Waterways
Centre for Freshwater Management

Diurnal Variation in Te Waihora Water Quality

Summer Scholarship Report

WCFM Report 2011-002

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Te Waihora/Lake Ellesmere as viewed from the west

Diurnal Variation in Te Waihora Water Quality

Abstract

During the summer of 2010/2011 research was carried out at Te Waihora/Lake Ellesmere to measure the extent of diurnal variation in important water quality parameters. Diurnal variation is the variation which occurs over a 24 hour period and in aquatic environments large diurnal variation can have significant adverse effects on the aquatic ecology. While water quality testing currently takes place on a regular basis at Te Waihora/Lake Ellesmere, spot testing is likely to miss important changes that take place over a 12 or 24 hour timeframe. The purpose of this study was to document the extremes of diurnal variation and to investigate the extent to which localised weather conditions influenced results. The study ran for a duration of 10 weeks with sampling taking place once a week. In total, seven 12 hour and three 24 hour sampling excursions occurred.

On each occasion water temperature, pH, dissolved oxygen and conductivity were measured on an hourly basis. During 24 hour monitoring nutrient and turbidity measurements were taken on a by-hourly basis. It was expected that the diurnal variation in Te Waihora/Lake Ellesmere would be large as the lake is shallow in nature, has little riparian vegetation and shade, and is eutrophic. Dissolved oxygen and pH were expected to peak at the warmest part of the day and return to normal overnight. The results showed diurnal variation to be significant within the lake, and pH and dissolved oxygen peaked much later in the day than expected. Weather conditions did influence results with the largest variations occurring on hot, calm days and the smallest variations on windy, overcast days.

Contents

Section 1 Introduction

1.1 Te Waihora/ Lake Ellesmere

Located on Canterbury's East Coast is Lake Ellesmere, a large, shallow, brackish and turbid lake (Taylor, 1996). Known by Tangata Whenua as Te Waihora, meaning 'water spread out', Lake Ellesmere covers some 20,000 hectares, with a total catchment area comprising of 256,000 hectares (Canterbury Regional Council, 1999). The lake is formed by a gravel bar which intermittently opens to the sea (map 1), receiving its water from surface water inflows largely sourced from groundwater flowing into the catchment (Williams, 2009). Many of the spring fed streams within the catchment experience extreme seasonal flow variability which can see flow rates drop to very low levels in the summer months.

Te Waihora has long been recognised as a significant cultural, economic, ecological and recreational asset to the Canterbury region. Maori traditionally valued the lake and it's catchment as a substantial mahinga kai resource and regards the lake as holding deep physical and spiritual importance (Taylor, 1996). The lake continues to support a customary, as well as a commercial fishery (Jellyman & Smith, 2009) and the life supporting functions of the lake makes it one of New Zealand's most important wetland systems, especially in regards to wildlife habitat (Taylor, 1996). The lake is utilised for a variety of recreational activities including game bird shooting, kite and wind surfing, and boating. While Lake Ellesmere is recognised as an important ecological asset concerns have arisen over its water quality. The location of Te Waihora makes it susceptible to anthropogenic alteration and agricultural run-off. The surrounding land area has been extensively modified and the lake itself is highly enriched and described as eutrophic (Taylor, 1996). Lake Ellesmere has high nutrient and sediment concentrations, a high phytoplankton biomass and low water clarity (Hayward & Ward, 2009).

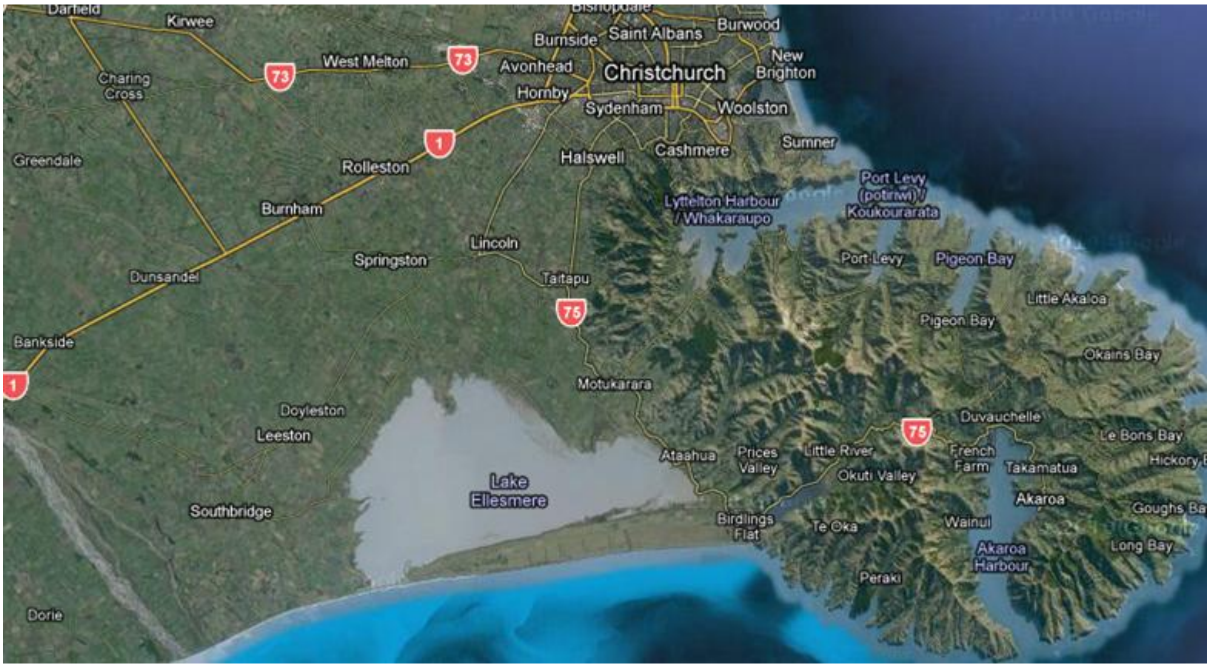


Figure 1. Te Waihora/ Lake Ellesmere Site Map, Google Maps: http://maps.google.co.nz/maps?hl=en&tab=wl

1.2 Phytoplankton Domination

Lake Ellesmere has undergone many changes over time with the most recent major change occurring during the Wahine storm in April 1968 (Wilks, 2010). Historically the margins of Te Waihora were covered in extensive beds of macrophytes (Jellyman *et al*., 2009). During the Wahine storm the lake changed from a clear macrophyte dominated system to being turbid and dominated by phytoplankton (Wilks, 2010). Although the macrophyte beds had historically undergone periods of decline prior to the storm, they had been able to re-establish themselves (Hughes *et al.*, 1974). However since the devastating Wahine storm they have never been able to re-establish (Jellyman *et al*., 2009). Research has been carried out to investigate the possibility of re-establishment for the purpose of improving water quality and clarity, reducing shore erosion and increasing productivity through increased habitat provision (Jellyman *et al*, 2009, Sagar *et al.*, 2004).

1.3 Management of the Lake

The Te Waihora Joint Management Plan (Ngai Tahu & DOC 2005) is a statutory plan between Te Runanga of Ngai Tahu and the Department of Conservation. The plan is designed to allow for effective integrated management and sets out the policies and methods for the future management of the Plan Area. The Canterbury Regional Council, Environment Canterbury, is responsible for monitoring and control of the Te Waihora lake levels, allocating water and discharge permits, and monitoring water quality. Although Environment Canterbury currently have five monitoring sites in which they frequently monitor water quality and water quality data is often collected from the lake (Hayward &

Ward, 2009, Taylor, 1996, Wilks, 2010) there is no data to quantify changes in water quality parameters over a 24 hour period.

1.4 Diurnal Variations in Water Quality

Significant variability in water quality parameters can occur over a 24 hour period. If extreme, variations in dissolved oxygen (DO) and pH (how acid or alkaline a water is) can adversely affect ecology, but will be missed in routine water quality monitoring programmes, which only sample a site once in any 24 hour period. DO and pH change as a consequence of photosynthesis; during the day, photosynthetic algae and other stream vegetation will raise DO and pH, reaching a maximum at the warmest, lightest part of the day (usually early afternoon). The pH and dissolved oxygen concentrations will return to more normal levels in the evening and overnight respiration will lower DO still further. This variation over a 24hr period is referred to as a “diurnal” variation, though it is often monitored only through daylight hours.

In eutrophic environments, high nutrient loads cause excessive algal growth. Shallow depth and lack of riparian shading will exaggerate the effects of temperature and light on photosynthesis. Therefore, in a eutrophic, shallow lake in open farm land, such as Te Waihora/ Lake Ellesmere, the variability in DO and pH can be extreme, with very high DO and pH conditions occurring mid-afternoon, and very low DO (even anoxic) conditions occurring during the night.

Section 2 Research Aim and Objectives

The aim of this research is to document the extremes of diurnal variation in important water quality parameters in Te Waihora/Lake Ellesmere. It will include the following objectives;

- To measure DO, pH and conductivity in surface water in the lake, at several key sites, over 12 hour and 24 hour time periods in the summer months of 2010/11
- To investigate to what extent diurnal variation is influenced by local weather conditions
- To determine diurnal variability (if any) in nutrient (nitrate and phosphate) and turbidity concentrations
- To identify any change in parameters with depth in the shallow lake

Section 3 Methods

The Lincoln University Studentship ran for a duration of 10 weeks, excluding a one week break over the Christmas period. During this period weekly field visits were carried out. Sampling began in the first week of December 2010 and was complete by the end of February 2011. During this time seven 12 hour monitoring field visits were conducted as well as three 24 hour visits.

3.1 Field Measurements

On each field visit the same parameters were tested on an hourly basis. Temperature, pH, DO and conductivity were tested with the use of a portable monitoring probe. Results were recorded onsite and later entered into an excel spreadsheet for analysis.

During the 12 hour field visits nitrate-nitrogen (NO_3-N), phosphorous (PO_4), and turbidity were tested with the use of a portable spectrophotometer and HACH reagent sachets in the morning (usually about 10.00am) and later again in the afternoon (about 3.30pm). Only the days where 24 hour monitoring was undertaken nitrate-nitrogen, phosphate, and turbidity were tested on a bi-hourly basis. The spectrophotometer measured turbidity in FAU (Formazin Attenuation Units) and this was later converted to NTU (Nephelometric Turbidity Units) with the use of 0, 10, and 100 NTU calibration solutions.

3.2 Sampling Sites and Times

Sampling was carried out by Kelly Fisher of Lincoln University, at three different sites (Figure 2a); the end of the Lower Selwyn Hutts Walkway, the Timberyard Road Domain, and Kaituna Lagoon (Figures 2b-2d).

The majority of sampling took place from the shore of the lake. On Tuesday the 8th of February 2011, Warwick Hill the Lincoln University Engineering Technician accompanied Pauline and I to both Te Waihora and Wairewa to measure vertical profiles in the lakes. During this time we used the Lincoln University boat to measure the water temperature, pH, DO, turbidity and nutrients at different depths on the lakes. Water samples were pumped up to the surface with the use of a bilge pump.

Sampling days were chosen with an aim of selecting a variety of different weather conditions. Weather forecasts were taken from www.metservice.co.nz. During monitoring weather conditions were noted down and Niwa's Cliflo climate database was later used to verify wind direction and speed, hourly temperature maximums and minimums, and hourly and daily rainfall. For monitoring carried out at the Lower Selwyn Hutts Walkway and Kaituna Lagoon Cliflow data was taken from the Lincoln Broadfield Ews station and from the Harts Creek Leeston station for Timberyard Road Domain.

Figure 2a: Sampling Locations at Te Waohora (Google Maps). Timberyard Road Domain ★, Lower Selwyn Hutts Walkway ★, Kaituna Lagoon ★, and the Vertical Profiles ● ○

Figure 2b Lower Selwyn Huts Walkway Sampling Site

Figure 2c. Timberyard Road Domain Monitoring Site

Figure 2d Kaituna Lagoon Sampling Location

Section 4 Results

4.1 Surface Water Conditions

4.1.1 Temperature

The largest water temperature variation was recorded at Kaituna Lagoon on the 1st of February 2011 as 6.8^{o}C (Table 1). The minimum water temperature on this occasion was 16.6^{o}C at 8.00am and the maximum water temperature was 23.4^{o}C at 4.00pm. This was followed closely by a variation of 6.4^{o}C at Timberyard Road on the 18th of the same month. In this instance the minimum water temperature was 20.0^{o}C at 7.00am (December 19th 2010) with the maximum measurement 26.4^{o}C at 6.00pm the evening before.

The smallest water temperature variation was recorded as 1.4^{o}C at the Lower Selwyn Hutts Walkway on the 2nd of December 2010 (table 1). Here the minimum water temperature was recorded at 8.00am as 17.6^{o}C and the maximum of 19.0^{o}C at 6.00pm. This was followed by a variation of 2.4^{o}C on the 7th of December 2010 at the Timberyard Road Domain.

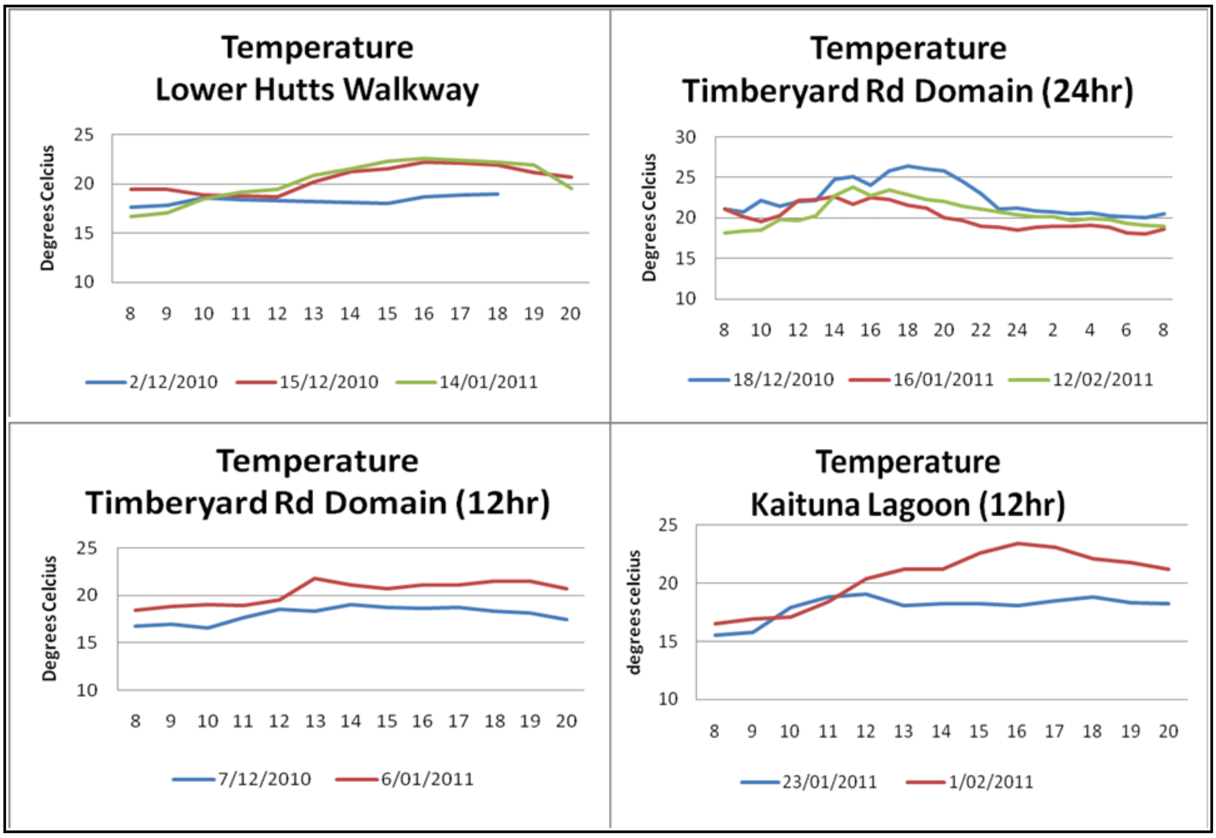
As would be expected water temperatures were at their lowest in the earlier hours of the morning with 8.00am recorded most frequently (Figure 3). In all, five from ten minimum temperatures were recorded at this time. This occurred twice at the Timberyard Road Domain, twice at the Lower Selwyn Hutts Walkway, and once at Kaituna Lagoon.

Table 1: Water Temperature variation maximums and minimums

Location	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway (12hr)	02/12/2010	19.0^{o}C, 6.00pm	17.6^{o}C, 8.00am	1.4^{o}C
	15/12/2010	22.2^{o}C, 4.00pm	18.7^{o}C, 12.00pm	3.5^{o}C
	14/01/2011	22.6^{o}C, 4.00pm	16.7^{o}C, 8.00am	5.9^{o}C
Timberyard Road Domain (12hr)	07/12/2010	19.0^{o}C, 2.00pm	16.6^{o}C, 10.00am	2.4^{o}C
	06/01/2011	21.8^{o}C, 1.00pm	18.4^{o}C, 8.00am	3.4^{o}C
Timberyard Road Domain (24hr)	18-19/12/2010	26.4^{o}C, 6.00pm	20.0^{o}C, 7.00am	6.4^{o}C
	16-17/01/2011	22.6^{o}C, 2.00pm	18.0^{o}C, 7.00am	4.6^{o}C
	12-13/02/2011	23.8^{o}C, 3.00pm	18.2^{o}C, 8.00am	5.6^{o}C
Kaituna Lagoon (12hr)	23/01/2011	19.1^{o}C, 12.00pm	15.5^{o}C, 9.00am	3.6^{o}C
	01/02/2011	23.4^{o}C, 4.00pm	16.6^{o}C, 8.00am	6.8^{o}C

The most frequently documented maximum water temperature time was 4.00pm. This was recorded three times, twice at the Lower Selwyn Hutts Walkway and once at Kaituna Lagoon. At Timberyard Road Domain the water temperature tended to peak earlier in the day between 1.00-3.00pm with the exception of December 18th where it peaked at 6.00pm (Figure 3).

Figure 3. Water temperature diurnal variation



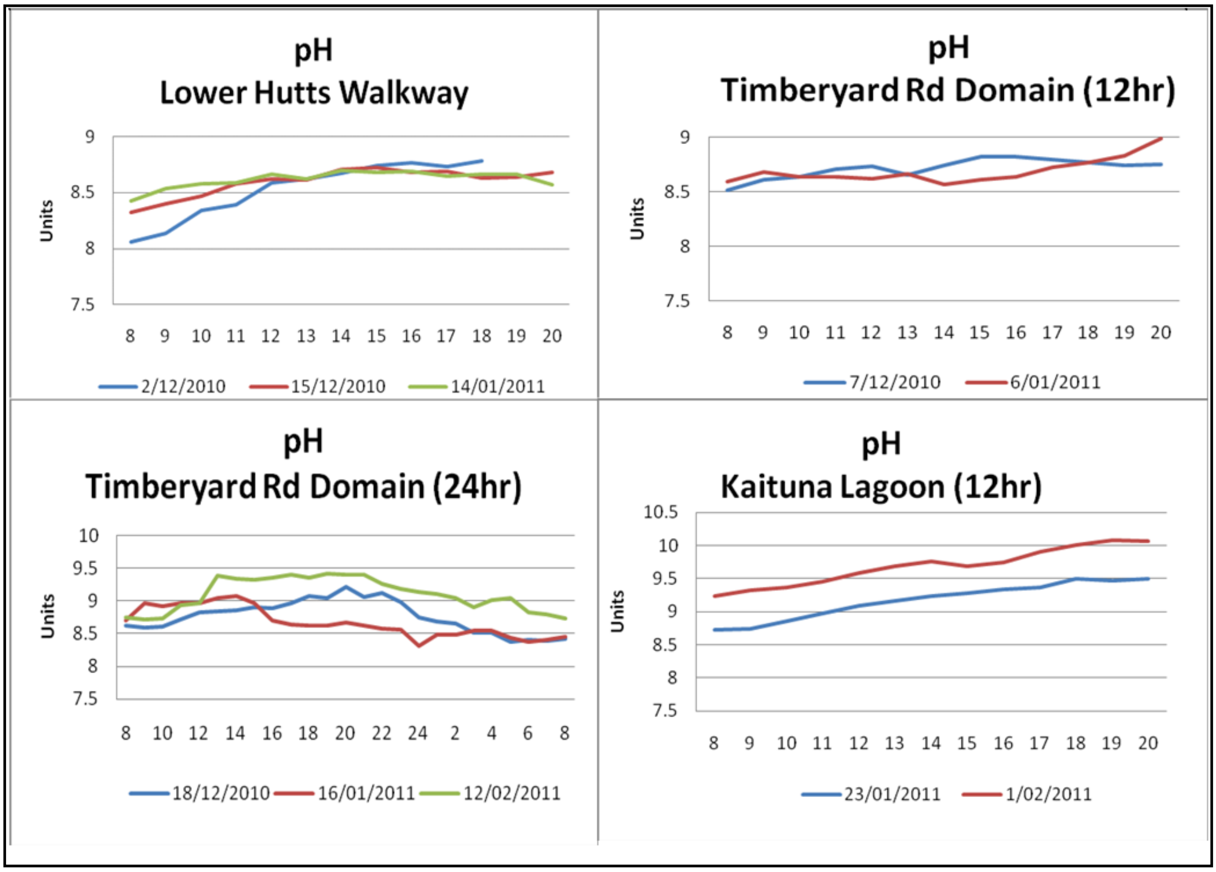
4.1.2 pH

The largest pH variation was recorded at Kaituna Lagoon as 0.84 units on the 1st of February 2011 (Table 2). This was followed very closely by a variation of 0.83 units at Timberyard Road Domain on the 18th of December 2010. The smallest pH variation was measured at the Lower Selwyn Hutts Walkway on the 2nd of December as 0.27 units.

Table 2: pH variation maximums and minimums

	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway	02/12/2010	8.78, 6.00pm	8.06, 8.00am	0.72 units
	15/12/2010	8.72, 3.00pm	8.32, 8.00am	0.40 units
	14/01/2011	8.70, 2.00pm	8.43, 8.00am	0.27 units
Timberyard Road Domain (12hr)	07/12/2010	8.82, 3 & 4.00pm	8.51, 8.00am	0.31 units
	06/01/2011	8.99, 8.00pm	8.57, 2.00pm	0.42 units
Timberyard Road Domain (24hr)	18-19/12/2010	9.21, 8.00pm	8.38, 5.00am	0.83 units
	16-17/01/2011	9.07, 2.00pm	8.31, 12.00am	0.76 units
	12-13/02/2011	9.42, 7.00pm	8.72, 9.00am	0.70 units
Kaituna Lagoon	23/01/2011	9.50, 8.00pm	8.72, 8.00am	0.78 units
	01/02/2011	10.08, 7.00pm	9.24, 8.00am	0.84 units

Figure 4. Water pH diurnal variation



As with water temperature, the minimum pH levels were most frequently found to occur at 8.00am. Six from ten minimum pH readings were documented at this time of the morning across all three monitoring locations (table 2). pH peaks were most frequent between 7.00-8.00pm with five from ten measured at this time. 7.00pm was recorded as having the maximum pH twice, at the Lower Selwyn Hutts Walkway and Kaituna Lagoon, and 8.00pm three times, twice at Timberyard Domain and once at Kaituna Lagoon (Figure 4).

4.1.3 Dissolved Oxygen

On the 1st of February 2011 at Kaituna Lagoon the largest variation in DO occurred. This saw a total DO rise of 10.82mg/L, increasing from 10.18mg/L at 9.00am to 20.27mg/L at 6.00pm (table 3). Timberyard Road Domain also experienced a large DO increase of 8.87mg/L on the 18th of December 2010. DO measurements recorded at the Lower Selwyn Hutts Walkway were significantly lower with the maximum variation being 2.87mg/L on the 2nd of February 2011 (graph set 3). The lowest variation in DO was recorded at the Timberyard Road Domain on the 7th of December 2010. On this occasion there was an increase in DO of 1.74mg/L. A similarly low increase was also recorded at the Lower Selwyn Hutts Walkway of 1.96mg/L.

8.00am and 9.00am were the most frequently recorded times for minimum DO levels (table 3). In total seven from ten minimums were recorded at these times across all three monitoring locations. 6.00pm was the most common time for maximum DO occurring on four from four occasions and again across all three monitoring sites.

Table 3. DO variation maximums and minimums

	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway	02/12/2010	12.22mg/L, 6.00pm	9.35mg/L, 8.00am	2.87mg/L
	15/12/2010	11.10mg/L, 2.00pm	8.32mg/L, 9.00am	2.78mg/L
	14/01/2011	11.32mg/L, 10.00am	9.36mg/L, 8.00pm	1.96mg/L
Timberyard Road Domain (12hr)	07/12/2010	10.97mg/L, 5.00pm	9.23mg/L, 9.00am	1.74mg/L
	06/01/2011	11.78mg/L, 7.00pm	9.28mg/L, 2.00pm	2.5mg/L
Timberyard Road Domain (24hr)	18-19/12/2010	15.82mg/L, 6.00pm	6.95mg/L, 5.00am	8.87mg/L
	16-17/01/2011	10.39mg/L, 8.00pm	5.94mg/L, 10.00am	4.45mg/L
	12-13/02/2011	10.89mg/L, 6.00pm	5.44mg/L, 8.00am	5.45mg/L
Kaituna Lagoon	23/01/2011	20.27mg/L, 6.00pm	10.18mg/L, 9.00am	10.09mg/L
	01/02/2011	18.08mg/L, 7.00pm	7.26mg/L, 8.00am	10.82mg/L

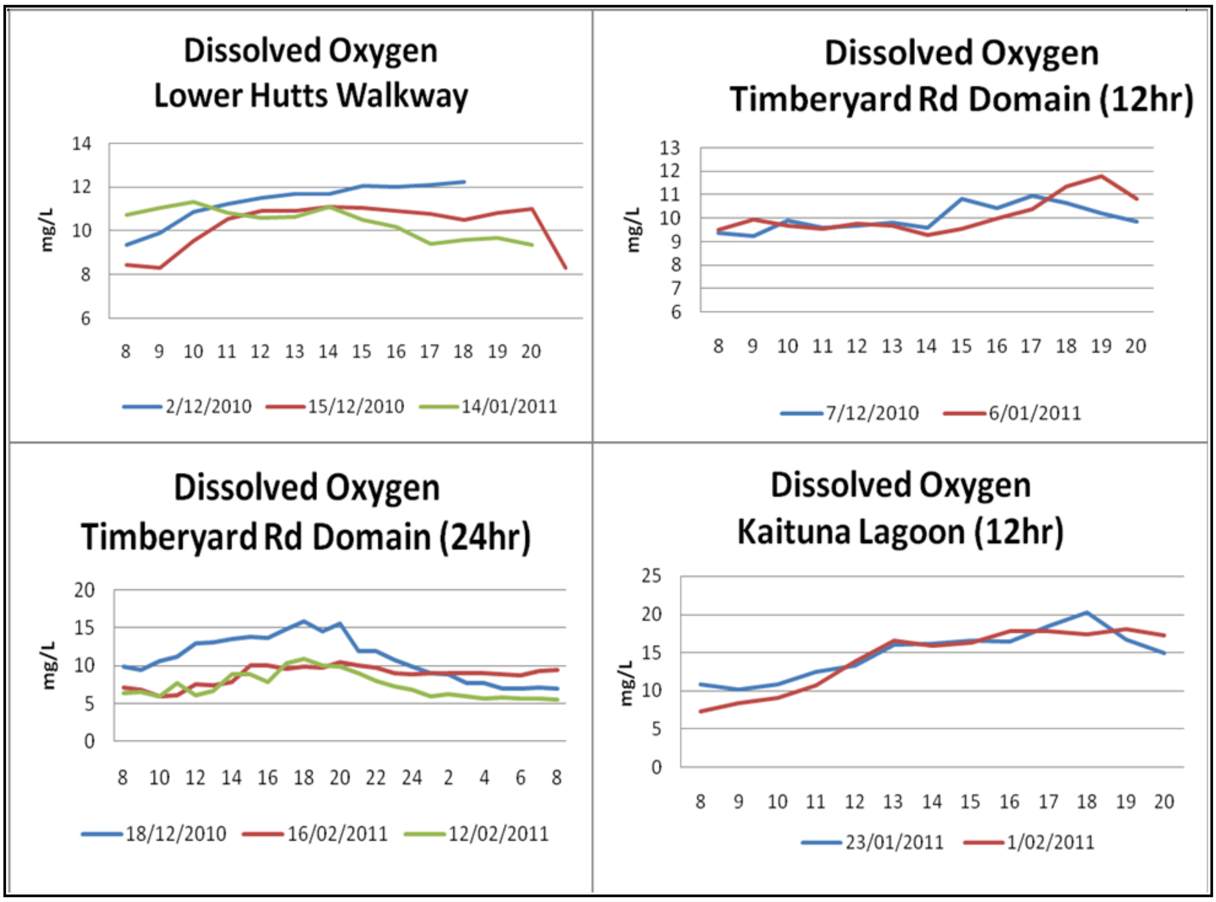


Figure 5. Diurnal DO variation

Dissolved Oxygen Saturation

The DO saturation maximum and minimum recordings correspond with the DO measurements above. Kaituna Lagoon showed the largest increase in DO saturation on the 1st of February 2011 of 136.8% (Table 4). At 9.00am the water was already 103.0% saturated with dissolved oxygen and at its peak at 6.00pm it had reached a saturation of 219.4%. Similarly Timberyard Road experienced a considerable saturation increase of 120.6% on the 18th of December 2010. DO saturation variation at the Lower Selwyn Hutts Walkway was not as sizeable with the largest increase 34.5% (Table 4). The smallest increase in DO saturation occurred at the Timberyard Road Domain on the 7th of December 2010. At 9.00am the water had been 95.5% saturated and increased to a peak of 117.3% at 5.00pm.

Table 4. Dissolved oxygen saturation variation maximums and minimums

	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway	02/12/2010	130.7%, 6.00pm	100.1%, 8.00am	30.6%
	15/12/2010	124.3%, 3.00pm	89.8%, 9.00am	34.5%
	14/01/2011	125.3%, 2.00pm	101.8%, 8.00pm	23.5%
Timberyard Road Domain (12hr)	07/12/2010	117.3%, 5.00pm	95.5%, 9.00am	21.8%
	06/01/2011	136.0%, 7.00pm	102.6%, 8.00am	33.4%
Timberyard Road Domain (24hr)	18-19/12/2010	198.2%, 6.00pm	77.6%, 5.00am	120.6%
	16-17/01/2011	117.8%, 4.00pm	66.2%, 10.00am	51.6%
	12-13/02/2011	127.5%, 6.00pm	58.9%, 8.00am	68.6%
Kaituna Lagoon	23/01/2011	219.4%, 6.00pm	103.0%, 9.00am	116.4%
	01/02/2011	212.9%, 4.00pm	76.1%, 8.00am	136.8%

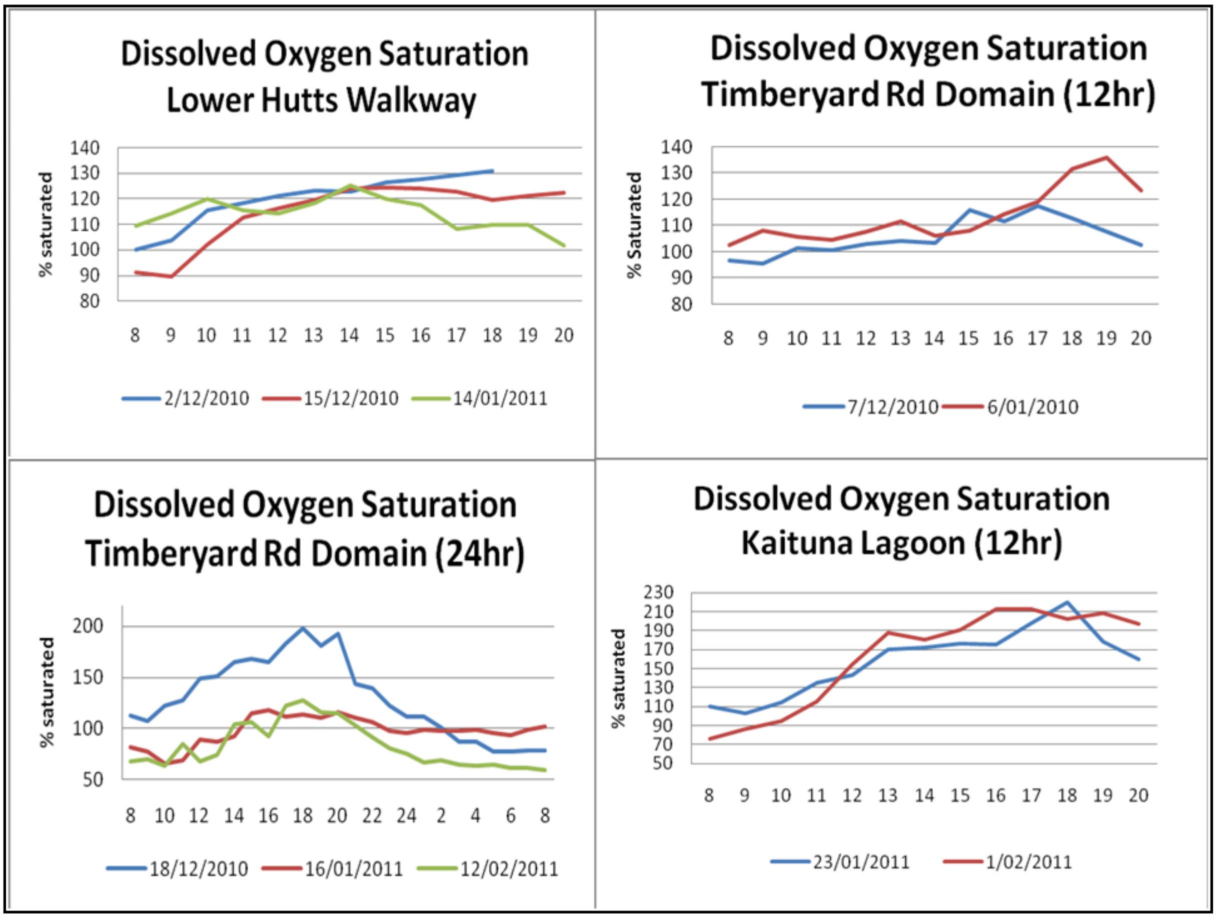


Figure 6. Diurnal dissolved oxygen saturation variation

4.1.4 Conductivity

The portable probe measured conductivity in milli Siemens per centimetre (mS/cm). Conductivity ranged from 4.84-11.00mS/cm across the three different monitoring locations (Table 5, Figure 7). The largest variation was recorded at the Lower Selwyn Hutts Walkway on the 15th of December 2010. This saw a minimum conductivity measure of 4.84mS/cm at midday (during heavy rain) and a high of 8.74mS/cm earlier in the day at 9.00am. The smallest variation was recorded as 0.12mS/cm at Kaituna Lagoon on the 23rd of January 2011. On this day conductivity varied from a minimum of 10.06mS/cm at 8.00am to 10.18mS/cm at 6.00pm.

Table 5: Conductivity variation maximums and minimums

	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway	02/12/2010	9.71mS/cm, 9.00am	7.57mS/cm,5&6.00pm	2.14mS/cm
	15/12/2010	8.74mS/cm, 9.00am	4.84mS/cm, 12.00pm	3.9mS/cm
	14/01/2011	9.56mS/cm, 8.00am	8.04mS/cm, 10.00am	1.52mS/cm
Timberyard Road Domain (12hr)	07/12/2010	8.54mS/cm, 4.00pm	7.39mS/cm, 12.00pm	1.15mS/cm
	06/01/2011	8.94mS/cm, 6.00pm	7.50mS/cm, 2.00pm	1.44mS/cm
Timberyard Road Domain (24hr)	18-19/12/2010	8.17mS/cm, 8.00am	7.58mS/cm, 5.00pm	0.59mS/cm
	16-17/01/2011	9.41mS/cm, 7.00pm	8.31mS/cm, 3.00am	1.1mS/cm
	12-13/02/2011	9.46mS/cm, 6.00pm	9.12mS/cm, 11.00am	0.34mS/cm
Kaituna Lagoon	23/01/2011	10.18mS/cm, 1.00pm	10.06mS/cm, 8.00am	0.12mS/cm
	01/02/2011	11.00mS/cm, 8.00pm	10.77mS/cm, 1.00pm	0.23mS/cm

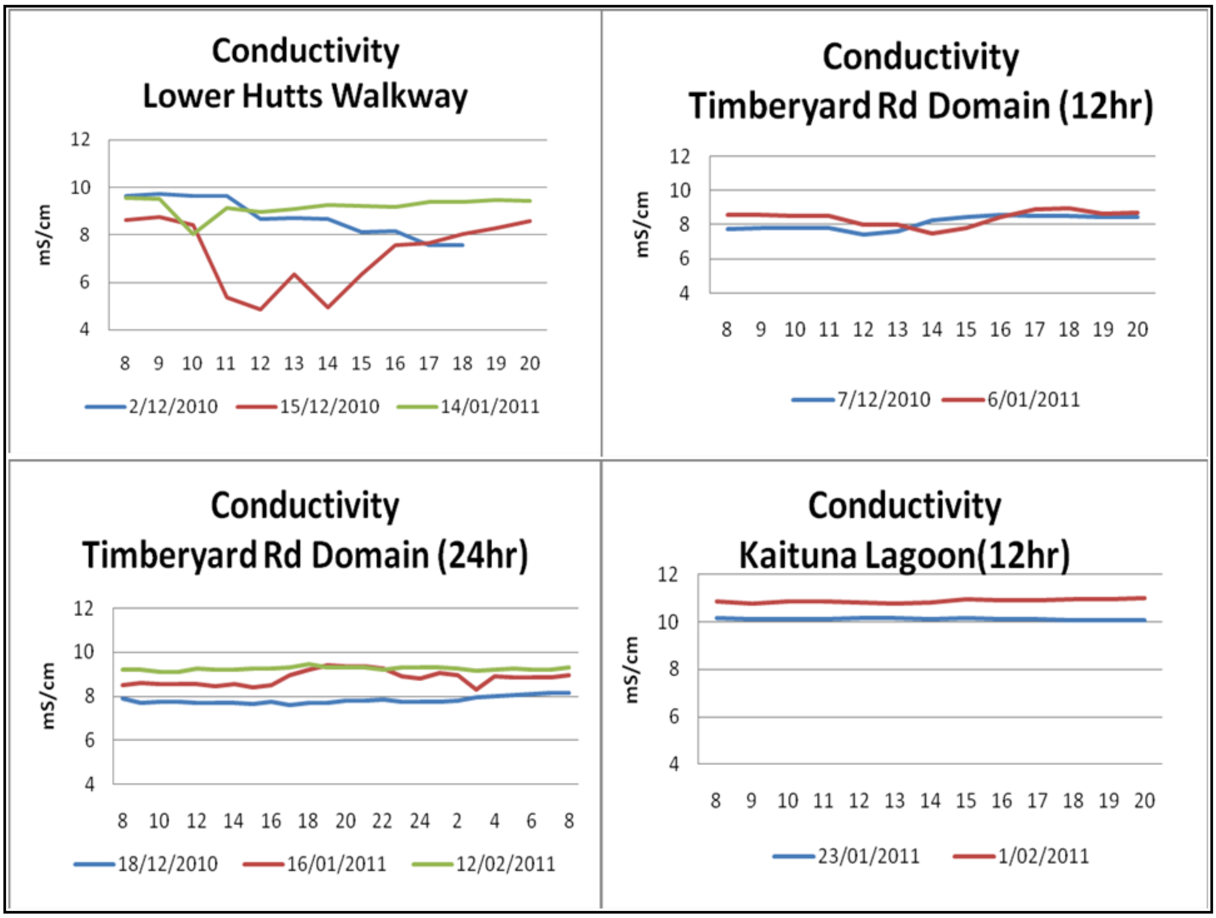


Figure 7. Diurnal conductivity variation

4.1.5 Turbidity

Lake Ellesmere is well renowned for its turbid nature. During the ten days of monitoring the highest NTU recording was at the Timberyard Road Domain on the 16th of January during a 24 hour sampling excursion at 5.00pm (Table 6, Figure 8). This was recorded as 286FAU and later converted to 380NTU. On the same day the largest variation in turbidity was noted, a total variation of 238NTU. The lowest turbidity was measured on the morning of the 1st of February at Kaituna Lagoon. This measurement was taken as 15FAU and later converted to 19NTU.

Table 6: Turbidity (NTU) variation maximums and minimums

	Date	Maximum	Minimum	Variation
Lower Selwyn Hutts Walkway	02/12/2010	116, morning	69, afternoon	47
	15/12/2010	170, afternoon	62, morning	108
	14/01/2011	316, afternoon	81, morning	235
Timberyard Road Domain (12hr)	07/12/2010	89, morning	73, afternoon	16
	06/01/2011	292, afternoon	160, morning	132
Timberyard Road Domain (24hr)	18-19/12/2010	203, 7.00pm	105, 3.00pm	98
	16-17/01/2011	380, 5.00pm	142, 1.00pm	238
	12-13/02/2011	279, 9.00am	198, 5.00am	81
Kaituna Lagoon	23/01/2011	69, morning	49, afternoon	20
	01/02/2011	20, afternoon	19, morning	1

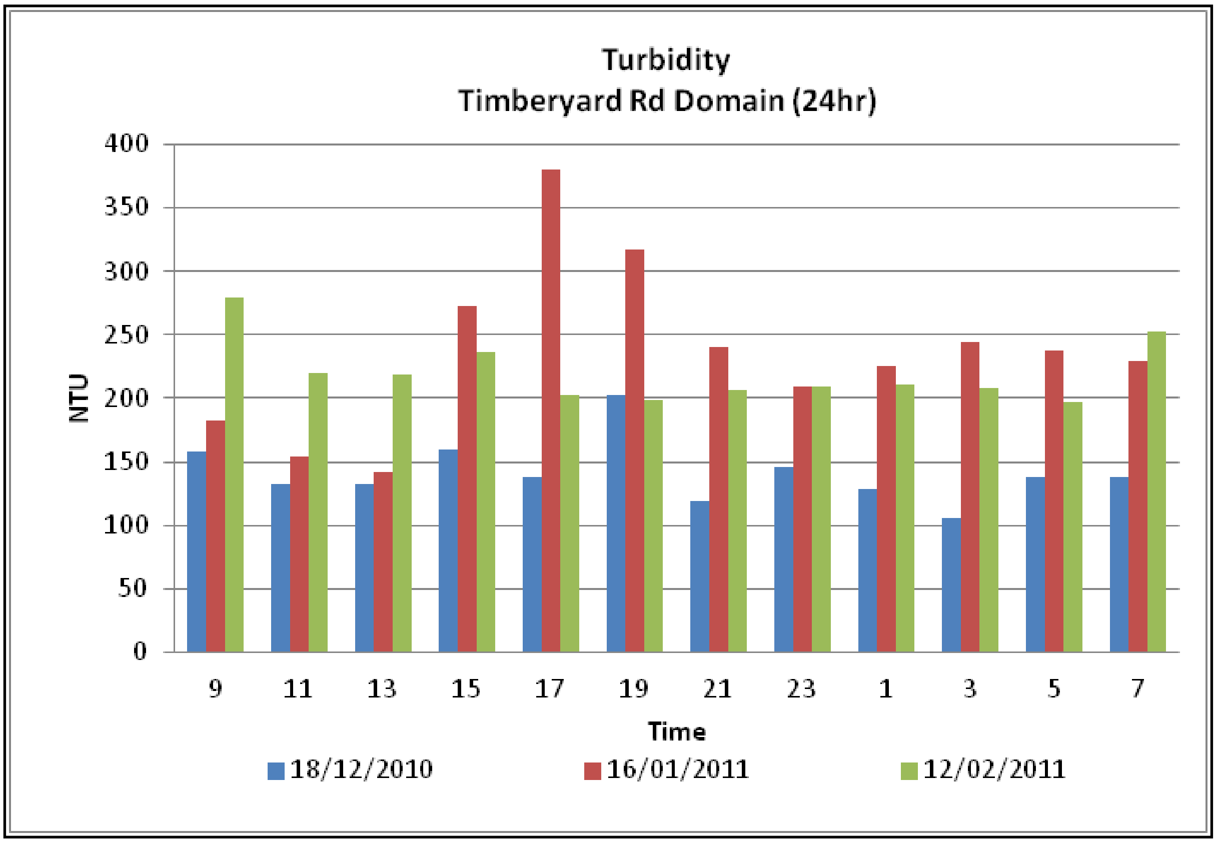


Figure 8: 24 hour turbidity variation at Timberyard Road Domain

4.1.6 Nutrients; NO_3-N and PO_4

Due to an error in the measurements carried out (using distilled water as a blank and an unfiltered, turbid sample yielding results that were too high), NO_3-N and PO_4 measurements were not accurate for the majority of the sampling carried out.

However, a reliable set of nitrate and phosphate samples were taken on the last 24 hour monitoring excursion at Timberyard Road Domain. On this occasion all nutrient water samples were filtered through a 0.45um filter prior to reagent addition. Nitrate measurements ranged from <DL to 0.6mg/L. Of the 12 samples carried out on this day, 7 were below detectable levels (<DL) as shown on Figure 8.

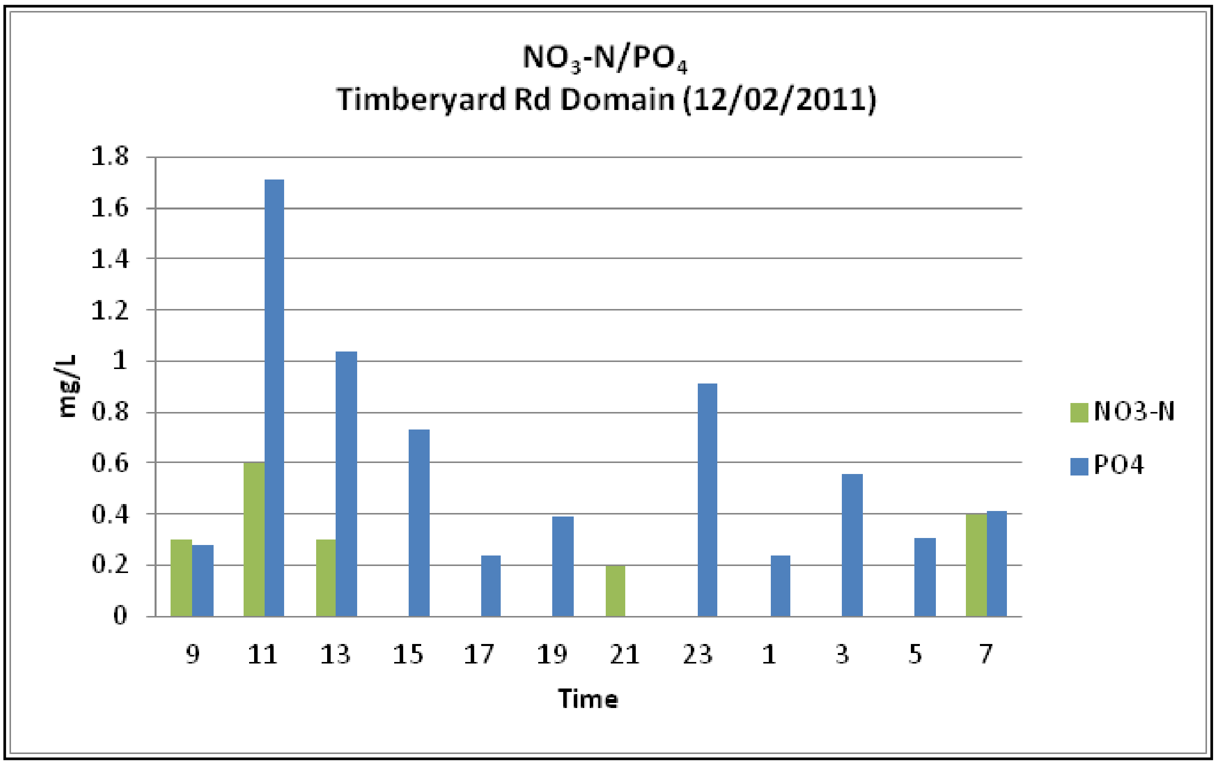


Figure 9: NO_3-N and PO_4 Variation at Timberyard Road Domain, 12/02/2011

Phosphate results showed a larger variation than for nitrate. The maximum PO_4 measurement was recorded as 1.71mg/L at 11.00am and the minimum (<DL) at 11.00pm.

4.2 Water Quality Depth Profiles

4.2.1. Main parameters

Water quality profiles were conducted out from the Lower Selwyn Hutts Walkway shoreline and out from Timberyard Road Domain on two separate occasions. Profiles taken at Timberyard Road Domain did not include turbidity or nutrient sampling as the bilge pump was not there to bring the water to the surface. The lake was approximately 1m deep at the sampling points.

Table 7: Water quality profile results, Lower Selwyn Hutts Walkway

Depth (m)	Water Temperature (^{o}C)	pH (units)	Dissolved Oxygen (mg/L)	DO Saturation (%)	Conductivity (mS/cm)	Turbidity (NTU)
Surface	17.9	9.50	101.7	8.47	10.29	331
0.5	17.6	9.51	101.3	8.5	10.31	367
1.0	20.0	8.89	99.3	8.26	10.10	455

Temperature and turbidity were greatest at depth. However, pH, DO, conductivity and turbidity values were all slightly lower at 1.0m depth at the Lower Selwyn Hutts Walkway (Table 8). Similar results were recorded out from Timberyard Road Domain.

4.2.2. NO_3-N and PO_4

Profile sampling was carried out offshore from the Lower Selwyn Hutts Walkway. Nitrate measurements showed little variation through the profile however phosphates were notably lower at the surface than at depth.

Table 8: NO_3-N and PO_4 Profile Results

Depth (m)	NO_3-N (mg/L)	PO_4 (mg/L)
Surface	0.3	0.99
0.5	0.1	1.75
1.0	0.2	1.75

Section 5 Discussion

Measuring diurnal variation in Te Waihora/Lake Ellesmere was important as it aides in our understanding how the environment changes over a 12 or 24 hour period. Large extremes in temperature, pH, DO, salinity, turbidity and nutrients can have a detrimental affect on aquatic ecology. This includes the animals, plants, fish, invertebrates and micro-organisms which depend upon the lake for their survival. Salinity, pH, DO and temperature stressors are naturally variable and are directly toxic to biota, however natural biological communities are generally adapted to site specific conditions (ANZECC, 2000). Nutrients and turbidity stressors are not toxic but still have the potential to directly influence eco-systems and biota.

5.1 Diurnal Variations in Key Parameters

Water temperature is an important water quality parameter, influencing the amount of oxygen that can be dissolved in the water (Course Reader, ERST203). Warmer water temperatures can accelerate photosynthesis and in turn lead to eutrophication. For the protection of aquatic eco-systems it is recommended that water temperatures do not increase more than 2^{o}C from their natural temperatures. As indicated in Table 1, there was only one day (02/12/2010) that water temperatures stayed within this variation. The largest water temperature increase was recorded as 6.4^{o}C, posing a potential threat to sensitive aquatic species.

pH measures how acidic or alkaline water is on a scale of 1-14. Animals and plants are adapted to certain ranges and increases or decreases outside of this range can lead to species loss or stress (Course Reader, ERST203). pH naturally varies as a result of photosynthetic activity as well as by the geology and soils within the catchment. pH also increases with increased salinity, for example a typical estuary would have a pH of 8.5 while freshwater would have a typical pH of 6.5-7.5. It is recommended that for the protection of aquatic ecosystems pH does not vary more than 0.5 units outside the natural range for freshwater or 0.2 units for marine waters. Te Waihora/Lake Ellesmere, which is brackish in nature, had a maximum variation of 0.84 units and a minimum of 0.27 units (table 2).

Dissolved oxygen is fundamental to the fish, invertebrates, micro-organisms and plants living in Te Waihora/Lake Ellesmere. It is given out as a by-product of photosynthesis and taken up through respiration. Aquatic plants and algae release DO into the water during the day and where there is excessive vegetation present the water can become super-saturated as is the case at Te Waihora/Lake Ellesmere. For the protection of aquatic eco-systems it is recommended that DO saturation remains above 70% saturated (Course Reader, ERST203). Conductivity was the parameter that showed the least variability throughout the sampling duration. On the 15th of December at the Lower Selwyn Hutts Walkway (Figure 1) the largest variation was recorded (3.9mS/cm or 3,900µS/cm). The lower than normal measurements (as low as 4.84mS/cm, Table 5) coincided with heavy rain. This monitoring

site was within close vicinity of the Selwyn River and this potentially had an impact on the results.

It was expected that pH and DO would peak at the warmest part of the day and return to normal overnight. With the shallow depth of the lake and the lack of riparian vegetation and shade the variation in water quality parameters was expected to be substantial. The latter was found to be true; however the former was proven different with pH and DO values only twice peaking at the warmest part of the day (15/12/2010 and 14/01/2011, both at the Lower Selwyn Huts Walkway (Tables 2 and 3). For pH, DO and water temperature, values generally peaked much later in the day than expected, most commonly between the hours of 6.00-8.00pm.

5.2 Turbidity and Nutrients

The change that occurred during the Wahine Storm of 1968 resulted in Te Waihora/Lake Ellesmere switching from a macrophyte dominated environment to a phytoplankton environment (Jellyman *et al.*, 2009). This regime change is colloquially known as "flipped". It is common that when "flipping" occurs, as at Te Waihora, that there is a decrease in water clarity and an increase in turbidity as a result of wind driven resuspension of sediments. Turbidity can reduce light transmission and many types of pollution, such as nitrogen and phosphorous, can attach to the suspended solids (Course Reader, ERST203). The results show that turbidity was highly variable throughout a 24 hour period and that variation was frequently affected by wind; an example of this can be seen on Figure 8. On the 16th of January a very strong southerly change occurred just after 1.00pm. High winds persisted until just after 7.00pm. The graph clearly shows that during the time of very high winds turbidity increased to very high levels.

Nutrient concentrations were only measured reliably on one occasion, but showed overall low, constant NO_3-N concentrations, but irregular PO_4 concentrations. The latter was also observed over this period at Wairewa/Lake Forsyth nearby, which experienced sudden sharp peaks in PO_4 concentrations (up to 0.8 mg/L; 2011 summer student - Pauline Robinson *pers comm*.)

5.3 The Effect of Weather Conditions

Weather conditions, including wind speed and direction, proved to have a significant influence on diurnal variation. The results show that the day with the highest variation of the water quality parameters temperature, pH, and DO occurred on the 1st of February 2011 at Kaituna Lagoon (tables 1, 2, 3, & 4). Early in the day there was very little wind and at 11.00am there was a change of wind direction from norwesterly to noreasterly and the wind speed subsequently increased. The maximum air temperature recorded at the Lincoln Broadfield Ews station was 23.4^{o}C. Perhaps more important in this instance was the visible presence of large amounts of aquatic vegetation and algae near to the sampling location (Figure 2). The large variation in water quality parameters at Kaituna were followed very closely by the variation recorded on the 18th of December 2010 at Timberyard Road

Domain. At this site aquatic vegetation was not as evident to the naked eye. During this day air temperatures recorded at the Hart's Creek weather station reached a maximum of 31.6^{o}C and wind throughout the day was only moderate.

At the other end of the spectrum the days with the smallest variation in water quality parameters occurred on the 7th of December 2010 at Timberyard Road Domain (Figure 3) and the 14th of January 2011 at the Lower Selwyn Huts Walkway. On the 7th of December the morning wind came from a southerly direction changing to north easterly at about 2.00pm. The minimum temperature recorded was at 8.00am as 8.4^{o}C and the maximum at 3.00pm as 20.6^{o}C.

The results indicate that the highest variation in water quality parameters occur on hot days with lower wind speeds. On hot, calm days water temperature showed the greatest increase and pH, DO and conductivity variation was more sizable than days of high winds and overcast conditions. With higher wind speed temperature increased as did pH but not as sizably as on days with little or no wind. During windy conditions conductivity variation was higher but DO variation was less.

5.4 Limitations of Study

Throughout this study there have been errors which have occurred during sampling. These mainly relate to nutrient samples and have resulted in the majority of the nutrient data being omitted from this report. It is also important to mention that the portable probe that was used for sampling was calibrated in the first week of the research. It was later tested in February 2011 and the pH probe was found to be 0.34units off.

While reading the results of the 12 hour sampling it is worth keeping in mind that many of the minimum values were recorded at 8.00am. This is the time that monitoring began and it is highly likely that lower measurements would have been recorded in the earlier hours of the morning had sampling taken place then, as was the case with two from three of the 24 hour samples. This further highlights how easily spot sampling can miss significant changes in water quality parameters.

5.5 Recommendation for Further Study

This study focused solely on diurnal variation at three separate points on the lake from the shore. In the future research could be carried out in which diurnal variation is measured spatially, say at five points in one location, and at different depths. Seasonal changes of diurnal variation would be interesting, as would diurnal variation with the spit open, particularly in relation to conductivity. It would be beneficial to carry out comprehensive invertebrate counts and identification to compliment the sampling results.

Section 6 Conclusion

The studentship which ran throughout the 2010/2011 summer was an opportunity to measure and document diurnal variation in one of Canterbury's most important water bodies. Large diurnal variation was measured at all three sampling locations and the variation was found to be substantially influenced by localised weather conditions, particularly sunny hot temperatures, wind, and overcast conditions.

Reference List

ANZECC & ARMCANZ. (2000). Australian and New Zealand guidelines for fresh and marinewater quality.

Canterbury Regional Council. (1999). *Lake Ellesmere, Te Waihora*. Christchurch, New Zealand: Canterbury Regional Council.

Hayward, S. & Ward, J. (2009). Water Quality in the Ellesmere Catchment. *In:* Hughey, K. & Taylor, K. (Eds.), *Te Waihora/ Lake Ellesmere: State of the Lake and Future Management* (pp.21-31). Christchurch, New Zealand: EOS Ecology.

Hughes, H., McColl, R., & Rawlence, D. (1974). *A review of the lake and its catchment.* DSIR Information Series 99. Wellington, New Zealand: Sigma Print.

Jellyman, D. & Smith, C. (2009). Native fish and fisheries. In: Hughey, K. & Taylor, K. (Eds.), *Te Waihora/ Lake Ellesmere: State of the Lake and Future Management* (pp.42-48). Christchurch, New Zealand: EOS Ecology.

Jellyman, D., Walsh, J., Winton, M., & Sutherland, D. (2009). *A review of the potential to re-establish macrophyte beds in Te Waihora (Lake Ellesmere).* Christchurch, New Zealand: Environment Canterbury.

Sagar, P., Hawes, I., Stephens, S., Jellyman, D., & Kelly, D. (2004). *Lake Ellesmere (Te Waihora): a review of water clarity and the potential for macrphyte growth, and the benthic invertebrates, fisheries and birds, and their feeding relationships*. Christchurch, New Zealand: Environment Canterbury.

Taylor, K. (1996). *The Natural Resources of Lake Ellesmere (Te Waihora) and its Catchment.* Christchurch, New Zealand: Canterbury Regional Council.

Ngai Tahu & DOC (2005) Te Waihora Joint Management Plan, Christchurch, New Zealand.

Wilks, T. (2010). *Response of benthic invertebrate fauna to fluctuating lake levels and salinity concentrations in Te Waihora/ Lake Ellesmere*. Unpublished Master's thesis, Canterbury University, Christchurch, New Zealand.

Williams, H. (2009). Groundwater and the 'living lake'. *In*: Hughey, K. & Taylor, K. (Eds.), *Te Waihora/ Lake Ellesmere: State of the Lake and Future Management* (pp.9-19). Christchurch, New Zealand: EOS Ecology.

Appendices

Note that all NO_3-N and PO_4-P concentrations, **except** those measured at Timberyard Rd Domain on 12/2/2011 (and possibly at Lower Selwyn Huts on 2/12/2010) are in error. They were measured on unfiltered water samples and the high turbidity of the lake water has interfered in the analysis, causing values to be too high.

A. Lower Selwyn Huts site data

Date 2/12/2010

Time (hr)	Temp (°C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	17.6	9.35	100.1	8.06	9.66	Very windy, o/c
9	17.8	9.91	103.6	8.14	9.71	
10	18.6	10.88	115.4	8.34	9.65	Wind dropping
11	18.4	11.21	118.5	8.39	9.65	
12	18.3	11.51	121.2	8.59	8.66	Warming, cloudy
13	18.2	11.7	123	8.62	8.71	
14	18.1	11.69	122.8	8.67	8.67	
15	18	12.06	126.6	8.74	8.12	Cooling, rain spots
16	18.7	12	127.6	8.77	8.15	Rain stopped, still
17	18.9	12.1	129.2	8.73	7.57	
18	19	12.22	130.7	8.78	7.57	Calm

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
10	0	0.7	88
15.3	0.1	0.67	53

Date 15/12/2010

Time (hr)	Temp(°C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	19.4	8.43	91.1	8.32	8.64	Lt rain, warm, still
9	19.4	8.32	89.8	8.4	8.74	
10	18.9	9.55	102.2	8.47	8.41	Colder, windier
11	18.8	10.55	112.7	8.58	5.38	
12	18.7	10.91	116.2	8.62	4.84	RAIN (heavy)
13	20.2	10.9	119.6	8.61	6.33	Clearing
14	21.2	11.1	124	8.71	4.93	Blue sky, windy
15	21.5	11.06	124.3	8.72	6.33	
16	22.2	10.91	124.2	8.68	7.58	Very windy
17	22.1	10.79	122.8	8.69	7.65	
18	21.9	10.52	119.5	8.63	8.03	Calmed down
19	21.1	10.83	121.1	8.64	8.3	
20	20.7	11	122.2	8.68	8.6	

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
10	1.2	1.75	47
15.3	0	1.13	128

Date 14/01/2011

Time (hr)	Temp (°C)	DO (mg/L)	DOsat (%)	pH	Cond(mS/cm)	Weather Conditions
8	16.7	10.71	109.5	8.43	9.56	Overcast, still
9	17.1	11.07	114.1	8.54	9.53	
10	18.5	11.32	119.9	8.58	8.04	Wind starting up
11	19.1	10.81	115.7	8.59	9.12	
12	19.4	10.59	114.3	8.66	8.95	Sun, WINDY
13	20.9	10.62	118.2	8.62	9.1	
14	21.5	11.1	125.3	8.7	9.24	Still windy
15	22.3	10.48	120.1	8.68	9.22	
16	22.6	10.18	117.5	8.69	9.18	
17	22.4	9.42	108.1	8.65	9.37	Really windy
18	22.2	9.6	109.9	8.66	9.38	
19	21.9	9.66	109.8	8.66	9.48	
20	19.5	9.36	101.8	8.57	9.42	Windy new direct

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
10	2.9	0.67	62
15.3	4.9	2.52	238

B. Timberyard Road Picnic Area

Date 7/12/2010

Time (hr)	Temp (°C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	16.8	9.39	96.7	8.51	7.73	Overcast
9	17	9.23	95.5	8.61	7.83	light rain, wind
10	16.6	9.88	101.4	8.64	7.81	
11	17.6	9.61	100.6	8.71	7.78	
12	18.5	9.68	103	8.73	7.39	Sun coming out
13	18.3	9.81	104	8.65	7.58	
14	19	9.61	103.3	8.74	8.28	
15	18.7	10.84	115.8	8.82	8.47	Wind dying out
16	18.6	10.44	111.4	8.82	8.54	
17	18.7	10.97	117.3	8.79	8.49	
18	18.3	10.65	112.9	8.77	8.51	
19	18.1	10.21	107.8	8.74	8.46	
20	17.4	9.84	102.4	8.75	8.45	

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
9	0	0.47	68
15.3	0	0.83	56

Date 6/01/2011

Time (hr)	Temp (°C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	18.4	9.51	102.6	8.59	8.59	Rain clearing, ltNE
9	18.8	9.94	107.9	8.68	8.58	
10	19	9.67	105.5	8.64	8.49	WINDY
11	18.9	9.57	104.4	8.64	8.53	
12	19.5	9.76	107.8	8.62	8	Clearing, windy
13	21.8	9.66	111.5	8.66	7.97	
14	21.1	9.28	105.9	8.57	7.5	
15	20.7	9.54	108.2	8.61	7.79	No wind, hot sun
16	21.1	10	114.3	8.64	8.45	Wind now S
17	21.1	10.39	118.9	8.72	8.86	Wind moving NE/S
18	21.5	11.37	131.4	8.77	8.94	
19	21.5	11.78	136	8.83	8.65	
20	20.7	10.84	123.2	8.99	8.68	Calm

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
9	1.1	2.7	121
12	1.56	2.9	150
16	2.33	4.7	220
20	1.3	2.8	131

24 hr sampling

Date 18/12/2010

Time (hr)	Temp (^{o}C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	21.1	9.93	113	8.62	7.9	Muggy, overcast
9	20.7	9.5	107.1	8.59	7.71	
10	22.1	10.55	122.3	8.61	7.76	
11	21.5	11.12	127.1	8.71	7.73	Light breeze
12	22	12.88	148.9	8.83	7.69	Cloud breaking up
13	22.1	13.06	151	8.84	7.69	
14	24.7	13.57	164.7	8.86	7.72	
15	25.1	13.75	168.3	8.91	7.63	
16	24.1	13.71	164.5	8.89	7.74	HOT
17	25.8	14.79	183.1	8.97	7.58	
18	26.4	15.82	198.2	9.08	7.72	Still hot
19	26.1	14.54	181.4	9.05	7.71	
20	25.8	15.5	192.3	9.21	7.8	Cloudy, muggy
21	24.5	11.87	143.5	9.06	7.79	
22	23	11.86	139.6	9.12	7.87	Sunset, windy
23	21.1	10.77	122.1	8.98	7.76	
24	21.2	9.81	111.4	8.75	7.75	
1	20.9	8.94	111.1	8.68	7.73	
2	20.8	8.92	100.5	8.65	7.8	Light rain
3	20.5	7.76	87.1	8.52	7.95	
4	20.6	7.72	86.8	8.51	7.99	
5	20.3	6.95	77.6	8.38	8.04	Sun rise
6	20.1	7.00	77.9	8.41	8.09	
7	20	7.04	78.2	8.39	8.16	
8	20.5	6.98	78.4	8.42	8.17	

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)	
9	0.6	2.2	119	
11	2.7	0.89	100	
13	2.3	2.22	100	
15	1.8	0.93	120	
17	2.3	0.95	104	
19	2.6	1.29	153	Boat nearby
21	1.7	1.15	90	
23	2.7	1.27	110	
1	1.9	1.04	97	
3	1.7	1.19	80	
5	1.4	1.18	104	
7	1.7	1.69	104	

Date

Time (hr)	Temp (^{o}C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	21.1	7.14	81.9	8.7	8.51	Windy
9	20.2	6.84	77.2	8.96	8.59	
10	19.6	5.94	66.2	8.92	8.56	Calm, warm, NW
11	20.3	6.06	68.5	8.97	8.54	
12	22.2	7.59	89.1	8.96	8.57	
13	22.3	7.42	87.1	9.04	8.44	Still, warm
14	22.6	7.82	92.2	9.07	8.56	Rapid change to S
15	21.7	9.97	115.1	8.96	8.43	
16	22.5	10.09	117.8	8.7	8.52	
17	22.3	9.55	111.1	8.64	8.97	
18	21.6	9.91	114	8.63	9.23	Wind same
19	21.2	9.7	110.3	8.62	9.41	
20	20	10.39	115.6	8.67	9.36	Calmed down
21	19.7	9.96	110.2	8.63	9.34	
22	19	9.75	106.2	8.58	9.25	
23	18.8	9.06	98.1	8.56	8.92	Dark
24	18.5	8.88	95.7	8.31	8.81	Very still
1	18.8	9.06	98.6	8.48	9.04	
2	19	8.98	97.7	8.49	8.98	
3	19	9.02	98.2	8.54	8.31	Light drizzle
4	19.1	9.01	98.3	8.55	8.9	RAIN
5	18.9	8.84	95.2	8.43	8.86	
6	18.2	8.77	94	8.37	8.86	
7	18	9.29	99.1	8.41	8.86	Rain cleared
8	18.6	9.45	101.8	8.46	8.97	Windy

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
9	2.8	1.17	138
11	2.8	1.14	116
13	2.5	1.01	107
15	2.4	2.25	205
17	5.5	2.41	286
19	4.3	2.75	239
21	3.4	1.94	181
23	2.6	2.02	158
1	3.8	2.84	170
3	2.7	1.43	184
5	2.4	1.6	179
7	3.7	1.79	173

Date 12/02/11

Time (hr)	Temp (^oC)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	18.2	6.34	67.5	8.75	9.19	Overcast
9	18.4	6.58	70.5	8.72	9.2	Warm
10	18.5	5.94	63.6	8.74	9.13	Wind stirring
11	19.8	7.72	85.1	8.93	9.12	
12	19.7	6.15	67.7	8.96	9.24	
13	20.3	6.65	74.2	9.39	9.21	Warm
14	22.7	8.93	104.2	9.34	9.2	
15	23.8	8.9	106	9.33	9.28	Hot, windy
16	22.8	7.9	92.5	9.36	9.28	
17	23.5	10.31	122.3	9.40	9.29	
18	22.9	10.89	127.5	9.35	9.46	
19	22.3	10.01	116.2	9.42	9.32	Wind died, warm
20	22	9.93	114.5	9.4	9.32	
21	21.5	9.07	103.6	9.4	9.32	Light rain
22	21.1	8.05	91.2	9.26	9.23	
23	20.8	7.22	81.2	9.19	9.33	Stopped raining
24	20.4	6.77	75.6	9.14	9.33	
1	20.2	6.01	66.8	9.11	9.31	RAIN
2	20.2	6.2	68.9	9.05	9.28	Stopped raining
3	19.7	5.88	64.7	8.91	9.16	Started again
4	19.9	5.72	63.2	9.02	9.22	
5	19.8	5.87	64.5	9.05	9.24	Heavy rain
6	19.3	5.62	61.1	8.83	9.23	
7	19.1	5.64	61.2	8.8	9.2	Stopped raining
8	19	5.44	58.9	8.74	9.29	Very calm

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
9	0.3	0.28	210
11	0.6	1.71	166
13	0.3	1.04	165
15	0	0.73	178
17	0	0.24	153
19	0	0.39	150
21	0.2	0	156
23	0	0.91	158
1	0	0.24	159
3	0	0.56	157
5	0	0.31	149
7	0.4	0.41	190

C. Kaituna Lagoon

Date 23/01/11

Time (hr)	Temp (°C)	DO (mg/L)	DOsat (%)	pH	Cond (mS/cm)	Weather Conditions
8	15.5	10.9	109.8	8.72	10.15	RAIN
9	15.8	10.18	103	8.74	10.14	Rain cleared
10	17.9	10.82	114.1	8.86	10.13	Sunny & calm
11	18.8	12.55	135.1	8.98	10.14	
12	19.1	13.27	143.8	9.09	10.15	Still, warm, o/c
13	18.1	15.99	170.3	9.16	10.18	Rain starting
14	18.2	16.13	172.2	9.23	10.1	Wind, no rain
15	18.2	16.53	176.5	9.28	10.16	Wind change
16	18.1	16.49	175.8	9.33	10.11	O/c, light wind
17	18.5	18.47	198.4	9.37	10.12	
18	18.8	20.27	219.4	9.49	10.07	Slight wind, o/c
19	18.3	16.68	178.9	9.47	10.08	
20	18.2	14.89	159.4	9.5	10.06	

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
10	1.8	0.74	53
15.3	1.3	0.66	38

Date 01/02/11

Time (hr)	Temp (^oC)	DO (mg/L)	DOsat (%)	pH	Cond(mS/cm)	Weather Conditions
8	16.5	7.26	76.1	9.24	10.85	Warm, still, sunny
9	16.9	8.36	86.2	9.32	10.8	
10	17.1	9.05	94.3	9.37	10.88	Slight breeze
11	18.4	10.76	115.3	9.46	10.87	lt wind, warm, sun
12	20.4	13.87	154.3	9.59	10.83	
13	21.2	16.55	187.4	9.69	10.77	Wind Increasing
14	21.2	15.88	181	9.76	10.82	Wind stronger
15	22.6	16.28	190.7	9.69	10.96	
16	23.4	17.85	212.9	9.74	10.94	Wind dying, warm
17	23.1	17.86	212.2	9.90	10.93	Calm, slt rain
18	22.1	17.39	202.7	10	10.96	Wind change
19	21.8	18.08	209	10.08	10.95	
20	21.2	17.24	197.1	10.06	11	

Time (hr)	NO3-N (mg/L)	PO4 (mg/L)	Turbidity (FAU)
10	0.9	1.78	15
15.3	1.2	0.2	16

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