Removal of Aquatic Weeds From Lagoon Creek, Herbert Catchment North Queensland: Trialling Novel Removal Methods and Demonstration of Environmental Benefits

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EXECUTIVE SUMMARY

Though located in an intensively developed agricultural area, surrounded by sugar cane, Lagoon Creek is one of the most important wetlands and fish habitats in the Herbert River floodplain. It consists of a number of deep connected lagoons and has previously been the subject of community action to restore its riparian vegetation. Lagoon Creek became significantly degraded during the 1990's and suffered a number of high profile fish kills. Since that time, the entire water surface has been covered by dense mats of water hyacinth – a floating exotic weed. The hyacinth mats have also been secondarily colonised by a number of other plants growing on top of the mats. This document reports on a project, funded through the Great Barrier Reef Coastal Wetlands Protection Programme – Pilot Program, to remove the weed mats and monitor the recovery of the water quality, fish, birds and other ecosystem values of Lagoon Creek.

Weed removal posed several challenges. The weed mats were more tightly bound to each other and also to the banks by vines and grasses growing from the banks than in previous weed removal projects. Additionally, access was restricted along most of the creek by steep banks and thick riparian vegetation. Even during floods, little weed material was dislodged from the mats. The key to this program was to free the floating weed masses and break this tight binding, facilitating mechanical removal of the weed biomass. The bankside bindings were sprayed with herbicide. Experimental aerial application of a brine solution helped break loose the weed mats. A flow event then washed away ~5ha of floating weeds, providing a boost to the removal program and saving many thousands of dollars in mechanical removal costs.

The remaining weed was then mechanically removed using a floating weed harvester to break up the mats and an excavator positioned on the bank to remove the weeds from the waterbody. Trialling the use of small boats in several configurations also boosted the weed removal effort by making transfer of weed mats to the excavator more efficient, and also by accessing areas the harvester could not reach. Modification of small aluminium boats to include a retractable pushing surface (e.g. a security screen door) at the boats bow, to push weed mats, was quite effective and saved both time and money.

Overall, it was estimated that over 17,500 tonnes wet weight (2850 tonnes dry weight) of weed mat (mostly water hyacinth) were removed from Lagoon Creek. This biomass is estimated to have included at least 36.68 tonnes of Nitrogen and 8.55 tonnes of Phosphorus.

Once the weed mats were removed, water quality improved and aquatic fauna increased. Dissolved oxygen saturation in the water was negligible prior to weed removal, limiting the survival of many aquatic species, especially fish. Shortly after weed removal, dissolved oxygen saturation in the near surface waters increased to a healthy range. Nutrient levels in the water column decreased 10-fold after weed removal. The number of waterbird and fish species increased after weed removal including the first barramundi recorded from the system since 2002. The system is expected to continue its recovery, as instream habitat develops and fauna has more time to colonise the newly opened habitat. However, because of the nature of the waterbody and the surrounding land use, it is likely to suffer various water quality problems, including fish kills, in the future.

This project has been an outstanding success and although Lagoon Creek still faces many management issues to retain and improve upon its newly found aquatic health, it now has greatly improved water quality and habitat values, and supports more species than prior to the removal of the weed mat. Due to the rapid rate at which water hyacinth grows, ongoing maintenance will be required to ensure the open status of the waterbody. Regular herbicide spraying of small hyacinth patches and occasional mechanical removal of larger weed patches will be critical to ensure the long-term health of Lagoon Creek.

1.0 INTRODUCTION

Lagoon Creek is a palaeochannel of the Herbert River that has formed a series of interconnected deepwater lagoons. As the largest freshwater body at the headwaters of Victoria Creek, a large tidal estuary that was once the main mouth of the Herbert River, Lagoon Creek has very high importance to a number of marine fish species that utilise freshwater habitats during some stages of their life cycle or rely on freshwater habitat as part of the food chain, including the recreationally and commercially important and iconic barramundi. With the destruction of many other wetlands on the Herbert River floodplain (Hogan and Graham, 1994), the importance of maintaining good quality habitat in Lagoon Creek has become even more critical than when the floodplain had more extensive wetlands.

Prior to its degradation during the 1990's, Lagoon Creek supported a healthy and diverse population of native fish and was recognised by local fishers as an important nursery for barramundi (*Lates calcarifer*) and other recreationally and commercially important fish species. Local recreational and commercial fishers have raised concerns that the water quality in Lagoon Creek was so poor that it was a major source of contaminated water leading to fish kills in downstream areas after heavy rainfall events.

Lagoon Creek became progressively degraded due to a weed invasion dominated by water hyacinth (*Eichhornia crassipes*) along most of its length. A secondary invasion of a range of introduced and native plants has resulted in a complete blanket covering of what were previously open waters in its impoundment (Figure 1). The most downstream reach of Lagoon Creek was historically subject to tidal intrusion, but since the construction of a tidal barrier many decades ago, it is now permanently freshwater, which may be enhancing growth of aquatic freshwater plants.

Lagoon Creek was selected as one of a number of sites for the implementation of the pilot program for the Australian Government's GBR Coastal Wetlands Protection Programme – Pilot Programme (CWPP-PP) because of its degraded condition, its value to the local community, its connectivity with estuarine areas, its potential environmental value once rehabilitated and the high level of confidence, based on previous experience from similar sites in the Burdekin (Perna 2003a, 2003b, Perna and Burrows 2005) that removal of the weed mats would result in rapid and substantial improvements in the health of Lagoon Creek.

The purpose of the Lagoon Creek rehabilitation project was to remove the weed mats and monitor the environmental benefits that accrue. This report presents the outcomes of both the weed removal program and the ecological monitoring. Monitoring of water quality, aquatic fauna (fish and birds) and habitat condition subsequent to weed removal was undertaken to demonstrate the benefits that resulted from removal of the weed mats.

Many other floodplain wetlands in North Queensland that are covered by floating aquatic weeds (eg, Sheep Station Creek – Perna 2003a, 2003b, Perna and Burrows 2005) typically experience severely hypoxic and often anoxic conditions throughout their entire water column. Previous studies for Lagoon Creek showed similar conditions when it was covered by these weeds and also reported elevated nutrient levels and concerns for potential ammonia toxicity (Pearson *et al.*, 2003). Lagoon Creek suffered from severe hypoxia and was incapable of supporting many of the aquatic species it would otherwise be expected to support (Pearson *et al.*, 2003). Lagoons studied in the Burdekin district showed rapid recovery of their dissolved oxygen status, aquatic habitats and fish communities after harvesting of water hyacinth mats (Perna 2003a, 2003b, Perna and Burrows 2005) but this was in the dry tropics whereas Lagoon Creek is in the wet tropics. Additionally, Burdekin weed removal projects have been associated with drainage systems that are being used to transport irrigation water, hence having a high dilution volume. This is the first project undertaking such large scale aquatic weed removal in the wet tropics and in an area without an irrigation network and as such the methods and expected results differ from that found in the dry tropics examples.

2.0 METHODOLOGY

2.1 Site Description

Lagoon Creek is located approximately 10 km east north-east of Ingham and is a remnant distributary channel on the lower Herbert River floodplain. It is bounded by Palm Creek to the south and a headwater along the general alignment of Mount Cordelia to the north. It drains a small floodplain catchment of approximately 18.5km^2 and acts as an overflow path for Palm Creek and the Herbert River in major floods in the Ingham district.

Lagoon Creek consist of a series of deepwater lagoons with a total surface area of ~27 hectares, and is impounded by a tidal barrier at latitude 18.6266ºS, longitude 146.2632ºE which prevents tidal intrusion and raises the water level by ~2 metres above natural levels. It drains into Victoria Creek before running into the Great Barrier Reef Lagoon to the west of the Palm Island Group. Land use in the Lagoon Creek catchment is dominated by intensive cropping of sugar cane with some remnant areas of lowland rainforest. Riparian vegetation has been re-established on the banks in the lower half of the creek reaches.

2.2 Monitoring Site Selection

Initial site selection was based on ensuring a spread of sites along the length of the creek to observe physical change through photographic records. Water quality monitoring sites were selected for the pre-harvest baseline data collection to provide an overview of water quality along the length of the deep water habitat that was earmarked for harvesting. Due to the harvesting schedule and equipment availability, water quality monitoring was focused on the downstream lagoon, which was the first harvested. Being adjacent to the estuary, this lagoon is of particularly high ecological value and being the first harvested, this provided the greatest opportunity for examining change subsequent to weed removal. Only the most downstream water quality monitoring site (LC014) remained constant throughout the project. Post-harvest monitoring sites remained constant but, with the exception of the downstream site (LC014), were not subject to as much detail in pre-harvest baseline sampling.

2.2 Water Quality

One separate surface grab water sample was collected prior to weed removal at each of four selected sites that were representative of habitat (defined by stream reach and plant community structure) in the Lagoon Creek system. These samples were analysed as described below. The first sample was collected prior to commencement of any weed harvesting, herbicide spraying or any other treatment (i.e. any activity which may potentially cause some level of disturbance to water quality characteristics of the lagoon).

Manual depth profiles were conducted at a number of representative sites on four occasions over a 24 hour period in order to monitor temporal changes in the vertical distribution of temperature, pH, conductivity, dissolved oxygen and turbidity. This was undertaken at four sites along the length of the lagoon in December 2005 (LC004, LC007, LC012 and LC014) to obtain a baseline and again in June, October and December 2006 at four sites on the downstream (harvested) lagoon (LC 009, LC 012, 100 metres upstream from LC013 and at LC014). Measurements were taken using Hydrolab field monitoring equipment. In addition, dataloggers were deployed at three of the sites for at least five days on three sampling visit (December 2005, June 2006 and December 2006). Due to equipment constraints, datalogging at the site 100 metres upstream of LC013 was only undertaken for 24 hours in June and December 2006 to monitor a shallow site for any difference in water quality. Dataloggers recorded the same physico-chemical parameters that were used in depth profiling and the sensors were positioned at approximately 30cm below the water surface under a float anchored to the bottom.

Water samples were collected at 50cm depth for laboratory analysis at the same locations and on the same visits as the field meter readings were taken. Samples were collected towards the end of each field trip and were placed on ice for transport to the ACTFR laboratory where they underwent analysis. Parameters tested included total suspended solids (TSS), total organic carbon (TOC), turbidity, cations, colour, total nitrogen (N), total phosphorous (P), total dissolved nutrients (TDN), dissolved inorganic nutrients (DIN's), pH, chloride concentration, sulphate content, carbonates and bicarbonates.

Table 1 Water Quality Sampling and Photographic Reference Sites

Site No.	Name	Latitude (ºS)	Longitude (ºE)	Original Condition
LC001	Rainforest	18.634886	146.218324	narrow creek, weed covered
LC002	Cane Drain	18.631041	146.223490	narrow creek, weed covered
LC003	Vince's Corner	18.626137	146.228965	widening, weed covered
LC004	Causeway	18.625515	146.235985	wide, small open area - tarpon
LC005	Spina's Bend	18.620412	146.240116	shallow run, grassy weeds
LC006	Tree Down	18.618867	146.244080	entrance – weed covered
LC007	Deep Lagoon	18.619296	146.246352	deep drop-off – weed covered
LC008	Narrow Neck	18.621260	146.250629	canopy – weed free
LC009	Junction South Bank	18.622992	146.251076	snags – weed covered
LC010	West End	18.622042	146.248836	deep – weed covered
LC011	Junction North Bank	18.622444	146.251438	canopy, weed free, shallow
LC012	Lagoon Centre Sth Bank	18.624122	146.256533	weed covered snags
LC013	Access Corner	18.625447	146.263168	sedge binding hyacinth
LC014	Tidal Barrier	18.626607	146.263214	small open croc hole

2.3 Photographic Monitoring and Visual Observations

Reference sites were selected for photographic monitoring for the duration of the project. Site locations were logged and cross-checked with two portable hand held Garmin GPS units that were recording 5 metres horizontal accuracy.

Baseline photographs were taken at each site for future reference and comparison between before and after harvesting of the floating weed mats. Flora and fauna (birds and fish) were observed briefly at each site and recorded. Details of sampling and reference sites are provided in Table 1 and Figure 1.

2.4 Organic Mass of Weed Mat

Organic biomass of the weeds was estimated from calculation of the surface area of the lagoon estimated from Geographic Information System (GIS) data combined with measurement of representative samples of floating vegetation types on Lagoon Creek. Representative samples of weed mat (including water hyacinth mixed with other weeds) were collected on 26 January 2006. One 0.25m² quadrat of weed was collected, using a pitch fork, at each of eight accessible sites selected at random. The samples were placed in the shade in plastic bags that were inverted and allowed to drain for 6 days. Samples were then weighed (wet weight) prior to being dried to a constant mass at 70ºC which took 4 days and re-weighed to determine their dry biomass per m². The average dry weight per square metre estimates obtained from these eight samples was then multiplied by the surface area of the infestation to calculate the total biomass. Minor losses during draining and drying could not be calculated and the final estimate is therefore conservative.

2.5 Nutrients in the Weed Mat

Four sub-samples of each of the eight weed mat samples (see section 2.3) were selected at random and tested for their nitrogen and phosphorus concentrations at the School of Tropical Biology, James Cook University. Total nitrogen was determined colorimetrically by the salicylate-hypochlorite method of Baethgen & Alley (1989), which allows a faster throughput of samples compared to the traditional distillation and titration method. Total phosphorus was determined by an adaptation of Murphy & Riley's (1967) single solution method (Anderson & Ingram, 1989). A full description of the laboratory methods is at Appendix A. As for organic mass calculations, the average concentrations were then used to calculate the total load. As small losses occurred whilst draining and drying the weed mat, the final nutrient calculations are conservative.

Figure 1 Sampling and Reference Sites on Lagoon Creek

2.6 Removal of the Weed Mat

A critical objective of this project was to avoid simply spraying the weed mats with herbicide and having the huge biomass sink into the water column, gradually decaying over a long time period. This decaying biomass would potentially create just as much or even more, ecological harm, than leaving the mats in place, and at the very least would be expected to substantially delay ecological recovery. Likely effects include total deoxygenation of the water column and development of potentially lethal ammonia concentrations as has been reported from other projects that killed weed mats rather than removing them (Mangas-Ramirez and Elias-Gutierrez, 2004). Although more expensive, it is essential that the majority of the weed biomass is removed from the lagoons to avoid adverse impacts.

Weed mats were removed using a variety of approaches, some of which were novel and thus required some trial and error. Although it was a major component of the removal program, due to the large volume of weed present, mechanical harvesting of the entire lagoon system by the floating harvester utilised to such great success in the Burdekin catchment, was not feasible within the budget available here. The weed mats in Lagoon Creek have survived several flood events by simply rising with the floodwater and then settling back into their original position as water level receded, with barely any loss of biomass. This was due to the tight binding together of the weed mats by secondary plants growing on top of the water hyacinth, and also by vines and grasses growing out from the bank and attaching the weed mat to the shore. Thus, we initially aimed to break these bindings in order to make flood removal of weed material more likely. This involved herbicide spraying of bank-side weeds to detach the mat from the bank and aerial application of a brine solution to break up mid-water mats.

Bank-side spraying of weeds attached to the bank was undertaken progressively by a team of two workers using a truck mounted reservoir and a long hose fitting. The team started with the bottom lagoon and worked their way upstream into the 2nd lagoon to maximise the potential for flushing out the weeds that became detached. A total of ~4.7Km of bank was sprayed prior to the first heavy rains, after which spraying was suspended until after the end of the wet season. 120 litres of Roundup Bio-active was applied at a concentration of 13ml/L taking a total of 23 man-days. This spraying was undertaken at the start of the wet season and was intended to ensure the sprayed weeds had time to break down and loosen their binding.

After an initial trial of aerial brine spraying that did not seem to affect the water hyacinth, field trials were undertaken on 10 February 2006 to determine appropriate saline spray application strengths and volumes. Applications of standard pool salt at strengths of 50 ml, 100 ml, 200 ml and 400 ml per m² were trialled at 140 gm/litre initially on one metre square quadrats that were representative of the weed mat. Effects of the application were assessed from visual observation three hours after application and rated on a scale of 1 to 5 with 1 being a minor effect and 5 being a major effect. After observing little effect, at this concentration, salt concentration was increased to 200 gm/litre and applied at 25 ml, 50 ml, 75 ml, 100 ml, 200 ml and 400 ml per m².

Salt spraying was subsequently undertaken on 22 February 2006 using a helicopter fitted with spray booms for agricultural spraying. The effective swath of the booms was 11 metres with 50 Teejet air injected nozzles on the booms. Eight nozzles were removed to increase the water application rate. Ten loads of 450 litres per load containing ~100Kg of salt/load were applied over ~ five hectares. The total time taken for the operation was ~ three hours not including travel time for the helicopter to and from the site but included an interruption by an unpredicted rain shower of ~30 minutes duration. Most of the applied salt actually remains on the plants (not going into the water) and in any case, the amount applied is minimal compared to the volume of water present and had no significant effect on water conductivity.

In April 2006 a flood event flushed approx 5 hectares of weed from the largest downstream lagoon. Mechanical harvesting was subsequently undertaken on two occasions. In May 2006, the remaining weed in this lagoon was harvested using the Burdekin Shire Council weed harvester, an excavator and three small unmodified boats. The boats were introduced because of the need to transport weed along the lagoon to an area where damage to riparian vegetation by the excavator could be minimised. In December 2006 the harvester, excavator and two modified small boats were used to harvest the remaining upstream accessible lagoons.

Mechanical removal of remaining weed mats in the downstream lagoon began mid 2006 with a floating weed harvester hired from Burdekin Shire Council and an excavator with a modified grab bucket sourced locally. The harvester and excavator were transported to the site on low loaders and the harvester was unloaded with two large industrial cranes. The harvester worked alone for two days to break up the weed mat before being joined by the excavator. On the third day, two 4.1 metre plastic boats fitted with 25hp motors were hired from local sources to join the operation. The harvester has previously been employed extensively working with excavators but not with the assistance of small boats. The harvester's ability to break up the weed mat was made easier by the earlier herbicide and brine spraying.

Methods trialled with the small boats included using a net to encircle weed "islands" cut by the harvester, and towing captured weed mats with one or both boats; using a net draped over a plastic floating pipe and pushing the pipe, and; dropping an anchor over the bow and using it to "hook" weed islands and push or pull them with the bow of the boat overhanging the weed (Figure 3a). The latter two methods proved successful in enhancing the operation of pushing weed mats (up to tennis court size or larger) to where it could be reached by the excavator for removal. An important aspect of this operation was the use of prevailing winds to assist the boats and harvester in moving weeds to the excavator.

2.7 Fauna Observations

Fauna monitoring was undertaken by a variety of methods. Visual observations of birds and fish using the lagoon area was undertaken during visits to collect water samples and monitor the response of the lagoons after rain events. Fish surveys were undertaken using a boat-mounted 2.5 GPP Smith-Root electrofisher. These were only undertaken in the most downstream reach as the upstream reaches of the creek were not harvested until later in the project and recruits entering the system from the estuary were more likely to be found in the most downstream reach anyway. The downstream reach was surveyed for fish on five occasions (3/3/06, 12/5/06, 28/9/06, 23/3/07 and 13/6/07), once prior to weed harvesting and four times after. Sampling in the pre-harvest necessitated the use of openings in the weed mats and was restricted to the four most downstream sites that were accessible, whereas post-harvest sampling enabled easier boat access to the full length of the lagoon. On all except the first occasion, ten sites between Site LC014 and Site LC010 at the western extremity of the reach were sampled All sites were sampled with a three minute shot of 15-20 second bursts of electricity interspersed with ~20 second rest periods to minimise stress on the fish on each occasion. Species were identified upon capture and then released.

Incidental monitoring of birds was done by visually observing and recording species and numbers during visits to Lagoon Creek.

2.8 Bathymetry and Sediment Size Analysis

Prior to weed removal, anecdotal information and limited sampling from access points on the creek banks was used to estimate depth of the lagoon. After weed removal was completed, the reaches downstream from Site LC004 were traversed by boat with a linked global positioning satellite receiver and depth sounder to collect a series of data points that were then used to build a model of the bathymetry of Lagoon Creek. Understanding the bathymetry of the lagoon is important to its management and water quality and habitat assessment.

Sediment size analysis was undertaken on samples collected during the June 2006 water quality monitoring at sites LC010, LC012, 100 metres upstream from LC013 and at LC014. Sediment samples were collected using a Van Veen Grab Sampler lowered over the side of the boat. Samples were then analysed in a laboratory for sediment size.

3.0 RESULTS AND DISCUSSION

3.1 Water Quality

3.1.1 Pre Weed Removal

A series of graphs showing grab water quality parameters from all visits to Lagoon Creek are shown in Appendix B but of note are the consistently low dissolved oxygen (DO) readings of less than 5% saturation and the small temperature (Temp) variation of 1ºC over a diel (i.e. 24-hour) cycle prior to weed removal. Figure 3a and b illustrate the differences between pre and post harvest DO at the same time of year. Site monitoring at Site LC007 showed potential stratification with 2.25ºC variation between surface water temperature and stream bed temperature although there was no obvious thermocline demarcation. Graphs showing diel variation in DO and temperature from data-loggers prior to weed removal are presented in Appendix B.

The quality of water flowing out from under the weed mat at the downstream end of the lagoons, and at the selected monitoring points was not suitable for habitation by most native fish species. Hydrogen sulphide (H_2S) was smelt at Site LC014 during flow events when there was turbulence to mix the water.

White plant-like matter growing on rocks at the barrier may have been sulfidic bacteria although identification was not undertaken (Figure 2). The water had an intense grey/brown/black coloration (Figure 2) suggestive of high levels of tannin or dissolved organic matter (DOM). The highest DO value recorded at this site before harvesting was undertaken was 6.8% saturation. This was recorded by a automated Hydrolab data-logger prior to the commencement of any flows under the weed mat.

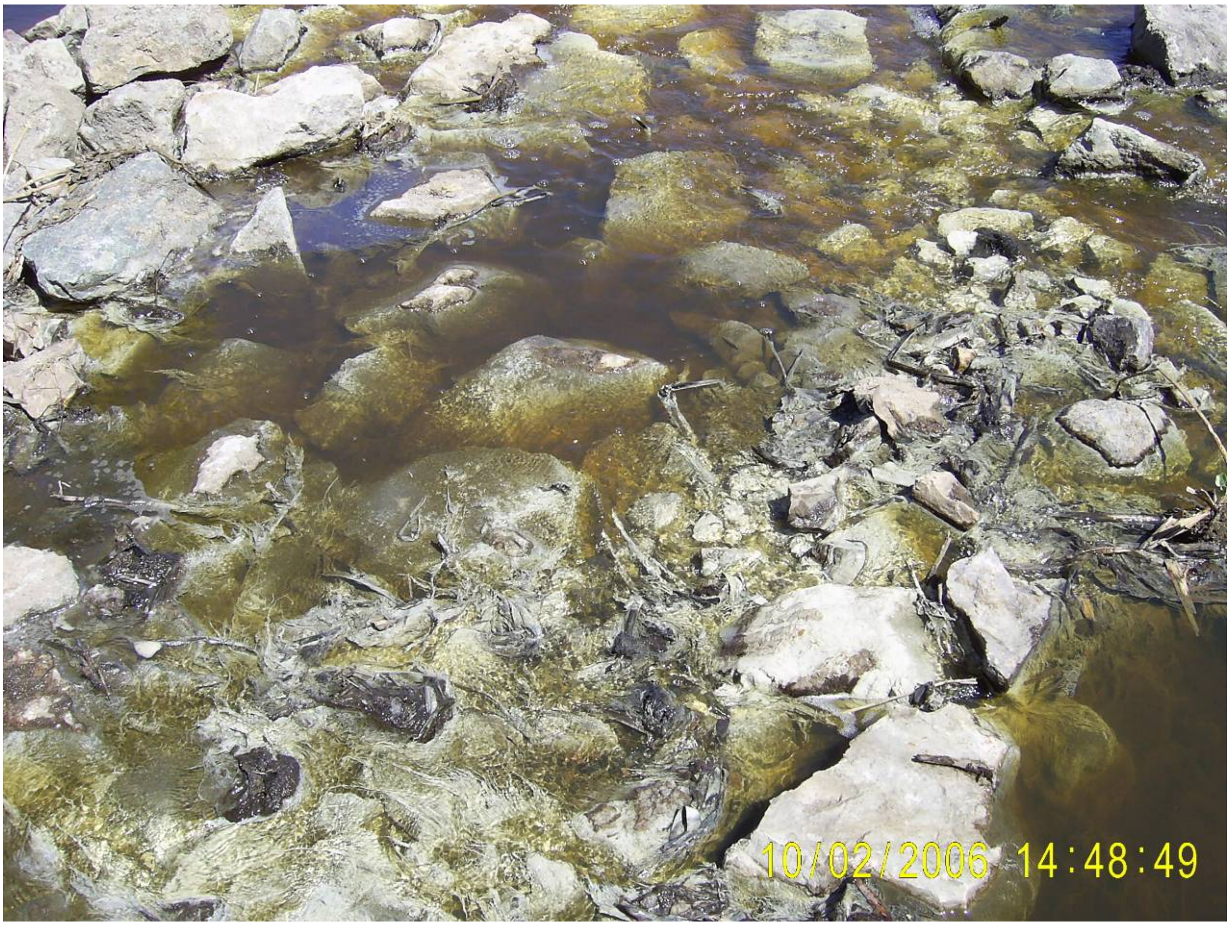


Figure 2 Water flowing over the tidal barrier at site 4 showing water colour and white benthic growth

Initial analysis of water samples indicated that the water was slightly acidic with elevated levels of total suspended solids and potassium. Nitrogen was even higher than previously recorded by ACTFR in

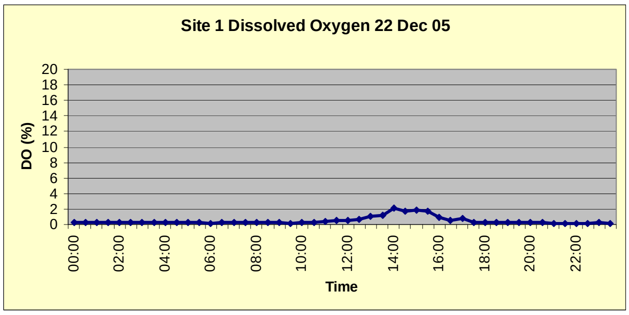
Lagoon Creek (Pearson *et al.* 2003) with 12500µg/L measured at Site LC 012. Ammonia was high in samples drawn from near the bottom of the water column at all sites and potentially at toxic levels but due to low pH, is not likely to have caused ammonia toxicity. Conductivity was consistent along the lagoon and true colour values were high which may be associated with the high organic load due to the weed mat. Very low DO as outlined above is likely to have been the limiting factor for aquatic organisms in Lagoon Creek prior to weed removal as has been the case in other lagoons with large weed infestations (Perna 2003a, 2003b, Perna and Burrows 2005).

3.1.2 Post Weed Removal

The response of water quality to weed removal was both sudden and extreme. Within a few days of weed removal, a green scum formed on the surface of some areas of the lower lagoon indicating a probable phytoplankton bloom. This is a positive sign reflecting the return of water column productivity. The lagoon water then changed colour over a two week period to dark tannin indicating a high loading of organic matter suspended in the water column. The water stabilised at this dark tannin colour for over 12 months although in the period from March to June 2007 there was some improved water clarity towards the outlet of the downstream lagoon (Site LC014) indicating a possible reduction in suspended organic matter. This was associated with a large increase in biomass of *Ceratophyllum*, a free-floating submerged native aquatic plant which was previously largely absent from the lagoon system prior to weed removal.

Prior to weed harvesting there was very little DO in the water column (Figure 3a), creating limiting conditions for the survival of many aquatic organisms. Following weed removal, DO increased greatly and was cycling within a healthy range suitable for all aerobic aquatic species (Figure 3b). Graphs for all water quality monitoring undertaken are at Appendix B.

The improvement in DO was combined with a ten-fold reduction in total nutrients in the water (Figure 3c). It would appear that, before it was removed, the weed mat was creating an environment that allowed accumulation of nutrients in the water column because of a combination of low DO and a climax vegetation community releasing accumulated nutrients. The weed mat was preventing any photosynthesis in the water and therefore preventing plant matter under the water from taking up the available nutrients. The apparent phytoplankton bloom after harvesting was a response to increased light availability in the water and the ability of algae and plants in the water to take some excess nutrients out of the water.



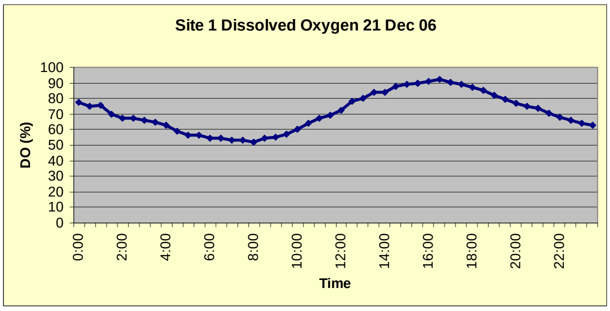


Figure 3a DO at Site LC014 prior to weed removal **Figure 3b** DO at Site LC014 after weed removal
(Note difference in scale of graphs)

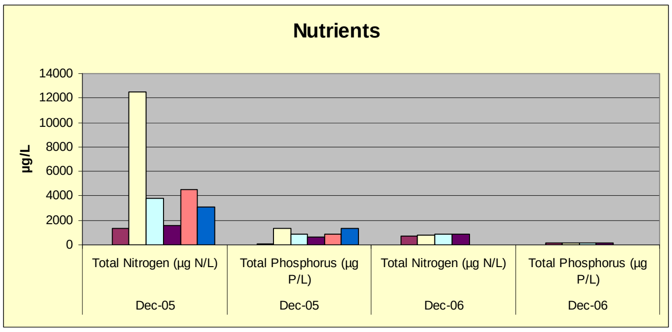


Figure 3c Graph showing difference in total nutrients before and after weed removal

3.2 Photographic Monitoring and Visual Observations

Prior to December 2005, Lagoon Creek was almost completely covered in a mat of weeds with a primary infestation of water hyacinth supporting a secondary invasion of a range of species including *Sporobolus virginicus*, *Urochloa mutica*, *Alternanthera philoxeroides*, *Potamogeton sulcatus*, *Cyperus eragrostis*, *Melaleuca* species and a range of other plants growing on top of the hyacinth mat in over 3 metres of water in some locations by January 2006 (Figure 4a and b) but was open water in January 2007 after weed removal (Figure 4c and d).

There were few small areas where any open water could be seen and at least one of the three open areas we visited was kept clear of weeds as a result of regular visits by a large saltwater crocodile. This was possibly the reason for the other open areas (See Appendix C). A small area of narrow creek joining the bottom two lagoons remained free of weed growth due to a full tree canopy shading out most plant growth at ground level.

Early season rain had very little effect on the weed infestation with a rain event from 23 to 26 January 2006 raising the water levels in the creek by ~ 1.5 metres. The weed mat floated up with the water level allowing the stream to flow beneath the mat and exit downstream of it. Effectively, the weed mat acted like a floating blanket with the water passing through the pipe that formed between the mat and the creek bed and banks. The weed mat prevented any effect of wind on the water to aerate surface layers and allow oxygen uptake in the water.

Sediment samples and bathymetric measurements could not be undertaken in this stage of the project due to the inability to move about in the weed mat.

Figure 4a Site LC007 in January 2006

Figure 4b Site LC012 in January 2006

Figure 4c Site LC007 January 2007

Figure 4d Site LC012 in January 2007

3.3 Organic Mass of Weed Mat

The wet weight of the weed mass averaged 646.27 tonne (T)/Hectare (Ha). With a surface area of water in Lagoon Creek (assuming the area between bank-side riparian vegetation) of 27 Ha, the estimated total wet weight of biomass in the lagoon was ~17500 T. The dry weight of the samples averaged 105.32 T/Ha for an estimated total dry weight of 2850 T. The weed mat biomass data is presented in Table B1. Due to minor losses in processing, these estimates are believed to be conservative.

3.4 Nutrients in the Weed Mat

Results from nutrient analysis of the weed mat showed a mean of 12.9±1.6SD mg/g Nitrogen (N) and 3.0±0.5mg/g of Phosphorus (P). The conservative estimated weights of the nutrients in the weed mat covering Lagoon Creek in December 2005 was 36765Kg of N and 8550Kg of P. Laboratory analysis data is presented in Table B2.

The nutrient concentrations in the weed mat are very high and warrant consideration for use as a soil ameliorant. The weed was stockpiled in heaps on the banks of Lagoon Ck, and within 12 months had broken down into rich organic mulch. Farmers in other areas have used the waste weed as a soil conditioner without any processing, to add organic matter to their soils. Caution should be used to ensure it is not applied at a time or in rates that may be harmful to soil health. Further research is required into the potential for processing the waste weed into soil ameliorants.

3.5 Removal of the Weed Mat

The effect of salt spraying varied with the volume and concentration of salt applied. Before and after photographs of the trial are shown in Figures 5a-f and results of the assessment of the field trial are given in Table B3. These results led to the recommendation to apply 100Kg of Sodium Chloride (NaCl)/450 litres water, to each half hectare as described in the methods. No Magnesium Sulfate (MgSO4) was added to the solution.

Final observations confirmed that the most cost-effective rate of application was 200gm/litre at 100ml/m² which had a rated effect of 4 (Figure 5e). Photographic images of the response to various applications are at Figures 5a-f.

Figure 5a Pre Spray Weed Mat

Figure 5b Brine effect 3 hrs after spraying with 140gm/L at 50ml/m^2 after 3 hours

Figure 5c Spraying with 100gm/L at 200ml/m^2 after 15 minutes

Figure 5d Spraying with 100gm/L at 200ml/m^2 after 3 hours

Figure 5e Spraying with 200gm/L at 200ml/m^2 after 3 hours

Figure 5f Spraying with 400gm/L at 200ml/ m^2 after 3 hours

Herbicide spraying was effective in killing the weeds immediately adjacent to the stream bank but two months after spraying the dead weed infestation had still not decayed sufficiently to break the hold on the banks. Middle and upper reaches of Lagoon Creek may be more difficult to access for future herbicide treatment of the bankside vegetation.

The effects of salt spraying were monitored on the day of the aerial spraying (22 Feb 2006) and again on 3 March 2006. The brine application killed the sedge community on top of the weed mats and caused some desiccation of water hyacinth but had little effect on other plant species and did not break up the weed mat within the first 6 weeks as the binding weeds maintained strength for some time after spraying and resisted flushing out by a rain event 2 weeks after spraying.

A subsequent rain event in April 2006 caused water in the lagoons to rise ~2 metres above normal height and this flushed out half of the weeds in the downstream end of the lower lagoon though the remaining mats remained intact. This second rain event cleared out approximately 5ha of water hyacinth when the previous similar-sized event 5 weeks earlier had very little effect, indicating the success of the aerial brine spraying when combined with bank-side spraying and the need to undertake both bank-side and aerial spraying some time before likely seasonal rain events that can flush weeds downstream. Using this method saved an estimated 10 days of harvesting operation with an estimated cost saving of $30 000.

During this event the flushed weed backed up against a cane tram bridge situated in the upper tidal section of Lagoon Creek, and this necessitated removal by a long-arm excavator. As the reach upstream of the tram bridge is narrow and largely clear of riparian vegetation, it was possible to walk the excavator along the bank and remove the weed from the water. While flushing is an effective means of clearing

weed mats it can not be relied on in all situations. Narrow channels and obstructions such as bridges can impede the weed mat from being flushed downstream.
Mechanical removal at Lagoon Creek provided challenges that had not been dealt with in previous harvesting activities. In contrast to previous water hyacinth removal projects in the Burdekin floodplain where the lagoons had low banks with little or no riparian vegetation to impede access, Lagoon Creek has thick riparian vegetation (much of it planted by the community through previous NHT projects) and steep banks along most of its length and this restricted access for the excavator. In-stream large woody debris also restricted the floating weed harvester and provided obstacles for weeds to snag on and make the mats difficult to transport. The type of weed harvester used is slow moving and draws over 60cm of water.

Although precise quantification of costs is difficult, it was estimated that the small boats saved up to 4 additional days work for the harvester and excavator. Including operators, the costs for the weed harvester and excavator totalled $2500/day compared with $720/day for both boats. This suggests a cost saving of $2800 for weed removal from 5 Ha of waterway.

It was thought however that the boats could be more effective if fitted with a rake, and a design was developed and built to trial in a second lagoon. Two small boats were fitted with mesh blades of different designs with one design constructed from a discarded security door. The second design used a mesh drop net supported by a floating sealed PVC tube but this proved more cumbersome to operate. Construction and equipment costs for the boat using a discarded security door totalled $200 plus one day's work by a local stakeholder and a cheap 2nd hand outboard motor costing $800. The small boats fitted with mesh blades were then able to push much larger weed mats than those used previously without rakes. Rake boats were also effective in pulling weeds from the banks and in collecting smaller patches of weeds that neither the harvester nor unmodified boats were able to clean up (Figure 6a and b).

Figure 6a Punt fitted with modified security door

Figure 6b Modified punt pushing weed mat

3.6 Fauna Observations

3.6.1 Fish

Because of its size, proximity to estuarine environments and reasonable riparian condition, Lagoon Creek has long been considered by local fishers as one of the more important fish habitats on the Herbert River floodplain. However, fish surveys in Lagoon Creek have been limited and no data is available for some of those that have been done there. Hogan and Graham (1994) provided some observations of the fish fauna from numerous wetlands on the Herbert River floodplain, showing that due to poor habitat condition and low DO, many had less fish species than expected. Although fish surveys have been previously been undertaken in Lagoon Creek, this is the first published account.

Hogan and Graham (1994) found a total of 43 fish species in freshwater on the Herbert River floodplain in 1994 although the largest number at any one location was 30 species in the Herbert River at Ripple Creek. The highest number of lagoonal species found was 14 species in Alligator Hole on Palm Creek. By comparison, Lagoon Creek is species poor with a total of 10 species identified in 5 surveys undertaken for this project (Table 2). This can be attributed to a combination of factors including the lack of high quality refugia for recruitment back into the creek from other nearby freshwater environments, the relatively small size of the catchment and the reliance on migration through a downstream marine environment that is itself highly modified, for most recruitment into the creek. One of the 10 species recorded was an exotic species – guppy. Although they are widespread in coastal streams of NE Queensland and have been recorded in the Ingham district before, as far as we are aware, this is the first official record of guppies from Lagoon Creek. Eel-tailed catfish (species not determined) have previously been recorded from fish kills in Lagoon Creek (Butler and Crossland 2003, Pearson *et al.* 2003) but were not recorded in our surveys.

Table 2 Results of Five Fish Surveys in Lagoon Creek

Species	**Common Name**	3/3/06	12/5/06	28/9/06	23/3/07	13/6/07
Ambassis agrammus	Glass perch				3	
Anguilla reinhardtii	Long-finned eel			38	2	4
Anguilla obscura	Short-finned eel	2	>100			
Poecilia reticulata	Guppy – exotic	5		50		1
Giurus margaritacea	Snakehead gudgeon	7	20	>100	31	3
Hypseleotris compressa	Empire gudgeon	32	>50	>100	74	6
Hypseleotris sp 1	Midgley's carp gudgeon		1		1	
Lates calcarifer	Barramundi					3
Megalops cyprinoides	Tarpon	24	2	22	11	82
Melanotaenia splendida	Eastern rainbowfish		1	1	48	>200
Nematolosa erebi	Bony bream				2	
Total No. Native Species		4	6	5	8	6
Cumulative No. Species		4	6	7	9	10

The change in the fish population structure since weed removal is encouraging although it is likely to take some time before population dynamics become stable. The capture of barramundi on 13 June 07 is particularly significant as this is the top fish predator species likely to access Lagoon Creek and they would have been unable to tolerate the previous hypoxic conditions in the creek when it was covered by weeds. To our knowledge, this is the first barramundi caught from Lagoon Creek in five years with the last fish reported in a fish kill in 2002 (Pearson *et al*., 2003). Although only three barramundi of relatively small size were caught, they must have been in the creek since March/April, the last time the creek flowed into the estuary with sufficient height to enable upstream migration from the estuary. This demonstrates that the water quality in Lagoon Creek over that time was sufficient to ensure their survival.

Sampling since harvesting has shown large increases in the total fish abundance with large schools of rainbowfish and tarpon observed. The apparent reduction in gudgeon species is more likely to be a factor of fish moving deeper into cover in the clearer water and therefore more difficult to capture This is in stark contrast to the limited fish communities observed using the same sampling methods before and immediately following harvesting of the weed mat. The fish population has shown a steady increase following an initial slow response and many species may now be breeding within the lagoon. The 2007 wet season was the first opportunity for fish to colonise Lagoon Creek since the weed mats were cleared. The fish diversity is expected to rise as more colonisation opportunities arise. Being a large and deep lagoon in the tropics, Lagoon Creek strongly stratifies. This, combined with the intensive surrounding land use, creates conditions for fish kills, as have occurred in the past. Whilst we have demonstrated an improvement in the fish communities of Lagoon Creek, this does not mean that fish kills will not occur here in the future. Butler and Crossland (2003) provide a summary of the limnology and water quality of Lagoon Creek with reference to its fish habitat values. That report draws heavily on the work of Pearson *et al.* (2003) and refers to assessments done on Lagoon Creek from 1999-2003, when the system was being grown over by water hyacinth.

3.6.2 Birds

Unlike fish, birds are highly mobile and able to more easily find alternative habitat. Water dependent birds are therefore able to recolonise rehabilitated habitat more quickly, although some species have a high dependency on fish as a food source. Prior to weed harvesting, the water bird population was observed on five occasions and only one species, magpie goose, was observed. After some preliminary clearing in February 2006, one additional species was observed, the comb-crested jacana. Sea eagles and kites were also observed but these species are wide ranging and not dependant on one lagoon system.

Like the fish, the bird population has gradually increased and species numbers have expanded. On 5 March 2007 whilst undertaking the collection of bathymetry data, ten species were observed including the previously absent whistling ducks, satin flycatchers, darters, white browed crakes and bitterns. Brahminy kites, whistling kites, sea eagles, magpie geese and jacanas were also observed. It is likely that the increasing fish population will attract a larger and more diverse bird population over time.

3.7 Bathymetry and Sediment Size Analysis

Deepwater lagoons in Lagoon Creek had depths of over 6 metres in two locations, one in each of the two largest and most downstream lagoons. In the most downstream lagoon at approximately 100 metres upstream from Site LC013, the depth does not exceed one metre in baseflow conditions across the whole width of the creek but then deepens again further downstream before flowing over the tidal barrier at the downstream end of the lagoon. The approximate volumetric capacity of Lagoon Creek 242 megalitres. It must be remembered that due to the tidal barrier, the water level of Lagoon Creek is elevated above natural by up to 2 metres. Bathymetric models developed from the data are at Appendix D.

Bottom sediment samples varied from a mix of course sand and gravel to fine colloids. Generally, course sediments were at the downstream end of the large lagoon at Site LC014 (although this may have been the result of floods washing gravel from the constructed access pad developed to allow launching of the weed harvester at Site LC013) and very fine sediments dominated at the upstream end at Site LC010. The fine sediments at the upstream end are likely to have been a result of this site having the longest history of weed infestation. The organic fraction of the sediments was not assessed. Results are with the bathymetric models at Appendix D.

4.0 CONCLUSIONS

The removal of aquatic weed mats from Lagoon Creek has been an outstanding success from an ecological perspective and it has also demonstrated a number of innovative methods that can be used to more easily and cost-effectively remove aquatic weed from other degraded wetlands. The recovery of both the fish and bird populations that are dependant on aquatic habitat has been encouraging and should continue to build momentum over the next few years.

The combined use of herbicide and brine to break up weed mats is an effective method if weed can be flushed downstream by seasonal rain events and it assisted in reducing the strength of the mat for mechanical harvesting. Mechanical harvesting was also enhanced by the modified small boats and there are many situations where small boats could be used without the weed harvester, so long as the weed mat is not bound together too strongly. There are however opportunities to expand the range of mechanical harvesting equipment but this will require further investment and trials to prove the technology.

Removing weed mats from the water may seem costly but potential damage to downstream infrastructure and navigation hazards in some waterways may prove to be more expensive than weed control programs. Further research needs to be done to investigate potential uses of harvested weed mats. Investigations undertaken during the project indicate that there is significant potential for the waste weed to be processed into organic soil ameliorant which may be a valuable commercial commodity.

Ongoing maintenance of weeds is essential to prevent Lagoon Creek (and other wetlands) becoming weed infested contaminated waterholes. Regular (eg, 3-5 times per year) herbicide spraying of small weed outbreaks combined with some mechanical removal of larger infestations can maintain the wetland in an open state whilst minimising the impacts on water quality and habitat and return previously marginal wetlands to functional habitat. The historical tidal intrusion into the downstream lagoon is prevented by the constructed tidal barrier at the bottom of Lagoon Creek. Occasional intrusion of brackish water would also be beneficial in controlling excessive growth of freshwater plants and weeds. However, as the tidal barrier enables the lower lagoon to be used to pump irrigation water, any such action would require landholder consultation.

Many of the initiatives introduced at Lagoon Creek should be considered for future projects. Whilst it may seem costly to remove weeds from wetlands, the benefits of improved environment, water quality and reduced risk to infrastructure in major floods are substantial and justify the investment.

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APPENDIX A

Laboratory Plant Nutrient Analysis Methods

Laboratory Plant Nutrient Analysis Methods

We use the single digestion method of Anderson & Ingram (1989) for the determination of N, P and cations. Air-dry soil or plant samples are ground to 0.2 mm, digested with sulphuric acid and hydrogen peroxide. Nitrogen is determined colorimetrically by the salicylate-hypochlorite method of Baethgen & Alley (1989), and phosphorus by an adaptation of Murphy and Riley's (1967) single solution method (Anderson & Ingram 1989). Aliquots of the digest can be analysed for cations (Na, K, Ca, Mg) using atomic absorption spectrophotometry. Some of the mineral forms of the cations are probably not present in the digest, so these do not strictly represent "total" concentrations, but are a useful index of what is potentially available for plants for comparative purposes. Subsamples of the air-dry soils are dried in an oven to determine moisture content, and nutrients are reported as % on an oven-dry basis.

Soil pH and electrical conductivity are determined using the standard method based on a 1:5 water extract (Rayment & Higginson 1992). Soil organic carbon is determined by the Heanes wet oxidation method - based on heating the sample with H_2SO_4 in the presence of dichromate (Rayment & Higginson 1992). External heating ensures complete oxidation, unlike the traditional Walkley & Black method. The carbon is determined from the concentration of chromic ions determined with a spectrophotometer.

Available P is determined by the modified Olsen method using an extracting solution of 0.5M $NaHCO_3$, adjusted to pH 8.5, a soil/solution ratio of 1:100 and an extraction time of 16 hours (Rayment & Higginson 1992). Soil nitrate can be determined simply and accurately using second derivative spectroscopy (Sempere *et al.*. 1993). Soil texture as % sand, silt and clay is estimated from the changes in specific gravity of a soil suspension using a Bouyoucos soil hydrometer (Anderson & Ingram 1989), after removal of organic matter with hydrogen peroxide, and dispersion of the particles by shaking overnight with sodium hexametaphosphate.

Note Re- Accuracy and Reproducibility Of Nutrient Analyses

When we first introduced the single digestion technique, we compared its accuracy against the standard Kjeldahl and mixed acid procedures using 10 replicates of ground banana leaf, and found no significant differences (Maycock 1991).

We rely on 3 methods to check the accuracy and reproducibility of our nutrient analyses:

1. I routinely analyse duplicate samples (and encourage novice operators to do the same), with the idea of repeating any which do not agree within 5 to 10%. **This doubles the time and cost of analyses, at least.** Errors can occur due to insufficient mixing of the digest in the digestion tubes prior to taking aliquots for analysis, or due to lack of care with the automatic pipettor. Uneven heating of the aluminium block can lead to differences in rate of digestion, but we check that all digests have cleared before terminating the digestion step. We have found that it is extremely rare to get discrepancies between duplicates when care is taken, so for larger batches of samples we initially only duplicated 10% of samples in each run, and then ceased duplication completely with larger batches.

2. Usually replicate samples are included in any set of analyses, so discrepancies between these indicate any need for further analysis. For example, in analysing soils from a site we usually take samples from 5 cores, to account for within-site variability. Generally soil samples show more variability than plant material. Topsoils are least homogeneous. There can be some settling of finer particles in ground samples.

3. The main check on reproducibility between analyses is the production of blanks with low and consistent values, and standards which give a good regression based on duplicates with low variability. A fresh set of duplicate blanks and standards are made up with each new batch of digestion mixture.

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APPENDIX B

Biomass Weights, Laboratory Nutrient Analysis, Brine Treatment Assessment and Water Quality Graphs

Table B1: Biomass Weights

Wet Weight							
S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
6.45	5.656	6.325	6.39	6.315	1.9	4.968	3.346
9.605	8.625	10.245	11.21	6.22	10.86	5.44	2.474
						11.79	11.435
16.055	14.281	16.57	17.6	12.535	12.76	22.198	17.255
						Total	129.254
							64.627
						Kg/Ha =	646270
							646.27T/Ha
							17449.29
							~17500T
Dry Weight							
1.658	1.614	1.504	1.352	1.664	1.052	1.126	1.506
-0.118	-0.118	-0.118	-0.118	-0.118	-0.118	-0.118	-0.118
1.54	1.496	1.386	1.234	1.546	0.934	1.008	1.388
						Total	10.532
						Kg/Ha =	105320
							105.32T/Ha
							105.32
							2843.64
							~2850T

Table B2: Laboratory Nutrient Analysis

TROPICAL VEGETATION DYNAMICS LAB - ANALYTICAL RESULTS

Date: 17/02/2006
Client: Vern Veitch (ACTFR)
Analyst: Kelly Kong
Queries to: Bob Congdon

No.	Sample	Weight (g)	Air-dry weight (g)	Oven-dry + vial	Vial (g)	Oven-dry weight (g)	% Air-dry moisture	Oven-dry weight (g)	N-abs	N-conc (ug/mL)	Total N (mg/g)	P-abs	P-conc (ug/mL)	Total P (mg/g)
1	Hyac.	0.148	0.623	13.185	12.636	0.549	11.9	0.130	0.324	20	11.5	0.395	5	3.0
2	Hyac.	0.151	0.642	13.747	13.177	0.570	11.2	0.134	0.313	19	10.8	0.356	5	2.6
3	Hyac.	0.152	0.469	14.670	14.252	0.418	10.9	0.135	0.449	29	15.9	0.378	5	2.8
4	Hyac.	0.153	0.865	15.330	14.533	0.797	7.9	0.141	0.388	24	13.0	0.422	6	3.0
5	Hyac.	0.164	0.581	13.561	13.046	0.515	11.4	0.145	0.399	25	13.0	0.592	8	4.0
6	Hyac.	0.148	0.842	14.603	13.854	0.749	11.0	0.132	0.369	23	13.2	0.496	6	3.7
7	Hyac.	0.152	0.410	14.234	13.868	0.366	10.7	0.136	0.344	21	11.8	0.358	5	2.6
8	Hyac.	0.149	0.553	14.319	13.821	0.498	9.9	0.134	0.401	25	14.2	0.34	5	2.5
1			0.489	14.940	14.507	0.433	11.5							
									Mean	23.5	12.9		5.5	3.0
									Stdev	3.1	1.6		1.1	0.5
									SEM	1.1	0.6		0.4	0.2

Table B4: Brine Treatment Assessment

Salt Treatment Field Trial Assessment

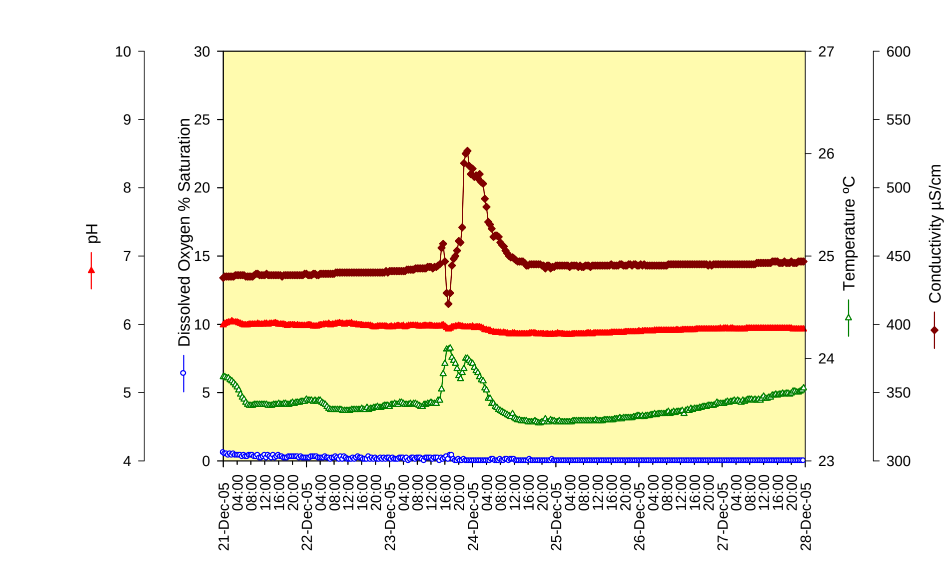
140gm/L				
Volume (ml/M)	50	100	200	400
Rating	1	2	2	3

200gm/L						
Volume (ml/M)	25	50	75	100	200	400
Rating	1	1	2	3	4	5

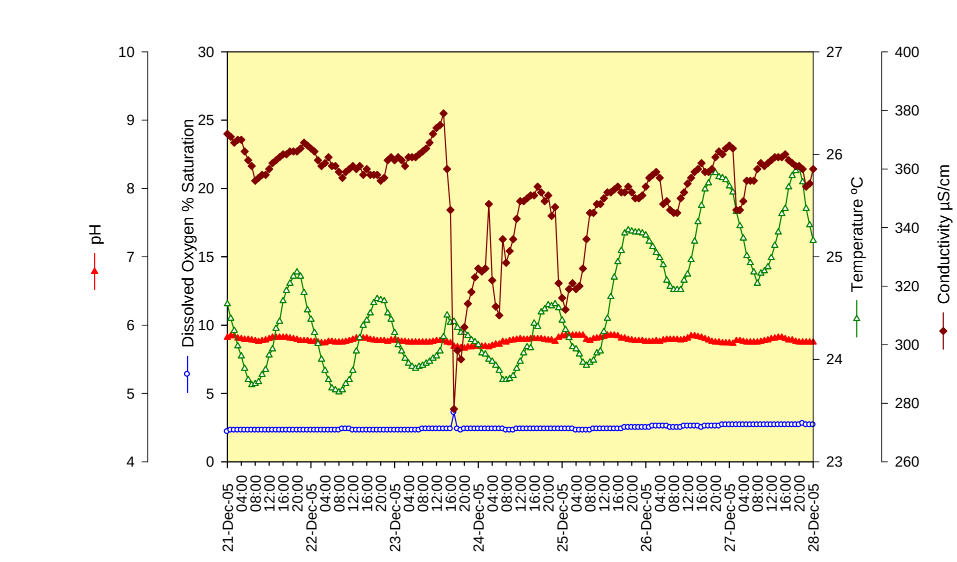
Note: 1 = minimal response; 5 = major response

Datalogger Data for December 2005 at Three Representative Sites on Lagoon Creek

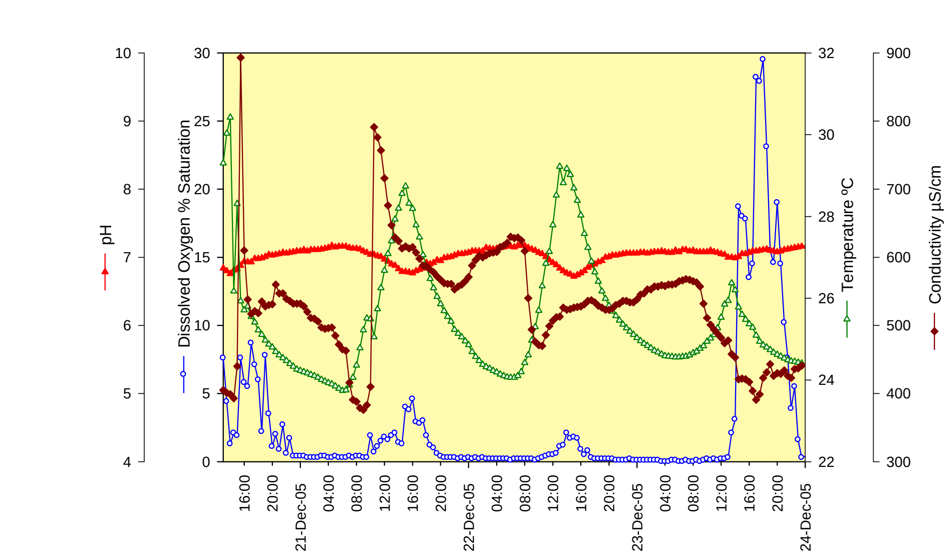
Lagoon Creek Site LC004 December 2005



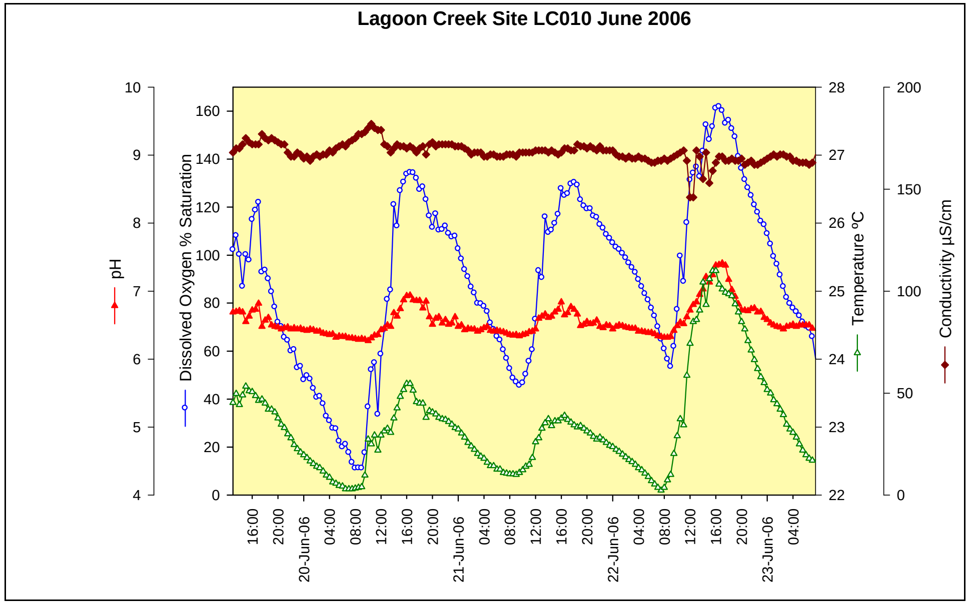
Lagoon Creek Site LC007 December 2005

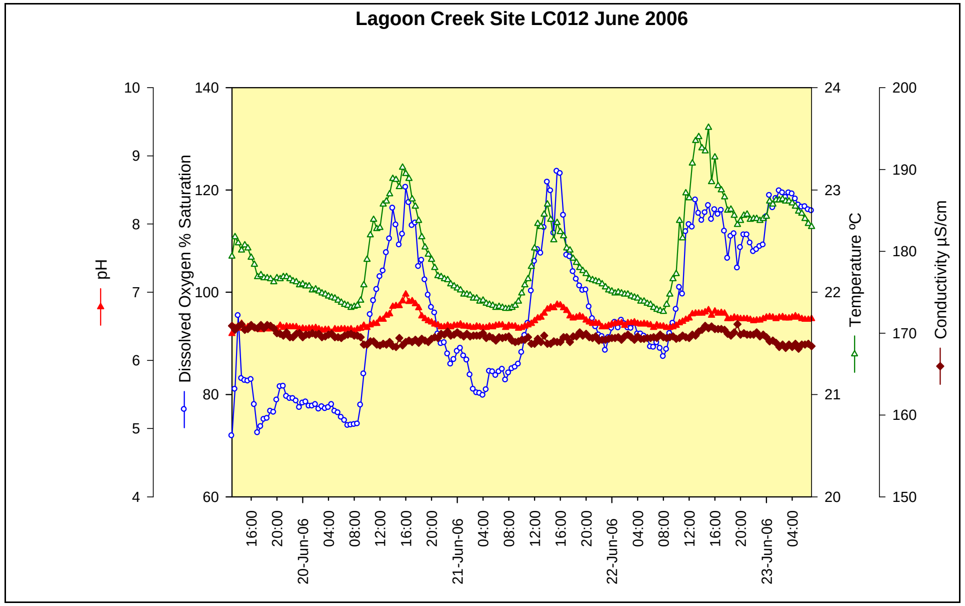


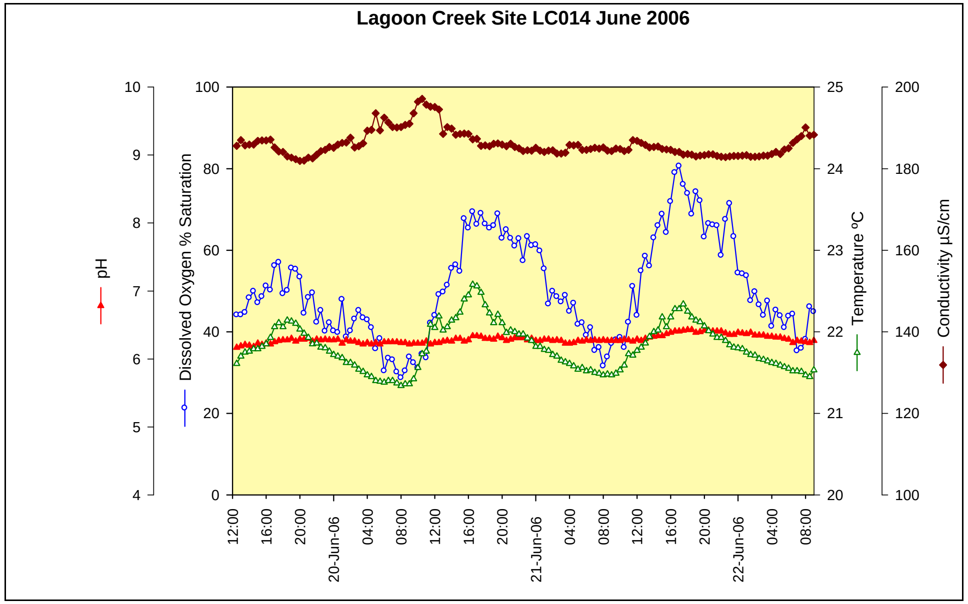
Lagoon Creek Site LC014 December 2005



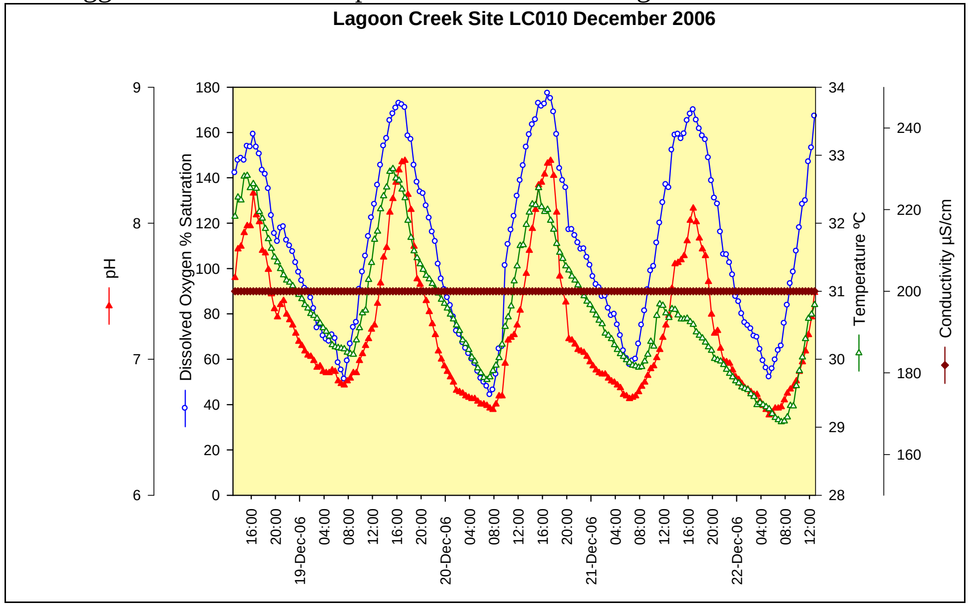
Datalogger Data for Three Representative Sites on Lagoon Creek in June 2006 (Note differences in scale for DO and Temp)

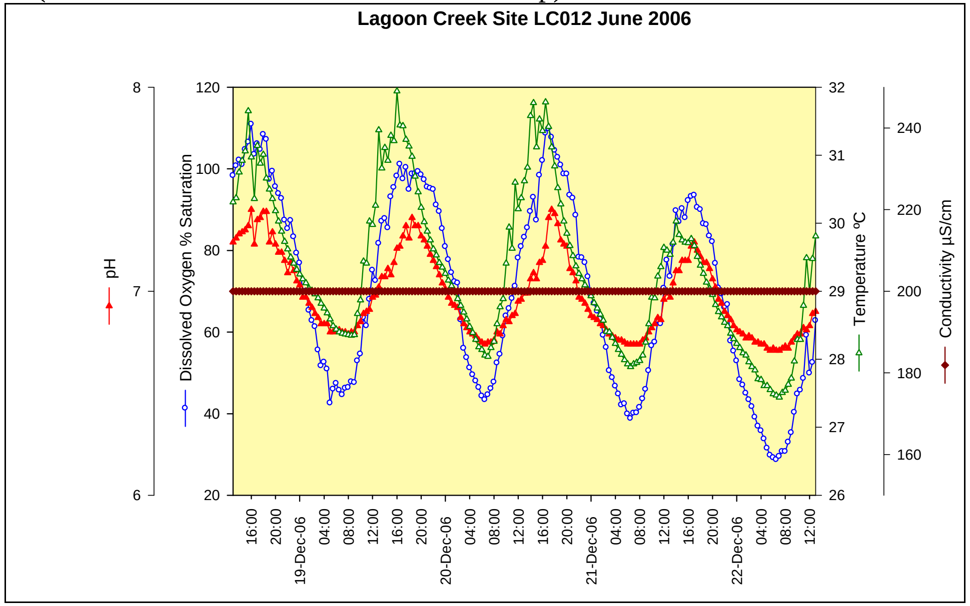


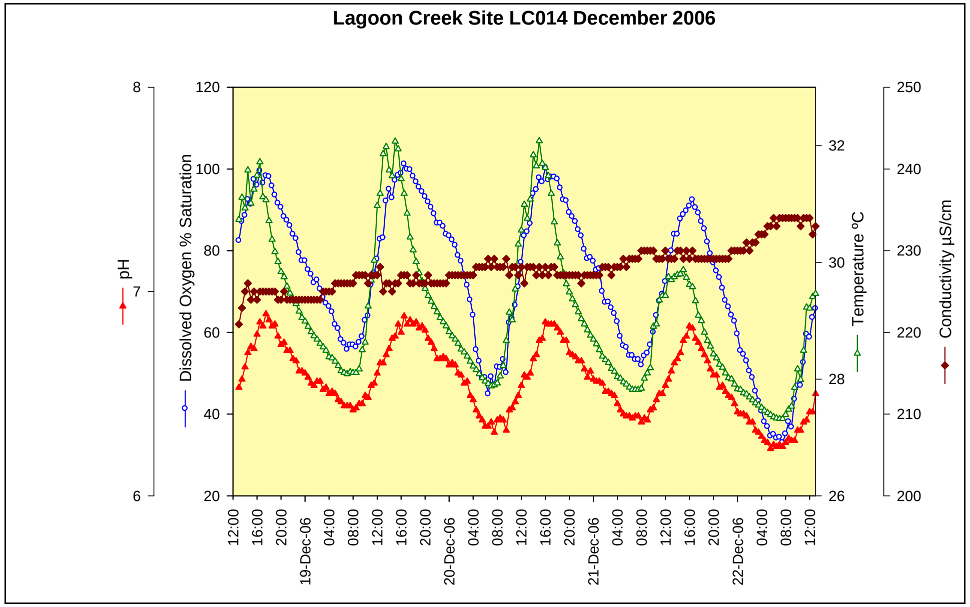




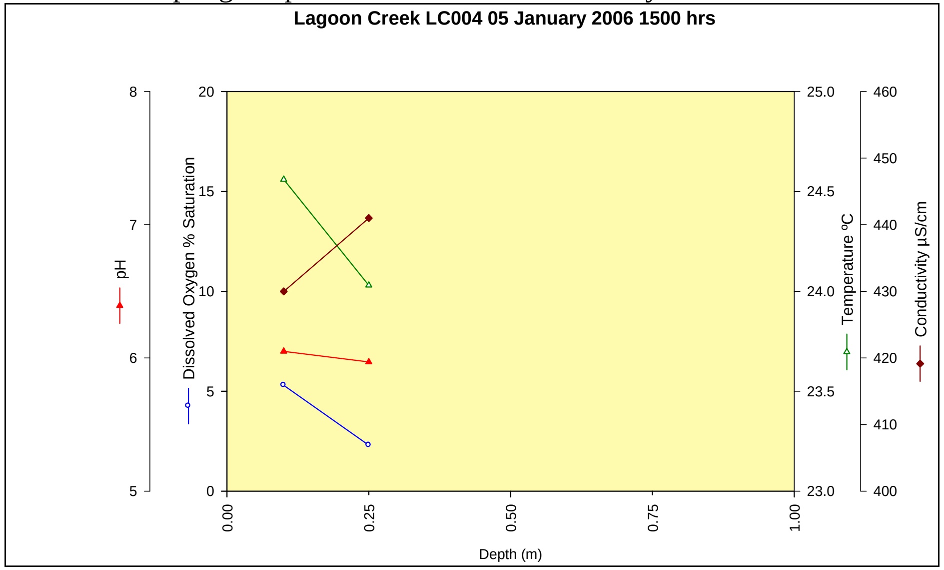
Datalogger Data for Three Representative Sites on Lagoon Creek in December 2006 (Note differences in scale for DO and Temp)

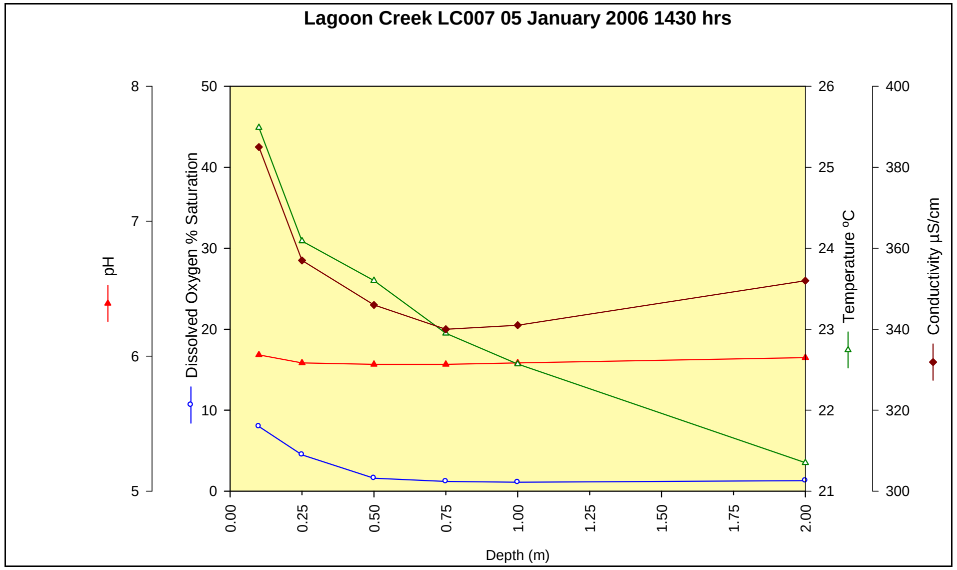


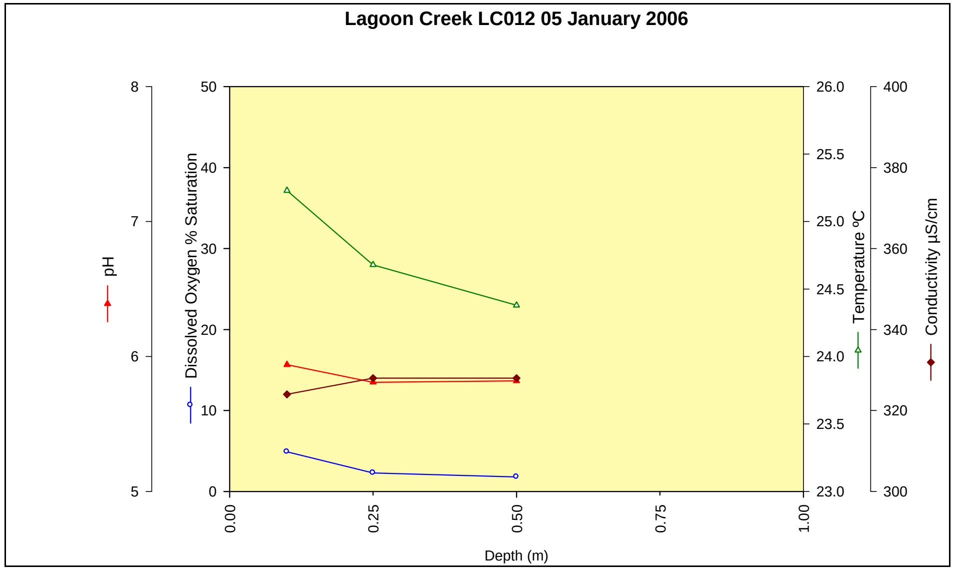


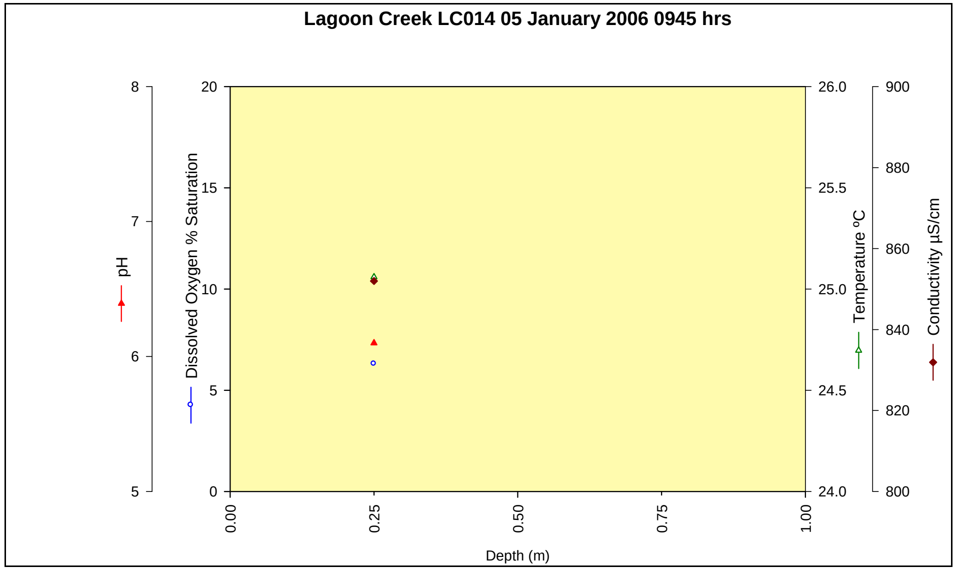


Stratified Sampling Graphs for December 2005/January 2006 – all sites

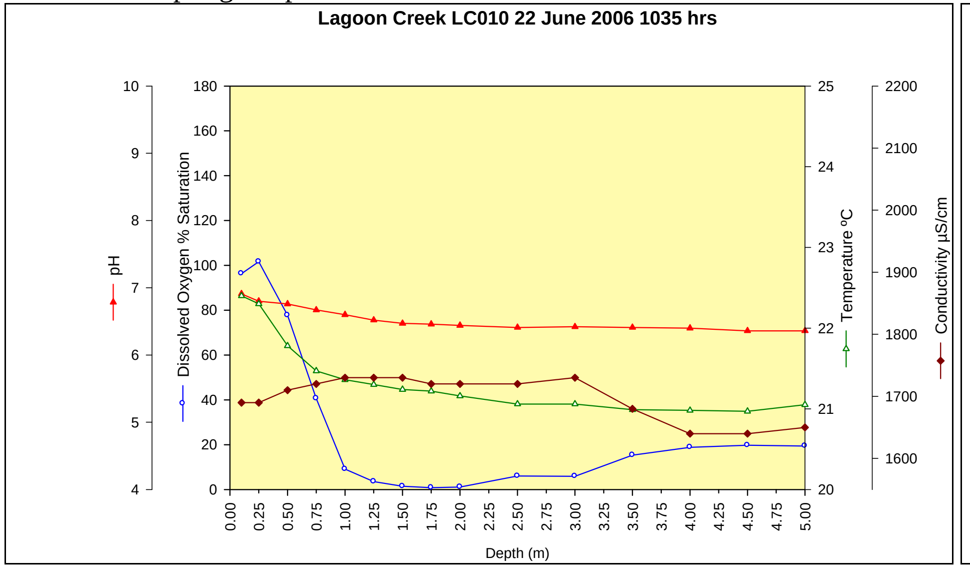


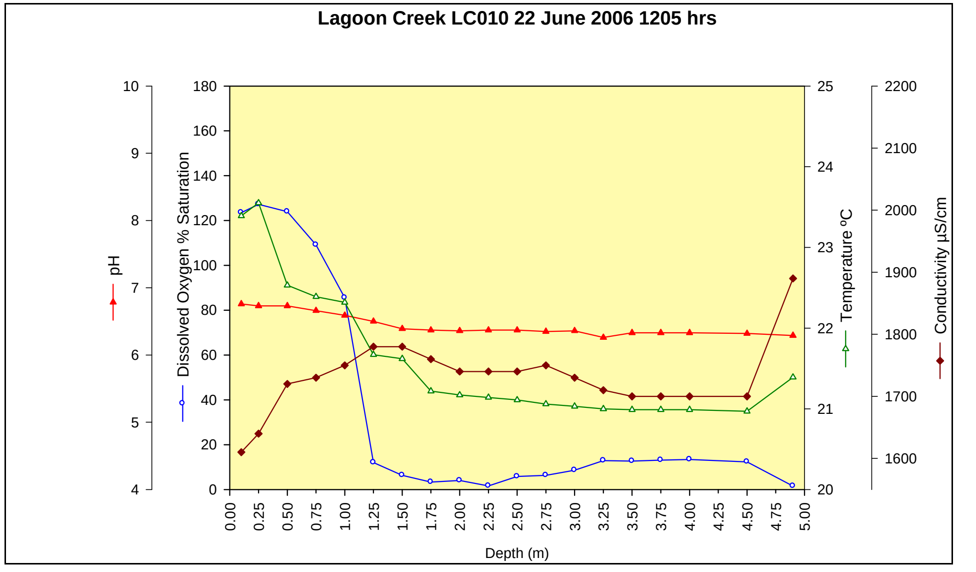


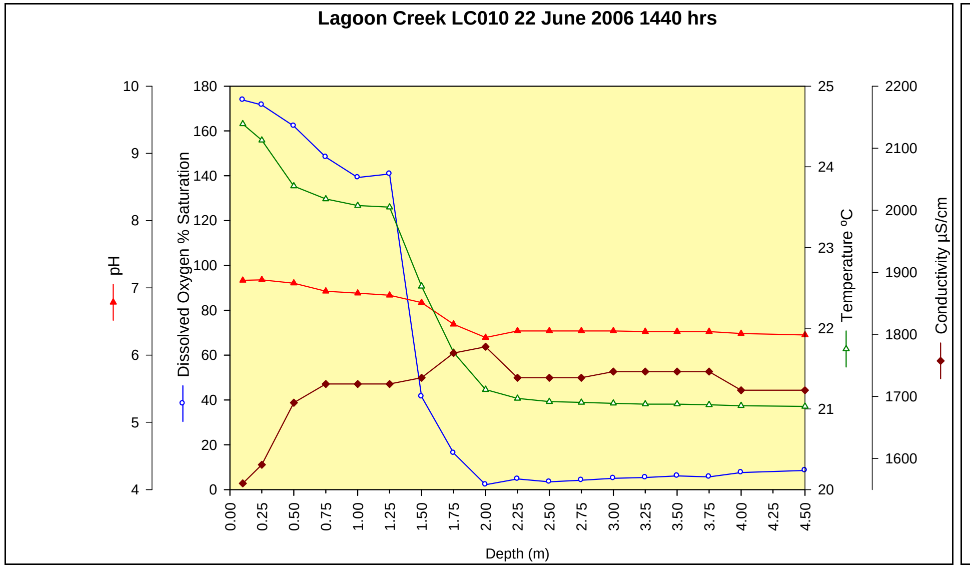


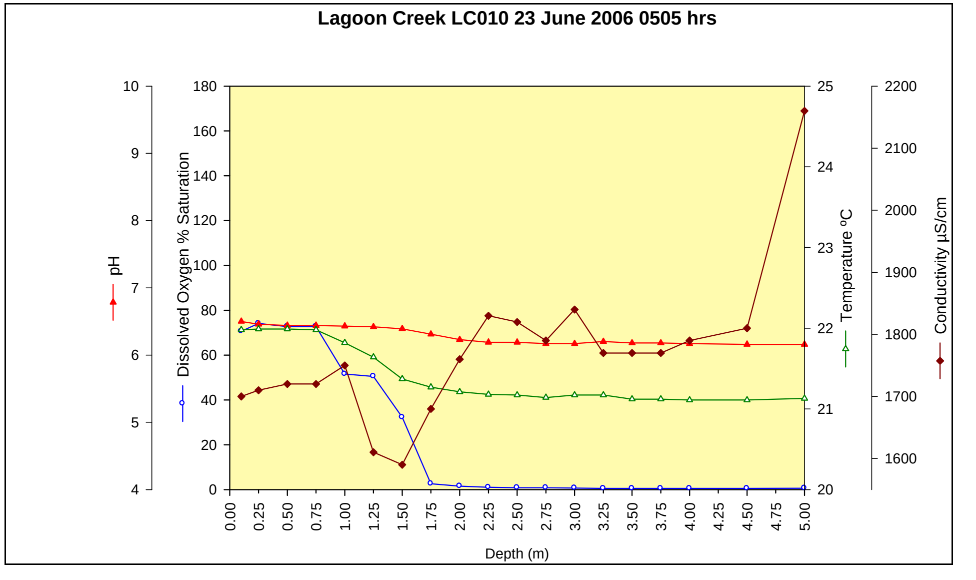


Stratified Sampling Graphs for June 2006 at Site LC010

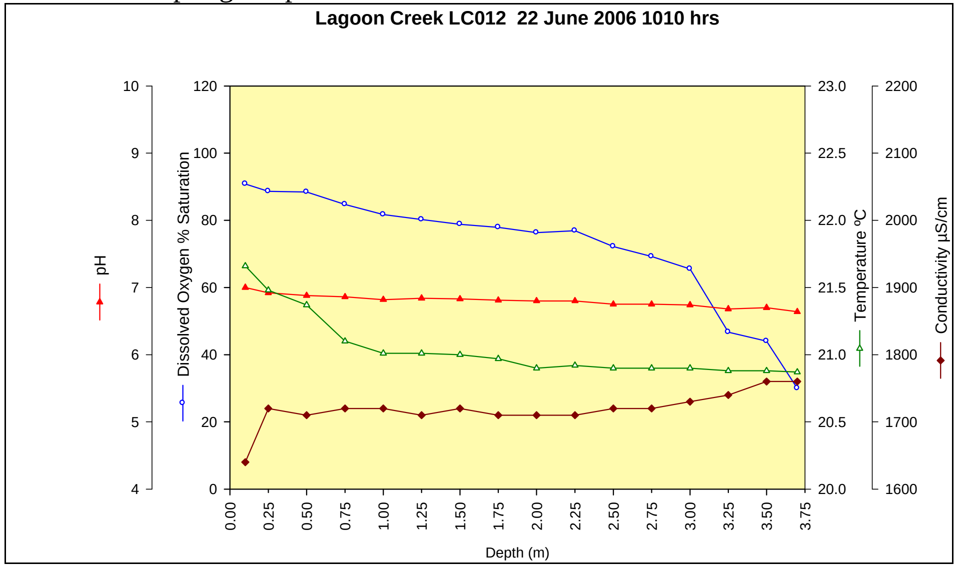


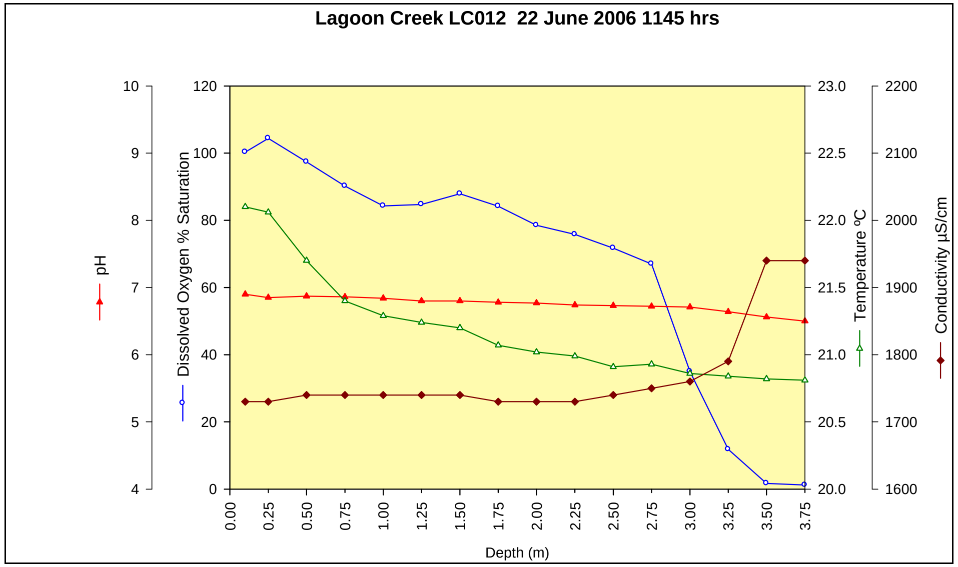


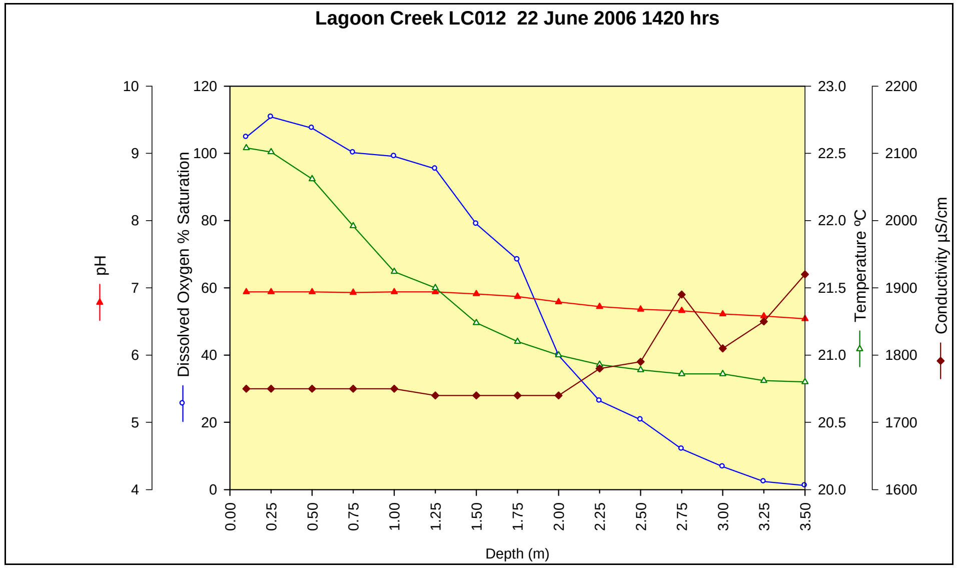


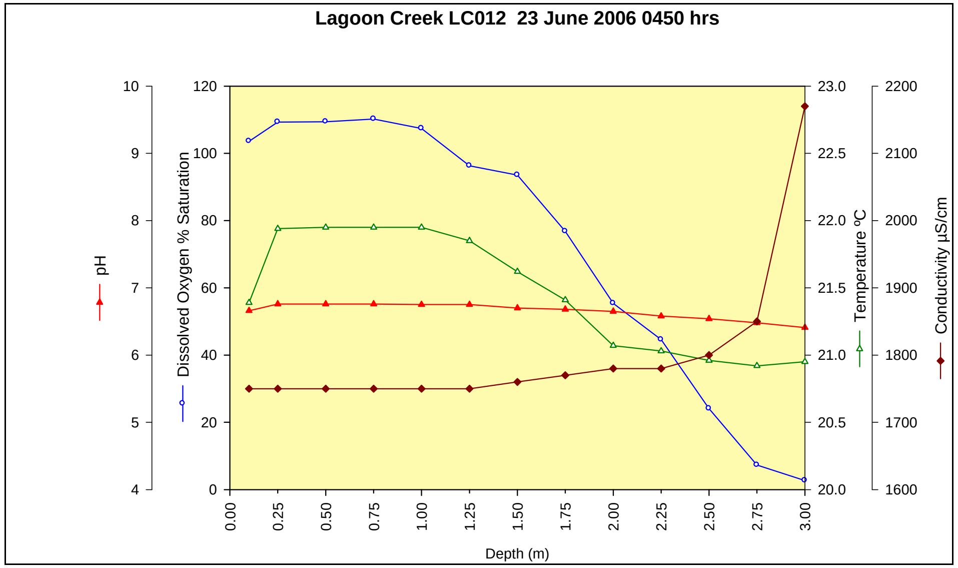


Stratified Sampling Graphs for June 2006 at Site LC012

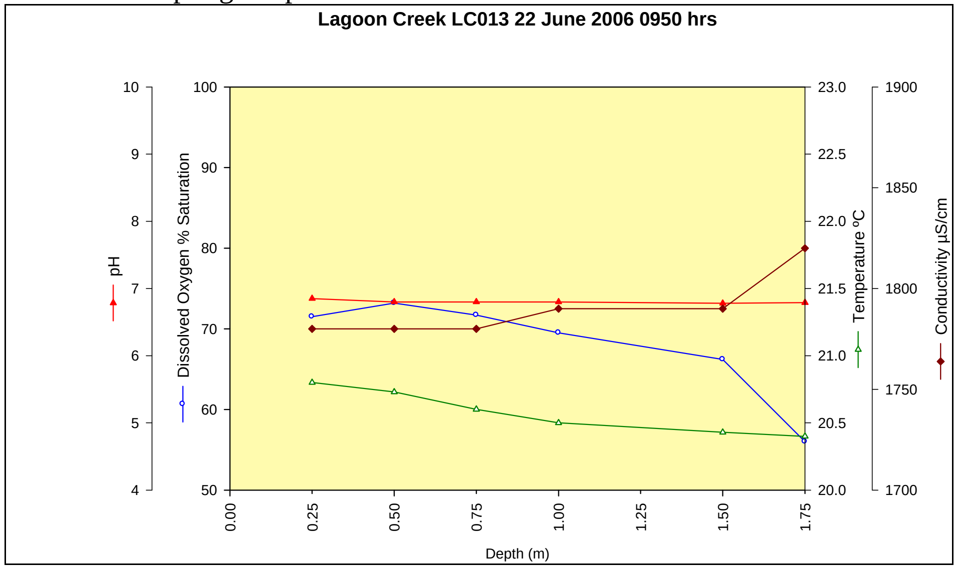


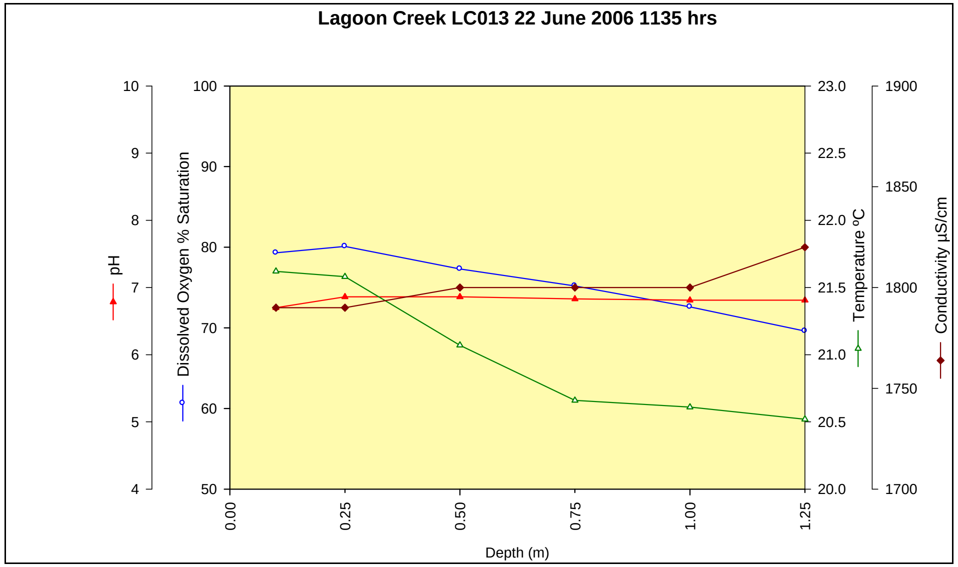


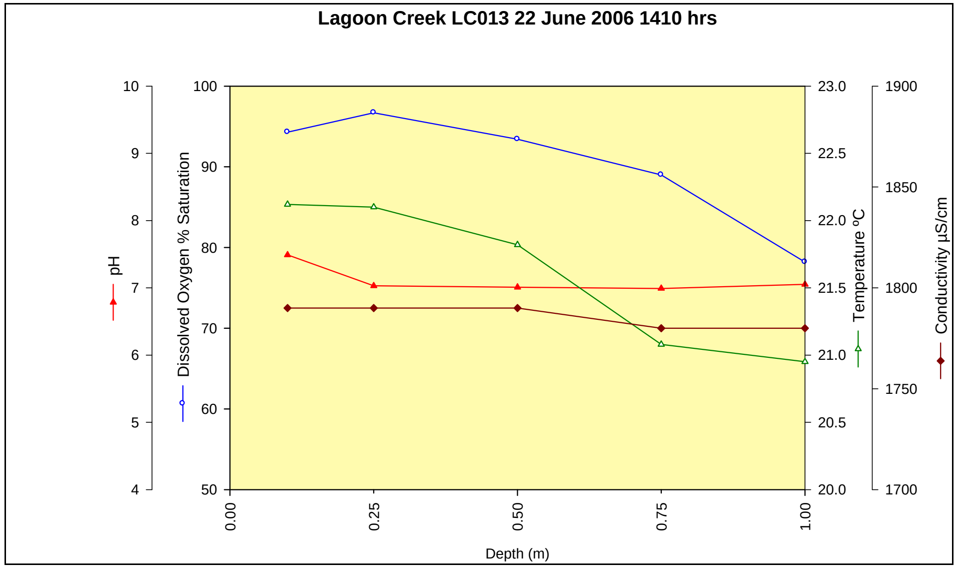


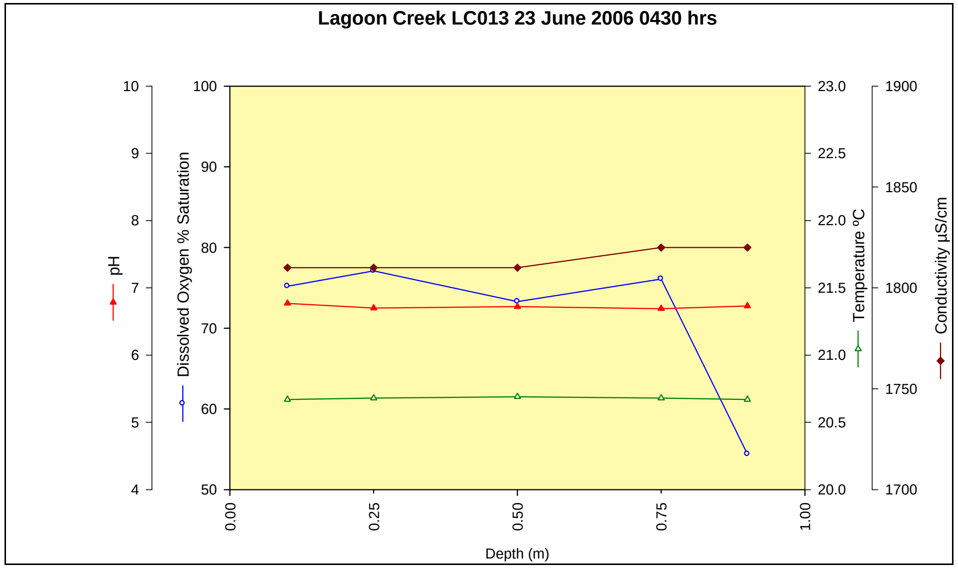


Stratified Sampling Graphs for June 2006 at Site LC013









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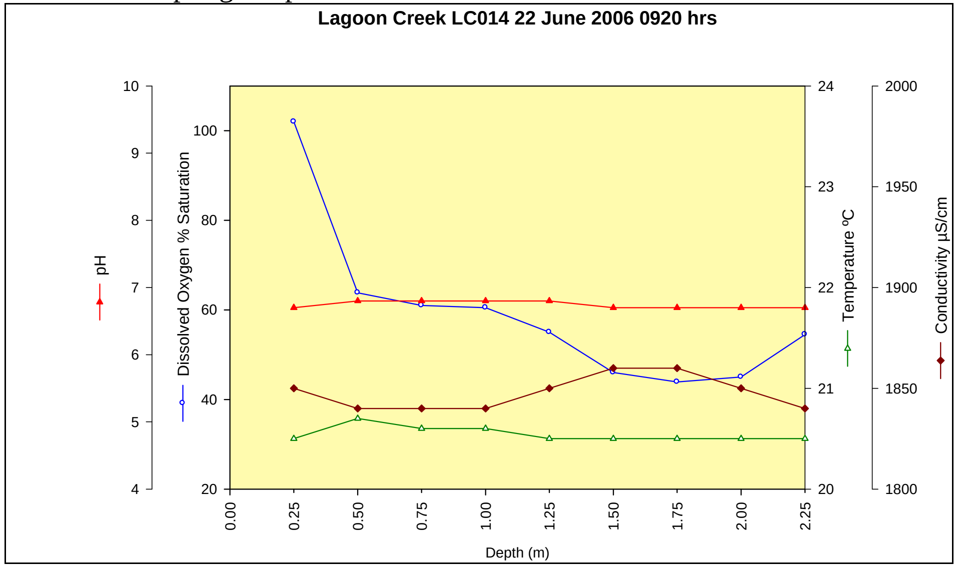
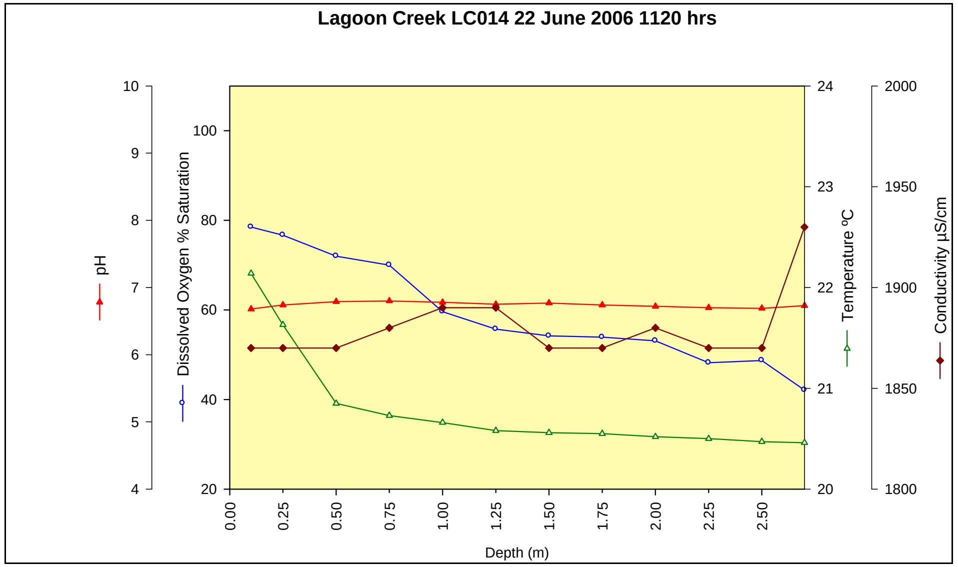
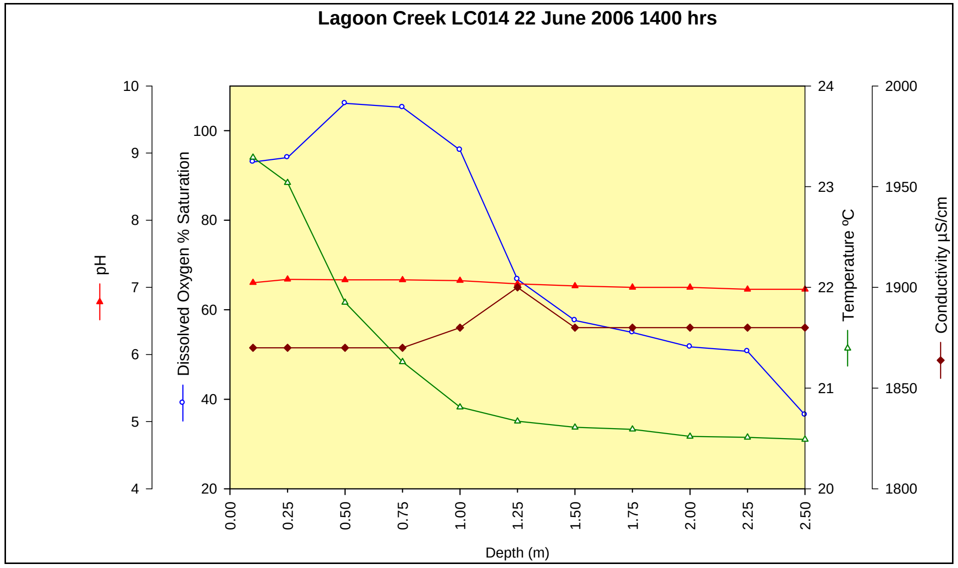
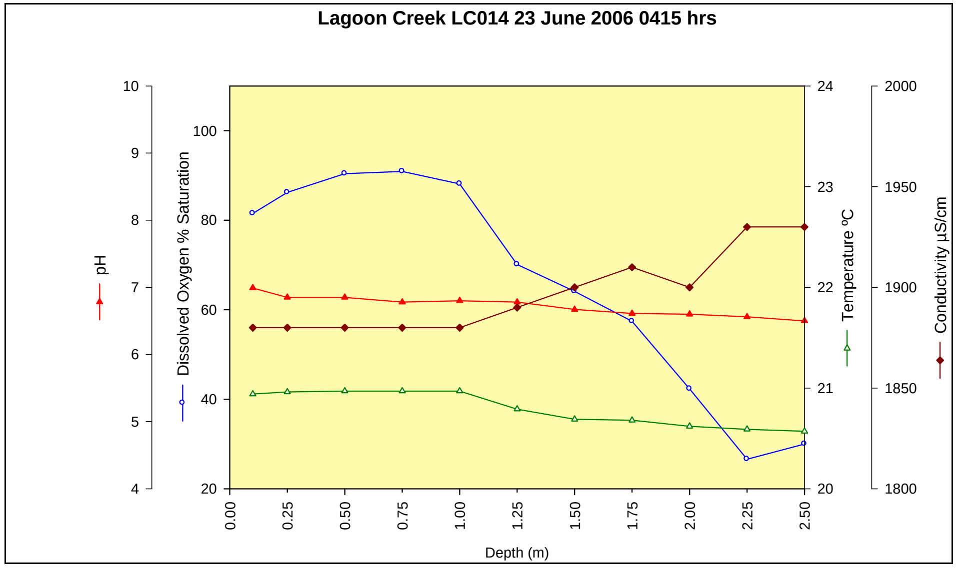
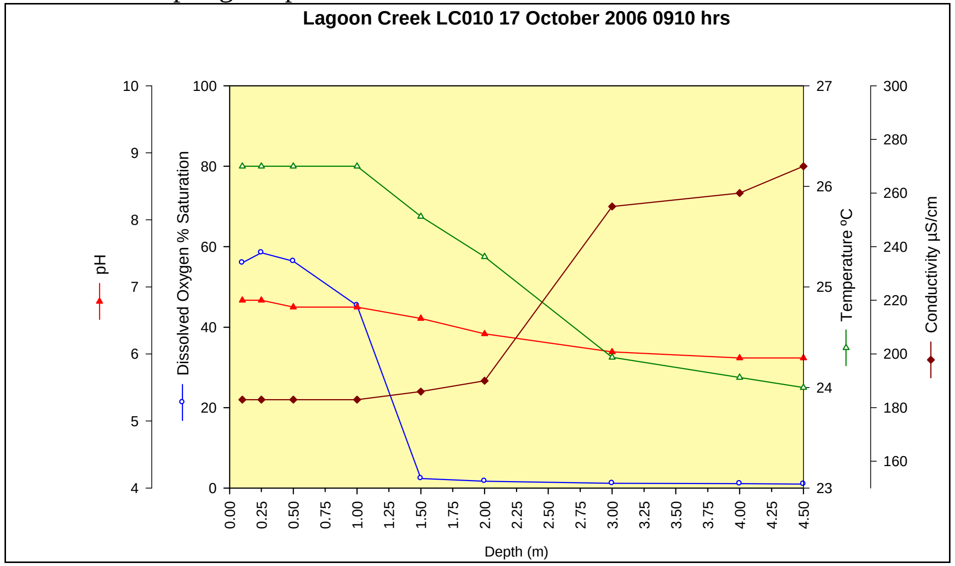


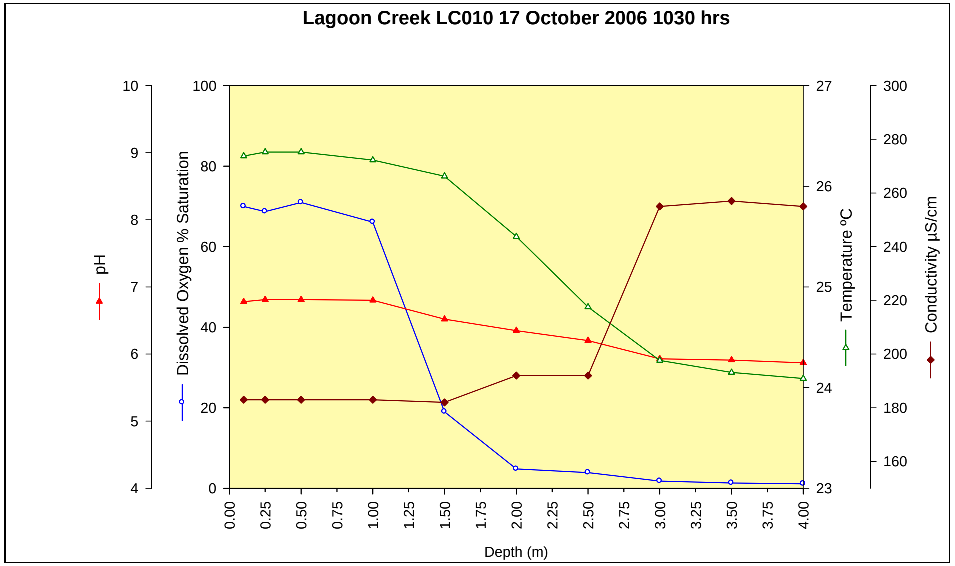


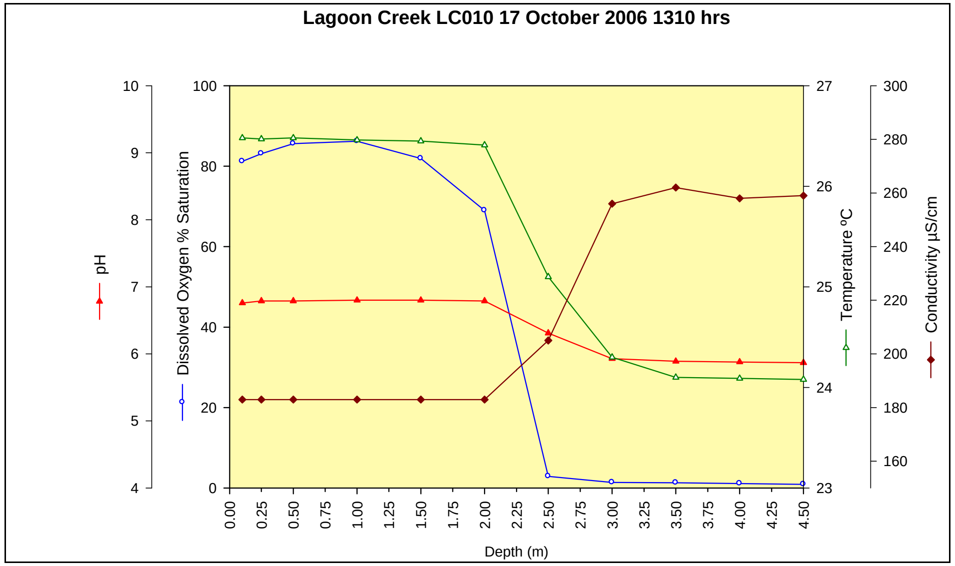


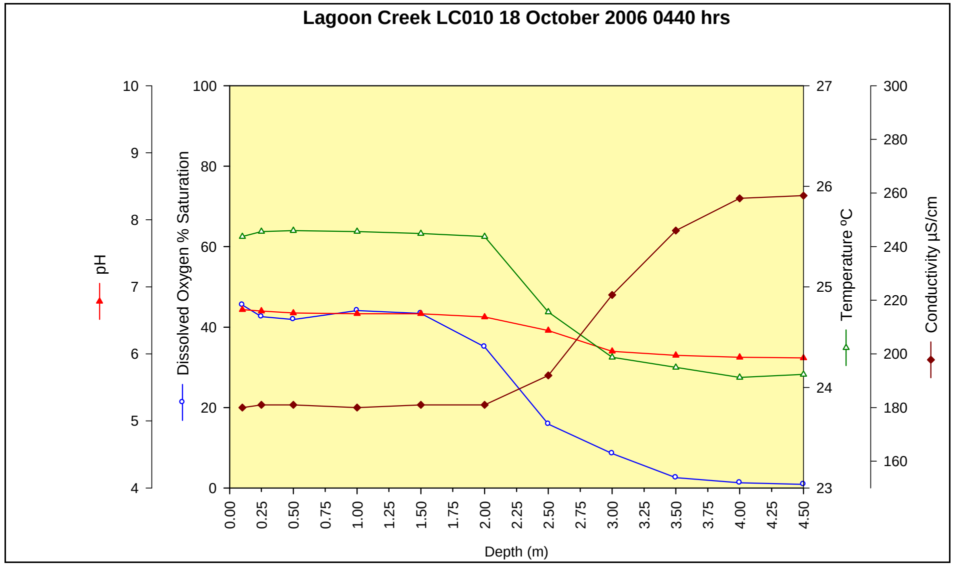


Stratified Sampling Graphs for October 2006 at Site LC010

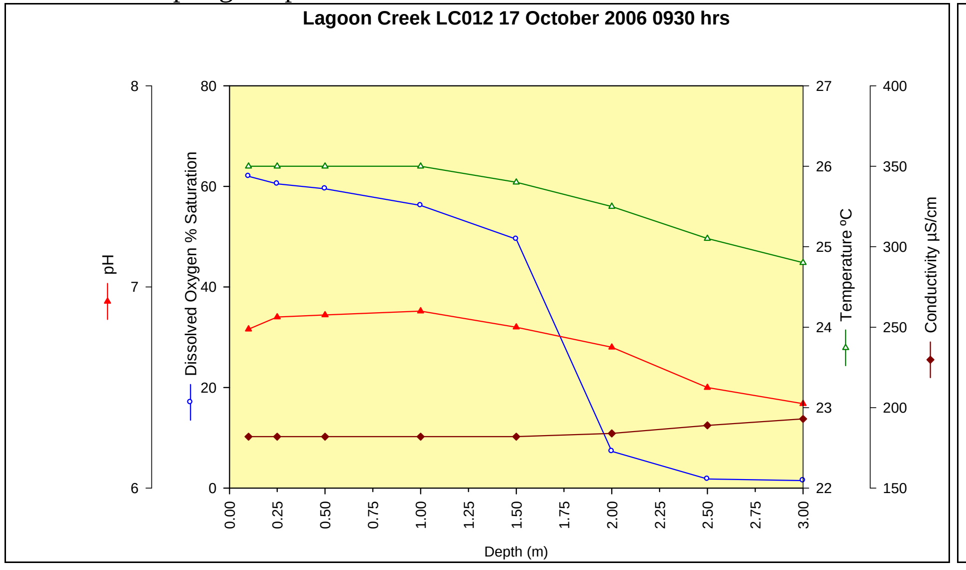


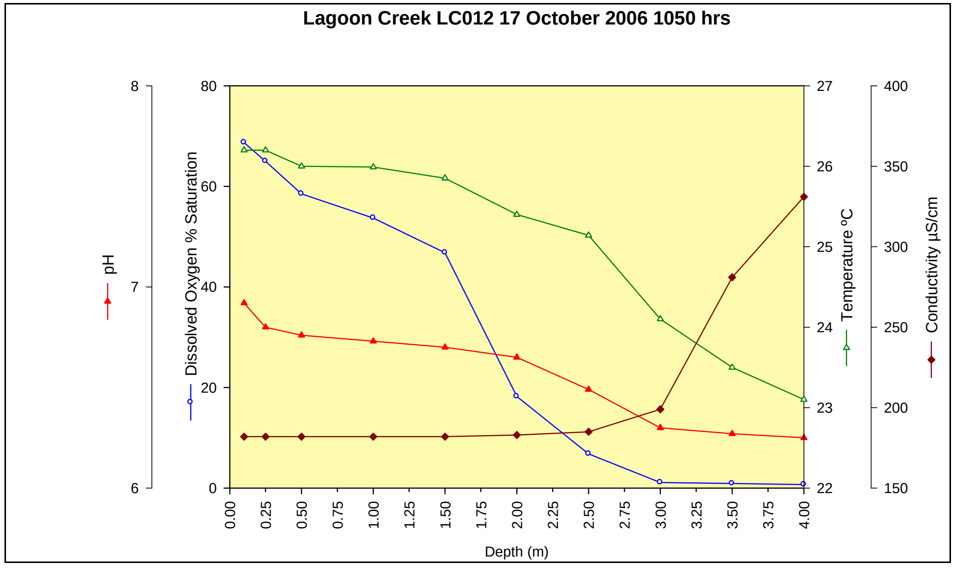


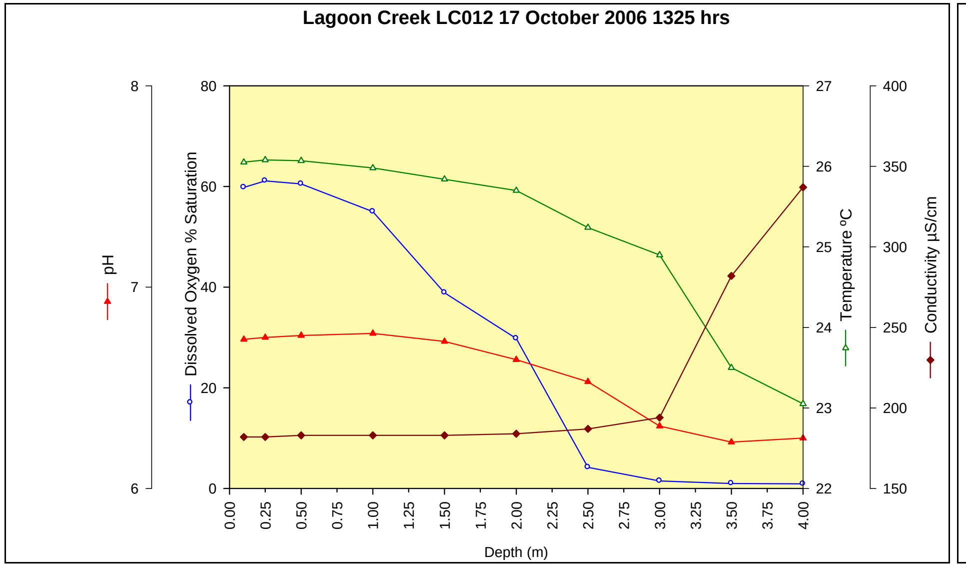


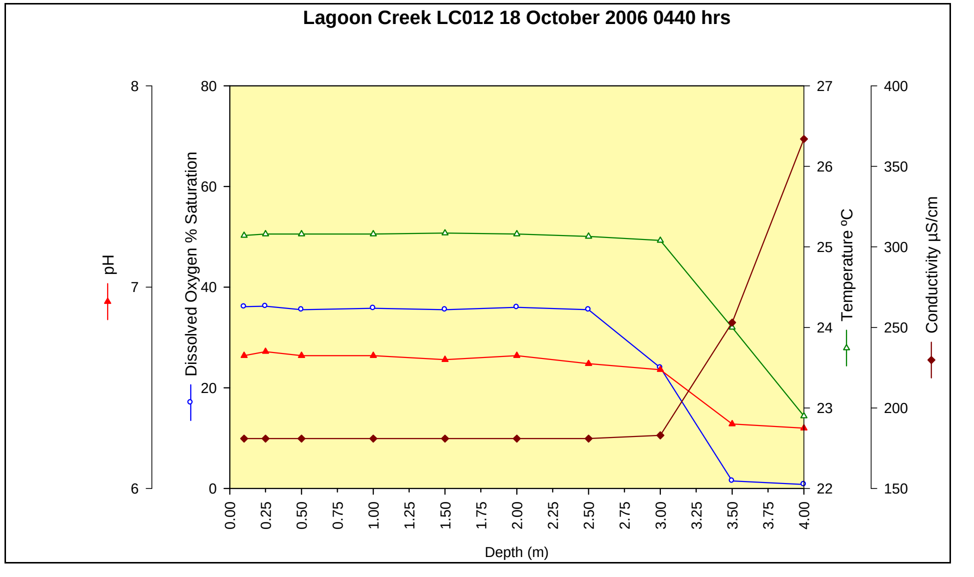


Stratified Sampling Graphs for October 2006 at Site LC012









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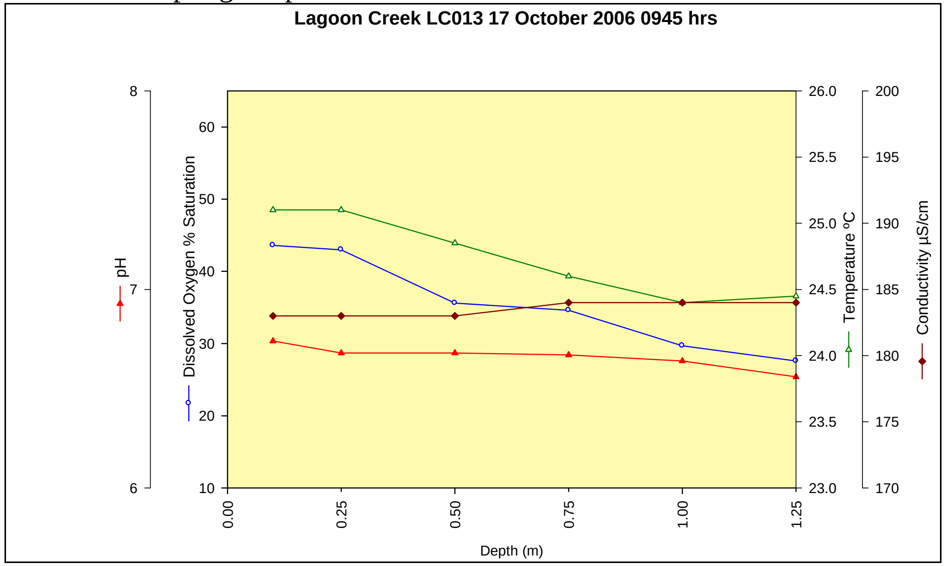

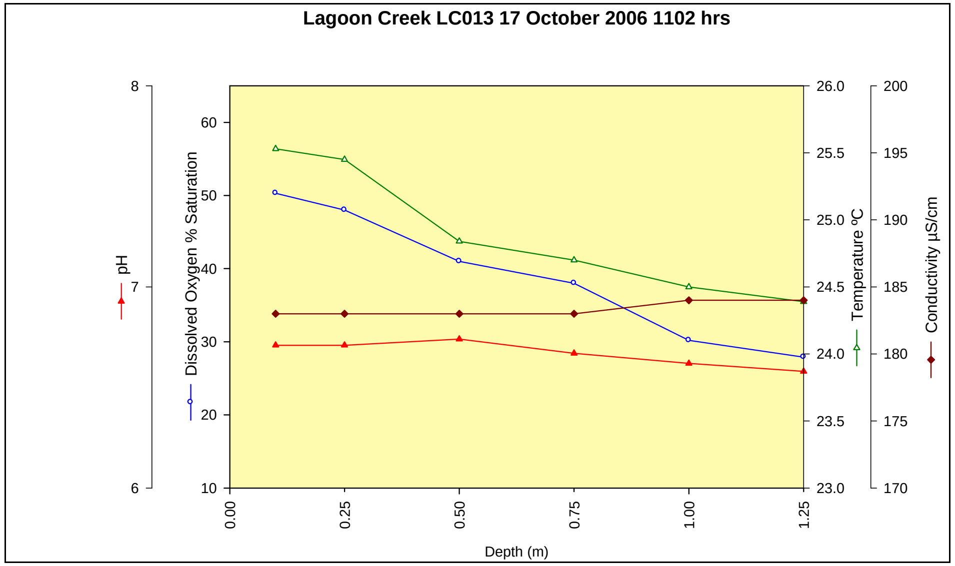

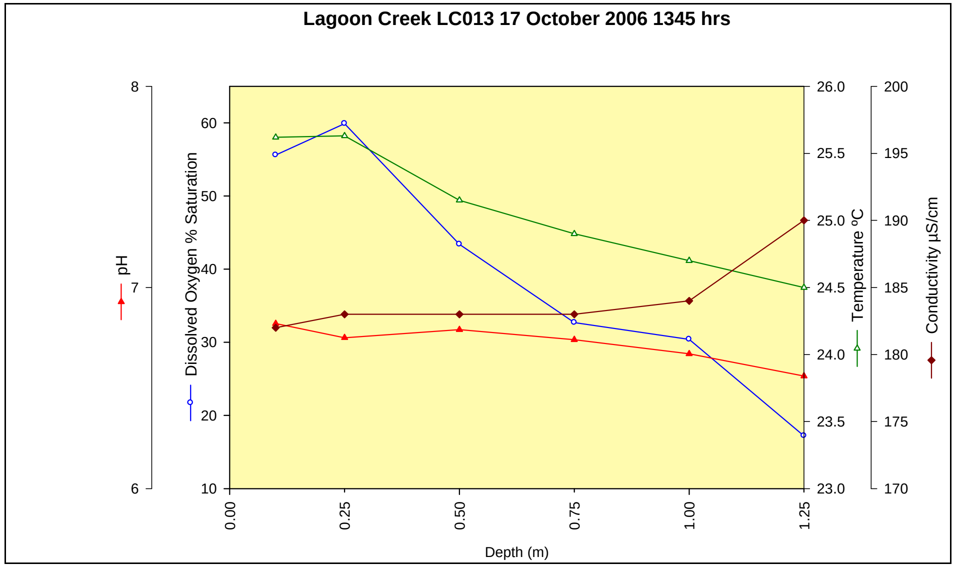

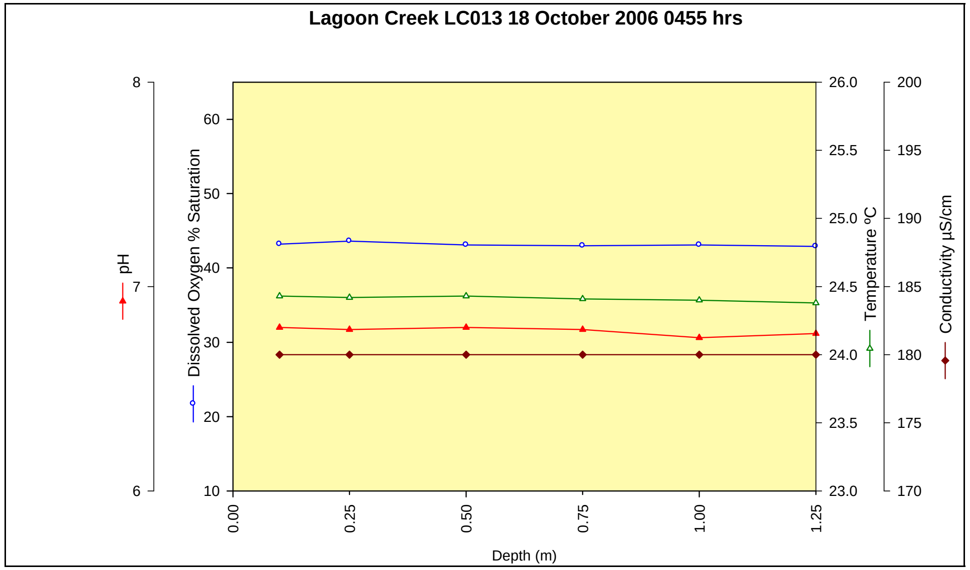

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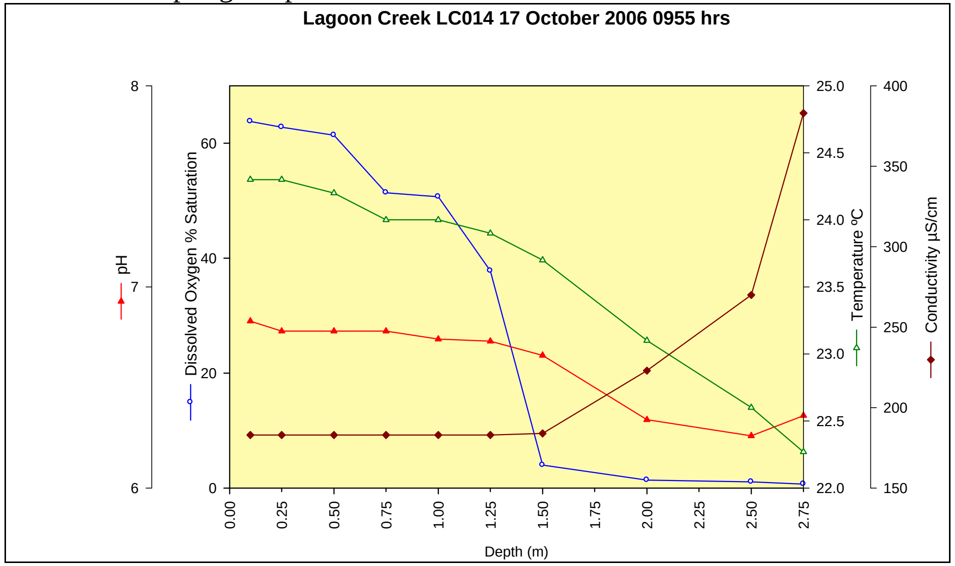
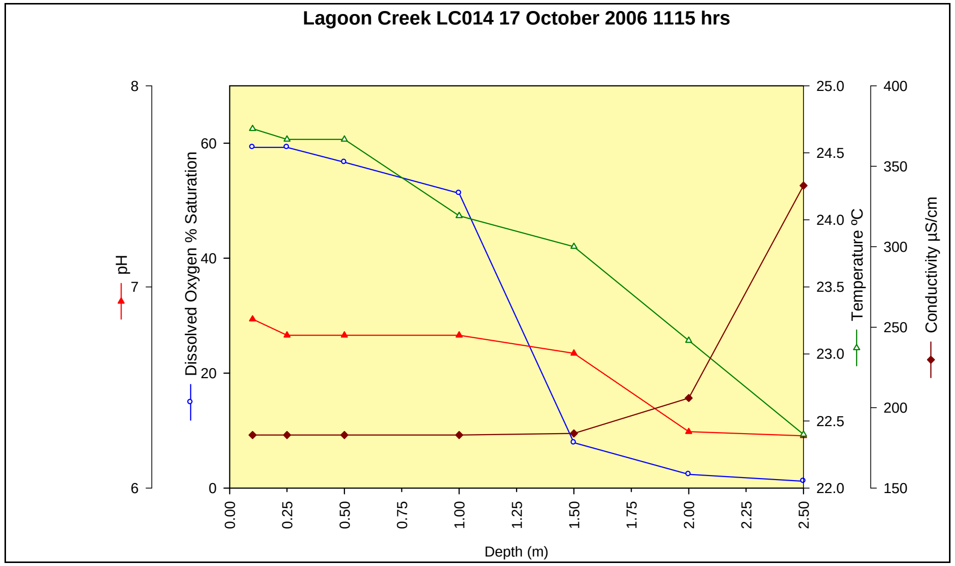
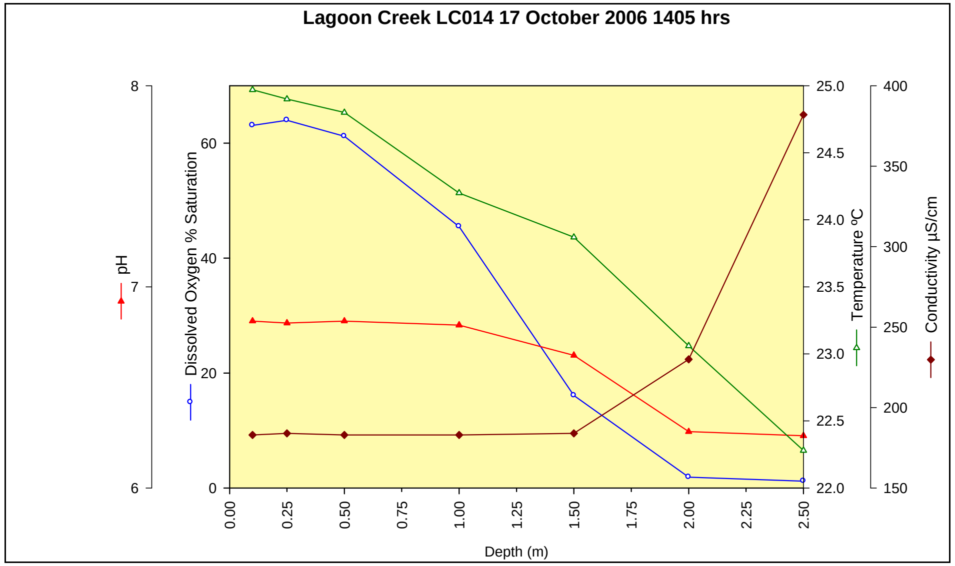
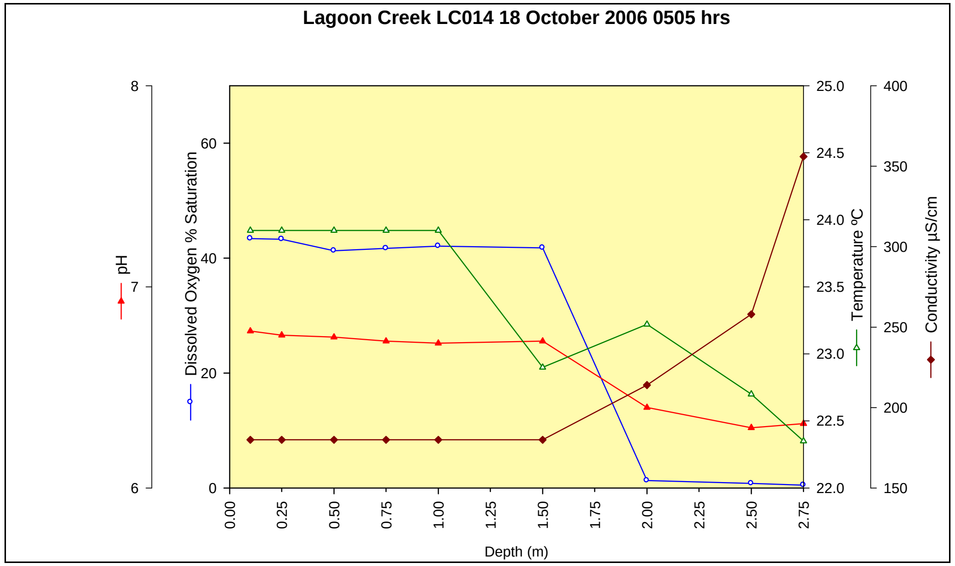
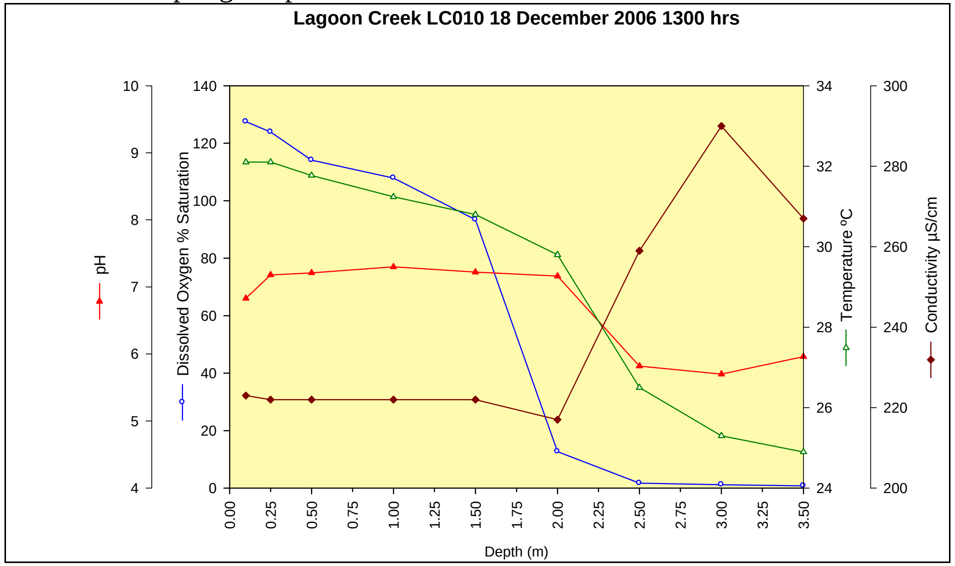


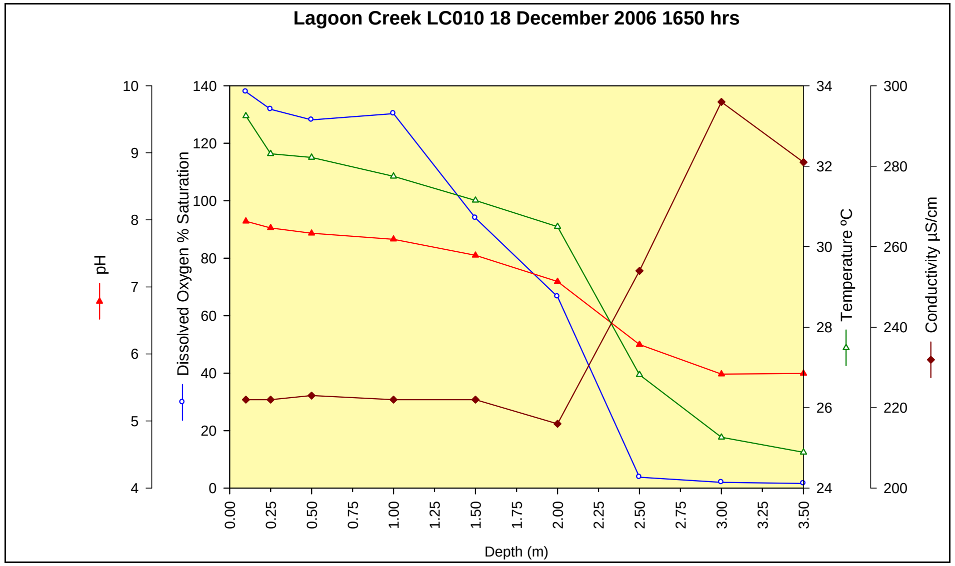


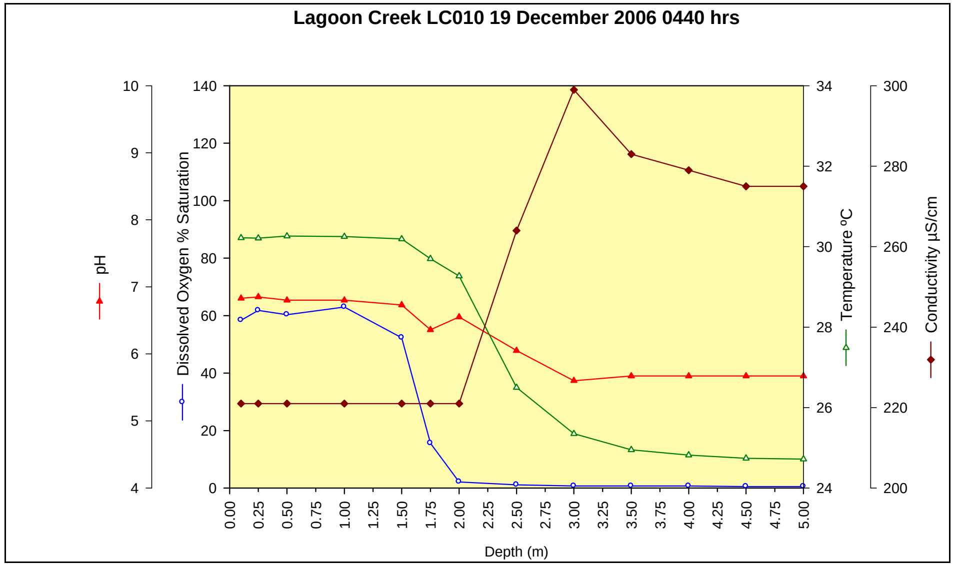


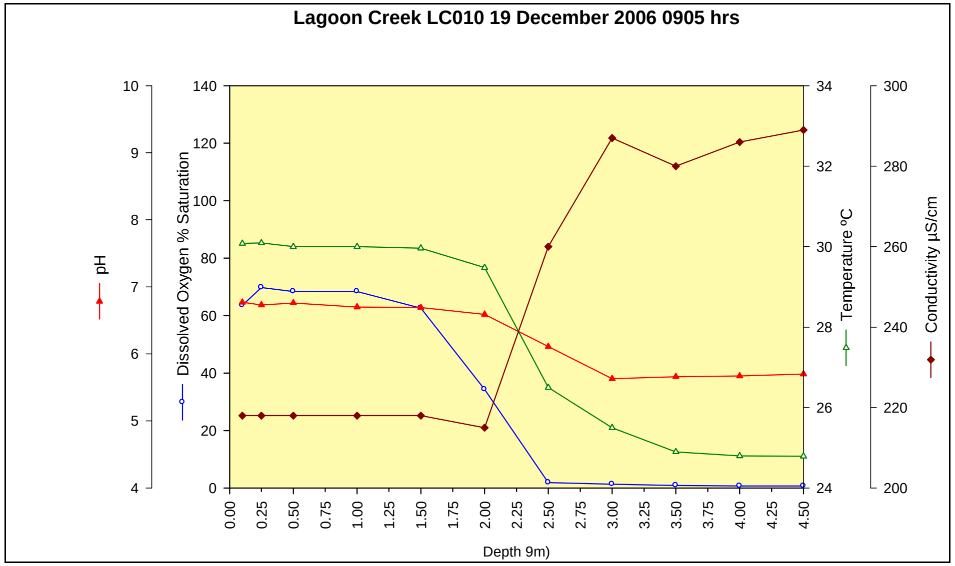


Stratified Sampling Graphs for December 2006 at Site LC010









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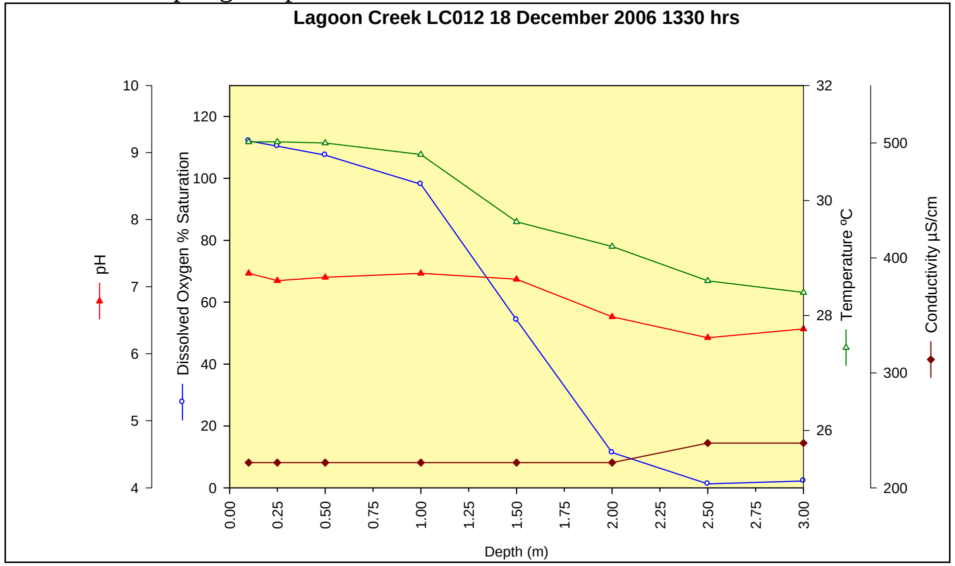
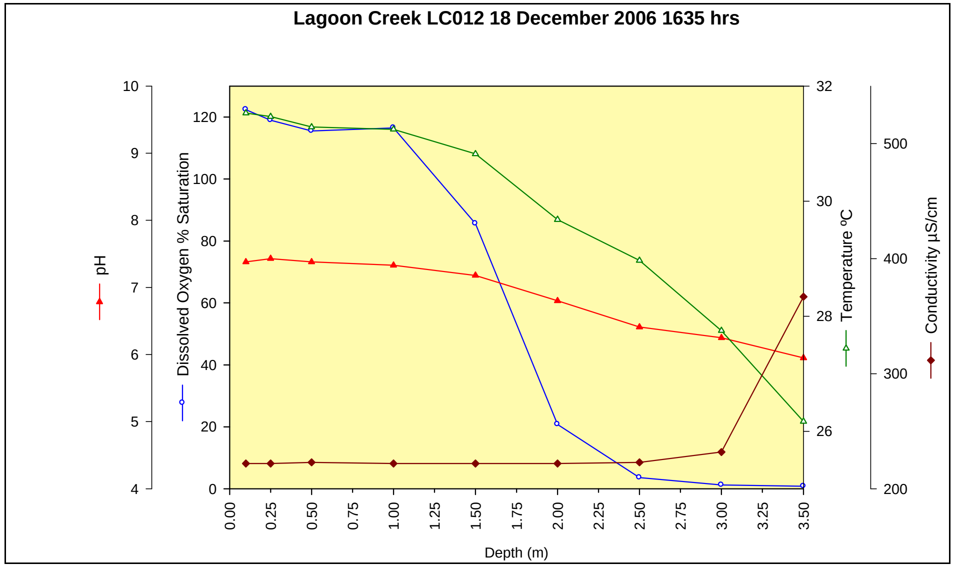
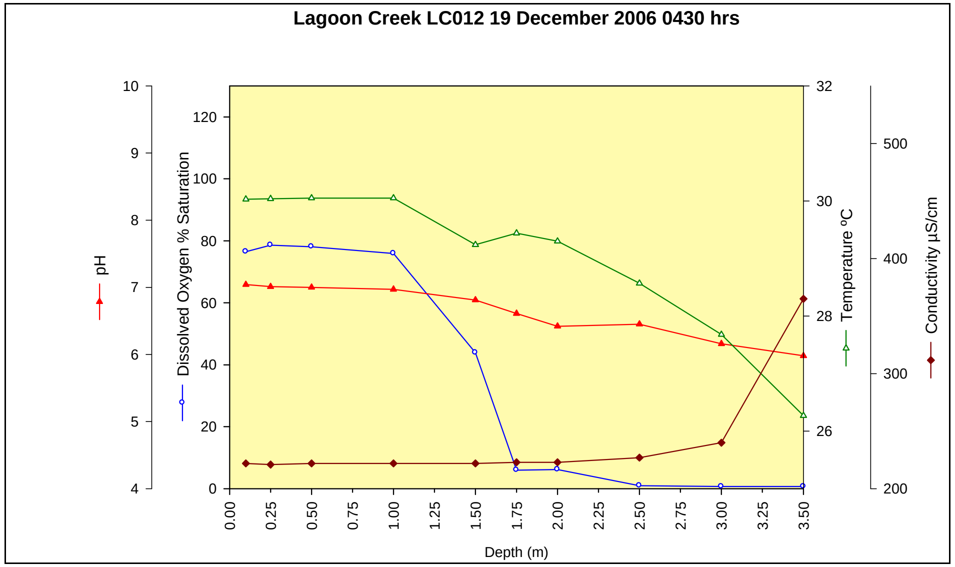
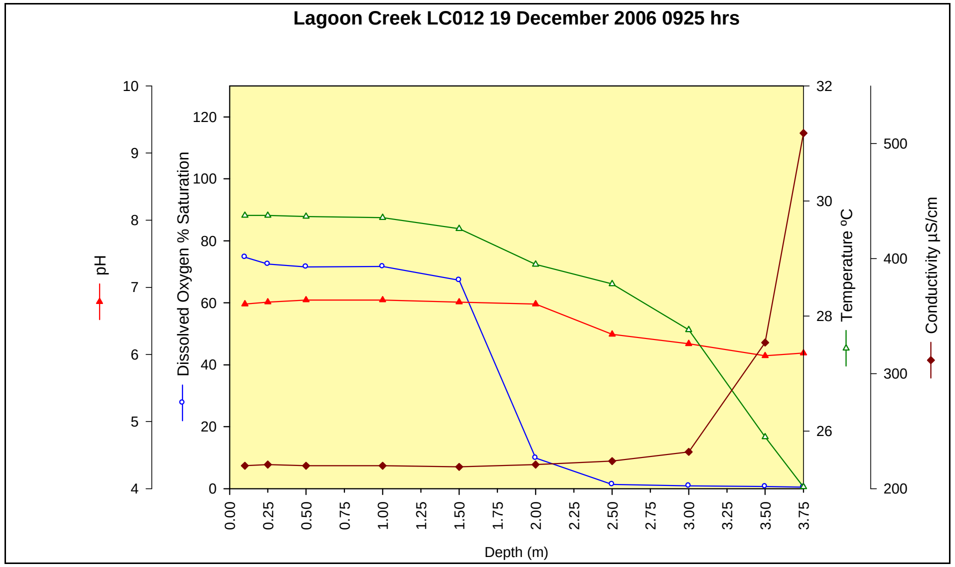
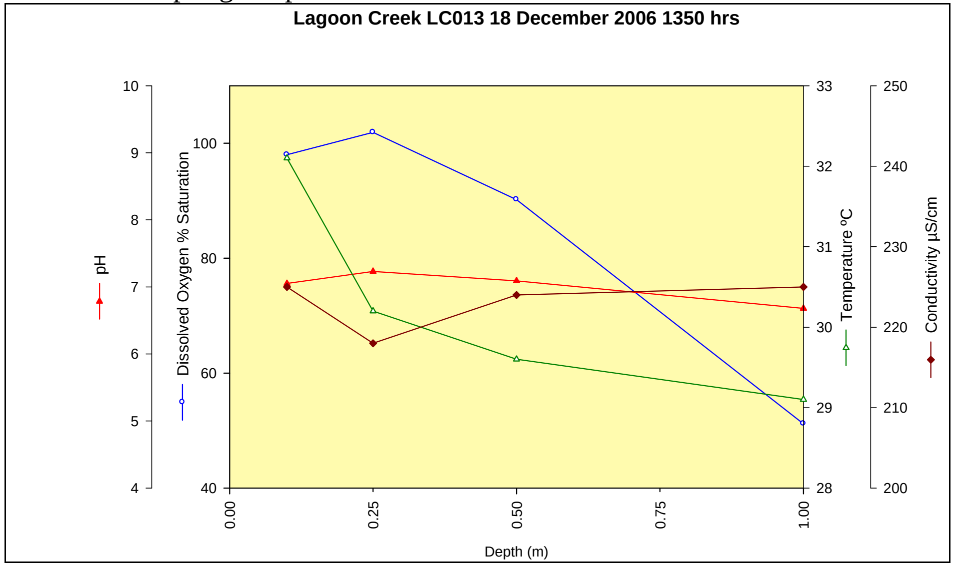


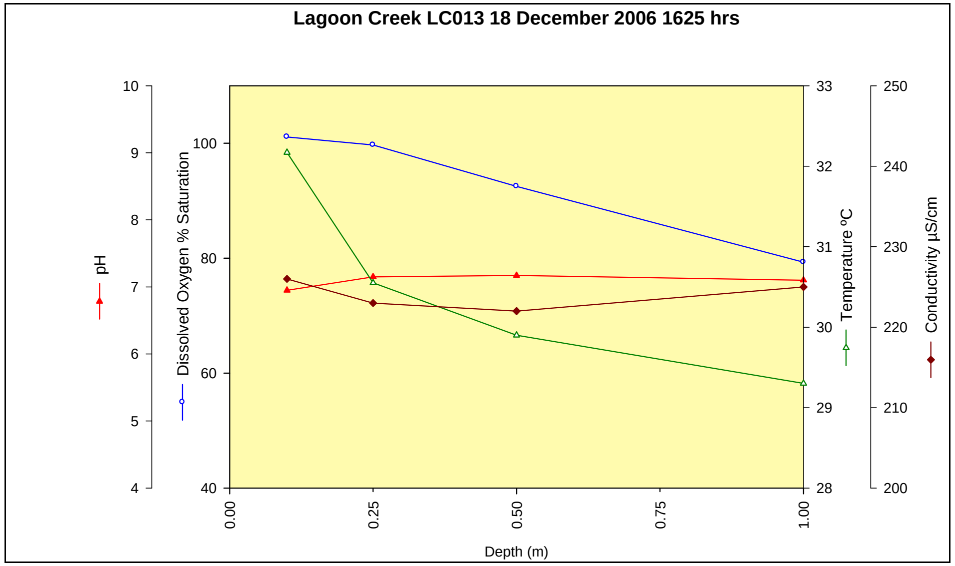


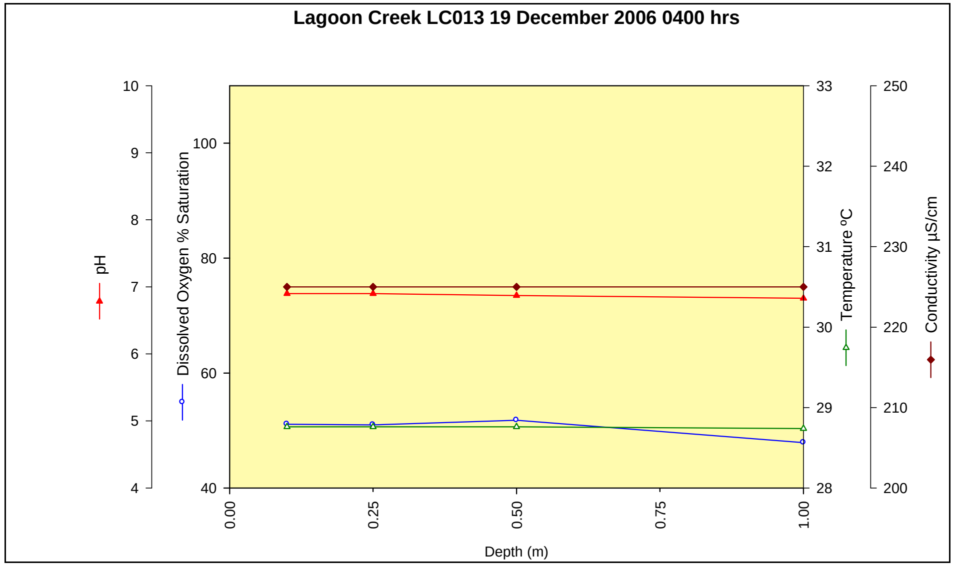


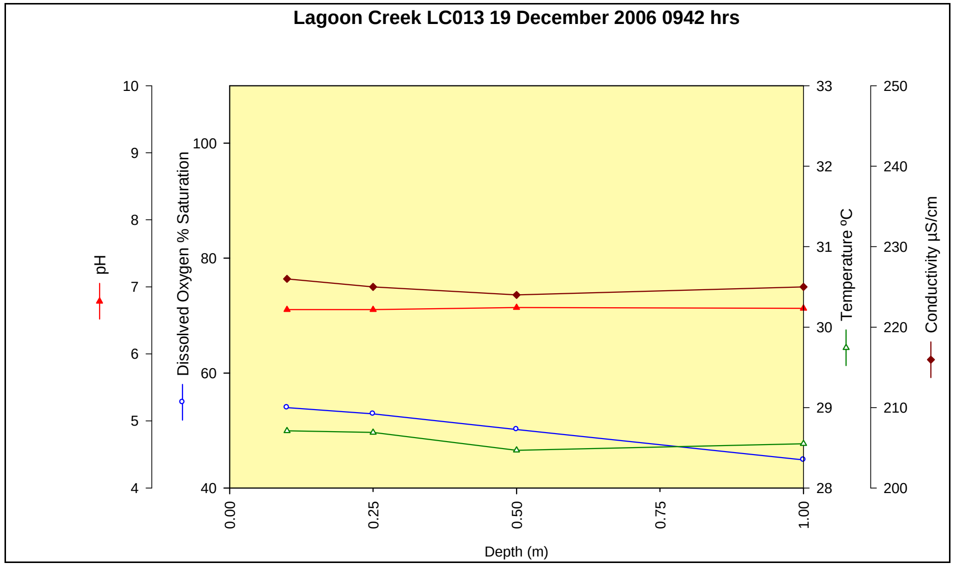


Stratified Sampling Graphs for December 2006 at Site LC013

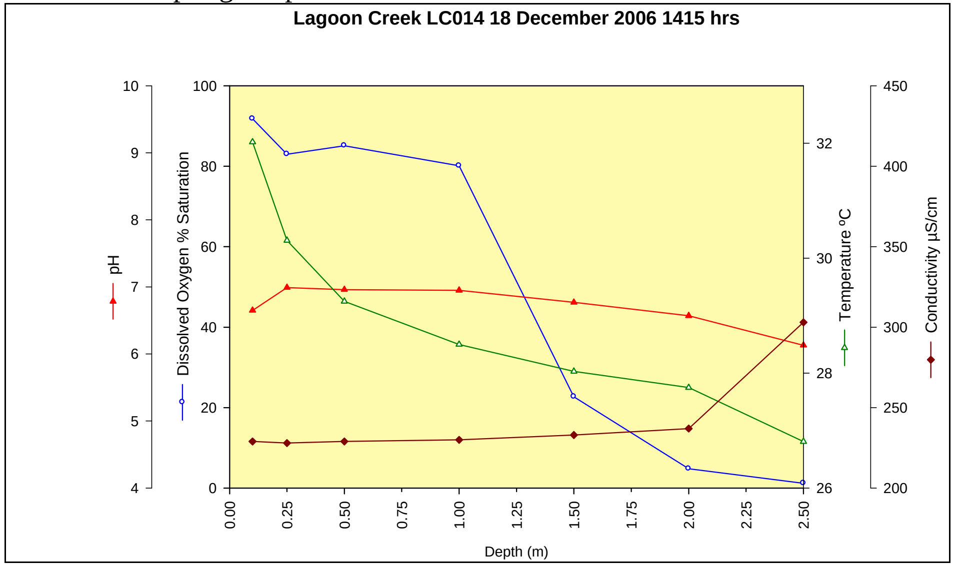


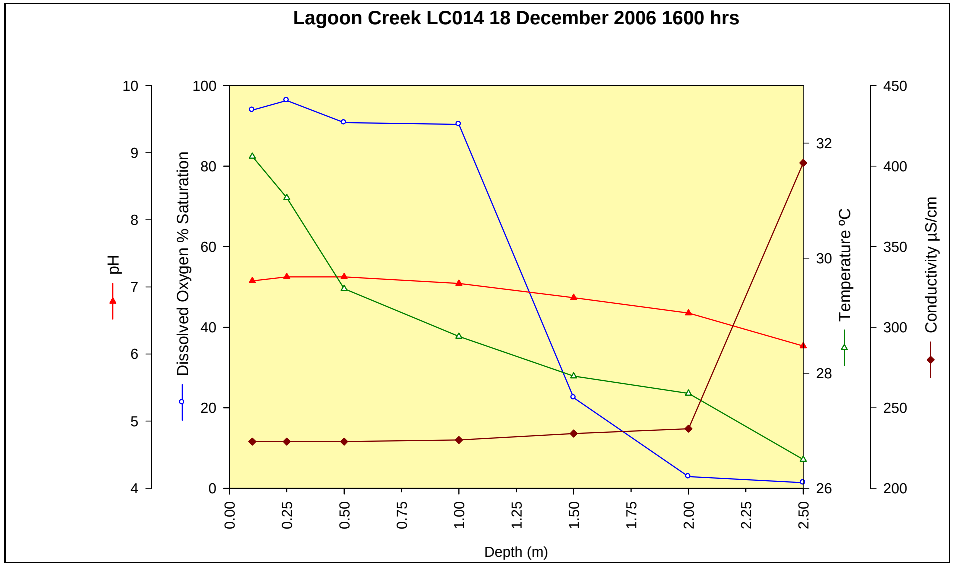


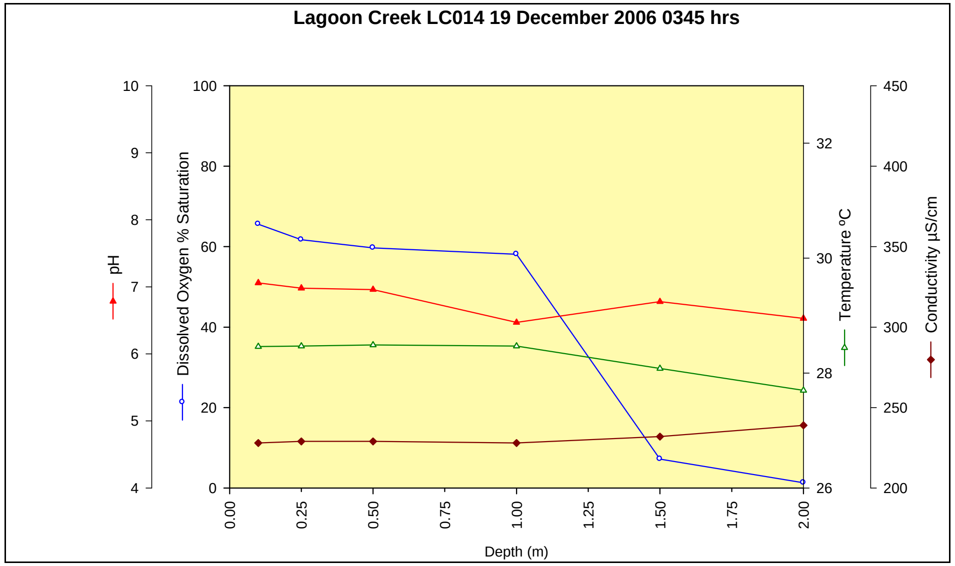


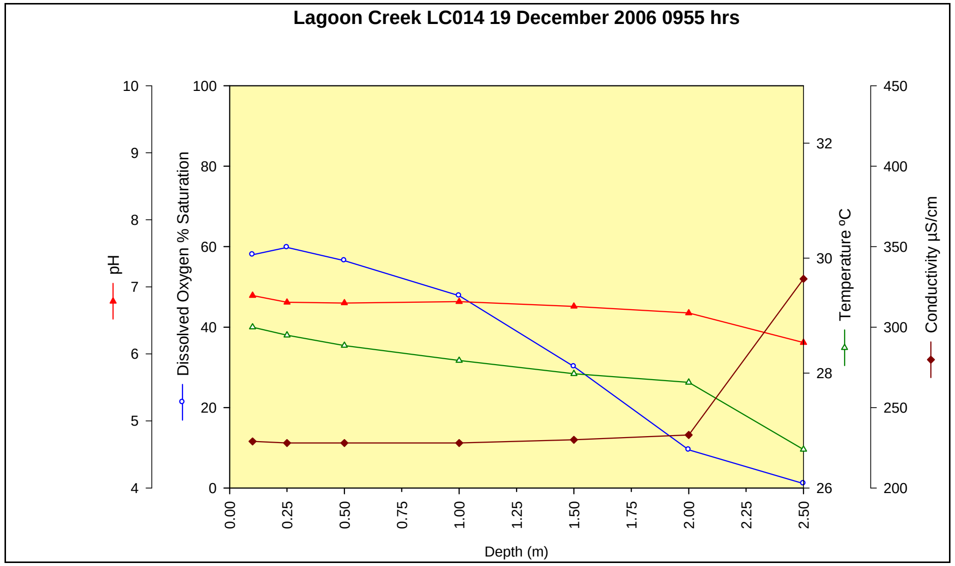


Stratified Sampling Graphs for December 2006 at Site LC014









APPENDIX C

Before and After Photographs of Harvested Monitoring Points

Figure C1: **Site LC004 looking north in Feb 06.**


Figure C2: **Site LC004 looking north in Jan 07 shortly after weed removal.**

Figure C3: **Site LC007 looking west in Dec 05.**


Figure C4: **Site LC007 looking west in Feb 07.**

Figure C5: **Site LC007 looking east in Dec 05.**


Figure C6: **Site LC007 looking east in Feb 07.**

Figure C7: **100m west of Site LC007 looking south in Feb 06.**


Figure C8: **100m west of Site LC007 looking south in Feb 07.**

Figure C9: **Probable croc hole 100m downstream from Site LC011 in Jan 06.**

Figure C10: **~200m downstream from Site LC011 Weed mat was flushed out by flood water downstream of this point.**

Figure C11: **Site LC013 looking west in Jan 06.**

Figure C12: **Site LC013 looking west in Jan 07.**


Figure C13: **Site LC014 looking north in Dec 05.**


Figure C14: **Site LC014 looking north in Jun 06 shortly after weed harvesting.**


Figure C15: **Site LC009 looking west in Jun 07.**


Figure C16: **Barra caught at Site LC010 in June 07.**


Figure C17: **Lagoon Creek downstream from Site LC004 in Apr 07.**


Figure C18: **Site LC014 in Jun 07 showing native submerged vegetation and clear water.**

APPENDIX D

Bathymetry Model and Sediment Graphs

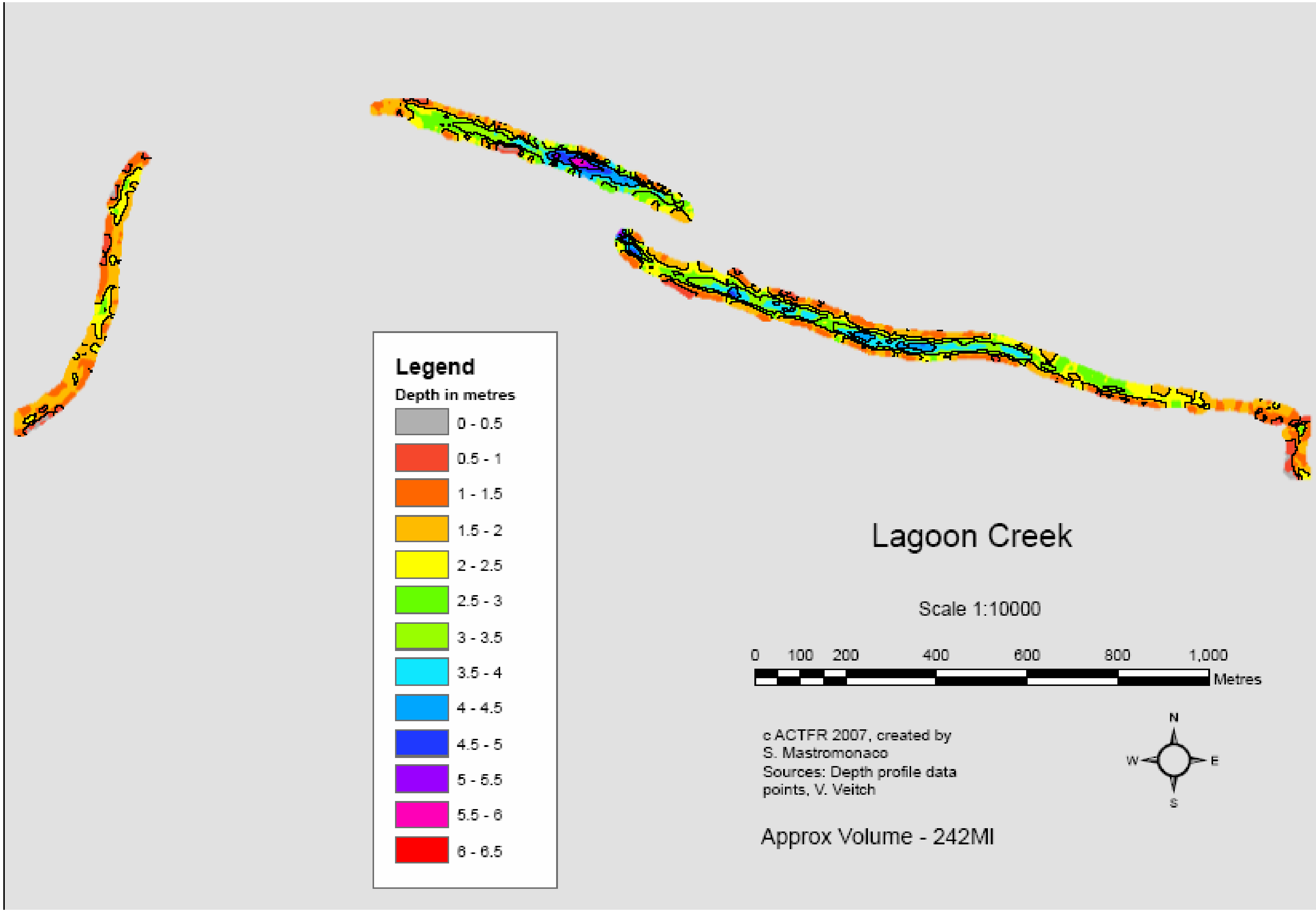


Figure D1: Bathymetric model overview of Lagoon Creek.

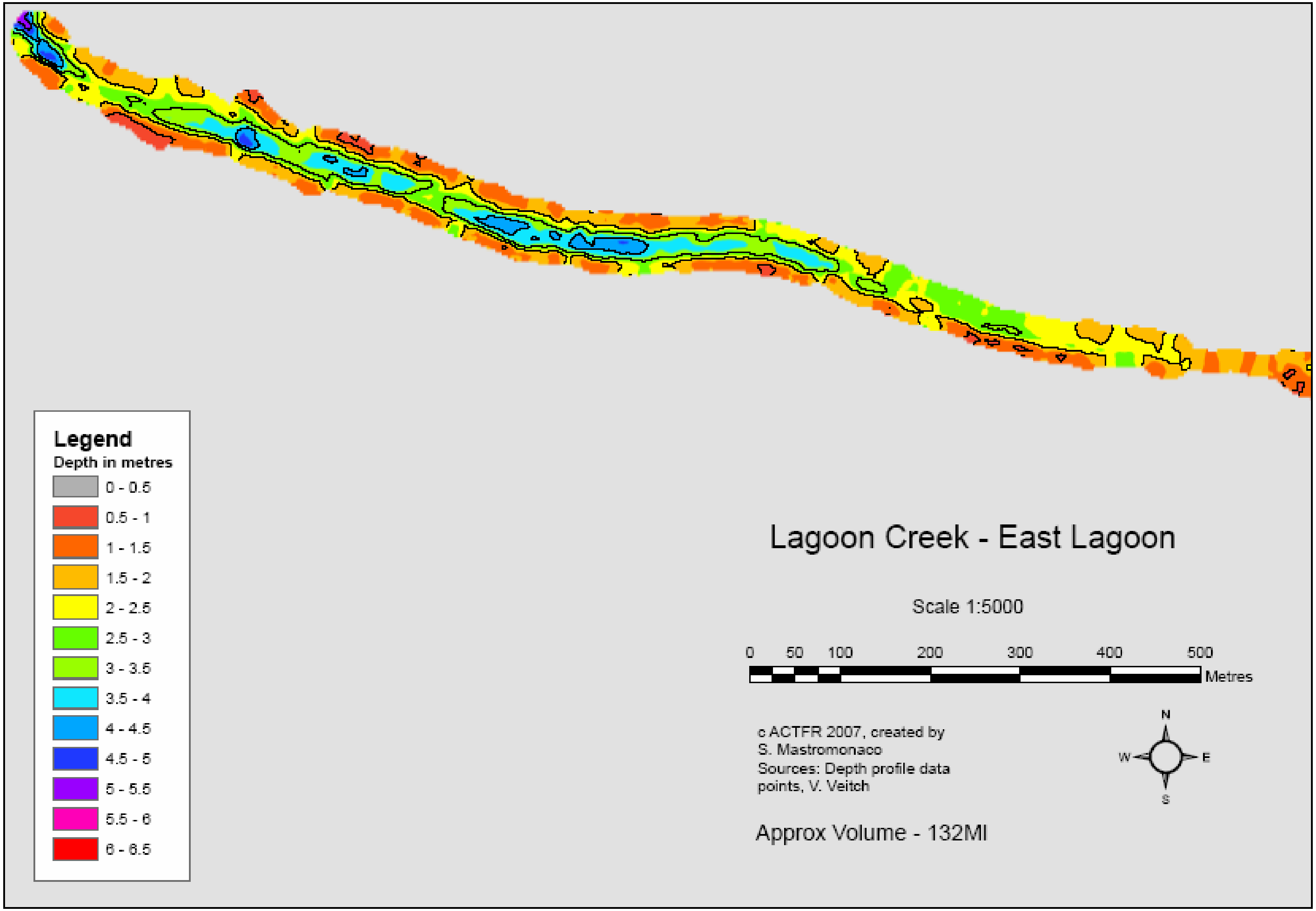


Figure D2: Bathymetric model downstream reach of Lagoon Creek from sites LC013 to LC010.

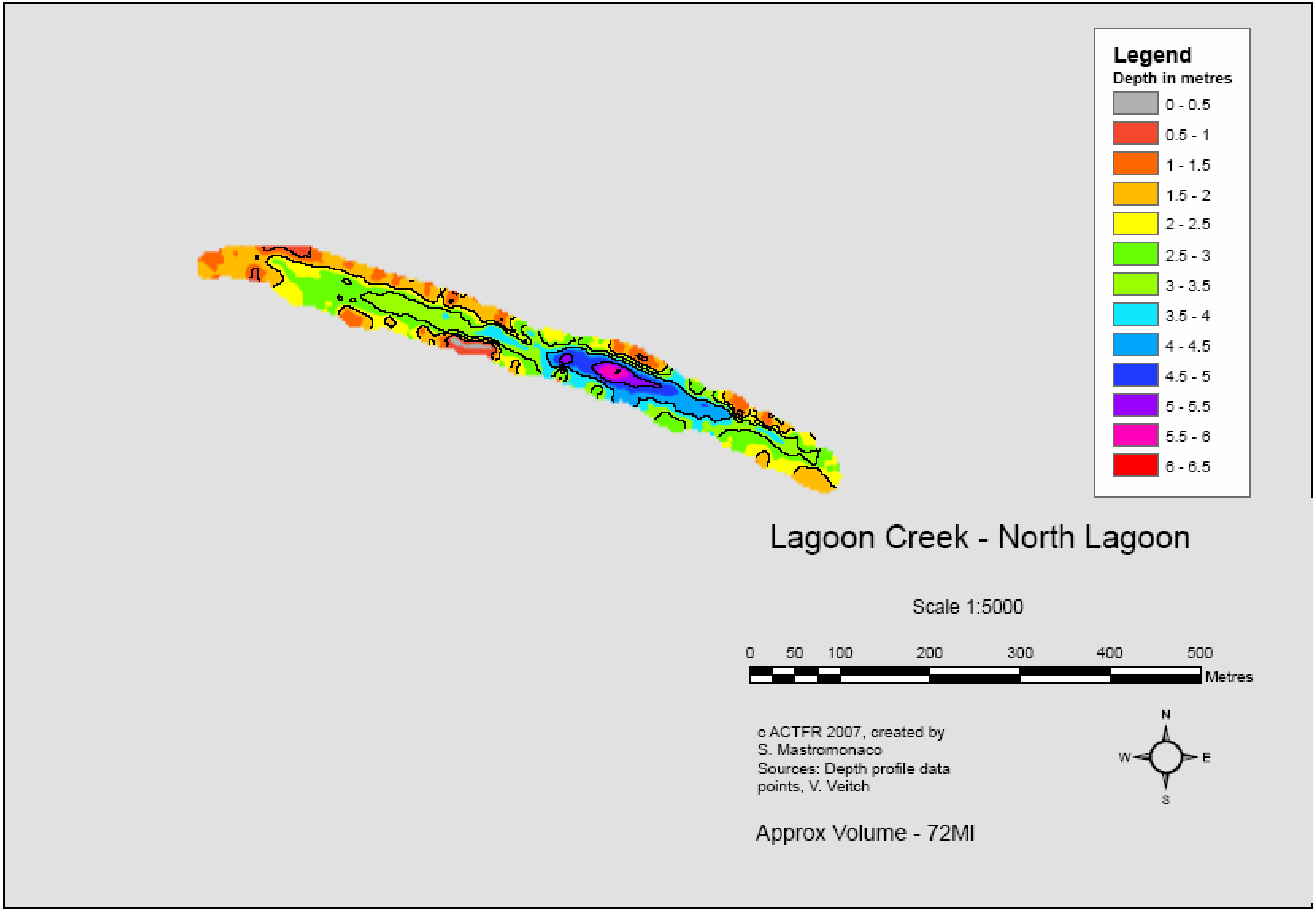


Figure D3: Bathymetric model middle reach of Lagoon Creek centred on Site LC007.

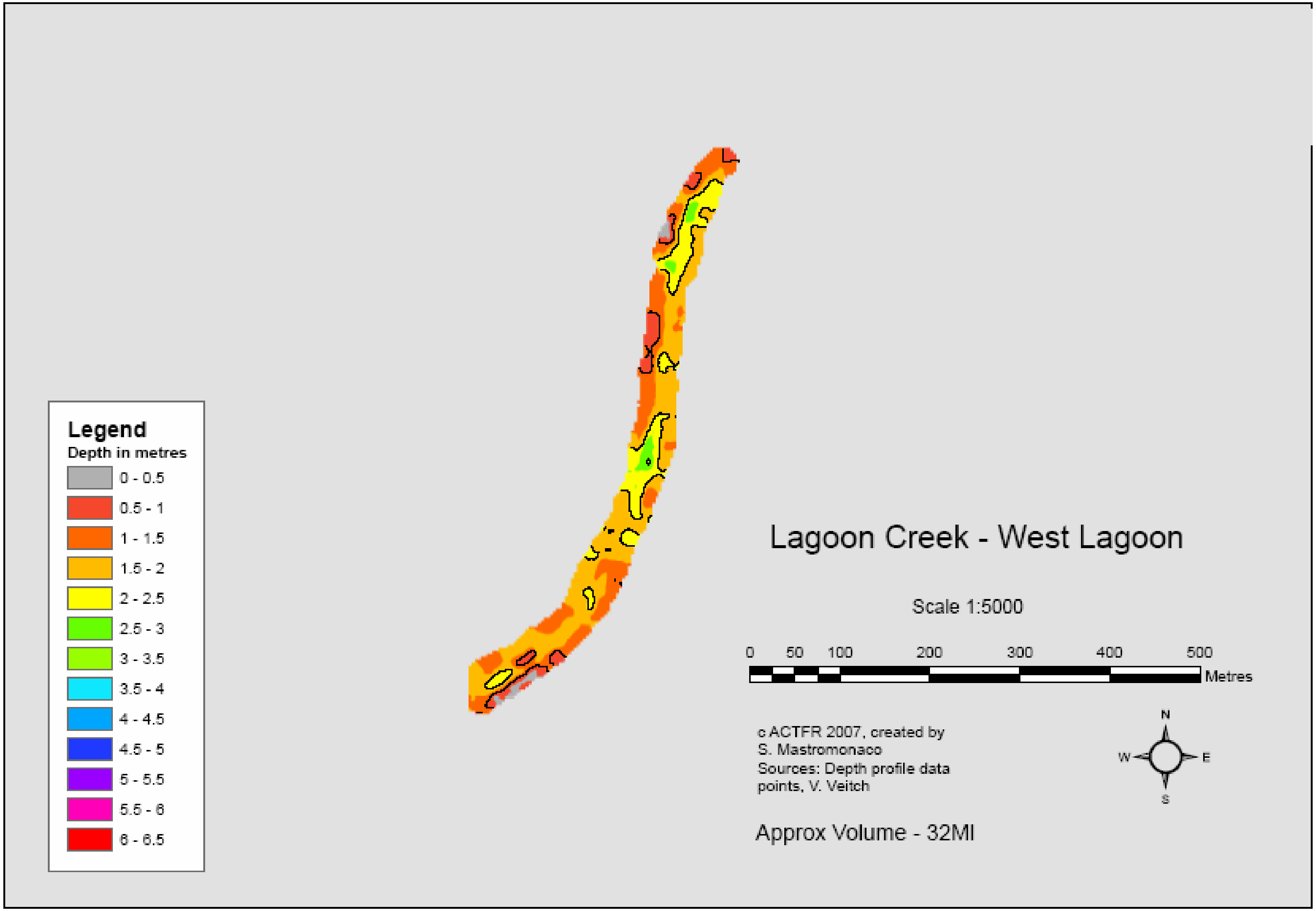


Figure D4: Bathymetric model upper reach of Lagoon Creek downstream from Site LC004.

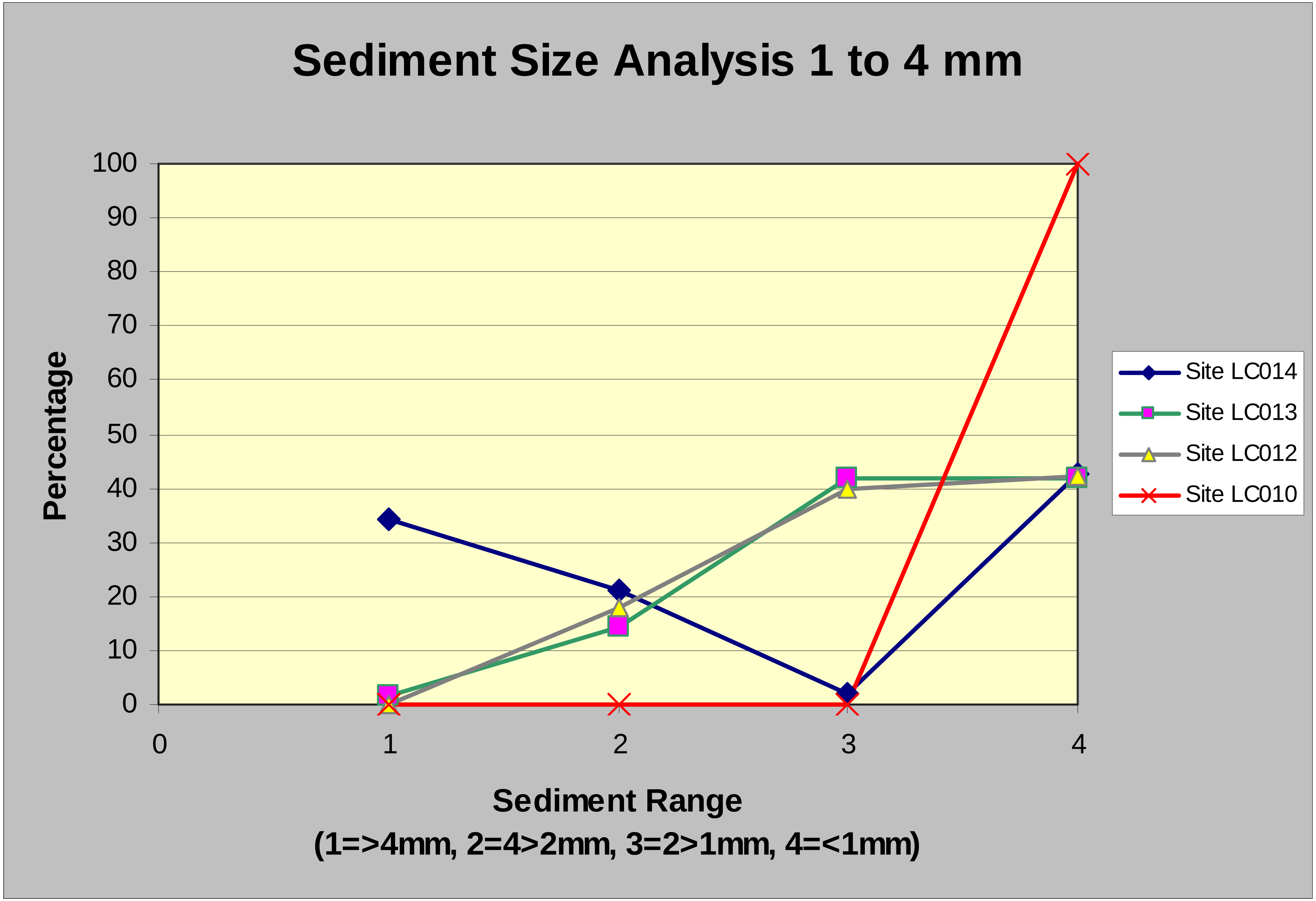


Figure D5: Sediment analysis for sediments from 1mm to 4mm at Site LC010, LC012, 100m upstream from LC013 and at LC014.