Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

November 2019

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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.

Dredging operations for the CDP were undertaken from 29 August to 29 November 2018. Post-dredge monitoring was undertaken until 11 March 2019, when a smaller dredging operation began for the reclamation works at Cashin Quay.

Monitoring results collected during November 2019 are presented within this report. This monthly report includes comparisons of turbidity data collected during the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). KZ filtered data are also included within the Appendix and are compared to compliance trigger values.

Note that due to unforeseen issues the database Cloud server was dysfunctional for certain periods in November resulting in some real time data not being displayed. Although physicochemical and ADCP data had backlogged and was able to be recovered, due to its logging configurations, data from the Watchkeeper ADCP unfortunately will not be able to be recovered.

Climatic Conditions: During November lower rainfall was recorded at Cashin Quay (24.6 mm) than during October 2019 (41.2 mm), with highest daily rainfall recorded on 10 November (8.2 mm). Flows from the Waimakariri River were elevated (>100 m^3/s) during the month with multiple high flows occurring between 8 and 20 November. Peaks ranged from 339 m^3/s to 808 m^3/s. The moderate to high volume of these freshwater flows is likely to have impacted Lyttelton harbour.

Monthly average air temperature (16.1°C) was somewhat higher than that recorded in October (11.6°C) in line with seasonal warming. Inshore winds were generally from east-north-easterly and west-south-westerly direction, with mean daily wind speeds > 15 kts recorded on 11 and 30 November. The highest offshore mean daily wind speeds (> 13.3 kts) were recorded on 11, 19 and 27 November, with greatest mean daily significant wave heights recorded on 9 November (1.82 m). Thus, metocean conditions were overall fairly stable for the month of November.

Currents: Data was only available for SG1 and SG3 ADCP sites, with SG2a (WatchKeeper) current data not available for November. Maximum near-surface and near-seabed currents at SG1 and SG3 occurred on different days to each other throughout November. Dominant metocean forces to explain maximum currents were due to corresponding significant wave events (>1m) from a north-easterly direction in addition to moderate to high inshore and offshore winds from a south-westerly direction.

Near-surface predominant current movement for SG1 tended to move in a north-northeast and east-southeast direction, while near-seabed currents moved in a westerly to north-easterly direction. In contrast SG3 trended similarly to previous months with predominant near-

surface currents moving in a northwest and east-southeast direction and near-seabed currents moved in a west-northwest and east-southeast direction.

Turbidity: Consistent with previous results, turbidity was higher overall at the inshore monitoring sites of the central and upper harbour than at the offshore and spoil ground monitoring locations. Mean turbidity values for November in addition to percentile statistics were lower than those recorded during the baseline monitoring period.

Elevated turbidity was recorded at all sites on multiple days within November (10 to 25 NTU), due to moderate to high inshore and offshore winds, significant wave >1m and rainfall. Elevated turbidity at some offshore sites (OS3, OS4 and OS7) was recorded again around 14 to 15 November following a period of large wave heights.

Benthic turbidity responded to both wind speed and wave height events in November, with mean benthic turbidity being more elevated than their surface counterparts, as typically observed.

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: Mean monthly temperatures were warmer in November than October with all sites displaying a seasonal increase. Consistent with October, warmer temperatures were recorded in the upper and central harbour than the offshore sites. Benthic temperatures were consistent with those at the surface indicating a well-mixed water column.

Consistent with previous reports, surface and benthic pH during November was similar across all sites. Higher flows from the Waimakariri River and localised rainfall from 8 November appear to have reduced conductivity at the spoil ground and offshore sites from 10 November. A second reduced conductivity event occurred on 26 November at OS1, OS5 and SG1. These offshore sites may have been affected by delayed impacts from a large acute peak flow of over 800 m^3/s from the Waimakariri, which had occurred on 17 November.

Dissolved oxygen (DO) concentrations fluctuated at all sites during November, with higher concentrations at the start of November and from 28 November. These fluctuations were most likely due to increased rainfall and water temperatures stimulating microalgal populations thus increasing photosynthesis and therefore oxygen production. Diurnal fluctuations in DO were observed at most sites for the month of November as typically observed. Benthic DO trended similarly to surface DO throughout November.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 13 November 2019, and once again a well-mixed water column was indicated. Thermal gradients were observed at the nearshore and offshore sites with decreasing DO down through the column.

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 euphotic depth as typically recorded during the monitoring program. Euphotic depths at the offshore monitoring locations were relatively high; estimated to be at 16 m at SG2. No exceedances of WQGs were observed for sub-surface during the November sampling.

As commonly observed, total and dissolved reactive phosphorous concentrations were highest at the inshore sites and decreased further offshore. Exceedances of the WQG for dissolved reactive phosphorous was recorded at the inner harbour sites and OS3, which is in contrast to October where only one site exceeded the guideline.

Concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites. As recorded in recent months, ammonia concentrations exceeded WQG at majority of the sites, while nitrogen oxides reduced in concentrations, compared to October, with only one site (SG3) above the WQG. Chlorophyll *a* concentrations were moderate across all sites with no sites exceeding the WQG.

Several metals were reported as below the limit of reporting (LOR) at all sites as commonly found. No dissolved metal fraction exceeded their designated WQG. Total aluminium concentrations exceeded designated WQG at all of the monitoring sites except the spoil ground sites. In contrast the dissolved and therefore readily bioavailable fraction, was detected within the inshore and offshore sites, but all were below WQG. Total aluminium, iron and manganese displayed a strong spatial difference with elevated concentrations found in the inshore locations, whereas offshore and spoil ground sites reported the lowest concentrations. Total and dissolved chromium, vanadium and molybdenum were also detected during November, with little spatial variability and a large component contained within the dissolved phase.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight were higher in November than October associated with the increased day lengths. As such, BPAR at both OS2 and OS3 also increased with multiple peaks of benthic light occurring throughout November, when ambient PAR was reasonably high and water turbidity was low.

Sedimentation: Overall accumulation of sediments at both OS2 and UH3 was evident in November. Periods of high sediment flux were evident at OS2 during periods of strong winds, elevated wave heights and therefore high turbidity, leading to an overall accumulation of 25 mm of sediment over the month. Sediment flux at UH3 was more stable as typically observed with a period of minor erosion occurring in mid-November, followed by a period of high sediment flux and the steady accumulation of sediments throughout November. This resulted in an overall accumulation of 8.3 mm of sediments at this location.

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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 program was designed.

Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016, progressing into dredge operations monitoring from 29 August 2018 with completion of works on 29 November 2018. Monitoring continued into a post-dredge phase up until 11 March 2019 when smaller scale dredging operations for the reclamation works commenced. 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.

2 METHODOLOGY

2.1 Approach

An overview of the methodology for the baseline and operations phases 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 several offshore locations.

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.

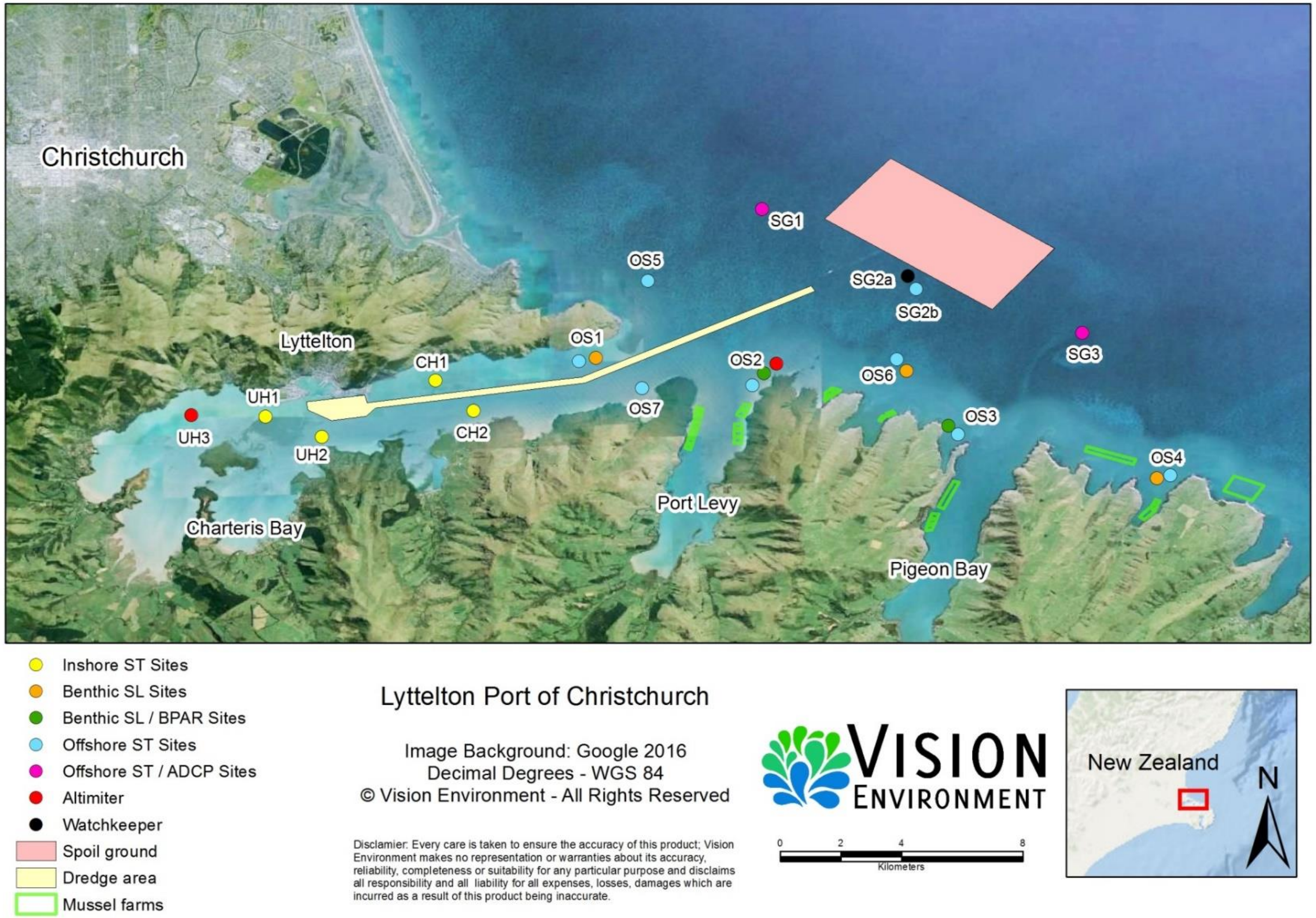


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 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 for November 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 13 November 2019. 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 Water Quality Guidelines

Water quality monitoring data from LYT were compared to the Australian and New Zealand Water Quality Guidelines (WQG) default trigger values (ANZG, 2018). In the absence of specific trigger values for New Zealand estuarine or marine ecosystems, the WQG suggest the use of 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 several metals. These guidelines refer to the dissolved fraction, as they are considered to be the potentially bioavailable fraction (ANZG, 2018). 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 24.6 mm of rainfall was recorded at Cashin Quay during November 2019, which was a decrease from the precipitation recorded in October (41.2 mm). Highest rainfall (8.2 mm) was recorded on 10 November, followed by 6.6 mm on 11 November (Metconnect, 2019) (Figure 2). Freshwater flows from the Waimakariri River, can be transported south along the coastline and enter Lyttelton Harbour several days post flow. Flows for November ranged between 81 m^3/s and 808 m^3/s with peaks recorded on the 8 November (763 m^3/s), 11 November 648 m^3/s and the 17 November (808 m^3/s), (ECAN, 2019). These higher flows recorded in addition to localised rainfall appeared to have reduced specific conductivity in early-mid November at certain sites.

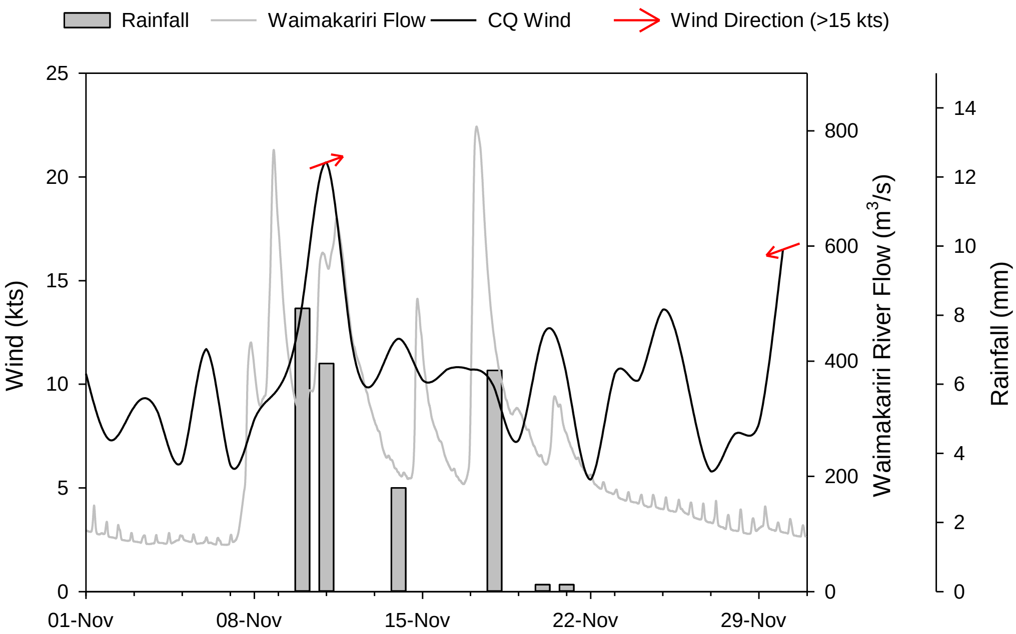


Figure 2 Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during November 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.

Inshore winds during November were generally from an east-north-easterly and north-easterly direction, followed by a number of days from the west-south-westerly direction (Metconnect, 2019). Highest mean winds speeds (20.7 kts) were recorded on 11 November from a west-south-westerly direction, with wind gusts > 40 kts also occurring from a south-westerly direction. Daily mean wind speeds > 15 kts were also recorded on the 30 November from east-north-easterly direction, while wind gusts > 40 kts were also recorded on the 18 November from a north-easterly direction.

Daily mean air temperatures at Cashin Quay ranged from 10°C to 24°C, resulting in a monthly mean temperature of 16.1°C, somewhat higher than the October mean temperature of 11.6°C (Metconnect, 2019).

Offshore significant wave height peaked at 1.82 m at 11:30 pm on 9 November, with other significant wave events > 1.5 m occurring on the 7, 8, 10, 14 and 30 November. Mean daily offshore wind speeds did not exceed > 15 kts with the highest mean daily offshore winds of > 13 kts recorded on 11, 19 and 27 November from southerly and west-north-westerly directions (Figure 3).

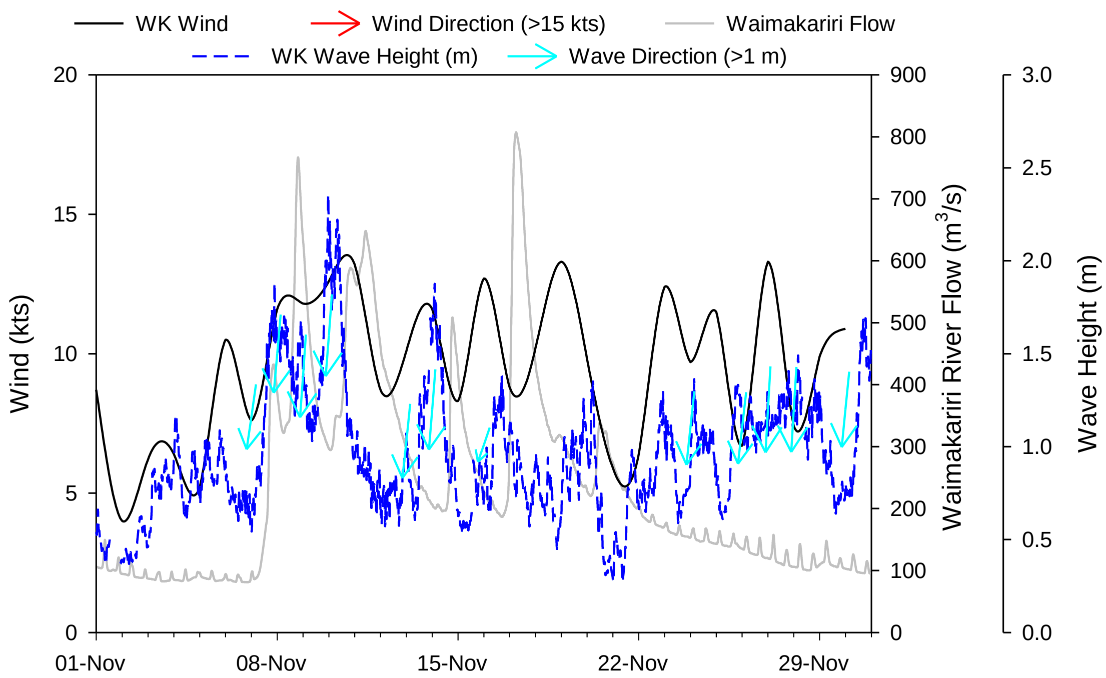


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during November 2019.

Note: Arrows indicate the direction of travel for offshore winds greater than 15 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, SG2a (Watchkeeper) and SG3, reporting the speed and direction of currents in a profile from the sea surface to seabed. Unfortunately, due to data connection issues, there was no available current data for the Watchkeeper ADCP at SG2a. Summary ADCP statistics of available data are presented within Table 2, and Figures 4 to 5. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 32 to 35 in the Appendix. Note that the ADCP data are presented in this report using the UTC time format.

Table 2 Parameter statistics for spoil ground ADCPs during November 2019.
Note no data for SG2a due to data availability.

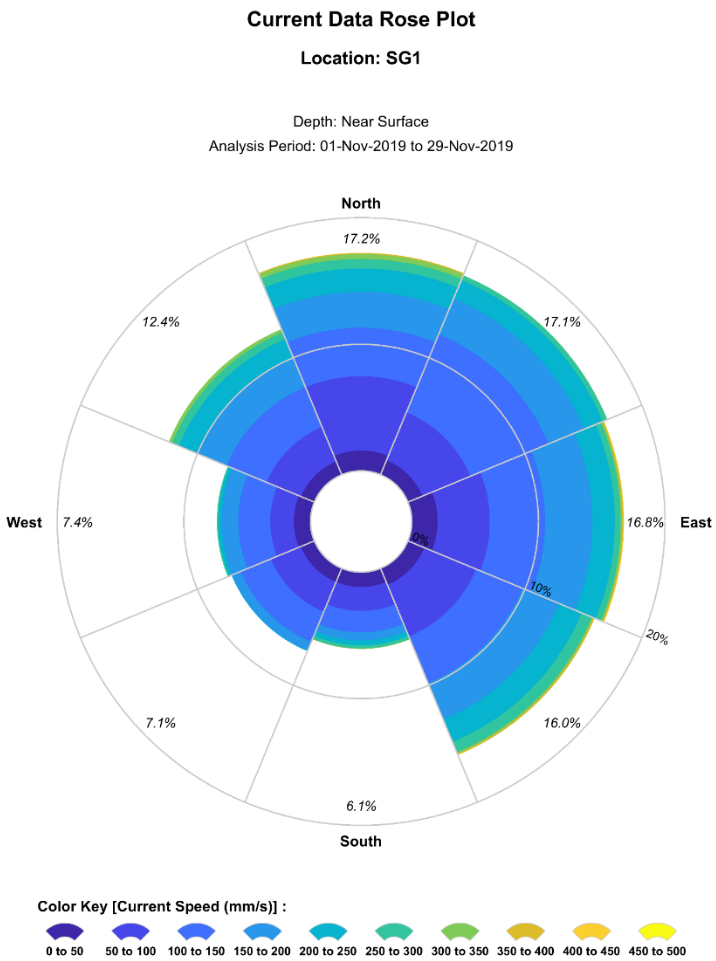
Parameter	Depth	Site		
		SG1	SG2a	SG3
Minimum current speed (mm/s)	*Near-surface*	2	-	3
	Near-seabed	1	-	1
Maximum current speed (mm/s)	*Near-surface*	405	-	422
	Near-seabed	364	-	409
Mean current speed (mm/s)	*Near-surface*	126	-	130
	Near-seabed	98	-	119
Standard deviation of current speed (mm/s)	*Near-surface*	66	-	74
	Near-seabed	53	-	63
Current speed, 95^{th} percentile (mm/s)	*Near-surface*	248	-	264
	Near-seabed	193	-	233

Maximum near-surface current speeds at SG3 (422 mm/s) and SG1 (405 mm/s) were recorded on the respective days of 10 and 27 November during periods of moderate offshore winds (daily mean of >12.6 kts with gusts >20 kts) from a south-westerly to west-north-westerly direction in addition to mean maximum significant wave heights >1 m.

Maximum near-seabed current speeds at SG1 (364 mm/s) and SG3 (409 mm/s) were recorded on different days to near-surface current speeds with maximums recorded on 16 and 13 November, respectively. Daily offshore wind speeds of >10 kts from a southerly or westerly direction, daily inshore wind speeds >10kts from a south-westerly direction and maximum significant wave heights >1 m could explain the increased near-seabed currents on these dates.

The time-series plots (Figures 32 to 35 in Appendix) illustrate time-varying current direction, whilst the current rose diagrams (Figures 4 to 5) depict the distribution of current direction and velocity in the near-surface and near-seabed layers. Note no SG2a (WatchKeeper) current roses have been able to be produced. When interpreting the current data, 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.

In contrast to previous months, currents at SG1 near-surface during November tended to move in a north-northeast (34.3%) and east-southeast (32.1%) direction, while the near sea-bed currents moved in even distribution from westerly to north-easterly (total of 56.5%). SG3 was similar to previous months with near-surface current moving in a northwest (19.5%) and east-southeast (42.8%) direction, and near-seabed currents moving in a west-northwest (35.8%) and east-southeast (35.4%) direction.



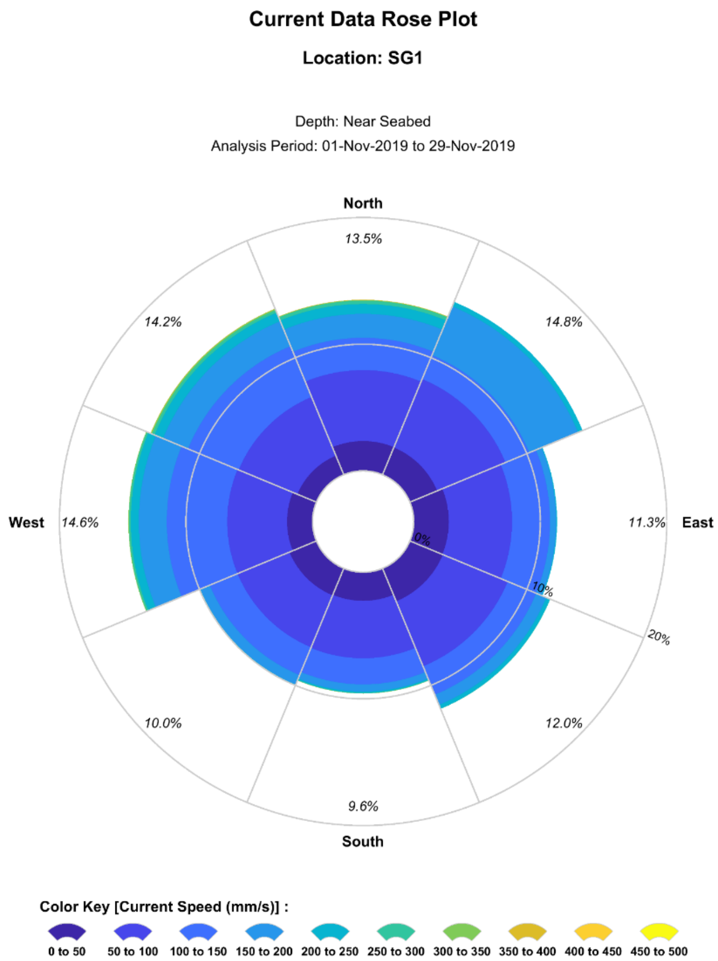


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during November 2019.
Speed intervals of 50 mm/s are used.

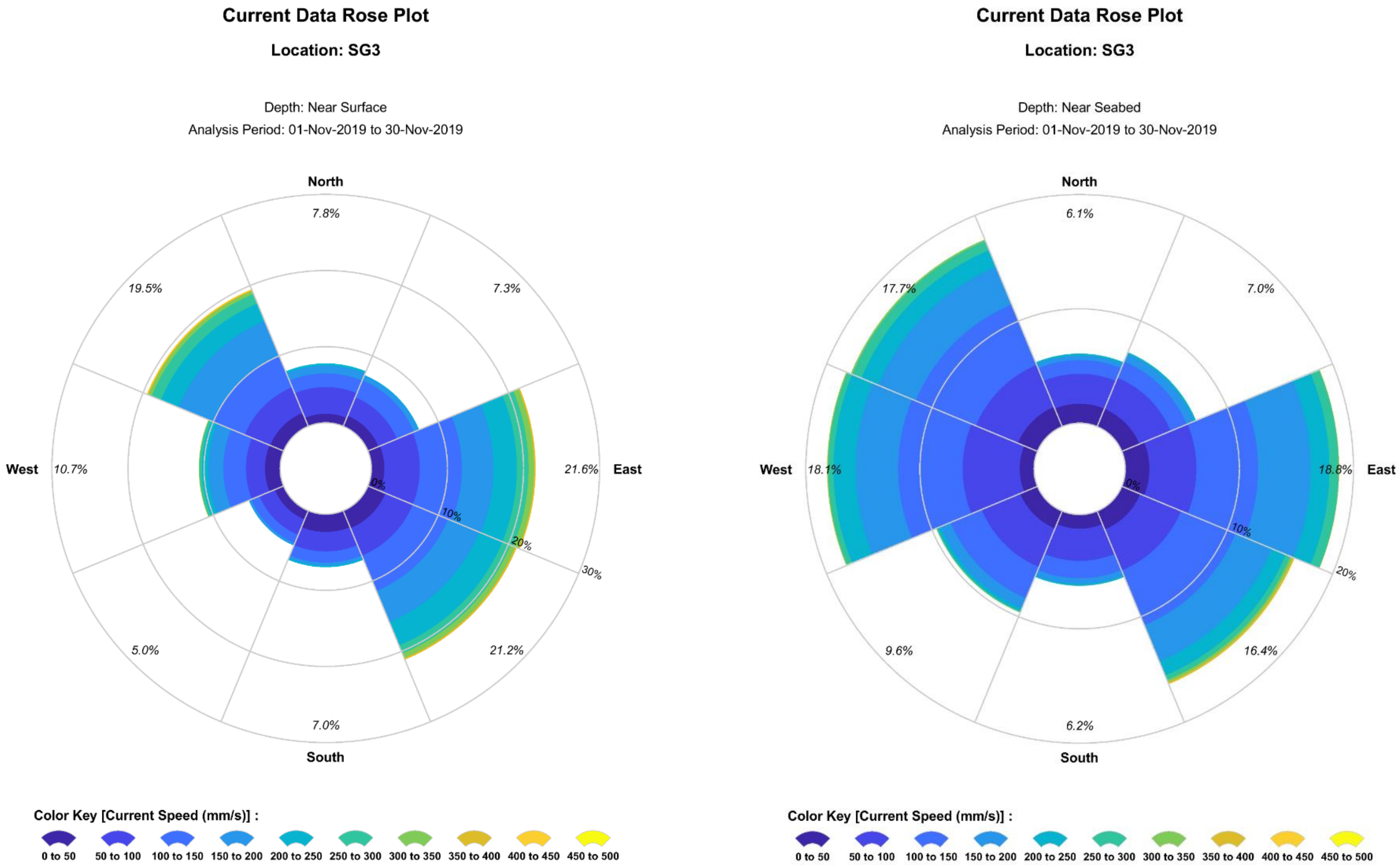


Figure 5 Near-surface and near-seabed current speed and direction at SG3 during November 2019.
Speed intervals of 50 mm/s are used.

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties 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 2019. 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 7 to 23. 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 a 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 2019 dredge monitoring data. Summary statistics for KZ filtered turbidity data, used for real time compliance monitoring during dredge operations, 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 39 to 42 in the Appendix.

November Turbidity:

Consistent with previous monitoring months, mean surface turbidity values were typically highest (monthly means of 3.9 to 6.5 NTU) at the inshore monitoring sites (Table 3 and Figure 6). Further offshore, the spoil ground sites (Table 4) exhibited lower surface turbidity values (0.8 to 2.1 NTU), which are likely due to the deeper water column limiting expressions of seafloor sediment resuspension at the sub-surface. As typically observed, nearshore sites experienced intermediate mean turbidity values (1.6 to 4.0 NTU) during November (Table 5).

During November turbidity across the inner harbour was relatively low (< 10 NTU) with exception of short lived turbidity peaks of >10 NTU on 11, 25 and 27 November, all recorded inner harbour sites in response to increased inshore winds (20 kts) and a localised period of higher rainfall (Figure 6).

Surface turbidity at the nearshore sites (OS1 to 4 and OS7) peaked on and during 10 to 11, 14 to 18, 27 to 28 November, immediately following periods of high inshore windspeeds, rainfall and increased wave heights in addition to offshore winds.

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks were also evident between 10 to 11 and 28 to 29 November, although less pronounced than at the inshore sites (Figures 10 and 11) This is likely due to greater depths at these sites, with less movement of benthic sediments during periods of higher wind speeds and wave heights. Increased flows from the Waimakariri may have also introduced turbidity laden freshwater to these sites during these periods.

Benthic:

Data return was gained for all of benthic sites during November, with missing data at OS1 and OS6 from 1 to 12 November due to previous sonde maintenance. Benthic turbidity data corresponded with surface measurements, with increased turbidity evident during early and late November, during periods of high winds and waves (Figure 6).

Table 3 Mean turbidity and statistics at inshore water quality logger sites during November 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for November are means ± se, range and percentiles (n = 2772 to 2809) Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface November	Surface Baseline
UH1	Mean ± se	6.5 ± 0.0	12
	Range	3.3 – 25	-
	99th	13.3	39
	95th	9.5	22
	80th	7.7	15
UH2	Mean ± se	6.5 ± 0.0	10
	Range	1.2 – 24.9	-
	99th	15.4	32
	95th	10.7	20
	80th	7.8	13
CH1	Mean ± se	4.8 ± 0.0	9
	Range	1.9 – 14.8	-
	99th	10.8	29
	95th	7.9	18
	80th	5.5	12
CH2	Mean ± se	3.9 ± 0.0	8
	Range	1.1 – 10.8	-
	99th	8.3	24
	95th	6.8	16
	80th	4.8	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during November 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for November are means ± se, range and percentiles (n = 2782 to 2837). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface November	Surface Baseline
SG1	Mean ± se	1.3 ± 0.0	4.2
	Range	<1 – 6	-
	99th	4.1	14
	95th	1.9	10
	80th	1.9	6.2
SG2	Mean ± se	2.1 ± 0.0	4.6
	Range	1.0 – 5.8	-
	99th	4.3	20
	95th	3.4	11
	80th	2.5	7.0
SG3	Mean ± se	0.8 ± 0.0	3.6
	Range	<1 – 5.5	-
	99th	2.4	13
	95th	1.8	7.7
	80th	1.2	4.8

Table 5 Mean turbidity and statistics at offshore water quality logger sites during November 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for November are means ± se, range and percentiles (n = 1779 to 2841). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface November	Surface Baseline	Benthic November
OS1	Mean ± se	2.6 ± 0.0	7.5	30.6 ± 0.6
	Range	<1 – 12.8	-	<1 – 152.2
	99th	8.6	24	114.2
	95th	5.0	16	76
	80th	3.3	10	46.1
OS2	Mean ± se	2.8 ± 0.0	6.4	37.3 ± 0.5
	Range	<1 – 15.9	-	4.9 – 189
	99th	9.9	18	133.5
	95th	7.7	13	86.9
	80th	3.8	9.0	54.3
OS3	Mean ± se	2.8 ± 0.0	6.6	26.1 ± 0.4
	Range	<1 – 17.6	-	<1 – 209.7
	99th	10.5	27	93.5
	95th	6.8	15	65.1
	80th	4.3	8.9	38.7
OS4	Mean ± se	4.0 ± 0.0	5.9	21.8 ± 0.4
	Range	<1 – 24.6	-	1.1 – 171.2
	99th	10.1	20	93.2
	95th	7.4	13	57
	80th	5.3	8.3	32.3
OS5	Mean ± se	1.6 ± 0.0	4.6	–
	Range	<1 – 9.9	-	–
	99th	7.0	19	–
	95th	4.2	11	–
	80th	2.5	6.4	–
OS6	Mean ± se	3.0 ± 0.0	4.7	25.8 ± 0.3
	Range	<1 – 8.7	-	3 – 117.6
	99th	6.6	19	77
	95th	5.3	12	56
	80th	4.1	7.2	36.3
OS7	Mean ± se	3.6 ± 0.0	6.4	–
	Range	<1 – 15.2	-	–
	99th	10.1	23	–
	95th	7.9	14	–
	80th	4.8	9.2	–

Comparison to Baseline:
Mean surface turbidity values during November were lower than the values calculated from the baseline monitoring period (Tables 3 to 5, Figures 6 to 11).

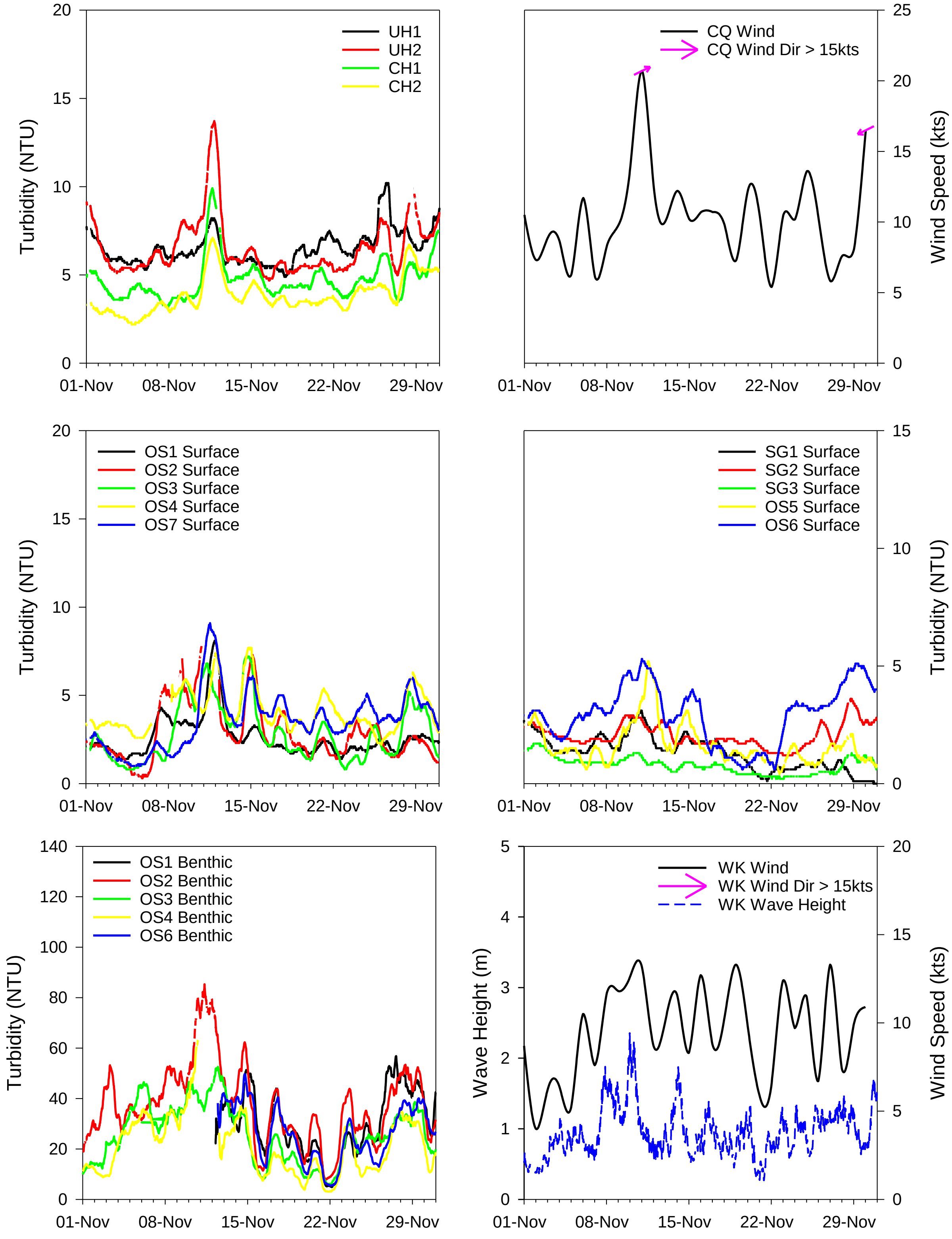


Figure 6 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations during November 2019.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots.

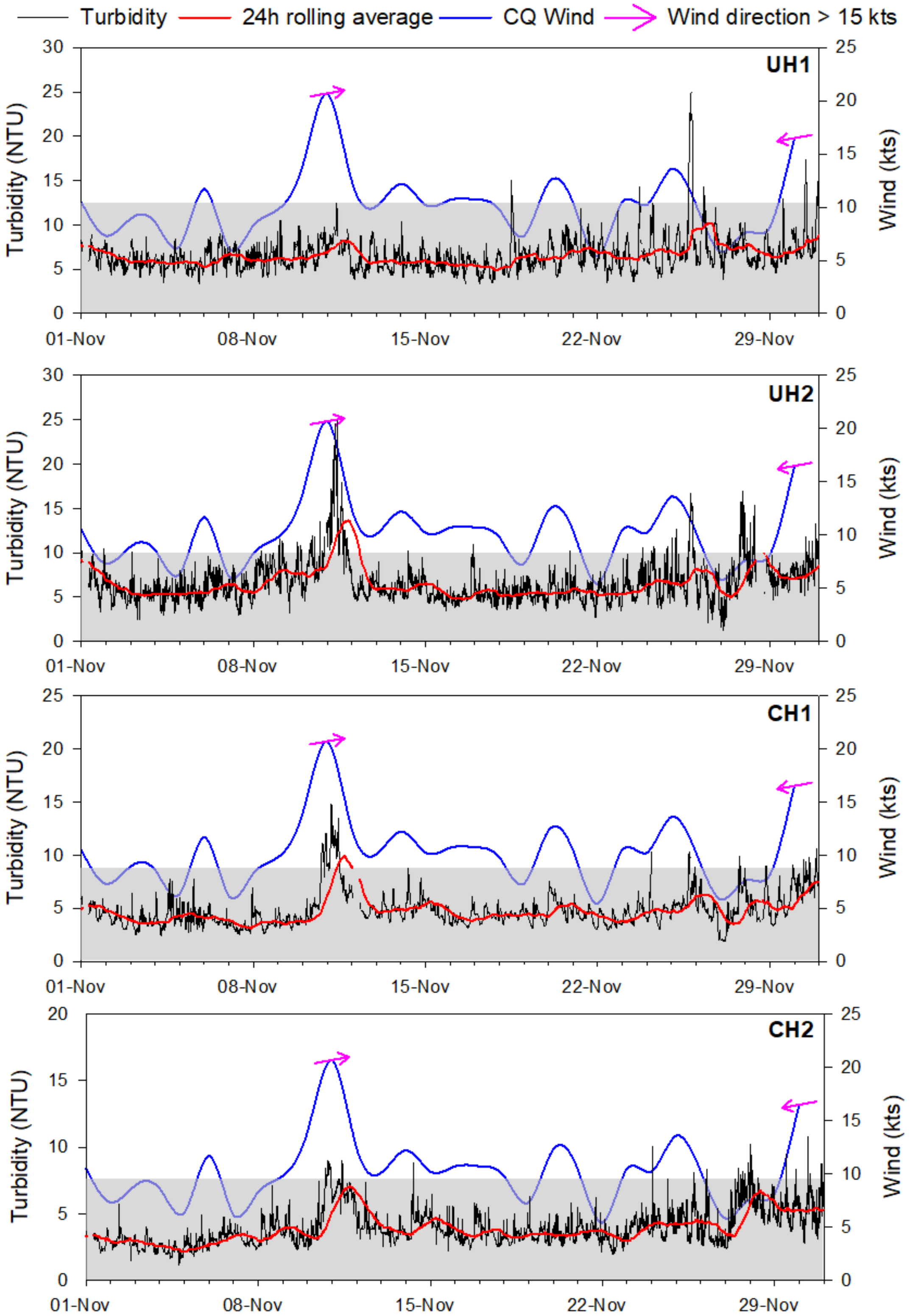


Figure 7 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during November 2019.
Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

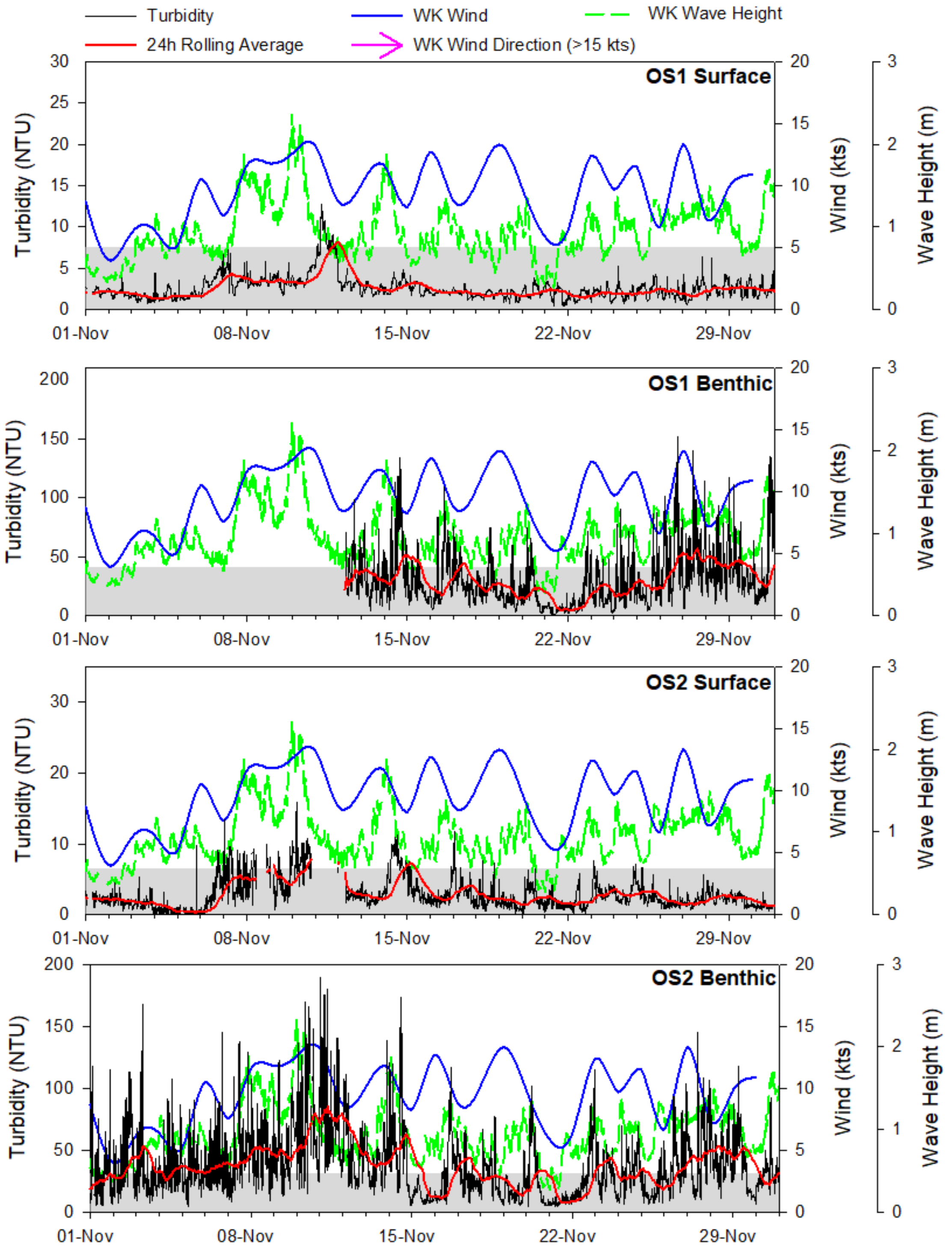


Figure 8 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity

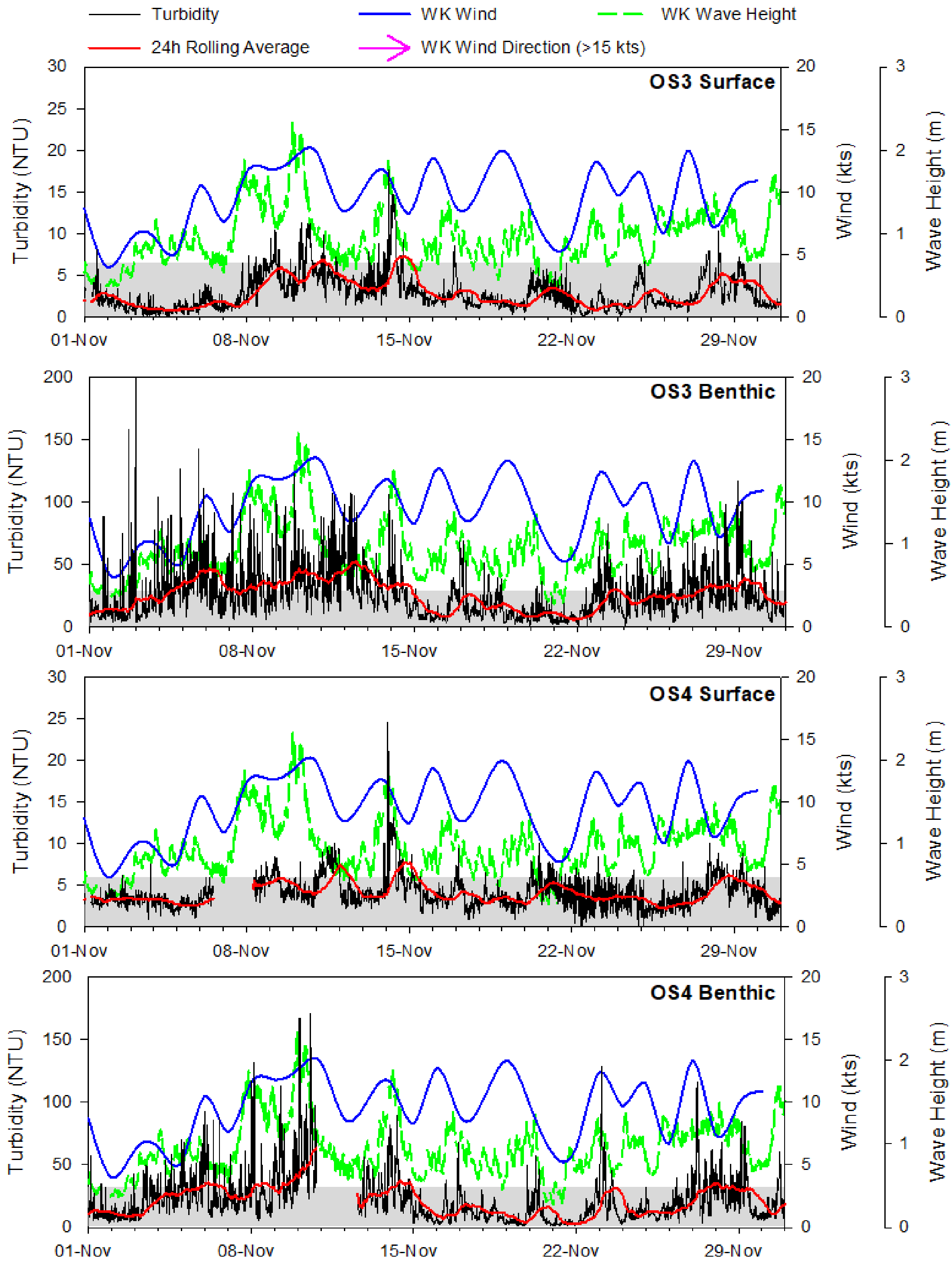


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

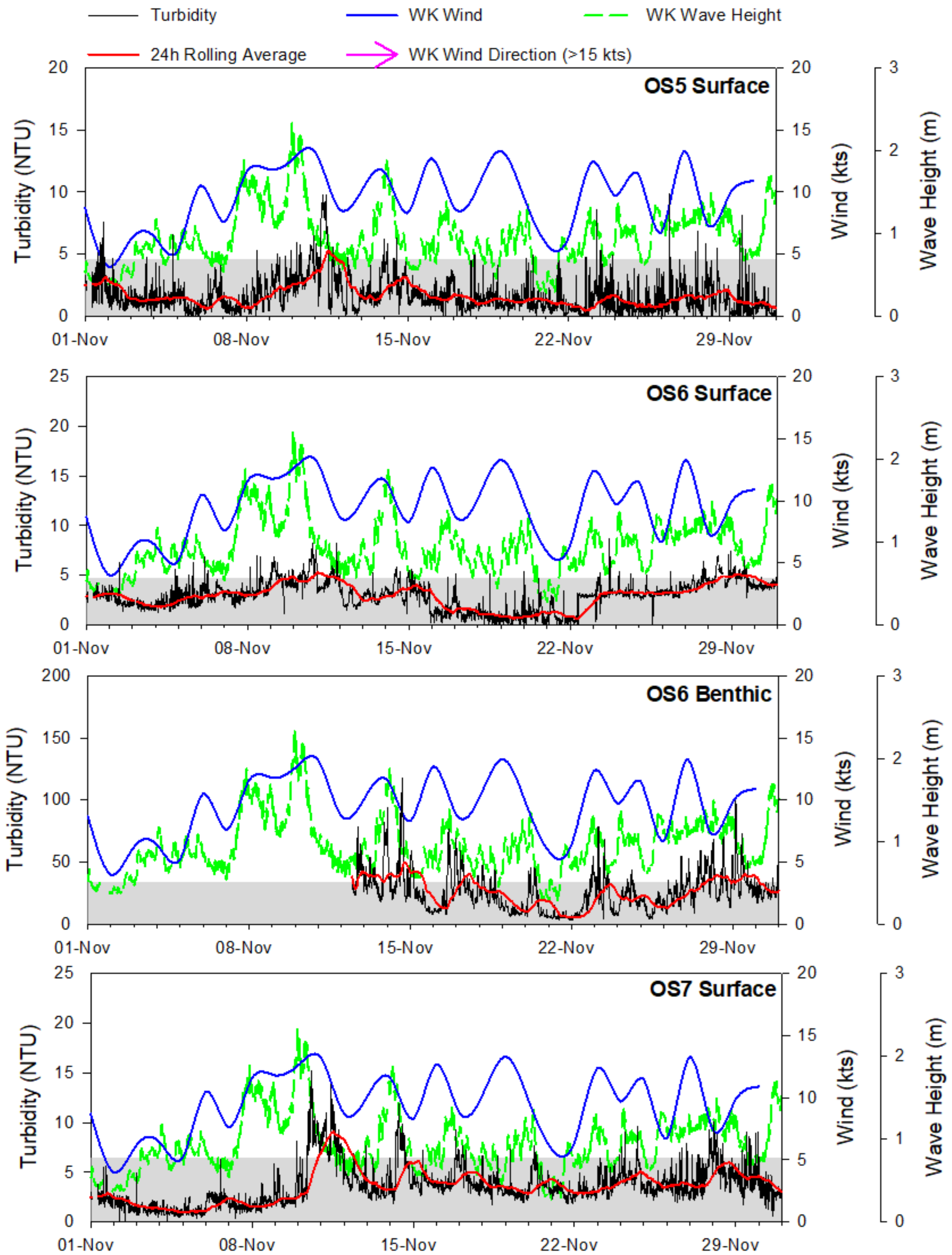


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

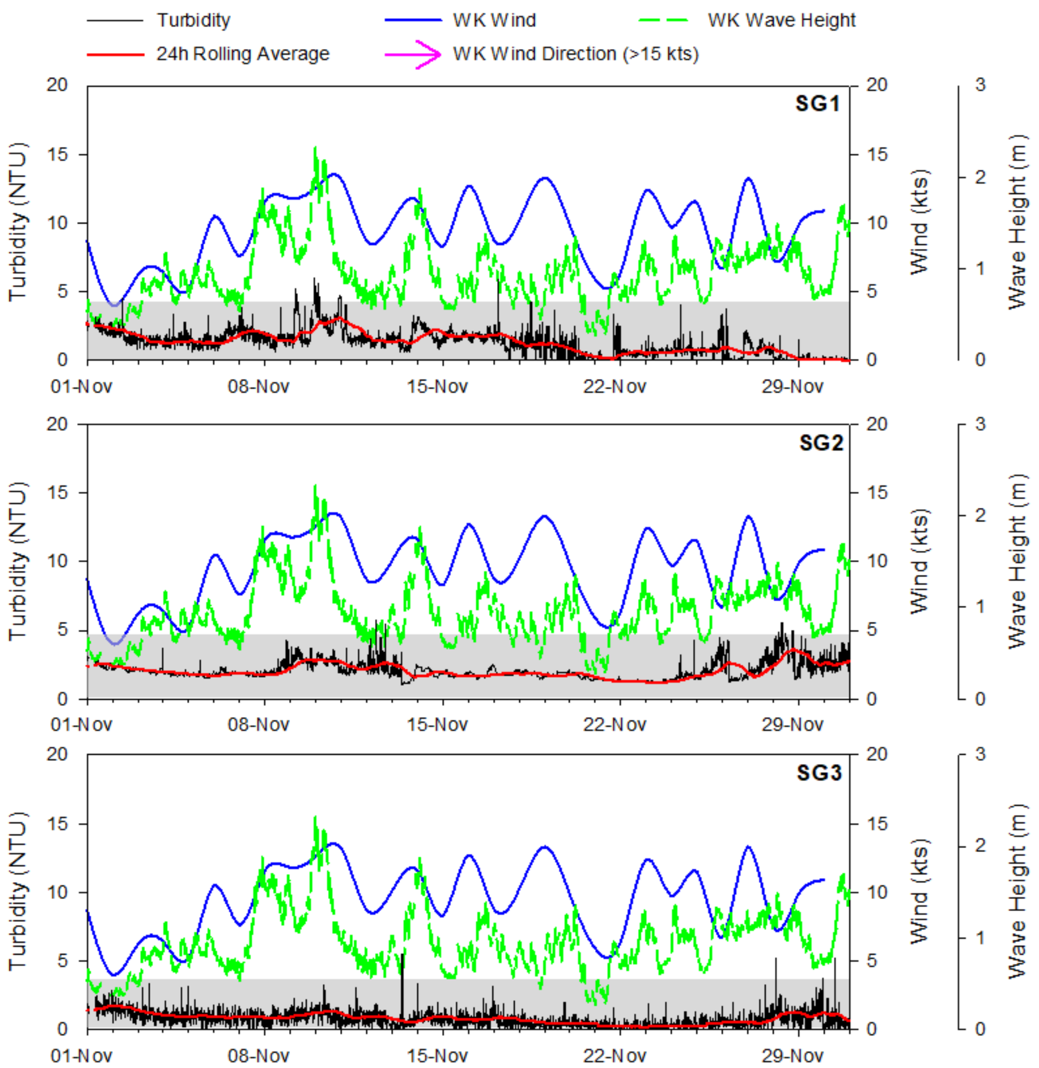


Figure 11 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during November 2019. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

3.2.2 Dredge Compliance Trigger Values

Management of dredge operations was guided using three tier levels of turbidity trigger values based on the higher order percentiles of baseline data (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 for 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 Site turbidity intensity values 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, Figures 12 to 14).

Table 7 Tier 3 intensity value exceedances and maximum hour counts during November 2019.

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

3.2.2.2 P99 Exceedance Counts Consented Removal

No validated P99 exceedance counts were removed during November 2019 (Table 8).

Table 8 Hour counts removed from monitoring statistics during November 2019.

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

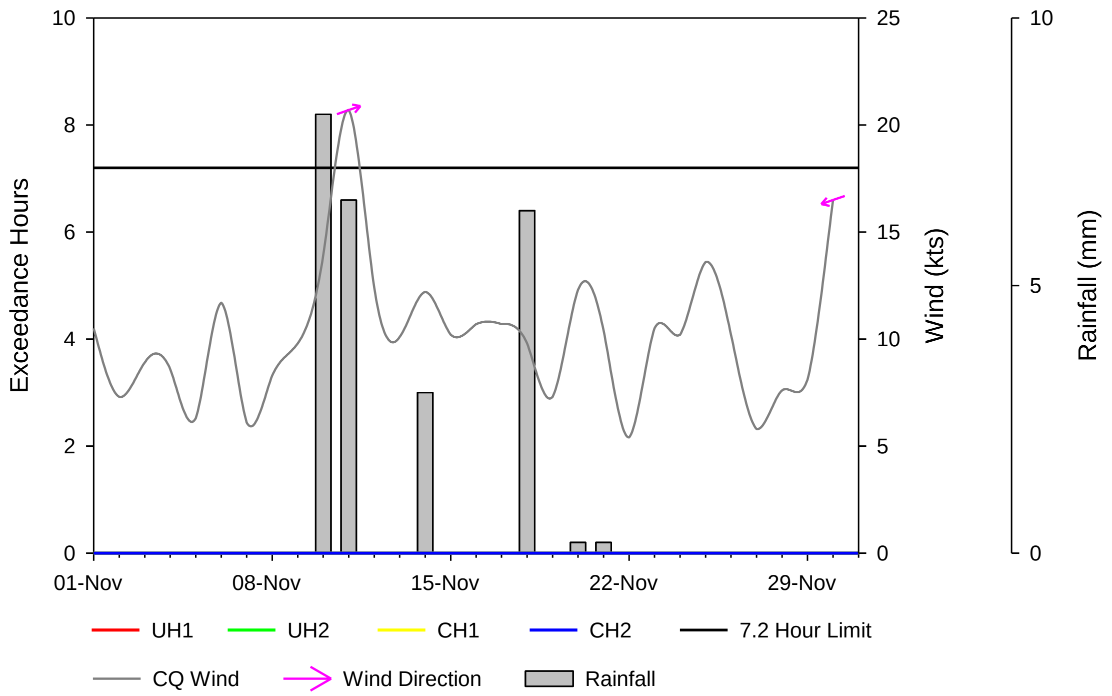


Figure 12 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during November 2019.

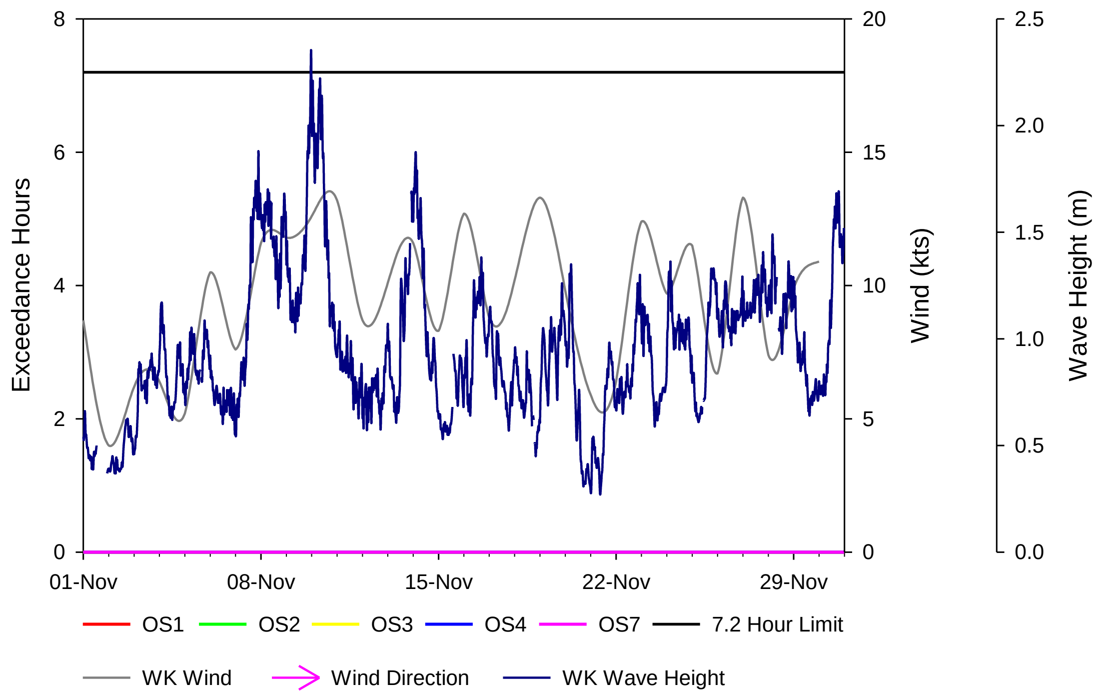


Figure 13 Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during November 2019.

Note there is no trigger value for the reference site OS4.

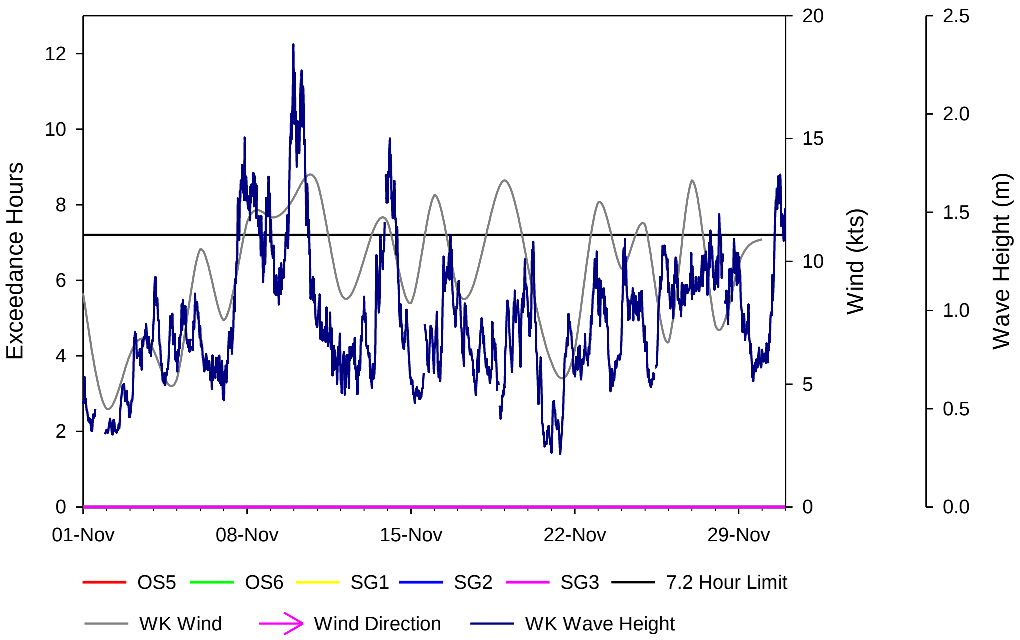


Figure 14 Tier 3 allowable hour counts at OS5, OS6, SG1, SG2b and SG3 after exceedance of the intensity values during November 2019.

3.2.3 Temperature

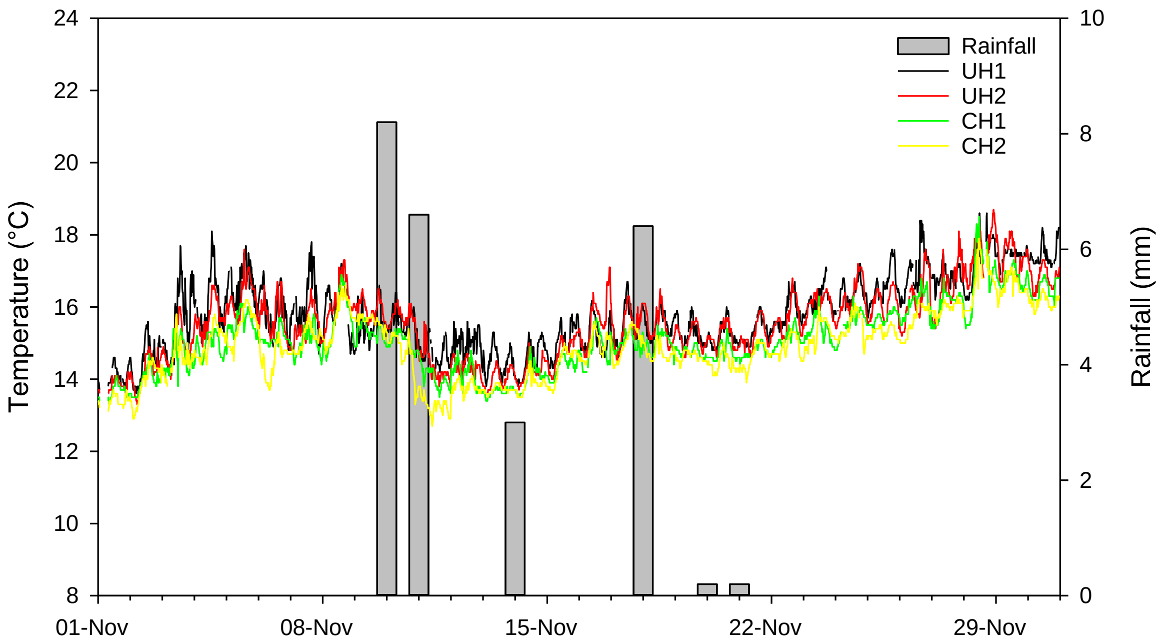
Mean monthly sea surface temperatures during November (14.1 to 15.8 °C) were warmer than those experienced during October (11.1 to 12.8°C) indicating the continuation of seasonal warming noted in previous months (Table 9). The temperature trend for November was an overall increase at all sites, with lower temperatures on the 11 and 20 November following periods of rainfall, high river flow and lower air temperatures (Figures 15 and 16).

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during November 2019.
Values are means ± se (n = 1797 to 2880).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	15.8 ± 0.0	–
UH2	15.6 ± 0.0	–
CH1	15.1 ± 0.0	–
CH2	14.9 ± 0.0	–
SG1	14.3 ± 0.0	–
SG2	14.3 ± 0.0	–
SG3	14.2 ± 0.0	–
OS1	14.7 ± 0.0	13.9 ± 0.0
OS2	14.5 ± 0.0	13.0 ± 0.0
OS3	14.3 ± 0.0	13.1 ± 0.0
OS4	14.1 ± 0.0	13.0 ± 0.0
OS5	14.4 ± 0.0	–
OS6	14.3 ± 0.0	12.8 ± 0.0
OS7	14.6 ± 0.0	–

Similar to October, slightly warmer temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites during November. Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed, particularly at the inner harbour and spoil ground sites.

Benthic temperatures were slightly lower than the overlying surface waters and displayed the same surface trends indicating a well-mixed water column.



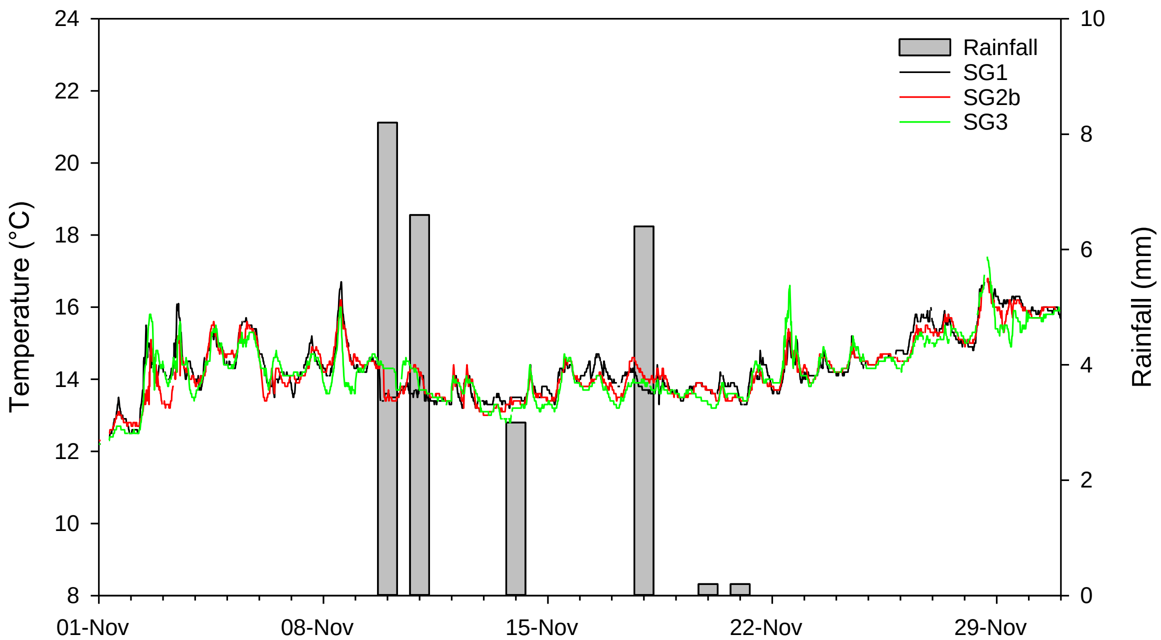


Figure 15 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during November 2019.

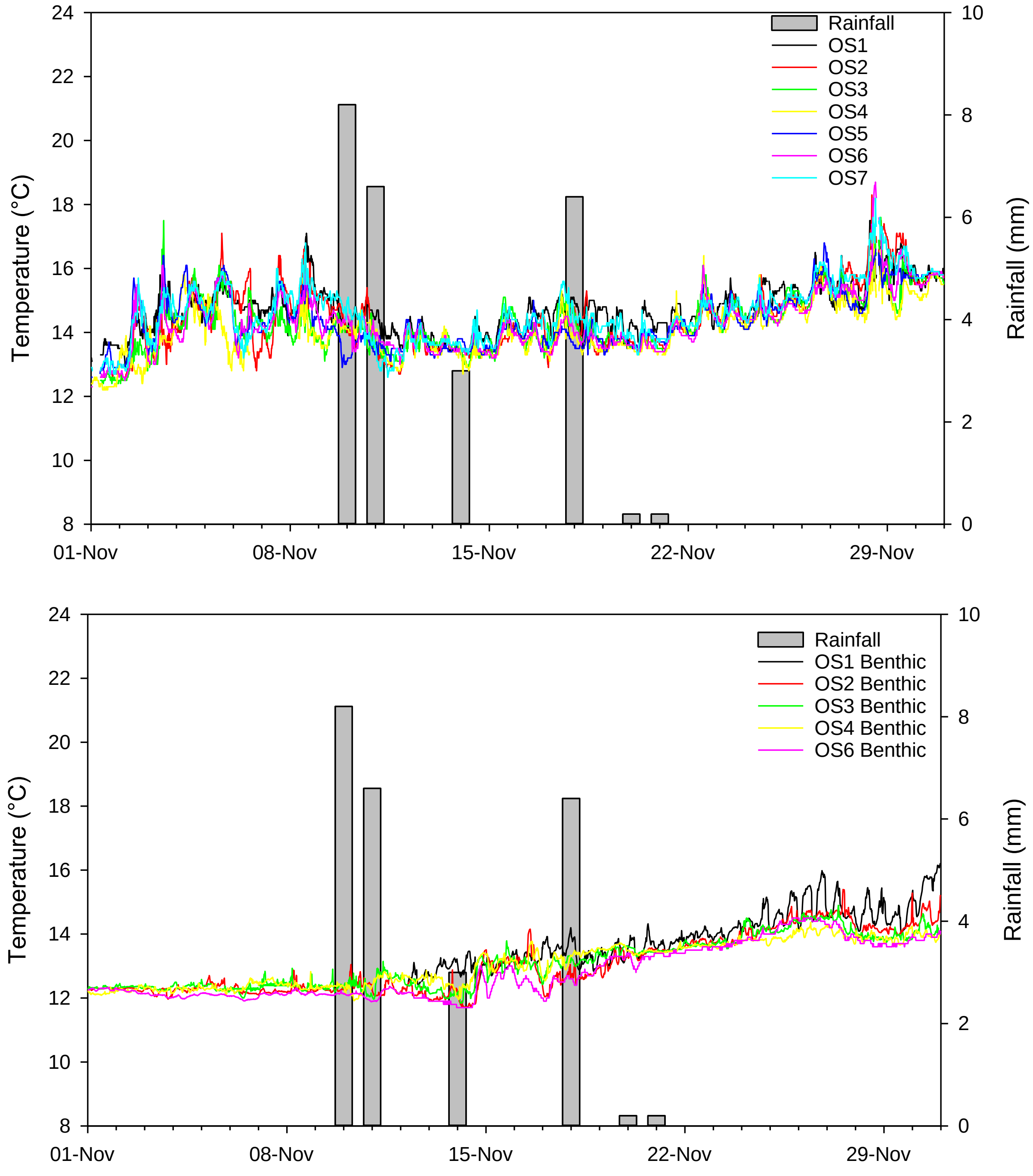


Figure 16 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during November 2019.

3.2.4 pH

The pH remained reasonably consistent across surface and benthic sites, with monthly means ranging between 8.0 and 8.2 (Table 10, Figures 17 and 18).

Table 10 Mean pH at inshore, spoil ground and offshore water quality sites during November 2019. *Values are means ± se (n = 1797 to 2880).*

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

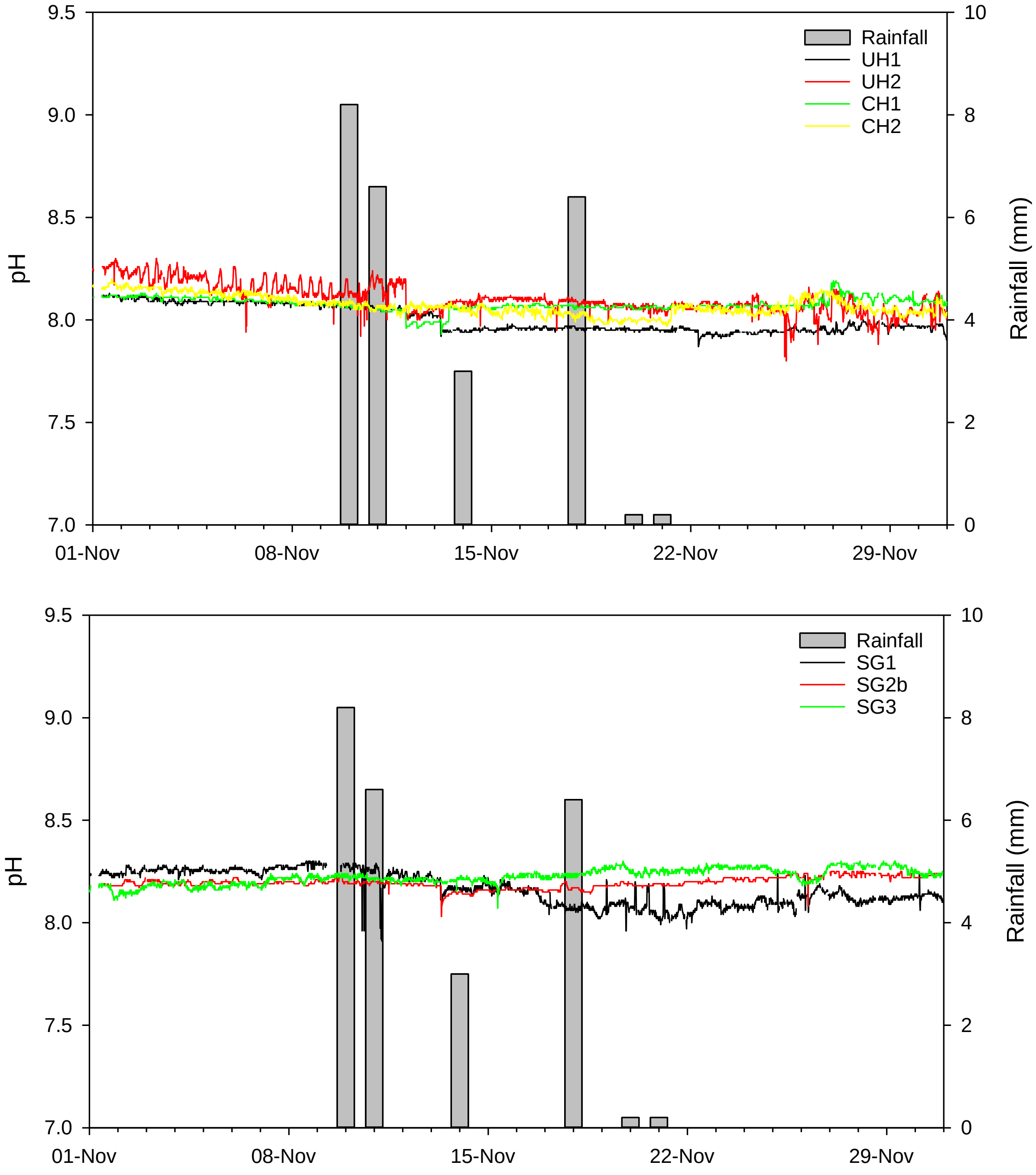


Figure 17 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2019.

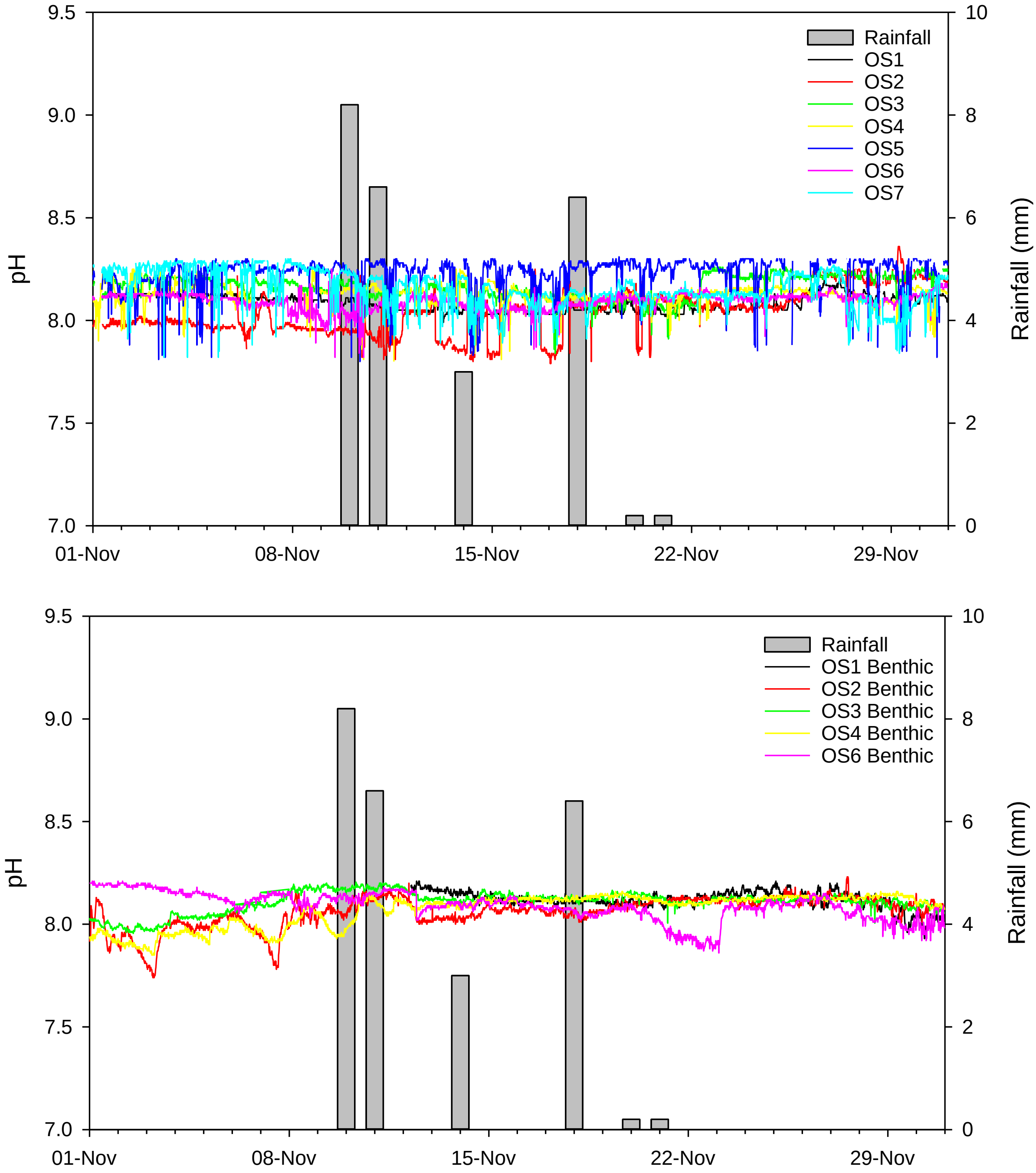


Figure 18 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during November 2019.

3.2.5 Conductivity

Surface conductivity in November ranged from 50.8 mS/cm to 53.5 mS/cm (Table 11, Figure 19 and 20), with benthic conductivity at similar levels, ranging from 52.7 mS/cm to 53.4 mS/cm.

Inner harbour sites recorded slightly lower mean conductivity values than offshore and spoil ground sites, which may reflect localised stormwater runoff. Higher flows from the Waimakariri River from 8 November appeared to have impacted conductivity at the spoil ground sites on 10 November, starting with SG1, then SG2 (dipping to 48 mS/cm) and to a lesser extent SG3 several hours later. The latter sites are furthest from the source point and therefore there is a longer delay before the freshwater reaches these sites. OS5 and OS6 also displayed some reduced conductivity for a short period at this time. A second decrease in conductivity on 26 November occurred initially at OS1, then OS5 and SG1 and may have been related to a short acute flow of >800 m^3/s from the Waimakariri River flow which occurred on 17 November but may have been delayed in reaching Lyttelton Harbour as the current hugged the coast.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during November 2019.
Values are means ± se (n = 1797 to 2862).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	50.8 ± 0.0	–
UH2	51.7 ± 0.0	–
CH1	51.4 ± 0.0	–
CH2	51.3 ± 0.0	–
SG1	53.1 ± 0.0	–
SG2	51.3 ± 0.0	–
SG3	53.5 ± 0.0	–
OS1	51.1 ± 0.0	53.4 ± 0.0
OS2	52.6 ± 0.0	52.7 ± 0.0
OS3	52.6 ± 0.0	52.7 ± 0.0
OS4	53.5 ± 0.0	53.0 ± 0.0
OS5	52.8 ± 0.0	–
OS6	52.5 ± 0.0	52.8 ± 0.0
OS7	52.8 ± 0.0	–

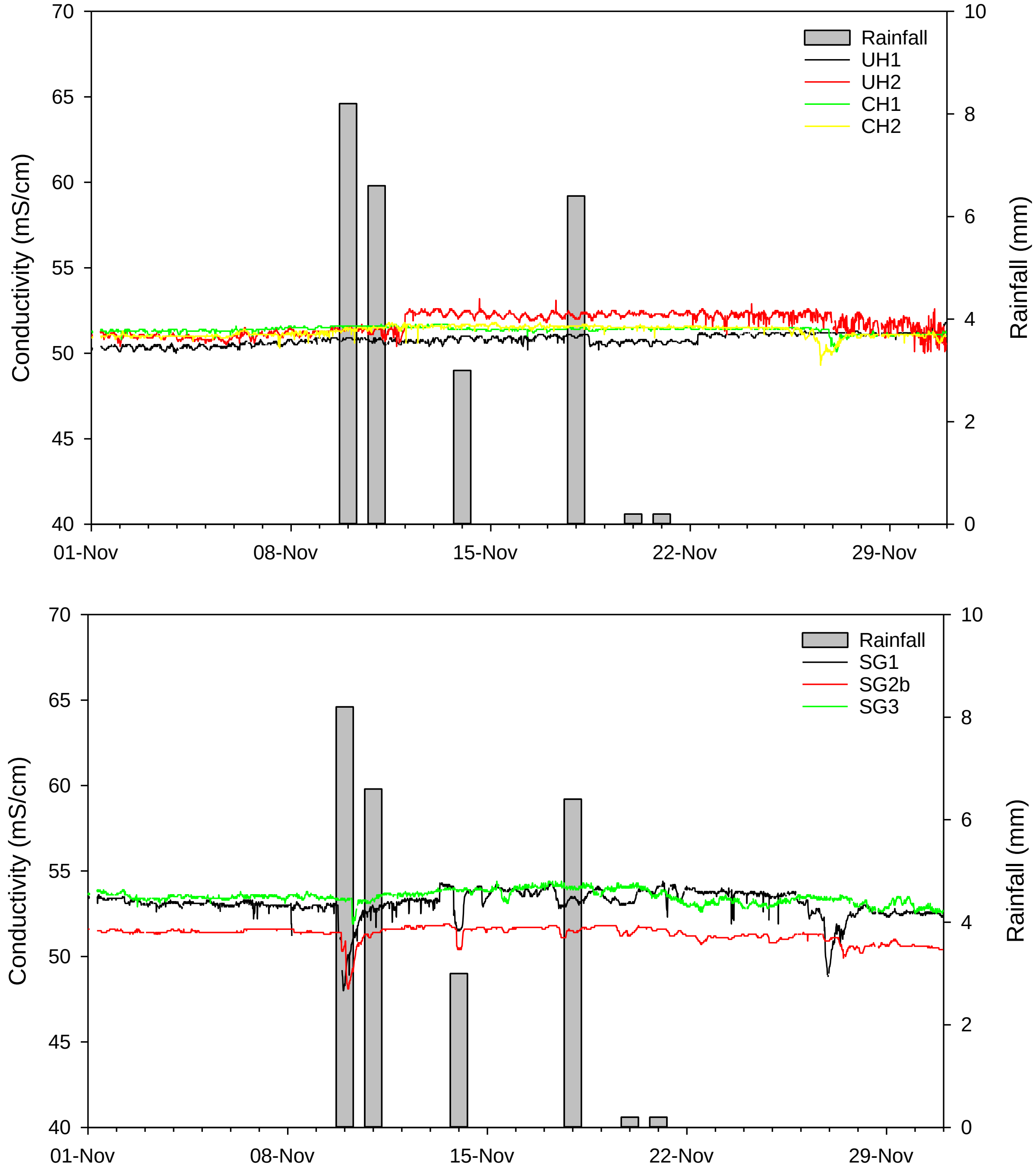


Figure 19 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2019.

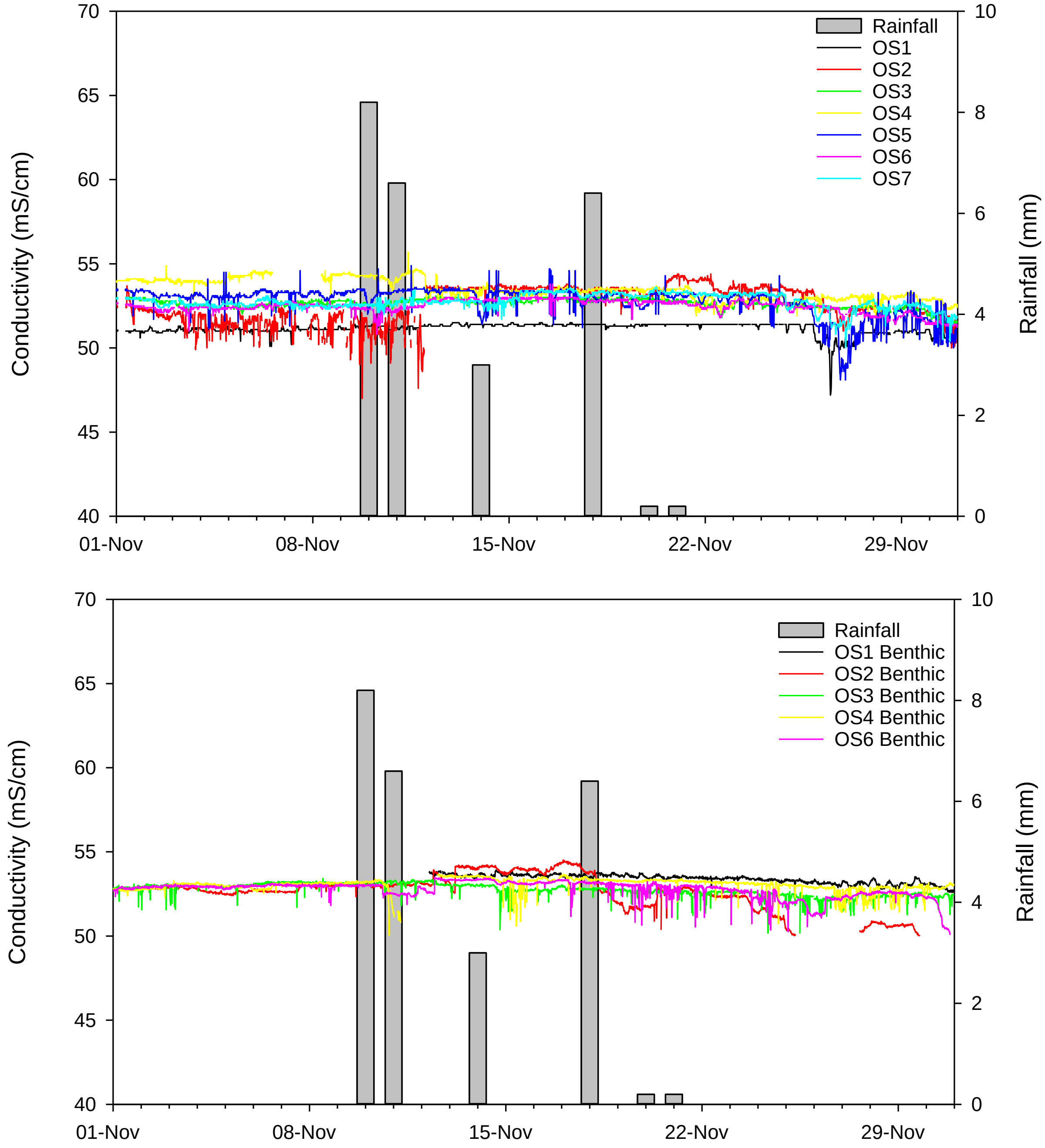


Figure 20 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during November 2019.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in November ranged from 99 to 106% saturation. DO concentrations were observed to decrease on the 11 and 21 November following periods of rainfall and concurrently with water temperatures. Warmer temperatures associated with increased sunlight following periods of rainfall likely stimulated microalgal growth, leading to increased photosynthesis and therefore increased DO concentrations. Flows from the Waimakariri River may have also introduced nutrients contributing to algal growth.

Mean monthly benthic DO concentrations were lower than corresponding surface readings ranging from 91 to 97% saturation (Table 12, Figures 21 and 22), indicative of lower photosynthesis at the benthos. Benthic DO however displayed a similar trend to surface cohorts.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during November 2019.
Values are means ± se (n = 1797 to 2870).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	100 ± 0	–
UH2	99 ± 0	–
CH1	101 ± 0	–
CH2	103 ± 0	–
SG1	105 ± 0	–
SG2	106 ± 0	–
SG3	104 ± 0	–
OS1	102 ± 0	97 ± 0
OS2	102 ± 0	91 ± 0
OS3	103 ± 0	94 ± 0
OS4	102 ± 0	97 ± 0
OS5	103 ± 0	–
OS6	103 ± 0	91 ± 0
OS7	103 ± 0	–

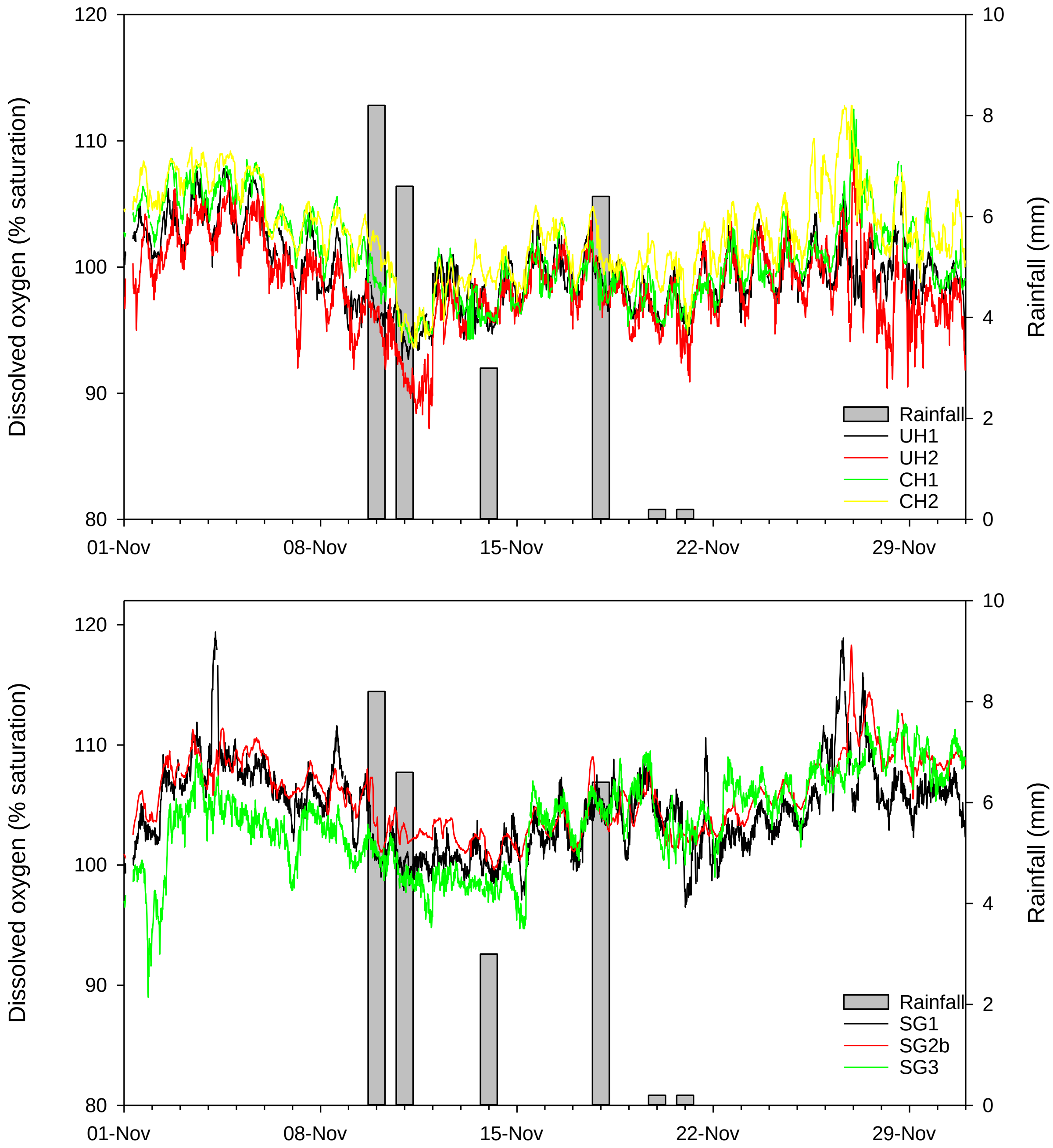


Figure 21 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during November 2019.

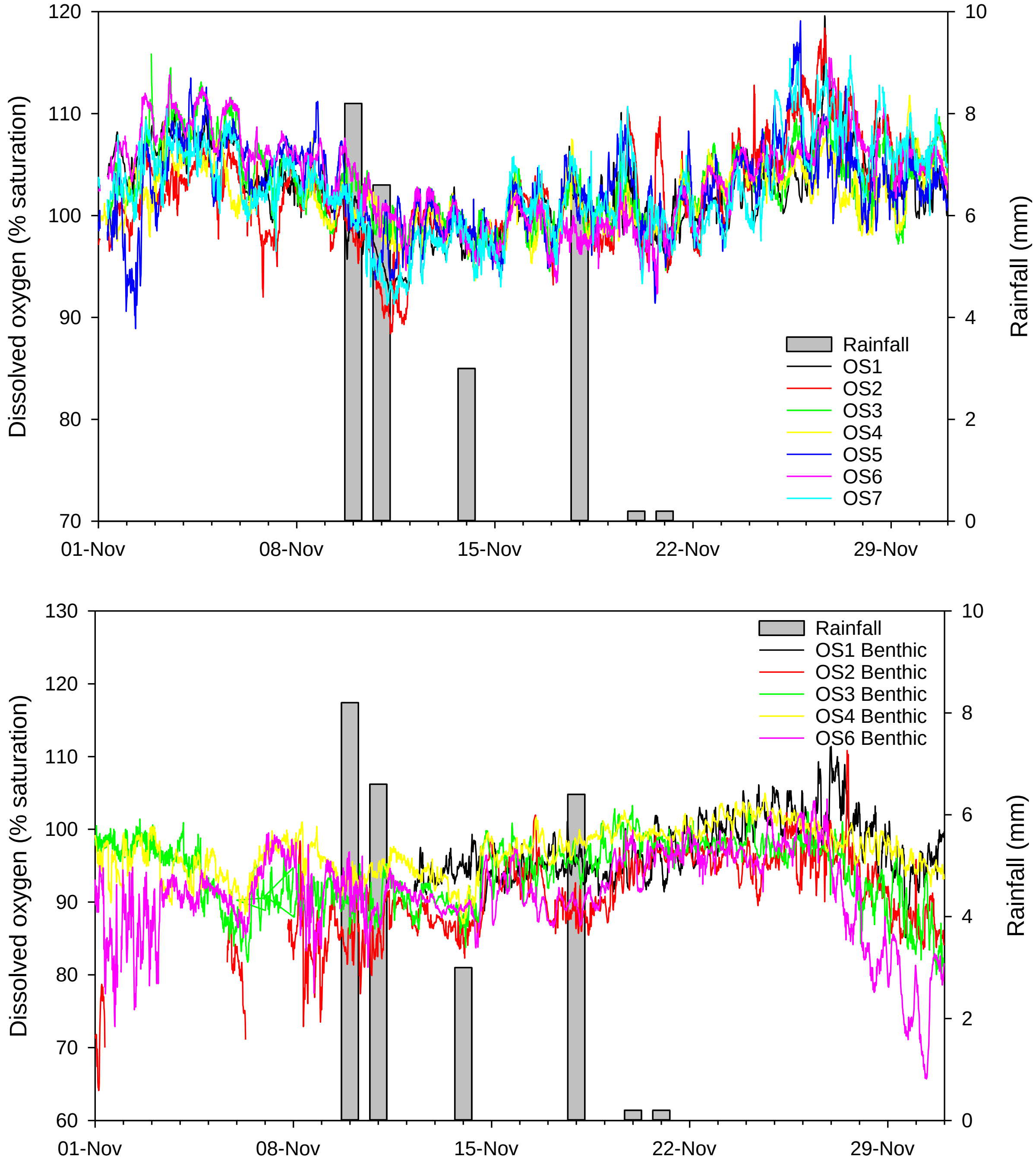


Figure 22 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during November 2019.

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 2019. 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 depth to which net photosynthesis can occur/where light levels are ~1% of those at the surface) were also calculated.

Water samples for the determination of TSS were 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 at the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, UH3, 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 23 to 25.

The relatively shallow sites of the upper and central harbour once again displayed well mixed conditions with little variability recorded in parameters through the water columnThe exception was UH3, where the top 1 m was characterised by slightly lower conductivity and higher temperature, DO and turbidity values, suggesting the influence of localised runoff from the preceding rainfall (Figure 23). Similar to the continuous loggers, the uppermost harbour sites of UH3 and UH1 exhibited the lowest conductivity and pH within the harbour and higher temperatures. Slightly increased turbidity near the benthos was also recorded at these sites, which is often observed due to shear forces (friction between the overlying moving water and the stationary seabed) providing energy for sediment resuspension.

Within the nearshore region, physicochemical profiles for conductivity and pH remained relatively consistent through the water column (Figure 24). Temperature, however, displayed a slight decreasing gradient with warmer surface waters due to increasing solar insolation. DO also declined from the surface to benthos, with marked changes at most sites ~10 m, most likely due to decreasing photosynthesis with depth. Turbidity was consistent through the water column until the benthos where turbidity increased, similar to the inshore sites.

Within the offshore region of the spoil ground, OS5 and OS6, the water column revealed the formation of a seasonal thermocline at 10 m, with DO, temperature, pH decreasing in concentrations at this depth (Figure 25), similar to the nearshore sites. Conductivity was otherwise similar to previous months with good mixing through the column. Turbidity remained stable until >10 m where it increased with depth due to benthic resuspension at all sites.

The shallowest euphotic depth of 4.7 m occurred within upper harbour monitoring sites UH3 (Table 13), which reflects the typically higher levels of turbidity experienced in this area (Figure 24). The deepest euphotic depth was calculated to be 16 m at SG2 (Table 15) where turbidity throughout the column was low. No exceedances of WQG were recorded at the sub-surface during the November vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the November 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 29 to 44 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	13/11/2019 07:22	Sub-surface	14.5 ± 0	7.9 ± 0	51.3 ± 0	97 ± 0	5.7 ± 0.1	7	0.9 ± 0	5.3
		Whole column	14.2 ± 0.6	7.9 ± 0	51.4 ± 0	96 ± 0	5.5 ± 0.1	–		
UH2	13/11/2019 08:14	Sub-surface	13.7 ± 0	8 ± 0	51.6 ± 0	97 ± 0	4.1 ± 0.1	6	0.6 ± 0.1	7.4
		Whole column	13.7 ± 0.5	8 ± 0	51.6 ± 0	97 ± 0	4.2 ± 0.1	–		
UH3	13/11/2019 07:43	Sub-surface	15.3 ± 0	8 ± 0	50.8 ± 0	98 ± 0	7.5 ± 0.1	12	1 ± 0.1	4.7
		Whole column	15 ± 0.6	8 ± 0	51 ± 0	98 ± 0	6.7 ± 0.1	–		
CH1	13/11/2019 08:42	Sub-surface	13.5 ± 0	8 ± 0	51.7 ± 0	96 ± 0	4.4 ± 0	4	0.8 ± 0	5.9
		Whole column	13.4 ± 0.4	8 ± 0	51.7 ± 0	96 ± 0	5.9 ± 0.5	–		
CH2	13/11/2019 09:00	Sub-surface	13.6 ± 0	8 ± 0	51.8 ± 0	99 ± 0	3.2 ± 0	4	0.5 ± 0	8.4
		Whole column	13.6 ± 0.5	8 ± 0	51.8 ± 0	98 ± 0	3.5 ± 0.1	–		
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 November 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 33 to 40 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	13/11/2019 09:53	Sub-surface	13.5 ± 0	8 ± 0	51.8 ± 0	97 ± 0	3.9 ± 0.1	6	0.7 ± 0	6.2
		Mid	13.2 ± 0	8 ± 0	51.9 ± 0	95 ± 0	3.9 ± 0.1	4		
		Benthos	12.9 ± 0	8 ± 0	51.9 ± 0	93 ± 0	11 ± 0.8	14		
		Whole column	13.2 ± 0.5	8 ± 0	51.9 ± 0	95 ± 0	5.6 ± 0.5	–		
OS2	13/11/2019 14:01	Sub-surface	13.7 ± 0	8.1 ± 0	51.9 ± 0	101 ± 0	2.3 ± 0	3	0.4 ± 0	10.6
		Mid	13.4 ± 0	8.1 ± 0	51.9 ± 0	100 ± 0	2.8 ± 0.1	<3		
		Benthos	12.3 ± 0.1	8 ± 0	52.2 ± 0	91 ± 1	18.9 ± 9.5	4		
		Whole column	13.3 ± 0.4	8.1 ± 0	52 ± 0	98 ± 1	5.3 ± 1.7	–		
OS3	13/11/2019 13:09	Sub-surface	13.9 ± 0	8.1 ± 0	51.9 ± 0	102 ± 0	2.2 ± 0	<3	0.4 ± 0	10.8
		Mid	13.4 ± 0	8.1 ± 0	52 ± 0	100 ± 0	2.7 ± 0.1	<3		
		Benthos	12.3 ± 0	8 ± 0	52.2 ± 0	92 ± 0	15.8 ± 2.7	13		
		Whole column	13.3 ± 0.4	8 ± 0	52 ± 0	99 ± 1	4.7 ± 0.8	–		
OS4	13/11/2019 12:43	Sub-surface	13.8 ± 0	8.1 ± 0	52 ± 0	102 ± 0	2.3 ± 0	<3	0.5 ± 0	8.8
		Mid	13.2 ± 0	8 ± 0	52.1 ± 0	99 ± 0	3.3 ± 0.4	3		
		Benthos	12.6 ± 0	8 ± 0	52.2 ± 0	94 ± 0	12.8 ± 0.7	33		
		Whole column	13.2 ± 0.4	8 ± 0	52.1 ± 0	99 ± 0	5.1 ± 0.6	-		
OS7	13/11/2019 09:23	Sub-surface	13.6 ± 0	8 ± 0	51.8 ± 0	98 ± 0	3.1 ± 0	<3	0.6 ± 0.1	7.3
		Mid	13.4 ± 0	8 ± 0	51.9 ± 0	97 ± 0	3.6 ± 0.2	5		
		Benthos	12.9 ± 0	8 ± 0	52 ± 0	93 ± 0	10.2 ± 0.7	18		
		Whole column	13.3 ± 0.5	8 ± 0	51.9 ± 0	96 ± 0	5 ± 0.5	–		
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 November 2019 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	13/11/2019 10:20	Sub-surface	13.4 ± 0	8 ± 0	51.9 ± 0	101 ± 0	2.3 ± 0	<3	0.5 ± 0	9.9
		Mid	13.2 ± 0	8 ± 0	51.9 ± 0	100 ± 0	2.4 ± 0	<3		
		Benthos	12.1 ± 0.1	8 ± 0	52.2 ± 0	89 ± 1	16.8 ± 3.6	24		
		Whole column	13 ± 0.4	8 ± 0	52 ± 0	98 ± 1	4.9 ± 1	–		
OS6	13/11/2019 13:34	Sub-surface	13.9 ± 0	8.1 ± 0	52 ± 0	103 ± 0	1.9 ± 0	<3	0.4 ± 0	11.8
		Mid	13.5 ± 0	8.1 ± 0	52.1 ± 0	103 ± 0	1.4 ± 0	<3		
		Benthos	11.8 ± 0	8 ± 0	52.3 ± 0	91 ± 0	29.7 ± 7.7	29		
		Whole column	13.1 ± 0.4	8.1 ± 0	52.1 ± 0	99 ± 1	6.6 ± 1.7	–		
SG1	13/11/2019 11:00	Sub-surface	13.5 ± 0	8.1 ± 0	52 ± 0	103 ± 0	1.4 ± 0	<3	0.4 ± 0	11.7
		Mid	13 ± 0.2	8.1 ± 0	52.1 ± 0	102 ± 1	1.5 ± 0.1	<3		
		Benthos	11.7 ± 0	8 ± 0	52.3 ± 0	91 ± 0	18.6 ± 4.5	18		
		Whole column	12.7 ± 0.4	8 ± 0	52.2 ± 0	99 ± 1	4.7 ± 1	–		
SG2	13/11/2019 11:36	Sub-surface	13.2 ± 0	8.1 ± 0	52.2 ± 0	103 ± 0	1.1 ± 0	3	0.3 ± 0	16.0
		Mid	13 ± 0	8.1 ± 0	52.3 ± 0	102 ± 0	1.1 ± 0	3		
		Benthos	11.8 ± 0	8 ± 0	52.3 ± 0	92 ± 0	13.5 ± 1.4	19		
		Whole column	12.7 ± 0.3	8 ± 0	52.3 ± 0	99 ± 1	3.6 ± 0.7	–		
SG3	13/11/2019 12:11	Sub-surface	13.3 ± 0	8.1 ± 0	52.2 ± 0	102 ± 0	1 ± 0	<3	0.4 ± 0	12.5
		Mid	12.8 ± 0.1	8.1 ± 0	52.2 ± 0	101 ± 0	1.3 ± 0.1	<3		
		Benthos	12 ± 0	8 ± 0	52.3 ± 0	93 ± 0	12.9 ± 0.7	7		
		Whole column	12.7 ± 0.3	8 ± 0	52.2 ± 0	99 ± 1	4 ± 0.7	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	

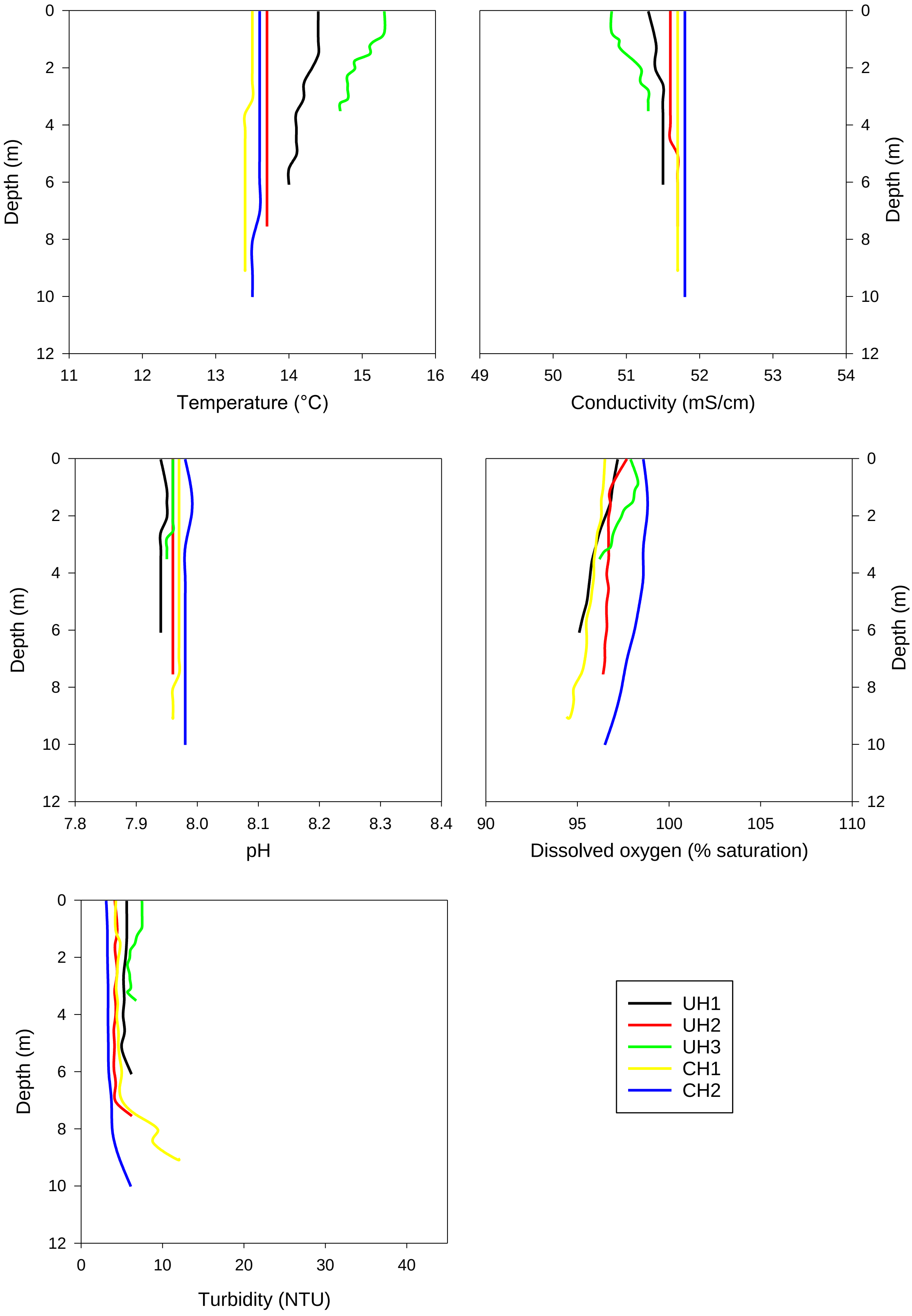


Figure 23 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 13 November 2019.

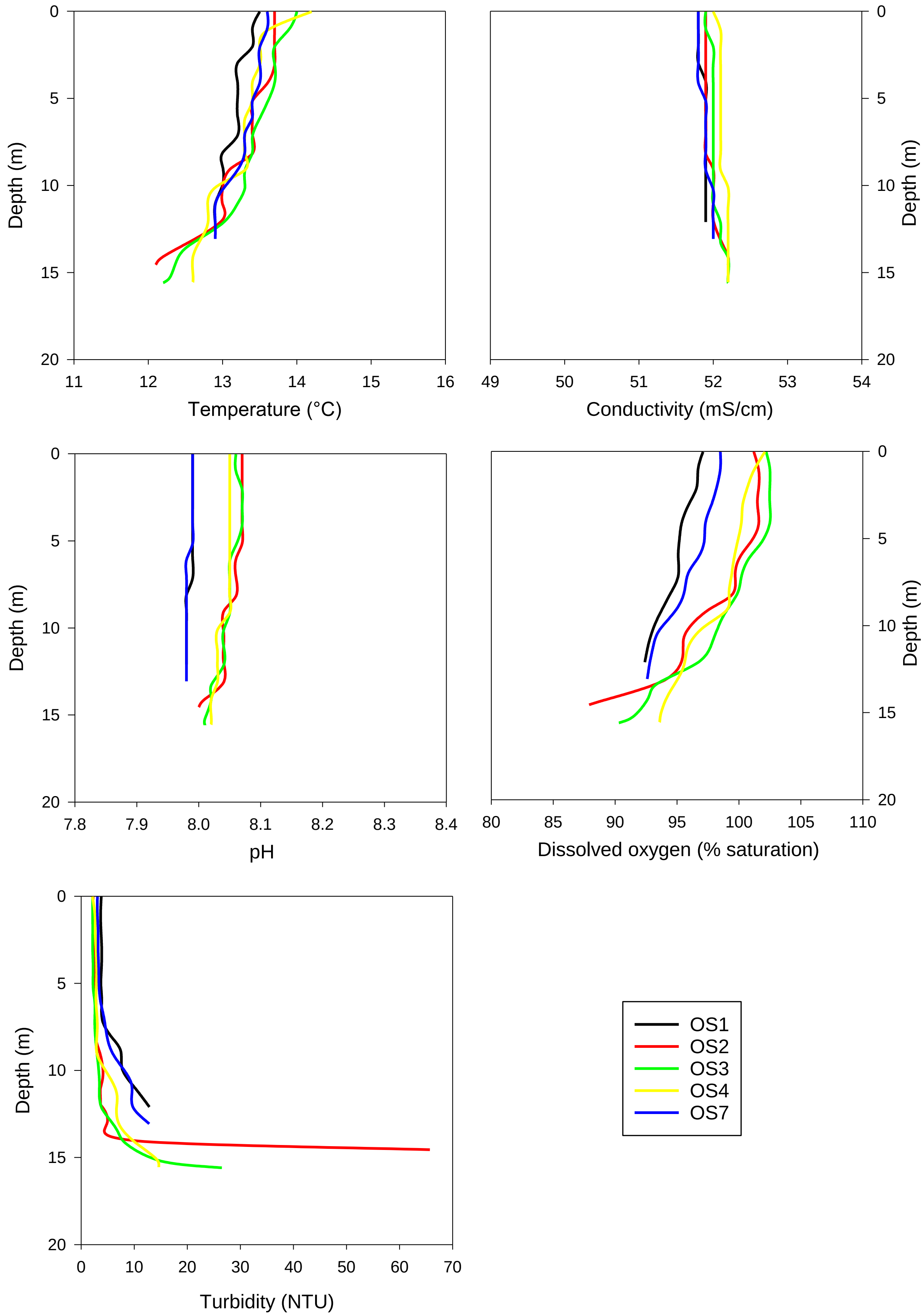


Figure 24 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 13 November 2019.

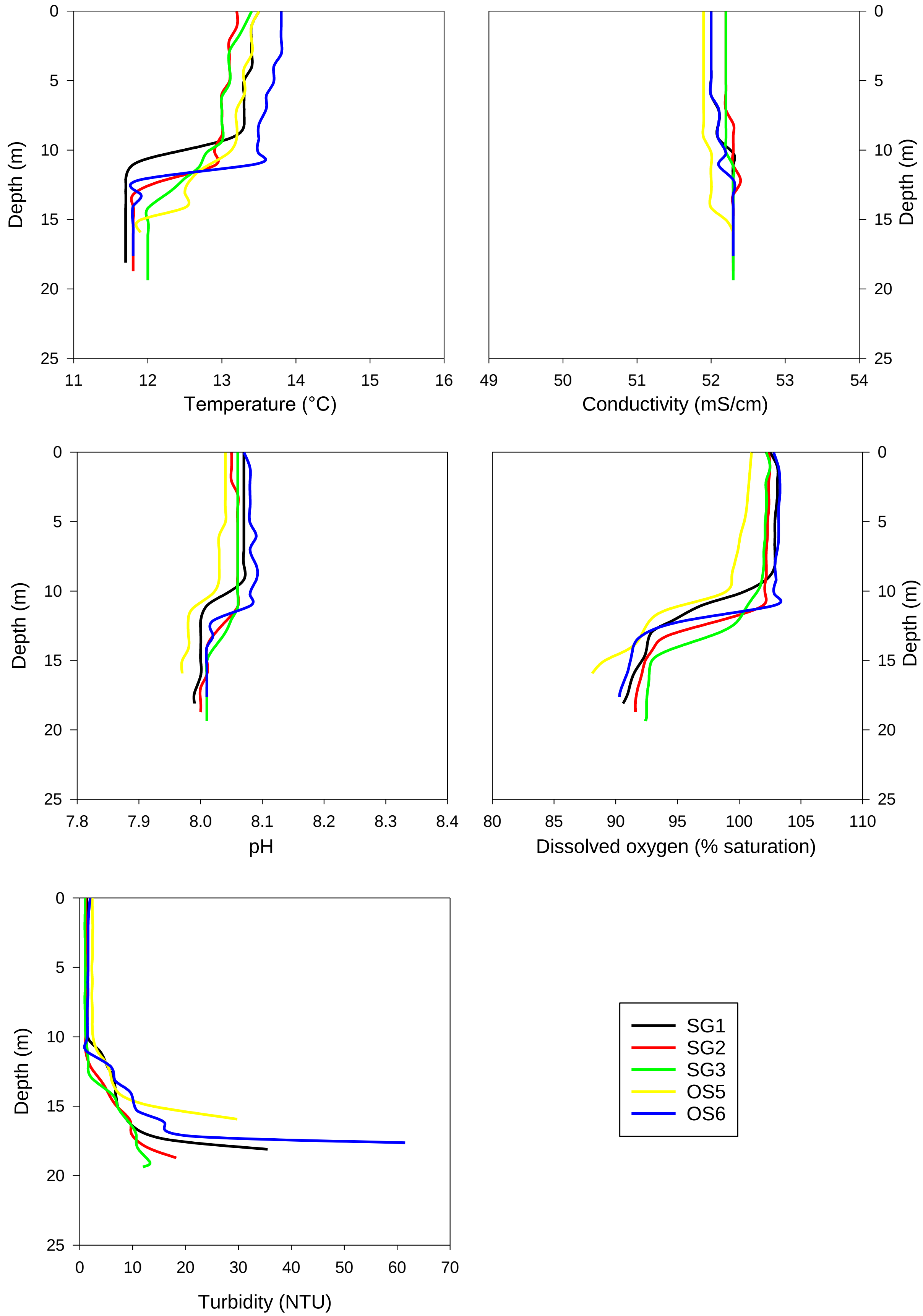


Figure 25 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 13 November 2019.

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 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 26. Data from the logger exchange date (12 November) were removed from the analyses.

Table 16 Total Daily PAR (TDP) statistics during November 2019.
Values are means ± se (n = 29 to 30). Note data from the BPAR exchange day on 12 November were not utilised in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m²/day)		
		Mean ± se	**Median**	**Range**
Base	-	31,517 ± 2,840	28,084	7,070 – 63,000
OS2	17	2,367 ± 413	1558	<0.1 – 6,747
OS3	14	2,301 ± 528	611	<0.1 – 8,300

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 was variable, ranging from 7,070 to 63,000 mmol/m^2/day (Table 16), substantially higher than the range recorded during September (12,055 to 34,700 mmol/m^2/day). The increase in ambient TDP is likely associated with the increased day lengths from October to November.

As a result of increased ambient PAR, mean BPAR at both OS2 and OS3 also increased in November (2,367 and 2,301 mmol/m^2/day respectively) from October (1,821 and 1,366 mmol/m^2/day, respectively). BPAR at both OS2 and OS3 recorded a number of peaks > 2000 mmol/m^2/day throughout the month when ambient PAR was reasonably high and water turbidity was low (< 5 NTU). A period of low BPAR was experienced at OS2 and OS3 from 8 to 14 November when turbidity was consistently elevated and ambient PAR was low most likely as a result of cloud cover when 14.8 mm rainfall was recorded.

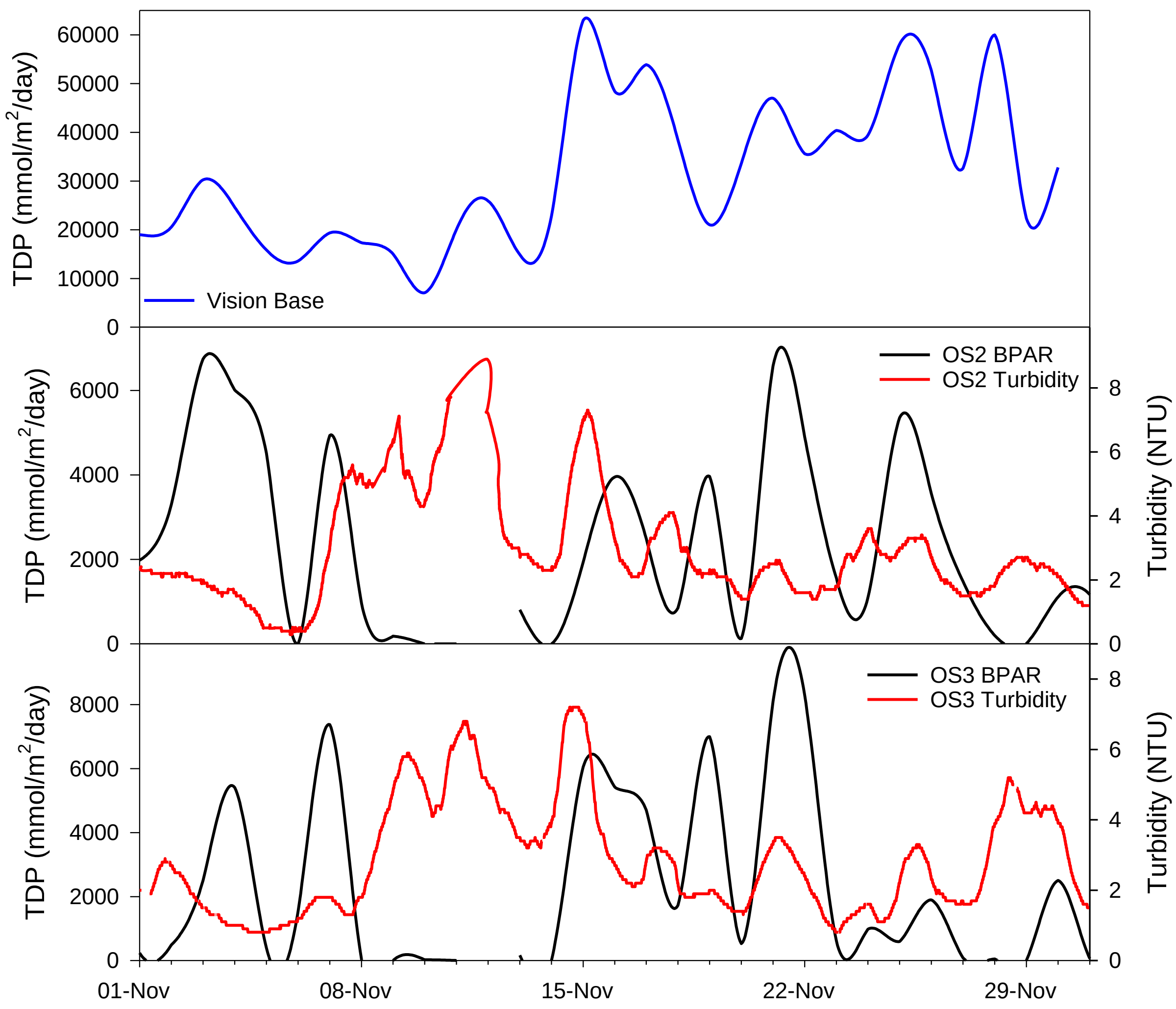


Figure 26 Total daily BPAR at OS2 and OS3 during November 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 12 November were not utilized in plots or statistics.

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.

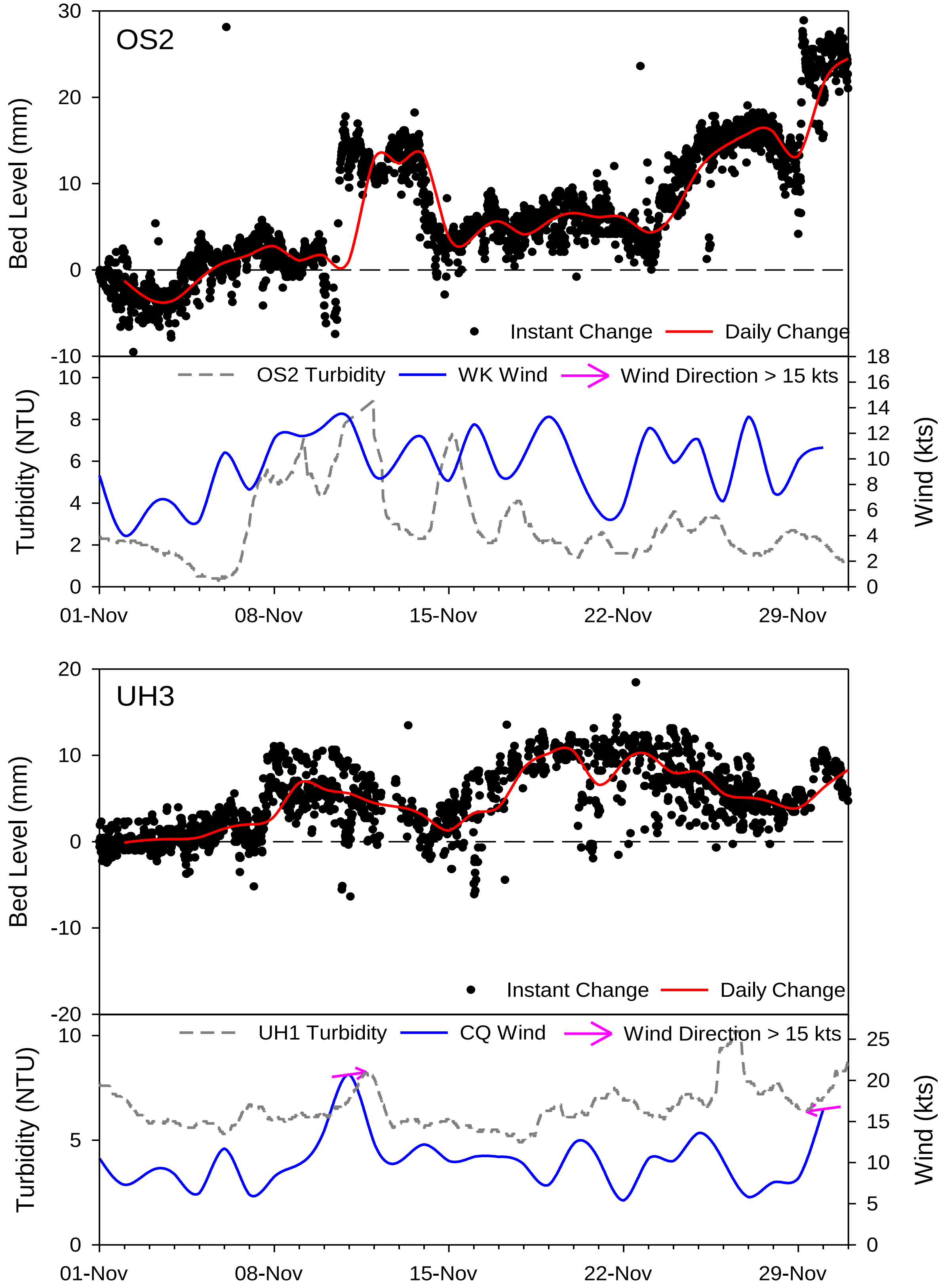


Figure 27 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during November 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction. *Note: Arrows indicate the direction of travel for winds greater than 15 knots.*

Bed level at the offshore site OS2 was quite dynamic in November with the start of the month recording a short period of slight erosion. Following on was a period of rapid accumulation (~20 mm) from 11 November followed by a period of short stability until 13 November, which occurred during a period of increased winds and turbidity. A rapid short period of bed erosion then occurred over the 14 to 15 which corresponded to increased significant wave heights >1 m. Bed level for the remainder of November resulted an overall accumulation of 20 mm interspersed with short periods of erosion. An overall accumulation of 25 mm was recorded in November 2019 (Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2. Bed level experienced a period of accretion of <10 mm until 9 November during a period of lighter inshore winds. Increase in inshore winds (17 kts) from a westerly direction correlated to the next period of high sediment flux and an overall sediment erosion to 16 November. The remainder of November displayed a period of high sediment flux with alternating periods of accretion and erosion. An overall accumulation of 8.3 mm was recorded in November 2019 (Table 17).

Table 17 Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 during November 2019.

Site	November 2019 Net bed level change (mm)
OS2	+25
UH3	+8.3

3.6 Water Samples

Discrete water sampling was conducted on 13 November 2019, 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 exhibited a typical spatial pattern with higher concentrations within the inner harbour and lowest concentrations at the spoil ground. Total phosphorous remained below the WQG of 30 µg/L at all sites, except for OS3 which reported 30 µg/L. In contrast to October, dissolved reactive phosphorous concentrations were below the WQG of 5 µg/L at the offshore and spoil ground sites, with the inner harbour and OS1 sites reporting values > WQG (5 µg/L). This may be a result of warmer temperatures stimulating algal growth with the utilisation of some available nutrients in the offshore areas. Localised rainfall in days prior to sampling may have generated increased concentrations at the inshore sites. Both total nitrogen and total kjeldahl nitrogen (TKN) were < LOR and < WQG at all sites.

Total ammonia ranged from 9 to 19 µg/L and similar to previous months the majority of sites exceeded the WQG (15 µg/L). This month continued the trend from September of decreasing NOx values, with all sites reporting values below the WQG (15 µg/L), except for SG3 (17.8 µg/L). Again, this may be utilisation by increasing algal populations.

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during November 2019.
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	6.8	<300	<200	12	2.4	3.4
UH2	16	5.8	<300	<200	17	5	3.1
UH3	22	10.1	<300	<200	15	<1	2.6
CH1	16	5.3	<300	<200	12	3.8	3.5
CH2	14	4.2	<300	<200	14	3.2	3.1
OS1	12	5.6	<300	<200	19	14.5	3.2
OS2	8	2.1	<300	<200	13	3.9	1.9
OS3	30	1.5	<300	<200	9	7.1	1.6
OS4	8	2.2	<300	<200	19	6.8	0.9
OS5	8	1.1	<300	<200	14	13.8	1.9
OS6	8	<1	<300	<200	11	2	1.5
OS7	12	3.7	<300	<200	15	2.7	2.8
SG1	6	<1	<300	<200	15	1.9	1
SG2	8	1.2	200	200	11	3.7	0.6
SG3	6	1.2	<300	<200	17	17.8	0.5
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

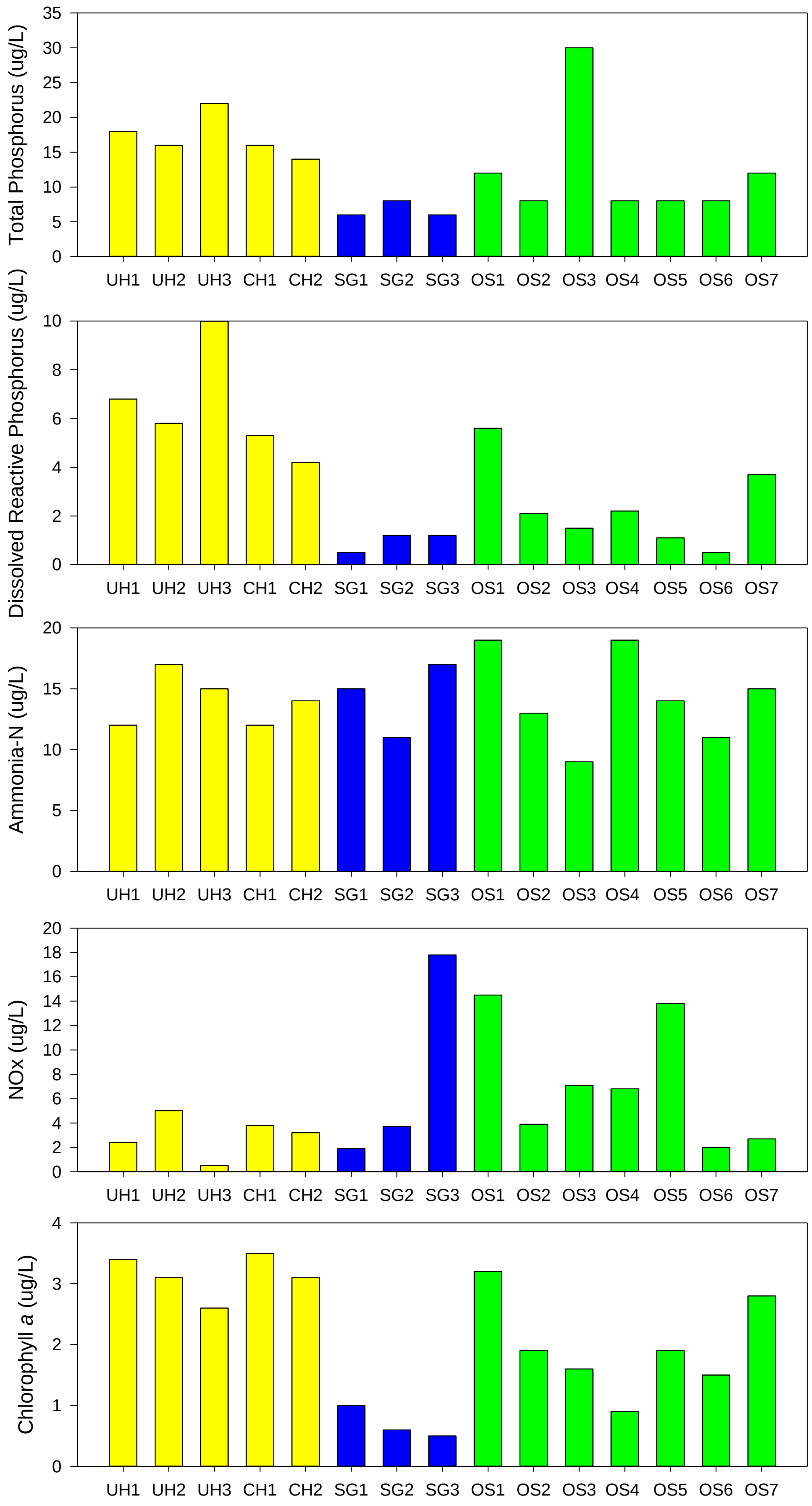


Figure 28 Nutrient and chlorophyll *a* concentrations at monitoring sites during November 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were <LOR.*

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, was elevated at all sites ranging from 0.5 at SG3 to 3.5 at CH1, but with no sites exceeding the WQG (4 µg/L) (Table 18). It should be noted that sampling was conducted earlier in the month and did not coincide with elevated DO concentrations which were recorded later in the month when chlorophyll *a* concentrations were most likely much higher.

3.6.2 Total and Dissolved Metals

Concentrations of several metals (Tables 19 to 21) 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), cobalt (<0.6 µg/L), mercury (<0.08 µg/L), nickel (<7 µg/L), silver (<0.4 µg/L) and tin (<5 µg/L) Total and dissolved selenium was <LOR at majority sites, except at UH3, OS3, OS5, OS7 and SG3 where the total fraction reported values >LOR. Total copper recorded values > > WQG (1.3 µg/L) at a number of sites (UH2 16.9 µg/L, CH1 5.3 µg/L, CH2 2.4 µg/L, OS6 3.3 µg/L), while the dissolved fraction remained <LOR, suggesting limited bioavailability. Dissolved copper values >LOR were recorded at UH3 (1.1 µg/L) but these concentrations were <WQG (1.3 µg/L). Total and dissolved lead and zinc was <LOR (lead <1 µg/L, zinc <4 µg/L) at all sites except for UH2 which reported values of lead 3.2 µg/L and zinc 10.1 µg/L. The dissolved fraction remained <LOR suggesting limited bioavailability. The elevated total copper, lead and zinc values at UH2 suggests sample contamination by particulate material as this was not reflected in dissolved concentrations.

In contrast to previous months reporting, dissolved aluminium and iron were detected at a number of sites. Dissolved aluminium was reported at values of 14 to 19 µg/L within the inner harbour and 16 to 19 µg/L offshore, although values were below the WQG (<24 µg/L) and thus there were no exceedances. Dissolved iron was reported at values of 4 and 7 µg/L within the inner harbour and values of 4 to 6 µg/L at the spoil ground. Concentrations of total aluminium (21 to 290 µg/L) were higher than the designated 95% species protection trigger value of 24 µg/L at all sites except the spoil ground sites where values were below the WQG. However, as the WQG is applicable to the dissolved fraction only (ANZG, 2018), no exceedances were recorded. As usually reported, both total aluminium and iron appeared to be generally higher at the inshore sites (90 to 290 µg/L and 101 to 470 µg/L, respectively) with minimum concentrations at the offshore and spoil ground sites (<21 to 105 µg/L and 4.7 to 18.4 µg/L, respectively).

Chromium, manganese, molybdenum and vanadium were recorded at the majority of sites in both total and dissolved forms. Chromium concentrations across the sites (<1 to 2.7 µg/L) were well below the 95% species protection trigger value of 4.4 µg/L from CrVI and 27.4 µg/L for CrIII. Similarly, recorded vanadium concentrations (1.2 to 2.5 µg/L) were well below the 95% species protection trigger value of 100 µg/L.

No trigger values are available for either manganese or molybdenum. Total and dissolved manganese concentrations ranged from <1 to 18.1 µg/L at inshore and offshore sites and were lower at spoil ground sites (<1 to 1.3 µg/L). Total and dissolved molybdenum concentrations exhibited little spatial variation, ranging from 10.8 to 12.2 µg/L, which was similar to previous monitoring results.

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during November 2019. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	15	18	19	14	14	24
	Total	196	143	290	129	90	
Arsenic	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.21	<0.21	<0.21	<0.21	<0.21	
Chromium	Dissolved	<1	1.1	<1	<1	1	Cr(III) 27.4 Cr(VI) 4.4
	Total	2	1.9	1.6	<1.1	1.6	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	1.1	<1	<1	1.3
	Total	<1.1	16.9	<1.1	5.3	2.4	
Iron	Dissolved	7	<4	<4	4	<4	-
	Total	270	240	470	168	101	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	3.2	<1.1	<1.1	<1.1	
Manganese	Dissolved	6.6	3.3	6.5	2.3	1.2	-
	Total	14.4	9.8	18.1	9.6	5.9	
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	11.5	11.6	11	11.4	11.5	-
	Total	10.8	11.4	10.8	11.3	11.7	
Nickel	Dissolved	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	4.3	<4.2	<4.2	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.43	<0.43	<0.43	<0.43	<0.43	
Tin	Dissolved	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	1.4	1.8	1.6	1.3	1.4	100
	Total	2.1	2.5	2.1	2.4	2.4	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4.2	10.1	<4.2	<4.2	<4.2	

Table 20 Total and dissolved metal concentrations at offshore monitoring sites during November 2019. *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	16	18	19	24
	Total	107	53	44	49	41	40	105	
Arsenic	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	
Chromium	Dissolved	<1	1	<1	<1	<1	1.4	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	<1.1	<1.1	1.3	<1.1	<1.1	<1.1	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	3.3	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	152	55	66	61	56	45	126	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.6	<1	<1	<1	<1	<1	<1	-
	Total	7.5	3.2	2.1	1.9	2.2	2.1	5.8	
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	11.5	11.7	11.8	11.8	11.8	11.9	11.9	-
	Total	11	11.3	11.1	11	11	11.9	11.2	
Nickel	Dissolved	<7	<7	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	4.7	<4.2	4.7	<4.2	4.5	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.43	<0.43	<0.43	<0.43	<0.43	<0.43	<0.43	
Tin	Dissolved	<5	<5	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	1.5	1.2	1.8	1.4	1.7	1.4	1.6	100
	Total	1.6	2	2.1	1.6	2.3	1.6	2.2	
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 21 Total and dissolved metal concentrations at spoil ground monitoring sites during November 2019.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	<21	<21	<21	
Arsenic	Dissolved	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	
Cadmium	Dissolved	<0.2	<0.2	<0.2	5.5
	Total	<0.21	<0.21	<0.21	
Chromium	Dissolved	1.2	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	<1.1	2.7	
Cobalt	Dissolved	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	6	4	-
	Total	10.6	18.4	4.7	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	<1	<1	<1	-
	Total	1.3	<1	<1	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11.3	12.2	12	-
	Total	11.5	11.4	11.6	
Nickel	Dissolved	<7	<7	<7	70
	Total	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	-
	Total	<4.2	<4.2	4.3	
Silver	Dissolved	<0.4	<0.4	<0.4	1.4
	Total	<0.43	<0.43	<0.43	
Tin	Dissolved	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	
Vanadium	Dissolved	1.9	1.7	1.7	100
	Total	2	1.6	1.9	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

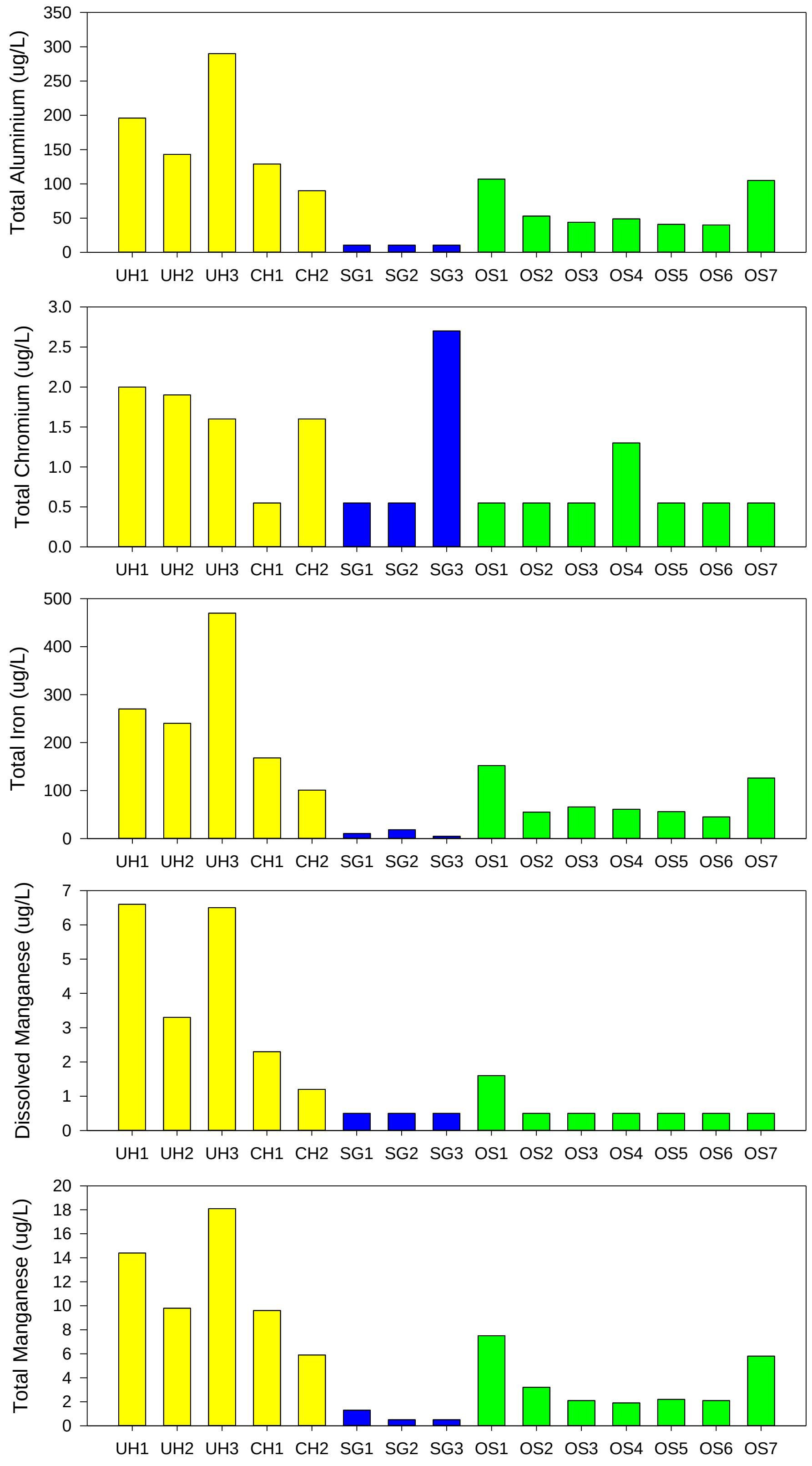


Figure 29 Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during November 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

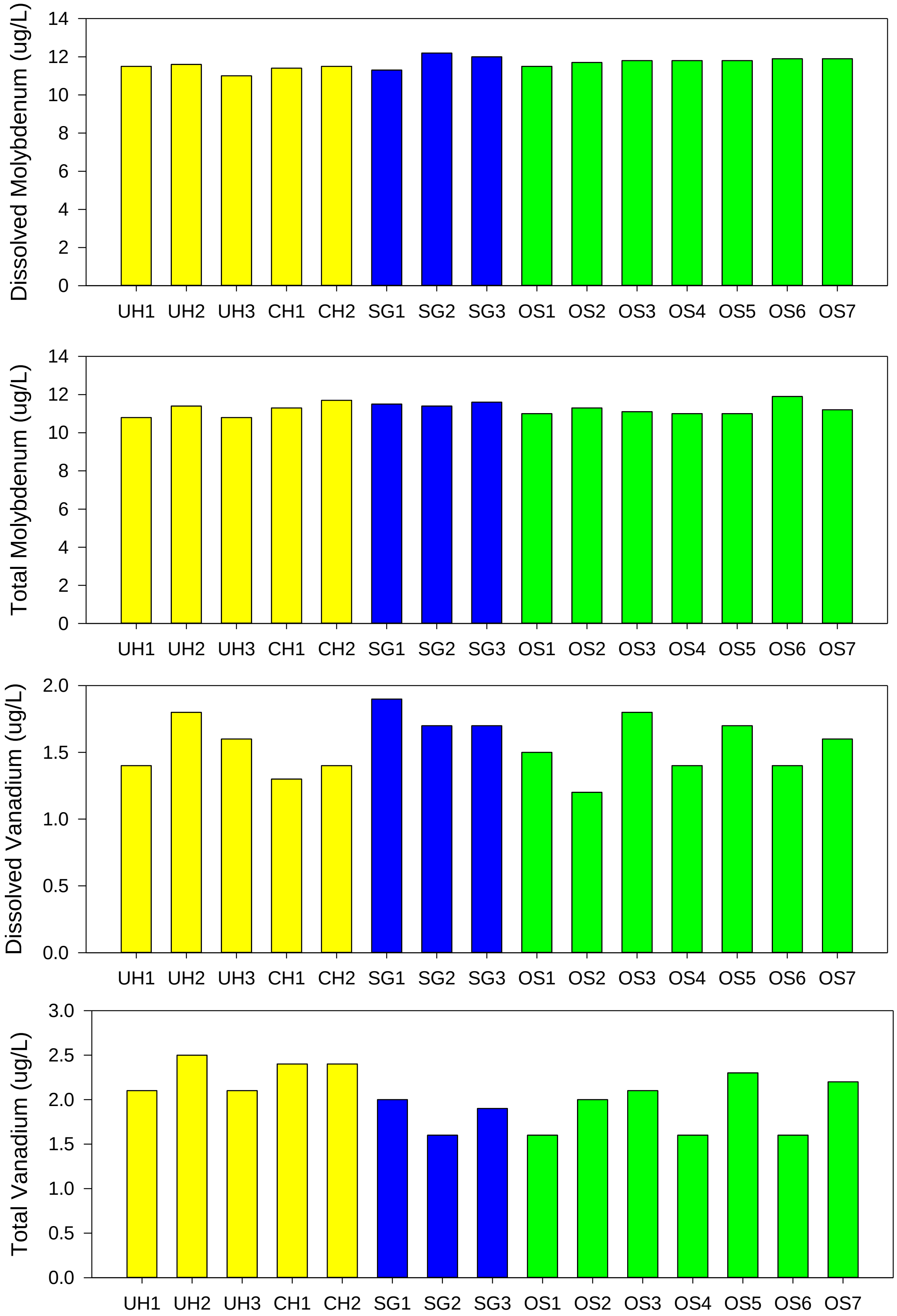


Figure 30 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during November 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

4 REFERENCES

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5 APPENDIX

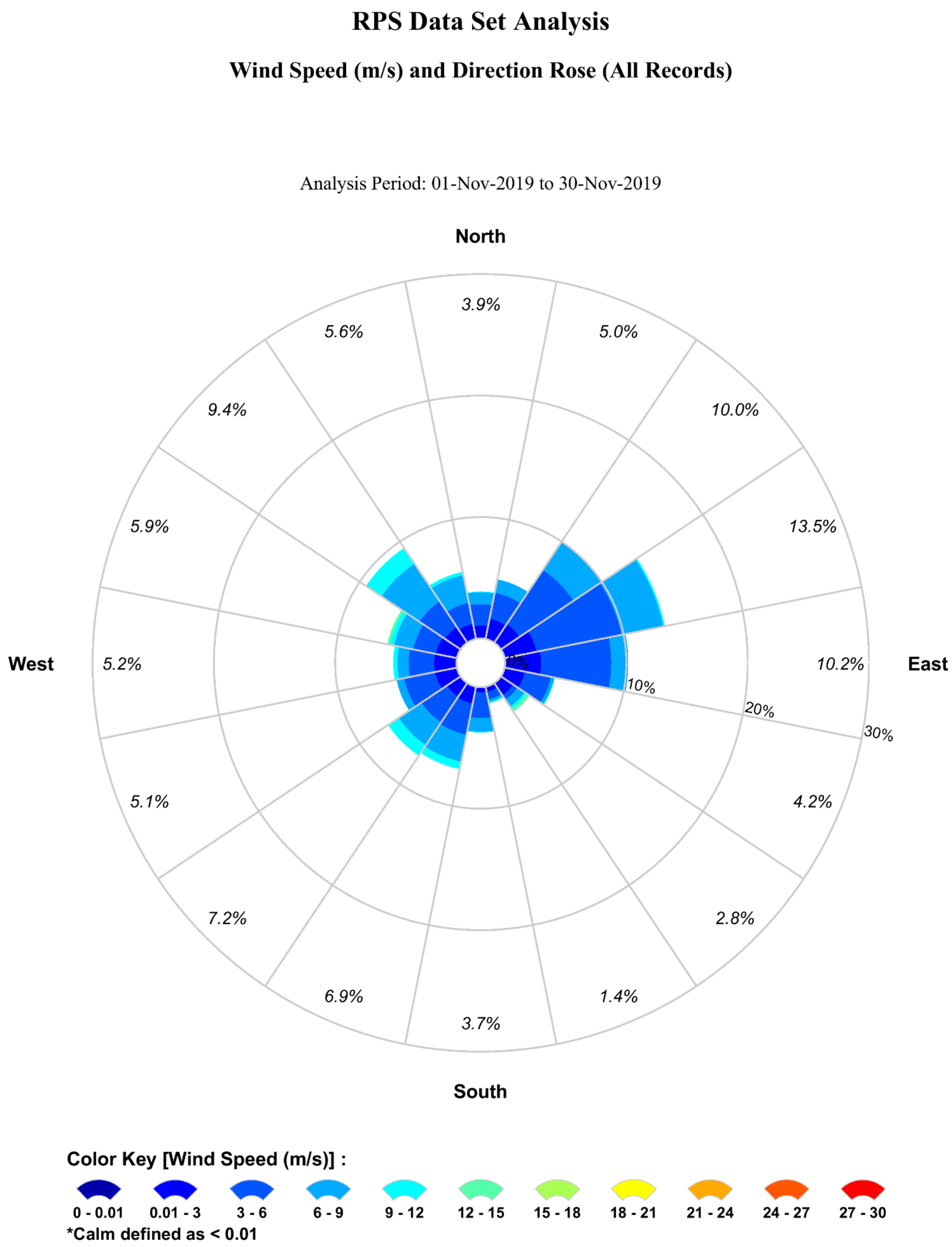


Figure 31 WatchKeeper wind speed (m/s) and direction rose (%) during November 2019.

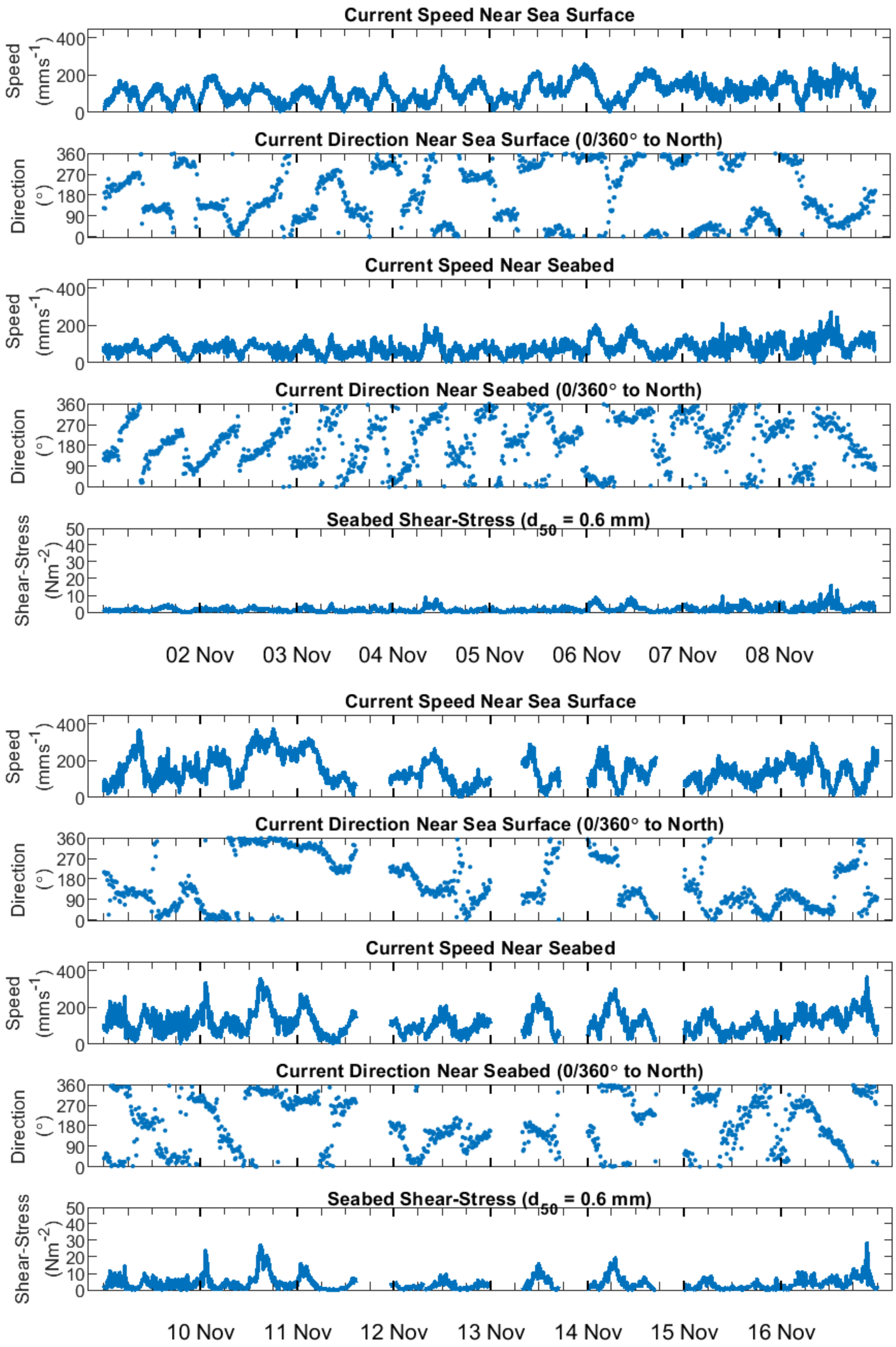


Figure 32 SG1 current speed, direction and shear bed stress 1 to 16 November 2019.

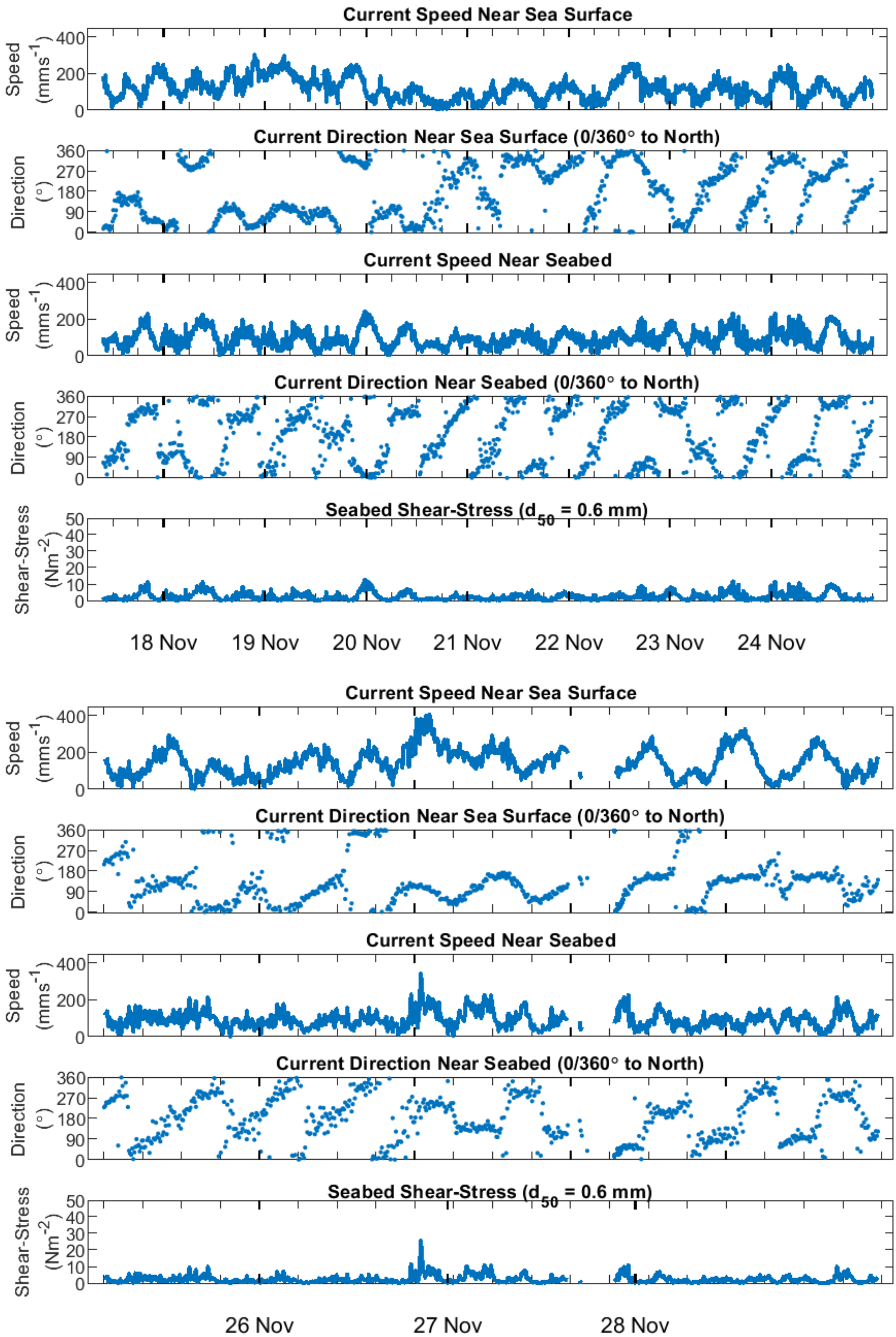
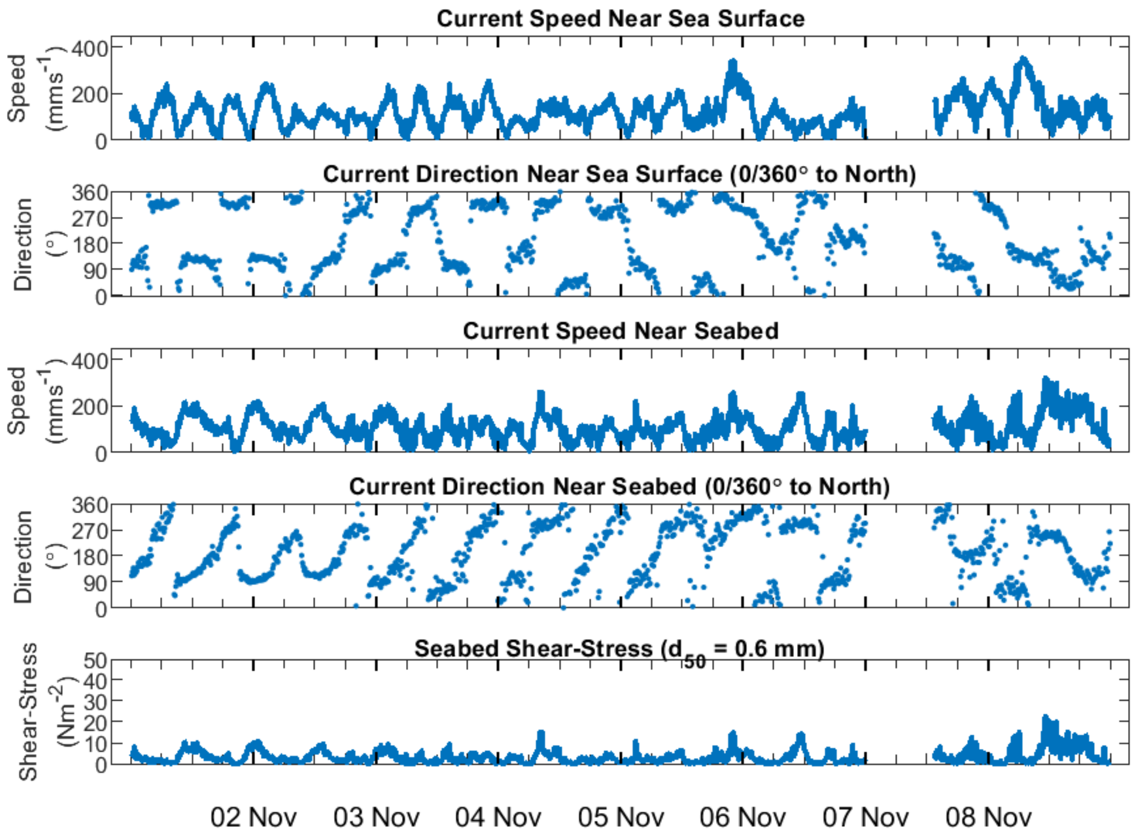


Figure 33 SG1 current speed, direction and shear bed stress 17 to 29 November 2019.



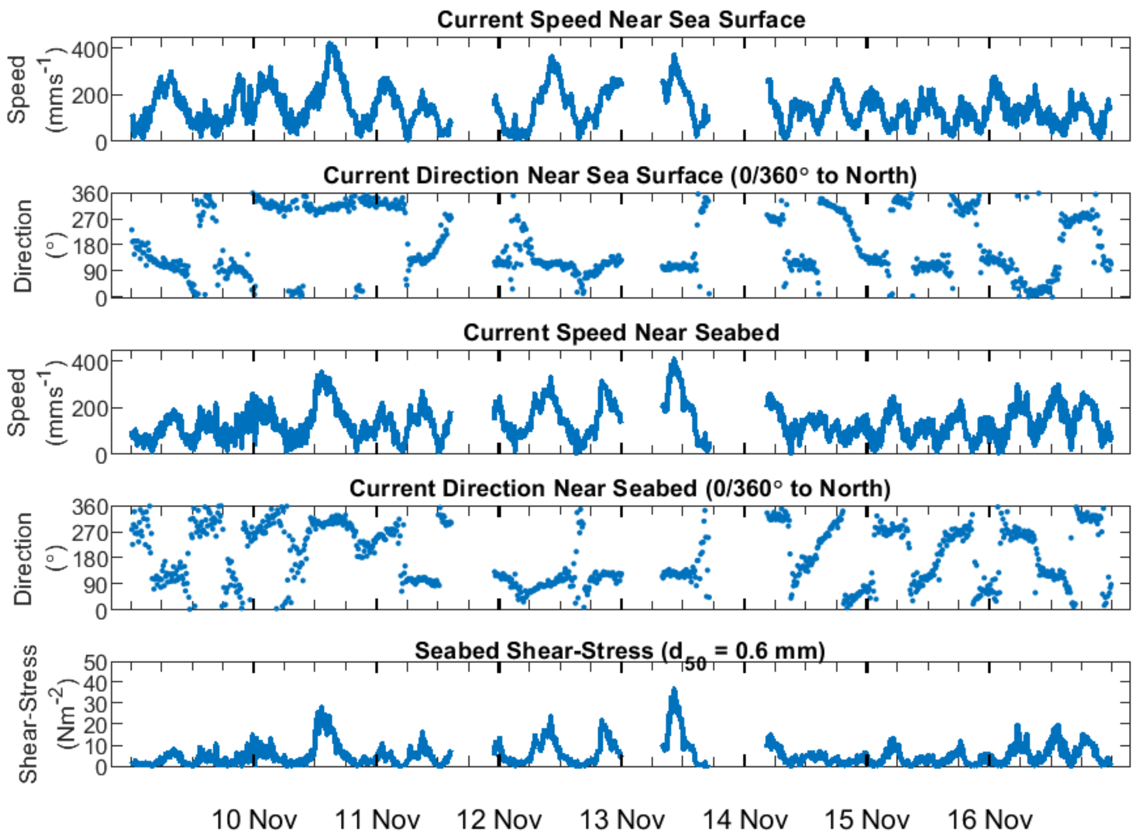
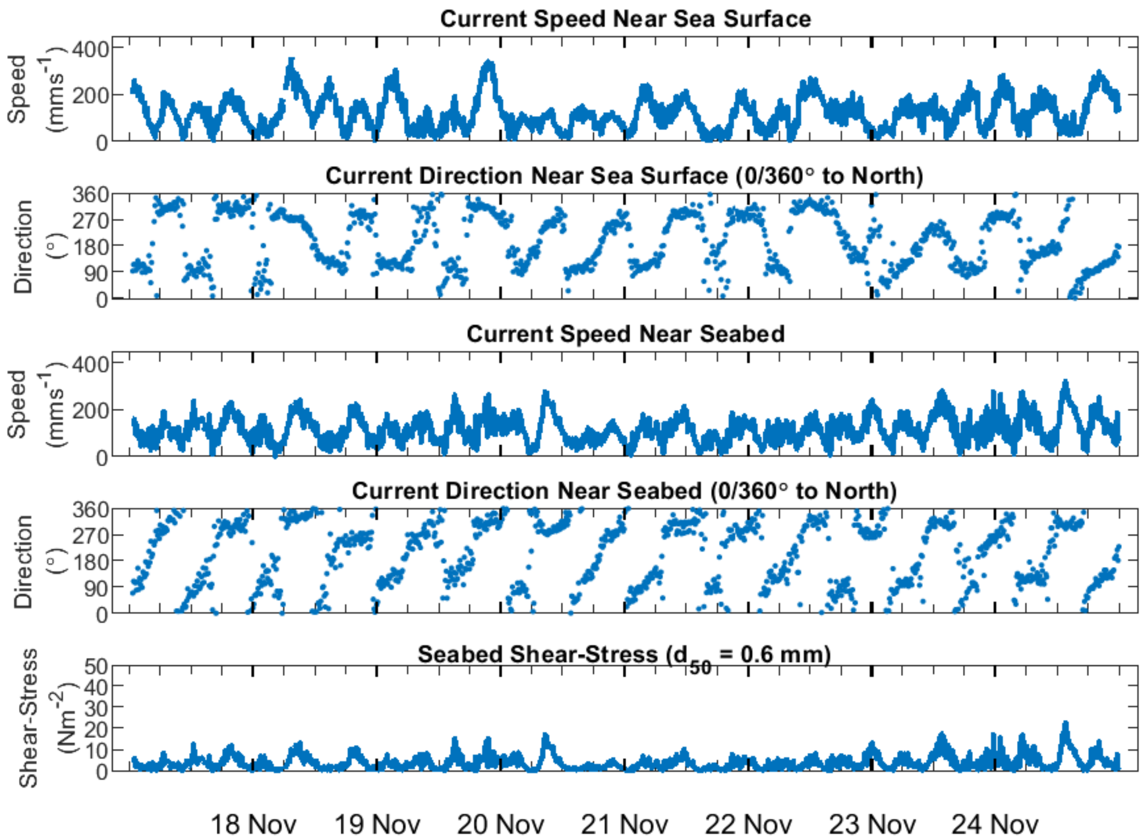


Figure 34 SG3 current speed, direction and shear bed stress 1 to 16 October 2019.



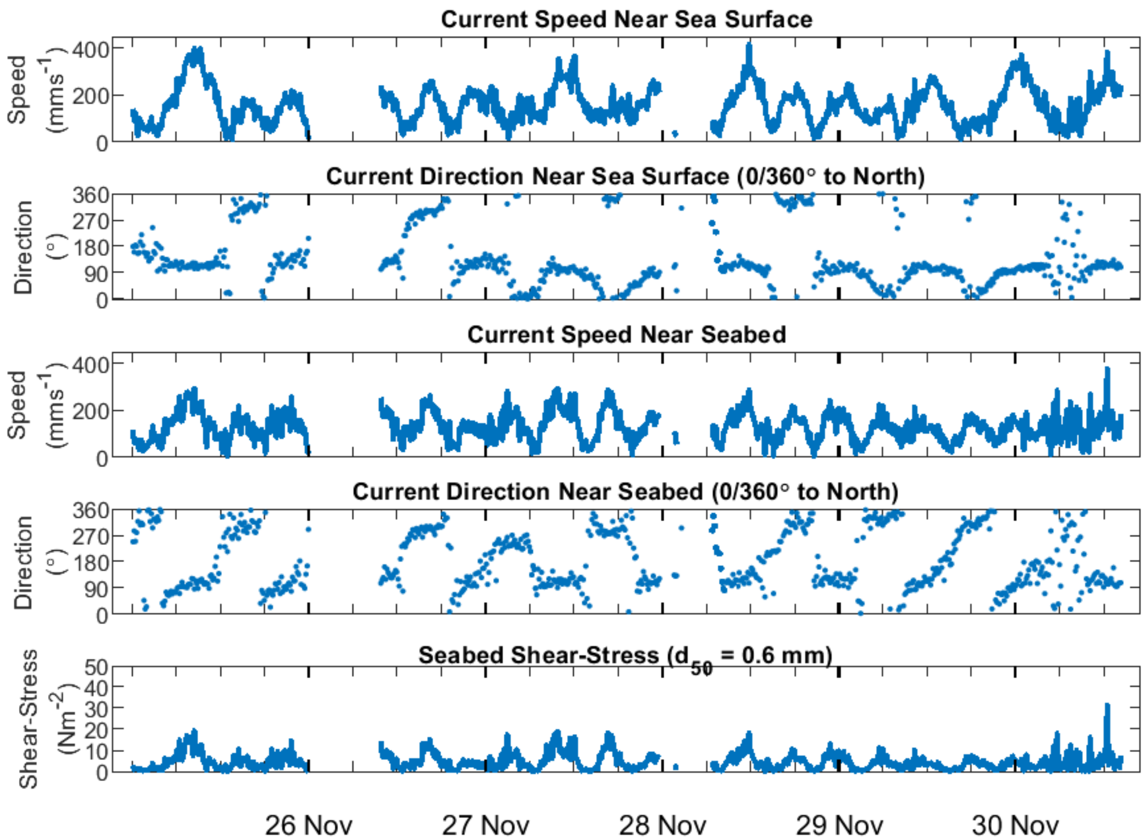


Figure 35 SG3 current speed, direction and shear bed stress 17 to 30 November 2019.

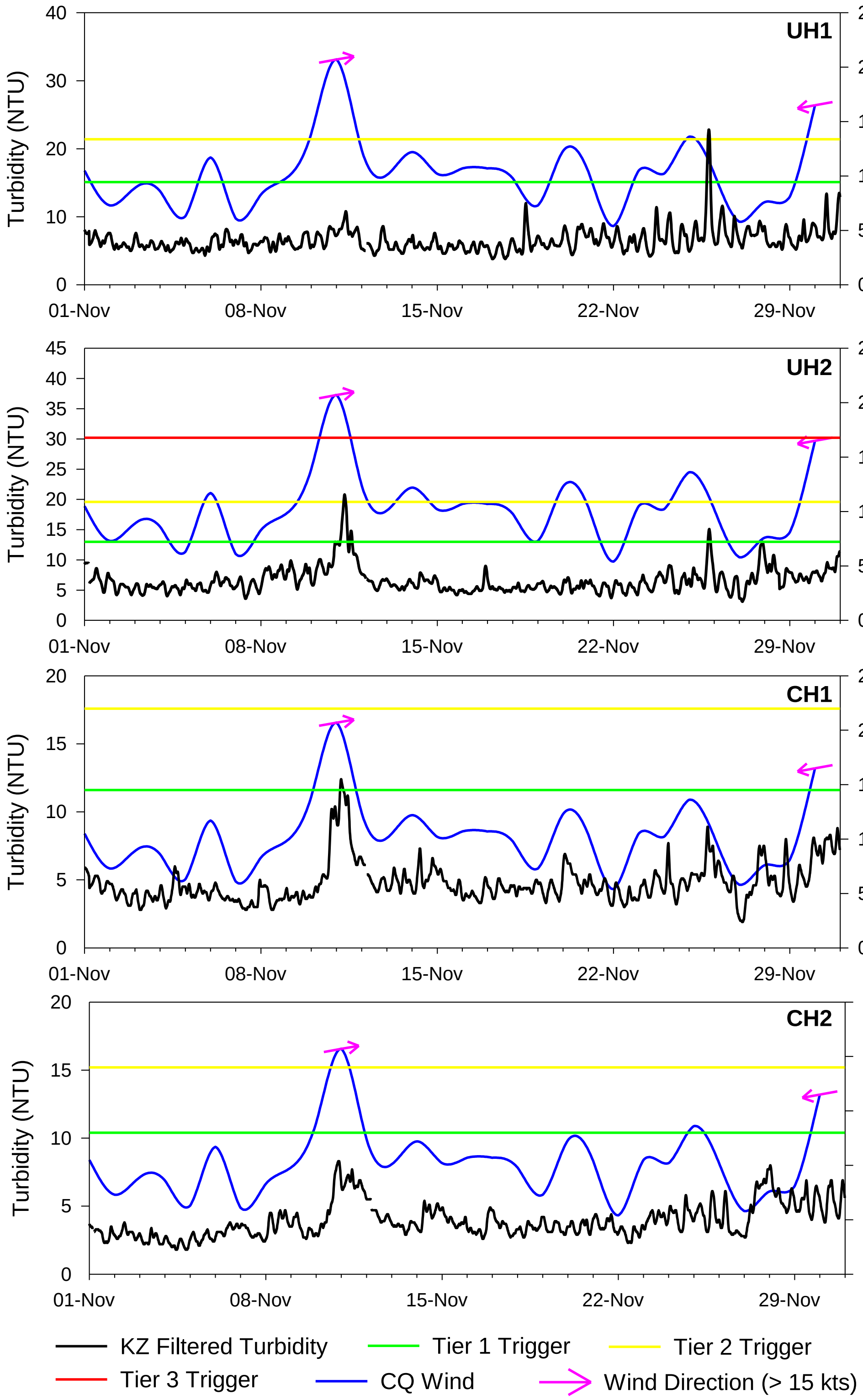


Figure 36 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

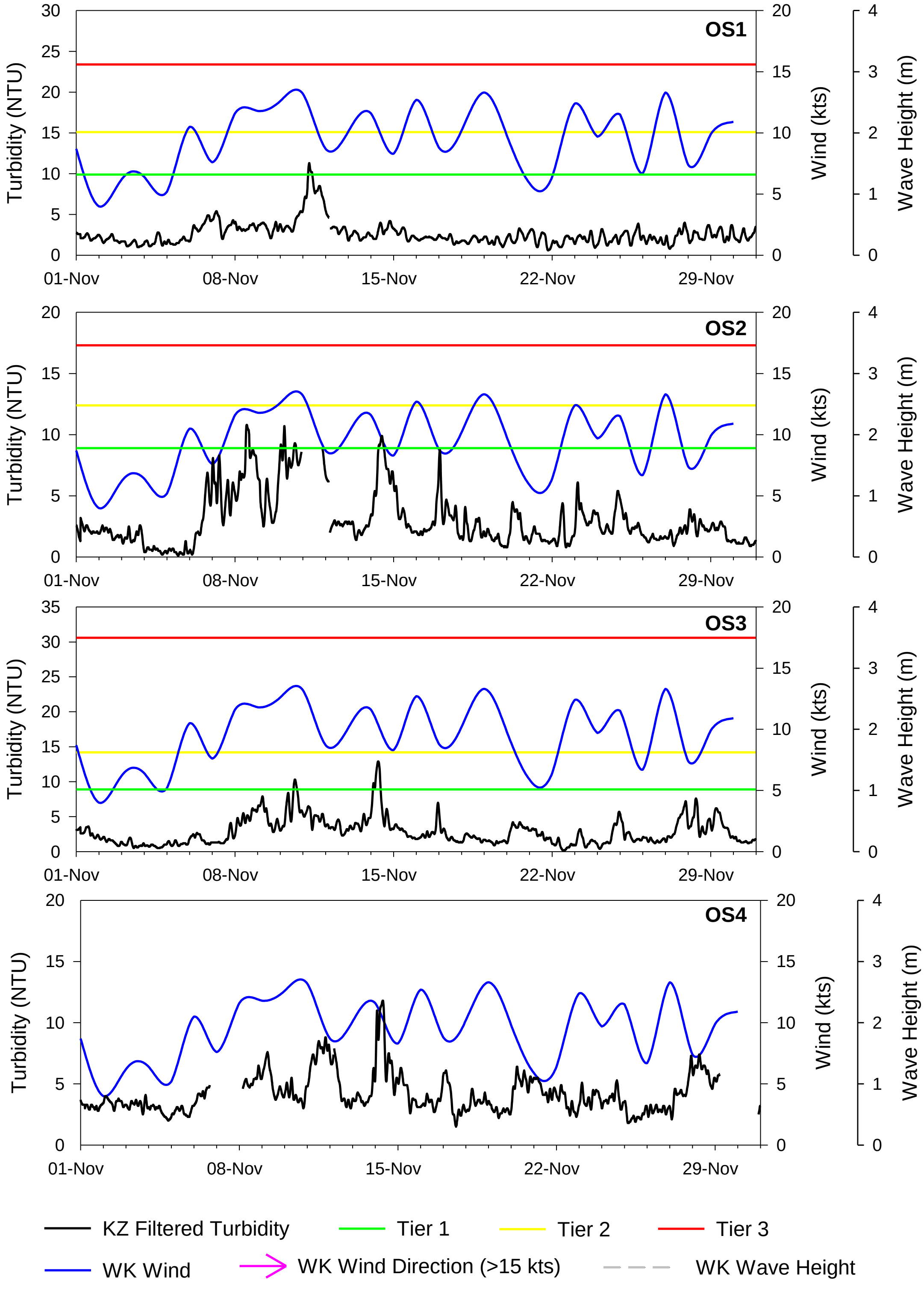


Figure 37 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

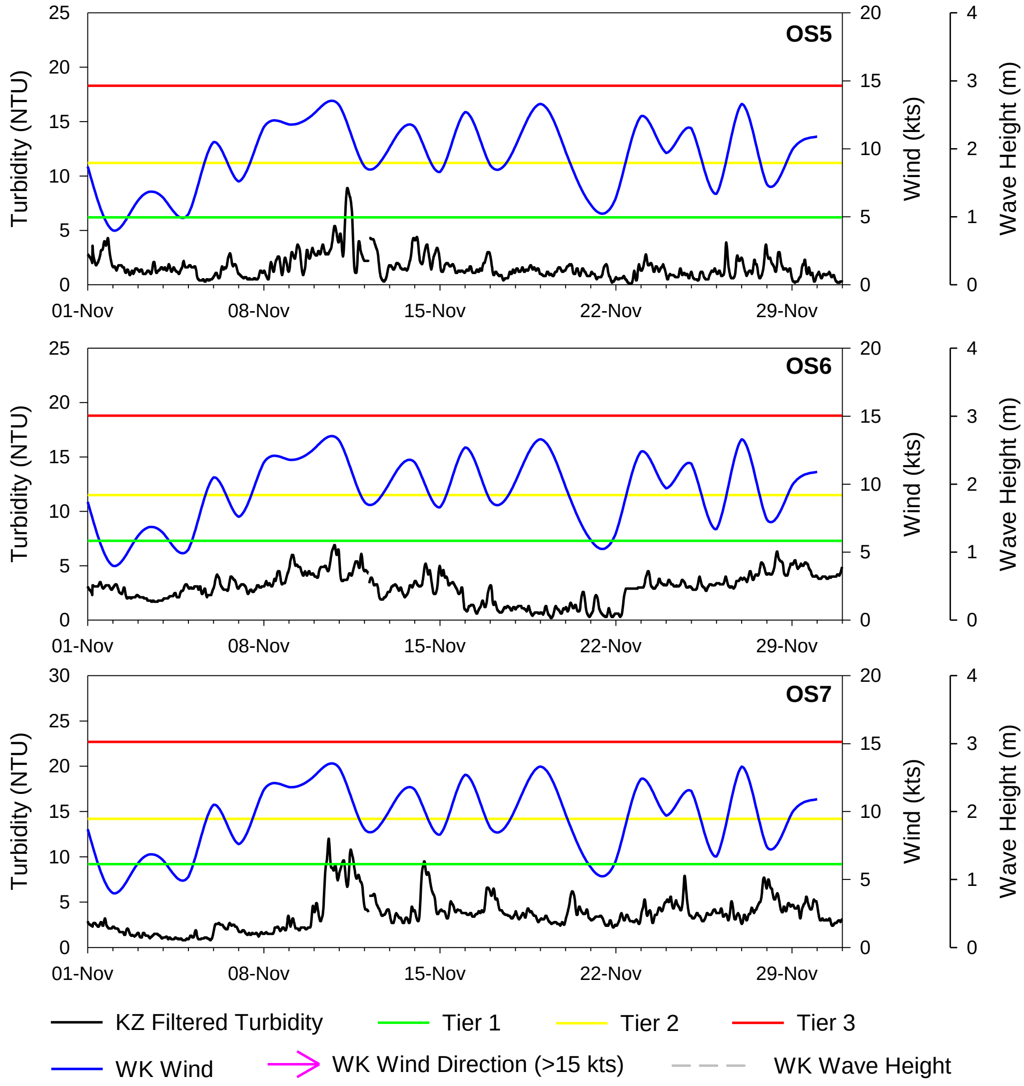


Figure 38 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

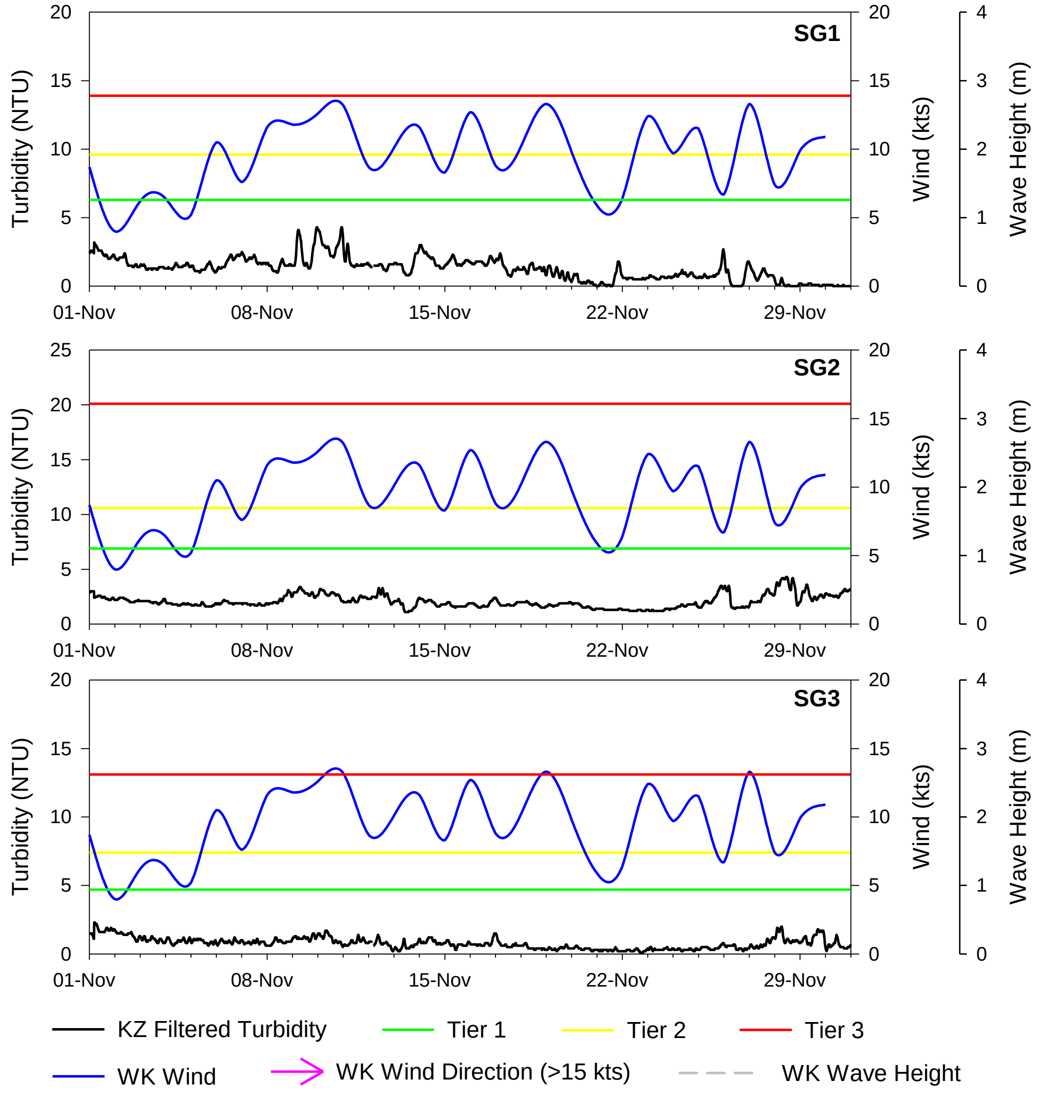


Figure 39 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during November 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 22 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during November 2019 and baseline period 1 November 2016 to 31 October 2017
Values for November are means ± se, range and percentiles (n = 2877 - 2878). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface November	Surface Baseline
UH1	Mean ± se	6.6 ± 0.0	12
	Range	3.8 – 22.8	2 – 155
	99th	12.7	37
	95th	9.1	21
	80th	7.5	15
UH2	Mean ± se	6.6 ± 0.0	9.9
	Range	3.1 – 20.8	2 – 59
	99th	14.7	29
	95th	10.5	19
	80th	7.8	13
CH1	Mean ± se	4.8 ± 0.0	8.8
	Range	1.9 – 12.4	<1 – 50
	99th	10.7	27
	95th	7.7	17
	80th	5.4	12
CH2	Mean ± se	3.9 ± 0.0	7.6
	Range	1.8 – 8.3	<1 – 39
	99th	7.7	22
	95th	6.6	15
	80th	4.7	10

Table 23 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during November 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for November are means ± se, range and percentiles (n = 2878). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface November	Surface Baseline
SG1	Mean ± se	1.3 ± 0.0	4.2
	Range	<1 – 4.3	<1 – 31
	99th	3.9	14
	95th	2.7	9.5
	80th	1.9	6.1
SG2	Mean ± se	2.1 ± 0.0	4.6
	Range	1.1 – 4.3	<1 – 33
	99th	4.1	20
	95th	3.2	10
	80th	2.6	6.9
SG3	Mean ± se	0.8 ± 0.0	3.6
	Range	<1 – 2.3	<1 – 22
	99th	1.9	13
	95th	1.6	7.3
	80th	1.1	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during November 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for November are means ± se, range and percentiles (n = 2576 to 2878). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface November	Surface Baseline
OS1	Mean ± se	2.6 ± 0.0	7.5
	Range	<1 – 11.3	<1 – 99
	99th	8.5	23
	95th	4.9	15
	80th	3.3	9.7
OS2	Mean ± se	3.0 ± 0.0	6.4
	Range	<1 – 10.8	<1 – 36
	99th	9.6	17
	95th	8.0	12
	80th	4.2	8.9
OS3	Mean ± se	2.8 ± 0.0	6.5
	Range	<1 – 12.9	<1 – 110
	99th	9.8	27
	95th	6.3	14
	80th	4.1	8.9
OS4	Mean ± se	4.2 ± 0.0	5.9
	Range	1.5 – 11.8	<1 – 35
	99th	9.9	18
	95th	7.2	13
	80th	5.3	8.1
OS5	Mean ± se	1.6 ± 0.0	4.6
	Range	<1 – 9.9	<1 – 35
	99th	7.0	18
	95th	4.2	11
	80th	2.5	6.1
OS6	Mean ± se	3.0 ± 0.0	4.7
	Range	<1 – 6.9	<1 – 37
	99th	6.1	18
	95th	5.2	11
	80th	4.1	7.1
OS7	Mean ± se	3.6 ± 0.0	6.3
	Range	0.8 – 12	<1 – 48
	99th	9.6	22
	95th	7.7	14
	80th	4.6	9.1

Table 25 Summary of Vision Environment quality control data for November 2019 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.
** Slightly higher concentrations in the field and lab blank, indicating potential sample contamination.*

Parameter	VE Field Blank (µg/L)	VE Lab Blank (µg/L)	Duplicate		
			UH1 (A) (µg/L)	UH1 (B) (µg/L)	Variation (%)
TSS	<3	<3	7	8	13
Dissolved Aluminium (µg/l)	<3	<3	15	21	33
Total Aluminium (µg/l)	<3.2	<3.2	196	210	7
Dissolved Arsenic (µg/l)	<1	<1	<4	<4	ND
Total Arsenic (µg/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Cadmium (µg/l)	<0.05	<0.05	<0.2	<0.2	ND
Total Cadmium (µg/l)	<0.053	<0.053	< 0.21	<0.21	ND
Dissolved Chromium (µg/l)	<0.5	<0.5	<1	<1	ND
Total Chromium (µg/l)	<0.53	<0.53	2	<1.1	ND
Dissolved Cobalt (µg/l)	<0.2	<0.2	<0.6	<0.6	ND
Total Cobalt (µg/l)	<0.21	<0.21	<0.63	<0.63	ND
Dissolved Copper (µg/l)	<0.5	<0.5	<1	<1	ND
Total Copper (µg/l)	<0.53	<0.53	<1.1	<1.1	ND
Dissolved Iron (µg/l)	<20	<20	7	<4	ND
Total Iron (µg/l)	<21	<21	270	290	7
Dissolved Lead µg/l)	<0.10	<0.10	<1	<1	ND
Total Lead (µg/l)	<0.11	<0.11	<1.1	<1.1	ND
Dissolved Manganese (µg/l)	<0.5	<0.5	6.6	5.6	16
Total Manganese (µg/l)	<0.53	<0.53	14.4	15.1	5
Dissolved Mercury (µg/l)	<0.08	<0.08	<0.08	<0.08	ND
Total Mercury (µg/l)	<0.08	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum (µg/l)	<0.2	<0.2	11.5	11.5	0
Total Molybdenum (µg/l)	<0.21	<0.21	10.8	10.8	0
Dissolved Nickel (µg/l)	<0.5	<0.5	<7	<7	ND
Total Nickel (µg/l)	<0.53	<0.53	<7	<7	ND
Dissolved Selenium (µg/l)	<1	<1	<4	<4	ND
Total Selenium (µg/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Silver (µg/l)	<0.1	<0.1	<0.4	<0.4	ND
Total Silver (µg/l)	<0.11	<0.11	<0.43	<0.43	ND
Dissolved Tin (µg/l)	<0.5	<0.5	<5	<5	ND
Total Tin (µg/l)	<0.53	<0.53	<5.3	<5.3	ND
Dissolved Vanadium (µg/l)	<1	<1	1.4	1.2	15
Total Vanadium (µg/l)	<1.1	<1.1	2.1	2.4	13
Dissolved Zinc (µg/l)	<1	<1	<4	<4	ND
Total Zinc (µg/l)	<1.1	<1.1	<4.2	<4.2	ND
Total Phosphorus (µg/l)	<4	<4	18	22	20
Dissolved Reactive Phosphorus (µg/l)	<4	<4	6.8	6.9	1
Total Nitrogen (µg/l)	<110	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN) (µg/l)	<100	<100	<200	<200	ND
Total Ammonia (µg/l)	<10	<10	12	11	9
Nitrate-N + Nitrite-N (µg/l)	<2	<2	2.4	1.8	29
Chlorophyll *a* (µg/L)	<0.2	<0.2	3.4	3.6	6