 6th. This baseline period was then immediately followed by aeration between February 6th and 13th (when Waterbeetles were turned on). Both unaerated and aerated week-long monitoring was then repeated again from February 13 to February 20th (unaerated) and from February 20th to February 27th (aerated). As the Waterbeetles were solar powered aeration did not occur outside of daylight hours.

Ponds 4, 5 and 6 and the final Drainage Channel were also profiled once-weekly (sometimes twice in one day) close to the sediment surface. Profiling was by a multiparameter probe (Datasonde - Hydrolab Quanta or Yeokal 612) on nine separate occasions 17/1/08 (midday), 30/1/08 (late afternoon), 6/2/08 (late afternoon), 13/2/08 (early morning and midday), 20/2/08 (early morning (prior to aeration commencing), midday), 27/2/08 (early morning (prior to aeration commencing)) and 4/5/08 (midday). Profiling water quality parameters measured were temperature, pH, electrical conductivity (EC), dissolved oxygen (mg/L and % saturation) and ORP. Profiles ran along a transect formed by the rope from Waterbeetle to the shore. This profiling was used to demonstrate the spatial extent of any significant aeration that may be occurring.

General observations and photographs were also taken each time sondes were deployed and profiles measured.

Weather data, particularly rainfall information for the Mount Lawley and Perth Airport sites was obtained from the Australian Bureau of Meteorology website (www.bom.gov.au).

4.2 Data analysis

Trends in physico-chemical parameters from the sondes were analysed by graphing in SigmaPlot 11 (Systat Software Inc., 2004). Following QA/QC of raw data, plots of water quality parameters over time were first checked for any obvious errors and clear outliers were removed. In order to improve clarity of variable changes over time, variable functions were smoothed with a negative exponential local smoothing technique using polynomial regression and weights calculated from the Gaussian function. These analyses focussed on understanding the variability in parameters between the four ponds and temporally to determine if nutrient mobilisation from the sediment was likely. Profile data were tabulated and graphed as appropriate. As per contract requirement, all data were then compared against available ANZECC/ARMCANZ aquatic ecosystem protection guidelines (default values of 95%) for physico-chemical parameters, both before and after aeration (ANZECC/ARMCANZ, 2000).

5 Results and Discussion

5.1 General observations

5.1.1 Weather observations

Although very little rain occurs during Perth summer and autumn months, unseasonal heavy rainfall occurred on February 7^{th}–8^{th} (47.6 mm) (www.bom.gov.au). Cloud cover was also greater during these dates and wind direction changed from seasonally prevailing south-west to south-east to east-north-east. No significant rainfall occurred after this period until monitoring ceased, however mean air temperature decreased significantly at the beginning of May. Other weather parameters remained largely unchanged over the monitoring period.

5.1.2 Aeration duration

A significant issue with the use of solar powered aeration devices such as the Waterbeetle was that aeration only occurred for less than 12 h day^{-1} (Figure 4). However, sediment and water column oxygen demand occurs throughout both day *and* night. In fact, it is likely that oxygen demand increases at night as the significant biomass of aquatic macrophyte and algae in the Liege Street Wetland ponds switch from photosynthesis to oxygen-consuming respiration.

Figure 4. Waterbeetle in Liege Street Wetland Pond 4 prior to sunrise and motor start surrounded by floating water fern (*Azolla pinnata*) at 0700 h, 27/02/2008.

5.1.3 Aquatic plants in wetland ponds

Potamogeton. crispus is a cosmopolitan submersed, floating stem plant. Although native to both flowing and still waterbodies in Australia, many species of *Potamogeton* have been recorded as troublesome and this is particularly so in low-flow and high-nutrient environments (Sainty & Jacobs, 2003). At the start of 2008 (until late February), *Potamogeton crispus* (curly pondweed) biomass was very high and covered the benthos of all wetland ponds studied (Figure 4). *Potamogeton* coverage declined in all ponds in late February 2008 probably due to shading by the eventual complete coverage of *Azolla* across the water surface.

It is likely that *Potamogeton* stands impeded both wind and Waterbeetle induced water column mixing, leading to greater water column stability and lowered rates of re-aeration. The sustained presence of *Potamogeton* after many weeks of Waterbeetle operation suggests that this species, which is also tolerant to moderately-fast flowing water (Sainty & Jacobs, 2003), is not likely to be negatively affected by slightly increased water flows such as by Waterbeetle activity. Indeed, slight increases in water flows may benefit such aquatic macrophytes stands by increasing rates of oxygen/carbon dioxide and nutrient diffusion that may have limited plant growth under a more static water column.

Figure 5. Waterbeetle in Liege Street Wetland Pond 4 with submerged curly pond weed (*Potamogeton crispus*) in the foreground at 1230 h, 11/01/2008.

Azolla pinnata (water fern) fixes nitrogen through a symbiotic relationship with the cyanobacteria *Anabaena azollae* which lives in the fern's leaves. Reproduction may be extremely rapid and is by vegetative growth with basal branches that break off the main stem which are dispersed by waterflows. Although native to Australia, and probably to the Swan Coastal Plain, *A. pinnata* is often considered a weed (Sainty & Jacobs, 2003). *Azolla* can quickly spread to cover open areas of water when it forms dense surface mats impeding water flow and surface diffusion of oxygen.

From around 25% coverage in January 2008 (Figure 5a), there was almost complete coverage by *Azolla* across the surface of all studied wetland ponds by late February 2008 (Figure 5b). However, unseasonally heavy rains flushing the ponds during 7th–8th February and the cooler air temperatures in May removed the majority of *Azolla* coverage by May 2008 (Figure 5c).

Figure 6. Waterbeetle a). operating in Liege Street Wetland Pond 6 at 1230 h on 11/01/2008, b). starting up on Pond 4 at 0800 h, 27/02/2008 and, c). operating in Pond 4 at 1100 h on 04/05/2008.

The spatial extent of aeration by the Waterbeetles was limited by the dense coverage of *Azolla* (see Figure 7). As shown by Figure 7, the water current caused by the Waterbeetles was only capable of pushing back the dense *Azolla* mat a short distance from the pond centre. The dense floating *Azolla* mat reduces the diffusion of oxygen into the water and the roots of the plant contribute to oxygen demand. This is likely to reduce efficiency of aeration by the Waterbeetles even though water column circulation by the devices might not be impacted (as it may take place under the *Azolla* mats). At night, the hole created by the Waterbeetle in the *Azolla* mat, closed and oxygen levels dropped sharply.

Figure 7. Waterbeetle surface disturbance area-of-effects in a). Liege Street Wetland Pond 4 and, b). Pond 6 during peak mixing at 1520 h, 06/02/2008.

5.2 Waterbeetle Aeration Trials

The data from the continuous monitoring (Datasondes) and spot measurements clearly show that the Waterbeetles were able to circulate water with noticeable changes in water physico-chemistry at distances up to 12 m away. However, the Waterbeetles failed to increase DO concentrations to meet ANZECC/ARMCANZ (2000) guidelines for 95% wetland receiving systems (>90%), and more relevantly to this study did not raise ORP sufficiently in most cases to prevent redox mediated sediment release of phosphorous.

Elements of water quality within the ponds appear to be extremely poor. During week 1 the Datasonde DO probes became 'poisoned' by constant contact with some of the chemicals in the water or being released from the sediments. This caused them to cease operation for the remaining monitoring periods. Furthermore, Sondes 3 and 4 then lost power part way through week 1, probably due to excessive polarisation of the DO Clark-type probes caused by the low ORP draining more current than would be normally expected. Nevertheless, any loss of this parameter from the monitoring suite was not significant as ORP measurements were simultaneously collected.

Sediment nutrient release can occur in a number of ways either individually or in combination. Typically a large portion of the phosphorous in sediments is bound to iron and manganese and it is this fraction that can be released from the sediment under forcing conditions of low ORP. Ferric iron (Fe^{3+}), is insoluble and binds phosphorous, is reduced to soluble ferrous (Fe^{2+}) when ORP levels drop below 100 mV releasing phosphorous. Manganese shows similar changes. Dissolved oxygen levels are often an unreliable indicator of ORP which is influenced by a range of other chemical processes.

ORP varied between ponds, with time and between sites within the ponds (Figure 7). Aeration tended to introduce some diurnal cycling of ORP from higher during the day to lower at night when the aerators were off. The magnitude of this cycling varied between times and ponds, however this cycle was generally not seen or was insignificant during periods of non aeration. This clearly shows that the aerators were increasing ORP values during hours of operation. Following sediment and hypolimnion disturbance caused by placing the Datasondes on the sediment, ORP appeared to take 2–3 days to stabilise. In the absence of aeration the ORP was <100 mV and on many locations dropped to -400 mV where methanogenesis may have occurred. These ORP values are extremely low and could reflect immersion of the probe in the upper sediment. However, the sonde probes were mounted on broad tiles to prevent this and so it is likely that these values are real and instead reflect *near*-sediment water physico-chemical conditions that better reflect sediment forcing than measurements higher in the water column. High oxygen demand in the sediments might account for the low ORP, although it is more likely that the incoming water was of very low quality with a high biological or chemical oxygen demand. If this is the case then aeration will likely be unable to raise oxygen levels as the oxygen is being rapidly consumed.

Bottom water temperatures were very similar between and within ponds and ranged from 20^{o}C to 27^{o}C. Temperature varied more greatly and on a distinctly diurnal basis when Waterbeetles were aerating than when they were not aerating. Pond water temperatures at the bottom began decreasing from after 19:30 h, soon after Waterbeetles were turned off, and began increasing again from 08:30 h, soon after Waterbeetles were turned back on again (Figure 7). The aerators appeared to be effective at circulating water at distances up to 7 m in all ponds measured.

Diurnal temperature fluctuations seen in the ponds during aeration saw daily water temperature changes of up to 3 degrees which was substantially higher than the typically <1^{o}C seen during periods of non-aeration. If wetland ponds are also intended as aquatic biota habitat, consequences of this type of change on biodiversity is unknown, but might further stress organisms coping with relatively poor water quality. Furthermore, circulation would result in warmer bottom waters which might enhance the growth rates of nuisance species such as midge larvae.

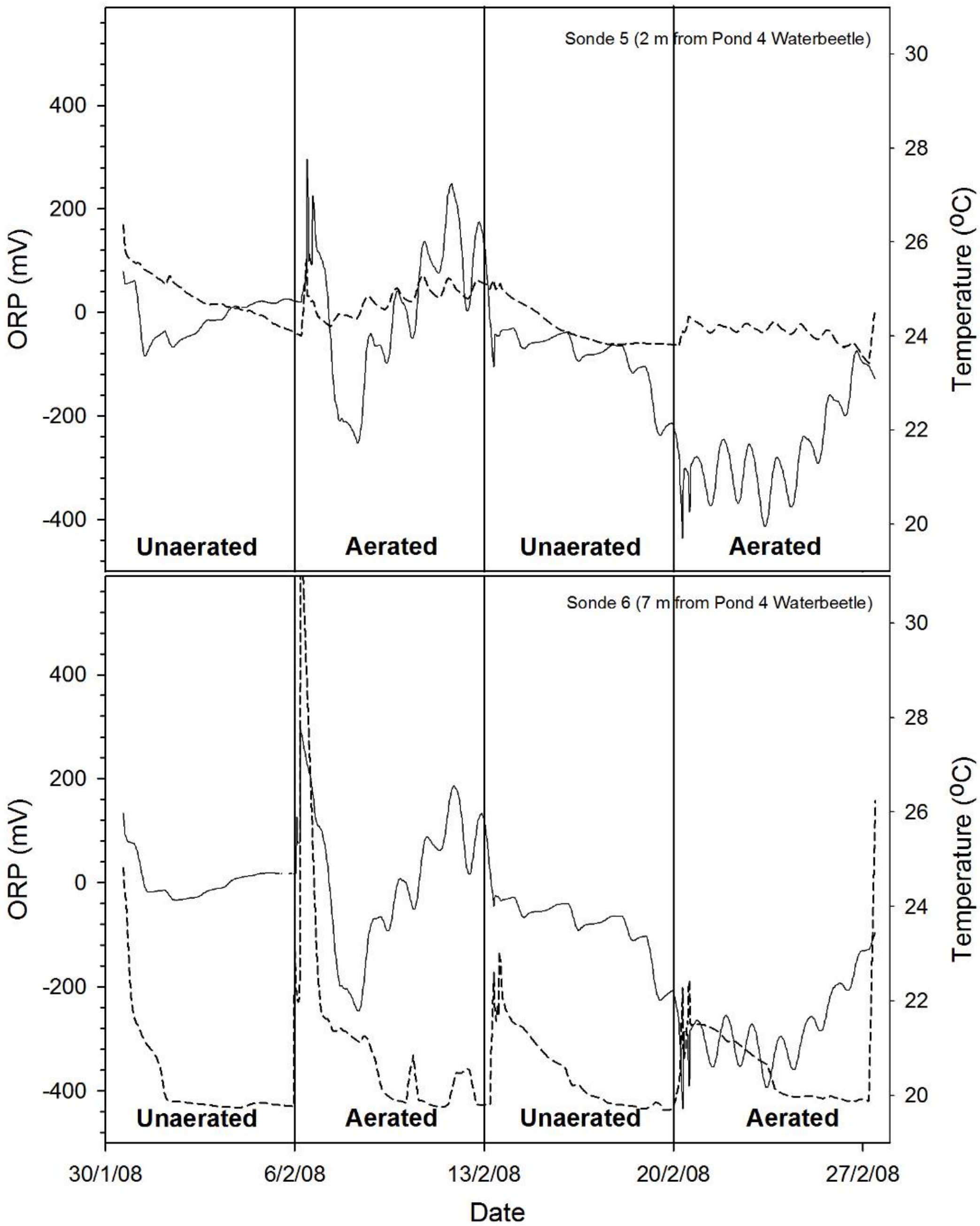

Figure 8a. Temperature (solid lines) and ORP (dotted lines) over time for Liege Street Wetland Pond 4 near and far monitoring points with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in ORP and temperature are due to removal and replacement of probes in the ponds. Sondes 3 and 4 lost power during week 1, resulting in a sudden changes in parameters.

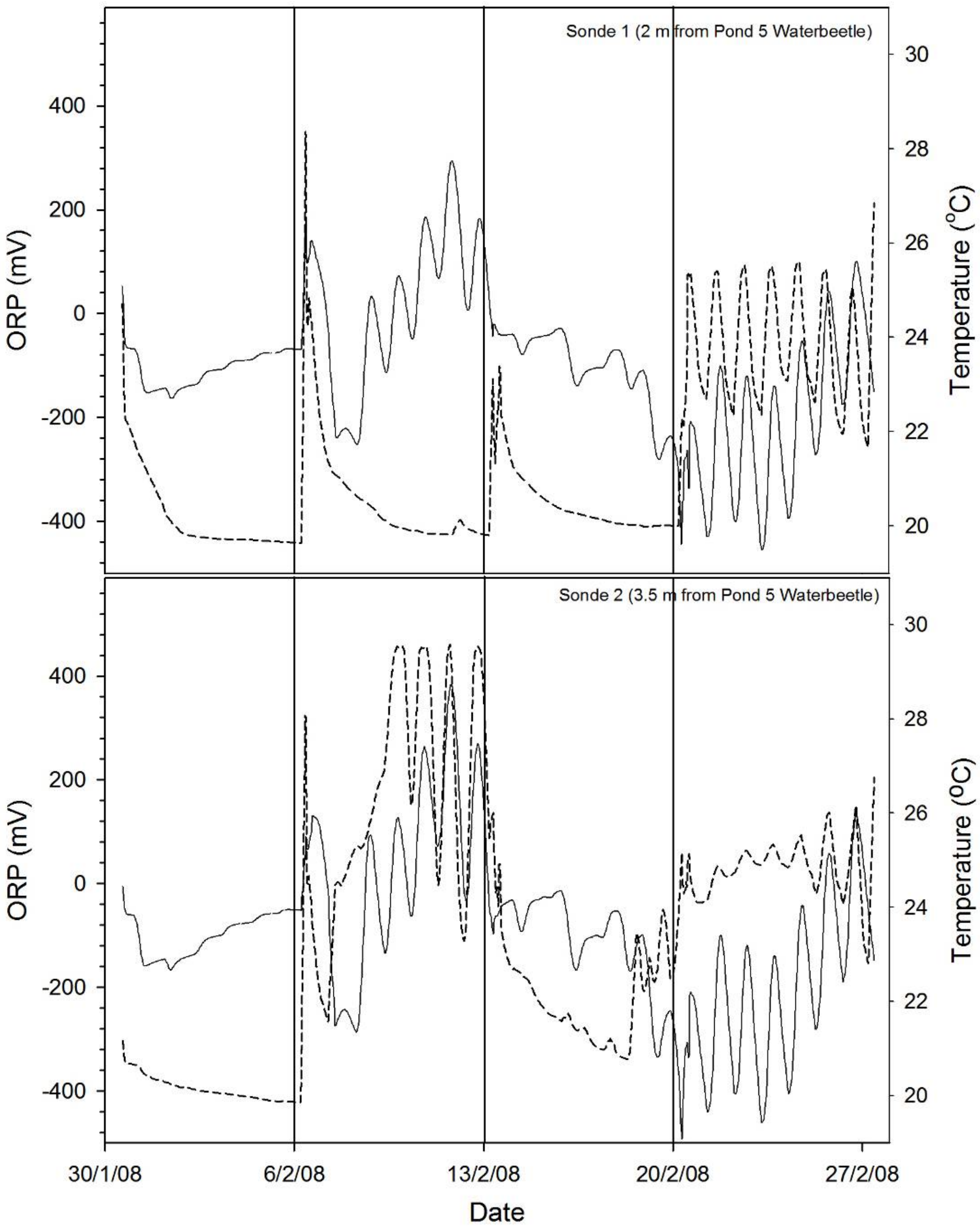

Figure 8b. Temperature (solid lines) and ORP (dotted lines) over time for Liege Street Wetland Pond 5 near and far monitoring points with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in ORP and temperature are due to removal and replacement of probes in the ponds. Sondes 3 and 4 lost power during week 1, resulting in a sudden changes in parameters.

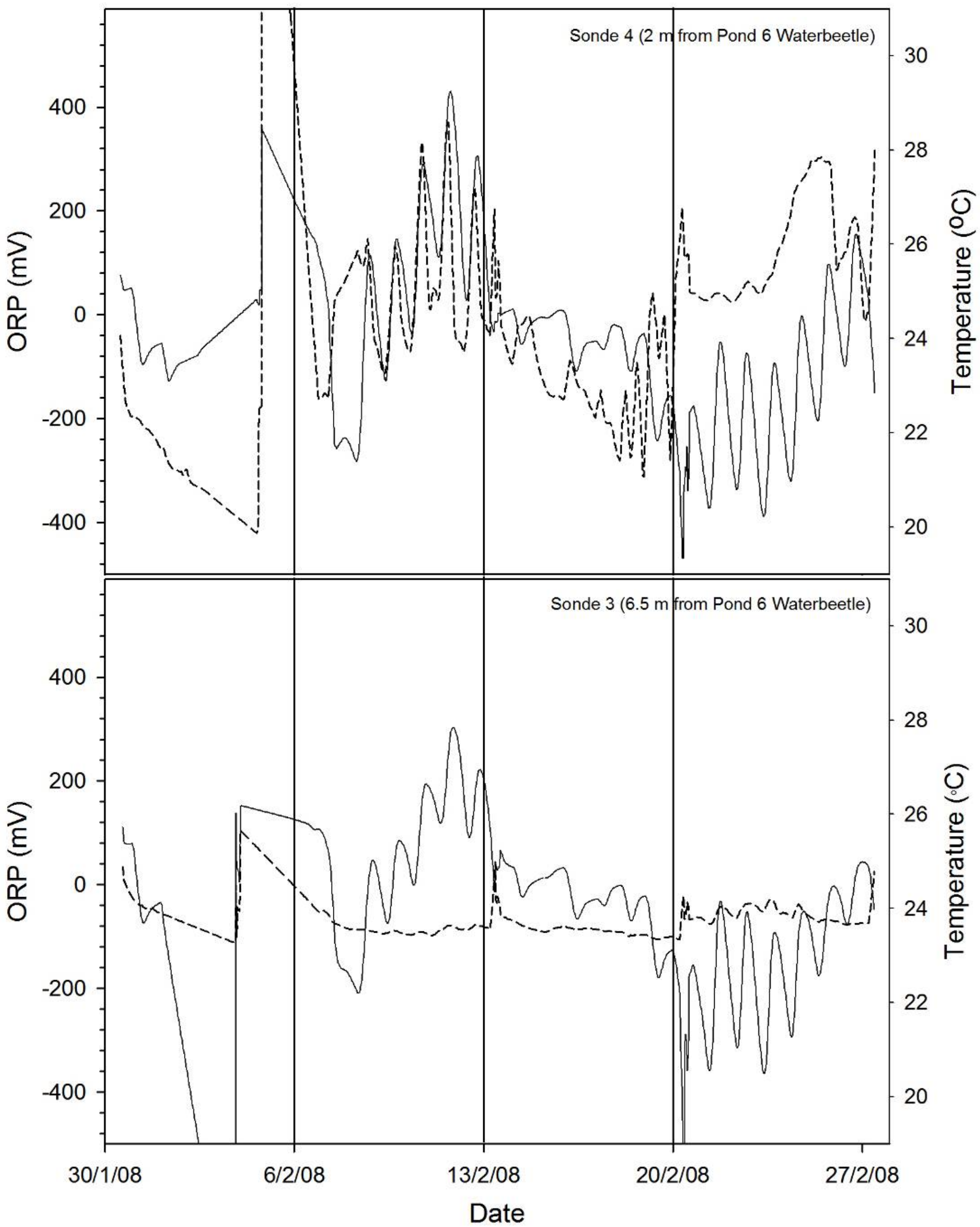

Figure 8c. Temperature (solid lines) and ORP (dotted lines) over time for Liege Street Wetland Pond 6 near and far monitoring points with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in ORP and temperature are due to removal and replacement of probes in the ponds. Sondes 3 and 4 lost power during week 1, resulting in a sudden changes in parameters.

The aerators appeared to have no effect on EC which changed little on a daily basis, or between ponds. pH showed a varied response ranging between 7 and 8.5 between ponds, distance from the aerator, with aeration and over time. A diurnal change in pH would be typical in a productive wetland, as it is influenced by photosynthetic activity, as CO_2 is used during the day increasing pH, which then drops over night, as diffusion replaces the CO_2. The loss of this diurnal variation on occasion is probably due to the coverage of the ponds with *Azolla*. As *Azolla* floats, it absorbs CO_2 directly from the atmosphere rather than water thereby not significantly altering water pH. Noticeable, is the more pronounced change in size of the diurnal fluctuations during periods of aeration particularly in the sites near the aerators. This suggests that during operation the aerators clear an area in the *Azolla*, allowing for some in-pond photosynthesis.

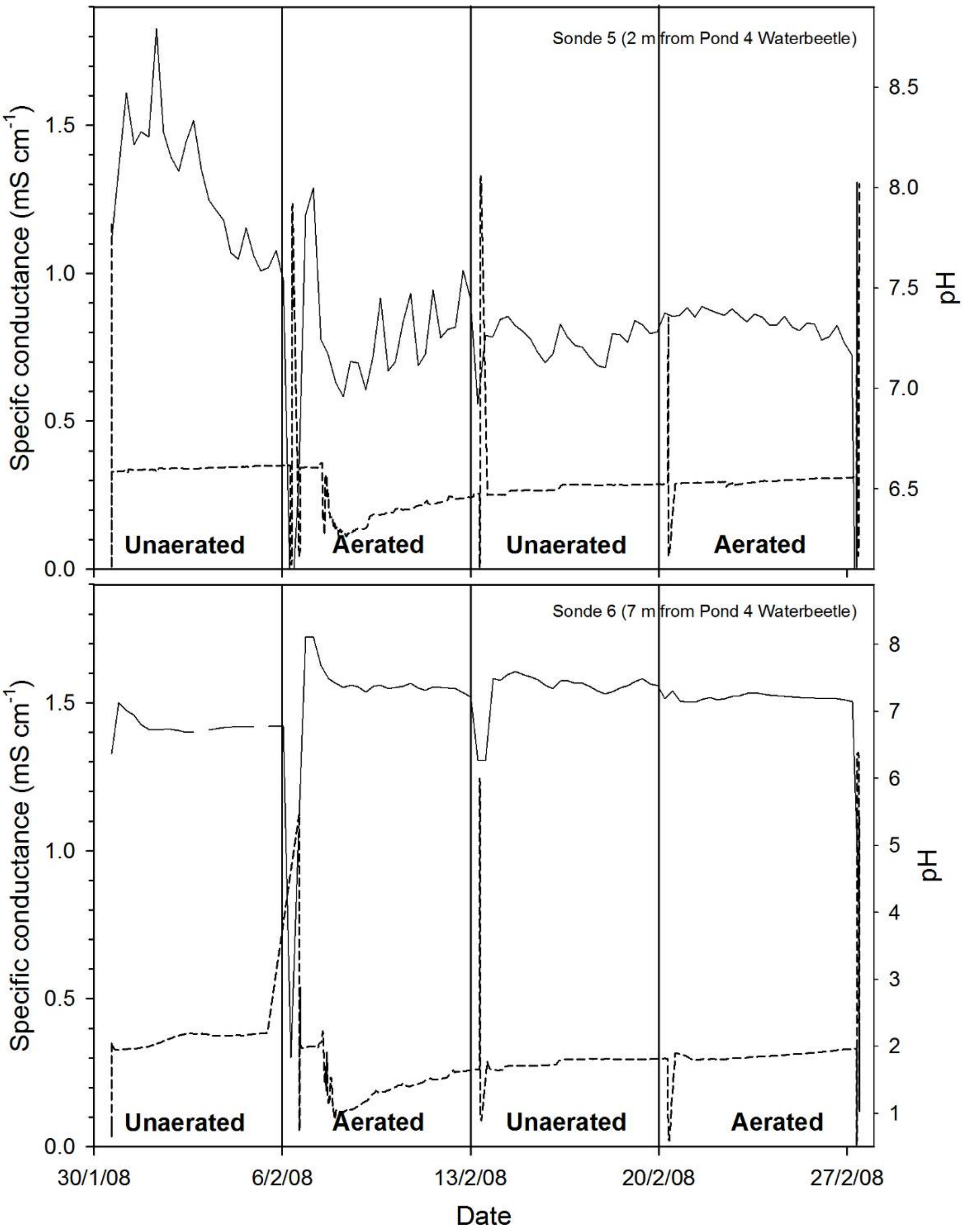

Figure 9a. Electrical conductivity (dotted lines) and pH (solid lines) over time for Liege Street Wetland Pond 4 near and far monitoring points, with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in EC and pH are due to removal and replacement of probes in the ponds.

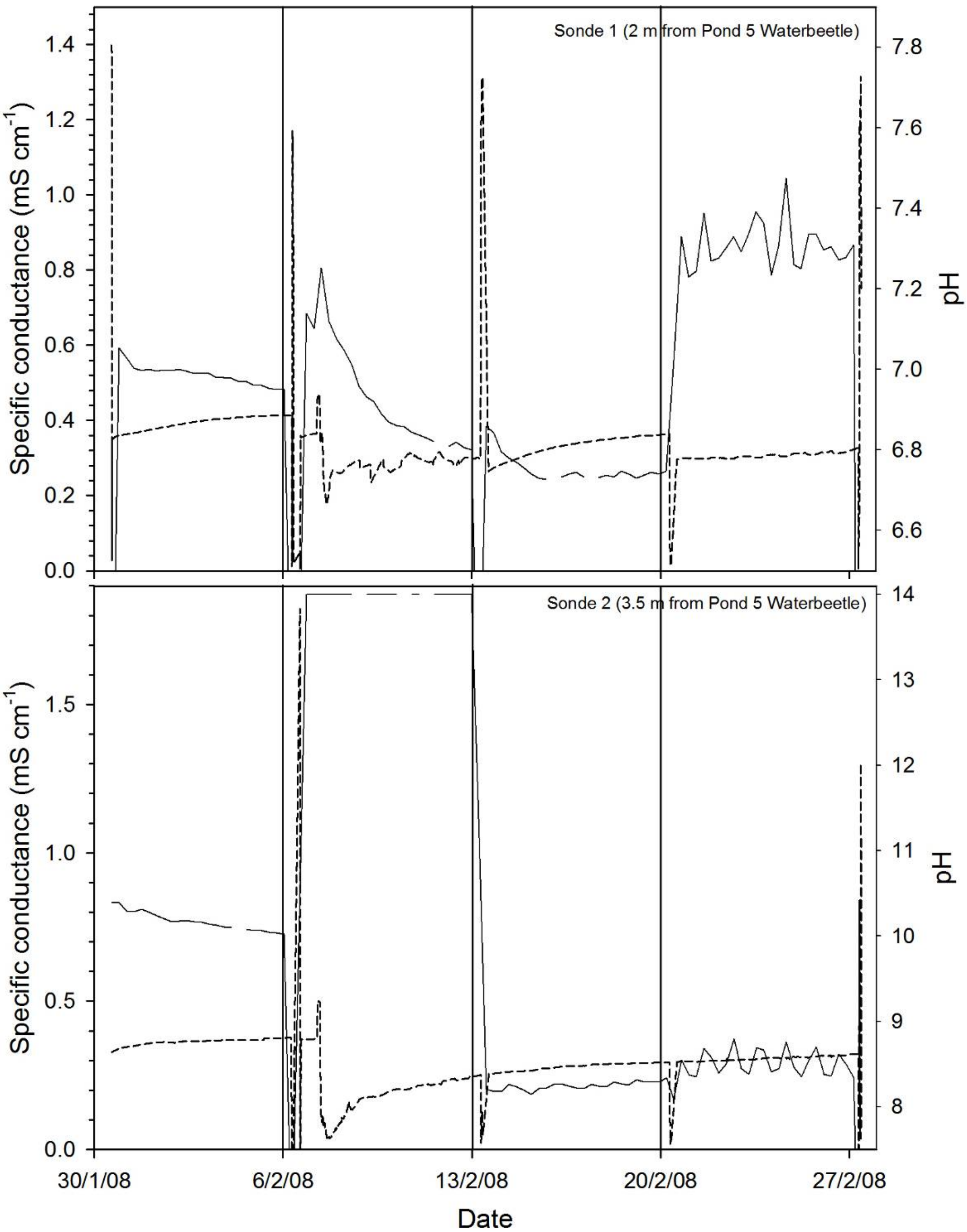

Figure 9b. Electrical conductivity (dotted lines) and pH (solid lines) over time for Liege Street Wetland Pond 5 near and far monitoring points, with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in EC and pH are due to removal and replacement of probes in the ponds.

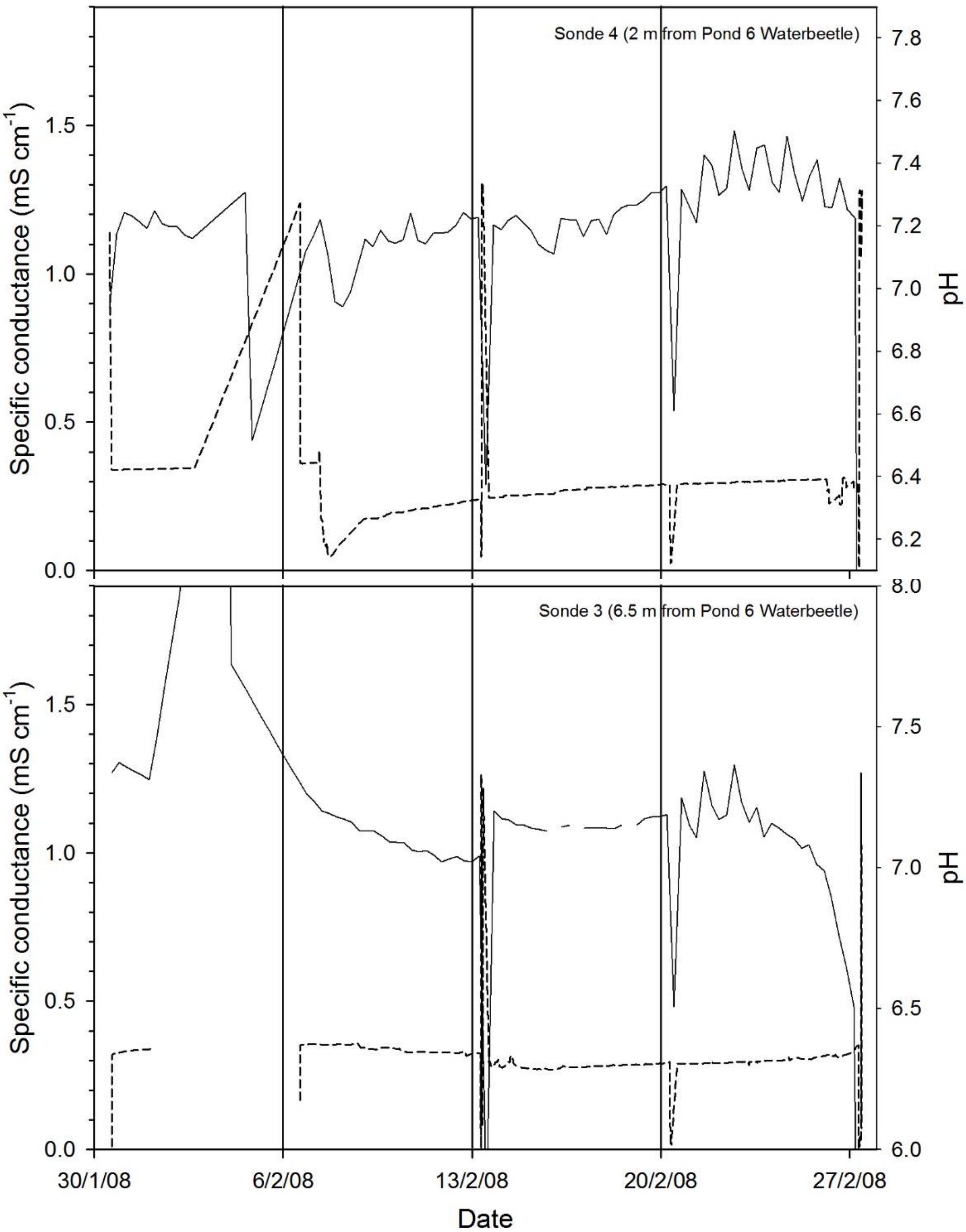

Figure 9c. Electrical conductivity (dotted lines) and pH (solid lines) over time for Liege Street Wetland Pond 6 near and far monitoring points, with and without Waterbeetle aeration. Vertical black lines indicate change in aeration regime. Note: sudden changes in EC and pH are due to removal and replacement of probes in the ponds.

The profiling results shown in Tables 1–3, demonstrate the effectiveness of the aerators in circulating water across a wider area of the wetland ponds. Electrical conductivity, pH and temperature did not vary between ponds or distance from the aerator on each sampling occasion. Only in Pond 4 at 6 m from the Waterbeetle, and only when the pond contained *P. crispus*, was the aerator able to raise dissolved oxygen levels to those that meet ANZECC/ARMCANZ (2000) guideline levels for the protection of aquatic systems in southwest Australia (slightly disturbed conditions) of 90-120% saturation. EC remained within the guideline range of 0.3–1.5 µS cm^{-1}. However, pH exceeded guidelines of 7–8.5 during the first few weeks of February where *P. crispus* dominated the ponds when a maximum pH of 10.2 was recorded. This extreme pH value indicates either extremely high rates of primary production (presumably by the high *P. crispus* biomass) or high pH in wetland influent waters. Nevertheless, ANZECC/ARMCANZ (2000) environmental guidelines are only applicable to the intrinsic value of the wetland for biodiversity habitat and are not applicable to its function as a treatment system.

Wetland discharge water quality entering the Canning River is shown in Table 4. Both EC (with an exception of 1.6 µS cm^{-1} recorded on 6/2/08) and pH in the wetland discharge was within guidelines. However, DO was always below guidelines level with only a maximum of 60% saturation ever recorded.

Despite Waterbeetle aeration raising DO concentrations to meet ANZECC/ARMCANZ (2000) guidelines in Pond 4 on one occasion, this did not result in an ORP of >-6 mV. This failure to improve ORP levels illustrates that, even with adequate oxygen levels, phosphorous release from the sediments is still likely in this system as phosphorous release commences at an ORP <100 mV. Interestingly, even on the 4/5/08 when *Azolla* Wetland pond surface coverage had diminished, Waterbeetle aerators were not able to raise dissolved oxygen levels to those required by the guidelines and ORP levels were all <-6 mV.

ORP in the spot measurements remained below 20 mV in Pond 4 on all occasions except on 13/2/08 and next to the shore. ORP levels next to the shore? were generally higher than seen in the logging data probably because the measurement was taken higher in the water column. ORP was similar to Pond 4 in the other ponds up to and including 13/2/08. On the 13/2/08 the operation of the aerators appears to have substantially improved ORP to >100 mV compared to <0 mV prior to sunrise. However this was not accompanied by a concomitant increase in DO concentrations. ORP was generally >50 mV in Ponds 5 & 6 on the 20/2/08 and 27/02/08, although this does not appear to be due to aerators with no real change in ORP visible between sunrise and afternoon on 20/2/08.

Table 1. Weekly multi-parameter water column profiles of Pond 4. White shaded box indicates Waterbeetle(s) off, light grey shaded box indicates Waterbeetles on and dark grey coloured box indicates Waterbeetles turned on but not yet started.

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(˚C)	Depth(m)
17/01/2008	Shore	1430	167	13.1	-27	1.3	9.8	29.6	0.0
	2m	1430	145	11.3	-16	1.3	9.8	26.6	0.5
	4m	1430	68	5.5	-23	1.3	9.4	26.1	1.0
	6m	1430	56	4.5	-6	1.3	9.2	25.7	1.0
	8m	1430	100	8.3	-30	1.3	9.8	25.6	1.0
	10m	1430	103	8.4	-20	1.3	9.7	25.6	1.0
	12m	1430	139	12.2	-21	1.3	9.8	26.0	1.0
	Beetle Bot	1430	128	10.2	-13	1.3	9.7	26.2	1.0
	Beetle Sur	1430	150	12.0	-19	1.3	9.9	26.7	0.0
30/01/2008	Shore	1630	111	11.4	-103	1.3	9.8	29.1	0.0
	2m	1630	22	1.8	-93	1.4	9.4	26.5	0.8
	4m	1630	4	0.3	-173	1.4	8.3	25.8	1.1
	6m	1630	9	0.8	-179	1.4	8.8	25.4	1.1
	8m	1630	17	1.4	-172	1.4	9.0	26.2	1.1
	10m	1630	14	1.1	-129	1.4	9.2	26.1	1.1
	12m				ND				
	Beetle Bot	1630	27	2.3	-129	1.4	9.1	25.7	1.0
	Beetle Sur	1630	187	14.0	-124	1.3	10.2	30.2	0.0
6/02/2008	Shore	1556	56	4.4	-105	1.4	9.3	27.5	0.0
	2m	1557	35	2.0	-109	1.4	9.1	26.6	0.7
	4m	1558	2	0.2	-155	1.4	8.2	26.1	1.1
	6m	1559	14	0.9	-180	1.4	9.8	26.2	1.1
	8m	1601	20	2.2	-161	1.4	8.9	26.2	1.2
	10m	1602	13	1.3	-149	1.4	8.9	26.2	1.0
	12m	1604	13	0.9	-159	1.4	8.9	26.2	0.9
	Beetle Bot	1606	8	0.4	-159	1.4	8.8	26.1	0.9
	Beetle Sur	1608	26	2.1	-159	1.4	8.9	26.2	0.0
13/02/2008	Shore	835	26	1.4	-63	1.0	8.3	24.1	0.0
	2m	836	3	0.3	-89	1.1	8.2	24.2	0.6
	4m	837	5	0.4	-104	1.0	8.1	24.2	1.0
	6m			ND					
	8m			ND					
	10m			ND					
	12m			ND					
	Beetle Bot			ND					
	Beetle Sur	ND							
	Shore	1402	91	7.1	216	0.8	8.3	28.8	0.0
	2m	1404	5	0.4	107	1.0	7.5	25.1	0.7
	4m	1407	10	0.8	120	1.0	7.5	25.0	0.9
	6m	1409	9	0.7	107	1.0	7.4	24.7	1.0
	8m	1411	2	0.1	85	1.0	7.4	24.6	1.0
	10m	1412	5	0.4	86	1.0	7.5	24.6	1.0
	12m	1413	5	0.4	90	1.0	7.5	24.7	1.0
	Beetle Bot	1414	5	0.4	110	1.0	7.5	24.7	1.1
	Beetle Sur	1415	144	10.7	155	0.9	8.9	28.6	0.0
20/02/2008	Shore	740	1	0.1	68	0.9	7.4	20.9	0.0
	2m	743	-2	-0.1	-133	0.9	7.1	21.2	1.0

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(˚C)	Depth(m)
	6m	745	0	0	-90	1.1	7.4	21.0	1.0
	9m	746	0	0	-95	0.9	7.3	21.0	0.9
	Beetle Bot	748	0	0	-84	1.1	7.4	21.0	0.8
	Beetle Sur	750	0	0	-68	1.1	7.1	20.9	0.0
	Shore	1355	11	0.9	107	1.1	7.5	22.2	0.0
	2m	1356	3	0.2	-25	1.1	7.4	21.3	0.9
	6m	1358	1	0.0	-39	1.1	7.5	21.4	0.9
	9m	1359	1	0.0	-52	0.9	7.5	21.3	1.0
	Beetle Bot	1400	4	0.3	-3	1.1	7.4	21.3	1.0
	Beetle Sur	1401	2	0.1	20	1.1	7.5	21.3	0.0
27/02/2008	Shore	ND	1	0.0	19	1.2	7.3	23.3	0.0
	2m	ND	0	0	-101	1.2	7.0	23.4	1.0
	6m	ND	0	0	-98	0.9	7.2	23.4	1.0
	9m	ND	0	.0	-109	0.9	7.2	23.5	1.0
	Beetle Bot	ND	0	0	-111	0.9	7.2	23.5	1.0
	Beetle Sur	ND	0	.0	-106	1.0	7.2	23.5	0.0
04/05/2008	Shore	1120	88.3	8.2	109	1.4	7.1	18.8	0.0
	2m	1121	71.3	6.7	18	1.4	7.5	18.2	0.9
	6m	1122	68	6.4	2	1.4	7.6	18.0	1.0
	9m	1123	67.4	6.4	-47	1.4	7.6	18.1	1.2
	Beetle Bot	1124	68.8	6.5	-29	1.4	7.6	18.1	1.0
	Beetle Sur	1125	70.4	6.7	-9	1.4	7.7	18.1	0.0

Table 2. Weekly multi-parameter water column profiles of Pond 5. White shaded box indicates Waterbeetle(s) off, light grey shaded box indicates Waterbeetles on and dark grey coloured box indicates Waterbeetles turned on but not yet started.

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(°C)	Depth(m)
17/01/2008	Shore	1330	78	6.1	-20	1.4	8.7	27.8	0.0
	2m	1330	54	4.2	-3	1.3	8.5	27.3	0.5
	4m	1330	52	4.1	2	1.4	8.4	27.3	0.8
	6m	1330	52	4.2	3	1.4	8.4	27.4	0.8
	8m	1330	51	4.1	-9	1.4	8.4	27.4	0.8
	Beetle Bot	1330	60	3.9	-55	1.4	8.4	27.4	1.0
	Beetle Sur	1330	54	4.3	-31	1.4	8.4	27.4	0.0
30/01/2008	Shore	1530	22	1.7	-80	1.5	7.7	28.5	0.0
	2m	1530	4	2.9	-110	1.5	7.9	25.2	0.6
	4m	1530	2	0.1	-205	1.5	7.6	24.3	0.9
	6m	1530	2	0.1	-230	1.5	7.5	23.9	1.1
	8m	1530	2	0.1	-228	1.5	7.6	23.9	1.0
	Beetle Bot	1530	1	0.1	-236	1.5	7.8	24.1	1.0
	Beetle Sur	1530	2	1.8	175	1.5	8.0	28.0	0.0
6/02/2008	Shore	1519	10	0.8	-30	1.6	6.6	25.9	0.0
	2m	1523	5	0.4	-85	1.6	7.9	25.9	1.0
	4m	1525	5	0.4	-99	1.6	7.9	25.9	0.8
	6m	1527	1	0.1	-151	1.6	7.7	25.0	0.8
	8m	1529	6	0.5	-125	1.6	7.9	25.9	1.0
	Beetle Bot	1530	5	0.4	-122	1.6	7.9	25.9	0.8
	Beetle Sur	1532	6	0.6	-110	1.6	7.9	25.9	0.0
13/02/2008	Shore	804	15	1.2	47	1.0	6.9	23.7	0.0
	2m	806	8	0.8	-28	1.0	7.6	23.6	0.6
	4m	807	3	0.3	-52	1.0	7.8	23.6	1.0
	6m	809	2	0.2	-85	1.0	7.8	23.5	1.1
	8m	811	4	0.4	-93	1.1	7.8	23.4	1.1
	Beetle Bot	813	2	0.1	-131	1.1	7.7	23.5	1.2
	Beetle Sur	814	9	0.7	-112	1.0	7.8	23.5	0.0
	Shore	1331	72	5.6	208	1.0	7.4	27.5	0.0
	2m	1333	30	2.4	203	1.0	7.2	25.1	0.6
	4m	1335	20	1.6	189	1.0	7.2	24.6	1.0
	6m	1336	24	1.9	178	1.0	7.2	24.6	1.0
	8m	1337	17	1.4	171	1.0	7.2	24.6	1.0
	Beetle Bot	1339	15	1.3	159	1.0	7.1	24.5	1.1
	Beetle Sur	1340	49	3.9	180	1.0	7.2	26.6	0.0
20/02/2008	Shore	753	16	1.4	118	1.1	7.4	19.9	0.0
	3m	755	12	1.0	107	1.2	7.3	20.1	0.8
	6m	756	7	0.6	90	1.2	7.3	20.0	1.0
	Beetle Bot	757	538	0.6	80	1.2	7.3	19.8	1.0
	Beetle Sur	758	14	1.2	103	1.3	7.3	20.1	0.0
	Shore	1345	42	3.7	130	1.1	7.5	22.0	0.0
	3m	1346	38	3.4	98	1.1	7.4	21.4	1.0
	6m	1348	25	2.2	42	1.2	7.3	21.4	1.0
	Beetle Bot	1349	33	2.9	63	1.2	7.4	21.4	1.1
	Beetle Sur	1351	36	3.2	94	1.1	7.4	21.5	0.0
27/02/2008	Shore	820	7	0.6	117	1.3	7.2	24.0	0.0

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(˚C)	Depth(m)
	3m	821	4	0.3	99	1.3	7.2	24.0	0.9
	6m	823	1	0.1	74	1.3	7.2	24.0	1.0
	Beetle Bot	825	0	0.0	-17	1.3	7.1	23.8	1.0
	Beetle Sur	827	2	0.2	82	1.3	7.2	23.8	0.0
4/05/2008	Shore	1140	45	4.3	9	1.3	7.4	17.7	0.0
	3m	1141	38	3.7	-32	1.3	7.3	17.7	1.0
	6m	1142	37	3.6	-30	1.3	7.3	17.7	1.0
	Beetle Bot	1143	38	3.7	-31	1.3	7.3	17.7	1.0
	Beetle Sur	1144	41	3.9	-15	1.3	7.3	17.7	0.0

Table 3. Weekly multi-parameter water column profiles of Pond 6. White shaded box indicates Waterbeetle(s) off, light grey shaded box indicates Waterbeetles on and dark grey coloured box indicates Waterbeetles turned on but not yet started.

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(˚C)	Depth (m)
17/01/2008	Shore	1400	46	3.9	7	1.4	8.5	27.8	0.0
	2m	1400	41	3.5	7	1.4	8.3	26.8	0.5
	4m	1400	40	3.5	-12	1.4	8.4	26.8	0.8
	6m	1400	40	3.3	-27	1.4	8.3	26.7	1.0
	8m	1400	10	0.9	-79	1.4	8.2	26.7	1.2
	10m	1400	37	2.9	-57	1.4	8.3	26.8	1.2
	Beetle Bot	1400	11	1.0	-92	1.4	8.2	26.7	1.3
	Beetle Sur	1400	43	3.3	-47	1.4	8.3	26.8	0.0
30/01/2008	Shore	1600	28	1.4	-100	1.5	8.1	28.0	0.0
	2m	1600	4	0.3	-151	1.5	8.0	26.2	0.6
	4m	1600	2	0.2	-170	1.5	8.0	25.6	0.7
	6m	1600	3	0.3	-192	1.5	8.0	25.3	0.9
	8m	1600	1	1.0	-192	1.5	8.0	25.2	1.0
	10m	1600	11	0.5	-172	1.5	7.9	25.3	1.3
	Beetle Bot	1600	1	0.1	-175	1.5	7.7	25.2	1.3
	Beetle Sur	1600	8	0.8	-165	1.4	8.0	27.0	0.0
06/02/2008	Shore	1451	10	0.8	14	1.6	7.4	26.6	0.0
	2m	1453	4	0.3	-89	1.6	7.7	25.9	0.8
	4m	1455	5	0.4	-99	1.5	7.8	25.9	0.9
	6m	1456	3	0.2	-104	1.5	7.8	25.9	1.1
	8m	1458	4	0.4	-96	1.6	7.9	25.9	1.1
	10m	1500	4	0.3	-100	1.6	7.9	26.0	1.2
	Beetle Bot	1501	1	0.1	-172	1.5	7.8	25.6	1.3
	Beetle Sur	1502	5	0.4	-153	1.6	7.9	26.0	0.0
13/02/2008	Shore	817	20	1.6	-60	1.0	8.0	24.2	0.0
	2m	819	8	0.8	-94	1.0	8.0	24.2	0.8
	4m	820	14	1.1	-83	1.0	8.0	24.2	0.8
	6m	821	8	0.7	-85	1.0	8.0	24.2	1.0
	8m	823	4	0.2	-95	1.0	8.0	24.2	1.2
	10m	825	13	1.1	-102	1.0	8.0	24.1	1.2
	Beetle Bot	826	1	0.1	-104	1.0	7.9	24.2	1.3
	Beetle Sur	828	12	1.1	-128	1.0	7.9	24.1	0.0
	Shore	1317	78	6.0	269	1.0	7.4	27.8	0.0
	2m	1320	48	3.8	257	1.0	7.4	25.4	0.6
	4m	1322	30	2.5	246	1.0	7.2	25.1	0.9
	6m	1324	27	2.2	225	1.0	7.2	24.8	1.1
	8m	1325	28	2.2	211	1.0	7.2	24.7	1.1
	10m	1326	26	2.1	195	1.0	7.2	24.8	1.2
	Beetle Bot	1327	24	2.0	182	0.9	7.2	24.7	1.2

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(˚C)	Depth (m)
	Beetle Sur	1329	51	4.1	192	1.0	7.3	26.3	0.0
20/02/2008	Shore	759	19	1.7	108	1.2	7.4	20.7	0.0
	4m	801	16	1.4	99	1.1	7.3	20.9	1.0
	8m	803	11	0.7	74	1.1	7.3	20.8	1.2
	Beetle Bot	804	12	1.0	94	1.1	7.3	20.8	1.2
	Beetle Sur	805	13	1.2	94	1.1	7.3	20.8	0.0
	Shore	1335	55	4.8	126	1.2	7.6	22.0	0.0
	4m	1336	46	4.0	106	1.2	7.5	21.8	1.0
	8m	1338	40	3.6	107	1.2	7.5	21.8	1.2
	Beetle Bot	1339	38	3.3	109	1.2	7.4	21.8	1.2
	Beetle Sur	1340	44	3.8	102	1.1	7.5	21.9	0.0
27/02/2008	Shore	801	20	1.6	169	1.2	7.0	24.6	0.0
	4m	803	14	1.1	117	1.2	7.2	24.7	1.0
	8m	805	8	0.7	86	1.2	7.2	24.7	1.2
	Beetle Bott	807	7	0.6	83	1.2	7.2	24.7	1.1
	Beetle Sur	809	11	0.9	100	1.2	7.3	24.7	0.0
04/05/2008	Shore	1134	45	4.4	43	1.3	7.4	18.0	0.0
4/05/2008	4m	1135	42	4.0	31	1.3	7.4	18.0	0.8
4/05/2008	8m	1136	39	3.7	-9	1.3	7.3	18.0	1.2
4/05/2008	Beetle Bot	1137	38	3.6	-27	1.3	7.3	18.0	1.2
4/05/2008	Beetle Sur	1138	43	4.0	-12	1.3	7.3	18.0	0.0

Table 4. Weekly multi-parameter water column profiles of Discharge Drain. White shaded box indicates Waterbeetle(s) off, light grey shaded box indicates Waterbeetles on and dark grey coloured box indicates Waterbeetles turned on but not yet started.

Date	Site	Time (h)	DO(%)	DO(mg/L)	ORP (mV)	EC(mS/cm)	pH	Temp(°C)	Depth(m)
17/01/2008	Surface	1400	50	4.0	18	1.4	8.1	26.5	0.0
	Bottom	1400	35	2.7	-49	1.4	8.1	26.2	0.5
30/01/2008	Surface	1600	0.1	1.0	-99	1.5	8.1	26.9	0.0
	Bottom	1600	0.3	2.9	-117	1.5	8.1	25.8	0.4
06/02/2008	Surface	1549	8	1.4	-129	1.6	7.2	25.7	0.0
	Bottom	1551	3	0.3	-175	1.6	7.8	25.6	0.5
13/02/2008	Surface	832	37	3.0	-49	1.0	8.1	24.2	0.0
	Bottom	830	35	2.9	-54	1.0	8.2	24.3	0.5
	Surface	1428	69	5.5	174	1.0	7.5	27.2	0.0
	Bottom	1427	56	4.4	176	0.9	7.5	26.5	0.4
20/02/2008	Surface	735	30	2.7	166	1.2	7.3	21.1	0.0
	Bottom	737	33	2.9	153	1.1	7.4	21.0	0.5
	Surface	1403	56	4.9	117	1.1	7.5	21.5	0.0
	Bottom	1404	51	4.3	115	1.1	7.5	21.6	0.5
27/02/2008	Surface	830	29	2.4	139	1.2	7.3	24.6	0.0
	Bottom	832	26	2.1	135	1.2	7.3	24.6	0.5
04/05/2008	Surface	1128	60	5.76	50	1.285	7.53	17.92	0.0
	Bottom	1129	57	5.4	35	1.288	7.42	17.89	0.5

6 Conclusions

Monitoring of the performance of aeration by Waterbeetles of three Liege Street Constructed Wetland ponds from January to May 2008 found that;

1. Submerged and floating aquatic macrophyte biomass may reach nuisance proportions leading to inhibition of mixing and further oxygen drawdown by respiration at night.
2. There is a very high oxygen demand (chemical and/or biological) in wetland pond sediments or in wetland influent water.
3. For pond aeration treatment to be successful, aeration must occur over the entire duration that oxygen demand occurs. That is, aeration must be made over a full 24 h per day.
4. The trialled Waterbeetle aerators were unable to achieve (except in isolated instances) the required levels of DO and ORP to ensure that phosphorous release did not occur.
5. Aerators were unable to achieve (except in isolated instances) the required levels of dissolved oxygen needed to reach ANZECC/ARMCANZ (2000) guidelines for wetland habitat water quality.
6. There was no direct correlation between dissolved oxygen concentrations and ORP in wetland ponds.

7 Recommendations

Following are recommendations based upon our previous experiences elsewhere, the results of this study and current scientific literature.

1. As demonstrated by extreme values logged for pH, ORP and the low DO, urban discharge into the wetland is often of extremely poor quality and potentially exceeds design parameters for an engineered nutrient removal wetland.

    - An investigation should be made into the nature and source of poor water quality entering Liege Street Wetland. Can inputs be altered through catchment management to enable the wetland to avoid high BOD water/sediment sources. Aeration location alternatives such as introduction of aeration weirs etc in influent drains could also enhance DO concentrations.

    - A study should investigate whether aeration (artificial or physical) could be implemented closer to the location of where the drains enter the wetland system. This would have the advantage of increasing dissolved oxygen but also enhance nitrification which in turn would enhance nitrogen removal through denitrification under anaerobic conditions. Currently the wetland performance for nitrogen removal is below what would be expected given the ORP conditions, which are favourable to denitrification.

2. In the absence of aeration activity, it is extremely likely that the low ORP value encountered near the water-sediment interface will also release heavy metals settled in the wetland ponds.

    - We recommend that the potential issue of heavy metal release from the sediments be investigated so that an effective prevention strategy can be developed.

3. Aquatic plant biomass (e.g., *Azolla* and *Potamogeton*) is likely contributing to low ORP and dissolved oxygen values, particularly those encountered over night.

    - Investigate the role aquatic plants are playing in the water quality and efficiency of the wetland treatment system in view of their management.

4. Wetland pond sediment is the main nutrient sink, therefore as low ORP may cause nutrient release it may then start acting as a nutrient source.

    - Investigate depth and chemical composition of pond sediments to determine the ongoing capacity for nutrient uptake.

5. We do not recommend continuing use of Waterbeetle aerators, as there is little demonstrable benefit of their use.

    - Any future aeration must account for the high resident aquatic macrophyte biomass, particularly complete wetland pond surface area coverage of *Azolla*.
    - Any future aeration must operate continuously over 24 h per day. Operational redundancy is also an important consideration as failure of an aerator may lead to significant nutrient export over a short-term.

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9 References

ANZECC/ARMCANZ (2000). *Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy Paper No 4*. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra. 1,500pp.

GHD Pty Ltd (2007). *Liege Street Wetland Performance Report 2005 to 2006.* GHD Pty Ltd, Perth, Australia. Prepared for the Swan River Trust.

Sainty, G. R. & Jacobs, S. W. L. (2003). *Waterplants in Australia - a field guide.* 4th edn, Sainty and Associates, Darlinghurst. 415pp.

Syrinx Environmental Pl (2004). *Liege Street Demonstration Wetland concept design*. Technical Report Syrinx Environmental Pl, Perth, Australia. 51pp.

Systat Software Inc. (2004). SigmaPlot for Windows. 9.01, Systat Software Inc., Point Richmond, California, USA.