Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

March 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, which commenced on 29 August 2018, were completed on 29 November 2018, taking the monitoring into a post dredge phase up until 11 March when a smaller dredging operation began for the reclamation works at Cashin Quay. Monitoring results collected during March 2019 are presented within this report. Continuing with the dredge phase monitoring report format, 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 are compared to compliance trigger values during reclamation dredging operations.

Climatic Conditions: Rainfall at Cashin Quay during March 2019 totalled 13.2 mm, a notable increase from the limited volume experienced during February. Freshwater outflow from the Waimakariri River was also increased, with a maximum outflow of 957 m^3/s recorded on 27 March. Daily averaged inshore wind speeds ranged from 5.6 to 19.3 knots for the month, with the maximum mean daily wind speed recorded on 30 March. Maximum wind gusts of 43 knots were recorded on 13 March.

Offshore, both wind speeds and wave heights displayed similar temporal variations over the month. Maximum significant wave heights of 2.35 m were recorded on 27 March, following maximum offshore wind speeds recorded on 26 March.

Daily mean air temperatures varied between 14 and 24°C, with a monthly average of 17°C that is similar to that of February 2019.

Currents: Diagnostic analyses of the ADCP units from sites SG1 and SG3 were completed in early March, with redeployment on 13 March. Current velocity and direction data recorded at the spoil ground site SG2a are once again available for the duration of March.

Surface current velocities at all three sites were elevated between 25 and 26 March, with the strongest flow observed at SG3 at 591 mm/s. As per previous reporting months, benthic currents were reported to be of lower velocity than those of the surface at SG1 and SG3. Similar timings of maximum benthic current velocities as those recorded at the surface, suggest that the forcing was expressed throughout the water column, and preceded maximum significant wave heights experienced during March.

Current direction data from SG1 indicate a strong dominance of flow in a south easterly direction at both the near-surface and near-seabed. Contrasting the conditions during February where bi-directional flow was observed, directional data from SG2a indicates a dominance of surface flow towards the east with a weak reverse component along the east-west axis. However, a more notable component of near-seabed current flow was observed towards the west. Further southeast at SG3, flow at the near-surface and near-seabed was predominately towards the east and southeast, with notable return flow to the west and northwest.

Turbidity: Consistent with previous results, turbidity was higher at the inshore monitoring sites of the central and upper harbour than at the nearshore and offshore monitoring locations. Mean turbidity values and higher order percentile statistics for March were lower than those recorded during the baseline monitoring period.

Continuing previous monthly trends, turbidity at site CH2–located in the southern harbour–tended to be lower than other inshore sites, reflecting tidal flow patterns within the harbour. Surface turbidity within the harbour initially declined at the start of the month, with increasing levels of suspended particulate matter associated with increased wind speeds and local rainfall on 8 March. Variability in surface turbidity then displayed an apparent correlation with inshore wind speeds, whereby increased winds provided sufficient energy for sediment resuspension. Rapid increases in surface turbidity between 23 and 27 March may have been related to elevated offshore wave heights being funnelled into the harbour.

A similar pattern in surface turbidity was also observed at the nearshore monitoring sites, with initially declining surface turbidity followed by two increases on 8 and 15 March that likely relate to localised rainfall events. Turbidity at the offshore site OS6 increased on 14 March, which may also reflect a delayed influence of terrestrial runoff. Further offshore at OS5 and the spoil ground sites, turbidity remained relatively stable over the first two weeks of the month. All nearshore and offshore monitoring locations displayed increased surface turbidity between 23 and 28 March in response to increased wave heights.

Benthic turbidity displayed a strong relationship with corresponding surface trends and significant wave height data, particularly at OS6. This similarity indicates well mixed conditions, with sufficient energy within the water column to transport resuspended sediments to the surface.

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

Other Physicochemical Parameters: Monthly mean surface water temperatures around Lyttelton Harbour were slightly cooler in March going against the slight warming trend observed during the previous months. Surface water temperatures are now following the cooling pattern which has been occurring in the mean monthly air temperatures. The warmest water temperatures were again recorded in the shallow waters of the upper and central harbour. All monitoring locations indicated a brief period of cooling around 8 March, with a second phase observed around 15 March associated with local rainfall. Dramatic declines were observed at all sites on the 29 March which remained till the end of the month and were associated with declines of up to 5ºC in ambient temperatures along with increased wind speeds. Benthic temperatures were cooler than the overlying surface waters, with warmer temperatures recorded within Lyttelton Harbour than those along the exposed coastline. Although benthic temperatures remained stable for the majority of the month, they also declined just prior to 29 March similar to their surface counterparts.

Consistent with previous reports, pH during March did not display any particular spatial or temporal patterns across the monitoring network. Rainfall may have had a small influence in lowering pH at inshore sites, however, there was no apparent effect on pH from the Waimakariri flow towards the end of the month. Benthic pH was lower and more stable across the month than that at the surface, however, a slight increase in pH at OS6 on 14 March may have been a result of increased benthic turbidity at the time.

Conductivity was also relatively stable for the first two weeks in March before being influenced by flows from the Waimakariri River. Some minor freshening occurred in the third week of March at all sites with a minor flow event, however, major declines in conductivity were recorded towards the end of the month associated with the larger flow event. Although more pronounced at the offshore and spoil ground sites, inshore sites were also affected by the freshwater intrusion. The flow coincided with increased wave heights at the time which may have advected freshwater deep into the harbour. Benthic waters were typically of higher conductivity, except for at OS1, OS2 and OS4. These sites may have been influenced by vertical mixing of fresher surface waters during the increased wind speed and wave height events.

Dissolved oxygen (DO) concentrations displayed elevated monthly mean values, particularly at spoil ground sites. Large diurnal fluctuations were observed at the southern sites (CH2 and UH2) within Lyttelton Harbour during the first week of March when temperatures were elevated. Large declines in DO following rainfall on 8 March were particularly noticeable at OS2, which declined by approximately 20% saturation before recovering. The second rainfall event mid-March also contributed to declines in DO except at inshore sites and was likely induced by lower photosynthetic activity due to cloud cover. Increased significant wave heights and offshore wind speeds may have induced increased DO at some sites due to turbulent mixing introducing oxygen. Mean monthly benthic DO concentrations were lower than at the surface as typically found, and once again displayed a high level of temporal variability over the month.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 7 March prior to dredge operations commencing on 11 March. Similar to profiles typically obtained during the monitoring program, inner harbour and nearshore monitoring sites indicated a well-mixed water column with only turbidity increasing near the benthos.

Further offshore, depth profiling indicated that vertical mixing was largely limited to the surface 10 metres of the water column. Below these surface waters, temperature, pH and DO all declined towards the benthos, while conductivity displayed a slight increase. In a similar manner to previous monitoring months, turbidity increased towards the seabed as seafloor sediments experienced resuspension.

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 21.9 m at OS5. No exceedances of WQG were observed for sub-surface turbidity during the March 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 were only exceeded at the inner harbour sites UH1-3 and the nearshore sites OS1 and OS2. Concentrations of total nitrogen and total kjeldahl nitrogen once again remained below detection limits at all sampling sites, with ammonia reported below the WQG of 15 µg/L across the monitoring network. Nitrogen oxide concentrations were variable with many sites below LOR. However, site OS1 reported an elevated concentration of 38 µg/L, more than double the WQG of 15 µg/L. Such elevated concentrations were not repeated in the duplicate sample also collected at OS1; indicating that these increased concentrations are likely a result of sample contamination. Chlorophyll *a*, an indicator of phytoplankton biomass, remained low during March.

Contrasting typical water quality observations in Lyttelton Harbour, concentrations of total mercury above laboratory LOR were reported for sites CH1 and OS2 (Tables 16 and 17) during the March sampling. Concentrations of dissolved mercury, for which WQG are applicable, remained below the 0.08 µg/L LOR. As typically observed, total aluminium concentrations exceeded designated WQG at all of the inshore and the majority of the offshore monitoring sites. Dissolved aluminium concentrations, however, remained below LOR across the network. In a similar pattern as aluminium, total copper concentrations were reported above the LOR at UH2, OS4 and OS5, with a slight exceedance of WQG at UH2 and the reference site OS4. All dissolved copper concentrations remained below laboratory LOR.

Of the remaining metals that do not have assigned WQG, concentrations of total iron were greatest in the upper harbour, with dissolved iron remaining below 10 µg/L across the monitoring network. These results indicate that iron within Lyttelton Harbour was predominately within the particulate phase. Slightly elevated concentrations of manganese were once again recorded in the upper harbour, with a relatively even split between dissolved and particulate components. Vanadium and molybdenum were also reported above LOR during March, with little spatial variability and a large component contained within the dissolved phase.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during March, in terms of the monthly mean, were lower than that experienced in February, despite displaying a similar range in conditions.

Despite increased ambient PAR during the first week of the month, BPAR at both sites was negligible due to elevated turbidity. From 7 March BPAR at OS2 and OS3 followed a similar trend to ambient PAR, due to turbidity values at both sites being relatively low (<10 NTU). However, despite elevated ambient PAR towards the end of the month, BPAR at both sites once again recorded zero to negligible values due to elevated turbidity (15 to 20NTU) created by high wind speeds and wave heights at the time preventing light penetration to the benthos.

Sedimentation: During the first two weeks of March, bed level at the harbour entrance demonstrated a slow period of erosion of approximately 13 mm, which did not appear to be related to metocean conditions. Recovery occurred up to 26 March which coincided with a period of declining turbidity and a potential settling of particles. From the 26 to 27 March, 74 mm of sediment was dramatically deposited on the sea floor, most likely sourced externally due to the increased wave heights and offshore wind speeds at the time. Bed level then remained stable to the end of the month. A net increase of 80 mm was recorded for March.

Similar to previous observations, bed level in the upper harbour at UH3 was more stable than at OS2, with little apparent correlation between inshore wind speed and bed level. A period of rapid erosion of approximately 30 mm occurred just prior to the mid-month rain event but did not appear to be related to metocean conditions. The system recovered with a net removal of 13 mm recorded for the month.

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Acronyms

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

1 INTRODUCTION

Lyttelton Port Company (LPC) is undertaking a Channel Deepening Project (CDP) to extend the existing navigational channel to allow larger vessels access to the Lyttelton Port of Christchurch (LYT), the South Island's largest port. Utilising background information provided by LPC and advice from the Technical Advisory Group (TAG) in relation to ambient conditions, locations of sensitive habitats and dredge impact hydrodynamic modelling scenarios, a water quality monitoring design was proposed for the initial 12 month baseline monitoring phase. Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016, progressing into dredge operations monitoring from 29 August with completion of works on 29 November 2018. Monitoring continued into a post dredge phase up until 11 March 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 a number of 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.

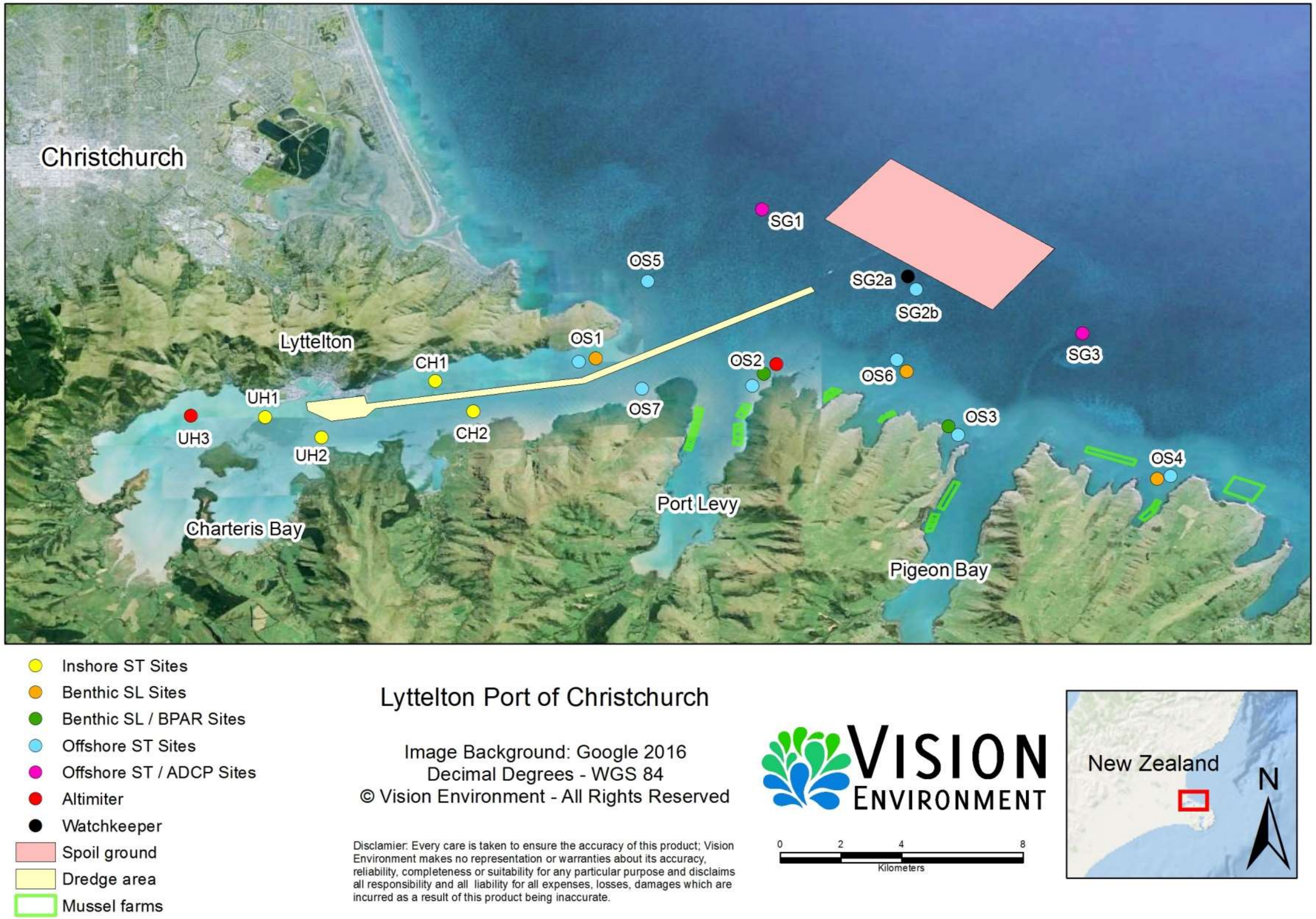


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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

This monthly report presents data collected from the 22 monitoring locations from 1 to 31 March 2019 during post dredge operations from 1 to 10 March and dredge operations from 11 March. Monthly water sampling and depth profiling was conducted on 7 March 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) (ANZECC/ARMCANZ, 2000) default interim trigger values. In the absence of specific default trigger values for estuarine or marine ecosystems, which are yet to be developed in New Zealand, the WQG suggest the use of interim trigger values for south-east Australian estuarine and marine ecosystems.

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

3 RESULTS & DISCUSSION

3.1 Metocean Conditions

3.1.1 Wind and precipitation

During March 2019, Cashin Quay received 13.2 mm of rainfall spread over 7 days (Figure 2); 7.8 mm more than that recorded during February. The majority of this rainfall was experienced on 8 (6.8 mm) and 15 (5.2 mm) March (Metconnect, 2019). Freshwater flows from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour several days later, displayed two peaks; one slight increase from 16 March, and a larger increase at the end of the month resulting in a maximum outflow of 957 m^3/s on 27 March 2019 (Figure 2) (ECAN, 2019).

Inshore winds were once again predominately from an east-north-east direction, with daily mean wind speeds ranging from 5.6 knots on 1 March to 19.3 knots on 30 March (Figure 2). The greatest maximum wind gusts were experienced on 13 March and reached 44 knots from a south westerly direction (Metconnect, 2018). Daily mean air temperatures at Cashin Quay ranged from 14 to 24°C, resulting in a monthly mean temperature of 17°C (Metconnect, 2019).

Offshore significant wave heights were variable throughout March, with trends similar to those of offshore wind speeds (Figure 3). Maximum significant wave heights were recorded at 2.35 m on 27 March, travelling in a south-south-westerly direction (Figure 3), following maximum daily mean offshore wind speeds of 16 knots recorded on 26 March. After a period of relatively calm conditions on 28 March, offshore wave heights then displayed an additional rapid increase towards the end of the month.

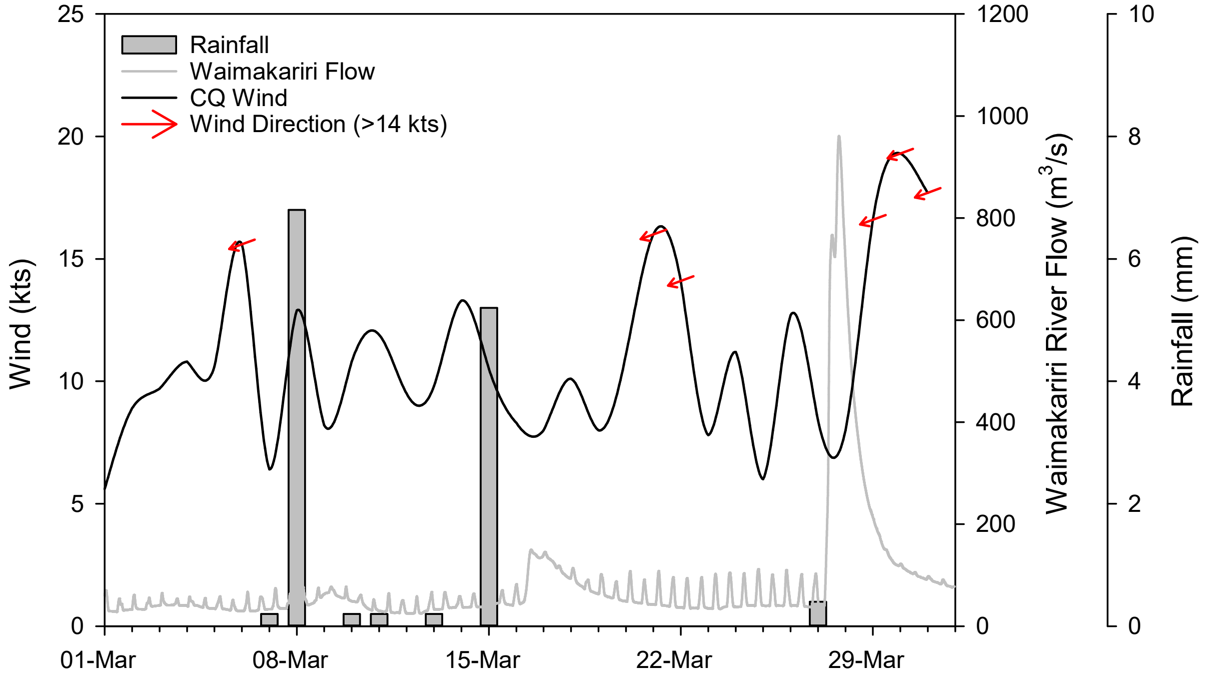


Figure 2 Inshore metocean conditions including daily averaged wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during March 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

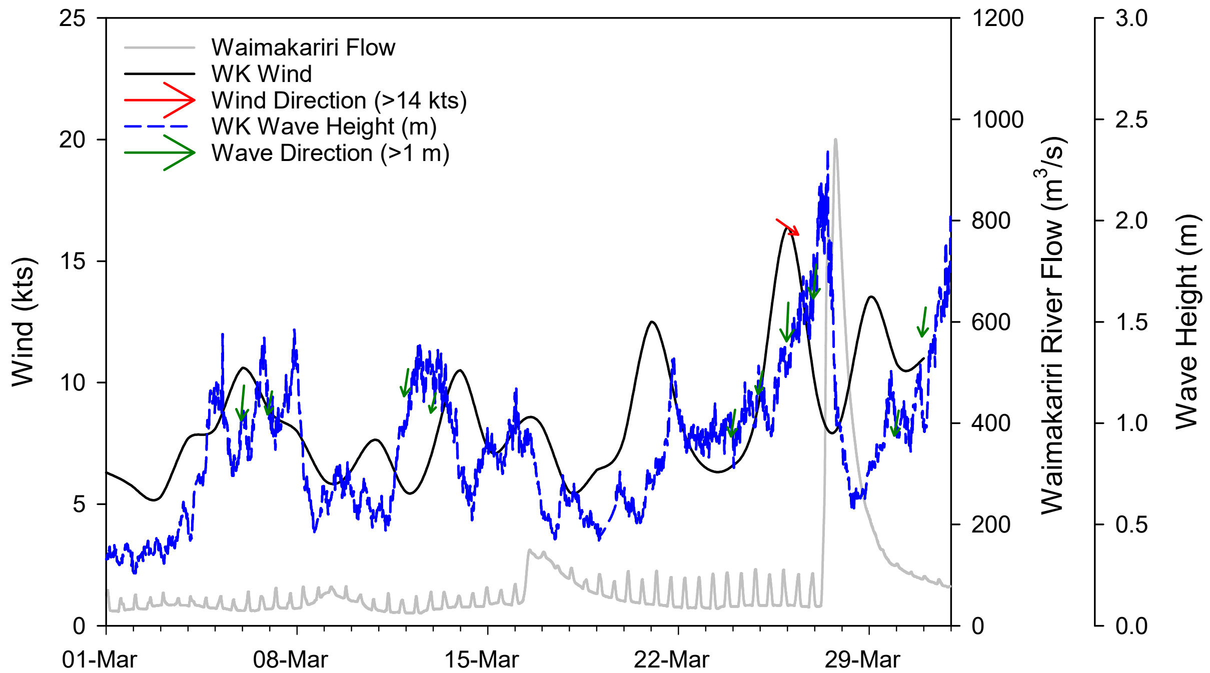


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during March 2019.
Note: Arrows indicate the direction of travel for offshore winds greater than 14 knots and offshore waves above 1 m significant wave height. Directions from the WatchKeeper buoy have not been corrected for magnetic declination.

3.1.2 Currents

Acoustic Doppler Current Profilers (ADCPs) are deployed at the spoil ground monitoring sites SG1, SG2a and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Unfortunately, both ADCP units at SG1 and SG3 stopped sending data in late August/early September 2018 and were removed from site from mid-January to 13 March 2019 for maintenance. Following redeployment, the timestamps of the telemetered data from SG1 and SG3 initially contained a 13 hour delay, which was corrected by RPS staff prior to data analysis. ADCP data collected from the WatchKeeper Buoy at SG2a are available for the duration of March. Summary ADCP statistics are presented within Figures 4 to 6 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 30 and 35 in the Appendix. Note that the ADCP data are presented in this report using the UTC time format.

The maximum near-surface current velocity at SG1 was recorded on 25 March reaching a speed of 387 mm/s (Table 2). Similarly, the minimum near surface current velocity was also enhanced at this time, reaching 111 mm/s c.f. 3-26 mm/s experienced during the remainder of the month. Surface currents at SG2a were also strong during this period, with a monthly maximum of 122 mm/s observed a day later on 26 March. Interestingly, minimum current velocities at this time remained low, ranging from 0-7 mm/s during March. Further south east at SG3, surface current velocities were also elevated between the 25 and 26 March, with a maximum velocity of 591 mm/s recorded on 25 March (Table 2).

Consistent with previous reports, near-seabed current velocities were reduced when compared to those of the surface at SG1 and SG3, however, they were greater than those recorded at the surface of SG2a (Table 2). This difference may be related to varying benthic topography across the spoil ground. Maximum near-seabed current velocities were elevated on 23, 24 and 25 March at SG2a, SG1 and SG3, respectively. The similar timings between maximum near-surface and near-benthic current velocities across the spoil ground suggests a water column wide forcing effect that preceded maximum significant wave heights experienced during March 2019 (Figure 3).

Table 2 Parameter statistics for spoil ground ADCPs during March 2019.

Parameter	Depth	Site		
		SG1	**SG2a**	**SG3**
Minimum current speed (mm/s)	*Near-surface*	3	0	1
	Near-seabed	2	2	2
Maximum current speed (mm/s)	*Near-surface*	387	122	591
	Near-seabed	299	246	509
Mean current speed (mm/s)	*Near-surface*	120	20	137
	Near-seabed	86	77	125
Standard deviation of current speed (mm/s)	*Near-surface*	70	15	82
	Near-seabed	42	41	68
Current speed, 95th percentile (mm/s)	*Near-surface*	254	50	287
	Near-seabed	159	158	250

The time-series plots (Figures 30 to 35 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, please note that the convention for defining current direction is the direction in which the current flows *towards*, which is the reference used throughout the figures presented (the opposite is true for wind direction, where the reference is the direction from which the wind is coming from).

Current direction data recorded at SG1 from 12 to 31 March indicate a dominance of flow in a south easterly direction (32.7%), with smaller components to the south (17.3%) and to the east (13.3%) (Figure 4). A similar pattern was observed at the near-seabed with a dominance of flow to the southeast. Contrasting the results from February, current direction data collected at SG2a once again indicated a strong dominance of flow towards the east (27% near-surface, 28.9% near-seabed) and relatively low return flow along the east-west axis. Near-seabed currents displayed a slightly larger component of bidirectional flow, similar to that recorded during February (Figure 5). At the south eastern edge of the spoil ground, currents at SG3 displayed a dominance of flow to the east and southeast at both the near-surface and near-seabed (Figure 6), with notable components in the opposing west and northwest directions (~10% and 16%, respectively).

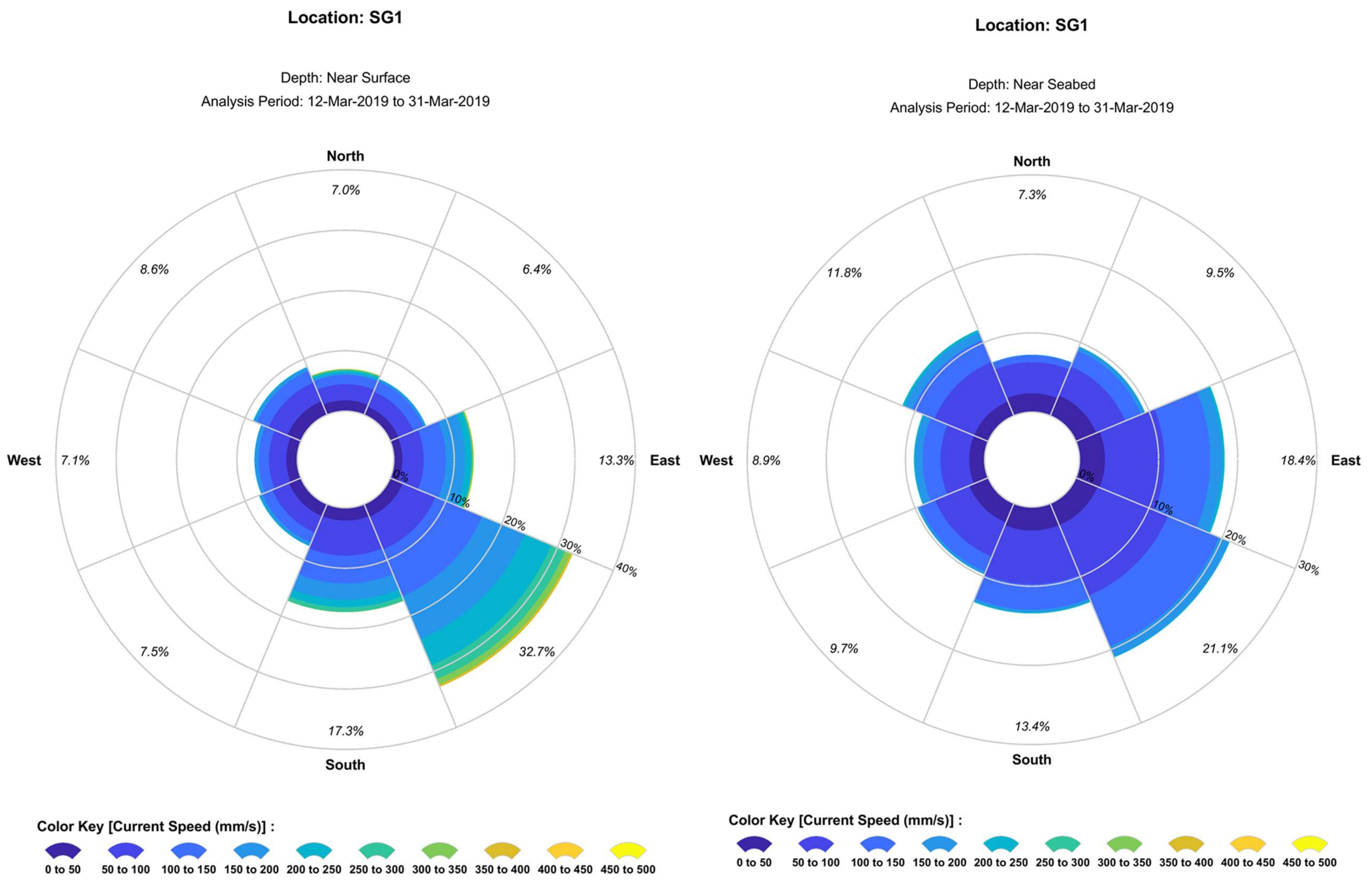


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during 12 to 31 March 2019.
Speed intervals of 50 mm/s are used

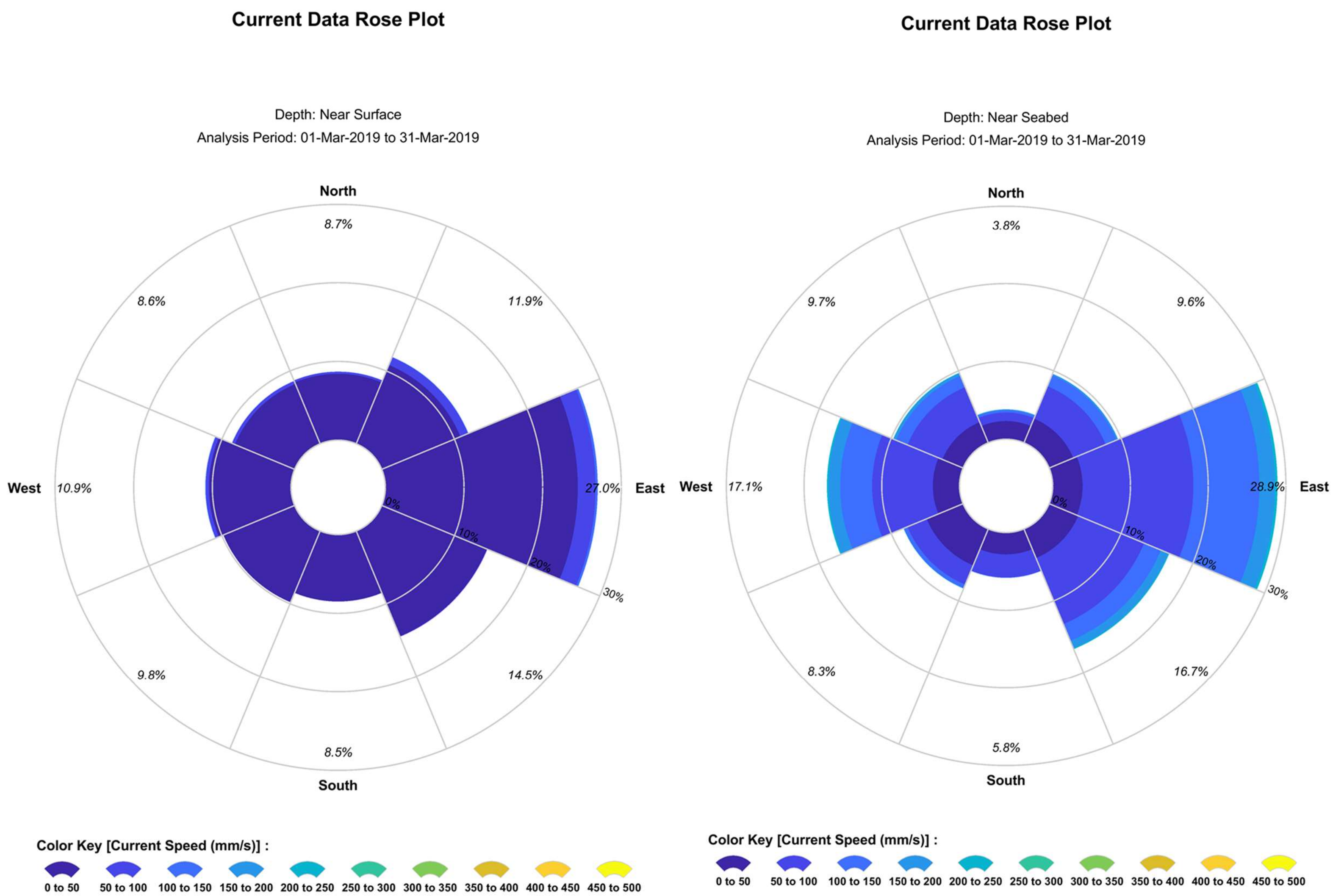
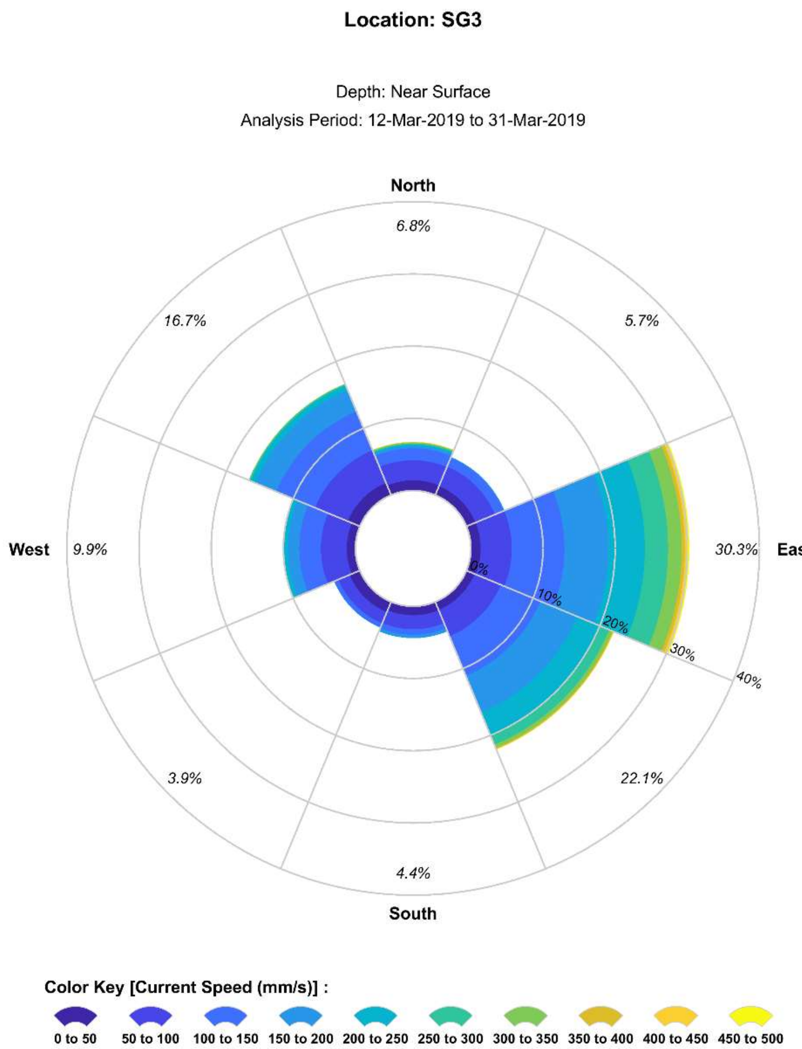


Figure 5 Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during March 2019.
Speed intervals of 50 mm/s are used



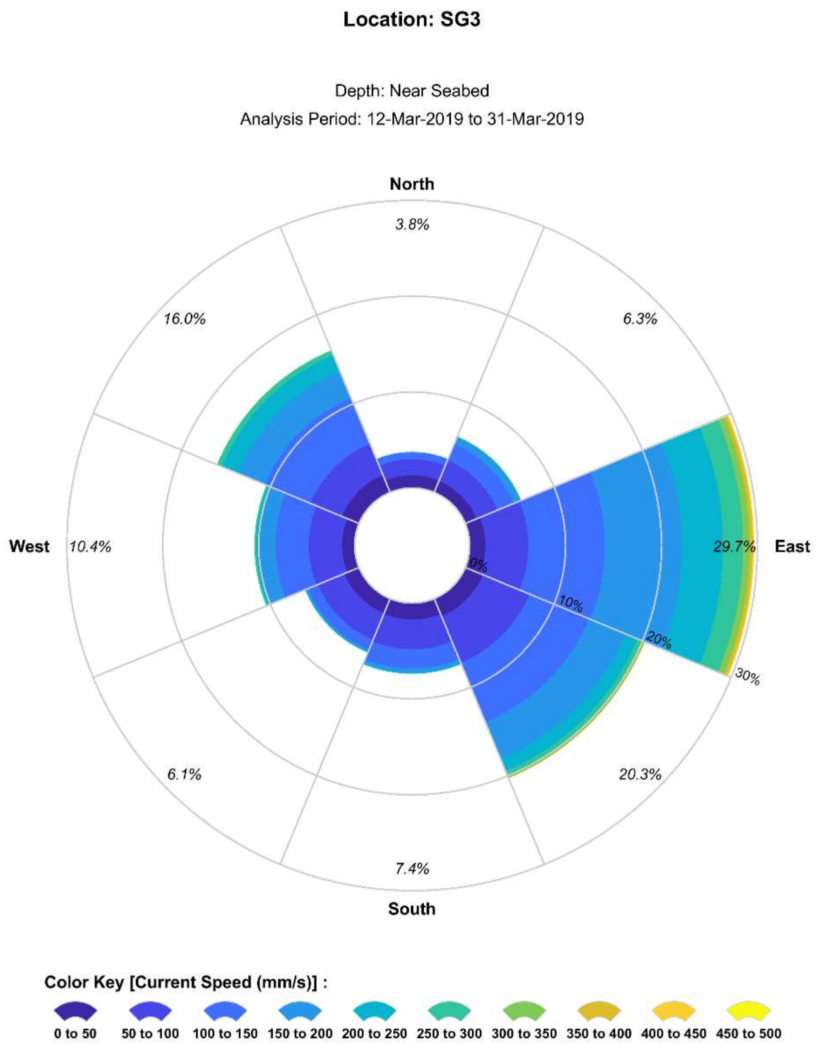


Figure 6 Near-surface and near-seabed current speed and direction at SG3 during 12 to 31 March 2019.
Speed intervals of 50 mm/s are used

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties (turbidity, temperature, conductivity [normalised to a reference temperature of 25°C], pH and DO) of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 7 March 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 March are presented in Tables 3 to 12. Validated datasets for surface and benthic measurements are also presented in Figures 7 to 20. Due to the inherent high level of variability in the turbidity datasets, a 24-hour rolling average has been calculated every 15 minutes to act as an interim smoothing technique and aid in data interpretation.

3.2.1 Turbidity

Of key importance within the real time parameters recorded are the surface turbidity measurements, due to their relevance to established trigger values for management of dredge operations. As such, summary turbidity statistics for the initial baseline period of monitoring from 1 November 2016 to 31 October 2017 (Fox, 2018) are also presented in Tables 3 to 5 to allow a comparison with the March 2019 post dredge and dredge 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 36 to 39 in the Appendix.

March Turbidity:

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 4.4 to 7.8 NTU) at the inshore monitoring sites (Table 3, Figure 7). Further offshore, the spoil ground sites exhibited lower (monthly means of 2.5 to 3.5 NTU) surface turbidity values (Table 4), which are likely due to the deeper water column limiting expressions of seafloor sediment disturbance at the sub-surface. As typically observed, nearshore sites experienced a wider range of turbidity values (1.3 to 4.8 NTU) during March (Table 5). Continuing previously observed trends, surface turbidity at CH2 on the southern side of the harbour remained notably lower than the remaining three inner harbour sites, likely reflecting tidal movements within the harbour where the southern edge is dominated by the incoming flood tide.

Turbidity across the inner harbour declined during the first few days of March, with increasing wind speeds and localised rainfall resulting in elevated turbidity levels around 8 March (Figure 7). Variability in measured surface turbidity at these sites then displayed a high level of similarity to inshore wind speeds, which provide the energy for vertical mixing and the resuspension of seafloor sediments. Rapid increases in turbidity observed between 23 and 27 March may also be related to elevated wave heights as measured at the spoil ground, which are likely to have been funnelled in to Lyttelton Harbour providing further energy for sediment resuspension (Figure 7). This suggestion of wave-induced sediment resuspension is further supported by declining turbidity levels on 30 and 31 March as significant wave heights declined, despite maximum inshore wind speeds being recorded at this time.

The nearshore sites of the monitoring program (OS1 to 4 and OS7) displayed a level of spatial consistency in surface turbidity trends, with initially declining turbidity followed by two sizeable peaks on 8 and 15 March (Figure 7). These periods of elevated turbidity are likely related to surface runoff associated with the two rainfall events recorded at Cashin Quay on these days. In a similar manner to the inner harbour sites, turbidity across the nearshore region displayed a large increase from 23 to 28 March as significant wave heights increased to monthly maxima on 27 March. As wave heights declined towards the end of the month, surface turbidity at all the nearshore sites was also reduced.

Further offshore at OS5, OS6 and the spoil ground sites, turbidity declined and then remained relatively stable during the first two weeks of the month. As expected, localised rainfall events did not appear to result in increased turbidity at most of these offshore sites, however, turbidity was observed to increase at OS6 from 14 March (Figure 11) that may reflect a terrestrial influence. Increased significant wave heights towards the end of the month also resulted in a period of increased offshore turbidity coinciding with the peaks recorded at the nearshore and inshore monitoring locations (Figure 7).

Comparison to Baseline:
Mean surface turbidity and higher order percentile statistics during March were lower than those calculated from the baseline monitoring period (Tables 3 and 5, Figures 8 to 12). Post-dredge data acquisition from CH1 had previously indicated elevated turbidity conditions at CH1, however, in a similar manner to reports following December 2018, mean surface turbidity and higher order percentile statistics from March were below average baseline conditions (Table 3).

Benthic:
Data recovery for March was limited for benthic sites OS1 and OS3, however, where data are available there appears to be a high level of consistency across sites. Variations in benthic turbidity displayed a high correspondence with offshore significant wave heights, particularly at OS6, with periods of increased wave energy coinciding with elevated turbidity levels. The high similarity between benthic and surface turbidity trends observed within the nearshore region indicates well mixed conditions, with sufficient energy added to the water column to bring resuspended sediments from the benthos to the surface (Figure 7).

Table 3 Mean turbidity and statistics at inshore water quality logger sites during March 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for March are means ± se, range and percentiles (n = 2824 to 2955) Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface March	Surface Baseline
UH1	Mean ± se	7.8 ± 0.0	12
	Range	<1 – 21	-
	99th	15	39
	95th	12	22
	80th	9.8	15
UH2	Mean ± se	7.0 ± 0.0	10
	Range	<1 – 17	-
	99th	14	32
	95th	11	20
	80th	8.4	13
CH1	Mean ± se	6.0 ± 0.0	9
	Range	1 – 19	-
	99th	12	29
	95th	9.7	18
	80th	7.6	12
CH2	Mean ± se	4.4 ± 0.0	8
	Range	<1 – 12	-
	99th	9.0	24
	95th	7.3	16
	80th	5.6	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during March 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for March are means ± se, range and percentiles (n = 1764 to 2956). Baseline values modified from Fox 2018.*

Site	Statistic	Turbidity (NTU) Surface March	Surface Baseline
SG1*	Mean ± se	2.9 ± 0.0	4.2
	Range	<1 – 8.7	-
	99th	6.6	14
	95th	5.7	10
	80th	4.5	6.2
SG2	Mean ± se	3.5 ± 0.0	4.6
	Range	<1 – 12	-
	99th	7.6	20
	95th	5.5	11
	80th	4.1	7.0
SG3*	Mean ± se	2.5 ± 0.0	3.6
	Range	<1 – 10	-
	99th	6.6	13
	95th	5.7	7.7
	80th	4.5	4.8

**Limited data available from SG1 and SG3 during March*

Table 5 Mean turbidity and statistics at offshore water quality logger sites during March 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for March are means ± se, range and percentiles (n = 0 to 2974). Baseline values modified from Fox 2018.*

Site	Statistic	Turbidity (NTU)		
		Surface March	Surface Baseline	Benthic March
OS1*	Mean ± se	2.3 ± 0.0	7.5	–
	Range	<1 – 11	-	–
	99th	7.0	24	–
	95th	5.2	16	–
	80th	3.6	10	–
OS2	Mean ± se	4.8 ± 0.0	6.4	25 ± 0
	Range	2 – 15	-	5 – 108
	99th	11	18	79
	95th	8.6	13	51
	80th	6.0	9.0	32
OS3*	Mean ± se	3.9 ± 0.1	6.6	21 ± 1
	Range	<1 – 20	-	2 – 99
	99th	15	27	84
	95th	9.4	15	54
	80th	5.2	8.9	29
OS4	Mean ± se	1.3 ± 0.0	5.9	23 ± 0
	Range	<1 – 19	-	2 – 188
	99th	12	20	103
	95th	5.2	13	64
	80th	2.1	8.3	31
OS5	Mean ± se	1.9 ± 0.0	4.6	–
	Range	<1 – 14	-	–
	99th	6.6	19	–
	95th	3.9	11	–
	80th	2.4	6.4	–
OS6	Mean ± se	2.6 ± 0.0	4.7	31 ± 0
	Range	<1 – 16	-	3 – 191
	99th	8.0	19	105
	95th	6.0	12	80
	80th	4.4	7.2	49
OS7	Mean ± se	2.9 ± 0.0	6.4	–
	Range	<1 – 16	-	–
	99th	9.2	23	–
	95th	6.7	14	–
	80th	4.4	9.2	–

**Limited benthic turbidity data available from OS1 and OS3 during March*

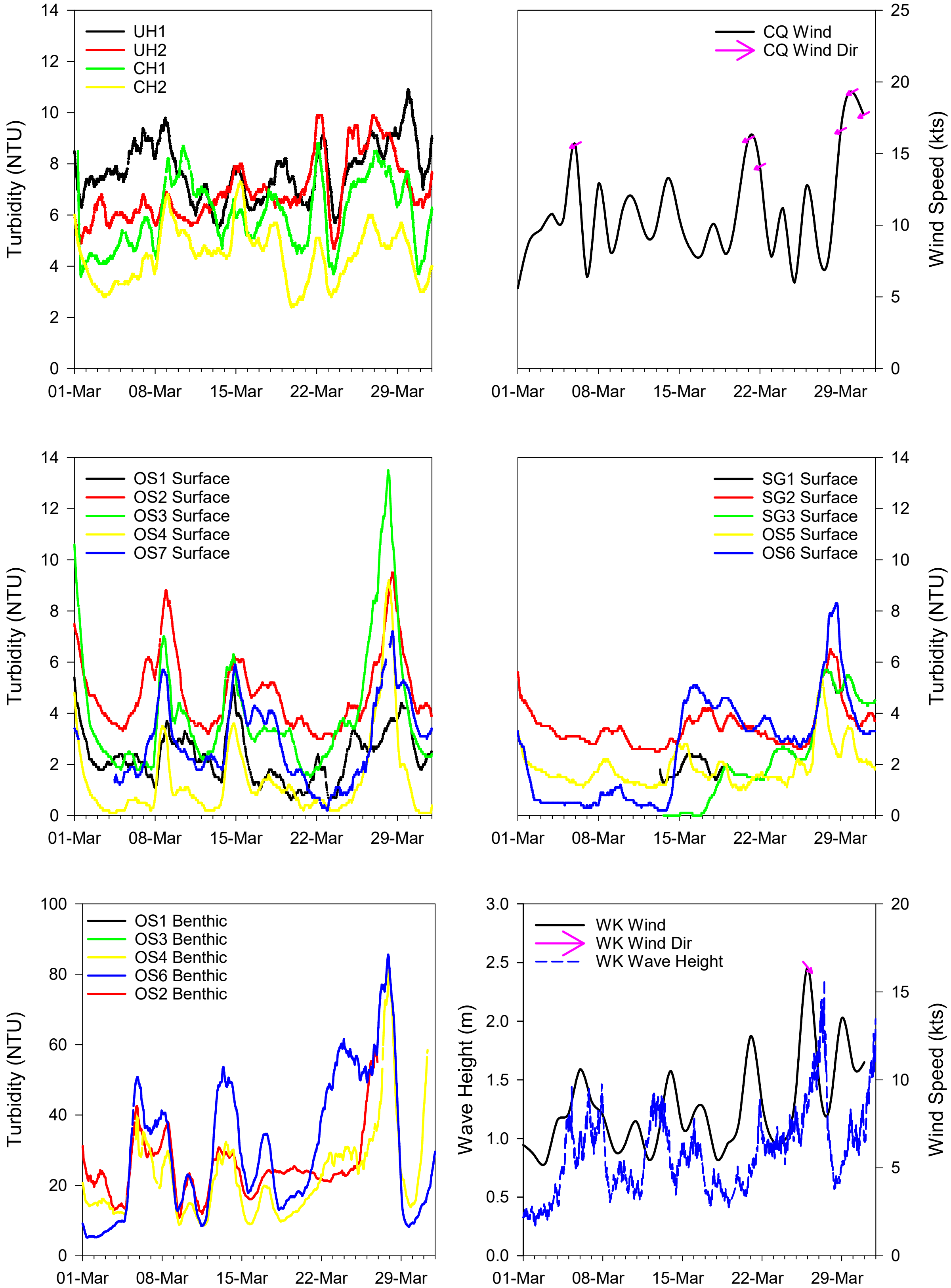


Figure 7 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

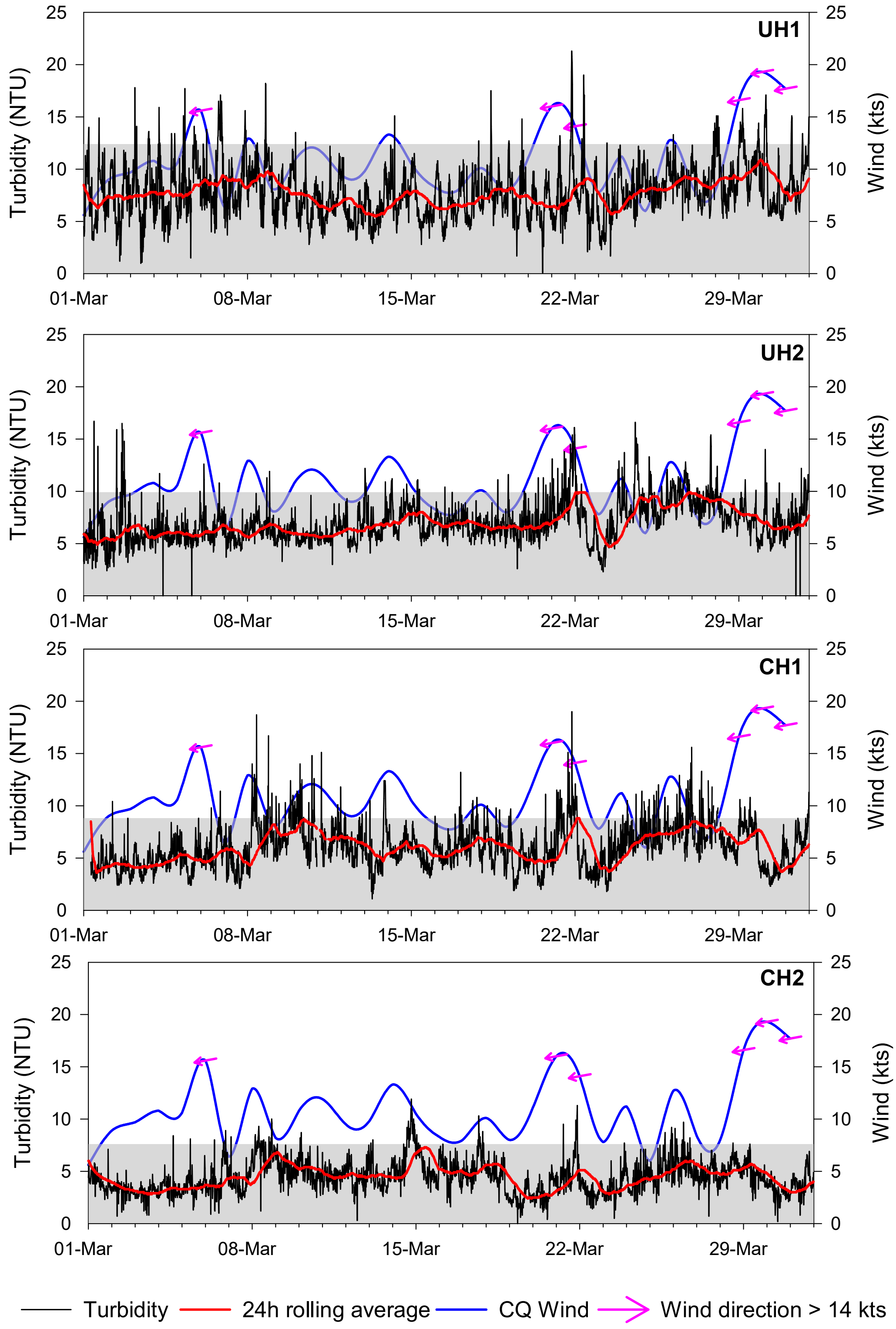


Figure 8 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during March 2019.
Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

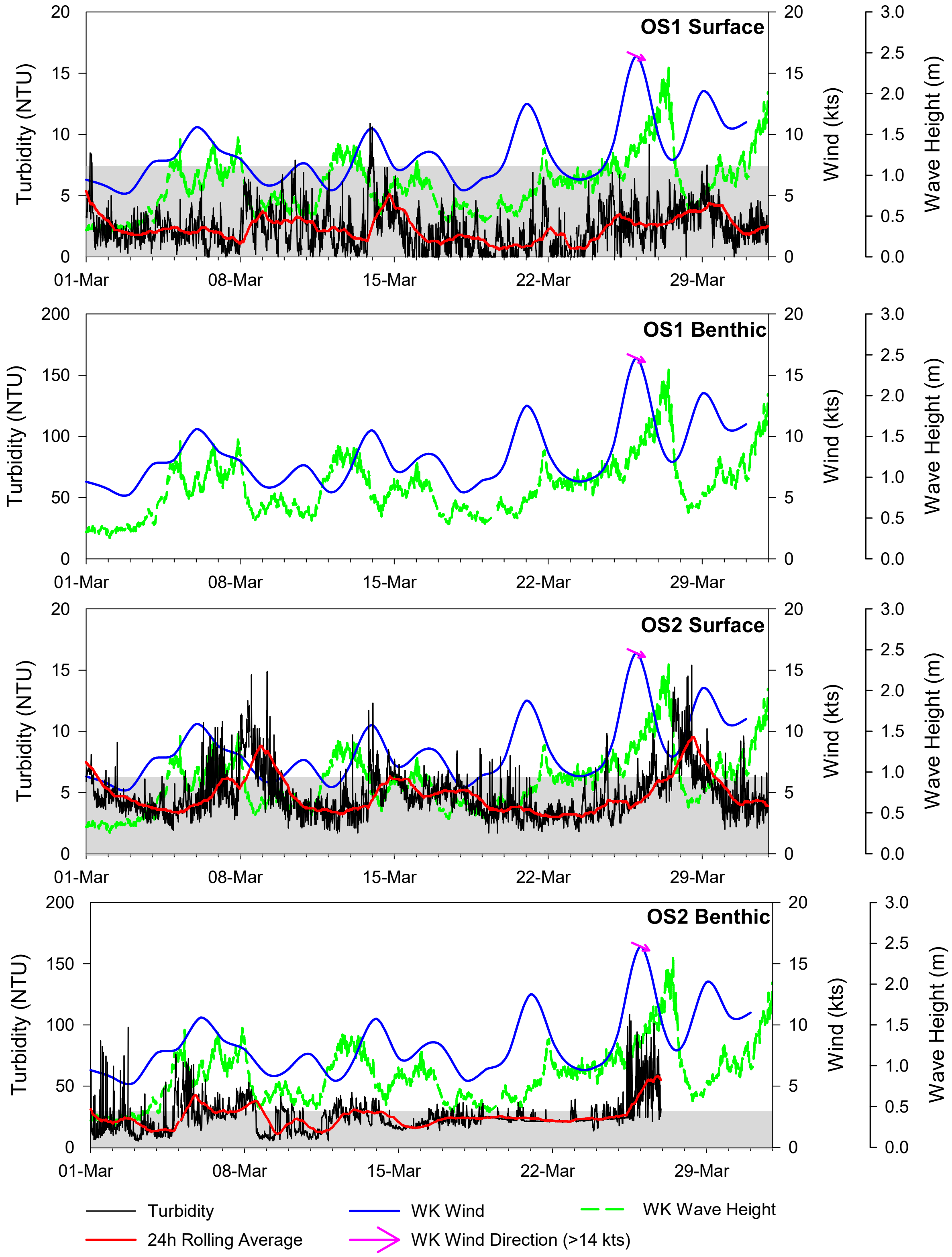


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

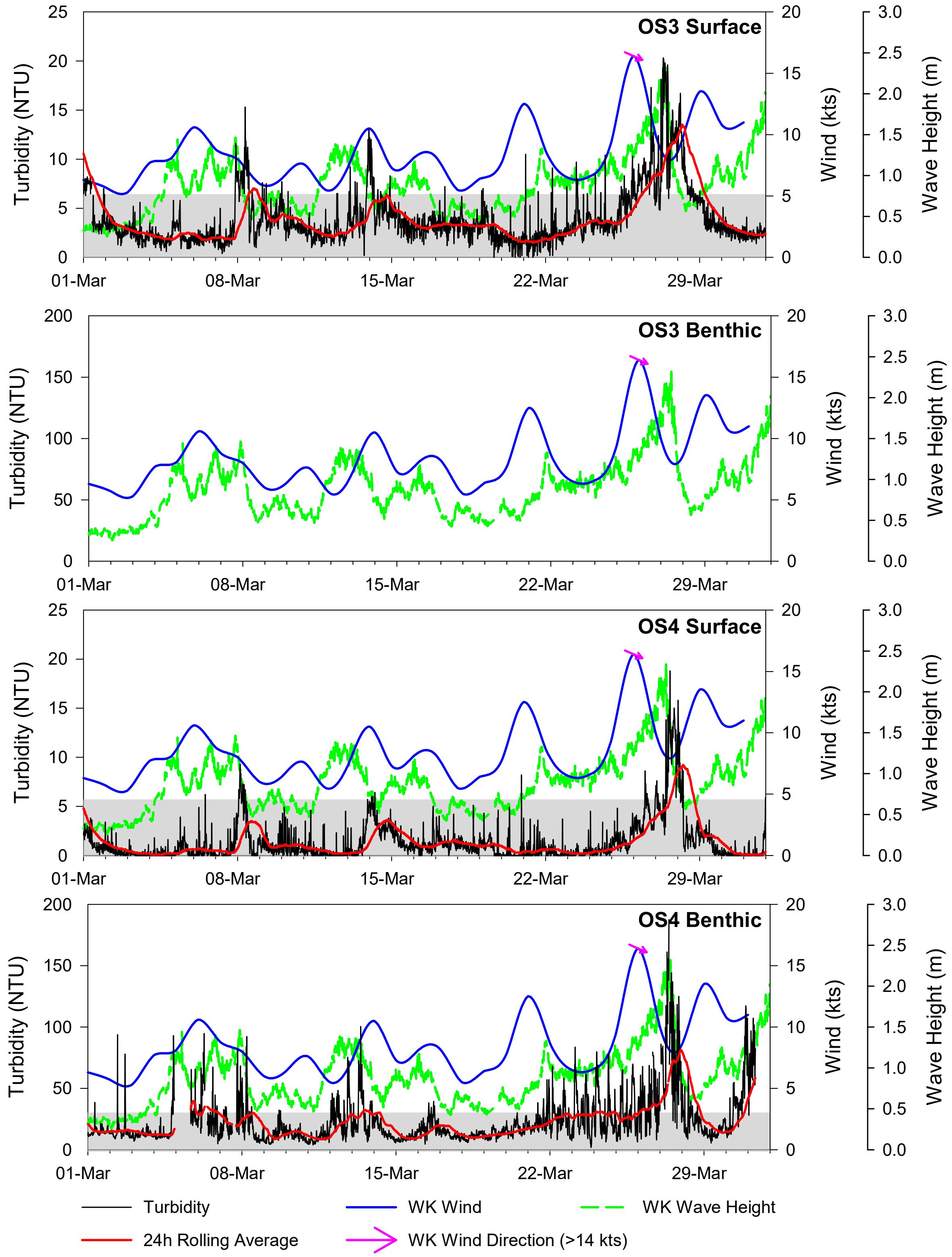


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during March 2019.

Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

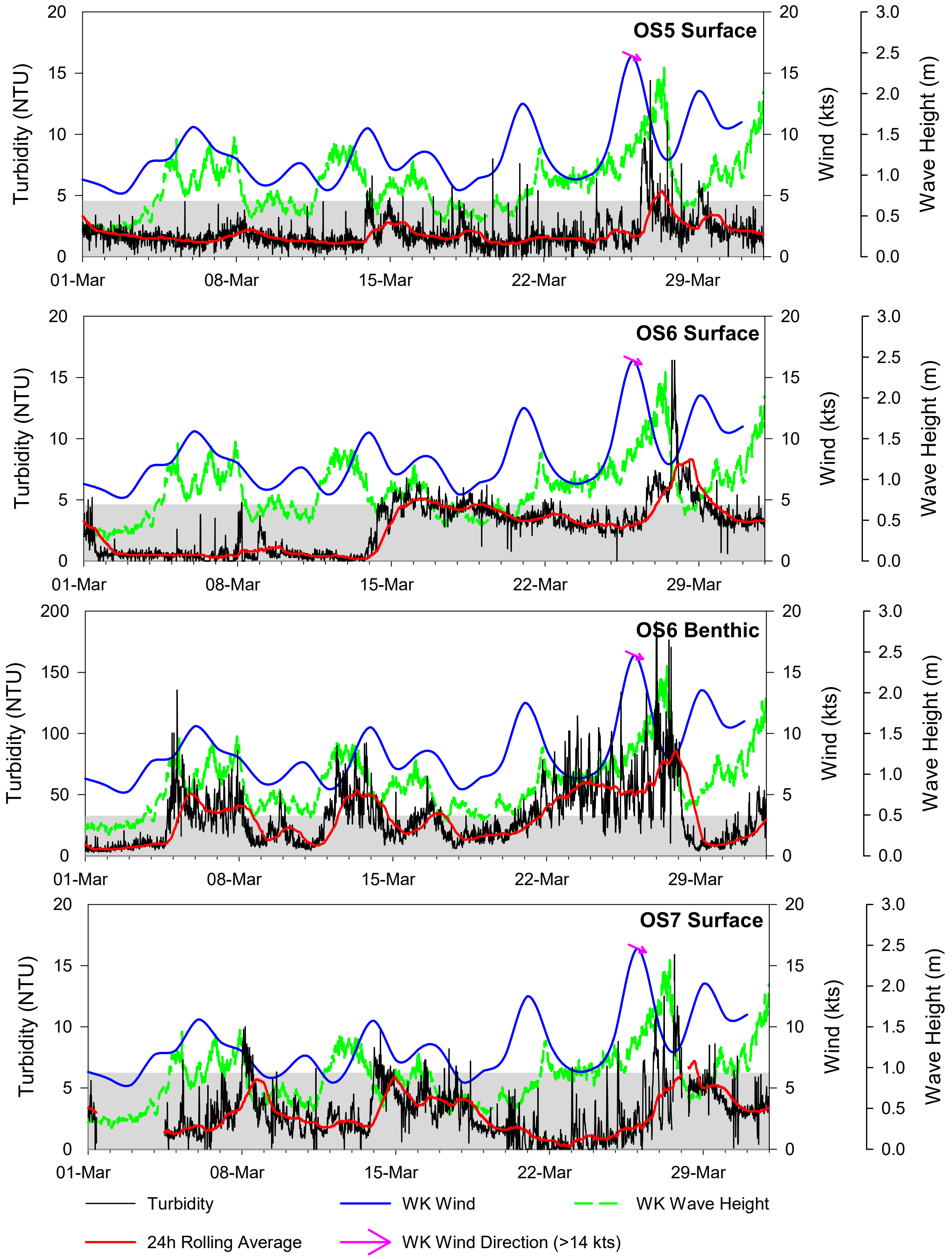


Figure 11 Surface turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

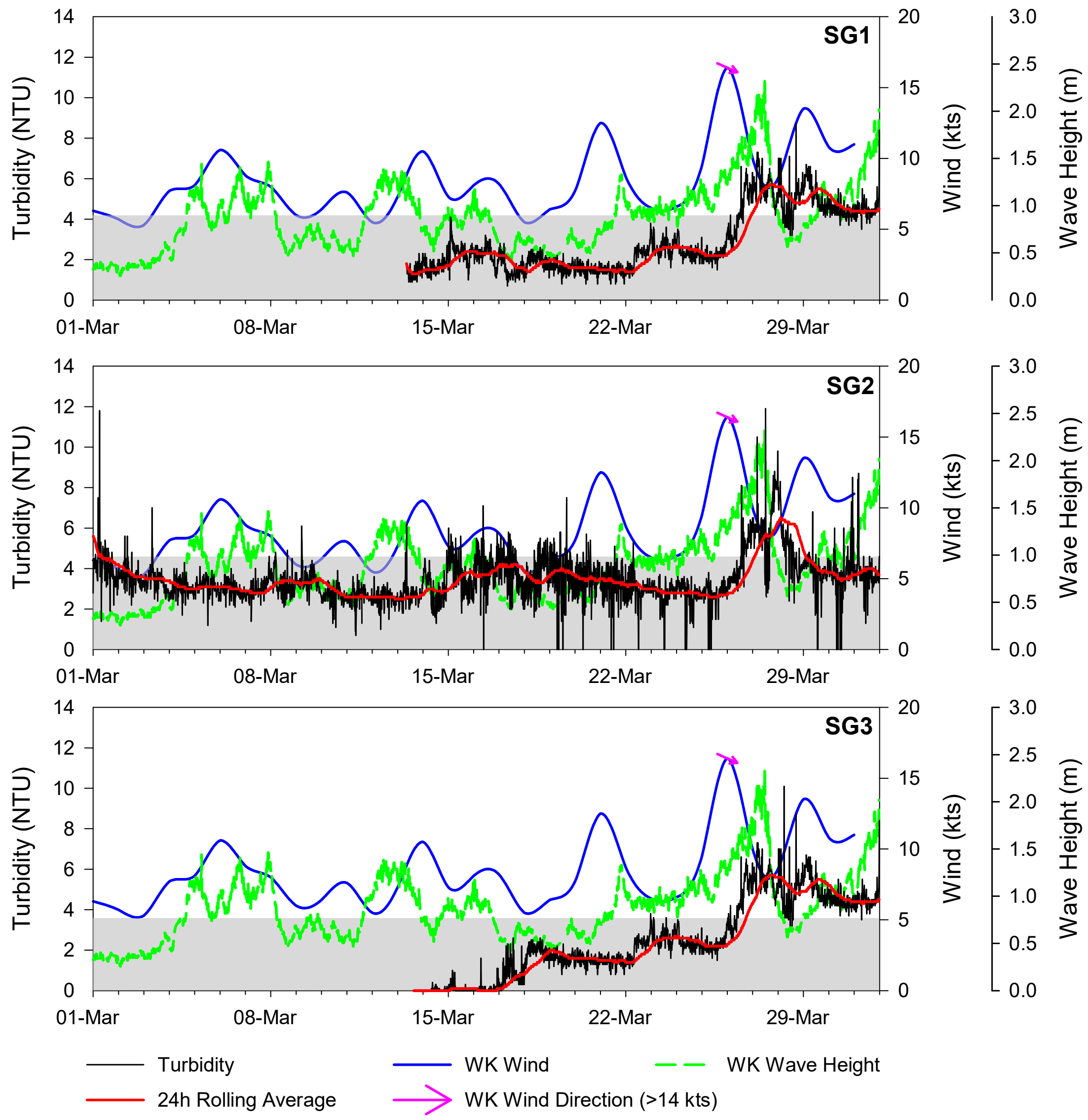


Figure 12 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

3.2.2 Dredge Compliance Trigger Values

Management of dredge operations following the commencement of works on 11 March 2019 was guided by the use of 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 Turbidity intensity values for each site and allowable hours of exceedance in rolling 30 day period.
Allowable hours for Tiers 1 and 2 are indicative only and non-binding as these are for internal LPC use only.

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

3.2.2.1 P99 Exceedance Counts

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

Table 7 Tier 3 intensity value exceedances and maximum hour counts during March 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

Surface turbidity levels during March were largely similar to or below baseline conditions, and as such no validated P99 exceedance counts were accumulated (Table 7) nor removed (Table 8).

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

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

3.2.3 Temperature

Mean monthly sea surface temperatures around Lyttelton Harbour were slightly cooler than those experienced during February, ranging from 17.3 to 18.3°C (Table 9) (c.f. 18.6 to 20°C in February). Similar to previous observations, the shallower waters of the upper and central harbour displayed the warmest mean temperatures, with monthly means of over 18°C.

All four inner harbour sites displayed a period of warming to 7 March, followed by slight cooling as cloud cover and associated rainfall decreased direct solar heating of the water column. A second phase of cooling was also observed around 15 March, following 5.2 mm of rainfall at Cashin Quay. (Figure 13). For the remainder of the month, inner harbour water temperatures remained relatively consistent, until a rapid decline in temperatures on 28 March. This period of cooling was also observed in the nearshore and offshore regions (Figures 13 and 14), which had previously displayed relatively stable temperature conditions. Of note at the nearshore reference site, OS4, was the presence of cooler surface waters than at the surrounding monitoring sites that may be an indication of an intrusion of a more southerly, cooler water mass around Banks Peninsula.

Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the surface temperature datasets. This higher frequency variability was particularly notable during the first week of March when incoming solar radiation was high (Figures 13 and 14).

Benthic temperatures were up to 0.8°C cooler than the overlying surface waters (Table 9), due to the higher thermal capacity of water providing an insulating effect from warming ambient air temperatures. Similar to observations during February, benthic temperatures at OS1 were warmer than the more exposed sites at OS3, OS4 and OS6 (Figure 14), with notably cooler temperatures at OS6 during the end of the month. Semidiurnal variability in benthic water temperatures was also notably greater at OS1 than at the other near-seabed monitoring locations.

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during March 2019.
Values are means ± se (n = 2656 to 2976).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	18.3 ± 0.0	–
UH2	18.3 ± 0.0	–
CH1	18.2 ± 0.0	–
CH2	18.1 ± 0.0	–
SG1*	17.3 ± 0.0	–
SG2	17.6 ± 0.0	–
SG3*	17.5 ± 0.0	–
OS1	18.0 ± 0.0	17.8 ± 0.0
OS2	17.9 ± 0.0	17.4 ± 0.0
OS3	18.1 ± 0.0	17.3 ± 0.0
OS4	17.6 ± 0.0	17.3 ± 0.0
OS5	17.8 ± 0.0	–
OS6	17.8 ± 0.0	17.1 ± 0.0
OS7	18.0 ± 0.0	–

**Limited data available for SG1 and SG3*

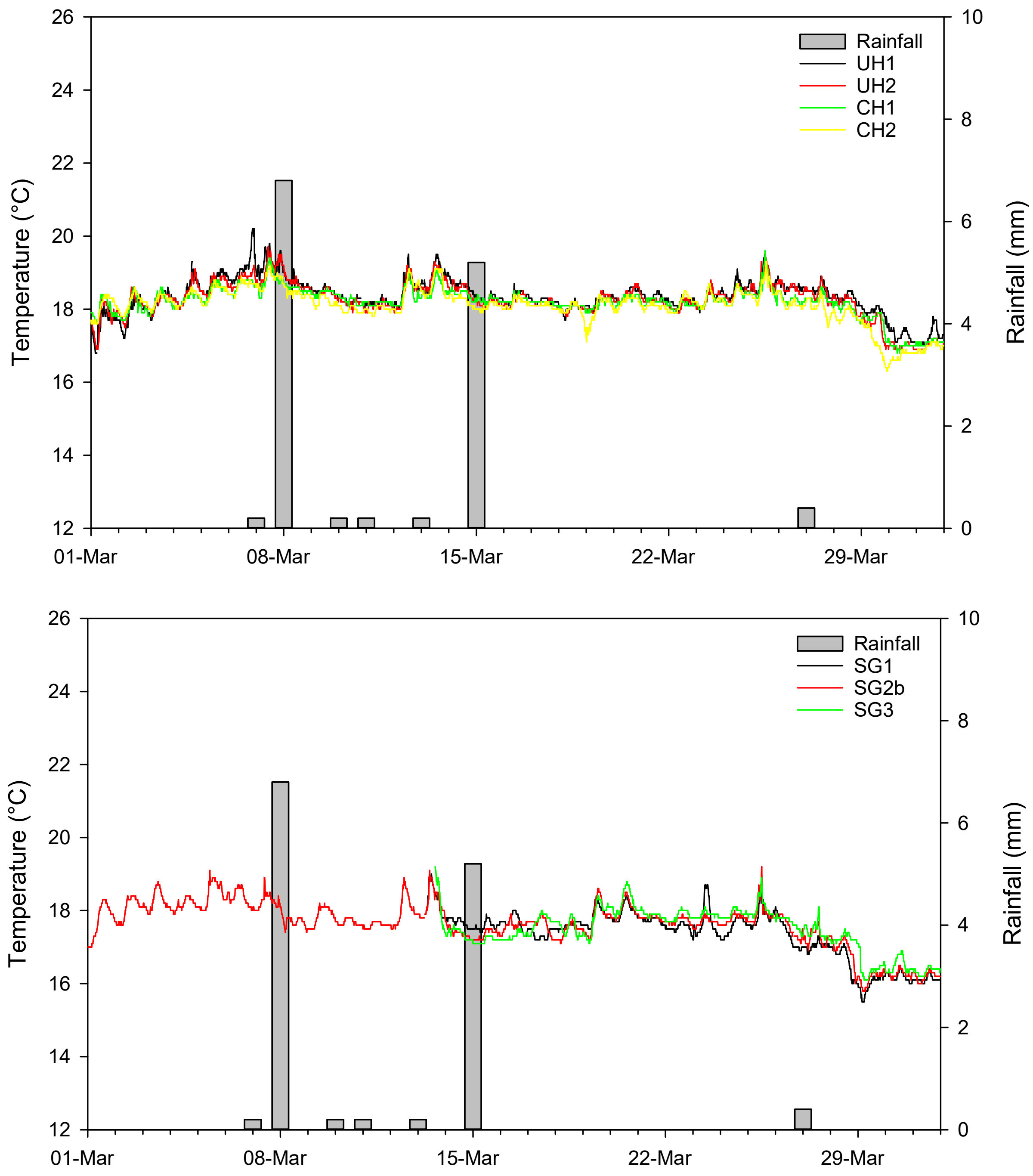
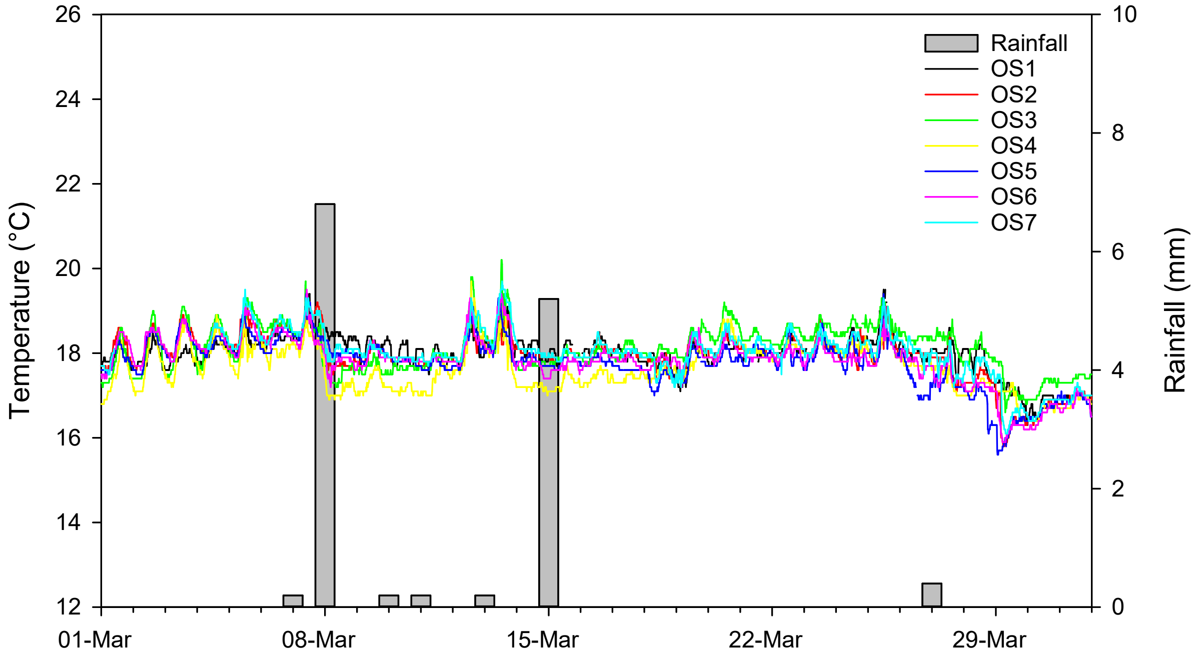


Figure 13 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during March 2019.



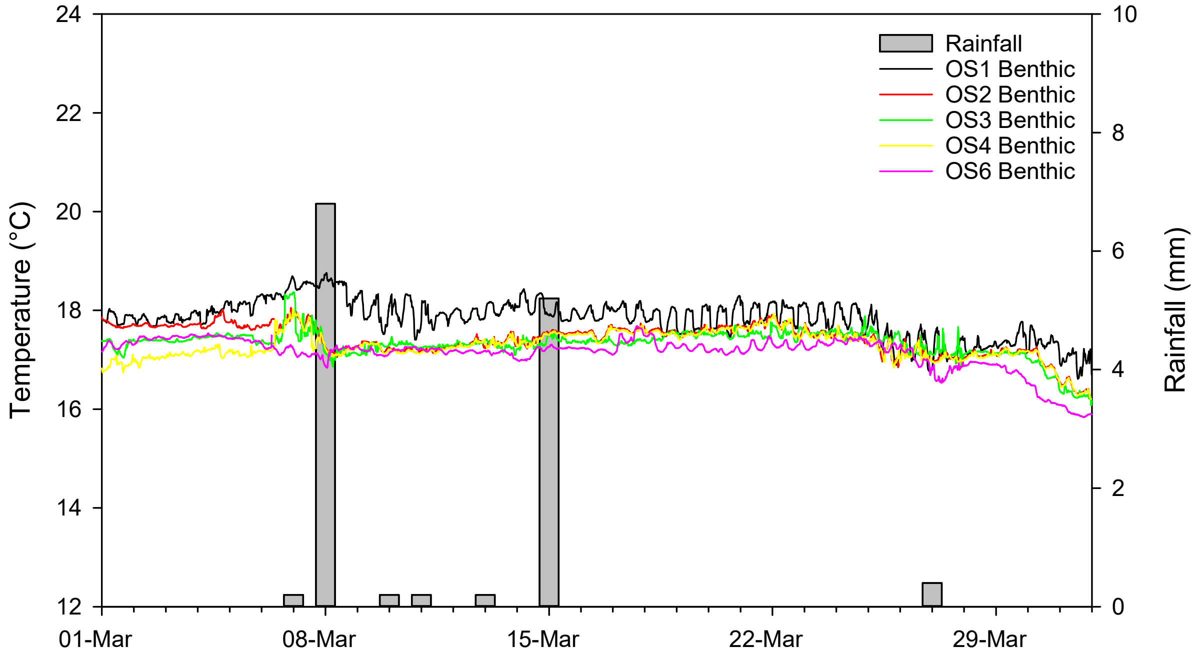


Figure 14 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during March 2019.

3.2.4 pH

Surface pH data collected during March did not indicate any strong spatial patterns, with monthly means ranging between 8.0 and 8.2 (Table 10). Some post calibration issues have been encountered with pH probes during March which has resulted in some unacceptable data. Firmware updates during April are expected to resolve these issues. Temporally, surface pH did not appear to display any particularly strong trends (Figures 15 and 16), with a slight decline observed at UH2 and the nearshore monitoring sites during rainfall on 8 March. Interestingly, Waimakariri outflow did not appear to result in a disturbance to the regular pH regime.

Benthic pH was typically lower than that at the surface, reflecting the increased rates of photosynthesis, and thus consumption of dissolved carbon dioxide, within the sunlit surface waters (Table 10). Temporally, benthic pH displayed limited variability throughout sonde deployment, as localised freshwater runoff following rainfall events that can be characterised by lower pH would likely be restricted to the surface waters. A slight increase in benthic pH at OS6 was recorded around 14 March that may be related to a similarly slight increase in benthic turbidity at this time (Figures 11 and 16).

Table 10 Mean pH at inshore, spoil ground and offshore water quality sites during March 2019. *Values are means ± se (n = 367 to 2976).*

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

**Limited data available for SG1 and SG3*

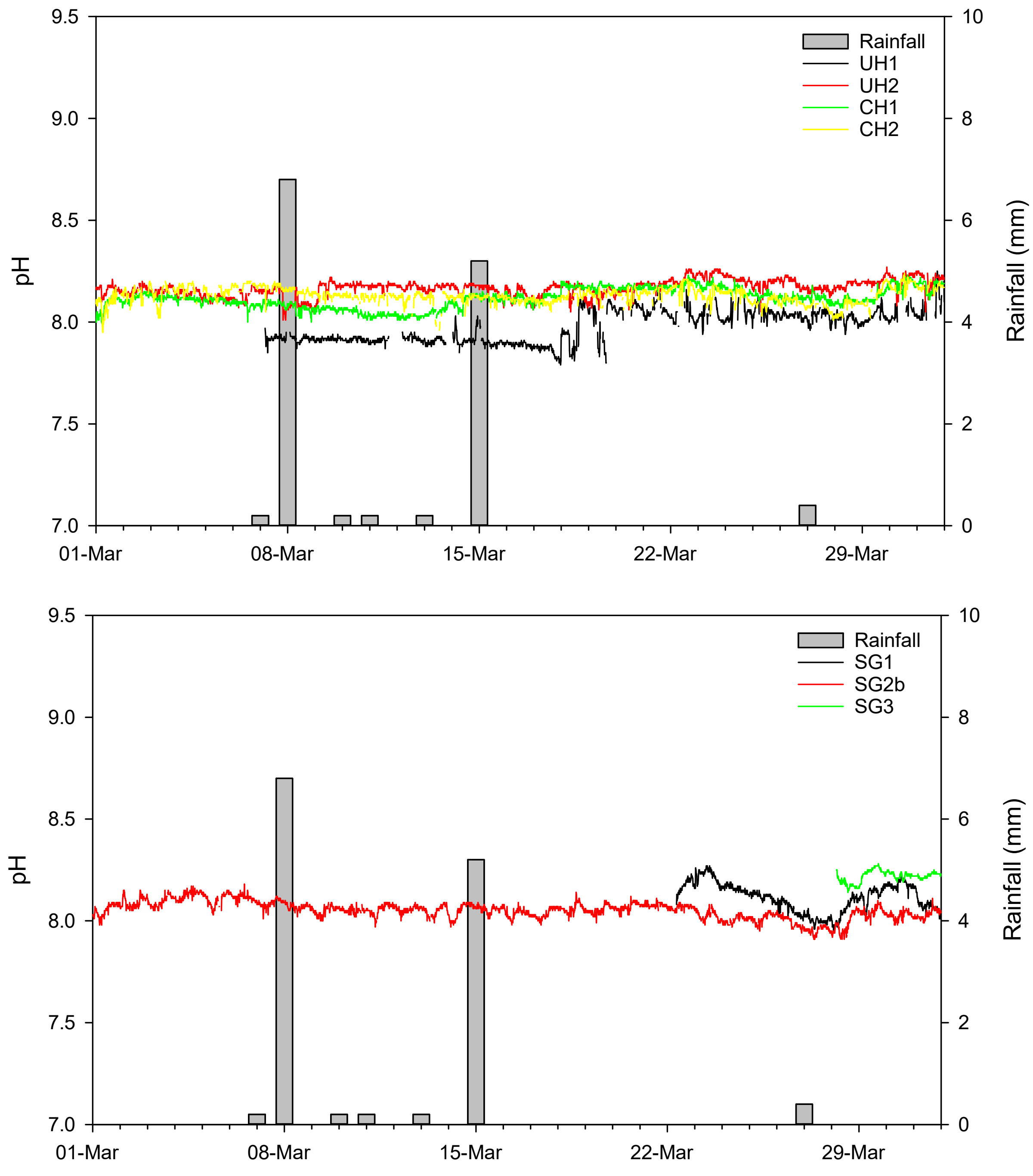


Figure 15 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during March 2019.

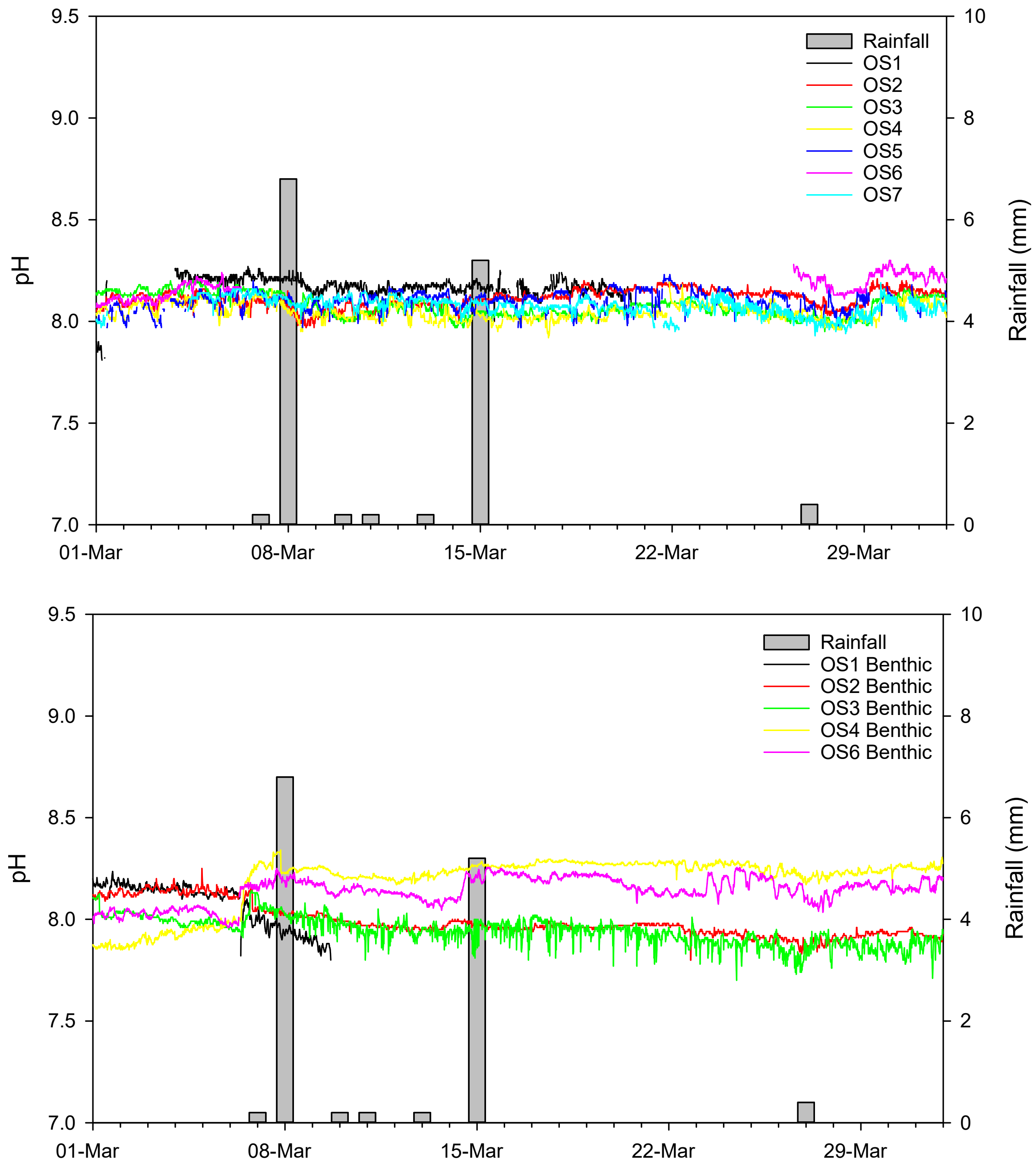


Figure 16 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at nearshore and offshore water quality sites during March 2019.

3.2.5 Conductivity

Surface conductivity in March ranged from 52.3 mS/cm at OS3 to 54.5 mS/cm at OS5 (Table 11), similar to monthly mean values calculated for February, however, these means are likely to have been influenced by intrusions of Waimakariri outflow entering the harbour. Across the monitoring network, conductivity remained relatively stable throughout the first two weeks of March, with little influence from the local rainfall events recorded at Cashin Quay (Figure 17). However, from 17 March conductivity declined at OS5 and then within Lyttelton Harbour itself as freshwater outflow from the Waimakariri was advected south and into the central harbour. Interestingly, this freshening did not appear to reach the upper harbour locations UH1 and UH2 (Figure 17). A smaller component of Waimakariri outflow was also advected offshore, with slight decreases in conductivity observed at SG1, then SG2b and then SG3 as the reduced salinity water mass moved south. Similar declines in conductivity across the monitoring network of increasing intensity were recorded around 23 and 28 March (Figures 17 and 18). The latter event represents a notable environmental response to maximum monthly Waimakariri River outflow of 957 m^3/s recorded on 27 March 2019 (Figure 2).

Benthic waters at OS1, OS2 and OS4 displayed lower mean monthly conductivity (51.2 to 52.7 mS/cm) than their corresponding surface waters (Table 11), which is unexpected within a vertically stable water column. Noise within the conductivity data collected from OS6 was also relatively high, and of greater amplitude than long term changes within the data (Figure 18). Interestingly benthic conductivity at OS1 and OS2 displayed declines on 24 and 22 March, respectively, that likely represent vertical mixing of low salinity surface waters influenced by Waimakariri River outflow to the seabed (Figure 18). This response is, however, somewhat delayed from the declines in conductivity recorded in the overlying surface waters.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during March 2019.
Values are means ± se (n = 1764 to 2972).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	53.8 ± 0.0	–
UH2	54.3 ± 0.0	–
CH1	52.9 ± 0.0	–
CH2	53.8 ± 0.0	–
SG1*	53.9 ± 0.0	–
SG2	54.2 ± 0.0	–
SG3*	54.1 ± 0.0	–
OS1	53.6 ± 0.0	51.2 ± 0.0
OS2	53.3 ± 0.0	52.7 ± 0.0
OS3	52.3 ± 0.0	52.3 ± 0.0
OS4	53.8 ± 0.0	51.7 ± 0.0
OS5	54.5 ± 0.0	–
OS6	53.6 ± 0.0	56.4 ± 0.0
OS7	53.1 ± 0.0	–

**Limited data available for SG1 and SG3*

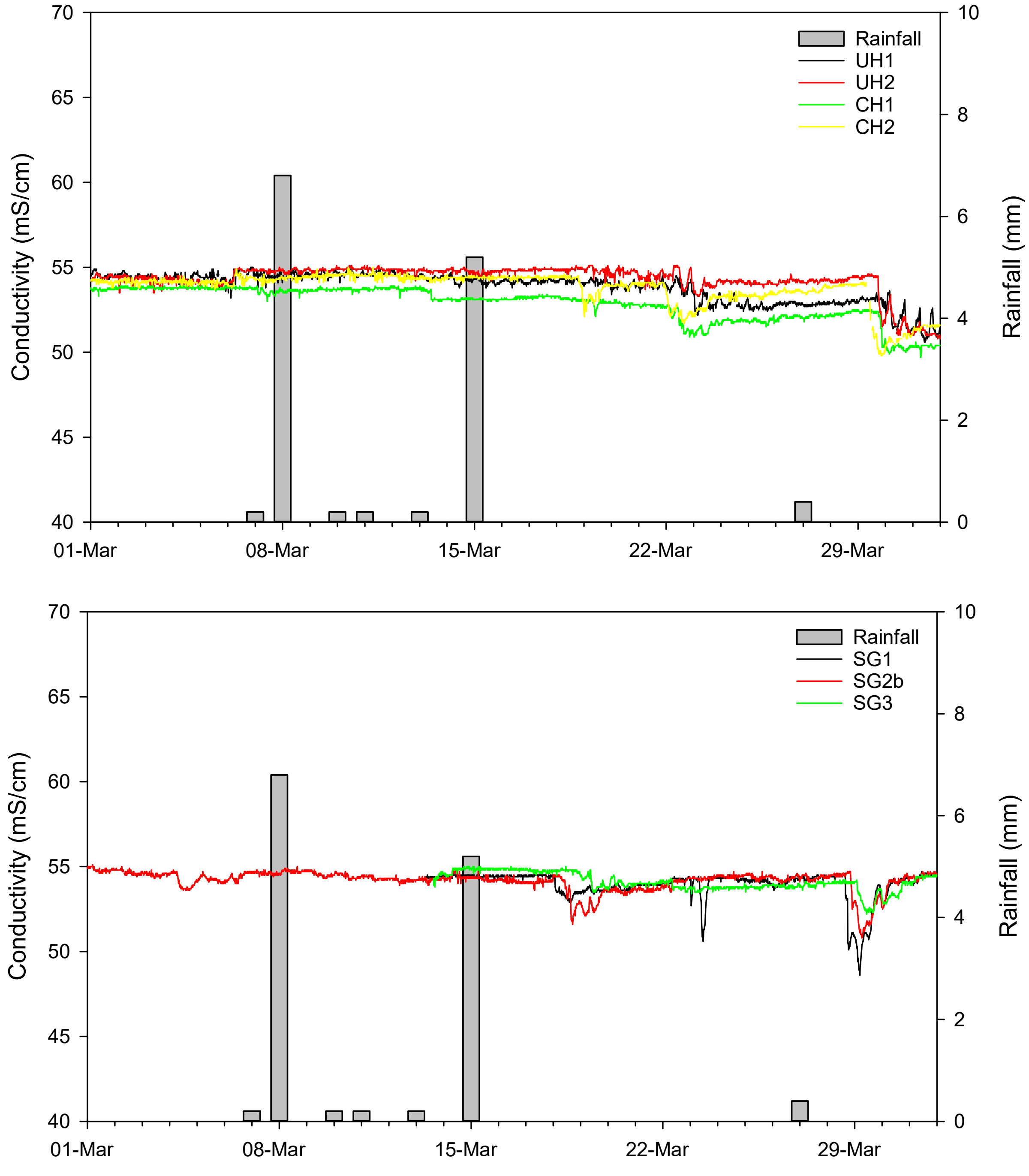
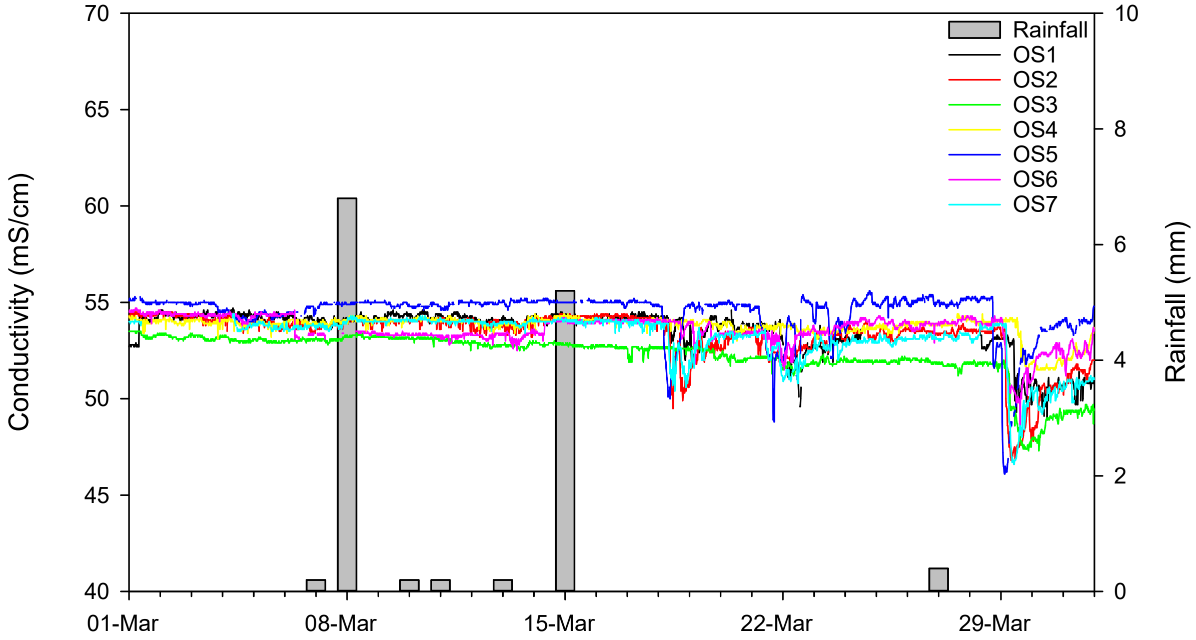


Figure 17 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during March 2019.



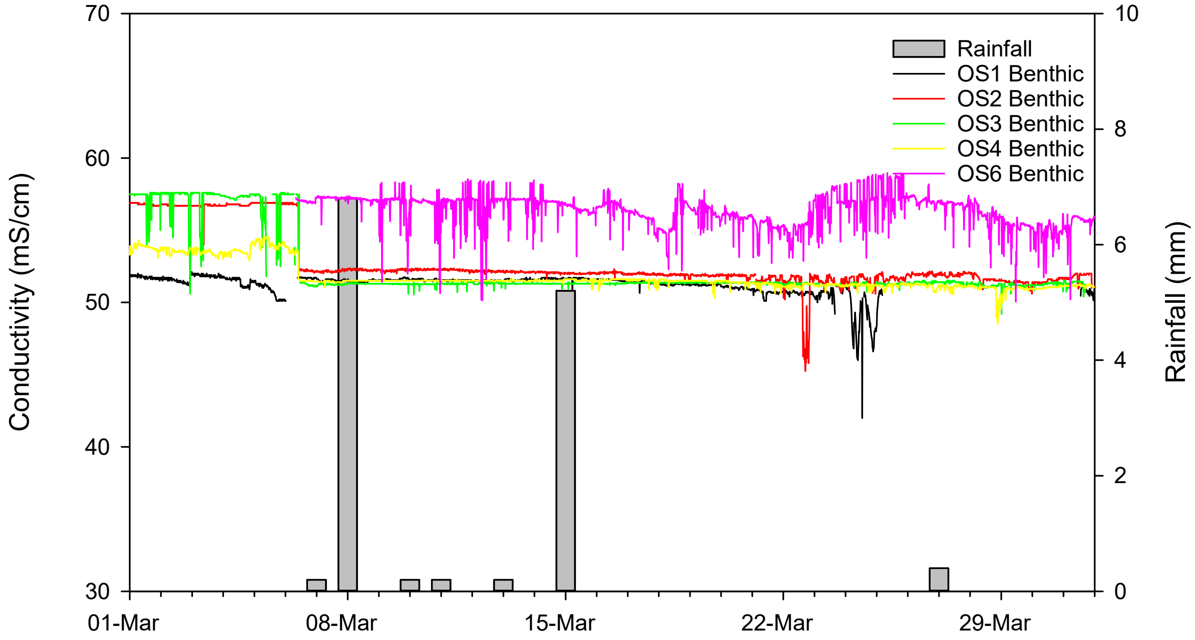


Figure 18 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during March 2019.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in March were high, ranging from 95% saturation at the harbour mouth, to 104% saturation at the more exposed spoil ground locations (Table 12). Large diurnal fluctuations in DO were recorded at the southern inner harbour sites (UH2 and CH2) during the first week of March when incoming solar radiation was high (Figure 19, Figure 24). Following the notable rainfall event recorded on 8 March, surface DO concentrations at OS2 dropped from ~90% saturation to <70% saturation; marking a larger decline in available oxygen than observed at any of the nearby monitoring locations. Bacterial degradation of localized algal populations may have been responsible for an increase in biological oxygen demand (BOD) at OS2. Recovery to similar conditions as the nearby sites was observed on 9 March, with limited diurnal variability observed across all sites except OS6 at this time (Figures 17 and 18).

A second period of notable declining DO concentrations was observed on 14 March, with only the inner harbour sites and SG3 remaining unaffected. This decline preceded the second day of notable rainfall on 15 March and therefore may be a representation of reduced solar insolation impacting *in situ* photosynthesis rates. Similarly reduced light availability for photosynthesis is likely to have induced the largest decline in surface DO concentrations from 26 March, as ambient solar radiation was at the monthly minimum at this time (Figure 24). Strong vertical mixing induced by increased significant wave heights and offshore wind speeds (Figure 3) is likely to have further amplified these low surface DO conditions as low DO benthic waters are mixed towards the surface. Interestingly, the amplitude of the declining DO concentrations was reduced in the nearshore sites, with turbulent mixing at the surface potentially providing additional oxygen to the surface waters. As environmental conditions calmed, surface DO concentrations increased across all sites at the end of the month (Figures 3, 19, 20).

As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings ranging from 81 to 90% saturation (Table 12), due to reduced photosynthesis (producing less oxygen) occurring at depth. Temporal variability in benthic DO concentrations was high; with data from OS3, OS4 and OS6 displaying declines in DO around 7 and 14 March (Figure 20). These changes were not mirrored in the data acquired from OS1 and OS2, from the harbour entrance, with benthic DO increasing or remaining stable during the first week of the month. Following 22 March changes in benthic DO closely mirrored those of the surface waters (Figure 20). Particularly strong diurnal variations in DO were recorded near the benthos at OS6 during this time.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during March 2019.
Values are means ± se (n = 1764 to 2975).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	99 ± 0	–
UH2	99 ± 0	–
CH1	99 ± 0	–
CH2	99 ± 0	–
SG1*	102 ± 0	–
SG2	104 ± 0	–
SG3*	102 ± 0	–
OS1	95 ± 0	90 ± 0
OS2	95 ± 0	85 ± 0
OS3	96 ± 0	81 ± 0
OS4	95 ± 0	84 ± 0
OS5	97 ± 0	–
OS6	100 ± 0	83 ± 0
OS7	99 ± 0	–

**Limited data available for SG1 and SG3*

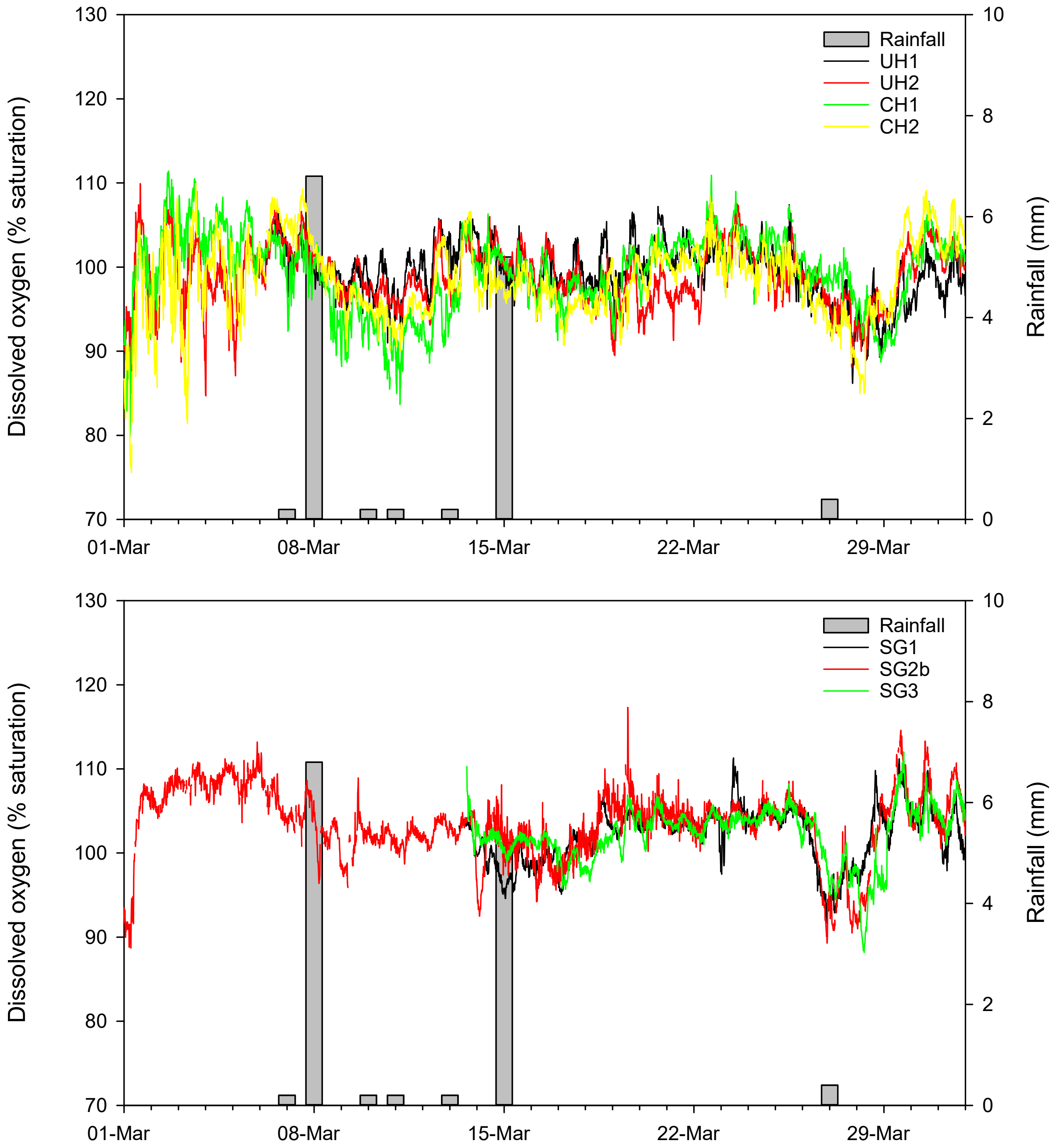
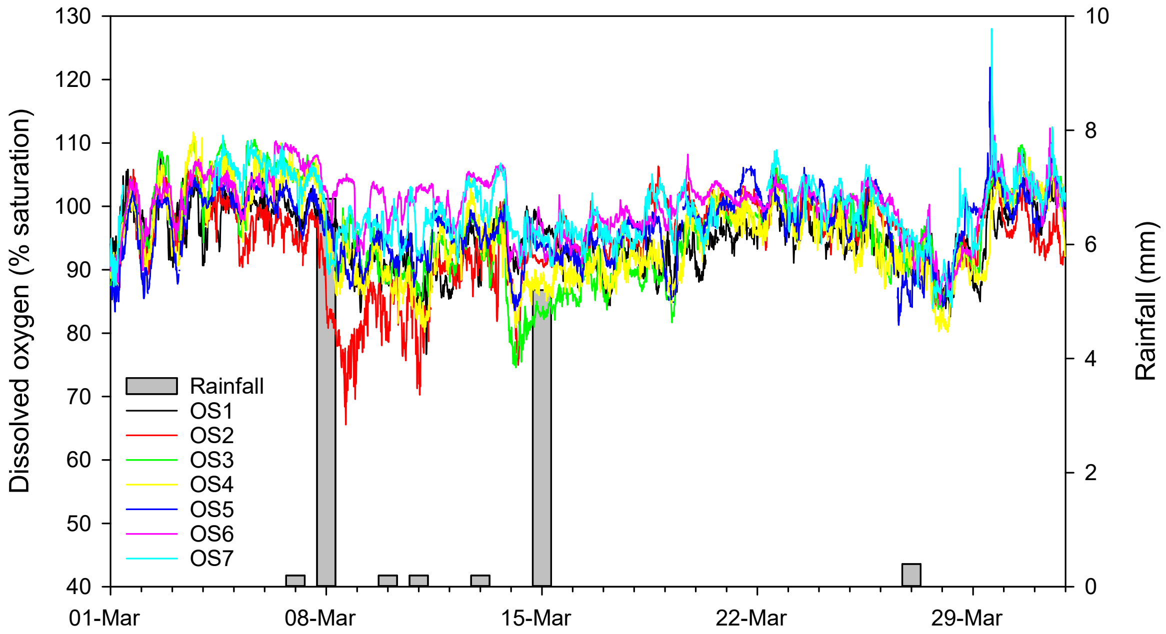


Figure 19 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during March 2019.



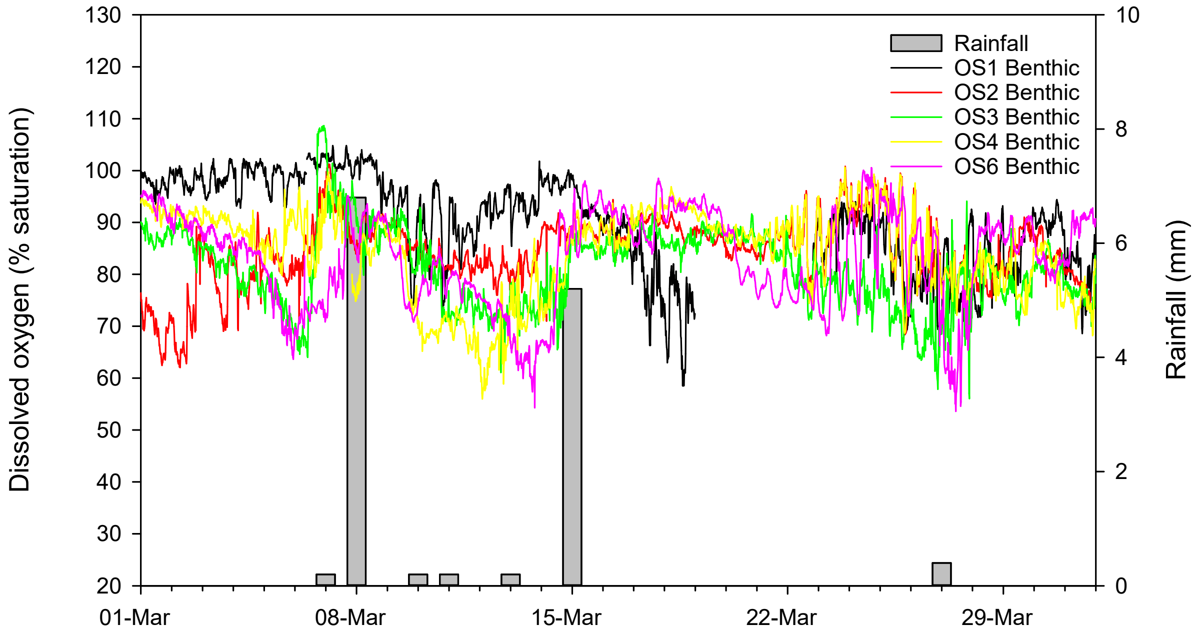


Figure 20 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during March 2019.

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 7 March 2019, prior to dredge operations commencing on 11 March. 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 also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, CH1 and CH2. Further information regarding the specific sampling methodology can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Statistical analyses of the resulting datasets are provided in Tables 13 to 15, with depth profile plots presented in Figures 21 to 23.

The relatively shallow sites of the upper and central harbour once again displayed well mixed conditions with little variation in measured parameters through the water column. The uppermost harbour site, UH3, consistently displayed the highest temperature, conductivity and turbidity values; reflecting turbulent mixing and enhanced solar warming in the shallower waters of this location. During February, deeper waters at CH2 displayed slightly warmer temperatures and higher salinity than the surface, however, this was not observed during the March profiling (Figure 21). Several sites indicated slightly increased turbidity at the seabed, which would typically be observed due to the shear forces (friction between the overlying moving water and the stationary seabed) providing energy for sediment resuspension.

Within the nearshore region, physicochemical data collected also indicate the persistence of strong vertical mixing within the water column. Water temperatures were slightly cooler than observed at the inshore sites, with little variation in temperature, conductivity, pH and DO with depth. Interestingly, pH was notably lower (by around 0.1 pH unit) at OS1 than at the nearby monitoring locations (Figure 22). Turbidity at all five sites increased towards the benthos as typically observed.

Within the offshore region of the spoil ground, OS5 and OS6, the water column was well mixed in the surface 10 meters. Below this, temperatures declined from around 18°C to 17°C, conductivity increased by 0.1 mS/cm, pH declined by 0.1 and DO declined by up to 30% saturation. Turbidity was very low in the surface waters offshore Lyttelton Harbour and, in a similar manner to the other sites, increased in close proximity to the seabed (Figure 23).

Relatively shallow euphotic depths of 9.6 and 5.9 m were calculated for sites OS2 and OS7 (Table 14), respectively, which reflect the somewhat higher levels of turbidity within the mid-depths (Figure 22). The deepest euphotic depth was calculated to be 21.9 m at OS5 (Table 15). There were no recorded of exceedances of WQG for the sub-surface during the March vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the March 2019 sampling event. *Values are means ± se (n = 5 to 6 for sub-surface, n = 18 to 30 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	07/03/2019 13:11	Sub-surface	19.6 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	103 ± 0	4.4 ± 0.1	10	1.0 ± 0.1	4.5
		Whole column	19.4 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	102 ± 0	4.6 ± 0.1	–		
UH2	07/03/2019 12:44	Sub-surface	19.2 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	101 ± 0	2.7 ± 0.1	8	0.8 ± 0.0	5.7
		Whole column	18.9 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	100 ± 0	3.9 ± 0.2	–		
UH3	07/03/2019 13:01	Sub-surface	19.6 ± 0.0	8.2 ± 0.0	55.1 ± 0.0	101 ± 0	5.7 ± 0.1	13	1.3 ± 0.0	3.5
		Whole column	19.5 ± 0.0	8.2 ± 0.0	55.1 ± 0.0	100 ± 0	6.3 ± 0.3	–		
CH1	07/03/2019 12:24	Sub-surface	18.9 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	105 ± 0	2.0 ± 0.1	6	0.9 ± 0.0	5.4
		Whole column	18.7 ± 0.0	8.2 ± 0.0	52.8 ± 1.7	103 ± 0	5.5 ± 1.8	–		
CH2	07/03/2019 12:09	Sub-surface	18.8 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	104 ± 0	1.5 ± 0.1	5	0.6 ± 0.0	7.3
		Whole column	18.7 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	103 ± 0	2.6 ± 0.4	–		
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 March 2019 sampling event. *Values are means ± se (n = 5 to 6 for sub-surface, mid and benthos, n = 29 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	07/03/2019 07:59	Sub-surface	18.2 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	103 ± 0	1.6 ± 0.1	5	0.3 ± 0.0	15.1
		Mid	18.2 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	102 ± 0	3.3 ± 0.3	7		
		Benthos	18.3 ± 0.0	8.1 ± 0.0	54.5 ± 0.0	101 ± 0	19 ± 10	11		
		Whole column	18.3 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	102 ± 0	5.6 ± 2.0	–		
OS2	07/03/2019 11:15	Sub-surface	18.5 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	104 ± 0	1.1 ± 0.0	5	0.5 ± 0.0	9.6
		Mid	18.3 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	104 ± 0	2.4 ± 0.7	4		
		Benthos	18.2 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	99 ± 0	12 ± 1	40		
		Whole column	18.3 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	102 ± 0	4.0 ± 0.8	–		
OS3	07/03/2019 10:34	Sub-surface	18.3 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	108 ± 0	0.0 ± 0.0	4	0.3 ± 0.0	14.8
		Mid	18.1 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	106 ± 0	0.4 ± 0.1	3		
		Benthos	17.8 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	103 ± 1	4.1 ± 1.8	15		
		Whole column	18.1 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	106 ± 0	0.8 ± 0.4	–		
OS4	07/03/2019 10:09	Sub-surface	18.0 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	106 ± 0	0.0 ± 0.0	6	0.3 ± 0.0	14.0
		Mid	17.5 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	105 ± 0	1.3 ± 0.4	<3		
		Benthos	17.0 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	100 ± 0	6.3 ± 0.4	6		
		Whole column	17.6 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	104 ± 0	1.6 ± 0.4	-		
OS7	07/03/2019 11:47	Sub-surface	18.7 ± 0.0	8.2 ± 0.0	54.3 ± 0.0	106 ± 0	1.4 ± 0.1	5	0.8 ± 0.0	5.9
		Mid	18.4 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	102 ± 0	5.1 ± 0.1	12		
		Benthos	18.3 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	101 ± 0	9.1 ± 2.7	12		
		Whole column	18.5 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	103 ± 0	4.5 ± 0.7	–		
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 March 2019 sampling event.
Values are means ± se (n = 5 to 6 for sub-surface, mid and benthos, n = 40 to 47 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	07/03/2019 08:20	Sub-surface	18.2 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	104 ± 0	0.9 ± 0.0	6	0.2 ± 0.0	21.9
		Mid	18.3 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	105 ± 0	0.0 ± 0.0	<3		
		Benthos	17.5 ± 0.0	8.1 ± 0.0	54.6 ± 0.0	88 ± 2	5.0 ± 0.8	8		
		Whole column	18.1 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	102 ± 1	1.1 ± 0.3	–		
OS6	07/03/2019 10:53	Sub-surface	18.4 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	106 ± 0	0.9 ± 0.0	5	0.3 ± 0.0	16.6
		Mid	18.1 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	107 ± 0	0.0 ± 0.0	4		
		Benthos	17.0 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	101 ± 3	2.8 ± 1.5	<3		
		Whole column	17.9 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	106 ± 1	0.7 ± 0.3	–		
SG1	07/03/2019 08:50	Sub-surface	18.1 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	105 ± 0	0.0 ± 0.0	4	0.2 ± 0.0	20.9
		Mid	17.7 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	105 ± 0	0.0 ± 0.0	<3		
		Benthos	17.0 ± 0.0	8.1 ± 0.0	54.7 ± 0.0	76 ± 1	12 ± 2	22		
		Whole column	17.7 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	99 ± 2	1.9 ± 0.7	–		
SG2b	07/03/2019 09:17	Sub-surface	18.0 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	105 ± 0	0.0 ± 0.0	<3	0.3 ± 0.0	17.1
		Mid	17.8 ± 0.1	8.2 ± 0.0	54.7 ± 0.0	105 ± 0	0.0 ± 0.0	<3		
		Benthos	16.7 ± 0.0	8.1 ± 0.0	54.7 ± 0.0	84 ± 0	13 ± 7	12		
		Whole column	17.5 ± 0.1	8.2 ± 0.0	54.7 ± 0.0	99 ± 1	2.1 ± 1.1	–		
SG3	07/03/2019 09:43	Sub-surface	18.2 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	106 ± 0	0.0 ± 0.0	<3	0.2 ± 0.0	18.7
		Mid	17.6 ± 0.1	8.2 ± 0.0	54.6 ± 0.0	102 ± 2	0.0 ± 0.0	<3		
		Benthos	16.5 ± 0.0	8.1 ± 0.0	54.8 ± 0.0	87 ± 0	4.7 ± 1.6	<3		
		Whole column	17.5 ± 0.1	8.2 ± 0.0	54.7 ± 0.0	99 ± 1	1.0 ± 0.3	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

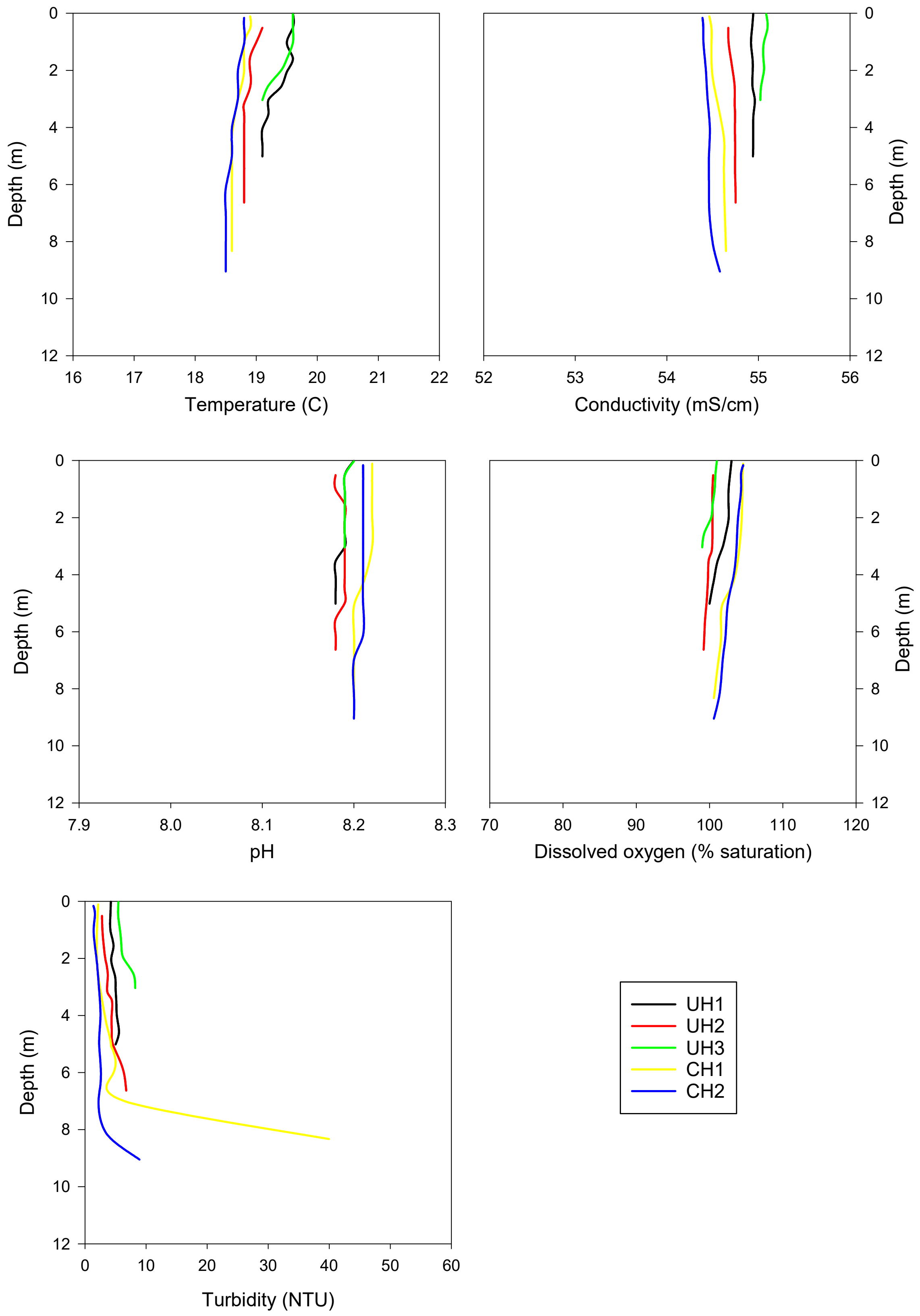


Figure 21 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 7 March 2019.

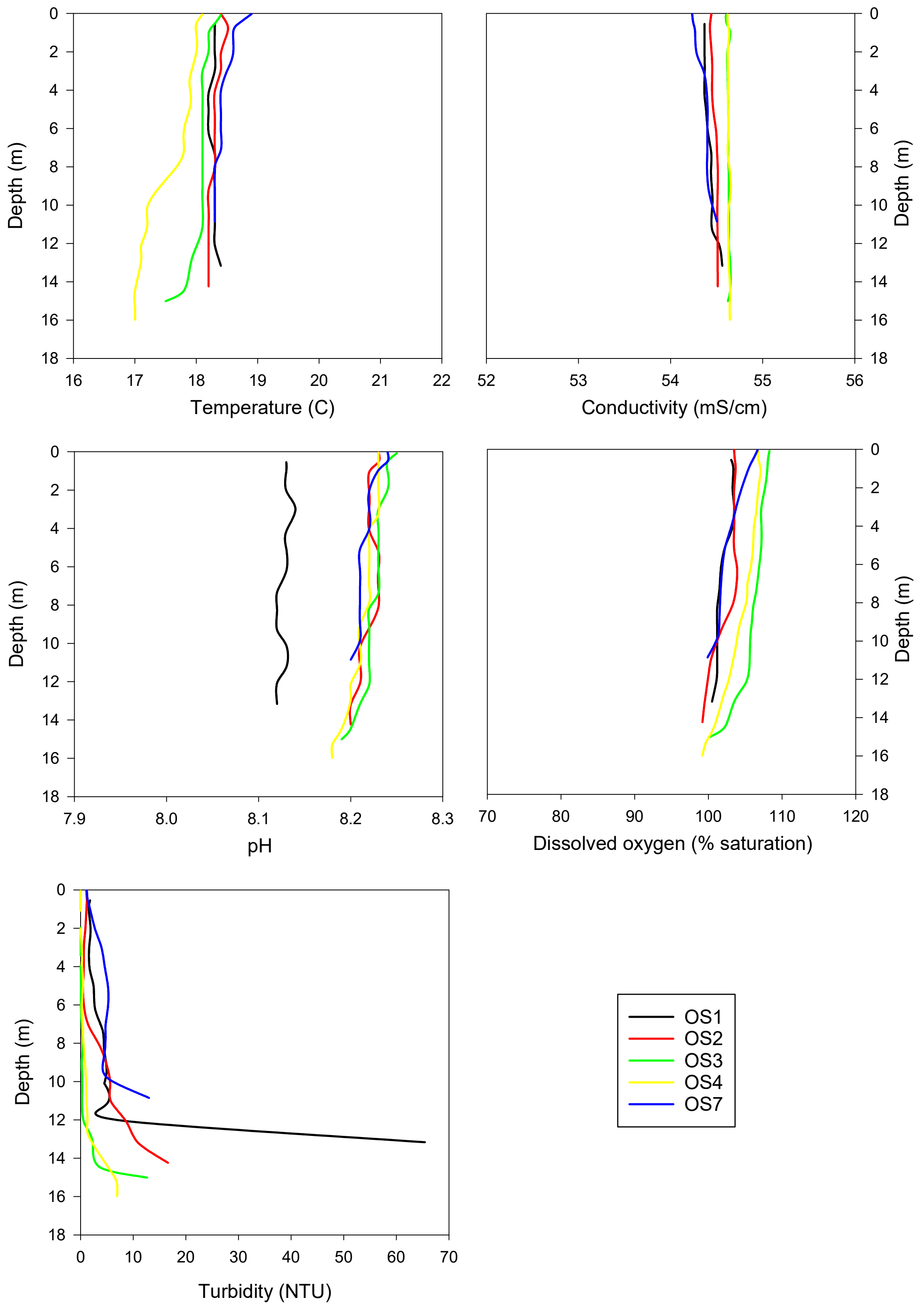


Figure 22 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 7 March 2019.

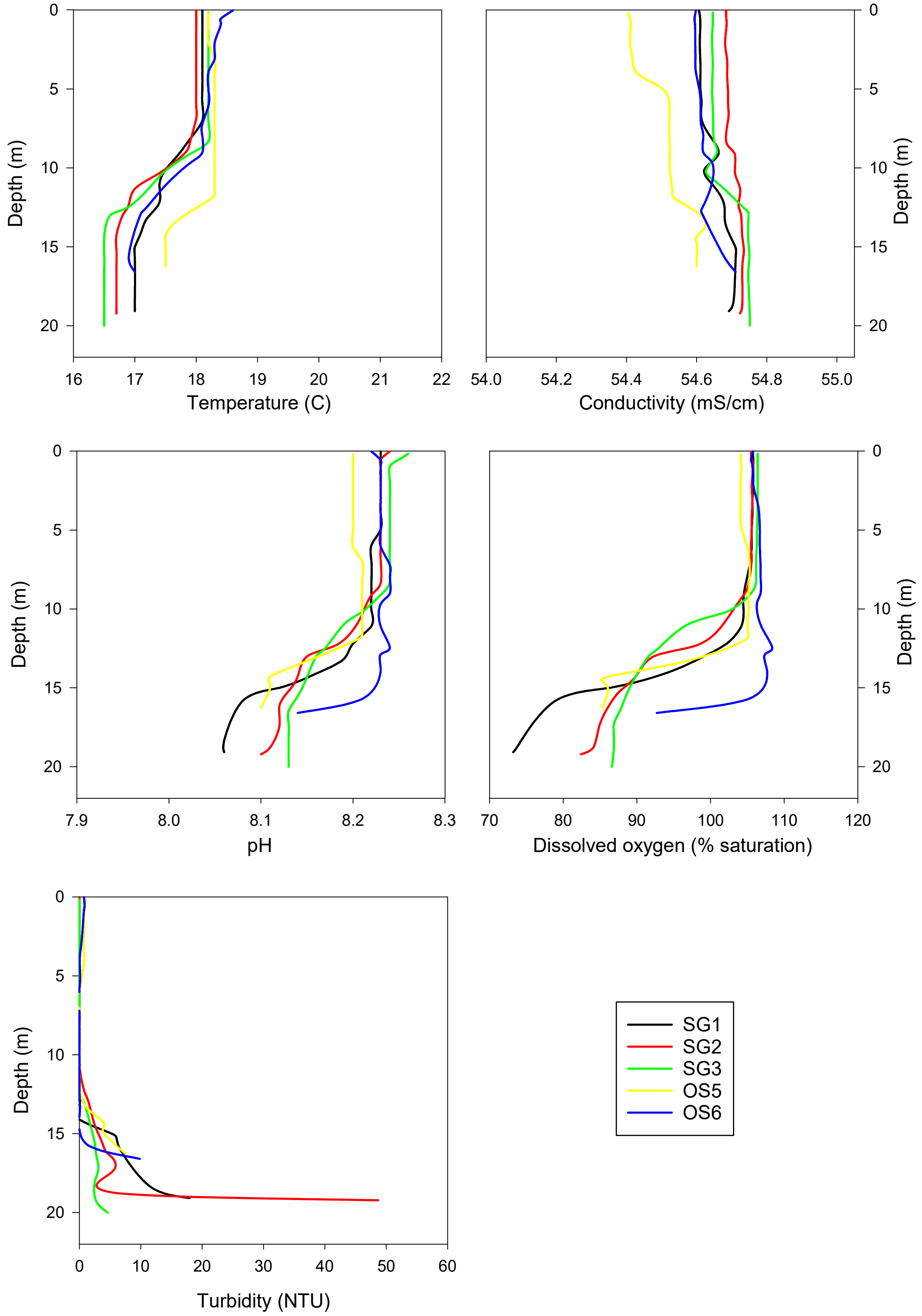


Figure 23 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 7 March 2019.

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 24. Data from the logger exchange date (6 March) were removed from the analyses.

Ambient PAR/total daily PAR (TDP, i.e., the amount of sunlight available to enter the water column), turbidity and the depth of the water column, all have a controlling factor on BPAR measurements. As typically observed in temperate regions with high levels of cloud cover, the amount of incoming solar radiation at VBCC displayed significant variation with values ranging from 13,200 to 53,800 mmol/m^2/day (Table 16). This is a similar range to that observed during February, however, the absolute values were lower, particularly within the monthly minima. This decline in available light, is apparent within the monthly mean TDP of only 26,603 mmol/m^2/day (Table 16) c.f. 41,754 mmol/m^2/day recorded during February.

Despite maximum TDP occurring during the first week of March, initially high surface turbidity at both OS2 and OS3 kept BPAR measurements negligible (Figure 24). Benthic PAR records at OS2 following 7 March displayed non-zero values that exhibited a similarity to ambient PAR recorded in Christchurch. Maximum BPAR intensity was recorded on 12 March at 28.2 mmol/m^2/day during a period of elevated incoming solar radiation and relatively low surface turbidity (Figure 24).

Further south at OS3, surface turbidity displayed a similar general pattern in BPAR as OS2, albeit at lower absolute intensities. However, as surface turbidity displayed a more rapid decline during the first week of the month, maximum BPAR at OS3 was recorded on 7 March reaching 19.35 mmol/m^2/day (Figure 24). For the following two weeks, BPAR measurements showed a similar pattern to ambient TDP when surface turbidity remained low.

Despite increases in ambient PAR recorded at Christchurch from 27 March, neither unit at OS2 or OS3 recorded any increases in BPAR over this time period (Figure 24). Surface and benthic turbidity both displayed large increases across the nearshore monitoring network at this time (Figure 7), and these increases in suspended particulate matter effectively blocked the transmission of light through the water column.

Table 16 Total Daily PAR (TDP) statistics during March 2019.
Values are means ± se (n = 30 to 31). Note data from the BPAR exchange day on 6 March were not utilized in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m²/day)		
		Mean ± se	Median	Range
Base	-	26,603 ± 2,137	23,800	4,900 – 46,700
OS2	17	3.3 ± 1.1	0.3	<0.01 – 28
OS3	14	1.5 ± 0.7	0.1	<0.01 – 19

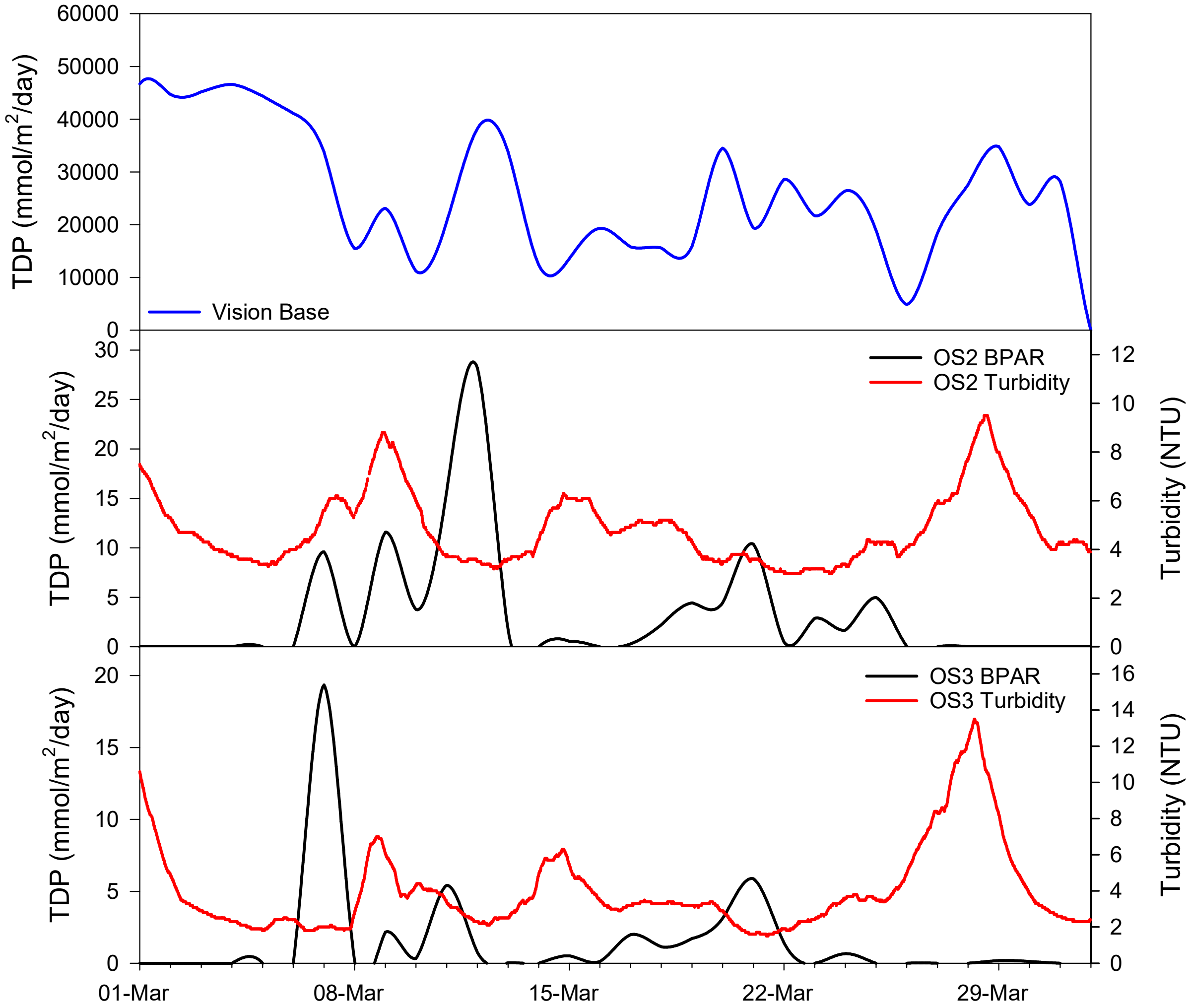


Figure 24 Total daily BPAR at OS2 and OS3 during March 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 6 March were not utilized in plots or statistics.

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:

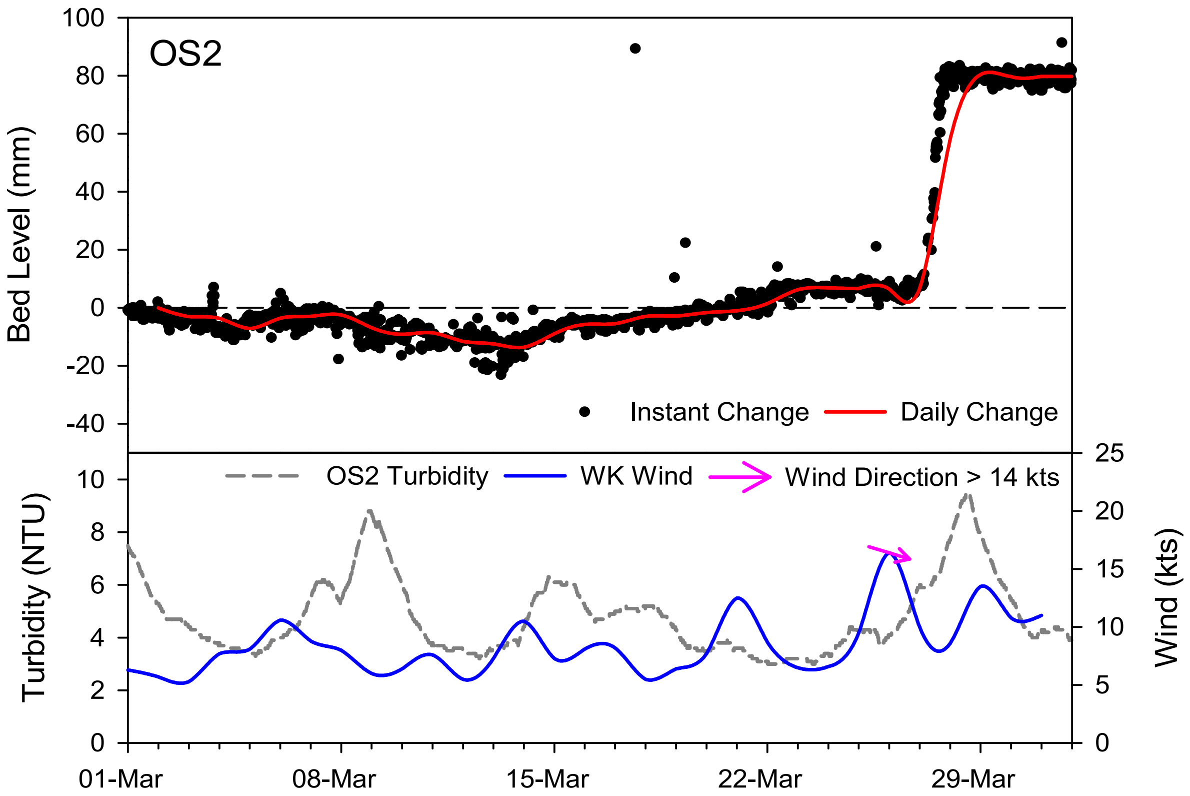
- Instantaneous bed level change calculated every 15 minutes indicating the level of sediment flux occurring at a set point in time; and
- Net cumulative change in bed level over a given period.

Bed level at the offshore site OS2 displayed a slow steady rate of erosion, with approximately 13.9 mm of sediment removed from the sea bed from 1 to 13 March 2019. This erosion does not appear to correlate well with either surface turbidity variations measured at OS2, nor with offshore wind speeds (Figure 25). Following the 13 March, slow deposition occurred with bed level increasing by 19.9 mm to 26 March. This settlement of particulate matter correlates well with a period of declining surface turbidity simultaneously recorded at OS2. The most prominent feature of the monthly bed level data is the rapid period of deposition where 74 mm of sediment was added to the seabed between 26 and 28 March (Figure 25). This event coincided with increased OS2 surface turbidity; driven by elevated offshore wave heights at this time (Figure 3) providing externally sourced sediments that settled out of the water column. For the remainder of the month, bed level remained stable with a net change of 80 mm recorded (Figure 25, Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2, with little apparent impact of inshore wind speed on sediment movement (Figure 25). In an opposing trend to that observed at the offshore OS2 site, bed level increased by 7.6 mm to 13 March. This trend was rapidly reversed between the 13 and 15 March where approximately 29.6 mm of sediment was removed from the sea bed. This shift in sediment dynamics does not appear to correlate with wind data and precedes the 5.2 mm of rainfall on 15 March (Figure 2). Following this rapid period of erosion, the system returned to gradual sedimentation with a further 8.7 mm of sediment deposited for the remainder of the month. Over the course of March, net bed level at UH3 declined by 13 mm (Table 17).

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

Site	March 2019 Net bed level change (mm)
OS2	+80
UH3	-13



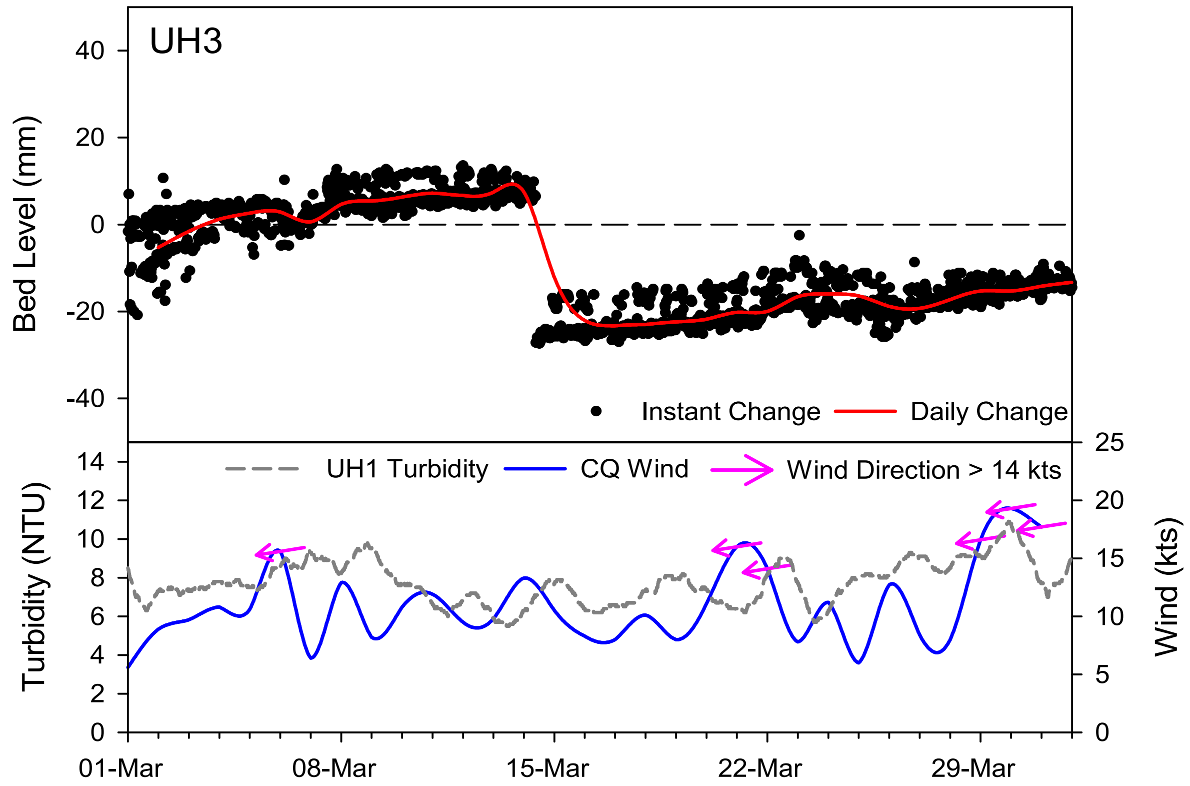


Figure 25 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during March 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction. *Note: Arrows indicate the direction of travel for winds greater than 14 knots.*

3.6 Water Samples

Discrete water sampling was conducted on 7 March 2019, in conjunction with vertical physicochemical profiling through the water column, prior to dredge operations commencing on 11 March. Quality assurance/quality control (QA/QC) procedures included a duplicate water sample collected at one site, in addition to a laboratory and field blank for each parameter. Further details on the specific sampling methodology can be found within the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Laboratory results associated with VE QA/QC procedures are presented in Table 25 of the Appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during March 2019 did not display such a high level of spatial variability as commonly observed during the monitoring program. Elevated concentrations were once again observed within the upper harbour, reaching 26 µg/L at UH3. However, between the remaining sites, concentrations ranged from 8 µg/L at OS3 to 16 µg/L at UH2 (Table 18, Figure 26). The water quality guideline (WQG) for total phosphorous (30 µg/L) was not exceeded at any sites during the month. Similar to previous months, exceedances of the 5 µg/L WQG for the more bioavailable dissolved reactive phosphorous were recorded within the upper harbour (UH1-3) and nearshore sites OS1 and OS2 (Table 18).

Of the remaining nutrients analysed, concentrations of total nitrogen and total kjeldahl nitrogen were below laboratory limits of reporting (LOR) at all sites, similar to previous months. Total ammonia ranged from 11 to 15 µg/L; slightly lower than those recorded during the February sampling and within the water quality guidelines. Nitrogen oxides concentrations were variable between sites, yet were typically <6 µg/L and therefore well below WQGs. The exception to this was observed at OS1, where concentrations within the 'A' duplicate were reported at 38 µg/L (Table 18). Contrasting this value, nitrogen oxides in the duplicate 'B' sample were only reported at 1.7 µg/L (Table 25), suggesting possible contamination in the original sample analysis.

Concentrations of chlorophyll a, an indicator of phytoplankton biomass, remained relatively low during March with no exceedances of the 4 µg/L WQG (Table 18).

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during March 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	14	10	<300	<200	12	2.8	3.7
UH2	16	6.7	<300	<200	12	1.4	2.1
UH3	26	12	<300	<200	15	2.2	2.5
CH1	14	4.7	<300	<200	11	<1	1.6
CH2	14	3.8	<300	<200	11	<1	1.7
OS1	11	5.1	<300	<200	12	38*	1.6
OS2	13	5.3	<300	<200	13	1.9	1.9
OS3	8	3.6	<300	<200	12	<1	0.9
OS4	12	4.4	<300	<200	12	2.6	1.1
OS5	12	4.5	<300	<200	12	5.9	2.1
OS6	14	4.9	<300	<200	14	1.2	1.6
OS7	12	3.3	<300	<200	11	<1	1.3
SG1	10	3.8	<300	<200	14	2.9	0.4
SG2	10	4.3	<300	<200	15	1.6	0.7
SG3	10	4.2	<300	<200	14	<1	0.5
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

**Likely sample contamination*

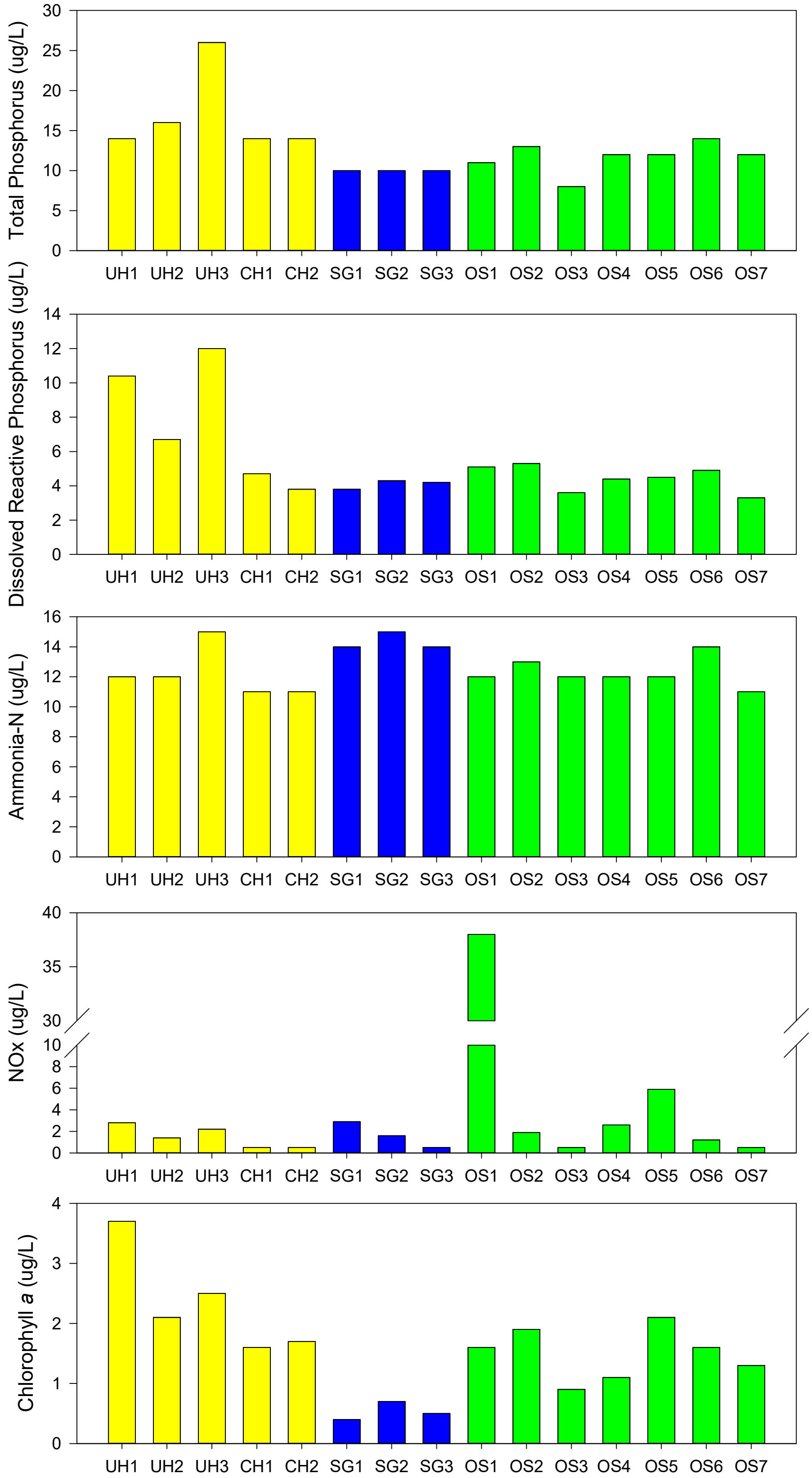


Figure 26 Nutrient and chlorophyll *a* concentrations at monitoring sites during March 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were < LOR. Note suspected sample contamination inducing elevated* NO_x *concentrations at OS1.*

3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (LOR) at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), cobalt (<0.6 µg/L), lead (<1 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5.3 µg/L) and zinc (<4.2 µg/L). Contrasting previous months, concentrations of total mercury exceeded the LOR of 0.08 µg/L at CH1 (0.43 µg/L) and OS2 (0.39 µg/L). Dissolved mercury concentrations, for which WQG are derived, remained below LOR at all monitoring locations (Tables 19 to 21).

As commonly observed, total aluminium concentrations were reported above the WQG of 24 µg/L (note that this WQG is designated for concentrations of the more readily available dissolved aluminium fraction) at all sites, except OS3 and the spoil ground locations. Concentrations of the more bioavailable dissolved fraction were below LOR (12 µg/L) at all sites (Tables 19 to 21, Figures 27 to 28). Total copper concentrations were above LOR at UH2, OS4 and OS5, with the WQG (1.3 µg/L) being slightly exceeded at the reference site OS4 (Tables 19 to 21). All dissolved copper concentrations remained below LOR (Tables 19 to 21). No further exceedances were reported during the March 2019 water quality sampling campaign (Tables 19 to 21).

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. During March, concentrations of total iron were largely elevated from values reported during the February sampling. The greatest concentrations of total iron were recorded in the upper harbour at UH3 and declined with increasing distance from the harbour head with the lowest concentrations at the spoil ground site SG1 (Figure 27). In a similar to pattern to aluminum, dissolved concentrations of iron were once again low (<10 µg/L) indicating that iron was predominantly present in the particulate phase, and thus not readily available for biological uptake (Tables 19 to 21).

Total and dissolved manganese concentrations were above LOR (<1 µg/L) at all monitoring sites during March. The highest concentrations were once again recorded in the upper harbour, with total concentrations approximately double those of the dissolved fraction; indicating a relatively even split of manganese between dissolved and particulate phases (Figure 27).

Consistent with previous monitoring reports, molybdenum concentrations during March displayed little spatial variation across the inshore and offshore monitoring network (Figure 28). Given the similarity between the dissolved and total metal concentrations, the majority of the molybdenum present appeared to be in the dissolved phase (Tables 19 to 21 and Figure 28) and thus readily dispersed across the region. Concentrations of total and dissolved vanadium displayed a similar pattern to that of molybdenum, with a large proportion of vanadium also present in the dissolved phase (Figure 28).

It should be noted that total chromium was detected in the lab blank at concentrations slightly above the laboratory LOR, however, field blank results for chromium remained below LOR (Table 25).

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during March 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	137	109	187	101	84	
Arsenic	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.3	<4.3	<4.3	<4.3	<4.3	
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	1.4	1.3	1.5	1.2	1.6	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.4	2.3	2.1	2.3	2.0	
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	1.3
	Total	<1.1	2.0	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	5	<4	-
	Total	270	290	520	197	220	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	6.5	5.1	6.7	2.9	2.7	-
	Total	12	9.1	16	6.6	5.6	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	0.43	<0.08	
Molybdenum	Dissolved	11	10	11	11	11	-
	Total	12	12	12	12	12	
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	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	2.2	2.4	2.8	1.8	2.2	100
	Total	2.5	1.8	2.8	2.6	2.6	
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 March 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	67	58	<13	25	42	39	65	
Arsenic	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4.3	<4.3	<4.3	<4.3	<4.3	<4.3	<4.3	
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	1.4	1.7	1.4	1.2	1.2	1.3	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.8	1.6	1.5	1.2	1.2	1.6	1.3	
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	1.5	1.2	<1.1	<1.1	
Iron	Dissolved	<4	6	10	6	5	<4	5	-
	Total	151	144	30	63	86	107	124	
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	1.8	1.7	1.6	1.5	2.0	1.8	-
	Total	4.5	3.9	1.9	2.0	3.1	3.9	3.6	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	0.39	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11	11	12	11	11	11	11	-
	Total	11	12	11	12	12	12	11	
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	<4.2	<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	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	
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	2.0	2.0	2.0	1.8	1.8	2.1	2.2	100
	Total	2.2	2.4	1.9	1.8	2.4	2.0	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 March 2019.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	<13	<13	<13	
Arsenic	Dissolved	<4	<4	<4	-
	Total	<4.3	<4.3	<4.3	
Cadmium	Dissolved	<0.2	<0.2	<0.2	5.5
	Total	<0.21	<0.21	<0.21	
Chromium	Dissolved	1.5	1.1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	1.2	1.4	
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	12	15	17	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.3	1.4	1.1	-
	Total	1.8	1.7	1.7	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11	12	11	-
	Total	12	12	12	
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	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	
Vanadium	Dissolved	2.0	2.1	2.0	100
	Total	2.2	2.0	2.6	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

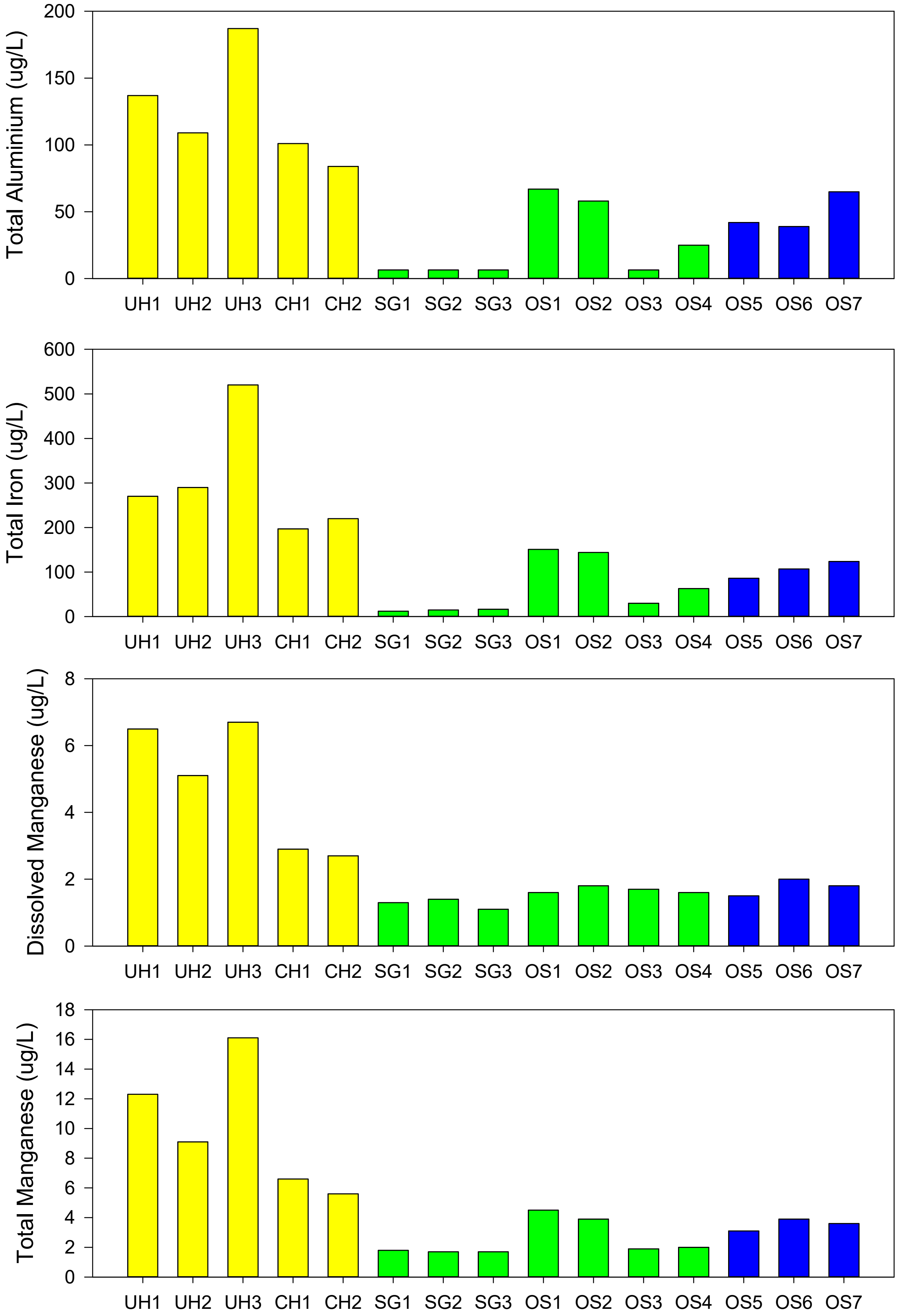


Figure 27 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during March 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

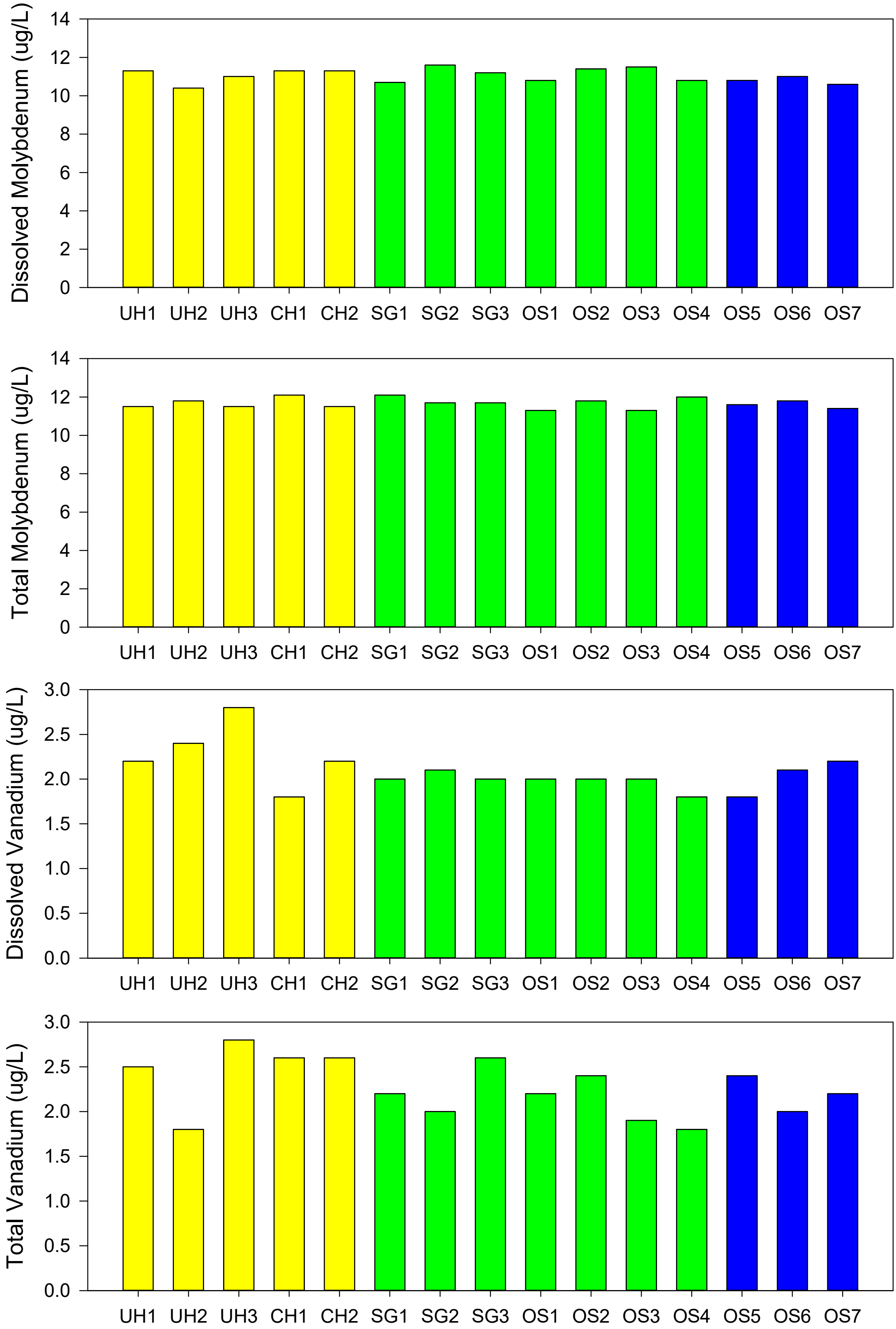


Figure 28 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during March 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

4 REFERENCES

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5 APPENDIX

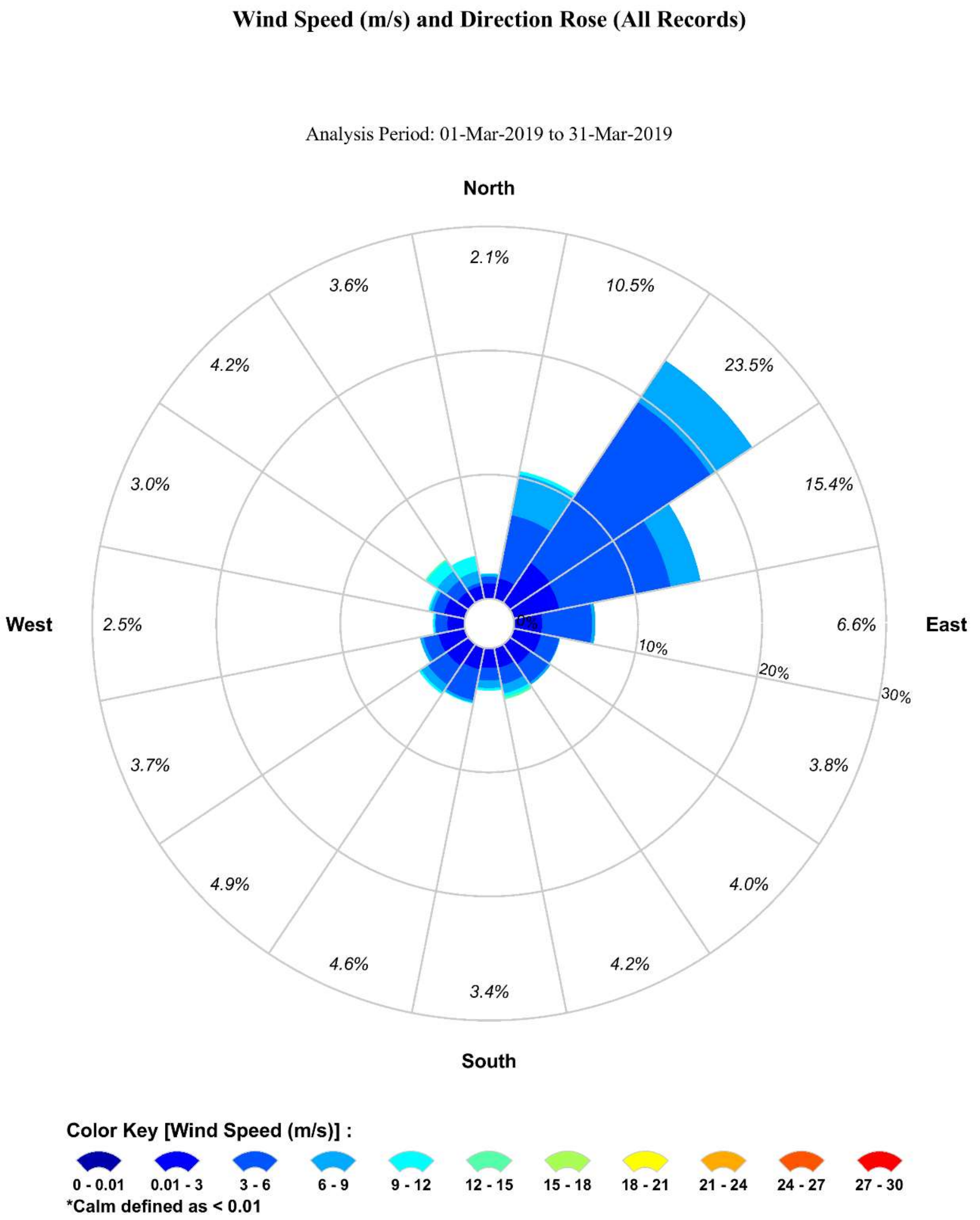

Figure 29 WatchKeeper wind speed (m/s) and direction rose (%) during March 2019.

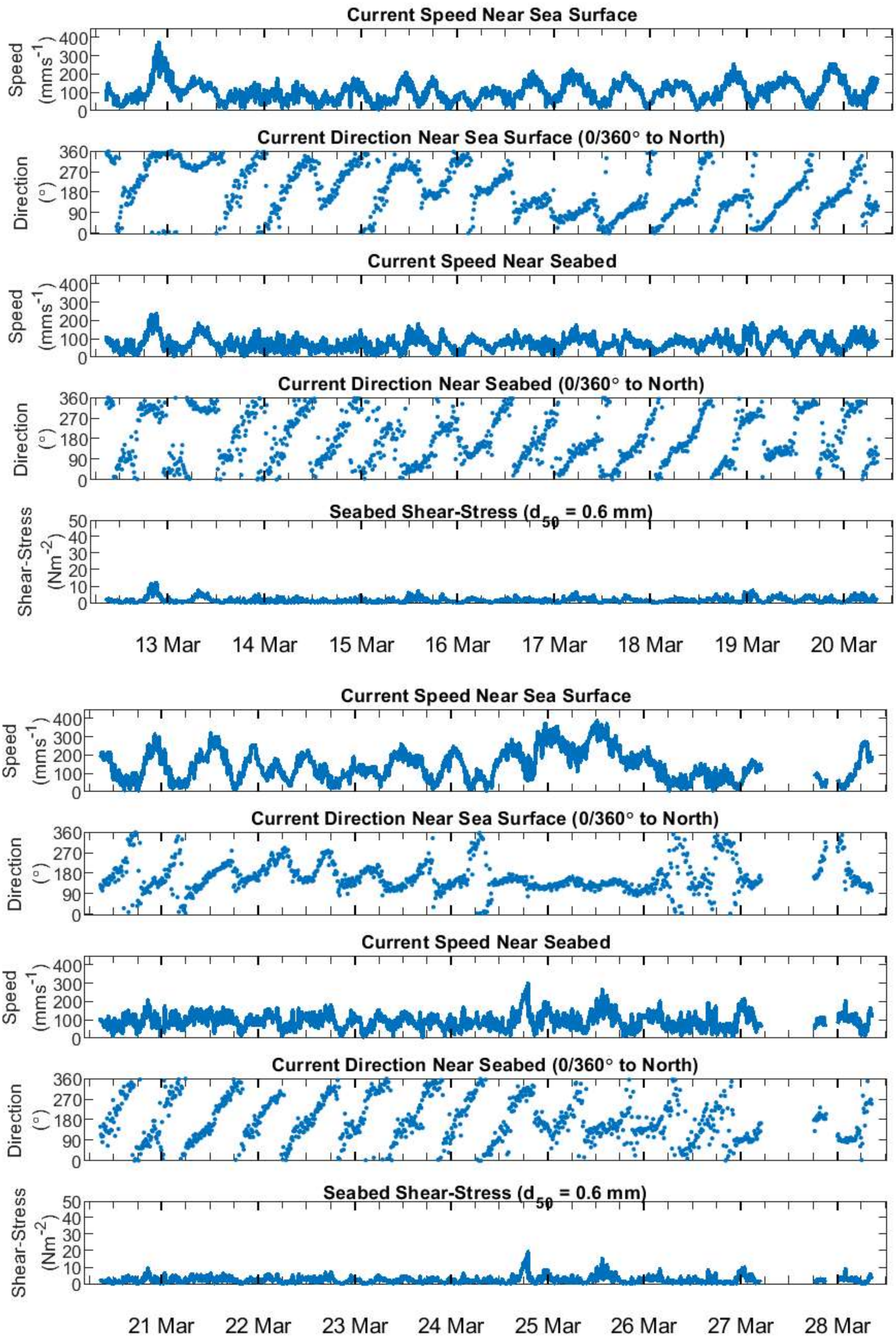

Figure 30 SG1 current speed, direction and shear bed stress 12 to 20 March 2019.

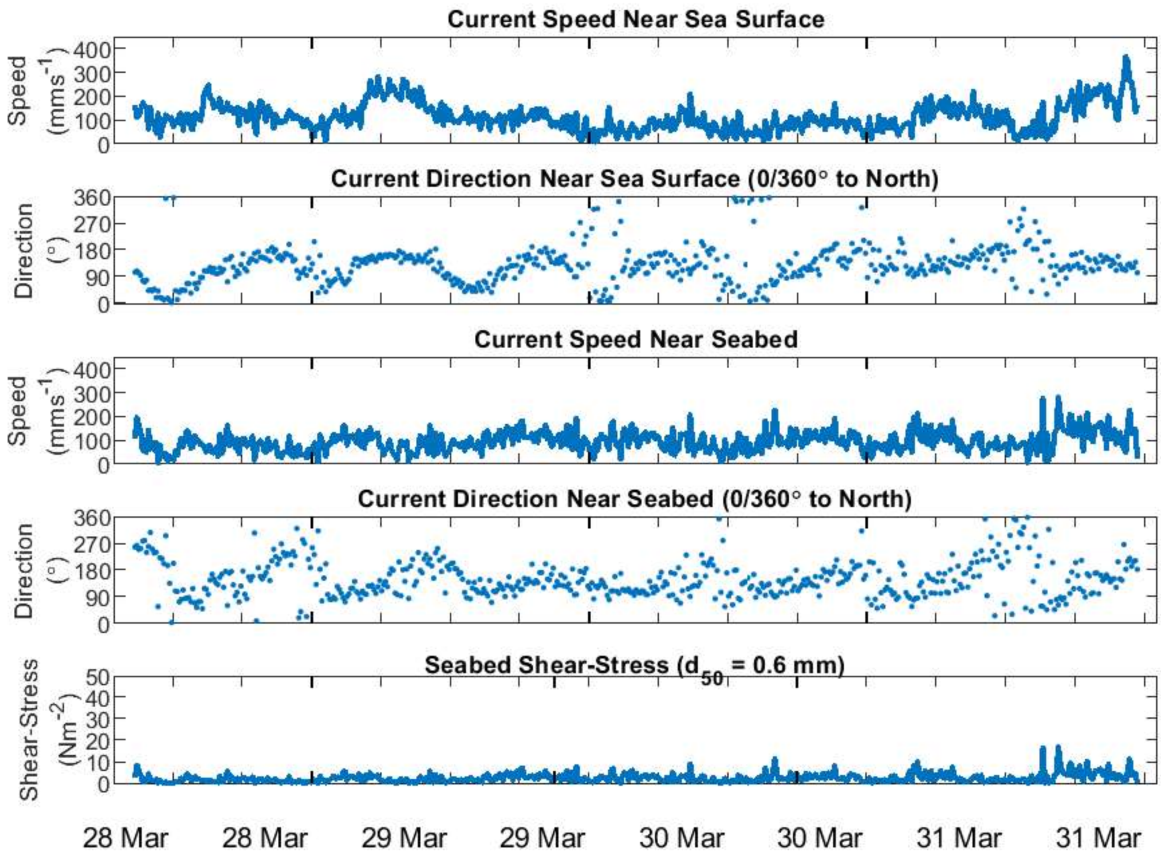

Figure 31 SG1 current speed, direction and shear bed stress 28 to 31 March 2019.

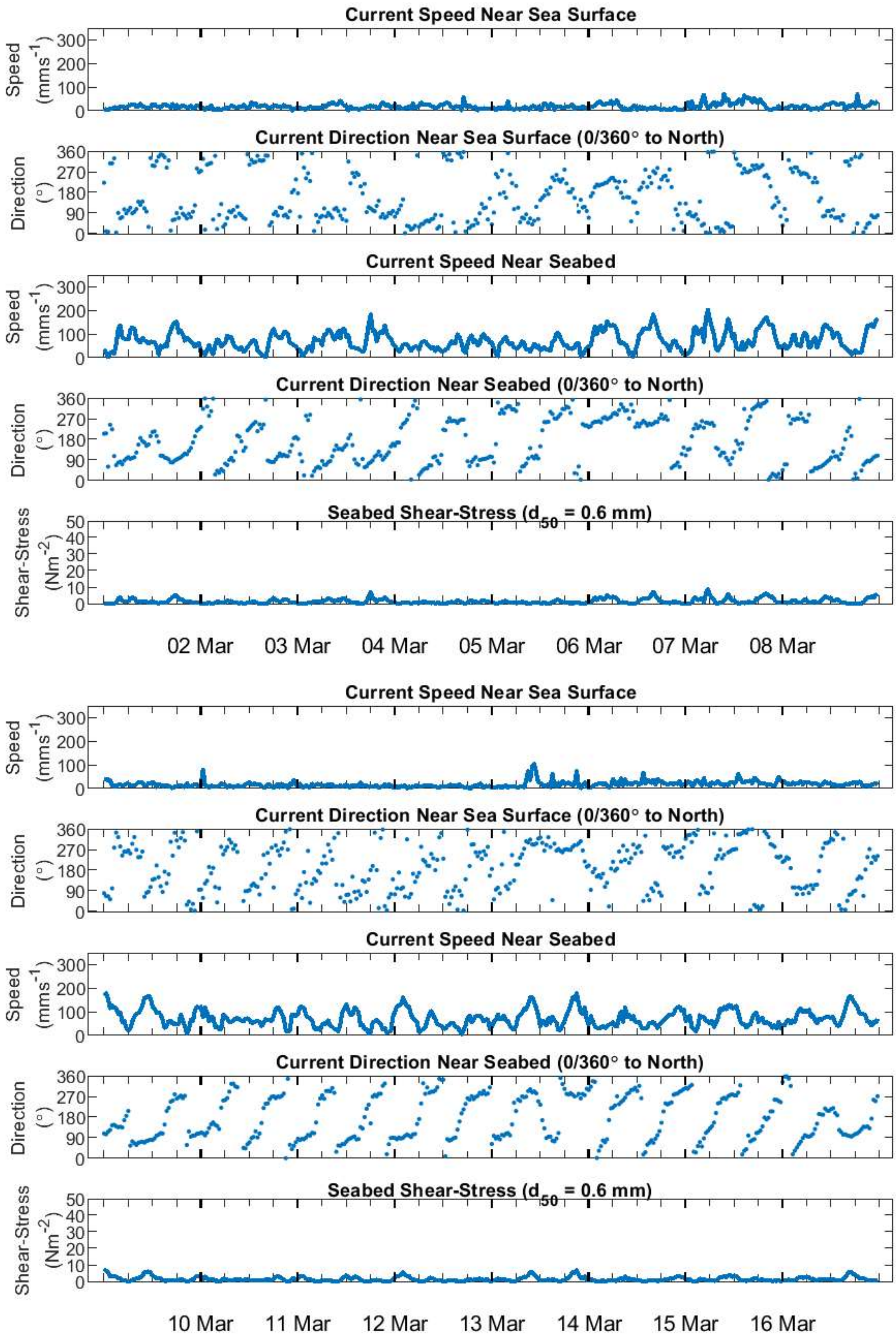

Figure 32 SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 March 2019.

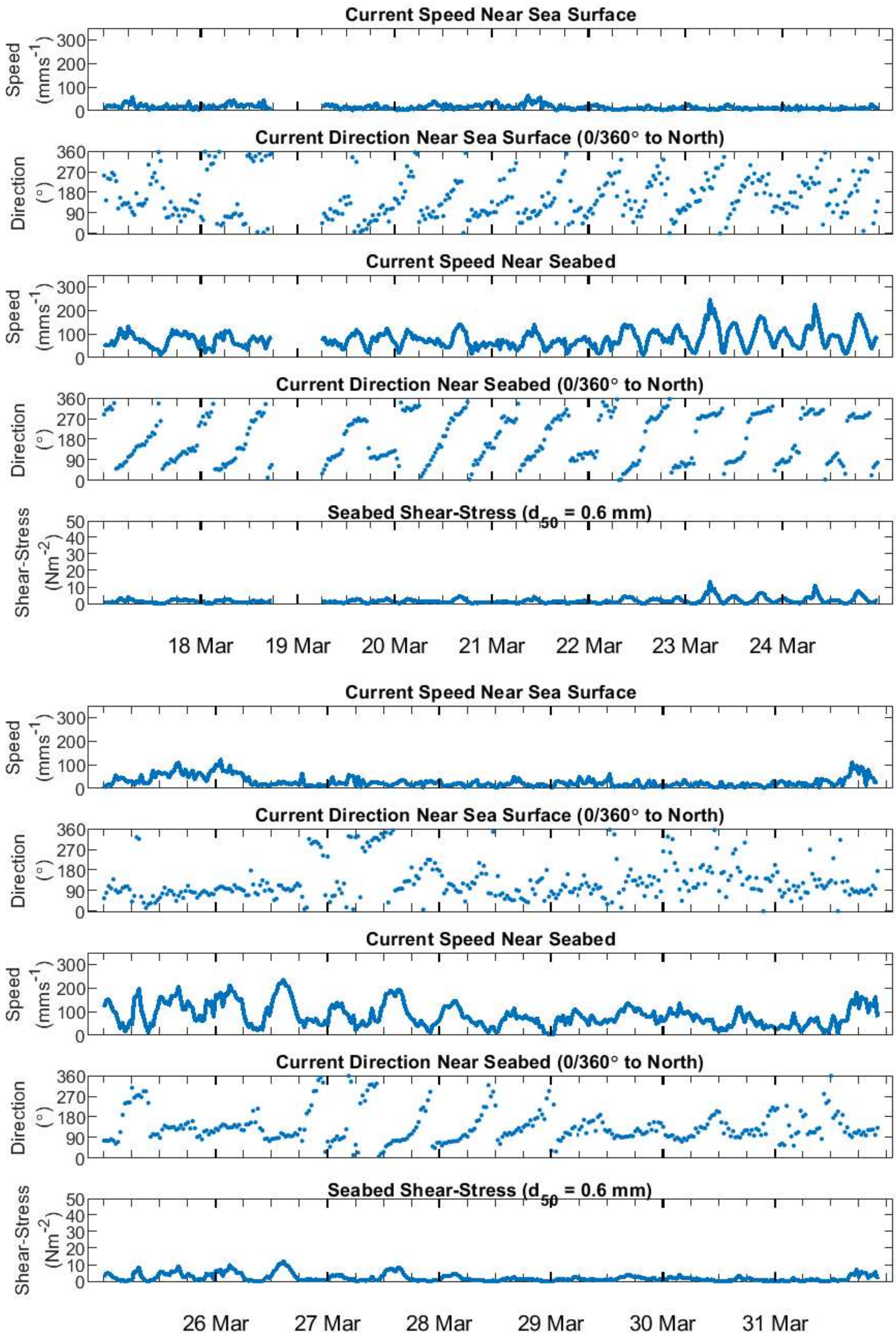

Figure 33 SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 31 March 2019.

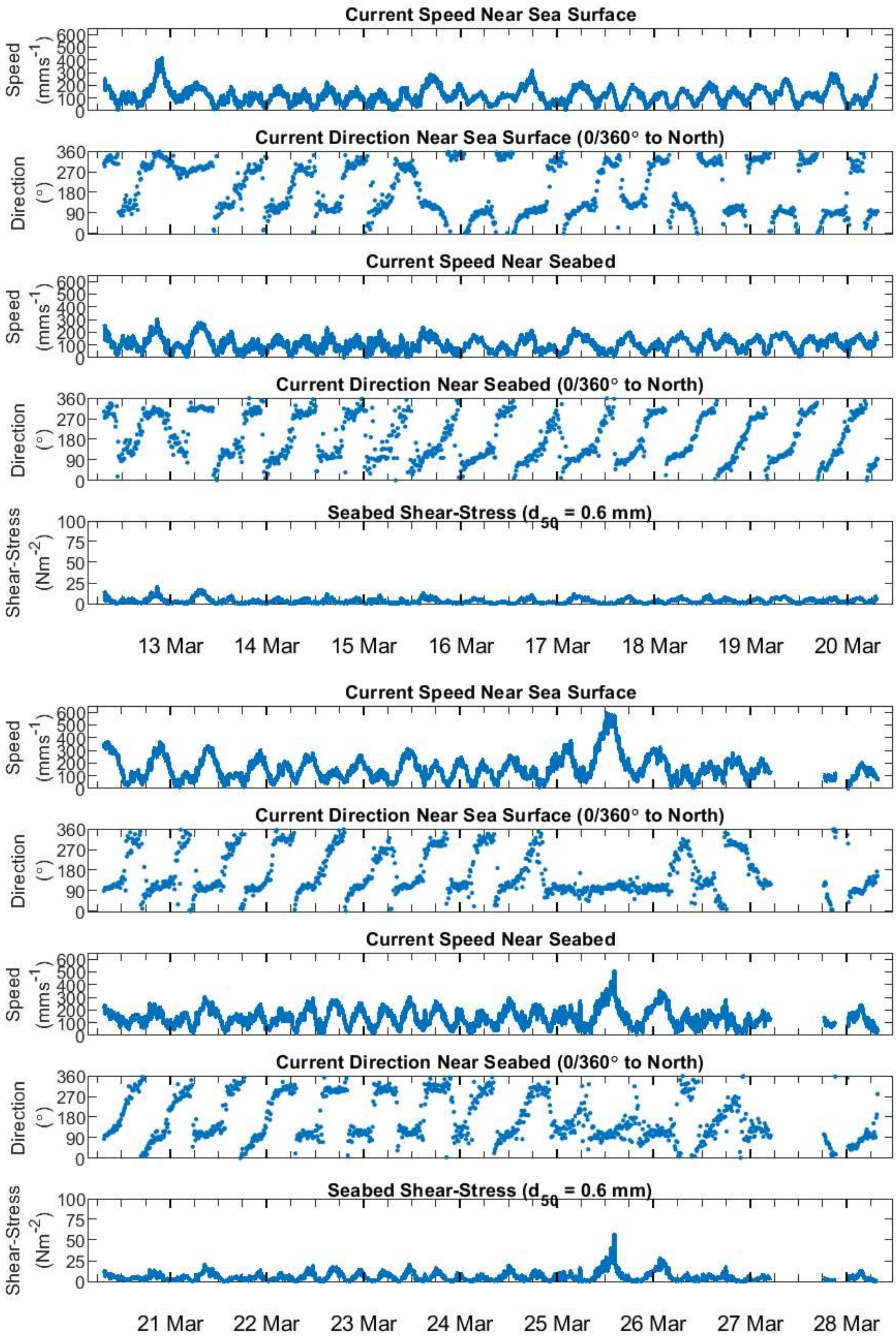

Figure 34 SG3 current speed, direction and shear bed stress 12 to 28 March 2019.

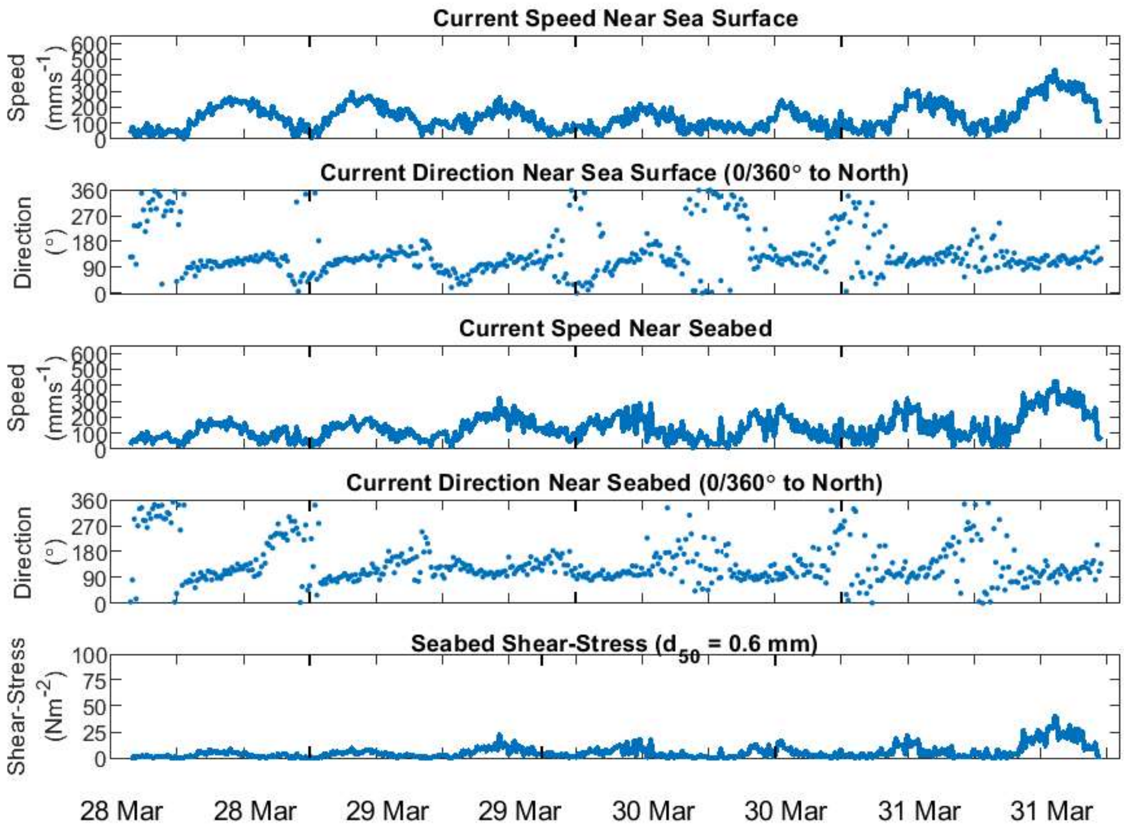

Figure 35 SG3 current speed, direction and shear bed stress 28 to 31 March 2019.

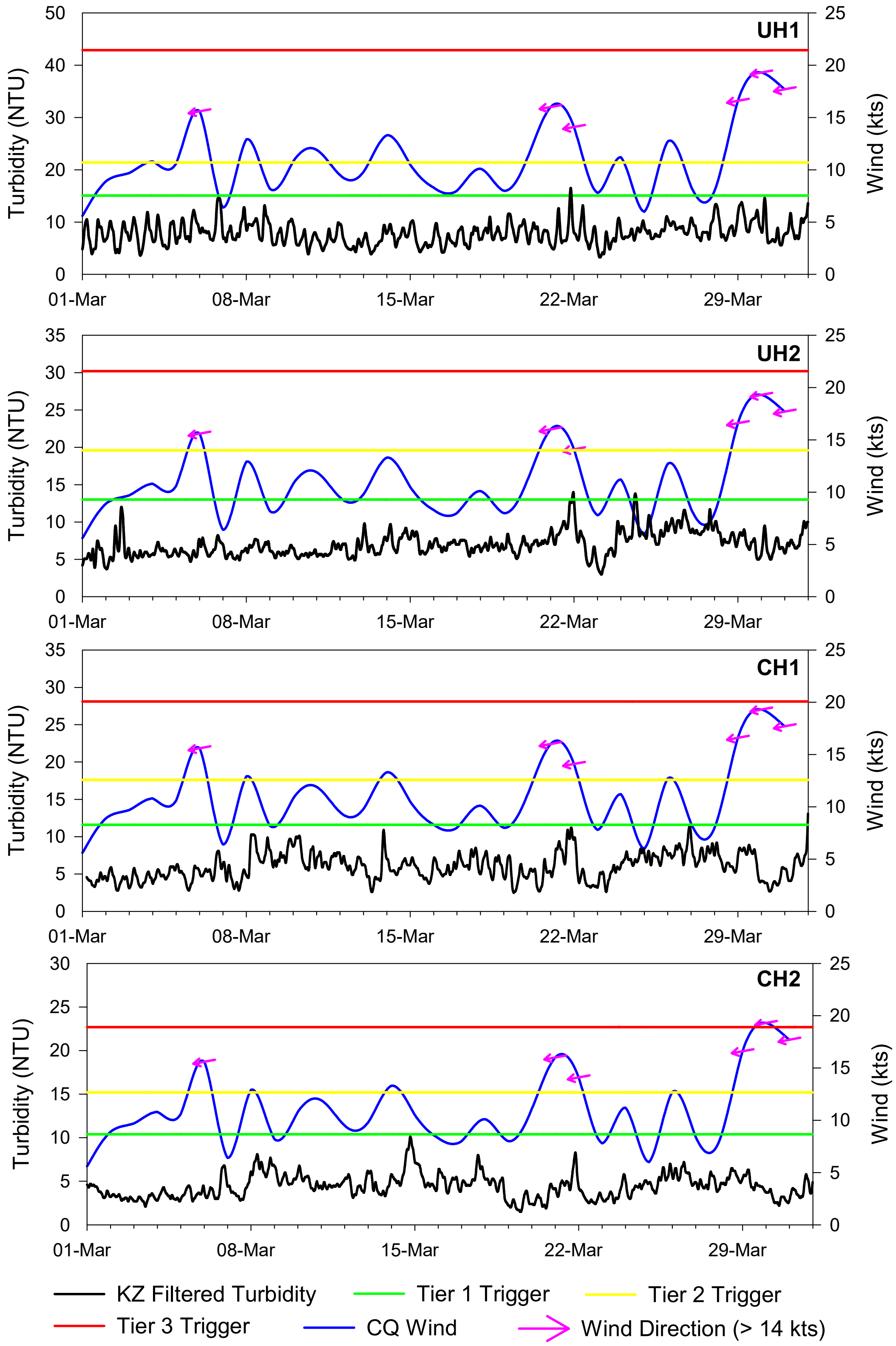

Figure 36 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

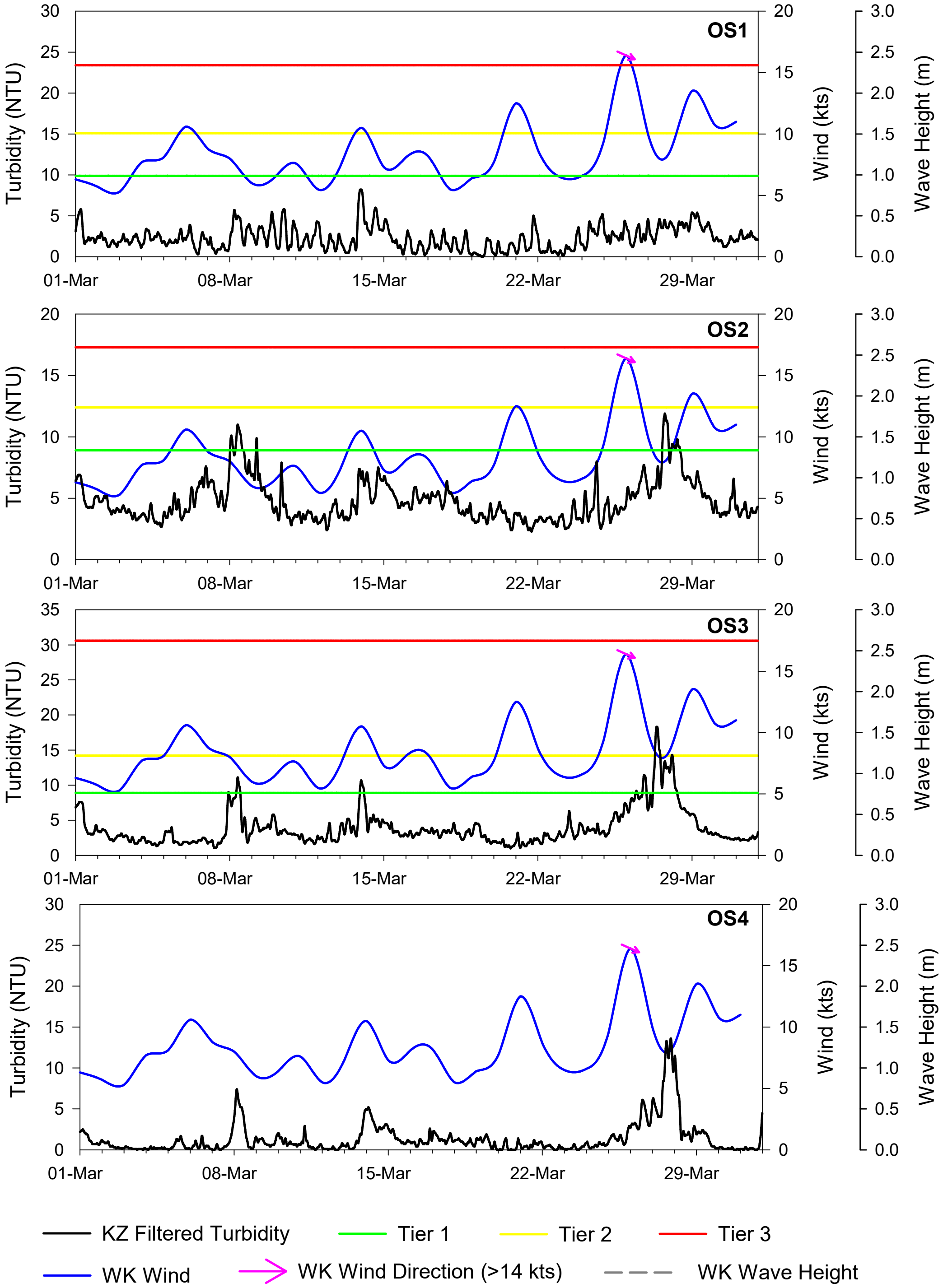

Figure 37 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

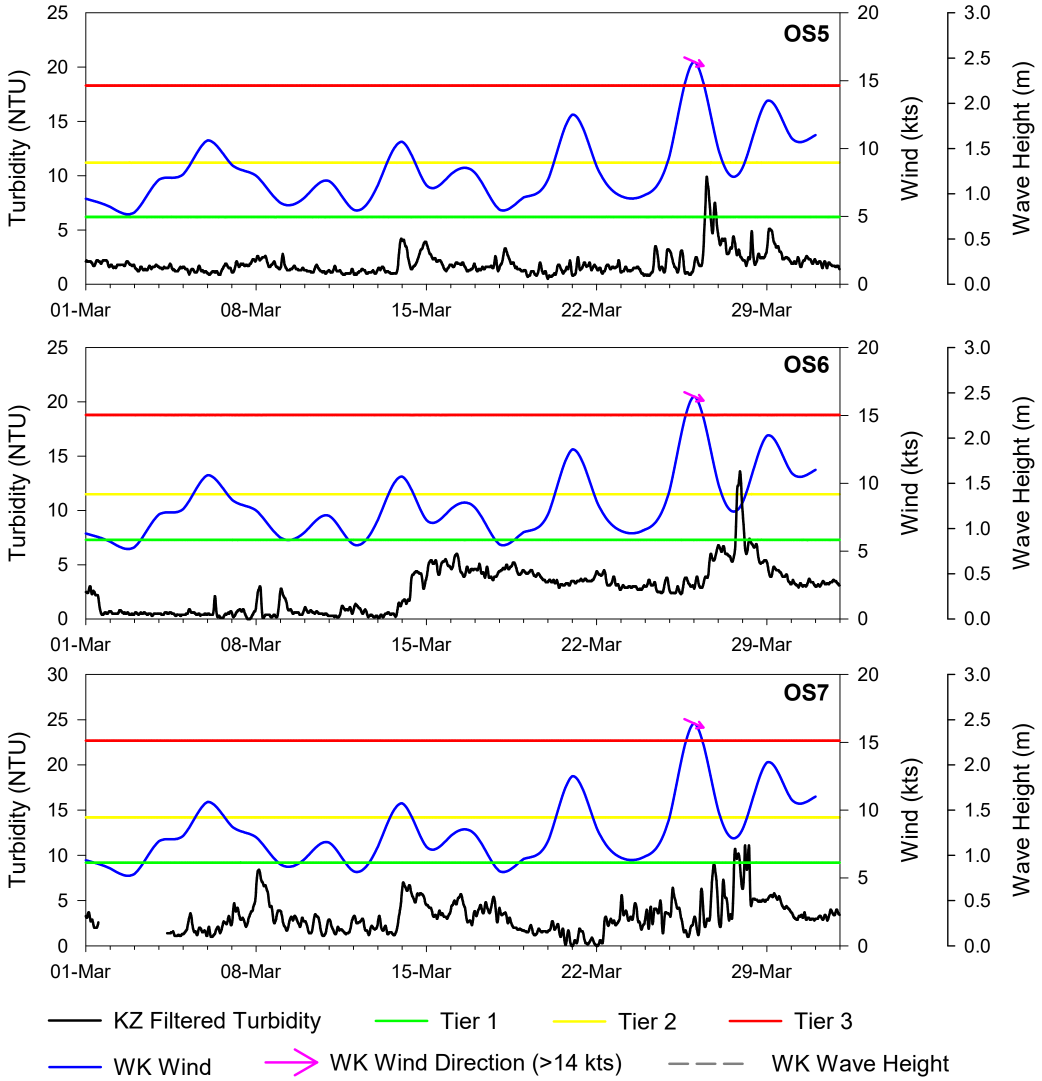

Figure 38 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during March 2019.

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

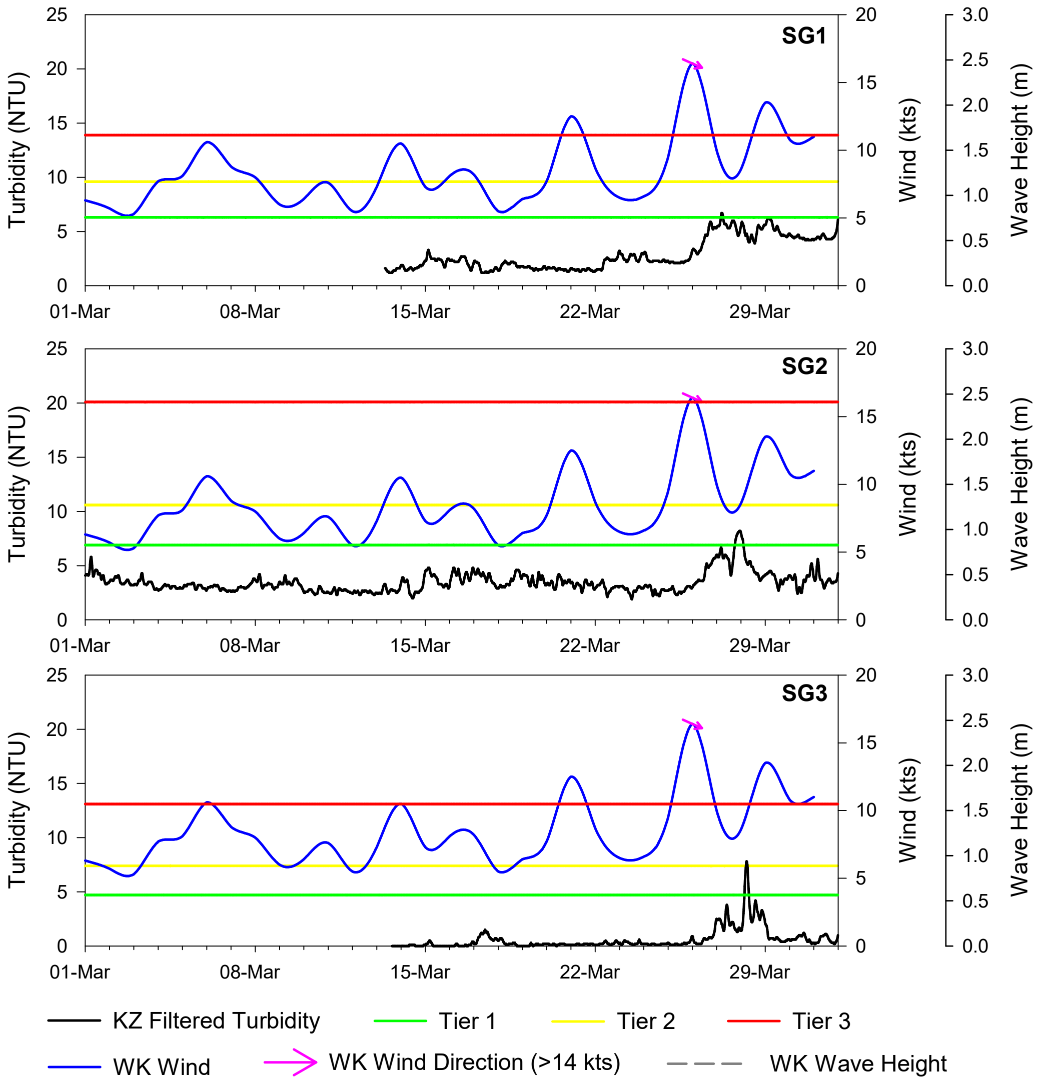

Figure 39 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during March 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 22 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during March 2019 and baseline period 1 November 2016 to 31 October 2017
Values for March are means ± se, range and percentiles (n = 2959 – 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface March	Surface Baseline
UH1	Mean ± se	7.9 ± 0.0	12
	Range	3 – 17	2 – 155
	99th	14	37
	95th	12	21
	80th	9.5	15
UH2	Mean ± se	7.0 ± 0.0	9.9
	Range	3 – 14	2 – 59
	99th	13	29
	95th	9.9	19
	80th	8.3	13
CH1	Mean ± se	6.0 ± 0.0	8.8
	Range	3 – 13	<1 – 50
	99th	11	27
	95th	9.1	17
	80th	7.6	12
CH2	Mean ± se	4.4 ± 0.0	7.6
	Range	2 – 10	<1 – 39
	99th	8.3	22
	95th	6.8	15
	80th	5.4	10

Table 23 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during March 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for March are means ± se, range and percentiles (n = 1764 – 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface March	Surface Baseline
SG1	Mean ± se	2.9 ± 0.0	4.2
	Range	1.2 – 6.7	<1 – 31
	99th	6.2	14
	95th	5.6	9.5
	80th	4.5	6.1
SG2	Mean ± se	3.5 ± 0.0	4.6
	Range	1.9 – 8.2	<1 – 33
	99th	7.3	20
	95th	5.2	10
	80th	4.0	6.9
SG3	Mean ± se	0.6 ± 0.0	3.6
	Range	<1 – 7.8	<1 – 22
	99th	4.6	13
	95th	2.5	7.3
	80th	0.8	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during March 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for March are means ± se, range and percentiles (n = 2705 – 2976). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface March	Surface Baseline
OS1	Mean ± se	2.3 ± 0.0	7.5
	Range	<1 – 8.2	<1 – 99
	99th	5.8	23
	95th	4.8	15
	80th	3.4	9.7
OS2	Mean ± se	4.8 ± 0.0	6.4
	Range	2 – 12	<1 – 36
	99th	11	17
	95th	8.4	12
	80th	5.9	8.9
OS3	Mean ± se	3.9 ± 0.0	6.5
	Range	1 – 18	<1 – 110
	99th	14	27
	95th	9.4	14
	80th	4.9	8.9
OS4	Mean ± se	1.3 ± 0.0	5.9
	Range	<1 – 14	<1 – 35
	99th	11	18
	95th	5.1	13
	80th	1.9	8.1
OS5	Mean ± se	1.9 ± 0.0	4.6
	Range	<1 – 9.9	<1 – 35
	99th	6.5	18
	95th	3.8	11
	80th	2.3	6.1
OS6	Mean ± se	2.7 ± 0.0	4.7
	Range	<1 – 14	<1 – 37
	99th	8.5	18
	95th	5.9	11
	80th	4.3	7.1
OS7	Mean ± se	3.2 ± 0.0	6.3
	Range	<1 – 11	<1 – 48
	99th	9.8	22
	95th	6.6	14
	80th	4.4	9.1

Table 25 Summary of Vision Environment quality control data for March 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.

Parameter	VE Field Blank (µg/L)	VE Lab Blank (µg/L)	Duplicate		
			OS1 A (µg/L)	OS1 B (µg/L)	Variation (%)
TSS	<3	<3	5	6	18
Dissolved Aluminium (ug/l)	<3	<3	<12	<12	ND
Total Aluminium (ug/l)	<3.2	<3.2	67	69	3
Dissolved Arsenic (ug/l)	<1	<1	<4	<4	ND
Total Arsenic (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Cadmium (ug/l)	<0.05	<0.05	<0.2	<0.2	ND
Total Cadmium (ug/l)	<0.053	<0.053	<0.21	<0.21	ND
Dissolved Chromium (ug/l)	<0.5	0.5	1.2	1.6	29
Total Chromium (ug/l)	<0.53	0.79*	1.8	<1.1	ND
Dissolved Cobalt (ug/l)	<0.2	<0.2	<0.6	<0.6	ND
Total Cobalt (ug/l)	<0.21	<0.21	<0.63	<0.63	ND
Dissolved Copper (ug/l)	<0.5	<0.5	<1	<1	ND
Total Copper (ug/l)	<0.53	<0.53	<1.1	1.2	ND
Dissolved Iron (ug/l)	<20	<20	<4	5	ND
Total Iron (ug/l)	<21	<21	151	133	13
Dissolved Lead (ug/l)	<0.1	<0.1	<1	<1	ND
Total Lead (ug/l)	<0.11	<0.11	<1.1	<1.1	ND
Dissolved Manganese (ug/l)	<0.5	<0.5	1.6	1.4	13
Total Manganese (ug/l)	<0.53	<0.53	4.5	4.1	9
Dissolved Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Total Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum (ug/l)	<0.2	<0.2	10.8	11.4	5
Total Molybdenum (ug/l)	<0.21	<0.21	11.3	11.1	2
Dissolved Nickel (ug/l)	<0.5	<0.5	<7	<7	ND
Total Nickel (ug/l)	<0.53	<0.53	<7	<7	ND
Dissolved Selenium (ug/l)	<1	<1	<4	<4	ND
Total Selenium (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Silver (ug/l)	<0.1	<0.1	<0.4	<0.4	ND
Total Silver (ug/l)	<0.11	<0.11	<0.43	<0.43	ND
Dissolved Tin (ug/l)	<0.5	<0.5	<5	<5	ND
Total Tin (ug/l)	<0.53	<0.53	<5.3	<5.3	ND
Dissolved Vanadium (ug/l)	<1	<1	2.0	2.2	10
Total Vanadium (ug/l)	<1.1	<1.1	2.2	2.2	0
Dissolved Zinc (ug/l)	<1	<1	<4	<4	ND
Total Zinc (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Total Phosphorus (ug/l)	<4	<4	11	12	9
Dissolved Reactive Phosphorus (ug/l)	<4	<4	5.1	3.9	27
Total Nitrogen (ug/l)	<110	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN) (ug/l)	<100	<100	<200	<200	ND
Total Ammonia (ug/l)	<10	<10	12	14	15
Nitrate-N + Nitrite-N (ug/l)	<2	<2	38⁺	1.7	183
Chlorophyll a (ug/L)	<0.2	<0.2	1.6	1.6	0

**Possible contamination of total chromium in the lab blank.*
⁺Possible contamination of Nitrate in the 'A' sample.