Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

October 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 October 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 October. Although some data had backlogged and was able to be recovered, overall this resulted in the following real time data loss for the month of October.

- Physiochemical loggers
  - Surface – no (or very minimal 2 hr) missing data
  - KZ and P99 – no missing data
- Metocean
  - Watchkeeper Significant wave height (13 to 22, 25 October)
  - Watchkeeper wind speed and direction (13 to 22, 25-28 October)
- ADCP
  - 13 to 21, 23 and 30 October 2019 (SG1). (68% recovered).
  - 13 to 19, 20, 21, 22 to 26 October 2019 (SG3). (57% recovered).
  - 1 to 31 October 2019 (WatchKeeper). *No complete days of data recorded (22% recovered).*

Although physicochemical data was almost fully recovered, due to their logging configurations, data from the Watchkeeper and ADCP unfortunately will not be able to be recovered.

Climatic Conditions: During October higher rainfall was recorded at Cashin Quay (41.2 mm) than during September 2019 (29.4 mm), with highest daily rainfall recorded on 23 October (8.0 mm). Flows from the Waimakariri River were moderate (<100 m^3/s) during the month with maximum flows occurring on the 1 (477 m^3/s) and 19 October (473 m^3/s). The low volume of these flows is unlikely to have impacted Lyttelton harbour.

Monthly average air temperature (11.6°C) was slightly higher than that recorded in September (10.3°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 2 and 15 October. From the limited offshore data, the highest offshore mean daily winds (15.7 kts) was recorded on 2 October, with greatest mean daily significant wave heights recorded on 27 October (1.3 m). Thus metocean conditions were overall fairly stable for the month of October.

Currents: Unfortunately data availability for all ADCP sites was poor to moderate with long periods of missing data. Maximum near-surface and near-seabed currents at SG1, SG2a (Watchkeeper) and SG3 occurred on different days to each other throughout October. Dominant metocean forces to explain maximum currents was due to corresponding significant wave events (>1m) from a north-easterly direction, moderate to high inshore winds with maximum wind gusts up to 50kts from a south-westerly direction, and high offshore winds from a south-easterly to southerly direction.

Near-surface and near-seabed predominant current movement for SG1 and SG3 tended to be in a northwest and southeast direction, somewhat similar to SG2a near-surface current directions. In contrast, near-seabed currents at SG2a, moved in a north-east and north-west 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 October 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 October (20 to 40 NTU), due to moderate to high inshore and offshore winds and rainfall. Elevated turbidity at most offshore sites was recorded again around 27 to 29 October following a period of large wave heights.

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

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: Mean monthly temperatures were warmer in October than September with all sites displaying a seasonal increase. Consistent with September, 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 October was similar across all sites, as was conductivity. Low flows from the Waimakariri River do not appear to have impacted conductivity at any sites.

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

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 9 October 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 17.8 m at SG3. No exceedances of WQGs were observed for sub-surface during the October 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 only one site (UH3), which is unlike previous months where all sites typically exceed 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 September, with all sites below 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, but the dissolved and therefore readily bioavailable fraction, remained undetectable. 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 October, 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 October than September associated with the increased day lengths. As such, BPAR at both OS2 and OS3 also increased with many peaks occurring throughout October, when ambient PAR was reasonably high and water turbidity was low.

Sedimentation: Overall accumulation of sediments at both OS2 and UH3 was evident in October. 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 17 mm over the month. Sediment flux at UH3 was more stable with a period of minor erosion occurring in mid-October, followed by slow and steady accumulation of sediments throughout October, resulting in an overall accumulation of 11 mm of sediments.

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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.

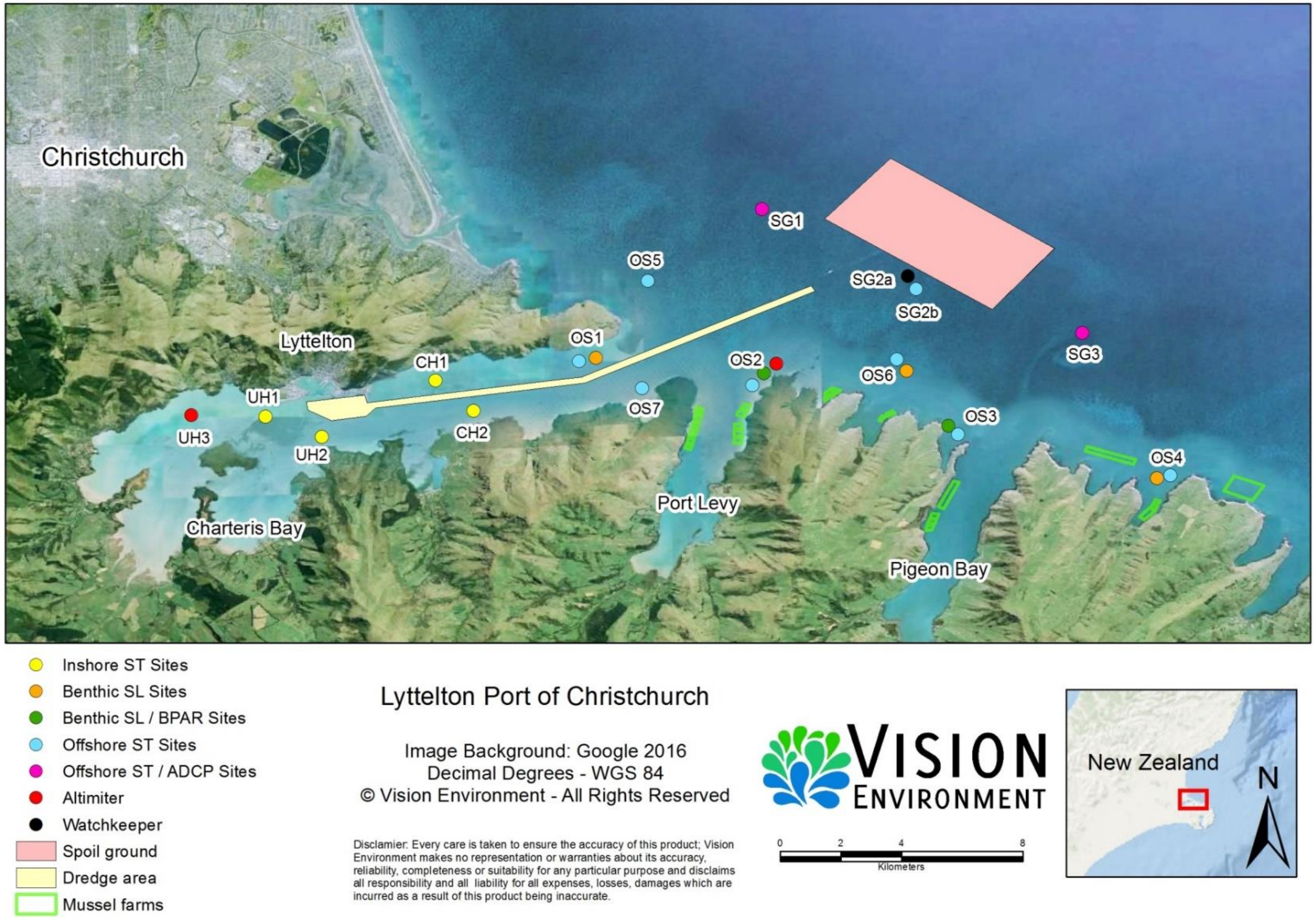


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 October 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 9 October 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 41.2 mm of rainfall was recorded at Cashin Quay during October 2019, an increase from the precipitation recorded in September (29.4 mm). Highest rainfall (8 mm) was recorded on 23 October, followed by 7.4 mm on 24 October (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 October ranged between 81 m^3/s and 477 m^3/s with peaks recorded on the 1 October (477 m^3/s), and the 19 October (473 m^3/s), (ECAN, 2019). However, the low flows recorded in October appeared to have little impact on harbour parameters.

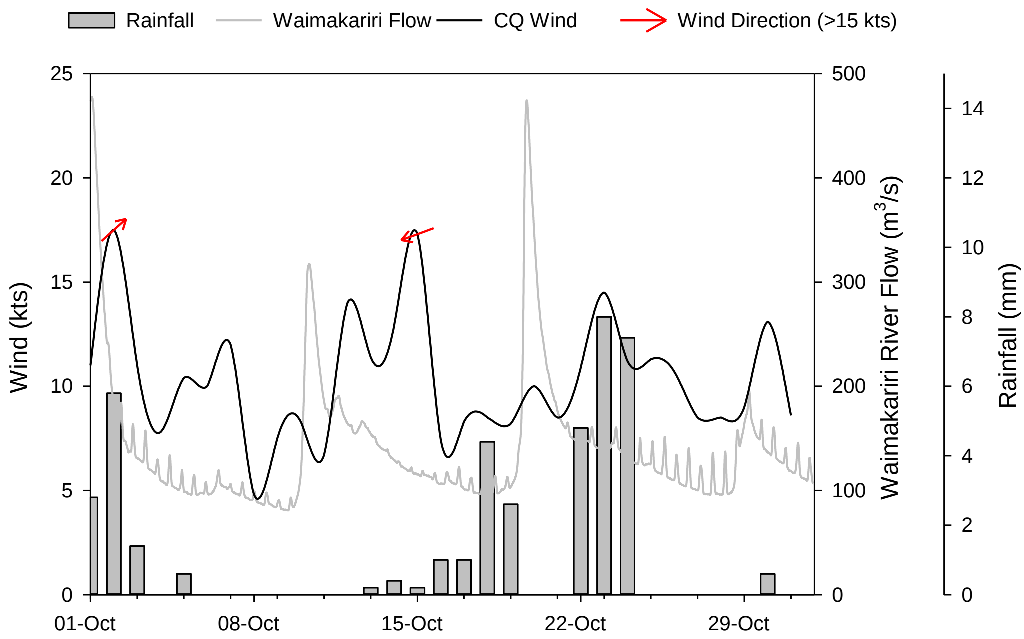


Figure 2 Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during October 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.

Inshore winds during October were generally from a east-north-easterly direction, and west-south-westerly winds (Metconnect, 2019). Highest mean winds speeds (17.5 kts) were recorded on 2 October from a south-westerly direction, with wind gusts > 40 kts occurring on the 2 and 3 October from a south-westerly to south-south-westerly direction. Daily mean wind speeds > 15 kts were also recorded on the 15 October from east-north-easterly direction, while wind gusts > 40 kts were also recorded on the 24 and 30 October.

Daily mean air temperatures at Cashin Quay ranged from 7°C to 18°C, resulting in a monthly mean temperature of 11.6°C, slightly higher than the September mean temperature of 10.3°C (Metconnect, 2019).

Availability of offshore metocean data was poor due to server downtime issues. Interpretation from the available data demonstrates the offshore significant wave height peaked at 1.82 m at 10:00 pm on 27 October, with other significant waves >1m occurring on the 7 and 10 October. Mean daily offshore wind speeds > 15 kts was recorded on the 2 October (15.7 kts) from a south-east-southerly direction (Figure 3).

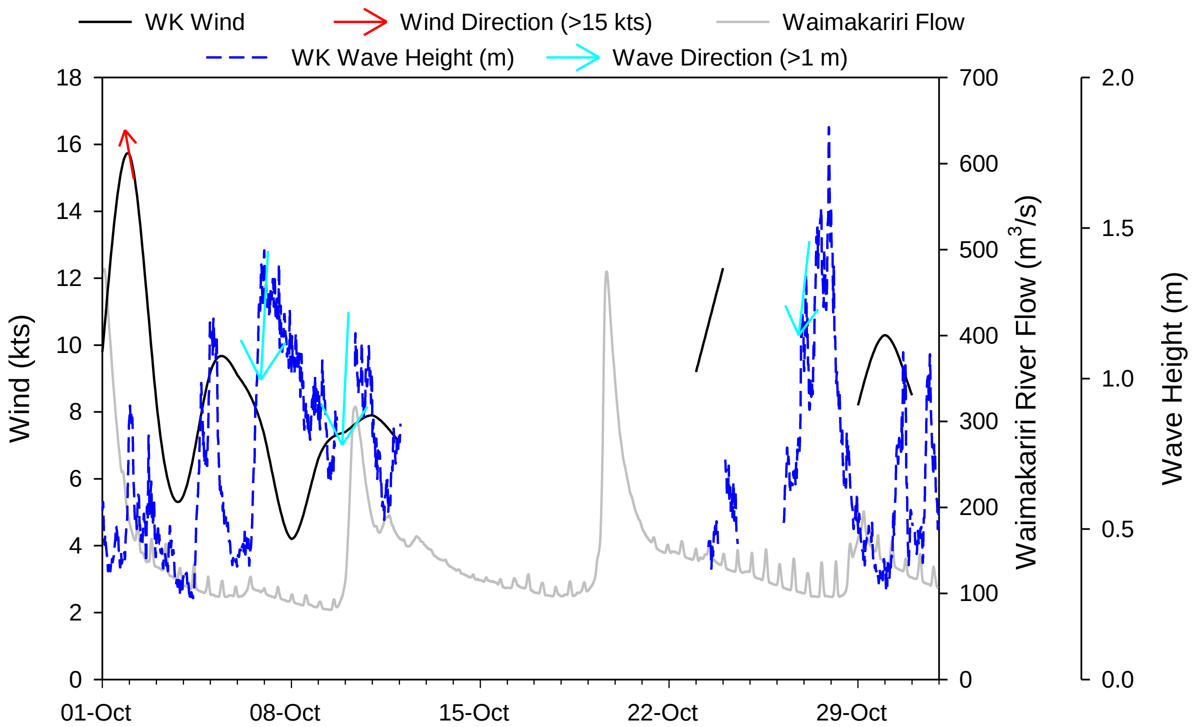


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during October 2019.
Note: Arrows indicate the direction 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. Missing data due to database issues.

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 database issues, October data recovery for SG1 and SG3 was poor (57 to 68%), while SG2a had 22% recovery and no complete days of data recorded. Summary ADCP statistics of available data are presented within Table 2, and Figures 4 to 6. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 33 and 38 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 October 2019.
Note data is skewed due to the amount of missing data.

Parameter	Depth	Site		
		SG1	SG2a	SG3
Minimum current speed (mm/s)	*Near-surface*	1	2	2
	Near-seabed	2	9	2
Maximum current speed (mm/s)	*Near-surface*	360	297	398
	Near-seabed	268	769	334
Mean current speed (mm/s)	*Near-surface*	104	65	123
	Near-seabed	80	121	115
Standard deviation of current speed (mm/s)	*Near-surface*	56	55	74
	Near-seabed	40	95	58
Current speed, 95th percentile (mm/s)	*Near-surface*	208	173	267
	Near-seabed	154	305	217

Maximum near-surface current speeds at SG1 (360 mm/s), SG2a (297 mm/s) and SG3 (398 mm/s) were recorded on the respective days 30, 23 and 31 October during periods of moderate offshore winds (daily mean of 8.5 kts with gusts >15kts) from a south-easterly to southerly direction and inshore winds (daily mean >8.6 kts with maximum gusts of 24 to 50 kts) from an south-westerly to west-south-westerly direction.

Maximum near-seabed current speeds at SG1 (263 mm/s), SG2a (297 mm/s) and SG3 (334 mm/s) were recorded on the different days to near-surface current speeds with maximums recorded on 24, 6, and 28 October respectively. Daily offshore wind speeds of >9 kts from an easterly or southerly direction and maximum significant wave heights >1 m (6 to 7 and 27 to 28 October) could explain the increased near-seabed currents on these dates.

The time-series plots (Figures 33 to 38 in Appendix) illustrate time-varying current direction, whilst the current rose diagrams (Figures 4 to 6) depict the distribution of current direction and velocity in the near-surface and near-seabed layers. 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.

Similar to previous months, currents at SG1 near-surface during October tended to move in a north-northwest (47%) and east-southeast (24.1%) direction, while the near sea-bed currents were slightly more dominant from the northwest: 16.1%. A similar pattern was evident at SG3, with near-surface current moving in a northwest (34.7%) and east-southeast (33.3%) direction, and near-seabed currents moving in a west-northwest (39.2%) and east-southeast (33.4%) direction.

Current movements at SG2a were found to be in a more east/west direction, similar to previous months. Near-surface currents moved in a north-northwest (31.4%) and east-northeast (35.7%) direction, while near-seabed currents moved in a west-northwest (27%) and east-southeast (27.3%) direction.

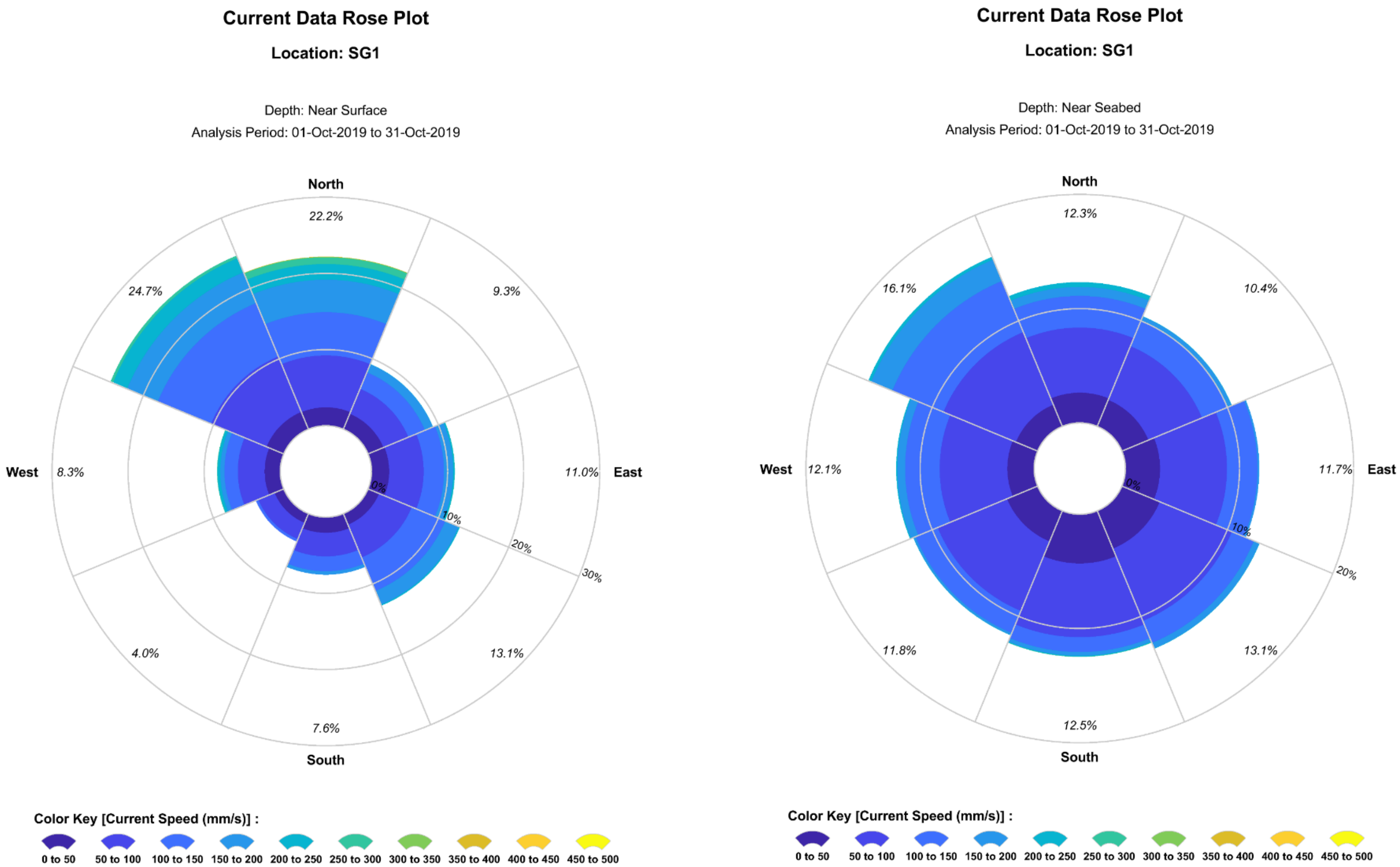
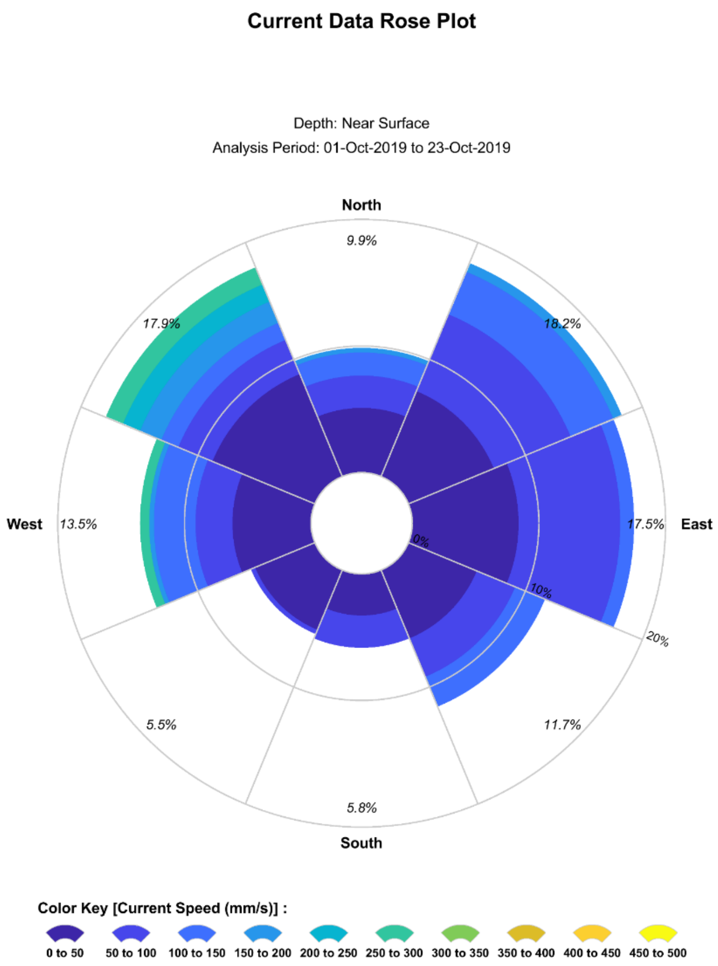


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during October 2019.
Speed intervals of 50 mm/s are used.



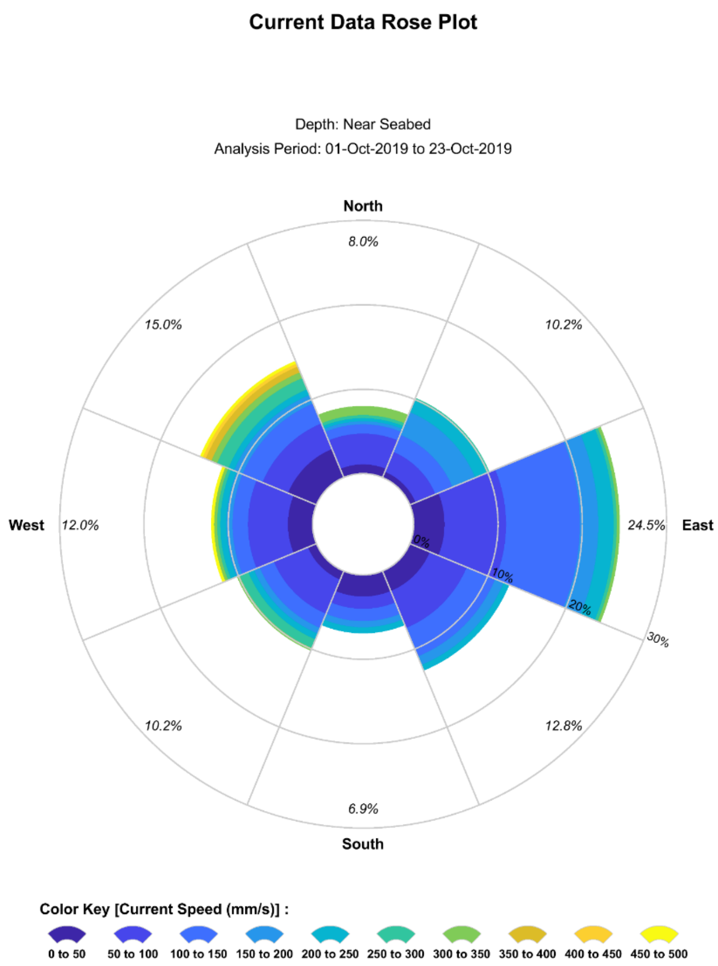


Figure 5 Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during October 2019.
Speed intervals of 50 mm/s are used.

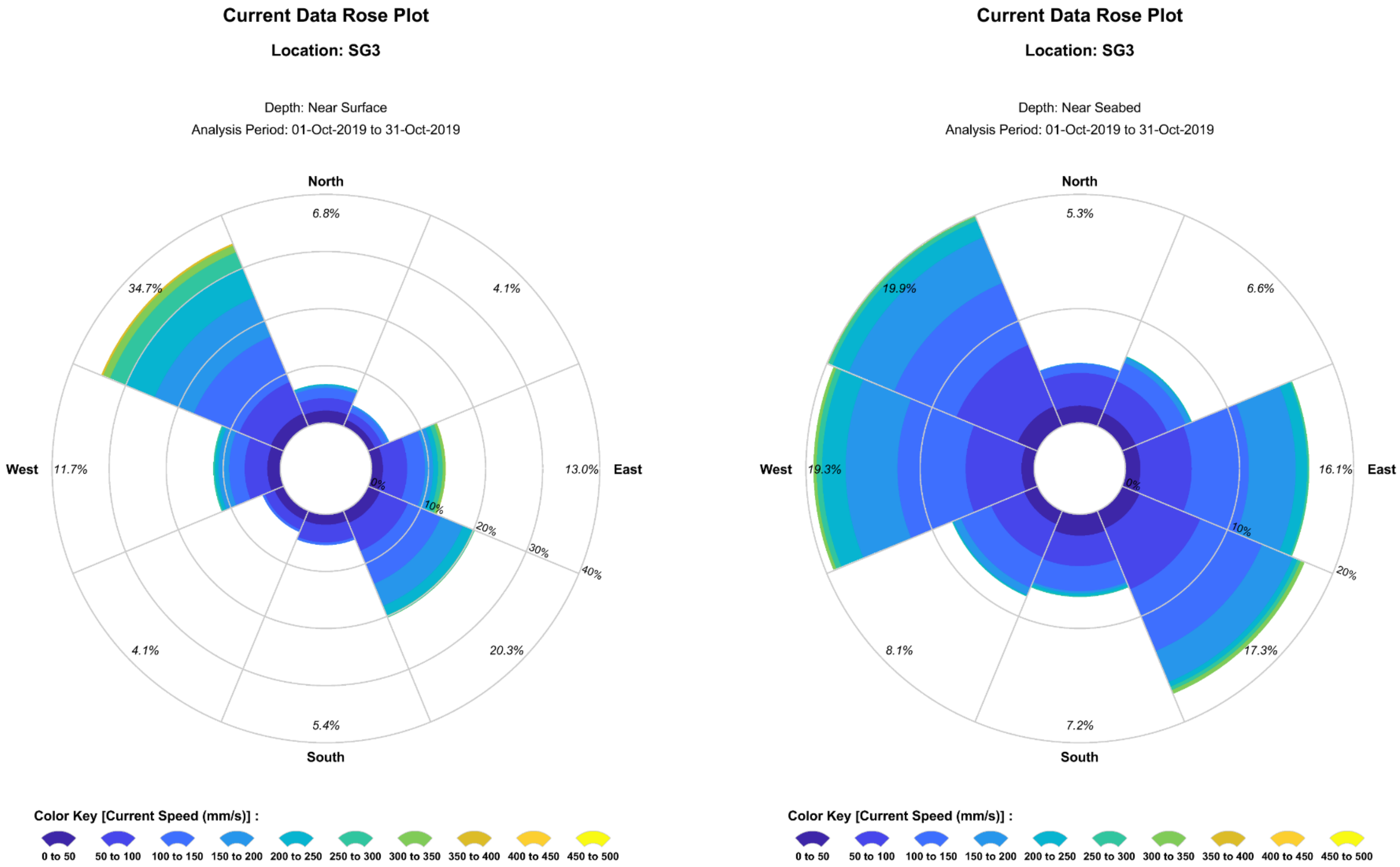


Figure 6 Near-surface and near-seabed current speed and direction at SG3 during October 2019.
Speed intervals of 50 mm/s are used.

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 9 October 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 September 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.

October Turbidity:

Consistent with previous monitoring months, mean surface turbidity values were typically highest (monthly means of 3.8 to 6.6 NTU) at the inshore monitoring sites (Table 3 and Figure 7). Further offshore, the spoil ground sites (Table 4) exhibited lower surface turbidity values (1.1 to 2.3 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 (1.7 to 4.1 NTU) during October (Table 5).

During October turbidity across the inner harbour was relatively low (< 10 NTU) with exception of short lived turbidity peaks of <50 NTU on 2 and 30 October at UH1 and UH2 in response to increased inshore winds and a localised period of higher rainfall (Figure 8).

Surface turbidity at the nearshore sites (OS1 to 4 and OS7) peaked on and during 6, 16 to 18 and 27 to 29 October, immediately following periods of high inshore windspeeds, rainfall and increased wave heights and possibly offshore winds where data was not available.

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks were also evident between 15 to 20 October, although less pronounced than at the inshore sites (Figures 11 and 12) 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.

Benthic:

Data return was gained for the majority of benthic sites during October. However, turbidity data was not able to be gained from OS1 and partially OS6 benthic due to sonde malfunction. For the remaining sites, benthic turbidity data corresponded with surface measurements, with increased turbidity evident during early and late October, during periods of high winds and waves where data was available (Figure 7).

Table 3 Mean turbidity and statistics at inshore water quality logger sites during October 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for October are means ± se, range and percentiles (n = 2953 to 2969) Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface October	Surface Baseline
UH1	Mean ± se	5.7 ± 0.0	12
	Range	2.5 – 40	-
	99th	11.3	39
	95th	8.4	22
	80th	6.7	15
UH2	Mean ± se	6.6 ± 0.1	10
	Range	2.8 – 45.4	-
	99th	18	32
	95th	10.9	20
	80th	7.7	13
CH1	Mean ± se	4.5 ± 0.0	9
	Range	2.0 – 9.8	-
	99th	8.1	29
	95th	7	18
	80th	5.6	12
CH2	Mean ± se	3.8 ± 0.0	8
	Range	1.0 – 8.2	-
	99th	6.4	24
	95th	5.7	16
	80th	4.4	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during October 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for October are means ± se, range and percentiles (n = 2959 to 2970). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface October	Surface Baseline
SG1	Mean ± se	2.3 ± 0.0	4.2
	Range	<1 – 10.8	-
	99th	5.7	14
	95th	3.9	10
	80th	2.9	6.2
SG2	Mean ± se	2.0 ± 0.0	4.6
	Range	1.1 – 5.1	-
	99th	3.7	20
	95th	2.9	11
	80th	2.3	7.0
SG3	Mean ± se	1.1 ± 0.0	3.6
	Range	<1 – 5.7	-
	99th	3.2	13
	95th	2.2	7.7
	80th	1.5	4.8

Table 5 Mean turbidity and statistics at offshore water quality logger sites during October 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for October are means ± se, range and percentiles (n = 225 to 2970). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface October	Surface Baseline	Benthic October
OS1	Mean ± se	4.1 ± 0.0	7.5	6.7 ± 0.2
	Range	<1 – 12.8	-	1.7 – 35.8
	99th	9.5	24	15.8
	95th	8.1	16	12.3
	80th	6.0	10	8.5
OS2	Mean ± se	2.4 ± 0.0	6.4	17.0 ± 0.3
	Range	<1 – 9.5	-	0.6 – 175
	99th	6.3	18	86.6
	95th	4.6	13	59.1
	80th	3.2	9.0	25.2
OS3	Mean ± se	2.9 ± 0.0	6.6	14 ± 0.2
	Range	<1 – 12	-	<1 – 153
	99th	8.6	27	59.2
	95th	6.0	15	38.7
	80th	3.8	8.9	20.7
OS4	Mean ± se	3.1 ± 0.0	5.9	20.8 ± 0.5
	Range	<1 – 23.4	-	<1 – 723
	99th	10.8	20	128.6
	95th	7.3	13	68.4
	80th	4	8.3	31.4
OS5	Mean ± se	1.7 ± 0.0	4.6	–
	Range	<1 – 8.6	-	–
	99th	4.7	19	–
	95th	3.3	11	–
	80th	2.4	6.4	–
OS6	Mean ± se	2.3 ± 0.0	4.7	27 ± 0.4
	Range	<1 – 9.9	-	2.2 – 362.6
	99th	6	19	118
	95th	4.1	12	65.1
	80th	3.1	7.2	38.5
OS7	Mean ± se	3.2 ± 0.0	6.4	–
	Range	<1 – 13.1	-	–
	99th	7.5	23	–
	95th	5.4	14	–
	80th	3.9	9.2	–

Comparison to Baseline:

Mean surface turbidity values during October were lower than the values calculated from the baseline monitoring period (Tables 3 to 5, Figures 8 to 12).

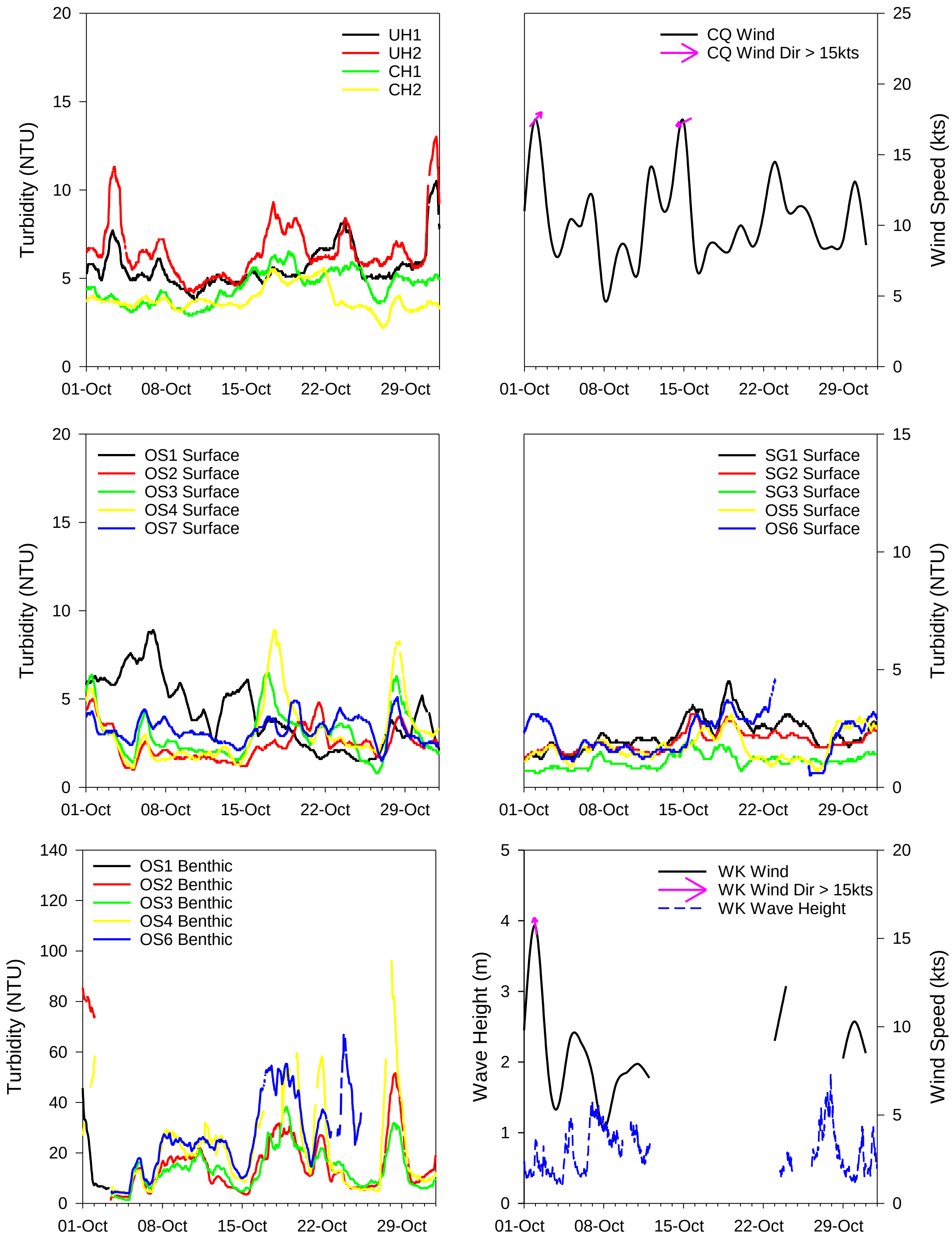


Figure 7 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots. No data available for OS1 benthic due to sonde malfunction.

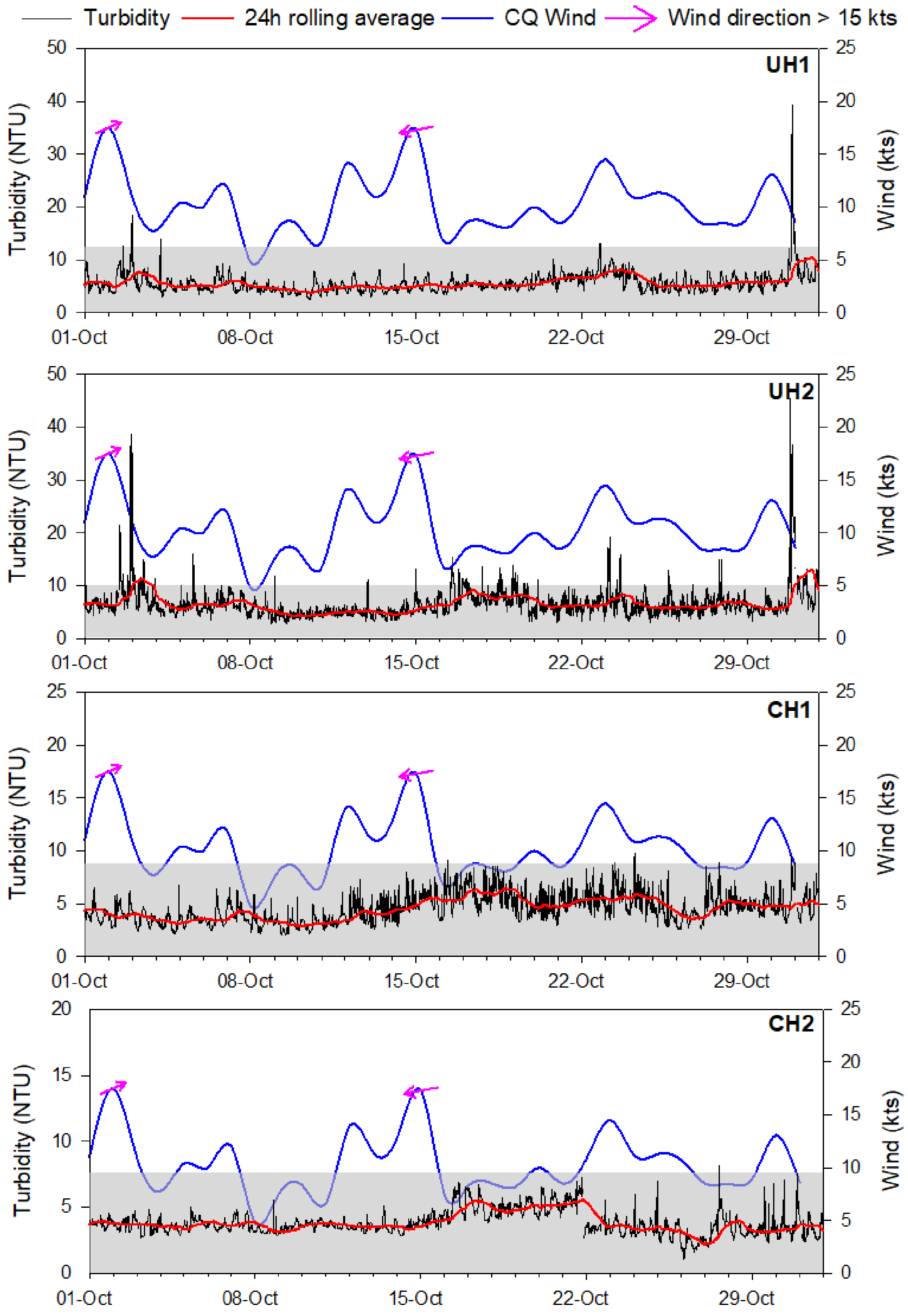


Figure 8 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during October 2019.
Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

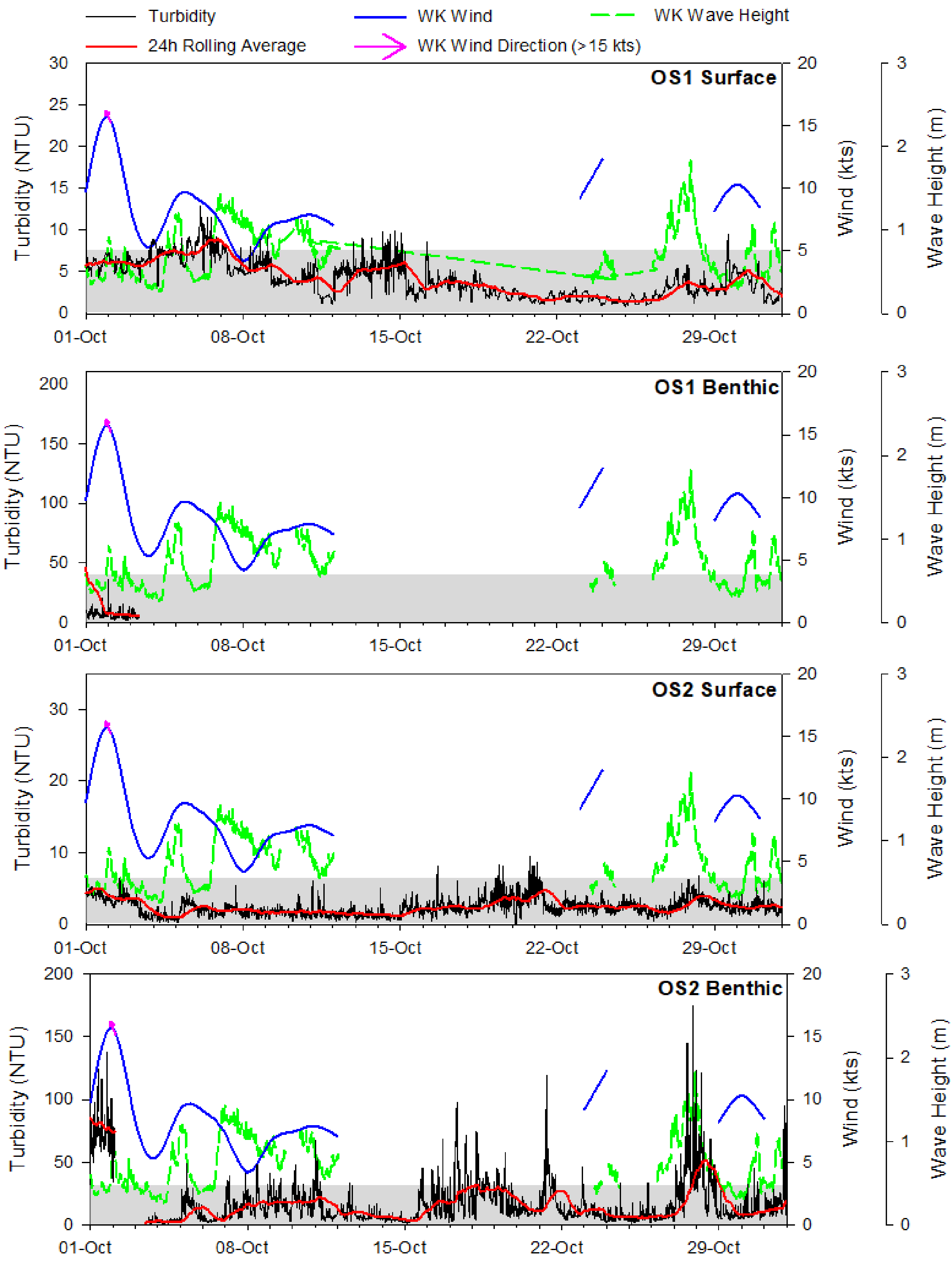


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity. No data available for OS1 benthic due to sonde malfunction.

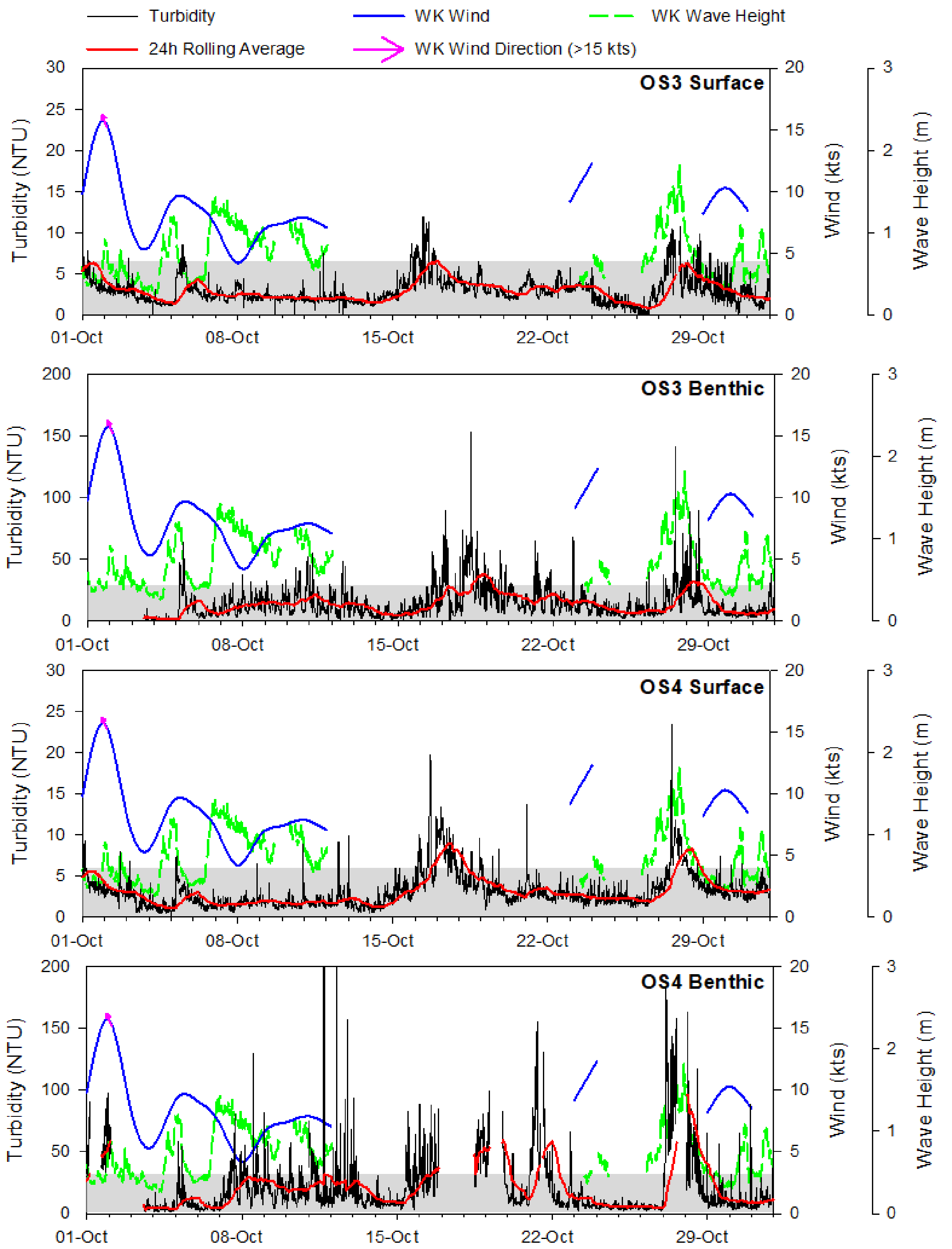


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

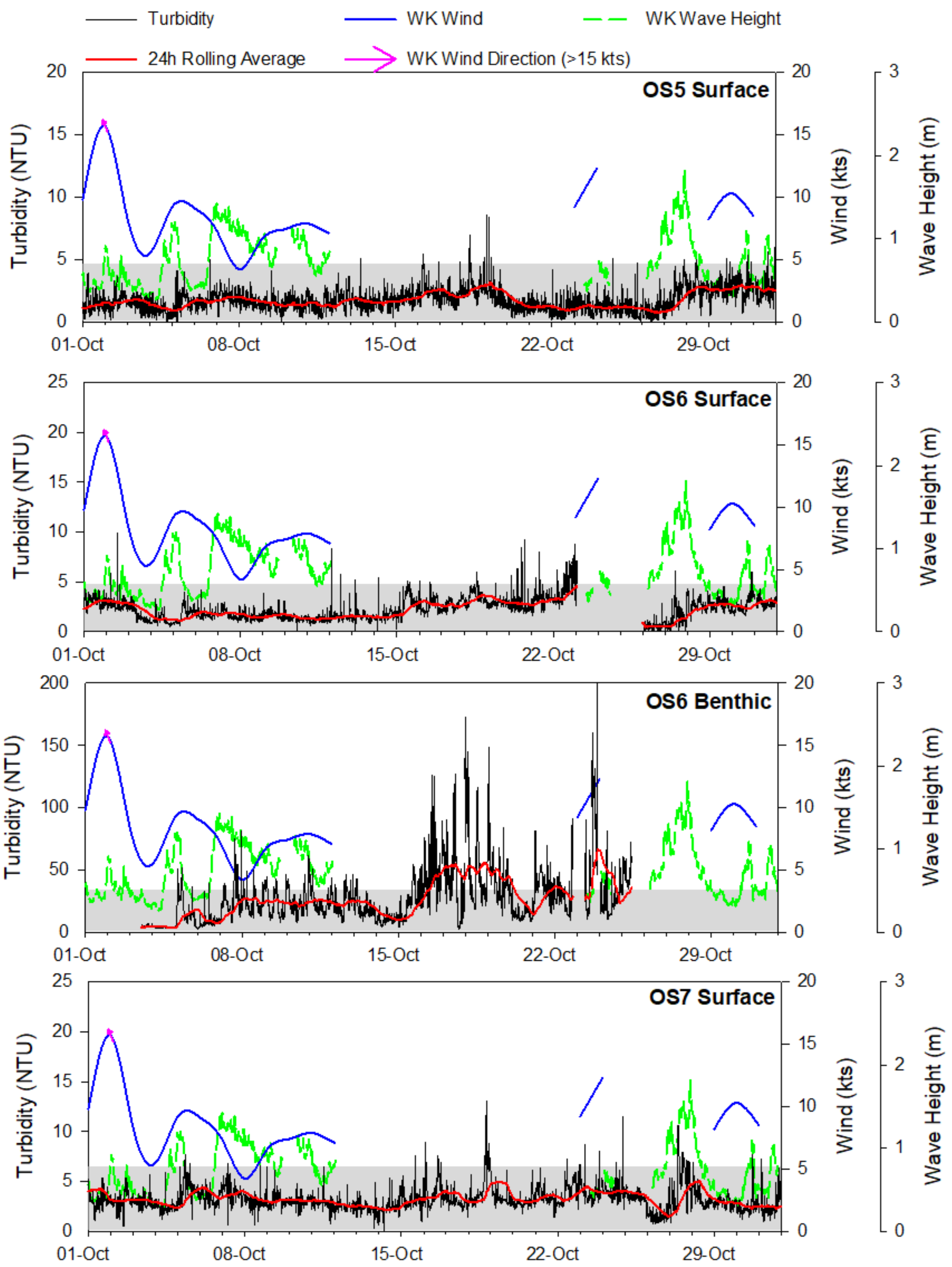


Figure 11 Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

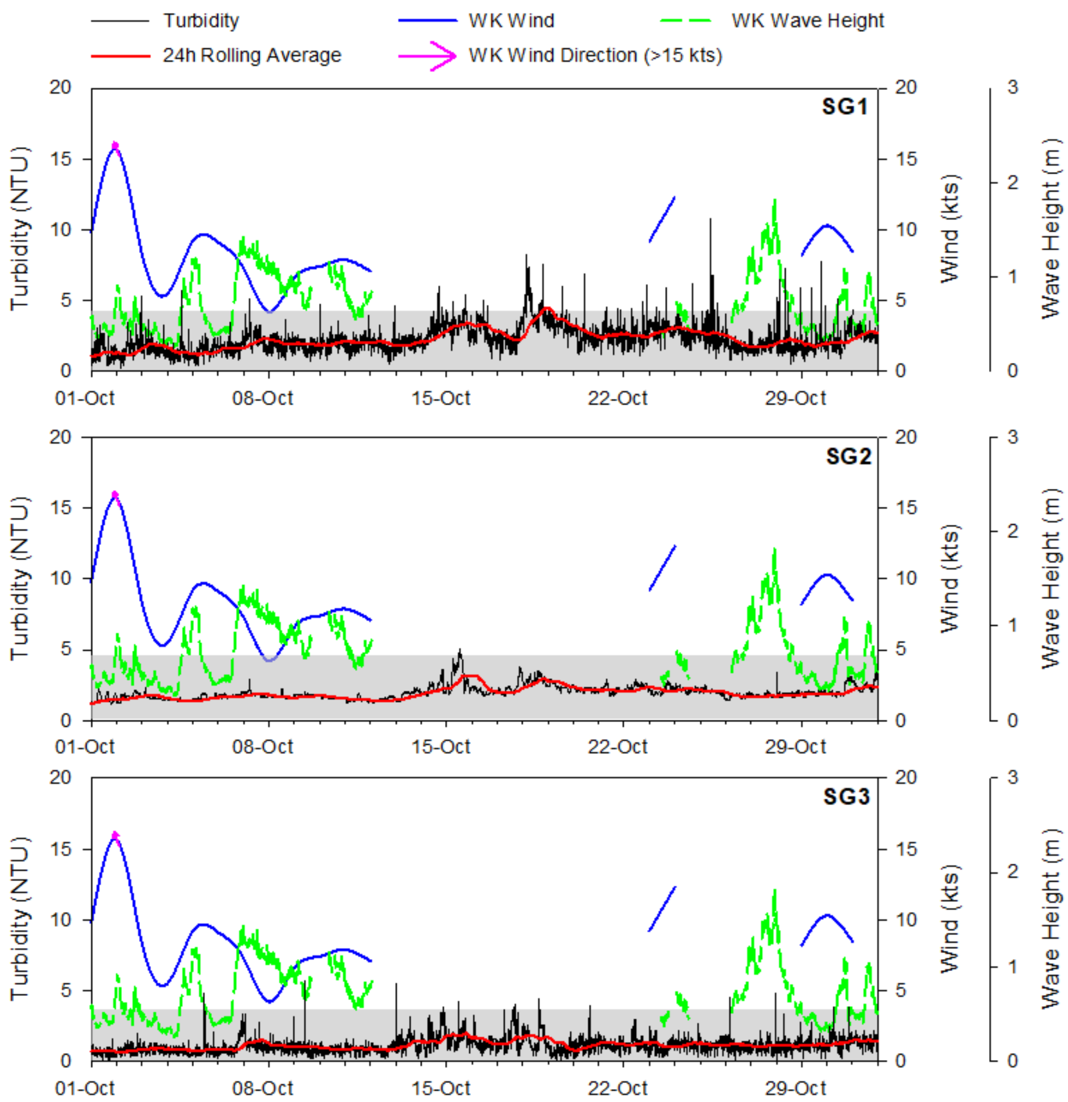


Figure 12 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during October 2019. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

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 October the Tier 3 intensity values were not exceeded at any site within the monitoring network (Table 7, Figures 13 to 15).

Table 7 Tier 3 intensity value exceedances and maximum hour counts during October 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 October 2019 (Table 8).

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

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

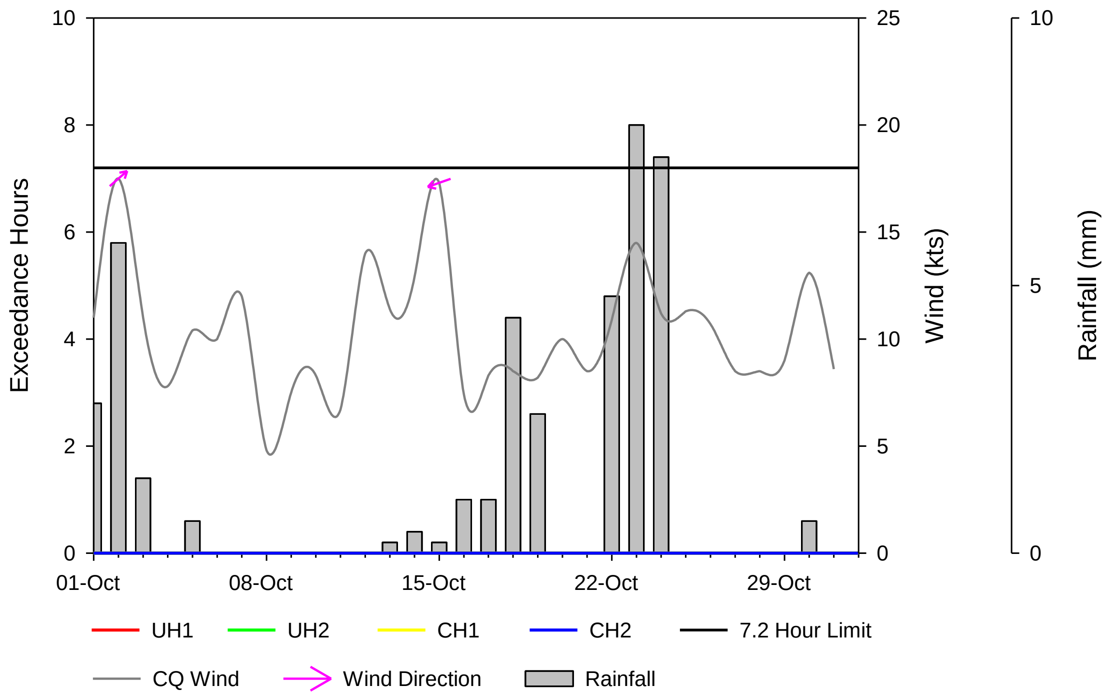


Figure 13 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during October 2019.

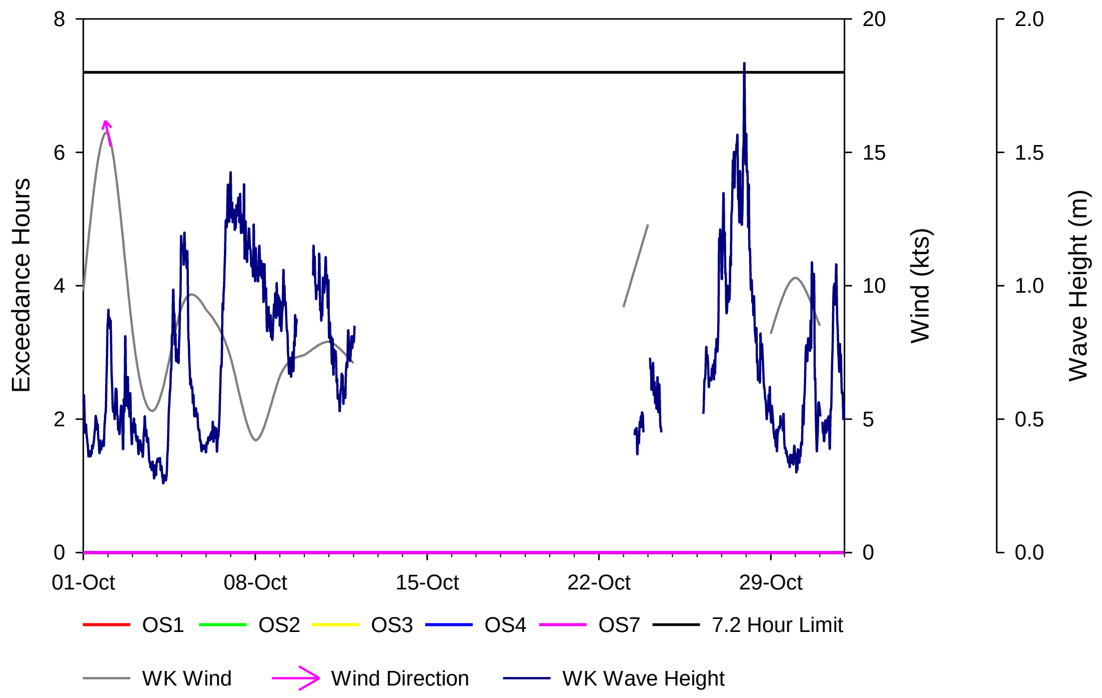


Figure 14 Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during October 2019.
Note there is no trigger value for the reference site OS4.

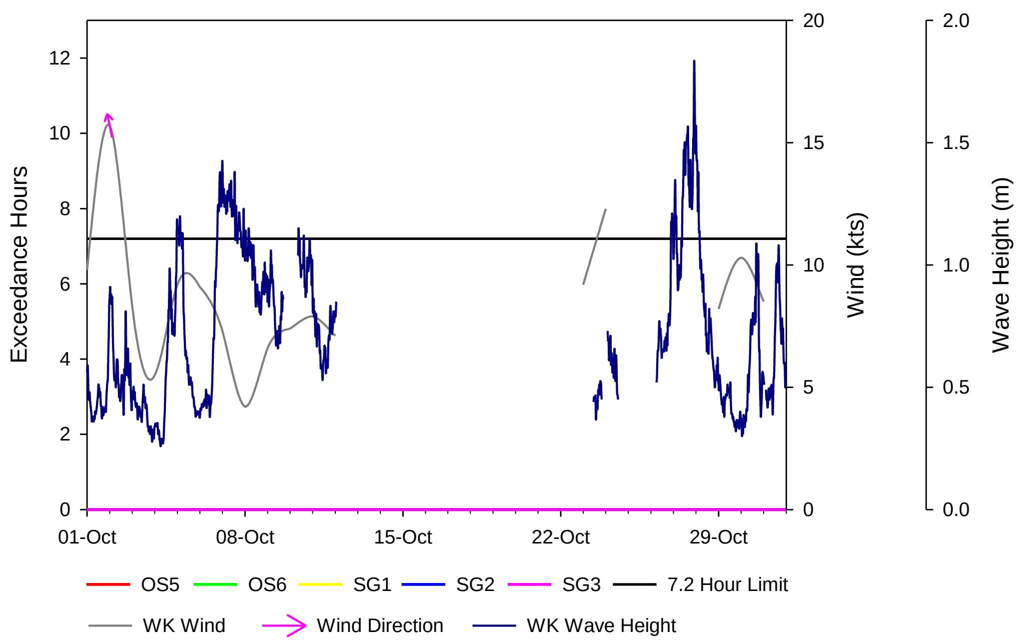


Figure 15 Tier 3 allowable hour counts at OS5, OS6, SG1, SG2b and SG3 after exceedance of the intensity values during October 2019.

3.2.3 Temperature

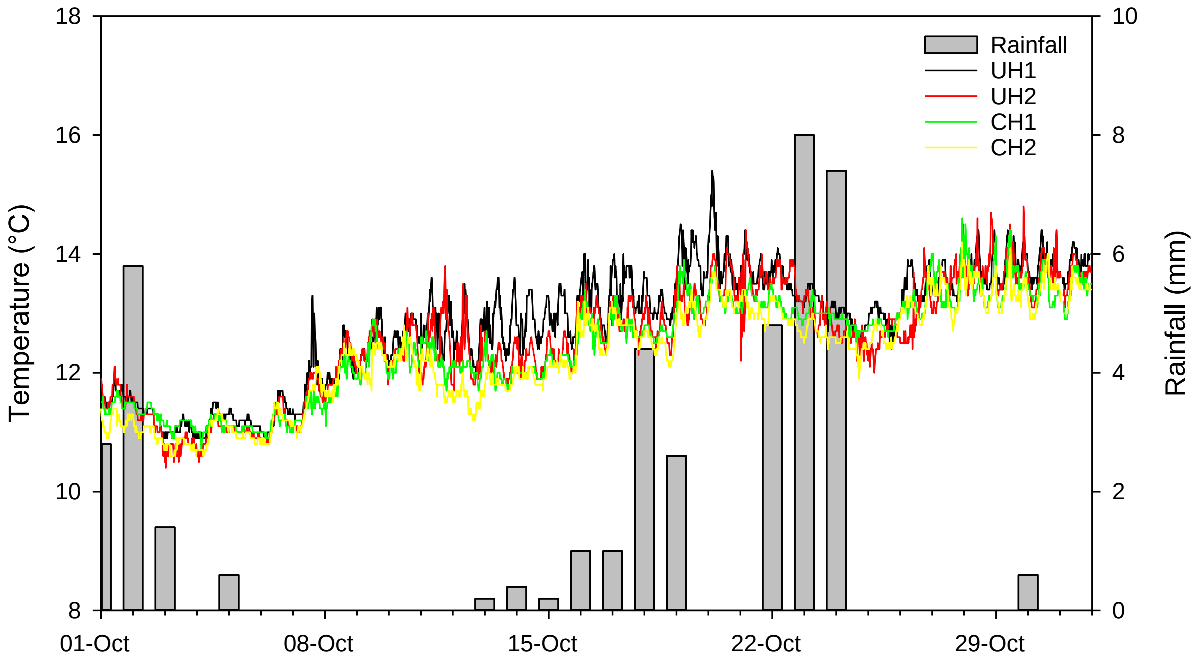
Mean monthly sea surface temperatures during October (11.1 to 12.8 °C) were slightly warmer than those experienced during September (10.1 to 10.6°C) indicating the continuation of seasonal warming noted in late September (Table 9). The temperature trend for October was an overall increase at all sites, with temporary lower temperatures on the 3 and 25 October following periods of rainfall and lower air temperatures (Figures 16 and 17).

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during October 2019.
Values are means ± se (n = 226 to 2976).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	12.8 ± 0.0	–
UH2	12.5 ± 0.0	–
CH1	12.4 ± 0.0	–
CH2	12.3 ± 0.0	–
SG1	11.8 ± 0.0	–
SG2	11.8 ± 0.0	–
SG3	11.7 ± 0.0	–
OS1	12.2 ± 0.0	11.0 ± 0.0
OS2	11.9 ± 0.0	11.4 ± 0.0
OS3	11.8 ± 0.0	11.3 ± 0.0
OS4	11.6 ± 0.0	11.3 ± 0.0
OS5	11.9 ± 0.0	–
OS6	11.8 ± 0.0	11.3 ± 0.0
OS7	12.1 ± 0.0	–

Similar to September, slightly warmer temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites during October. 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.



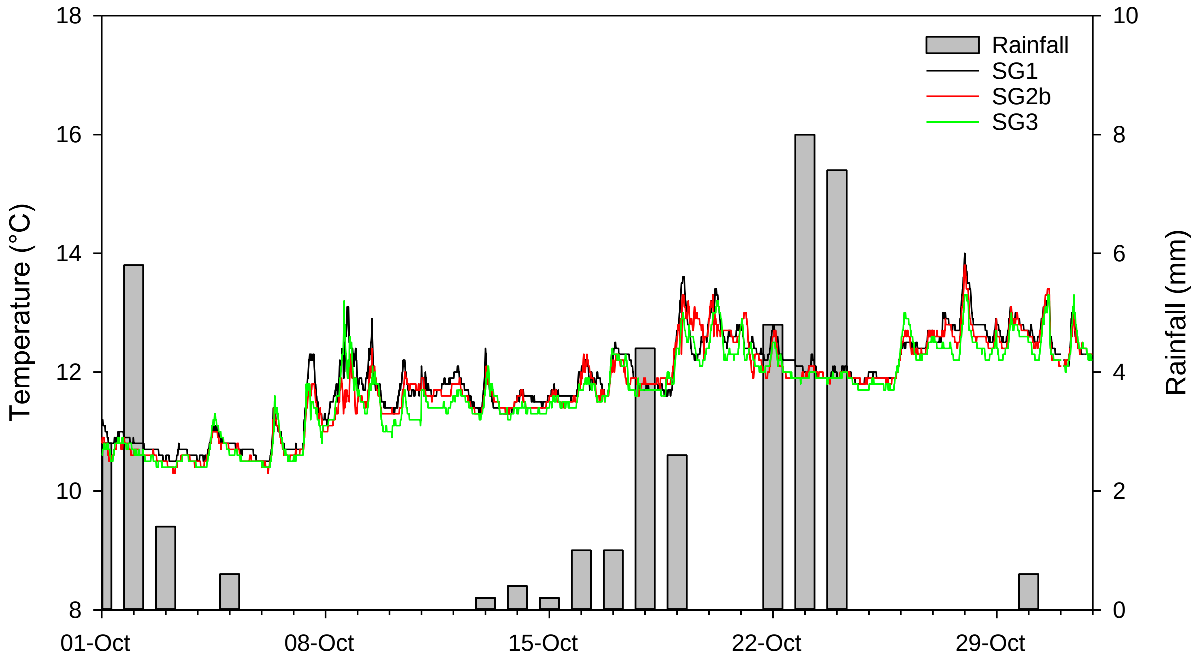
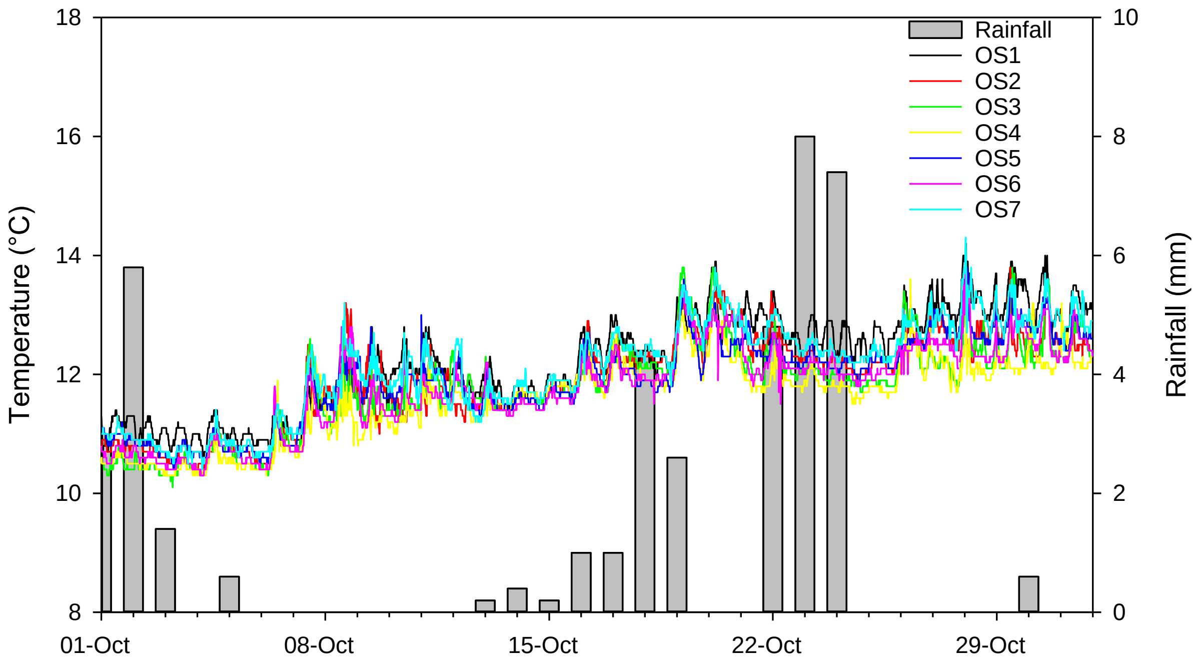


Figure 16 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during October 2019.



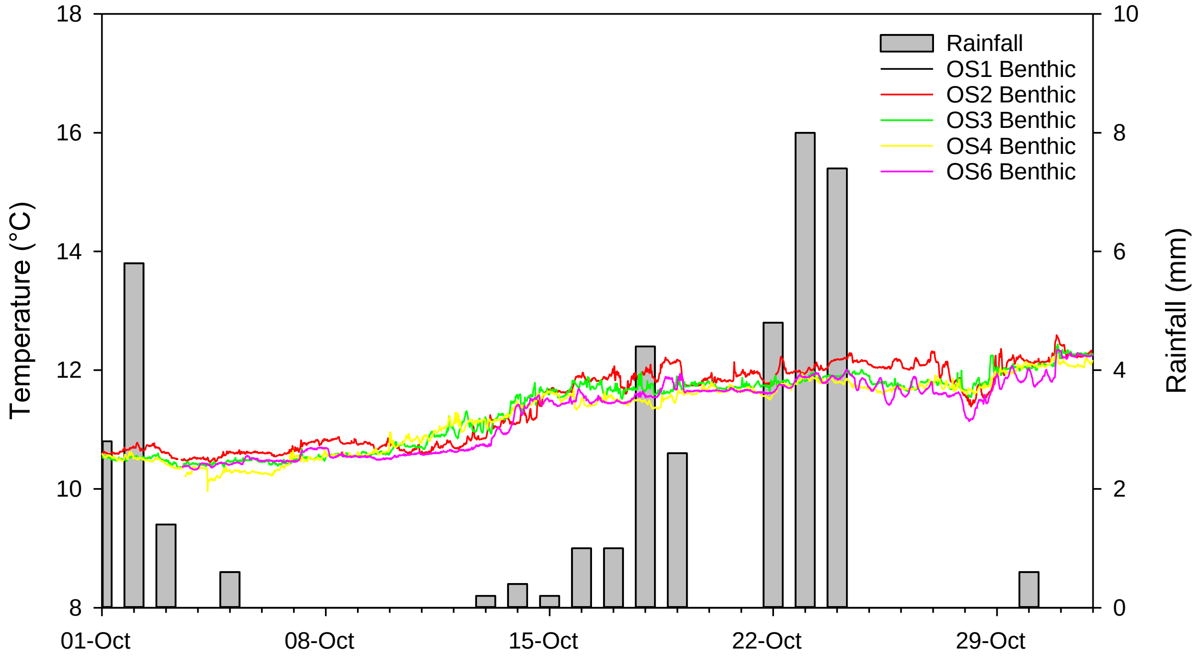


Figure 17 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during October 2019.
No data available for OS1 benthic due to sonde malfunction.

3.2.4 pH

The pH remained reasonably consistent across surface and benthic sites, with monthly means ranging between 7.8 and 8.2 (Table 10, Figures 18 and 19).

Table 10 Mean pH at inshore, spoil ground and offshore water quality sites during October 2019. *Values are means ± se (n = 173 to 2974).*

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

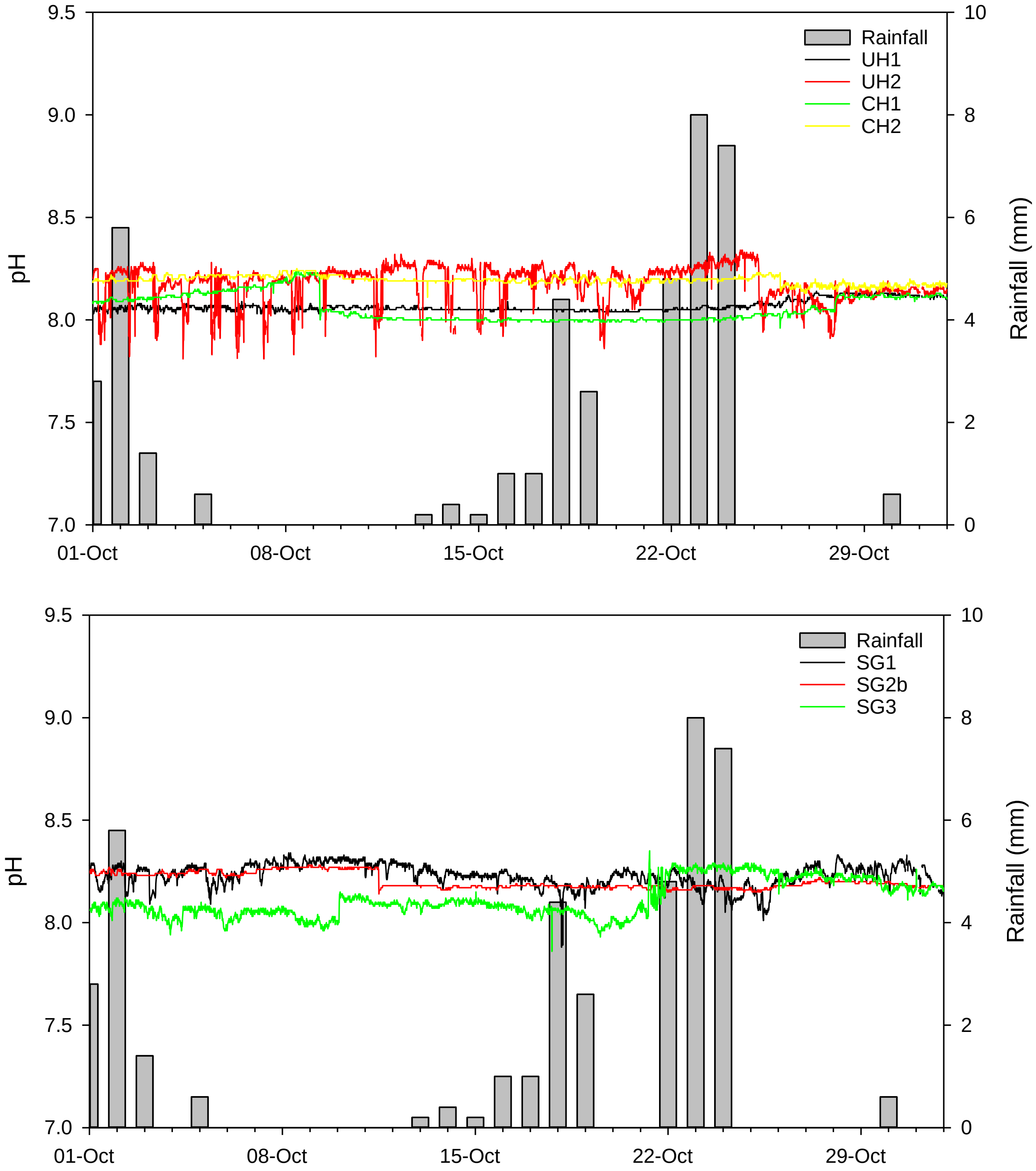
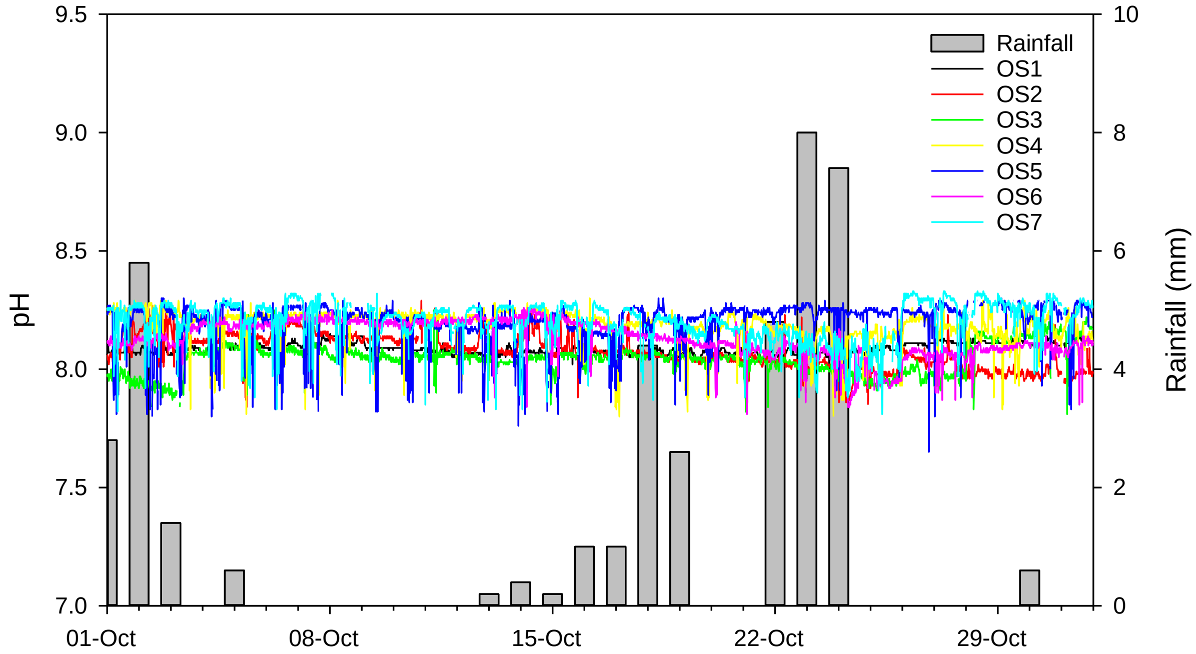


Figure 18 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2019.



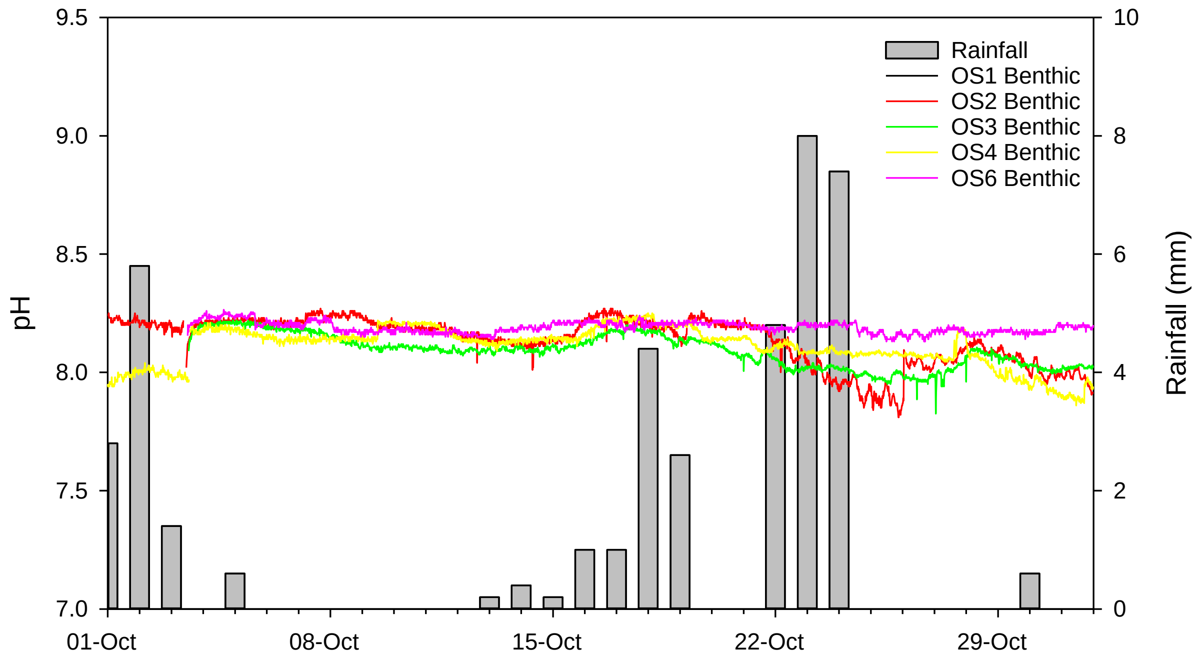


Figure 19 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during October 2019.
No data available for OS1 benthic due to sonde malfunction.

3.2.5 Conductivity

Surface conductivity in October ranged from 50.6 mS/cm to 54.0 mS/cm (Table 11, Figure 20 and 21), with benthic conductivity at similar levels, ranging from 52.9 mS/cm to 53.5 mS/cm.

Inner harbour sites recorded slightly lower mean conductivity values than offshore and spoil ground sites, which may reflect localised runoff. Low flows from the Waimakariri River were recorded during October and did not appear to have impacted conductivity at any sites.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during October 2019.
Values are means ± se (n = 2138 to 2971). ND no data due to sonde malfunction

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	50.6 ± 0.0	–
UH2	52.3 ± 0.0	–
CH1	51.6 ± 0.0	–
CH2	51.5 ± 0.0	–
SG1	53.4 ± 0.0	–
SG2	51.6 ± 0.0	–
SG3	53.6 ± 0.0	–
OS1	51.2 ± 0.0	ND
OS2	52.1 ± 0.0	52.9 ± 0.0
OS3	53.5 ± 0.0	53.3 ± 0.0
OS4	54.0 ± 0.0	53.5 ± 0.0
OS5	53.7 ± 0.0	–
OS6	54.0 ± 0.0	53.1 ± 0.0
OS7	53.7 ± 0.0	–

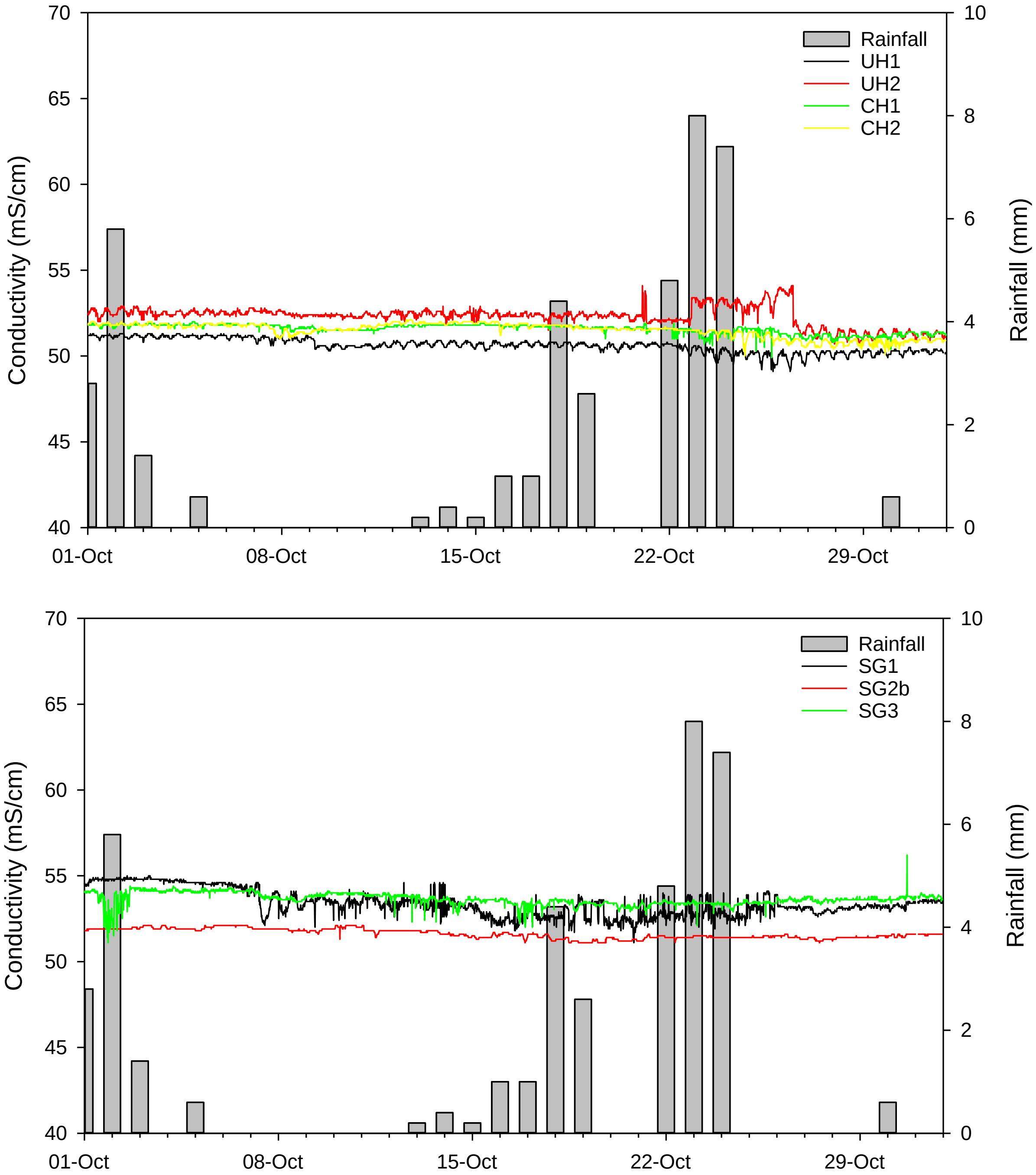


Figure 20 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2019.

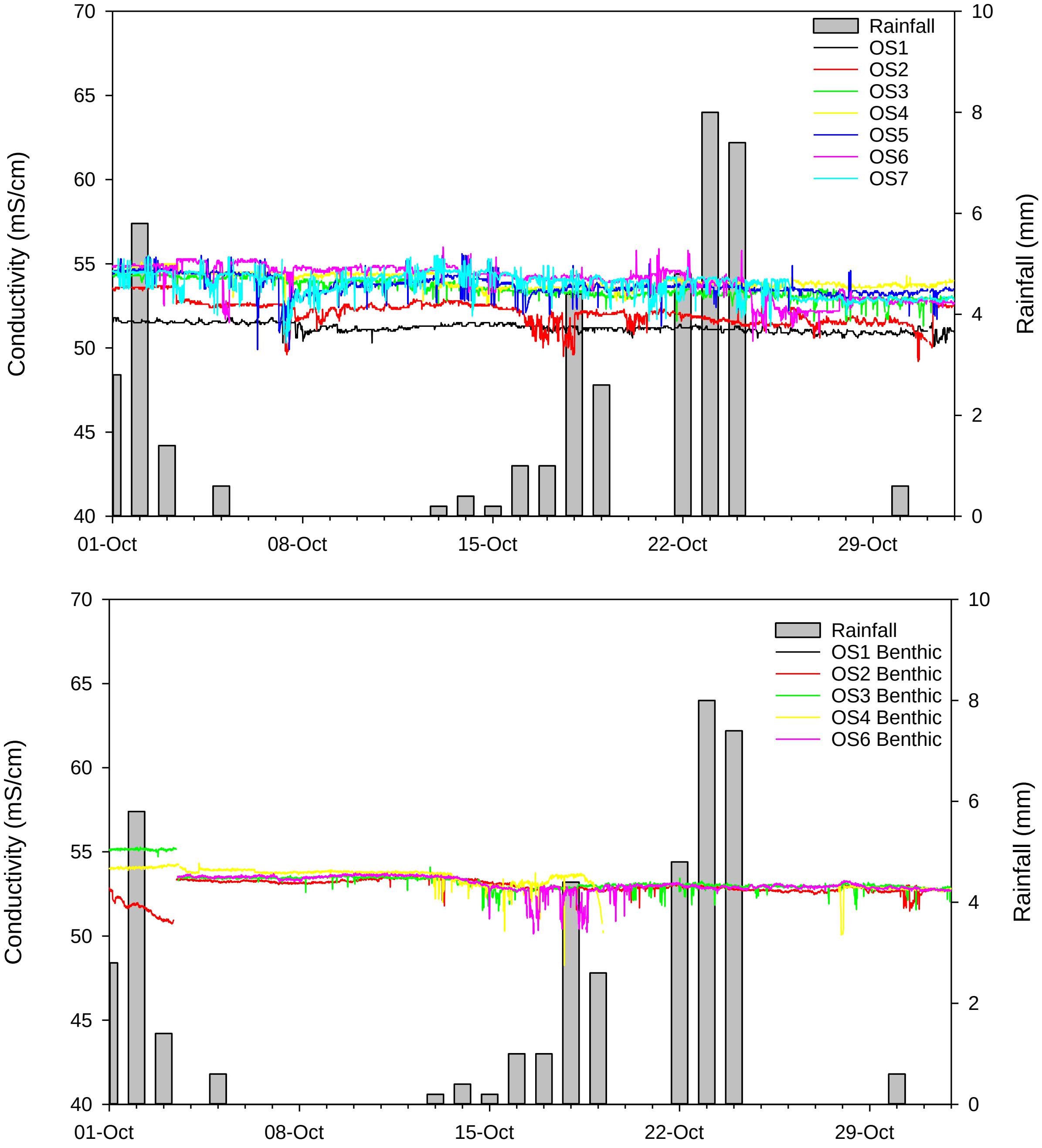


Figure 21 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during October 2019.
No data available for OS1 benthic due to sonde malfunction.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in October ranged from 100 to 105% saturation. Higher DO concentrations were observed on the 9 and 28 October following periods of rainfall. Warmer temperatures associated with increased sunlight following periods of rainfall likely stimulated microalgal growth, leading to increased photosynthesis and therefore increased DO concentrations.

Mean monthly benthic DO concentrations were lower than corresponding surface readings ranging from 93 to 99% saturation (Table 12, Figures 22 and 23), 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 October 2019.
Values are means ± se (n = 226 to 2976).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	101 ± 0	–
UH2	100 ± 0	–
CH1	103 ± 0	–
CH2	105 ± 0	–
SG1	101 ± 0	–
SG2	104 ± 0	–
SG3	100 ± 0	–
OS1	103 ± 0	97± 0
OS2	100 ± 0	93 ± 0
OS3	100 ± 0	95 ± 0
OS4	104 ± 0	99 ± 0
OS5	102 ± 0	–
OS6	101 ± 0	97 ± 0
OS7	100 ± 0	–

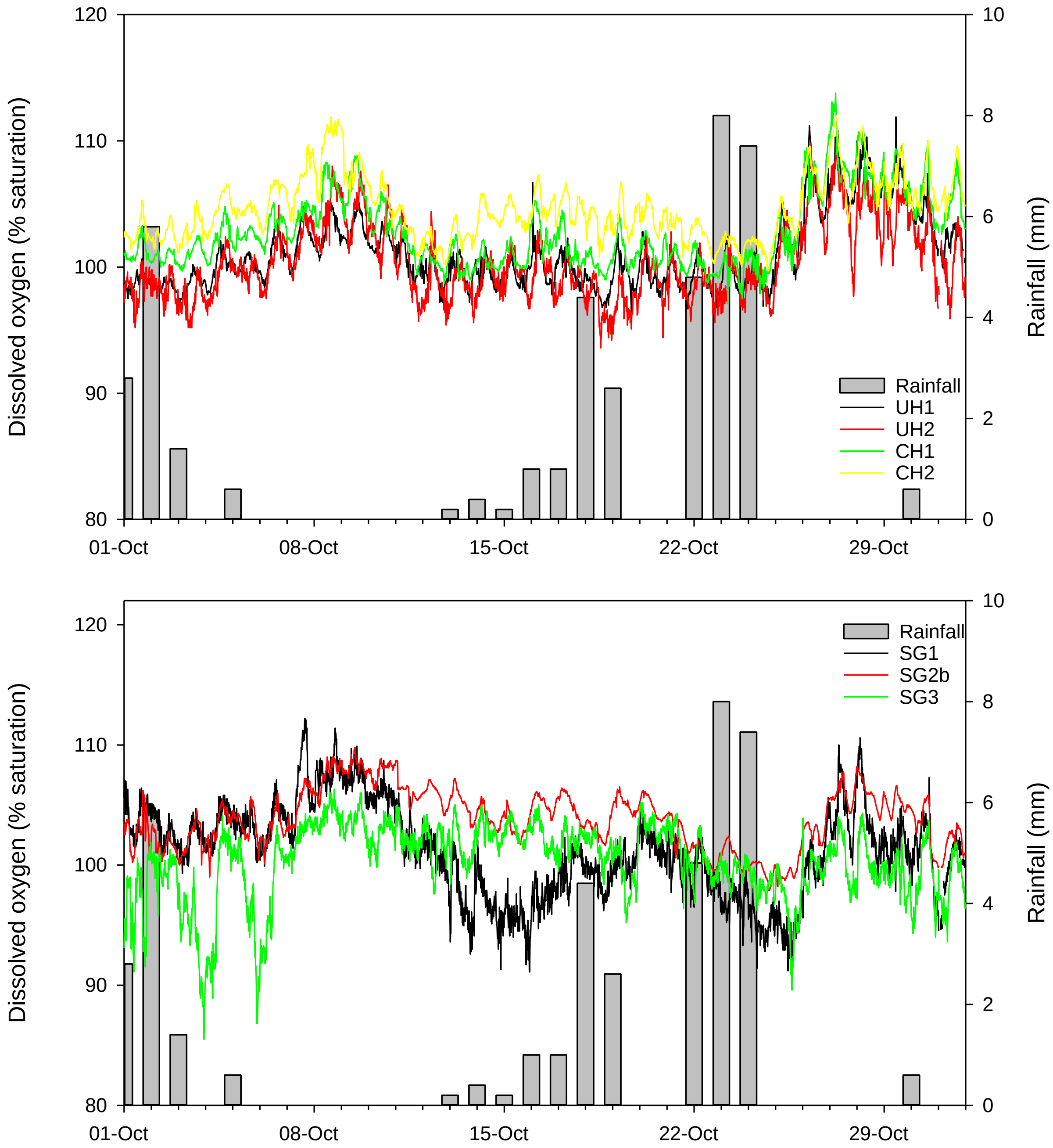
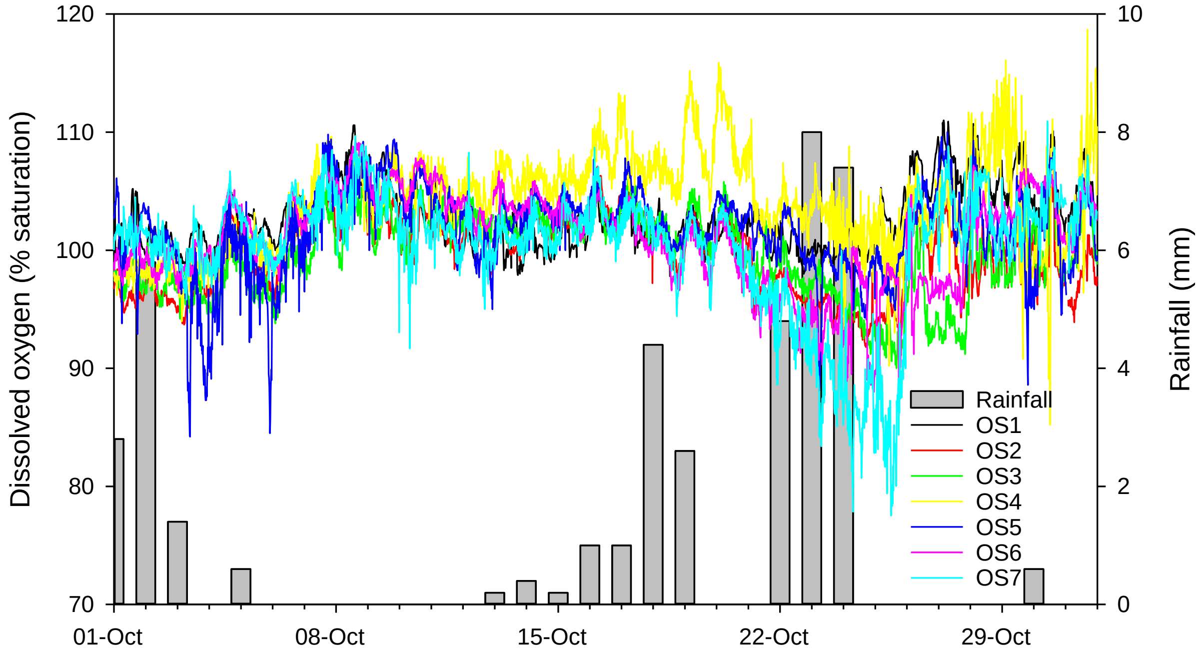


Figure 22 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during October 2019.



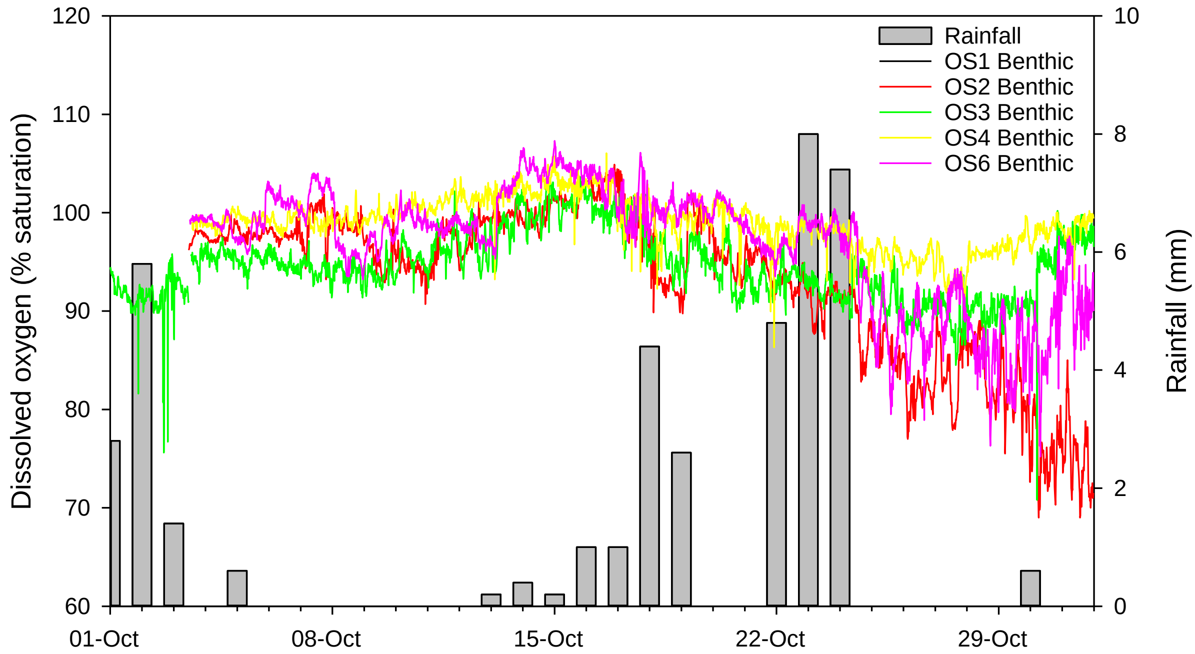


Figure 23 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during October 2019.
No data available for OS1 benthic due to sonde malfunction.

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 9 October 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 24 to 26.

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 column, except for CH2, where DO and temperature values decreased after 4 m depth (Figure 24). Similar to the continuous loggers, the uppermost harbour sites of UH3 and UH1 exhibited the lowest conductivity, pH and dissolved oxygen within the harbour and higher temperatures. 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 25). 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 ~7m, 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 5 m, with DO also decreasing in concentrations at this depth (Figure 26), similar to the nearshore sites. Conductivity and pH were otherwise similar to previous months with good mixing through the column. Turbidity remained stable until >15 m where it increased with depth due to benthic resuspension at a number of sites.

The shallowest euphotic depth of 4.2 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 17.8 m at SG3 (Table 15) where turbidity throughout the column was low. No exceedances of WQG were recorded at the sub-surface during the October vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the October 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 24 to 42 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	09/10/2019 07:39	Sub-surface	12.4 ± 0	8 ± 0	50.1 ± 0	102 ± 0	4.2 ± 0.1	6	0.9 ± 0.1	4.9
		Whole column	12.3 ± 0.4	8 ± 0	50.2 ± 0	102 ± 0	4.7 ± 0.1	–		
UH2	09/10/2019 08:21	Sub-surface	12.5 ± 0	8 ± 0	50.3 ± 0	104 ± 0	2.5 ± 0	3	0.6 ± 0	7.4
		Whole column	12.4 ± 0.4	8 ± 0	50.4 ± 0	103 ± 0	3.5 ± 0.5	–		
UH3	09/10/2019 08:00	Sub-surface	12.8 ± 0	8 ± 0	49.9 ± 0	102 ± 0	5.8 ± 0.1	12	1.1 ± 0	4.2
		Whole column	12.8 ± 0.5	8 ± 0	49.9 ± 0	102 ± 0	6 ± 0.1	–		
CH1	09/10/2019 08:44	Sub-surface	11.9 ± 0	8.1 ± 0	50.5 ± 0	104 ± 0	2.7 ± 0	4	0.6 ± 0	8.4
		Whole column	11.8 ± 0.3	8.1 ± 0	50.5 ± 0	103 ± 0	3.5 ± 0.4	–		
CH2	09/10/2019 09:03	Sub-surface	11.9 ± 0	8.1 ± 0	50.5 ± 0	105 ± 0	2.2 ± 0	<3	0.7 ± 0	7.1
		Whole column	11.5 ± 0.3	8.1 ± 0	50.6 ± 0	102 ± 0	4 ± 0.3	–		
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 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 32 to 42 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	09/10/2019 09:47	Sub-surface	11.6 ± 0	8.1 ± 0	50.6 ± 0	104 ± 0	2.3 ± 0	<3	0.5 ± 0	8.6
		Mid	11.3 ± 0	8.2 ± 0	50.7 ± 0	103 ± 0	2.2 ± 0	<3		
		Benthos	11.1 ± 0	8.2 ± 0	50.8 ± 0	102 ± 0	12.4 ± 3.4	32		
		Whole column	11.4 ± 0.3	8.1 ± 0	50.7 ± 0	103 ± 0	4.1 ± 0.9	–		
OS2	09/10/2019 14:10	Sub-surface	11.7 ± 0	8.3 ± 0	50.9 ± 0	107 ± 0	1.6 ± 0	<3	0.5 ± 0.1	9.1
		Mid	11 ± 0	8.3 ± 0	51.1 ± 0	104 ± 0	1.9 ± 0.2	4		
		Benthos	10.6 ± 0	8.3 ± 0	51.2 ± 0	95 ± 0	7.5 ± 0.3	22		
		Whole column	11.1 ± 0.2	8.3 ± 0	51.1 ± 0	103 ± 1	3.3 ± 0.4	–		
OS3	09/10/2019 13:03	Sub-surface	11.6 ± 0	8.2 ± 0	51.1 ± 0	104 ± 0	1.6 ± 0	<3	0.4 ± 0	12.7
		Mid	10.8 ± 0	8.3 ± 0	51.2 ± 0	104 ± 0	1.5 ± 0	4		
		Benthos	10.6 ± 0	8.2 ± 0	51.4 ± 0	97 ± 1	10.6 ± 2.8	15		
		Whole column	11 ± 0.2	8.3 ± 0	51.2 ± 0	102 ± 0	3 ± 0.6	–		
OS4	09/10/2019 12:33	Sub-surface	11.3 ± 0	8.2 ± 0	51.2 ± 0	103 ± 0	1.6 ± 0	4	0.4 ± 0	12.6
		Mid	10.8 ± 0	8.2 ± 0	51.3 ± 0	102 ± 0	1.7 ± 0	<3		
		Benthos	10.7 ± 0	8.2 ± 0	51.3 ± 0	100 ± 0	9.9 ± 3.8	32		
		Whole column	10.9 ± 0.2	8.2 ± 0	51.3 ± 0	102 ± 0	2.9 ± 0.7	-		
OS7	09/10/2019 09:27	Sub-surface	11.7 ± 0	8.1 ± 0	50.5 ± 0	106 ± 0	1.7 ± 0	<3	0.6 ± 0	7.8
		Mid	11.1 ± 0	8.1 ± 0	50.8 ± 0	102 ± 0	2.5 ± 0.1	<3		
		Benthos	10.9 ± 0	8.1 ± 0	51 ± 0	99 ± 1	22.2 ± 6.6	13		
		Whole column	11.3 ± 0.3	8.1 ± 0	50.8 ± 0	103 ± 1	5.9 ± 1.8	–		
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 2019 sampling event.
Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 42 to 50 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	09/10/2019 10:15	Sub-surface	11.8 ± 0	8.2 ± 0	50.5 ± 0	108 ± 0	1.5 ± 0	<3	0.4 ± 0	12.0
		Mid	11 ± 0.1	8.2 ± 0	50.9 ± 0	109 ± 0	1.2 ± 0.1	<3		
		Benthos	10.6 ± 0	8.2 ± 0	51.2 ± 0	97 ± 1	32.4 ± 11.7	19		
		Whole column	11.1 ± 0.2	8.2 ± 0	50.9 ± 0	105 ± 1	5.9 ± 2.3	–		
OS6	09/10/2019 13:33	Sub-surface	11.8 ± 0	8.3 ± 0	51 ± 0	105 ± 0	1.5 ± 0	<3	0.3 ± 0	13.7
		Mid	10.7 ± 0	8.3 ± 0	51.3 ± 0	105 ± 1	1 ± 0	<3		
		Benthos	10.5 ± 0	8.3 ± 0	51.4 ± 0	96 ± 0	10.8 ± 1.8	3		
		Whole column	11 ± 0.2	8.3 ± 0	51.2 ± 0	103 ± 1	2.8 ± 0.6	–		
SG1	09/10/2019 10:49	Sub-surface	12 ± 0	8.2 ± 0	50.7 ± 0	108 ± 0	1.2 ± 0	<3	0.3 ± 0	15.2
		Mid	10.7 ± 0	8.2 ± 0	51.2 ± 0	104 ± 0	1.1 ± 0	<3		
		Benthos	10.6 ± 0	8.2 ± 0	51.2 ± 0	99 ± 1	28.2 ± 16.5	14		
		Whole column	11 ± 0.2	8.2 ± 0	51 ± 0	105 ± 0	4.6 ± 2.4	–		
SG2	09/10/2019 11:21	Sub-surface	11.7 ± 0	8.2 ± 0	51 ± 0	108 ± 0	1.1 ± 0	3	0.4 ± 0	11.6
		Mid	10.7 ± 0	8.2 ± 0	51.1 ± 0	101 ± 0	1.9 ± 0	3		
		Benthos	10.6 ± 0	8.2 ± 0	51.3 ± 0	93 ± 0	15.9 ± 4.5	7		
		Whole column	11 ± 0.2	8.2 ± 0	51.1 ± 0	102 ± 1	3.5 ± 0.9	–		
SG3	09/10/2019 11:56	Sub-surface	11.7 ± 0	8.2 ± 0	51.2 ± 0	107 ± 0	1.1 ± 0	4	0.3 ± 0	17.8
		Mid	10.5 ± 0	8.2 ± 0	51.5 ± 0	102 ± 0	1 ± 0	<3		
		Benthos	10.5 ± 0	8.2 ± 0	51.5 ± 0	99 ± 0	4.5 ± 0.7	5		
		Whole column	10.8 ± 0.2	8.2 ± 0	51.4 ± 0	103 ± 0	1.6 ± 0.2	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	

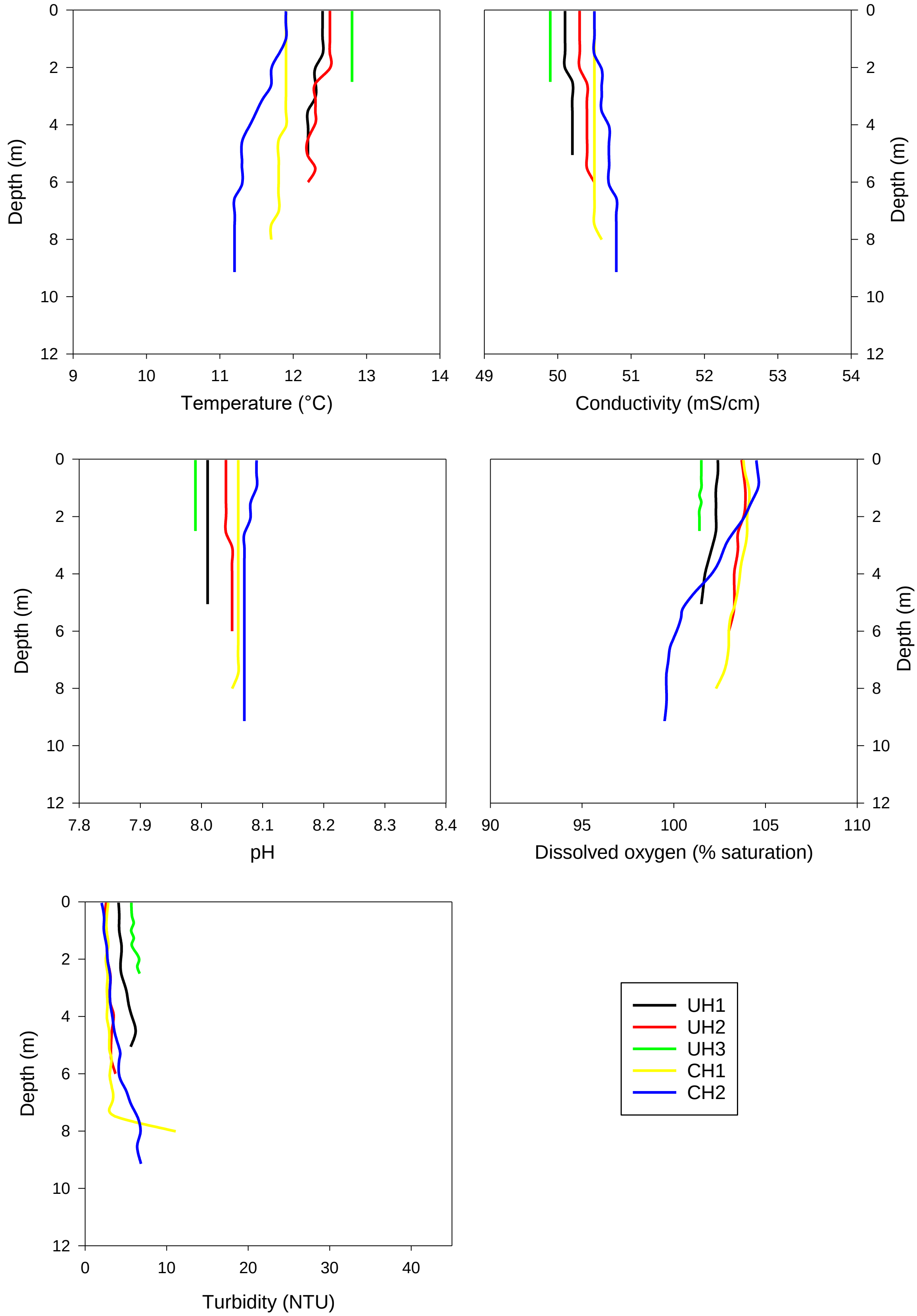


Figure 24 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 9 October 2019.

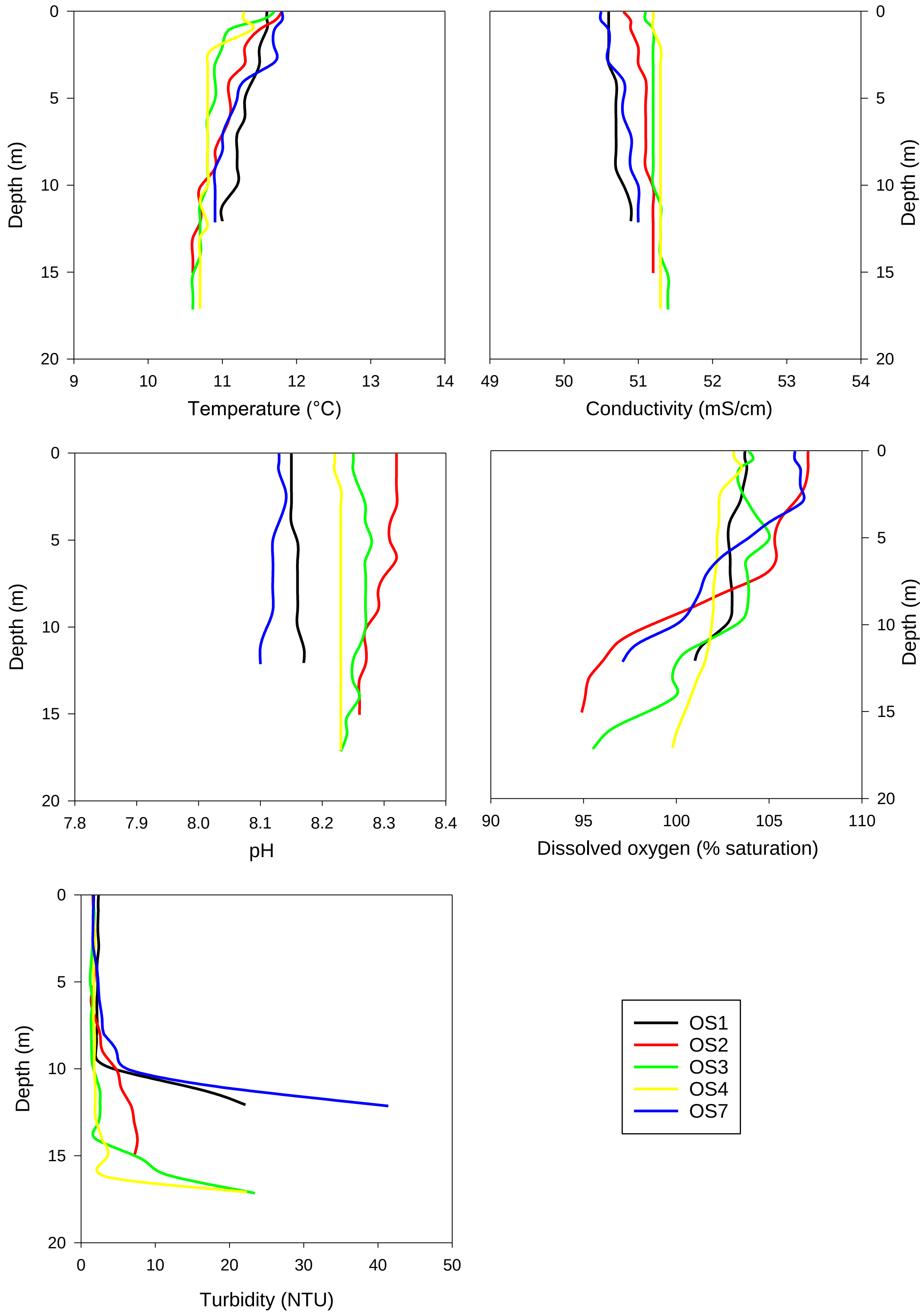


Figure 25 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 9 October 2019.

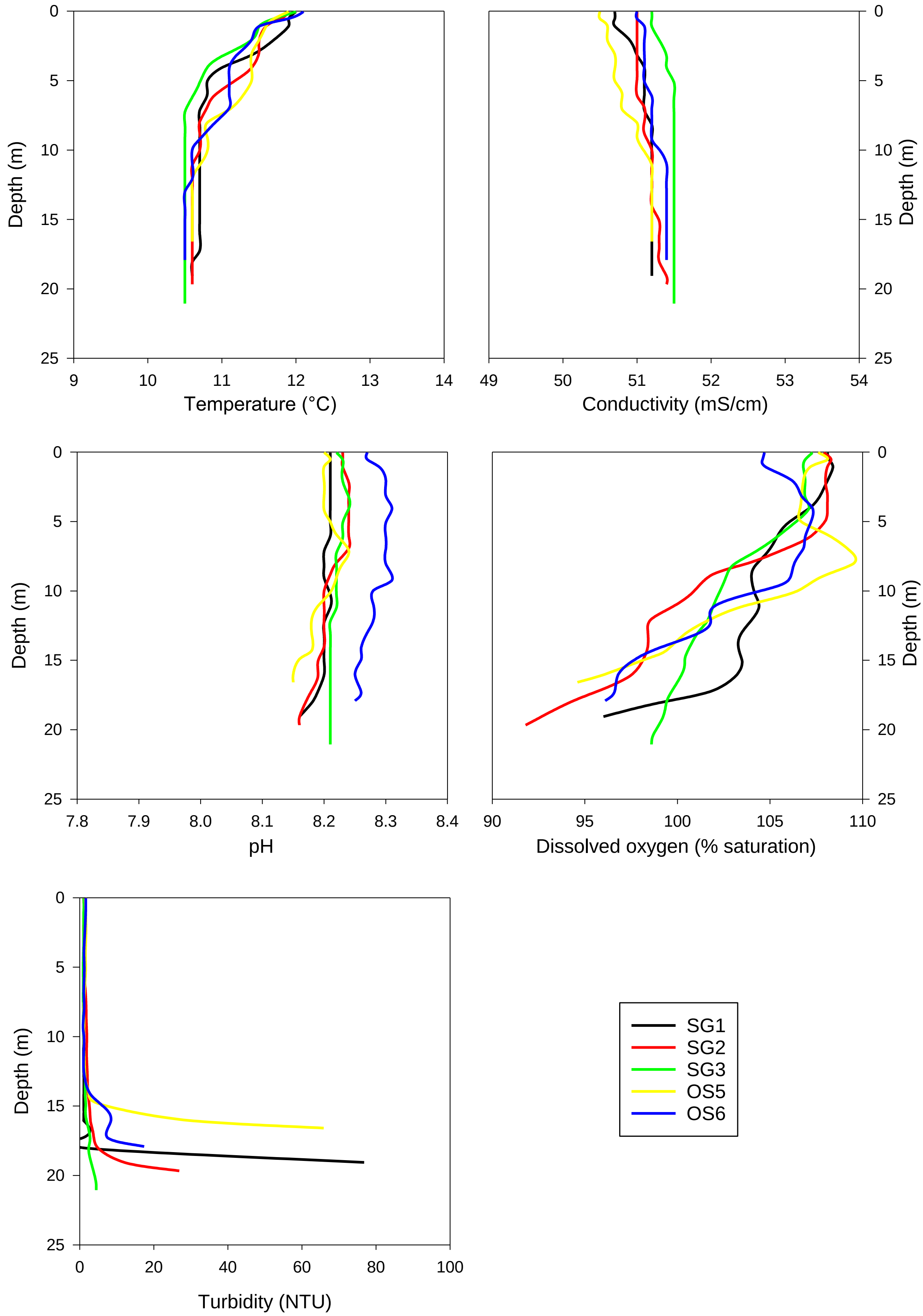


Figure 26 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 9 October 2019.

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 27. Data from the logger exchange date (3 October) were removed from the analyses.

Table 16 Total Daily PAR (TDP) statistics during October 2019.
Values are means ± se (n = 29 to 30). Note data from the BPAR exchange day on 3 October were not utilised in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m²/day)		
		Mean ± se	Median	Range
Base	-	19,798 ± 930	18,523	12,055 – 34,700
OS2	17	1,821 ± 271	1339	<0.01 – 5221
OS3	14	1,366 ± 330	479	<0.01 – 7410

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 12,055 to 34,700 mmol/m^2/day (Table 16), higher than the range recorded during September (4,600 to 29,600 mmol/m^2/day). The increase in ambient TDP is likely associated with the increased day lengths from September to October.

Mean BPAR at both OS2 and OS3 also increased in October (1,821 and 1,366 mmol/m^2/day respectively) from September (1,324 and 1,305 mmol/m^2/day, respectively), most likely due to increased ambient PAR. 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 OS3 from mid-October when turbidity was consistently elevated at this site compared to earlier in the month.

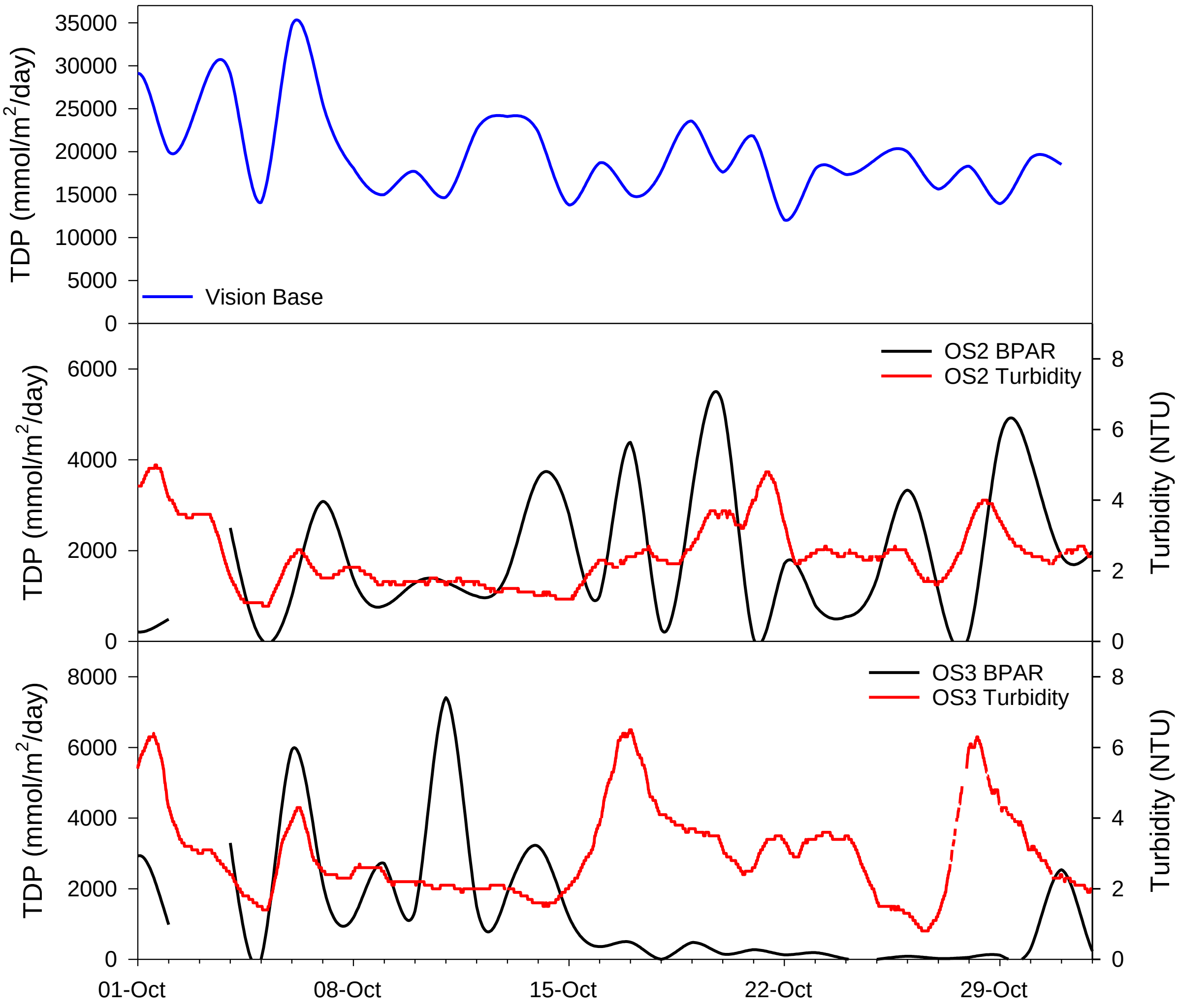


Figure 27 Total daily BPAR at OS2 and OS3 during October 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 3 October were not utilized in plots or statistics.

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.

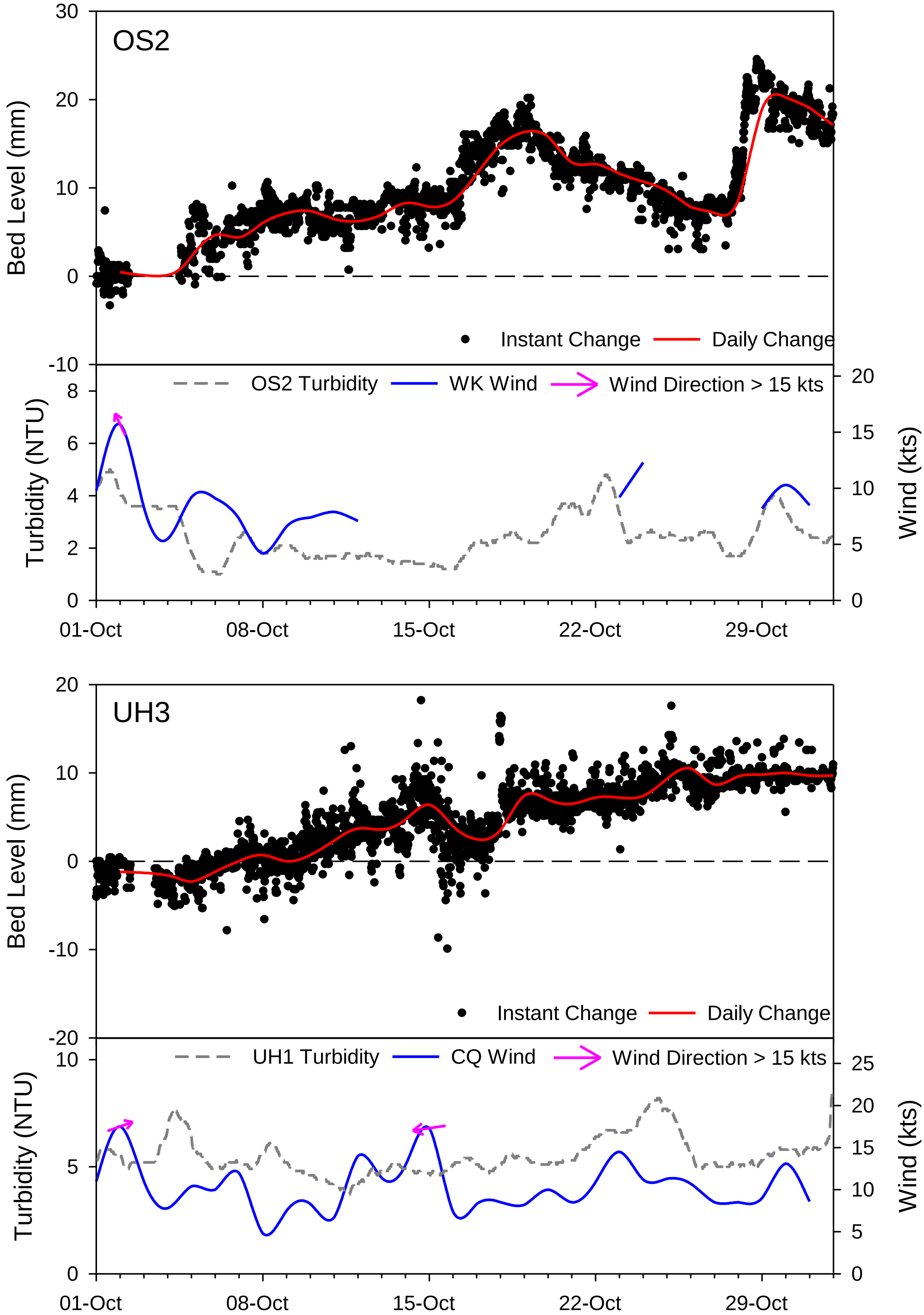


Figure 28 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during October 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction. *Note: Arrows indicate the direction of travel for winds greater than 15 knots.*

Overall, sediment accumulation was evident at the offshore site OS2 during early October, beginning with approximately 20 mm being accumulated from 1 to 19 October. This was followed by a period of erosion of ~15 mm from 20 to 27 October, associated with moderate to high inshore wind speeds (8 to 14 kts) from an easterly direction. Bed level then rapidly accumulated ~20 mm on the 28 October, associated with a period of significant wave height >1.5 m. A period of small erosion at the end of the month lead to an overall accumulation of 17 mm of sediment during October 2019 (Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2 but with an overall deposition recorded for October. Slight erosion (~ 5 mm) and high sediment flux was apparent at UH3 following on from a period of moderate to strong inshore winds (17.3 kts) from a east-north-easterly direction, on 15 October. Prior to and following this event, steady accumulation was observed. An overall accumulation of 11 mm was recorded in October 2019 (Table 17).

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

Site	October 2019 Net bed level change (mm)
OS2	+17
UH3	+11

3.6 Water Samples

Discrete water sampling was conducted on 9 October 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. In contrast to previous months, dissolved reactive phosphorous concentrations were below the WQG of 5 µg/L at the majority of sites, with only UH3 reporting a value above the WQG (7.6 µg/L). This may be a result of warmer temperatures stimulating algal growth with the utilisation of some available nutrients.

Both total nitrogen and total kjeldahl nitrogen (TKN) were < LOR and < WQG at all sites.

Total ammonia ranged from 12 to 19 µg/L and like previous months 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). Again, this may be utilisation by increasing algal populations. Inner harbor sites reported values <LOR, while higher concentrations were recorded in the offshore (1 to 4.9 µg/L) and spoil ground sites (2.5 to 8.1 µg/L).

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, was elevated at all sites ranging from 1.5 at UH2 and SG3 to 2.7 at OS6, but with no sites exceeding the WQG (4 µg/L) (Table 18).

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during October 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	22	4.5	<300	<200	12	<1	2.4
UH2	8	<1	<300	<200	18	<1	1.5
UH3	22	7.6	<300	<200	13	<1	1.9
CH1	16	<1	<300	<200	12	<1	2.5
CH2	8	<1	<300	<200	16	<1	2.6
OS1	9	<1	<300	<200	17	<1	2.4
OS2	8	<1	<300	<200	17	1	2.6
OS3	8	1.3	<300	<200	13	3.7	1.9
OS4	12	1.3	<300	<200	19	2.8	2.4
OS5	8	<1	<300	<200	16	4.9	2.4
OS6	10	<1	<300	<200	12	1.7	2.7
OS7	10	<1	<300	<200	18	3.8	2.5
SG1	7	<1	<300	<200	17	3.5	2.2
SG2	6	<1	<300	<200	16	8.1	2.1
SG3	4	<1	<300	<200	13	2.5	1.5
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

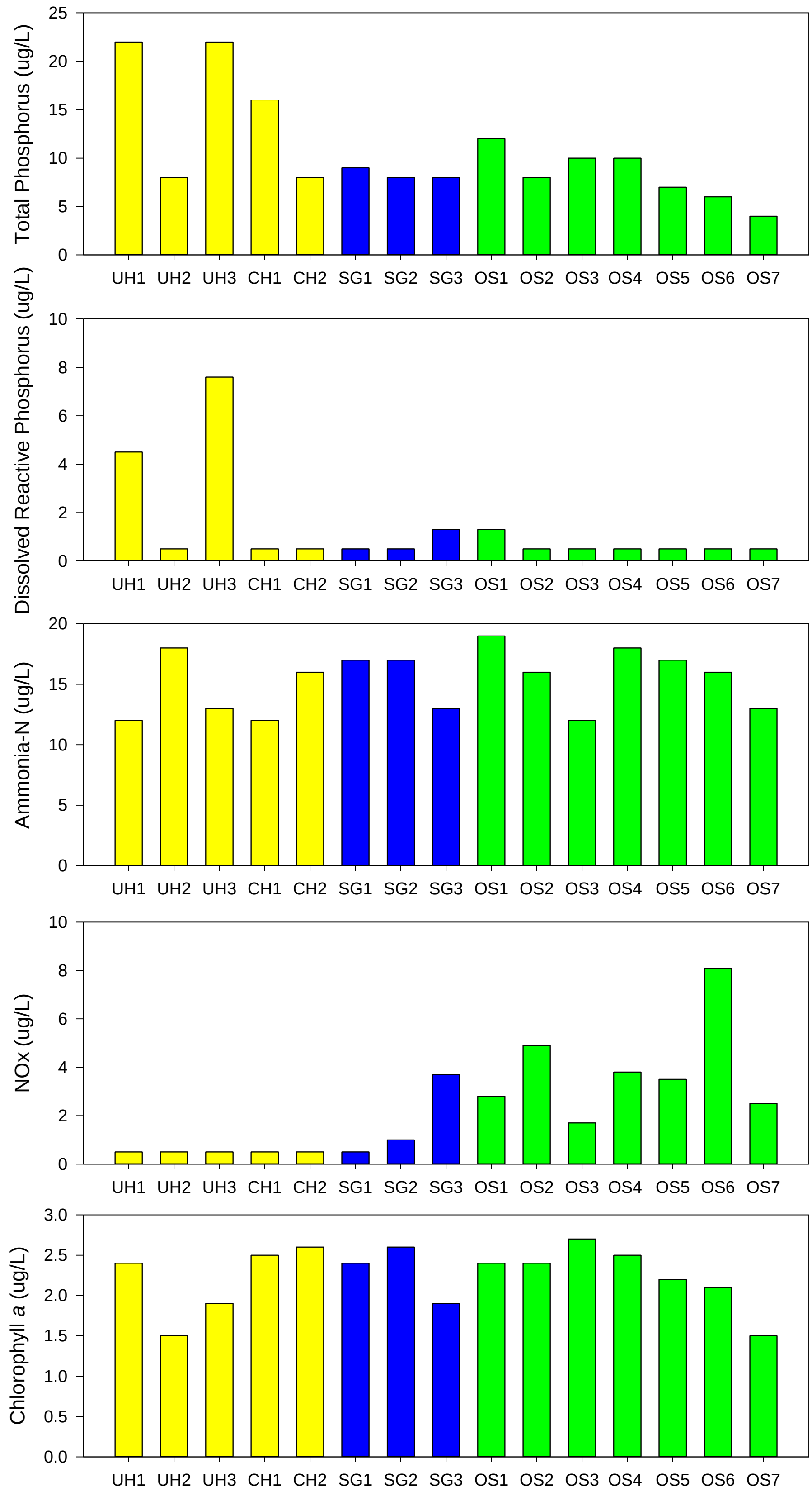


Figure 29 Nutrient and chlorophyll *a* concentrations at monitoring sites during October 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were <LOR.*

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), lead (<1 µg/L), mercury (<0.08 µg/L), nickel (<7 µg/L), silver (<0.4 µg/L), tin (<5 µg/L) and zinc (<4 µg/L). Total and dissolved selenium was <LOR at all sites, except at OS2 and OS3 where the total fraction reported values >LOR. Total and dissolved copper was < LOR at all sites, except at UH1 where total copper 3.2 µg/L exceeded the WQG (1.3 µg/L), while the dissolved fraction remained <LOR, suggesting limited bioavailability. Dissolved copper values >LOR were recorded at CH2 and OS7 (1.1 µg/L) but these concentrations were <WQG.

While concentrations of total aluminium and iron were detected, dissolved concentrations of these metals were < LOR, indicating limited bioavailability. Concentrations of total aluminium (21 to 240 µg/L) were higher than the designated 95% species protection trigger value of 24 µg/L at all sites except the spoilground 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 (49 to 240 µg/L and 65 to 370 µg/L, respectively) with minimum concentrations at the offshore and spoil ground sites (<21 to 56 µg/L and 25 to 26 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 2.3 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 (1.1 to 2.2 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 1.6 to 12.6 µg/L at inshore and offshore sites and were lower at spoil ground sites (1.5 to 3.6 µg/L). Total and dissolved molybdenum concentrations exhibited little spatial variation, ranging from 10.1 to 11.6 µg/L, similar to previous monitoring results.

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during October 2019. *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	139	73	240	81	49	
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	1.3	1.2	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.3	<1.1	<1.1	1.3	<1.1	
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	3.2	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	-
	Total	220	106	370	97	65	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	6.3	4.5	6.2	5	3.1	-
	Total	10.7	7.9	12.6	7.6	5.1	
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	11.1	11.2	10.1	10.9	10.9	-
	Total	11	11.2	11.1	11.3	10.8	
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	<4.2	<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	1.4	1.4	1.6	1.1	100
	Total	2.2	1.6	1.8	1.4	1.3	
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 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	<12	<12	<12	24
	Total	56	39	38	46	33	35	44	
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	1.2	2.1	1.1	<1	1.6	<1	1.2	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.3	2.1	1.8	1.3	1.8	1.7	<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	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	77	47	51	52	50	42	55	
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	4.2	1.6	1.6	1.3	1.9	1.6	2	-
	Total	7	3.5	3	2.2	3.7	3	3.8	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	0.09	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10.7	10.7	11	11.4	11.3	11.3	10.9	-
	Total	11.4	10.9	11.3	11.4	11.5	10.9	11.4	
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	5.6	4.5	<4.2	<4.2	<4.2	<4.2	
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	1.4	1.9	1.3	1.7	1.4	1.6	100
	Total	1.5	1.5	2.2	1.8	1.8	1.3	1.8	
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 October 2019.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		SG1	SG2b	SG3	WQG
Aluminium	Dissolved	<12	<12	<12	24
	Total	<21	21	23	
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	<1	1.1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	1.7	2.4	
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	<4	<4	-
	Total	25	25	26	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.5	1.6	1.5	-
	Total	3.6	2.6	1.6	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11.6	11.5	11.1	-
	Total	11.5	11.3	11.4	
Nickel	Dissolved	<7	<7	<7	70
	Total	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	
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	1.4	1.8	1.8	100
	Total	1.5	1.5	1.5	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

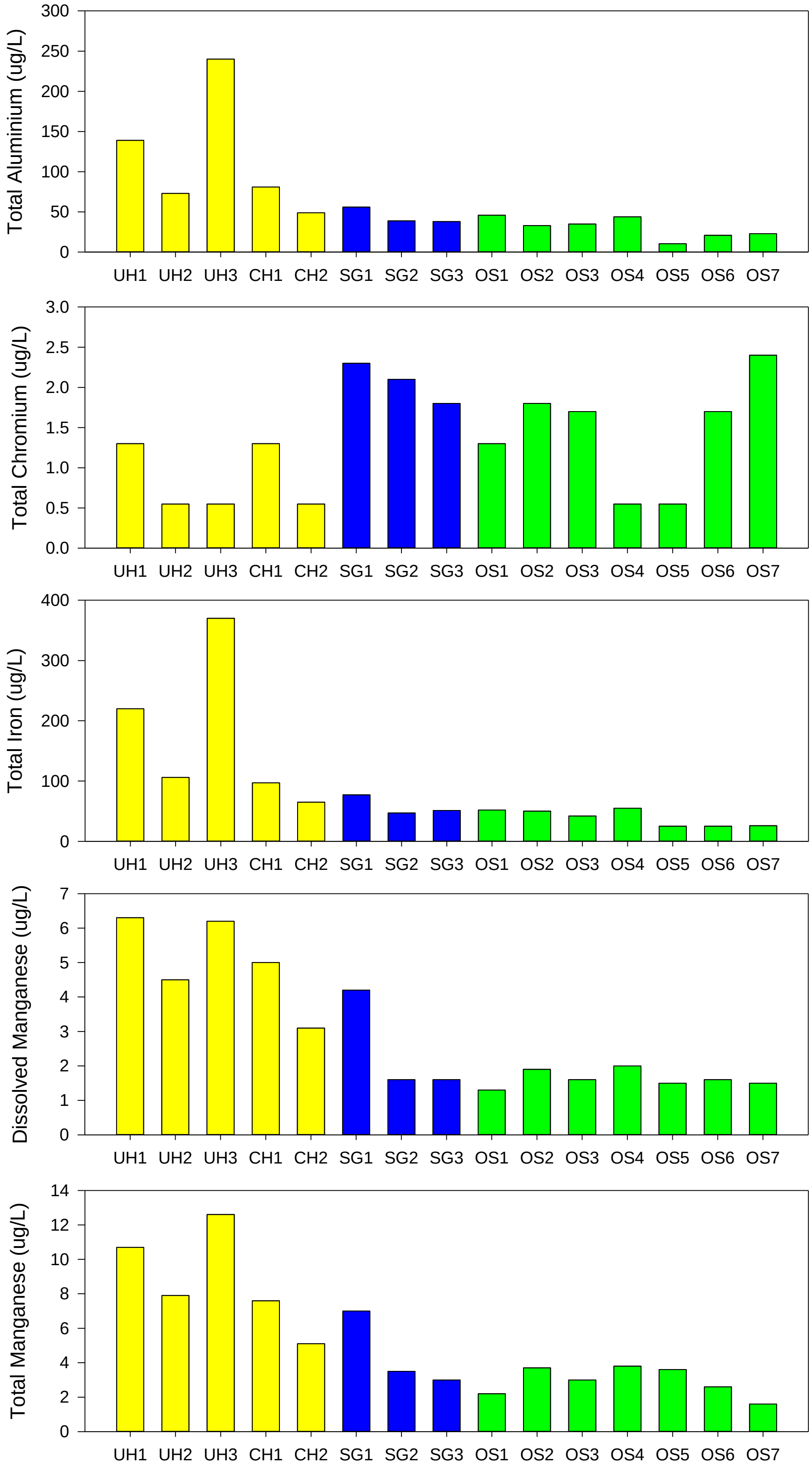


Figure 30 Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during October 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

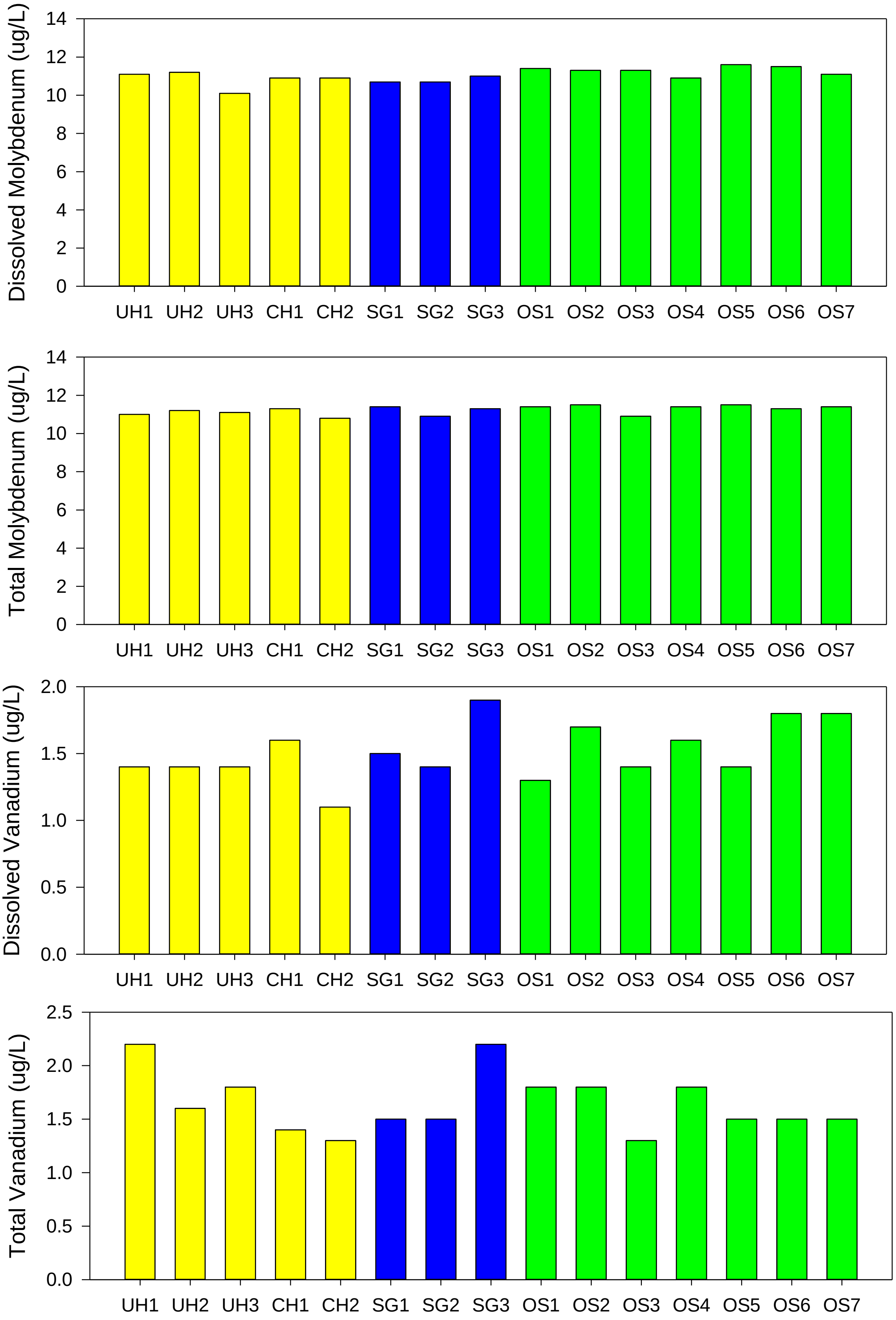


Figure 31 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during October 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

4 REFERENCES

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5 APPENDIX

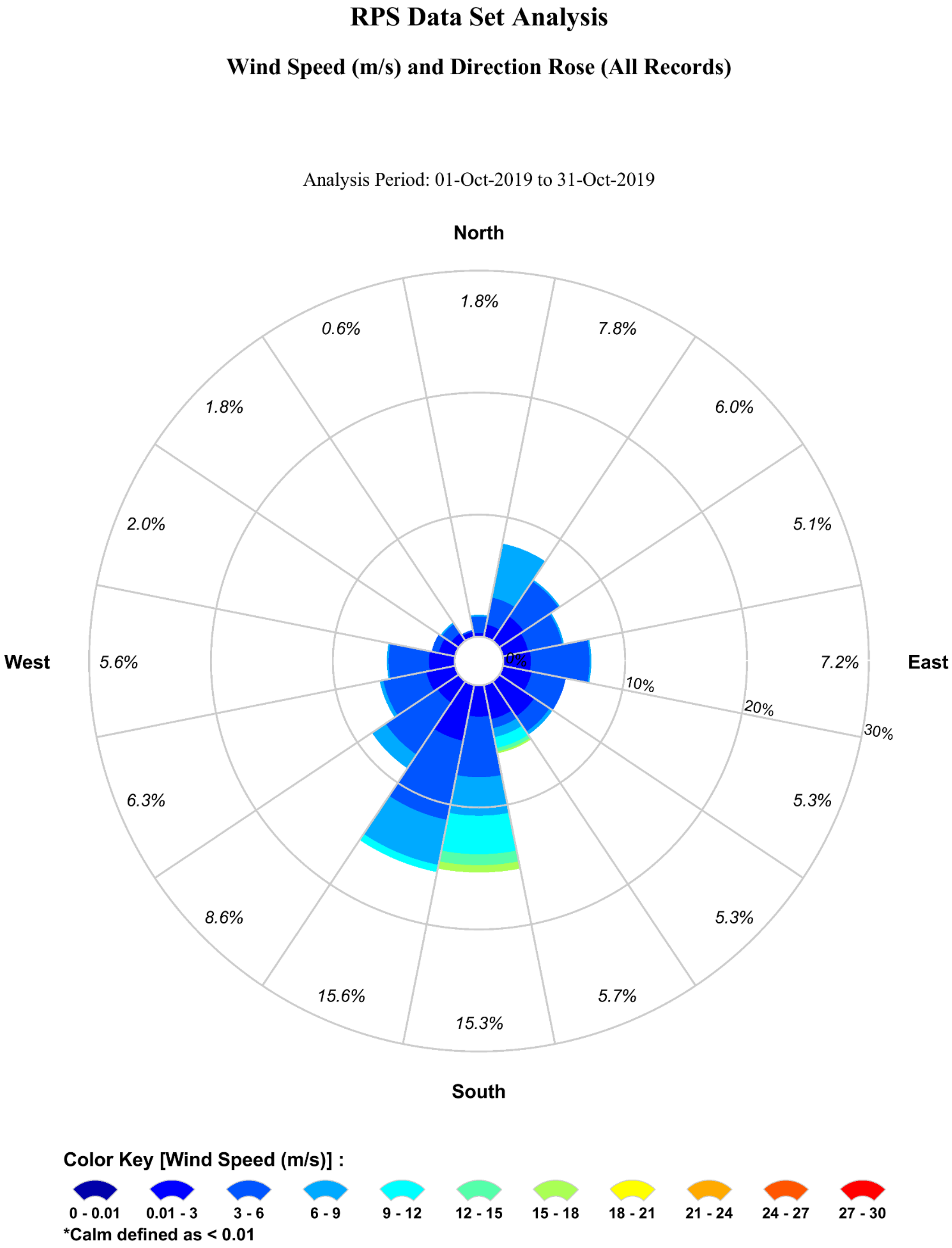

Figure 32 WatchKeeper wind speed (m/s) and direction rose (%) during October 2019.

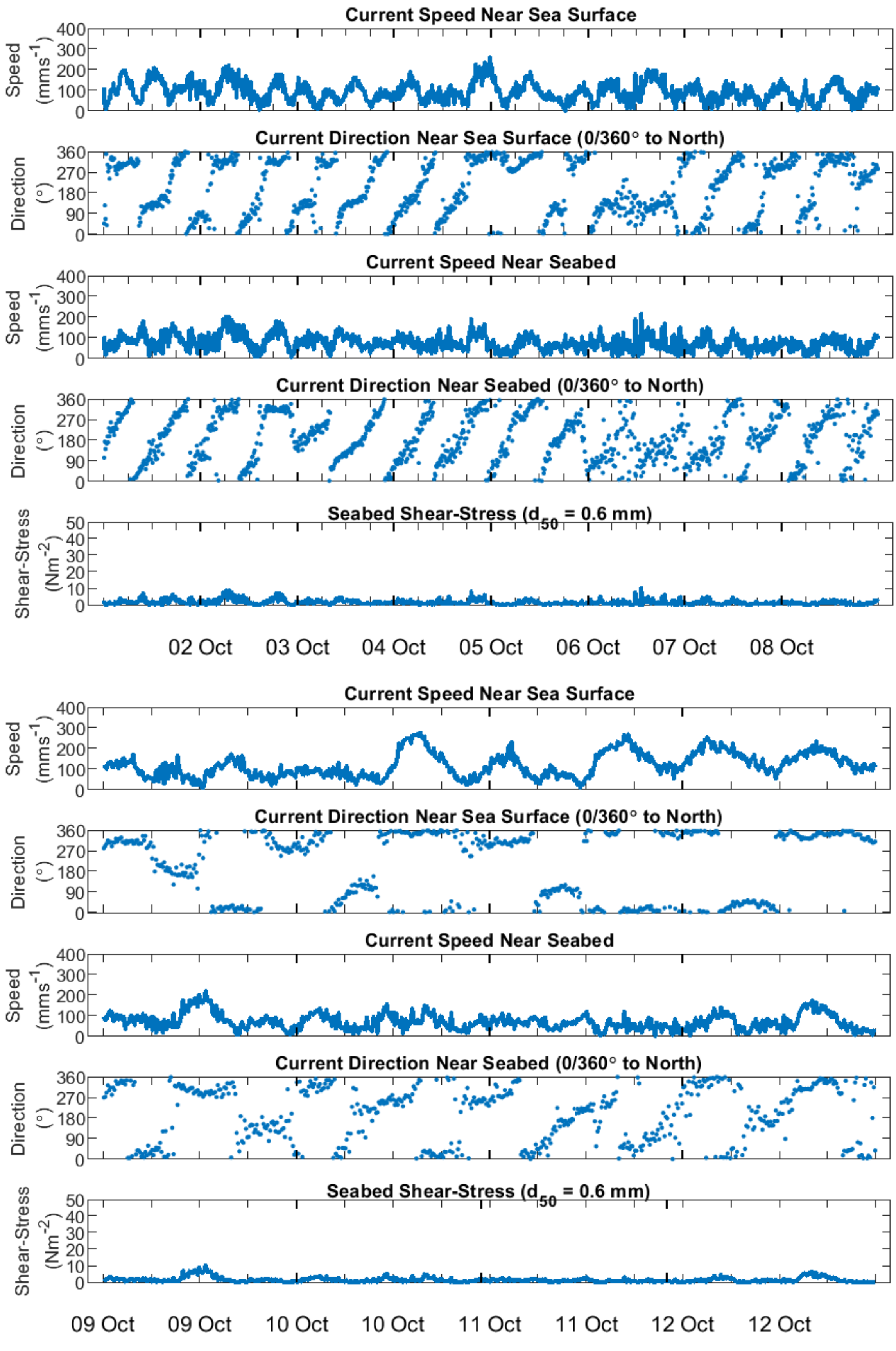

Figure 33 SG1 current speed, direction and shear bed stress 1 to 12 October 2019.

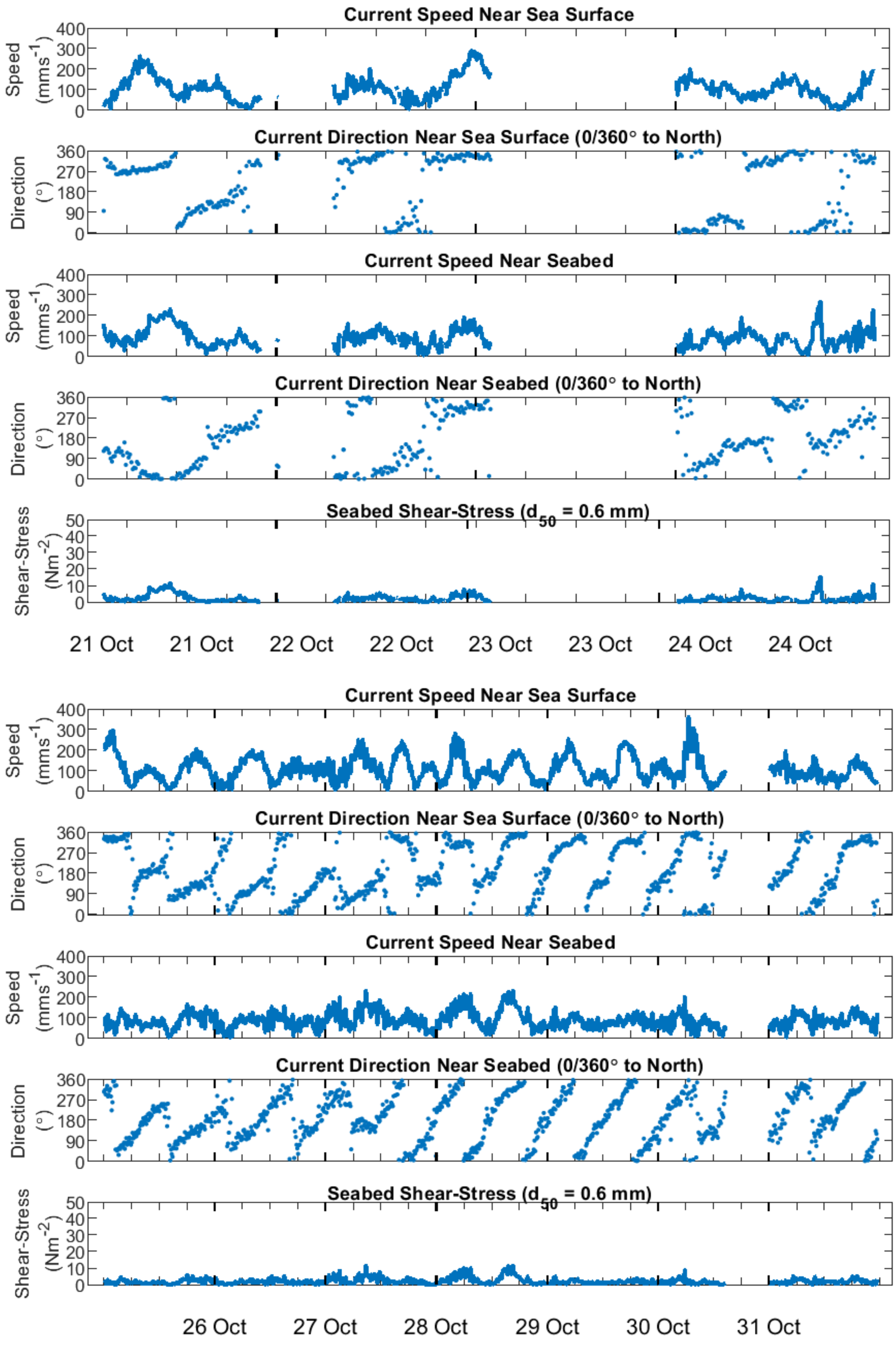

Figure 34 SG1 current speed, direction and shear bed stress 21 to 31 October 2019.

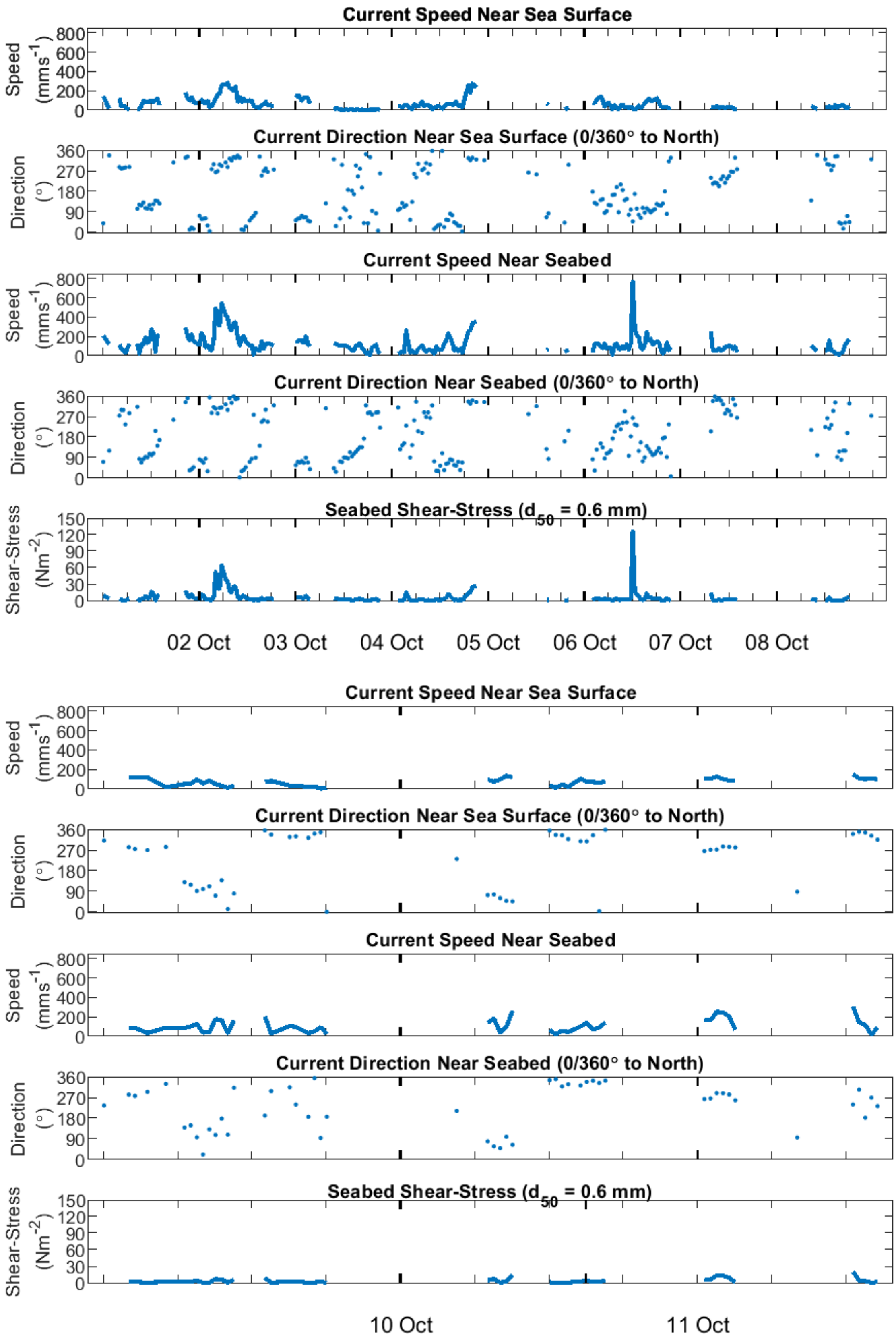

Figure 35 SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 11 October 2019.

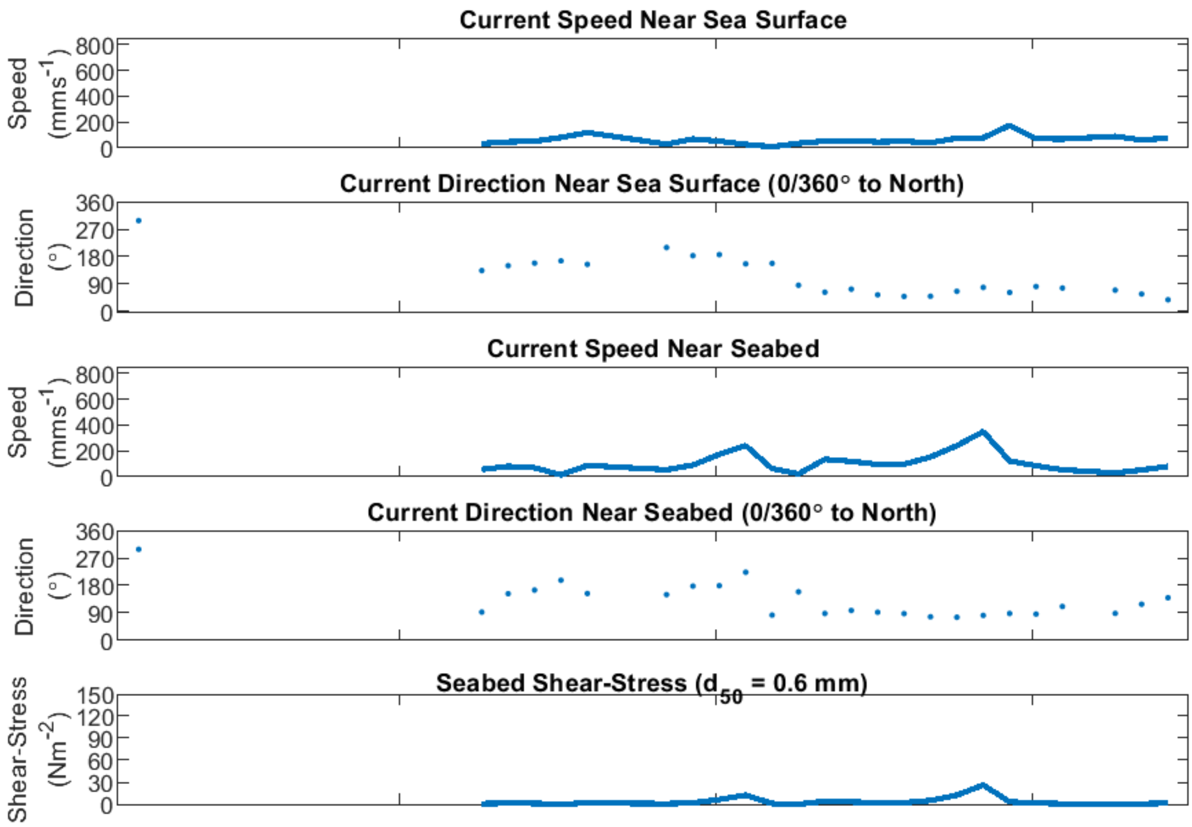

Figure 36 SG2a (WatchKeeper) current speed, direction and shear bed stress 27 to 31 October 2019. No data for 13 to 27 October.

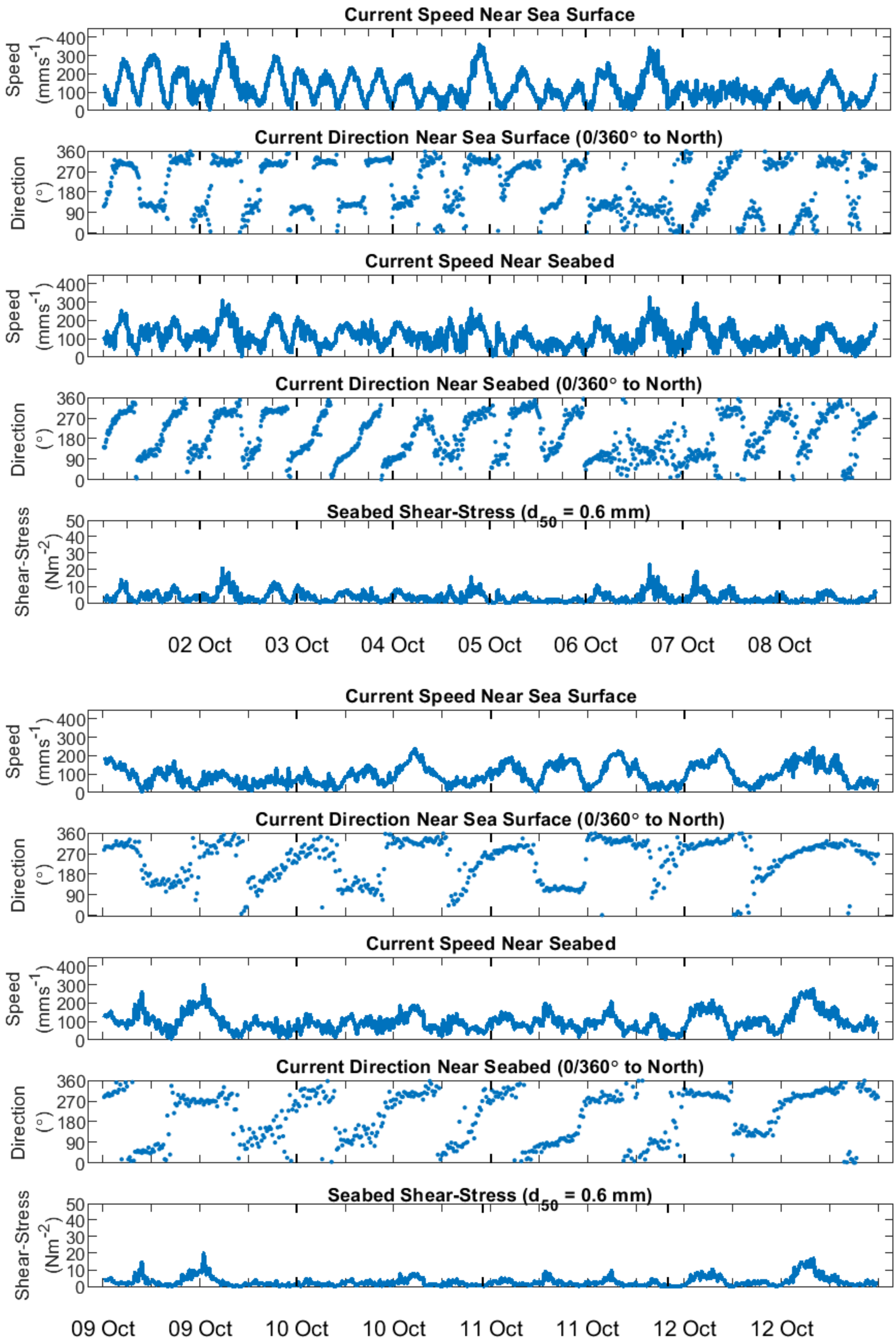

Figure 37 SG3 current speed, direction and shear bed stress 1 to 12 October 2019.

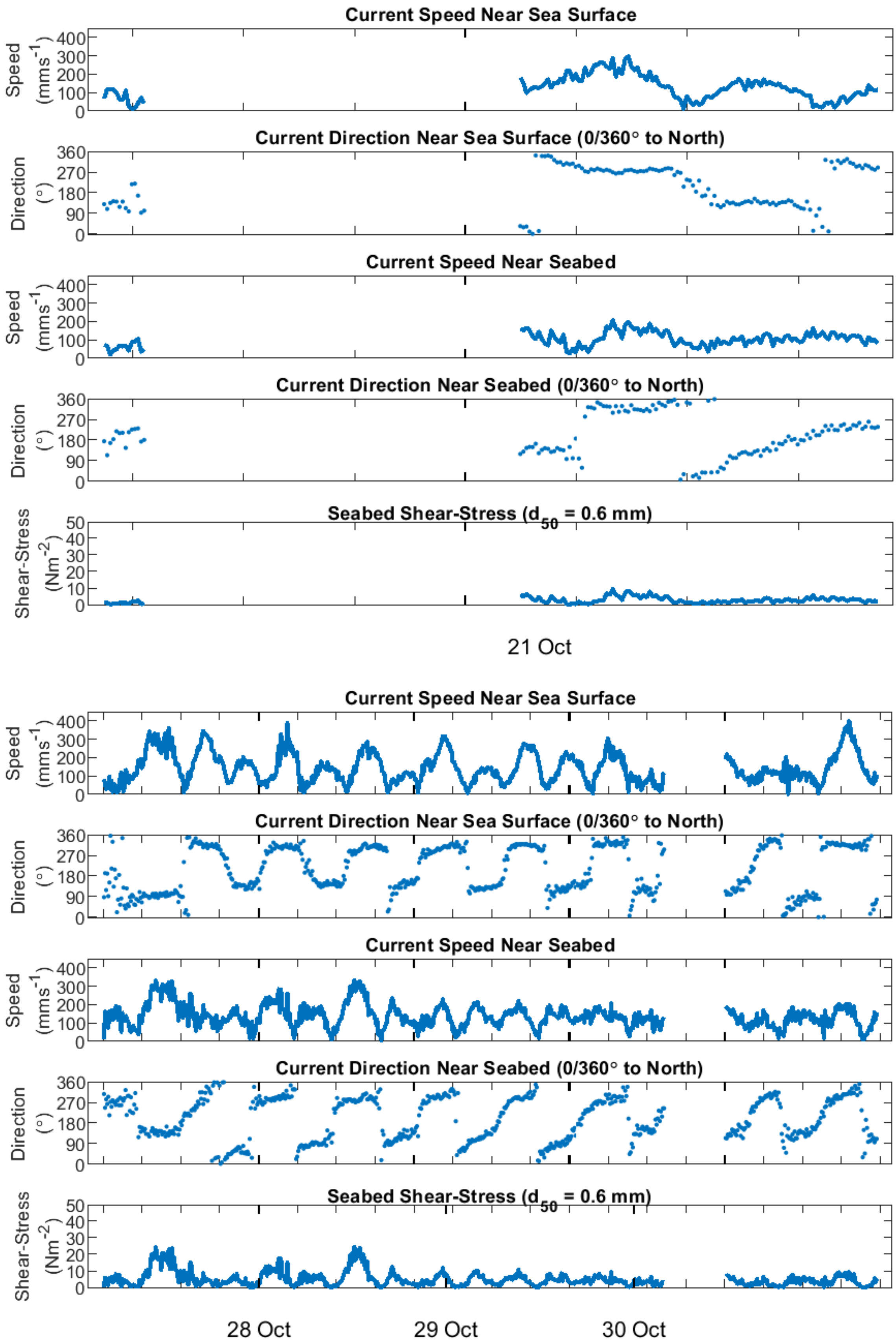

Figure 38 SG3 current speed, direction and shear bed stress 20 to 31 October 2019.

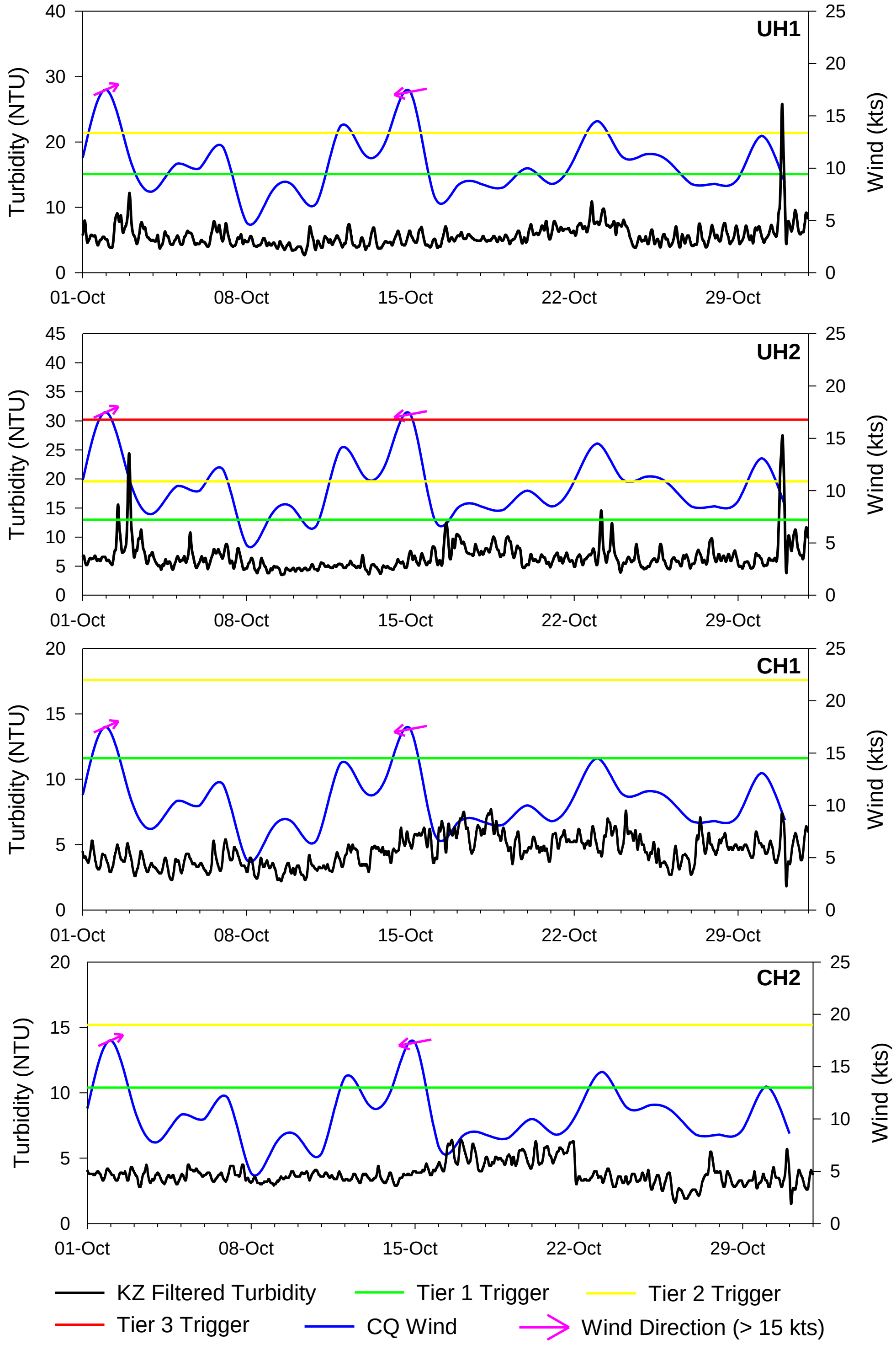

Figure 39 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

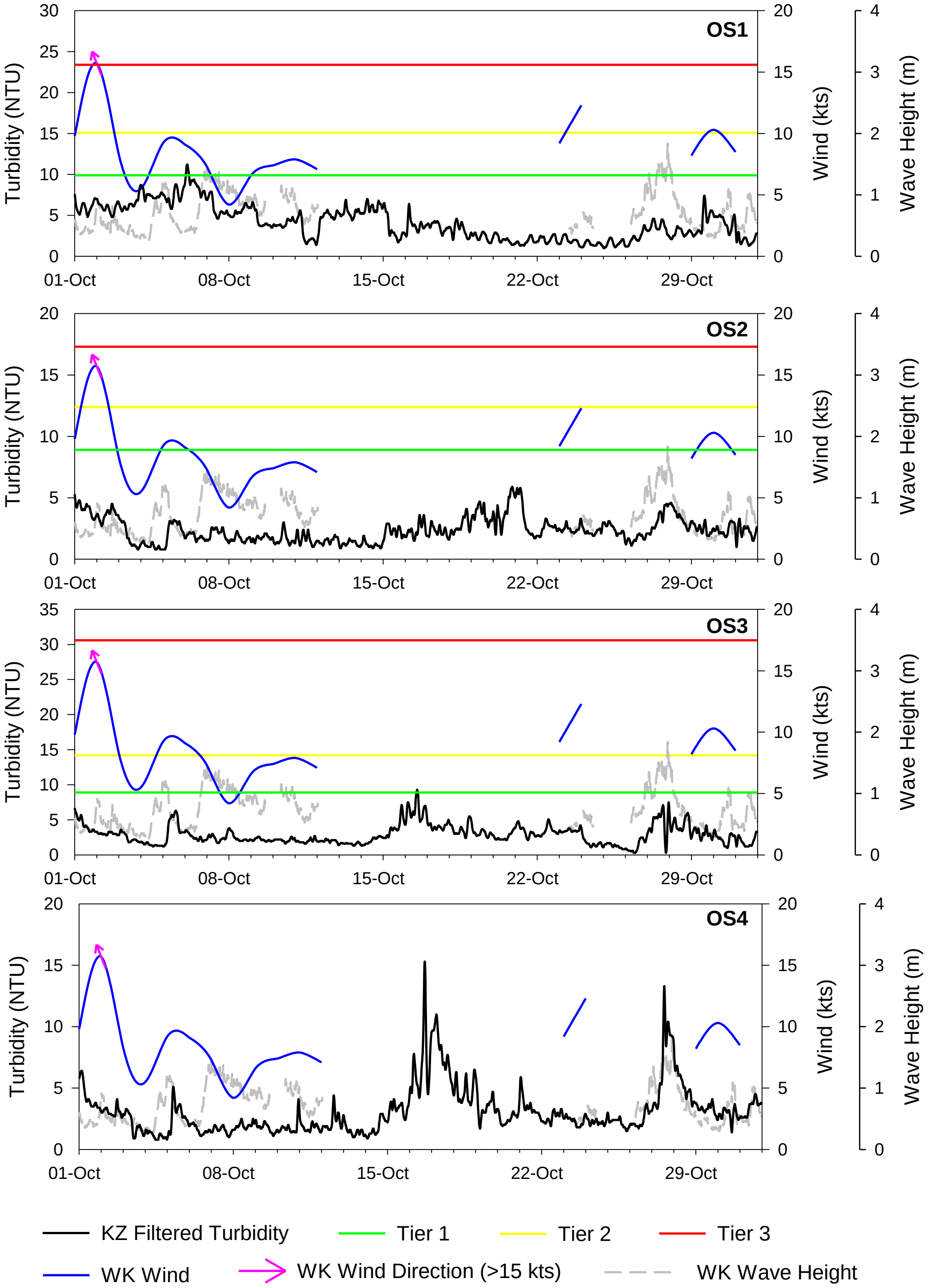

Figure 40 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

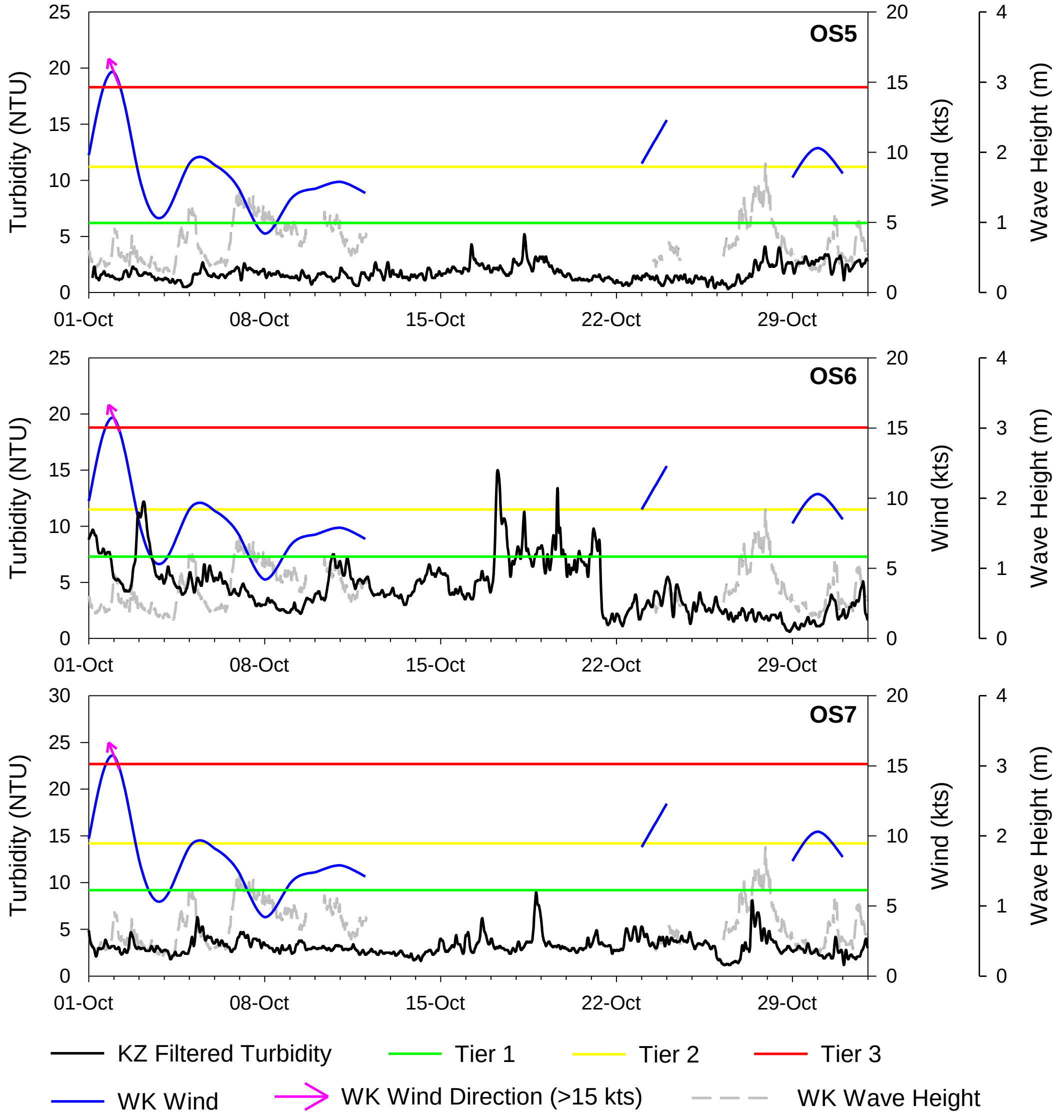

Figure 41 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

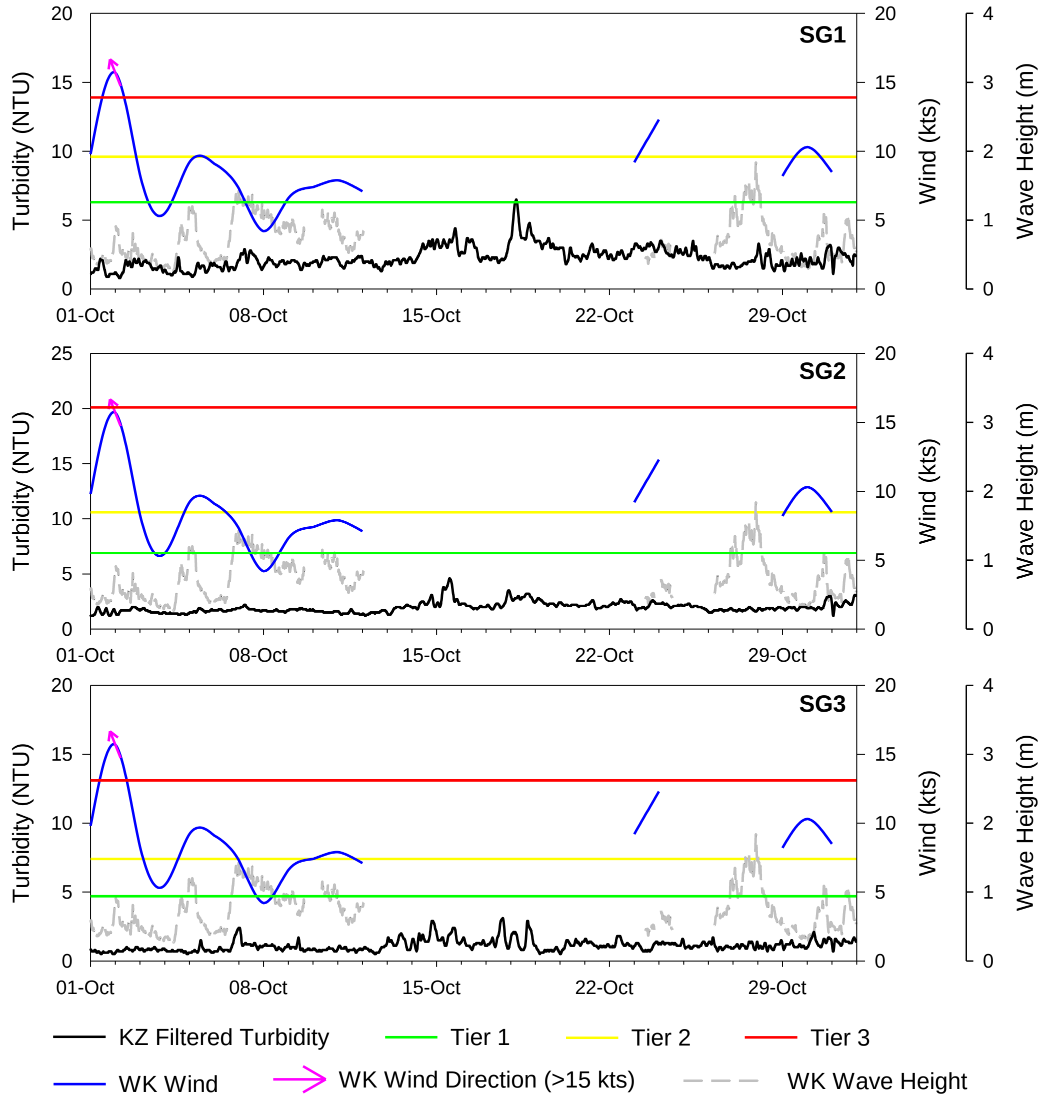

Figure 42 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during October 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 22 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during October 2019 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	KZ Filtered Turbidity (NTU)		
	Statistic	Surface October	Surface Baseline
UH1	Mean ± se	5.6 ± 0.0	12
	Range	2.7 – 25.8	2 – 155
	99th	10.8	37
	95th	7.9	21
	80th	6.7	15
UH2	Mean ± se	6.5 ± 0.0	9.9
	Range	3.5 – 27.5	2 – 59
	99th	17.4	29
	95th	10.2	19
	80th	7.5	13
CH1	Mean ± se	4.5 ± 0.0	8.8
	Range	1.8 – 7.7	<1 – 50
	99th	7.3	27
	95th	6.3	17
	80th	5.5	12
CH2	Mean ± se	3.8 ± 0.0	7.6
	Range	1.5 – 6.4	<1 – 39
	99th	6.2	22
	95th	5.6	15
	80th	4.4	10

Table 23 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during October 2019 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	KZ Filtered Turbidity (NTU)		
	Statistic	Surface October	Surface Baseline
SG1	Mean ± se	2.3 ± 0.0	4.2
	Range	<1 – 6.5	<1 – 31
	99th	4.7	14
	95th	3.5	9.5
	80th	2.9	6.1
SG2	Mean ± se	2.0 ± 0.0	4.6
	Range	1.2 – 4.6	<1 – 33
	99th	3.7	20
	95th	2.8	10
	80th	2.3	6.9
SG3	Mean ± se	1.1 ± 0.0	3.6
	Range	<1 – 3.1	<1 – 22
	99th	2.7	13
	95th	1.9	7.3
	80th	1.4	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during October 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for October are means ± se, range and percentiles (n = 2962 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface October	KZ Filtered Turbidity (NTU) Surface Baseline
OS1	Mean ± se	1.4 ± 0.0	7.5
	Range	1 – 11.2	<1 – 99
	99th	9.2	23
	95th	7.7	15
	80th	6	9.7
OS2	Mean ± se	2.4 ± 0.0	6.4
	Range	<1 – 5.9	<1 – 36
	99th	5.4	17
	95th	4.3	12
	80th	3.2	8.9
OS3	Mean ± se	2.9 ± 0.0	6.5
	Range	<1 – 9.3	<1 – 110
	99th	7.0	27
	95th	5.6	14
	80th	3.7	8.9
OS4	Mean ± se	3.1 ± 0.0	5.9
	Range	<1 – 15.3	<1 – 35
	99th	10.4	18
	95th	7	13
	80th	3.8	8.1
OS5	Mean ± se	1.7 ± 0.0	4.6
	Range	<1 – 5.2	<1 – 35
	99th	3.9	18
	95th	3.0	11
	80th	2.3	6.1
OS6	Mean ± se	2.0 ± 0.0	4.7
	Range	<1 – 5.9	<1 – 37
	99th	4.7	18
	95th	3.7	11
	80th	3	7.1
OS7	Mean ± se	3.2 ± 0.0	6.3
	Range	1.2 – 9	<1 – 48
	99th	6.9	22
	95th	4.8	14
	80th	3.8	9.1

Table 25 Summary of Vision Environment quality control data for October 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		
			UH3 (A) (µg/L)	UH3 (B) (µg/L)	Variation (%)
TSS	<3	<3	12	12	0
Dissolved Aluminium (µg/l)	<3	<3	<12	<12	ND
Total Aluminium (µg/l)	<3.2	<3.2	240	220	9
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	1.2	1.7	34
Total Chromium (µg/l)	<0.53	<0.53	<1.1	1.8	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	2.4	ND
Dissolved Iron (µg/l)	<20	<20	<4	<4	ND
Total Iron (µg/l)	<21	<21	370	370	0
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	6.2	5.4	14
Total Manganese (µg/l)	<0.53	<0.53	12.6	12.8	2
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	10.1	11	9
Total Molybdenum (µg/l)	<0.21	<0.21	11.1	10.7	4
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	2.2	44
Total Vanadium (µg/l)	<1.1	<1.1	1.8	2.7	40
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	22	19	15
Dissolved Reactive Phosphorus (µg/l)	<4	<4	7.6	7.5	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	13	19	38
Nitrate-N + Nitrite-N (µg/l)	<2	<2	<1	167	ND
Chlorophyll *a* (µg/L)	<0.2	<0.2	1.9	2	5