Towards a Farm Scale Best Management Practice for the Eradication of the Noxious Weed *Hymenachne Amplexicaulis* in Sandringham Lagoon, Mackay, Queensland

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1.0 Introduction

The risk of weed infestation in fresh water ecosystems is a well recognised problem in tropical and semi tropical areas of Australia. In the Mackay Whitsunday Natural Resource Management (MWNRM) region the introduced grass *Hymenachne amplexicaulis* has been identified as a weed that poses a potential risk to the natural (i.e. fresh water rivers and wetlands and possible flow through effects to the Great Barrier Reef Lagoon) and economic (cane growing) well being of the region.

This report details the findings of a six month, farm scale research project designed to establish an effective eradication strategy for Hymenachne infestations of various sizes. Field research was conducted in the fresh water wetland Sandringham Lagoon located approximately 15km south of the regional hinterland city of Mackay. The project was designed around the needs of Sugar Cane growers, with emphasis on delivery of management strategies that individual farmers could employ for Hymenachne infestations with similar characteristics to those found in the research area.

1.1 Hymenachne Biology and Ecology

Hymenachne amplexicaulis is a semi-aquatic perennial grass introduced to Queensland in 1988 as a "ponded pasture" from South and Central America. Hymenachne is a robust, rhizomatous grass that can grow to a height of 1.5 meters. Its erect stems emerge from a prostrate base and are filled with aerenchyma (white pith). Roots may be produced at the lower nodes of the stem. The leaf blades are mostly lanceolate and cordate at the base and are 10-45cm long and up to 3cm wide. Leaves strongly clasp the

stem at the leaf base, which is the significant difference between the native hymenachne (*H. acutigluma*) whose leaves don't. Flower heads are spike-like, cylindrical, 20-40cm long and sometimes branched.

In the Mackay area and Queensland in general the plant is in its early stages of spread and has the potential to colonise much larger areas than where it currently exists. Based on climate modelling, hymenachne has the potential to grow within suitable habitats in coastal and sub-coastal freshwater wetlands of Queensland, probably extending into northeast New South Wales. The majority of problematic infestations are expected to be associated with riverbanks and freshwater, seasonal wetlands where there is a high influx of nutrient and sediments from upstream agricultural sources (NRM&E, 1999).

Soil moisture content is an important factor in the survival and abundance of hymenachne. The plant requires sub-soil moisture in the dry season and fails to live if this moisture doesn't exist. Hymenachne is highly persistent and can survive prolonged periods of flooding, up to 297 consecutive days (Tejos, 1980).

Hymenachne prefers full sun and in some situations can be suppressed by shading with overhanding trees. The plant can't survive if it is defoliated or weakened and a flood inundates the plant so that it can't maintain leaves above the water (Commonwealth of Aust. and National Weeds Strategy, 2001).

Reproduction occurs vegetatively in addition to seeds. Broken stems/stolons fragments can be transported large distances with water as its vector, where it can disperse in public

waterways (stormwater run-off), irrigation storage facilities, sugar cane crops and natural wetlands.

Flowering occurs from April to June, with seeds set from April through to August. Within wet years anecdotal evidence suggests plants can flower and set seed over a longer length of time.

Figure 1 A typical stand of Hymenachne *amplexicaulis*, where the width of the photo area is just over 1m.

1.2 Problems Associated with Hymenachne

In August 1988, hymenachne was approved for release by the Queensland Herbage Plant Liason Committee, which recommended registration on the submission of the Department of Primary Industries (Wildin, 1989a, 1989b). As a dry season high protein cattle fodder in ponded or seasonally inundated areas hymenachne was introduced in

situations where the water was to deep for Para grass. The first sign of hymenachne being problematic came in the late 1980's when cane farmers noticed the plant had escaped from pastures and naturalised in the 'Red Lily Lagoon' area of the lower Burdekin, coastal North Queensland (Schultz, 1997).

Hymenachne is problematic as it invades and dominates waterways including rivers, creeks, drains and lagoons. It affects waterways by:

- Degrading water quality – Heavy infestations affect photosynthesis in other water plants by reducing the amount of sunlight available. Open water surface air exchange is also affected. As plant material decomposes it uses oxygen, causing water pollution and stagnation, which in turn affects water quality and may result in aquatic plant and animal deaths. A loss of native flora and fauna has ecological and economical impacts, with tourism likely to be affected.

- Interference with economics – Stock may have difficulty gaining access to drinking water under heavy infestations.

  When flooding occurs floating masses of plant have potential to drag down established fences, block drainage ditches and damage bridges. Within low lying poor drained land hymenachne can invade sugar cane crops, causing crop contamination and increased production costs. Irrigation equipment performance may also be reduced by hymenachne presence.

  The fishing industry is concerned as hymenachne may invade and modify juvenile barramundi areas. Additionally pondage banks planted with hymenachne may interfere with marine plain saltwater inundation, affecting

numerous estuarine species (Commonwealth of Aust. and National Weeds Strategy, 2001)

- Flooding – Dense hymenachne can cause modification/diversion of current watercourses. Hymenachne reduces the flow capacity of some waterway networks and may increase the risk of flooding.

- Safety and health risks – Entangled masses of hymenachne increase the risk of children and livestock becoming caught and drowning.

  Mosquitoes that carry numerous disease risks including (Ross River and encephalitis) breed and shelter within dense hymenachne mats.

1.3 Legislation and Background

Hymenachne, described by some, as Queensland worst environmental weed, became a Class 2 declared plant with the introduction of the *Land Protection (Pest and Stock Route Management) Act 2002.* Prior to this act, Hymenachne was not declared under the *Rural Lands Protection Act 1986.* A Class 2 plant is defined as being established in the State and is causing, or has the potential to cause, an adverse economic, environmental or social impact in the State, another State or a part of the State or another State. Under the *Land Protection (Pest and Stock Route Management) Act 2002* Local Governments which have Hymenachne within the shire will need to incorporate the plant into their Local Government Pest Management Plans. The Shires Pest Management Plan will define what the Local Governments goal/objective is with Hymenachne and how they plan to achieve this goal. Hymenachne control goals may differ between Local Government bodies pending on such factors as; current distribution and density;

resources available; feasibility of control, and; community expectations. Sandringham Lagoon the project area defined within this report falls within Mackay City Council Local Government area. Mackay City Council within their draft 2004/2005 Pest Management Plan have defined Hymenachne as a high priority pest, with a goal to control and reduce Hymenachne from waterways under council and private control.

Although not mapped precisely within the past, Hymenachne was not considered a significant pest within Mackay City Council. For several years prior to the project Hymenachne was seen to be visually increasing in distribution and density within the Mackay region. Hymenachne management as with all pest management is best achieved using a preventative approach rather than a cure. As Hymenachne appeared to be in its infancy as a pest, immediate management of the pest issue was essential prior to Hymenachne filling its niche within the area. Benefits of undertaking control at this stage far outweigh costs associated with future management.

Hymenachne control includes either manual (fire, mechanical, hand removal) or chemical control. As Hymenachne is an attached water plant manual removal whilst water is present is difficult and thus chemical control is usually the most time/resource efficient control method. Given some water is usually present when chemical control is undertaken the Mackay Community, in particular the cane industry were interested in determining effective chemical control quantities which don't, or least minimise, environmental off target risks. The regions catchments are adjacent to the Great Barrier Reef World Heritage Area and thus the community is aware and wary of any chemical usage within waterways. The need to undertake effective Hymenachne management with minimal environmental consequence is the basis of undertaking this project.

1.4 Project Limitations

Only chemicals readily available for stakeholder use and registered for Hymenachne use where considered for this project. The only registered product is:-

PER4718 Minor off label use –

Roundup Biactive Herbicide by Monsanto plus other registered products specifically approved for use in aquatic situations contain 360g/L Glyphosate Isopropylamine salt as their only active constituent at a maximum rate of 14 L/Ha, for all bodies of water which may be flowing; non-flowing, transient and also on margins of streams, lakes and dams, in channels and drains.

This chemical was utilised within this project.

To ensure site parameters were as similar as possible four sites where chosen within the one hydrologic system. Limitations of this project include:-

- Recommendations on spraying areas quantities are limited to hymenachne area coverage's stipulated in a given area.
- Recommendations are based only on the use of Monsanto's Roundup Biactive or other registered products which have an active ingredient concentration of 360g/L of Glyphosphate as isopropylamine salt.
- Environmental parameters and the associated effects of chemical use may differ slightly from water system to water system. Water quality threshold levels

within Sandringham may not necessarily be the same for similar systems and thus consistent threshold levels can't be stipulated.

- The project was undertaken during the regions wet season and thus results may differ in that of dryer periods.

1.5 Chemistry of Glyphosate

As mentioned above Roundup bioactive herbicide containing an active constituent of 360g/L Glyphosate Isopropylamine salt was utilised within this project. Glyphosate is a broad-spectrum, systemic, post-emergence herbicide that is phloem mobile and is readily translocated throughout the plant (Franz et al, 1997). The major pathway of uptake of glyphosate in plants is through the foliage, although some plant uptake may occur. Humidity and surfactants increase the absorption of the chemical into plant foliage. From the leaf surface, glyphosate molecules are absorbed into the plant cells. Glyphosates primary action is the inhibition of a chloroplast – localized enzyme, which prevents the biosynthesis of essential aromatic amino acids. These acids are required by plants in protein synthesis and to produce many secondary plant products such as growth promoters, growth inhibitors, phenolics and lignin (Franz et al, 1997). Visible effects including yellowing through to complete browning of above ground growth and deterioration of underground plant parts may appear seven days post spraying on most perennial weeds.

Glyphosate is highly soluble in water and is stable in water at pH 3, 5, 6 and 9 @ 35°C (Schuette, 1998). Studies conducted in Manatoba Canada (Kirkwood, 1979) suggest that glyphosates loss from water is through sediment absorption and microbial degradation.

The rate of degradation in water is slower than soil, because there are fewer microorganisms in water than in most soils. Thus for all aquatic systems, sediment appears to be the major sink for glyphosate residue. Glyphosate is relatively immobile in most soil environments as a result of its strong absorption to soil particles (Schuette, 1998). Although absorbed strongly to soil, glyphosate will not readily move through soil. Sprankle et al (1975) found that the prime factor in determining the amount of glyphosate absorbed to soil particles is the soil phosphate level and that glyphosate is bound to soil through the phosphanic acid moiety. Glyphosate competes with inorganic phosphate for soil binding sites and the degree of binding depends on availability of unoccupied phosphate binding sites (Schuette, 1998). Glyphosates primary route of decomposition is through soil microbial breakdown.

1.6 Physiography and Land Use

The project site, Sandringham Lagoon (Figure 1), is a small (give size) coastal lagoon which is approximately 8 kilometres in entirety. It is situated east of the Connors Range and is approximately 15 kilometres south of Mackay. The lagoon flows directly into Sandringham Bay, which forms part of the South Pacific Ocean. Additional waterways flowing into the Sandringham bay and adjacent to Sandringham lagoon include; Sandy creek, Bell creek; Alligator creek and Splitters creek.

The closest Hydrological gauging stations to the project site include Te Kowai station, which is approximately 15 kilometres north of the project area, and Homebush station which is approximately 13 kilometres west of the project area. No major geographical features occur between the project site and the gauging stations.

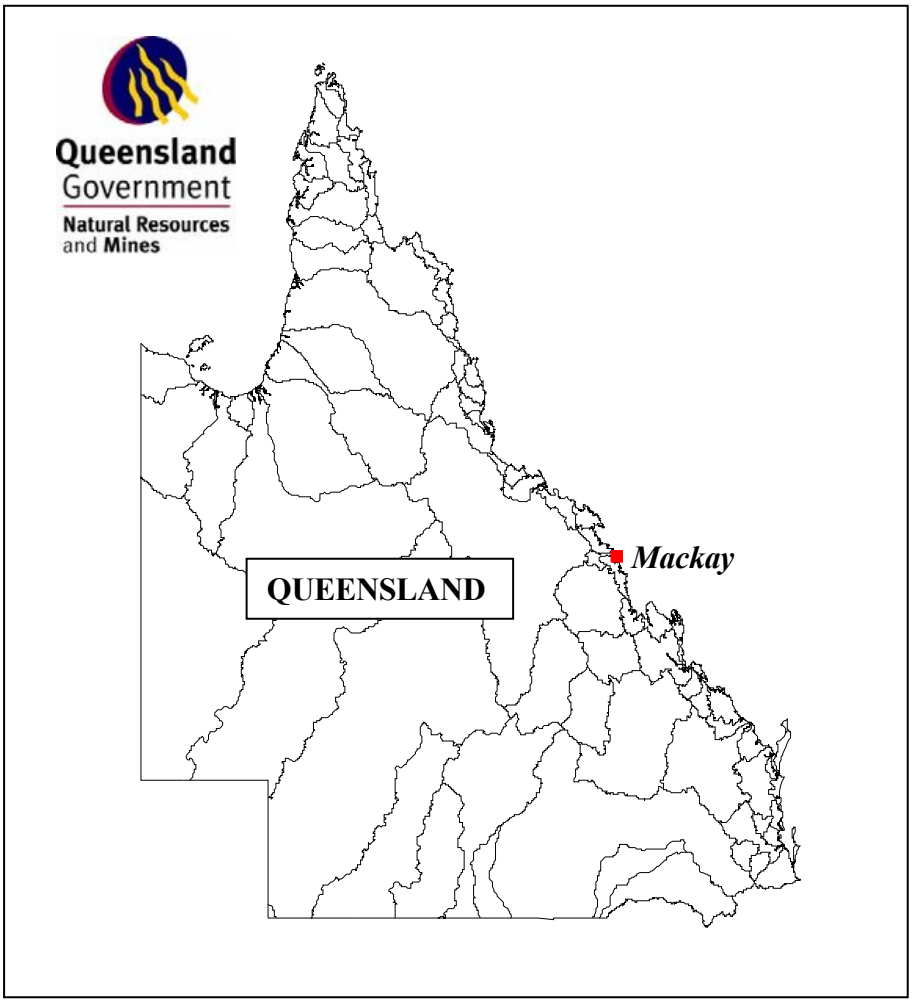

Figure 2 Regional Locality Map with Sandringham Lagoon located approximately 15km south of Mackay in the Mackay Whitsunday Natural Resource Management Region.

Average rainfall recorded for a combination of both station data from 1906 – 2004 is 1606mm. Figure 3 is a graph of the total monthly rainfall events captured at the Homebush gauging station (located within 10km of Sandringham Lagoon) during the project period. As can be seen from the graph the major rainfall events occurred from December 2003 to February 2004. It must be noted that the project period occurred within Mackay regions wet season.

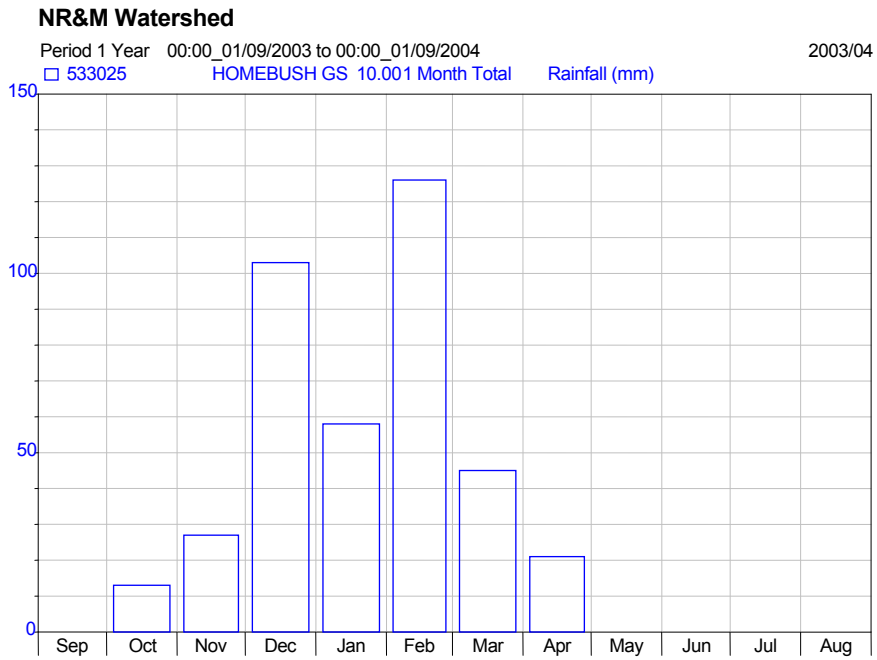

Figure 3 Histogram showing the distribution of rainfall events in the Sandringham Lagoon area during the period of the research.

Further detailed data of daily rainfall events during the project period captured from the Homebush gauging station can be viewed on the Department of Natural Resources and Mines Watershed Database.

Hymenachne flowers from April to June and thus optimum chemical control is prior to this. For effective Hymenachne chemical control at least ¾ of the plant needs to be above water level and thus the lower the water level the more strategic the control. Optimum conditions would be those where waterways/ponds dry up and maximum foliage chemical intake is achieved, whilst not affecting aquatic ecosystems. Water levels in Sandringham Lagoon during the period of the research area shown in Figure 4.

Hymenachne needs to be monitored post initial control as up to 4-5 follow-up spraying may be required. If non-aquatic areas are burnt post chemical control (plants should be burnt prior to seeding) regeneration from seedlings is minimal. Burning post seed set, seedlings will emerge.

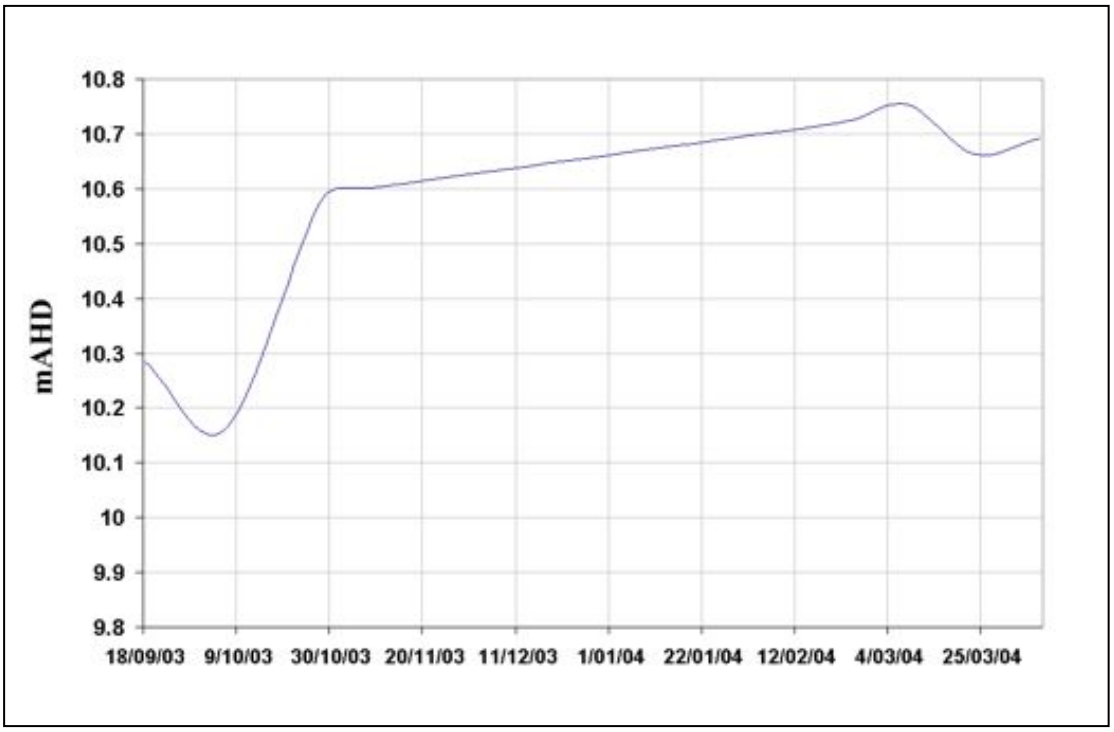

Figure 4 Water levels recorded in Sandringham Lagoon during the research period.

2.0 Methodology

The following section details key methods used during site selection, spraying and water quality monitoring for the six month collaborative program at Sandringham Lagoon. Methods employed and results derived are aimed primarily at farmers and land managers. Results of this investigation will form a launching platform for a more comprehensive research program investigating the relationships between eradication of Hymenachne and impacts upon water quality, in particular dissolved oxygen.

2.1 Site Selection

Sites were chosen primarily due to percentage of hymenachne present, proximity to other sites, and ease of access. Four sites were chosen (Figures. 5 and 6), three of which where spraying would occur, and one control site. Each site area was 60m in length,.

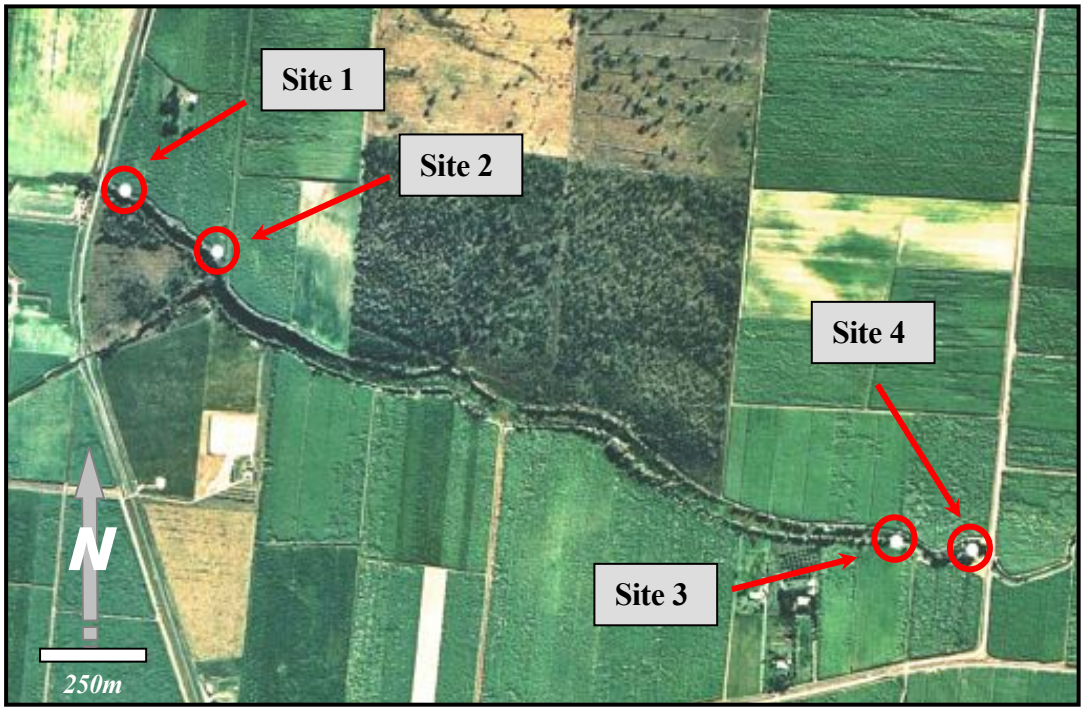

Figure 5 Map of Sandringham Lagoon showing the four sites where water quality sampling occurred.

Figure 6 Sites at Sandringham lagoon where water quality monitoring occurred.

the width depending on the creek banks and the body of water .

An important aim of this project was to create a realistic "farmer oriented" spraying schedule designed to eradicate an infestation(s) in a given water body with the minimal impact upon water quality possible. In order to create a realistic project we chose different sites (with different conditions Table 1) within the one creek system, as would be experienced by individual farmers, as opposed to similar sites within different creeks.

	mE	mN	Site area	Water volume at site	Percentage cover of Hymenachne	Areal coverage of Hymenachne	Estimated mass of Hymenachne
Site 1	719886	7643812	900m^2	4500m^3	15%	135m^2	405kg
Site 2	719889	7643724	1200m^2	5400m^3	7%	84m^2	252kg
Site 3	721631	7642916	420m^2	630m^3	40%	168m^2	504kg
Site 4	721789	7642926	300m^2	450m^3	50%	150m^2	450kg

Table 1 Site characteristics.

The perceived advantage of designing the spraying regime around sites with different site criteria, specifically degree of infestation of hymenachne, was that the results of the project would relate to realistic conditions in a given locality. Consequently, we have proposed a farm scale best management scheme for addressing infestations of different sizes within a given locality.

The strength of this approach is it's realism, whereby a farmer may adopt our program if the water body on his property is infested with differing amounts of Hymenachne in different places (such as seen at Sandringham Lagoon). The disadvantage of our adopted technique is that it only provides data for areas similar in infestation and site type as

found at Sandringham Lagoon, and has limited application in other areas. It is our aim to substantiate this detailed project with further research structured around a more methodological approach where initial conditions, specifically infestation size and anthropogenic factors, specifically amounts of chemical used, change incrementally.

2.2 Site Descriptions

The control site (site 1) was the farthest upstream. This was chosen so as to limit any influence from downstream spraying sites, presuming a limited or negligible upstream hydraulic flow. The site was characterised by steep banks, relatively little hymenachne (none on the northern bank, where water quality sampling occurred), and a moderate degree of tree cover. Water depth is reported as up to 5m deep, and is the deepest site investigated. The site is directly adjacent to the North Pacific Rail-line, where the creek width tapers to approximately 5m wide. This tapering represents the eastern end of the Sandringham Lagoon system.

Site 2 is characterised by a wider body of water than site 1, less tree coverage, and a higher amount of naturally occurring Persecaria sp.. The bank is less steep than site 1, and forms an important roosting area for bird life, particularly the Whistling Duck. Site 2 is approximately 100m downstream from site 1. Hymenachne occurs on both sides of the creek, yet is more dense on the northern side, where the water quality monitoring occurred. Depth of the water column ranges from <1m in the shallows to 4 - 5m depth in the center. As no herbicide was applied to site 1, there was presumably no downstream contamination at site 2.

Site 3 is characterised by a narrow body of water with large amounts of hymenachne on both sides and in the central body of the creek. The water at this site was shallower than at sites 1 and 2 (no greater than 1.5m depth). Presumably this is why hymenachne occurred throughout the creek. Persecaria sp is abundant around the edges, which are characteristically quite shallow. During low flow conditions this site is prone to surface algal build-ups. Site 3 is approximately 1.5km downstream from site 2, and is hydraulically disconnected from site 2 during drier periods.

Site 4 is approximately 150m further downstream from site 3, and the most heavily affected with hymenachne. It is the least wide of all the sites, and the water is typically less than 1m deep. The banks are slightly steeper than site 3, and are covered in Persciaria sp and hymenachne. Like site 3, hymenachne covers both banks and the central area of the creek. Water quality monitoring occurred on the southern side of the creek. The greater water depth at sites 3 and 4, as opposed to sites 1 and 2 will impact upon the behaviour of dissolved oxygen, whereby the sites will typically experience greater oxygen cycling as the smaller volumes are more susceptible to change.

2.3 Spraying Schedule

Typically a farmer would, given appropriate conditions, blanket spray a given area to affect a hymenachne kill. This project approaches the spraying paradigm from the persepective of;

1) What quantity of Hymenachne can be successfully controlled during a spray event without adverse impacts on water quality ?

2) What will the results of the kill be in terms of water quality ?

In accordance with the managerial / farmer focus of the program, spraying of hymenachne at each site was designed to assess how different quantities of glyphosphate affect the eradication of hymenachne and consequently relate weed death to the impact on water quality.

This process involved assessing the amount of hymenachne present at each site, then periodically spraying certain percentages of the weed at each site over the projects life (Table 2). Thus by the end of the project all the hymenachne at each site was sprayed,

	% Hymenachne sprayed per event	**Number of spray events**	**Total glyphosphate used (mg)**	**Total glyphosphate used (L)**
Site 1	0	0	0	0
Site 2	25%	8	230400	0.82
Site 3	33%	6	627480	1.743
Site 4	50%	4	559440	1.554

Table 2 Total spray data for each site.

only at different quantities and timeframes, as opposed to the traditional application of one blanket spray.

No spray was applied to site 1, the control site. Site 2 was designated the 25% spray site, site 3 the 33% spray site, and site 4 the 50% spray site. Thus at each site 25%, 33% or 50% of the hymenachne was sprayed during each spray event. This occurred until all the hymenachne had been sprayed, and was followed up by spraying of regrowth, if necessary. Consequently quantities of glyphosphate sprayed at each site differed in accordance to the amount of hymenachne at the site (Table 3). Table 3 also provides data pertaining to the area of hymenachne sprayed at each site during each spraying event,

	Data type	17/10/03	13/11/03	11/12/03	13/01/04	10/02/04	09/03/04
Site 1	Glyphosphate used	0mL	0mL	0mL	0mL	0mL	0mL
	Area sprayed	$0m^2$	$0m^2$	$0m^2$	$0m^2$	$0m^2$	$0m^2$
	Hymenachne killed	0kg	0kg	0kg	0kg	0kg	0kg
Site 2	Glyphosphate used	0mL	0mL	320mL	200mL	200mL	100mL
	Area sprayed	$0m^2$	$0m^2$	$21m^2$	$21m^2$	$21m^2$	$21m^2$
	Hymenachne killed	0kg	0kg	63kg	63kg	63kg	63kg
Site 3	Glyphosphate used	400mL	500mL	520mL	190mL	133mL	0mL
	Area sprayed	$55.44m^2$	$55.44m^2$	$55.44m^2$	follow up	follow up	follow up
	Hymenachne killed	166kg	166kg	166kg	follow up	follow up	follow up
Site 4	Glyphosphate used	600mL	800mL	100mL	54mL	0mL	0mL
	Area sprayed	$75m^2$	$75m^2$	follow up	follow up	follow up	follow up
	Hymenachne killed	225kg	225kg	follow up	follow up	follow up	follow up

Table 3 Spray data and spraying regimes for each site (based on *Hymenachne amplexicaulis* weights of 3kg per m^2 as determined for this research).

the amount of glyphosphate used (as concentrate) and the estimated weight of hymenachne sprayed.

The advantage of this staggered approach is that it provides details to managers of waterways, especially farmers, of the most effective amount of glyphosphate to use for an expected eradication outcome and relates this to the impact upon water quality via death and decay of the weed in the water column.

Application of glyphoshate occurred via a hand held extension pump directly onto the plant stem, as eradication effectiveness of the glyphosphate increases when ingested into the plant aerially. This technique also minimised the potential for eradication of Persecaria sp.. The herbicide used was Monsanto's Roundup Biactive (NRA Approval No. 48518/1102) which has an active indredient conecentration of 360,000mg/L of glyphosphate as isopropylamine & mono-ammonium salts.

2.4 Water Quality Monitoring

Sampling for physico – chemical parameters, namely; temperature; dissolved oxygen; pH; electrical conductivity and water clarity was performed at each of the four sites on a bi-monthly basis for a period of six months. The objective of the sampling regime was to assess water quality changes associated with spraying and eventual death and decay of Hymenachne. Each variable was sampled during the morning, midday and evening, referred to as the diurnal suite. Orthophosphate was sample once a day at each site.

Diurnal sampling involved assessing physico – chemical parameters at three times during the day. To maintain sample regularity each site was sampled in the same order, namely; site 4 sampled first; site 3 sampled second; site 1 sampled third; site 2 sampled last. Consequently monthly sampling typically occurred at similar times at each place.

Sampling was conducted in conjunction with spraying. For one spray event there were two sampling events. Typically sampling would occur the day before a spraying event, and two weeks after an event. Results show that this degree of sampling was adequate to reveal major physico – chemical trends, including consumption of oxygen, and resultant recovery curves, associated with the degradation of biota caused by the spraying.

In order to accommodate the temporal data, a database (Appendix 1) was constructed where each sampling was assigned an individual number (termed a POSKEY number). The database holds 151 POSKEY numbers, which represents six months of diurnal sampling, and two months of point sampling, prior to the onset of the spraying.

Physico – chemical parameters from a site with 100% Hymenachne cover was also chosen to periodically compare against the four main sites. In each case the dissolved oxygen concentrations in the site with 100% Hymenachne were lower than the four sites, even during peak death times, when dissolved oxygen concentrations were low (Figure 7). These result reveals the extremely pervasive nature of Hymenachne within a riverine ecosystem, highlighting the necessity of eradication of the weed in the aquatic environment.

This data supports the conclusion that the do nothing approach will not be effective in managing *Hymenachne amplexicaulis* in fresh water ecosystems in the Mackay Whitsunday Natural Resource Management Region.

At the site with 100% hymenachne infestation it was also qualitatively noted that there was less natural wildlife both in and around the water. Presumably the lower dissolved oxygen levels result in the loss of native fish and invertebrate species, whilst the physical clogging of the wetland results in the loss of roosting and feeding areas for birds. At this site there was a noticeable loss of biodiversity.

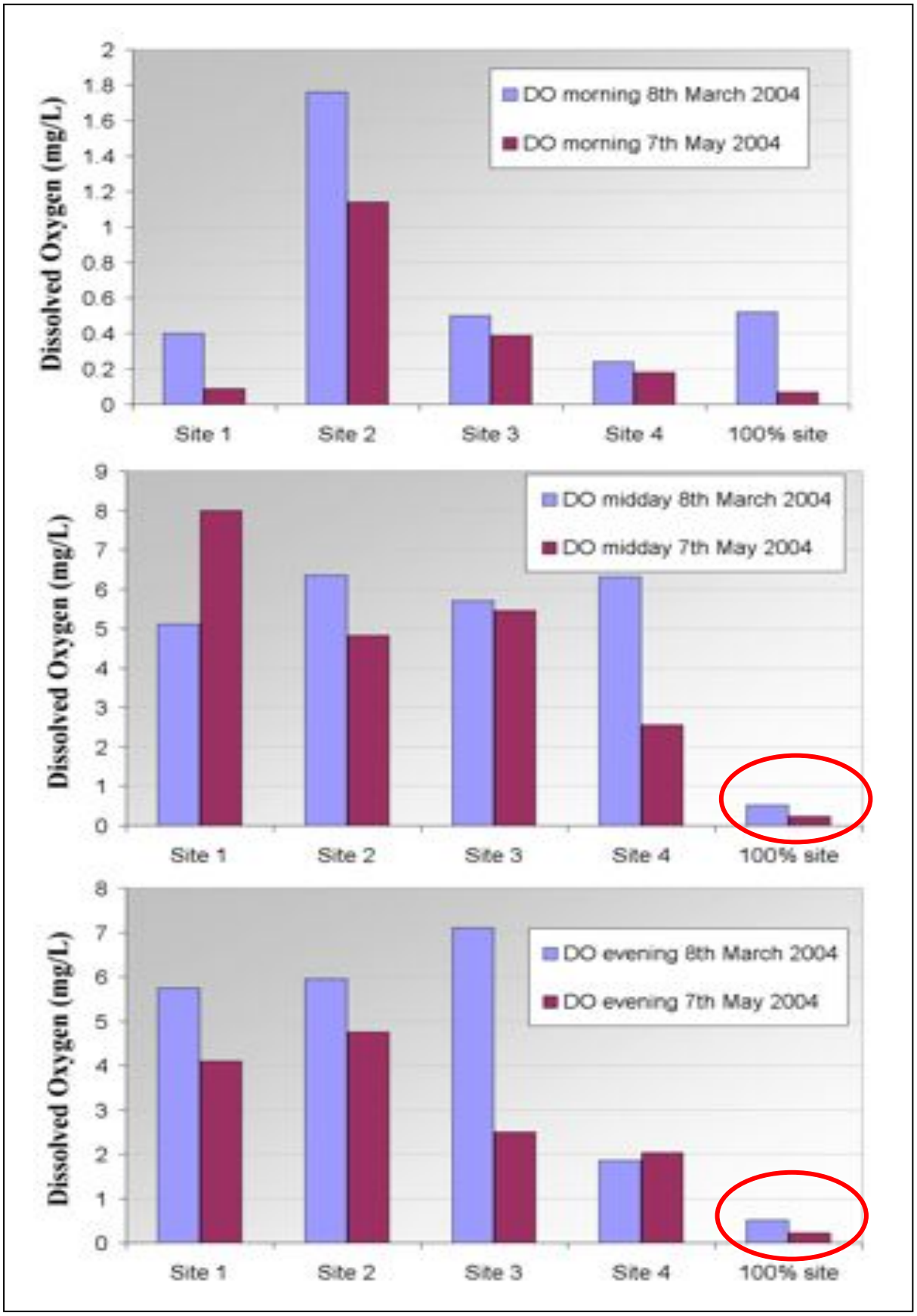

Figure 7 Comparison of diurnal dissolved oxygen data from water quality sites and site with 100% hymenachne. Red circles show the suppressed dissolved oxygen concentrations, highlighting the impact of hymenachne upon the oxygen cycle.

3.0 Results

Presented below are the results, mainly in graph form, of water quality monitoring for the six month life of the project. Due to it's biological significance, and it's highly variable behaviour in aquatic environments, dissolved oxygen is deemed the critical parameter, and will be reported most extensively in the following section.

3.1 Dissolved Oxygen

Dissolved oxygen is vital to life in the aquatic ecosystem. The natural fluctuation of dissolved oxygen during a diurnal cycle typically follows the trend of biological activity in the water column. Broadly speaking, when there is a lot of sunlight (i.e. midday conditions to afternoon conditions) there is a high degree of photosynthesis (growth of cells), resulting in the production of oxygen (equation 1). The cycle is reversed during plant respiration at night (equation 2), consequently, early morning samples are typically expected to have low dissolved oxygen levels.

Equation 1 $6H20 + 6CO2 \rightarrow C6H12O6 + 6O2$ **(photosynthesis)**

Equation 2 $C6H12O6 + 6O2 \rightarrow 6CO2 + 6H2O$ **(respiration)**

Expected diurnal trends were observed in Sandringham Lagoon prior to spraying, however, post spraying (and subsequent death of hymenachne) these trends became substantially impaired. Table 4 lists mean and standard deviation for all dissolved oxygen data collected. Each site has high standard deviations, revealing the high degree

	Morning		Midday		Evening	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Site 1	0.68	0.70	5.30	2.23	4.53	2.13
Site 2	1.05	0.69	5.95	1.11	5.69	2.12
Site 3	0.65	0.28	3.85	1.91	3.04	1.70
Site 4	0.26	0.08	2.90	1.50	2.37	2.10

Table 4 Data matrix listing mean and standard deviation results for diurnal sampling of dissolved oxygen (mg/L) at all sites.

of variation in dissolved oxygen concentrations. This high degree of difference is due to both natural and anthropogenic factors.

Sampling for dissolved oxygen occurred using WTW Oxi330i meter and probe. Calibration of the probe occurred prior to every sample. Duplication of results at key sites reveals less than 2% instrumental / analytical error. Dissolved oxygen was sampled as both % saturation and mg/L, yet are reported in mg/L.

3.1.1 Site 1

Figure 8 reveals that for all sampling events dissolved oxygen concentrations were lower for the morning than for the midday or evening. This is an expected result, and reflects the natural cycle of oxygen within riverine ecosystems. Typically the highest concentrations of oxygen occur during the day (midday samples), though this reflects site weather conditions. For instance, during cloudy conditions dissolved oxygen concentrations were occasionally higher for evening samples than midday samples.

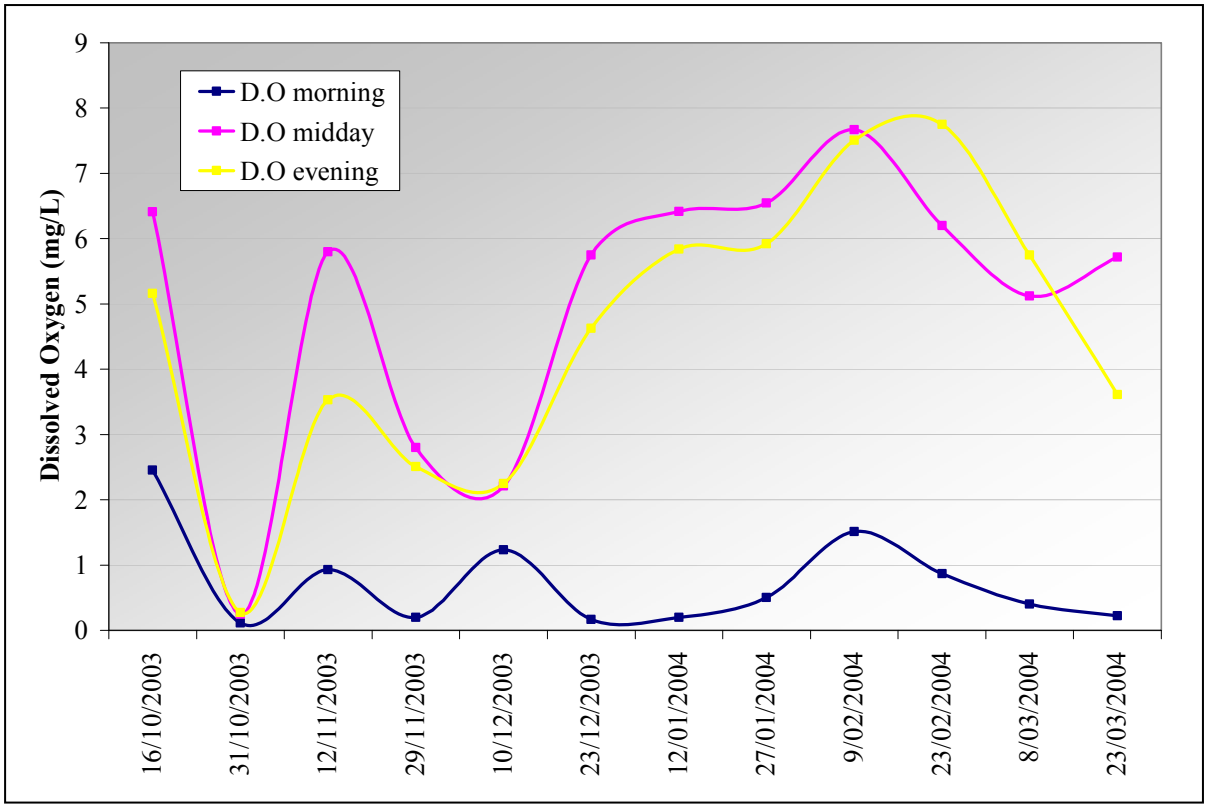

Figure 8 Results of diurnal water quality monitoring at site 1 (control)

This degree of variability is reflected in the data matrix (Table 4). In general most samples follow the expected trend of low concentrations in the morning getting higher during the day. However, the low concentrations of dissolved oxygen throughout the day on the 31/10/2003 cannot be accounted for, as it was a clear day, and no controlled spraying occurred.

The degree of tree cover is the likely reason for low levels, however, it is possible that the farmer whose land is adjacent to Sandringham Lagoon had sprayed prior to the inception of the program without our knowledge, and we are witnessing oxygen loss due to subsequent weed death.

3.1.2 Site 2

Mean and standard deviation data for site 2 displays a more normal distribution (Table 4), suggesting less deviation from normal conditions. Broadly speaking, dissolved oxygen at site 2 follows the expected trends of low morning concentrations, and higher midday and evening concentrations (Figure 9). Like site 1, the exception is 31/10/2003, where the evening was overcast and there was 100% shading at site 2.

The first spray controlled occurred on 11/12/03. Field observations report that the spray is affecting a hymenachne kill, however there is no clear evidence that dissolved oxygen is being suppressed in the water. Prior to our investigation the farmer had sprayed to clear hymenachne. It is likely that the spraying caused a hymenachne kill (as seen by dead hymenachne at the site before our controlled spraying), which resulted in low levels of dissolved oxygen before the 13/12/2003. This could account for the lack of impact upon the dissolved oxygen after our first spraying event.

It is also possible that the relatively small amount of glyphosphate used, as a function of the sparcity of hymenachne in the study area, created no observable impact upon the dissolved oxygen concentration.

3.1.3 Site 3

Site 3 represents a well controlled experiment, the data from which follows a relatively well constrained normal distribution where dissolved oxygen concentrations are typically lower than at sites 2 or 1 (Table 4 and Figure 10).

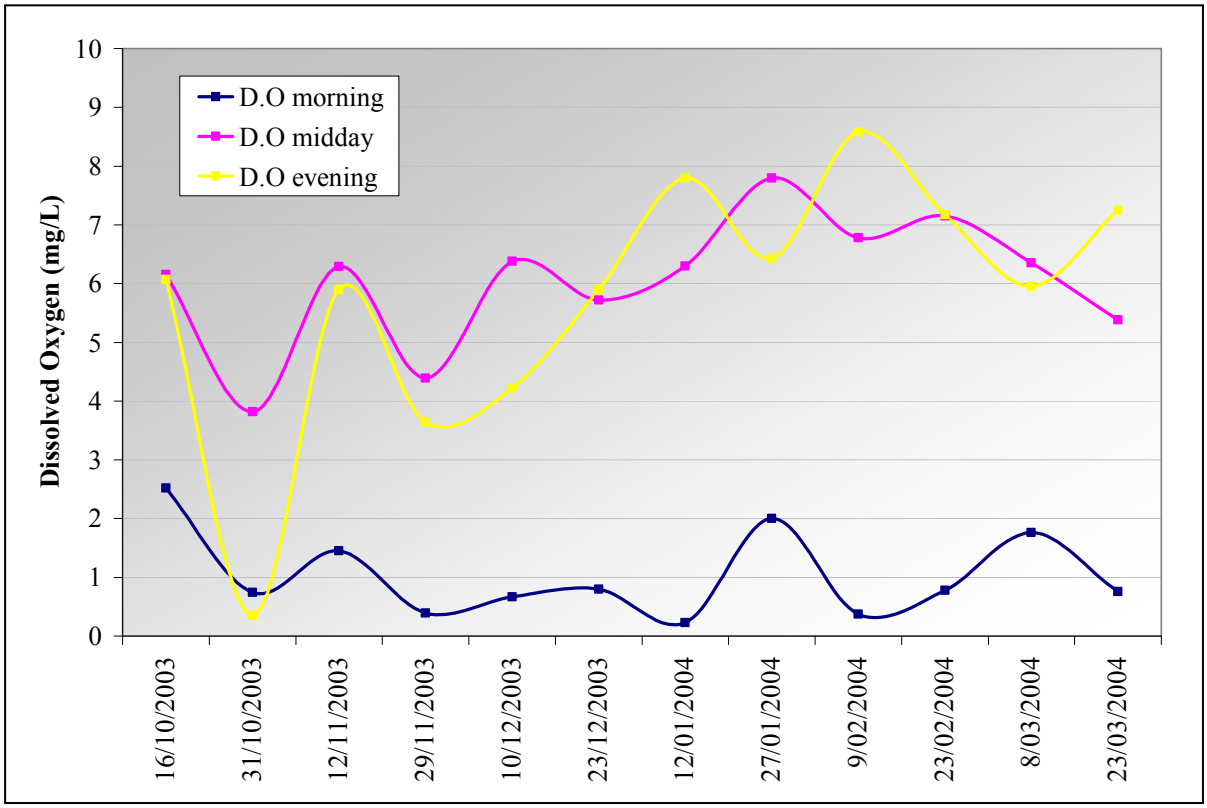

Figure 9 Results of diurnal water quality monitoring at site 2.

The data well reflect the impact of weed death upon dissolved oxygen. After the first spray event, on the 17/10/2003, field and water quality observations reveal dead hymenachne and low levels of dissolved oxygen. These levels remain low until the end of the bulk spraying, 13/01/04, after which distinct recovery curves can be seen.

Follow up spraying occurred after 13/01/2003, though only 20% of the amount of the initial bulk spray was used (see managmenet outcomes). The falling dissolved oxygen levels of the 07/04/2003 reflect water becoming stagnant, and losing oxygen due to a combination of natural processes (i.e. hydrological discontinuity and therefore no recharged oxygen) and anthropogenic factors (i.e. accumulation of algal build-ups that reduce the amount of light penetrating the water column which will be used for photosynthesis).

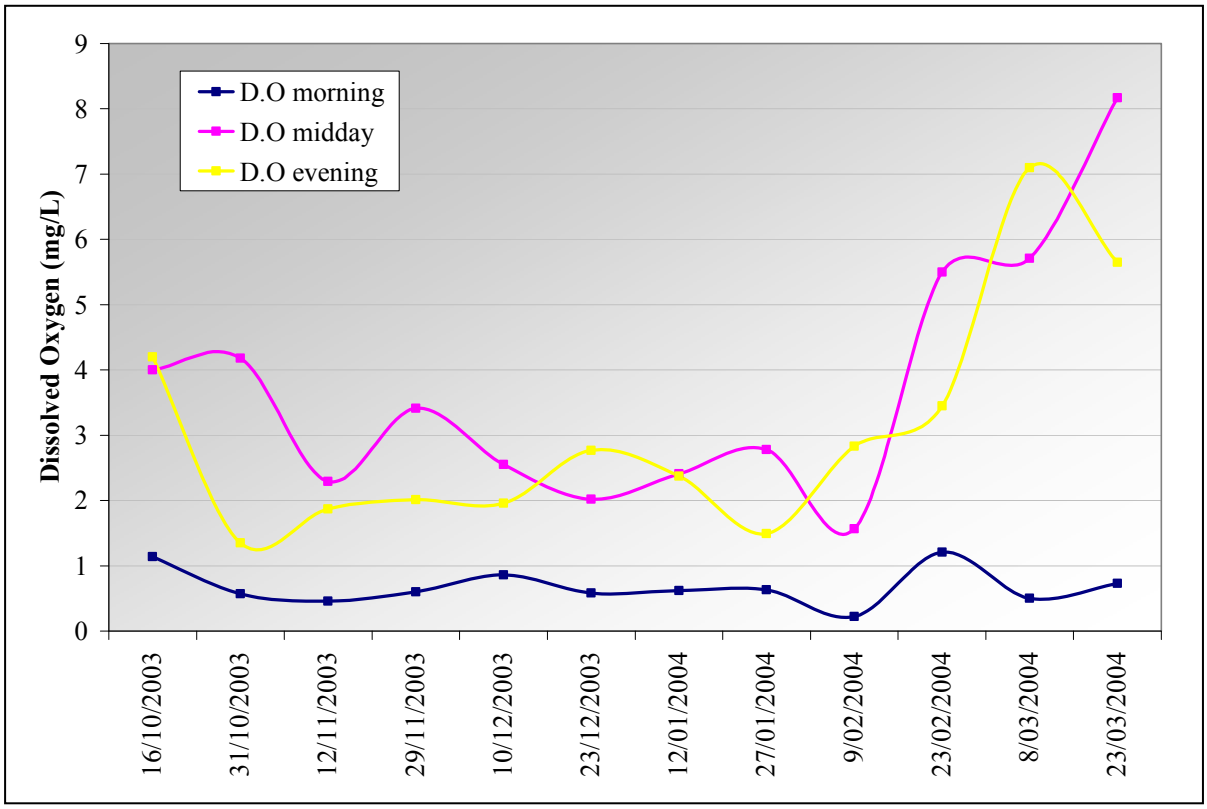

Figure 10 Results of diurnal water quality monitoring at site 3.

The relationship between the algal build up and the death of hymenachne is not clear, however, it is presumed the increased concentration of PO_4^3 (nb PO_4^3 refers to inorganic dissolved PO_4^3) post the death of the hymenachne facilitate the algal development. This hypotheses conforms to the PO_4^3 data collected, where at the times there is a high algal scum, there is no recordable PO_4^3, and when there is no scum, there is on average 0.1mg/L PO_4^3. Presumably the algae grow the most when there is available PO_4^3.

However, the equipment used to collect PO_4^3 data only report a qualitative concentration below 0.2mg/L. Thus all data taken for PO_4^3 need be reviewed in a subjective manner. This means they are correct, but with a higher degree of inaccuracy than the other data collected in this program.

3.1.4 Site 4

Data collected at site 4 (Table 4) show typically suppressed dissolved oxygen levels with high standard deviations. Broadly speaking this reflects both death of hymenachne and resultant loss of oxygen, and a degree of natural interaction (i.e. stagnation) which is not properly understood.

Graphical results of the data (Figure 11) show that after the first spray, 17/10/2003, dissolved oxygen is steadily lost over the next month due to death of hymenachne. Post the second spray, 13/11/2003, a slight recovery occurs followed by a four month trough of consistently low morning, midday and evening dissolved oxygen levels. Two weeks after the last follow up, the recovery begins, however, recovery rates are slow due to both loss of oxygen via decomposing vegetation and natural stagnation.

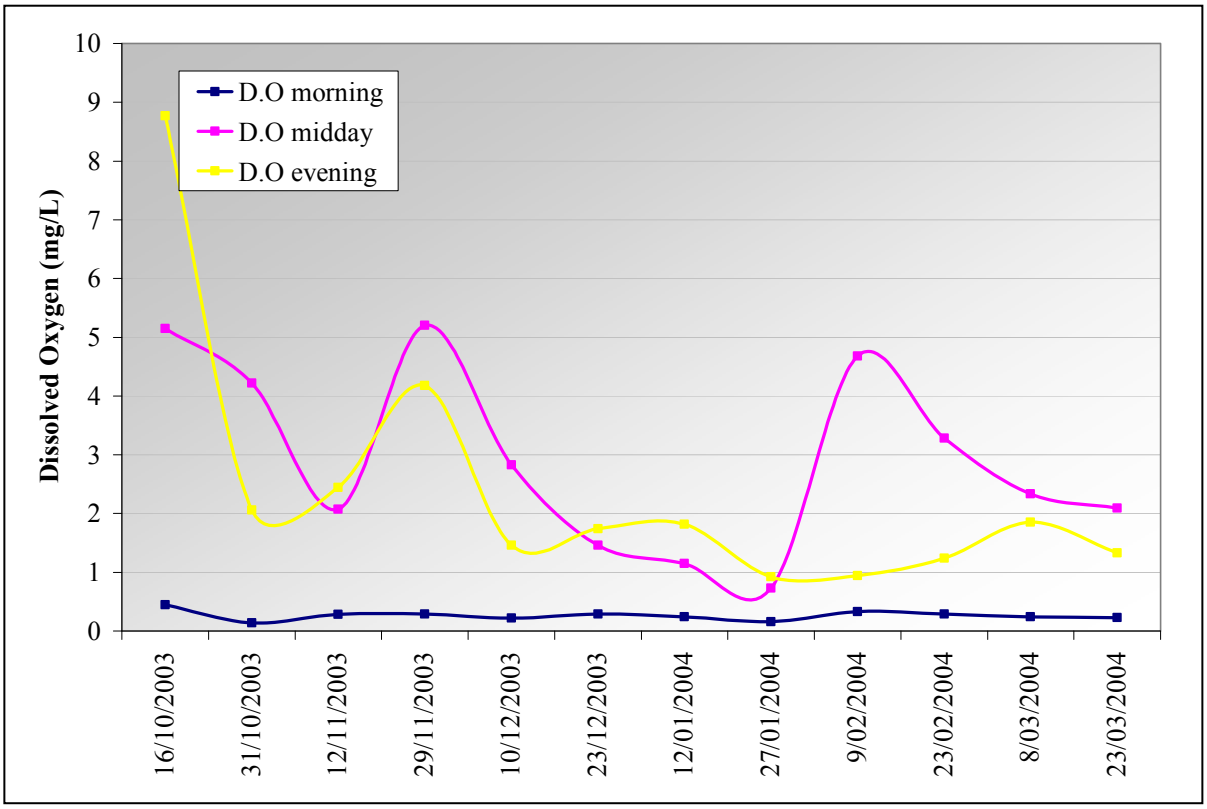

Figure 11 Results of diurnal water quality monitoring at site 4.

Regardless of the affect on water quality, the spraying schedule for site 4 is not as effective as for site 3, as evidenced by regrowth of small clusters of hymenachne after the bulk and follow up spraying. Consequently this result suggests to achieve an effective eradication of hymenachne, at Sandringham Lagoon, after the first spray follow up sprays must occur more than twice.

It is thus probable that one of the factors controlling the effectiveness of weed death, in Sandringham Lagoon, is the rate of application (specifically the time between spraying events) and not strictly the quantity of chemical used.

3.1.5 Dissolved Oxygen Conclusions

Dissolved oxygen levels at all sites are affected by spraying and eventual death. Typically it takes at least one month to register the full impact of dissolved oxygen post a spray event, however, after two weeks dissolved oxygen loss is observed. Recovery curves are dependent on the amount of hymenachne killed, and the rate at which weed decomposition is allowed to occur (i.e. the time between spray events).

The system of death with the greatest impact is blanket spraying (such as at site 4 and 3), however this also has the greatest impact upon dissolved oxygen. The system of spraying with least death is spraying small amounts (such as at site 2), this also has the least impact upon dissolved oxygen. However, in areas of large hymenachne infestation this spraying system would require too much labour. The system of spraying that has worked most effectively in Sandringham Lagoon, in terms of amount of hymenachne kill and loss of oxygen, is the spraying of 33% of the hymenachne (site 3).

However to properly assess the most environmentally sensitive way to apply glyphosphate (and other chemicals), a project structured towards answering the question, when should we apply chemical, and not necessarily how much chemical should we apply should be undertaken. One avenue would be to conduct a 33% spraying program at 3 or 4 different sites where application occurred at staggered intervals (i.e. 1 month, 2 months and 3 months). The objective would be to assess the recovery rates of dissolved oxygen, thus addressing how long the creek system would remain in anoxic conditions post a spraying event.

3.2 pH

For all sites pH is within acceptable limits for natural riverine environments. The lowest pH level recorded was 5.89 from site 4 on the 27/01/2004, the week after the follow up spraying was finished. The highest pH level was recorded at site 1 on the 23/02/2004. This date also corresponds to the highest dissolved oxygen reading from site 1, and correlates well to natural cycles.

	Morning		Midday		Evening	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Site 1	6.48	0.08	6.85	0.24	6.81	0.30
Site 2	6.45	0.16	6.80	0.20	6.83	0.26
Site 3	6.18	0.14	6.22	0.11	6.21	0.18
Site 4	6.30	0.17	6.31	0.22	6.30	0.25

Table 5 Data matrix listing mean and standard deviation results for diurnal sampling of pH at all sites.

The pH cycle fluctuates in a similar manner to the dissolved oxygen cycle, however variances within a diel range are not as large (Table 5 and Figure 12). Variations observed during monitoring, reflect natural cycles of pH, with the exception of sites 3 and 4, where the death of up to approximately 1500kg of hymenachne at each site have resulted in the liberation of organic acids, resulting in the drop of pH of about 0.4 – 0.6 pH units. The death of approximately 850kg of hymenachne at site 2 has resulted in shifts of approximately 0.2 pH units. These shifts are not considerable, and not expected to harm aquatic life within the natural pH range found in Sandringham Lagoon.

3.3 Electrical Conductivity

Electrical conductivity levels (Table 6) varied in accordance with meteoric input (rainfall). A noticeable decrease in EC levels occurred after rain, for instance on the 29/11/2003, the EC dropped from 190 to 50 µS/cm (Figure 12).

	Morning		Midday		Evening	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Site 1	195.62	49.95	189.45	45.60	174.36	60.69
Site 2	190.28	46.08	187.73	45.00	176.32	57.35
Site 3	183.08	51.73	169.38	48.13	155.26	57.79
Site 4	187.98	54.07	179.21	54.40	161.88	60.71

Table 6 Data matrix listing mean and standard deviation results for diurnal sampling of electrical conductivity (µS/cm) at all sites.

Electrical conductivities at all sites were broadly similar, ranging from 41.9 – 253µS/cm, with little to no discernable diurnal differences. There is no perceived effect upon electrical conductivity due to spraying and death of hymenachne.

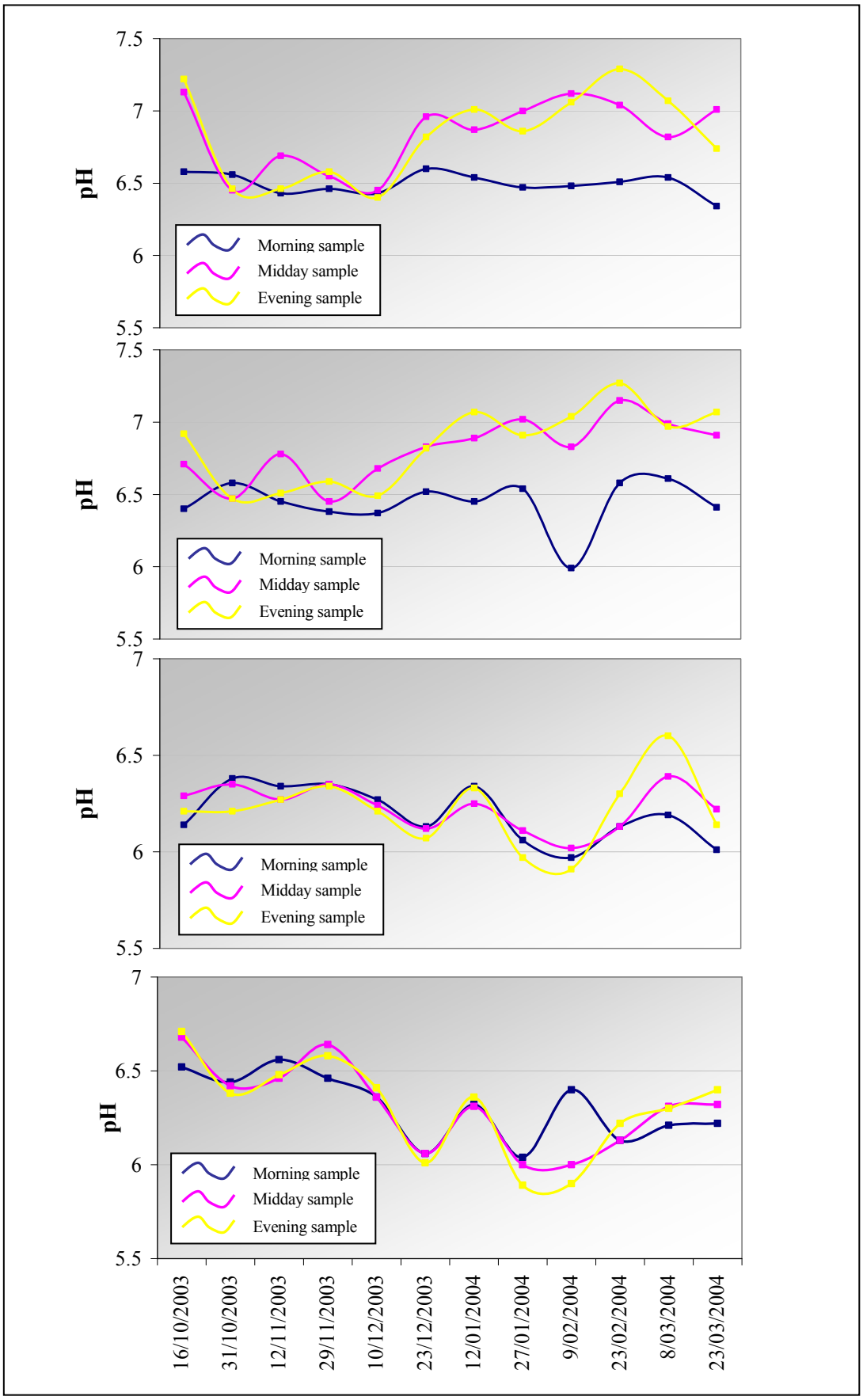

Figure 12 pH levels recorded from diurnal sampling at Sandringham Lagoon.

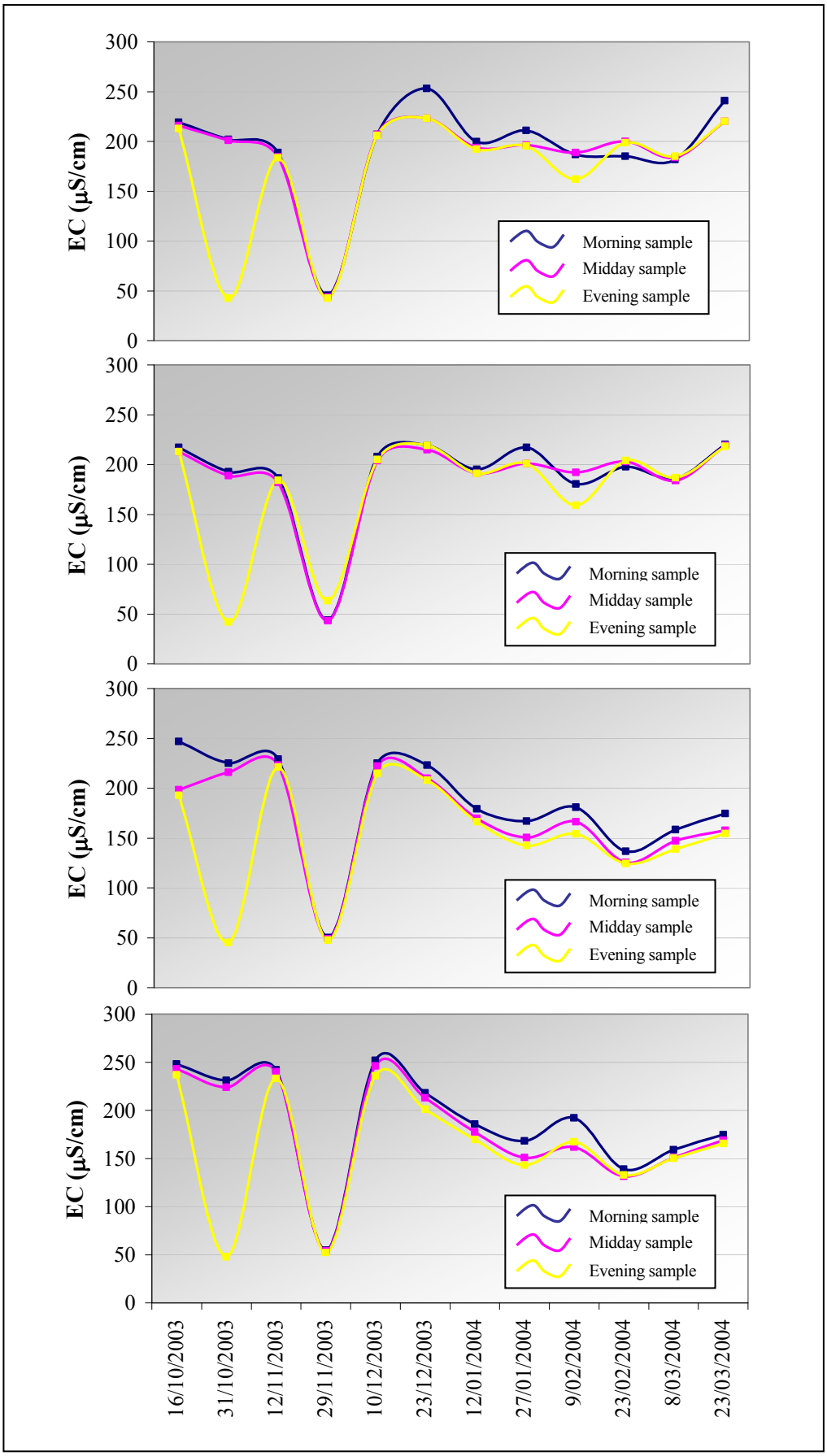

Figure 13 Electrical conductivity levels recorded during diurnal sampling at Sandringham Lagoon.

3.4 Temperature

As with electrical conductivity, there is no discernable relationship with the death of hymenachne due to spraying and temperature. Table 7 is a list of averages and standard deviations from all water temperature readings taken during the project.

	Morning		Midday		Evening	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Site 1	27.43	1.77	30.55	2.70	30.01	3.01
Site 2	27.28	1.75	30.78	2.36	30.05	2.48
Site 3	25.19	1.74	30.15	2.38	29.21	2.31
Site 4	25.12	2.45	28.78	2.05	27.38	1.95

Table 7 Data matrix listing mean and standard deviation results for diurnal sampling of temperature (°C) at all sites.

Temperature ranges from 19.6C, taken at 7:15am on 16/10/2003, to 35.1C taken at 1:49pm on 23/02/2004. The temperature range for morning samples is 19.6 – 29.8°C, the temperature range for midday samples is 25.4 – 35.1°C and the temperature range for evening samples is 23.5 – 34.2°C (Figure 14).

This range is in accordance with daily and seasonal values for a water body of this size that undergoes temporary hydraulic disconnection, and poses no threat to organisms.

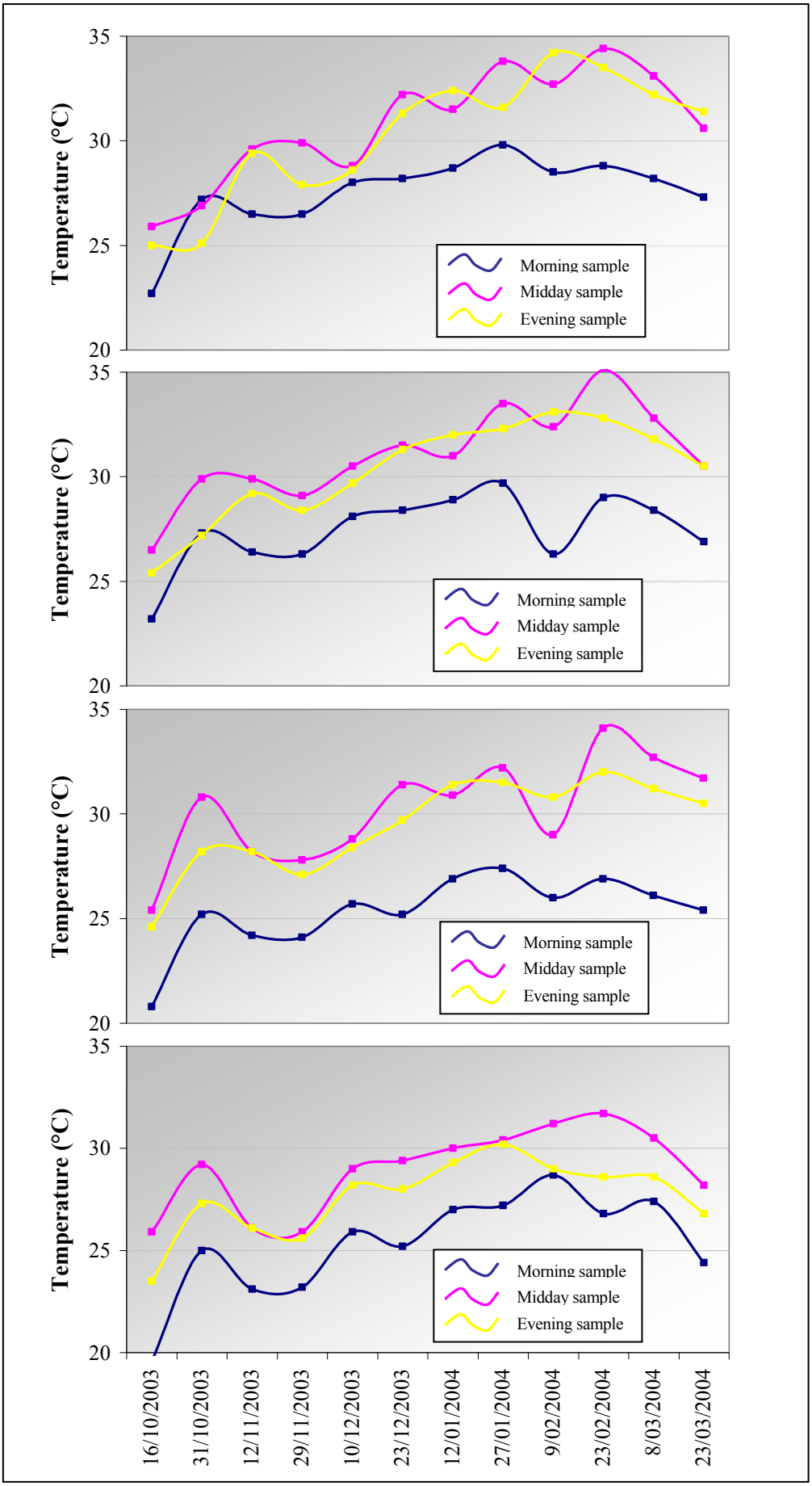

Figure 14 Temperature levels recorded during diurnal sampling at Sandringham Lagoon.

4.0 Management Outcomes

This project was established in an attempt to assess the most appropriate manner of spraying Sandringham Lagoon and other similar areas infested with Hymenachne. Critical components of the project are thus; effectivenss of kill, and; affect of kill on water quality. In accordance with these criteria, this project has yielded three specific management outcomes :

1) The "do nothing" approach is not an effective management approach

2) For sites where the infestation is small (i.e. <10% of area) the quarterly spray

3) regime is effective both in terms of weed kill and impact upon dissolved oxygen.

4) For sites where infestation is large (40 - 50% of the area) the third of site spraying regime is effective, both in terms of weed kill and impact upon the dissolved oxygen cycle.

Monitoring of water quality parameters has shown that the "do nothing" approach is not an effective managerial technique for *Hymenachne amplexicaulis* infestations. This recommendation was derived from comparison of dissolved oxgen data from sites 1 to 4 with the 100% hymenachne infestation site. This comparison revealed that the 100% infested site consistently supported lower diurnal dissolved oxygen levels than any of the sites where spraying occurred, even after the main spraying events (Figure 7).

Over time the sustained effects of dissolved oxygen levels lower than those necessary to support a healthy aquatic ecosystem (ANZEC 2000) will result in the loss of biodiversity. Whereas an intensive spray event will rid the system of Hymenachne after which ecosystem recovery will occur more effectively. The effects of eradication of Hymenachne upon fish and invertebrate populations is a future monitoring project which could utilise the results of this research as a baseline.

Figures 15 shows the relationship between the amount of glyphosphate sprayed and the impact upon the dissolved oxygen cycle at each site. For the third and half sites (sites 3 & 4 respectively), spraying impacts heavily upon the dissolved oxygen cycle, with changes in dissolved oxygen occurring within the first two weeks of the first spray event. For the quarter site (site 2) there is less of an impact upon the dissolved oxygen cycle post the first spray event. Change at the quarter site occurs only after multiple spraying events. The reason for the less immediate impact upon dissolved oxygen at site 2 versus the immediate impact at sites 3 & 4 is the amount of hymenachne present, and thus the proportionate decrease in dissolved oxygen as a function of increased rotting biomass.

This is an important outcome from this project, which shows that for areas affected with small infestations (i.e.hymenachne covers <10% of the area), spraying in accordance to a quarterly regime is effective, both in terms of the hymenachne kill and the low impact upon the dissolved oxygen cycle. For this spraying regime the average dissolved oxygen levels never drop below 3.5mg/L. Whether or not this is enough oxygen to support biological diversity is unclear, however, based on the high water bird activity at this site, it is probable that this site hosts a healthy invertebrate and piscean ecosystem. As this ecosystem was apparently “active” throughout the projects life, the assumption that

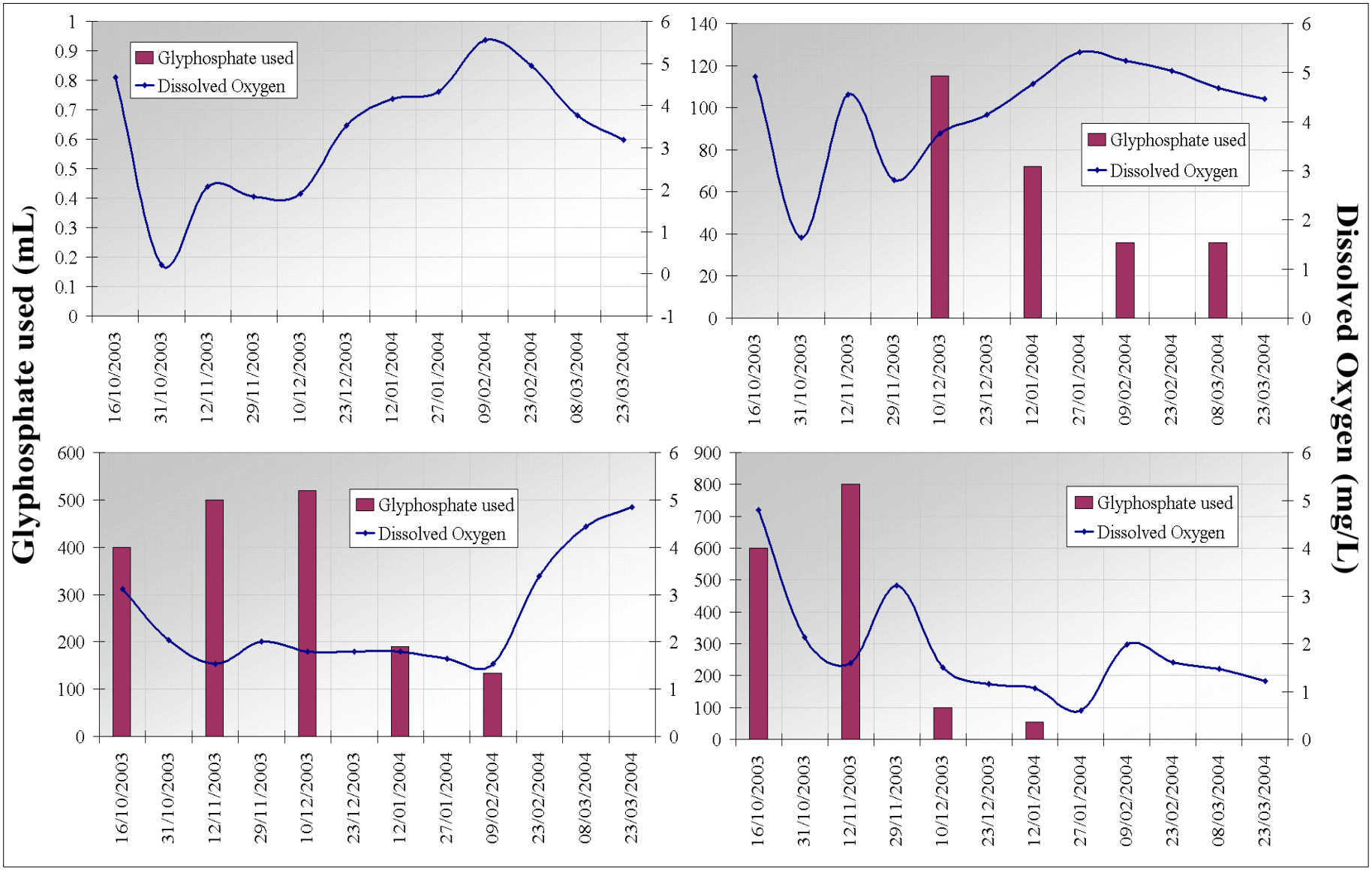

Figure 15 Plots showing glyphosphate used versus averaged dissolved oxygen at each site throughout over the project.

3.5mg/L dissolved oxygen is high enough is valid. However, these assumptions have been made on qualitative field observations, and it is recognised biological focussed research is necessary to properly assess ecosystem health.

From a farm management approach, it is thus most effective to spray hymenachne when it only infests small areas (<10%) of a waterbody. If small infestations do occur, it is best to spray in conjunction with a quarter spray regime.

Where hymenachne covers areas >40% of the waterbody, spraying in a quarterly regime is not effective in terms of weed death. In heavily impacted areas the two most appropriate spraying regimes are the third and half regimes (i.e. sites 3 & 4 respectively). These regimes, however, also have the most impact upon the dissolved oxygen cycle.

Figure 16 shows the averaged impacts of each spraying regime upon dissolved oxygen. It is apparent that the third and half spraying regimes have the most impact upon dissolved oxygen. However it is necessary to utilise one of these spraying regimes for heavily infested sites. To assess the impact each regime has upon the oxygen cycle it is beneficial to compare the response curves, both for loss of dissolved oxygen and recovery of dissolved oxygen.

Figures 17 and 18 are compiled response curves for sites 3 and 4. Detailed curves are for the first spray event, the total spraying event and the recovery curve, registered from the end of the spraying at the respective sites. Each plot has a best fit trend analysis curve plus algebraic formul

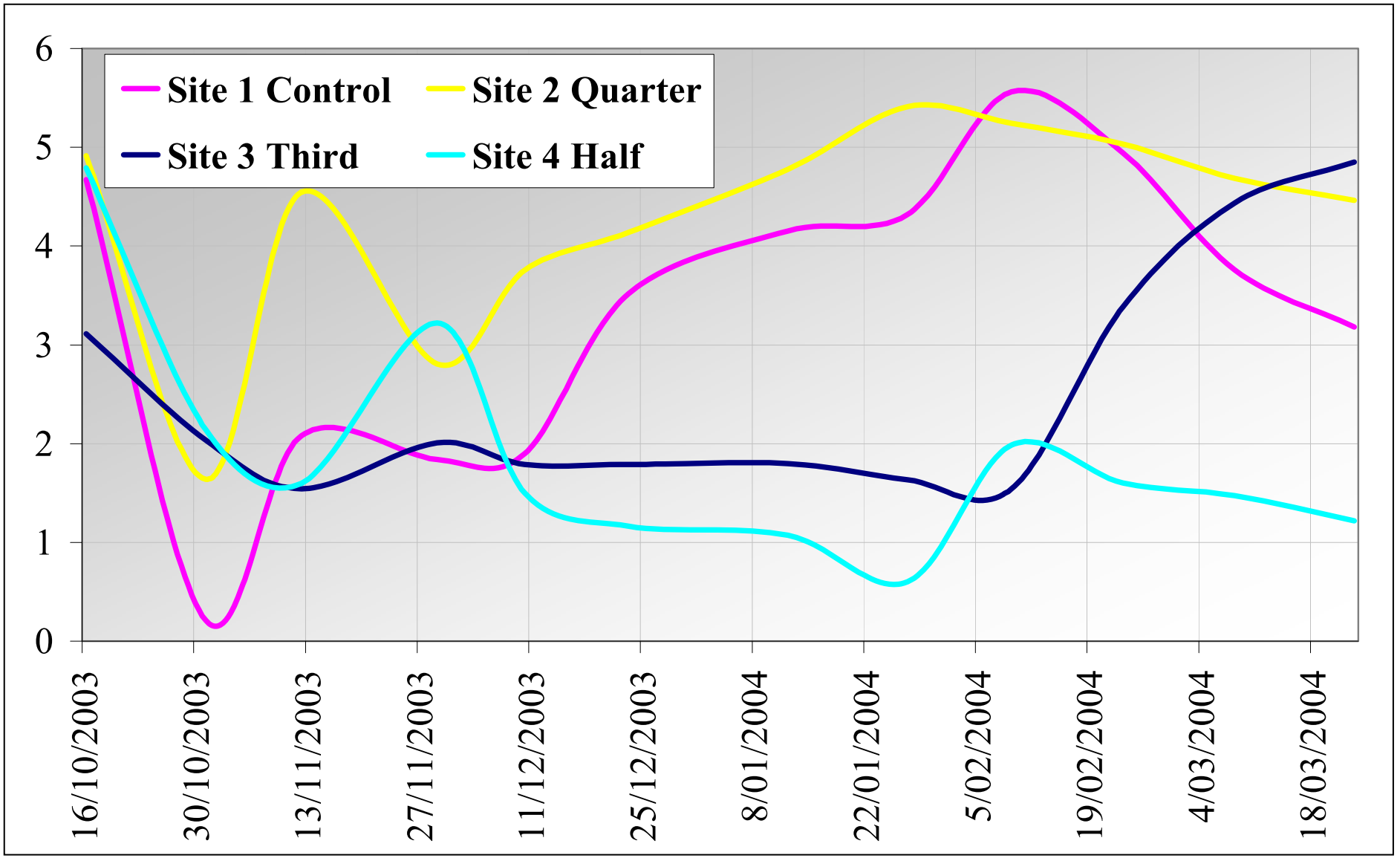

Figure 16 Plots showing the average dissolved oxygen concentrations from each site throughout the project.

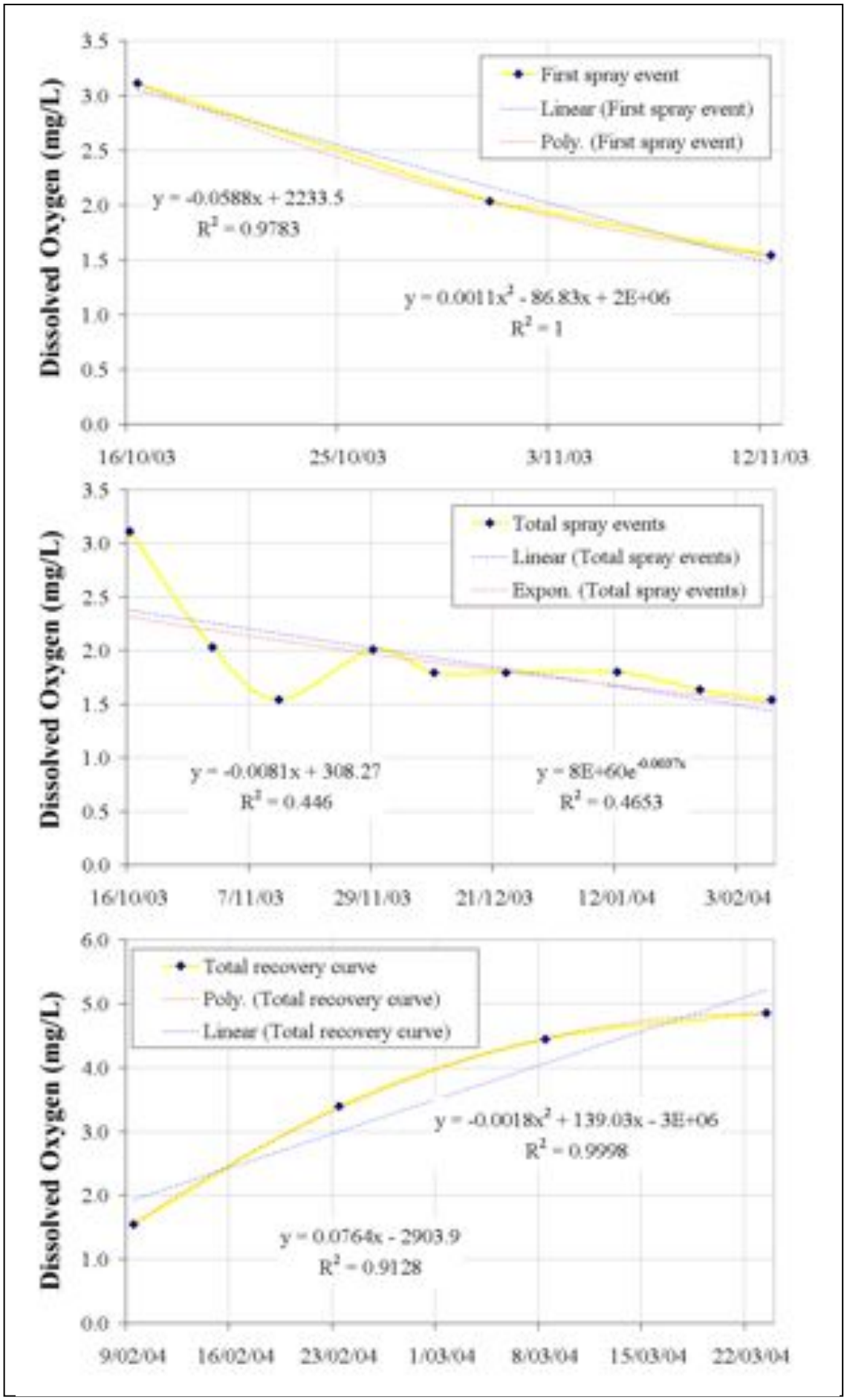

Figure 17 Response curves for dissolved oxygen at site 3

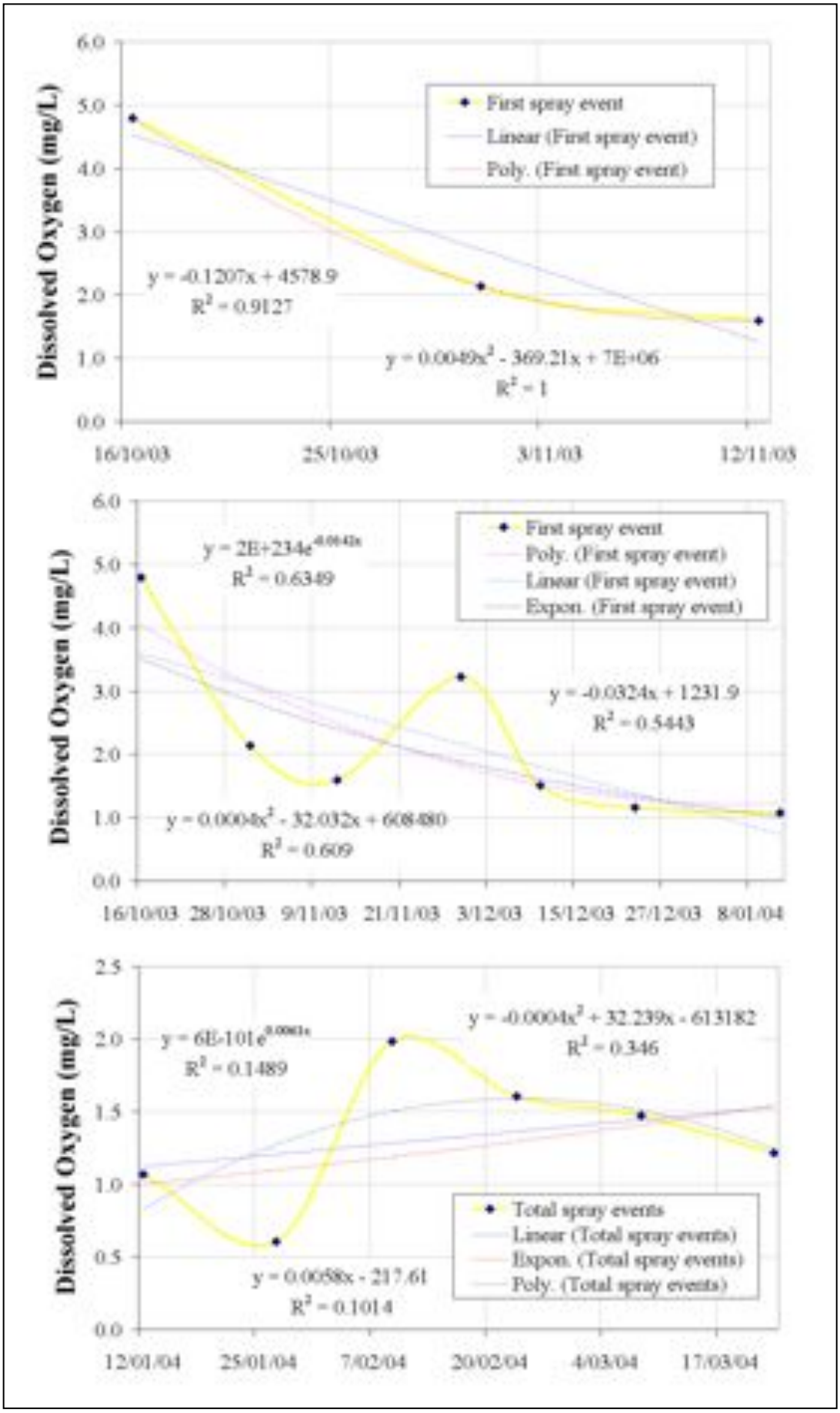

Figure 18 Response curves for dissolved oxygen at site 4

These plots show how dissolved oxygen changes in regards to specific spraying events in Sandringham Lagoon. Based on these data we were able to synthesize two curves that can be used to assess how dissolved oxygen is likely to respond in the natural environment (Figure 19). However, the limitations of the project (particularly size of project area and coverage of water and the effects these variable have on biogeochemical cycling of oxygen) must be applied when using the formulae derived outside of the study area.

Consequently the data should only be used in a subjective capacity, to give an idea of how oxygen changes in response to quantity of hymenachne sprayed. Essentially these data show that through a more comprehensive spraying and monitoring program (see future research) predictive curves based on area / quantity of weed sprayed and expected loss of dissolved oxygen can be created.

Assesment of Sandringham Lagoon curves (Figs X.X and X.X) reveal that at site 3 dissolved oxygen behaves differently than at site 4. This response is characterised by :

1) A more rapid recovery curve
2) Recovery to higher concentrations at site 3.

These results alone suggest the spraying regime employed at site 3 have less impact upon the dissolved oxygen cycle than the regime employed at site 4. However, these are strengthened by the patchy regrowth of Hymenachne approximately 1 month after the final spraying.

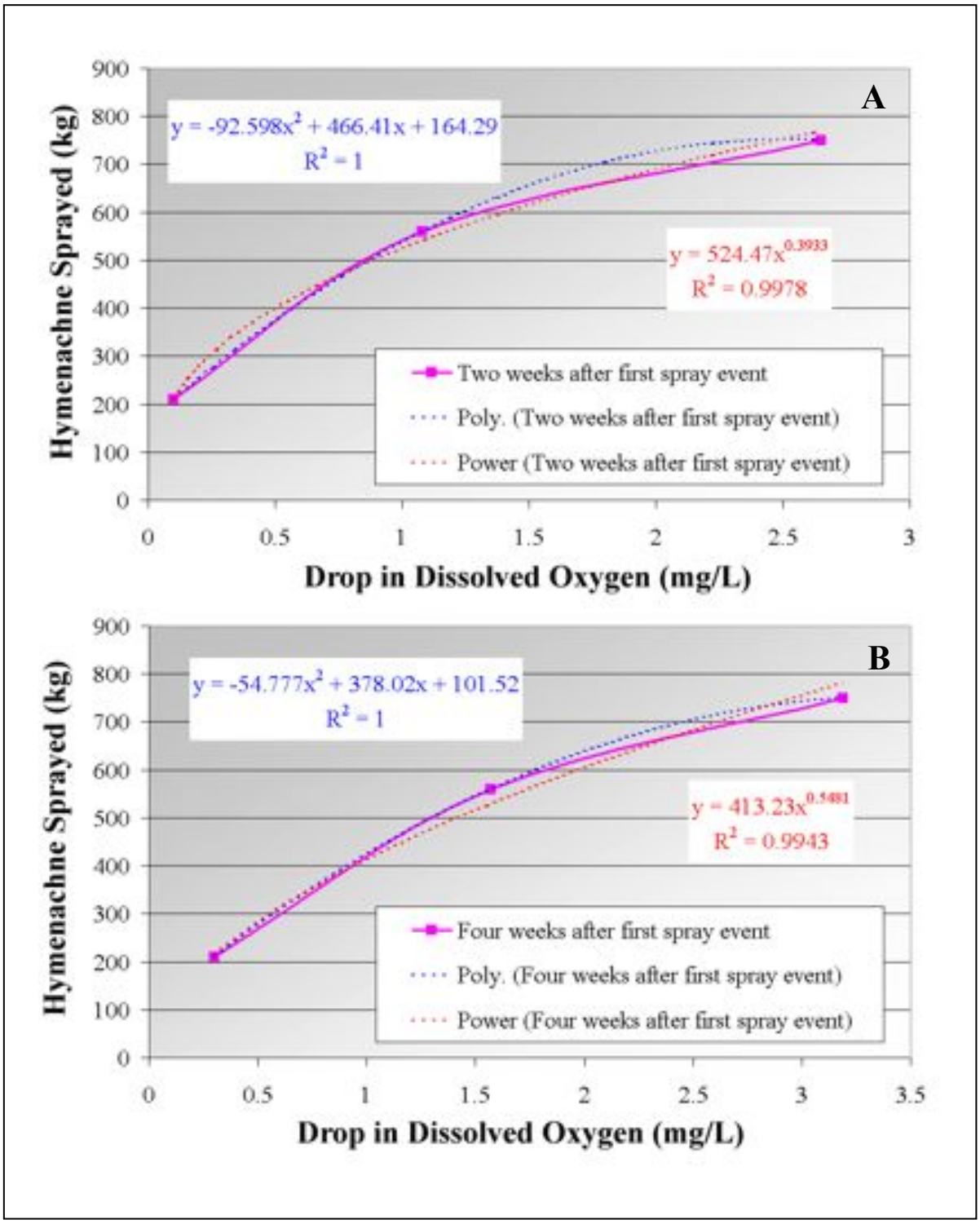

Figure 19 Plots A & B represent data taken from all sites showing the relationship between the amount of Hymenachne sprayed and the associated drop in dissolved oxygen concentrations (mg/L) within Sandringham Lagoon. The data are endemic to the site conditions and based on different spray regimes. Consequently limitations exist as to the use of the plots as a quantitative predictive tool, however, the plots have been designed to be used as a first glance subjective appraisal of the relationship between amount of weed sprayed and loss of dissolved oxygen in the water.

5.0 Conclusions

This project has resulted in four specific conclusions related to the best management practice of eradication of Hymenachne within Sandringham Lagoon, and other similar sized fresh water creeks within the Mackay region.

1) The "do nothing" approach is not an effective management system for Hymenachne. This conclusion is based on water quality data monitored at a site with a 100% infestation of Hymenachne. Dissolved oxygen concentrations at this site were consistently low (always <1mg/L, and mostly <0.5mg/L). These data represent worst case scenarios as most Hymenachne infestations in the Mackay area do not currently occur as 100% infestations of the waterbody. However, given the rapid and pervasive germination and survival rates of Hymenachne, if present infestations are not properly managed they will develop into 100% infestations.

2) The best management practice for eradication of Hymenachne is spraying when there is no water. However, if there is water present (and there typically will be) the death of all the hymenachne at one time will result in massive decreases of dissolved oxygen for long periods of time. Thus in order to minimise changes in the natural dissolved oxygen concentrations of the water we propose a staggered spraying regime, between 3 and 4 months (depending on the size of the infestation) designed to kill the weed and limit the drop in dissolved oxygen associated with the death and decomposition of the weed.

3) For areas within Sandringham Lagoon where the Hymenachne infestation is <10% (a total of 84m2), the most effective spraying regime is a staggered spraying regime designed to spray a quarter of the infestation per month over 4 months. Initially one quarter of the infestation is sprayed, then the next month another quarter is sprayed, etc, until 4 months have elapsed and all the sites have been sprayed. Once all sites have been sprayed, minor follow up sprays focussed on specific problem areas (i.e. patchy regrowth, etc) should occur. This methodology results in an effective weed kill and limits the drop in dissolved oxygen concentrations associated with the decomposition of the dead weed in the water column.

4) For areas within Sandrigham Lagoon where Hymenachne infestation was between 40 – 50% (a total of 150 – 168m2), a slightly higher than average infestation size for the Mackay area, the most effective spraying regime is based on spraying a third of the infestation over a three month period. Even though this spraying regime results in low levels of dissolved oxygen for prolonged periods of time, it is the least deleterious on the natural dissolved oxygen cycle, and, with minor follow up spraying, it effects a successful weed kill.

6.0 Future Research

1) For sites where Hymenachne infestations are large, there will always be a decrease in water quality following spraying. However, it is perceived (through observational data) that the poor water quality facilitated by the presence of the Hymenachne is more deleterious for the aquatic ecosystem than the poor water quality associated with a drop in dissoloved oxygen after a responsible spraying program. Thus there exists the possibility for a well structured quantitative research program investigating the aquatic health of Hymenachne infested waterbodies, prior to, during and after a spraying regime. The project should focus on invertebrate populations, piscean populations as well as physico – chemical behaviour.

2) As this program was structure towards a hands on approach within the same waterbody (i.e. most beneficial to farmers and land managers), there exists the possibility of a program where initial conditions (predominantly the size of Hymenachne infestation and the amounts and rates of Hymenachne sprayed within the waterbody) are the same. As it is impossible to find multiple sites with exactly the same conditions within one creek system, it is suggested a number of similar creeks with similar sized Hymenachne infestations, be investigated. This different catchment conditions may result in problems endemic to specific areas. However, if successful such an approach will yield better predictive mangement tools (see Figure 19) based on knowledge of change in dissolved oxygen induced via controlled spraying.

7.0 References

Appendix A

POSKEY	Site	Date	Time	D.O.(mg/L)	pH	EC (uS/cm)	Temp. (degC)
11	1	16/10/2003	8:40	2.45	6.58	219	22.7
12	2	16/10/2003	9:20	2.52	6.4	217	23.2
13	3	16/10/2003	7:55	1.14	6.14	247	20.8
14	4	16/10/2003	7:15	0.45	6.52	248	19.6
15	1	16/10/2003	14:35	6.41	7.13	216	25.9
16	2	16/10/2003	14:55	6.15	6.71	213	26.5
17	3	16/10/2003	14:15	4	6.29	198.2	25.4
18	4	16/10/2003	13:45	5.15	6.68	243	25.9
19	1	16/10/2003	18:35	5.16	7.22	213	25
20	2	16/10/2003	18:45	6.07	6.92	213	25.4
21	3	16/10/2003	18:18	4.2	6.21	192.8	24.6
22	4	16/10/2003	18:00	8.77	6.71	237	23.5
23	1	31/10/2003	7:45	0.11	6.56	202	27.2
24	2	31/10/2003	8:10	0.74	6.58	192.7	27.3
25	3	31/10/2003	7:20	0.57	6.38	225	25.2
26	4	31/10/2003	7:00	0.14	6.44	231	25
27	1	31/10/2003	13:05	0.25	6.45	201	26.9
28	2	31/10/2003	13:20	3.82	6.47	188.9	29.9
29	3	31/10/2003	12:40	4.18	6.35	216	30.8
30	4	31/10/2003	12:20	4.22	6.42	224	29.2
31	1	31/10/2003	17:55	0.27	6.46	42.5	25.1
32	2	31/10/2003	18:10	0.35	6.47	41.9	27.2
33	3	31/10/2003	17:50	1.35	6.21	45.2	28.2
34	4	31/10/2003	17:15	2.06	6.38	47.8	27.3
35	1	12/11/2003	8:05	0.93	6.43	188.9	26.5
36	2	12/11/2003	8:22	1.45	6.45	186.4	26.4
37	3	12/11/2003	7:35	0.46	6.34	229	24.2
38	4	12/11/2003	7:10	0.28	6.56	242	23.1
39	1	12/11/2003	12:50	5.8	6.69	184.5	29.6
40	2	12/11/2003	13:20	6.29	6.78	181.7	29.9
41	3	12/11/2003	12:27	2.29	6.27	223	28.2
42	4	12/11/2003	12:10	2.07	6.46	240	26.1
43	1	12/11/2003	17:45	3.53	6.46	183.4	29.4
44	2	12/11/2003	17:57	5.9	6.51	184	29.2
45	3	12/11/2003	17:20	1.87	6.27	221	28.2
46	4	12/11/2003	17:05	2.44	6.48	233	26.1
47	1	29/11/2003	8:00	0.2	6.46	45.6	26.5
48	2	29/11/2003	8:20	0.39	6.38	43.9	26.3
49	3	29/11/2003	7:25	0.6	6.35	50.1	24.1
50	4	29/11/2003	7:10	0.29	6.46	54.5	23.2
51	1	29/11/2003	12:55	2.8	6.55	43.6	29.9
52	2	29/11/2003	13:12	4.39	6.45	43.2	29.1
53	3	29/11/2003	12:30	3.41	6.35	48.7	27.8
54	4	29/11/2003	12:00	5.2	6.64	53.9	25.9
55	1	29/11/2003	18:47	2.51	6.58	42.6	27.9
56	2	29/11/2003	18:06	3.64	6.59	63.5	28.4
57	3	29/11/2003	17:25	2.01	6.34	47.6	27.1
58	4	29/11/2003	17:05	4.18	6.58	52.3	25.6
59	1	10/12/2003	8:05	1.23	6.43	207	28
POSKEY	**Site**	**Date**	**Time**	**D.O.(mg/L)**	**pH**	**EC (uS/cm)**	**Temp. (degC)**

60	2	10/12/2003	8:25	0.67	6.37	208	28.1
61	3	10/12/2003	7:25	0.86	6.27	225	25.7
62	4	10/12/2003	7:07	0.22	6.36	252	25.9
63	1	10/12/2003	13:10	2.21	6.45	207	28.8
64	2	10/12/2003	13:25	6.38	6.68	204	30.5
65	3	10/12/2003	12:47	2.55	6.24	222	28.8
66	4	10/12/2003	12:25	2.83	6.36	246	29
67	1	10/12/2003	17:35	2.25	6.4	206	28.6
68	2	10/12/2003	17:50	4.22	6.49	205	29.7
69	3	10/12/2003	17:10	1.96	6.21	215	28.4
70	4	10/12/2003	16:55	1.46	6.41	236	28.2
71	1	23/12/2003	8:05	0.17	6.6	253	28.2
72	2	23/12/2003	8:23	0.8	6.52	219	28.4
73	3	23/12/2003	7:35	0.58	6.13	223	25.2
74	4	23/12/2003	7:10	0.29	6.06	218	25.2
75	1	23/12/2003	12:55	5.75	6.96	223	32.2
76	2	23/12/2003	13:25	5.72	6.83	215	31.5
77	3	23/12/2003	12:27	2.02	6.12	210	31.4
78	4	23/12/2003	12:06	1.46	6.06	213	29.4
79	1	23/12/2003	17:40	4.63	6.82	223	31.3
80	2	23/12/2003	18:01	5.9	6.82	219	31.3
81	3	23/12/2003	17:17	2.77	6.07	208	29.7
82	4	23/12/2003	16:55	1.74	6.01	201	28
83	1	12/01/2004	8:07	0.2	6.54	199.6	28.7
84	2	12/01/2004	8:26	0.23	6.45	195.1	28.9
85	3	12/01/2004	7:40	0.62	6.34	179.1	26.9
86	4	12/01/2004	7:10	0.24	6.32	185.6	27
87	1	12/01/2004	12:50	6.42	6.87	193.7	31.5
88	2	12/01/2004	13:23	6.3	6.89	191	31
89	3	12/01/2004	12:27	2.41	6.25	169.7	30.9
90	4	12/01/2004	12:00	1.15	6.31	177.6	30
91	1	12/01/2004	18:05	5.84	7.01	192	32.4
92	2	12/01/2004	18:27	7.8	7.07	191	32
93	3	12/01/2004	17:37	2.37	6.33	166.4	31.4
94	4	12/01/2004	17:06	1.82	6.36	169.5	29.3
95	1	27/01/2004	8:45	0.5	6.47	211	29.8
96	2	27/01/2004	9:05	2	6.54	217	29.7
97	3	27/01/2004	8:05	0.63	6.06	166.9	27.4
98	4	27/01/2004	7:20	0.16	6.04	168.3	27.2
99	1	27/01/2004	13:05	6.55	7	196.5	33.8
100	2	27/01/2004	13:21	7.8	7.02	201	33.5
101	3	27/01/2004	12:37	2.78	6.11	150.5	32.2
102	4	27/01/2004	12:10	0.73	6	150.7	30.4
103	1	27/01/2004	18:10	5.92	6.86	195.5	31.6
104	2	27/01/2004	18:30	6.43	6.91	201	32.3
105	3	27/01/2004	17:50	1.49	5.97	142.5	31.5
106	4	27/01/2004	17:15	0.92	5.89	143.1	30.2
107	4	09/02/2004	8:30	0.33	6.4	192.2	28.7
108	1	09/02/2004	8:45	1.51	6.48	186.9	28.5
POSKEY	**Site**	**Date**	**Time**	**D.O.(mg/L)**	**pH**	**EC (uS/cm)**	**Temp. (degC)**
109	3	09/02/2004	7:35	0.22	5.97	180.7	26

110	2	09/02/2004	8:55	0.37	5.99	180.6	26.3
111	1	09/02/2004	12:45	7.67	7.12	188.9	32.7
112	2	09/02/2004	13:06	6.78	6.83	192	32.4
113	3	09/02/2004	12:05	1.57	6.02	166.4	29
114	4	09/02/2004	12:15	4.68	6	161.7	31.2
115	1	09/02/2004	17:35	7.51	7.06	162	34.2
116	2	09/02/2004	18:00	8.58	7.04	159	33.1
117	3	09/02/2004	17:10	2.83	5.91	154.2	30.8
118	4	09/02/2004	16:55	0.94	5.9	167.4	29
119	1	23/02/2004	7:15	0.87	6.51	185.2	28.8
120	2	23/02/2004	7:30	0.78	6.58	197.8	29
121	3	23/02/2004	8:25	1.21	6.13	136.5	26.9
122	4	23/02/2004	8:05	0.29	6.13	139	26.8
123	1	23/02/2004	13:26	6.2	7.04	200	34.4
124	2	23/02/2004	13:49	7.15	7.15	203	35.1
125	3	23/02/2004	12:45	5.5	6.13	125.3	34.1
126	4	23/02/2004	12:05	3.28	6.13	131.3	31.7
127	1	23/02/2004	18:15	7.75	7.29	198.6	33.5
128	2	23/02/2004	18:30	7.17	7.27	204	32.8
129	3	23/02/2004	17:50	3.45	6.3	124.3	32
130	4	23/02/2004	17:20	1.24	6.22	132.8	28.6
131	1	08/03/2004	8:20	0.4	6.54	181.9	28.2
132	2	08/03/2004	8:35	1.76	6.61	186.2	28.4
133	3	08/03/2004	7:23	0.5	6.19	158.5	26.1
134	4	08/03/2004	6:55	0.24	6.21	159.2	27.4
135	1	08/03/2004	13:19	5.12	6.82	183.7	33.1
136	2	08/03/2004	13:33	6.35	6.99	183.7	32.8
137	3	08/03/2004	12:29	5.71	6.39	147.2	32.7
138	4	08/03/2004	11:55	2.33	6.31	150.9	30.5
139	1	08/03/2004	18:45	5.75	7.07	185.1	32.2
140	2	08/03/2004	18:35	5.95	6.97	186.7	31.8
141	3	08/03/2004	17:45	7.1	6.6	139.1	31.2
142	4	08/03/2004	17:25	1.85	6.3	150.3	28.6
143	1	23/03/2004	8:40	0.22	6.34	241	27.3
144	2	23/03/2004	8:25	0.76	6.41	220	26.9
145	3	23/03/2004	8:00	0.73	6.01	174.7	25.4
146	4	23/03/2004	7:30	0.23	6.22	174.7	24.4
147	1	23/03/2004	13:30	5.72	7.01	220	30.6
148	2	23/03/2004	13:10	5.38	6.91	219	30.5
149	3	23/03/2004	12:50	8.17	6.22	157.7	31.7
150	4	23/03/2004	12:20	2.09	6.32	168.9	28.2
151	1	23/03/2004	17:35	3.61	6.74	220	31.4
153	3	23/03/2004	17:15	5.65	6.14	154.3	30.5
154	4	23/03/2004	17:00	1.33	6.4	165.4	26.8
154	2	23/03/2004	17:50	7.25	7.07	218	30.5

Appendix B

POSKEY	Site	Date	Time	Turbidity (NTU's)
11	1	16/10/2003	8:40	20
12	2	16/10/2003	9:20	<10
13	3	16/10/2003	7:55	<10
14	4	16/10/2003	7:15	13.5
23	1	31/10/2003	7:45	18
24	2	31/10/2003	8:10	21
25	3	31/10/2003	7:20	22
26	4	31/10/2003	7:00	26
35	1	12/11/2003	8:05	9
36	2	12/11/2003	8:22	<10
37	3	12/11/2003	7:35	<10
38	4	12/11/2003	7:10	15
47	1	29/11/2003	8:00	<10
48	2	29/11/2003	8:20	<10
49	3	29/11/2003	7:25	13
50	4	29/11/2003	7:10	20
59	1	10/12/2003	8:05	<10
60	2	10/12/2003	8:25	<10
61	3	10/12/2003	7:25	10.5
62	4	10/12/2003	7:07	30
71	1	23/12/2003	8:05	15
72	2	23/12/2003	8:23	14
73	3	23/12/2003	7:35	21
74	4	23/12/2003	7:10	19
83	1	12/01/2004	8:07	<10
84	2	12/01/2004	8:26	<10
85	3	12/01/2004	7:40	<10
86	4	12/01/2004	7:10	14
87	1	12/01/2004	12:50	<10
88	2	12/01/2004	13:23	<10
89	3	12/01/2004	12:27	<10
90	4	12/01/2004	12:00	15
91	1	12/01/2004	18:05	<10
92	2	12/01/2004	18:27	<10
93	3	12/01/2004	17:37	<10
94	4	12/01/2004	17:06	14
95	1	27/01/2004	8:45	<10
96	2	27/01/2004	9:05	<10
97	3	27/01/2004	8:05	<10
98	4	27/01/2004	7:20	<10
107	4	09/02/2004	8:30	<10
108	1	09/02/2004	8:45	<10
109	3	09/02/2004	7:35	<10
110	2	09/02/2004	8:55	<10
119	1	23/02/2004	7:15	14
120	2	23/02/2004	7:30	14
121	3	23/02/2004	8:25	<10

122	4	23/02/2004	8:05	<10
123	1	23/02/2004	13:26	16
POSKEY	**Site**	**Date**	**Time**	**Turbidity (NTU's)**
124	2	23/02/2004	13:49	17
125	3	23/02/2004	12:45	32
126	4	23/02/2004	12:05	30
127	1	23/02/2004	18:15	12
128	2	23/02/2004	18:30	12
129	3	23/02/2004	17:50	23
130	4	23/02/2004	17:20	25
131	1	08/03/2004	8:20	10
132	2	08/03/2004	8:35	10
133	3	08/03/2004	7:23	50
134	4	08/03/2004	6:55	17
135	1	08/03/2004	13:19	10
136	2	08/03/2004	13:33	12
137	3	08/03/2004	12:29	17
138	4	08/03/2004	11:55	23
139	1	08/03/2004	18:45	21
140	2	08/03/2004	18:35	20
141	3	08/03/2004	17:45	17
142	4	08/03/2004	17:25	23
143	1	23/03/2004	8:40	15
144	2	23/03/2004	8:25	12
145	3	23/03/2004	8:00	16
146	4	23/03/2004	7:30	21
147	1	23/03/2004	13:30	10
148	2	23/03/2004	13:10	10
149	3	23/03/2004	12:50	10
150	4	23/03/2004	12:20	17
151	1	23/03/2004	17:35	10
153	3	23/03/2004	17:15	10
154	4	23/03/2004	17:00	10
154	2	23/03/2004	17:50	10

Turbidity was assessed using a standard Water Clarity Tube

Appendix C

POSKEY	Site	Date	Time	P (mg/L)
11	1	16/10/2003	8:40	0.05
12	2	16/10/2003	9:20	0.1
13	3	16/10/2003	7:55	0.05
14	4	16/10/2003	7:15	0.1
23	1	31/10/2003	7:45	0.4
24	2	31/10/2003	8:10	0.125
25	3	31/10/2003	7:20	0.75
26	4	31/10/2003	7:00	0.05
35	1	12/11/2003	8:05	0.2
36	2	12/11/2003	8:22	0.1
37	3	12/11/2003	7:35	0.2
38	4	12/11/2003	7:10	0.2
47	1	29/11/2003	8:00	0.1
48	2	29/11/2003	8:20	1.25
49	3	29/11/2003	7:25	0.175
50	4	29/11/2003	7:10	0.1
59	1	10/12/2003	8:05	0.05
60	2	10/12/2003	8:25	0.015
61	3	10/12/2003	7:25	0.0125
62	4	10/12/2003	7:07	0.0125
71	1	23/12/2003	8:05	0.2
72	2	23/12/2003	8:23	0.125
73	3	23/12/2003	7:35	0.1
74	4	23/12/2003	7:10	0.175
83	1	12/01/2004	8:07	0.1
84	2	12/01/2004	8:26	0.1
85	3	12/01/2004	7:40	0.1
86	4	12/01/2004	7:10	0.15
95	1	27/01/2004	8:45	0
96	2	27/01/2004	9:05	0
97	3	27/01/2004	8:05	0
98	4	27/01/2004	7:20	0.2
107	4	09/02/2004	8:30	0.2
108	1	09/02/2004	8:45	0
109	3	09/02/2004	7:35	0
110	2	09/02/2004	8:55	0
119	1	23/02/2004	7:15	0
120	2	23/02/2004	7:30	0
121	3	23/02/2004	8:25	0
122	4	23/02/2004	8:05	0.2
126	4	23/02/2004	12:05	0
132	2	08/03/2004	8:35	0.05
134	4	08/03/2004	6:55	0.15
135	1	08/03/2004	13:19	0.05
137	3	08/03/2004	12:29	0
138	4	08/03/2004	11:55	0.05
140	2	08/03/2004	18:35	0.05

142	4	08/03/2004	17:25	0.05
147	1	23/03/2004	13:30	0.1
POSKEY	**Site**	**Date**	**Time**	**P (mg/L)**
148	2	23/03/2004	13:10	0
149	3	23/03/2004	12:50	0
150	4	23/03/2004	12:20	0

P (total inorganic soluble phosphorous) was assessed using Merck colourimetric semi-quantitative equipment.