# Port of Weipa Ambient Marine Water Quality Monitoring Program

# (January 2018 – July 2018)

**Nathan Waltham, Christina Buelow, James Whinney, Rachael Macdonald**

**Report No. 18/20**

**November 2018**

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A Report for North Queensland Bulk Ports Corporation

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# SUMMARY POINTS


**Background**

1. North Queensland Bulk Ports has implemented an ambient marine water quality monitoring program surrounding the Port of Weipa. The objectives of the program are to establish a long term water quality dataset to characterise marine water quality conditions within the waters around this port operation, necessary in order to support future planned activities.
2. This program has incorporated a combination of spot field measurements and high frequency continuous data loggers, laboratory analysis for a range of nutrient, herbicides and heavy metals.

**Climatic conditions**

1. The total 2017/18 wet season rainfall across the study was within the 50$^{th}$ percentile of the distribution of total annual wet season rainfall recorded in the region (1914 to 2018). The total rainfall was 1,567 mm, with 38 % recorded during January 2018.
2. The daily average wind speed and direction recorded at Weipa airport for the reporting period was predominantly from the east and south east (>50% of reporting days), and these south-easterly winds were relatively strong (>24 km/hr) in comparison to wind speeds in other directions (typically <18 km/hr).

**Water chemistry**

1. Field water quality conditions were measured at all sites for water temperature, electrical conductivity, pH, dissolved oxygen, and secchi disk depth on a 6wkly basis, for three depth horizons (surface (0.2m), mid water and bottom).
2. Water column was well mixed during each survey, with little differences among the three horizons examined. Secchi disk to depth ratio (Zeu:Z) ranged between 20 and 70% of the water column at sites, suggesting that optical water clarity on survey days were generally average to fair.
3. Turbidity was generally low at the water surface horizon, and increased with water depth. This pattern is probably related to the bottom horizon being proximal to the sea floor, and the effects of remobilised sediments. The elevated turbidity in the bottom horizon becomes an important consideration when examining sensitive receptor habitats, such as seagrass that are sensitive to water clarity changes. Measuring bottom horizon turbidity is a very relevant component of this program; surface measurements for turbidity, or indeed suspended solid concentrations, might not be an entirely relevant measure when the objective is to protect and enhance benthic habitats.
4. Particulate nutrient concentrations exceed relevant guidelines. Chlorophyll-*a* concentrations were also regularly elevated above the guideline, likely in response to elevated available nutrient concentrations.
5. Ultra-trace heavy metals are non-detectable for sites, the same is true for water pesticides and herbicides
6. An assessment of the plankton community (both phytoplankton and zooplankton) was completed during this reporting period. There was a clear separation in the plankton community between surveys – the limited data so far prevents any further detailed assessment at this stage.
7. It is important to note that while multiple surveys have been completed throughout the initial reporting period (January 2018-July 2018), a lack of data spanning an entire year precludes any detailed assessment and conclusions regarding seasonal variability in water quality conditions. However, as the program continues a comprehensive understanding will be developed.

**Sediment deposition and turbidity**

1. Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in North Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment, and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week.
2. An important finding here was that deposition data indicated larger deposits compared to other north Queensland coastal marine sites investigated during this period.

**Photosynthetically active radiation (PAR)**

1. Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids.
2. Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter. Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites and sites of closer proximity to one another were more similar than distant sites.
3. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations, the relationship between these two parameters is not always strong. At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats. For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.

**Recommendations**

1. The program commenced in January 2018. As more data becomes available, a more detailed assessment of water quality conditions will be possible, to assist in characterising water quality conditions in and surrounding the Port of Weipa. There are no recommendations to yet change the current sampling regime at the Port of Weipa.

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# 1 INTRODUCTION

## 1.1 Port operations

The Port of Weipa is situated on the western side of Cape York Peninsula in northern Queensland (Figure 1.1). It is located within the township of Weipa, where the Embley, Mission and Pine River's converge and discharge into the Gulf of Carpentaria. The port has a series of operational and associated loading/unloading facilities. The port is operated by North Queensland Bulk Ports Corporation (NQBP). Along with other NQBP ports in Queensland, Port of Weipa requires routine maintenance dredging to maintain declared navigational depths within the swing basin and berth areas, departure path and aprons. Any dredging activity necessary in the operating ports in the region are undertaken in accordance with Commonwealth and State approvals.

## 1.2 Program outline

In order to better define the potential impacts associated with port operations and to characterise the natural variability in key water quality parameters within the adjacent sensitive habitats, NQBP committed to an ambient marine water quality monitoring program in and around the coastal waters of Weipa (Figure 1.1; Table 1.1). As part of this program, water quality parameters are being investigated at a range of sites to build on 19 years of seagrass monitoring and three years of monitoring of photosynthetically active radiation (PAR) that has already been undertaken by NQBP. This monitoring program contains a range of ambient water quality components that collectively continue to characterise the natural variability in key water quality parameters, including those experienced at the nearest sensitive receiving habitat, predominately seagrass (Taylor et al., 2015).

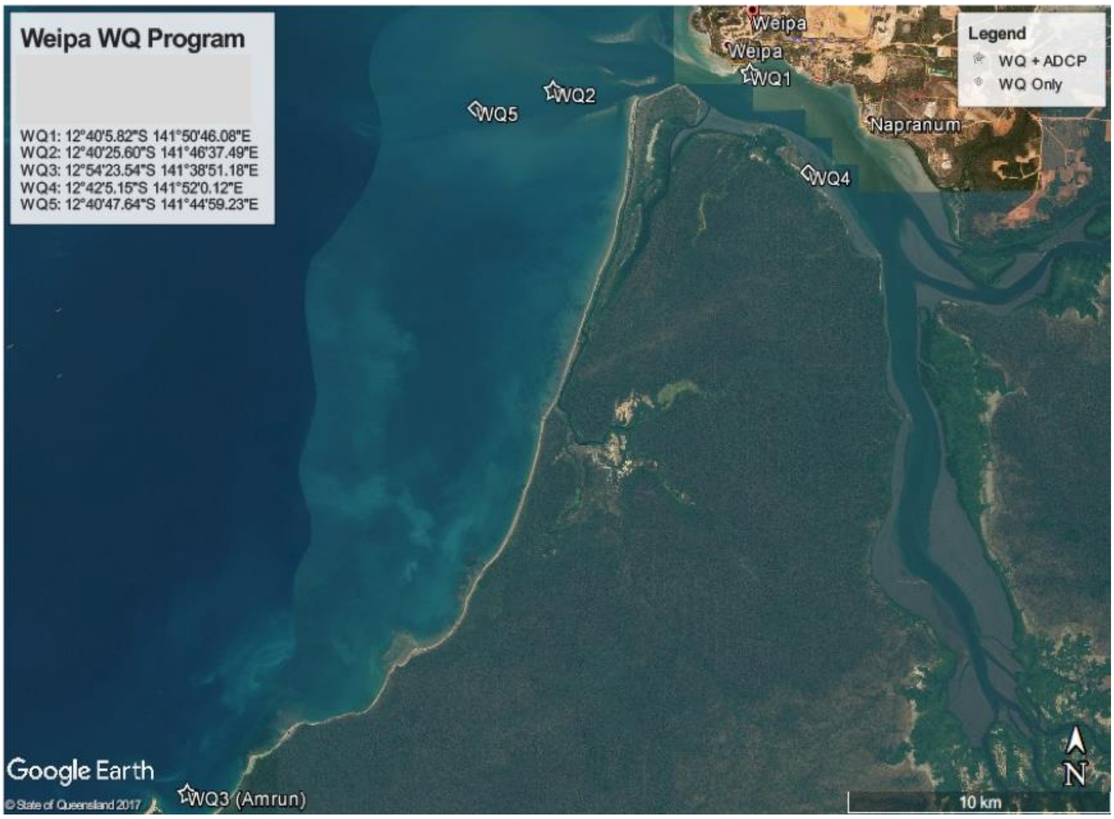



**Figure 1.1** Locations of the marine water quality monitoring program sites during 2017/18 program

**Table 1.1** Locations of the ambient marine water quality monitoring program sites

| Location | AMB site no. | Lat. | Long. | Water quality | Deposition /PAR logger |
|---|---|---|---|---|---|
| **WQ1** | 1 | 12° 40' 16.5" | 141° 50' 42.0" | Yes | Yes |
| **WQ2** | 2 | 12° 40' 25.7" | 141° 46' 36.1" | Yes | Yes |
| **WQ3A** | 3A | 12° 54' 22.7" | 141° 38' 50.1" | Yes | Yes |
| **WQ3** | 3 | 12°56.943' | 141° 35.901' | Yes | Yes |
| **WQ4** | 4 | 12° 41' 32.5" | 141° 52' 12.3" | Yes | Yes |
| **WQ5** | 5 | 12° 40' 47.5" | 141° 44' 58.2" | Yes | Yes |

## 1.3 Rainfall and river flows

The total wet season rainfall (1567mm) during the reporting period was just below the long term average (Figure 1.2). Most of this total rainfall (35%) occurring in January 2018, though March 2018 also had high rainfall (482mm; 30%) associated with a tropical cyclone that cross through the region (Cyclone Nora). The influence of rainfall and therefore catchment flow can clearly change from year to year, which highlights precisely the reason for long term commitment to ambient marine monitoring programs.

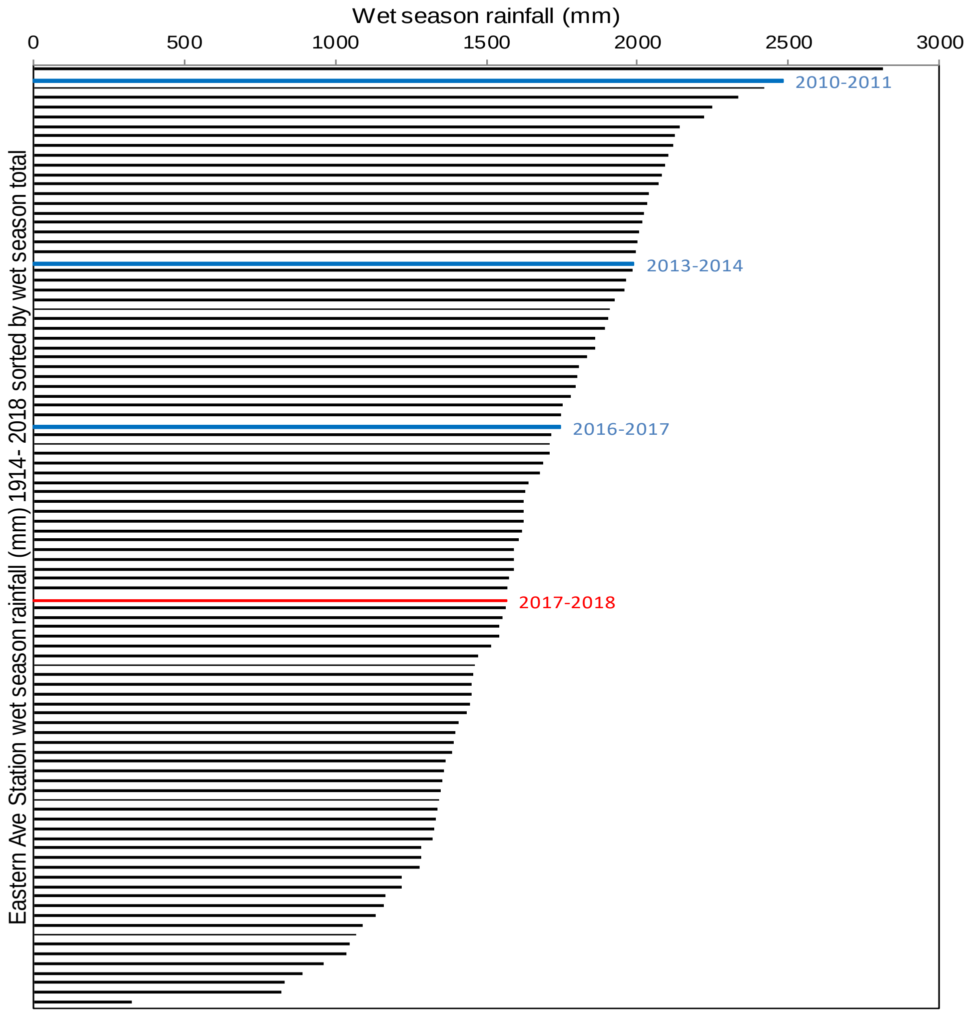


**Figure 1.2** BOM wet season (Nov – March) rainfall data for Eastern Av Station (Weipa, station number 27042) ranked in order of decreasing total rainfall (mm). Blue bars show total rainfall over the past few years, and the red bar represents the 2017/18 ambient marine water quality monitoring period

The only local river gauging station near to Weipa is on the Watson River, which is located ~75 km south and does not discharge into the Mission River system where the Port is located. Therefore, although Watson River water flow (Megalitres/day) has been used throughout this report to provide context for Port water quality conditions, results regarding the influence of water discharge on water quality variability should be interpreted with caution.

The hydrograph for Watson River (Figure 1.3) shows a distinct rise and fall in the hydrograph in early February 2018, following monsoonal rainfall patterns typical for this region. Weipa is located in tropical environment where wet season rainfall can result in prolonged and elevated river discharge during November to March. A peak in water discharge can also be seen in late March 2018, corresponding with Cyclone Nora (Figure 1.4).

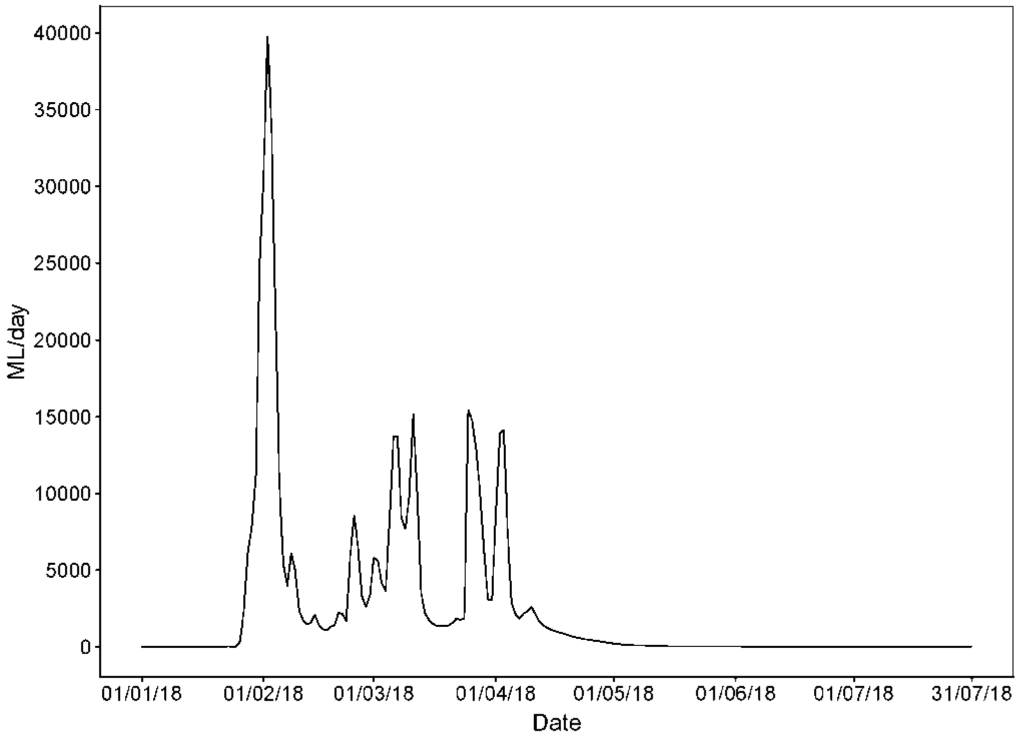



**Figure 1.3** Flow (Megalitres/day) recorded for Watson River during January 2018 – July 2018

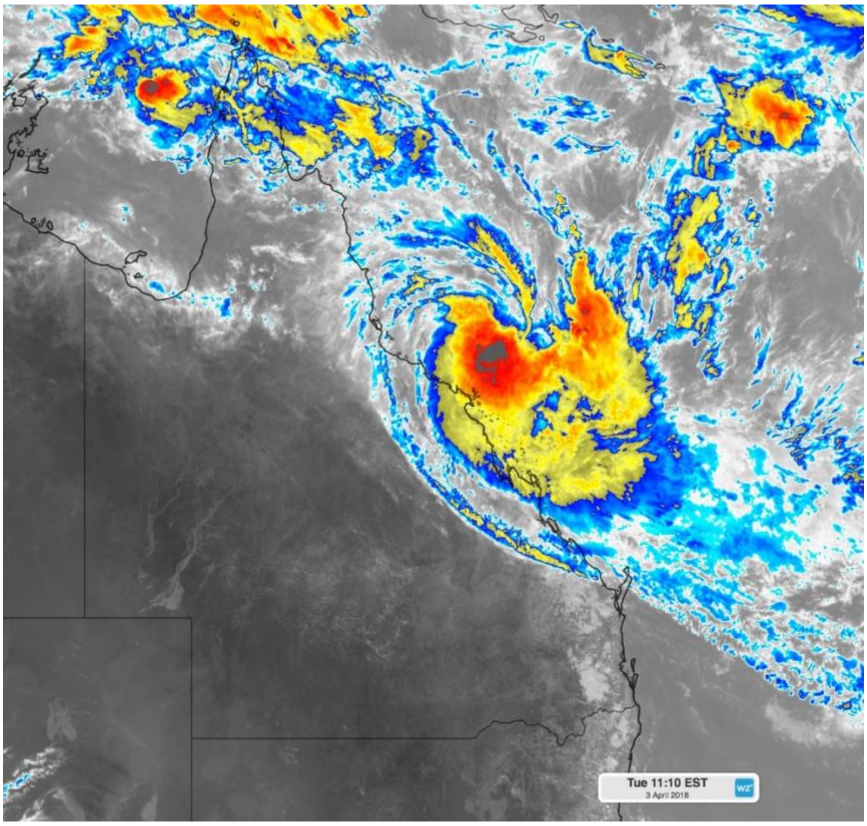



**Figure 1.4** Cyclone Nora crossing the Weipa region (March 2018)

## 1.4 Wind

The daily average wind direction recorded at Weipa airport for the reporting period was predominantly from the south east and east (more than 50% of reporting days) and reached speeds > 24km/hr (Figure 1.5).

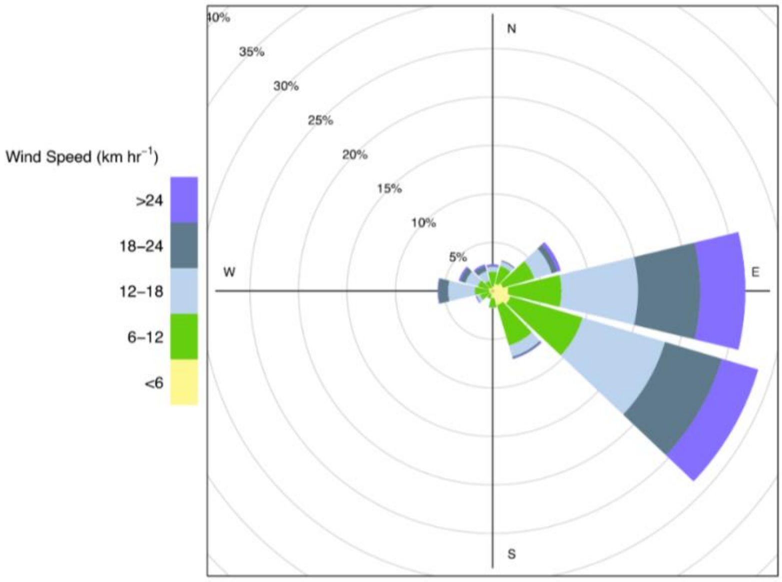



**Figure 1.5** Daily average wind direction and strength recorded at the Weipa Airport throughout January 2018 to July 2018

## 1.5 Project objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region within and adjacent to Port of Weipa. This report provides a review and analysis of data collected between January and July 2018. These data are part of a longer term commitment to monitor and characterise receiving water quality conditions, to support future planned asset management and protection of this coastal port.

# 2 METHODOLOGY

## 2.1 Ambient water quality

Spot water quality samples were collected at sites approximately on a 6wk basis (Table 2.1) from a research vessel. At each site, a calibrated multiprobe is used to measure water temperature, salinity, dissolved oxygen (%), pH, and turbidity (Figure 2.1). In addition to spot measurements, secchi disk depth is recorded, as a measure of the optical clarity of the water column, along with light attenuation using a LiCor meter. These field *in-situ* measurements are recorded at three depth horizons: a) surface (0.25m); b) mid-depth; and c) bottom horizon.

In aligning with the ambient marine water quality monitoring in other NQBP ports (Ports of Mackay and Hay Point, and Port of Abbott Point) the water quality program design below was completed. The list of parameters examined consisted:

- Ultra-trace dissolved metals : arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn);
- Nutrients (particulate nitrogen and phosphorus);
- Chlorophyll-*a*; and
- Pesticides/herbicides (Low LOR suite (EP234(A-I)) including: diuron, ametryn, atrazine, terbutryn. Note that pesticides are suspected to be in low concentrations during periods of low rainfall runoff, and only detectable following rainfall. As a consequence sampling of only two events at all sites for pesticides, one during the dry and a wet season – though note that the timing of each are dependent on prevailing weather conditions, so the timing of each survey could differ from year to year.

**Figure 2.1** TropWATER staff conducting field water quality sampling

**Table 2.1** Summary of instrument maintenance and water quality surveys completed during the 2017/18 reporting period

| Date | Nutrients, Chloro | Metals, herbicides | Plankton | Logger maintenance |
|---|---|---|---|---|
| **January 2018** | Yes | - | Yes-Zooplankton only | Yes |
| **March 2018** | Yes | - | Yes | Yes |
| **April 2018** | Yes | Yes | Yes –Phytoplankton only | Yes |
| **June 2018** | Yes | - | - | Yes |
| **July 2018** | Yes | - | - | Yes |

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e., DERM 2009b; APHA 2005; Standards Australia 1998). Field collected water samples were stored on ice in eskies immediately during field trips aboard the vessel, and transported back to refrigeration, before delivery to the TropWATER laboratory. For chlorophyll analysis, water was placed into a 1L dark plastic bottle and placed on ice for transportation back to refrigeration. For dissolved metals and nutrients, water was passed through a 0.45 µm disposable membrane filter (Sartorius), fitted to a sterile 60 mL syringe (Livingstone), and placed into 60 mL bottles (metals) and 10 mL bottles (nutrients) for posterior analysis in the laboratory. (The use of these field sampling equipment and procedures have been previously shown to reduce the risk of contamination of samples, contributing to false positive results for reporting; TropWATER, 2015). Unfiltered sample for total nitrogen and total phosphorus analysis were frozen in a 60 mL tube. All samples are kept in the dark and cold until processing in the laboratory, except nutrients which are stored frozen until processing.

Water for chlorophyll determination was filtered through a Whatman 0.45 µm GF/F glass-fibre filter with the addition of approximately 0.2 mL of magnesium carbonate within (less than) 12 hours after collection. Filters are then wrapped in aluminium foil and frozen. Pigment determinations from acetone extracts of the filters were completed using spectrophotometry, method described in 'Standard Methods for the Examination of Water and Wastewater, 10200 H. Chlorophyll'.

Water samples are analysed using the defined analysis methods and detection limits outlined in Table 2.2. In summary, all nutrients were analysed using colorimetric method on OI Analytical Flow IV Segmented Flow Analysers. Total nitrogen and phosphorus and total filterable nitrogen and phosphorus are analysed simultaneously using nitrogen and phosphorous methods after alkaline persulphate digestion, following methods as presented in 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method' and in 'Standard Methods for the Examination of Water and Wastewater, 4500-P F. Automated Ascorbic Acid Reduction Method'. Nitrate, Nitrite and Ammonia were analysed using the methods 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method', 'Standard Methods for the Examination of Water and Wastewater, 4500-NO2- B. Colorimetric Method', and 'Standard Methods for the Examination of Water and Wastewater, 4500-NH3 G. Automated Phenate Method', respectively. Filterable Reactive Phosphorous is analysed following the method presented in 'Standard Methods for the Examination of Water and Wastewater, 4500-P F. Automated Ascorbic Acid Reduction Method'. Filterable heavy metals, and herbicides are analysed by Australian Laboratory Service (ALS).

For all water quality plots, boxes are $20^{th}$ and $80^{th}$ quantile, centre line is median, and whiskers represent the $5^{th}$ and $95^{th}$ percentile.

**Table 2.2** Water analyses performed during the program

| Parameter | APHA method number | Reporting limit |
|---|---|---|
| **Routine water quality analyses** | | |
| pH | 4500-$H^+$ B | - |
| Conductivity (EC) | 2510 B | 5 µS/cm |
| Total Suspended Solids (TSS) | 2540 D @ 103 - 105°C | 0.2 mg/L |
| Turbidity | 2130 B | 0.1 NTU |
| Salinity | | |
| Dissolved Oxygen | | |
| Light Attenuation | | |
| **Pesticides/herbicides** | | |
| *Organophosphate pesticides* | In house LC/MS method: EP234A | 0.0002-0.001 µg/L |
| *Thiocarbamates and Carbamates* Thiobencarb | In house LC/MS method: EP234B | 0.0002 µg/L |
| *Dinitroanilines* Pendimethalin | In house LC/MS method: EP234C | 0.001 µg/L |
| *Triazinone Herbicides* Hexazinone | In house LC/MS method: EP234D | 0.0002 µg/L |
| *Conazole and Aminopyrimidine Fungicides* Propiconazole, Hexaconazole, Difenoconazole, Flusilazole, Penconazole | In house LC/MS method: EP234E | 0.0002 µg/L |
| *Phenylurea Thizdiazolurea Uracil and Sulfonylurea Herbicides* Diuron, Ametryn, Atrazine, Cyanazine, Prometryn, Propazine, Simazine, Terbuthylazine, Terbutryn | In house LC/MS method: EP234F | 0.0002 µg/L |
| **Nutrients** | | |
| Total Nitrogen and Phosphorus (TN/TP) | Simultaneous 4500-$NO_3^-$ F and 4500-P F analyses after alkaline persulphate digestion | 25 µg N/L<br>5 µg P/L |
| Filterable nutrients (nitrate, nitrite, ammonia, Nox) | 4500-$NO_3^-$ F | 1 µg N/L |
| Ammonia | 4500- $NH_3$ G | 1 mg N/L |
| Filterable Reactive Phosphorus (FRP) | 4500-P F | 1 µg P/L |
| Chlorophyll | 10200-H | 0.1 µg/L |
| **Trace Metals** | | |
| Arsenic, Cadmium, Copper, Lead, Nickel, Silver, Zinc, Mercury | 3125B ORC/ICP/MS | 0.05 to 100 µg/L |

## 2.2 Plankton community

At all sites, a 60µm plankton net (for phytoplankton) and a 500µm plankton net (for zooplankton) was towed behind the survey vessel for approximately 100m. The boat speed is reduced to approximately 6kts, with a GPS point taken at the start and end of each plankton tow. At the end of each plankton tow, the nets are retrieved, and the contents retained in the plastic jar attached to the net was immediately transferred to preservation containers. Samples were identified to the lowest possible taxon.

a) b) c)

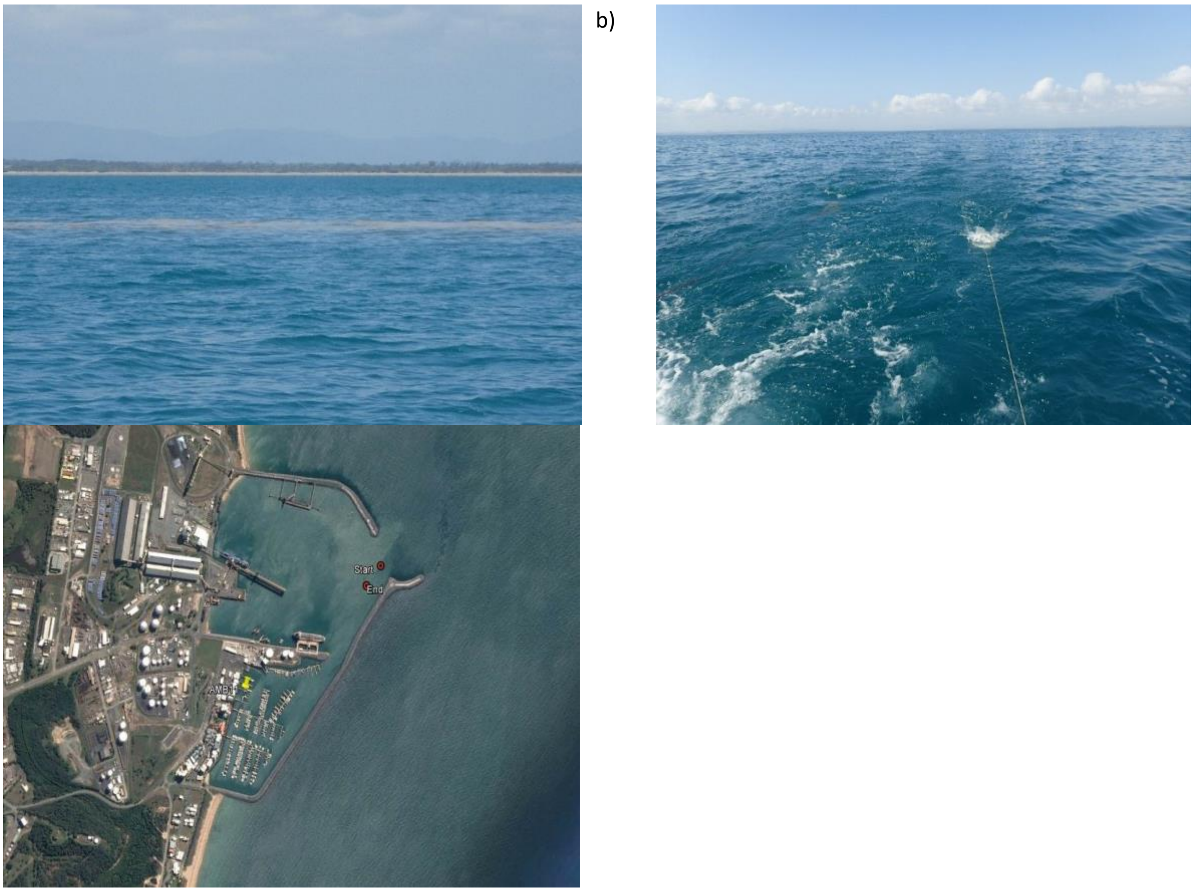



**Figure 2.2** Example plankton sample during November 2015 survey. a) Trichodesmium bloom on sea surface; b) phytoplankton (60µm) tow behind the survey vessel; and c) AMB 11 (Mackay Harbour) yellow dot ambient marine water quality site, black dots start and end of plankton tow

## 2.3 Multiparameter water quality logger

Sediment deposition, turbidity, Photosynthetically Available Radiation (PAR), water depth, Root Mean Squared (RMS) water depth and water temperature were measured at seven sites using multiparameter water quality instruments manufactured at the Marine Geophysics Laboratory, School of Engineering and Physical Sciences, James Cook University (Figure 2.3). These instruments are based on a Campbell's Scientific 1000 data logger that has been programmed to measure and store these marine physical parameters using specifically designed sensors.

### 2.3.1 Turbidity

The turbidity sensor provides data in Nephelometric Turbidity Unit's equivalent (NTUe) and can be calibrated to Suspended Sediment Concentration (SSC) in mg/L (Larcombe et al., 1995). The sensor is located on the side of the logger, pointing parallel light-emitting diodes (LED) and transmitted through a fibre optic bundle. The backscatter probe takes 250 samples in an eight second period to attain an accurate turbidity value. The logger is programmed to take these measurements at 10 minute intervals. The sensor interface is cleaned by a mechanical wiper at a two hour interval allowing for long deployment periods where bio-fouling would otherwise seriously affect readings.

It must be noted the international turbidity standard ISO7027 defines NTU only for 90 degree scatter, however, the Marine Geophysics Laboratory instruments obtain an NTUe value using 180 degree backscatter as it allows for much more effective cleaning. Because particle size influences the angular scattering functions of incident light (Ludwig and Hanes 1990; Conner and De Visser 1992; Wolanski et al., 1994; Bunt et al., 1999), instruments using different scattering angles can provide different measurements of turbidity (in NTU). This has to be acknowledged if later comparison between instruments collecting NTUe and NTU are to be made. To enhance the data, all sites were calibrated to provide a measure of SSC (mg/L) and enable for the accurate comparison between 90 degree backscatter and 180 degree backscatter measurements.

### 2.3.2 Sediment deposition

Deposition is recorded in Accumulated Suspended Sediment Deposition (ASSD) (mg/cm2). The sensor is wiped clean of deposited sediment at a 2 hour interval to reduce bio-fouling and enable sensor sensitivity to remain high. The deposition sensor is positioned inside a small cup shape (16mm diameter x 18mm deep) located on the flat plate surface of the instrument facing towards the water surface. Deposited sediment produces a backscatter of light that is detected by the sensor. Deposited sediment is calculated by subtracting, from the measured data point, the value taken after the sensor was last wiped clean. This removes influence of turbidity from the value and re-zeros the deposition sensor every 2 hours.

If a major deposition event is in progress, the sensor reading will increase rapidly and will be considerably above the turbidity sensor response. Gross deposition will appear as irregular spikes in the data where the sediment is not removed by the wiper but by re-suspension due to wave or current stress. When a major net deposition event is in progress the deposited sediment will be removed by the wiper and the deposition sensor reading should fall back to a value similar to the turbidity sensor. The data will have a characteristic zigzag response as it rises, perhaps quite gently, and falls dramatically after the wipe (see Ridd et al., 2001).

Deposition data is provided as a measurement of deposited sediment in mg/cm$^2$ and as a deposition rate in mg/cm$^2$/day. The deposition rate is calculated over the 2 hour interval between sensor wipes and averaged over the day for a daily deposition rate. The deposition rate is useful in deposition analysis as it describes more accurately the net deposition of sediment by smoothing spikes resulting from gross deposition events.

### 2.3.3 Pressure

A pressure sensor is located on the horizontal surface of the water quality logging instrument. The pressure sensor is used to determine changes in water depth due to tide and to produce a proxy for wave action. Each time a pressure measurement is made the pressure sensor takes 10 measurements over a period of 10 seconds. From these 10 measurements, average water depth (m) and Root Mean Square (RMS) water height are calculated. RMS water height, Drms, is calculated as follows:

$$D_{rms} = \sqrt{\sum_{n=1}^{10} (D_n - \overline{D})^2 / n}$$

*Equation 1* : where Dn is the *n*th of the 10 readings and $\overline{D}$ is the mean water depth of the *n* readings.

The average water depth and RMS water depth can be used to analyse the influence that tide and water depth may have on turbidity, deposition and light levels at an instrument location. The RMS water height is a measure of short term variation in pressure at the sensor. Changes in pressure over a 10 second time period at the sensor are caused by wave energy. RMS water height can be used to analyse the link between wave re-suspension and SSC. It is important to clearly establish that RMS water height is not a measurement of wave height at the sea surface. What it does provide is a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. For example, two sites both have the same surface wave height, site one is 10m deep and has a measurement of 0.01 RMS water height and site two is 1m deep and has a measurement of 0.08 RMS water height. Even though the surface wave height is the same at both sites, the RMS water height is greater at the shallower site and we would expect more re-suspension due to wave shear stress at this site.

**2.3.4 Water temperature**

Water temperature values are obtained with a thermistor that records every 10 minutes. The sensor is installed in a bolt that protrudes from the instrument and gives sensitive temperature measurements.

a)

b)

**Figure 2.3** Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

**2.3.5 Photosynthetically Active Radiation (PAR)**

A PAR sensor, positioned on the horizontal surface of the water quality logging instrument, takes a PAR measurement at ten (10) minute intervals for a one second period. To determine total daily PAR (mol photons $m^2$/day) the values recorded are multiplied by 600 to provide of PAR for a 10 minute period and then summed for each day.

## 2.4 Marotte current meter

The Marotte HS (High Sampling Rate) is a drag-tilt current meter invented at the Marine Geophysics Laboratory (Figure 2.4). The instrument records current speed and direction with an inbuilt accelerometer and magnetometer. The current speed and direction data are smoothed over a 10-minute period. The instruments are deployed attached the nephelometer frames and data is download when the instruments are retrieved. Inclusion of this current meter has been added to the program as a way to trial new technology, gather new data and to value add to project outcomes and deliverables.

a)


b)

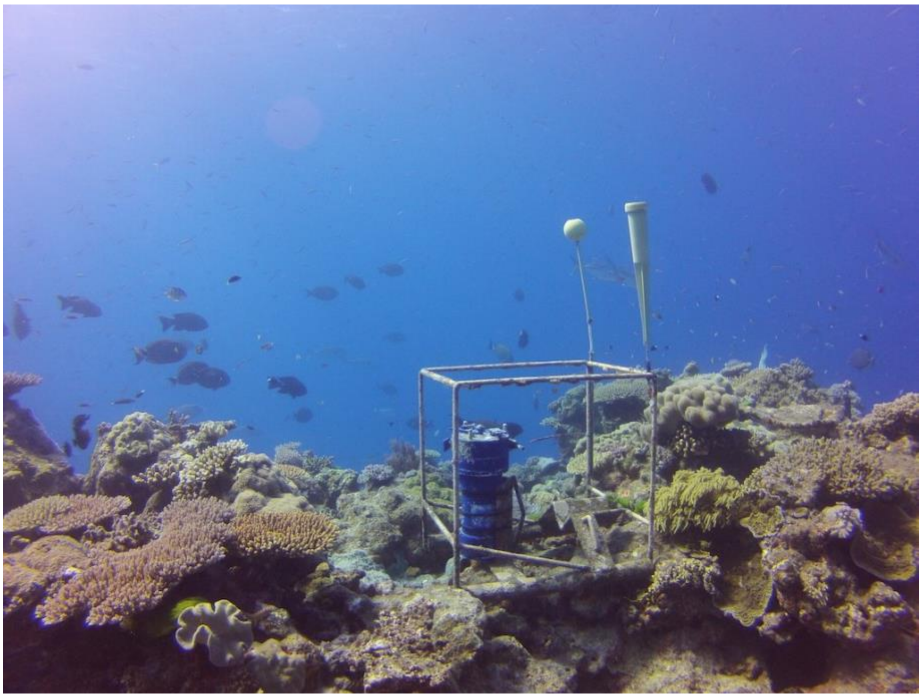


**Figure 2.4** a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte at Moore Reef. Image courtesy of Eric Fisher

### 2.4.1 Measuring environmental controls on SSC

Stepwise regression analysis was used to investigate the environmental controls on SSC at the ambient sites, with data selected including:

**(a) Ambient sites:**
[1] "WQ1" "[2] “WQ2"
[3] "WQ3" [4] "WQ4"
[5] "WQ5"

**(b) River Gauge Station:**
[1] "Watson River"

**(c) Wind Station:**
[1] "Station 027045 – Weipa airport"

**(d) Tide Gauge Station:**
[1] "Rocky River Gauge"

In this assessment, the environmental parameters with control on SSC were analysed by stepwise regression analysis followed by relative importance analysis (Grömping, 2006) using R language (R Core Team, 2015). The stepwise analysis allowed the selection of the environmental variables that explain the SSC variability in the water column. The relative importance analysis allowed these selected variables to be ranked based on their overall explanation of the SSC variability. In order to visualize the effect of each environmental parameter selected in the stepwise analysis, a partial plot analysis (Crawley, 2007) was carried out. These partial plots indicate the dependence between SSC and each selected variable when all the other variables in the model are kept constant (Crawley, 2007). The data set used in the stepwise analysis was log-transformed, if needed, in order to satisfy requirements for regression analysis. For each site, all the following variables were tested in an initial model against SSC: RMS of water depth, mean daily wind, maximum tide amplitude and the Pioneer and Sandy River discharges. These rivers were selected due to their proximity to the sampling sites. The Rocky River gauge station was ceased in November, 2014, so it was not include in the analysis. Mean daily wind was calculated from 8 daily readings decomposed into NE-SW and NW-SE components. Maximum tide amplitude was calculated as the maximum absolute difference between two consecutive maximum or minimum tide readings. Wind components were calculated as the mean value of 8 daily measurements decomposed to in two diagonals, NE-SW and NW-SE. Variables presenting autocorrelation were excluded based on a variance inflation test (Fox and Monett, 1992) > 4 and outliers were removed based on Bonferroni Outlier Test (Cook and Weisberg 1982).

# 3 RESULTS AND DISCUSSION

## 3.1 Ambient water quality

### 3.1.1 Spot water quality physio-chemical

For the reporting period between January and July 2018 water temperature ranged between 25 and 30°C (Figure 3.1). There seems to be a seasonal effect on water temperatures in the region, with the highest water temperatures observed during surveys in the summer months, and cool water temperatures observed during the winter months. These patterns are consistent throughout the water column, indicating that the water column profile is vertically well mixed. There are no guidelines for water temperature in coastal areas, however, temperature is an essential interpretative aid for ecological assessment in environments. For example, species such as fish and other animals have thermal stress point which causes discomfort and could be misconstrued as being a toxicological impact (example are the coral trout; Johansen et al. 2015). There were no observed or known impacts on aquatic species in the region during this monitoring period.

Electrical conductivity (EC) was stable across all sites, with little evidence of changing conditions through the water column (Figure 3.2). Overall EC has remained between 38 mS/cm and 49 mS/cm, generally indicating oceanic conditions. During the present reporting period, salinity (ppt) was recorded in the field. To correct for this, we generated a relationship between water sample measured EC during trips and field salinity records, and then back calculated for EC measurements in the field. While the relationship between laboratory EC and salinity was good, the corrected EC field data (shown in Figure 3.2) appears stable among sites and surveys. The data is presented here for completeness, but use of these data will require caution.

Dissolved oxygen saturation levels ranged between 85 to 110% (Figure 3.3). There was some local variability among sites, though this is really minor. These data represent only a few months of monitoring, and longer term records will further record underlying patterns and trends, should any exist in this region.

Field pH measurements were stable across sites and depths primarily ranging between 7.8 and 8.3 (Figure 3.4). Similar to DO%, these data represent only a few months of monitoring, and it is difficult to establish underlying patterns and trends at this early stage of the program.

Field turbidity measurements typically ranged between <1 to 130 NTU (Figure 3.5). Turbidity is similar among sites and relatively consistent throughout the water column (Figure 3.5b). Secchi disk depth (m) is a vertical measure of the optical clarity of water column and ranged between 1 and 5m (Figure 3.6a). The range measured is a response to localised variation in water quality, most likely a difference in tidal stage among sites during a survey – some sites may have been surveyed on an ebbing or flooding tide where water depth was lower or higher, short term localised changes in turbidity that is associated with tide (see section 3.2) or algal blooms that reduce vertical clarity. The secchi disk depth to depth ratio (Zeu:Z, Figure 3.6b) was calculated for each site and survey. This ratio corrects the secchi disk depth for water depth. This ratio ranged between 15 and 60% of the water column.

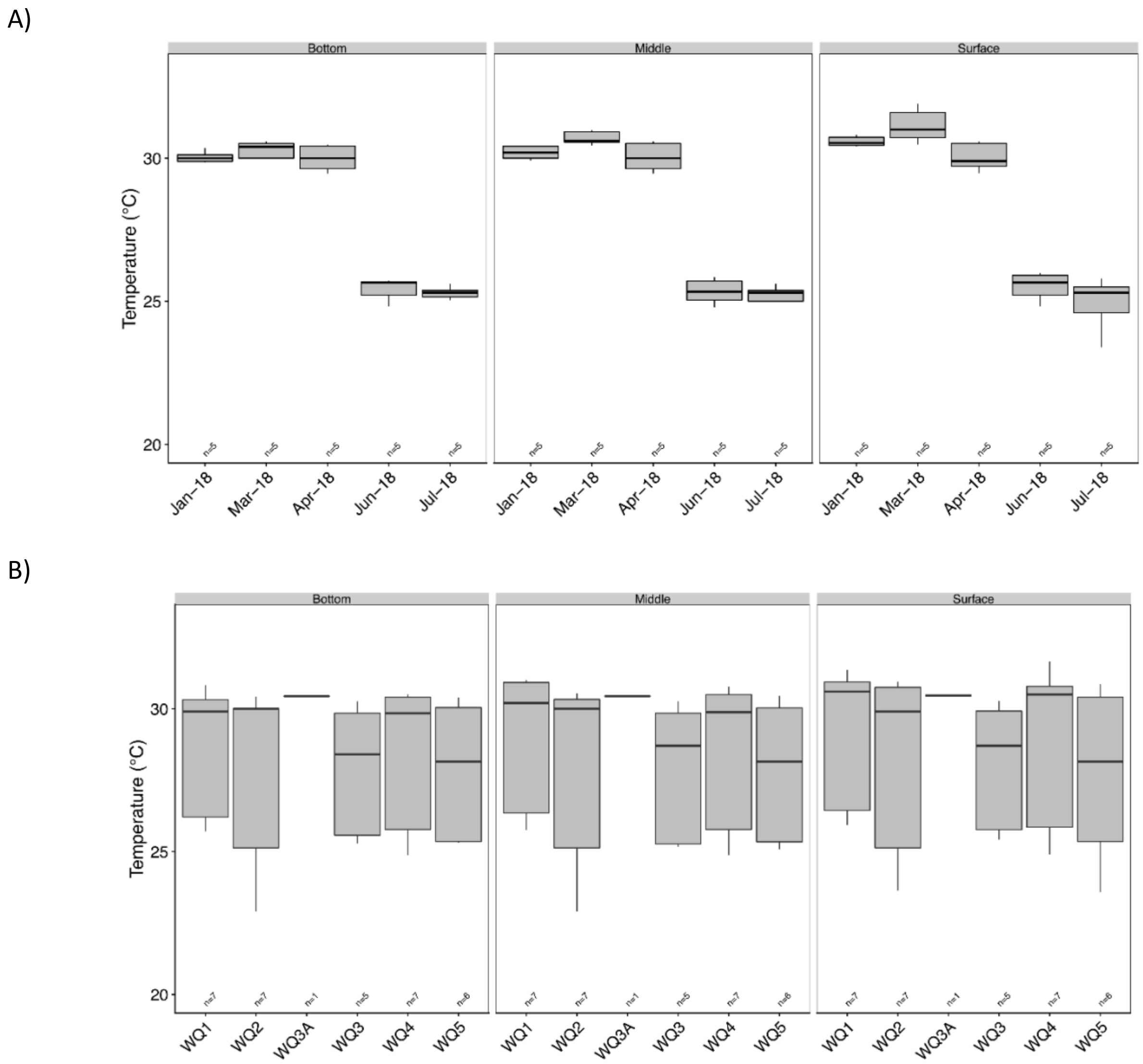
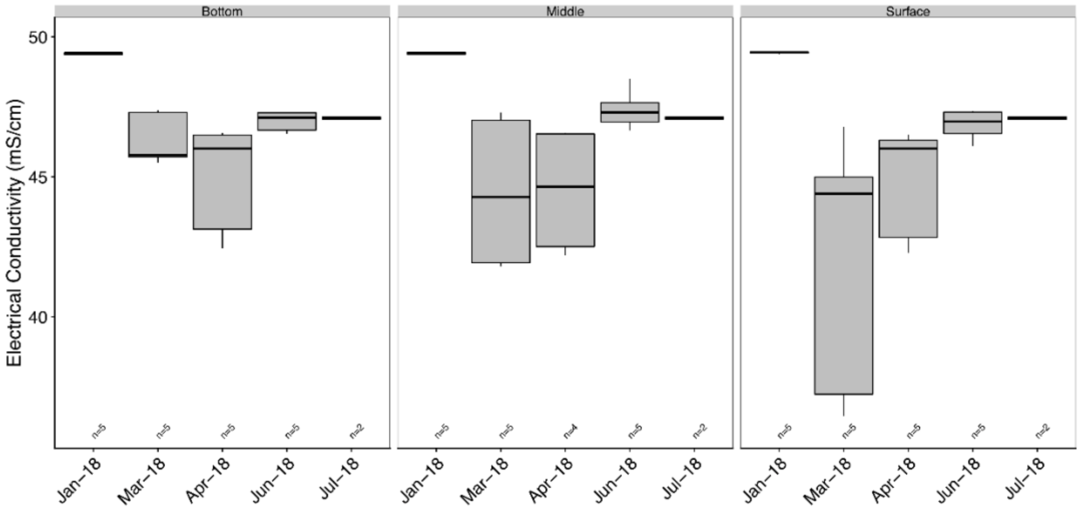



**Figure 3.1** Water temperature box plots recorded: (a) the three depth horizons during each survey (sites pooled) from January 2018 to July 2018 and (b) the three depth horizons for each site (pooled across all months)

A)




B)

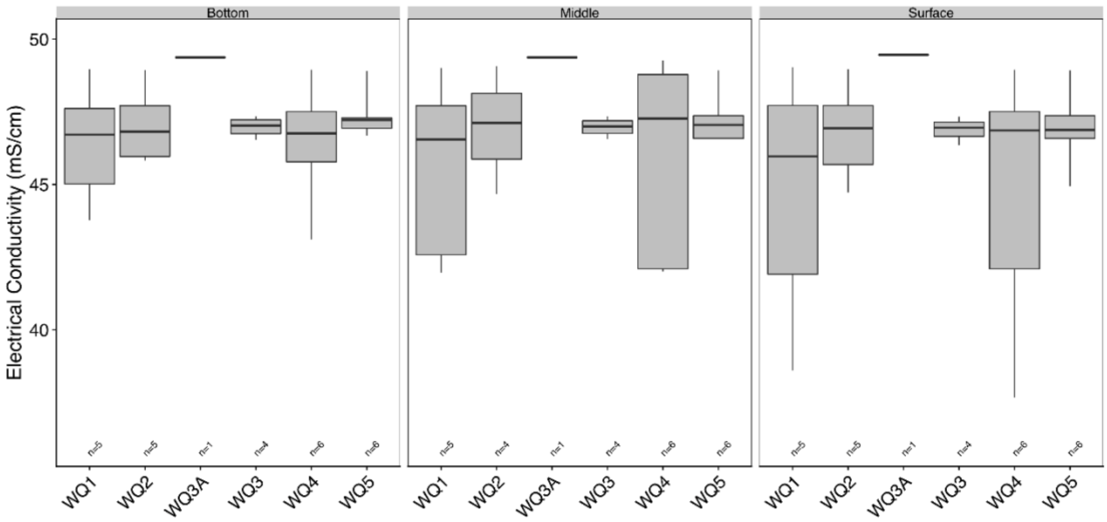
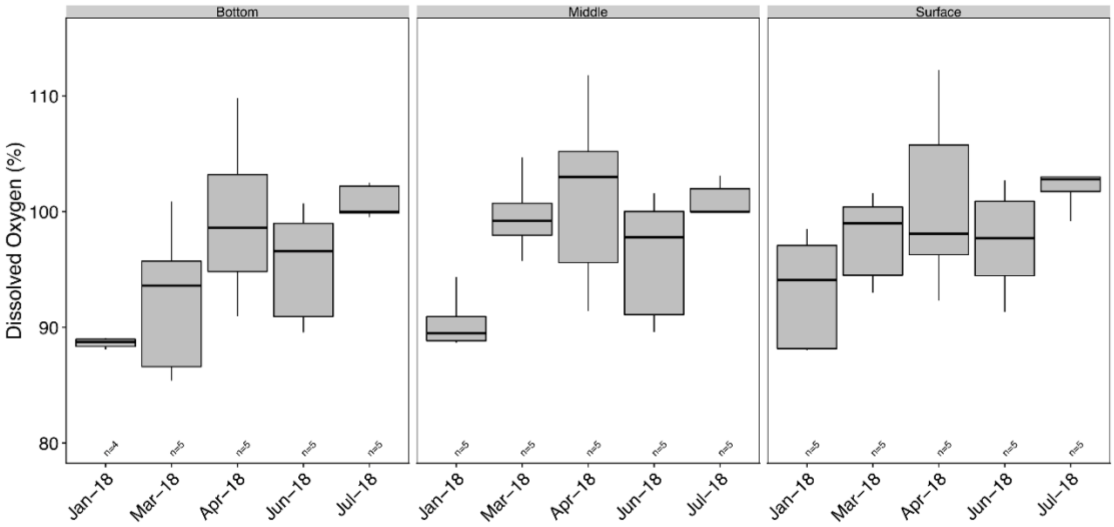



**Figure 3.2** Salinity box plots recorded: (a) the three depth horizons during each survey (sites pooled) from January 2018 to July 2018 and (b) the three depth horizons for each site (pooled across all months)

A)




B)

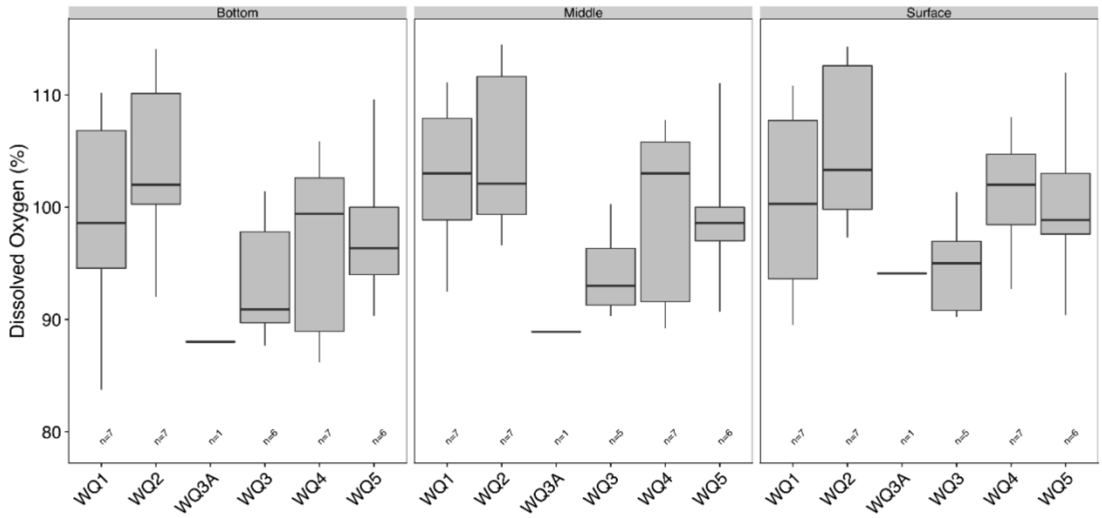



**Figure 3.3** Dissolved oxygen box plots recorded: (a) the three depth horizons during each survey (sites pooled) from January 2018 to July 2018 and (b) the three depth horizons for each site (pooled across all months)

A)

B)

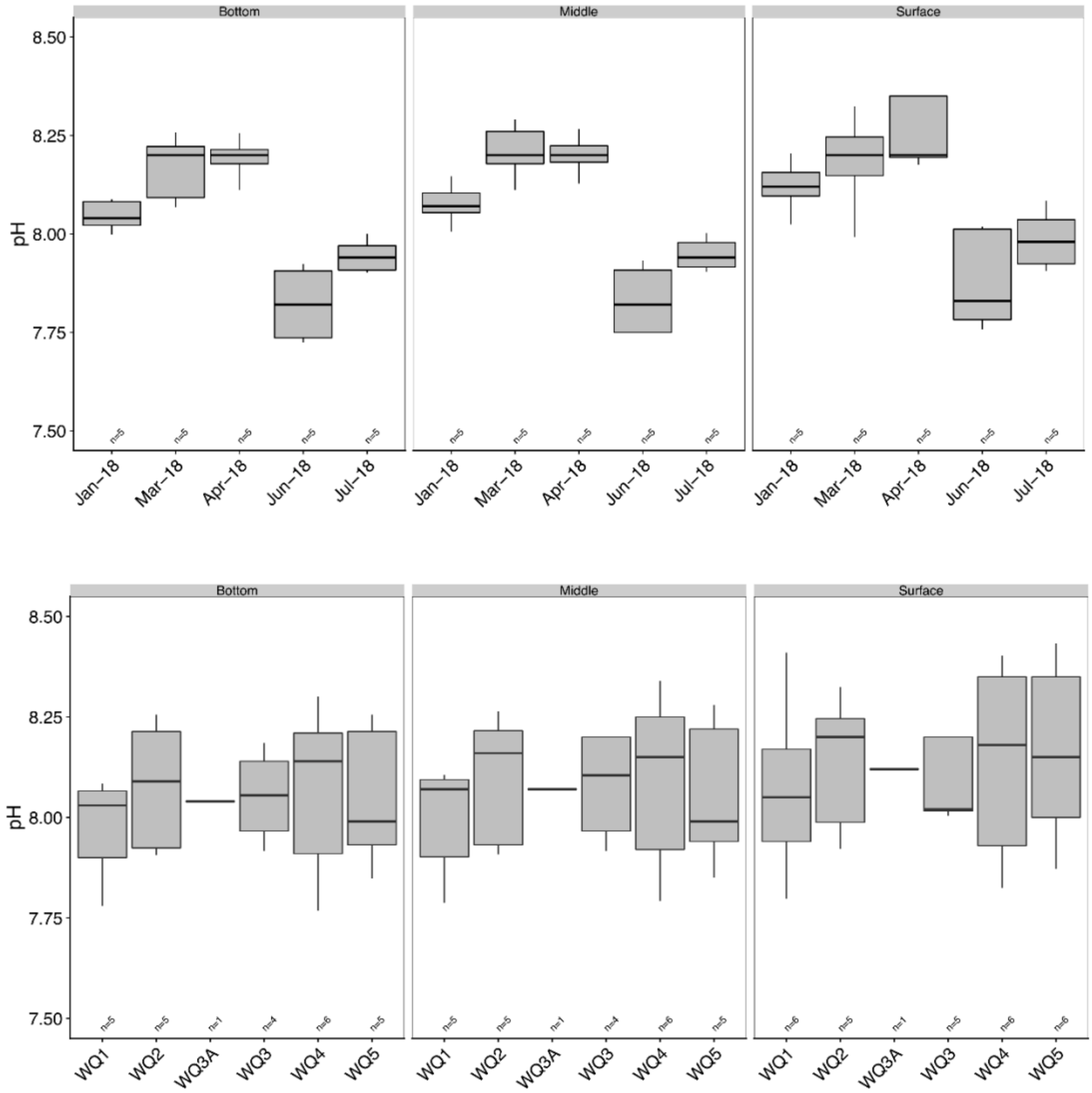



**Figure 3.4** pH box plots recorded: (a) three depth horizons during each survey (sites pooled) where colour indicates monitoring period: (a) the three depth horizons during each survey (sites pooled) from January 2018 to July 2018 and (b) the three depth horizons for each site (pooled across all months)

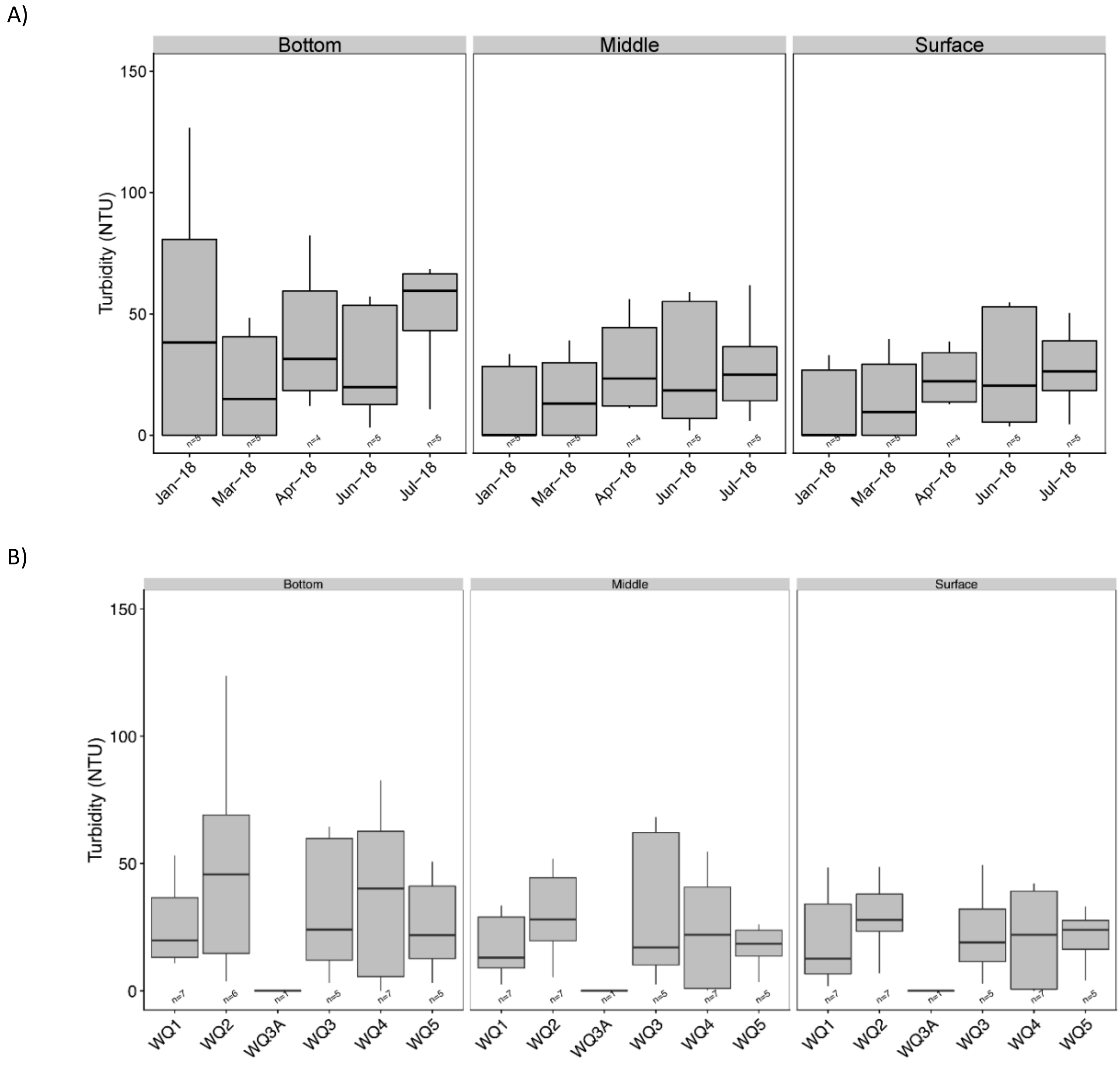
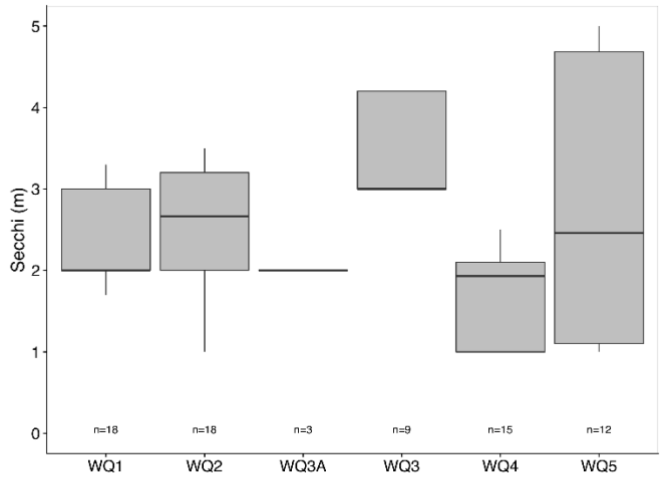



**Figure 3.5** Turbidity box plots recorded: (a) the three depth horizons during each survey (sites pooled) from January 2018 to July 2018 and (b) the three depth horizons for each site (pooled across all months)

A)




B)

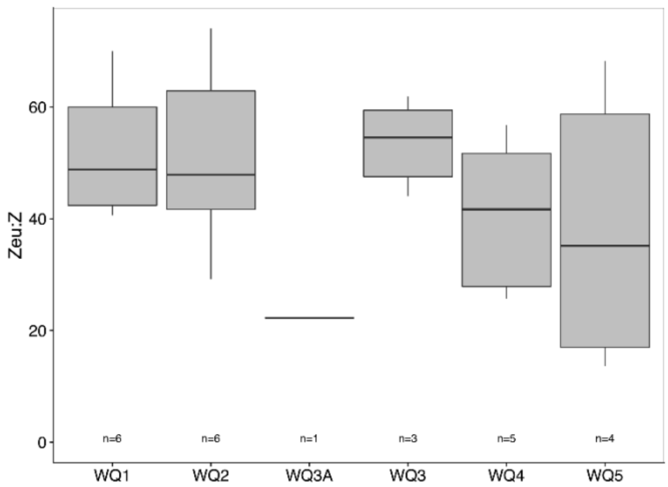



**Figure 3.6** (A) Water secchi disk depth for all sites (surveys pooled); and (b) light attention depth to depth ratio (Zeu:Z) for sites (surveys pooled)

### 3.1.2 Nutrients and chlorophyll-*a*

Particulate nitrogen (PN) and phosphorus (PP) concentrations were compared to the Water Quality Guidelines for the Great Barrier Marine Park Authority (GBRMPA, 2010) and the Queensland Water Quality Guidelines (DEHP, 2013). (Note that Weipa is not within the Great Barrier Reef World Heritage Area (GBRWHA), but GBRMPA guidelines are used to provide context when comparing to NQBP's other east-coast Ports that are located adjacent to the GBRWHA). Particulate nitrogen concentrations have exceeded the guideline (Figure 3.7a). Despite high concentrations during certain months, PN is generally similar across all sites, with concentrations exceeding guidelines, the exception is WQ 2 where the median is below the guideline (Figure 3.7b).

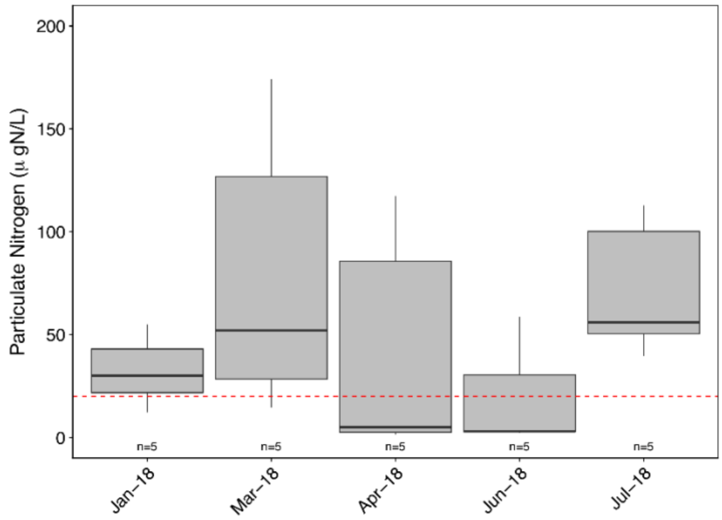
High concentrations of PN might be associated with a range of different factors, such as the contribution from local land use activities, whereby despite low rainfall, there would be still some base flow from rivers and local rainfall that is known to contribute to nutrient loadings to coastal regions along the east coast of Queensland (Brodie et al. 2012; Kroon et al. 2012; Schaffelke et al. 2012; Logan et al. 2014). It is also possible that township municipal waste treatment at Weipa could contribute to high PN concentrations, or that concentrations could be naturally high due to adjacent soil conditions. Other sources of nutrients might be via remobilisation of coastal sediments, and release of available nutrients adsorbed to coastal sediments (Devlin et al. 2012). Elevated nutrients might also be related to reprocessing of nutrients with algal blooms, where there has been an obvious trichodesmium (a marine cyanobacteria; Capone et al. 1997) bloom across the region during most surveys, but most notably during late spring and early summer. Although surveys thus far have recorded PN concentrations that exceed the GBRMPA guidelines, additional data from multiple years is required to make inferences regarding the natural variability in concentrations at the Port of Weipa. This will help to inform local guidelines that are specific to the Port of Weipa and encompass natural variability in water quality conditions.

Particulate phosphorus concentrations continue to be variable from survey to survey and site to site (Figure 3.8). Concentrations are generally above the guidelines, most notably at WQ 4 and WQ 5. Although particulate phosphorus concentrations are above GBRMPA guidelines, continued monitoring will determine baseline natural variability at Weipa and help to inform local guidelines.

Chlorophyll-*a* concentrations were elevated above the guidelines (Figure 3.9). It is not clear with the limited data whether these results reflect summer wet season conditions, in which case winter concentrations are lower, or whether these results reflect generally elevated conditions in this region because of local conditions.

Relationships between nutrient levels (i.e. PN, PP, Chlor-a, and Phaeophytin-a) across all sites and sampling periods were positive but weak (correlation coefficients (r) ranged between 0.17 – 0.65) the exception is PN and Phaeophytin-a which was not significant (Figure 3.10).

A)




B)

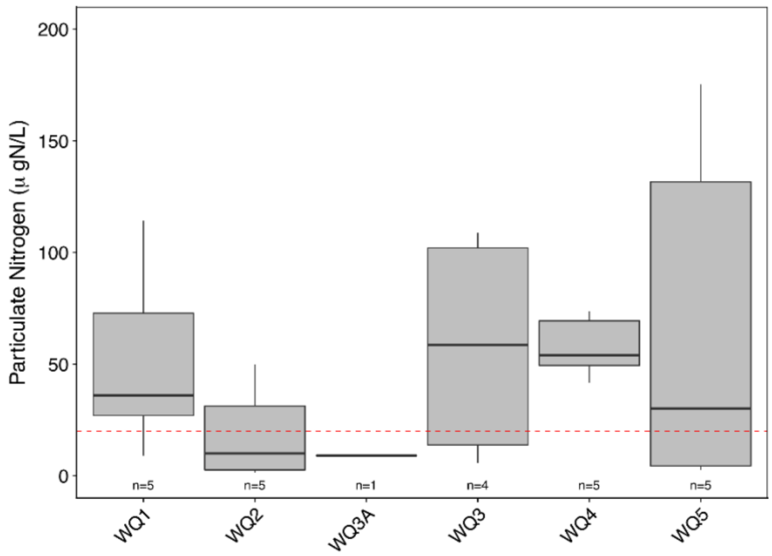
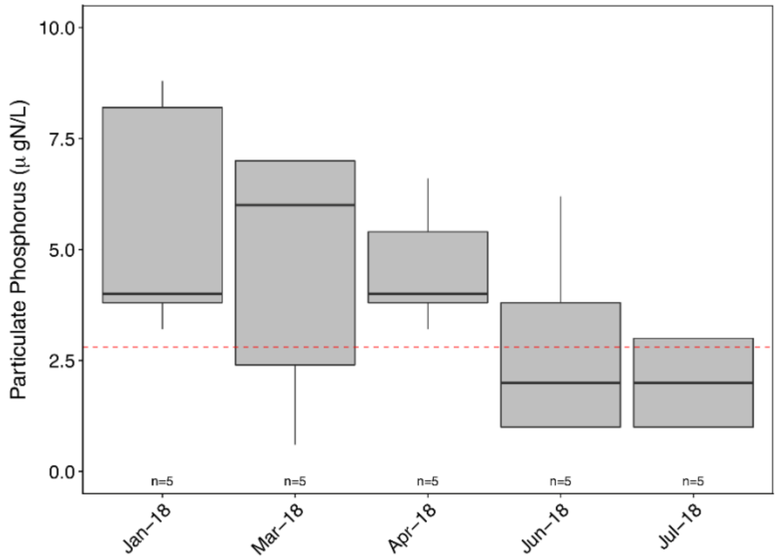



**Figure 3.7** Particulate nitrogen box plots: (a) during each survey (sites pooled) from January 2018 to July 2018 and (b) at each site over this same survey period (surveys pooled)

A)




B)

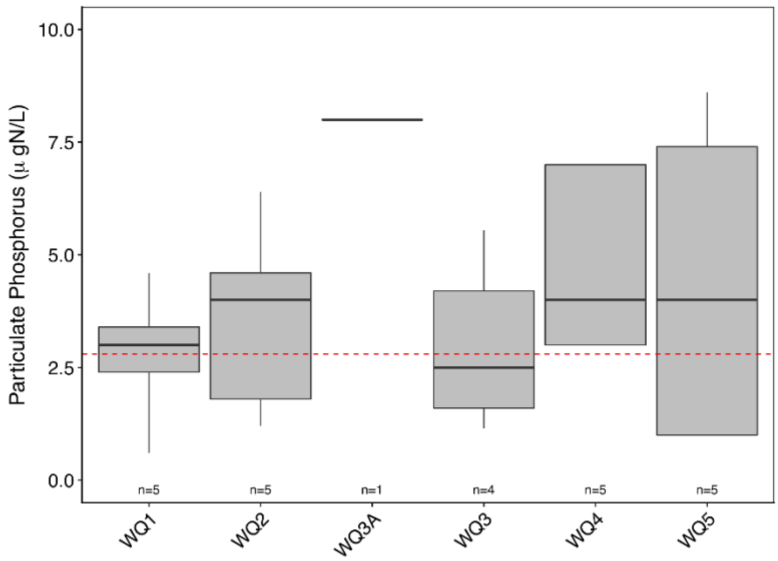
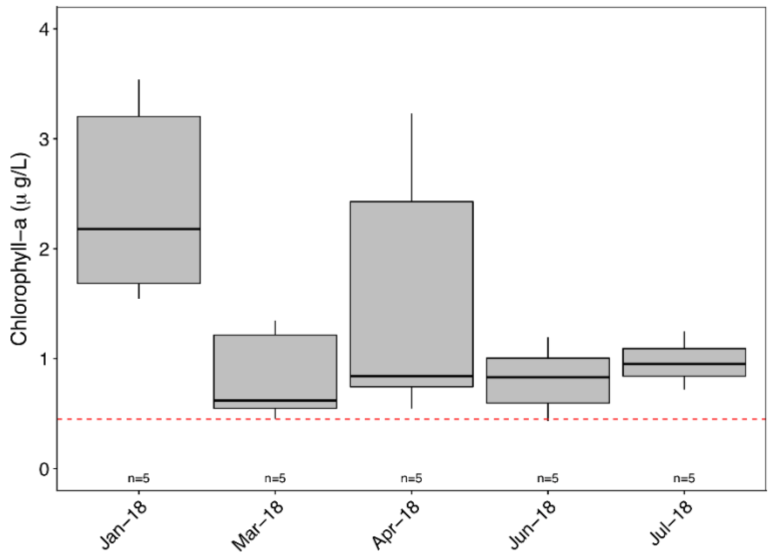



**Figure 3.8** Particulate phosphorus box plots: (a) during each survey (sites pooled) from January 2018 to July 2018 and (b) at each site over this same survey period (surveys pooled)

A)




B)

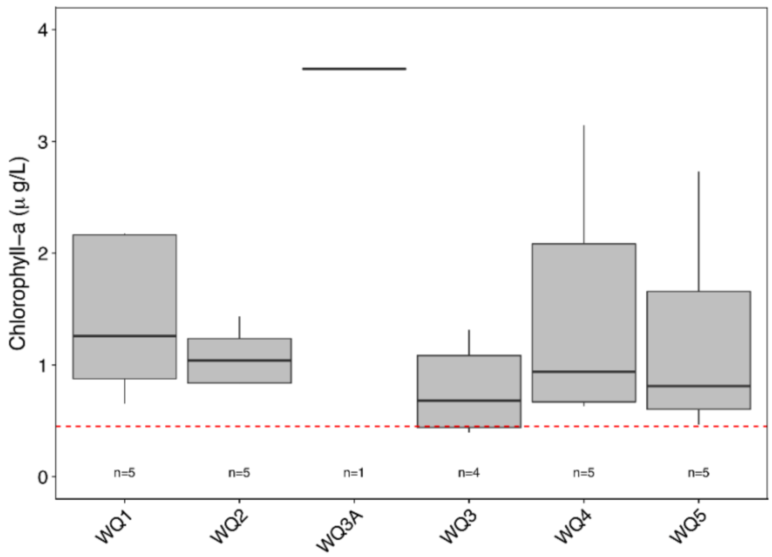



**Figure 3.9** Chlorophyll-*a* box plots: (a) during each survey (sites pooled) from January 2018 to July 2018 and (b) at each site over this same survey period (surveys pooled)

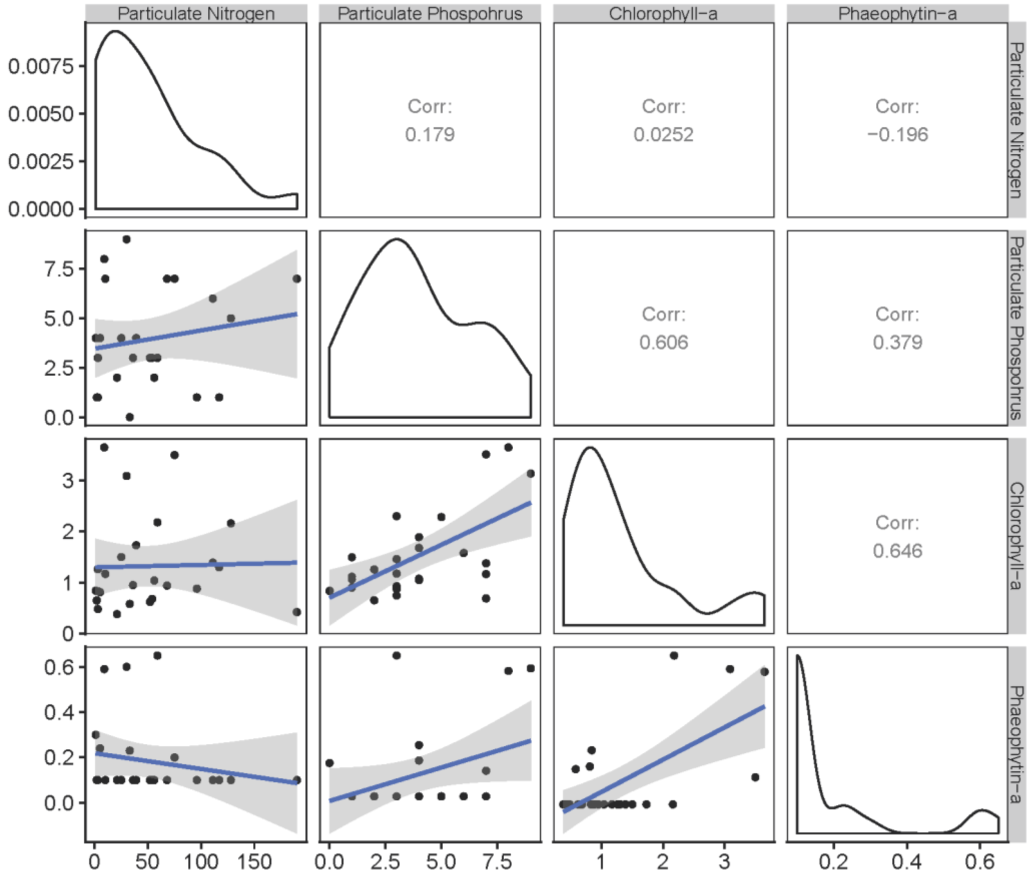



**Figure 3.10** Scatterplot of nutrient relationships at pooled across all sites and surveys. Lines of best fit with 95% confidence intervals are displayed in blue, and correlation coefficients are shown in corresponding plots. Density plots show the distribution of the data

### 3.1.3 Ultra-trace water heavy metals

Ultra-trace heavy metal concentrations were compared to the ANZECC and ARMCANZ 2000 water quality guidelines (ANZECC, 2000). Most of the filterable metals were not detected above the Limit of Reporting (LOR), the exception to this was arsenic (Table 3.1). No ANZECC guideline exists has been established for arsenic. Arsenic is released into the environment naturally by weathering of arsenic-containing rocks and volcanic activity. It can be in the form of As (III) or As (V), which can be toxic to marine aquatic life. A low reliability marine guideline trigger value of 4.5 µg/L for As (V) and 2.3 µg/L for As (III) has been derived (ANZECC, 2000), however, these trigger guidelines are only an indicative interim working level. Measured concentrations were recorded below these low reliability guidelines.

**Table 3.1** Summary statistics for metals data recorded at all sites during the program. Values are pooled across sites. Values are compared to the ANZECC 95% protection guideline values (2000). (-) sample not collected

| | | Arsenic | Cadmium | Copper | Lead | Nickel | Silver | Zinc | Mercury | Tributyltin |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unit | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | mg/L | ngSn/L |
| | LOR | - | 0.2 | 1 | 0.2 | 0.5 | 0.1 | 5 | 0.001 | 2 |
| | ANZECC | - | 5.5 | 1.3 | 4.4 | 70 | 1.4 | 15 | 0.4 | 0.006 |
| Apr-18 | Mean | 1.5 | <0.2 | <1 | 0.1 | <0.5 | <0.1 | 5.6 | - | - |
| | Min | 1.3 | <0.2 | <1 | 0.1 | <0.5 | <0.1 | <5 | - | - |
| | Max | 1.6 | <0.2 | 1 | 0.1 | <0.5 | <0.1 | 10 | - | - |

**3.1.4 Water pesticides and herbicides**

The major pesticide and herbicide concentrations were not detected above the limit of reporting (Table 3.2). Where possible, these concentrations were compared to the water quality improvement guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) to provide context for comparisons to NQBP's other east-coast Ports, and all detected concentrations were well below the 95% protection values. During this reporting period Diuron and Atrazine have been detected, though these results require caution given they represent only a single record.

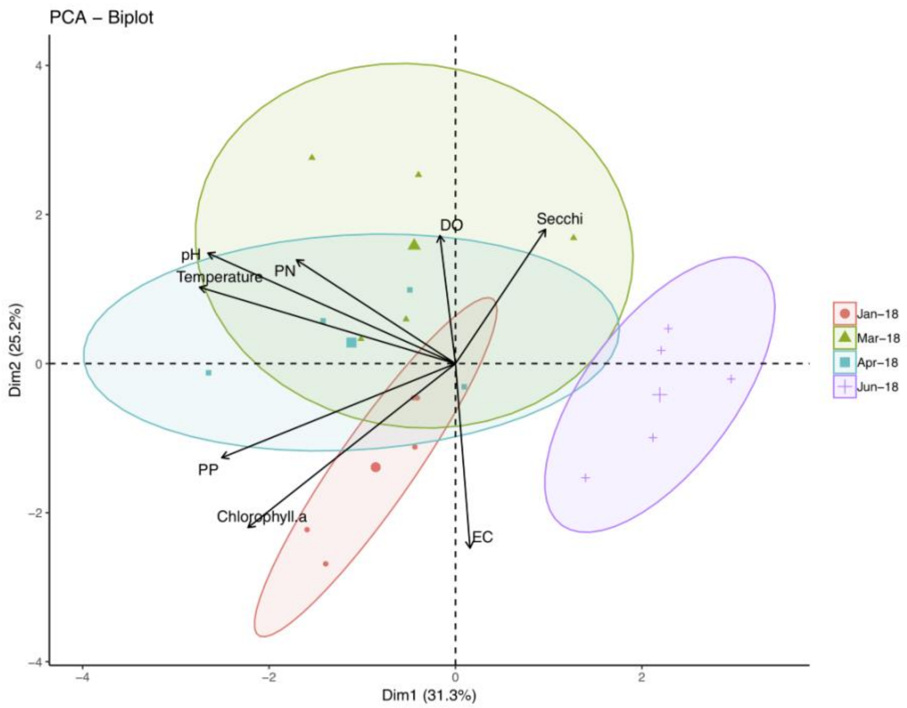
**Table 3.2** Summary (average) statistics for pesticides/herbicides recorded at all sites during the program (all values are µg/L). Values are pooled across sites for each survey and compared to the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) 95% protection level. Mackay-Whitsunday Water Quality Improvement Plan 2014-2021 Water Quality Objectives (WQO's) are also included to assess tracking

| Survey | Guideline | Atrazine | Ametyn | Diuron | Hexazinone | Tebutryn |
|---|---|---|---|---|---|---|
| | GBRMPA (2010) | 1.4 | 1.0 | 1.6 | 1.2 | - |
| April 2018 | | 0.00014 | 0.0001 | 0.0017 | 0.0001 | 0.0001 |

**3.1.5 Ordination of data**

Spot water quality measurements have been collected at all sites for water temperature, electrical conductivity, dissolved oxygen (%), pH, turbidity, and light attenuation. In addition to these spot measurements, secchi depth has also been recorded, as a measure of the optical clarity of the water column. Field in-situ measurements have been recorded at three depth horizons; surface (0.25m), middle, and the bottom horizon. These measurements continue to assist in characterising water quality conditions within the water column, among sites and surveys. Principal components analysis (PCA) was used to explore relationships between physiochemical and nutrient data collected at the water surface at each site during each month of sampling. Results show that 56.5% of the variability among sites and sampling months is explained by physiochemical and nutrient variables (Figure 3.11). Electrical conductivity (EC) is negatively correlated with dissolved oxygen (DO), and these variables are not associated with any monthly (Figure 3.11A) or seasonal (Figure 3.11B) differences between sites. Increasing values of particulate nutrients (PN and PP), pH, temperature, and chlorophyll-*a* are negatively correlated with the June 2018 survey period (Figure 3.10A). (Note that while differences in water quality parameters between the wet season surveys (January – March 2018) and dry season surveys (April – July 2018) have been explored, a full year of data is required to allow any conclusions regarding seasonality to be made. Furthermore, although April is technically considered a dry season month, environmental conditions in April 2018 were likely to be more typical of the wet season due to continued rainfall associated with Cyclone Nora on March 24th, 2018).

A)




B)

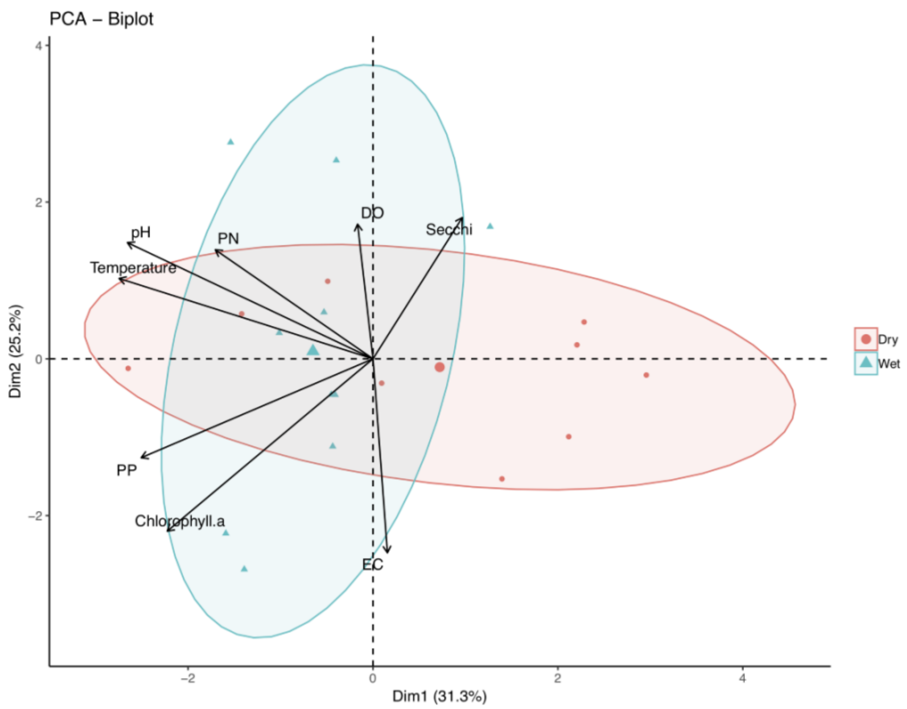



**Figure 3.11** Principal components analysis (PCA) exploring relationships between nutrients and physiochemical parameters (black vectors) and monitoring sites. The 95% confidence interval ellipses show overall differences between: A) sites grouped by year and B) sites grouped by season. Vector labels are abbreviated as follows: PP = Particulate Phosphorus, PN = Particulate Nitrogen, EC = Electrical Conductivity, and DO = Dissolved Oxygen. Total variance explained by Dimension 1 and Dimension 2 = 56.5%

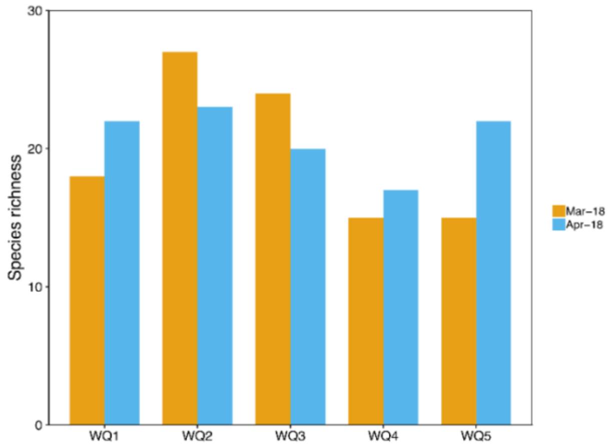
## 3.2 Plankton communities

### 3.2.1 Diversity and abundance

A total of 45 phytoplankton species have been identified, comprising cyanobacteria, diatoms, flagellates and green algae taxa. Several species were recorded at all sites, including *Azpeita spp, Bacteriastrum spp, Rhizosolenia spp*, *Chaetoceros spp*, *Chlamydomonas spp, Dinophysis caudata, Guinardia spp, Odontella spp, Rhizosolenia spp, and Thalassionema spp.* In March 2018, WQ2 had the highest phytoplankton species richness (27 species), while WQ4 and WQ5 had the lowest species richness (15 species) (Figure 3.12a). The highest abundance was recorded in April 2018 at WQ1, mainly due to increases in *Rhizsolenia* and *Thalassionema* spp. (Figure 3.12b).

A total of 18 different species of zooplankton were recorded during all surveys. Larval fish and eggs were the only taxa to be recorded at all sites. WQ2 had the highest diversity (13 species) in March 2018 (Figure 3.13a). Zooplankton diversity was lower in January 2018 compared to March 2018 at all sites, and was lowest at WQ1 with only one species recorded (Figure 3.13a) Similarly, the total abundance of zooplankton was higher in March 2018 compared to January 2018, with the lowest number of individuals recorded at WQ1 and the highest at WQ5 (Figure 3.13b).

A)




B)

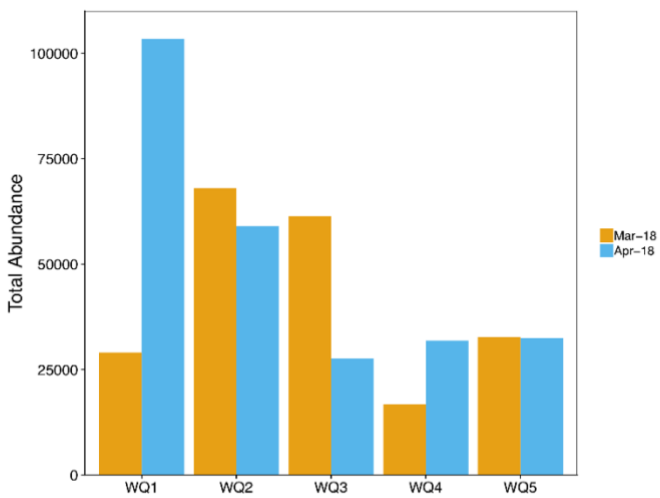
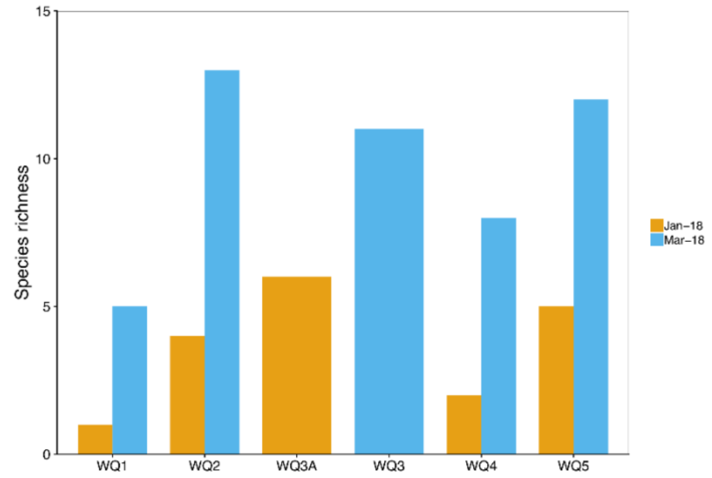


**Figure 3.12** a) Species richness of phytoplankton; and b) total abundance of phytoplankton at each site during the following survey periods: March and April 2018

A)




B)

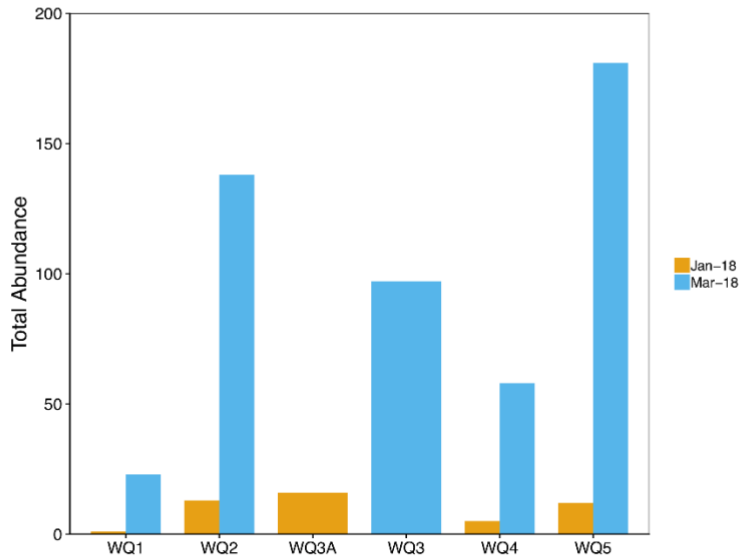



**Figure 3.13** a) Species richness of zooplankton and b) total abundance of zooplankton at each site during the following survey periods: January and March 2018

### 3.2.1 Plankton ordinations

Exploratory statistical analysis of the plankton using non-dimensional scaling (nMDS) revealed distinct differences in species composition of phytoplankton (Figure 3.14) and zooplankton (Figure 3.15) between surveys. These results represent only a small number of surveys; future sampling will gradually increase the database, whereby additional analysis and interpretation will be possible.

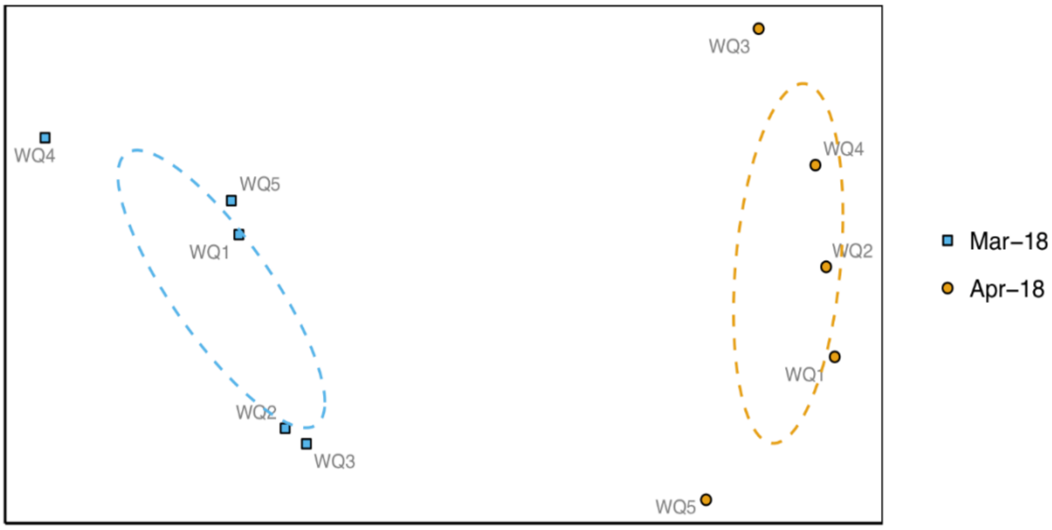



**Figure 3.14** Non-dimensional ordination plot for phytoplankton collected during six survey periods throughout 2018. Dashed lines represent 95% confidence interval ellipses for each survey period. Data has been squared root transformed on the Bray Curtis distance matrix (stress = 0.05, Clarke and Gorley 2006)

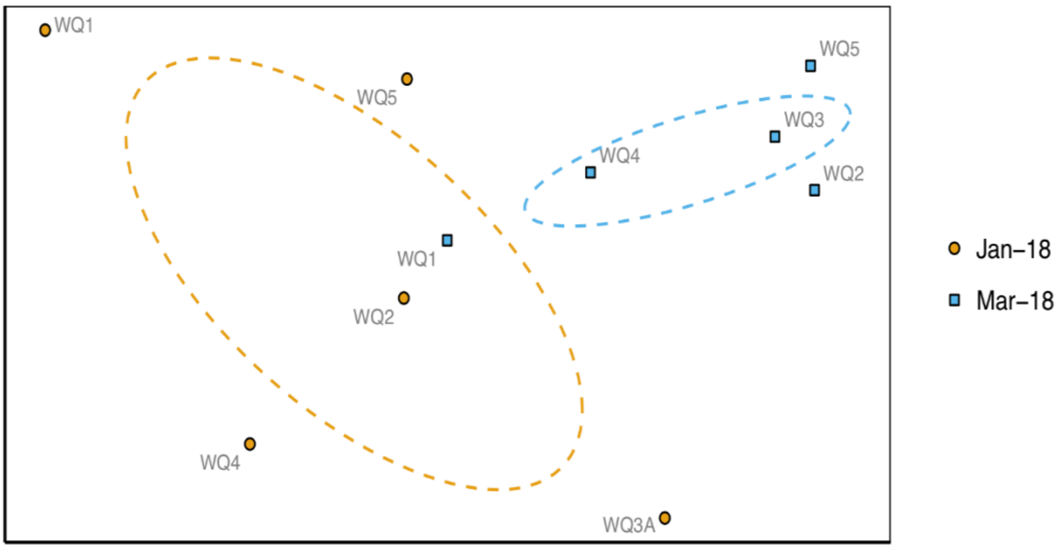



**Figure 3.15** Non-dimensional ordination plot for zooplankton collected during two survey periods in 2018. Dashed lines represent 95% confidence interval ellipses for each survey period. Data has been squared root transformed on the Bray Curtis distance matrix (stress = 0.06, Clarke and Gorley 2006)

## 3.3 Multiparameter water quality logger

Data is presented throughout the text (and in attached appendices) in a time series format, monthly and yearly statistical summaries. The box plots provide a visual representation of the descriptive statistics for Suspended Sediment Concentration (SSC), deposition rate (mg $cm^{-2}$ $day^{-1}$), water temperature (°C), RMS water height (m) and PAR (mol $m^{-2}$ $day^{-1}$). In the box plots, the central diamonds represent the mean value, the central line represents the median value and the central box represents the range of the middle two quartiles. The vertical bars represent the range of the 90$^{th}$ percentile and 10$^{th}$ percentile data points.

### 3.3.1 RMS water height

RMS water height values are mostly driven by weather events and this is clearly evident in the data as peaks in RMS water heights are observed at the same times at all sites over the survey year. Variation in the magnitude of RMS water height values during peak events and during non-event periods differs among sites due to differences in water depth and site exposure to wave energy. The RMS water height data from this survey year shows the sites can be categorised into three groups. Figure 3.16 provides a box plot of the yearly statistics of RMS at sites and this offers an effective visual representation of the three categories described below.

The lowest value RMS category consisted of WQ1 and WQ4. These sites had much lower RMS values than all other sites with a median RMS water height of 0.002 and 0.001 m respectively. The lowest variance in RMS values (10$^{th}$ percentile = 0.00, 90$^{th}$ percentile = 0.03) (Table 3.3). These results are due to the site being positioned within the Embley River.

WQ2 and WQ5 have higher RMS values of approximately 0.02 m and 0.06 m respectively. This is due to more exposed positions in the channel outside of the river, with WQ5 being the farthest from shore and the most exposed. As mentioned in the methodology, RMS water height is a proxy for wave energy or wave shear stress at the ocean floor (Macdonald 2015). This increased RMS leads to higher SSC values at these sites. This information illustrates that these sites are directly influenced by very similar wave shear stress and therefore differences between sites needs to be attributed to other parameters such as current, depth and benthic geology.

WQ3 has a median RMS of 0.01, and a mean of 0.03. This site has a very different position to the other four sites, being close to the coast, yet exposed to winds from the north-west.

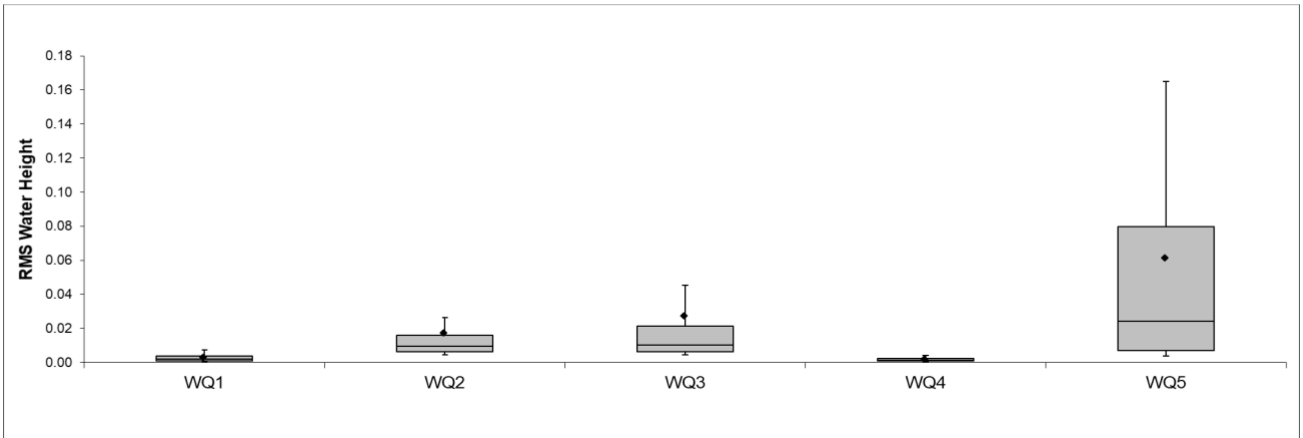



**Figure 3.16** Box plot of RMS water height (m) at the five sites for the monitoring period from January to July 2018

**Table 3.3** Summary of RMS water height (m) statistics at the five sites for the monitoring period from January to July 2018

| Site | WQ1 | WQ2 | WQ3 | WQ4 | WQ5 |
|---|---|---|---|---|---|
| **Mean** | 0.003 | 0.017 | 0.027 | 0.002 | 0.062 |
| **median** | 0.002 | 0.010 | 0.010 | 0.001 | 0.024 |
| **min** | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| **lower quartile** | 0.001 | 0.006 | 0.006 | 0.001 | 0.007 |
| **upper quartile** | 0.004 | 0.016 | 0.021 | 0.002 | 0.080 |
| **max** | 0.084 | 0.696 | 1.034 | 0.080 | 0.983 |
| **90th percentile** | 0.007 | 0.026 | 0.045 | 0.004 | 0.165 |
| **10th percentile** | 0.001 | 0.004 | 0.004 | 0.000 | 0.004 |
| **n** | 22312 | 16994 | 15359 | 24180 | 24351 |
| **St. Dev** | 0.004 | 0.036 | 0.070 | 0.003 | 0.090 |
| **St. Error** | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |

Figures 3.17 provides an example of when weather driven wave energy in combination with tide are evident in the RMS data for WQ1 during the reporting period. Figure 3.17 shows several large spikes in RMS water height throughout the displayed period. These spikes are the result of weather driven wave events and are followed by periods where RMS water height falls to its background value as the weather events pass. Comparing the 12-point averaged trend line with the water depth data shows a similar periodicity in the RMS water height and water depth data. It is interesting to note that a reduction in water depth does align with the periodic peaks in RMS water height and it is thought that other factors such as current and changes in the sites exposure at different tides alters the wave dynamics of the site.

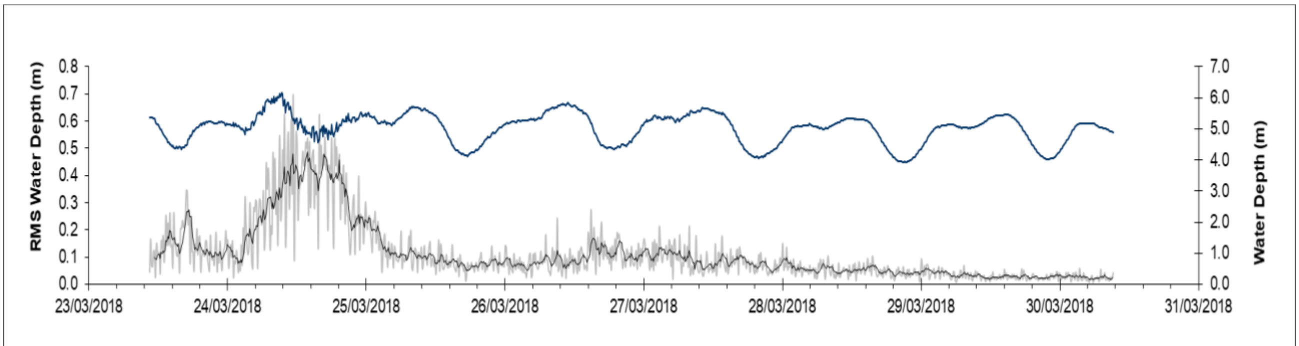



**Figure 3.17** WQ2 RMS water height (gray), 12 point moving average RMS trend line (black) and water depth (blue). Data shows a periodic wave event around the 24th of March 2018, followed by a calmer period

### 3.3.2 NTUe/SSC

The NTUe/SSC time series data at each site (seen in the appendix) follows a typical pattern of low background values with recurring peak events. These peak events occurred at the same times at each site and coincide with peaks in RMS water height. This is a typical pattern which is similar to data collected in coastal locations in north Queensland by the James Cook University Marine Geophysics group (Ridd et al., 2001). Yearly statistical values and individual peak values differ between sites. These differences are the result of variation in influencing factors such as RMS water height, site depth, benthic geology, hydrodynamics and proximity to river mouths. Figure 3.18 provides a box plot of the yearly statistics of SSC values at sites, while Table 3.4 summaries the same yearly statistics.

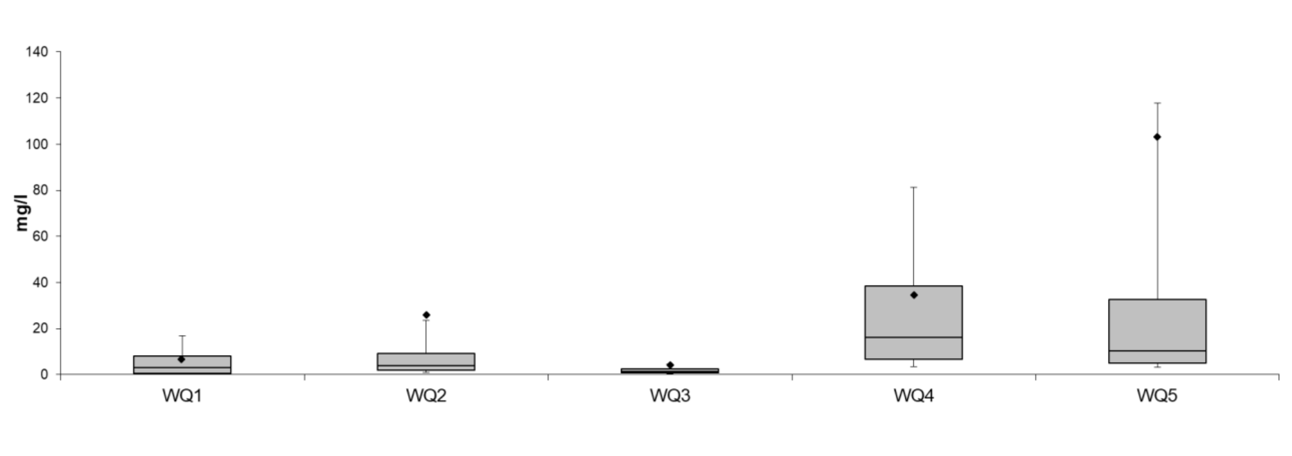



**Figure 3.18** Box plot of SSC (mg/L) at the five sites for the monitoring period from January to July 2018

**Table 3.4** Summary of SSC (mg/L) statistics at the seven sites for the monitoring period from January to July 2018

| Site | WQ1 | WQ2 | WQ3 | WQ4 | WQ5 |
|---|---|---|---|---|---|
| **Mean** | 6.67 | 26.02 | 4.17 | 34.50 | 103.21 |
| **median** | 3.02 | 3.94 | 1.24 | 16.14 | 10.26 |
| **min** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **lower quartile** | 0.49 | 1.92 | 0.71 | 6.71 | 5.05 |
| **upper quartile** | 7.98 | 9.25 | 2.52 | 38.30 | 32.45 |
| **max** | 267.57 | 5904.24 | 317.38 | 911.58 | 9986.78 |
| **90th percentile** | 16.84 | 23.42 | 4.62 | 81.33 | 117.81 |
| **10th percentile** | 0.20 | 1.01 | 0.46 | 3.36 | 3.12 |
| **n** | 21620 | 16475 | 15018 | 20471 | 23718 |
| **St. Dev** | 12.09 | 208.39 | 17.64 | 55.58 | 630.34 |
| **St. Error** | 0.08 | 1.62 | 0.14 | 0.39 | 4.09 |

### 3.3.3 Deposition

Deposition of sediment is a natural process occurring in all coastal marine waters. Suspended sediment naturally deposits in environments where the systems energy is not sufficient to keep it suspended. Deposition of sediment in a marine environment is of interest to environmental monitoring studies when it changes from its natural state. The Water Quality Guidelines for the Great Barrier Reef Marine Park (2010) references De'ath and Fabricius (2008) note that 10 mg $cm^{-2}$ $day^{-1}$ sedimentation is valid in areas of coarse sediment, but that where sediments are smaller and of high organic content the trigger limits need to be lower. The guidelines set the sedimentation trigger value at a mean annual value of 3 mg $cm^{-2}$ $day^{-1}$ and a daily maximum of 15 mg $cm^{-2}$ $day^{-1}$. (Note that the GBRMPA 2010 guidelines are used to provide context for comparison to NQBP's other east-coast Ports.) The statistical summary of the daily average deposition rates for each site are presented in Figure 3.19 as box plots and summarised in Table 3.5.

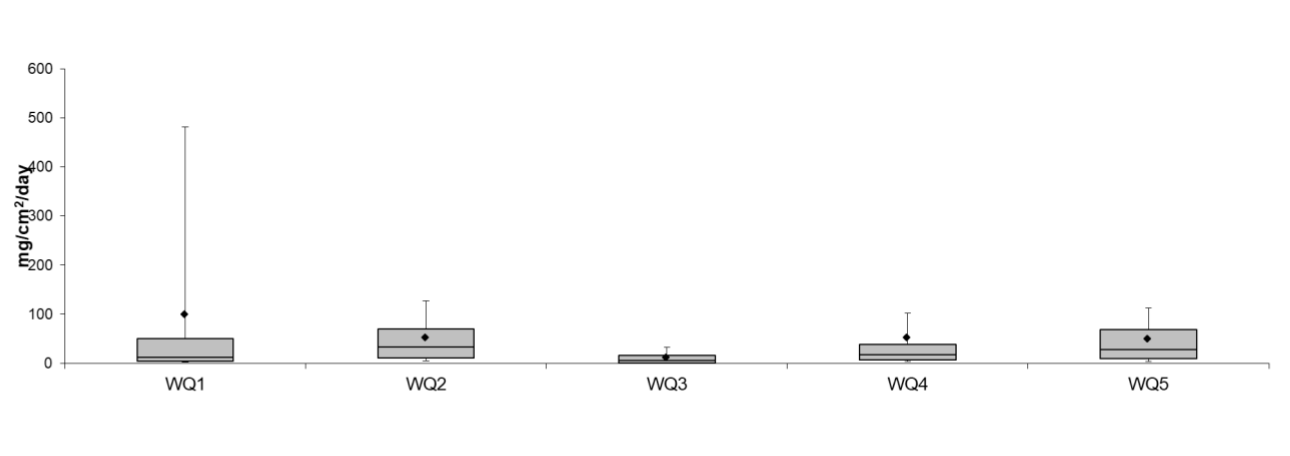



**Figure 3.19** Box plot of two-hourly deposition rate (mg/cm²/day) at the five sites for the monitoring period from January to July 2018

**Table 3.5** Summary of two-hourly deposition rate (mg/cm²/day) statistics at the five sites for the monitoring period from January to July 2018

| Site | WQ1 | WQ2 | WQ3 | WQ4 | WQ5 |
|---|---|---|---|---|---|
| **Mean** | 100.28 | 52.50 | 11.48 | 52.88 | 50.28 |
| **median** | 12.01 | 33.40 | 4.68 | 17.20 | 27.17 |
| **min** | 0.47 | 0.36 | 0.24 | 1.22 | 0.53 |
| **lower quartile** | 3.50 | 11.20 | 0.65 | 6.96 | 8.74 |
| **upper quartile** | 49.82 | 69.43 | 15.60 | 38.70 | 68.26 |
| **max** | 864.63 | 357.11 | 64.02 | 779.32 | 419.44 |
| **90th percentile** | 481.98 | 127.54 | 32.10 | 101.73 | 111.95 |
| **10th percentile** | 1.55 | 5.17 | 0.33 | 3.94 | 3.89 |
| **n** | 98 | 107 | 40 | 63 | 150 |
| **St. Dev** | 202.41 | 60.86 | 16.05 | 121.54 | 69.28 |
| **St. Error** | 20.45 | 5.88 | 2.54 | 15.31 | 5.66 |

The data indicates that WQ1 had the greatest deposition with a mean of 100.28 mg $cm^{-2}$ $day^{-1}$ but with a median daily average deposition rate of 12.01 mg $cm^{-2}$ $day^{-1}$, which is lower than sites WQ2, 3 and 5. Again, it is suggested that the median rather than the mean values be used in analysis to provide an un-skewed value of the data. The median daily average deposition rate ranged from 4.68-27.17 mg $cm^{-2}$ $day^{-1}$ across all five sites. These values may be more easily visualised by calculating them into the thickness of the sediment deposited. For example, using the relationship between density, mass and volume: a deposition value of 5 mg $cm^{-2}$ $day^{-1}$ is equivalent to a layer of sediment of thickness less than 35 µm, assuming a sediment density of 1.5 g/cm3.

It can be seen in the time series deposition data (see appendix) that deposition tends to peak following high RMS water height events but with a lag so that peak deposition occurs at a time when RMS water height has decreased to near background levels. An explanation for this lag is that as waves resuspend sediment, little deposition is expected because the energy in the system will keep the sediment in suspension. It is only when waves decrease and there is no longer enough energy in the system to keep the same quantity of sediment in suspension that deposition begins to occur.

### 3.3.4 Water temperature

The statistical summary of the water temperature for each site are presented in Figure 3.20 as box plots and summarised in Table 3.6. Water temperature data matched closely among all sites. Seasonal changes in water temperature were apparent, with the mean monthly temperature peaking between January and April at approximately 29.1-29.9 °C (Figure 3.20); a factor that was also observed in the field in-situ water temperature surveys. The lowest mean monthly temperatures were observed between June and July, where values dropped to 24.8-25.1 °C. Decreases in temperature over short time periods match with increases in RMS water depth. Water temperature is generally not considered to be a compliance condition for approval operations, however the temperature data presented here holds importance in future interpretation of ecological processes in the region, and across the GBR (e.g. Johanson et al., 2015).

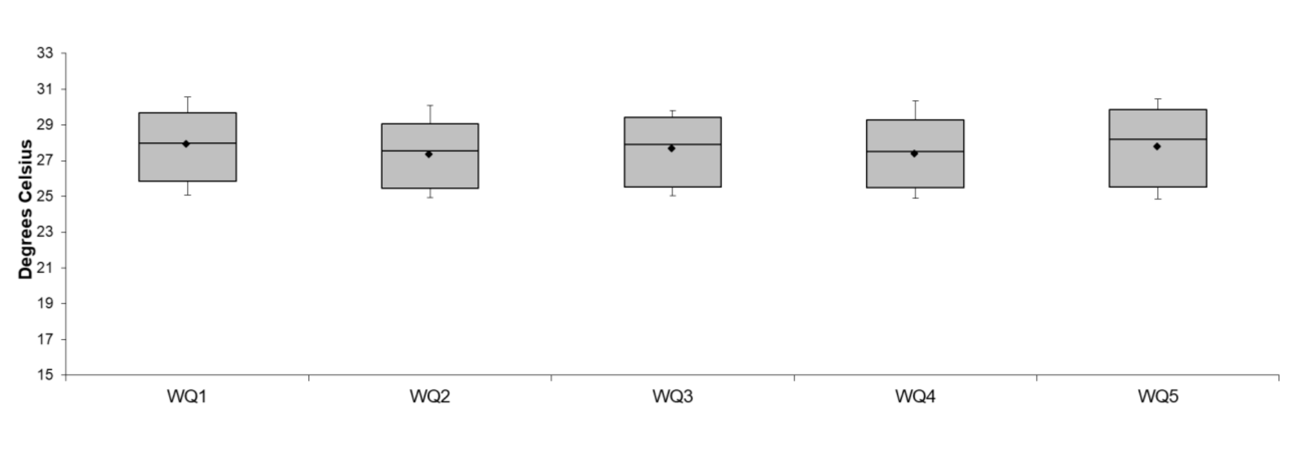



**Figure 3.20** Box plot of the water temperature (°C) at the five sites for the monitoring period from January to July 2018

**Table 3.6** Summary of water temperature (°C) statistics at the five sites for the monitoring period from January to July 2018

| Site | WQ1 | WQ2 | WQ3 | WQ4 | WQ5 |
|---|---|---|---|---|---|
| **Mean** | 27.93 | 27.38 | 27.70 | 27.41 | 27.82 |
| **median** | 28.00 | 27.56 | 27.90 | 27.53 | 28.19 |
| **min** | 24.37 | 24.38 | 24.44 | 23.24 | 20.45 |
| **lower quartile** | 25.85 | 25.47 | 25.52 | 25.48 | 25.53 |
| **upper quartile** | 29.67 | 29.07 | 29.44 | 29.30 | 29.87 |
| **max** | 36.57 | 31.41 | 32.62 | 33.41 | 31.30 |
| **90th percentile** | 30.55 | 30.09 | 29.81 | 30.33 | 30.47 |
| **10th percentile** | 25.09 | 24.93 | 25.06 | 24.90 | 24.87 |
| **n** | 22311 | 16994 | 15359 | 17134 | 24351 |
| **St. Dev** | 2.03 | 1.91 | 1.81 | 2.05 | 2.15 |
| **St. Error** | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |

### 3.3.5 Photosynthetically active radiation (PAR)

Benthic photosynthetically active radiation (PAR) was monitored at the five sites from January to July 2018, although it should be noted that standalone PAR has been monitored in these locations since 2015. The statistical summary of the PAR for each site are presented in Figure 3.21 as box plots and summarised in Table 3.7. Mean levels of benthic PAR varied from 0.78 to 3.01 mol $m^{-2}$ $day^{-1}$. WQ2 had the greatest variance and highest mean and median (3.01 and 2.69 mol $m^{-2}$ $day^{-1}$ respectively), which is due to the shallow site location. Considering the mean depth of WQ3 (7.33 m), light levels may be considered comparatively high, which is likely due to site characteristics. This includes distance from river, sheltered location and grain size profile, making WQ3 a comparatively clean site in terms of suspended sediment.

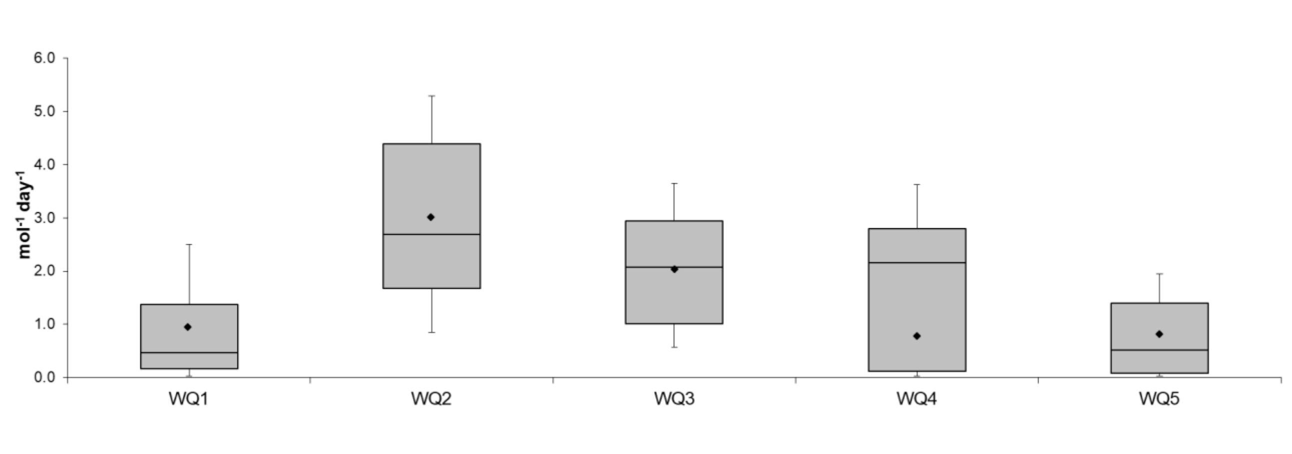



**Figure 3.21** Box plot of the daily PAR (mol $m^{-2}$ $day^{-1}$) at the five sites for the monitoring period from January to July 2018

**Table 3.7** Summary of daily PAR (mol $m^{-2}$ $day^{-1}$) statistics at the five sites for the monitoring period from January to July 2018

| Site | WQ1 | WQ2 | WQ3 | WQ4 | WQ5 |
|---|---|---|---|---|---|
| **Mean** | 0.95 | 3.01 | 2.03 | 0.78 | 0.81 |
| **median** | 0.47 | 2.69 | 2.07 | 0.54 | 0.52 |
| **min** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **lower quartile** | 0.16 | 1.68 | 1.01 | 0.11 | 0.01 |
| **upper quartile** | 1.38 | 4.39 | 2.95 | 1.17 | 1.40 |
| **max** | 4.37 | 7.58 | 4.69 | 3.61 | 4.47 |
| **90th percentile** | 2.50 | 5.30 | 3.64 | 2.00 | 1.95 |
| **10th percentile** | 0.03 | 0.85 | 0.56 | 0.03 | 0.02 |
| **n** | 154 | 118 | 105 | 167 | 168 |
| **St. Dev** | 1.08 | 1.80 | 1.22 | 0.81 | 0.00 |
| **St. Error** | 0.09 | 0.17 | 0.12 | 0.06 | 0.06 |

Using these above summary statistics and graphical representations of the full time series data (Figure 3.22) and monthly variational data (Figure 3.23) per site, we describe trends and temporal differences among sites and investigate possible drivers of significant decreases in PAR.

Benthic PAR was highly variable within sites throughout the monitoring period of this year, with peaks and troughs occurring both regularly and intermittently over time. Semi-regular oscillations between low and high PAR levels were overridden by larger episodic events caused by storm or rainfall events.

Investigating the monthly variation among sites shows a period of decreased daily PAR levels from January to February 2018, with local peaks of daily PAR in April and May 2018 across all sites.

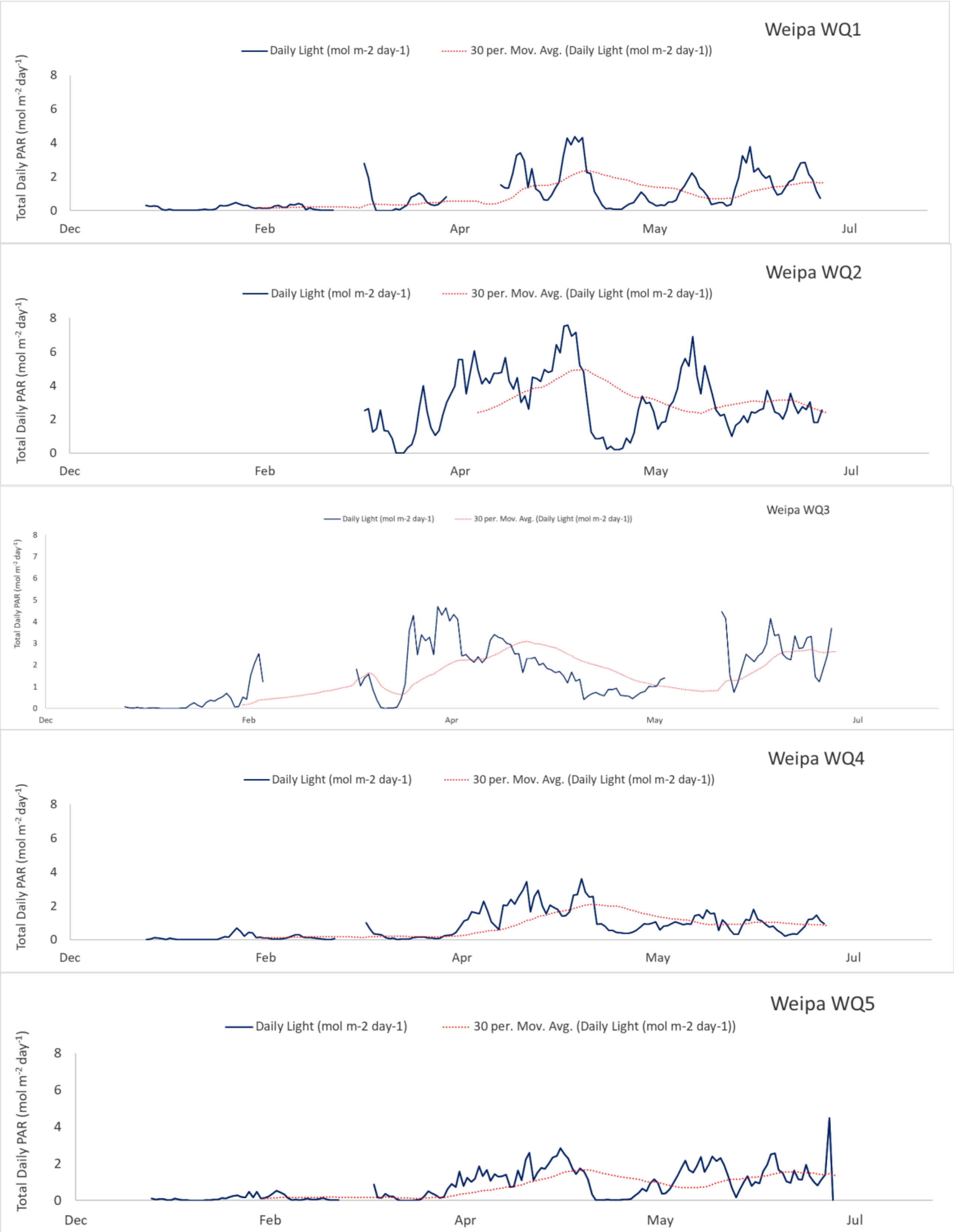



**Figure 3.22** Time series of mean total daily PAR (mol m-2 day-1) recorded at all sites for the monitoring period from January to July 2018

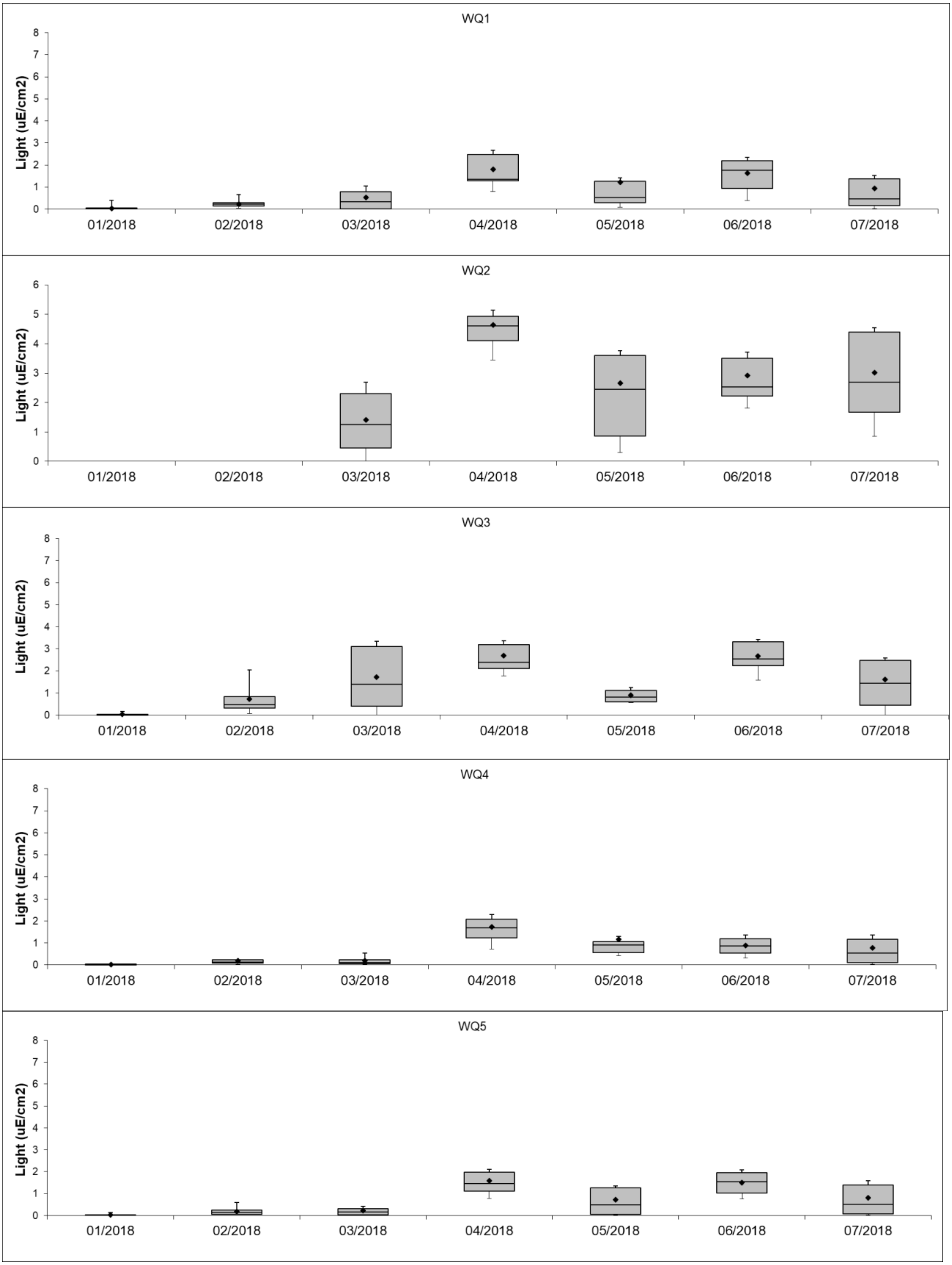



**Figure 3.23** Monthly boxplots illustrating the variation in total daily PAR (mol photons m2 day -1) at the five representative sites

### 3.4.1 Similarities in patterns of PAR among sites

As sites were located at various depths below the lowest astronomical tide datum (LAT), direct comparisons of PAR among sites are not statistically valid. Therefore, the similarity in patterns of PAR over time among different sites was compared by plotting total daily PAR to examine the strength of the relationship using pairwise comparisons (Figure 3.24). The strength of the linear relationship between sites was measured using an $R^2$ value shown on each pairwise scatterplot.


**Figure 3.24** Scatterplots of the pairwise comparisons among sites indicating the strength of the relationships between patterns of daily PAR. $R^2$ values are presented for each comparison

Relationships in patterns of benthic PAR are found among distant coastal sites that were located in similar environments. For example, WQ1 and WQ4 have the highest correlation, $R^2$ = 0.56, which is expected due to similar site characteristics. The next highest correlation is WQ5 and WQ4 ($R^2$ = 0.44), however these two sites are very different in terms of location. WQ1 and WQ2 exhibited the least similarities among other coastal sites with very weak relationships in pairwise comparisons ($R^2$ = 7E-05). This analysis assists in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region.

### 3.4.2 Relationship between light attenuation and suspended solid concentrations

In sediment-rich coastal waters, the dominant physical process that reduces PAR light intensity is scattering, which if turbidity levels are high enough, can cause underwater light to become isotropic. Investigations into the light attenuation coefficient provides an insight into the dynamic relationship between suspended solid concentrations and PAR light intensities.

Absorption and scattering describe the attenuation of light through water by interacting in a nonlinear and complex fashion within the radiative transport equations (Mobley 1994). These equations cannot be solved analytically; however the diffuse attenuation coefficient ($k_d$) (averaged across the PAR waveband 400-700 nm) may be approximated in ocean waters by using Beer-Lambert's law (Gordon 1989; Dennison et al. 1993; Kirk 1994),

$$I_z = I_{z0} e^{-k_d(z-z_0)}$$

where $I_{z0}$ and $I_z$ are the downward directed irradiances at an upper depth ($z_0$) and a lower depth ($z$) respectively, and $k_d$ is the diffuse attenuation coefficient (averaged across the PAR waveband 400-700 nm) (Jerlov 1976; Kirk 1977). $k_d$ is comprised of a component due to clear water and a component due to SSC.

Light attenuation and suspended sediment concentration (*SSC*) are examined for all five sites. A general relationship is found, whereby as SSC increases, light levels decrease exponentially, as is well described by Beer-lambert's Law. An example of this relationship can be seen in Figure 3.25 where during periods of high SSC, light is attenuated and when SSC exceeds approximately 10 mg/L, light extinction occurs.

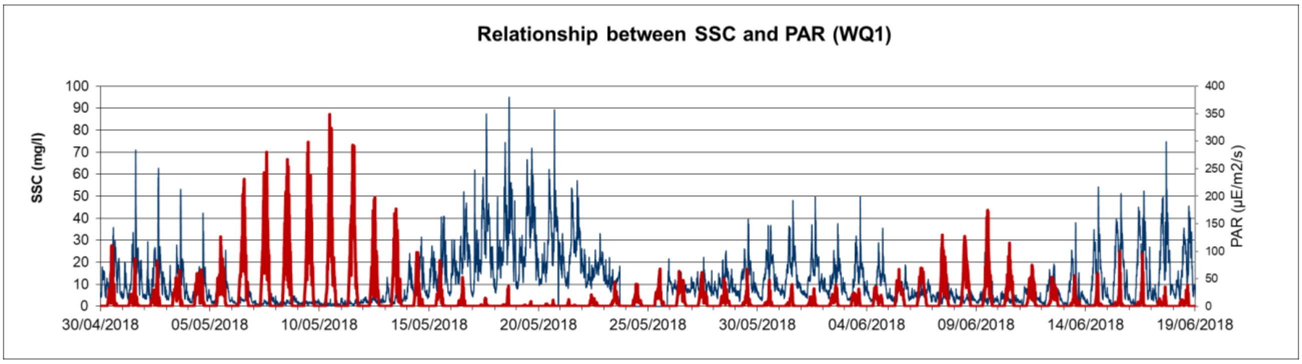



**Figure 3.25** A typical example of the relationship between SSC and PAR light, showing light levels decreasing as SSC increases during May-June 2018 at WQ1

### 3.4.3 Current meter

Current meter data was collected at all five sites. Marotte HS current meter instruments were deployed from March 2018 to July 2018 for sites WQ1, WQ2, WQ3, WQ4; while only the month of July 2018 was recorded for WQ5 due to data loss.

The current meter data indicates the prominent current direction and velocity at each site. Data shows that coastal current, tidal current or a combination of both influence current direction and magnitude. The figures below display the current meter data in current rose and average current speed rose diagrams. The current rose diagrams provide a visual representation of relative prominence of current velocity and direction. The average current speed rose diagrams displays the average current speed in every direction. Presented together these diagrams highlight the prominent direction of current and the average velocity of the current in this direction.

A video illustrating how the current speed and direction changes over time at each site is shared privately on YouTube: https://www.youtube.com/watch?v=RiI78egwL1k

### *WQ1*

The current at WQ1 ranges from East to West with peaks at ENE and W and average velocities ranging between 0.05 m/s and 0.27 m/s (as shown in Figures 3.26 and 3.27). This is in line with expected tidal current directions at the site.

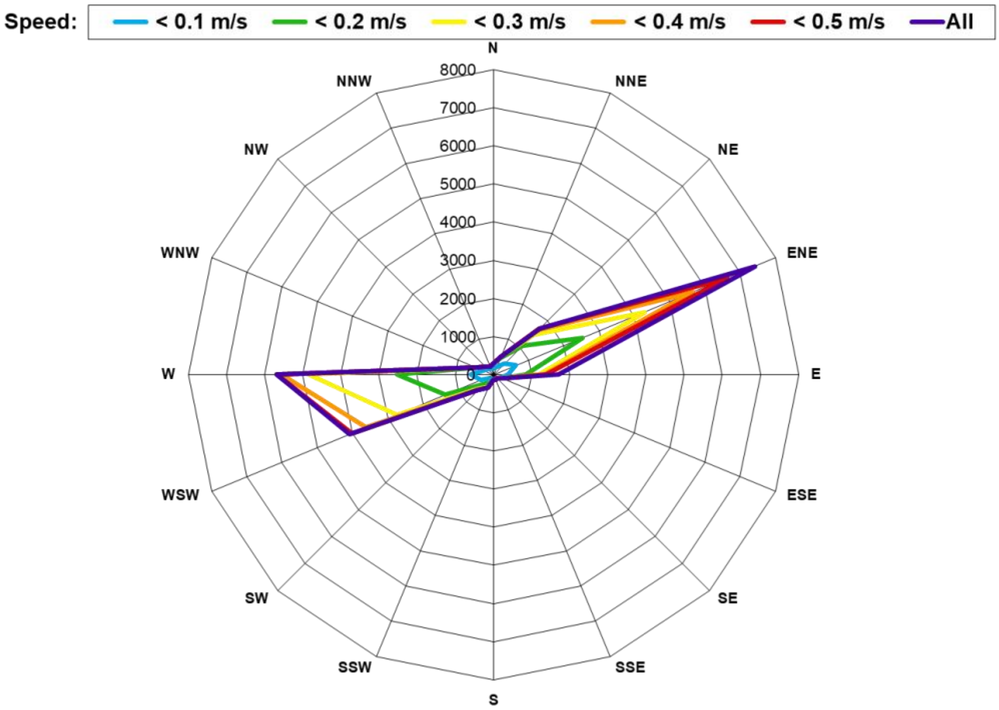



**Figure 3.26** Current rose at WQ1 for the monitoring period from March 2018 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

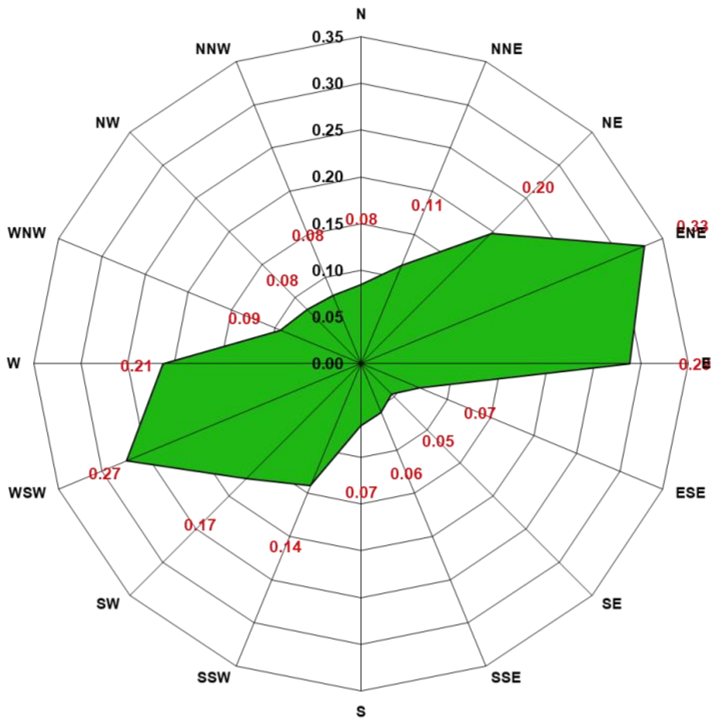



**Figure 3.27** Average current speed rose at WQ1 for the monitoring period from March 2018 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

### *WQ2*

The current at WQ2 flows between SW and NE directions with average velocities between 0.03 m/s and 0.22 m/s (as shown in Figures 3.28 and 3.27). The current directions are similar to that of WQ5 as expected, due to the similarity of the locations and the directions suggest that these currents are tidal.

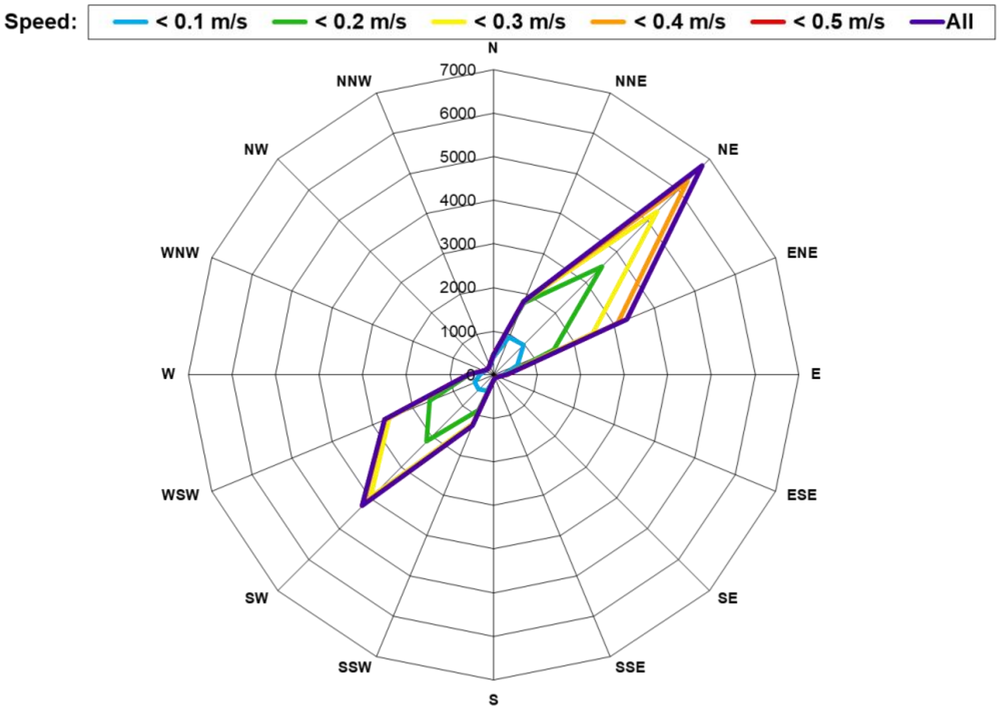



**Figure 3.28** Current rose at WQ2 for the monitoring period from March 2018 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

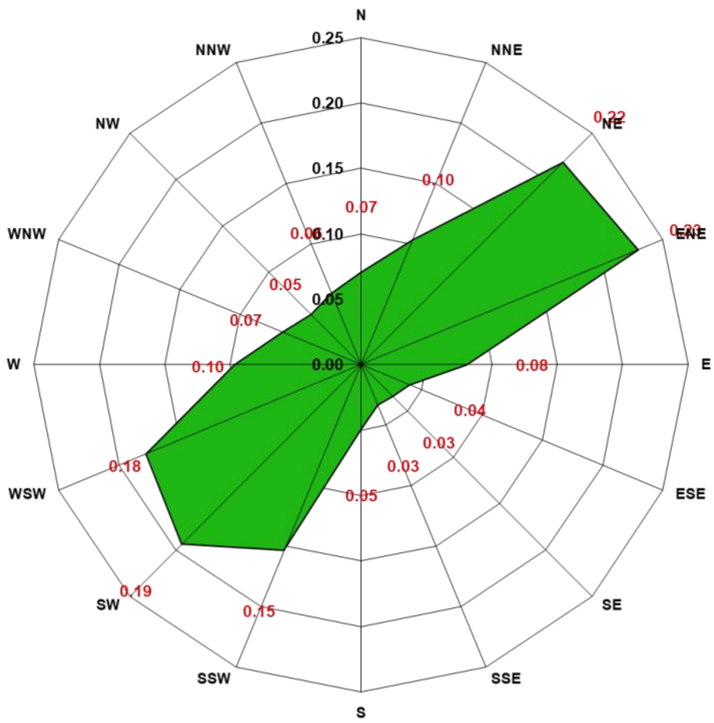



**Figure 3.29** Average current speed rose at WQ2 for the monitoring period from March 2018 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

***WQ3***

The current at WQ3 flows predominantly in the SSW direction with average current speed velocities ranging from 0.03 m/s to 0.1 m/s (as shown in Figures 3.30 and 3.31). As expected, the currents at this site flow both along the coast in both directions.

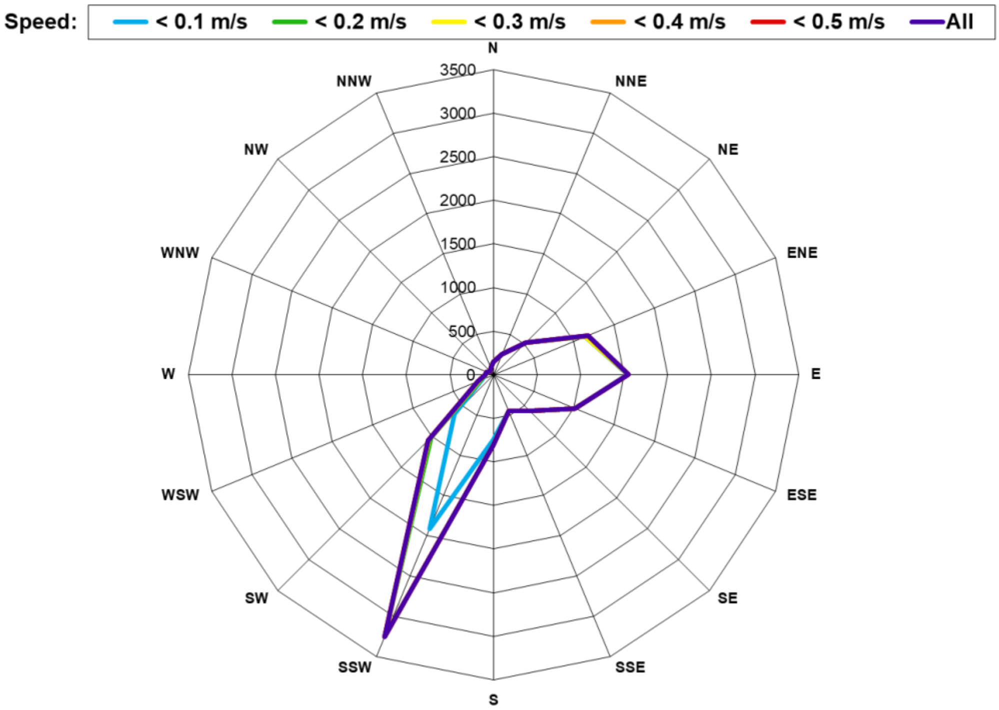



**Figure 3.30** Current rose at WQ3 for the monitoring period from March 2018 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

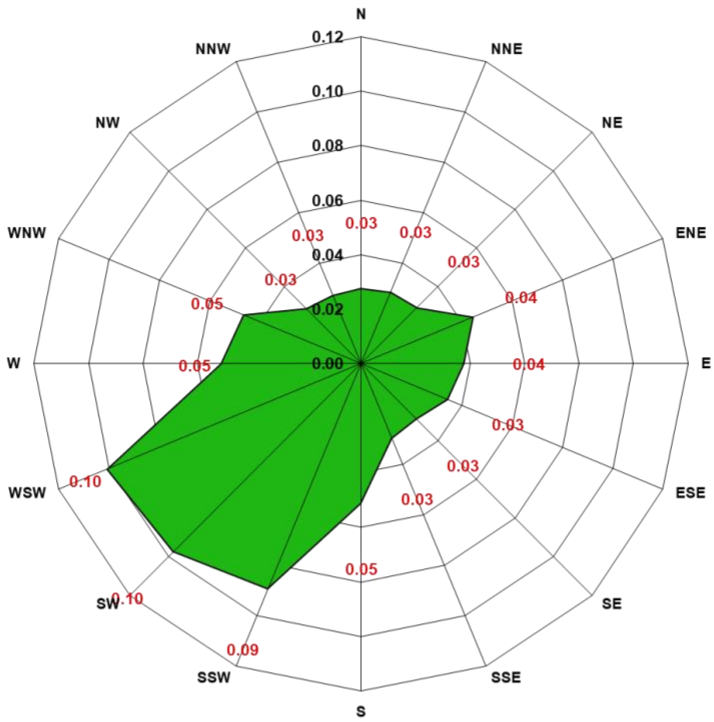



**Figure 3.31** Average current speed rose at WQ3 for the monitoring period from March 2018 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

### *WQ4*

The currents that dominate the site WQ4 are in the NW and SE directions (Figure 3.32). An average current velocity of 0.22 and 0.32 m/s were recorded in these respective directions (Figure 3.33). This lines up with the direction of the river at this location.

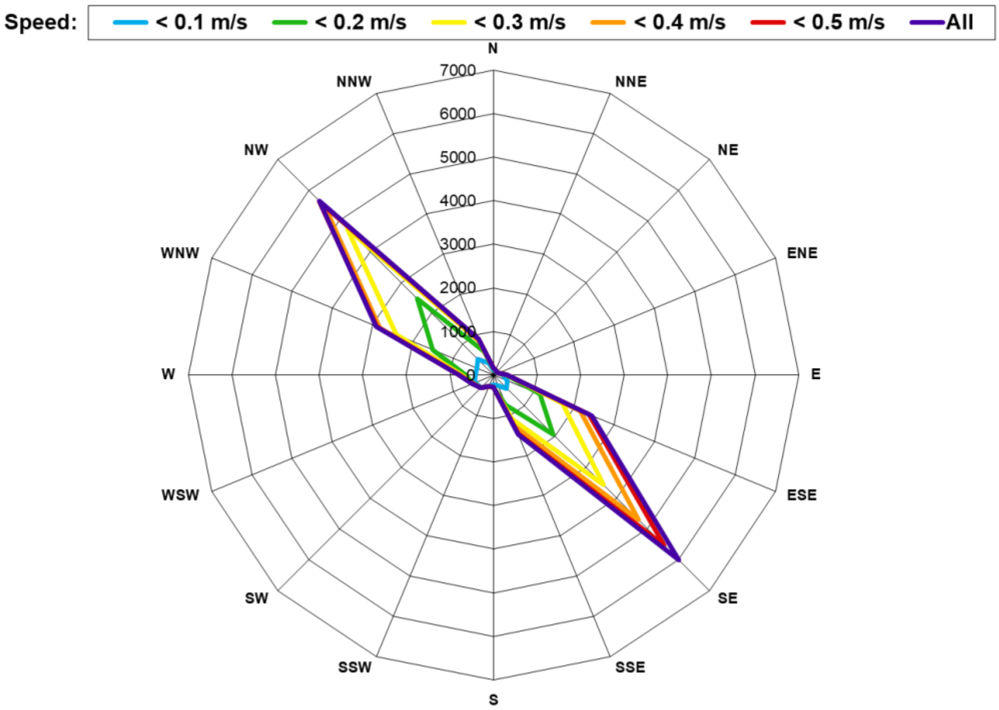



**Figure 3.32** Current rose at WQ4 for the monitoring period from March 2018 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

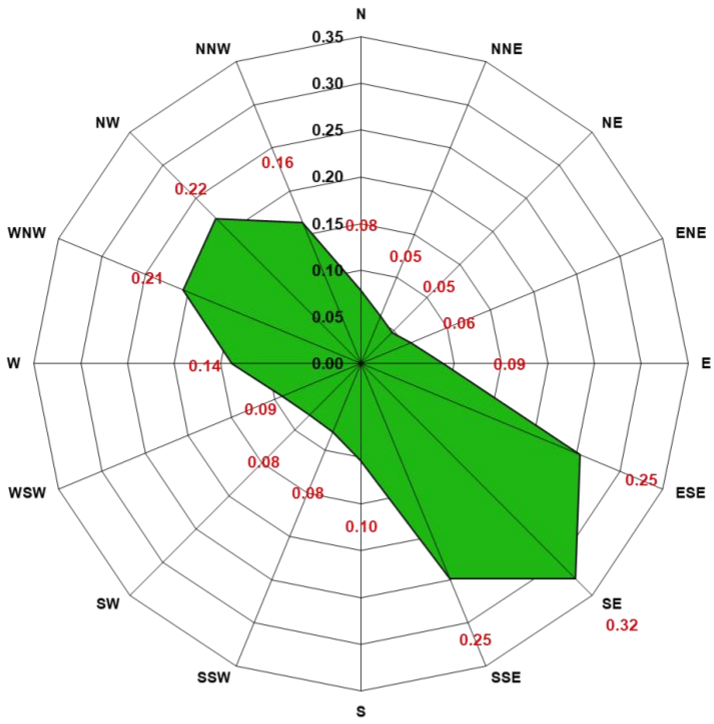



**Figure 3.33** Average current speed rose at WQ4 for the monitoring period from March 2018 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

### *WQ5*

The current at WQ5 flows predominantly from NE to SW with peaks at WSW and NE, and average velocities ranging between 0.04 m/s and 0.15 m/s (as shown in Figures 3.34 and 3.35). The current directions are similar to that of WQ2 as expected, due to the similarity of the locations and the directions suggest that these currents are tidal.

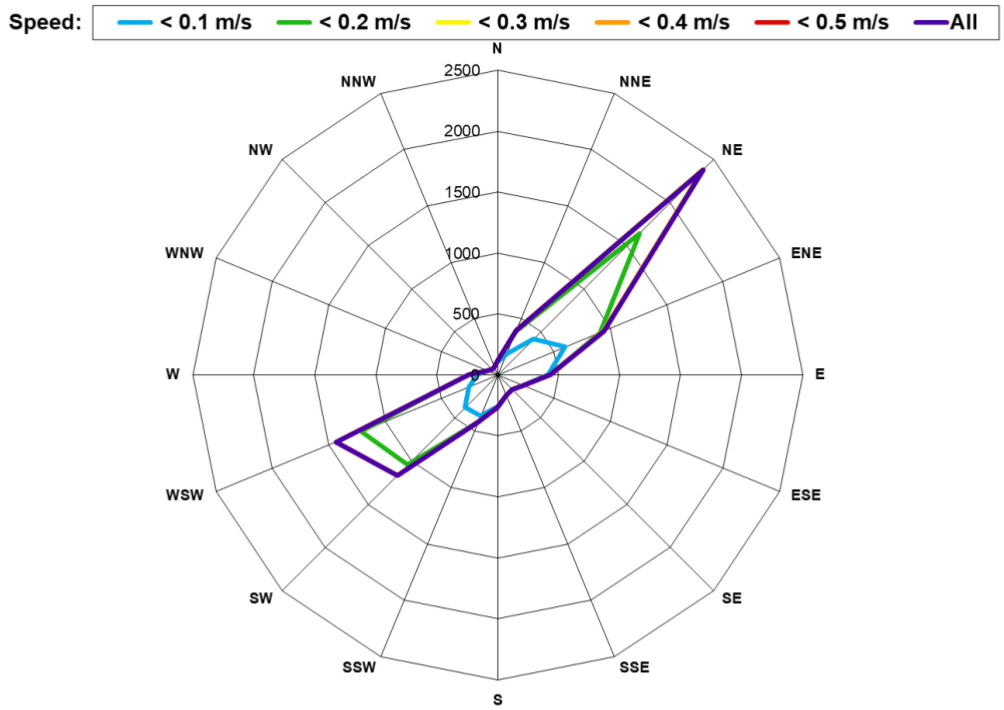



**Figure 3.34** Current rose at WQ1 for the monitoring period from July 2018 to September 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

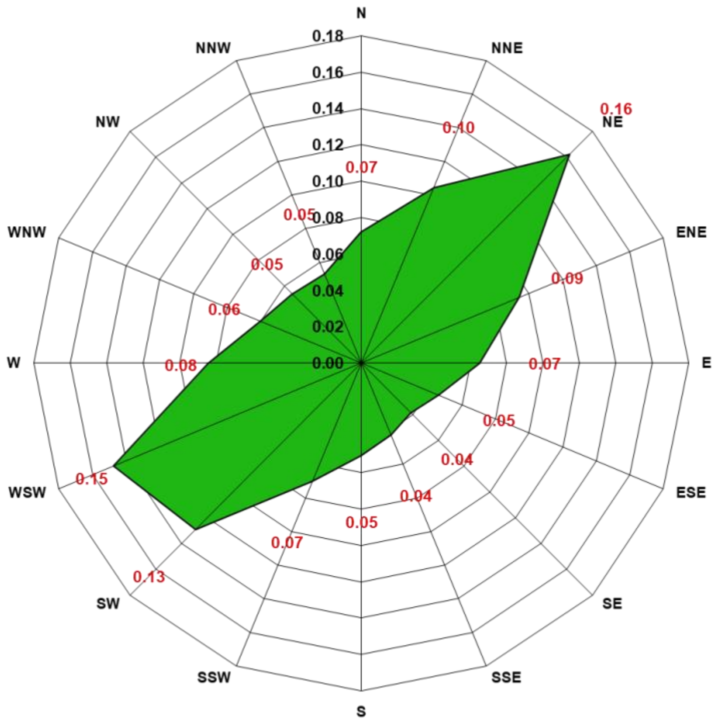



**Figure 3.35** Average current speed rose at WQ1 for the monitoring period from July 2018 to September 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

## 3.5 River Plumes

### 3.5.1 Site specific outputs

An important note here is that the Watson river is located ~75km south of the Mission River system adjacent to the Port of Weipa, and therefore Watson River discharge is only a proxy of actual discharge in Mission River. Given the variable nature of rainfall and river charges, some caution is required with the final interpretation of these analysis.

*WQ1*

A stepwise regression analysis was run against the WQ1 data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth, the Watson River discharge, and tide amplitude explained 70% of the SSC variability (Table 3.8). The relative importance analysis suggested that RMS of water depth is the most influential parameter on SSC (61% of overall $R^2$), followed by Watson River discharge (27% of overall $R^2$) and tidal amplitude (11% of overall $R^2$; Figure 3.36). Partial effects plots (Figure 3.37) show that SSC decreases with water depth and river discharge, and increases with tidal amplitude.

**Table 3.8** Statistical summary of the stepwise regression analysis to WQ1 data

| | WQ1 | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | -13.97 | -16.97 – -10.97 | **<0.001** |
| log(RMS) | -2.31 | -2.75 – -1.87 | **<0.001** |
| log(Watson+1) | -0.26 | -0.35 – -0.17 | **<0.001** |
| Amplitude | 1.57 | 1.05 – 2.09 | **<0.001** |
| Observations | 90 | | |
| $R^2$ / adjusted $R^2$ | 0.704 / 0.694 | | |

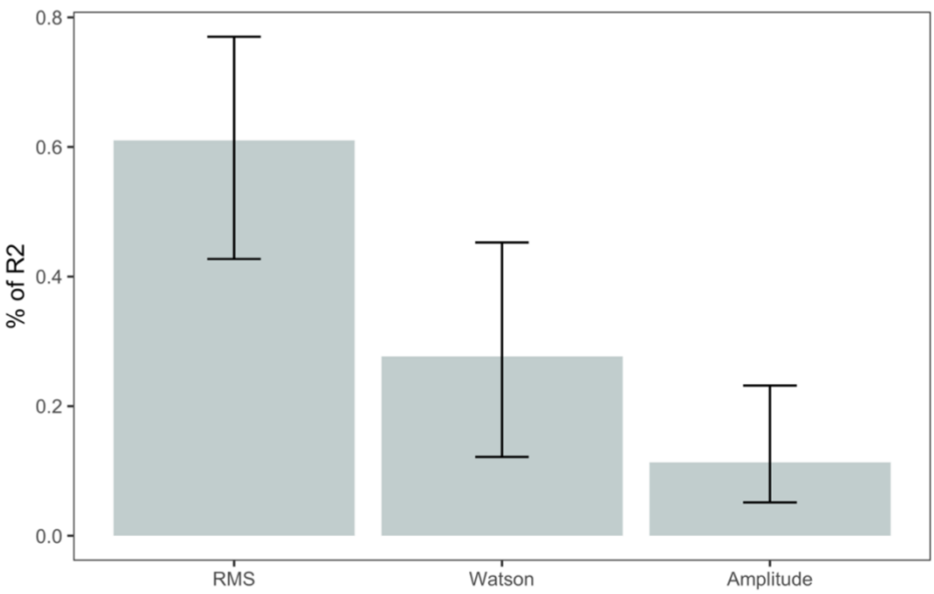



**Figure 3.36** WQ1 bootstrapping relative importance analysis following a stepwise multiple regression analysis. Barsrepresent 95% bootstrap confidence intervals, and % of r squared values are normalised to sum 100%

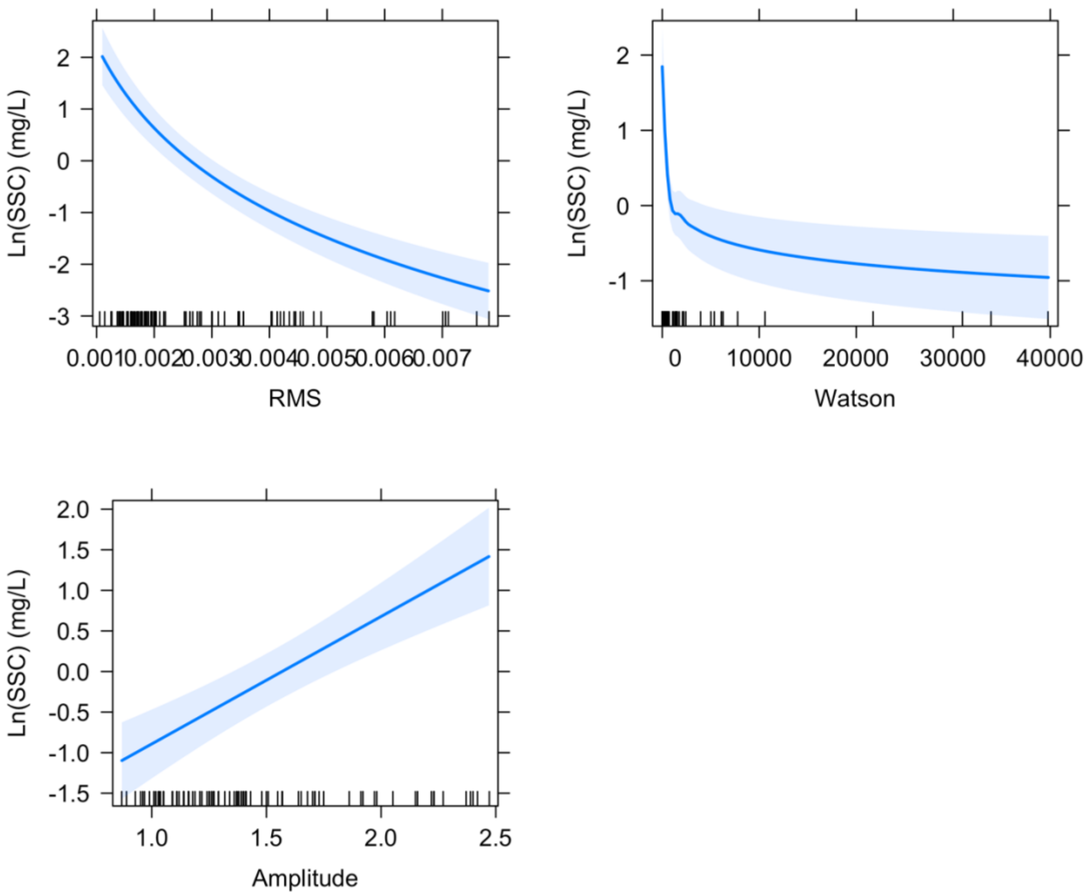



**Figure 3.37** Partial effect plots for WQ1 parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

*WQ2*

A stepwise regression analysis was run against the WQ2 data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth, Watson River discharge, the NESW wind component, and tidal amplitude explained 76% of the SSC variability (Table 3.9). The relative importance analysis suggested that RMS of water depth is the most influential parameter on SSC (54% of overall $R^2$), followed by Watson River discharge (28% of overall $R^2$), tidal amplitude (14% of overall $R^2$), and the NESW wind component (3% of overall $R^2$) (Figure 3.38). Results of the partial effects plots (Figure 3.39) followed expected trends for SSC in relation to each environmental parameter selected in the model. Clear patterns in SSC were observed against all the environmental parameters, with SSC increasing in relation to all environmental predictors (Figure 3.39).

**Table 3.9** Statistical summary of the stepwise regression analysis to WQ2 data

| | WQ2 | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 3.60 | 2.81 – 4.38 | **<0.001** |
| log(RMS) | 0.96 | 0.81 – 1.10 | **<0.001** |
| log(Watson+1) | 0.19 | 0.16 – 0.23 | **<0.001** |
| wind NESW | 0.06 | 0.04 – 0.09 | **<0.001** |
| Amplitude | 0.94 | 0.68 – 1.19 | **<0.001** |
| Observations | 109 | | |
| $R^2$ / adjusted $R^2$ | 0.775 / 0.767 | | |

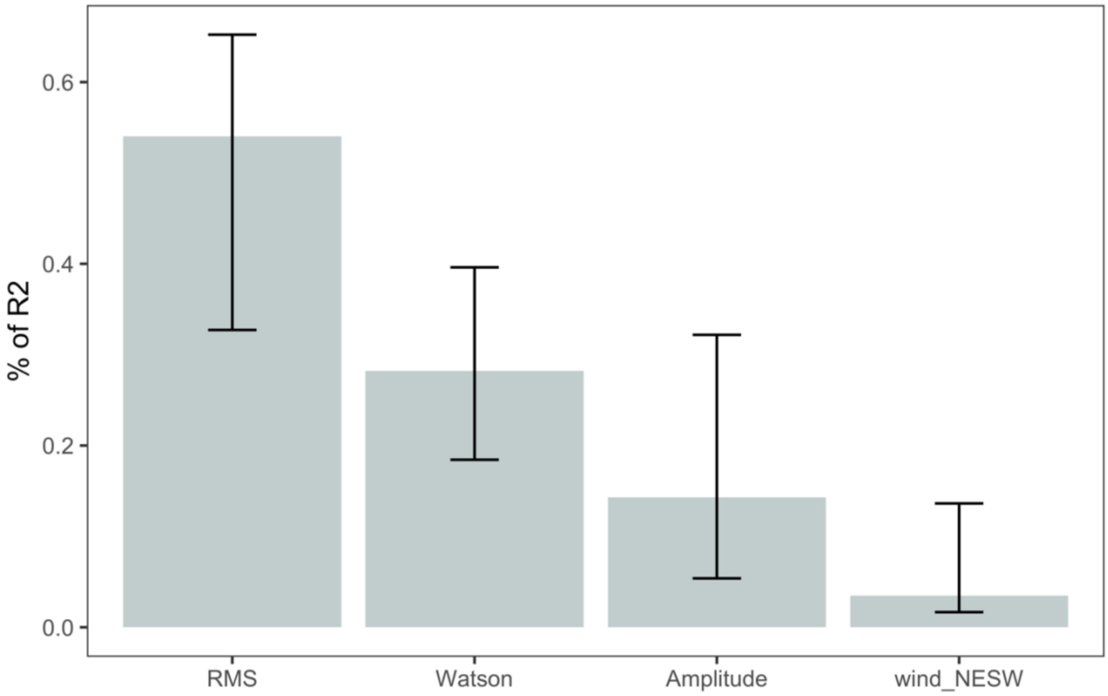



**Figure 3.38** WQ2 bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalised to sum 100%

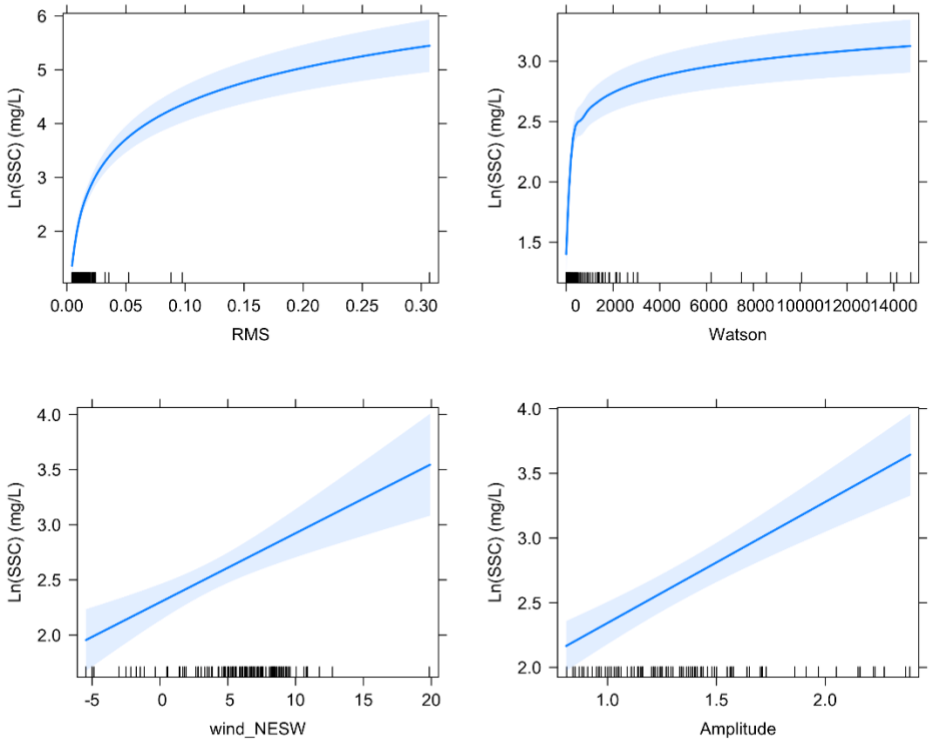



**Figure 3.39** Partial effect plots for WQ2 parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

*WQ3A*

A stepwise regression analysis was run against the WQ3A data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth was the only environmental parameter significantly related to SSC, explaining 91% of the SSC variability (Table 3.10). The partial effect plot (Figure 3.40) follows the expected trend, showing that SSC increases in relation to increasing RMS of water depth.

**Table 3.10** Statistical summary of the stepwise regression analysis to WQ3A data

| | **WQ3A** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 7.82 | 7.35 – 8.30 | **<0.001** |
| log(RMS) | 1.41 | 1.24 – 1.57 | **<0.001** |
| Observations | 29 | | |
| $R^2$ / adjusted $R^2$ | 0.912 / 0.909 | | |

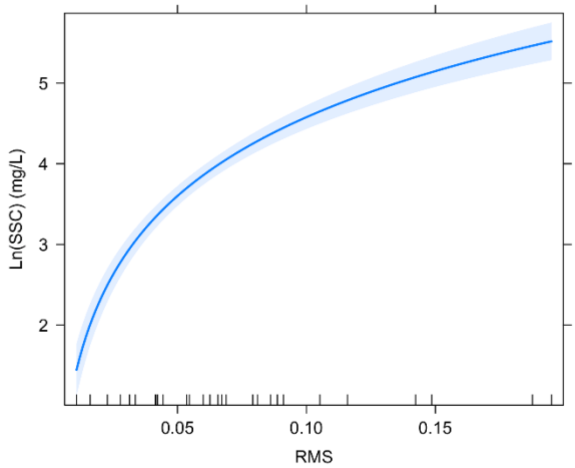



**Figure 3.40** Partial effect plot for WQ3A RMS affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

*WQ3*

A stepwise regression analysis was run against the WQ3 data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth, the NESW wind component, and tidal amplitude were the environmental parameters that were significantly related to SSC, explaining 90% of the SSC variability (Table 3.11). The relative importance analysis suggested that RMS of water depth is the most influential parameter on SSC (94% of overall $R^2$), followed by the NESW wind component (3% of overall $R^2$) and tidal amplitude (2.5% of overall $R^2$) (Figure 3.41). The partial effect plot (Figure 3.42) shows that SSC increases in relation to increasing RMS of water depth and a stronger NESW wind component, but decreases in relation to tidal amplitude.

**Table 3.11** Statistical summary of the stepwise regression analysis to WQ3 data

| | WQ3 | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 4.85 | 4.30 – 5.41 | **<0.001** |
| log(RMS) | 0.92 | 0.82 – 1.01 | **<0.001** |
| wind NESW | 0.05 | 0.03 – 0.07 | **<0.001** |
| Amplitude | -0.51 | -0.79 – -0.22 | **0.001** |
| Observations | 44 | | |
| $R^2$ / adjusted $R^2$ | 0.899 / 0.891 | | |

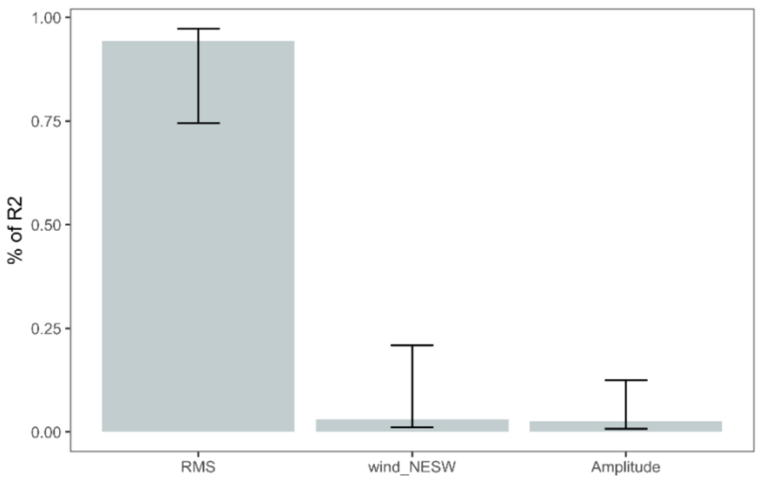



**Figure 3.41** WQ3 bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

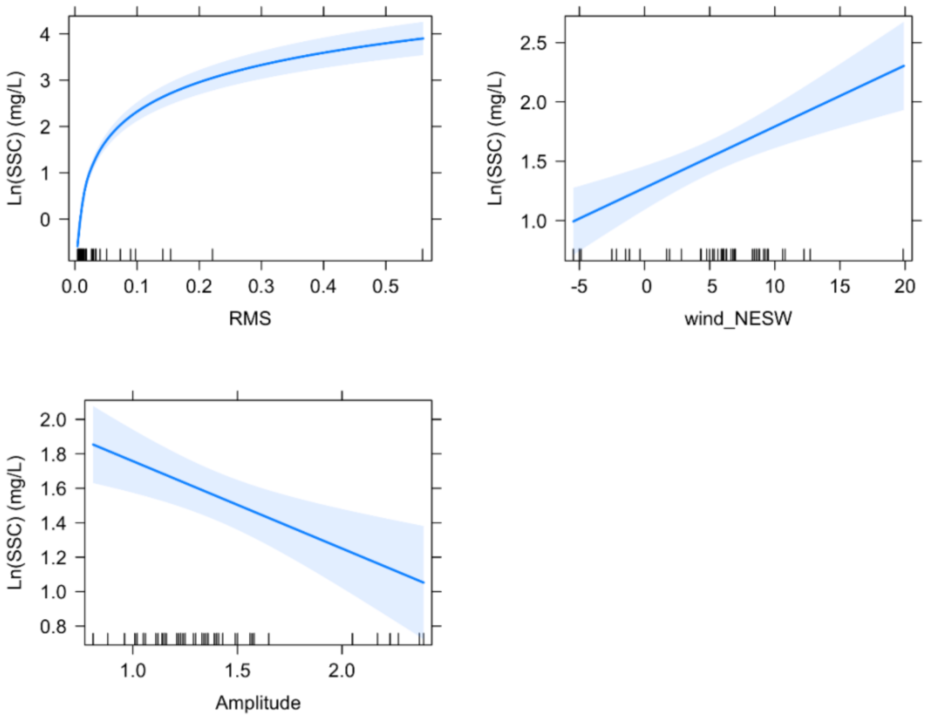



**Figure 3.42** Partial effect plots for WQ3 parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

*WQ4*

A stepwise regression analysis was run against the WQ4 data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. Watson river discharge, the NESW wind component and tidal amplitude explained 53% of the SSC variability (Table 12). The relative importance analysis suggested that Watson River discharge is the most influential parameter on SSC (52% of overall $R^2$), followed by tidal amplitude (29% of overall $R^2$), and the NESW wind component (20% of overall $R^2$) (Figure 3.43). Results of the partial effects plots (Figure 3.44) followed expected trends for SSC in relation to each environmental parameter selected in the model. An increase in SSC was observed with increases in Watson River discharge and tidal amplitude (Figure 3.44). Alternatively, stronger the winds coming from the east (i.e. positive values for wind_NESW) were related to lower SSC values (Figure 3.44).

**Table 3.12** Statistical summary of the stepwise regression analysis to WQ4 data

| | **WQ4** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 1.78 | 1.26 – 2.30 | **<0.001** |
| log(Watson+1) | 0.11 | 0.07 – 0.15 | **<0.001** |
| wind NESW | -0.04 | -0.06 – -0.01 | **0.014** |
| Amplitude | 0.87 | 0.54 – 1.20 | **<0.001** |
| Observations | 69 | | |
| $R^2$ / adjusted $R^2$ | 0.531 / 0.509 | | |

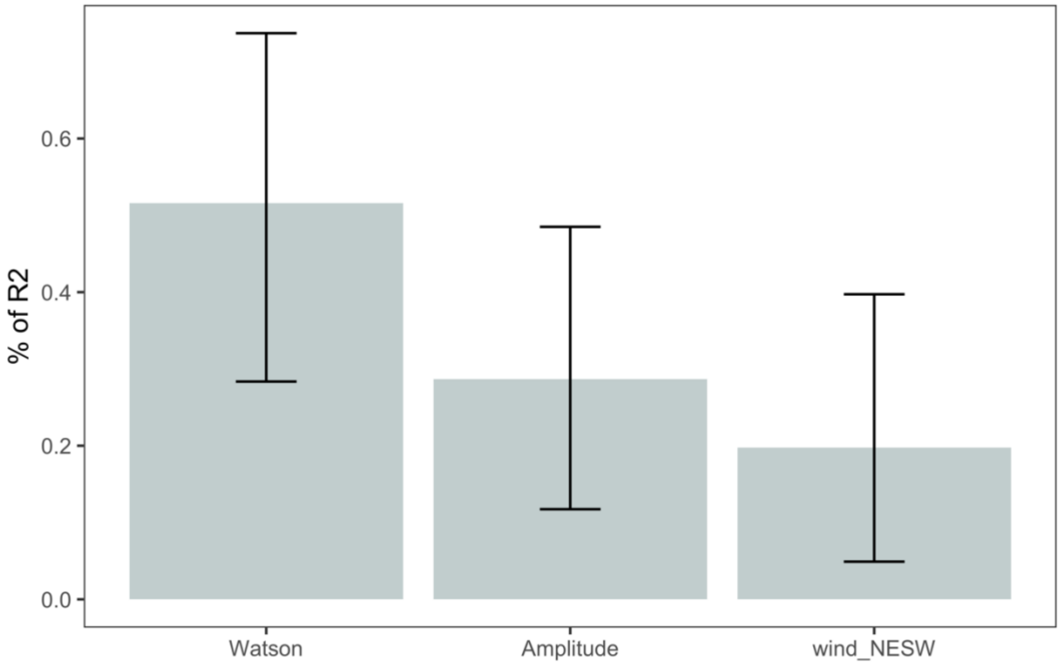



**Figure 3.43** WQ4 bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

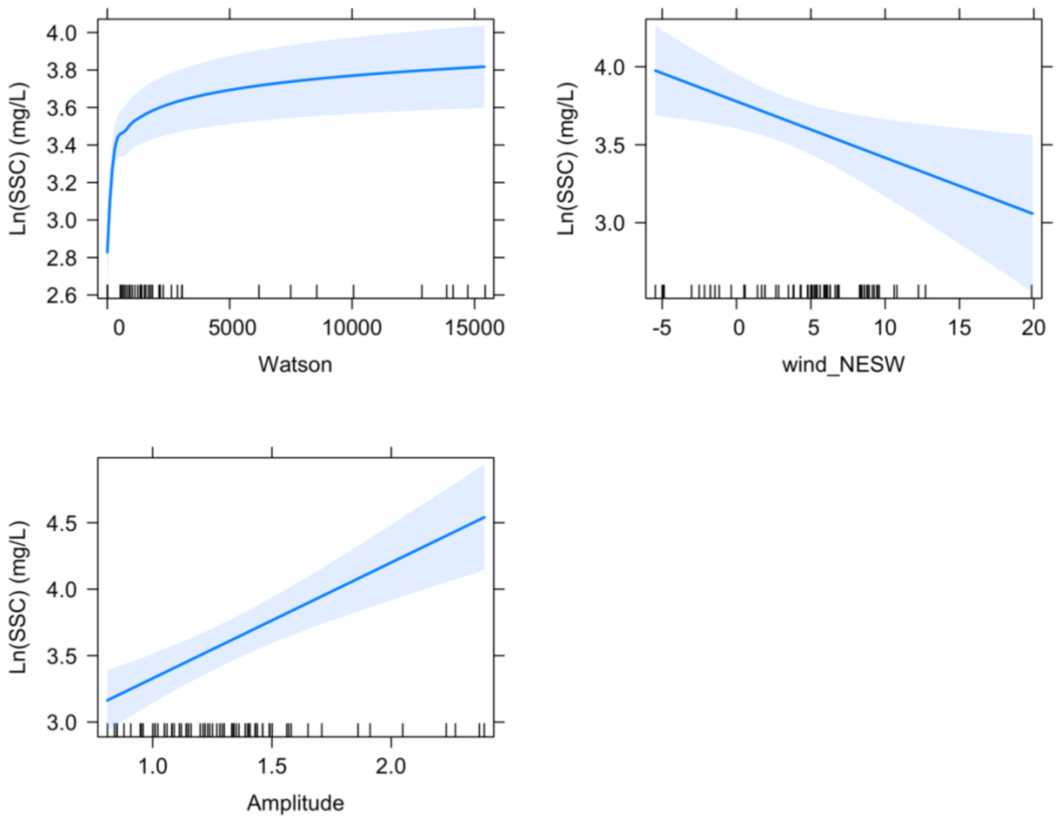



**Figure 3.44** Partial effect plots for WQ4 parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

*WQ5*

A stepwise regression analysis was run against the WQ5 data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth and Watson River discharge explained 56% of the SSC variability (Table 3.13). The relative importance analysis suggested that RMS of water depth and Watson River discharge were similar in their contribution to explaining SSC variability (50.1% and 49.8% of overall $R^2$, respectively) (Figure 3.45). Results of the partial effects plots (Figure 3.46) followed expected trends for SSC in relation to each environmental parameter selected in the model. Overall, an increase in SSC was observed with increases in RMS water depth and Watson River discharge.

**Table 3.13** Statistical summary of the stepwise regression analysis to WQ5 data

| | WQ5 | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 3.63 | 3.15 – 4.12 | **<0.001** |
| log(RMS) | 0.59 | 0.48 – 0.71 | **<0.001** |
| log(Watson+1) | 0.26 | 0.21 – 0.31 | **<0.001** |
| Observations | 158 | | |
| $R^2$ / adjusted $R^2$ | 0.561 / 0.555 | | |

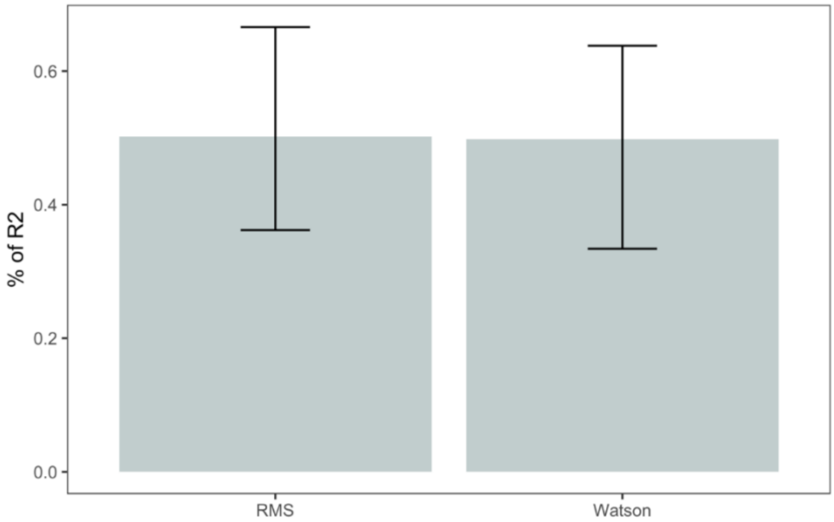



**Figure 3.45** WQ5 bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

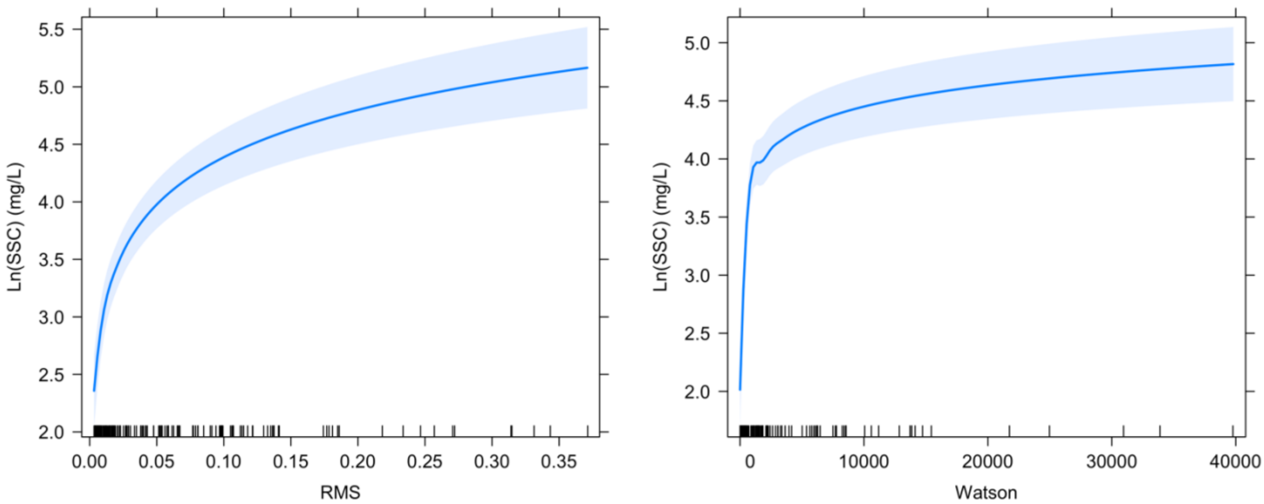



**Figure 3.46** Partial effect plots for WQ5 parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

# 4 CONCLUSIONS AND RECOMMENDATIONS

## 4.1 Conclusions

### 4.1.1 Climatic conditions

- An important factor to consider in interpreting data during this year of monitoring is that the 2017/18 wet season was in the order of the 40 %ile for the region.
- Comparison of these data with future years will be important to characterise ambient water quality conditions, particularly should the program experience above average rainfall in the future.
- The wind speed and direction recorded the study period has been a useful inclusion in this assessment. The daily average wind speed and direction recorded at Weipa airport for the reporting period (2017/18) was predominantly from the east and south east (> than 50% of the reporting days) and were of relatively higher speeds (> 24km/hr) in comparison to wind from other directions.

### 4.1.2 Ambient water quality

- There seems to be a seasonal pattern for water temperature emerging, with highest temperatures experienced during summer months, while winter months experience cooler conditions. This pattern will be monitored in future reports.
- The water column profile for dissolved oxygen, temperature, electrical conductivity and pH continue to be well mixed. The exception continues to be turbidity which is generally higher at bottom horizon, contributing to a distinct separation of water horizons. This pattern for turbidity is probably related to the bottom horizon being proximal to the sea floor and the remobilisation of sediments. The elevated turbidity in the bottom horizon becomes an important consideration when examining sensitive receptor habitats, such as seagrass which are sensitive to water clarity changes. Measuring bottom horizon turbidity is a very relevant component of this program; surface measurements for turbidity, or indeed suspended solid concentrations, might not be an entirely relevant measure when the objective is to protect and enhance benthic habitats.
- Particulate nitrogen and phosphorus is elevated above relevant guidelines. Given the relatively few data points, it is not clear whether these results reflect local underlying seasonal and site conditions, or reflect conditions influenced by the tropical cyclone that passed through the region during this monitoring period. It is possible also that the contributing factors to these data results might include localised signal associated with runoff from land use activities.
- Chlorophyll-*a* concentrations continue to exceed relevant guidelines, particularly when associated with high nutrient concentrations. Again, it is not clear whether these concentrations reflect the wet season influence or outline broader influences in the region.
- Phytoplankton and zooplankton communities had a very different species composition between surveys completed so far, which could reflect local seasonal conditions – this pattern will be further explored as more data becomes available for the region.
- Trace heavy metals were below guidelines among sites, though limited data is available yet to understand whether this pattern is more general for the region. The same is the case for water pesticides and herbicides.

### 4.1.3 Sediment deposition and turbidity

- Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in North Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment (Orpin and Ridd 2012), and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week.

- An important finding here was that deposition data indicated larger deposits compared to other north Queensland coastal marine sites investigated during this period.

#### 4.1.4 Photosynthetically active radiation (PAR)

- Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles (Orpin and Ridd 2012), and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids (Fabricius et al., 2013).
- Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter (Kirk 1985; Davis-Colley and Smith 2001). Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites and sites of closer proximity to one another were more similar than distant sites.
- While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations (Erftemeijer and Lewis 2006; Erftemeijer et al., 2012), the relationship between these two parameters is not always strong (Sofonia and Unsworth 2010). At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.

### 4.2 Recommendations

#### 4.2.1 Consolidation of the water quality loggers

Given this monitoring program has commenced in January 2018 it is recommended that the current program remain into the 2018/19 period. It will be important to ensure that the site network is ready to capture a full wet season, in order to characterise the upper water quality conditions for the region.

#### 4.2.2 Data base repository

An electronic version of the ambient marine water quality database has been prepared as an annexure to this report. It currently comprises MS-Excel Workbooks containing raw data files including results for water chemistry (*in-situ* field measurements, nutrients, filterable metals, pesticides/herbicides) collected as during the quarterly sampling, and all the continuous high frequency logger data files for sediment deposition, PAR, turbidity, water temperature, and RMS recorded during the period January and July 2018. This data base continues to be maintained by

TropWATER personal, with back up copy archived on the James Cook University network with restricted access.

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# 6 APPENDIX

## A.1 Calibration procedures

### Turbidity/Deposition Calibration

The turbidity and deposition sensors on each instrument are calibrated to a set of plastic optical standards that give consistent NTU return values. This enables the calculation of raw data values into NTU values. The NTU values can then be converted into SSC and ASSD values through the SSC calibration process. Deposition sensors are calibrated to give measurements in units of $mg/cm^2$ using the methodology outlined in Ridd *et al* (2000) and Thomas *et al* (2003). Instruments are calibrated every six months or after every deployment. Sediment samples are taken at each deployment site and used to determine sediment calibration coefficients used to account for variations in grain size and shape that can alter the implied SSC value.

### SSC Calibration

An instrument is placed in a large container (50 l) with black sides and the output is read on a computer attached to the logger. Saltwater is used to fill the container. Sediment from the study site is added to a small container of salt water and agitated. The water-sediment slurry is then added to the large container which is stirred with a small submerged pump. A water sample is taken and analysed for total suspended sediment (TSS) using standard laboratory techniques in the ACTFR laboratory at JCU which is accredited for these measurements. Approximately 6 different concentrations of sediment are used for each site. TSS is then plotted against the NTU reading from the logger for each of the different sediment concentrations. A linear correlation between NTU and SSC is then calculated. The correlations typically have an $r^2$ value equal to or greater than 0.9.

### Light Calibration

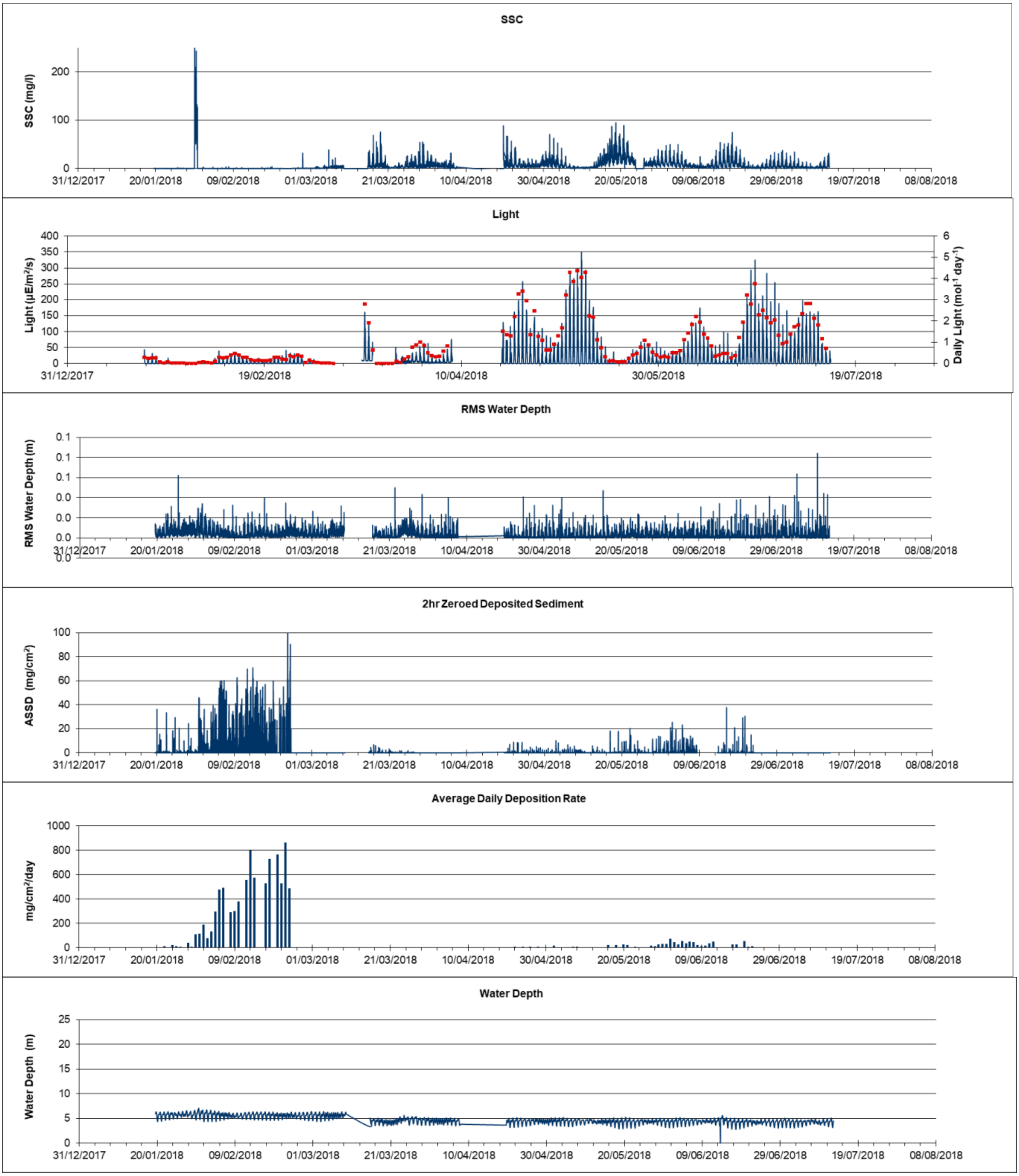
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration coefficient is used to ensure accurate reporting of PAR data. An in field comparison between the logger light sensor and LICOR U250A is made on deployment of the instruments to ensure accurate reporting of the data. In field calibration of the nephelometer light sensor against the LICOR U250A at varying depth has been carried out to account for changes in sensitivity changes at depth.

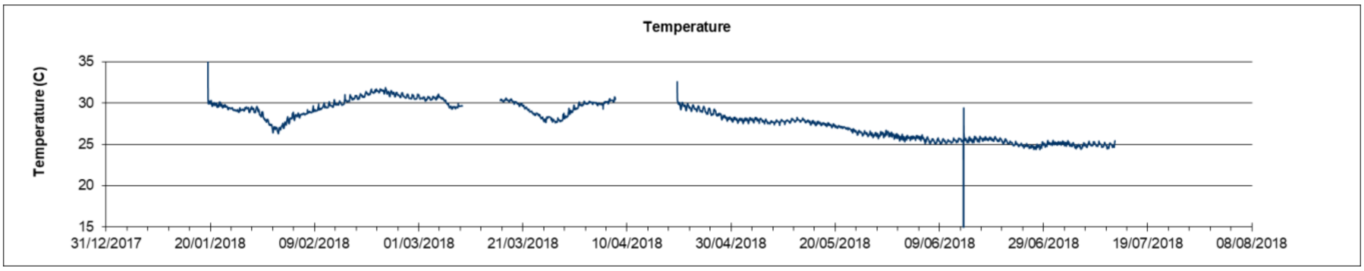
### Pressure Sensor Calibration

All pressure sensors are calibrated against a pressure gauge and the pressure is converted into depth in metres.

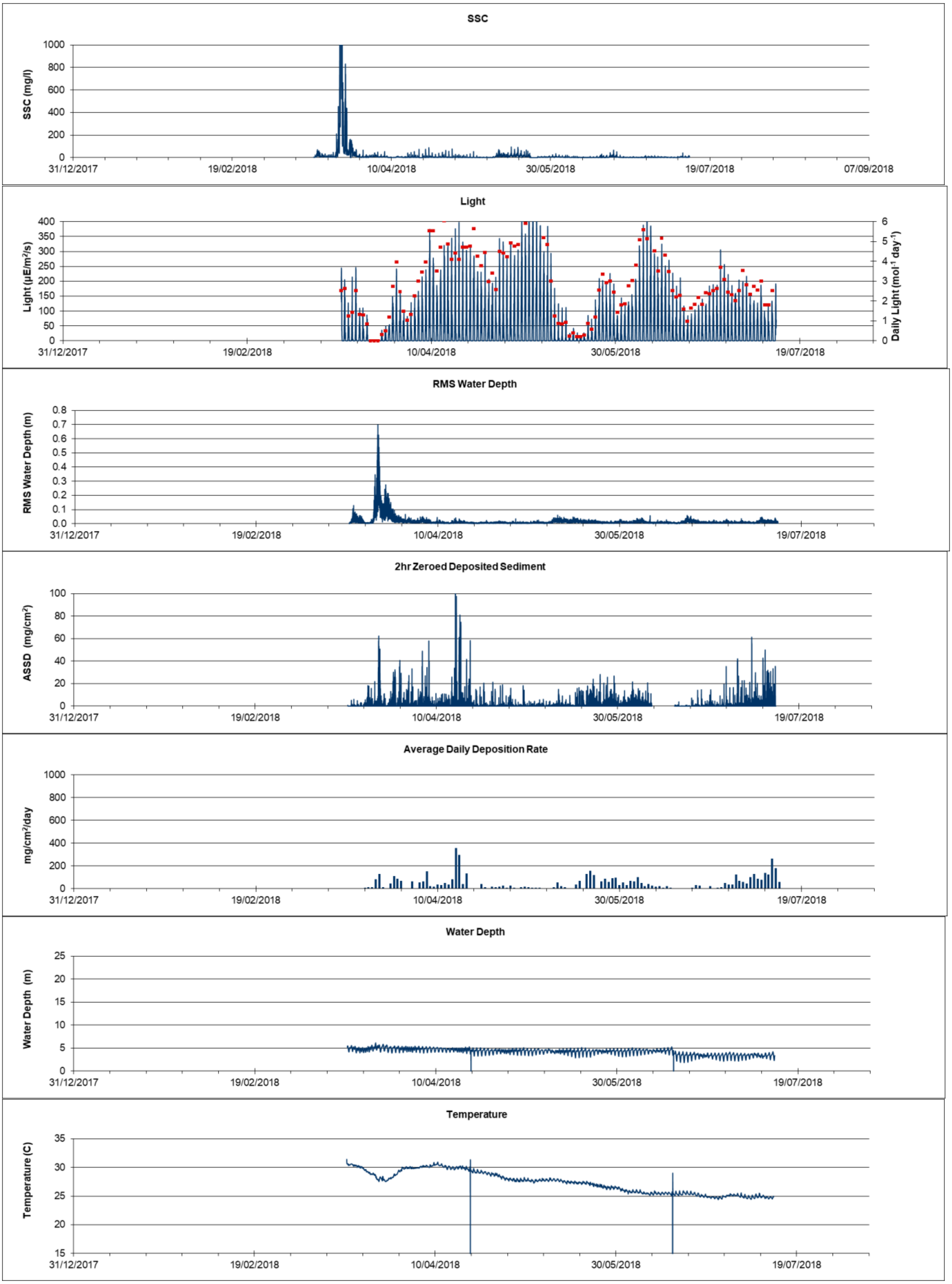
## A.2 Time Series Data

WQ1

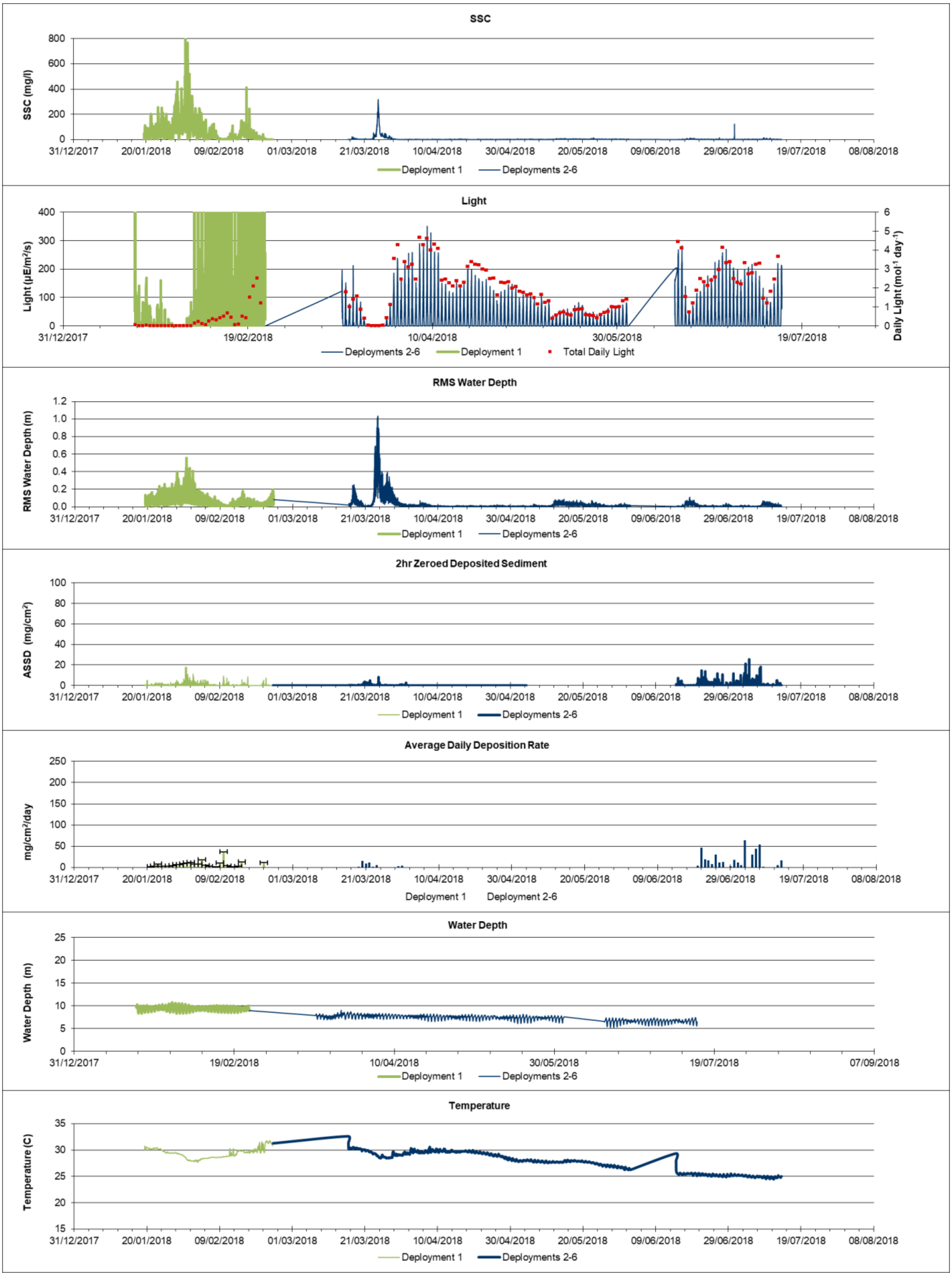



Temperature
Temperature (C)
35
30
25
20
15
31/12/2017
20/01/2018
09/02/2018
01/03/2018
21/03/2018
10/04/2018
30/04/2018
20/05/2018
09/06/2018
29/06/2018
19/07/2018
08/08/2018

## WQ2

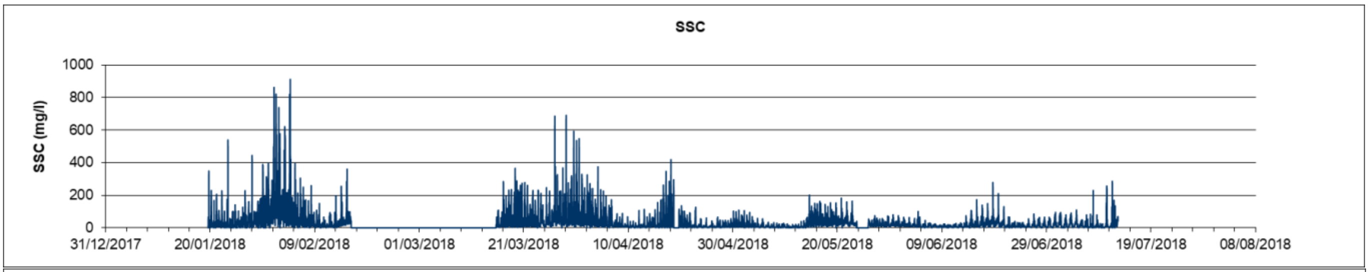

SSC
SSC (mg/l)
1000
800
600
400
200
0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
07/09/2018
Light
Light (µE/m²/s)
Daily Light (mol⁻¹ day⁻¹)
400
350
300
250
200
150
100
50
0
6
5
4
3
2
1
0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
RMS Water Depth
RMS Water Depth (m)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
2hr Zeroed Deposited Sediment
ASSD (mg/cm²)
100
80
60
40
20
0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
Average Daily Deposition Rate
mg/cm²/day
1000
800
600
400
200
0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
Water Depth
Water Depth (m)
25
20
15
10
5
0
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
Temperature
Temperature (C)
35
30
25
20
15
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018

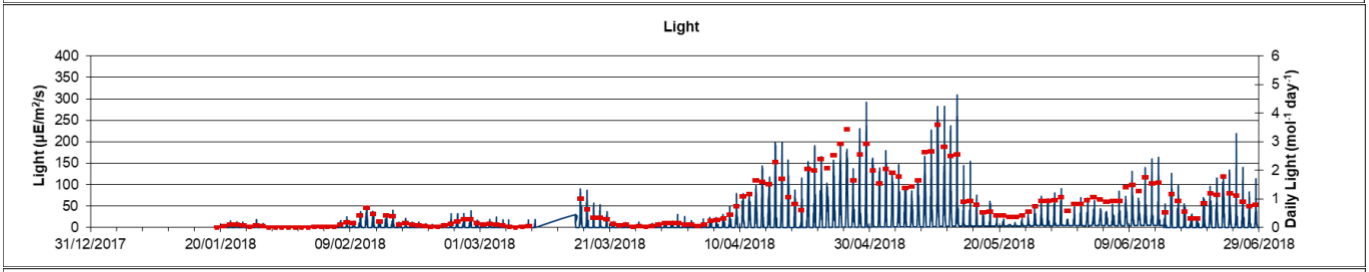
## WQ3

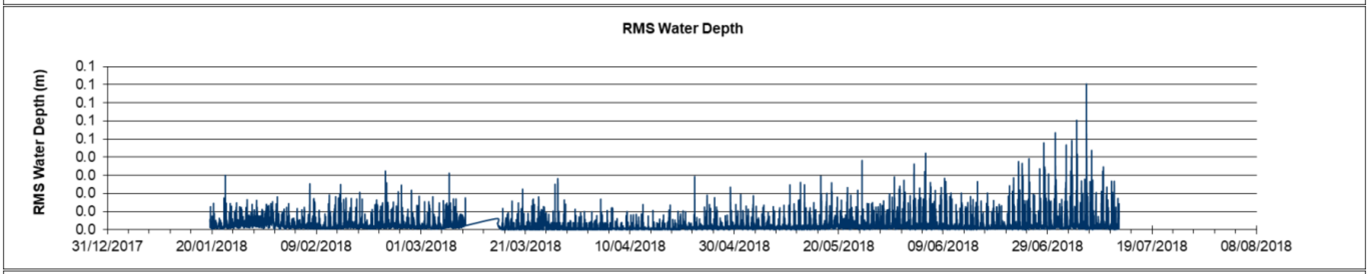


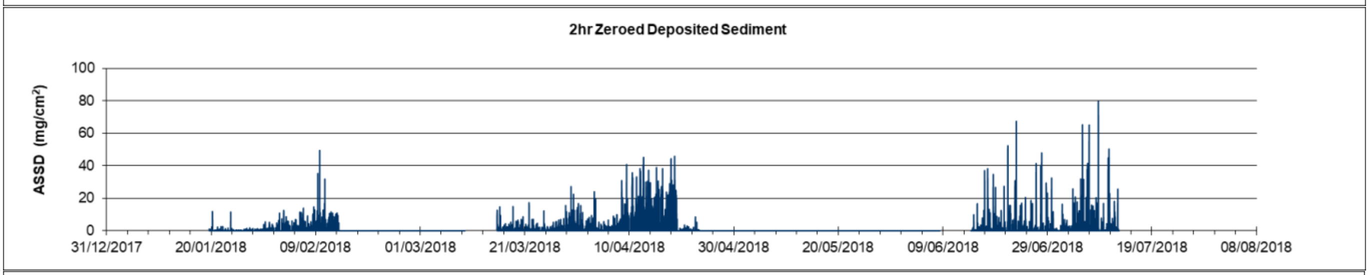

Please note for WQ3 that the deployment 1 data (in green) and the data from deployments 2-6 (in blue) have been separated because the instrument was moved in between deployments.

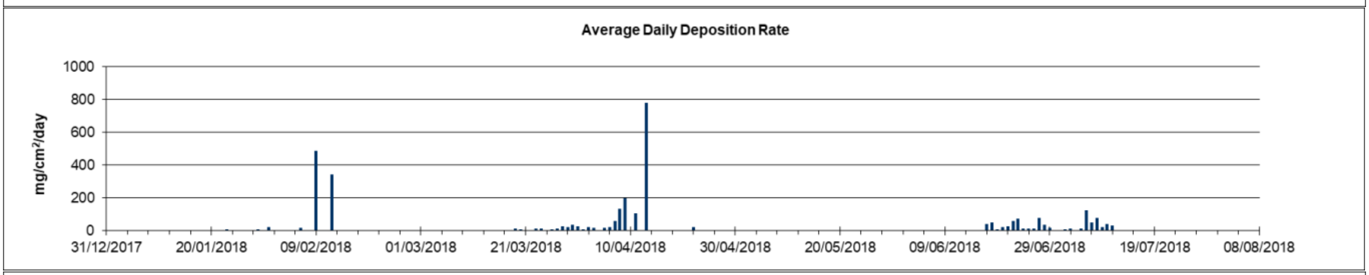
## WQ4

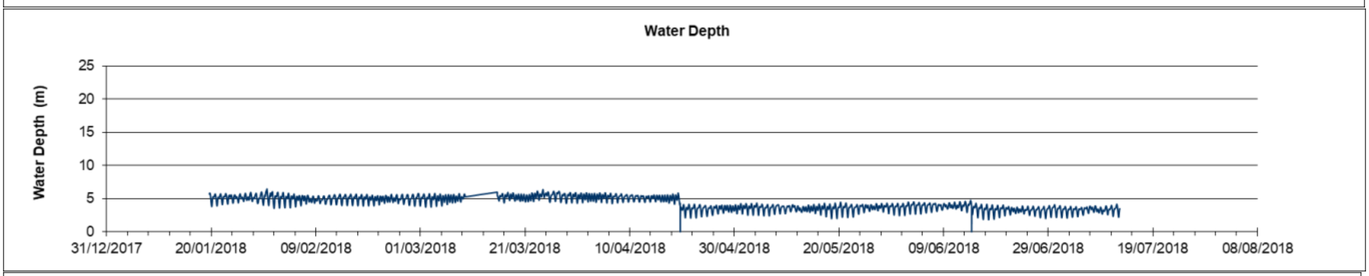

SSC
SSC (mg/l)
0 200 400 600 800 1000
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

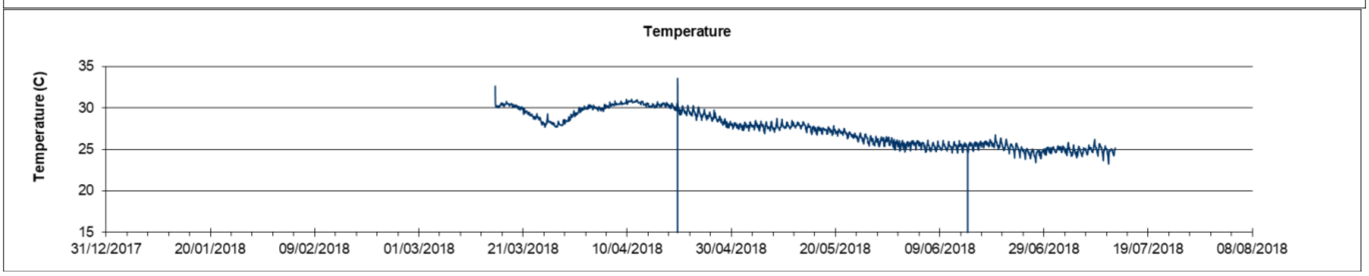

Light
Light (µE/m²/s)
0 50 100 150 200 250 300 350 400
Daily Light (mol⁻¹ day⁻¹)
0 1 2 3 4 5 6
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018


RMS Water Depth
RMS Water Depth (m)
0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.1 0.1
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

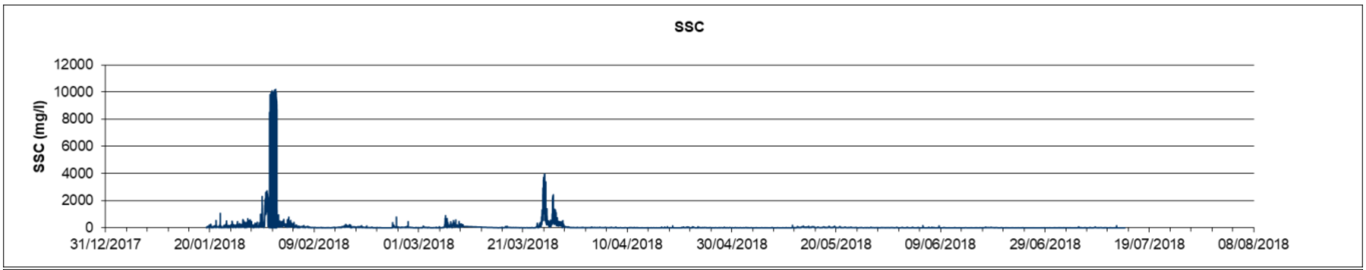

2hr Zeroed Deposited Sediment
ASSD (mg/cm²)
0 20 40 60 80 100
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

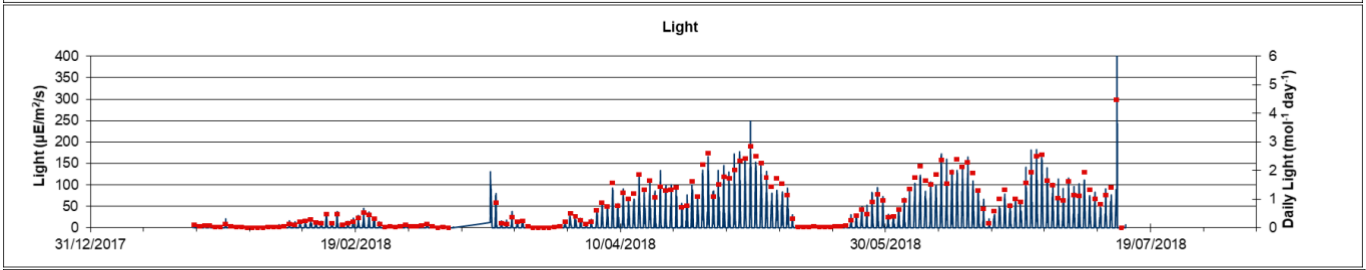

Average Daily Deposition Rate
mg/cm²/day
0 200 400 600 800 1000
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

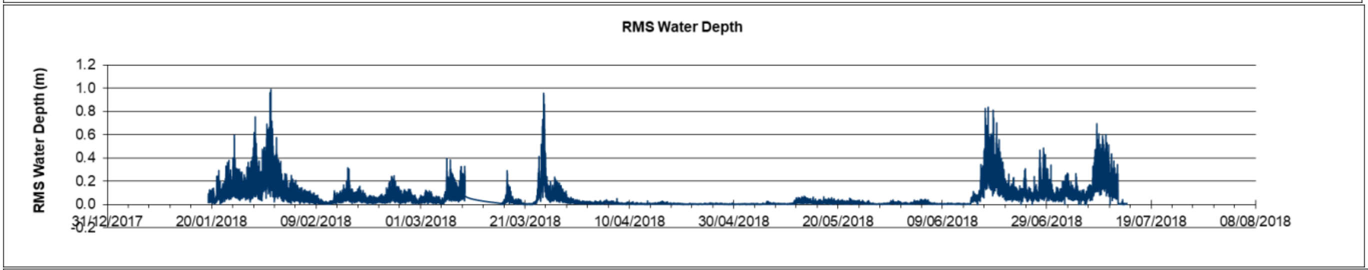

Water Depth
Water Depth (m)
0 5 10 15 20 25
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

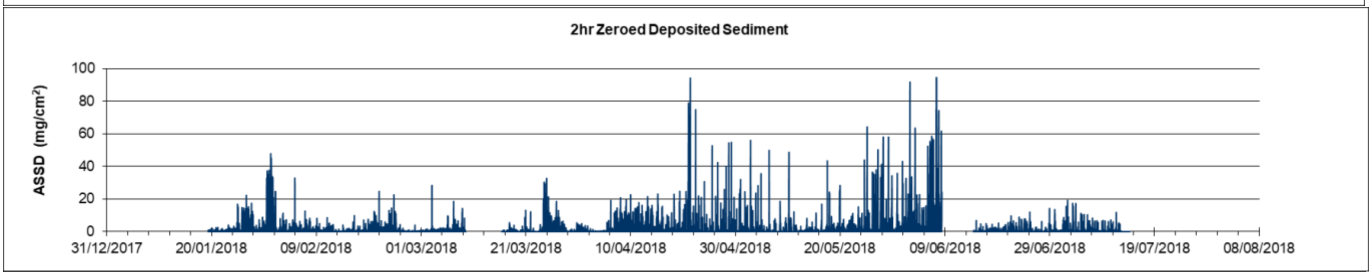

Temperature
Temperature (C)
15 20 25 30 35
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

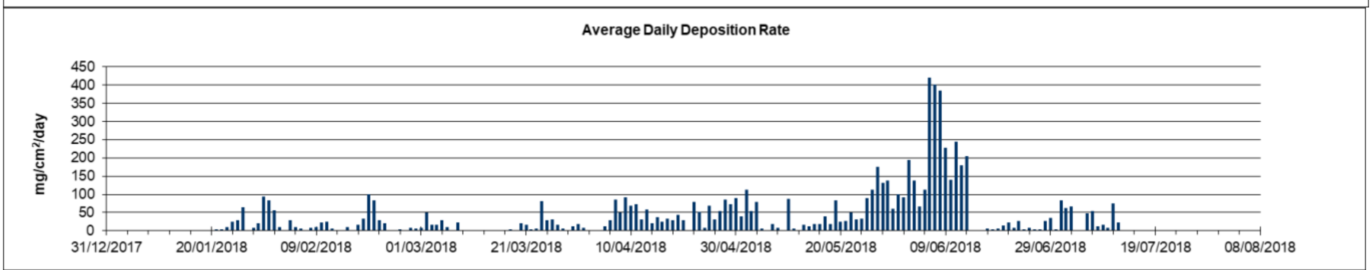
## WQ5

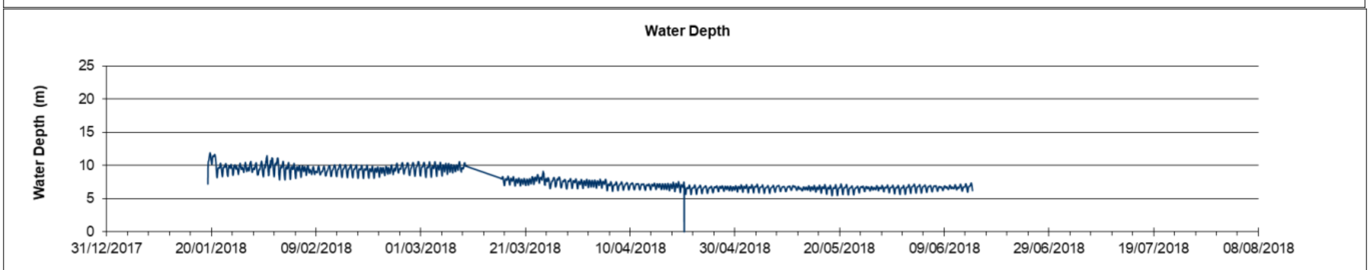

SSC
SSC (mg/l)
0 2000 4000 6000 8000 10000 12000
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

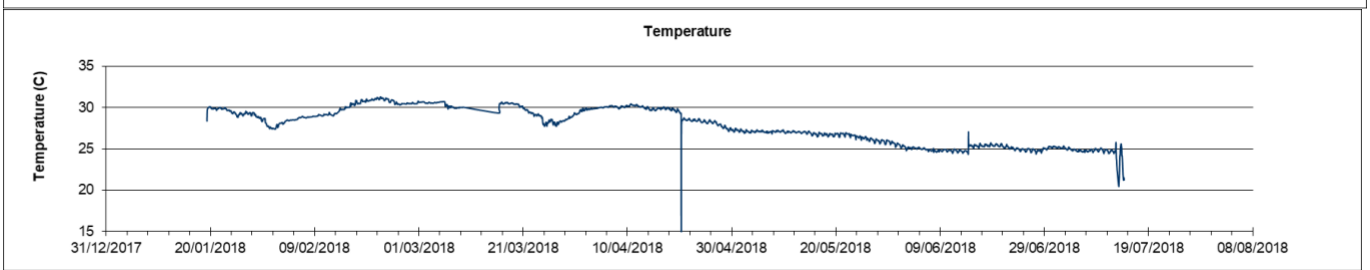

Light
Light (µE/m²/s)
0 50 100 150 200 250 300 350 400
Daily Light (mol¹ day⁻¹)
0 1 2 3 4 5 6
31/12/2017 19/02/2018 10/04/2018 30/05/2018 19/07/2018


RMS Water Depth
RMS Water Depth (m)
-0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018


2hr Zeroed Deposited Sediment
ASSD (mg/cm²)
0 20 40 60 80 100
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018


Average Daily Deposition Rate
mg/cm²/day
0 50 100 150 200 250 300 350 400 450
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018


Water Depth
Water Depth (m)
0 5 10 15 20 25
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018


Temperature
Temperature (C)
15 20 25 30 35
31/12/2017 20/01/2018 09/02/2018 01/03/2018 21/03/2018 10/04/2018 30/04/2018 20/05/2018 09/06/2018 29/06/2018 19/07/2018 08/08/2018

## A.3 Summary of monthly statistics

**WQ1**

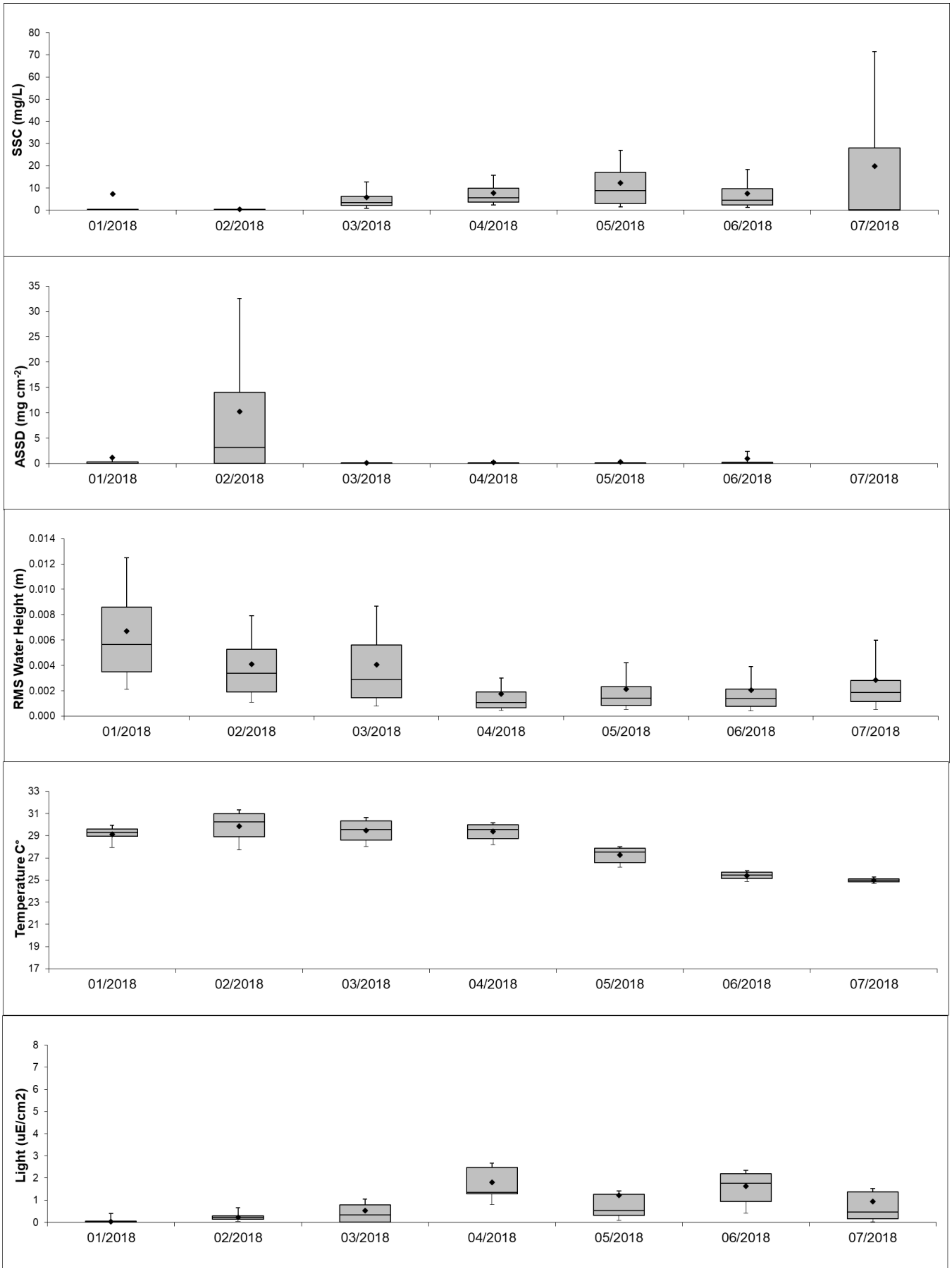
| | SSC 01/2018 | SSC 02/2018 | SSC 03/2018 | SSC 04/2018 | SSC 05/2018 | SSC 06/2018 | SSC 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 7.37 | 0.31 | 5.71 | 7.74 | 12.19 | 7.60 | 19.84 |
| median | 0.21 | 0.21 | 3.44 | 5.56 | 8.73 | 4.49 | 0.05 |
| min | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.02 |
| lower | 0.17 | 0.17 | 2.00 | 3.65 | 3.03 | 2.32 | 0.03 |
| upper | 0.27 | 0.27 | 6.10 | 9.82 | 17.03 | 9.75 | 28.03 |
| max | 267.57 | 31.90 | 75.57 | 87.68 | 94.99 | 73.66 | 194.76 |
| 90th percentile | 0.39 | 0.44 | 12.76 | 15.70 | 27.06 | 18.41 | 71.60 |
| 10th percentile | 0.12 | 0.12 | 0.76 | 2.38 | 1.35 | 1.25 | 0.02 |
| n | 1789 | 3696 | 3478 | 2550 | 4140 | 4292 | 1687 |
| St. Dev | 30.07 | 1.06 | 7.17 | 6.94 | 12.12 | 8.30 | 34.02 |
| St. Error | 0.71 | 0.02 | 0.12 | 0.14 | 0.19 | 0.13 | 0.83 |

| | ASSD 01/2018 | ASSD 02/2018 | ASSD 03/2018 | ASSD 04/2018 | ASSD 05/2018 | ASSD 06/2018 | ASSD 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 1.11 | 10.21 | 0.11 | 0.22 | 0.34 | 0.93 | |
| median | 0.00 | 3.16 | 0.00 | 0.00 | 0.00 | 0.00 | |
| min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| lower | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | |
| upper | 0.30 | 14.04 | 0.05 | 0.06 | 0.08 | 0.21 | |
| max | 46.01 | 110.83 | 6.82 | 8.89 | 20.14 | 37.92 | |
| 90th percentile | 1.07 | 32.60 | 0.22 | 0.36 | 0.43 | 2.36 | |
| 10th percentile | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| n | 1707 | 2579 | 1682 | 1614 | 4276 | 2375 | |
| St. Dev | 4.52 | 14.86 | 0.44 | 0.85 | 1.47 | 3.00 | |
| St. Error | 0.11 | 0.29 | 0.01 | 0.02 | 0.02 | 0.06 | |

| | RMS 01/2018 | RMS 02/2018 | RMS 03/2018 | RMS 04/2018 | RMS 05/2018 | RMS 06/2018 | RMS 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.0067 | 0.0041 | 0.0041 | 0.0017 | 0.0021 | 0.0021 | 0.0029 |
| median | 0.0056 | 0.0034 | 0.0029 | 0.0011 | 0.0014 | 0.0014 | 0.0019 |
| min | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| lower | 0.0035 | 0.0019 | 0.0015 | 0.0006 | 0.0008 | 0.0008 | 0.0011 |
| upper | 0.0086 | 0.0053 | 0.0056 | 0.0019 | 0.0023 | 0.0021 | 0.0028 |
| max | 0.0623 | 0.0400 | 0.0500 | 0.0409 | 0.0471 | 0.0413 | 0.0841 |
| $90^{th}$ percentile | 0.0125 | 0.0079 | 0.0087 | 0.0030 | 0.0042 | 0.0039 | 0.0060 |
| $10^{th}$ percentile | 0.0021 | 0.0011 | 0.0008 | 0.0005 | 0.0005 | 0.0004 | 0.0005 |
| n | 1795 | 4032 | 3417 | 2608 | 4462 | 4307 | 1687 |
| St. Dev | 0.0048 | 0.0032 | 0.0037 | 0.0026 | 0.0026 | 0.0029 | 0.0044 |
| St. Error | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0001 |

| | Temp 01/2018 | Temp 02/2018 | Temp 03/2018 | Temp 04/2018 | Temp 05/2018 | Temp 06/2018 | Temp 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 29.14 | 29.86 | 29.46 | 29.37 | 27.26 | 25.39 | 24.96 |
| median | 29.28 | 30.23 | 29.56 | 29.54 | 27.52 | 25.43 | 24.96 |
| min | 26.45 | 26.30 | 27.61 | 27.72 | 25.64 | 24.37 | 24.42 |
| lower | 28.93 | 28.89 | 28.62 | 28.74 | 26.57 | 25.12 | 24.82 |
| upper | 29.58 | 30.97 | 30.35 | 29.97 | 27.85 | 25.69 | 25.11 |
| max | 36.57 | 31.88 | 31.08 | 32.59 | 28.27 | 29.29 | 25.44 |
| $90^{th}$ percentile | 29.94 | 31.33 | 30.62 | 30.15 | 28.00 | 25.85 | 25.26 |
| $10^{th}$ percentile | 27.95 | 27.70 | 28.00 | 28.21 | 26.17 | 24.84 | 24.69 |
| n | 1795 | 4032 | 3417 | 2607 | 4462 | 4307 | 1687 |
| St. Dev | 0.76 | 1.36 | 0.95 | 0.73 | 0.69 | 0.39 | 0.21 |
| St. Error | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |

| | Light 01/2018 | Light 02/2018 | Light 03/2018 | Light 04/2018 | Light 05/2018 | Light 06/2018 | Light 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.04 | 0.23 | 0.52 | 1.80 | 1.22 | 1.63 | 0.95 |
| median | 0.02 | 0.23 | 0.34 | 1.35 | 0.54 | 1.77 | 0.47 |
| min | 0.01 | 0.02 | 0.00 | 0.62 | 0.06 | 0.27 | 0.00 |
| lower | 0.01 | 0.14 | 0.02 | 1.28 | 0.30 | 0.94 | 0.16 |
| upper | 0.04 | 0.30 | 0.78 | 2.49 | 1.27 | 2.19 | 1.38 |
| max | 0.11 | 0.47 | 2.79 | 3.40 | 4.37 | 3.76 | 4.37 |
| $90^{th}$ percentile | 0.07 | 0.39 | 0.98 | 3.25 | 4.04 | 2.80 | 2.50 |
| $10^{th}$ percentile | 0.01 | 0.05 | 0.00 | 0.79 | 0.09 | 0.40 | 0.03 |
| n | 13 | 28 | 24 | 17 | 31 | 30 | 154 |
| St. Dev | 0.03 | 0.13 | 0.67 | 0.94 | 1.42 | 0.91 | 1.08 |
| St. Error | 0.01 | 0.02 | 0.14 | 0.23 | 0.26 | 0.17 | 0.09 |


SSC (mg/L)
ASSD (mg cm-2)
RMS Water Height (m)
Temperature C°
Light (uE/cm2)
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

**WQ2**

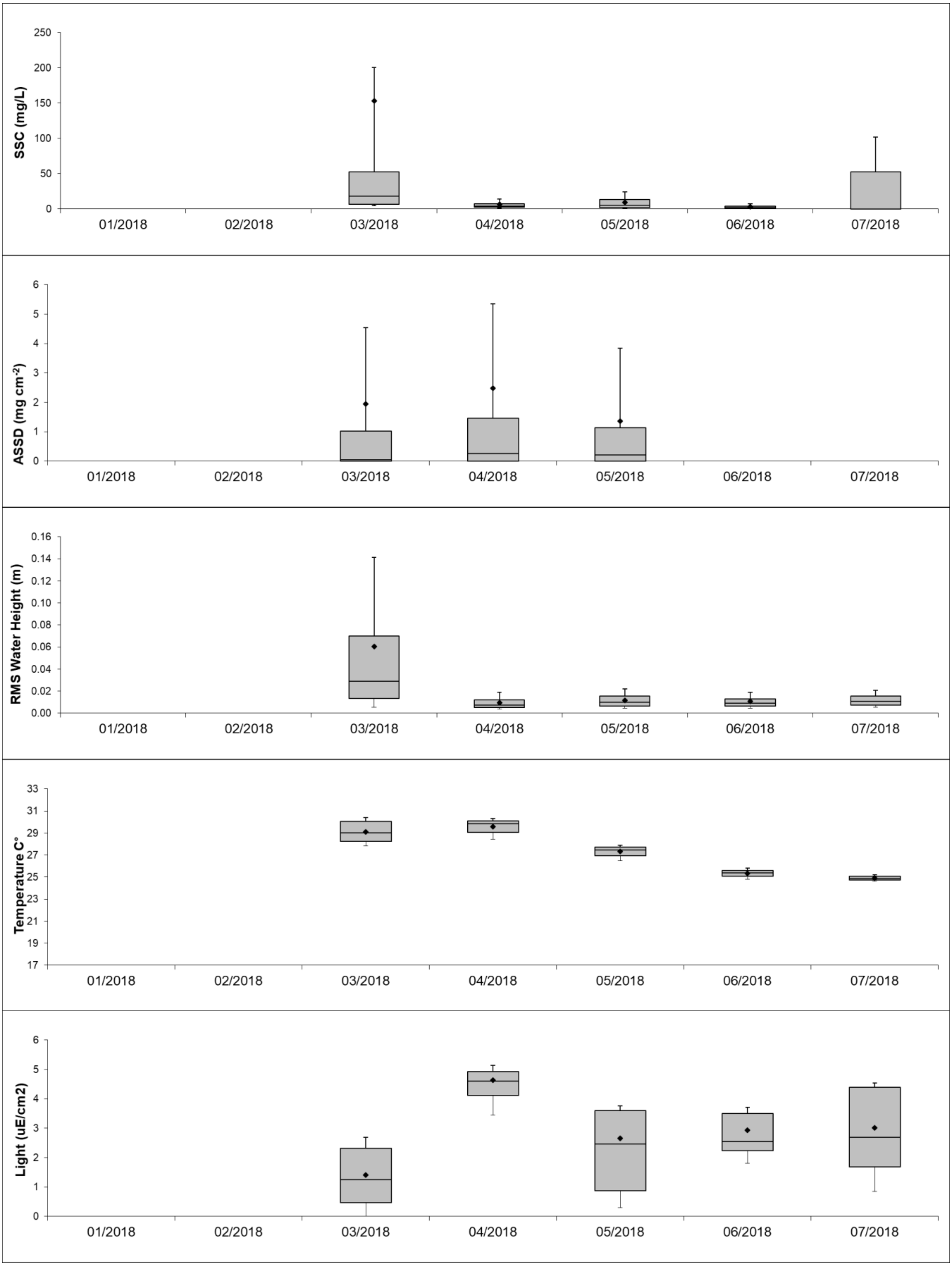
| | SSC 01/2018 | SSC 02/2018 | SSC 03/2018 | SSC 04/2018 | SSC 05/2018 | SSC 06/2018 | SSC 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | | | 153.58 | 6.69 | 9.69 | 3.51 | 29.63 |
| median | | | 17.99 | 4.16 | 5.58 | 2.09 | 0.00 |
| min | | | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 |
| lower | | | 6.97 | 2.46 | 2.00 | 1.11 | 0.00 |
| upper | | | 52.63 | 7.39 | 13.17 | 3.95 | 52.54 |
| max | | | 5904.24 | 88.57 | 94.85 | 66.90 | 216.83 |
| $90^{th}$ percentile | | | 200.29 | 14.42 | 24.56 | 7.52 | 101.69 |
| $10^{th}$ percentile | | | 4.58 | 1.61 | 1.01 | 0.53 | 0.00 |
| n | | | 2217 | 4156 | 4125 | 4304 | 1674 |
| St. Dev | | | 550.98 | 7.91 | 11.22 | 4.69 | 45.50 |
| St. Error | | | 11.70 | 0.12 | 0.17 | 0.07 | 1.11 |

| | ASSD 01/2018 | ASSD 02/2018 | ASSD 03/2018 | ASSD 04/2018 | ASSD 05/2018 | ASSD 06/2018 | ASSD 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | | | 1.94 | 2.49 | 1.37 | | |
| median | | | 0.05 | 0.26 | 0.21 | | |
| min | | | 0.00 | 0.00 | 0.00 | | |
| lower | | | 0.00 | 0.00 | 0.00 | | |
| upper | | | 1.02 | 1.47 | 1.13 | | |
| max | | | 60.90 | 127.16 | 28.09 | | |
| $90^{th}$ percentile | | | 4.54 | 5.35 | 3.84 | | |
| $10^{th}$ percentile | | | 0.00 | 0.00 | 0.00 | | |
| n | | | 2149 | 4153 | 4180 | | |
| St. Dev | | | 5.87 | 8.55 | 3.06 | | |
| St. Error | | | 0.13 | 0.13 | 0.05 | | |

| | RMS 01/2018 | RMS 02/2018 | RMS 03/2018 | RMS 04/2018 | RMS 05/2018 | RMS 06/2018 | RMS 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | | | 0.0605 | 0.0096 | 0.0118 | 0.0107 | 0.0123 |
| median | | | 0.0288 | 0.0074 | 0.0098 | 0.0091 | 0.0107 |
| min | | | 0.0011 | 0.0011 | 0.0015 | 0.0006 | 0.0021 |
| lower | | | 0.0133 | 0.0051 | 0.0063 | 0.0065 | 0.0075 |
| upper | | | 0.0700 | 0.0121 | 0.0154 | 0.0130 | 0.0158 |
| max | | | 0.6956 | 0.0668 | 0.0610 | 0.0590 | 0.0467 |
| $90^{th}$ percentile | | | 0.1412 | 0.0189 | 0.0219 | 0.0189 | 0.0209 |
| $10^{th}$ percentile | | | 0.0055 | 0.0037 | 0.0044 | 0.0047 | 0.0055 |
| n | | | 2226.0000 | 4314.0000 | 4462.0000 | 4314.0000 | 1674.0000 |
| St. Dev | | | 0.0878 | 0.0067 | 0.0073 | 0.0064 | 0.0066 |
| St. Error | | | 0.0019 | 0.0001 | 0.0001 | 0.0001 | 0.0002 |

| | Temp 01/2018 | Temp 02/2018 | Temp 03/2018 | Temp 04/2018 | Temp 05/2018 | Temp 06/2018 | Temp 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | | | 29.11 | 29.57 | 27.32 | 25.34 | 24.90 |
| median | | | 29.02 | 29.83 | 27.48 | 25.37 | 24.88 |
| min | | | 27.52 | 27.63 | 25.87 | 24.38 | 24.42 |
| lower | | | 28.22 | 29.05 | 26.96 | 25.07 | 24.72 |
| upper | | | 30.04 | 30.11 | 27.72 | 25.60 | 25.07 |
| max | | | 31.41 | 31.29 | 28.25 | 28.89 | 25.56 |
| $90^{th}$ percentile | | | 30.42 | 30.32 | 27.89 | 25.81 | 25.22 |
| $10^{th}$ percentile | | | 27.84 | 28.42 | 26.49 | 24.81 | 24.62 |
| n | | | 2226 | 4314 | 4462 | 4314 | 1674 |
| St. Dev | | | 0.96 | 0.73 | 0.53 | 0.37 | 0.23 |
| St. Error | | | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |

| | Light 01/2018 | Light 02/2018 | Light 03/2018 | Light 04/2018 | Light 05/2018 | Light 06/2018 | Light 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | | | 1.41 | 4.64 | 2.66 | 2.92 | 3.01 |
| median | | | 1.25 | 4.60 | 2.45 | 2.54 | 2.69 |
| min | | | 0.00 | 2.59 | 0.21 | 0.98 | 0.00 |
| lower | | | 0.46 | 4.11 | 0.87 | 2.23 | 1.68 |
| upper | | | 2.31 | 4.93 | 3.60 | 3.51 | 4.39 |
| max | | | 3.97 | 7.51 | 7.58 | 6.90 | 7.58 |
| $90^{th}$ percentile | | | 2.87 | 5.93 | 5.60 | 4.60 | 5.30 |
| $10^{th}$ percentile | | | 0.00 | 3.45 | 0.30 | 1.81 | 0.85 |
| n | | | 16 | 30 | 31 | 30 | 118 |
| St. Dev | | | 1.19 | 1.04 | 2.18 | 1.26 | 1.80 |
| St. Error | | | 0.30 | 0.19 | 0.39 | 0.23 | 0.17 |


SSC (mg/L)
ASSD (mg cm-2)
RMS Water Height (m)
Temperature C°
Light (uE/cm2)
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

**WQ3**

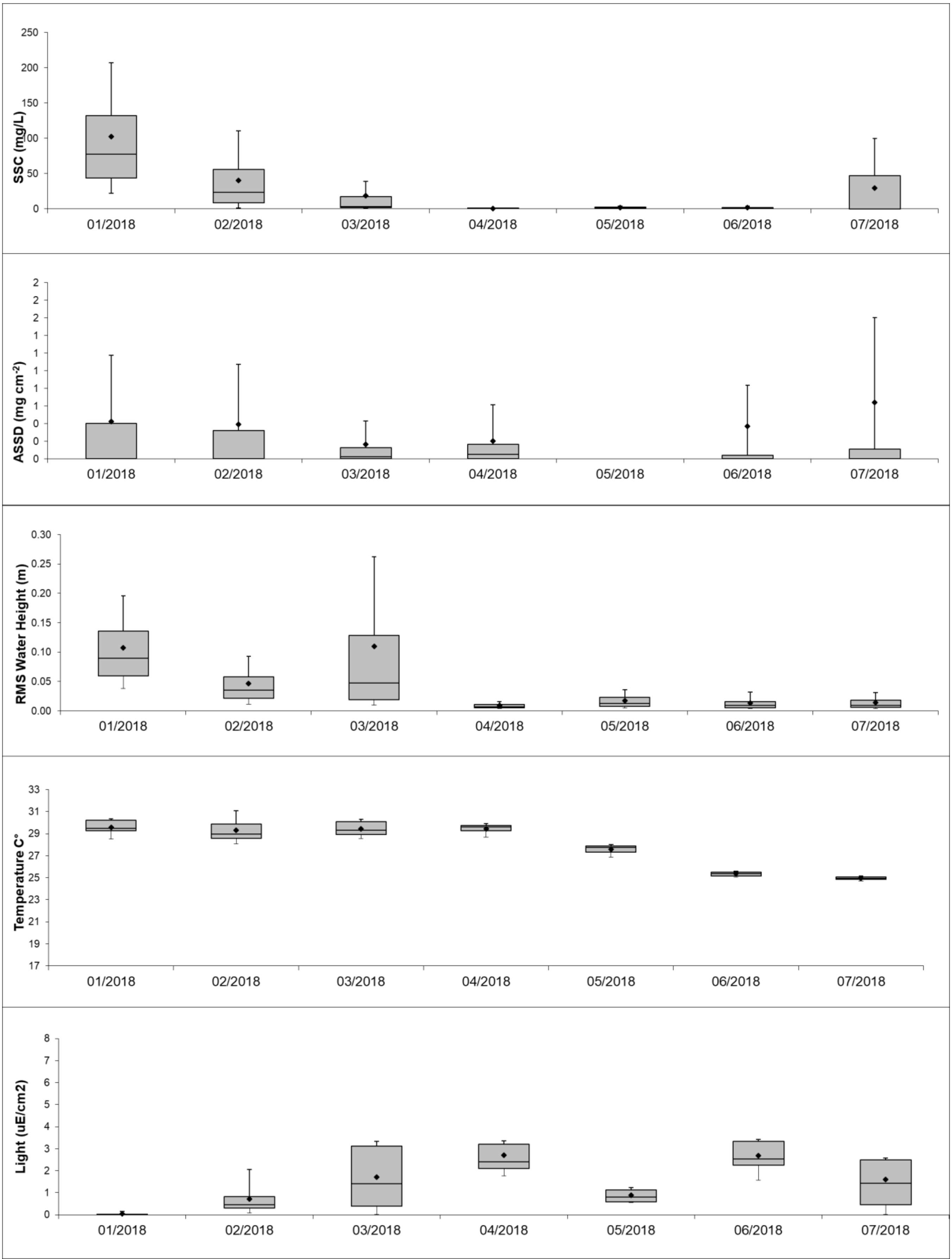
| | SSC 01/2018 | SSC 02/2018 | SSC 03/2018 | SSC 04/2018 | SSC 05/2018 | SSC 06/2018 | SSC 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 102.96 | 40.79 | 18.88 | 0.75 | 2.21 | 1.79 | 29.61 |
| median | 77.68 | 23.61 | 3.57 | 0.63 | 1.91 | 1.15 | 0.07 |
| min | 0.35 | 0.00 | 0.24 | 0.00 | 0.33 | 0.00 | 0.01 |
| lower | 43.97 | 8.91 | 1.94 | 0.45 | 1.18 | 0.72 | 0.05 |
| upper | 132.55 | 55.86 | 17.53 | 0.87 | 2.86 | 1.99 | 47.31 |
| max | 814.10 | 411.40 | 317.38 | 6.85 | 13.38 | 121.51 | 220.07 |
| 90th percentile | 207.55 | 110.64 | 38.91 | 1.21 | 3.91 | 3.69 | 100.09 |
| 10th percentile | 22.55 | 1.42 | 1.00 | 0.32 | 0.78 | 0.43 | 0.04 |
| n | 1783 | 2985 | 2232 | 3998 | 4459 | 2510 | 1728 |
| St. Dev | 92.00 | 47.13 | 42.67 | 0.55 | 1.40 | 3.20 | 46.94 |
| St. Error | 2.18 | 0.86 | 0.90 | 0.01 | 0.02 | 0.06 | 1.13 |

| | ASSD 01/2018 | ASSD 02/2018 | ASSD 03/2018 | ASSD 04/2018 | ASSD 05/2018 | ASSD 06/2018 | ASSD 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.42 | 0.39 | 0.16 | 0.20 | | 0.37 | 0.64 |
| median | 0.00 | 0.00 | 0.03 | 0.05 | | 0.00 | 0.00 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| lower | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| upper | 0.40 | 0.32 | 0.13 | 0.17 | | 0.04 | 0.11 |
| max | 17.76 | 11.04 | 8.09 | 2.58 | | 14.44 | 25.40 |
| 90th percentile | 1.18 | 1.07 | 0.43 | 0.61 | | 0.84 | 1.60 |
| 10th percentile | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| n | 1782 | 2498 | 2207 | 109 | | 2329 | 1671 |
| St. Dev | 1.14 | 0.96 | 0.43 | 0.39 | | 1.31 | 2.24 |
| St. Error | 0.03 | 0.02 | 0.01 | 0.04 | | 0.03 | 0.05 |

| | RMS 01/2018 | RMS 02/2018 | RMS 03/2018 | RMS 04/2018 | RMS 05/2018 | RMS 06/2018 | RMS 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.1073 | 0.0462 | 0.1095 | 0.0089 | 0.0172 | 0.0137 | 0.0138 |
| median | 0.0892 | 0.0351 | 0.0476 | 0.0071 | 0.0124 | 0.0090 | 0.0093 |
| min | 0.0089 | 0.0000 | 0.0020 | 0.0000 | 0.0012 | 0.0010 | 0.0013 |
| lower | 0.0598 | 0.0213 | 0.0194 | 0.0051 | 0.0073 | 0.0056 | 0.0058 |
| upper | 0.1361 | 0.0583 | 0.1282 | 0.0106 | 0.0233 | 0.0161 | 0.0182 |
| max | 0.5416 | 0.4082 | 1.0337 | 0.0709 | 0.0871 | 0.1103 | 0.0694 |
| $90^{th}$ percentile | 0.1959 | 0.0932 | 0.2622 | 0.0161 | 0.0361 | 0.0318 | 0.0309 |
| $10^{th}$ percentile | 0.0384 | 0.0117 | 0.0098 | 0.0037 | 0.0050 | 0.0040 | 0.0041 |
| n | 1795.0000 | 3277.0000 | 2238.0000 | 4318.0000 | 4462.0000 | 2516.0000 | 1728.0000 |
| St. Dev | 0.0697 | 0.0388 | 0.1585 | 0.0062 | 0.0135 | 0.0130 | 0.0116 |
| St. Error | 0.0016 | 0.0007 | 0.0034 | 0.0001 | 0.0002 | 0.0003 | 0.0003 |

| | Temp 01/2018 | Temp 02/2018 | Temp 03/2018 | Temp 04/2018 | Temp 05/2018 | Temp 06/2018 | Temp 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 29.57 | 29.29 | 29.42 | 29.46 | 27.59 | 25.38 | 24.94 |
| median | 29.50 | 28.96 | 29.31 | 29.61 | 27.73 | 25.36 | 24.96 |
| min | 27.90 | 27.65 | 28.43 | 27.95 | 26.25 | 24.86 | 24.44 |
| lower | 29.28 | 28.57 | 28.93 | 29.27 | 27.33 | 25.15 | 24.84 |
| upper | 30.20 | 29.85 | 30.07 | 29.75 | 27.90 | 25.48 | 25.07 |
| max | 30.59 | 31.80 | 32.62 | 30.59 | 28.26 | 29.36 | 25.36 |
| $90^{th}$ percentile | 30.34 | 31.08 | 30.30 | 29.91 | 28.01 | 25.58 | 25.16 |
| $10^{th}$ percentile | 28.51 | 28.07 | 28.56 | 28.70 | 26.85 | 25.06 | 24.69 |
| n | 1795 | 3277 | 2238 | 4318 | 4462 | 2516 | 1728 |
| St. Dev | 0.69 | 1.03 | 0.66 | 0.48 | 0.44 | 0.33 | 0.18 |
| St. Error | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |

| | Light 01/2018 | Light 02/2018 | Light 03/2018 | Light 04/2018 | Light 05/2018 | Light 06/2018 | Light 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.05 | 0.73 | 1.72 | 2.70 | 0.89 | 2.68 | 1.61 |
| median | 0.01 | 0.46 | 1.40 | 2.40 | 0.81 | 2.54 | 1.43 |
| min | 0.00 | 0.06 | 0.00 | 1.64 | 0.40 | 0.74 | 0.00 |
| lower | 0.00 | 0.32 | 0.40 | 2.10 | 0.60 | 2.25 | 0.45 |
| upper | 0.03 | 0.83 | 3.11 | 3.20 | 1.13 | 3.33 | 2.49 |
| max | 0.25 | 2.52 | 4.69 | 4.63 | 1.68 | 4.46 | 4.69 |
| $90^{th}$ percentile | 0.15 | 1.82 | 3.58 | 4.13 | 1.37 | 4.05 | 3.39 |
| $10^{th}$ percentile | 0.00 | 0.07 | 0.01 | 1.77 | 0.56 | 1.58 | 0.01 |
| n | 13 | 16 | 21 | 30 | 26 | 22 | 140 |
| St. Dev | 0.08 | 0.74 | 1.53 | 0.86 | 0.35 | 0.93 | 1.31 |
| St. Error | 0.02 | 0.18 | 0.33 | 0.16 | 0.07 | 0.20 | 0.11 |



SSC (mg/L)
250
200
150
100
50
0
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018
ASSD (mg cm⁻²)
2
2
2
1
1
1
1
1
0
0
0
RMS Water Height (m)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Temperature C°
33
31
29
27
25
23
21
19
17
Light (uE/cm2)
8
7
6
5
4
3
2
1
0

**WQ4**

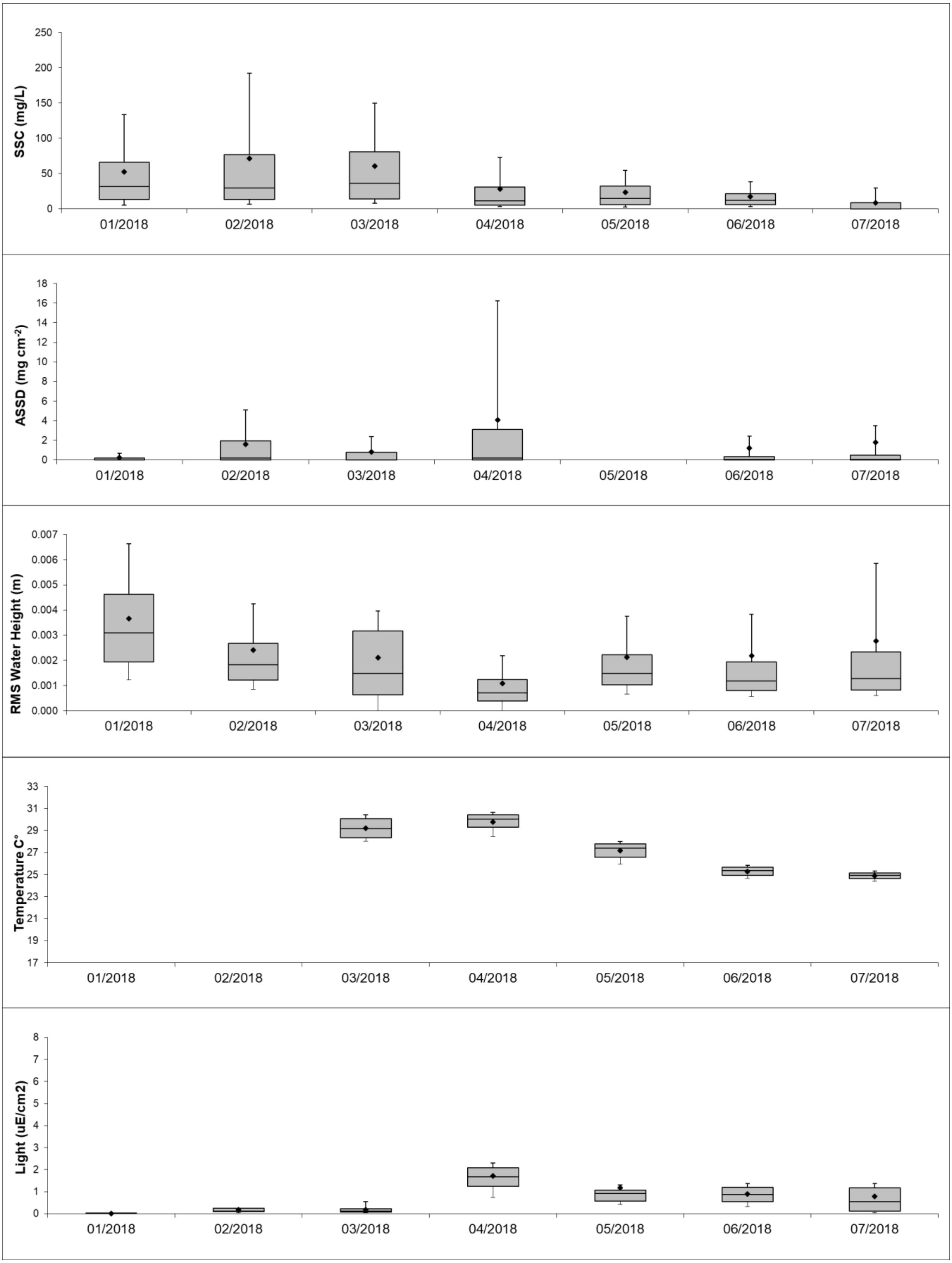
| | SSC 01/2018 | SSC 02/2018 | SSC 03/2018 | SSC 04/2018 | SSC 05/2018 | SSC 06/2018 | SSC 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 52.80 | 71.51 | 60.83 | 28.06 | 23.41 | 17.51 | 8.87 |
| median | 31.91 | 29.83 | 36.33 | 11.41 | 15.13 | 11.92 | 0.02 |
| min | 0.00 | 0.00 | 2.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| lower | 13.29 | 13.69 | 14.12 | 5.17 | 5.82 | 5.72 | 0.00 |
| upper | 66.24 | 77.23 | 80.99 | 30.92 | 32.13 | 21.27 | 8.82 |
| max | 538.23 | 911.58 | 689.47 | 417.87 | 199.41 | 276.25 | 155.98 |
| 90th percentile | 134.04 | 192.58 | 149.77 | 72.69 | 54.41 | 38.52 | 29.74 |
| 10th percentile | 5.06 | 6.90 | 8.16 | 3.08 | 2.62 | 3.53 | 0.00 |
| n | 1692 | 2152 | 2344 | 4164 | 4140 | 4297 | 1683 |
| St. Dev | 61.44 | 107.27 | 70.93 | 42.49 | 24.72 | 18.89 | 18.12 |
| St. Error | 1.49 | 2.31 | 1.47 | 0.66 | 0.38 | 0.29 | 0.44 |

| | ASSD 01/2018 | ASSD 02/2018 | ASSD 03/2018 | ASSD 04/2018 | ASSD 05/2018 | ASSD 06/2018 | ASSD |
|---|---|---|---|---|---|---|---|
| Mean | 0.24 | 1.61 | 0.83 | 4.05 | | 1.22 | 1.80 |
| median | 0.00 | 0.20 | 0.00 | 0.17 | | 0.02 | 0.02 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| lower | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| upper | 0.17 | 1.91 | 0.77 | 3.09 | | 0.32 | 0.48 |
| max | 11.58 | 48.88 | 27.21 | 45.14 | | 66.00 | 79.23 |
| 90th percentile | 0.66 | 5.09 | 2.39 | 16.21 | | 2.42 | 3.48 |
| 10th percentile | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 |
| n | 1753 | 1119 | 2155 | 1993 | | 2344 | 1618 |
| St. Dev | 0.75 | 3.44 | 2.05 | 7.74 | | 4.65 | 6.28 |
| St. Error | 0.02 | 0.10 | 0.04 | 0.17 | | 0.10 | 0.16 |

| | RMS 01/2018 | RMS 02/2018 | RMS 03/2018 | RMS 04/2018 | RMS 05/2018 | RMS 06/2018 | RMS |
|---|---|---|---|---|---|---|---|
| Mean | 0.0037 | 0.0024 | 0.0021 | 0.0011 | 0.0021 | 0.0022 | 0.0028 |
| median | 0.0031 | 0.0018 | 0.0015 | 0.0007 | 0.0015 | 0.0012 | 0.0013 |
| min | 0.0004 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| lower | 0.0019 | 0.0012 | 0.0006 | 0.0004 | 0.0010 | 0.0008 | 0.0008 |
| upper | 0.0046 | 0.0027 | 0.0032 | 0.0012 | 0.0022 | 0.0019 | 0.0023 |
| max | 0.0300 | 0.0324 | 0.0312 | 0.0293 | 0.0382 | 0.0535 | 0.0804 |
| 90th percentile | 0.0066 | 0.0042 | 0.0040 | 0.0022 | 0.0037 | 0.0038 | 0.0058 |
| 10th percentile | 0.0012 | 0.0009 | 0.0000 | 0.0000 | 0.0007 | 0.0006 | 0.0006 |
| n | 1781 | 4032 | 3584 | 4316 | 4462 | 4318 | 1683 |
| St. Dev | 0.0025 | 0.0024 | 0.0023 | 0.0015 | 0.0025 | 0.0036 | 0.0051 |
| St. Error | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 |

| | Temp 01/2018 | Temp 02/2018 | Temp 03/2018 | Temp 04/2018 | Temp 05/2018 | Temp 06/2018 | Temp |
|---|---|---|---|---|---|---|---|
| Mean | | | 29.21 | 29.80 | 27.17 | 25.28 | 24.88 |
| median | | | 29.19 | 30.05 | 27.41 | 25.35 | 24.92 |
| min | | | 27.68 | 27.48 | 24.94 | 23.41 | 23.24 |
| lower | | | 28.36 | 29.30 | 26.56 | 24.95 | 24.64 |
| upper | | | 30.10 | 30.44 | 27.77 | 25.65 | 25.13 |
| max | | | 32.64 | 33.41 | 28.74 | 26.75 | 26.21 |
| 90th percentile | | | 30.41 | 30.65 | 28.01 | 25.83 | 25.33 |
| 10th percentile | | | 28.01 | 28.46 | 25.96 | 24.66 | 24.38 |
| n | | | 2351 | 4316 | 4462 | 4318 | 1683 |
| St. Dev | | | 0.90 | 0.82 | 0.79 | 0.49 | 0.41 |
| St. Error | | | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |

| | Light 01/2018 | Light 02/2018 | Light 03/2018 | Light 04/2018 | Light 05/2018 | Light 06/2018 | Light |
|---|---|---|---|---|---|---|---|
| Mean | 0.02 | 0.19 | 0.19 | 1.72 | 1.17 | 0.89 | 0.78 |
| median | 0.01 | 0.12 | 0.11 | 1.68 | 0.92 | 0.87 | 0.54 |
| min | 0.00 | 0.01 | 0.01 | 0.30 | 0.36 | 0.20 | 0.00 |
| lower | 0.00 | 0.08 | 0.06 | 1.23 | 0.57 | 0.54 | 0.11 |
| upper | 0.01 | 0.24 | 0.23 | 2.08 | 1.06 | 1.19 | 1.17 |
| max | 0.09 | 0.70 | 1.01 | 3.43 | 3.61 | 1.77 | 3.61 |
| 90$^{th}$ percentile | 0.03 | 0.43 | 0.34 | 2.60 | 2.63 | 1.54 | 2.00 |
| 10$^{th}$ percentile | 0.00 | 0.03 | 0.03 | 0.73 | 0.43 | 0.32 | 0.03 |
| n | 13 | 28 | 24 | 30 | 31 | 30 | 167 |
| St. Dev | 0.02 | 0.17 | 0.22 | 0.75 | 0.87 | 0.47 | 0.81 |
| St. Error | 0.01 | 0.03 | 0.05 | 0.14 | 0.16 | 0.09 | 0.06 |


SSC (mg/L)
250
200
150
100
50
0
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018
ASSD (mg cm⁻²)
18
16
14
12
10
8
6
4
2
0
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018
RMS Water Height (m)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018
Temperature C°
33
31
29
27
25
23
21
19
17
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018
Light (uE/cm2)
8
7
6
5
4
3
2
1
0
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

**WQ5**

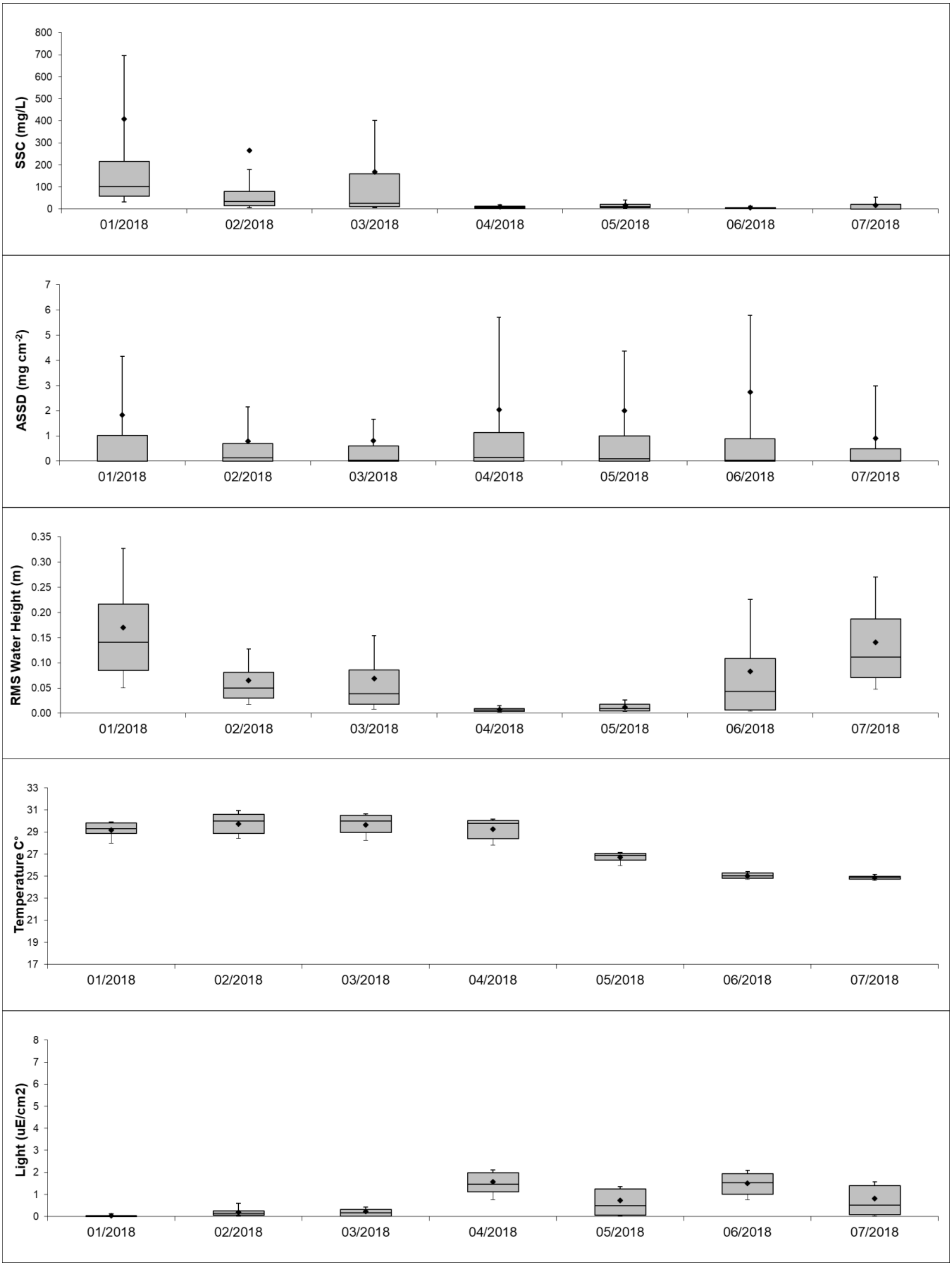
| | SSC 01/2018 | SSC 02/2018 | SSC 03/2018 | SSC 04/2018 | SSC 05/2018 | SSC 06/2018 | SSC 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 407.95 | 266.72 | 169.24 | 10.46 | 16.89 | 6.94 | 17.38 |
| median | 102.05 | 33.31 | 25.18 | 7.43 | 10.39 | 5.03 | 0.00 |
| min | 2.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| lower | 58.53 | 14.28 | 10.75 | 4.26 | 5.33 | 3.69 | 0.00 |
| upper | 215.23 | 79.27 | 159.87 | 13.32 | 20.81 | 7.33 | 22.38 |
| max | 9975.32 | 9986.78 | 3969.54 | 149.61 | 194.46 | 166.97 | 3076.73 |
| 90$^{th}$ percentile | 695.50 | 178.56 | 401.12 | 20.09 | 40.74 | 11.88 | 54.17 |
| 10$^{th}$ percentile | 32.28 | 6.14 | 5.47 | 2.47 | 3.03 | 2.64 | 0.00 |
| n | 1756 | 3683 | 3470 | 4100 | 4452 | 4312 | 1728 |
| St. Dev | 1177.15 | 1273.10 | 422.25 | 10.44 | 18.33 | 7.90 | 85.29 |
| St. Error | 28.09 | 20.98 | 7.17 | 0.16 | 0.27 | 0.12 | 2.05 |

| | ASSD 01/2018 | ASSD 02/2018 | ASSD 03/2018 | ASSD 04/2018 | ASSD 05/2018 | ASSD 06/2018 | ASSD 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 1.83 | 0.79 | 0.82 | 2.05 | 2.01 | 2.73 | 0.91 |
| median | 0.00 | 0.12 | 0.04 | 0.14 | 0.09 | 0.05 | 0.02 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| lower | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| upper | 1.02 | 0.69 | 0.61 | 1.14 | 1.01 | 0.89 | 0.50 |
| max | 47.77 | 32.89 | 32.71 | 93.75 | 63.56 | 94.63 | 18.90 |
| 90$^{th}$ percentile | 4.17 | 2.15 | 1.67 | 5.72 | 4.36 | 5.79 | 2.99 |
| 10$^{th}$ percentile | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| n | 1760 | 3804 | 3371 | 4175 | 4355 | 3371 | 1525 |
| St. Dev | 5.19 | 2.06 | 2.56 | 6.38 | 6.18 | 9.35 | 2.31 |
| St. Error | 0.12 | 0.03 | 0.04 | 0.10 | 0.09 | 0.16 | 0.06 |

| | RMS 01/2018 | RMS 02/2018 | RMS 03/2018 | RMS 04/2018 | RMS 05/2018 | RMS 06/2018 | RMS 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.1704 | 0.0652 | 0.0691 | 0.0076 | 0.0126 | 0.0828 | 0.1405 |
| median | 0.1411 | 0.0500 | 0.0388 | 0.0061 | 0.0094 | 0.0435 | 0.1111 |
| min | 0.0039 | 0.0025 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| lower | 0.0853 | 0.0306 | 0.0179 | 0.0040 | 0.0048 | 0.0067 | 0.0710 |
| upper | 0.2168 | 0.0813 | 0.0864 | 0.0097 | 0.0178 | 0.1084 | 0.1874 |
| max | 0.9831 | 0.5752 | 0.9548 | 0.0517 | 0.0720 | 0.8369 | 0.6947 |
| 90$^{th}$ percentile | 0.3275 | 0.1280 | 0.1538 | 0.0147 | 0.0269 | 0.2262 | 0.2702 |
| 10$^{th}$ percentile | 0.0507 | 0.0175 | 0.0078 | 0.0027 | 0.0031 | 0.0041 | 0.0478 |
| n | 1795 | 4032 | 3479 | 4314 | 4462 | 4318 | 1728 |
| St. Dev | 0.1215 | 0.0554 | 0.0930 | 0.0052 | 0.0101 | 0.1093 | 0.0984 |
| St. Error | 0.0029 | 0.0009 | 0.0016 | 0.0001 | 0.0002 | 0.0017 | 0.0024 |

| | Temp 01/2018 | Temp 02/2018 | Temp 03/2018 | Temp 04/2018 | Temp 05/2018 | Temp 06/2018 | Temp 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 29.20 | 29.74 | 29.67 | 29.28 | 26.71 | 25.05 | 24.84 |
| median | 29.32 | 30.01 | 29.99 | 29.79 | 26.87 | 25.02 | 24.84 |
| min | 27.41 | 27.38 | 27.74 | 26.47 | 25.19 | 24.34 | 22.15 |
| lower | 28.87 | 28.87 | 28.95 | 28.41 | 26.46 | 24.83 | 24.74 |
| upper | 29.83 | 30.62 | 30.52 | 30.03 | 27.07 | 25.28 | 24.98 |
| max | 30.11 | 31.30 | 30.73 | 30.46 | 27.41 | 27.02 | 25.78 |
| 90$^{th}$ percentile | 29.92 | 30.96 | 30.64 | 30.17 | 27.16 | 25.43 | 25.16 |
| 10$^{th}$ percentile | 28.00 | 28.42 | 28.25 | 27.81 | 25.95 | 24.69 | 24.63 |
| n | 1795 | 4032 | 3479 | 4314 | 4462 | 4318 | 1728 |
| St. Dev | 0.70 | 1.03 | 0.91 | 0.95 | 0.47 | 0.28 | 0.32 |
| St. Error | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 |

| | Light 01/2018 | Light 02/2018 | Light 03/2018 | Light 04/2018 | Light 05/2018 | Light 06/2018 | Light 07/2018 |
|---|---|---|---|---|---|---|---|
| Mean | 0.04 | 0.18 | 0.23 | 1.58 | 0.72 | 1.51 | 0.81 |
| median | 0.02 | 0.14 | 0.17 | 1.46 | 0.49 | 1.54 | 0.52 |
| min | 0.00 | 0.01 | 0.00 | 0.73 | 0.02 | 0.16 | 0.00 |
| lower | 0.00 | 0.05 | 0.02 | 1.12 | 0.05 | 1.02 | 0.07 |
| upper | 0.04 | 0.25 | 0.31 | 1.98 | 1.26 | 1.94 | 1.40 |
| max | 0.13 | 0.53 | 0.89 | 2.85 | 2.16 | 2.57 | 4.47 |
| $90^{th}$ percentile | 0.11 | 0.45 | 0.59 | 2.44 | 1.73 | 2.37 | 1.95 |
| $10^{th}$ percentile | 0.00 | 0.03 | 0.00 | 0.77 | 0.03 | 0.77 | 0.02 |
| n | 13 | 28 | 23 | 30 | 31 | 30 | 168 |
| St. Dev | 0.04 | 0.15 | 0.27 | 0.60 | 0.67 | 0.62 | 0.83 |
| St. Error | 0.01 | 0.03 | 0.06 | 0.11 | 0.12 | 0.11 | 0.06 |


SSC (mg/L)
ASSD (mg cm⁻²)
RMS Water Height (m)
Temperature C°
Light (uE/cm2)
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

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