Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

October 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 October 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 October 2018 are presented within this report, including information detailing dredge trigger value exceedances and management

Climatic Conditions: Cashin Quay experienced 22.8 mm of rainfall over five days during October 2018. Freshwater additions to the region through the southerly transported Waimakariri River outflow was limited, with river flow at the Old Harbour Bridge remaining below 200 m^3/s. Maximum mean daily inshore wind speeds of 16.3 knots were recorded on 30 October.

Offshore, significant wave heights peaked at 1.7 m on 6 October, notably lower than those experienced during September. Air temperatures continued the seasonal warming trend, with a monthly average of 12°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 9, 10, 12 and 24 October, coinciding with increased wave heights. At the seabed, maximum current velocities were reported on 10 October; 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 October were below those recorded during the baseline monitoring period, with the exception of CH1 where elevated turbidity levels likely induced by extreme weather events during September were still apparent.

Higher turbidity values were recorded at sites along the northern harbour edge during the first two weeks of October, with mid-month rainfall events and elevated inshore wind speeds increasing turbidity in the upper harbour area for a period of time. A secondary increase in turbidity was also recorded following an addition period of elevated wind speeds on 30 October.

Monitoring sites on the exposed coastline south of Lyttelton Harbour (OS2, OS3 and OS4) displayed low turbidity values during October. Contrasting this pattern, monitoring sites within the mouth of Lyttelton Harbour displayed a small amplitude cyclicity in turbidity that appeared to correlate well with trends in the benthic dataset.

Further offshore, surface turbidity at sites OS5 and OS6 increased mid-month when during elevated southerly offshore wind speeds, although wave heights remained relatively low during this period. A secondary period of increased turbidity experienced at the end of October did not appear to correlate with changes in offshore metocean conditions.

Similarly timed increases in benthic turbidity were recorded across the monitoring network, which in turn correlated well with periods of increased offshore wave heights. Increased energy associated with larger waves is likely to provide the forces necessary to resuspend seabed sediments and thus generate elevated benthic turbidity levels.

Dredge Compliance Turbidity Trigger Values: During October, 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 September. Reversing the spatial relationship between sites during austral winter, the warmest temperatures were recorded in the shallow waters of the upper and central harbour. Brief periods of cooling were observed following rainfall events during mid-October. An additional cooling phase was also recorded at OS3, OS4 and OS6 and to a lesser extent at SG2b and SG3 on 25 October. Benthic temperatures were up to 1.9°C lower than those of the surface and displayed similar temporal trends, albeit at a slower rate.

Consistent with previous reports, conductivity and pH during October did not display any particular spatial or temporal patterns across the monitoring network. In a similar manner to previous monitoring months, benthic pH data displayed a greater level of stability across the month, due to the reduced impact of biological activity at depth.

Relatively high dissolved oxygen concentrations were recorded during October, indicating the presence of phytoplankton blooms in the region. Localised rainfall events from 10 to 15 and 25 October resulted in declining DO concentrations, with relatively rapid recovery once these events ceased. Benthic DO displayed a slight decline between 8 and 22 October that may reflect *in situ* consumption through the degradation of sinking organic material associated with these blooms.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 17 October. Similar to the profiles obtained during September, the inner harbour monitoring sites indicated a well-mixed water column. Benthic waters at these sites were characterised by slight increases in turbidity near the seabed.

Outside of Lyttelton Harbour, vertical profiling of the nearshore and offshore sites indicated the formation of a seasonal thermocline as solar insolation warms the surface waters. As commonly observed throughout the monitoring program, turbidity also increased towards the seabed. However, due to the greater water depth than within the harbour, such increases in benthic turbidity were unlikely to have a notable influence on the calculations of vertical light attenuation.

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. Near-seabed data at the spoil ground and offshore sites displayed greater levels of turbidity and TSS concentrations than at the sub-surface, most likely due to resuspension of sediments by near-seabed currents. Euphotic depth at the spoil ground was high; estimated to be at 13.6 m at SG1. No exceedances of WQG were observed for sub-surface turbidity during the October sampling.

Similar to previous months, total phosphorous concentrations were higher inshore and decreased increasing distance offshore. Only the upper harbour site, UH3, exceeded WQG, although elevated concentrations were also recorded at the reference site OS4. Concentrations of dissolved reactive phosphorous exceeded WQGs at both UH3 and OS4. WQGs were also exceeded for ammonia at sites CH2, OS1, OS3 and OS4 and nitrogen oxides at OS3. Consistent with previous monitoring, concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites.

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, exceeded WQG at UH1, UH2 and CH1 suggesting the presence of a phytoplankton bloom within the harbour. Despite elevated levels of dissolved reactive phosphorous and ammonia at OS4, chlorophyll *a* concentrations remained low.

As typically observed within Lyttelton Harbour, total aluminium concentrations exceeded designated WQG at most sites. However, concentrations of dissolved aluminium were undetectable (<12 µg/L), indicating that the majority of aluminium present was associated with particulate matter and thus deemed less biologically available. Of the remaining metals with designated WQG, no exceedances were reported.

While no WQG are available for iron, concentrations exhibited a large decrease from the elevated concentrations recorded during September 2018, particularly in the upper harbour. Similar to patterns observed during September, sampling during October also indicated somewhat elevated concentrations of dissolved manganese across the network and increased total vanadium concentrations within the inshore and nearshore environments. Increased concentrations of these two metals have occasionally been detected during the baseline period.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during October displayed a greater range than during September, resulting in an increase in the monthly mean ambient PAR. Benthic PAR intensities were once again greater at OS3 than at OS2, with values reaching up to 74.2 mmol/m^2/day, compared to a maximum of 25.6 mmol/m^2/day at OS2, most likely due the shallower water depth at OS3. A combination of reduced surface turbidity and elevated incident solar radiation resulted in higher BPAR throughout the month.

Sedimentation: Altimeter data from site OS2, near the mouth of Lyttelton Harbour indicated relatively stable seafloor conditions, with only a brief period of erosion on 2 October. Variation in offshore wind speeds did not appear to have resulted in notable changes in bed level, with a net bed level change of only +2 mm experienced during October.

Bed level in the upper harbour was also relatively stable during October, following a brief period of erosion at the start of the month. However, in late October, increasing surface turbidity at UH1 coincided with seafloor erosion at UH3, resulting in a net bed level change of -5 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.

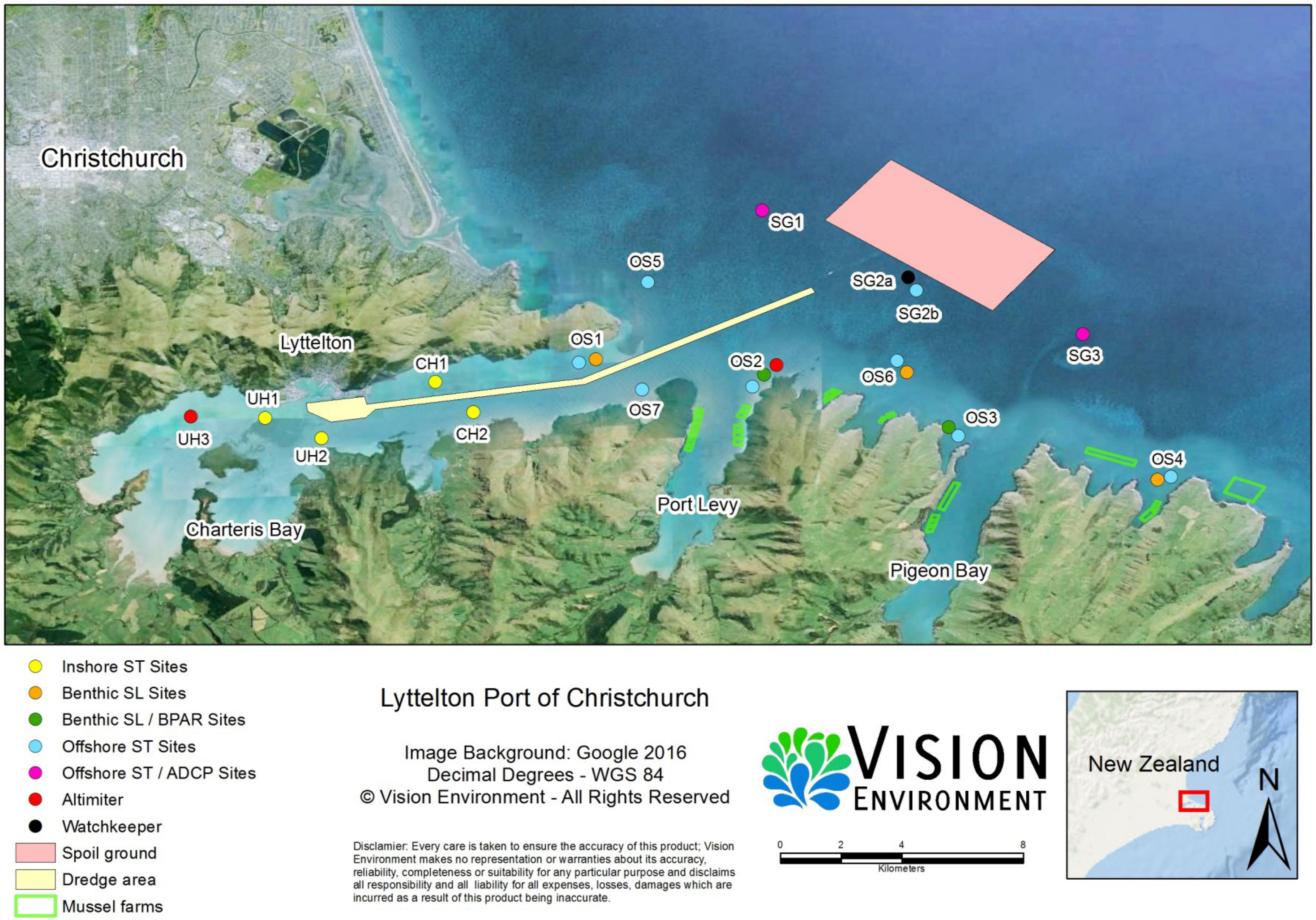


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 31 October 2018 during dredging operations. 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 October 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 October 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 22.8 mm rainfall was received at Cashin Quay over 9 days during October (Figure 2). The majority of this precipitation (10.6 mm) occurred on 12 October, with rainfall of 4.4 mm experienced on 25 October (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 limited, with flows remaining below 200 m^3/s for the duration of the month (ECAN, 2018). Maximum daily mean inshore wind speeds measured at Cashin Quay were recorded at 16.3 knots on 30 October, from a south-westerly direction, with gusts of up to 38 knots recorded (Figure 2). Between the 12 and 14 October, wind gusts ranged between 33 and 45 knots (Metconnect, 2018).

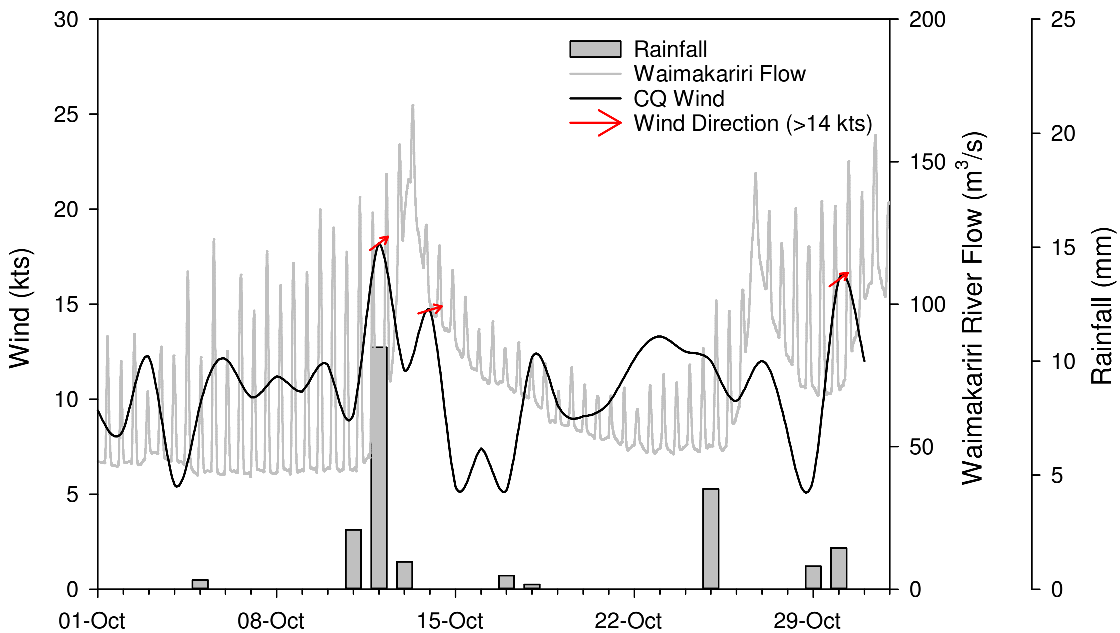


Figure 2 Inshore metocean conditions, including daily averaged wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during October 2018.
Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

Offshore significant wave heights peaked at 1.7 m on 6 October, travelling in a southerly direction (Figure 3) following maximum offshore wind gusts of 32 and 29 knots on 5 and 6 October, respectively. The maximum daily mean offshore wind speeds occurred on 12 October at 15.7 knots, but did not appear to result in a significant change in offshore significant wave heights (Figure 3).

Daily mean air temperatures at Cashin Quay ranged from 8 to 16°C, resulting in a slightly warmer monthly mean temperature of 12°C (Metconnect, 2018).

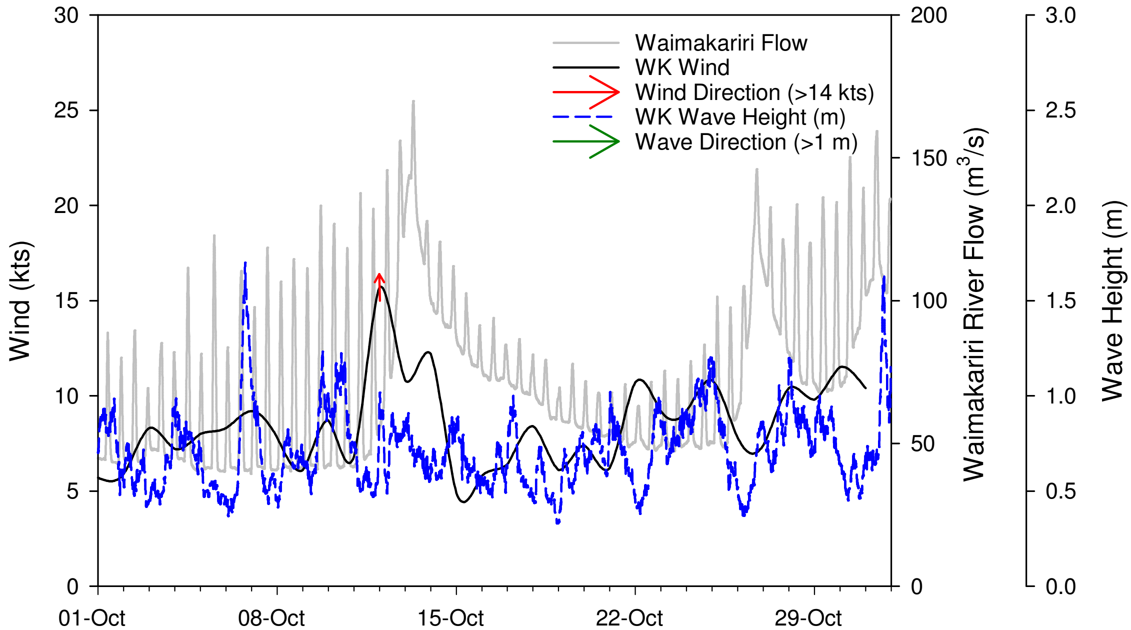


Figure 3 Offshore metocean conditions, including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during October 2018.

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 and have not been removed from the spoil ground due to the requirement for turbidity monitoring 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 31in the Appendix.

The maximum near-surface current velocity at SG2a was recorded on 31 October at 278 mm/s (Table 2), coinciding with increased offshore significant wave heights (Figure 3). Current velocities greater than 230 mm/s were also recorded earlier in the month on the 9, 10, 12 and 24 October. Near the seabed, maximum current velocities of 234 mm/s were recorded on 10 October. Interestingly, the monthly mean current speed for the near-seabed (90 mm/s) was greater than that recorded for the near surface (79 mm/s).

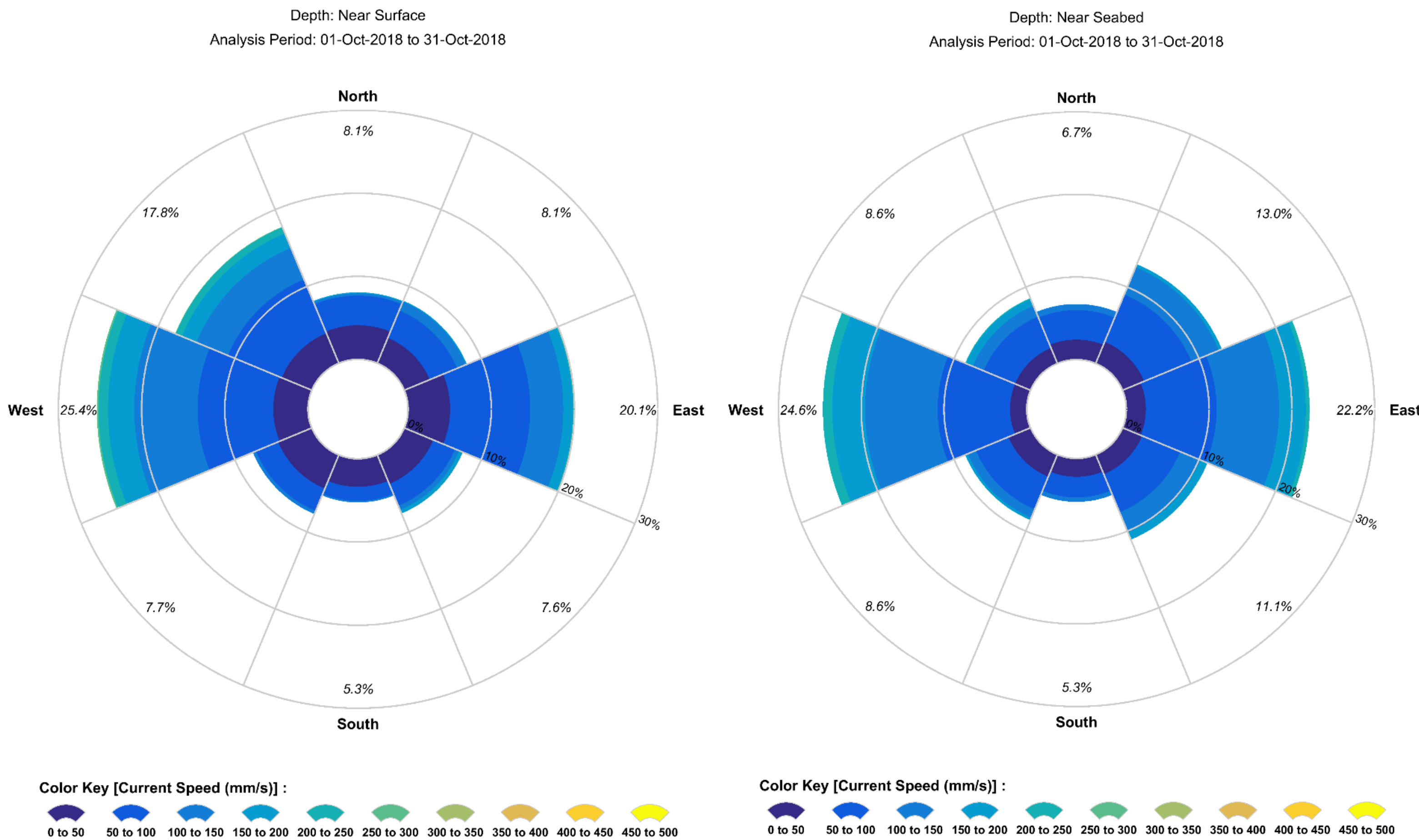


Figure 4 WatchKeeper near-surface and near-seabed current speed and direction 1 to 31 October 2018.
Speed intervals of 50 mm/s are used

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

Parameter	SG2a	
	Near-surface	*Near-seabed*
Minimum current speed (mm/s)	3	3
Maximum current speed (mm/s)	278	234
Mean current speed (mm/s)	79	90
Standard deviation of current speed (mm/s)	48	45
Current speed, 95th percentile (mm/s)	171	173

The time-series plots (Figures 30 and 31 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 September 2018, current direction data from SG2a during October 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 17 October 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 October 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 October data. Summary statistics for KZ filtered turbidity data used for real time compliance monitoring, are also presented in Tables 22 to 24 in the Appendix. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 32 to 35 in the Appendix.

October Turbidity:

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 6.5 to 11 NTU) at the inshore monitoring sites (Tables 3 to 5, Figure 5).

Further offshore, the spoil ground sites exhibited lower (monthly means of 1.8 to 4.0 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 (2.7 to 5.6 NTU) during October (Table 5).

During the first two weeks of October, surface turbidity levels at the northern inner harbour monitoring sites of UH1 and CH1, were greater than those observed along the southern edge. Following rainfall and elevated inshore winds from 10 to 14 October (Figure 2), turbidity at the upper harbour sites increased rapidly (Figure 5) indicating either sediment resuspension and/or terrestrial runoff of fine particles. However, turbidity at CH2 appeared to have remained relatively unaffected by these wind events, with levels around 5 NTU for the majority of the month. As inshore wind speeds declined, turbidity in the upper harbour also decreased as particles settled to the seabed, with a secondary turbidity increase observed with elevated winds speeds on 30 October (Figures 5 and 6).

A similar spatial trend was also evident at the offshore monitoring sites during October. Monitoring sites on the exposed coastline south of Lyttelton Harbour (OS2, OS3 and OS4) typically displayed low turbidity values, with a notable decline observed at OS4 during the latter half of the month (Figures 5 and 8). The remaining two locations (OS1 and OS7), located within the northern and southern edges of the harbour mouth, displayed small amplitude cyclicity throughout the month that appeared to correlate well with patterns observed within the benthic dataset. Turbidity at OS7 increased on 24 and 25 October, which may be due to offshore waves travelling in a south-westerly direction being channelled directly into the bay behind OS7.

Further offshore, surface turbidity at all three spoil ground sites and sites OS5 and OS6 was elevated on 14 and 15 October (Figure 5). This increase coincided with elevated southerly winds, however wave heights remained relatively low at this period of time (Figure 3). A secondary peak in offshore turbidity was also observed on 26 and 27 October (Figure 3) despite significant wave heights and offshore wind speeds remaining minimal at that period of time.

Comparison to Baseline:

Mean surface turbidity and high order percentile statistics from the majority of monitoring sites were below those calculated for the baseline monitoring period (Tables 3 to 5, Figures 6 to 10). The single 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, with reductions in the 95th and 80th percentile values compared to September 2018, indicating a gradual recovery following the extreme weather events of September.

Benthic:

Benthic data recovery from the continuous loggers at OS1 during October was low, with higher recovery from benthic sites OS2, OS3, OS4 and OS6. Where available, benthic data indicate a similarly timed cyclicity in turbidity across the monitoring network (Figure 5). These patterns correlated well with changes in significant wave height measured at the WatchKeeper buoy at SG2a, with elevated turbidity levels occurring during or slightly after periods of increased wave height (Figures 7 to 9). During periods of elevated wave height, increased energy within the water column allows the resuspension of seafloor sediments resulting in increased turbidity levels.

Table 3 Mean turbidity and statistics at inshore water quality logger sites during October 2018 and Baseline period 1 November 2016 to 31 October 2017
Values for October are means ± se, range and percentiles (n = 2913 to 2972) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface October	Surface Baseline
UH1	Mean ± se	9.9 ± 0.1	12
	Range	<1– 34	-
	99th	21	39
	95th	16	22
	80th	12	15
UH2	Mean ± se	7.7 ± 0	10
	Range	2 – 34	-
	99th	17	32
	95th	12	20
	80th	9.2	13
CH1	Mean ± se	11 ± 0	9
	Range	3 – 45	-
	99th	26	29
	95th	19	18
	80th	13	12
CH2	Mean ± se	6.5 ± 0.1	8
	Range	<1 – 27	-
	99th	17	24
	95th	12	16
	80th	8.1	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during October 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for October are means ± se, range and percentiles (n = 2953 to 2975). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface October	Surface Baseline
SG1	Mean ± se	2.2 ± 0.0	4.2
	Range	<1 – 11	-
	99th	7.3	14
	95th	4.6	10
	80th	2.8	6.2
SG2	Mean ± se	4.0 ± 0.0	4.6
	Range	<1 – 15	-
	99th	11	20
	95th	8.8	11
	80th	5.9	7.0
SG3	Mean ± se	1.8 ± 0.0	3.6
	Range	<1 – 8.7	-
	99th	5.6	13
	95th	3.9	7.7
	80th	2.6	4.8

Table 5 Mean turbidity and statistics at offshore water quality logger sites during October 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for October are means ± se, range and percentiles (n = 124 to 2973). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface October	Surface Baseline	Benthic October
OS1	Mean ± se	5.6 ± 0.0	7.5	83 ± 5
	Range	<1 – 27	-	16 – 282
	99th	12	24	271
	95th	9.2	16	163
	80th	7.2	10	123
OS2	Mean ± se	3.7 ± 0.0	6.4	16 ± 0
	Range	<1 – 13	-	4 – 157
	99th	7.9	18	66
	95th	6.1	13	43
	80th	4.6	9.0	21
OS3	Mean ± se	5.0 ± 0.0	6.6	16 ± 0
	Range	1 – 16	-	2 – 170
	99th	11	27	54
	95th	9.1	15	37
	80th	6.6	8.9	22
OS4	Mean ± se	2.7 ± 0.0	5.9	15 ± 0
	Range	<1– 9.5	-	2 – 217
	99th	7.0	20	93
	95th	5.5	13	40
	80th	4.0	8.3	20
OS5	Mean ± se	3.8 ± 0.0	4.6	–
	Range	<1 – 11	-	–
	99th	8.3	19	–
	95th	6.7	11	–
	80th	5.0	6.4	–
OS6	Mean ± se	3.8 ± 0.0	4.7	12 ± 0
	Range	<1 – 14	-	<1 – 51
	99th	11	19	34
	95th	8.4	12	26
	80th	6.0	7.2	17
OS7	Mean ± se	5.4 ± 0.0	6.4	–
	Range	<1 – 26	-	–
	99th	13	23	–
	95th	9.6	14	–
	80th	7.1	9.2	–

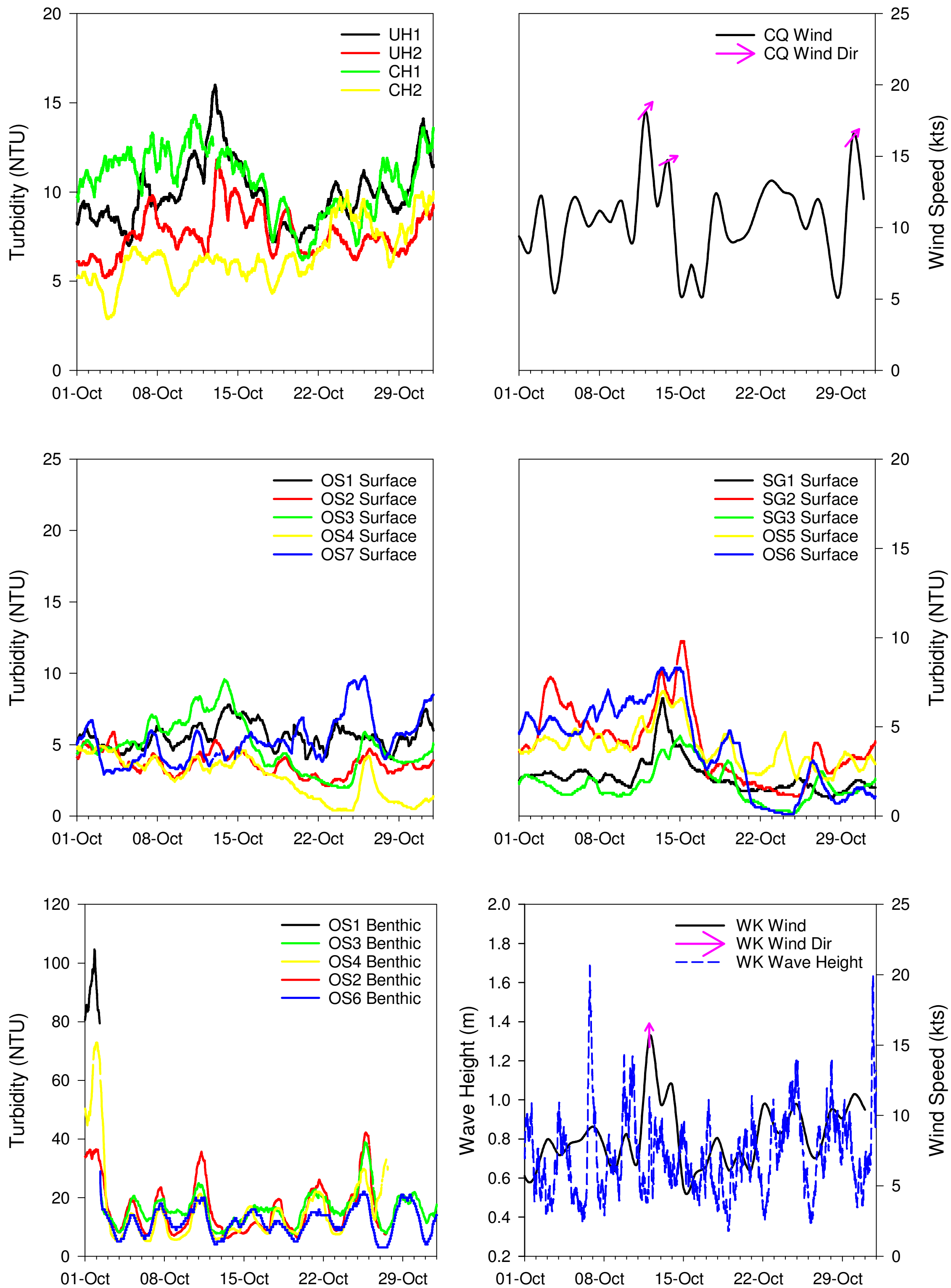


Figure 5 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

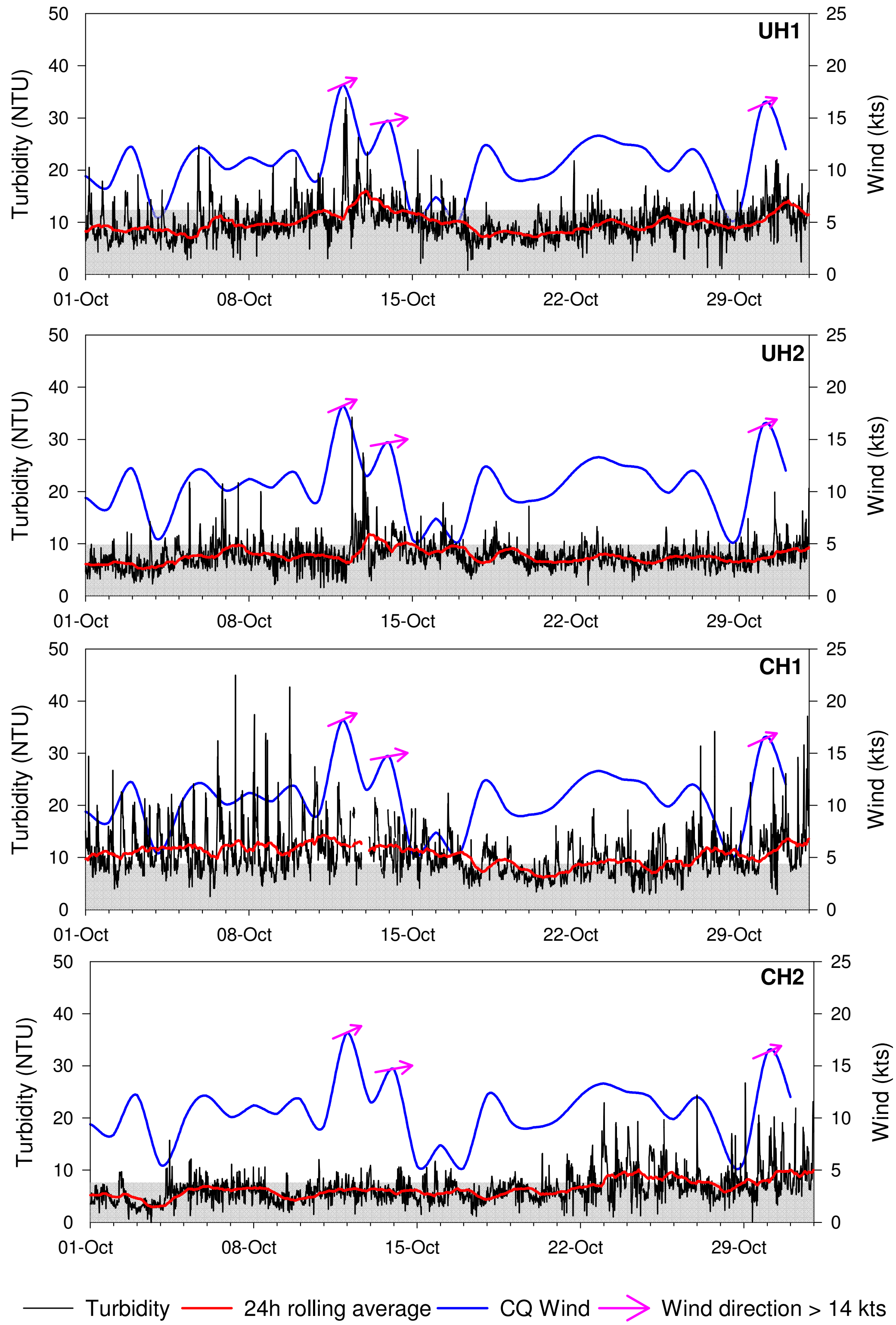


Figure 6 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

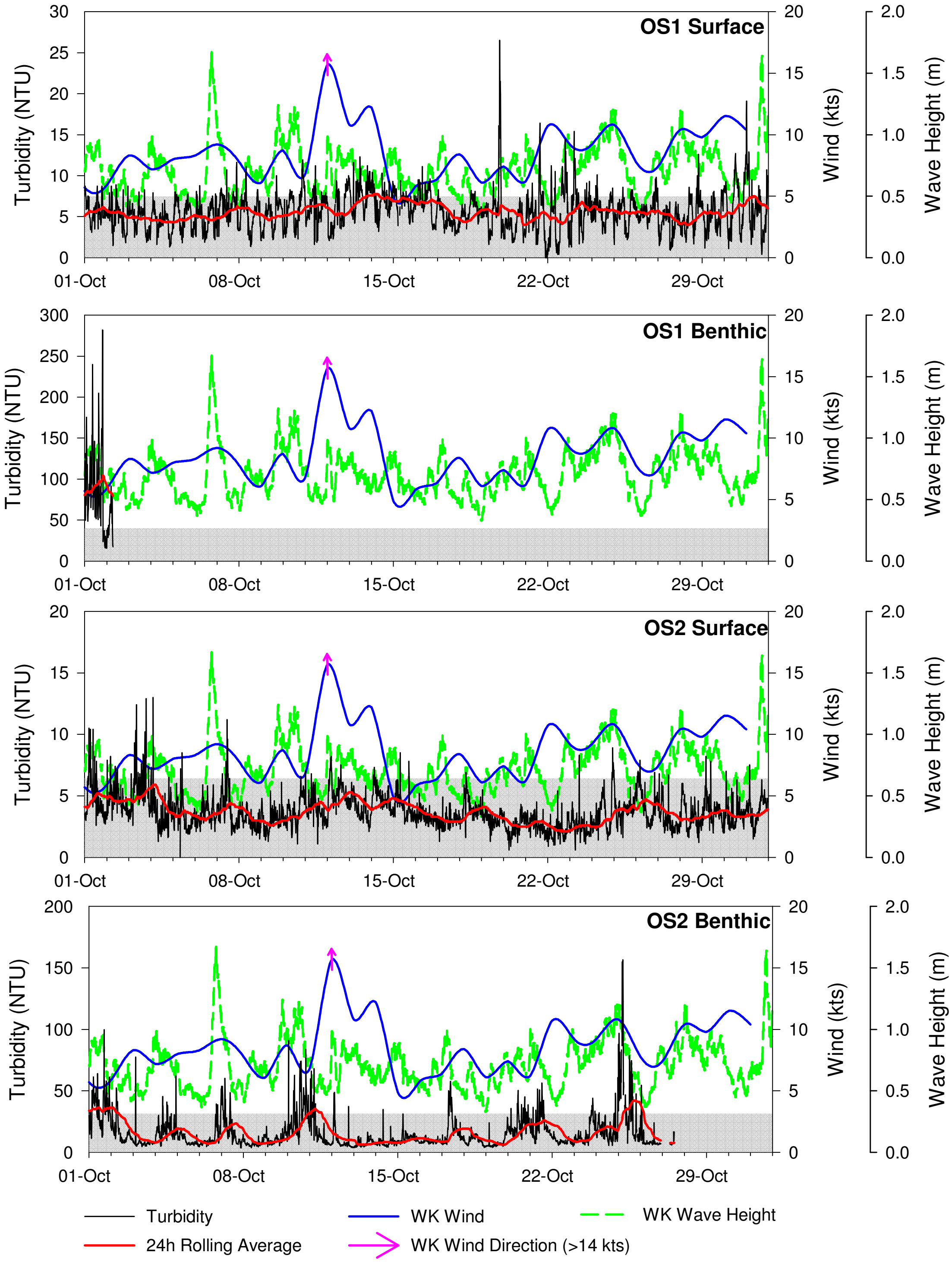


Figure 7 Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

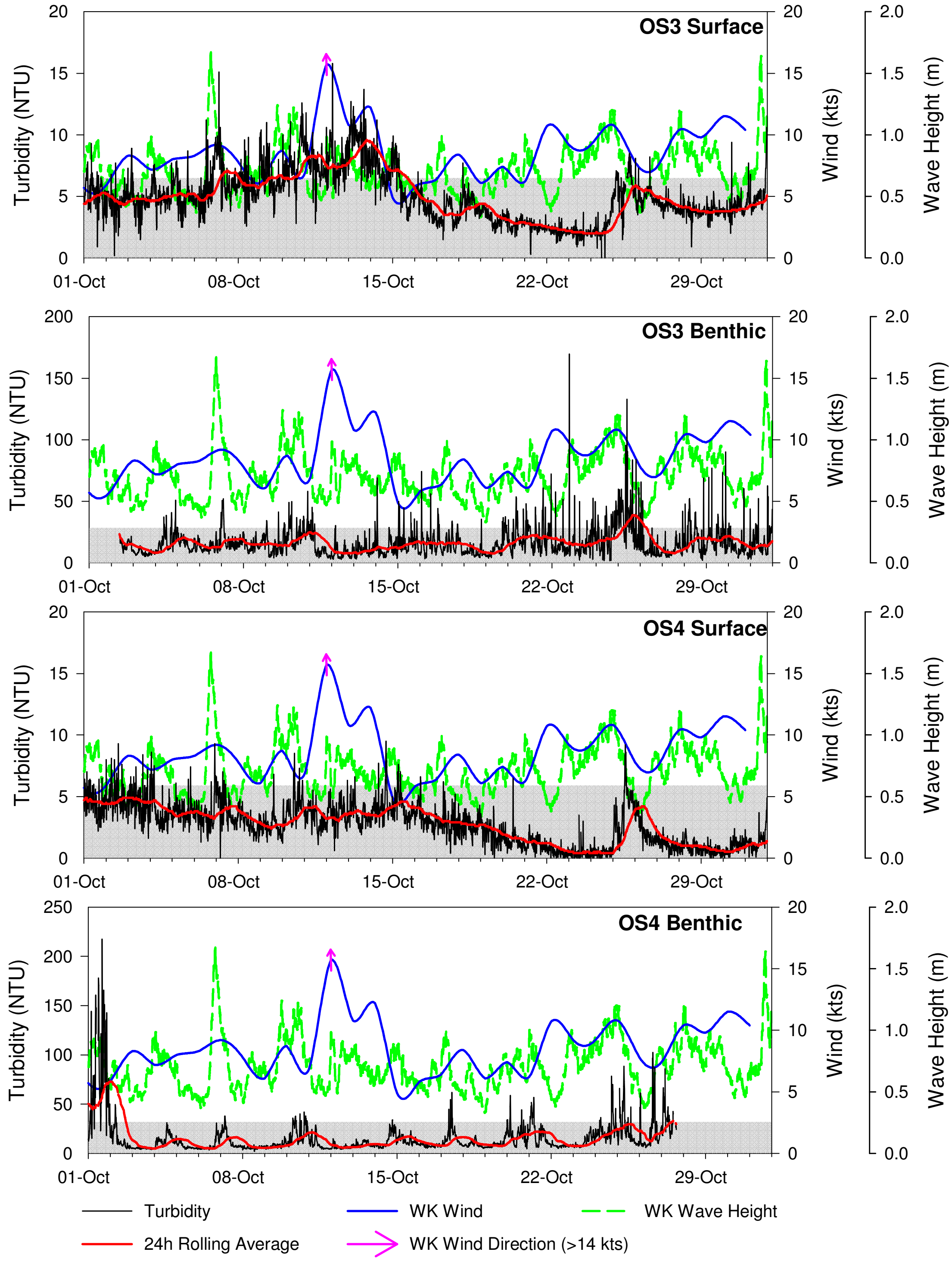


Figure 8 Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

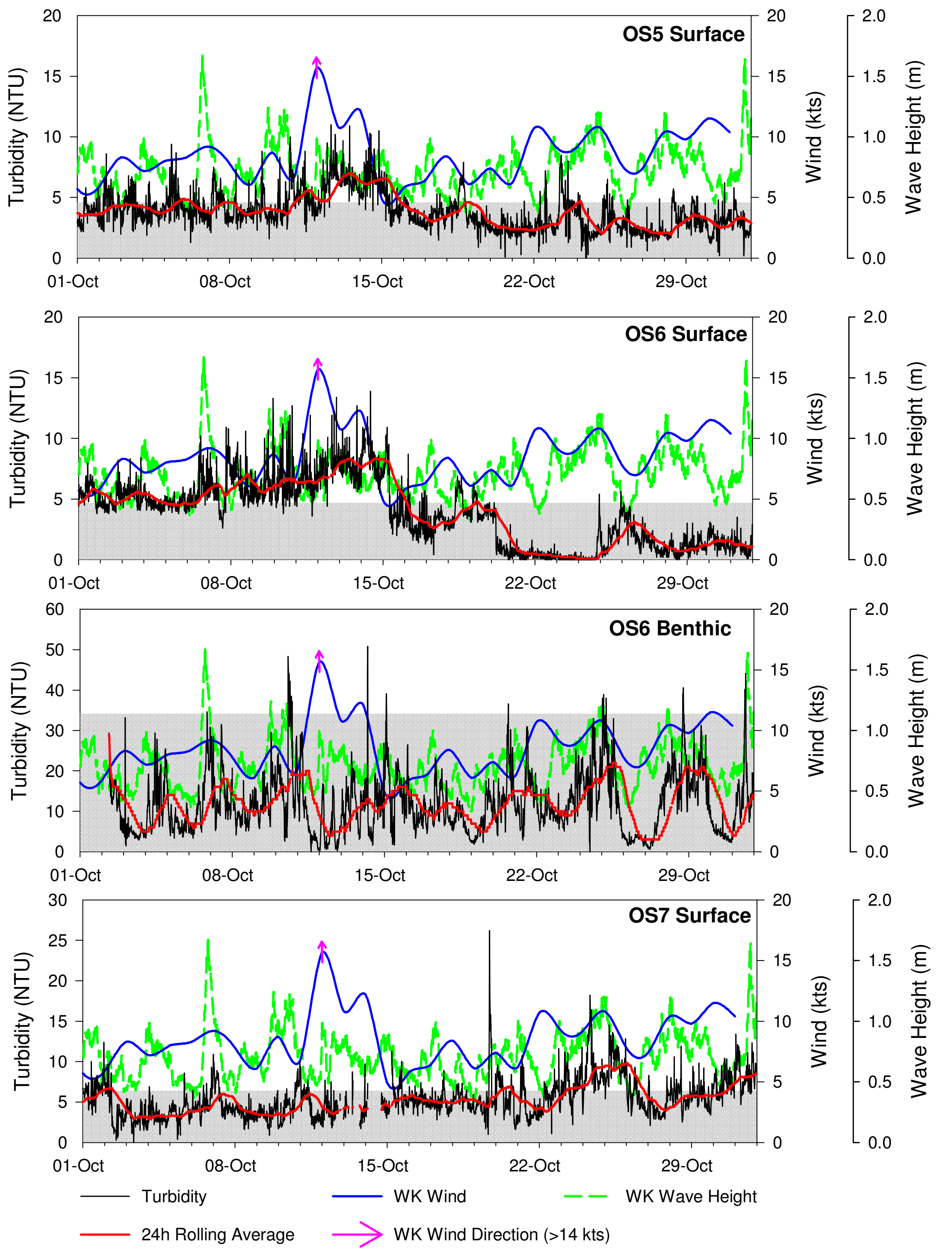


Figure 9 Surface and benthic turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

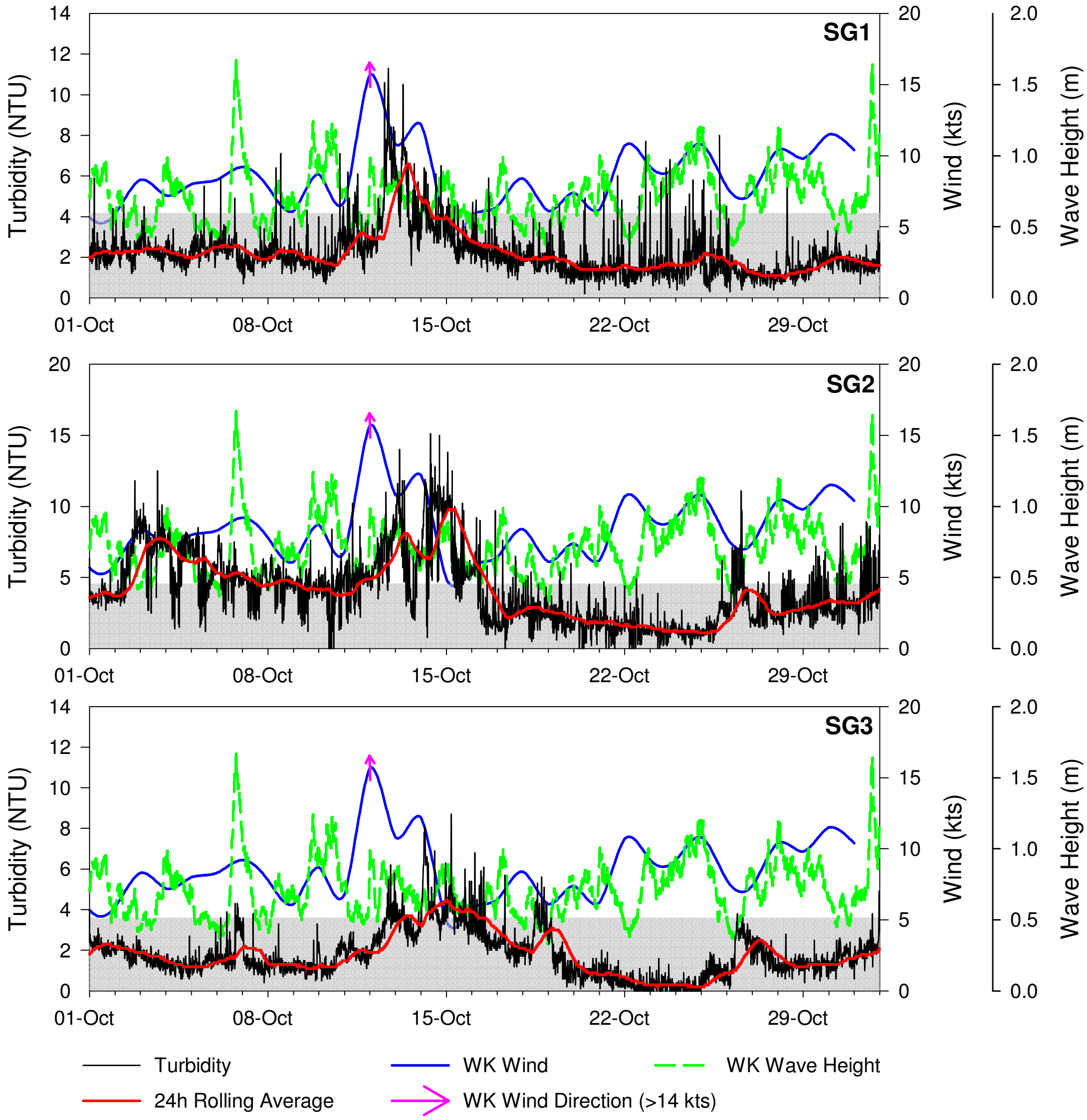


Figure 10 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

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 (80^{th} percentile) and Tier 2 (95^{th} 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 (99^{th} 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 October the Tier 3 intensity values were not exceeded at any site within the monitoring network (Table 7, Figures 11 and 12)

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

Site	P99 Count >7.2 Hours Start Time	P99 Count >7.2 Hours End Time	Maximum P99 Count (Hours)
UH1	–	–	0.00
UH2	–	–	0.75
CH1	–	–	3.00
CH2	–	–	3.00
OS1	–	–	0.00
OS2	–	–	0.00
OS3	–	–	2.30
OS4		Reference site	
OS5	–	–	0.00
OS6	–	–	0.00
OS7	–	–	0.00
SG1	–	–	0.00
SG2	–	–	0.00
SG3	–	–	0.00

3.2.2.2 P99 Exceedance Counts Consented Removal

Surface turbidity levels during October were largely similar to or below baseline conditions, and as such no P99 exceedance counts were accumulated (Table 8). Figures 11 and 12 indicate the 'recovery' of counts accumulated during October as the 30-day moving average window progresses.

Table 8 Hour counts removed from monitoring statistics during October 2018.

Site	Start Time (NZST)	End Time (NZST)
–	–	–

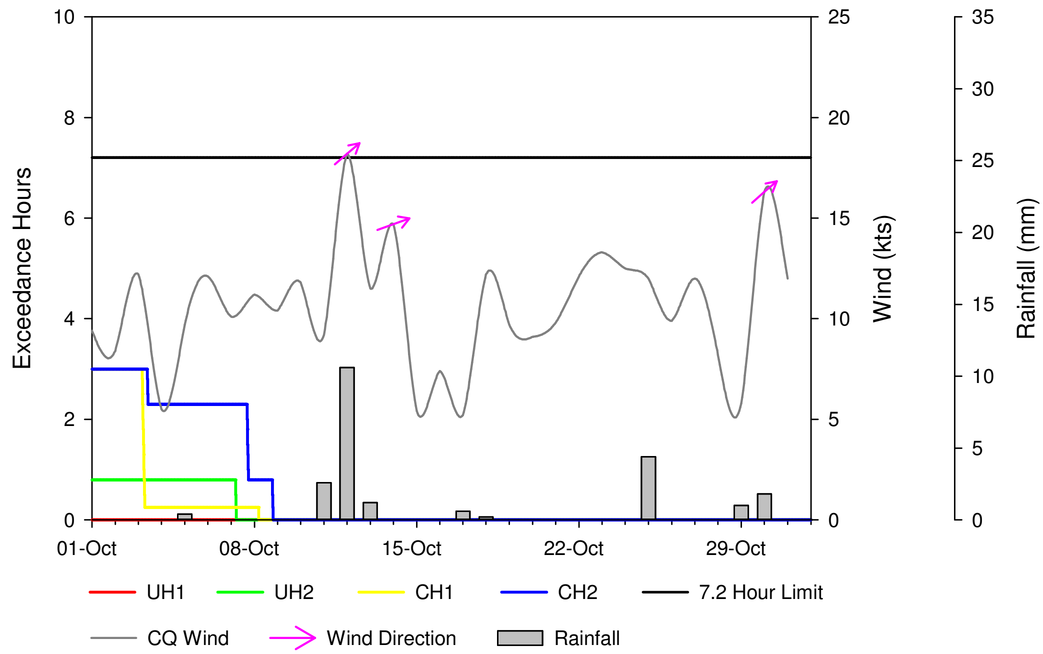


Figure 11 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity value during October 2018.
Black horizontal line indicates the maximum allowable counts of 7.2 hours.

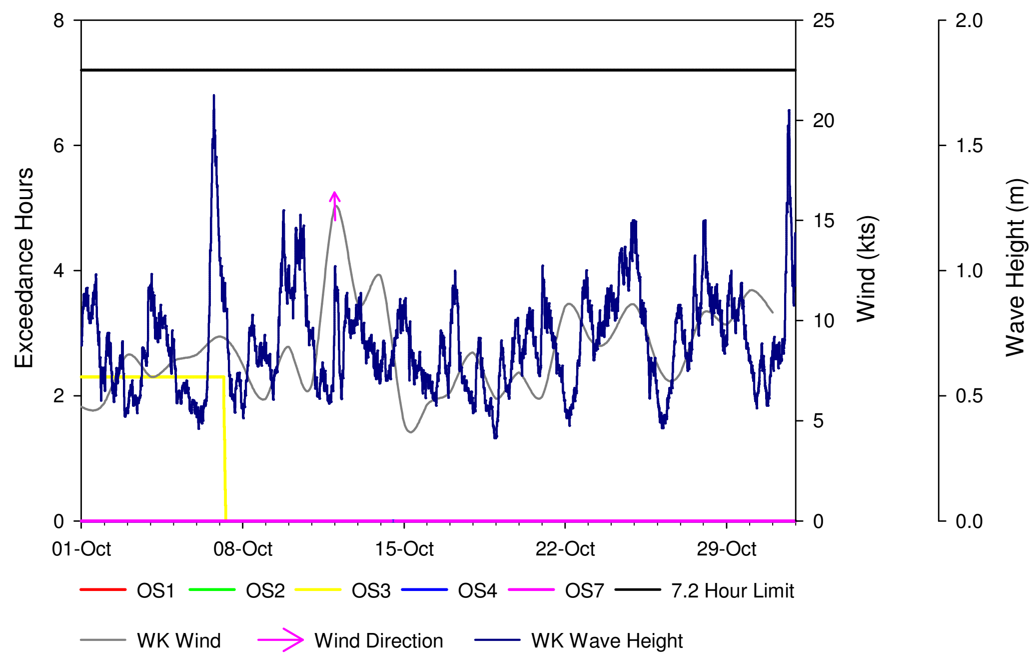


Figure 12 Tier 3 allowable hour counts at OS1, OS2, OS3 and OS7 after exceedance of the intensity value during October 2018.
Note there is no trigger value for reference site OS4. Black horizontal line indicates the maximum allowable counts of 7.2 hours.

3.2.3 Temperature

Average surface water temperatures during October were once again warmer than those experienced during the previous month, ranging from 12.6 to 13.8°C (Table 9), compared to 10.4 to 10.9°C in September. In contrast to the winter months, the shallow waters of the upper and central harbour displayed the warmest mean temperatures. All sites exhibited a warming trend across the month, with small decreases occurring during periods of rainfall from 10 to 15 October (Figures 13 and 14). Interestingly, additional cooling was observed at sites OS3, OS4 and OS6, and to a lesser extent SG2b and SG3, on 25 October (Figures 13 and 14), suggesting the presence of cooler surface waters. Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the datasets.

Benthic monthly mean temperatures were up to 1.9°C cooler than those of the surface waters and displayed a similar temporal pattern with cooling during mid-month rainfall. Recovery from this cooling event was at a lower rate than at the corresponding surface waters, due to the reduced influence of solar insolation at depth. Rapid declines in benthic temperature were also observed at sites OS2 and OS3 on 24 and 25 October.

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during October 2018.
Values are means ± se (n = 2846 to 2975).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	13.8 ± 0.0	–
UH2	13.6 ± 0.0	–
CH1	13.3 ± 0.0	–
CH2	13.2 ± 0.0	–
SG1	12.8 ± 0.0	–
SG2	12.7 ± 0.0	–
SG3	12.7 ± 0.0	–
OS1	13.1 ± 0.0	12.7 ± 0.0
OS2	12.9 ± 0.0	12.2 ± 0.0
OS3	12.7 ± 0.0	12.0 ± 0.0
OS4	12.6 ± 0.0	11.9 ± 0.0
OS5	13.0 ± 0.0	–
OS6	12.8 ± 0.0	11.9 ± 0.0
OS7	13.0 ± 0.0	–

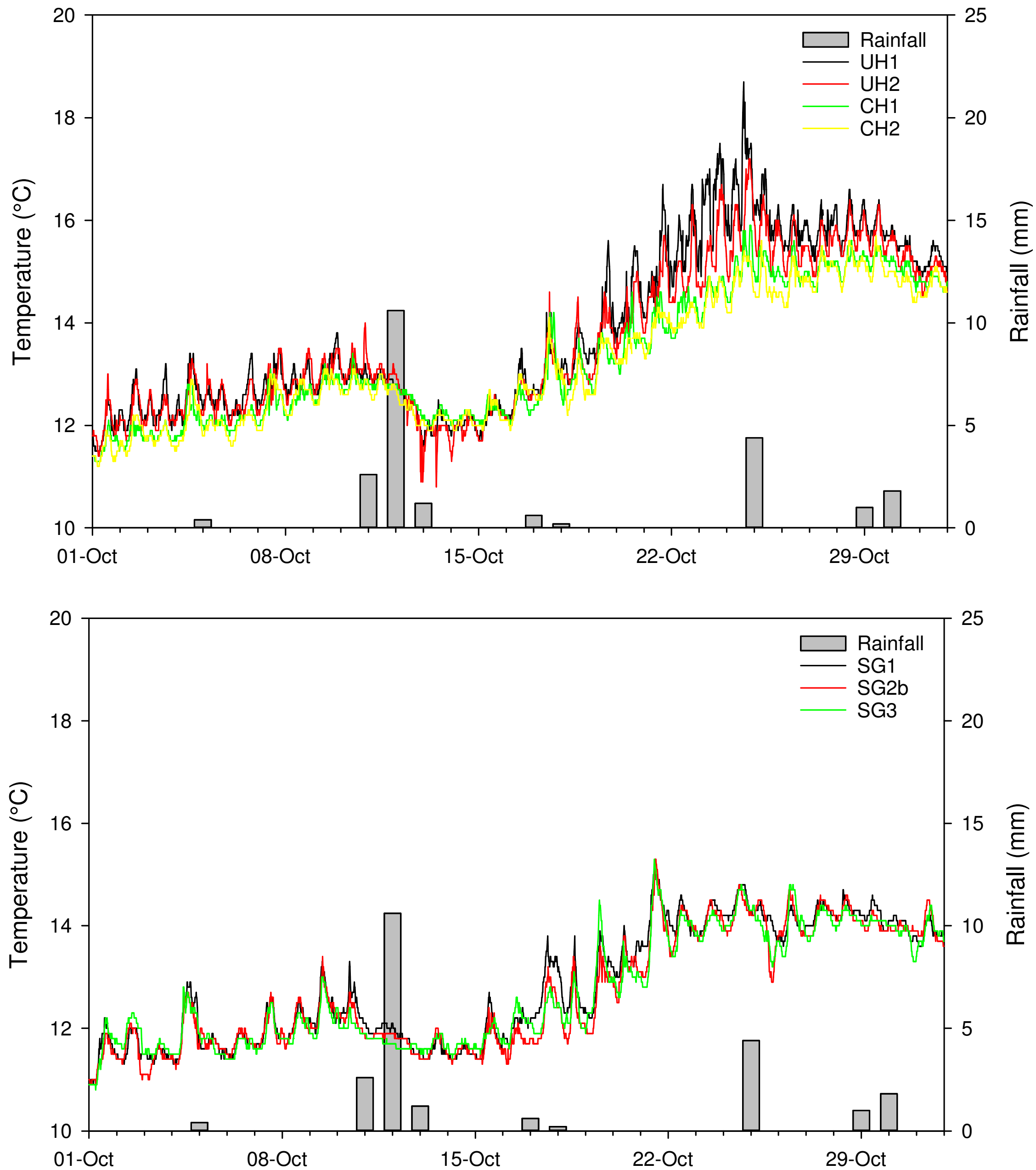
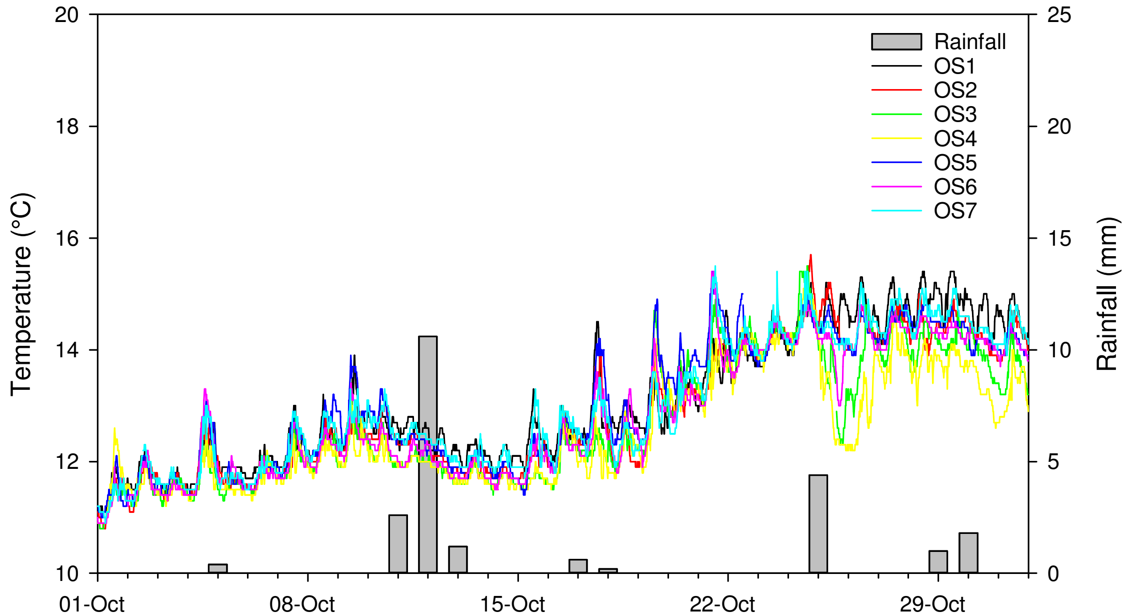


Figure 13 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during October 2018.



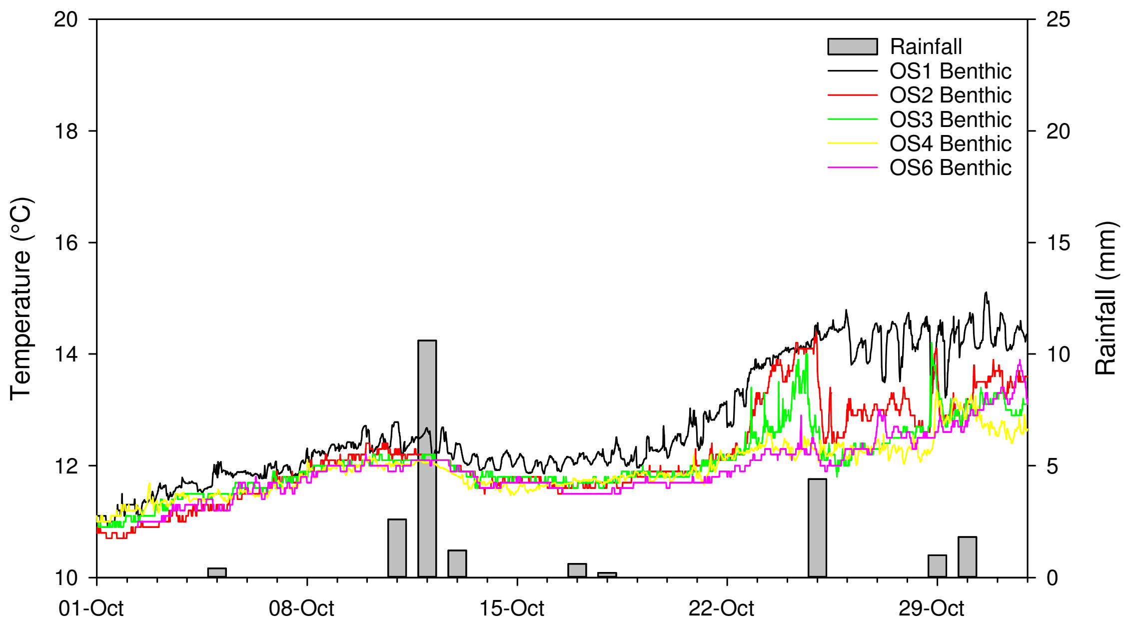


Figure 14 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites during October 2018.

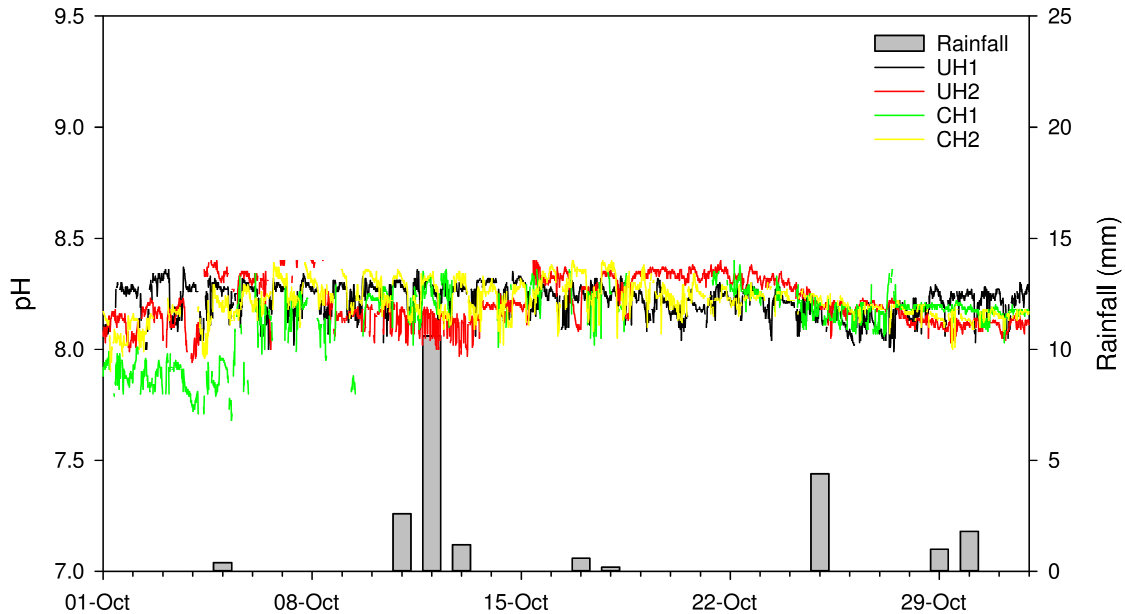
3.2.4 pH

Once again, pH data collected from surface sondes did not demonstrate any strong spatial patterns, with mean monthly surface pH for October ranging from 8.0 to 8.3 (Table 10). Temporally, surface pH did not appear to display any trends associated with the month's rainfall events (Figures 15 and 16) with a high level of variability inherently incorporated within the data.

As expected, benthic pH displayed greater stability than that of the surface waters (Figure 16), due to the reduced influence of photosynthesis and respiration at depth.

Table 10 Mean pH at inshore, spoil ground and offshore water quality sites during October 2018. *Values are means ± se (n = 124 to 2970).*

Site	pH	
	Surface loggers	Benthic loggers
UH1	8.2 ± 0.0	–
UH2	8.2 ± 0.0	–
CH1	8.1 ± 0.0	–
CH2	8.2 ± 0.0	–
SG1	8.1 ± 0.0	–
SG2	8.2 ± 0.0	–
SG3	8.3 ± 0.0	–
OS1	8.1 ± 0.0	7.7 ± 0.0
OS2	8.2 ± 0.0	7.9 ± 0.0
OS3	8.0 ± 0.0	7.9 ± 0.0
OS4	8.1 ± 0.0	8.0 ± 0.0
OS5	8.2 ± 0.0	–
OS6	8.1 ± 0.0	7.8 ± 0.0
OS7	8.2 ± 0.0	–



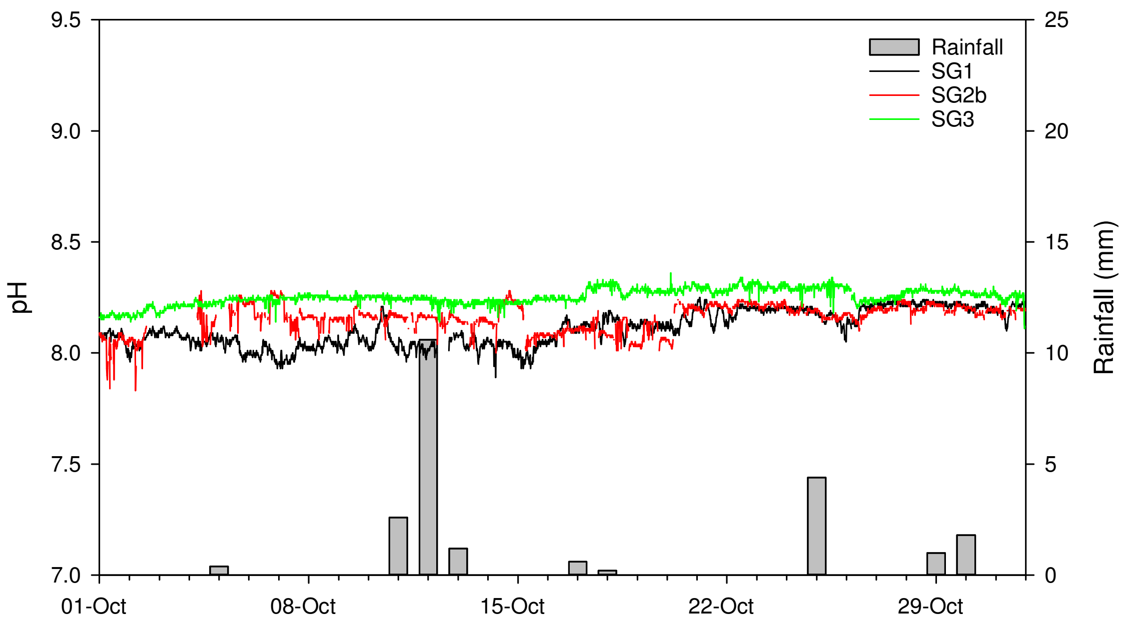
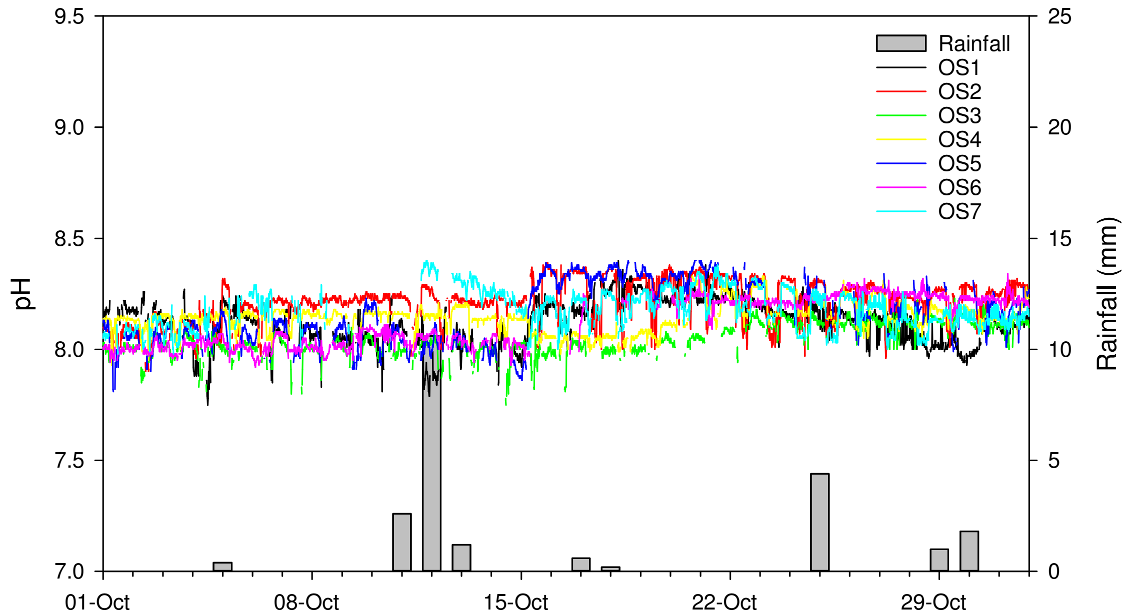


Figure 15 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2018.



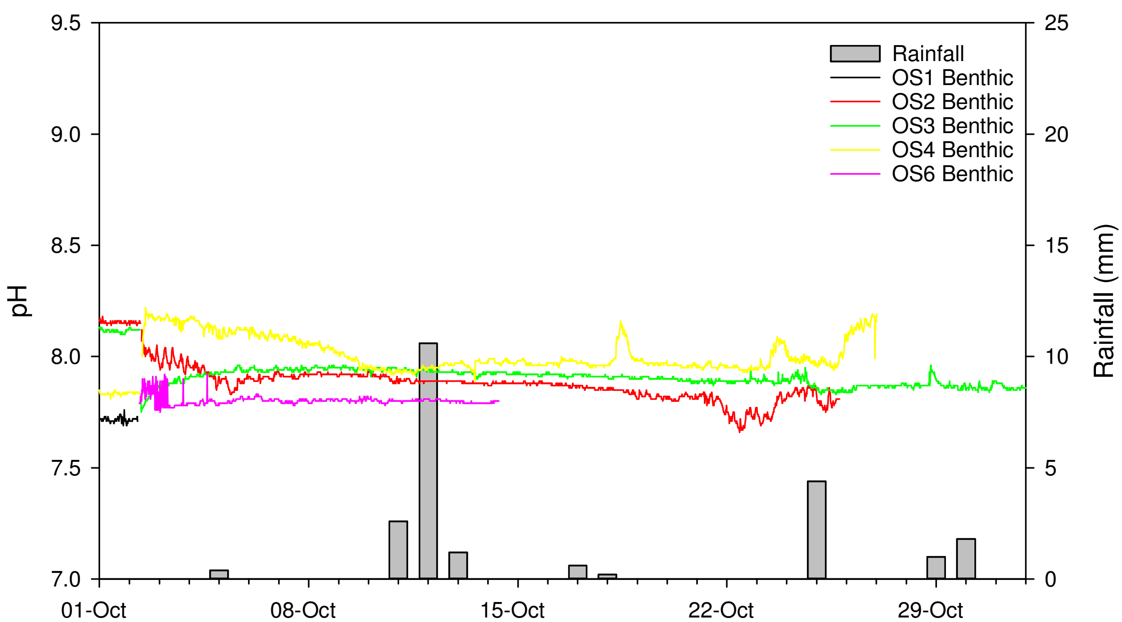


Figure 16 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at offshore water quality sites during October 2018.

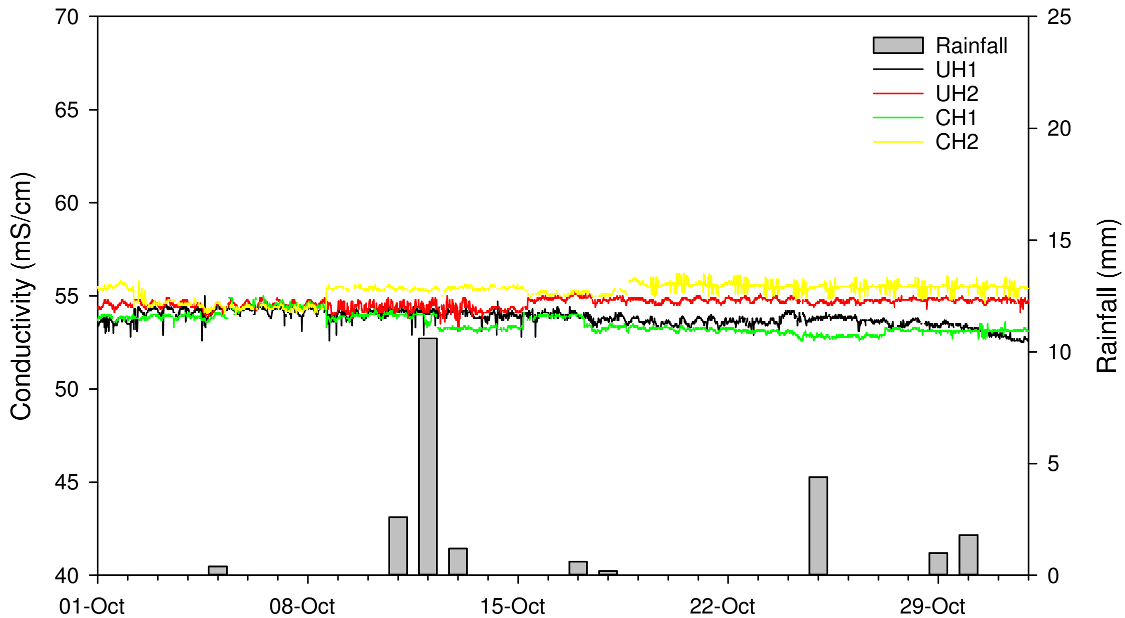
3.2.5 Conductivity

Similar to previous months, no spatial patterns across the monitoring sites were evident for conductivity (Table 11). In a similar manner to pH, conductivity did not display any notable temporal changes, with little impact from localised rainfall events (Figures 17 and 18). Cooler temperatures observed at the southern nearshore and spoil ground sites were not accompanied by reduced conductivity, which can often be an indication of freshwater runoff.

Benthic conductivity was typically higher at than the corresponding surface values, similar to previous monitoring months (Table 11). In a similar manner to the surface dataset, periods of localised rainfall did not result in variability in benthic conductivity (Figure 18), with slight noise likely induced by subtle differences between the dual sensors deployed at each site.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during October 2018.
Values are means ± se (n = 2482 to 2970).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	53.8 ± 0.0	–
UH2	54.6 ± 0.0	–
CH1	53.5 ± 0.0	–
CH2	55.3 ± 0.0	–
SG1	55.1 ± 0.0	–
SG2	55.8 ± 0.0	–
SG3	55.4 ± 0.0	–
OS1	54.4 ± 0.0	55.2 ± 0.0
OS2	54.9 ± 0.0	57.6 ± 0.0
OS3	54.6 ± 0.0	55.8 ± 0.0
OS4	54.5 ± 0.0	54.0 ± 0.0
OS5	54.3 ± 0.0	–
OS6	54.1 ± 0.0	58.5 ± 0.0
OS7	53.5 ± 0.0	–



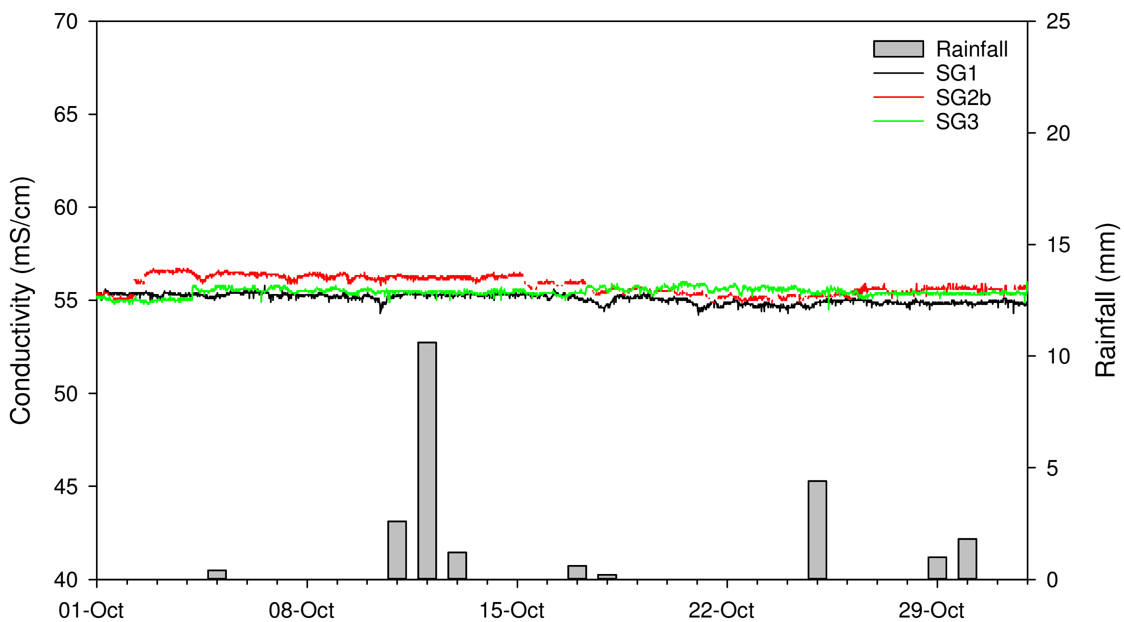


Figure 17 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2018.

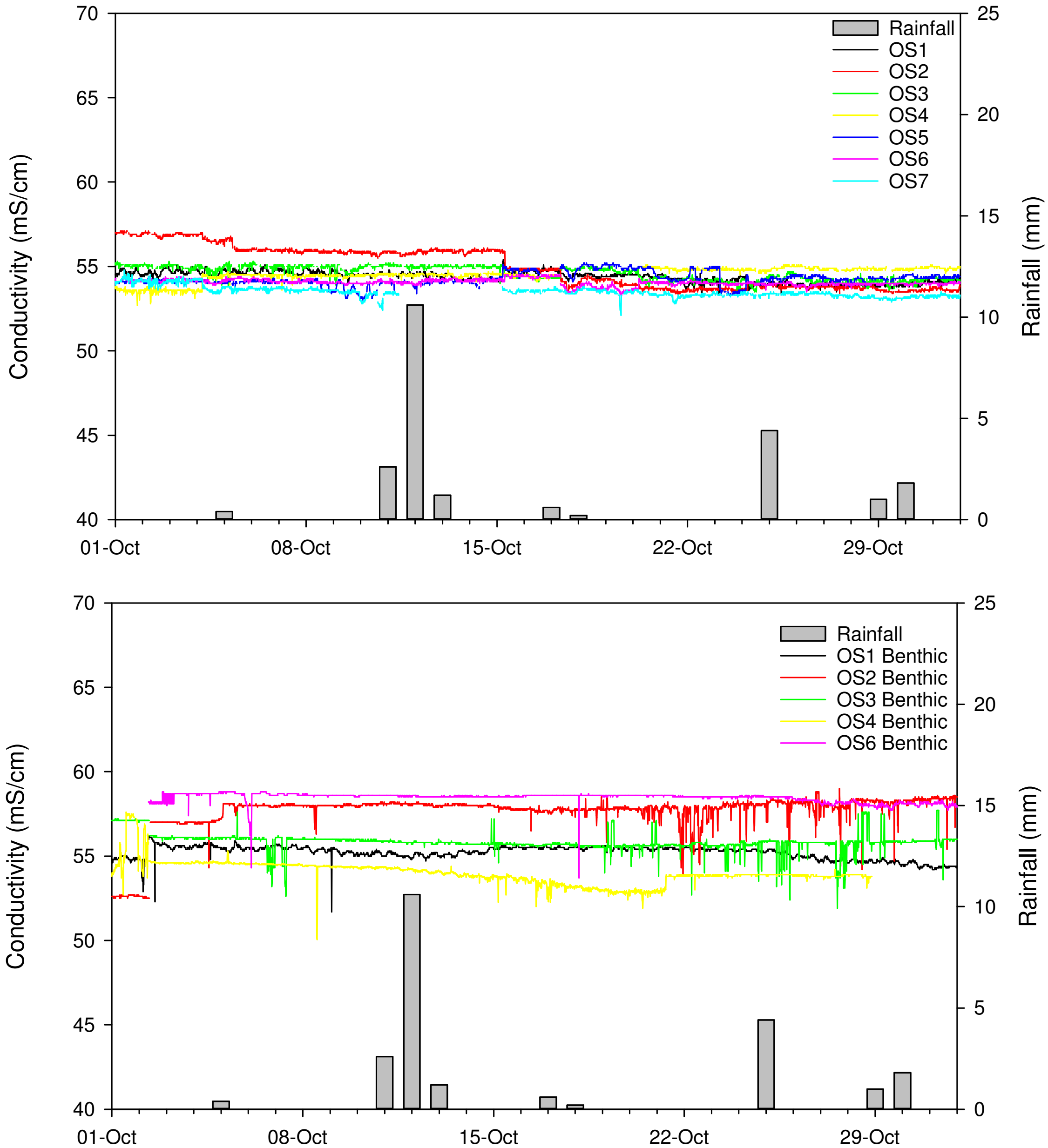


Figure 18 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites during October 2018.

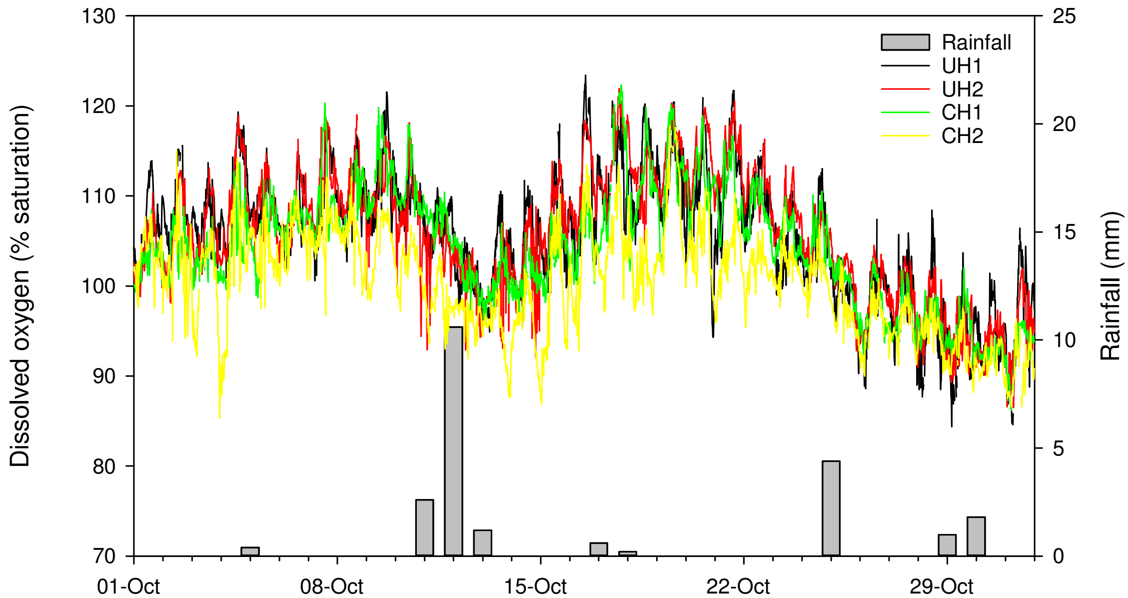
3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations were elevated compared to September, ranging from 97 to 106% saturation, with no apparent spatial patterns across the sites (Table 12). All surface sites displayed similar temporal trends, with declining DO concentrations during the mid-month rainfall (Figures 19 and 20). A second decline in dissolved oxygen occurred during rainfall in late October, most pronounced at the northern spoil ground sites SG1 and SG2b yet evident to some extent at all sites.

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. Concentrations of dissolved oxygen appeared to decline near the seabed between 8 and 22 October (Figure 20), which may be a reflection of *in situ* consumption through respiration as dead phytoplankton associated with the surface bloom sink towards the benthos.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during October 2018.
Values are means ± se (n = 2846 to 2975).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	106 ± 0	–
UH2	106 ± 0	–
CH1	104 ± 0	–
CH2	100 ± 0	–
SG1	103 ± 0	–
SG2	103 ± 0	–
SG3	102 ± 0	–
OS1	100 ± 0	100 ± 0
OS2	102 ± 0	92 ± 0
OS3	97 ± 0	94 ± 0
OS4	101 ± 0	95 ± 0
OS5	106 ± 0	–
OS6	103 ± 0	92 ± 0
OS7	103 ± 0	–



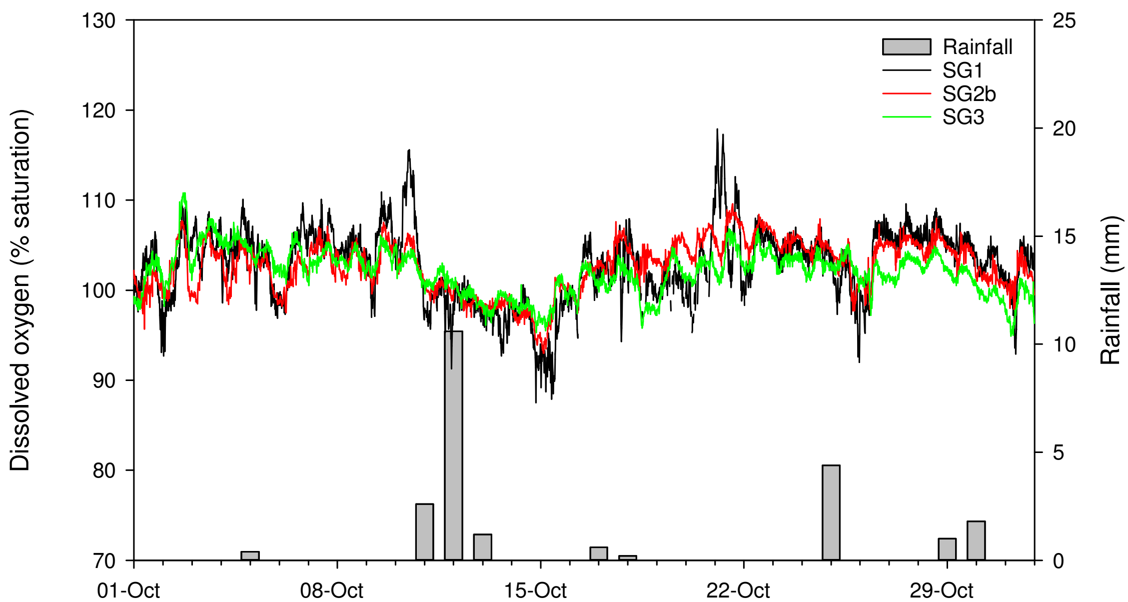
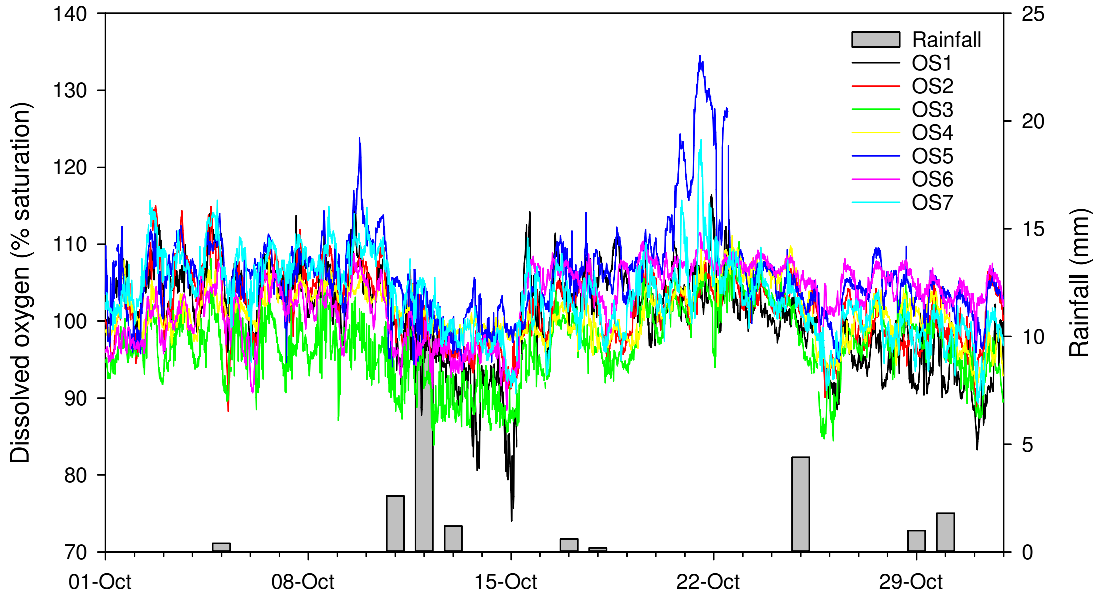


Figure 19 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2018.



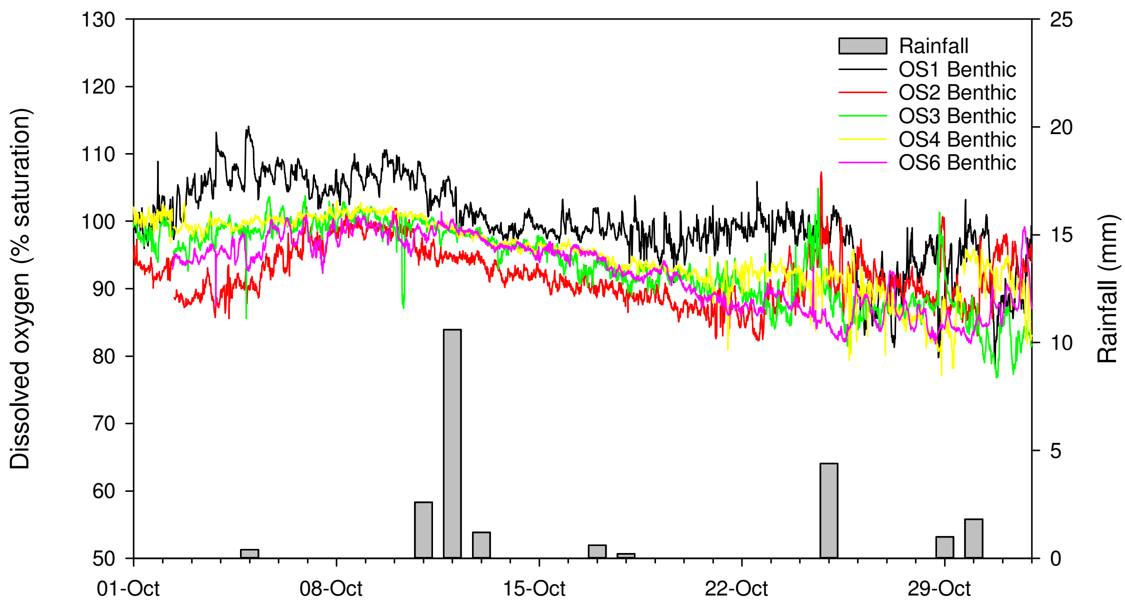


Figure 20 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites during October 2018.

3.3 Physicochemistry Depth Profiling & TSS

On 17 October 2018, vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling. 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 13 to 15, with depth profile plots presented in Figures 21 to 23.

The relatively shallow sites of the upper and central harbour were once again vertically well mixed. Benthic waters within the harbour at CH2 were also characterised by slight increases in turbidity (Figure 21, Table 13). The highest levels of sub-surface turbidity and TSS were once again recorded at the upper harbour site UH1 (5.5 NTU, 12 mg/L TSS; Table 13), however, these values were well within the turbidity WQGs and notably lower than those recorded during the September sampling. Elevated surface DO concentrations were recorded at all five inner harbour sites, with concentrations at UH1, UH2 and CH1 exceeding the WQG of 110% saturation (Table 13). These increased levels of oxygen within the water column are likely a reflection of increased photosynthesis associated with a phytoplankton bloom within the harbour.

Within the nearshore environment, vertical profiles for conductivity, pH and DO remained relatively consistent throughout the water column (Figure 22). Temperature data, however, indicated the formation of thermal stratification through the presence of a slight seasonal thermocline as increasing solar insolation warms the surface waters. This temperature gradient was weakest at the exposed sites OS3 and OS4, where wave action is likely to increase vertical mixing and reduce the level of warming in the surface waters. In a similar manner to the inner harbour sites, turbidity increases near the seabed were evident at all sampling sites.

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 13.6 m at SG1 (Table 15). Vertical profiling at these offshore sites also revealed the formation of a seasonal thermocline between 5 and 10 m depth at all the observed locations. Interestingly, surface waters at the northernmost sites OS5 and SG1 also displayed slightly lower conductivity values (Figure 23). Benthic turbidity levels were once again elevated near the seabed, however due to the depth of water at these sites, sea floor resuspension exerted a minimal effect on light attenuation calculations.

Aside from elevated surface DO concentrations in the inner harbour, no further exceedances of WQG were observed for the sub-surface during the October sampling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the October 2018 sampling event. *Values are means ± se (n =6 for sub-surface, n = 16 to 34 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	17/10/2018 06:03	Sub-surface	12.6 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	113 ± 0	5.5 ± 0.1	12	1.1 ± 0.1	4.3
		Whole column	12.6 ± 0.0	8.0 ± 0.0	52.4 ± 0.0	113 ± 0	5.9 ± 0.1	–		
UH2	17/10/2018 06:54	Sub-surface	12.5 ± 0.0	8.1 ± 0.0	52.4 ± 0.0	114 ± 0	3.8 ± 0.1	9	0.9 ± 0.0	5.2
		Whole column	12.5 ± 0.0	8.1 ± 0.0	52.5 ± 0.0	114 ± 0	5.0 ± 0.3	–		
UH3	17/10/2018 06:15	Sub-surface	12.8 ± 0.0	8.0 ± 0.0	52.1 ± 0.0	108 ± 0	4.7 ± 0.1	9	1.0 ± 0.0	4.8
		Whole column	12.8 ± 0.0	8.0 ± 0.0	52.1 ± 0.0	109 ± 0	5.9 ± 0.5	–		
CH1	17/10/2018 07:23	Sub-surface	12.5 ± 0.0	8.1 ± 0.0	52.6 ± 0.0	112 ± 0	2.9 ± 0.0	6	0.8 ± 0.0	5.6
		Whole column	12.4 ± 0.0	8.1 ± 0.0	52.6 ± 0.0	110 ± 0	4.4 ± 0.4	–		
CH2	17/10/2018 07:09	Sub-surface	12.5 ± 0.0	8.0 ± 0.0	52.8 ± 0.0	108 ± 0	2.8 ± 0.0	5	0.7 ± 0.1	7.0
		Whole column	12.4 ± 0.0	8.0 ± 0.0	52.8 ± 0.0	107 ± 0	5.4 ± 1.6	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the October 2018 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 31 to 41 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	17/10/2018 07:39	Sub-surface	12.4 ± 0.0	8.0 ± 0.0	52.8 ± 0.0	108 ± 0	2.9 ± 0.0	7	0.6 ± 0.0	7.7
		Mid	12.2 ± 0.0	8.0 ± 0.0	52.9 ± 0.0	107 ± 0	3.0 ± 0.1	5		
		Benthos	12.0 ± 0.0	8.0 ± 0.0	52.9 ± 0.0	103 ± 0	13 ± 3	32		
		Whole column	12.2 ± 0.0	8.0 ± 0.0	52.9 ± 0.0	106 ± 0	5.1 ± 0.9	–		
OS2	17/10/2018 10:26	Sub-surface	12.2 ± 0.0	8.0 ± 0.0	52.9 ± 0.0	107 ± 0	1.7 ± 0.0	6	0.6 ± 0.1	7.3
		Mid	11.8 ± 0.1	8.0 ± 0.0	53.0 ± 0.0	104 ± 1	4.0 ± 0.4	11		
		Benthos	11.6 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	98 ± 0	12 ± 1	34		
		Whole column	11.9 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	104 ± 1	5.0 ± 0.7	–		
OS3	17/10/2018 09:47	Sub-surface	12.0 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	103 ± 0	1.5 ± 0.0	4	0.5 ± 0.0	9.6
		Mid	11.6 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	99 ± 0	2.5 ± 0.1	7		
		Benthos	11.5 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	97 ± 0	32 ± 17	16		
		Whole column	11.7 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	100 ± 0	7.0 ± 3.0	–		
OS4	17/10/2018 09:24	Sub-surface	11.7 ± 0.0	7.9 ± 0.0	53.0 ± 0.0	100 ± 0	3.3 ± 0.1	8	0.6 ± 0.0	7.6
		Mid	11.6 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	98 ± 0	4.4 ± 0.1	11		
		Benthos	11.6 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	98 ± 0	18 ± 7	22		
		Whole column	11.6 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	99 ± 0	6.2 ± 1.2	-		
OS7	17/10/2018 10:40	Sub-surface	12.4 ± 0.0	8.0 ± 0.0	52.9 ± 0.0	104 ± 0	2.6 ± 0.1	6	0.6 ± 0.0	8.2
		Mid	12.0 ± 0.1	8.0 ± 0.0	52.9 ± 0.0	103 ± 1	3.2 ± 0.3	8		
		Benthos	11.6 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	99 ± 0	20 ± 8	33		
		Whole column	12.0 ± 0.1	8.0 ± 0.0	52.9 ± 0.0	102 ± 0	6.2 ± 1.9	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 15 Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during the October 2018 sampling event.
Values are means ± se (n =4 to 6 for sub-surface, mid and benthos, n = 38 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	17/10/2018 07:56	Sub-surface	12.3 ± 0.0	8.0 ± 0.0	52.7 ± 0.0	107 ± 0	1.3 ± 0.0	4	0.4 ± 0.0	11.8
		Mid	11.6 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	104 ± 0	1.2 ± 0.0	5		
		Benthos	11.5 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	97 ± 1	23 ± 8	8		
		Whole column	11.9 ± 0.1	8.0 ± 0.0	52.9 ± 0.0	104 ± 1	4.7 ± 1.8	–		
OS6	17/10/2018 10:07	Sub-surface	12.2 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	106 ± 0	1.3 ± 0.0	3	0.4 ± 0.0	11.1
		Mid	11.4 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	102 ± 0	1.8 ± 0.1	4		
		Benthos	11.3 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	98 ± 0	13 ± 5	4		
		Whole column	11.7 ± 0.1	8.0 ± 0.0	53.1 ± 0.0	103 ± 1	3.5 ± 0.9	–		
SG1	17/10/2018 08:14	Sub-surface	12.2 ± 0.0	8.0 ± 0.0	52.8 ± 0.0	109 ± 0	1.0 ± 0.0	4	0.3 ± 0.0	13.6
		Mid	11.4 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	105 ± 0	1.2 ± 0.0	4		
		Benthos	11.3 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	99 ± 0	6.0 ± 1.2	7		
		Whole column	11.7 ± 0.1	8.0 ± 0.0	53.0 ± 0.0	105 ± 1	2.0 ± 0.3	–		
SG2b	17/10/2018 08:36	Sub-surface	12.0 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	106 ± 0	1.2 ± 0.0	4	0.4 ± 0.0	11.2
		Mid	11.4 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	104 ± 1	1.6 ± 0.1	5		
		Benthos	11.3 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	97 ± 0	22 ± 14	3		
		Whole column	11.6 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	103 ± 1	4.4 ± 2.0	–		
SG3	17/10/2018 09:00	Sub-surface	11.8 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	105 ± 0	1.3 ± 0.0	<3	0.4 ± 0.0	10.8
		Mid	11.4 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	102 ± 0	2.5 ± 0.2	5		
		Benthos	11.4 ± 0.0	7.9 ± 0.0	53.1 ± 0.0	98 ± 0	11 ± 3	<3		
		Whole column	11.6 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	102 ± 0	3.4 ± 0.6	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

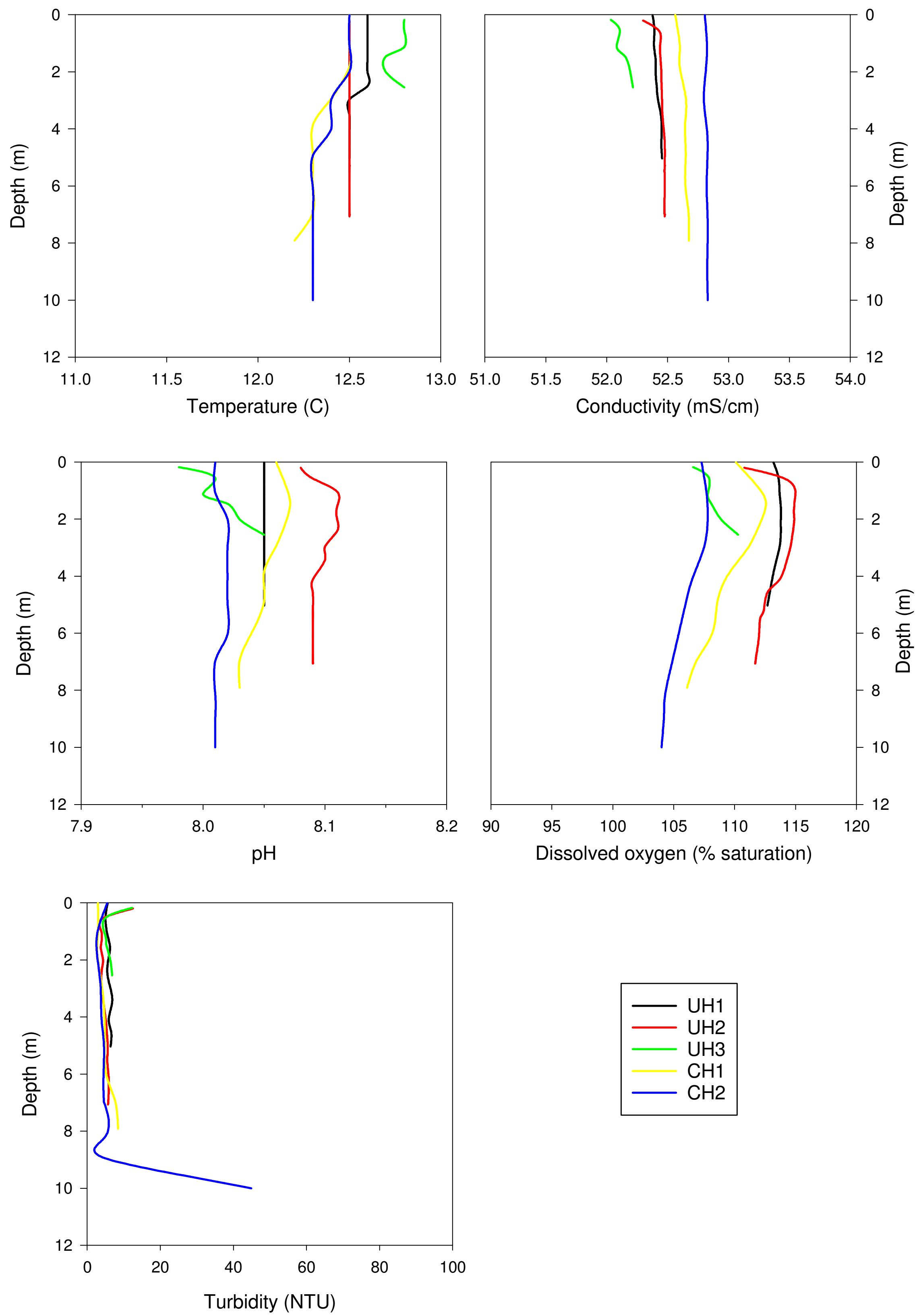


Figure 21 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 17 October 2018.

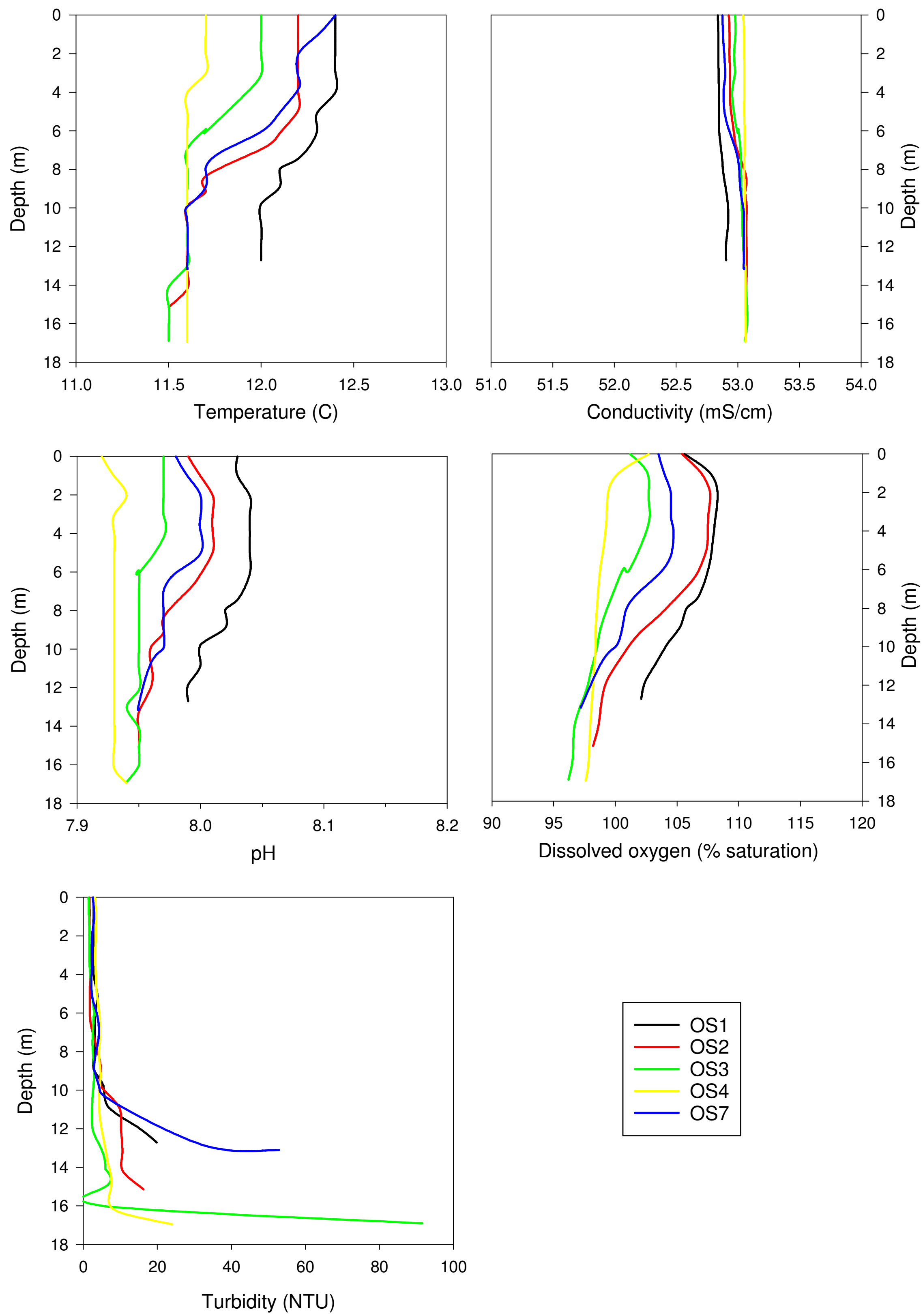


Figure 22 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 17 October 2018.

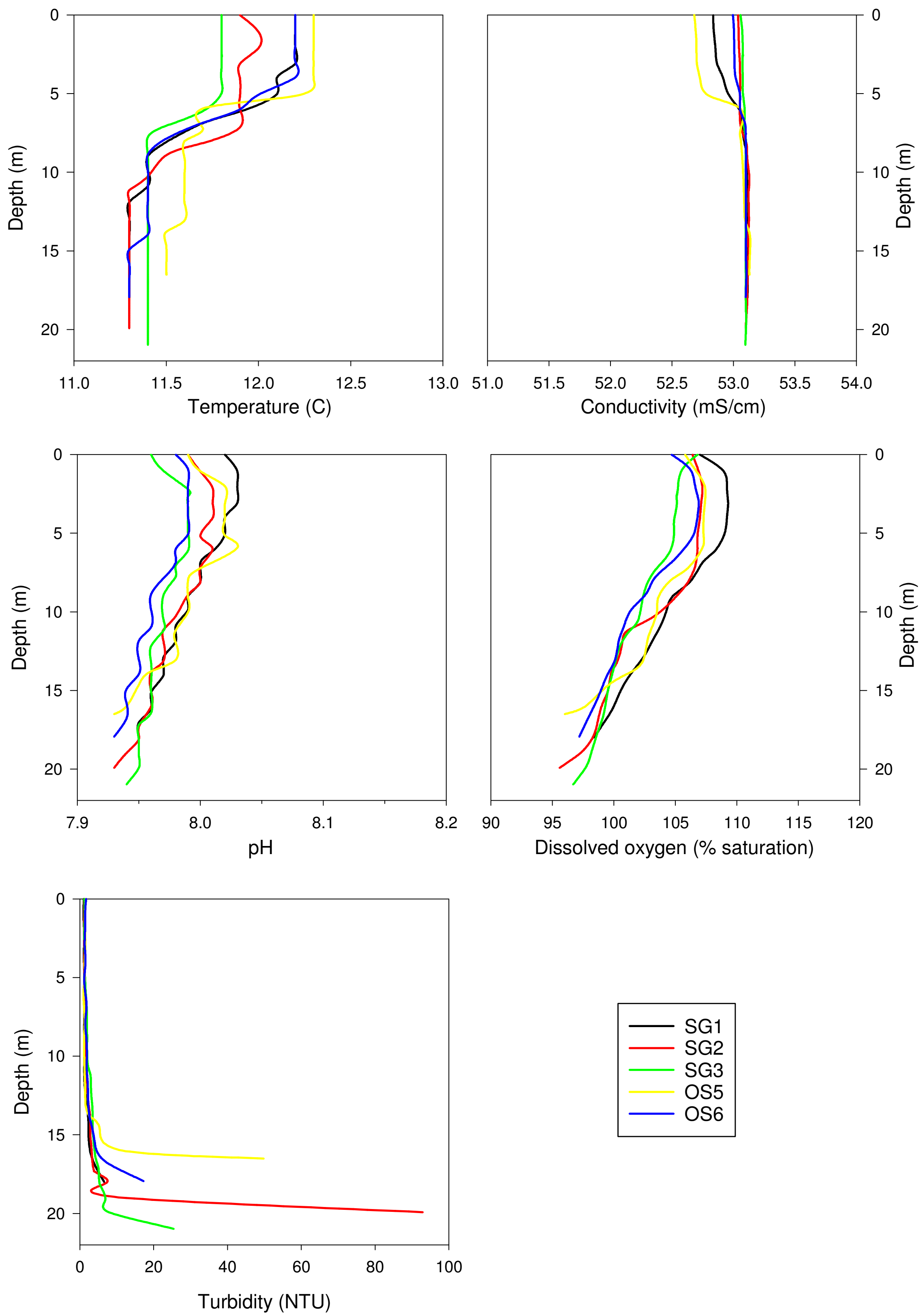


Figure 23 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 17 October 2018.

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 16, with the collected data from benthic and VBCC sensors presented in Figure 24. Data from the logger exchange date (2 October) were removed from the analyses.

Table 16 Total Daily PAR (TDP) statistics during October 2018.
Values are means ± se (n = 30). Note data from the BPAR exchange day on 2 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	-	33,950 ± 2,207	38,300	8,140 – 49,200
OS2	17	3.2 ± 0.1	1.3	0.03 – 25.6
OS3	14	9.9 ± 3.3	3.3	<0.01 – 74.2

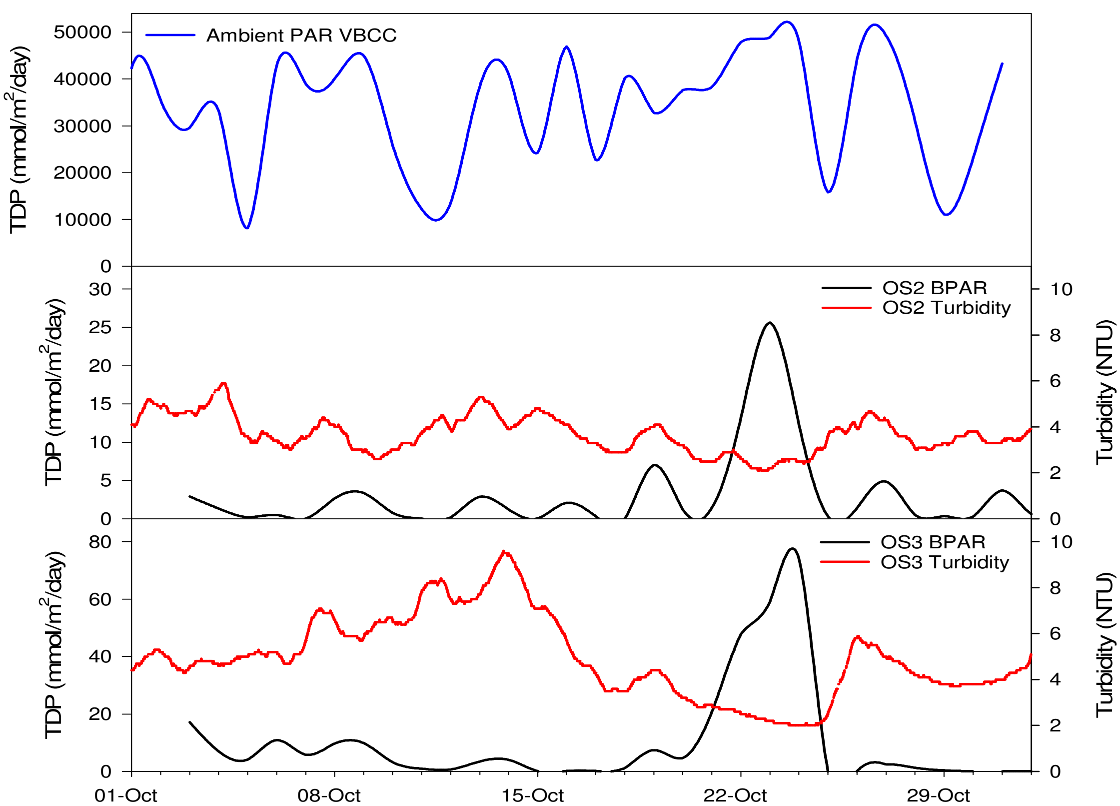


Figure 24 Total daily BPAR at OS2 and OS3 during October 2018 compared to ambient PAR and corresponding surface turbidity.
Note data from the BPAR exchange day on 2 October were not utilized in plots or statistics.

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 8,140 to 49,200 mmol/m^2/day (Table 16). Maximum TDP was notably higher than that observed during September at 33,950 mmol/m^2/day, and multiple days of non-zero BPAR readings were recorded (Figure 24).

Benthic PAR recorded at OS2 during October displayed multiple peaks that corresponded well with peaks recorded in incident solar radiations recorded at VBCC. The largest of these BPAR peaks occurred on 23 October with light intensities reaching 25.6 mmol/m^2/day. This notable increase in benthic light availability occurred during the minimum observed surface turbidity at OS2, which allowed more light to filter through the water column to the seabed.

Due to the slightly shallower water depth at OS3, mean total daily BPAR during October was over three times that observed at OS2, at 9.9 mmol/m^2/day. Peaks in BPAR at OS3 were at similar times as OS2. However, the highest BPAR measurements were recorded a day later on 24 October at 74.2 mmol/m^2/day when surface turbidity dropped below 4 NTU.

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.

Daily averaged altimeter readings at the entrance of Lyttelton Harbour (site OS2) indicated a relatively stable seabed during October (Figure 25). Following a brief period of erosion and recovery on 2 October, bed level remained similar to conditions observed at the start of the month. Changes in offshore wind speed, including a peak on 12 October do not appear to result in either erosion of deposition of sea floor sediments at OS2. Over the course of the month, mean bed level increased by 2 mm (Table 17).

Table 17 Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 during October 2018.

Site	October 2018 Net bed level change (mm)
OS2	+2
UH3	-5

In the upper harbour, at UH3, bed level also appeared to be stable. While slight erosion from 2 to 5 October was apparent, recovery to conditions similar to the beginning of the month was relatively rapid (Figure 25). During the final week of the month, variability increased, with increasing surface turbidity at UH1 coinciding with sea floor erosion at UH3. Interestingly, maximum monthly surface turbidity recorded at UH1 on 13 October did not correspond to sea floor erosion at UH3, suggesting that the suspended material may be externally sourced. During October, net bed level at UH3 dropped by 5 mm (Table 17).

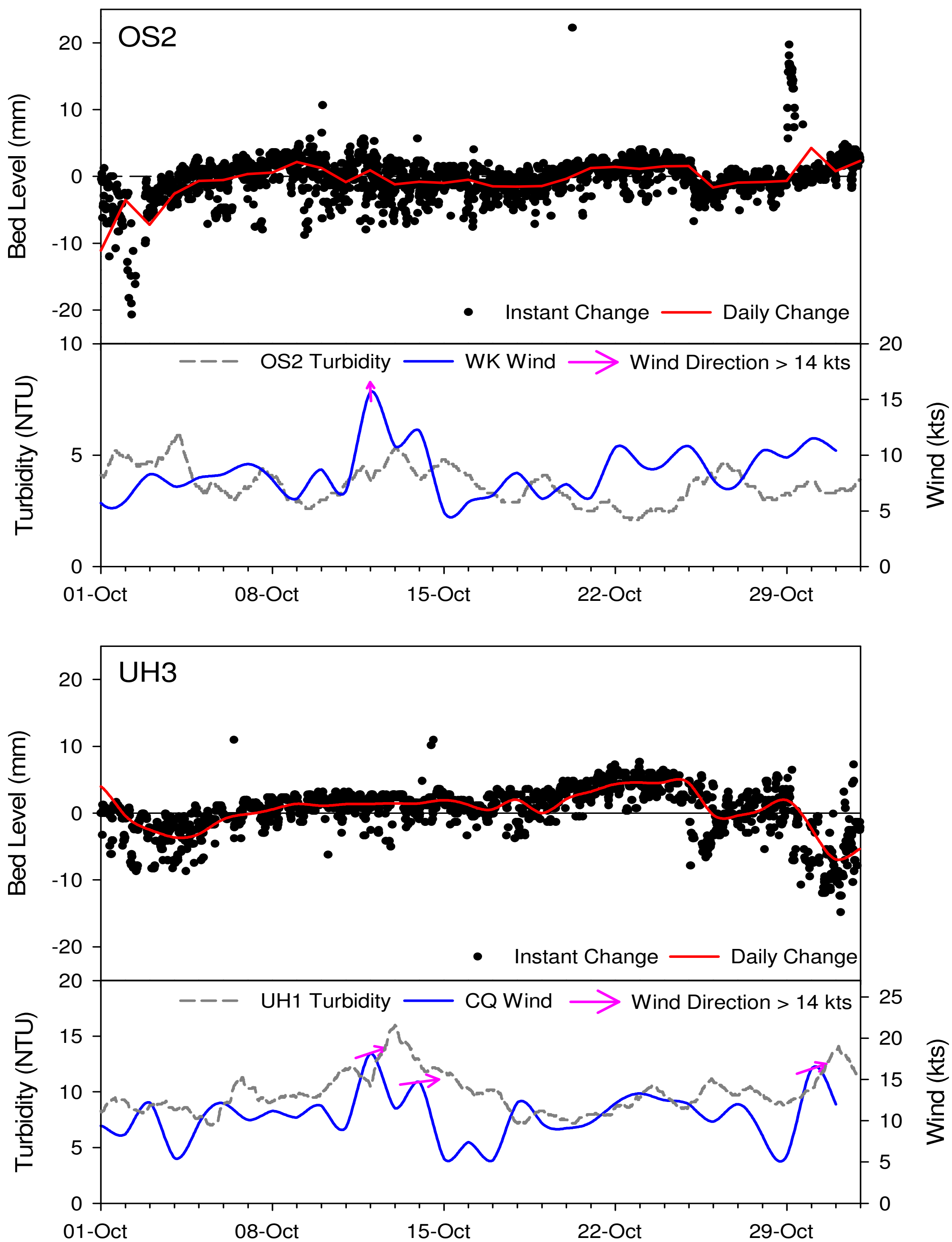


Figure 25 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during October 2018 compared to ambient surface turbidity (24 hour rolling average) wind speed and direction.
Note: Arrows indicate the direction of travel for winds greater than 14 knots.

3.6 Water Samples

Discrete water sampling was conducted on 17 October 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 October 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 18, Figure 26).. The water quality guideline (WQG) for total phosphorous (30 µg/L) was exceeded only at the upper harbour site UH3 (42 µg/L). Interestingly, the reference site OS4 displayed an anomalously high total phosphorous concentrations of 20 µg/L. Mirroring this pattern, concentrations of dissolved reactive phosphorous also exceeded WQGs at UH3 and OS4, with concentrations of 9.6 and 6.4 µg/L, respectively. Further offshore at the spoil ground monitoring sites, concentrations of dissolved reactive phosphorous were below laboratory detection limits (Table 18).

Of the remaining nutrients analysed, concentrations of total nitrogen and total kjeldahl nitrogen were below laboratory limits of reporting (LOR) at all sites. Ammonia exceeded the WQG (15 µg/L) at CH2, OS1, OS3 (20 to 21 µg/L) and reference site OS4 (32 µg/L). The nitrogen oxide WQG (15 µg/L) was exceeded only at OS3 (20 µg/L), with most sites containing concentrations <LOR (Table 18).

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass exceeded the WQG (4 µg/L) at the northern inner harbor sites UH1, UH2 and CH1 (4.2 to 8.1 µg/L). Despite elevated concentrations of dissolved reactive phosphorous and ammonia at OS4, concentrations of chlorophyll *a* were relatively low (0.8 µg/L).

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). Similar to previous months, total and dissolved zinc was also below LOR (<4.2 µg/L), with the exception of a detectable concentration at OS3 (12 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 the offshore locations OS6, SG2b and SG3. Concentrations of the more bioavailable dissolved fraction were <LOR (12 µg/L) at all sites 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.

Of the remaining metals analysed that have assigned WQGs, no exceedances were reported during the October 2018 water quality sampling campaign (Tables 19 and 20).

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during October 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	26	4.3	<300	<200	11	<1	8.1
UH2	24	3.4	<300	<200	11	<1	4.5
UH3	42	9.6	<300	<200	10	1.9	1.5
CH1	18	3.2	<300	<200	12	<1	4.2
CH2	18	4.3	<300	<200	21	2.0	3.0
OS1	14	3.0	<300	<200	20	5.1	1.8
OS2	12	1.6	<300	<200	12	<1	1.8
OS3	12	3.8	<300	<200	21	20	1.1
OS4	20	6.4	<300	<200	32	11	0.8
OS5	8	2.1	<300	<200	14	<1	2.0
OS6	8	1.3	<300	<200	11	4.1	1.3
OS7	16	3.8	<300	<200	10	6.5	1.6
SG1	10	<1	<300	<200	12	<1	1.6
SG2	10	<1	<300	<200	13	<1	1.8
SG3	10	<1	<300	<200	12	3.7	1.2
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

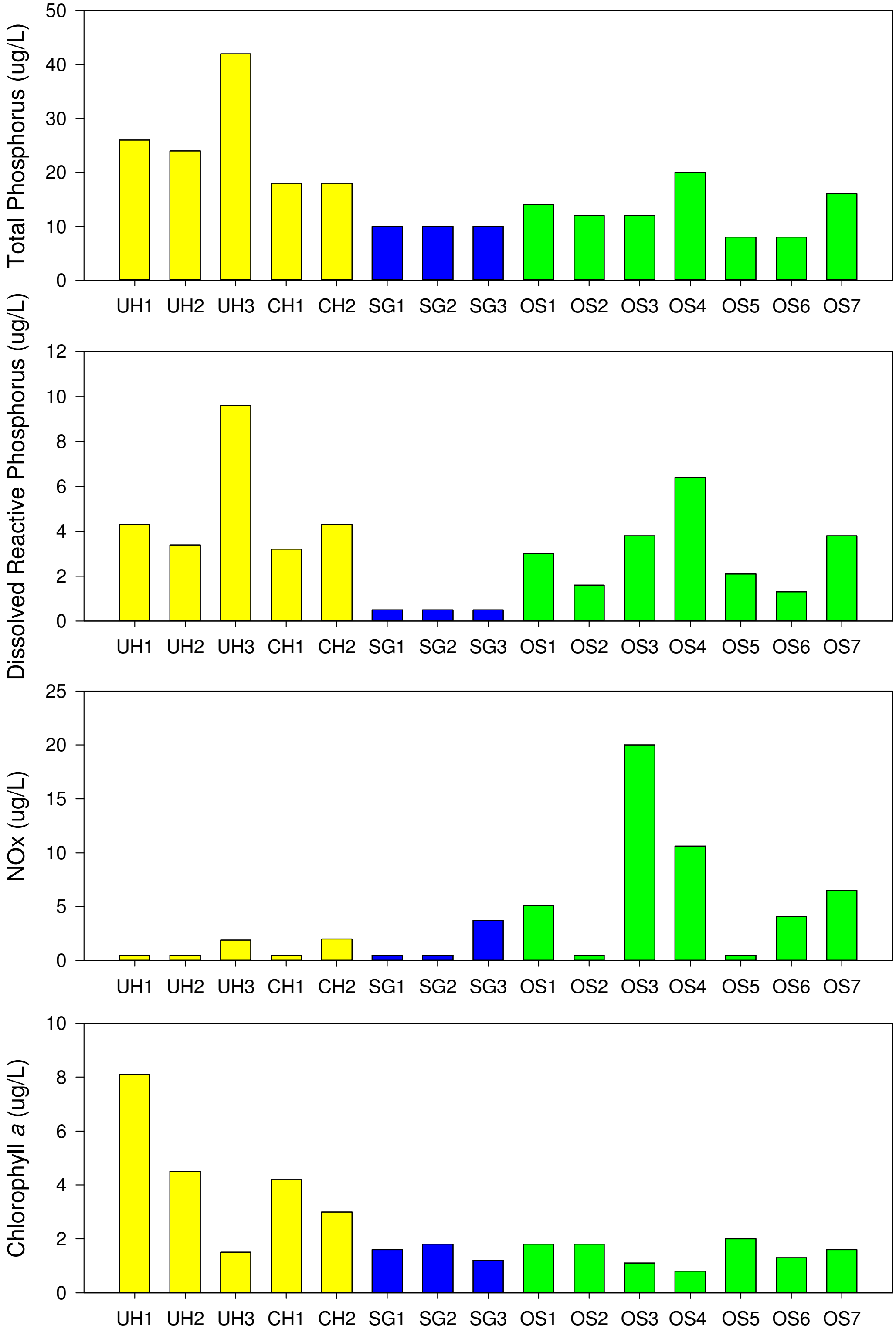


Figure 26 Nutrient and chlorophyll *a* concentrations at monitoring sites during October 2018. *Values which were <LOR, were plotted as half LOR. Total nitrogen, TKN and ammonia concentrations were not plotted as all or most sites were < LOR.*

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during October 2018. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	<12	<12	<12	<12	<12	24
	Total	135	82	123	44	43	
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	1.2	1.2	1.0	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	<1	<1	1.1	<1	
Cobalt	Dissolved	1.0	0.9	0.8	0.8	0.8	1.0
	Total	0.8	0.8	0.9	0.8	0.7	
Copper	Dissolved	<1	<1	<1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	
Iron	Dissolved	10	9	8	<4	<4	-
	Total	210	135	200	79	78	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	
Manganese	Dissolved	29	25	13	21	12	-
	Total	34	29	19	25	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	12	12	12	12	13	-
	Total	12	12	13	13	13	
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	2.7	2.6	2.2	2.6	2.5	100
	Total	3.1	3.0	2.6	2.8	2.7	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	

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

Metal (µg/L)		Sites							WQG
		OS1	OS2	OS3	OS4	OS5	OS6	OS7	
Aluminium	Dissolved	<12	<12	<12	<12	<12	<12	<12	24
	Total	92	44	28	71	52	<13	60	
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	1.3	<1	1.7	<1	1.0	1.1	1.4	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.8	<1	1.6	1.2	1.4	<1	1.2	
Cobalt	Dissolved	0.8	0.8	0.7	0.8	0.7	0.7	<0.6	1.0
	Total	0.7	<0.6	0.8	0.8	0.7	0.7	0.7	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	<1	<1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	149	69	45	280	46	50	95	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	<1	<1	
Manganese	Dissolved	11	3.7	2.1	1.4	1.7	1.8	5.8	-
	Total	14	6.3	3.9	3.7	4.1	3.9	9.4	
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	12	12	12	12	12	12	13	-
	Total	12	12	12	13	13	13	12	
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	2.3	1.8	1.8	1.4	1.8	1.9	1.9	100
	Total	2.7	2.3	1.7	1.9	1.9	1.9	2.4	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	12	<4.2	<4.2	<4.2	<4.2	

Table 21 Total and dissolved metal concentrations at spoil ground monitoring sites during October 2018. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	27	21	<13	
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	1.2	1.2	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	<1	1.2	
Cobalt	Dissolved	0.9	0.7	<0.6	1.0
	Total	0.8	0.7	<0.6	
Copper	Dissolved	1.5	<1	<1	1.3
	Total	<1	<1	<1	
Iron	Dissolved	<4	<4	<4	-
	Total	46	35	32	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1	<1	<1	
Manganese	Dissolved	3.1	1.9	2.5	-
	Total	4.2	2.9	1.5	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	13	13	13	-
	Total	12	12	12	
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	1.9	1.5	1.6	100
	Total	1.7	1.8	1.8	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

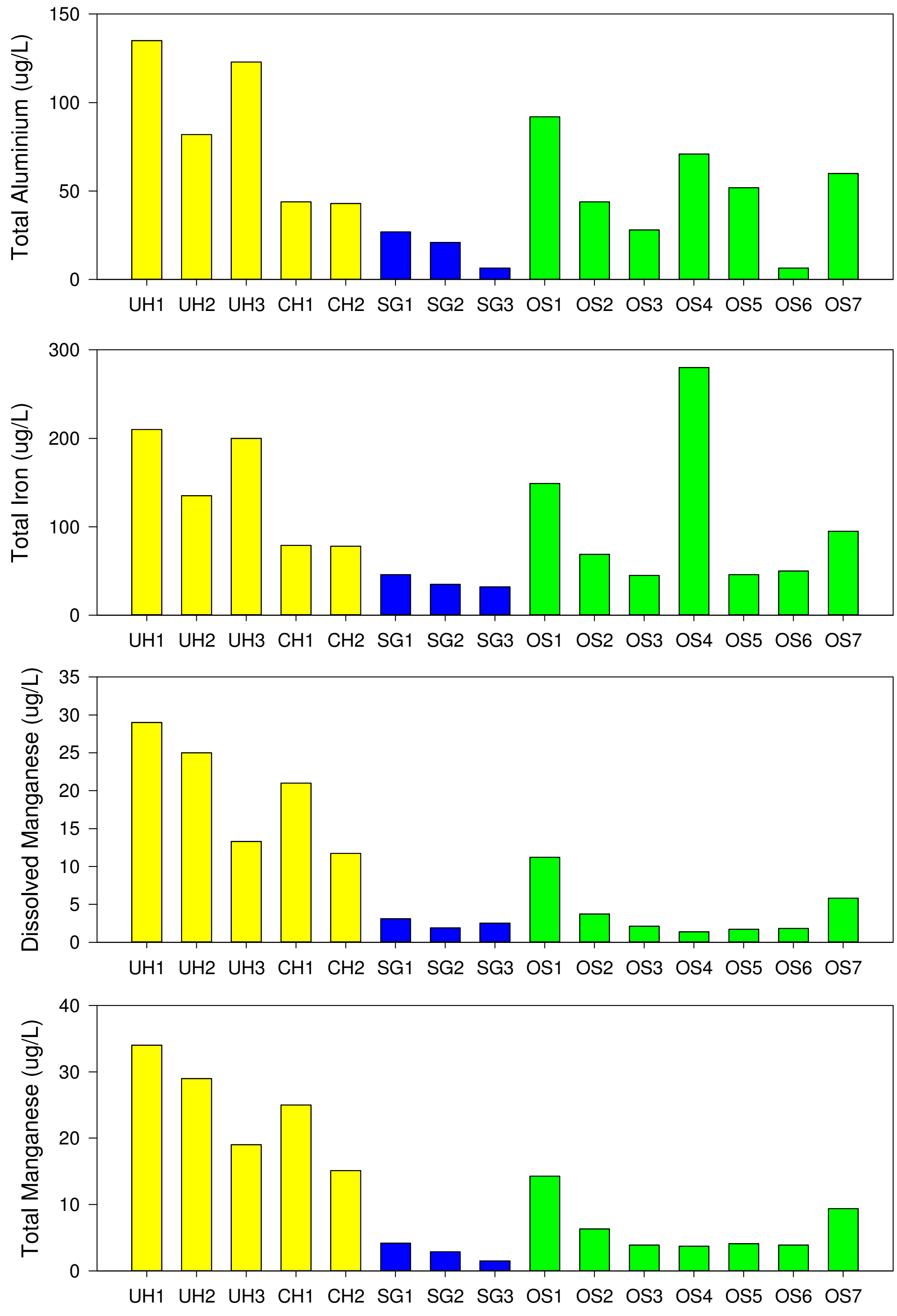


Figure 27 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during October 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

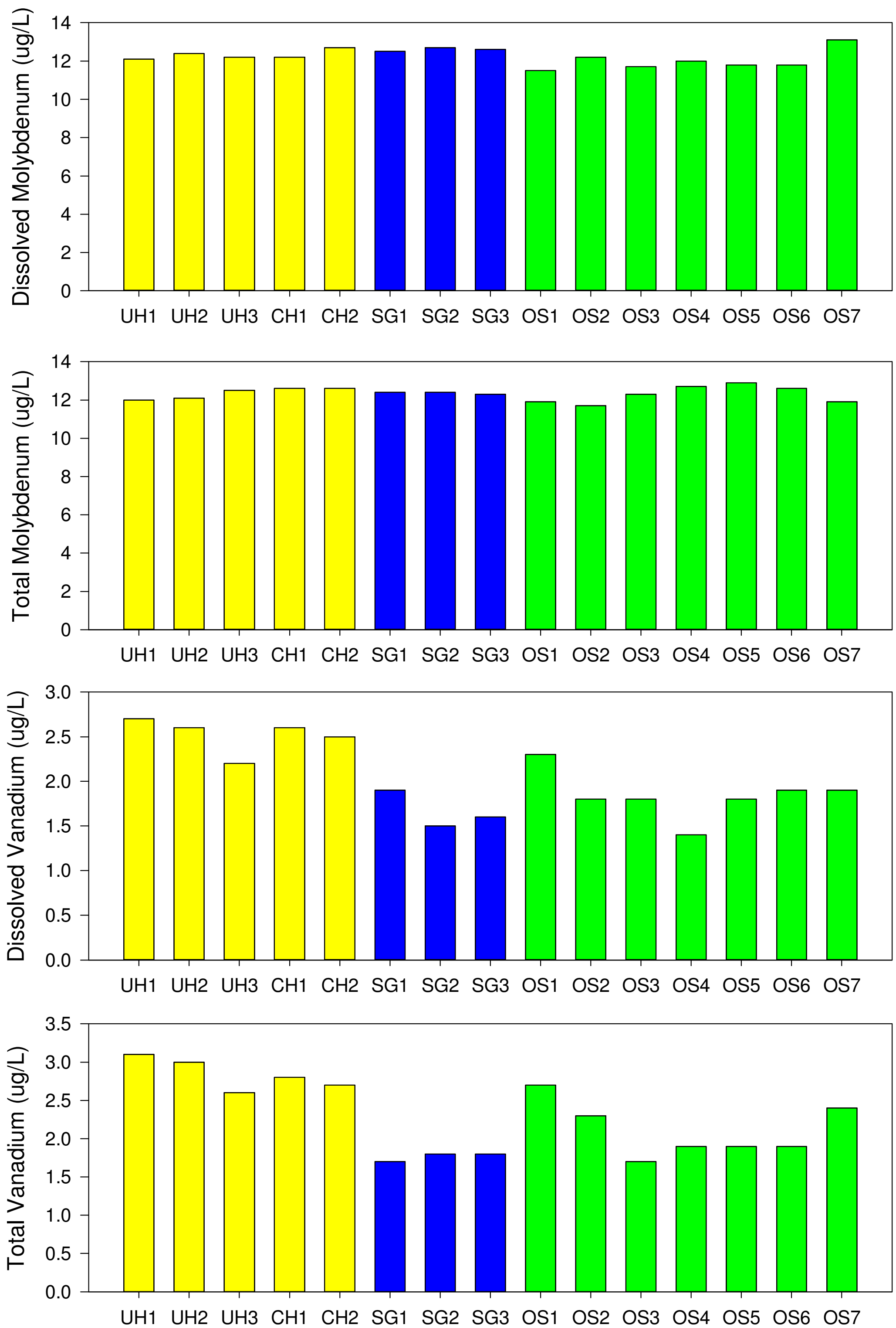


Figure 28 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during October 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. During September 2018, elevated concentrations of total iron were recorded in the upper harbor (700 µg/L at UH1). Decreased concentrations were evident in October 2018, with a maximum total iron concentration of 210 µg/L at UH1 (Table 19), coinciding with the highest concentrations of sub-surface TSS (Table 13). Similar to patterns in aluminum, dissolved concentrations of iron were r low (≤ 10 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 27).

Consistent with previous monitoring reports, molybdenum concentrations during October displayed little spatial variation across the monitoring network (Figure 28). 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 19 to 21 and Figure 28). 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 28).

4 REFERENCES

ANZECC/ARMCANZ. 2000. National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting. Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand

APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. Port City Press, Baltimore, USA.

ECAN. 2018. Environment Canterbury Regional Council.https://www.ecan.govt.nz/data/rainfall-data/sitedetails/325616

Envisor. 2018. Environmental Monitoring and Management Plan. LPC Channel Deepening Project: Stage 1.

Fox, D. R. 2018. Turbidity triggers for Lyttelton Port Company's Channel Deepening Project. Environmetrics Australia, Melbourne, Australia

Metconnect. 2018. Meteorological Service of New Zealand http://www.metconnect.co.nz/metconnect/index.php

MetOcean. 2016a. Lyttelton Port Company Channel Deepening Project – Simulations of suspended sediment plumes generated from the deposition of spoil at the offshore capital disposal site. MetOcean Solutions Ltd, New Plymouth, New Zealand

MetOcean. 2016b. Lyttelton Port Company Channel Deepening Project – Simulations of Dredge Plumes from Dredging Activities in the Channel. MetOcean Solutions Ltd, New Plymouth, New Zealand

Vision Environment. 2017. Lyttelton Port Company Channel Deepening Project Water Quality Environmental Monitoring Methodology – August 2017. . Gladstone, Australia

5 APPENDIX

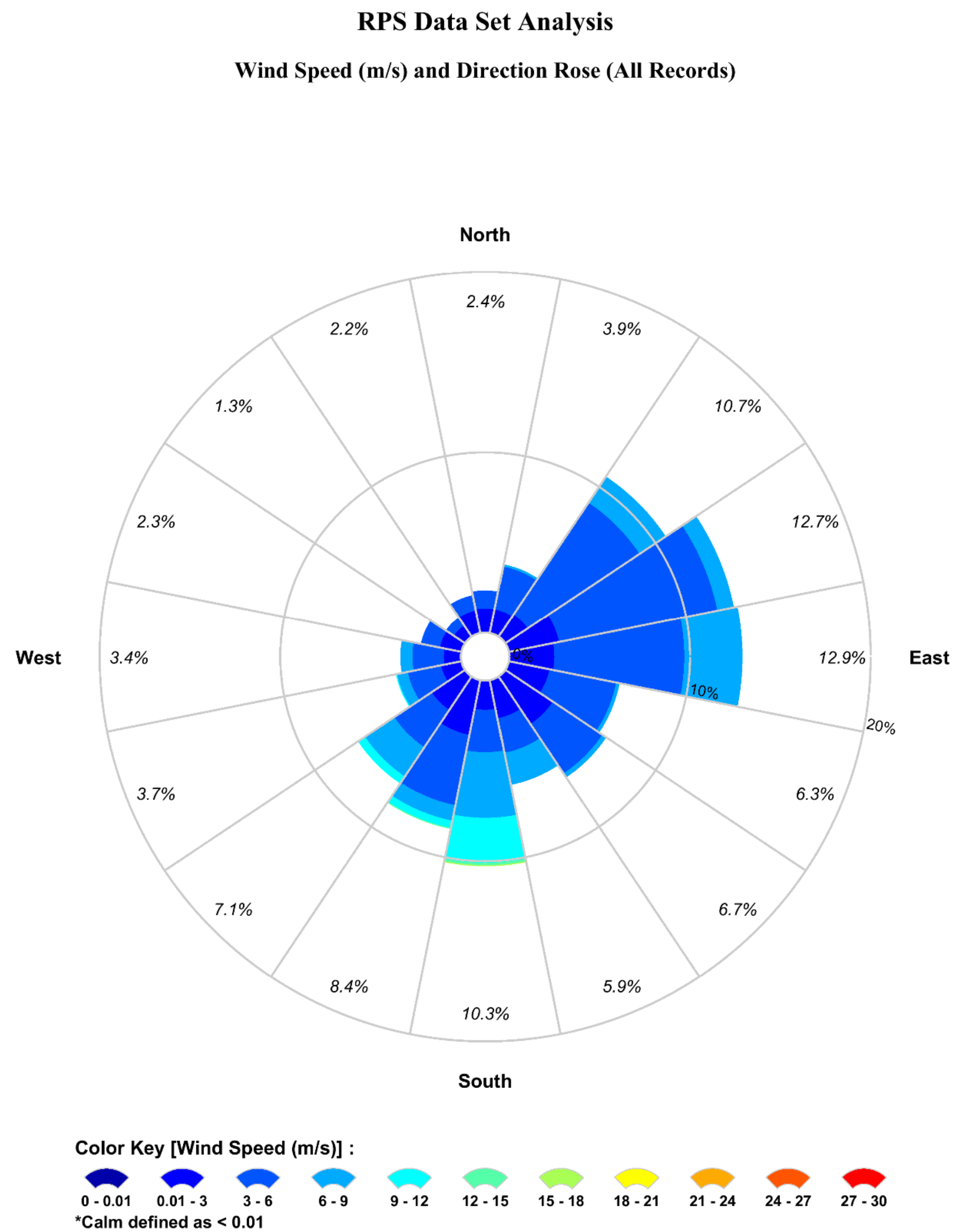


Figure 29 WatchKeeper wind speed (m/s) and direction rose (%) during October 2018.

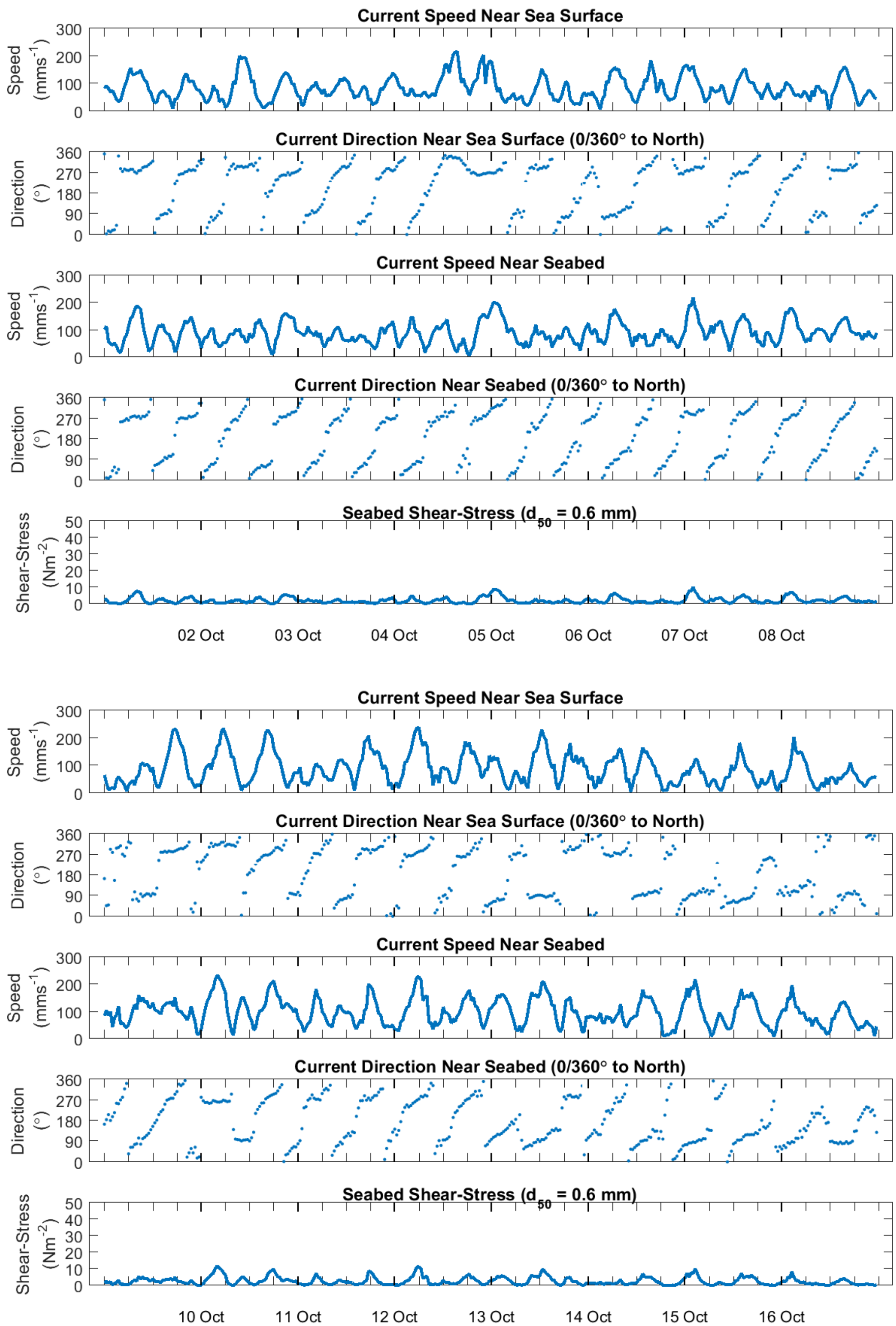


Figure 30 SG2a current speed, direction and shear bed stress 1 to 8 and 9 to 16 October 2018.

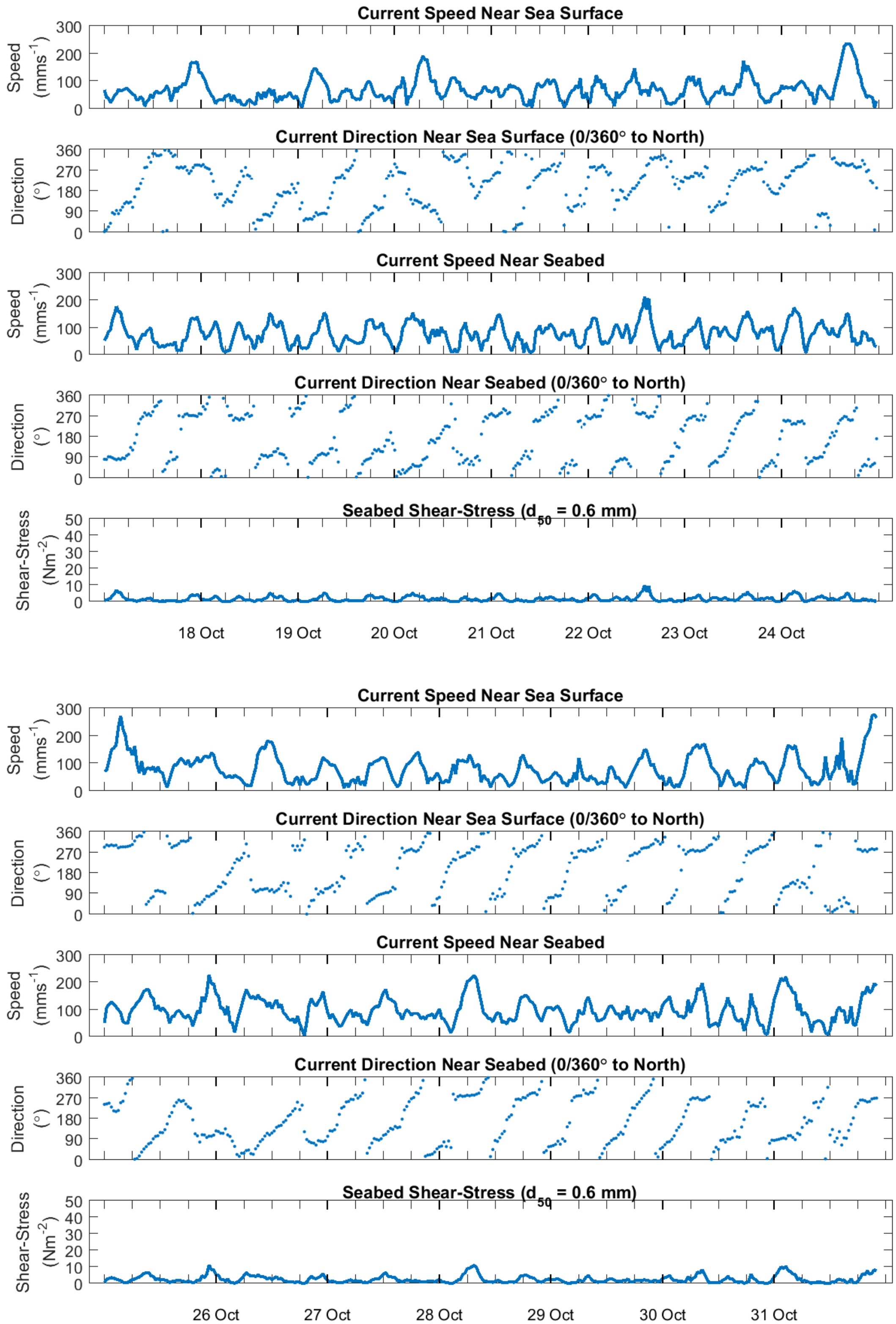


Figure 31 SG2a current speed, direction and shear bed stress 17 to 24 and 25 to 31 October 2018.

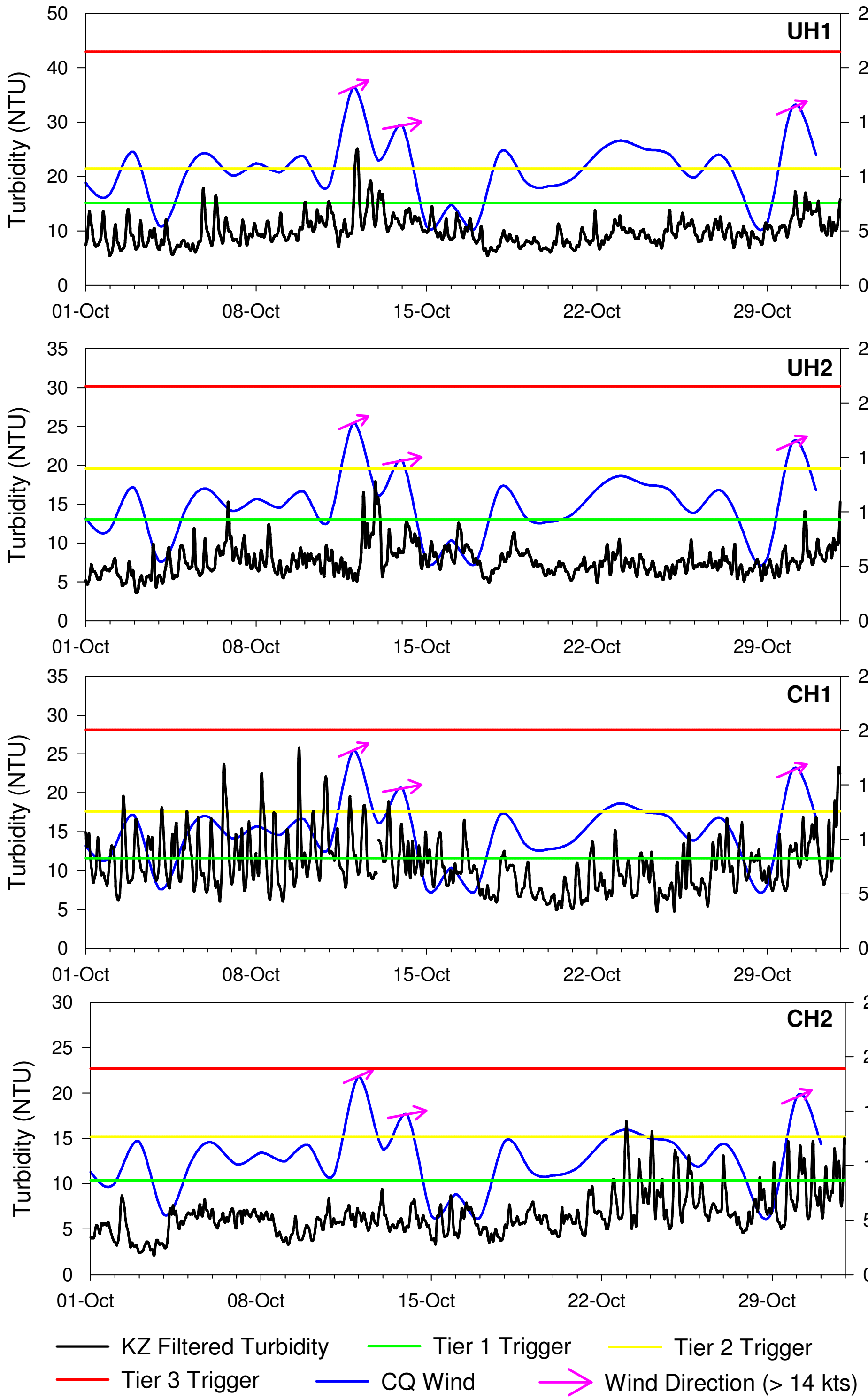


Figure 32 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

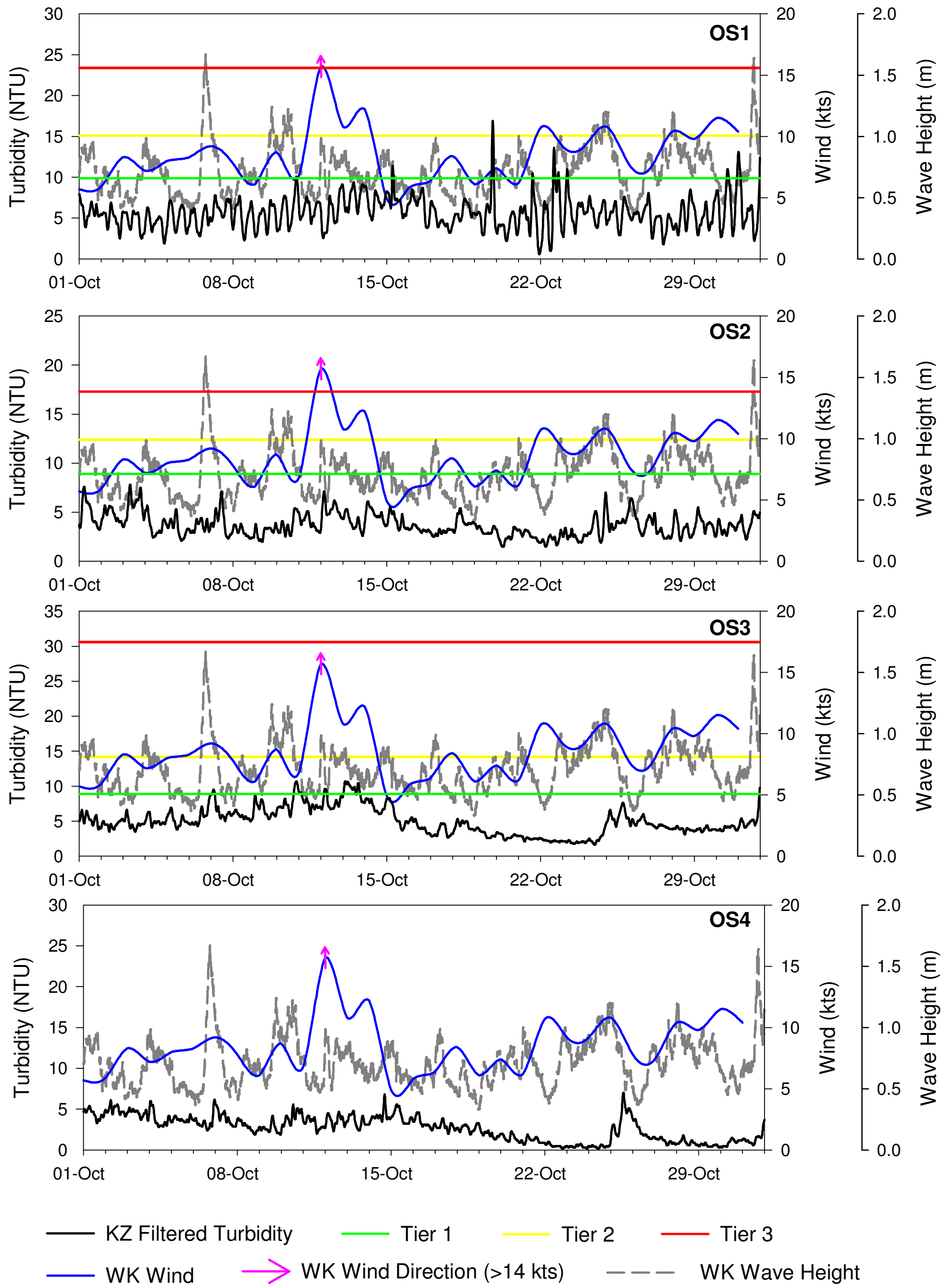


Figure 33 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during October 2018.

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.

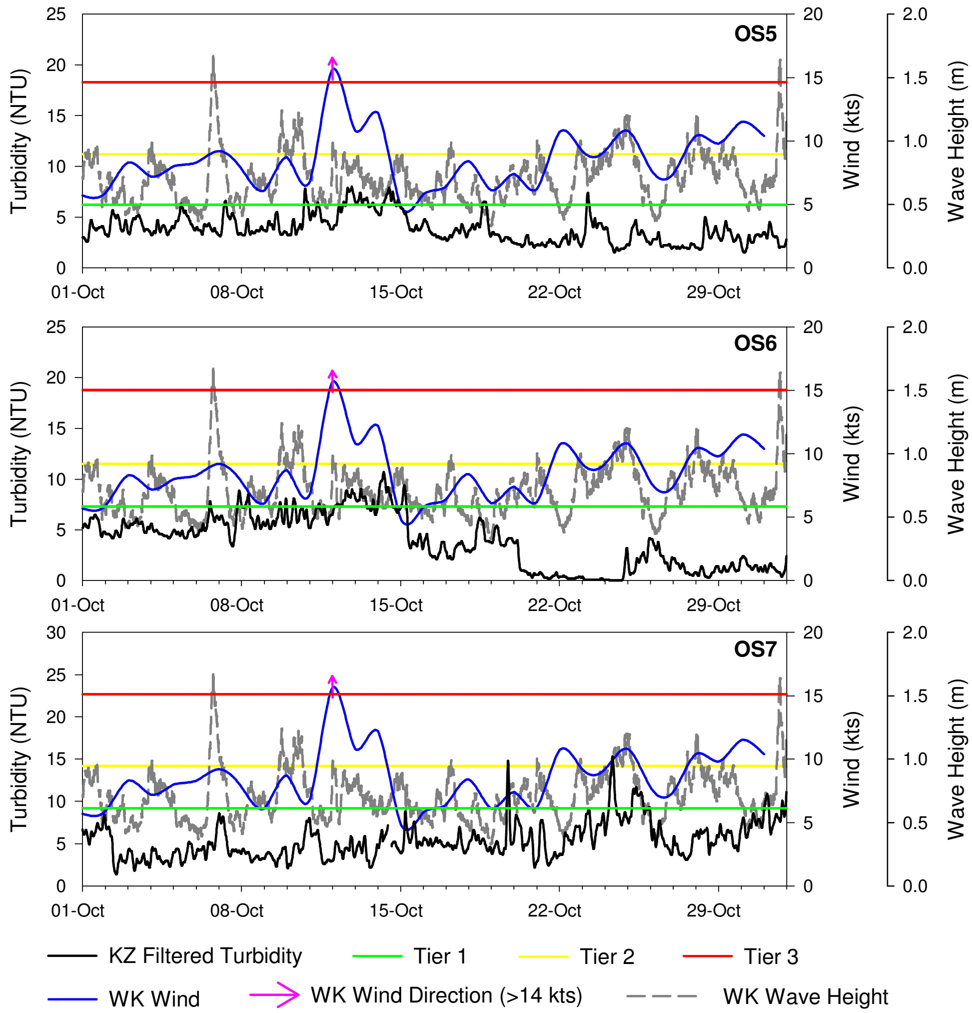


Figure 34 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during October 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

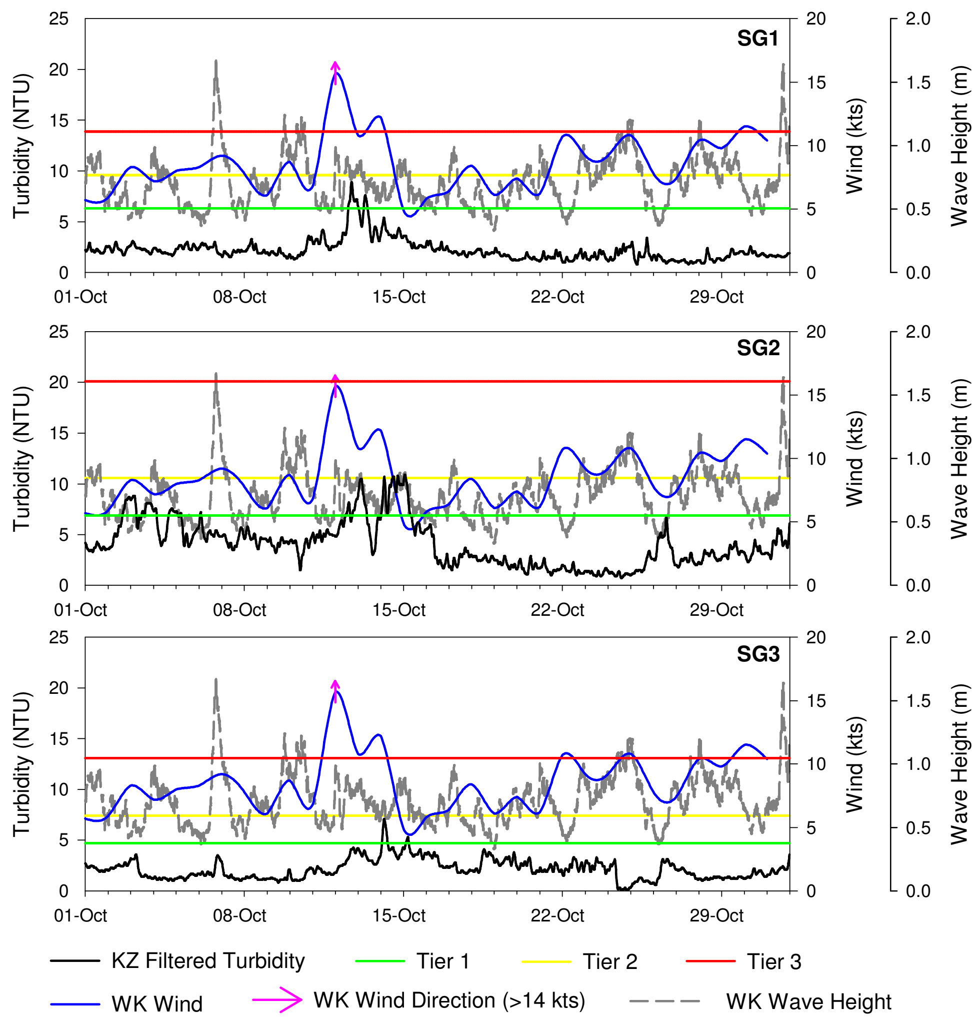


Figure 35 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during October 2018.

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.

Table 22 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during October 2018 and baseline period 1 November 2016 to 31 October 2017
Values for October are means ± se, range and percentiles (n = 2969 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface October	Surface Baseline
UH1	Mean ± se	9.9 ± 0.0	12
	Range	6 – 25	2 – 155
	99th	18	37
	95th	15	21
	80th	12	15
UH2	Mean ± se	7.7 ± 0.0	9.9
	Range	4 – 18	2 – 59
	99th	15	29
	95th	11	19
	80th	8.9	13
CH1	Mean ± se	11 ± 0	8.8
	Range	5 – 26	<1 – 50
	99th	22	27
	95th	17	17
	80th	13	12
CH2	Mean ± se	6.5 ± 0.0	7.6
	Range	2 – 17	<1 – 39
	99th	14	22
	95th	11	15
	80th	7.7	10

Table 23 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during October 2018 and baseline period 1 November 2016 to 31 October 2017.
Values for October are means ± se, range and percentiles (n = 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface October	Surface Baseline
SG1	Mean ± se	2.2 ± 0.0	4.2
	Range	<1 – 9	<1 – 31
	99th	7.1	14
	95th	4.1	9.5
	80th	2.6	6.1
SG2	Mean ± se	4.1 ± 0.0	4.6
	Range	<1 – 11	<1 – 33
	99th	11	20
	95th	8.5	10
	80th	5.6	6.9
SG3	Mean ± se	2.1 ± 0.0	3.6
	Range	<1 – 7.1	0.2 – 22
	99th	5.0	13
	95th	3.9	7.3
	80th	2.9	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during October 2018 and baseline period 1 November 2016 to 31 October 2017.
Values for October are means ± se, range and percentiles (n = 69 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface October	Surface Baseline
OS1	Mean ± se	5.6 ± 0.0	7.5
	Range	<1 – 17	<1 – 99
	99th	11	23
	95th	8.8	15
	80th	7.0	9.7
OS2	Mean ± se	3.7 ± 0.0	6.4
	Range	1.5 – 7.8	<1 – 36
	99th	7.0	17
	95th	5.8	12
	80th	4.6	8.9
OS3	Mean ± se	5.0 ± 0.0	6.5
	Range	2 – 11	<1 – 110
	99th	10	27
	95th	8.8	14
	80th	6.6	8.9
OS4	Mean ± se	2.7 ± 0.0	5.9
	Range	<1 – 7.0	<1 – 35
	99th	5.9	18
	95th	5.0	13
	80th	4.1	8.1
OS5	Mean ± se	3.8 ± 0.0	4.6
	Range	1.5 – 8.0	<1 – 35
	99th	7.6	18
	95th	6.5	11
	80th	4.8	6.1
OS6	Mean ± se	3.8 ± 0.0	4.7
	Range	<1 – 11	<1 – 37
	99th	9.2	18
	95th	8.2	11
	80th	6.2	7.1
OS7	Mean ± se	5.4 ± 0.0	6.3
	Range	1 – 15	<1 – 48
	99th	12	22
	95th	9.0	14
	80th	7.0	9.1

Table 25 Summary of Vision Environment quality control data for October 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		
		UH1 A (µg/L)	UH1 B (µg/L)	Variation (%)
Total Suspended Solids	<3	12	12	0
Dissolved Aluminium	<3	<12	<12	ND
Total Aluminium	<3.2	135	121	10
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	1.2	ND
Total Chromium	<0.53	<1.1	1.4	ND
Dissolved Cobalt	<0.2	1	0.9	10
Total Cobalt	<0.21	0.81	0.81	0
Dissolved Copper	<0.5	<1	<1	ND
Total Copper	<0.53	<1.1	1.5	ND
Dissolved Iron	<20	10	<4	ND
Total Iron	<21	210	187	11
Dissolved Lead	<0.1	<1	<1	ND
Total Lead	<0.11	<1.1	<1.1	ND
Dissolved Manganese	<0.5	29	28	3
Total Manganese	<0.53	34	35	3
Dissolved Mercury	<0.08	<0.08	<0.08	ND
Total Mercury	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum	<0.2	12.1	12.3	2
Total Molybdenum	<0.21	12	12.3	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	2.7	2.8	4
Total Vanadium	<1.1	3.1	3.3	6
Dissolved Zinc	<1	<4	<4	ND
Total Zinc	<1.1	<4.2	<4.2	ND
Total Phosphorus	<4	26	28	7
Dissolved Reactive Phosphorus	<4	4.3	4	7
Total Nitrogen	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN)	<100	<200	<200	ND
Total Ammonia	<10	11	11	0
Nitrate + Nitrite	<2	<1	<1	ND
Chlorophyll *a*	<0.2	8.1	8.3	2