Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

November 2018

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Summary

Since September 2016, Vision Environment (VE) has been undertaking water quality monitoring for the Environmental Monitoring and Management Plan (EMMP) associated with the Lyttelton Port Company (LPC) Channel Deepening Project (CDP) (Envisor, 2018). Baseline datasets were acquired from three spoil ground sites (SG1, SG2 and SG3), seven offshore sites (OS1 to OS7) and five inshore sites (UH1 to UH3, CH1 and CH2) to assess potential impacts of the dredging project.

During the November 2018 monitoring period, construction works as part of the 'Lyttelton Harbour wastewater scheme' (which commenced in July 2018) and dredging operations for the CDP (which commenced on 29 August 2018) were ongoing. As such, the monthly report has been expanded to include comparisons of turbidity data collected during the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). Monitoring results collected during November 2018 are presented within this report, including information detailing dredge trigger value exceedances (where applicable) and management. Main works dredging was completed by the Fairway on 17 November with the sweeper operating up until 29 November, thus completing the first phase of dredging works.

Climatic Conditions: Cashin Quay experienced 52 mm of rainfall during November 2018, which was almost 2.5 times that experienced in the previous month. Waimakariri River outflow was typically limited to below 200 m^3/s at the Old Harbour Bridge, except from 9 to 13 November when flows increased to over 1700 m^3/s within a few hours. This resulted in significant changes in a number of physiochemical parameters at all sites. Mean inshore wind speeds were slightly higher in November peaking 22.3 knots on 25 November with peak wave heights of 2.0 m occurring on 27 November two days later. Air temperatures continued the seasonal warming trend, with a monthly average of 13°C.

Currents: Unfortunately, both ADCP units at sites SG1 and SG3 remained offline during October 2018. However, current data received from the Watchkeeper buoy at SG2a is included within this report. It should be noted that although the telemetry system is not receiving ADCP data from SG1 and SG3, it is possible that the units are internally logging and that the data may be acquired through a manual download at a later date.

Elevated near-surface current speeds (>230 mm/s) were recorded on 3, 7, 16, 18, 24 and 25 November, coinciding with increased wave heights and wind speeds. At the seabed, maximum current velocities (304 mm/s) were reported on 8 November; with the monthly mean benthic velocity greater than that reported for the near-surface region. Consistent with previous directional data acquired from SG1 and SG3, currents at SG2a displayed a strong dominance of flow along an east-west axis.

Turbidity: Consistent with previous reports during baseline monitoring, turbidity was higher at the inshore monitoring sites of the central and upper harbour, than at nearshore and offshore monitoring locations. Mean turbidity values for November were generally below or similar to those recorded during the baseline monitoring period. The exception was site CH1 where turbidity levels were slightly more elevated, as they were in September and October 2018 at this site.

Turbidity in November trended similarly to October for the first two weeks where the northern inner harbour sites (UH1 and CH1) continued to display higher turbidity values than those in the southern harbour (UH2 and CH2). A dramatic decline in turbidity was experienced at

inshore and nearshore sites in mid-November when a large volume of freshwater from the Waimakariri River entered the harbour. The mixing of large amounts of fresh water with turbid saline environments results in changes in the chemical properties of fine sediment particles, allowing them to coalesce forming heavier particles, which then flocculate and settle out of suspension. This resulted in sudden declines in turbidity at these sites on 12 November. Turbidity at the two most north western sites (SG1 and OS5) were also impacted by a turbid wedge which preceded the freshwater flow. Remaining sites trended similarly to one another. The exception was site UH2, which was likely additionally impacted by local rainfall and sediment run off/resuspension from 18 November, resulting in elevated turbidity compared to other inshore sites. All sites displayed elevated turbidity peaks towards the end of the month in response to peak wind speeds and wave heights with benthic turbidity sites trending similarly to their surface counterparts.

Dredge Compliance Turbidity Trigger Values: During November, there were no exceedances of the Tier 3 intensity values at any site within the monitoring network.

Other Physicochemical Parameters: Monthly mean surface water temperatures around Lyttelton Harbour continued the warming trend observed during the previous months. Reversing the spatial relationship between sites during austral winter, the warmest temperatures continued to be recorded in the shallow waters of the upper and central harbour. Brief periods of cooling were observed during the two main rainfall events during November. Benthic temperatures were once again up to 1.9°C lower than those of the surface but were relatively stable and unresponsive compared to surface temperatures, until towards the end of the month.

Consistent with previous reports, pH during November did not display any particular spatial or temporal patterns across the monitoring network. However, in contrast to previous months which experienced lower rainfall and insignificant flow events from the Waimakariri River, conductivity in November was quite volatile. The large flow event mentioned previously resulted in sudden drops in conductivity at all surface sites from 6 mS/cm at the inshore sites to 13 mS/cm at spoil ground and offshore sites. Offshore sites recovered relatively quickly due to mixing with oceanic waters but conductivity within the harbour remained lower than background for the remainder of the month. Benthic conductivity was unaffected by the freshwater inundation.

Relatively high dissolved oxygen (DO) concentrations were recorded during the first two weeks of November, indicating the presence of phytoplankton blooms in the region. Localised rainfall events on 9 and 20 November resulted in large declines in DO concentrations, with relatively slow recovery once these events had ceased. There appeared to be no impact from the freshwater flow event on surface DO, and which initially also appeared to have little impact on benthic DO. However, declines in benthic DO several days later at all sites except OS4 may have been a result of increased biological oxygen demand due to the decay of sinking detritus or organic matter.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 13 November, one day after the freshwater inundation. The depth profiles at all sites generally indicate a well-mixed water column with occasional thermoclines at the deeper sites. This was the case for turbidity in November which displayed typical elevations at the benthos due to resuspension. However, temperature, pH and DO in November demonstrated declining gradients through the water column at all sites, while conductivity demonstrated the reverse trend. The former physicochemical parameters maintained the decreasing gradient with depth, however conductivity became consistent from 5 m depth. This is a result of heavier saline water being overlain by lighter freshwater. Sites OS3 and OS4 did not display conductivity gradients being the sites furthest in distance from the Waimakariri River mouth.

Turbidity and total suspended solids (TSS) measurements for surface waters were again elevated at inshore sites compared to the offshore areas, resulting in the shallowest estimations of the euphotic depth as typically recorded during the baseline monitoring. Typically, site UH1 exhibits the highest turbidity and TSS results, however site UH2 in November displayed elevated column profiles which were also reflected in the surface logger results. Euphotic depth at the spoil ground was high; estimated to be at 14.5 m at SG1. No exceedances of WQG were observed for sub-surface turbidity during the October sampling.

Total phosphorous and dissolved reactive phosphorous concentrations were higher inshore and decreased increasing distance offshore as commonly found, however in contrast to previous months there were no exceedances of the WQGs at any of the sites. There was only a slight exceedance of WQG for ammonia at one site and an exceedance of nitrogen oxide at SG1 appears to be an anomalous result. Consistent with previous monitoring, concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites. Thus, nutrient concentration overall appeared to be reduced in November.

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, were elevated at some sites but below WQG across the harbour. However, it is suspected that concentrations may have been more elevated prior to the sampling date as evidenced by high DO concentrations and depleted nutrients perhaps having contributed to a prior algal bloom.

As typically observed within Lyttelton Harbour, total aluminium concentrations exceeded designated WQG at most sites. However, concentrations of dissolved aluminium were detected at all but four sites. This was in contrast to October, where concentrations at all sites were undetectable (<12 µg/L), indicating that the majority of aluminium present was associated with particulate matter and thus deemed less biologically available. Regardless, none of the dissolved concentrations were above WQG, as were the remaining metals with designated WQG, with the exception of dissolved copper which slightly exceeded WQG at two sites.

While no WQG are available for iron, concentrations exhibited a large decrease from the elevated concentrations recorded during September and also to those in measured in October 2018. The reduction in both total aluminium and iron in November may be a result of the settling of suspended sediment particles due to the flocculation process associated with fresh water inundation. Similar to patterns observed during previous months, sampling during November also indicated somewhat elevated concentrations of dissolved manganese across the network and increased total vanadium and molybdenum concentrations within the inshore and nearshore environments. Increased concentrations of these metals have occasionally been detected during the baseline period.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during November displayed a greater range than during previous months, resulting in an increase in the monthly mean ambient PAR. Benthic PAR intensities were once again greater at OS3 than at OS2, due the shallower water depth at OS3, although in November the difference was not as high most likely due to the elevated turbidity experienced at OS3. A combination of reduced surface turbidity and elevated incident solar radiation resulted in higher BPAR throughout the month, particularly during periods of reduced precipitation in the middle of the month.

Sedimentation: Altimeter data from site OS2, near the mouth of Lyttelton Harbour indicated changing seafloor conditions, which was in contrast to the previous month and reflected a response to the various meteorological events which occurred in November. An initial period of erosion in response to elevated wind speeds at the beginning of the month was replaced by rapid deposition in response to the settling of flocculated sediment particles, caused by the freshwater inundation. The bed level remained stable for most of the month despite some elevated wind speed events until monthly peak wind speeds and wave heights towards the end of the month triggered another period of erosion. The overall bed level change for November was deposition of 4.6 mm.

Unfortunately, little data was recovered from the altimeter at OS3 in the upper harbour due to it having been tipped on its side. This included missing the the freshwater inundation event. Up until 8 November there was a period of deposition resulting in a bed level increase of 3.8 mm.

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Acronyms

ADCP	Acoustic Doppler Current Profiler
BPAR	Benthic Photosynthetically Active Radiation
BSL	Benthic self-logging sonde
CDP	Channel Deepening Project
DO	Dissolved oxygen
ECan	Environment Canterbury
EMMP	Environmental Monitoring and Management Plan
K_d	Light attenuation coefficient
KZ filter	Kolmogorov-Zurbenko filter
LOR	Limits of Reporting
LPC	Lyttelton Port Company
LYT	Lyttelton Port of Christchurch
NTU	Nephelometric Turbidity Units
PAR	Photosynthetically Active Radiation
QA/QC	Quality Assurance/Quality Control
SL	Self-Logger
ST	Subsurface telemetry
ST/ADCP	Subsurface telemetry/Acoustic Doppler Current Profiler
TAG	Technical Advisory Group
TDP	Total daily PAR
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
VBCC	Vision Base Christchurch
VE	Vision Environment
WK	WatchKeeper telemetered weather station
WQG	Water Quality Guidelines

1 INTRODUCTION

Lyttelton Port Company (LPC) is undertaking a Channel Deepening Project (CDP) to extend the existing navigational channel to allow larger vessels access to the Lyttelton Port of Christchurch (LYT), the South Island's largest port. Utilising background information provided by LPC and advice from the Technical Advisory Group (TAG) in relation to ambient conditions, locations of sensitive habitats and dredge impact hydrodynamic modelling scenarios, a water quality monitoring design was proposed for the initial 12 month baseline monitoring phase. Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016, continuing into a second year that now extends into the current phase of dredge operations. The interpreted environmental data provided by VE supports the process of the Environmental Monitoring and Management Plan (EMMP) for the LPC CDP (Envisor, 2018) and will assist to ascertain the potential impacts of the project.

As per the Resource Consent (CRC172522) conditions and the EMMP, trigger values were developed from the extensive baseline datasets to allow adaptive dredge management based on real time turbidity monitoring. The Tier 1 to Tier 3 trigger levels – based on higher order percentiles (80^{th}, 95^{th} and 99^{th}) of the collected background (baseline) turbidity data– allow management and mitigation measures to be undertaken in order to conduct dredging operations in an environmentally sustainable manner.

2 METHODOLOGY

2.1 Approach

An overview of the methodology for baseline and operations phase of water quality monitoring is provided in this section. A more detailed description of the importance of the measured parameters and the specific methodology for the CDP data collection and processing protocols, can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

2.1.1 Monitoring Locations and Equipment

Guided by the results of preliminary hydrodynamic modelling (MetOcean, 2016a, b) in addition to advice from the TAG, baseline and dredge operations monitoring sites were located outside the area of predicted direct impact (i.e. dredge footprint and offshore disposal ground), but within the zone of dredging and dredge material placement influence, in addition to being in the vicinity of sensitive receptors (e.g. mussels farms and important mahinga kai sites). For ease of identification the harbour was divided into four areas: spoil ground (SG); offshore (OS); central harbour (CH); and upper harbour (UH), in which 15 locations were selected for monitoring (Figure 1). In each area, one to three monitoring sites were selected for the deployment of the various individual types of equipment, which are identified in Table 1. A total of 22 monitoring units were deployed across the 15 locations.

The offshore monitoring area (encompassing monitoring sites SG1 to SG3 and OS1 to OS7) is a deep water (generally >15 m) oceanic environment, where turbidity appears to be mostly driven by wind speeds and wave heights, resulting in resuspension of material from the benthos. A combination of both surface loggers and benthic loggers have been utilised at a number of offshore locations.

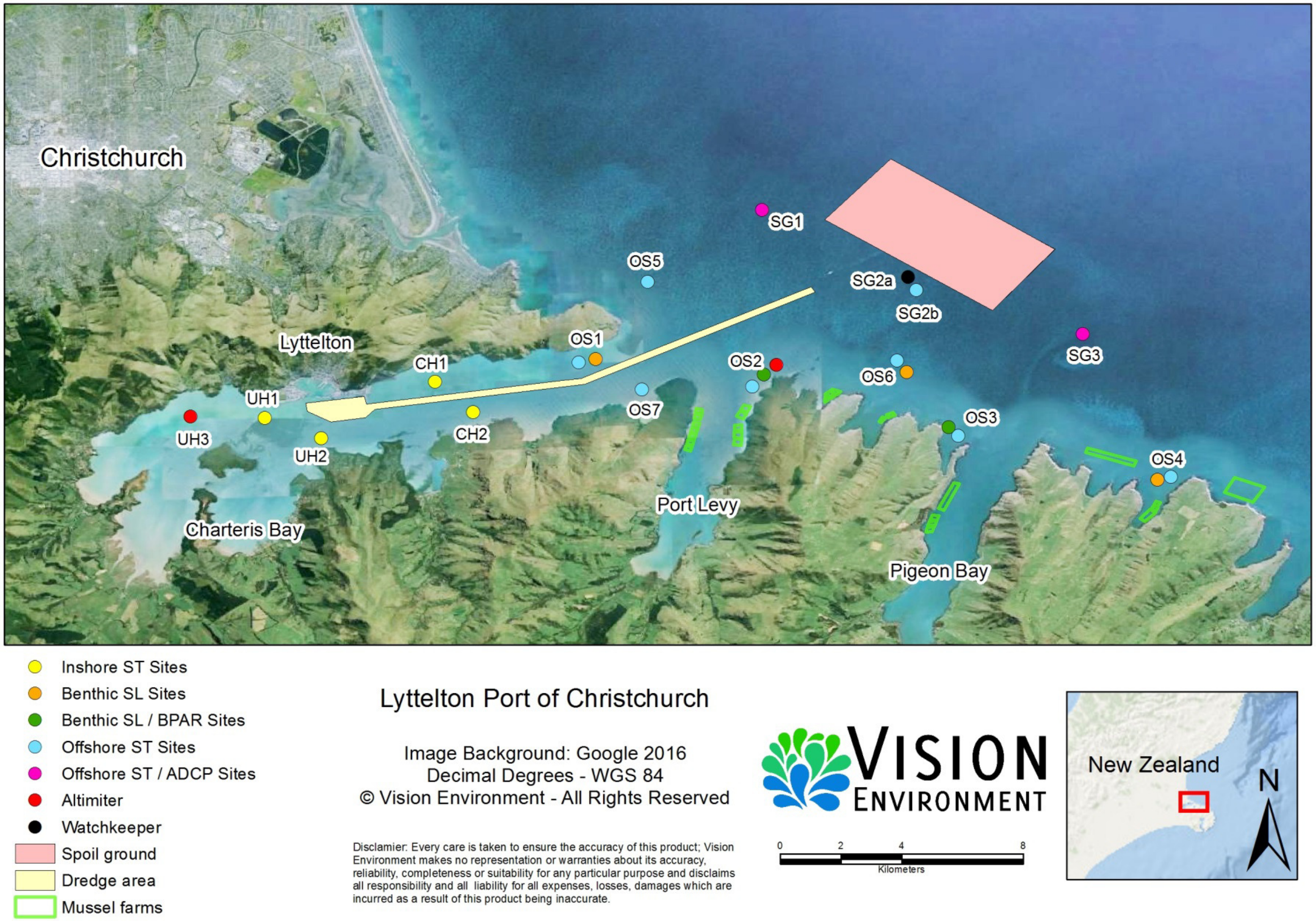


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

The inshore monitoring area (including monitoring sites CH1 and CH2, and UH1 to UH3) is a shallow (<10 m depth) marine environment that, in addition to wind speeds and wave heights, is also influenced by tides (~ 0.2 m/s). The water column is well mixed at these sites, with little to no stratification. Therefore, surface loggers only have predominantly been utilised at these sites.

Table 1 Summary of monitoring sites and deployment equipment for the LPC Channel Deepening Project.
ST = subsurface telemetry, SL = self-logger, BSL = benthic self-logger, BPAR = benthic photosynthetically active radiation, and ADCP = Acoustic Doppler Current Profiler, WK = WatchKeeper telemetered weather station.

Site	WK	ST/ADCP	ST	BSL sonde	BSL sonde/BPAR	Altimeter
	WatchKeeper telemetered weather station with currents and waves	Subsurface telemetered dual physico-chemistry and currents	Subsurface telemetered dual physico-chemistry	Benthic self-logging dual physico-chemistry	Benthic self-logging dual physico-chemistry and self-logging BPAR	Benthic self-logging dual altimeter
SG2a	√					
SG2b			√			
SG1		√				
SG3		√				
OS1			√	√		
OS2			√		√	√
OS3			√		√	
OS4			√	√		
OS5			√			
OS6			√	√		
OS7			√			
CH1			√			
CH2			√			
UH1			√			
UH2			√			
UH3						√
Total	1	2	12	3	2	2

The comprehensive water quality component of the program involves the monitoring of:

- Physicochemistry, including turbidity; temperature; pH; conductivity and dissolved oxygen (DO);
- Light attenuation (Photosynthetic Active Radiation or PAR);
- Benthic light (Benthic Photosynthetic Active Radiation or BPAR);
- Total Suspended Solids (TSS);
- Sedimentation rates;
- Nutrients and chlorophyll *a*;
- Metals (total and dissolved); and
- Organic compounds (biannually).

This monthly report presents data collected from the 22 monitoring locations from 1 to 30 November 2018 during dredging operations. Monthly water sampling was conducted on 13 November. Main works dredging was completed by the Fairway on 17 November with the sweeper operating up until 29 November, thus completing the first phase of dredging works. A summary of climatic conditions during this period is provided, in addition to the results of continuous and discrete water sampling with comparisons to the baseline monitoring period.

2.1.2 Dredge Compliance Triggers

As per the Resource Consent (CRC172522) conditions, there are two turbidity triggers (Tier 1 and Tier 2) and one compliance level tier (Tier 3) that are based on the 80th, 95th and 99th percentiles of smoothed Kolmogorov-Zurbenko (KZ) filtered baseline data, respectively. Each monitoring location has been assigned a unique allowable turbidity intensity and duration (Fox, 2018). The turbidity intensity is a measure of the absolute turbidity following smoothing with the KZ filter, whereas the allowable duration represents the amount of time in a 30 day rolling window that the turbidity at any given monitoring site may exceed the specified turbidity intensity value. Once the turbidity intensity has been exceeded for the allowable duration, a trigger event occurs, requiring management actions that are dependent on the level of turbidity experienced. The trigger event ceases when either the turbidity drops below the allowable intensity, the allowable hours are no longer in exceedance, or the event is considered an extraordinary natural event. The Tier 1 and Tier 2 turbidity triggers are internal triggers, alerting the Consent Holder Project Team and Dredging Operator that the turbidity at the monitoring location has increased (either dredging or natural cause related). The Tier 3 Compliance Level trigger requires dredging at the location of the trigger event to cease (Envisor, 2018).

Turbidity data collected in November during dredging operations have been compared to turbidity statistics calculated for the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). Additionally, KZ filtered data collected during November has been compared to established Tier 1 to Tier 3 trigger values in a similar manner to the procedure for real time dredge management.

2.1.3 Water Quality Guidelines

Water quality monitoring data from LYT were compared to the Australian and New Zealand Water Quality Guidelines (WQG) (ANZECC/ARMCANZ, 2000) default interim trigger values. In the absence of specific default trigger values for estuarine or marine ecosystems, which are yet to be developed in New Zealand, the WQG suggest the use of interim trigger values for south-east Australian estuarine and marine ecosystems.

Total metals represent the concentration of metals determined in an unfiltered sample (those bound to sediments or colloidal particles in addition to dissolved metals), while dissolved metals are defined as those which pass through a 0.45 µm membrane filter (APHA, 2005). Specific trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived for a number of metals. These guidelines refer to the dissolved fraction, as they are considered to be the potentially bioavailable fraction (ANZECC/ARMCANZ, 2000). The LYT coastal environment could be described as slightly-to-moderately disturbed, therefore the 95% WQG trigger value was considered appropriate for comparison.

3 RESULTS & DISCUSSION

3.1 Metocean Conditions

3.1.1 Wind and precipitation

A total of 52.0 mm rainfall was received at Cashin Quay over 13 days during November which was almost 2.5 times the precipitation recorded in October which occurred over a lesser time period (Figure 2). The majority of the precipitation (13.8 and 13 mm) occurred on 9 and 20 November, respectively (Metconnect, 2018). Freshwater flows (Figure 2) from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour several days later, were generally less than 200 m^3/s for the duration of the month except for a period between 9 to 13 November (ECAN, 2018). Flows increased from 117 to 1407 m^3/s within a one-hour period on 9 November, peaking at 1717 m^3/s a few hours later (Figure 3). Maximum daily mean inshore wind speeds measured at Cashin Quay were recorded at 22.3 knots on 25 November, from an east-north-easterly direction, with gusts of up to 37 knots (Figure 2)(Metconnect, 2018).

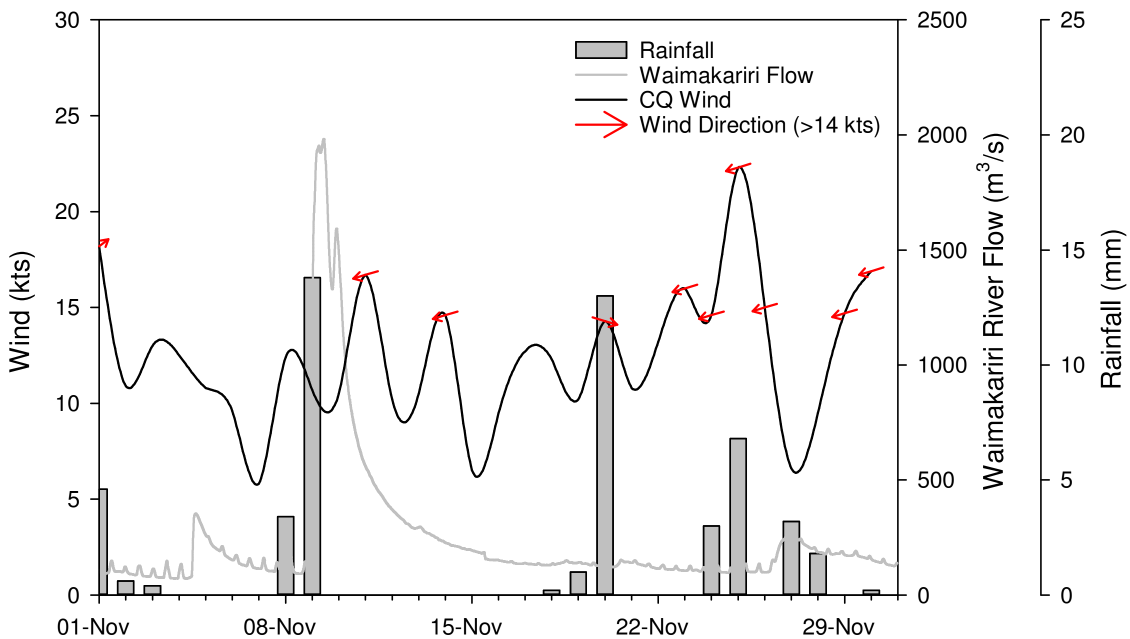


Figure 2 Inshore metocean conditions, including daily averaged wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during November 2018.

Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

Offshore significant wave heights peaked at 2.0 m on 27 November, travelling in a south westerly direction (Figure 3). Wind speeds and gusts during this time were relatively low. The average and maximum offshore wind speeds and gusts of 19 and 28.6 knots respectively, occurred several days earlier on 20 November (Figure 3).

Daily mean air temperatures at Cashin Quay ranged from 7 to 26°C, resulting in a slightly warmer monthly mean temperature of 13°C (Metconnect, 2018).

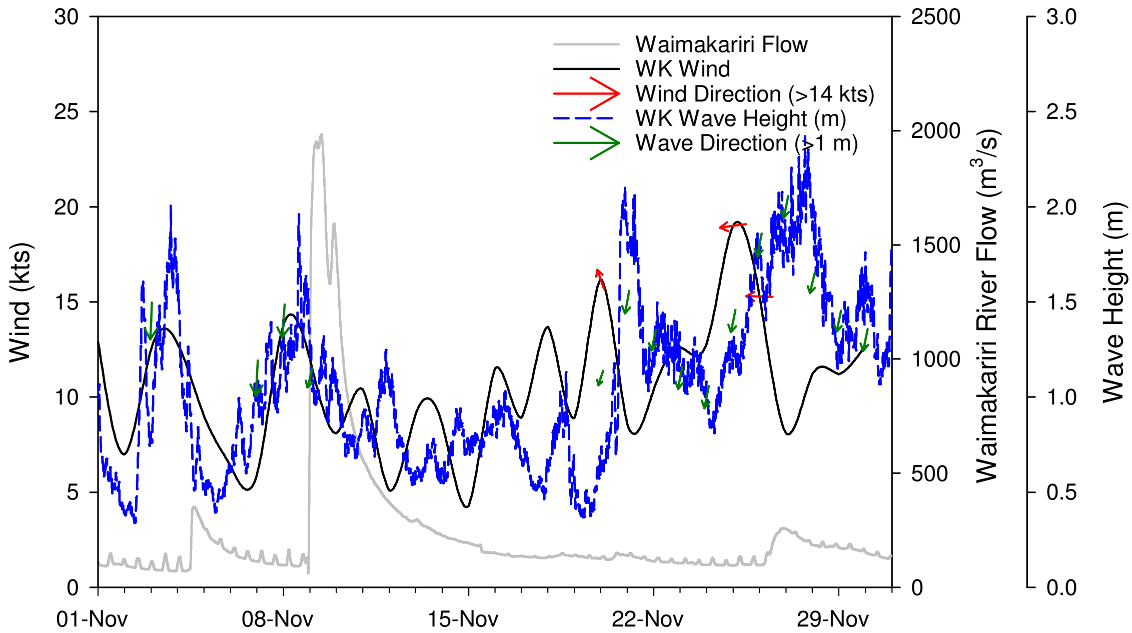


Figure 3 Offshore metocean conditions, including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during November 2018.
Note: Arrows indicate the direction of travel for offshore winds greater than 14 knots and offshore waves above 1 m significant wave height. Directions from the WatchKeeper buoy have not been corrected for magnetic declination.

3.1.2 Currents

Acoustic Doppler Current Profilers (ADCPs) are deployed at the spoil ground monitoring sites SG1 and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Unfortunately, both ADCP units stopped sending data in late August/early September 2018 and have not been removed from the spoil ground for maintenance due to the requirement for turbidity monitoring to continue at these sites. Whilst no data are being transferred over the telemetry system, it is likely that the units are internally logging and the data may be available through manual download at a later date.

In the interim, additional ADCP data collected from the WatchKeeper Buoy at SG2a are provided within this report. Summary ADCP statistics are presented within Figure 4 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 30 and 31 in the Appendix.

The maximum near-surface current velocity at SG2a was recorded on 30 November at 277 mm/s (Table 2), coinciding with increased offshore significant wave heights which occurred on the 27 November (Figure 3). Near-surface current velocities greater than 230 mm/s were also recorded throughout the month on the 3, 7, 16, 18, 24 and 25 November. Near the seabed, maximum current velocities of 304 mm/s were recorded on 8 November. The monthly mean current speed for the near-seabed (100 mm/s) was greater than that recorded for the near surface (90 mm/s).

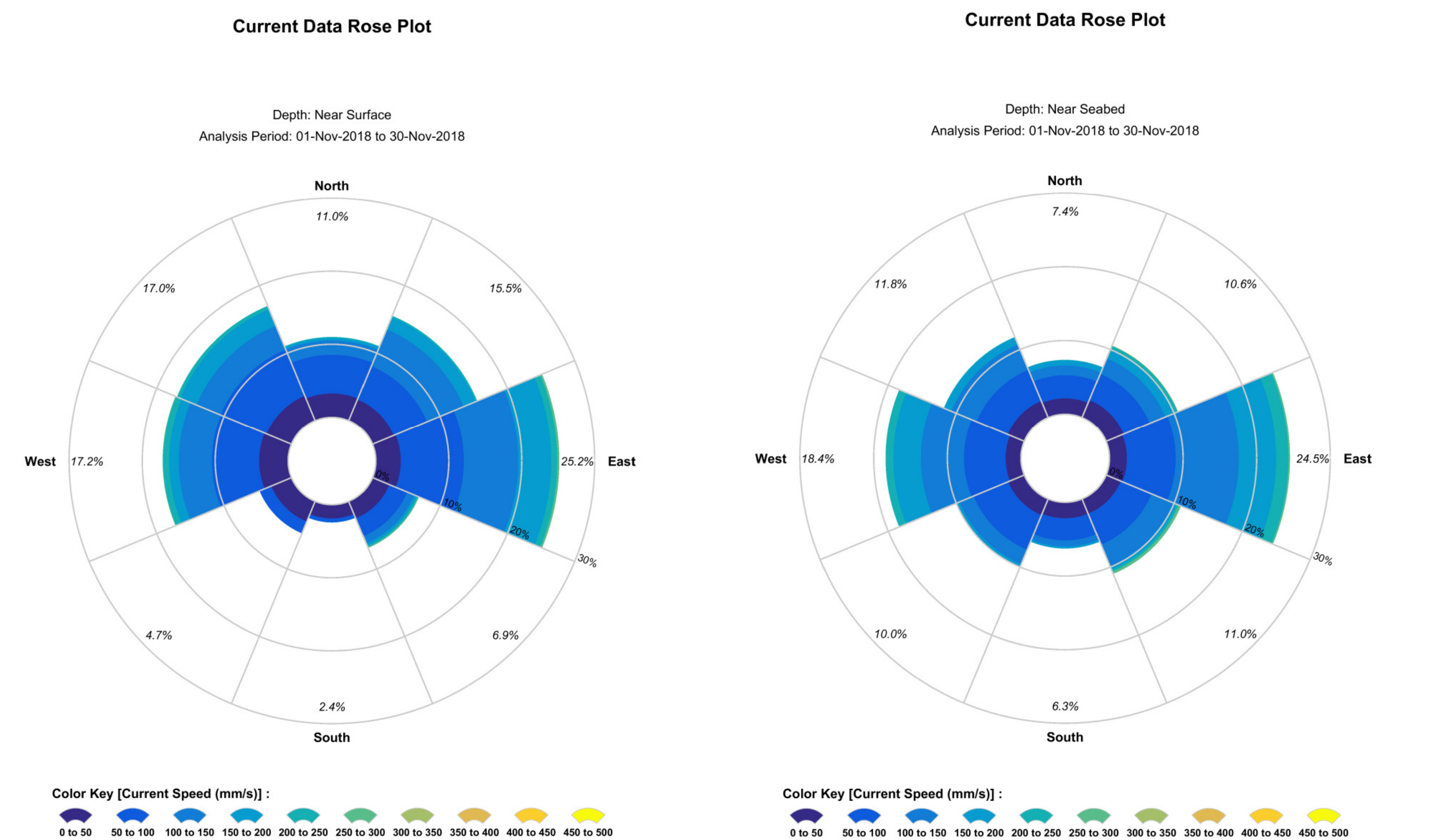


Figure 4 WatchKeeper near-surface and near-seabed current speed and direction during November 2018.
Speed intervals of 50 mm/s are used

Table 2 Parameter statistics for ADCP at SG2a (WatchKeeper buoy) during November 2018.

Parameter	SG2a	
	Near-surface	*Near-seabed*
Minimum current speed (mm/s)	1	3
Maximum current speed (mm/s)	277	304
Mean current speed (mm/s)	90	100
Standard deviation of current speed (mm/s)	52	52
Current speed, 95^{th} percentile (mm/s)	184	196

The time-series plots (Figures 28 and 29 in Appendix) illustrate time-varying current direction, whilst the current rose diagram (Figure 4) depicts the distribution of current direction and velocity in the near-surface and near-seabed layers. When interpreting the current data, please note that the convention for defining current direction is the direction in which the current flows *towards*, which is the reference used throughout the figures presented (the opposite is true for wind direction, where the reference is the direction from which the wind is coming from).

Similar to the data recorded during October 2018, current direction data from SG2a during November displayed a strong dominance of flow along the east-west axis, both at the near-surface and near-seabed (Figure 4).

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties (turbidity, temperature, conductivity [normalised to a reference temperature of 25°C], pH and DO) of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 13 November 2018. Further details regarding the methodology used can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017).

Summary statistics for each physicochemical parameter recorded during November are presented in Tables 3 to 12. Validated datasets for surface and benthic measurements are also presented in Figures 5 to 20. Due to the inherent high level of variability in the turbidity datasets, a 24-hour rolling average has been calculated every 15 minutes to act as an interim smoothing technique and aid in data interpretation.

3.2.1 Turbidity

Of key importance within the real time parameters recorded are the surface turbidity measurements, due to their relevance to established trigger values for management of dredge operations. As such, summary turbidity statistics for the initial baseline period of monitoring from 1 November 2016 to 31 October 2017 (Fox, 2018) are also presented in Tables 3 to 5 to allow a comparison with the November data. Summary statistics for KZ filtered turbidity data used for real time compliance monitoring, are also presented in Tables 21 to 23 in the Appendix. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 30 to 33 in the Appendix.

November Turbidity:

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 7.8 to 12 NTU) at the inshore monitoring sites (Tables 3 to 5, Figure 5).

Further offshore, the spoil ground sites exhibited lower (monthly means of 2.3 to 2.9 NTU) surface turbidity values (Table 4), which are likely due to the deeper water column limiting disturbance expressions at the sub-surface. As typically observed, nearshore sites experienced intermediate turbidity values (2.4 to 6.6 NTU) during November (Table 5).

Continuing the trend observed in October, during the first two weeks of November, surface turbidity levels at the northern inner harbour monitoring sites of UH1 and CH1, were greater than those observed along the southern edge (UH2 and CH2). However there was a dramatic drop in turbidity at all inshore sites on 11 November which did not appear to be related to changes in local metocean (wind and rain) conditions (Figure 5). Flows from the Waimakariri River increased dramatically from 117 to over 1400 m^3/s in only a few hours on 9 November sending a wedge of freshwater towards the harbour. This was detected by significant drops in conductivity which occurred at all monitoring sites beginning two days later at the spoil ground sites on 11 November and impacting inshore sites by the following day. Historically the inshore sites have generally not been affected by flows from the Waimakariri River, which typically continue down the coast. On this occasion the freshwater entered the upper harbour and conductivity at these sites dropped by up to 6 mS/cm. The introduction of large amounts of freshwater to turbid saline water bodies causes a change in the chemical properties of fine suspended sediment particles allowing them to coalesce more readily into larger particles and flocculate out of suspension. This is likely to have resulted in the sudden decline in turbidity of up to 8 NTU at inshore sites on 12 November.

From this period, inshore turbidity displayed an increasing trend to the remainder of the month but with site UH2 displaying greater overall turbidity and higher peaks than the remaining sites (Figure 5). This may have been related to consistent local rainfall from the 18 November in addition to higher wind speeds on 27 November, resulting in sediment resuspension and/or additional terrestrial runoff of fine particles. Similar to October, turbidity at CH2 tended to be less responsive to these driving factors, with turbidity at this site generally remaining 5 NTU lower compared to other inshore sites.

Nearshore monitoring sites displayed similar turbidity values and trends to one another, generally responding to changes in wind speed. Typically the sites on the exposed coastline south of Lyttelton Harbour (OS2, OS3 and OS4) display lower turbidity values than remaining nearshore sites, but during November only site OS4 recorded turbidity values noticeably lower than the other sites (Figure 5).

The spoil ground and offshore sites tended to trend similarly during November, with the exception of SG1, which digressed from 10 to 13 November displaying 24 hour rolling average turbidity values up to 6 NTU higher. OS5 to a lesser extent also displayed slightly more elevated turbidity than the other sites on 12 November. As the two most north western sites closest to the Waimakariri River mouth (Figure 1) and the first to display rapid declines in conductivity at this time, it is likely that they were both influenced by a turbid wedge which preceded the freshwater flow, an observation that has been recorded previously. As the freshwater flow passes the harbour entrance it then becomes mixed within the harbour tidal currents and the impact of the turbid wedge is reduced at more south eastern sites. Elevated wave heights on 27 November seemed to have had a greater influence on turbidity at SG3 than remaining offshore sites.

Benthic:

Benthic data recovery from OS1 was limited. No data was available for the benthic unit at OS6 as it was not able to be located during the monthly maintenance visit. A replacement unit has been deployed. Benthic sites responded to increased wind and wave events trending similarly to their surface counterparts.

Table 3 Mean turbidity and statistics at inshore water quality logger sites during November 2018 and Baseline period (1 November 2016 to 31 October 2017).
Values for November are means ± se, range and percentiles (n = 2837 to 2866) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface November	Surface Baseline
UH1	Mean ± se	12 ± 0.	12
	Range	1– 36	-
	99th	25	39
	95th	20	22
	80th	15	15
UH2	Mean ± se	11 ± 0	10
	Range	1 – 42	-
	99th	28	32
	95th	19	20
	80th	14	13
CH1	Mean ± se	11 ± 0	9
	Range	2 – 47	-
	99th	25	29
	95th	19	18
	80th	14	12
CH2	Mean ± se	7.8 ± 0.1	8
	Range	<1 – 34	-
	99th	18	24
	95th	14	16
	80th	10	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during November 2018 and Baseline period (1 November 2016 to 31 October 2017).
Values for November are means ± se, range and percentiles (n = 2861 to 2879). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface November	Surface Baseline
SG1	Mean ± se	2.9 ± 0.0	4.2
	Range	<1 – 16	-
	99th	11	14
	95th	7.3	10
	80th	3.9	6.2
SG2	Mean ± se	2.5 ± 0.0	4.6
	Range	<1 – 13	-
	99th	8.2	20
	95th	5.9	11
	80th	3.8	7.0
SG3	Mean ± se	2.3 ± 0.0	3.6
	Range	<1 – 12	-
	99th	7.5	13
	95th	4.7	7.7
	80th	2.8	4.8

Comparison to Baseline:

Mean surface turbidity and higher order percentile statistics from the majority of monitoring sites were below those calculated for the baseline monitoring period for offshore and nearshore sites (Tables 3 to 5, Figures 6 to 10). At inshore sites turbidity statistics in November 2018 tended to be lower, or similar to baseline. Similar to the previous month the exception to this observation was at site CH1; where the monthly mean was 2 NTU greater than that of the baseline (Table 3). However, the 99th percentile for CH1 was slightly lower than that of the baseline monitoring period as it was in October. In contrast to the previous month, the 95th and 80th percentile values were also slightly raised in a similar finding to that observed in September 2018, when weather conditions were quite volatile.

Table 5 Mean turbidity and statistics at offshore water quality logger sites during November 2018 and Baseline period (1 November 2016 to 31 October 2017).
*Values for November are means ± se, range and percentiles (n = 1422 to 2878). Baseline values modified from Fox 2018. *Note that no benthic data able to be retrieved from OS6 as loggers were not able to be located.*

Site	Statistic	Turbidity (NTU)		
		Surface October	Surface Baseline	Benthic November
OS1	Mean ± se	6.6 ± 0.1	7.5	45 ± 1
	Range	<1 – 20	-	8 – 210
	99th	16	24	138
	95th	12	16	105
	80th	8.6	10	63
OS2	Mean ± se	5.0 ± 0.0	6.4	30 ± 0
	Range	1 – 19	-	3 – 171
	99th	14	18	108
	95th	10	13	76
	80th	6.2	9.0	45
OS3	Mean ± se	5.2 ± 0.1	6.6	27 ± 0
	Range	<1 – 23	-	3 – 199
	99th	17	27	101
	95th	12	15	65
	80th	7.3	8.9	38
OS4	Mean ± se	2.4 ± 0.0	5.9	30 ± 1
	Range	<1 – 14	-	1 – 202
	99th	10	20	141
	95th	7.3	13	95
	80th	4.1	8.3	48
OS5	Mean ± se	3.5 ± 0.0	4.6	–
	Range	<1 – 15	-	–
	99th	8.9	19	–
	95th	6.8	11	–
	80th	4.9	6.4	–
OS6	Mean ± se	2.6 ± 0.0	4.7	*
	Range	<1 – 30	-	
	99th	13	19	
	95th	7.0	12	
	80th	3.6	7.2	
OS7	Mean ± se	6.1 ± 0.1	6.4	–
	Range	1 – 20	-	–
	99th	16	23	–
	95th	12	14	–
	80th	8.8	9.2	–

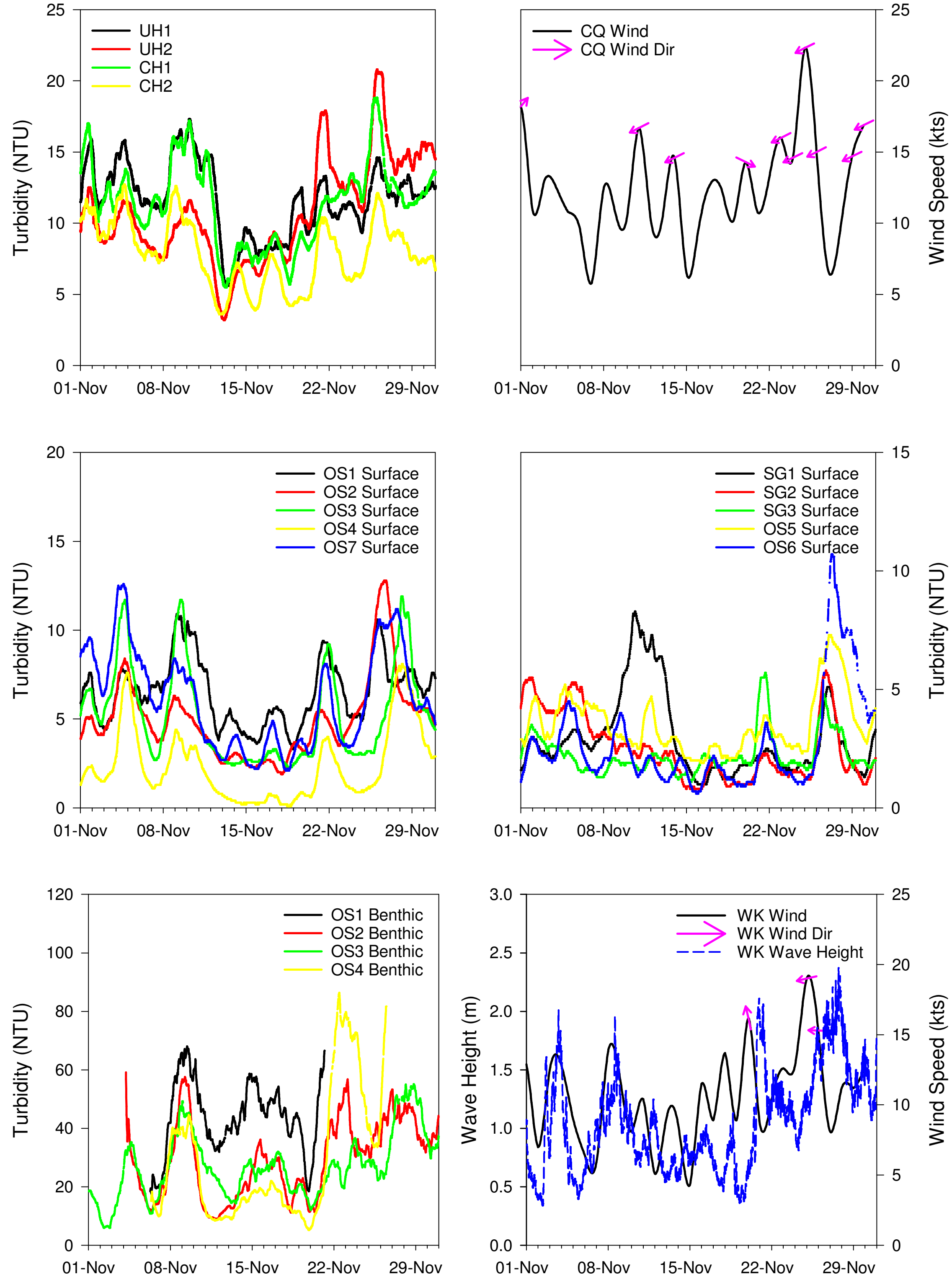


Figure 5 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

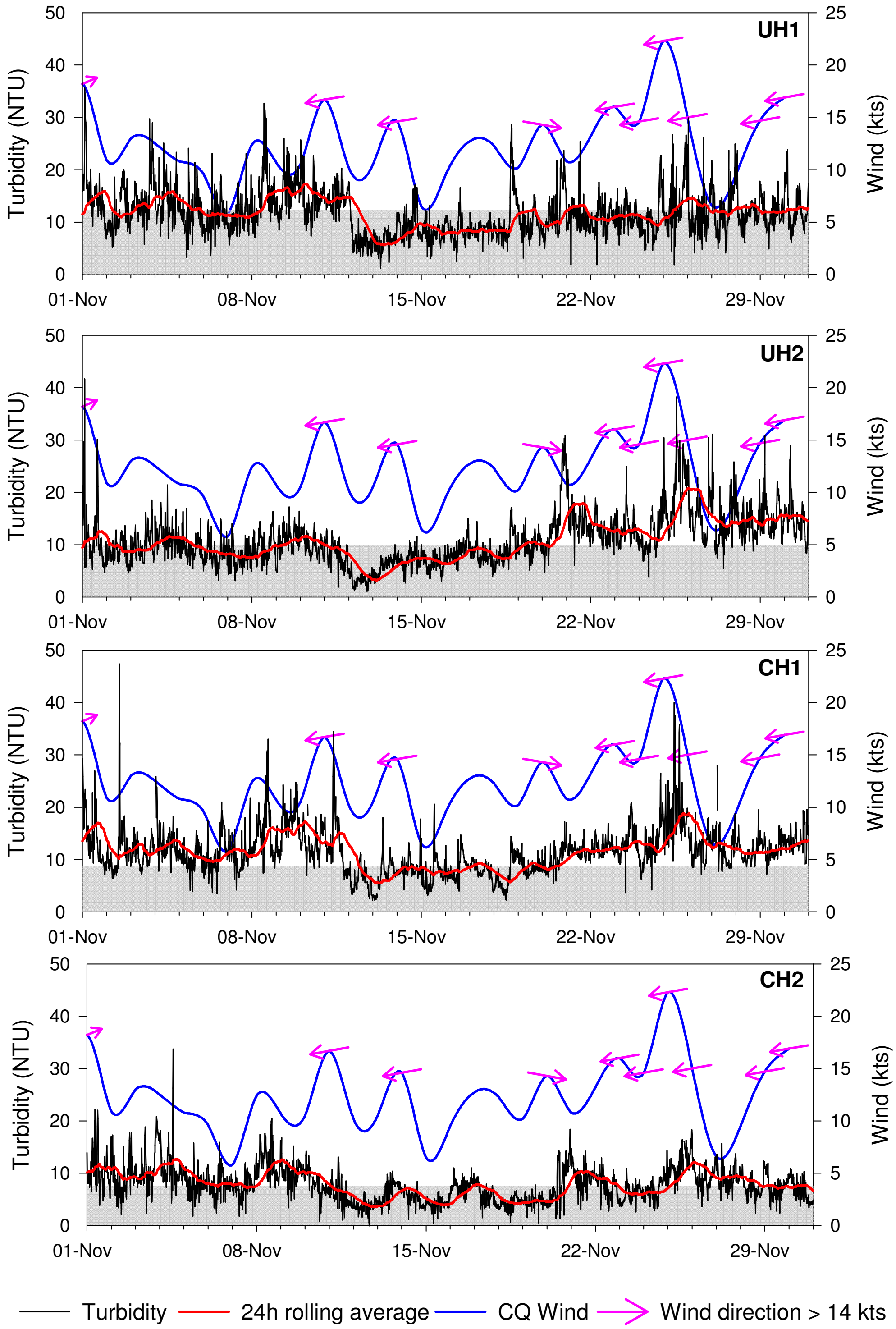


Figure 6 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during November 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

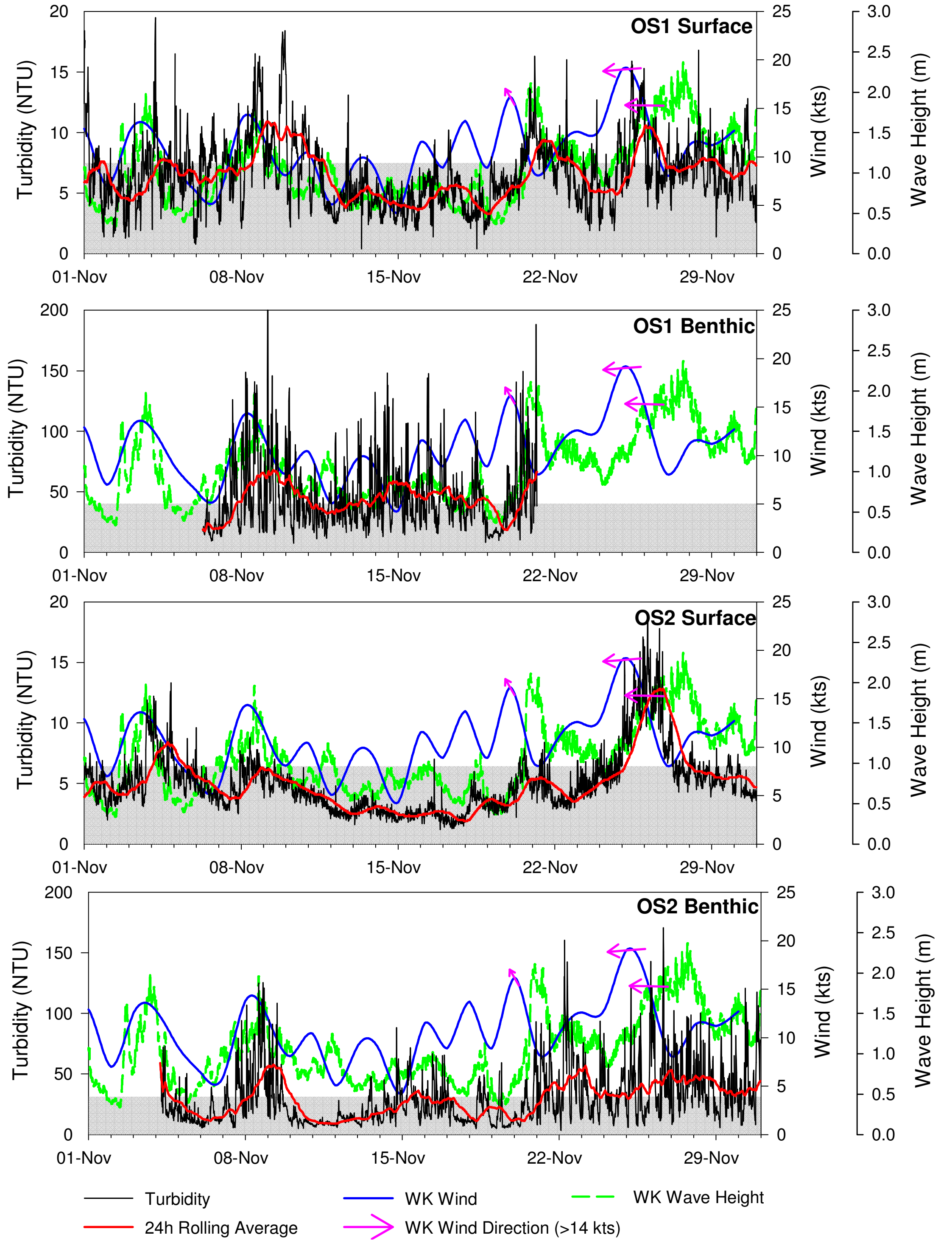


Figure 7 Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) during November 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

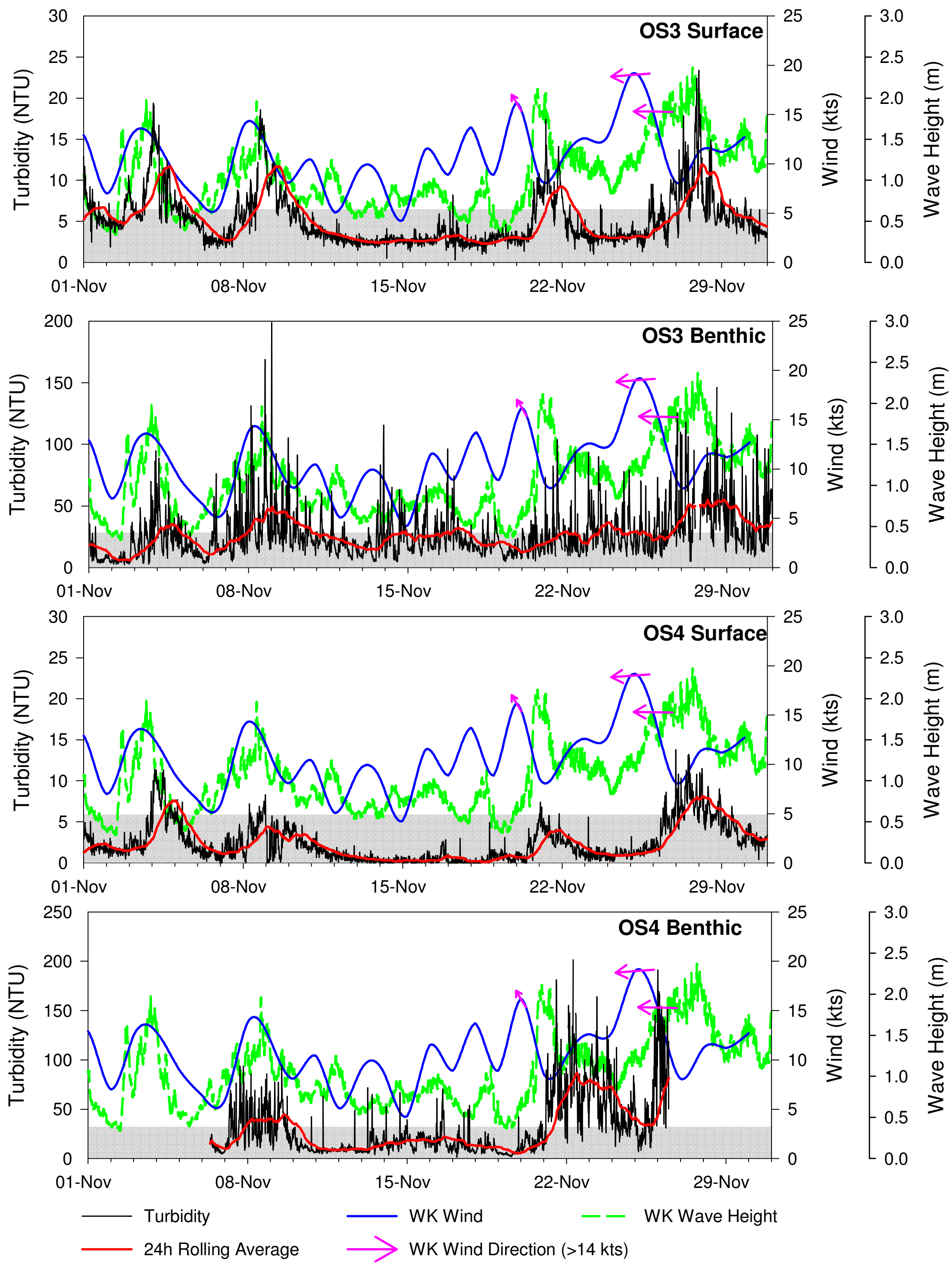


Figure 8 Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) during November 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

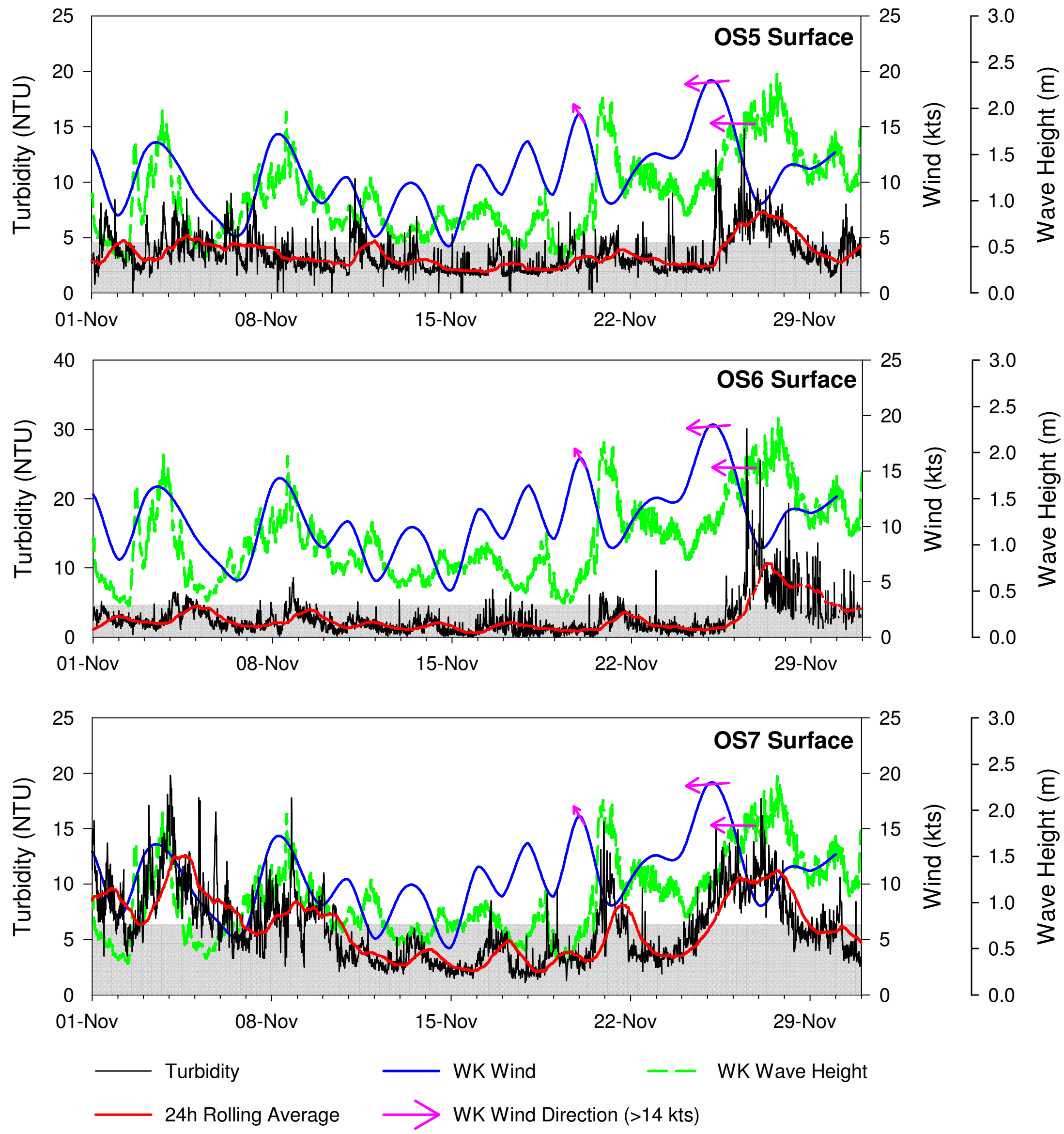


Figure 9 Surface turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) during November 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity. No benthic data at OS6.

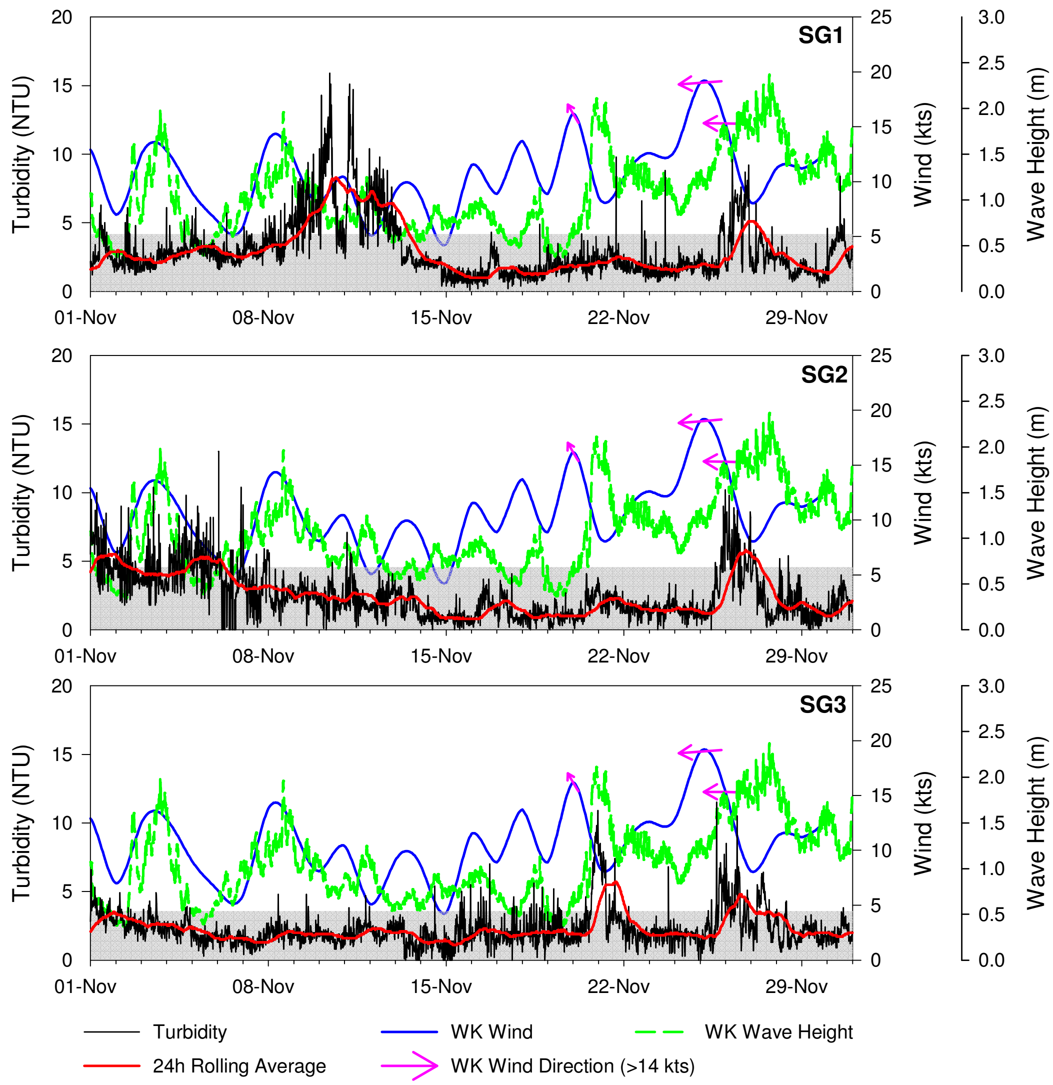


Figure 10 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during November 2018. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.*

3.2.2 Dredge Compliance Trigger Values

Management of dredge operations from commencement of the works on the 29 August 2018 was guided by the use of three tier levels of turbidity trigger values based on the higher order percentiles (refer Section 2.1.2). Tier 1 (80th percentile) and Tier 2 (95th percentile) intensity values are designated for LPC internal use and provide early warning mechanisms of elevated turbidity conditions. A compliance alert is 'tripped' if:

1) The current KZ smoothed turbidity reading is above the relevant Tier 3 (99th percentile) intensity level; **and**
2) The cumulative time of exceedances defined in 1) during the current 30 day rolling window exceeds the allowable hours given.

The Tier 1 to 3 intensity levels for KZ smoothed data and allowable hours calculated for the project (Fox, 2018), are outlined in Table 6.

Table 6 Turbidity intensity values for each site and allowable hours of exceedance in rolling 30 day period.
Allowable hours for Tiers 1 and 2 are indicative only and non-binding as these are for internal LPC use only.

Site	Tier 1	Tier 2	Tier 3
UH1	15.1	21.7	42.9
UH2	13.0	19.6	30.2
CH1	11.6	17.6	28.1
CH2	10.4	15.2	22.7
OS1	9.9	15.1	23.4
OS2	8.9	12.4	17.3
OS3	8.9	14.2	30.6
OS4	Reference site		
OS5	6.2	11.2	18.3
OS6	7.3	11.5	18.8
OS7	9.2	14.2	22.7
SG1	6.3	9.6	13..9
SG2	6.9	10.6	20.1
SG3	4.7	7.4	13.1
Allowable hours	144	36	7.2

3.2.2.1 P99 Exceedance Counts

During November, the Tier 3 intensity values were not exceeded at any site within the monitoring network (Table 7).

Table 7 Tier 3 intensity value exceedances and allowable hour counts during November 2018.

Site	P99 Count >7.2 Hours Start Time	P99 Count >7.2 Hours End Time	Maximum P99 Count (Hours)
UH1	–	–	0.00
UH2	–	–	0.00
CH1	–	–	0.00
CH2	–	–	0.00
OS1	–	–	0.00
OS2	–	–	0.00
OS3	–	–	0.00
OS4	Reference site		
OS5	–	–	0.00
OS6	–	–	0.00
OS7	–	–	0.00
SG1	–	–	0.00
SG2	–	–	0.00
SG3	–	–	0.00

3.2.3 Temperature

Average surface water temperatures during November were once again warmer than those experienced during the previous month, ranging from 14.7 to 16.1°C (Table 8), compared to 12.6 to 13.8°C in October. Once again the shallow waters of the upper and central harbour displayed the warmest mean temperatures, which is in contrast to the winter months. All sites exhibited a warming trend across the month, with small decreases occurring during periods of heavier rainfall particularly around 8 November and from 18 to 22 November (Figures 11 and 12). Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the datasets.

Similar to October benthic monthly mean temperatures were up to 1.9°C cooler than those of the surface waters. Temporal patterns were only similar to surface patterns towards the end of the month, with benthic temperature tending to remain fairly stable prior to that. There appeared to be little impact on benthic temperature from the freshwater inundation on 11 November, nor from the two major rainfall events during November. Site OS1 continued to demonstrate cyclical responses to tidal variation.

Table 8 Mean temperature at inshore, spoil ground and offshore water quality sites during November 2018.
Values are means ± se (n = 506 to 2880). Data from 1 to 6 Nov only at OS6*

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	16.1 ± 0.0	–
UH2	15.9 ± 0.0	–
CH1	15.2 ± 0.0	–
CH2	15.5 ± 0.0	–
SG1	15.0 ± 0.0	–
SG2	14.9 ± 0.0	–
SG3	14.8 ± 0.0	–
OS1	15.3 ± 0.0	14.4 ± 0.0
OS2	15.2 ± 0.0	14.0 ± 0.0
OS3	14.9 ± 0.0	13.9 ± 0.0
OS4	14.7 ± 0.0	13.9 ± 0.0
OS5	15.2 ± 0.0	–
OS6	15.0 ± 0.0	13.1 ± 0.0
OS7	15.3 ± 0.0	–

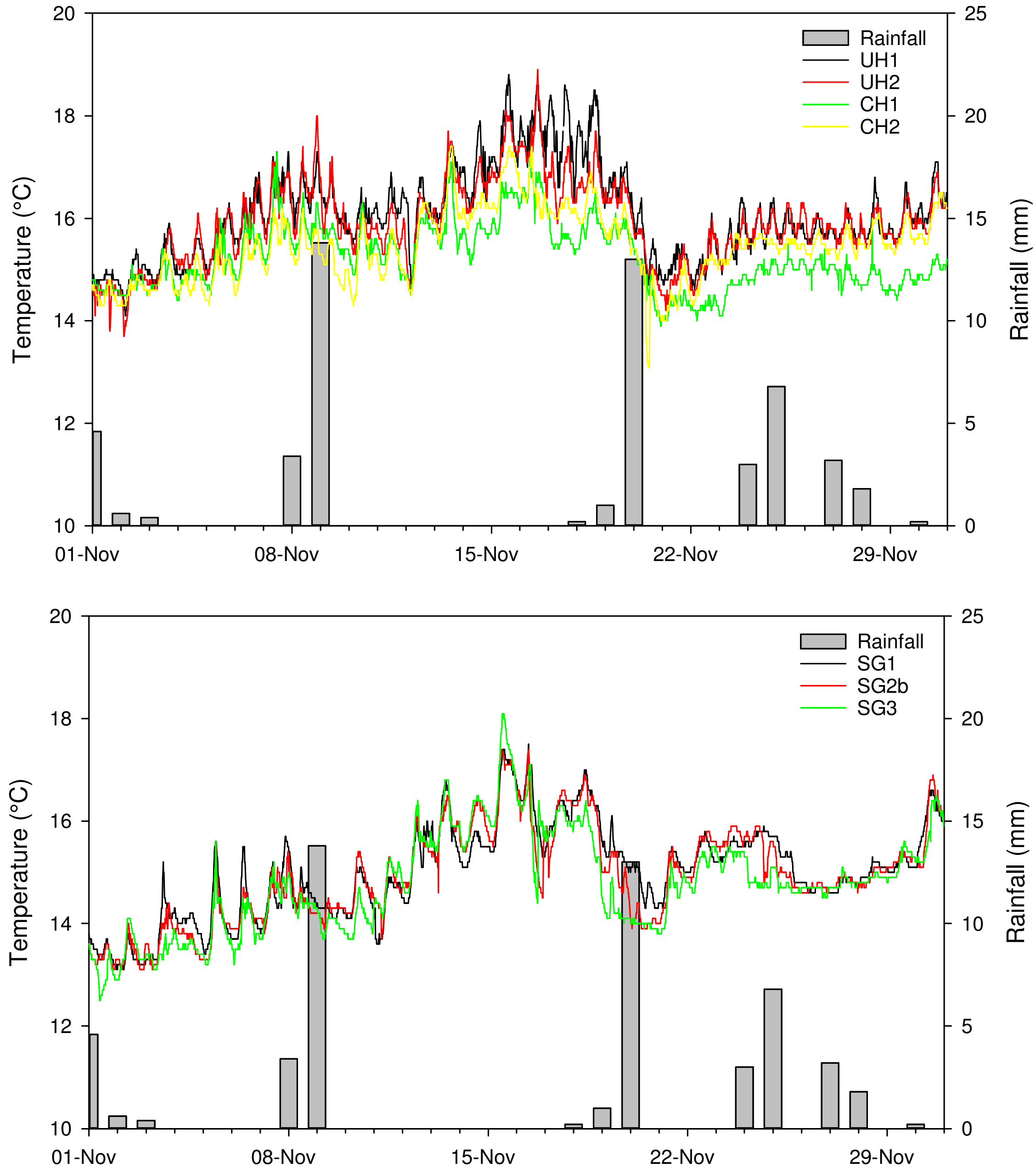
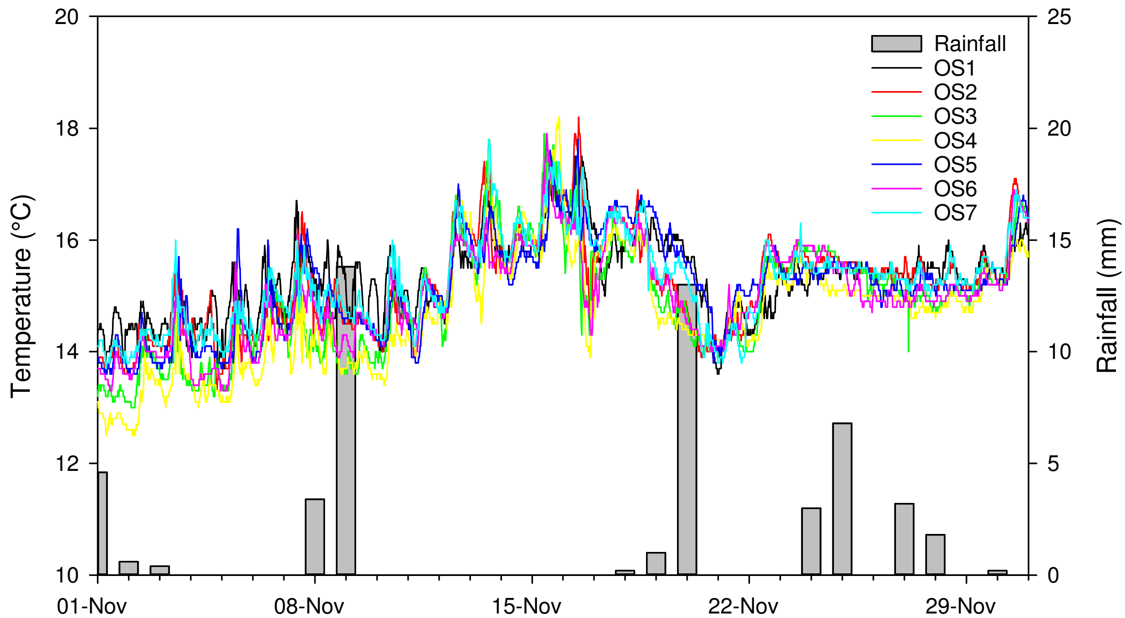


Figure 11 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during November 2018.



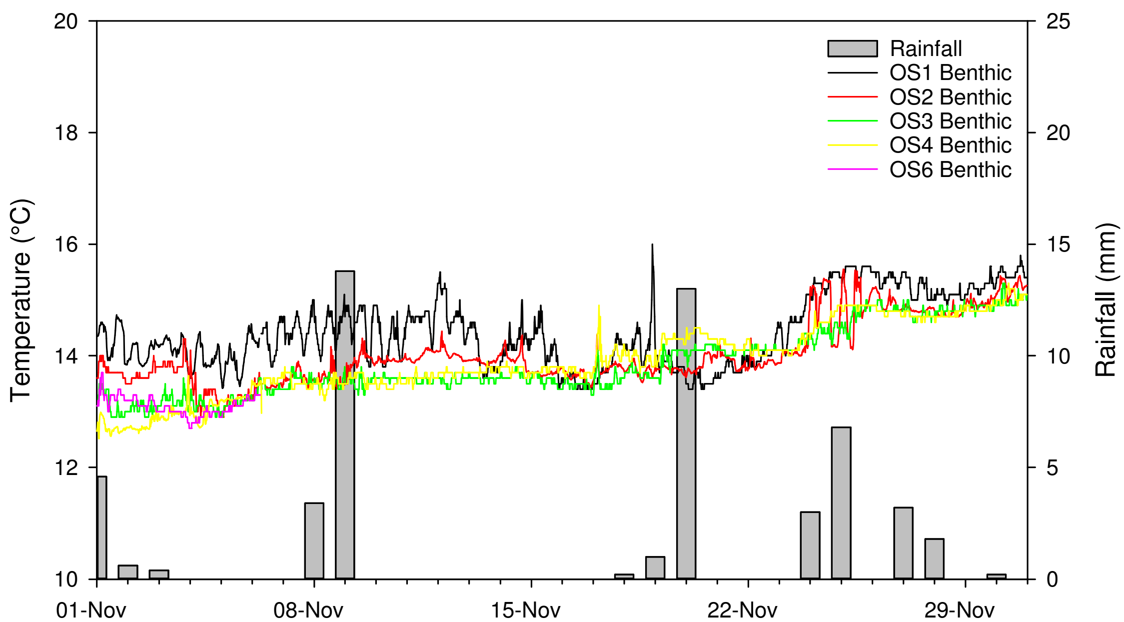


Figure 12 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites during November 2018.

3.2.4 pH

Once again, the pH data collected from surface sondes did not demonstrate any strong spatial patterns, with mean monthly surface pH for November ranging from 8.0 to 8.2 (Table 9). Temporally, surface pH did not appear to display any trends associated with the month's two major rainfall events (Figures 13 and 14) except for slight declines in pH at the inshore sites. There was a high level of variability inherently incorporated within the data as typically observed.

As expected, benthic pH (Table 9) displayed greater stability than that of the surface waters (Figure 14), due to the reduced influence of photosynthesis and respiration at depth.

Table 9 Mean pH at inshore, spoil ground and offshore water quality sites during November 2018. *Values are means ± se (n = 1629 to 2880). No data available at OS6*

Site	pH	
	Surface loggers	Benthic loggers
UH1	8.1 ± 0.0	–
UH2	8.0 ± 0.0	–
CH1	8.1 ± 0.0	–
CH2	8.1 ± 0.0	–
SG1	8.1 ± 0.0	–
SG2	8.2 ± 0.0	–
SG3	8.1 ± 0.0	–
OS1	8.1 ± 0.0	7.9 ± 0.0
OS2	8.1 ± 0.0	8.0 ± 0.0
OS3	8.1 ± 0.0	7.9 ± 0.0
OS4	8.2 ± 0.0	7.8 ± 0.0
OS5	8.1 ± 0.0	–
OS6	8.2 ± 0.0	*
OS7	8.1 ± 0.0	–

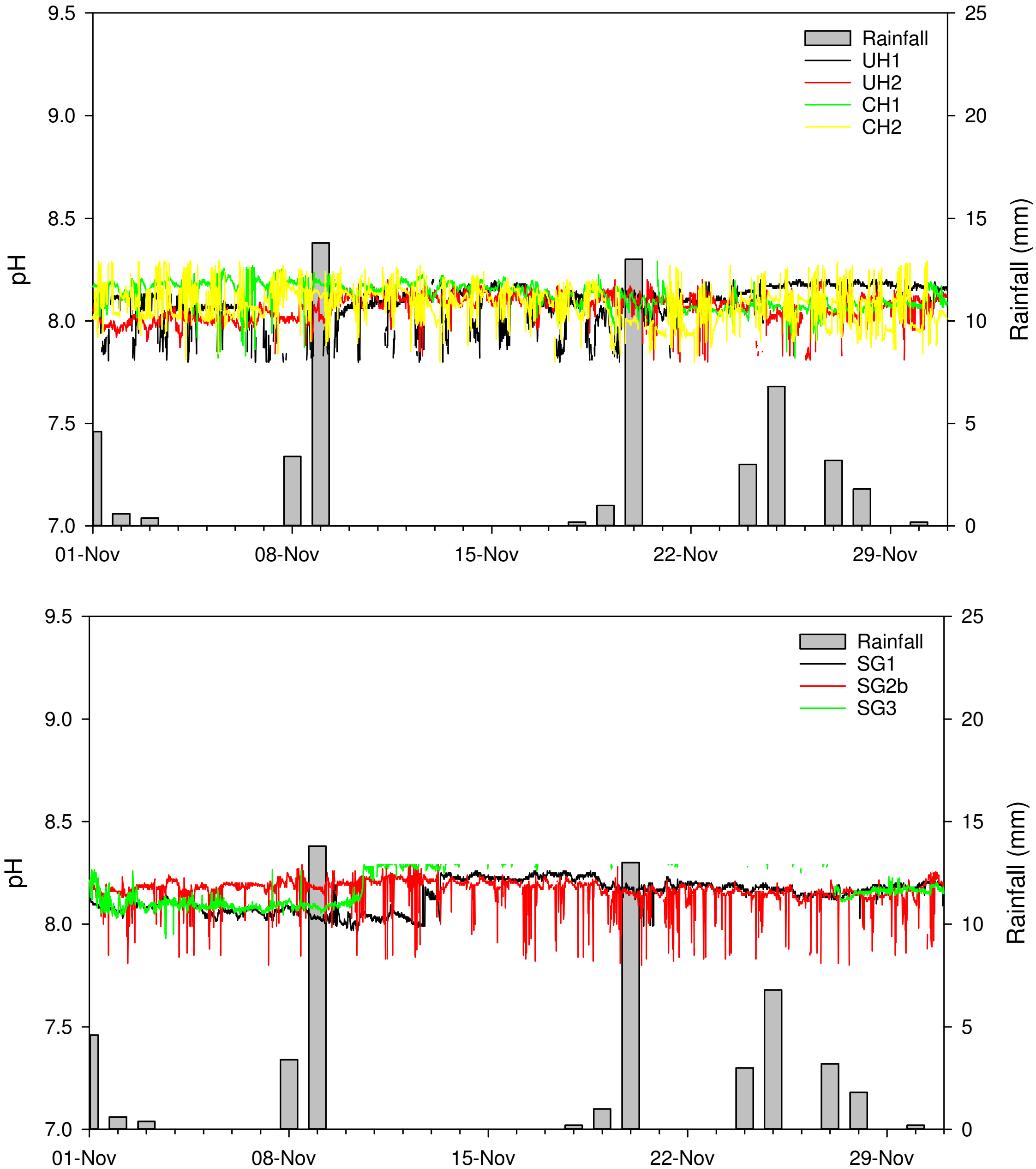


Figure 13 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2018.

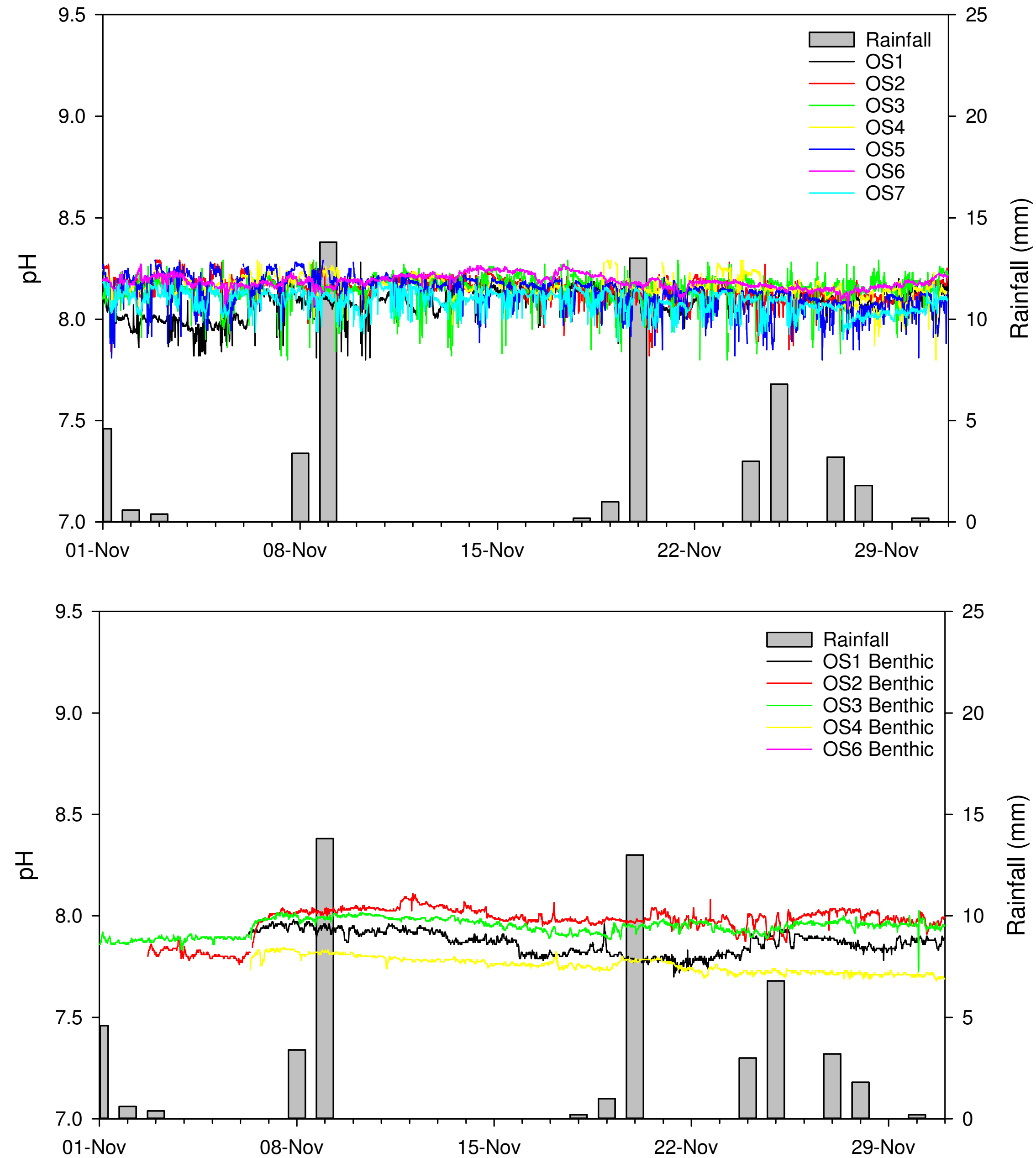


Figure 14 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at offshore water quality sites during November 2018.

3.2.5 Conductivity

Although no spatial patterns across the monitoring sites were evident for conductivity (Table 10), in contrast to previous months where minimal rainfall and flows from the Waimakariri River were experienced, notable temporal patterns across the monitoring sites were observed in November. Conductivity in November ranged from 52.1 to 54.7 mS/cm compared to 53.5 to 55.8 mS/cm in October due to the combined influence of higher local rainfall and large freshwater inputs from the Waimakariri River into the harbour.

As typically observed with large flows from the Waimakariri River (Figure 4) which began influencing monitoring sites from 11 November, there was a staged pattern of influence as the freshwater traversed both down the coast and into the harbour entrance. The offshore sites of OS5 and SG1 were the first to be impacted followed by OS2 and OS7 as the currents moved in an anticlockwise direction (Figures 15 and 16). Declines of up to 13 mS/cm were experienced at sites SG1 and OS5. Within 24 hours inner harbour sites also displayed conductivity declines up to 6 mS/cm as the freshwater entered the harbour on the incoming tides, as did sites OS3 and OS4 as the freshwater traversed east down the coast past Pigeon Bay.

Table 10 Mean conductivity at inshore, spoil ground and offshore water quality sites during November 2018.
Values are means ± se (n = 499 to 2880).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	52.1 ± 0.0	–
UH2	53.0 ± 0.0	–
CH1	52.2 ± 0.0	–
CH2	53.7 ± 0.0	–
SG1	53.5 ± 0.0	–
SG2	53.8 ± 0.0	–
SG3	54.7 ± 0.0	–
OS1	52.4 ± 0.0	54.1 ± 0.0
OS2	52.1 ± 0.0	54.8 ± 0.0
OS3	53.3 ± 0.0	54.1 ± 0.0
OS4	54.4 ± 0.0	53.6 ± 0.0
OS5	52.8 ± 0.0	–
OS6	52.9 ± 0.0	57.8 ± 0.0
OS7	52.2 ± 0.0	–

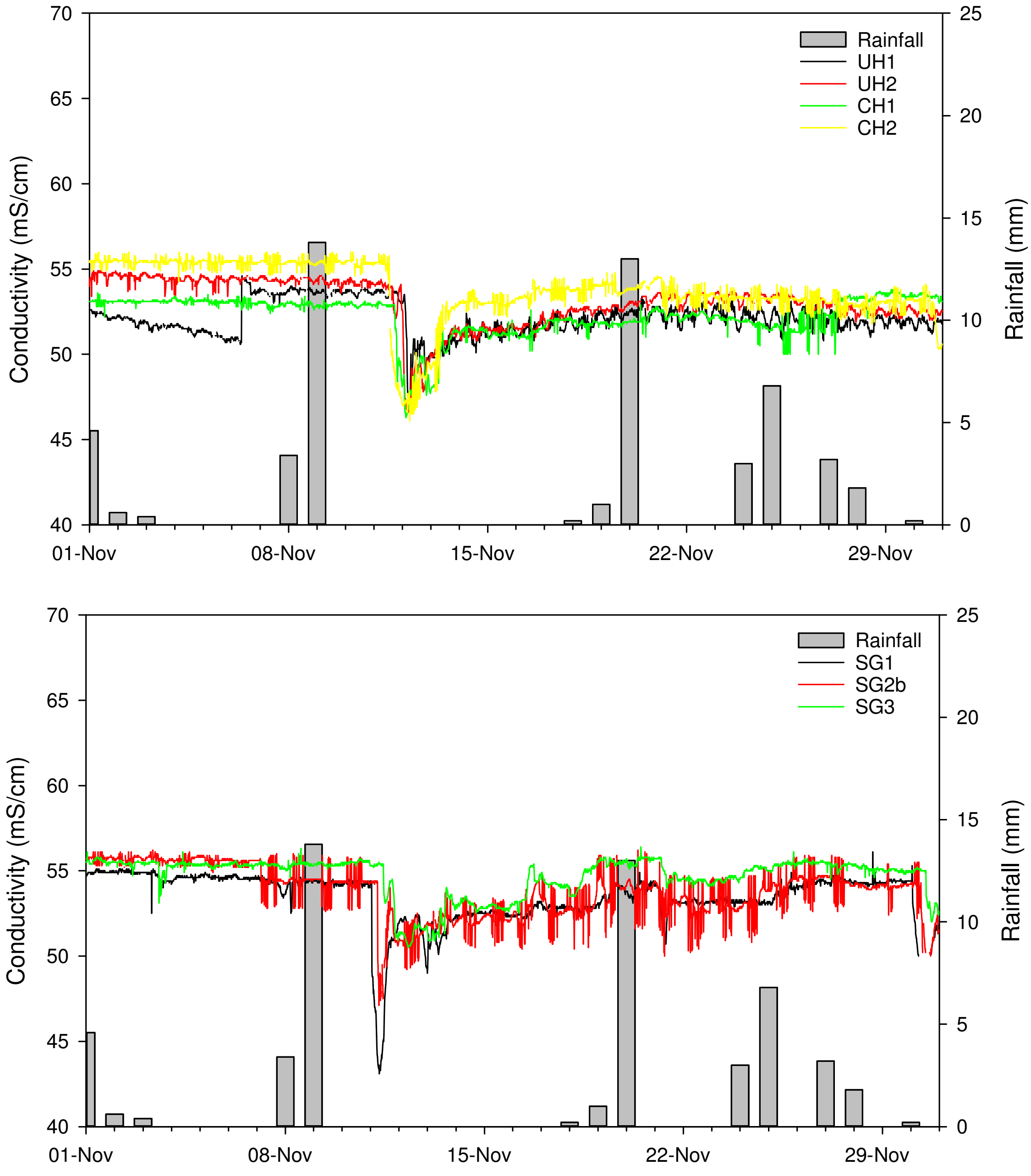


Figure 15 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2018.

Recovery at the offshore sites of OS5 and SG1 was quite rapid due to mixing with ocean currents whereas the nearshore and inshore sites displayed lower than typical salinity for up to a week after the event (Figures 15 and 16). A smaller decline in conductivity at spoil ground and offshore sites only on 30 November may be related to a smaller flow event from the Waimakariri, which had occurred several days prior.

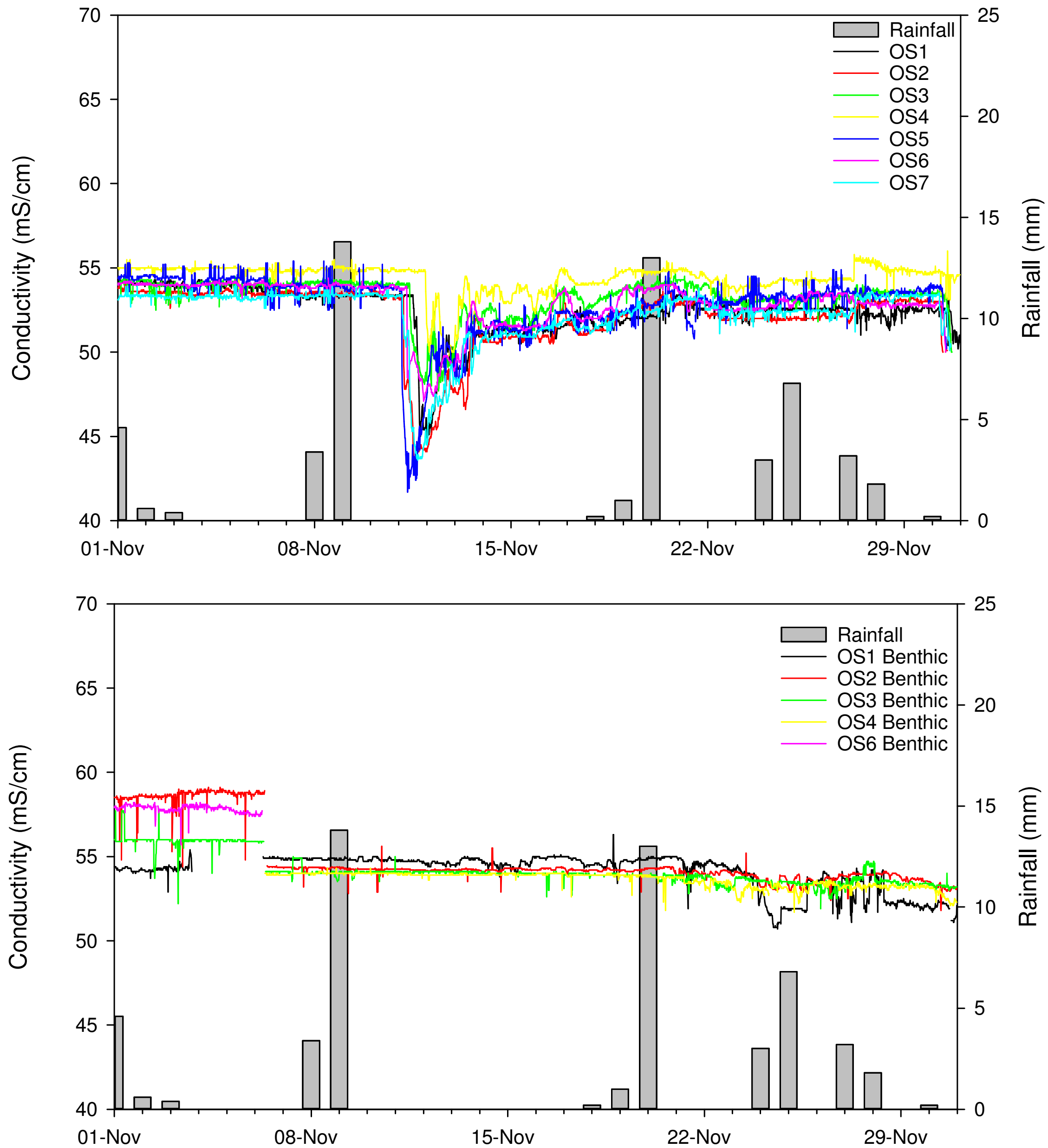


Figure 16 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites during November 2018.

Benthic conductivity data was typically higher than the corresponding surface values, similar to previous monitoring months (Table 10). In contrast to the surface dataset, the freshwater flow from the Waimakariri River did not result in variability in benthic conductivity (Figure 16). Nor did periods of localised rainfall which similarly had little impact on surface sites.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations were overall lower in November (94 to 101% saturation) compared to October (97 to 106% saturation), but similar to those recorded in September (Table 11). DO declined from peaks at inshore sites of 120% on 7 November to lows of 84% on 10 November, after the local large rainfall event of 8 and 9 November. The extent of the declines was not as apparent at the more oceanic sites (Figures 17 and 18). Declines were also evident at all sites during the second large precipitation event from 18 November, although not as large due to the DO not having recovered fully to typical background conditions, from the previous event. Increased cloud cover is likely to have resulted in reductions in photosynthesis and thus oxygen generation. Although chlorophyll *a* concentrations measured in samples collected on 13 November were elevated at some sites it is likely that they were higher prior to the initial rain event with the increased algal mass responsible for the previously elevated DO concentrations, particularly in the inshore area. The influx of freshwater on 12 November had little influence on DO concentrations apart from increasing the variability at some sites. DO began to recover towards the end of the month with the cessation of precipitation events.

Table 11 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during November 2018.
Values are means ± se (n = 503 to 2880).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	96 ± 0	–
UH2	94 ± 0	–
CH1	96 ± 0	–
CH2	95 ± 0	–
SG1	101 ± 0	–
SG2	101 ± 0	–
SG3	97 ± 0	–
OS1	96 ± 0	89 ± 0
OS2	98 ± 0	86 ± 0
OS3	97 ± 0	89 ± 0
OS4	100 ± 0	95 ± 0
OS5	101 ± 0	–
OS6	102 ± 0	91 ± 0
OS7	99 ± 0	–

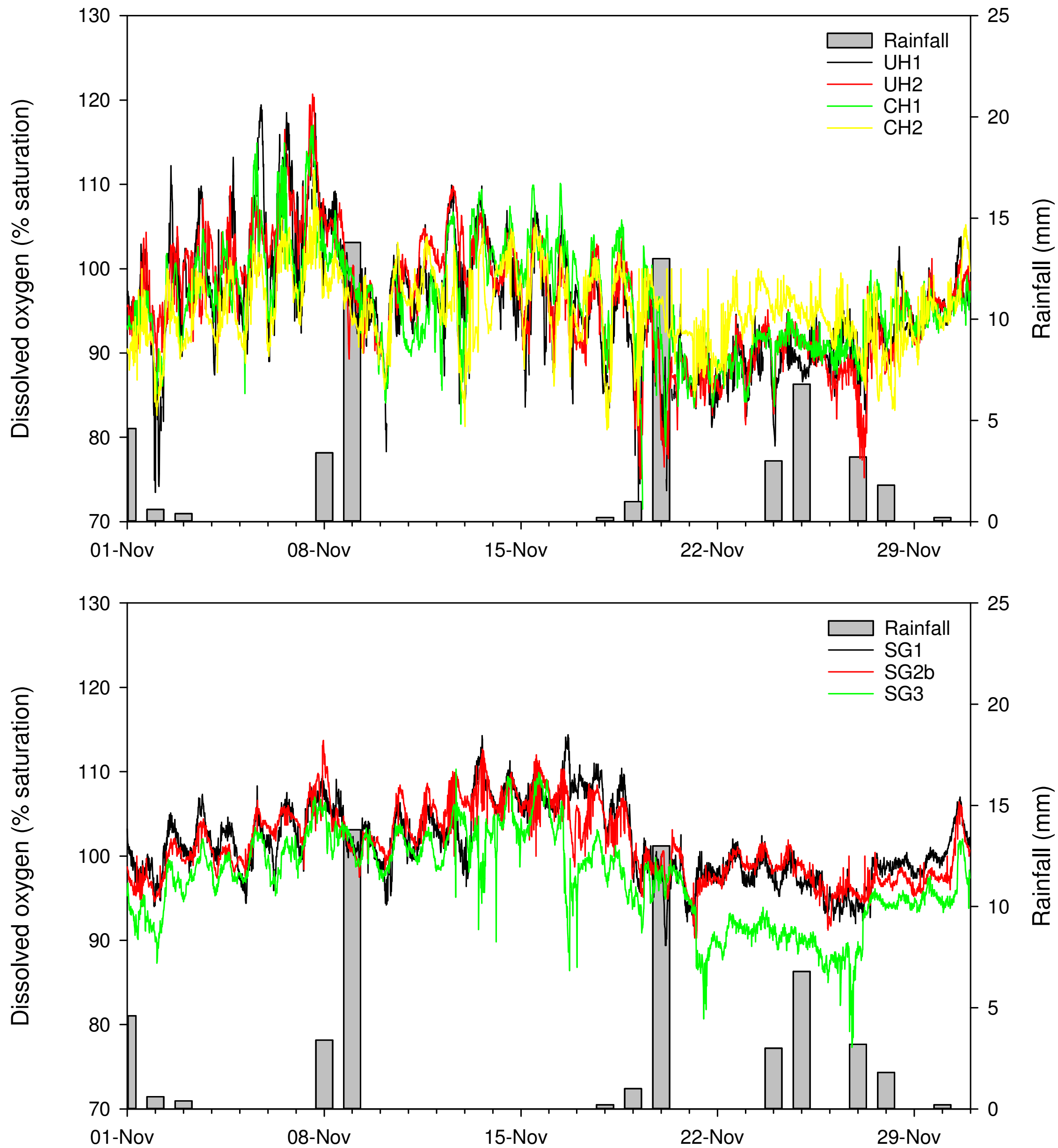


Figure 17 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2018.

As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings, due to reduced photosynthesis (producing less oxygen) occurring at depth (Table 11). There initially appeared to be little influence on benthic DO from the freshwater inundation on 11 November. However, concentrations of DO declined near the seabed from 13 November (Figure 18) at all sites except OS4 before recovering from 21 November. This may be a reflection of *in situ* consumption through biological oxygen demand (BOD) as detritus associated with sediment and colloid particles settled towards the benthos.

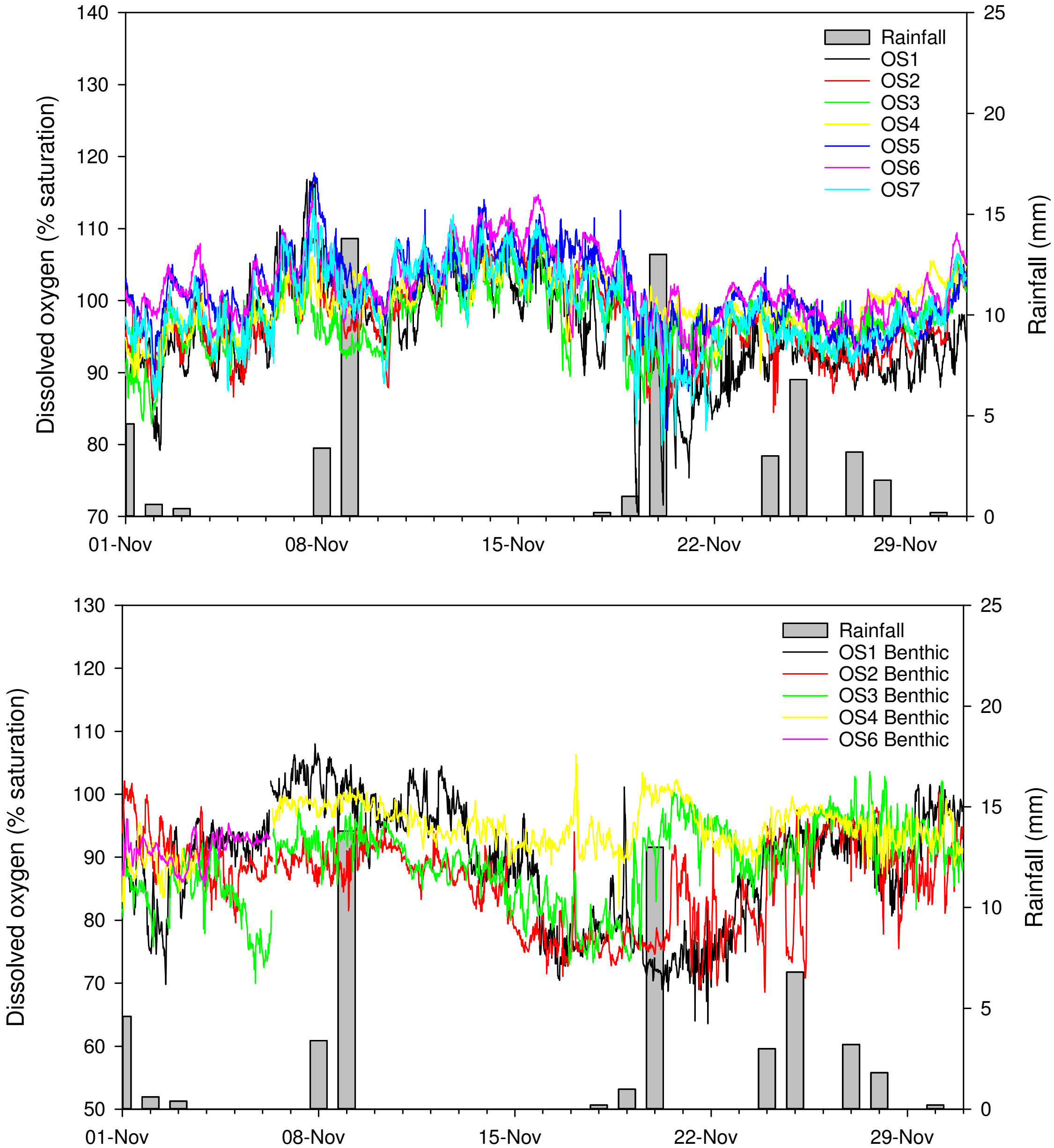


Figure 18 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites during November 2018.

3.3 Physicochemistry Depth Profiling & TSS

Vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling on 13 November. In addition to the previously discussed physicochemical parameters, the light attenuation rate (K_d, the rate at which light or PAR diminishes with depth through the water column) and resultant euphotic depth (the theoretical depth to which photosynthesis can occur/where light levels are ~1% of those at the surface) were also calculated.

Water samples for the determination of TSS were also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, CH1 and CH2. Further information regarding the specific sampling methodology can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Statistical analyses of the resulting datasets are provided in Tables 12 to 14, with depth profile plots presented in Figures 19 to 21.

The relatively shallow sites of the upper and central harbour which are generally vertically well mixed, displayed altering gradients for some parameters (Figure 19). Although turbidity remained consistent with depth, temperature, pH and DO demonstrated slight declines with depth while conductivity showed a reverse trend (Figure 19). Sampling was undertaken one day after the inner harbour was influenced by large freshwater flows from the Waimakariri River. This was reflected in the conductivity profiles with denser saline waters towards the benthos and lighter freshwater at the surface. Sites were more similar to one another in terms of conductivity compared to the previous month. Profiles for the offshore sites (OS1 to OS4 and OS7) were similar to those in October except for conductivity, which varied up to 6 mS/cm among sites at the surface (OS2<OS1<OS7<OS3 and OS4 which were similar in concentration). At 10 m depth from the surface, conductivity among sites became similar and remained consistent through the water column (Figure 20). Temperature profiles also displayed a steeper gradient in the thermocline than in October. Results were similar at the spoil ground sites although variability in surface conductivity among sites was not as great and the conductivity at sites converged at a shallower depth than at the offshore sites (Figure 21). Subsurface and whole column conductivity at all sites in November (46.6 to 52.6 mS/cm) was much lower than in October (52.1 to 53.1) reflecting the freshwater input throughout the water column (Tables 12 to 14).

Benthic waters within the harbour at CH2 and UH2 were also characterised by slight increases in turbidity (Figure 19, Table 12), the latter displaying the highest levels of sub-surface turbidity (7.6 NTU, Table 12), which is normally evident at upper harbour site UH1. Values at all sites were well within the turbidity WQGs and similar to that recorded during the October sampling, but lower than those in September. As previously observed during baseline monitoring, the clearest waters were observed at the deeper offshore spoil ground sites, with the calculated euphotic depth extending down to 14.5 m at SG1 (Table 13), which was a similar result to that in October.

There were no exceedances of WQG for the sub-surface during the November sampling.

Table 12 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the November 2018 sampling event. *Values are means ± se (n = 4 to 6 for sub-surface, n = 20 to 36 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
UH1	13/11/2018 07:04	Sub-surface	16.0 ± 0.0	8.0 ± 0.0	48.5 ± 0.0	106 ± 1	5.5 ± 0.1	8	1.1 ± 0.1	4.2
		Whole column	16.0 ± 0.0	8.0 ± 0.0	49.5 ± 0.2	103 ± 1	7.9 ± 0.6	–		
UH2	13/11/2018 07:14	Sub-surface	16.1 ± 0.0	8.0 ± 0.0	48.3 ± 0.0	106 ± 0	7.6 ± 0.9	5	1.2 ± 0.0	3.8
		Whole column	16.0 ± 0.0	8.0 ± 0.0	49.8 ± 0.2	101 ± 1	9.5 ± 0.9	–		
UH3	13/11/2018 06:13	Sub-surface	15.8 ± 0.0	7.9 ± 0.0	48.2 ± 0.0	107 ± 0	4.7 ± 0.3	8	1.0 ± 0.0	4.5
		Whole column	16.0 ± 0.0	7.9 ± 0.0	48.5 ± 0.1	107 ± 0	7.4 ± 0.6	–		
CH1	13/11/2018 07:44	Sub-surface	15.7 ± 0.0	8.0 ± 0.0	48.0 ± 0.0	107 ± 0	4.2 ± 0.5	8	1.4 ± 0.1	3.3
		Whole column	15.5 ± 0.1	8.0 ± 0.0	49.7 ± 0.3	103 ± 1	25 ± 6	–		
CH2	13/11/2018 07:29	Sub-surface	15.9 ± 0.0	8.0 ± 0.0	48.5 ± 0.0	106 ± 0	3.0 ± 0.1	4	1.1 ± 0.0	4.0
		Whole column	15.4 ± 0.1	8.0 ± 0.0	50.3 ± 0.3	102 ± 1	7.6 ± 0.7	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the November 2018 sampling event. *Values are means ± se (n = 4 to 6 for sub-surface, mid and benthos, n = 38 to 39 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS1	13/11/2018 07:57	Sub-surface	15.4 ± 0.0	8.1 ± 0.0	48.2 ± 0.0	106 ± 0	5.3 ± 2.3	10	0.8 ± 0.0	6.1
		Mid	15.1 ± 0.2	8.0 ± 0.0	50.7 ± 0.4	104 ± 1	2.8 ± 0.3	7		
		Benthos	13.7 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	93 ± 0	24 ± 4	10		
		Whole column	14.8 ± 0.2	8.0 ± 0.0	50.4 ± 0.3	102 ± 1	9 ± 1.9	–		
OS2	13/11/2018 10:50	Sub-surface	16.4 ± 0.1	8.1 ± 0.0	46.6 ± 0.2	109 ± 0	2.7 ± 0.3	5	0.6 ± 0.0	8.0
		Mid	14.2 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	101 ± 1	2.8 ± 0.4	4		
		Benthos	13.9 ± 0.0	8.0 ± 0.0	52.5 ± 0.0	92 ± 0	17 ± 9	8		
		Whole column	14.8 ± 0.2	8.0 ± 0.0	50.9 ± 0.4	102 ± 1	5.4 ± 1.7	–		
OS3	13/11/2018 10:11	Sub-surface	15.3 ± 0.1	8.0 ± 0.0	51.7 ± 0.1	107 ± 0	1.0 ± 0.0	<3	0.5 ± 0.0	10.0
		Mid	13.7 ± 0.0	8.0 ± 0.0	52.6 ± 0.0	96 ± 0	1.7 ± 0.1	5		
		Benthos	13.5 ± 0.0	8.0 ± 0.0	52.7 ± 0.0	93 ± 0	9.3 ± 4.5	23		
		Whole column	14.2 ± 0.1	8.0 ± 0.0	52.3 ± 0.1	99 ± 1	2.8 ± 0.8	–		
OS4	13/11/2018 09:50	Sub-surface	14.4 ± 0.0	8.0 ± 0.0	52.3 ± 0.0	103 ± 0	0.9 ± 0.0	<3	0.5 ± 0.0	9.1
		Mid	13.6 ± 0.0	8.0 ± 0.0	52.7 ± 0.0	97 ± 0	2.5 ± 0.1	8		
		Benthos	13.5 ± 0.0	8.0 ± 0.0	52.7 ± 0.0	96 ± 0	8.6 ± 1.7	<3		
		Whole column	13.9 ± 0.1	8.0 ± 0.0	52.6 ± 0.0	99 ± 0	2.9 ± 0.5	-		
OS7	13/11/2018 11:08	Sub-surface	15.6 ± 0.0	8.1 ± 0.0	49.9 ± 0.0	108 ± 0	2.7 ± 0.0	5	0.7 ± 0.0	6.2
		Mid	14.7 ± 0.1	8.0 ± 0.0	52.0 ± 0.1	102 ± 0	2.7 ± 0.3	5		
		Benthos	13.9 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	94 ± 1	14 ± 4	6		
		Whole column	14.9 ± 0.1	8.0 ± 0.0	51.2 ± 0.2	103 ± 1	5.2 ± 1.0	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during the November 2018 sampling event.
Values are means ± se (n =6 for sub-surface, mid and benthos, n = 40 to 49 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS5	13/11/2018 08:13	Sub-surface	15.4 ± 0.0	8.1 ± 0.0	49.2 ± 0.1	110 ± 0	1.9 ± 0.0	<3	0.5 ± 0	9.4
		Mid	14.1 ± 0.0	8.0 ± 0.0	52.1 ± 0.0	105 ± 0	0.9 ± 0.0	<3		
		Benthos	13.2 ± 0.0	7.9 ± 0.0	52.6 ± 0.0	88 ± 1	5.0 ± 1.0	21		
		Whole column	14.4 ± 0.1	8.0 ± 0.0	51.3 ± 0.2	103 ± 1	2.1 ± 0.3	–		
OS6	13/11/2018 10:31	Sub-surface	15.8 ± 0.0	8.1 ± 0.0	48.9 ± 0.1	108 ± 0	0.8 ± 0.0	3	0.6 ± 0	8.3
		Mid	14.0 ± 0.0	8.0 ± 0.0	52.5 ± 0.0	95 ± 0	2.1 ± 0.1	5		
		Benthos	13.2 ± 0.0	7.9 ± 0.0	52.7 ± 0.0	87 ± 0	12 ± 3	22		
		Whole column	14.3 ± 0.1	8.0 ± 0.0	51.7 ± 0.2	97 ± 1	3.4 ± 0.7	–		
SG1	13/11/2018 08:41	Sub-surface	15.2 ± 0.0	8.1 ± 0.0	49.9 ± 0.0	109 ± 0	1.1 ± 0.0	3	0.4 ± 0	11.2
		Mid	14.0 ± 0.0	8.0 ± 0.0	52.1 ± 0.0	107 ± 1	0.9 ± 0.1	4		
		Benthos	13.4 ± 0.0	8.0 ± 0.0	52.6 ± 0.0	93 ± 0	2.6 ± 0.2	8		
		Whole column	14.2 ± 0.1	8.0 ± 0.0	51.5 ± 0.2	104 ± 1	1.3 ± 0.1	–		
SG2b	13/11/2018 09:07	Sub-surface	15.5 ± 0.0	8.1 ± 0.0	49.4 ± 0.2	109 ± 0	4.5 ± 1.7	<3	0.4 ± 0	10.4
		Mid	14.2 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	101 ± 1	1.0 ± 0.1	3		
		Benthos	13.3 ± 0.0	7.9 ± 0.0	52.7 ± 0.0	87 ± 0	21 ± 11	5		
		Whole column	14.3 ± 0.1	8.0 ± 0.0	51.7 ± 0.2	101 ± 1	4.7 ± 1.7	–		
SG3	13/11/2018 09:26	Sub-surface	15.5 ± 0.0	8.1 ± 0.0	48.6 ± 0.0	108 ± 0	1.3 ± 0.3	<3	0.3 ± 0	14.5
		Mid	13.8 ± 0.0	8.0 ± 0.0	52.7 ± 0.0	106 ± 0	0.5 ± 0.1	<3		
		Benthos	13.2 ± 0.0	8.0 ± 0.0	52.8 ± 0.0	94 ± 0	8.4 ± 5.8	<3		
		Whole column	14.1 ± 0.1	8.0 ± 0.0	51.9 ± 0.2	103 ± 1	1.9 ± 0.8	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

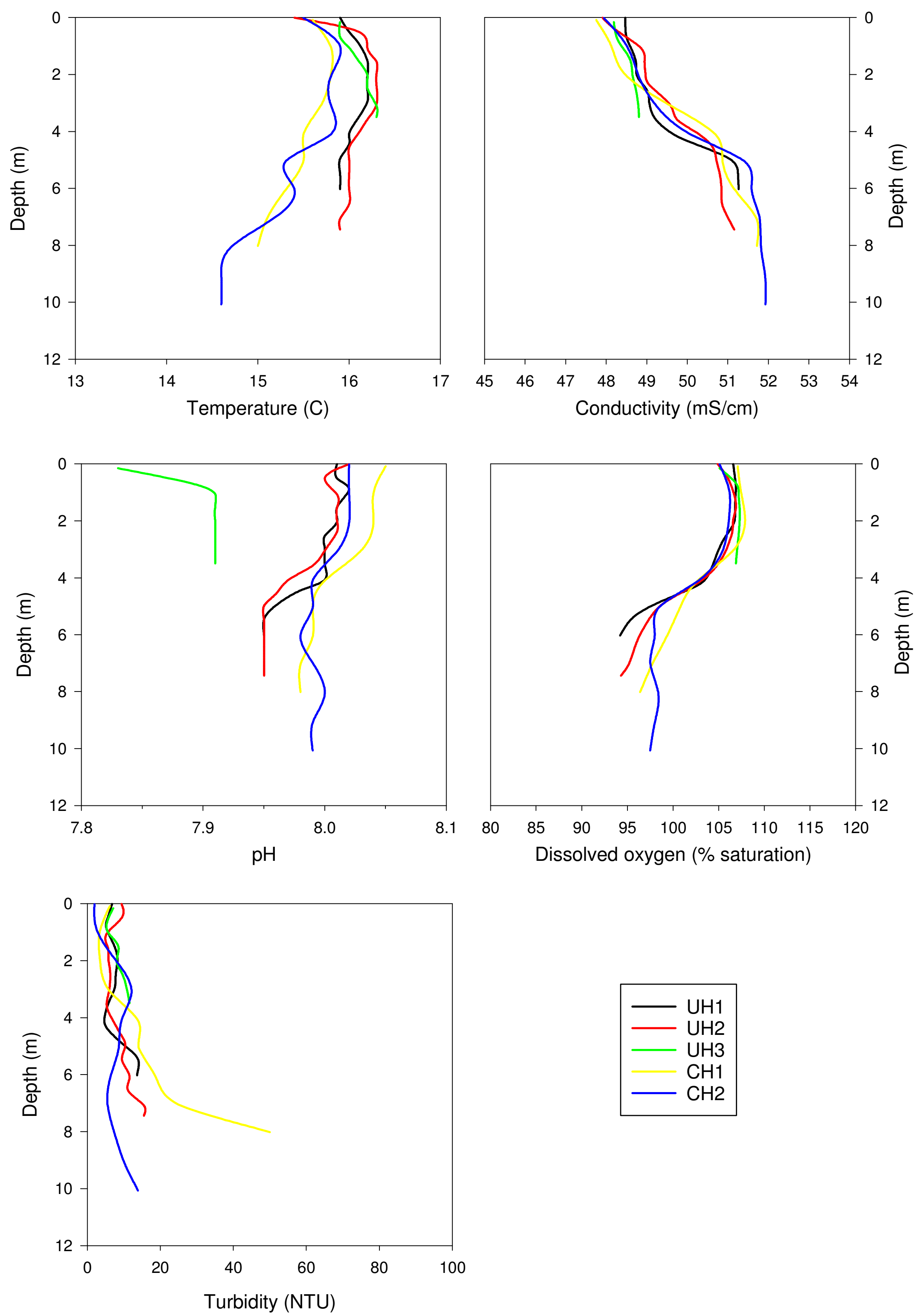


Figure 19 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 13 November 2018.

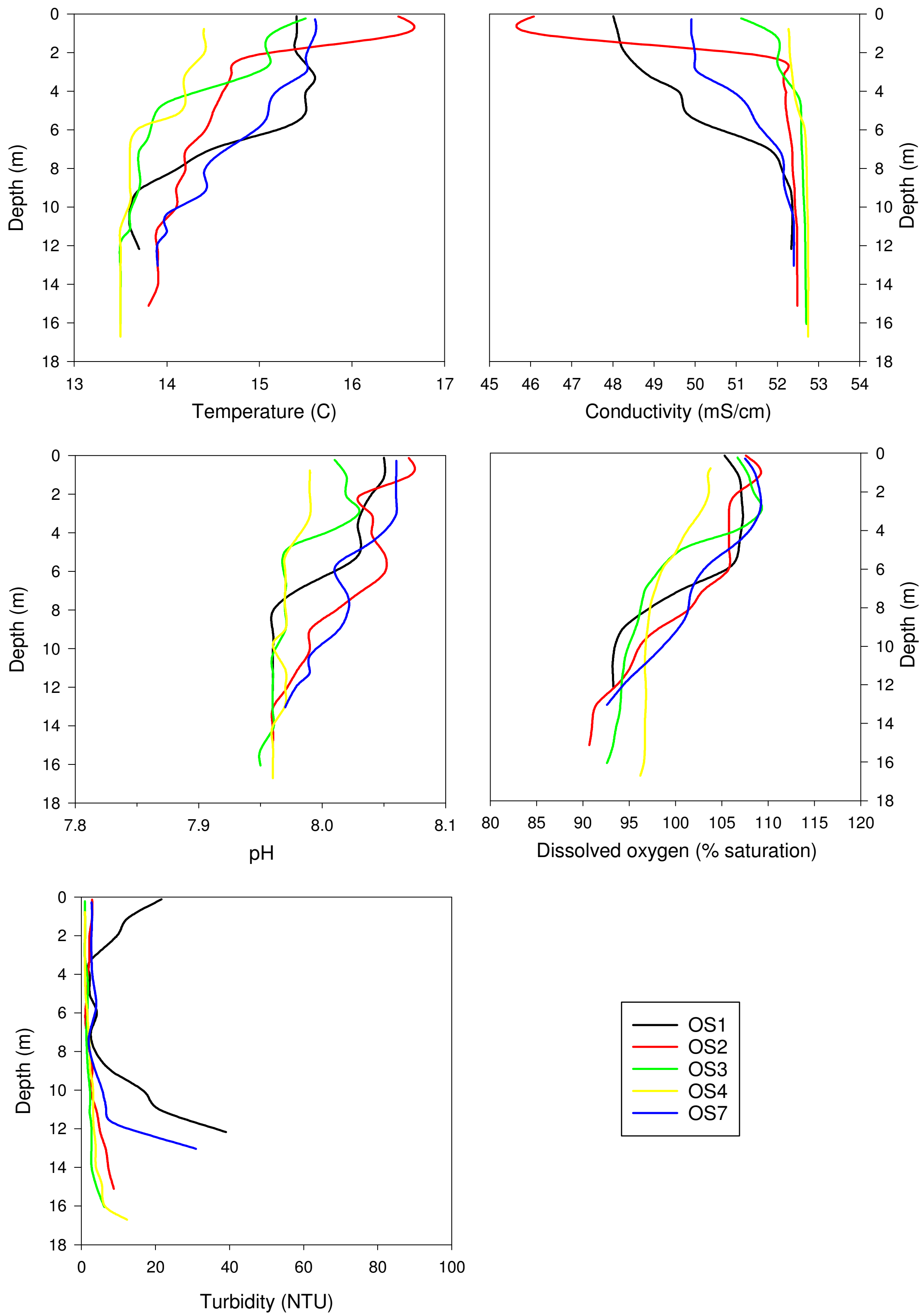


Figure 20 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 13 November 2018.

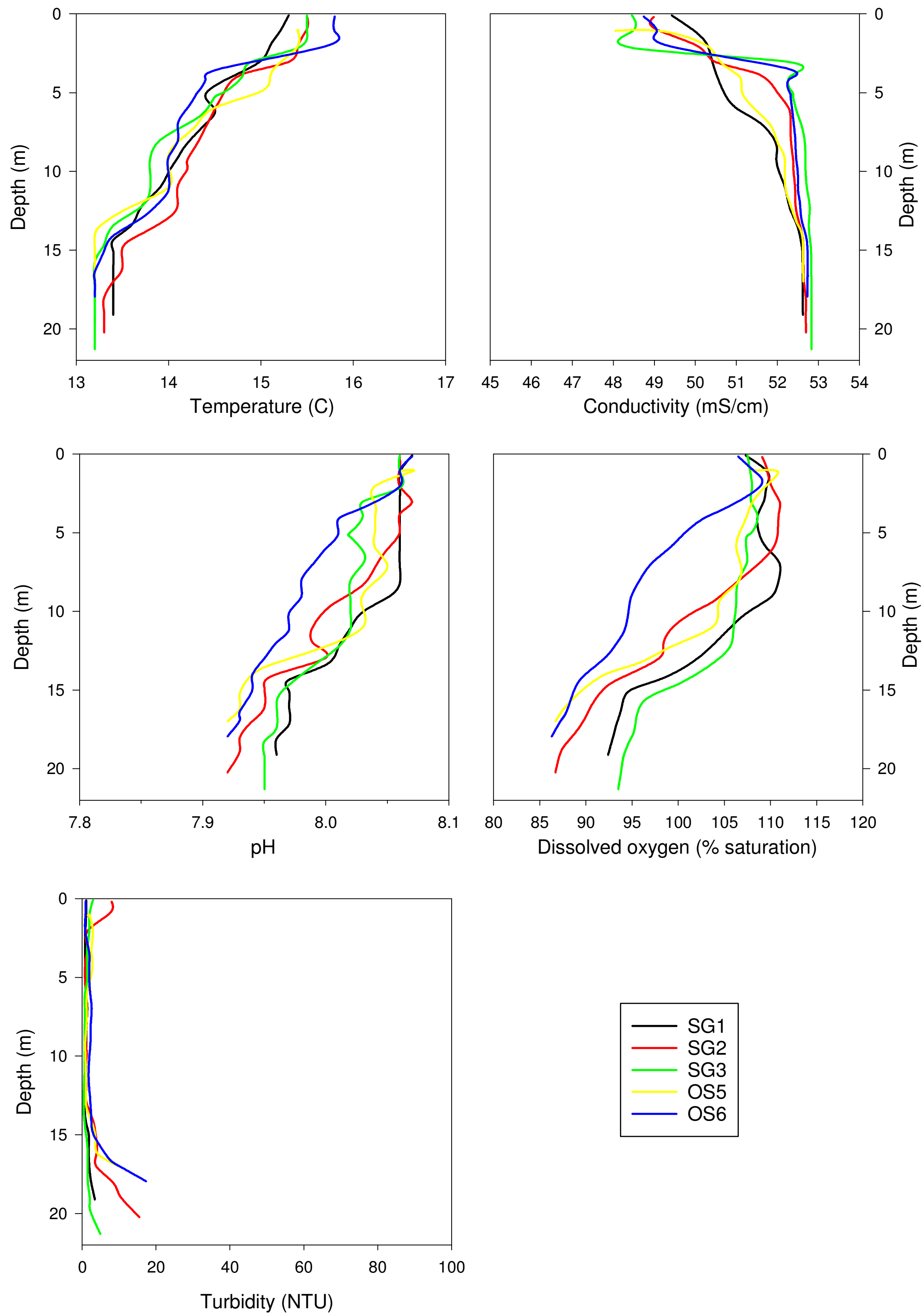


Figure 21 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 13 November 2018.

3.4 Continuous BPAR Loggers

Benthic PAR, or the amount of light reaching the benthos that can be utilised for photosynthesis, was measured at two offshore sites (OS2 and OS3) by autonomous dual PAR Odyssey loggers. Benthic PAR was compared to ambient PAR measured by telemetered PAR loggers located at the Vision Environment office in Christchurch (Vision Base Christchurch, VBCC) in order to account for variations in daily light intensity such as those induced by cloud cover. Further information on the specific methodology used in BPAR measurements can be obtained from the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

Statistical analyses on the monthly BPAR datasets are presented in Table 15, with the collected data from benthic and VBCC sensors presented in Figure 22. Data from the logger exchange date (6 November) were removed from the analyses.

Ambient PAR/total daily PAR (TDP) i.e., the amount of sunlight available to enter the water column), turbidity and the depth of the water column, all have a controlling factor on BPAR measurements. As typically observed in temperate regions with high levels of cloud cover, the amount of incoming solar radiation at VBCC displayed significant variation, with values ranging from 12,700 to 55,300 mmol/m^2/day (Table 15). Maximum TDP (38,353 mmol/m^2/day) was notably higher than that observed during October (33,950 mmol/m^2/day), and again multiple days of non-zero BPAR readings were recorded (Figure 22).

Benthic PAR at both OS2 and OS3 displayed the highest TDP from 11 to 21 November when ambient incident solar radiations recorded at VBCC was consistently elevated between rain periods and turbidity was the lowest at both sites. Both sites responded to a secondary peak in ambient TDP around 23 November although the response at OS3 was lower due to more elevated turbidity at this site, preventing less light from filtering through the water column to the seabed. Typically mean total daily BPAR at OS3 is far greater (over three times higher in October) than at OS2 because of its shallower location, however the difference between sites (1.8 *c.f.* 2.8 mmol/m^2/day at OS2 and OS3, respectively) in November was much less potentially due to the elevated turbidity experienced at OS3.

Table 15 Total Daily PAR (TDP) statistics during November 2018.
Values are means ± se (n = 29 to 30). Note data from the BPAR exchange day on 6 October were not utilized in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m^2/day)		
		Mean ± se	**Median**	**Range**
Base	-	38,353 ± 2,420	42,850	12,700 – 55,300
OS2	17	1.8 ± 0.6	0.7	<0.01 – 11
OS3	14	2.5 ± 0.8	0.3	<0.01 – 17

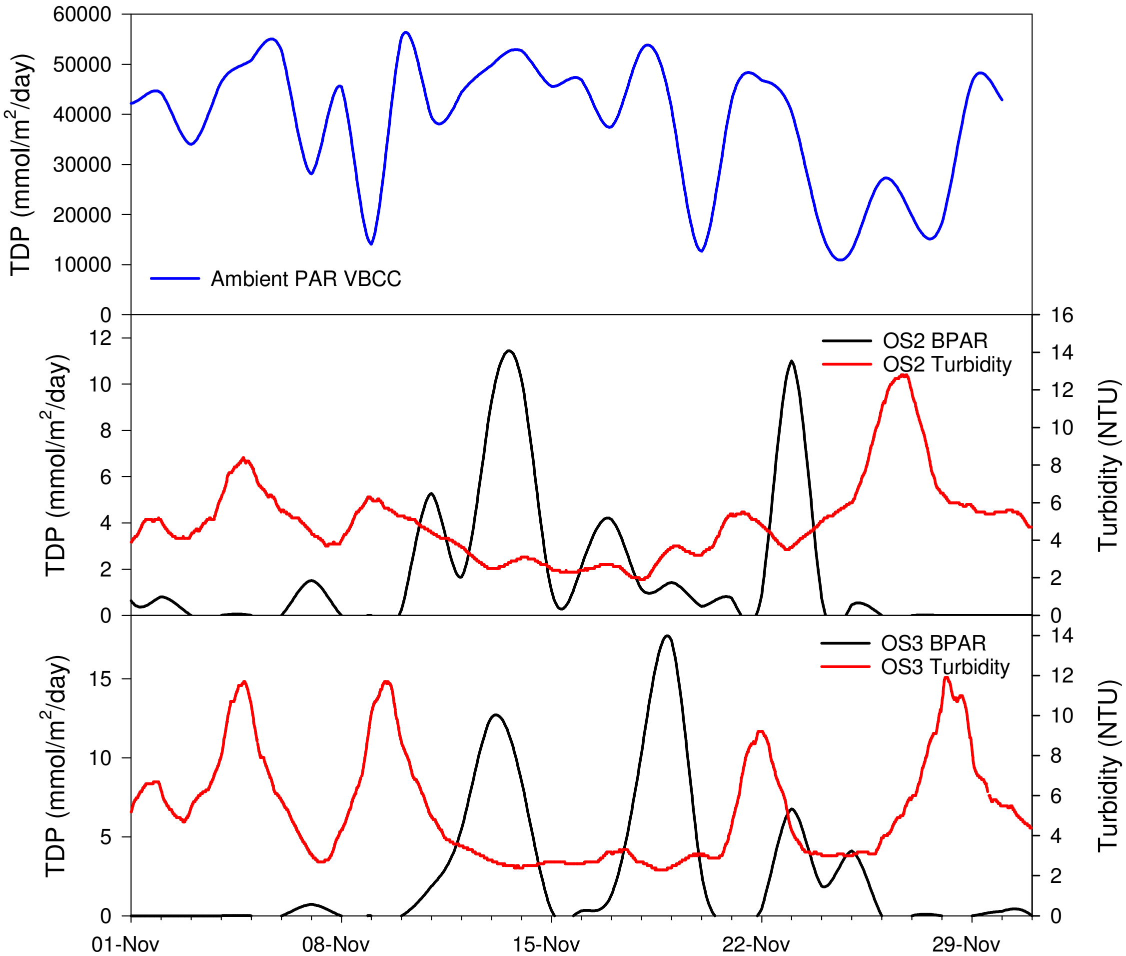


Figure 22 Total daily BPAR at OS2 and OS3 during November 2018 compared to ambient PAR and corresponding surface turbidity.
Note data from the BPAR exchange day on 6 November were not utilized in plots or statistics.

3.5 Continuous Sedimentation Loggers

Data on sediment deposition/erosion rates were collected at the inshore site UH3 and offshore site OS2, using ALTUS acoustic altimeters located approximately between 200 and 600 mm above the seabed in drop down frames. Further details on the specific methodology used can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017).

Changes in energy from wind waves, currents and/or tidally induced flows can result in variations in sedimentation patterns, ranging from deposition of sediments originating from another location, resuspension of sediments with no net change in the seabed or the resuspension of sediments and transportation to another location. Altimeters provide two forms of information to help identify these processes:

- Instantaneous bed level change calculated every 15 minutes indicating the level of sediment flux occurring at a set point in time; and
- Net cumulative change in bed level over a given period.

From the beginning of November daily averaged altimeter readings at the entrance of Lyttelton Harbour (site OS2) indicated a period of erosion of up to 10 mm which corresponded to elevations in wind speeds from variable directions and increased turbidity (Figure 23). From 7 to 10 November this trend was reversed with deposition of over 20 mm being observed. The period corresponded with elevated wind speeds from a north east direction, combined with local rainfall. At this time wind speeds abated, and the harbour was inundated by freshwater which had traversed down the coast from the Waimakariri River. The mixing of fresh waters with turbid saline waters is likely to have induced flocculation of finer sediment particles which then settled more readily from suspension. This resulted in a stable bed level and lower turbidity despite some periodic occasions of elevated wind speed (Figure 23). The higher wind speed event of the 27 November combined with increased wave heights altered the status quo resulting in sudden erosion of 10 mm followed by minor recovery. Over the course of the month, mean bed level increased by 4.6 mm (Table 16).

Unfortunately, no data was available for UH3 in the upper harbour from 6 November due to the unit likely having been tipped on its side (Figure 23). Thus the sediment flocculation event of 12 November has not been captured. Up until that point there was a period of steady deposition with 3.8 mm being recorded (Table 16).

Table 16 Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 during November 2018.
**Note that UH3 data from 1 to 5 November only due to equipment malfunction after exchange on 6 November*

Site	November 2018 Net bed level change (mm)
OS2	+4.6
UH3	+3.8*

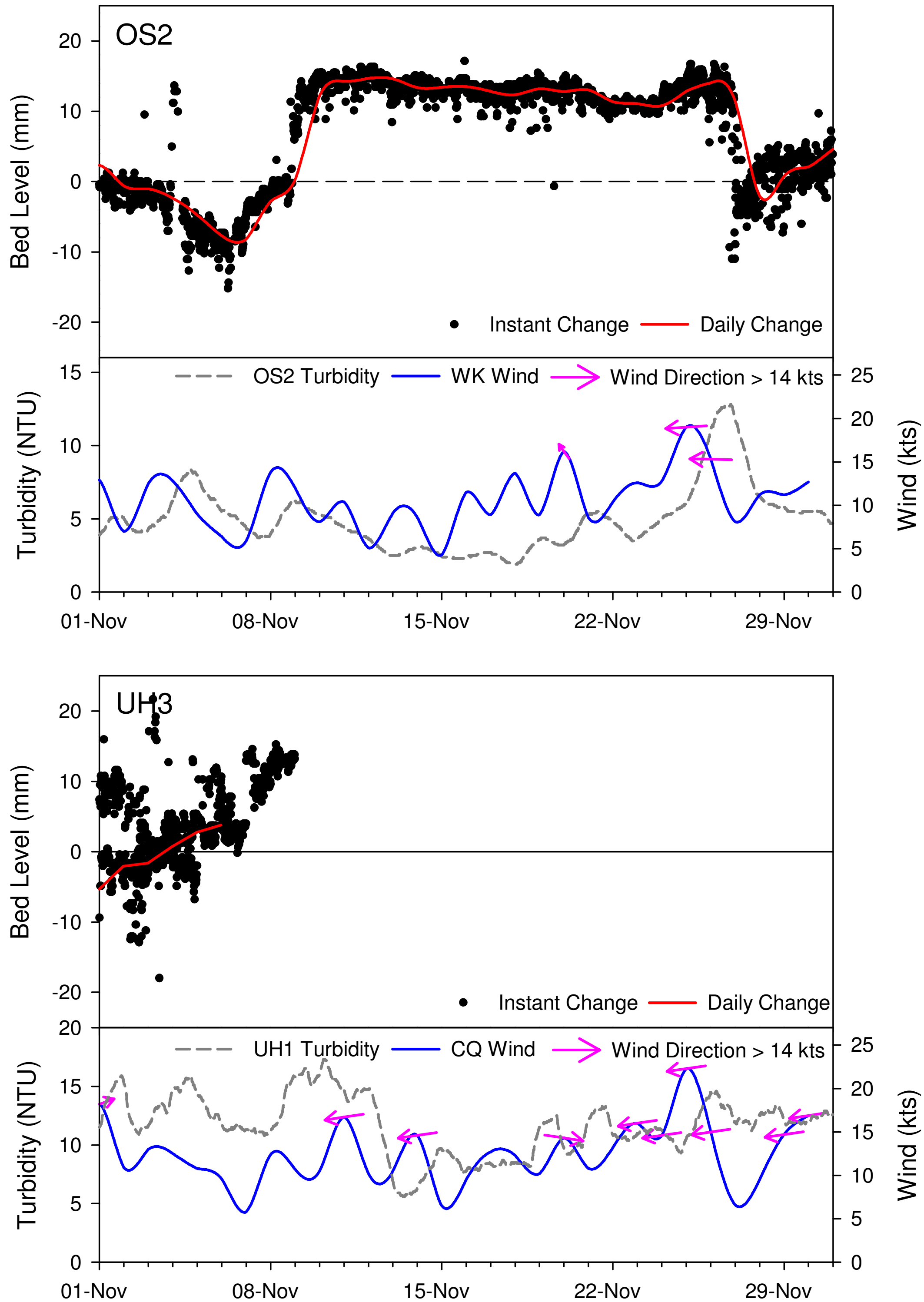


Figure 23 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during November 2018 compared to ambient surface turbidity (24 hour rolling average) wind speed and direction.

*Note: Arrows indicate the direction of travel for winds greater than 14 knots. *Note that UH3 data from 1 to 5 November only due to equipment malfunction after exchange on 6 November*

3.6 Water Samples

Discrete water sampling was conducted on 13 November 2018, in conjunction with vertical physicochemical profiling through the water column. Quality assurance/quality control (QA/QC) procedures included a duplicate water sample collected at one site, in addition to a laboratory and field blank for each parameter. Further details on the specific sampling methodology can be found within the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Laboratory results associated with VE QA/QC procedures are presented in Table 25 of the appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during November 2018 displayed a similar spatial pattern to previous months, with higher concentrations reported in the shallower upper and central harbour sites decreasing further offshore (Table 17, Figure 24). The water quality guideline (WQG) for total phosphorous (30 µg/L) which is historically typically exceeded at more than one site was not exceeded in November. Highest concentration of 18 µg/L was recorded at UH1, which is a common finding. Dissolved reactive phosphorous displayed the same spatial trends as total phosphorous with no exceedances of the 5 µg/L WQG at any site (Table 17).

Of the remaining nutrients analysed, concentrations of total nitrogen and total kjeldahl nitrogen were below laboratory limits of reporting (LOR) at all sites, similar to previous months. Ammonia slightly exceeded the WQG (15 µg/L) at only one site; OS3 (16 µg/L) in November compared to exceedances at four sites in October. The nitrogen oxide WQG (15 µg/L) was exceeded at SG1 (194 µg/L), although this value appears to be an anomaly with the majority of sites typically well below the WQG (Table 17).

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass remained below the WQG (4 µg/L) at all sites although concentrations at UH1 and OS6 were elevated. It is suspected that prior to the sampling date, chlorophyll *a* are likely to have been higher as evidenced by the elevated DO and reduced bioavailable nutrients that may have been depleted due to increased algal biomass production.

3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (LOR) at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), lead (<1 µg/L), mercury (<0.08 µg/L) nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L) and tin (<5.3 µg/L).

As typically reported, total aluminium concentrations were above the WQG of 24 µg/L (note that this WQG is designated for concentrations of the more readily available dissolved aluminium fraction) at all sites, except at site SG2b (Figures 25 and 26). Concentrations of the more bioavailable dissolved fraction ranged between <LOR (12 µg/L) and 20 µg/L. This is in contrast to the previous month where at all sites were <LOR (12 µg/L) indicating that the majority of the total aluminium present was associated with the particulate phase, and thus is not considered readily available for biological uptake. Regardless, none of the sites exceeded the WQG. Dissolved copper also exceeded the WQG (1.3 µg/L) at site CH2 (2.1 µg/L) and SG1 (1.6 µg/L).

Of the remaining metals analysed that have assigned WQGs, no exceedances were reported during the November 2018 water quality sampling campaign (Tables 18 to 20).

Table 17 Concentrations of nutrients and chlorophyll *a* at monitoring sites during November 2018.
Values outside recommended WQG are highlighted in blue.

Site	Parameter (µg/L)						
	Total Phosphorus	Dissolved Reactive Phosphorus	Total Nitrogen	Total Kjeldahl Nitrogen (TKN)	Total Ammonia	Nitrogen Oxides (NOx)	Chlorophyll *a*
UH1	18	4.4	<300	<200	11	<1	3.1
UH2	12	3.1	<300	<200	11	7.9	2.3
UH3	16	3.0	<300	<200	10	3.6	2.3
CH1	14	2.2	<300	<200	12	<1	1.7
CH2	16	4.2	<300	<200	14	1.3	2.3
OS1	10	2.7	<300	<200	11	<1	2.0
OS2	8	1.3	<300	<200	11	<1	1.4
OS3	10	4.2	<300	<200	16	<1	1.2
OS4	10	4.3	<300	<200	14	1.5	1.4
OS5	8	1.0	<300	<200	11	1.8	1.6
OS6	6	1.2	<300	<200	12	<1	1.5
OS7	14	2.5	<300	<200	11	2.8	3.6
SG1	6	1.5	300	<200	11	194	1.9
SG2	8	<1	<300	<200	12	5.2	1.4
SG3	8	1.2	<300	<200	11	1.6	1.2
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

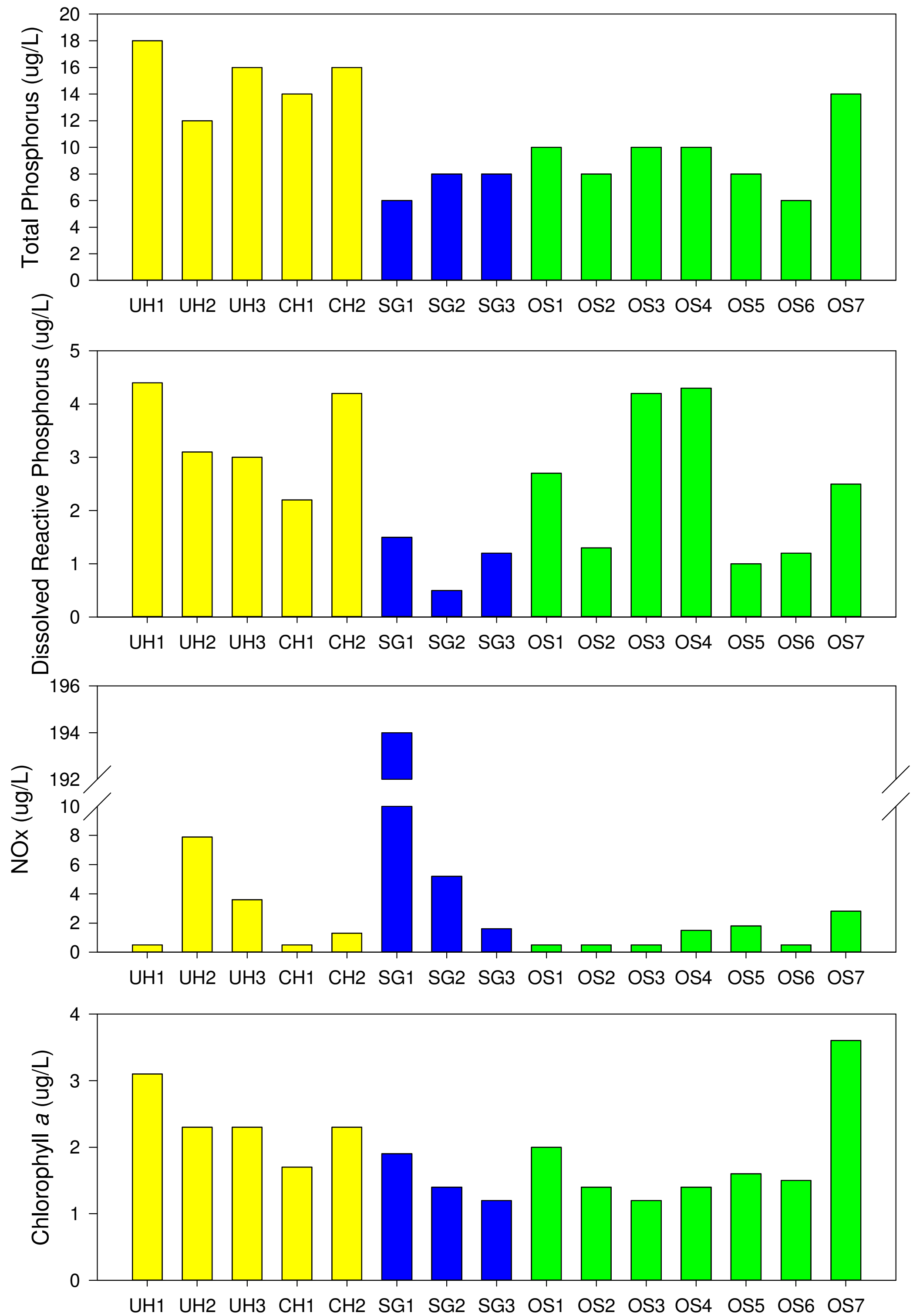


Figure 24 Nutrient and chlorophyll *a* concentrations at monitoring sites during November 2018. *Values which were <LOR, were plotted as half LOR. Total nitrogen, TKN and ammonia concentrations were not plotted as all or most sites were < LOR.*

Table 18 Total and dissolved metal concentrations at inshore monitoring sites during November 2018. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	17	20	19	<12	14	24
	Total	117	53	86	84	53	
Arsenic	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	<0.2	<0.2	
Chromium	Dissolved	1.1	1.7	1.0	1.3	1.5	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.0	<1	1.9	2.1	<1	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.6	<0.6	<0.6	<0.6	<0.6	
Copper	Dissolved	1.3	<1	<1	<1	2.1	1.3
	Total	<1	<1	<1	<1	<1	
Iron	Dissolved	<4	<4	<4	<4	<4	-
	Total	220	54	210	124	56	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	
Manganese	Dissolved	14	11	11	11	12	-
	Total	20	15	17	14	15	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10	10	10	10	10	-
	Total	11	11	11	10	10	
Nickel	Dissolved	<6	<6	<6	<6	<6	70
	Total	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<1.6	<1.6	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	<1.7	<1.7	
Vanadium	Dissolved	2.0	2.0	2.1	1.5	2.1	100
	Total	2.5	2.3	2.4	2.1	2.4	
Zinc	Dissolved	<4	4.0	<4	5.0	4.0	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 19 Total and dissolved metal concentrations at offshore monitoring sites during November 2018.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		OS1	OS2	OS3	OS4	OS5	OS6	OS7	WQG
Aluminium	Dissolved	13	18	<12	<12	12	<12	<12	24
	Total	48	59	27	21	31	29	41	
Arsenic	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Chromium	Dissolved	<1	1.3	1.4	<1	1.3	1.4	1.4	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	1.2	<1	<1	<1	1.8	1.5	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	
Copper	Dissolved	<1	<1	<1	<1	<1	1.3	<1	1.3
	Total	<1	<1	<1	<1	<1	<1	<1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	41	49	28	19	24	40	53	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	<1	<1	
Manganese	Dissolved	10	3.6	2.6	2.0	4.6	3.5	10	-
	Total	13	5.2	3.5	3.0	6.5	5.4	12	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10	9.5	11	11	10	10	10	-
	Total	11	10	11	12	11	11	11	
Nickel	Dissolved	<6	<6	<6	<6	<6	<6	<6	70
	Total	<7	<7	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	<4	<4	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	
Vanadium	Dissolved	2.1	1.6	1.8	1.5	1.6	1.5	2.5	100
	Total	2.0	1.7	2.0	1.9	1.7	1.5	2.1	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 20 Total and dissolved metal concentrations at spoil ground monitoring sites during November 2018. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		SG1	SG2b	SG3	WQG
Aluminium	Dissolved	14	14	15	24
	Total	30	24	27	
Arsenic	Dissolved	<4	<4	<4	-
	Total	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	
Chromium	Dissolved	<1	<1	1.2	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	1.4	1.6	
Cobalt	Dissolved	<0.6	<0.6	<0.6	1.0
	Total	<0.6	<0.6	<0.6	
Copper	Dissolved	<1	<1	<1	1.3
	Total	1.6	<1	<1	
Iron	Dissolved	<4	<4	<4	-
	Total	22	28	17	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1	<1	<1	
Manganese	Dissolved	5.2	2.7	2.7	-
	Total	7.8	5.7	4.3	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10	10	9.8	-
	Total	11	12	11	
Nickel	Dissolved	<6	<6	<6	70
	Total	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	-
	Total	<4	<4	<4	
Silver	Dissolved	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	
Tin	Dissolved	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	
Vanadium	Dissolved	1.8	1.3	1.7	100
	Total	1.7	1.9	1.5	
Zinc	Dissolved	6.0	<4	<4	15
	Total	<4.2	<4.2	<4.2	

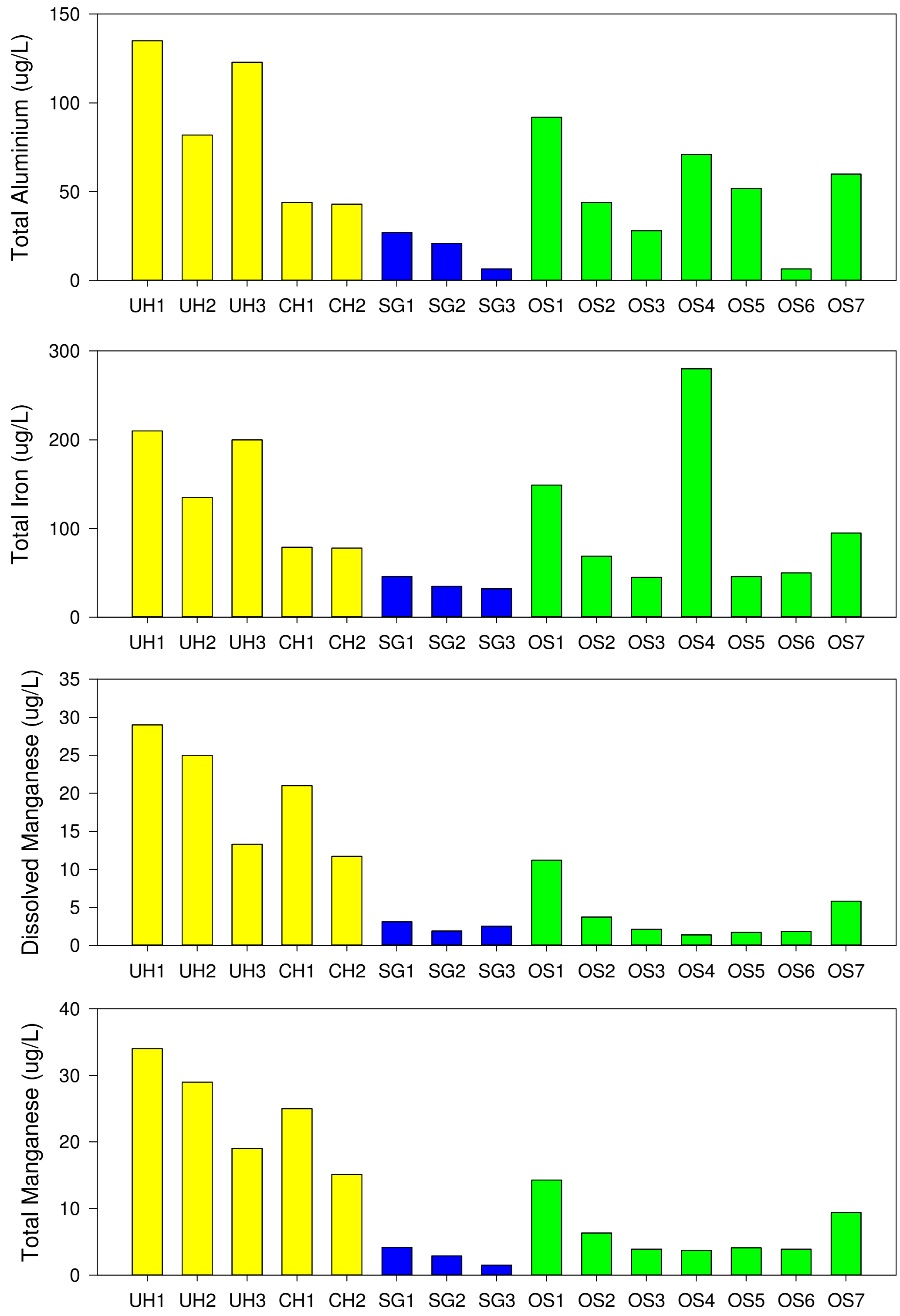


Figure 25 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during November 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

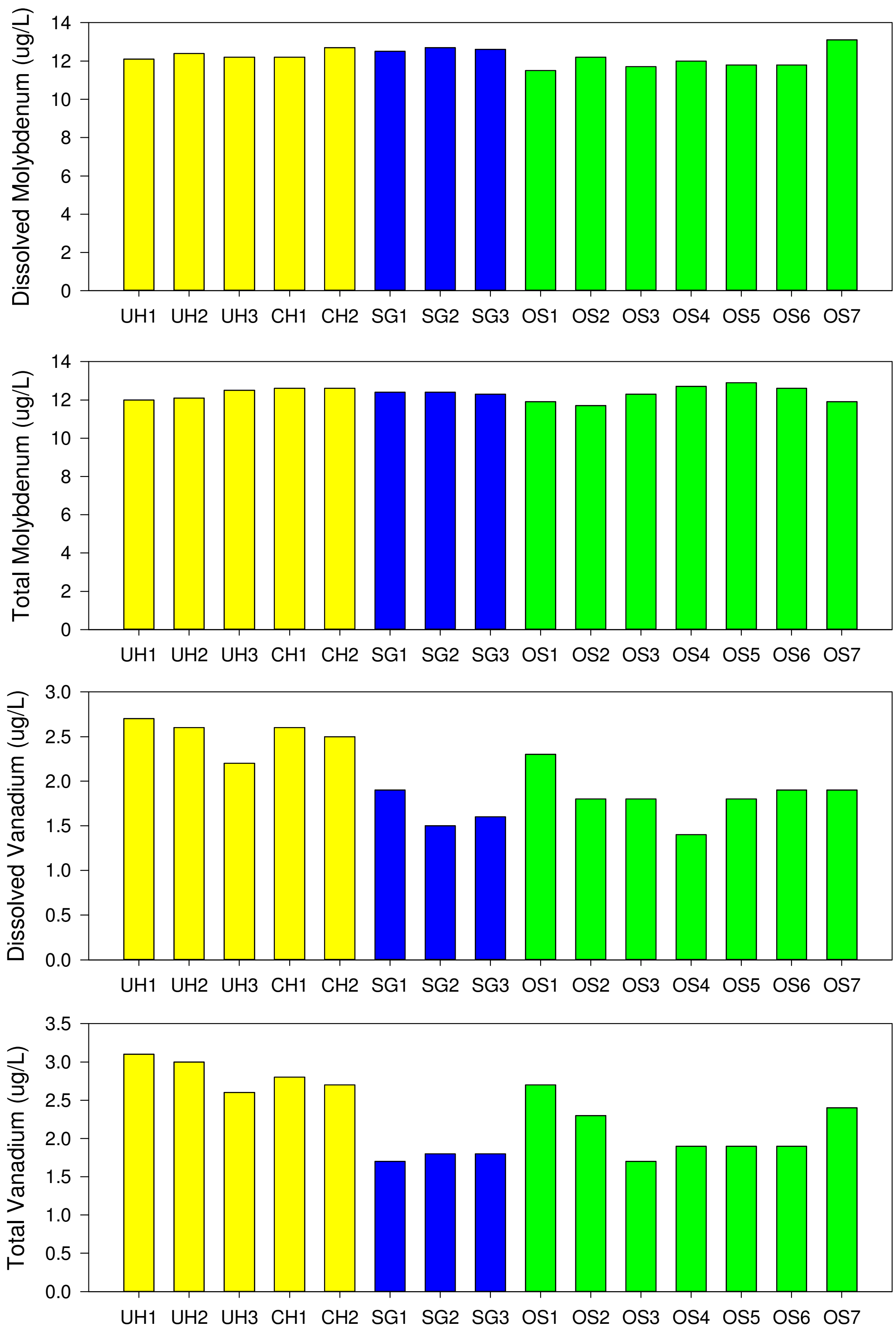


Figure 26 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during November 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. During November concentrations of total iron were low (maximum 117 µg/L at OS2) with most sites < 100 µg/L. This is in contrast to September and October 2018, where maximum concentrations of 700 and 210 µg/L respectively, were recorded. Similar to patterns in aluminum, dissolved concentrations of iron were again low (below LOR ≤ 4 µg/L) and therefore iron within Lyttelton Harbour and the surrounds was predominantly present in the particulate phase, and thus not readily available for biological uptake.

Total and dissolved manganese were detected at all sites, with highest concentrations again recorded in the inner harbor. Relatively similar values for the dissolved and total components were reported, suggesting a high proportion of the total manganese present in the harbour was in the dissolved phase (Figure 25).

Consistent with previous monitoring reports, molybdenum concentrations during November displayed little spatial variation across the monitoring network (Figure 26). Given the similarity between the dissolved and total metal concentrations, the majority of appeared to be present in the dissolved phase, allowing efficient mixing and therefore a lack of spatial variation across the monitoring sites (Tables 17 to 20 and Figure 26). Concentrations of total vanadium in the inshore and nearshore monitoring sites were slightly elevated compared to the nearshore and offshore regions, with a large proportion also present in the dissolved phase (Figure 26).

4 REFERENCES

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5 APPENDIX

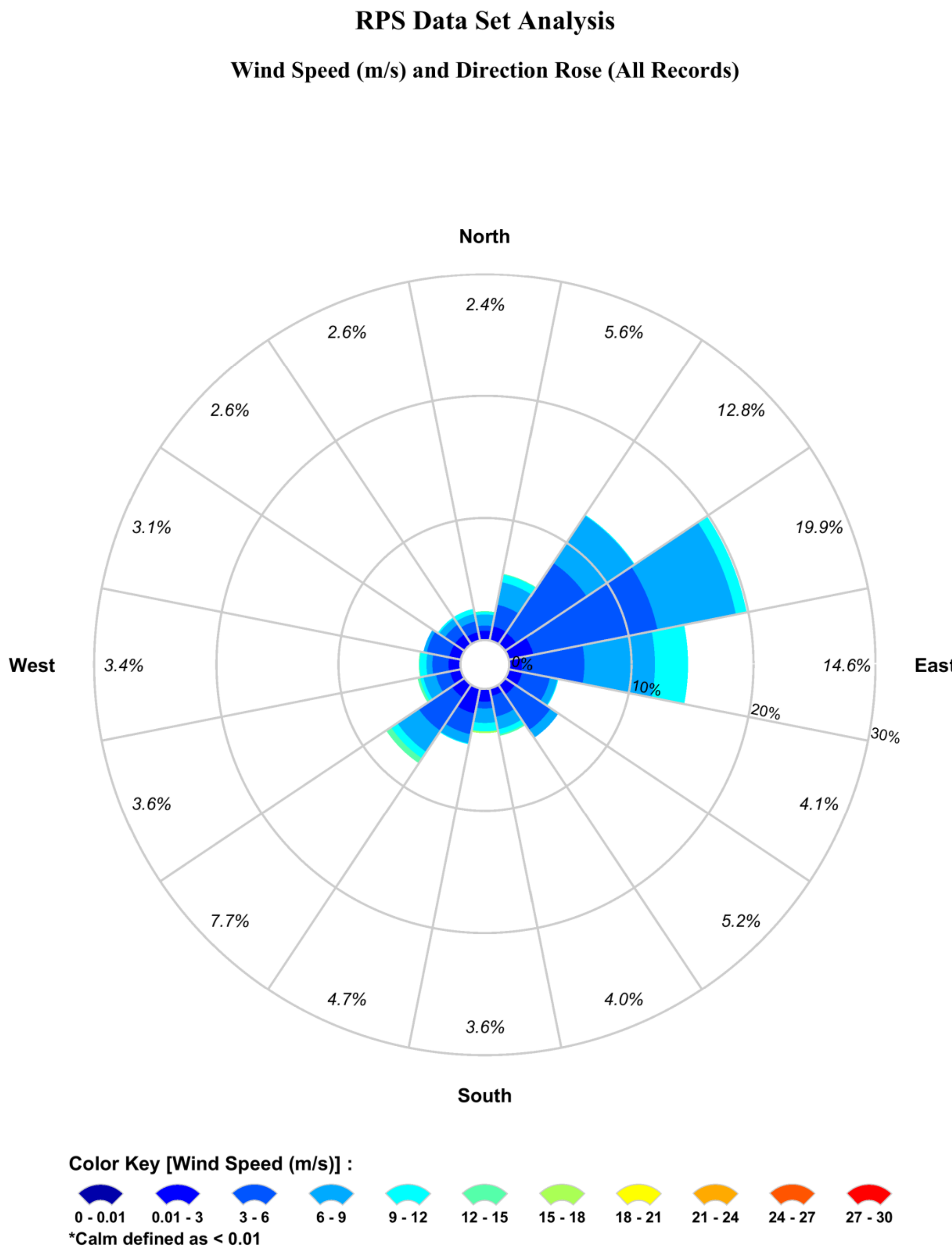
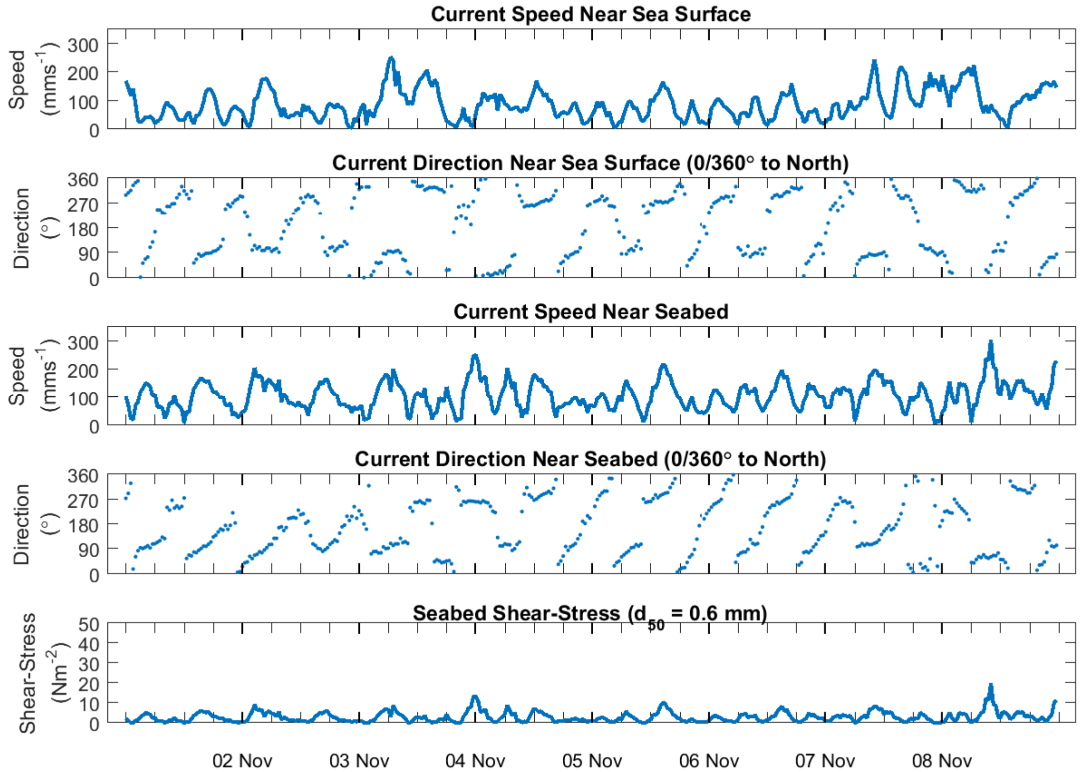


Figure 27 WatchKeeper wind speed (m/s) and direction rose (%) during November 2018.



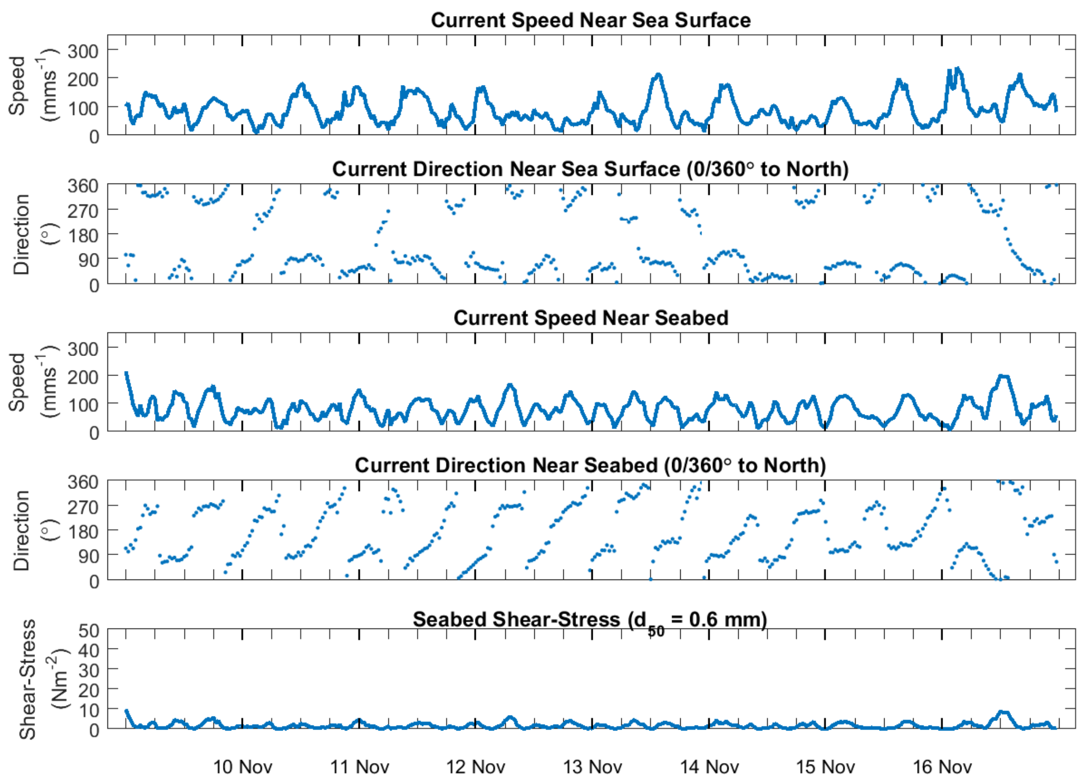


Figure 28 SG2a current speed, direction and shear bed stress 1 to 16 November 2018.

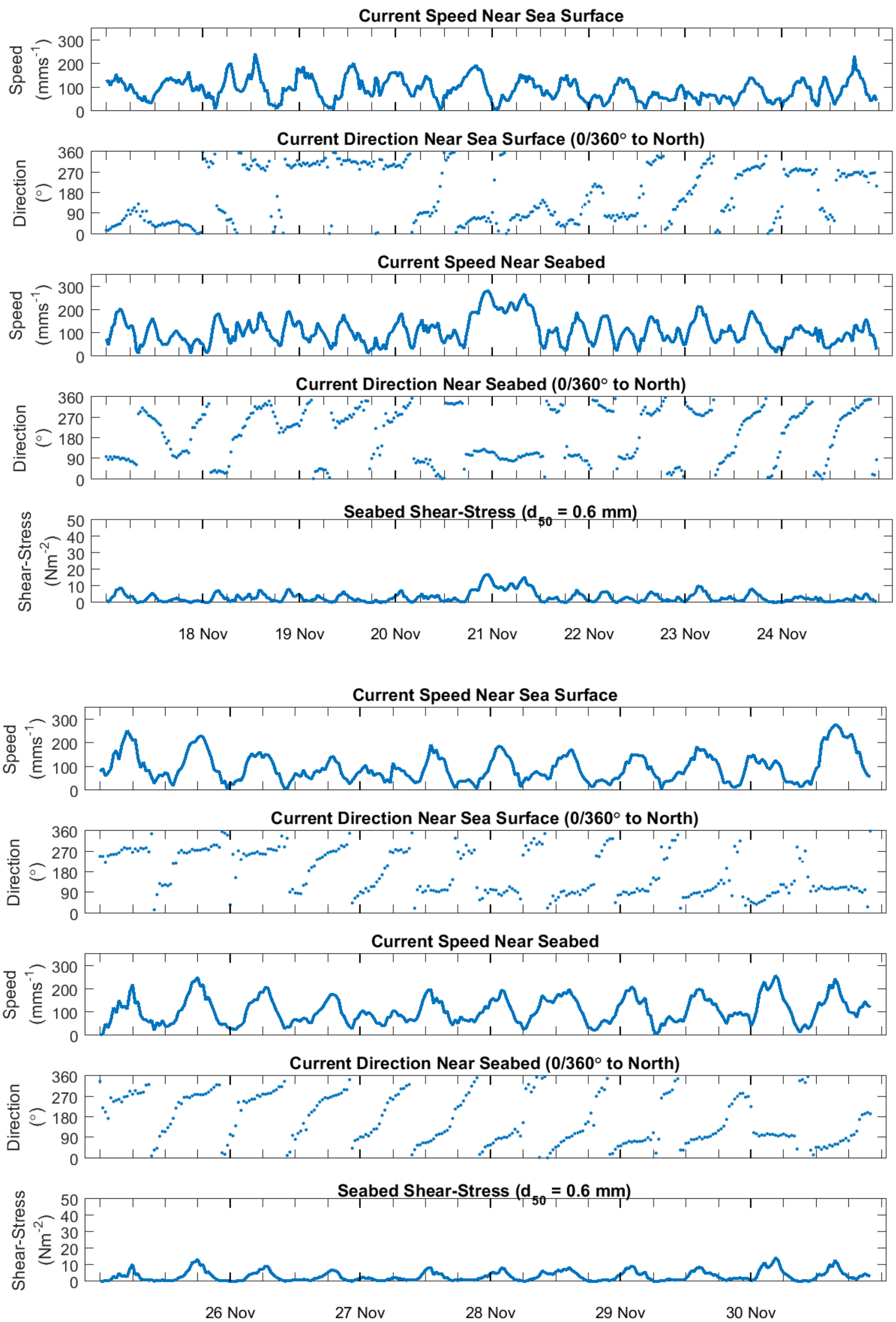


Figure 29 SG2a current speed, direction and shear bed stress 17 to 30 November 2018.

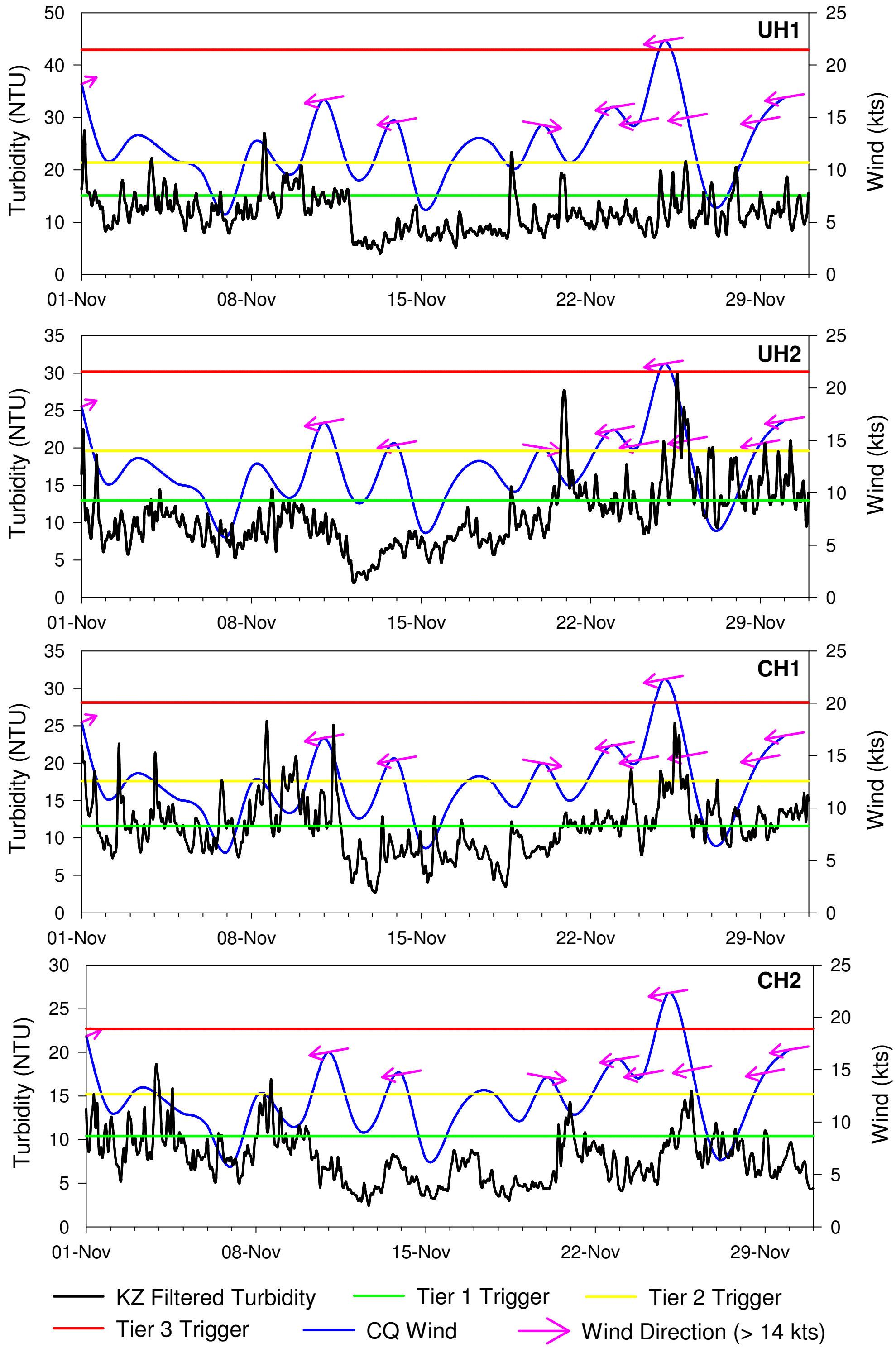


Figure 30 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during November 2018.

Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

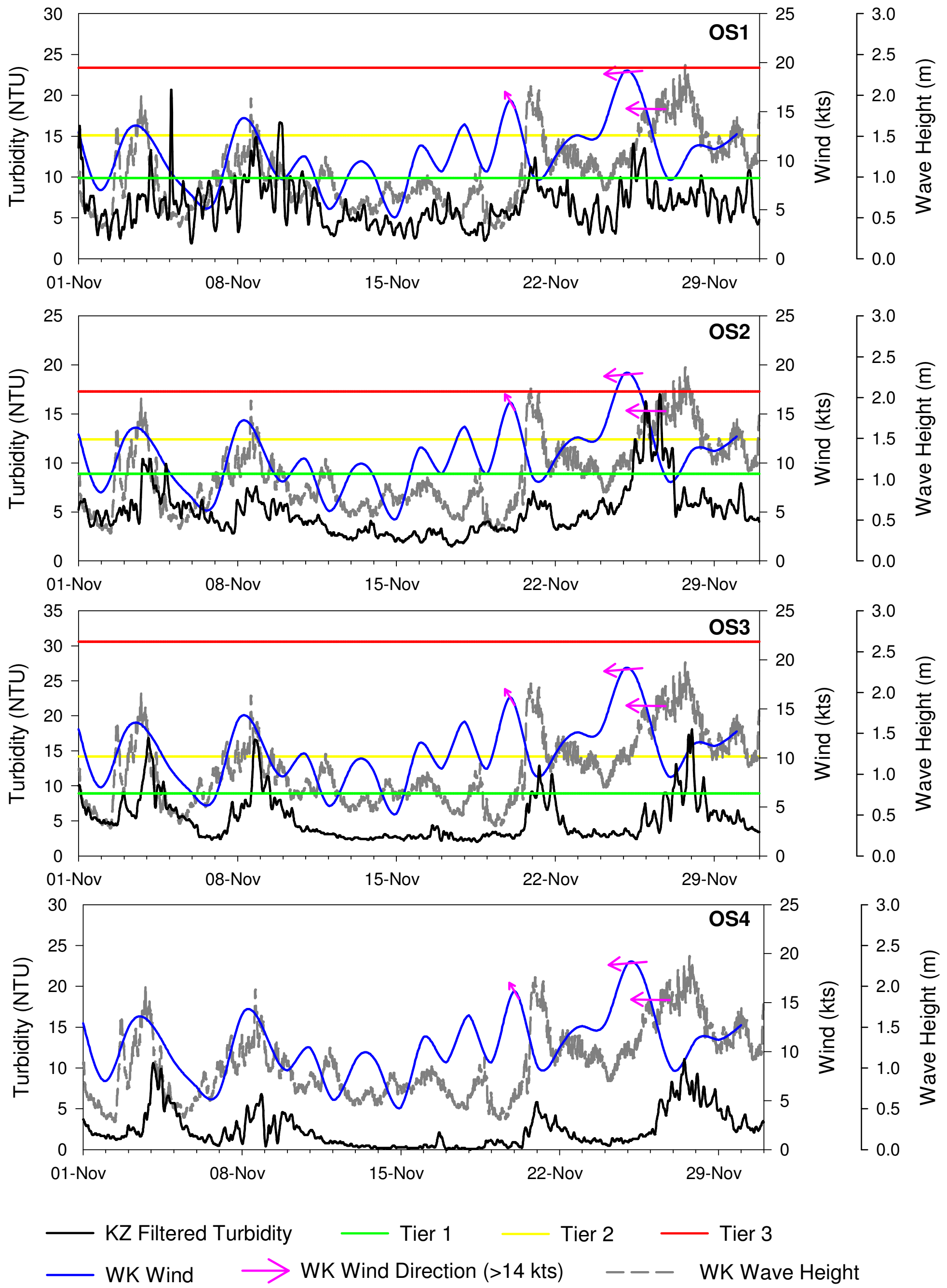


Figure 31 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during November 2018.

Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

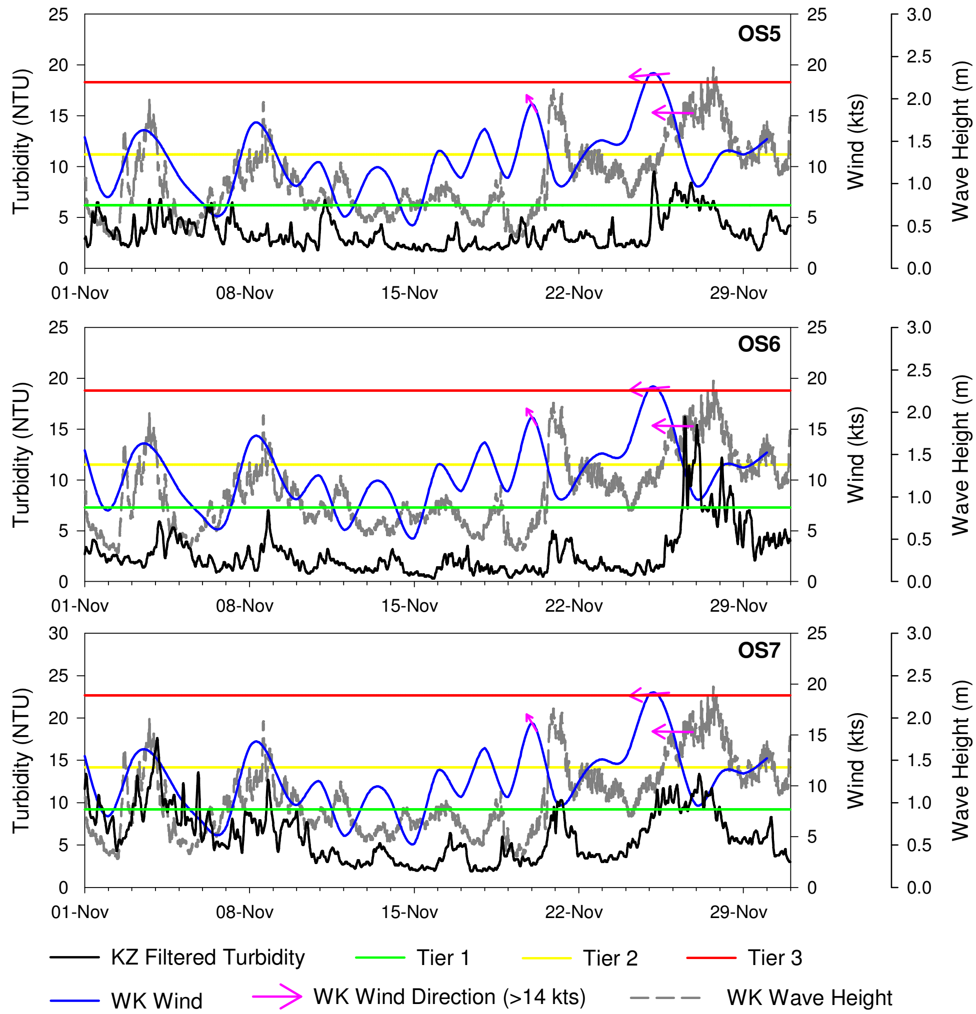


Figure 32 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during November 2018.

Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

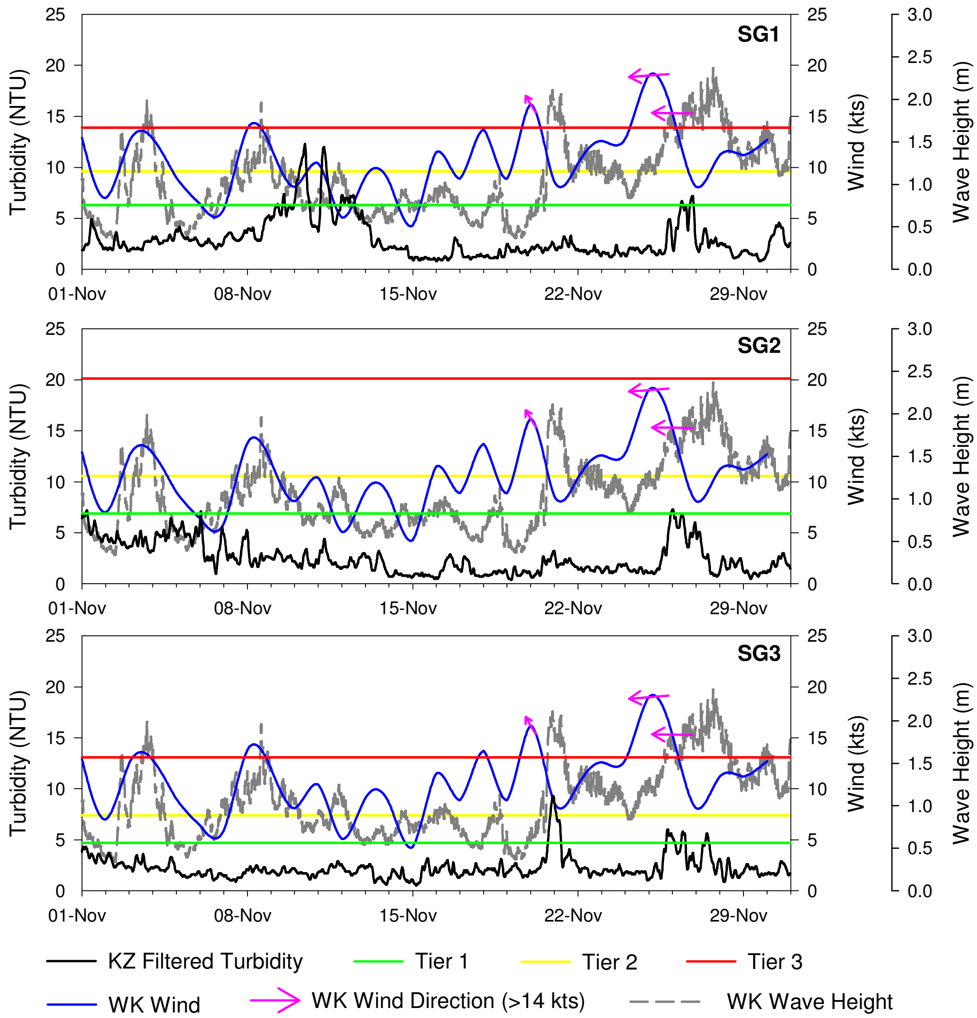


Figure 33 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during November 2018.

Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 21 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during November 2018 and baseline period 1 November 2016 to 31 October 2017
Values for November are means ± se, range and percentiles (n = 2880). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface November	Surface Baseline
UH1	Mean ± se	12 ± 0	12
	Range	4 – 28	2 – 155
	99th	22	37
	95th	18	21
	80th	15	15
UH2	Mean ± se	11 ± 0	9.9
	Range	2 – 30	2 – 59
	99th	25	29
	95th	19	19
	80th	14	13
CH1	Mean ± se	11 ± 0	8.8
	Range	3 – 26	<1 – 50
	99th	23	27
	95th	18	17
	80th	14	12
CH2	Mean ± se	7.8 ± 0.1	7.6
	Range	2 – 19	<1 – 39
	99th	16	22
	95th	13	15
	80th	10	10

Table 22 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during November 2018 and baseline period 1 November 2016 to 31 October 2017.
Values for November are means ± se, range and percentiles (n = 2880). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface November	Surface Baseline
SG1	Mean ± se	2.9 ± 0.0	4.2
	Range	<1 – 12	<1 – 31
	99th	11	14
	95th	6.9	9.5
	80th	4.0	6.1
SG2	Mean ± se	2.5 ± 0.0	4.6
	Range	<1 – 7.3	<1 – 33
	99th	6.8	20
	95th	5.5	10
	80th	4.0	6.9
SG3	Mean ± se	2.3 ± 0.0	3.6
	Range	<1 – 9.3	0.2 – 22
	99th	7.0	13
	95th	4.3	7.3
	80th	2.7	4.7

Table 23 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during November 2018 and baseline period 1 November 2016 to 31 October 2017.
Values for November are means ± se, range and percentiles (n = 2880). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface November	Surface Baseline
OS1	Mean ± se	6.6 ± 0.0	7.5
	Range	2 – 21	<1 – 99
	99th	15	23
	95th	12	15
	80th	8.4	9.7
OS2	Mean ± se	5.0 ± 0.0	6.4
	Range	2 – 17	<1 – 36
	99th	15	17
	95th	10	12
	80th	6.1	8.9
OS3	Mean ± se	5.2 ± 0.1	6.5
	Range	2 – 18	<1 – 110
	99th	16	27
	95th	11	14
	80th	7.2	8.9
OS4	Mean ± se	2.4 ± 0.0	5.9
	Range	<1 – 11	<1 – 35
	99th	9.6	18
	95th	7.1	13
	80th	4.1	8.1
OS5	Mean ± se	3.5 ± 0.0	4.6
	Range	1.7 – 9.5	<1 – 35
	99th	7.9	18
	95th	6.6	11
	80th	4.7	6.1
OS6	Mean ± se	2.8 ± 0.0	4.7
	Range	<1 – 16	<1 – 37
	99th	12	18
	95th	7.3	11
	80th	3.9	7.1
OS7	Mean ± se	6.1 ± 0.1	6.3
	Range	2 – 18	<1 – 48
	99th	14	22
	95th	12	14
	80th	8.8	9.1

Table 24 Summary of Vision Environment quality control data for November 2018 water sampling. *ND = not determined as one or more samples was below LOR. Variation between duplicate field samples ≥ 50% has been highlighted in blue. High variation indicates heterogeneity within the water column.*

Parameter	VE Field Blank (µg/l)	Duplicate		
		OS5 A (µg/L)	OS5 B (µg/L)	Variation (%)
Total Suspended Solids	<3	8	8	0
Dissolved Aluminium	<3	19	18	5
Total Aluminium	<3.2	86	60	30
Dissolved Arsenic	<1	<4	<4	ND
Total Arsenic	<1.1	<4.2	<4.2	ND
Dissolved Cadmium	<0.05	<0.2	<0.2	ND
Total Cadmium	<0.053	<0.21	<0.21	ND
Dissolved Chromium	<0.5	1	1.6	38
Total Chromium	<54000	1.9	1.7	11
Dissolved Cobalt	<0.2	FALSE	FALSE	ND
Total Cobalt	<0.21	<0.63	<0.63	ND
Dissolved Copper	<0.5	<1	<1	ND
Total Copper	<0.53	<1.1	<1.1	ND
Dissolved Iron	<20	<4	<4	ND
Total Iron	<21	210	78	63
Dissolved Lead	<0.1	<1	<1	ND
Total Lead	<0.11	<1.1	<1.1	ND
Dissolved Manganese	<0.5	11.3	11.6	3
Total Manganese	<0.53	17.4	15.1	13
Dissolved Mercury	<0.08	<0.08	<0.08	ND
Total Mercury	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum	<0.2	10.3	10.3	0
Total Molybdenum	<0.21	10.5	10.3	2
Dissolved Nickel	<0.5	<7	<7	ND
Total Nickel	<0.53	<7	<7	ND
Dissolved Selenium	<1	<4	<4	ND
Total Selenium	<1.1	<4.2	<4.2	ND
Dissolved Silver	<0.1	<0.4	<0.4	ND
Total Silver	<0.11	<0.43	<0.43	ND
Dissolved Tin	<0.5	<5	<5	ND
Total Tin	<0.53	<5.3	<5.3	ND
Dissolved Vanadium	<1	2.1	2.3	9
Total Vanadium	<1.1	2.4	2.4	0
Dissolved Zinc	<1	<4	<4	ND
Total Zinc	<1.1	<4.2	<4.2	ND
Total Phosphorus	<4	16	22	27
Dissolved Reactive Phosphorus	<4	3	3.6	17
Total Nitrogen	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN)	<100	<200	<200	ND
Total Ammonia	<10	10	11	9
Nitrate + Nitrite	<2	3.6	2.4	33
Chlorophyll *a*	<0.2	2.3	2.5	8