Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

February 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.

Construction works as part of the 'Lyttelton Harbour wastewater scheme', which commenced in July 2018, were completed on 14 December 2018. 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. Monitoring results collected during February 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, which although not applicable to the post dredge phase of monitoring are compared to compliance trigger values during dredging operations.

Climatic Conditions: Rainfall at Cashin Quay during February 2019 totalled only 5.4 mm, notably lower than that experienced during previous months. Freshwater outflow from the Waimakariri River was also notably lower than experienced during January, with discharge remaining below 180 m^3/s. Daily averaged inshore wind speeds ranged from 7.3 to 19.3 knots for the month, with the peak mean daily winds speed of 19.3 knots recorded on 8 February and maximum wind gusts of 40 knots recorded on 28 February.

Offshore, both wind speeds and wave heights remained variable over the month displaying a reduced similarly in patterns during the first two weeks of February. Maximum significant wave heights were recorded on 12 February, at a time when offshore wind speeds remained less than 11 knots.

Air temperatures displayed a slight cooling, with a monthly average of 17°C that was 1°C cooler than January 2019.

Currents: ADCP units at sites SG1 and SG3 remained offline during February 2019 and are currently awaiting redeployment following diagnostic analysis in Christchurch. Current velocity and direction data received from the Watchkeeper buoy at SG2a are instead included within this report.

Maximum near-surface current velocities at SG2a were recorded on 1 February 2019 yet did not correlate well with maxima in any other measured offshore metocean parameter. Benthic current velocity at this time were comparable to the monthly maximum, experienced on 20 February, suggesting that this forcing was experienced throughout the water column. In a contrasting manner, the maximum benthic current velocity experienced on 20 February was not mirrored within the surface dataset.

Contrasting the typical results obtained from SG1 and SG3, current velocities at SG2a were reported to be greater at the near-seabed, displaying a strong dominance of easterly flows. Within the surface waters, current direction data once again indicate a bidirectionality of flow along the east-west axis during February.

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 February 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 within the harbour. Surface turbidity at UH1 was notably elevated at the start of the month, yet this difference from the remaining inner harbour sites was reduced by 9 February as turbidity declined. The upper harbour sites displayed a strong response to a sustained period of elevated winds from 11 to 17 February, with CH1 also displaying a long-term increase in turbidity during the final week of February.

Nearshore and offshore monitoring sites displayed a similar pattern of turbidity that appears to have been controlled largely by offshore significant wave heights. Turbidity initially declined from the start of the month, increased briefly around 14 Feb and once again declined during the final week of February. Unfortunately, no surface turbidity data are available for SG1 and SG3, as the buoys were removed from site at this time. Similar to previous monitoring months, benthic turbidity units trended similarly to one another and displayed temporal variability similar to offshore wave and surface turbidity conditions.

Other Physicochemical Parameters: Monthly mean surface water temperatures around Lyttelton Harbour continued the slight warming trend observed during the previous months, despite a slight cooling in the mean monthly air temperature. 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 February, with a second phase observed from 15 February to the end of the month. Benthic temperatures were cooler than the overlying surface waters, with warmer temperatures recorded within Lyttelton Harbour than those along the exposed coastline. A large cooling in benthic water temperature was observed at OS1 on 14 February that was not recorded at any of the other monitoring sites.

Consistent with previous reports, pH during February did not display any particular spatial or temporal patterns across the monitoring network. A drop in benthic pH at OS3 and OS6 was, however, reported during early February, as elevated offshore wave heights resulted in increased benthic turbidity. Conductivity in February was also relatively stable, with some minor freshening recorded at SG2 and some of the nearshore and offshore locations around 3 and 4 February. Benthic waters were typically of higher conductivity, except for at OS4 and OS6, where mean values may have been skewed by incomplete data recovery.

Dissolved oxygen (DO) concentrations displayed similar monthly mean values as recorded during January, with a continuation of the large fluctuations at the northern sites within Lyttelton Harbour during the first half of the month. This variability was greatest at UH1, where concentrations dropped to less than 40% saturation. Mean monthly benthic DO concentrations were lower than at the surface, 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 11 February. Similar to profiles typically obtained during the monitoring program, inner harbour and nearshore monitoring sites indicated a well-mixed water column. Interestingly, benthic waters at CH2 displayed slightly higher conductivity and temperature at depth.

Further offshore, vertical profiling once again indicated strong vertical mixing, with relatively rapid declines in pH and DO near the benthos at OS1 as turbidity increased. The remaining nearshore sites indicated the typically observed pattern of slightly declining temperature, pH and DO concentration with depth from the surface. Surface waters within Lyttelton Harbour were also observed to be slightly fresher than those of the more exposed sites at OS3 and OS4.

Profiles collected at the offshore sites also indicated declining temperatures with depth, with warmer and fresher surface waters observed at OS5. Dissolved oxygen and pH both displayed variable vertical profiles with subsurface maxima observed in both parameters ~10 m at OS6 and SG2. Increases in benthic turbidity were once again observed in many of the profiles, as commonly observed.

Turbidity and total suspended solids (TSS) measurements for surface waters were again elevated at inshore sites compared to the offshore areas, resulting in the shallowest estimations of the euphotic depth as typically recorded during the monitoring program. Euphotic depth at the offshore monitoring locations was relatively high; estimated to be at 34.2 m at OS6. No exceedances of WQG were observed for sub-surface turbidity during the February 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 UH3 and CH1. Total ammonia also displayed concentrations exceeding WQG at these two sites. Concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites. Nitrogen oxide concentrations were variable with many sites below LOR and concentrations of 34 and 45 µg/L reported for UH1 and OS7, respectively. Given the wide range of concentrations reported, it is likely that these elevated values are an indication of sample contamination; also suggested by the duplicate sample at UH1 that indicated nitrogen oxides below LOR. Chlorophyll *a*, an indicator of phytoplankton biomass, slightly exceeded WQG at UH3, OS2 and OS7

As typically observed, total aluminium concentrations exceeded designated WQG at all of the inshore and offshore monitoring sites. Dissolved aluminium concentrations remained below LOR, except at UH1 where the sample was likely affected by contamination. Exceedances of dissolved copper WQG during January were not repeated during the February sampling and total iron concentrations had also declined. In a similar pattern to aluminium, levels of dissolved iron were once again relatively low, indicating a dominance of iron in 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 during February, with little spatial variability and a large component contained within the dissolved phase.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during February, in terms of the monthly mean, were similar to that experienced in January and as such trends in BPAR were once again apparent within the benthic datasets.

Increased ambient PAR during the first week of the month resulted in increases in BPAR at both sites. Despite the greater water depth at OS2, BPAR was greater at this site due to the higher surface turbidity levels observed at OS3 during this time. Maximum BPAR was however observed on 10 February at OS2 and 11 February at OS3 during periods of elevated incoming ambient PAR and low surface turbidity. For the remainder of the month, surface turbidity increased and BPAR displayed the expected corresponding decrease. Non-zero benthic PAR at OS2 was also observed on 17 to 19 February, yet peaks remained below 15 mmol/m^2/day as ambient PAR was submaximal and surface turbidity was recorded at around 4 NTU.

Sedimentation: During the first 10 days of February, bed level at the harbour entrance was relatively stable until a period of rapid sediment deposition resulted in a bed level increase of 146 mm between 10 and 12 February, during a period of elevated significant wave heights. Following this increase, sediments at OS2 remained relatively stable till a period of sediment erosion between 13 and 15 February where 57 mm of sediment was removed and the system reached a new equilibrium. Increased offshore wind speeds on 21 February were likely responsible for a second brief period of sediment erosion that was the followed by deposition through to the end of the month. Over the course of February 2019, there was 124 mm of sediment deposited on the seabed at OS2.

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. Data were only available from 7 February from this site and suggest relatively stable conditions despite a slight disparity in the absolute bed level measured by the dual sensors. A slight period of sedimentation was observed between 24 and 25 February, with bed level stabilising once again for the remainder of the month despite increasing wind speeds. From 7 to 28 February, net bed level increased by 16 mm.

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Acronyms

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

1 INTRODUCTION

Lyttelton Port Company (LPC) is undertaking a Channel Deepening Project (CDP) to extend the existing navigational channel to allow larger vessels access to the Lyttelton Port of Christchurch (LYT), the South Island's largest port. Utilising background information provided by LPC and advice from the Technical Advisory Group (TAG) in relation to ambient conditions, locations of sensitive habitats and dredge impact hydrodynamic modelling scenarios, a water quality monitoring design was proposed for the initial 12 month baseline monitoring phase. Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016, progressing into dredge operations monitoring from 29 August to completion of works on 29 November 2018. Monitoring is now continuing into a post dredge phase. 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 baseline and operations phase of water quality monitoring is provided in this section. A more detailed description of the importance of the measured parameters and the specific methodology for the CDP data collection and processing protocols, can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

2.1.1 Monitoring Locations and Equipment

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

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

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.

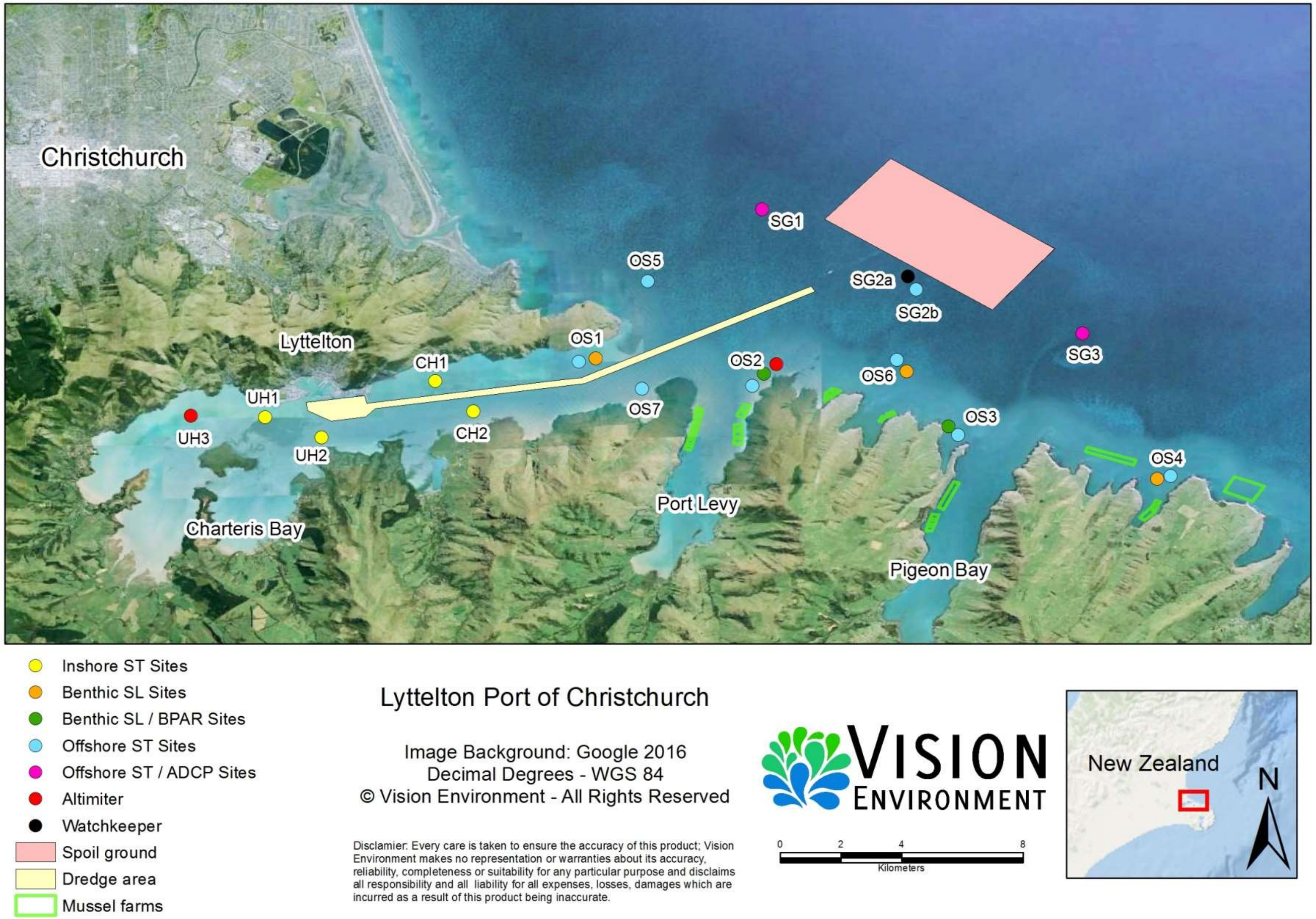


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 28 February 2019 during post dredge operations. Monthly water sampling and depth profiling was conducted on 11 February 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 February 2019, Cashin Quay received only 5.4 mm of rainfall spread over 6 days (Figure 2); 20.2 mm less than that recorded during the previous month. The majority of this rainfall was experienced during the final week of February, with two days of rainfall also occurring on 14 and 15 February (Metconnect, 2019). Freshwater flows (Figure 2) from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour several days later, were also notably reduced, with flow remaining below 180 m^3/s for the duration of the month (ECAN, 2019).

Inshore winds were predominately from an east-north-east direction, ranging from a daily mean of 7.3 to a maximum daily mean of 19.3 knots on 8 February (Figure 2). The greatest maximum wind gusts were experienced on 28 February reaching 40 knots from a south westerly direction (Metconnect, 2018). Daily mean air temperatures at Cashin Quay ranged from 12 to 23°C, resulting in a monthly mean temperature of 17°C, 1°C cooler than the January monthly mean (Metconnect, 2019).

Offshore significant wave heights were quite variable during the majority of the month, displaying a relationship with changes in offshore wind speeds during the second half of the month. Maximum significant wave heights were recorded at 2.76 m on 12 February, travelling in a south-south-westerly direction (Figure 3), with no similarly timed increase in locally recorded wind speeds.

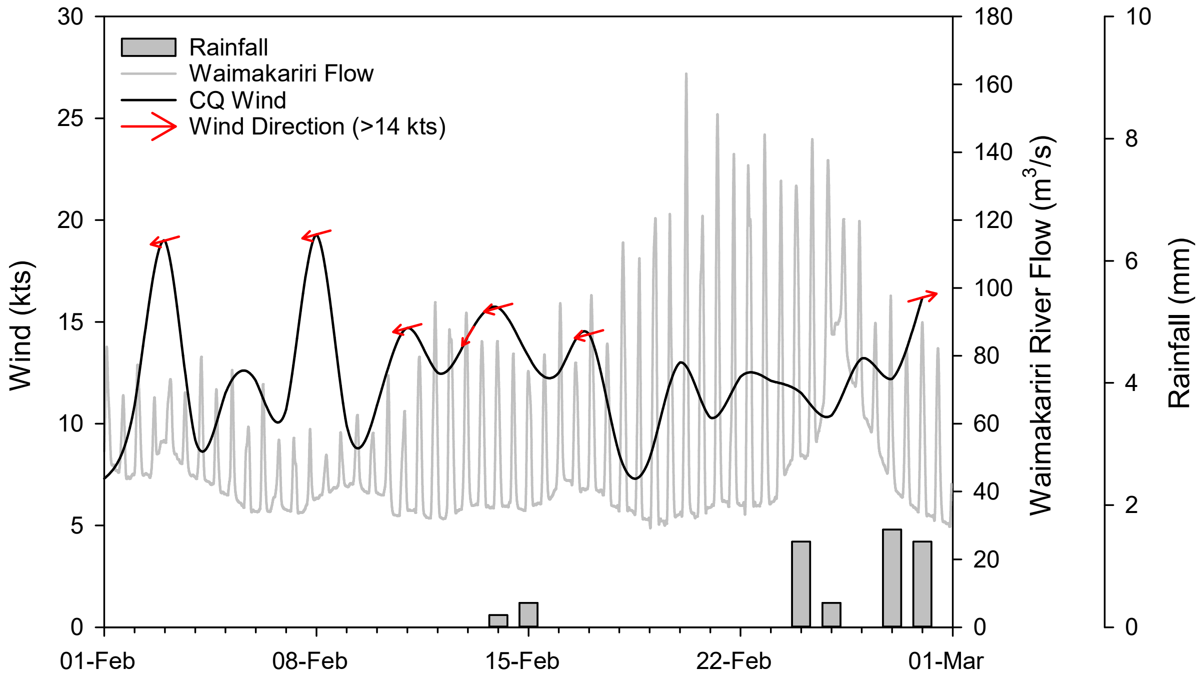


Figure 2 Inshore metocean conditions including daily averaged wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during February 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

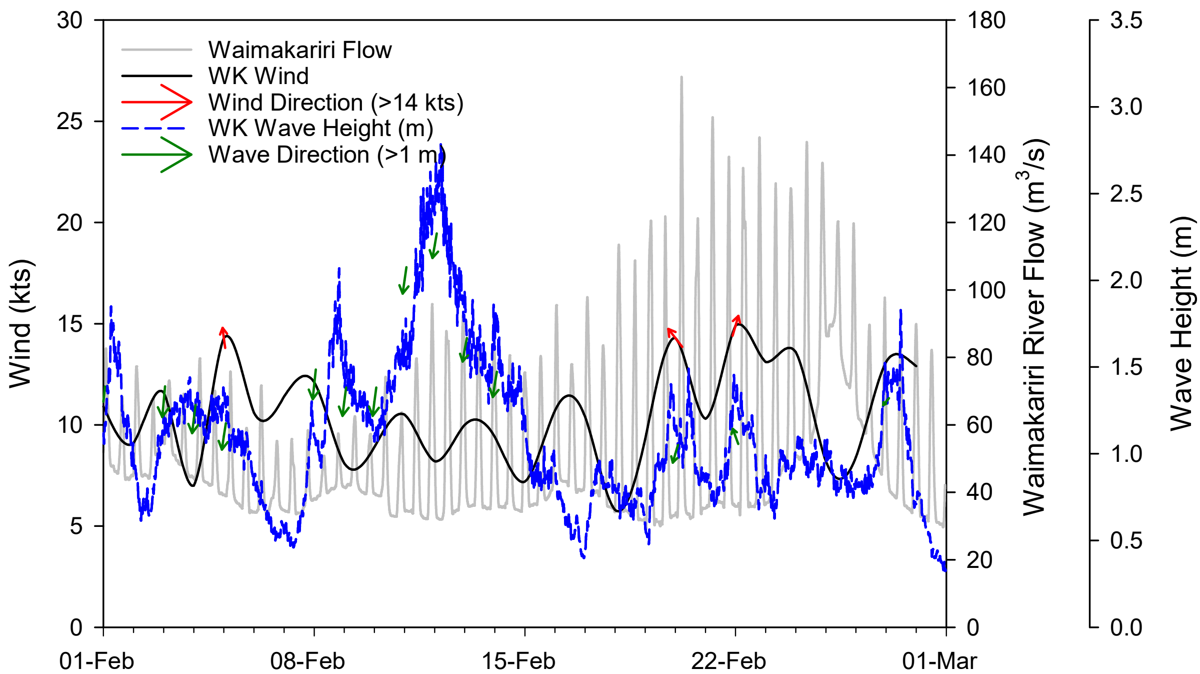


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during February 2019.
Note: Arrows indicate the direction 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 and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Unfortunately, both ADCP units stopped sending data in late August/early September 2018 and were removed from site on 18 and 14 January, respectively.

ADCP data collected from the WatchKeeper Buoy at SG2a are provided within this report in lieu of the regular spoil ground site data. Summary ADCP statistics are presented within Figure 4 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 28 and 29 in the Appendix.

The maximum near-surface current velocity at SG2a was recorded on 1 February at 212 mm/s (Table 2), a period that does not coincide with notable increases in any other offshore metocean conditions (Figure 3). Near the seabed, current velocities of 383 and 386 mm/s were recorded on 1 and 20 February, respectively (Table 2, Figure 3). Elevated benthic currents on 1 February indicate rapid currents throughout the water column, most likely due to some regional forcing rather than localised conditions. Maximum benthic velocities recorded on 20 February coincide with increases in offshore wind speed, however, were not mirrored in the surface waters. This suggests that these currents were restricted to deeper waters at the spoil ground.

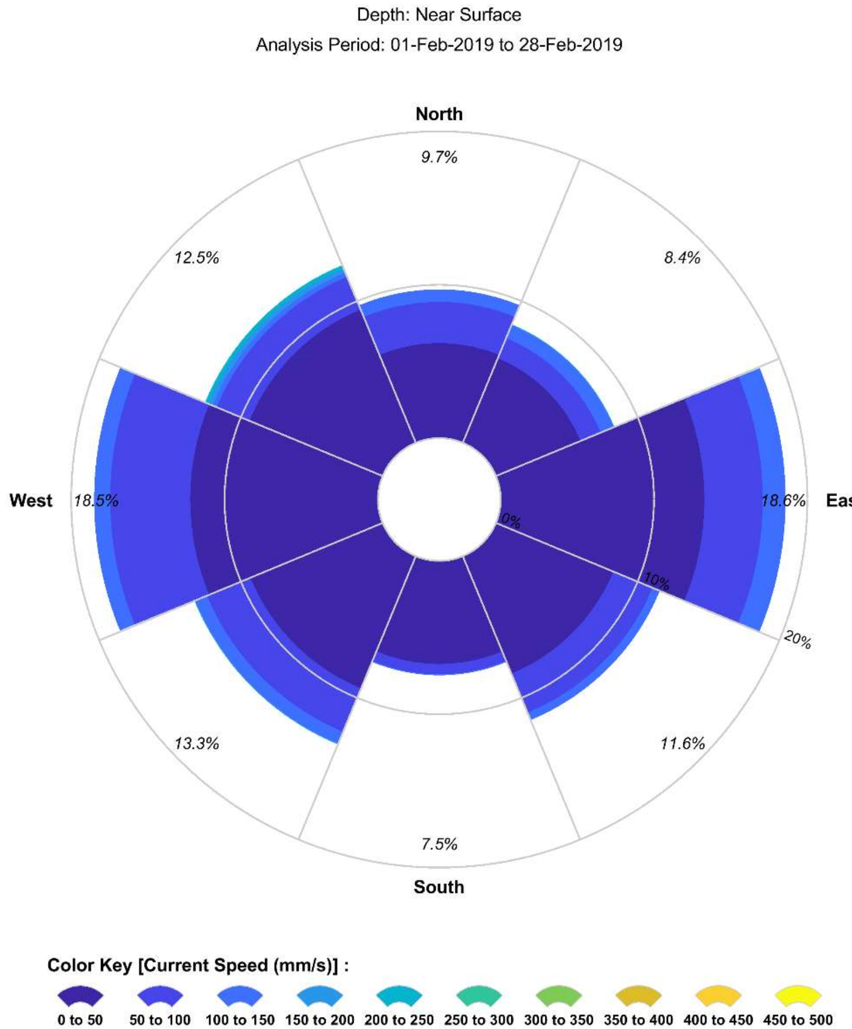
The monthly mean current speed for the near-seabed (96 mm/s) was greater than that recorded for the near surface (41 mm/s), contrasting typical observations from SG1 and SG3 and possibly reflecting benthic topography at SG2.

Table 2 Parameter statistics for ADCP at SG2a (WatchKeeper buoy) during February 2019.

Parameter	SG2a	
	Near-surface	*Near-seabed*
Minimum current speed (mm/s)	1	5
Maximum current speed (mm/s)	212	386
Mean current speed (mm/s)	41	96
Standard deviation of current speed (mm/s)	32	56
Current speed, 95th percentile (mm/s)	106	195

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

Previous data recorded from SG2a during December 2018 and January 2019 have displayed a strong dominance of surface flow to the east rather than bidirectional flow along an east-west axis as recorded during October and November (Figure 4). During February, this bidirectionality along the east-west axis had returned, possibly indicating the passing of a mesoscale eddy in the area. Near-seabed current direction during February continued to display a greater component of flow along the east-west axis, with a large dominance of easterly flows (30.1% c.f. 13.7% to the west) (Figure 4).



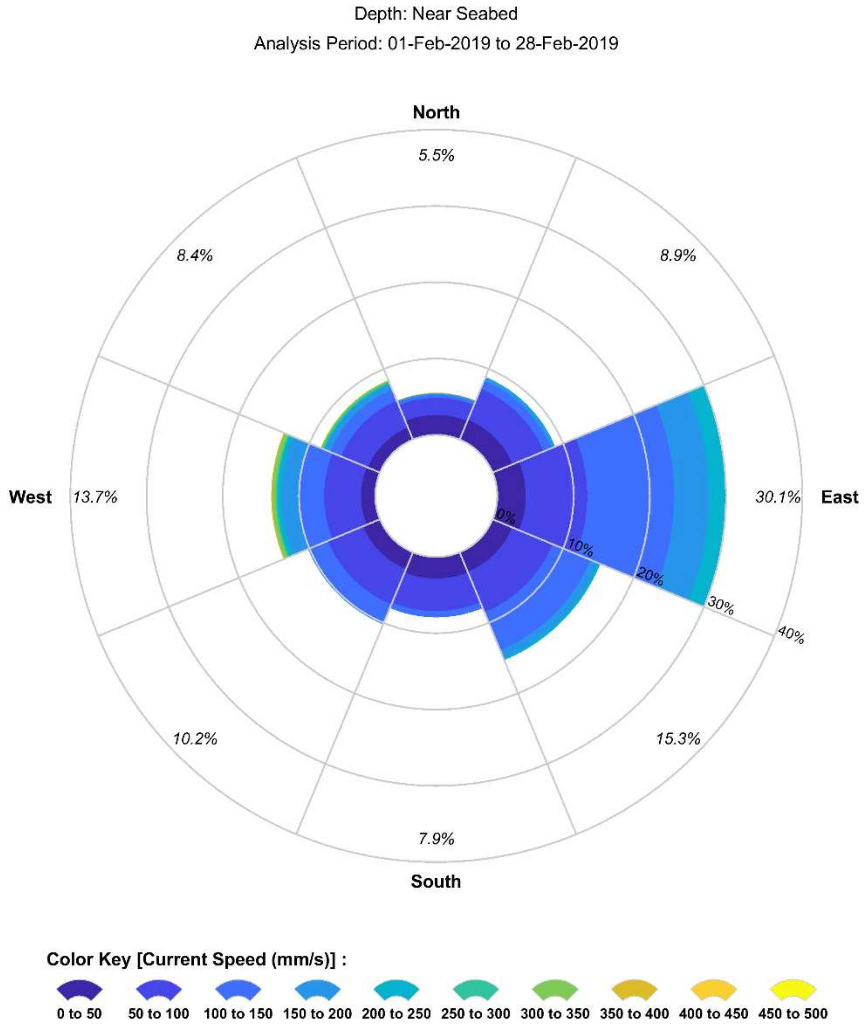


Figure 4 WatchKeeper near-surface and near-seabed current speed and direction during February 2019.
Speed intervals of 50 mm/s are used

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 11 February 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 February are presented in Tables 3 to 12. Validated datasets for surface and benthic measurements are also presented in Figures 5 to 21. 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 February 2018 post dredge data.

Summary statistics for KZ filtered turbidity data used for real time compliance monitoring during dredge operations but not applicable during the post dredge phase, are also presented in Tables 19 to 21 in the Appendix for comparison with previous months dredge compliance reports. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 30 to 33 in the Appendix.

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 5.8 to 11 NTU) at the inshore monitoring sites (Table 3, Figure 5). Further offshore, the spoil ground sites exhibited lower (monthly mean of 3.3 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 intermediate turbidity values (1.5 to 5.5 NTU) during February (Table 5). Continuing previously observed trends, surface turbidity at CH2 on the southern side of the harbour remained lower than the remaining three inner harbour sites, likely reflecting tidal movements within the harbour where the southern edge is dominated by the flood tide.

During the first week of February, turbidity at the upper harbour head (UH1) was notably higher than the remaining upper and central harbour locations, as recorded during the final week of January. However, this difference was minimised over time as surface turbidity at UH1 declined to values similar to the nearby site UH2 on 9 February (Figures 5 and 6). All inner harbour sites displayed a slight increase in turbidity following elevated inshore wind speeds on 3 and 7 February (Figure 5), however, the long-term trend was of a decline to minimum values around 10 February. The shallower upper harbour sites displayed a strong response to a period of sustained elevated wind speeds from 11 to 17 February. Surface turbidity at CH1 displayed a notable increase for the remainder of the month that did not appear to relate well with inshore wind speed dynamics (Figures 5 and 6).

The nearshore sites of the monitoring program (OS1 to 4 and OS7) displayed a level of spatial consistency in surface turbidity trends, with small variations likely a response to changes in wind speed (Figure 5). In a similar manner to the inshore monitoring locations, surface turbidity at all nearshore sites also declined from the start of the month to 10 February. At the more exposed regions of OS2, OS3 and OS4, turbidity increased around 13 February in response to elevated offshore significant wave heights at this time (Figure 5). All of the nearshore sites also displayed notable increases in surface turbidity towards the end of the month that was not mirrored in the upper harbour dataset.

Further offshore at SG2, OS5 and OS6, a similar pattern to the nearshore region was observed. Elevated surface turbidity was recorded at the beginning of the month, which declined to 11 February. Greater significant wave heights induced a period of increased turbidity during the middle of the month, with increasing turbidity once again observed in the final weeks of February. Throughout the month, offshore turbidity levels were highest at SG2 and lowest at OS6 (Figure 5). Unfortunately, data were not available from SG1 and SG3 as both buoys had been retrieved during January for manual ADCP data download and diagnostics.

Benthic:

Benthic data recovery for February was somewhat 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, with periods of increased wave energy coinciding with elevated turbidity levels. This was quite noticeable during the middle of the month, when offshore wave heights were particularly high (Figure 5). As wave heights declined on 28 February to less than 0.5 m, turbidity at all benthic sites displayed a rapid decline as the energy required for particle suspension was lost from the system.

Table 3 Mean turbidity and statistics at inshore water quality logger sites during February 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for February are means ± se, range and percentiles (n = 2589 to 2681) Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface February	Surface Baseline
UH1	Mean ± se	11 ± 0	12
	Range	<1 – 39	-
	99th	28	39
	95th	21	22
	80th	15	15
UH2	Mean ± se	7.6 ± 0.1	10
	Range	<1 – 29	-
	99th	19	32
	95th	14	20
	80th	9.6	13
CH1	Mean ± se	7.1 ± 0.1	9
	Range	<1 – 20	-
	99th	16	29
	95th	13	18
	80th	9.5	12
CH2	Mean ± se	5.8 ± 0.0	8
	Range	<1 – 17	-
	99th	12	24
	95th	9.6	16
	80th	7.3	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during February 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for February are means ± se, range and percentiles (n = 0 to 2676). Baseline values modified from Fox 2018.*

Site	Statistic	Turbidity (NTU) Surface February	Surface Baseline
SG1*	Mean ± se	–	4.2
	Range	–	-
	99th	–	14
	95th	–	10
	80th	–	6.2
SG2	Mean ± se	3.1 ± 0.0	4.6
	Range	<1 – 11	-
	99th	8.4	20
	95th	5.9	11
	80th	4.0	7.0
SG3*	Mean ± se	–	3.6
	Range	–	-
	99th	–	13
	95th	–	7.7
	80th	–	4.8

**Units were not deployed at SG1 and SG3 during February*

Table 5 Mean turbidity and statistics at offshore water quality logger sites during February 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for February are means ± se, range and percentiles (n = 473 to 2687). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface February	Surface Baseline	Benthic February
OS1	Mean ± se	5.2 ± 0.0	7.5	43 ± 1
	Range	<1 – 18	-	2 – 148
	99th	12	24	126
	95th	9.2	16	105
	80th	6.7	10	69
OS2	Mean ± se	4.4 ± 0.0	6.4	42 ± 1
	Range	<1 – 16	-	5 – 179
	99th	10	18	126
	95th	8.0	13	95
	80th	5.6	9.0	65
OS3	Mean ± se	5.5 ± 0.1	6.6	21 ± 0
	Range	1 – 27	-	3 – 117
	99th	16	27	84
	95th	11	15	58
	80th	7.6	8.9	28
OS4	Mean ± se	2.0 ± 0.0	5.9	38 ± 1
	Range	<1 – 15	-	5 – 201
	99th	9.0	20	129
	95th	6.1	13	95
	80th	3.1	8.3	59
OS5	Mean ± se	2.0 ± 0.0	4.6	–
	Range	<1 – 4.6	-	–
	99th	4.3	19	–
	95th	3.5	11	–
	80th	2.5	6.4	–
OS6	Mean ± se	1.5 ± 0.0	4.7	45 ± 1
	Range	<1 – 8.3	-	3 – 148
	99th	5.5	19	125
	95th	3.4	12	95
	80th	2.1	7.2	65
OS7	Mean ± se	3.8 ± 0.0	6.4	–
	Range	<1 – 17	-	–
	99th	10	23	–
	95th	7.5	14	–
	80th	5.1	9.2	–

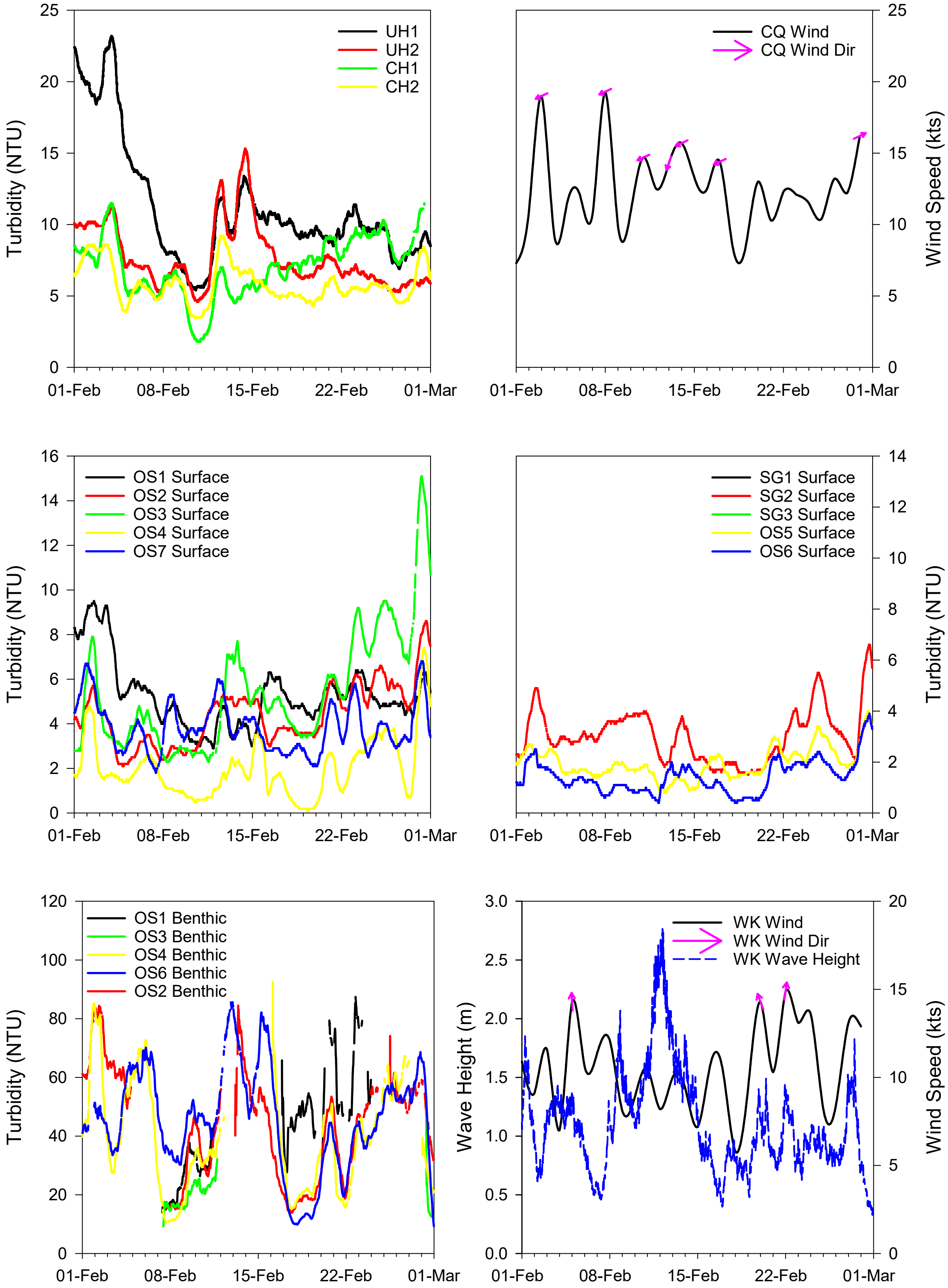


Figure 5 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

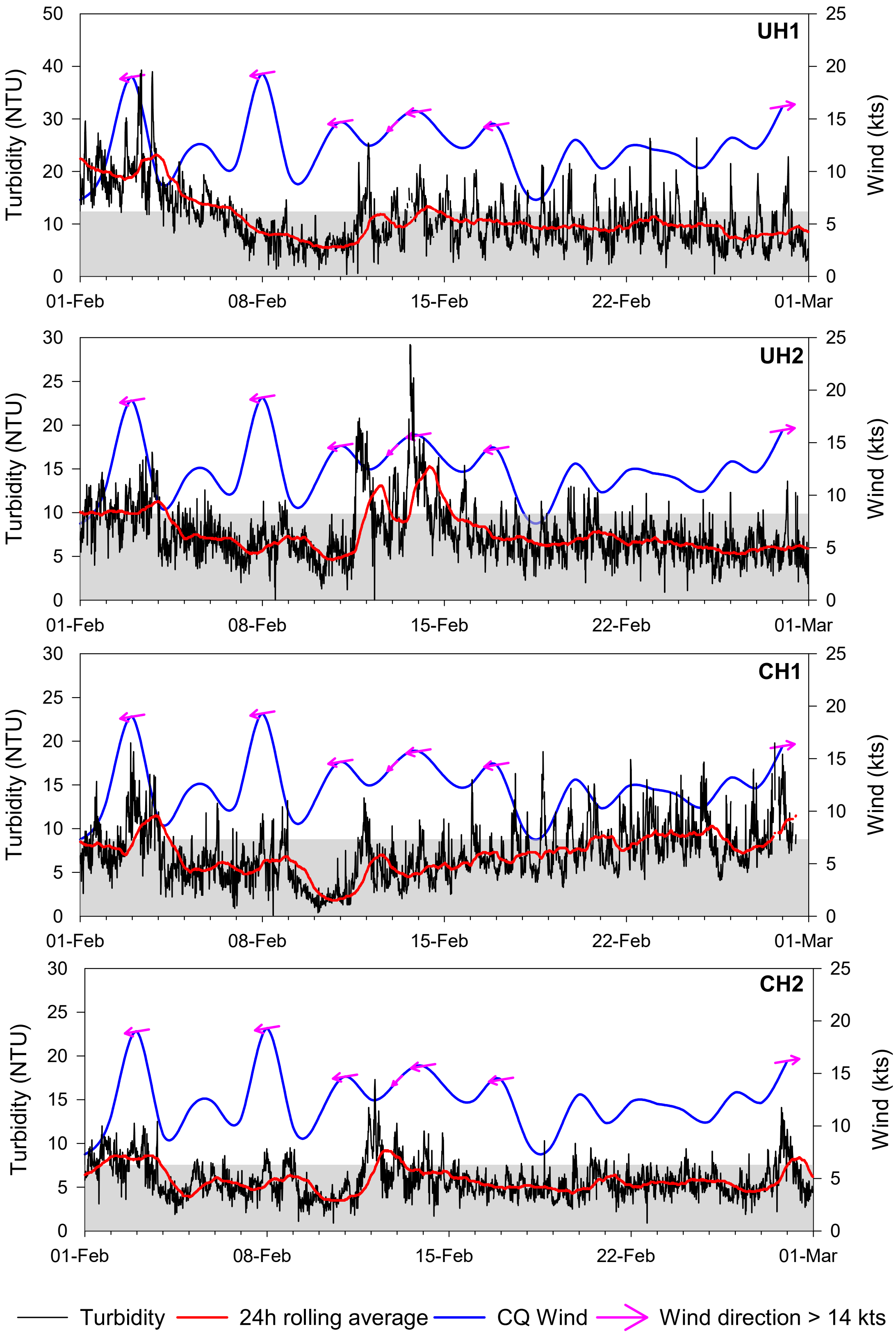


Figure 6 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

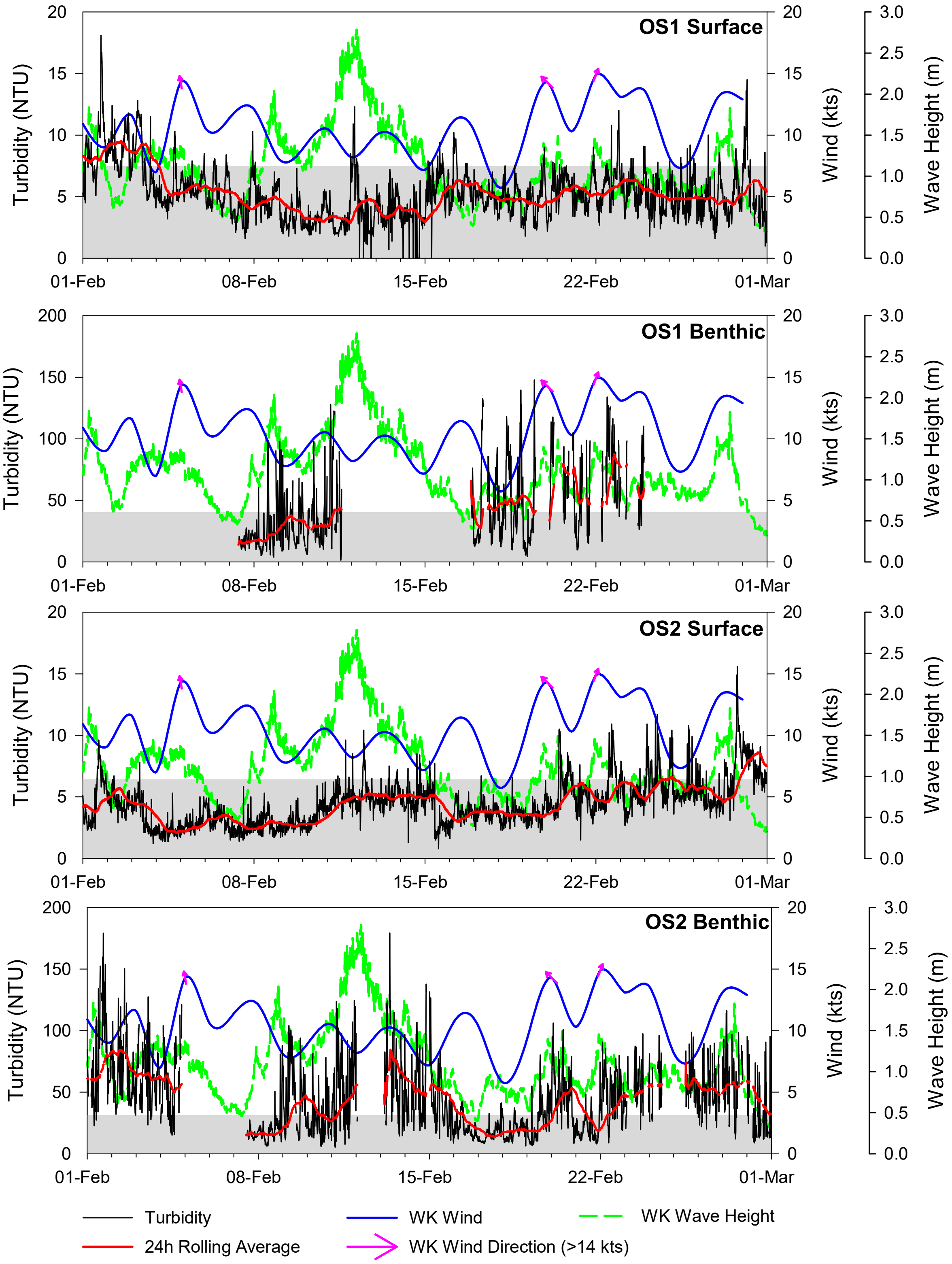


Figure 7 Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

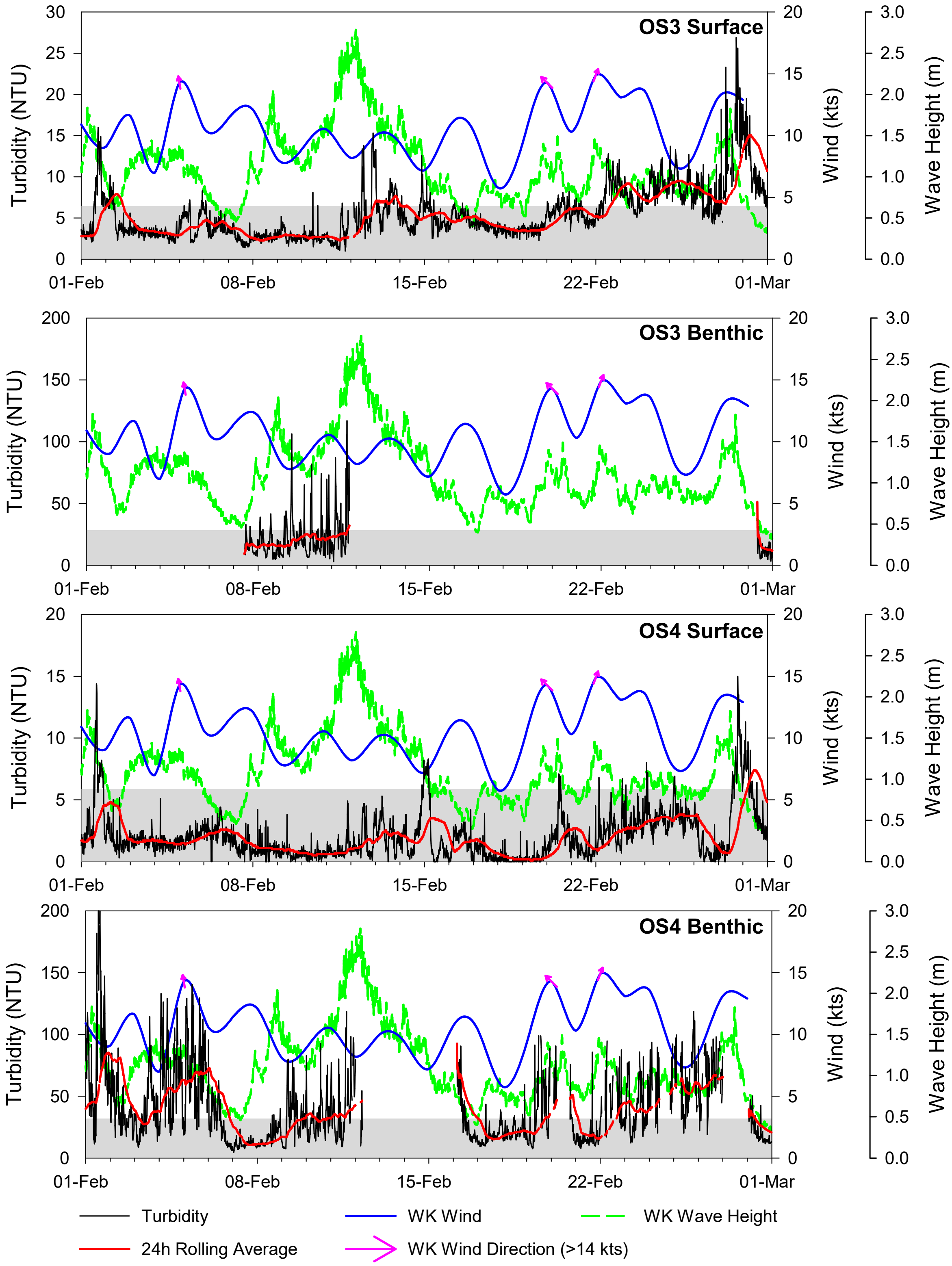


Figure 8 Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

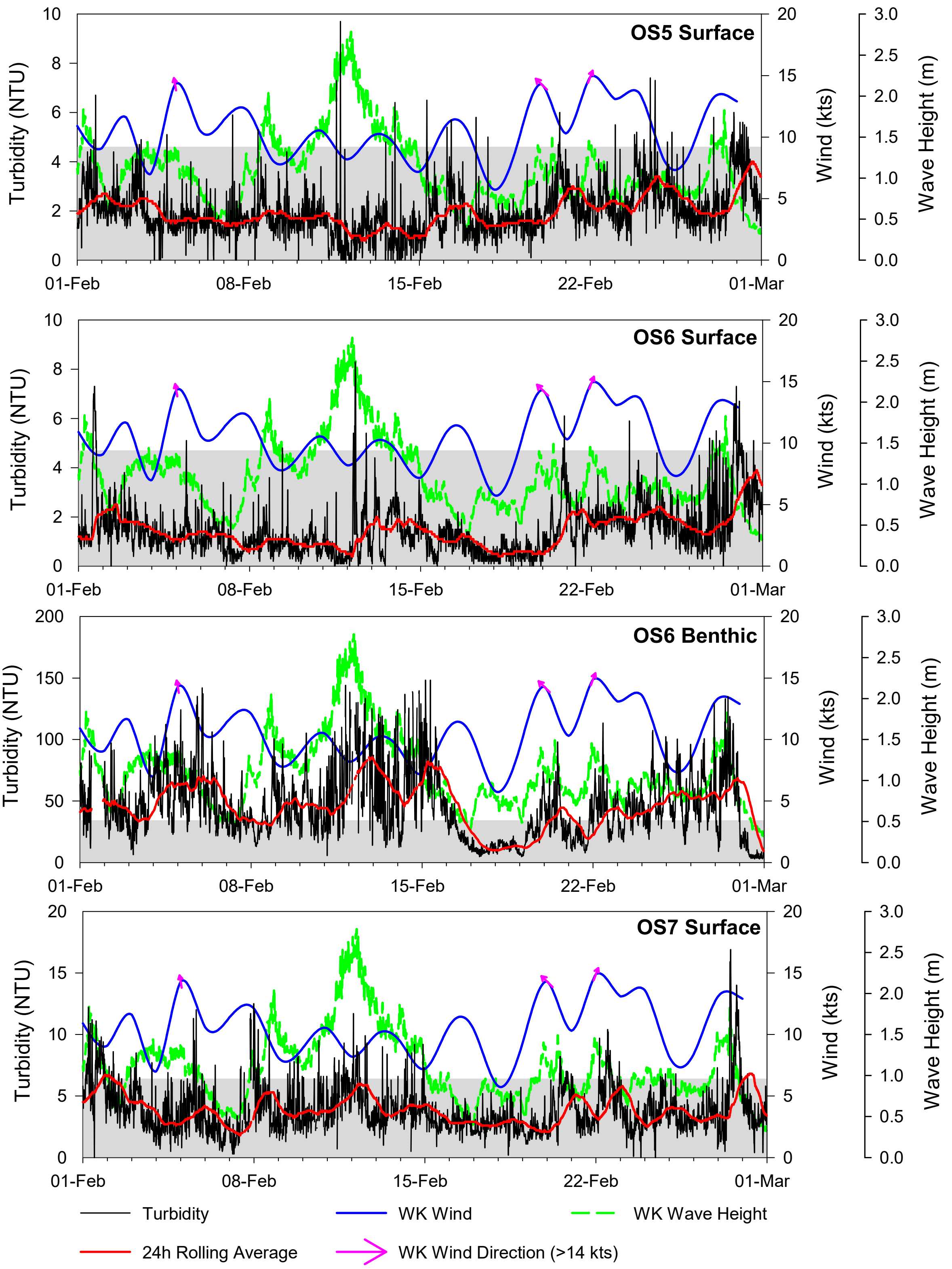


Figure 9 Surface turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

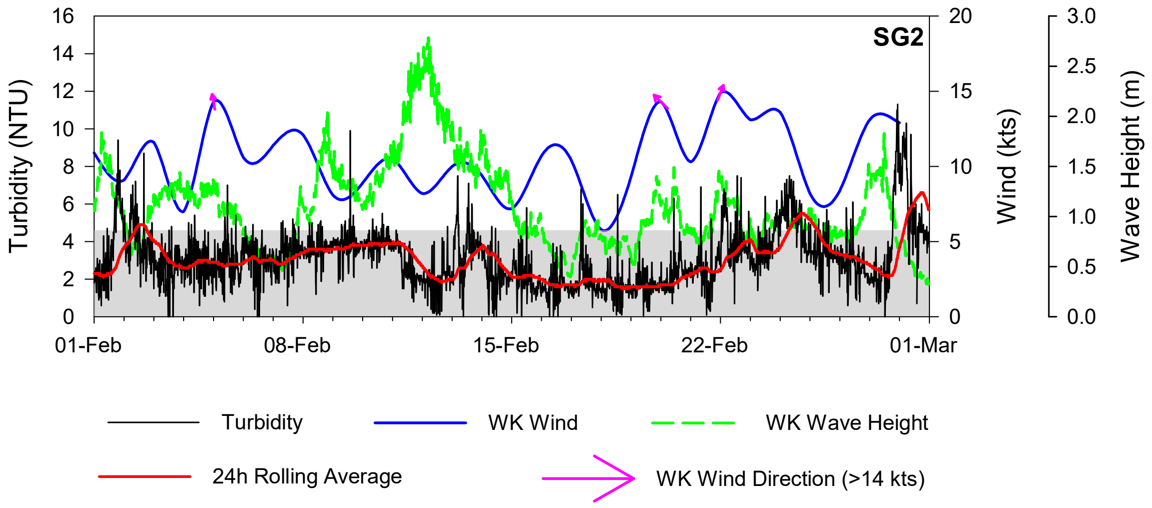


Figure 10 Surface turbidity at spoil ground site SG2b during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

Comparison to Baseline:
Mean surface turbidity and higher order percentile statistics during February were lower than those calculated from the baseline monitoring (Tables 3 and 5, Figures 6 to 10). Post-dredge data acquisition from CH1 had previously indicated elevated turbidity conditions at CH1, however, in a similar manner to the January and December report, mean surface turbidity and higher order percentile statistics from February were below average baseline conditions (Table 3).

3.2.2 Temperature

Ambient air temperatures during February were slightly cooler than in January (Metconnect, 2019), however, cooling was not mirrored within the surface waters that experienced monthly means ranging from 18.6 to 20°C (Table 6) (c.f. 18.1 to 19.9°C in January). Similar to previous observations, the shallower waters of the upper and central harbour displayed the warmest mean temperatures with monthly means of over 19.6°C.

All surface sites displayed a slight period of cooling centred around 8 February, followed by recovery to temperatures similar to those experienced at the beginning of the month. From the 15 February a second phase of cooling was observed at all sites, this time extending through the remainder of the month (Figures 11 and 12). The greatest rate of cooling occurred from 23 February, during which light rainfall was experienced at Cashin Quay. Cloud cover associated with precipitation may have resulted in enhanced cooling as direct solar insolation would have been reduced.

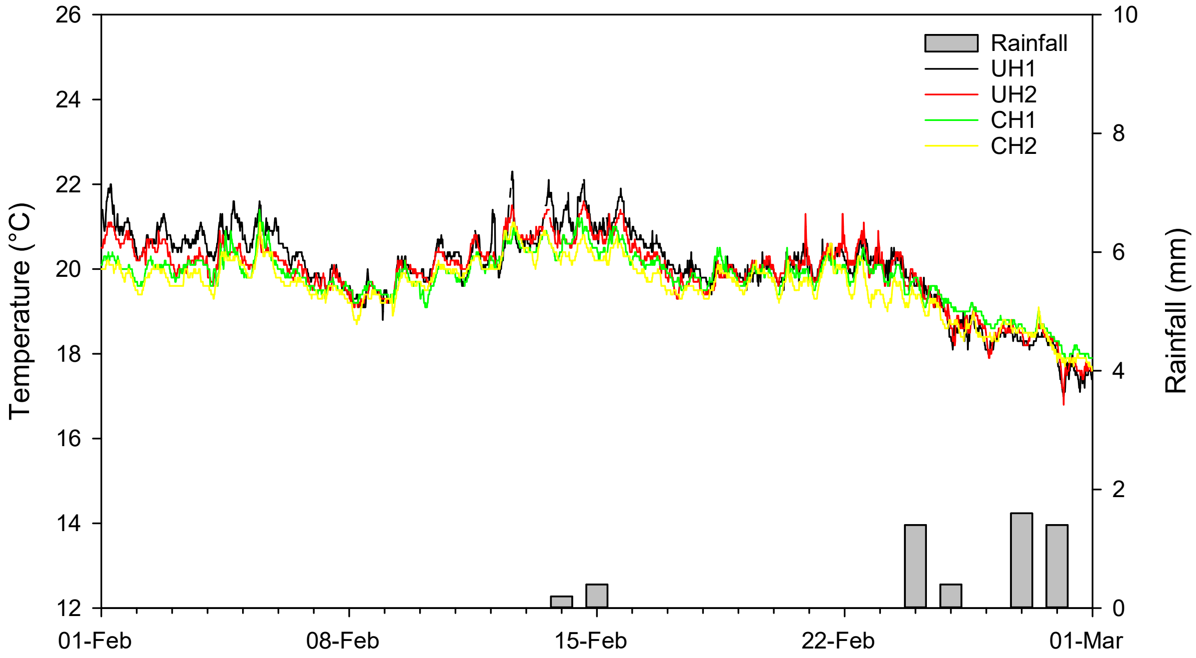
Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the surface temperature datasets. This higher frequency variability was particularly notable within the shallower water sites within Lyttelton Harbour where tidal cycles resulted in the largest changes in water depth.

Benthic temperatures were around 1°C cooler than the overlying surface waters, due to the higher thermal capacity of water providing an insulating effect from warming ambient air temperatures (Table 6). Similar to observations during January, benthic temperatures at OS1 and OS2 were warmer than the more exposed sites at OS3, OS4 and OS6 (Figure 12). This spatial variation was reduced during the final week of February, and a large cooling of benthic waters at OS1 on 14 February was not mirrored at any other benthic location. Semidiurnal variability in benthic water temperatures was also notably greater at OS1 than at the other near-seabed monitoring locations.

Table 6 Mean temperature at inshore, spoil ground and offshore water quality sites during February 2019.
Values are means ± se (n = 2656 to 2688).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	20.0 ± 0.0	–
UH2	19.9 ± 0.0	–
CH1	19.8 ± 0.0	–
CH2	19.6 ± 0.0	–
SG1*	–	–
SG2	18.6 ± 0.0	–
SG3*	–	–
OS1	19.5 ± 0.0	19.1 ± 0.0
OS2	19.2 ± 0.0	18.2 ± 0.0
OS3	18.9 ± 0.0	17.7 ± 0.0
OS4	18.6 ± 0.0	17.2 ± 0.0
OS5	19.0 ± 0.0	–
OS6	18.9 ± 0.0	17.5 ± 0.0
OS7	19.4 ± 0.0	–

**No data available for SG1 and SG3*



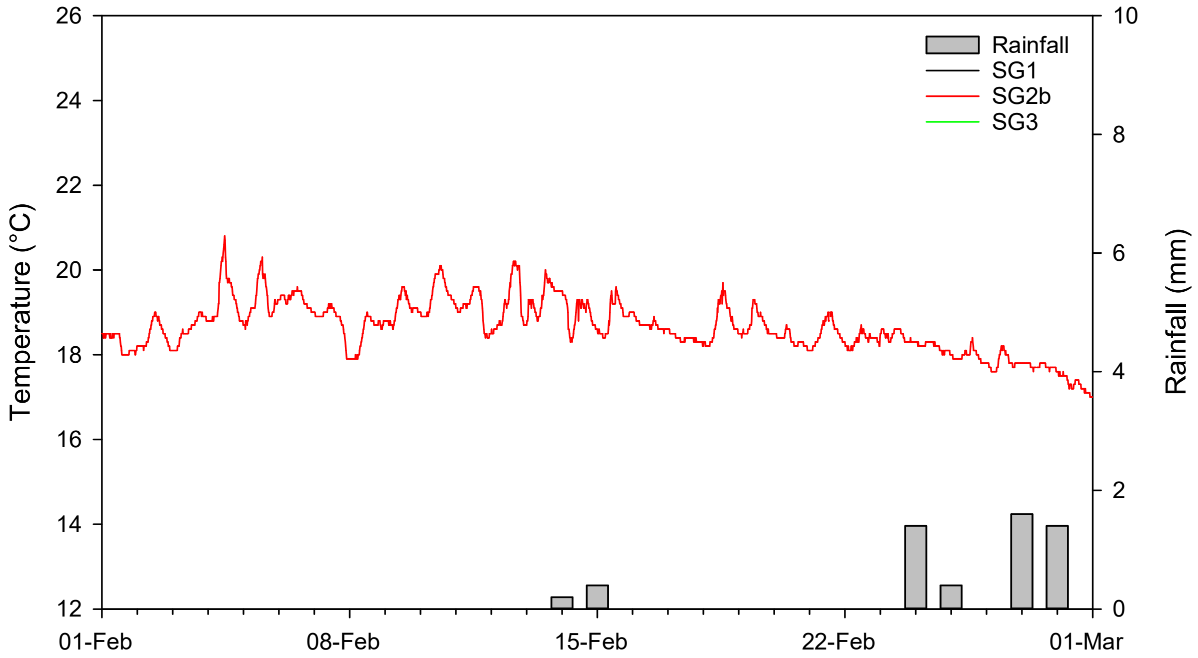
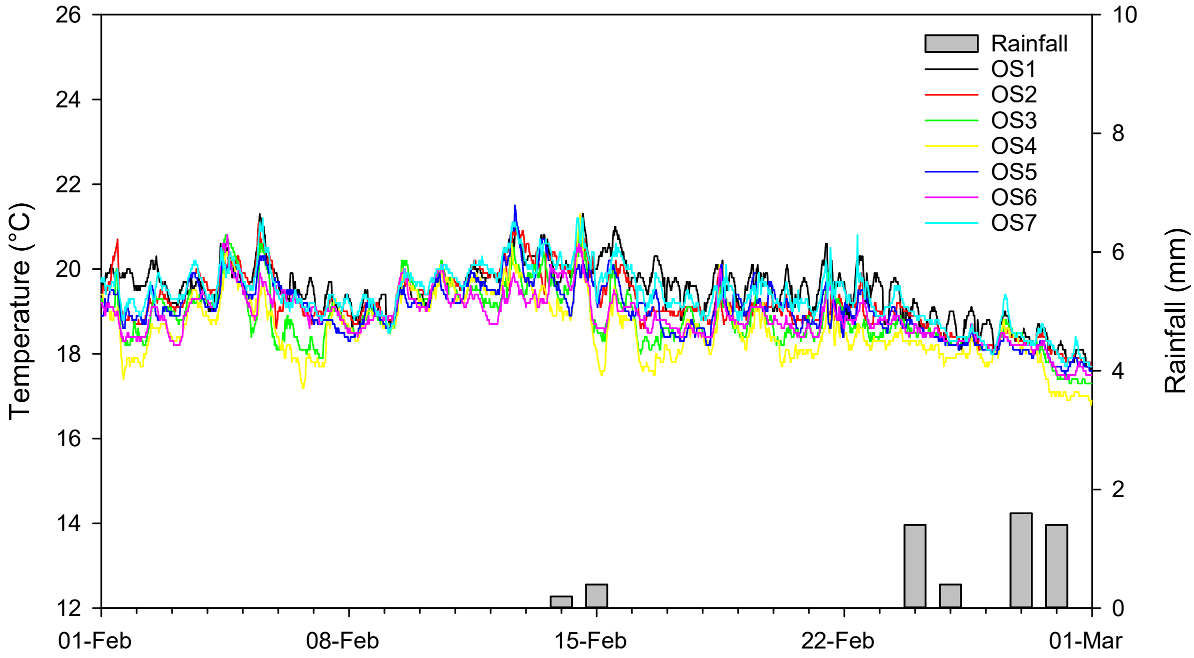


Figure 11 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG2b) water quality sites and rainfall during February 2019.



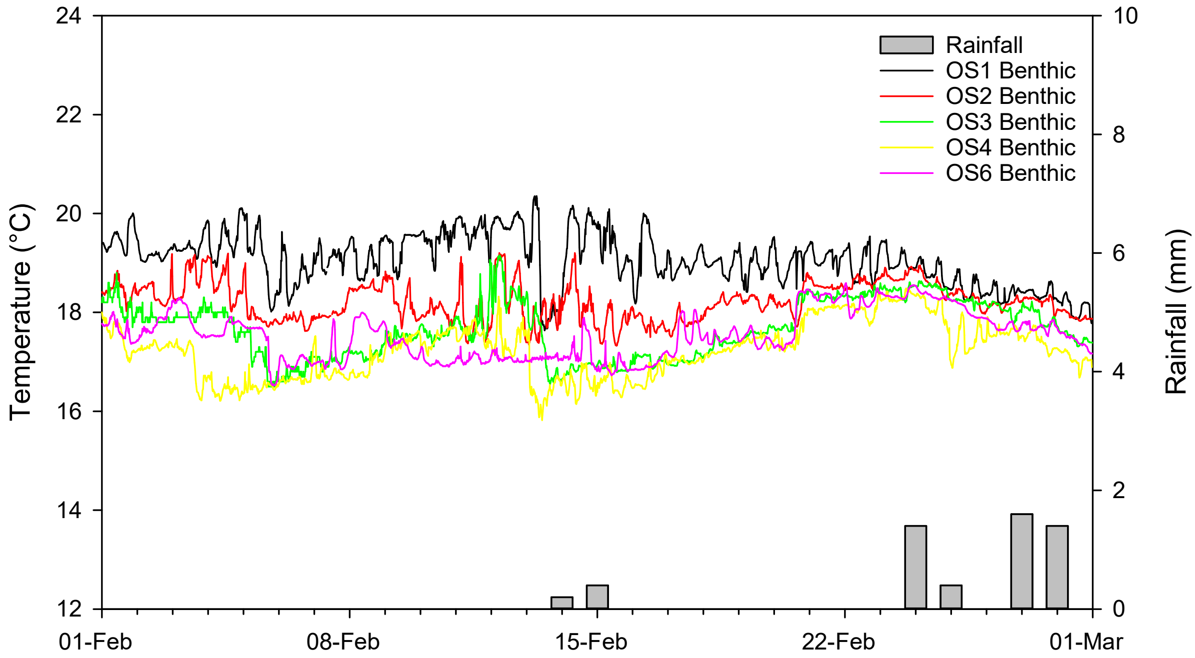


Figure 12 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites during February 2019.

3.2.3 pH

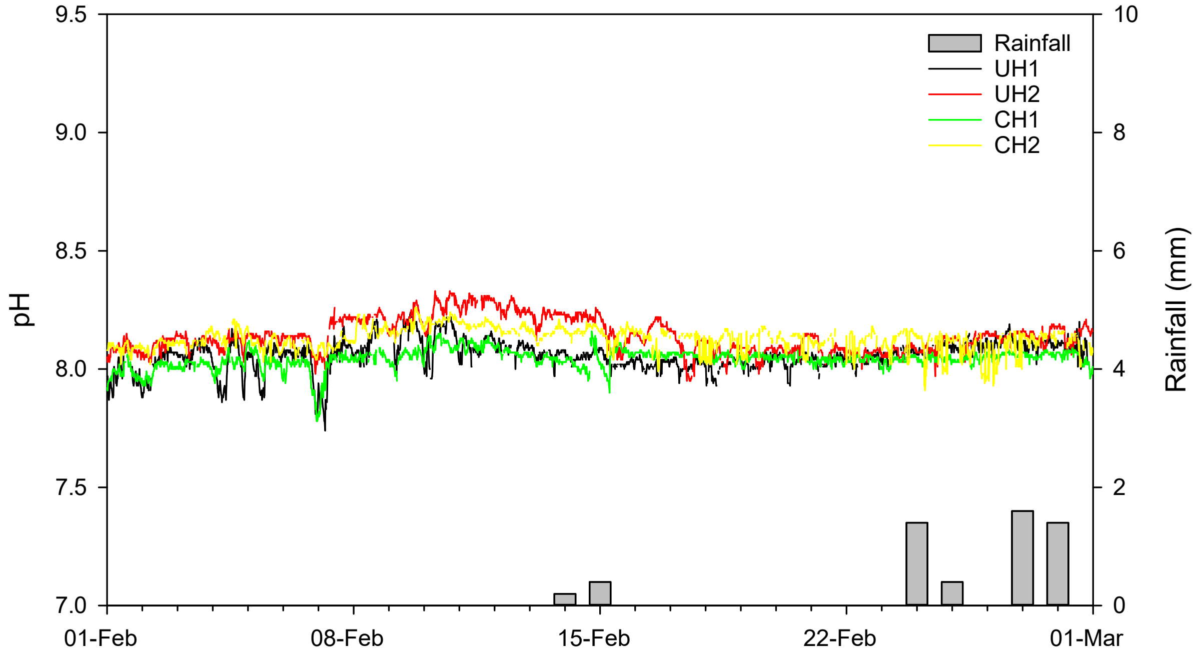
Surface pH data collected during February does not indicate any strong spatial patterns, with monthly means ranging between 8.0 and 8.2 (Table 7). Temporally, surface pH did not appear to display any notable trends (Figures 13 and 14), with minimal rainfall events and Waimakariri outflow that may otherwise have provided a disturbance to the regular pH regime (Figure 2).

The relationship between monthly mean surface and benthic pH was spatially variable, with higher benthic pH at OS1 and OS2, and lower benthic pH at the remaining sites. Within each deployment period, benthic pH has previously been relatively stable. During February, however, benthic pH displayed a sharp decline from 8 to 15 February at sites OS3 and OS6. This drop in pH may be related to elevated benthic turbidity as increased wave activity provided energy sufficient for the resuspension of seafloor sediments (Figure 14).

Table 7 Mean pH at inshore, spoil ground and offshore water quality sites during February 2019. *Values are means ± se (n = 1953 to 2686).*

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

**No data available for SG1 and SG3*



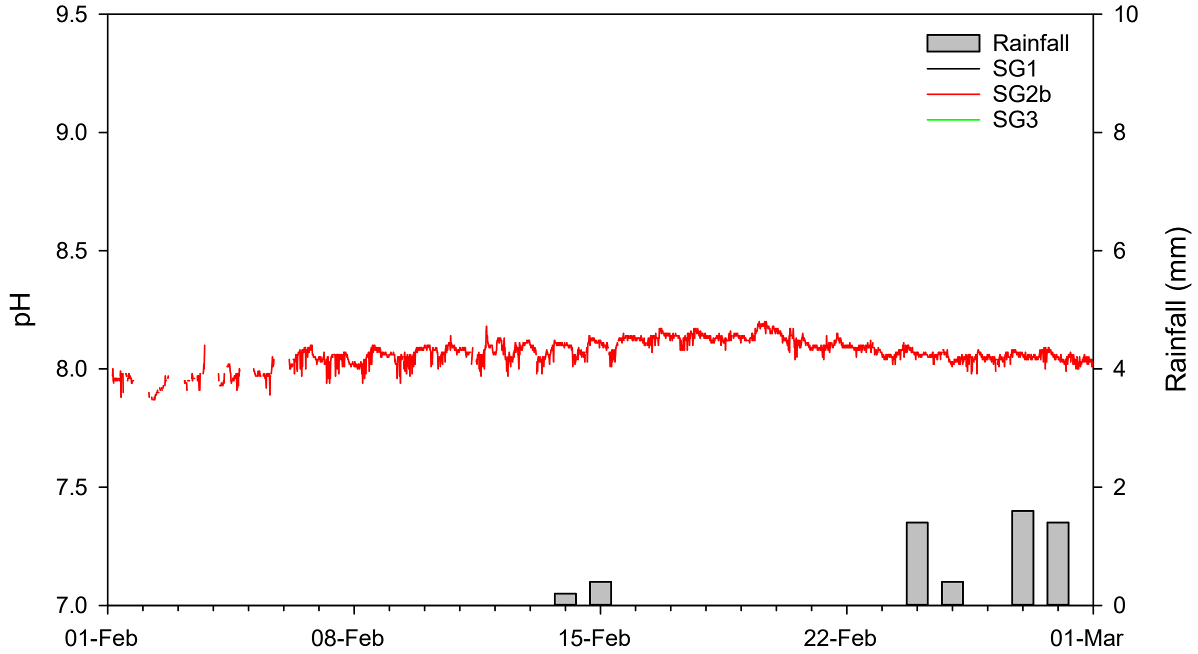


Figure 13 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG2b) water quality sites during February 2019.

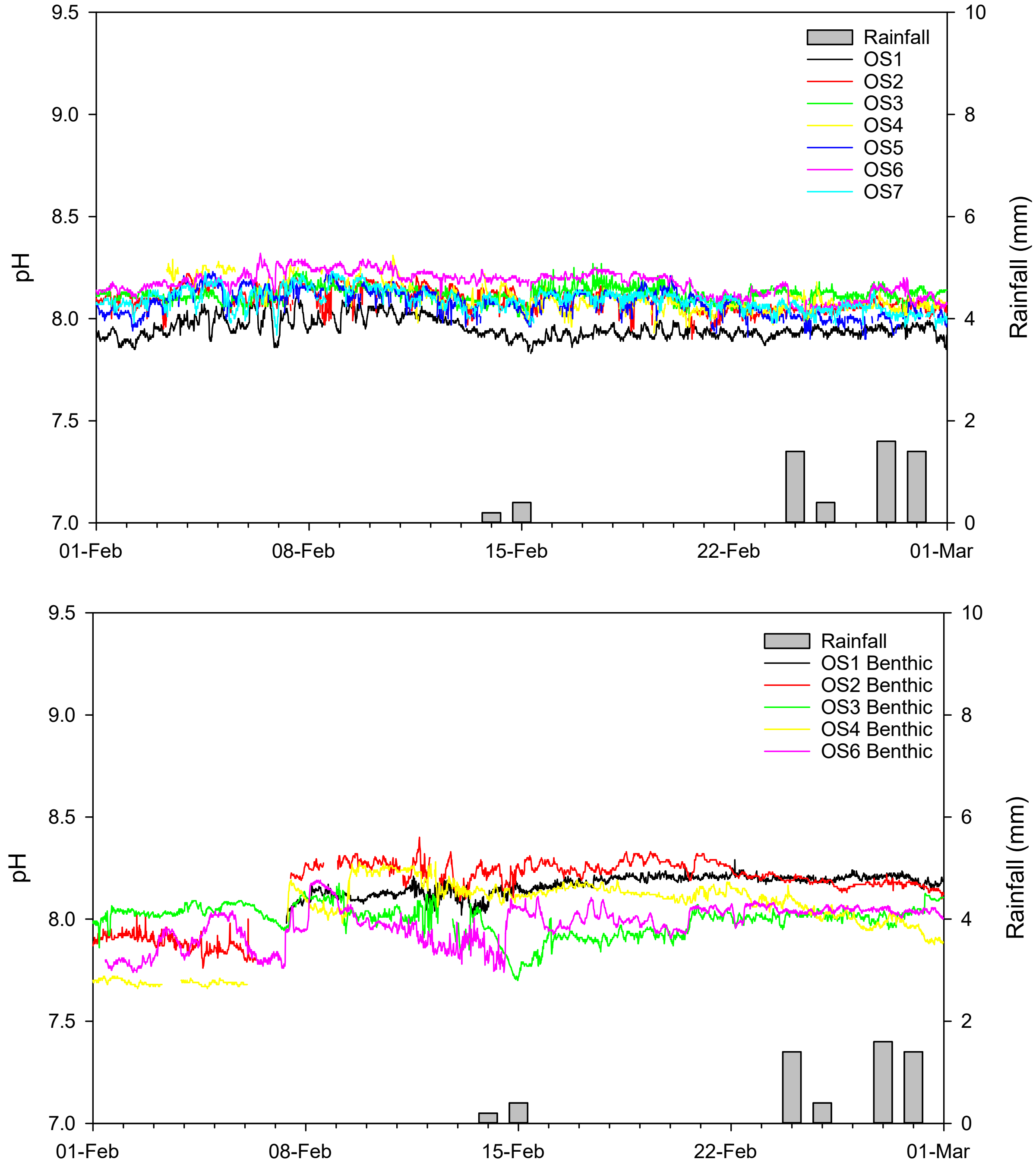


Figure 14 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at offshore water quality sites during February 2019.

3.2.4 Conductivity

Surface conductivity in February ranged from 52.2 mS/cm at OS1 to 54.4 mS/cm at SG2 (Table 8), similar to monthly mean values calculated for January. Within the upper and central harbour, conductivity remained relatively stable throughout February, with little rainfall or Waimakariri outflow that could result in surface freshening recorded at Cashin Quay (Figure 15). Slight decreases in conductivity were recorded at the spoil ground and several nearshore and offshore monitoring sites around 3 and 4 February, however these decreases were of a relatively small amplitude (Figures 15 and 16).

Benthic waters at OS1 to OS3 displayed higher mean monthly conductivity (53.9 to 56.4 mS/cm) than their corresponding surface waters (Table 8), as would be expected within a vertically stable water column. Data recovery from the benthic loggers at OS4 and OS6 was incomplete for the month, which may have resulted in the slightly lower mean conductivity values at the benthos compared to the surface at these locations (Figure 16).

Table 8 Mean conductivity at inshore, spoil ground and offshore water quality sites during February 2019.
Values are means ± se (n = 1505 to 2673).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	54.0 ± 0.0	–
UH2	53.8 ± 0.0	–
CH1	52.7 ± 0.0	–
CH2	53.6 ± 0.0	–
SG1*	–	–
SG2	54.4 ± 0.0	–
SG3*	–	–
OS1	52.2 ± 0.0	52.8 ± 0.0
OS2	53.6 ± 0.0	55.3 ± 0.0
OS3	53.3 ± 0.0	55.8 ± 0.0
OS4	54.0 ± 0.0	53.6 ± 0.0
OS5	54.1 ± 0.0	–
OS6	54.0 ± 0.0	53.5 ± 0.0
OS7	53.4 ± 0.0	–

**No data available for SG1 and SG3*

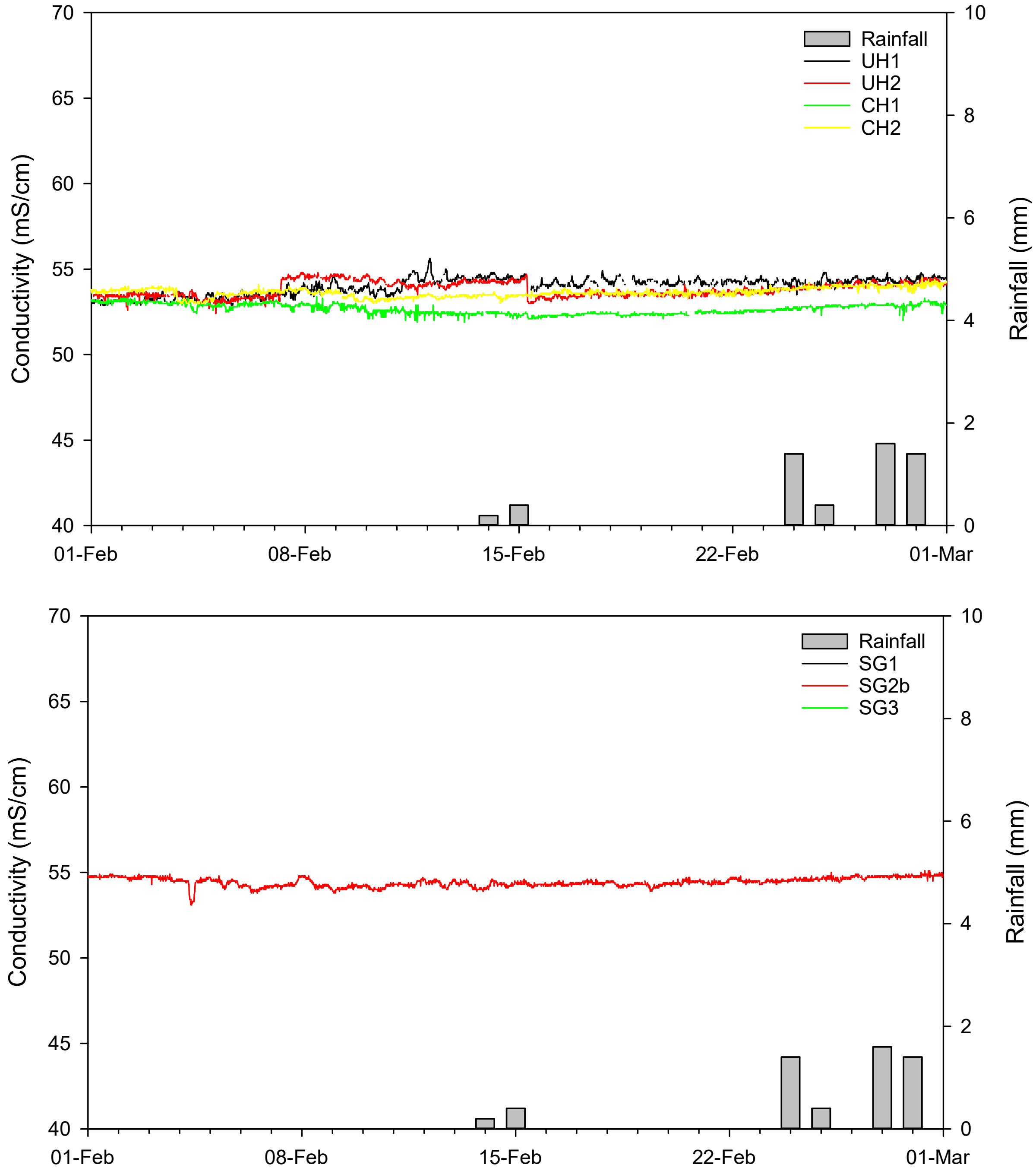


Figure 15 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG2b) water quality sites during February 2019.

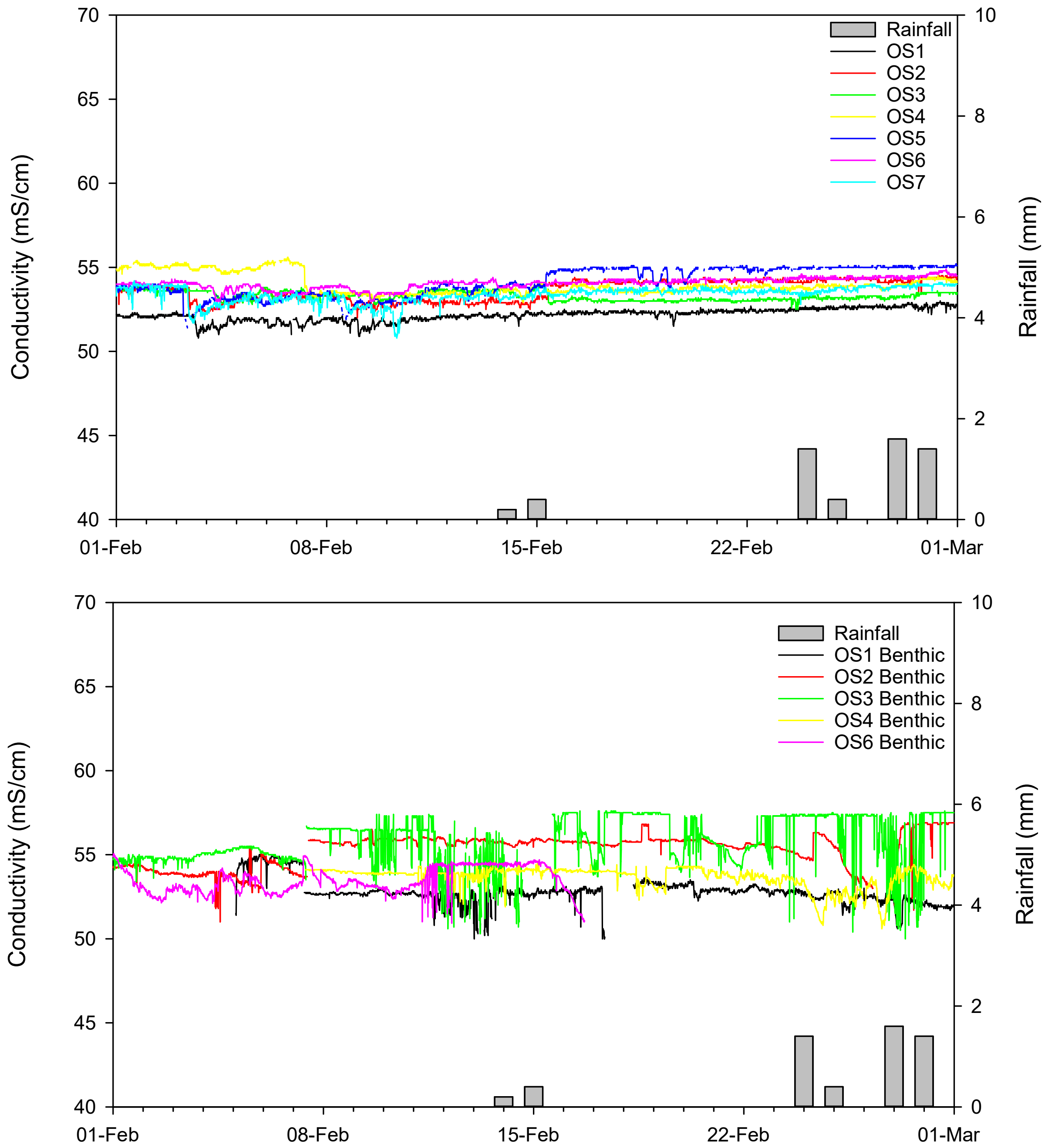


Figure 16 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites during February 2019.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in February were high, ranging from 94% saturation in the upper harbour to 103% saturation at the spoil ground (Table 9). Large fluctuations in DO recorded in the northern inner harbour sites during January continued during the first half of February (Figure 17). This variation was once again greatest at UH1 where concentrations of DO dropped to <40% saturation on 7 February. Despite the lowest DO concentrations being recorded at all inner harbour monitoring locations during this time, there was no apparent increase in turbidity or metocean conditions that could explain such low values (Figure 2, Figure 5). Interestingly, nearshore and offshore sites also displayed a smaller amplitude decline in DO concentration on 7 February (Figures 17 and 18). From 20 February, surface DO concentrations at the offshore and nearshore monitoring sites displayed a slight decline. This reduction may be representative of reduced photosynthesis in the water column as surface turbidity increases (Figures 5, 17 and 18).

As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings ranging from 80 to 92% saturation (Table 9), due to reduced photosynthesis (producing less oxygen) occurring at depth. Temporal variability in benthic DO concentrations was high; greater than that observed within the surface datasets. These variations did not appear to show a strong relationship with offshore metocean and turbidity conditions, however, elevated turbidity around 13 February was associated large declines in benthic DO (Figure 18).

Table 9 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during February 2019.
Values are means ± se (n = 2349 to 2688).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	94 ± 0	–
UH2	98 ± 0	–
CH1	94 ± 0	–
CH2	95 ± 0	–
SG1*	–	–
SG2	103 ± 0	–
SG3*	–	–
OS1	98 ± 0	92 ± 0
OS2	99 ± 0	84 ± 0
OS3	99 ± 0	78 ± 0
OS4	98 ± 0	80 ± 0
OS5	99 ± 0	–
OS6	100 ± 0	81 ± 0
OS7	98 ± 0	–

**No data available for SG1 and SG3*

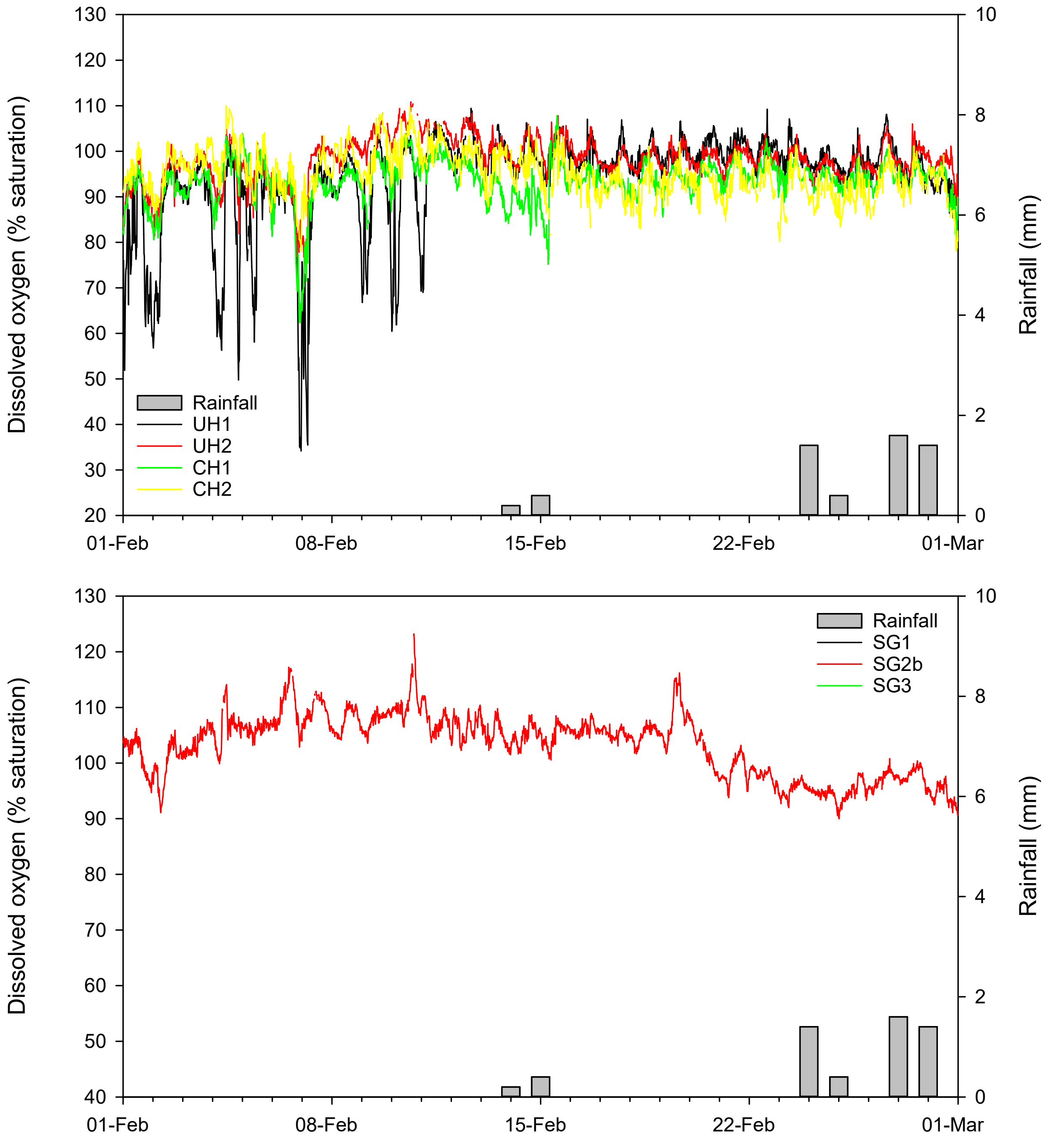


Figure 17 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG2b) water quality sites during February 2019.

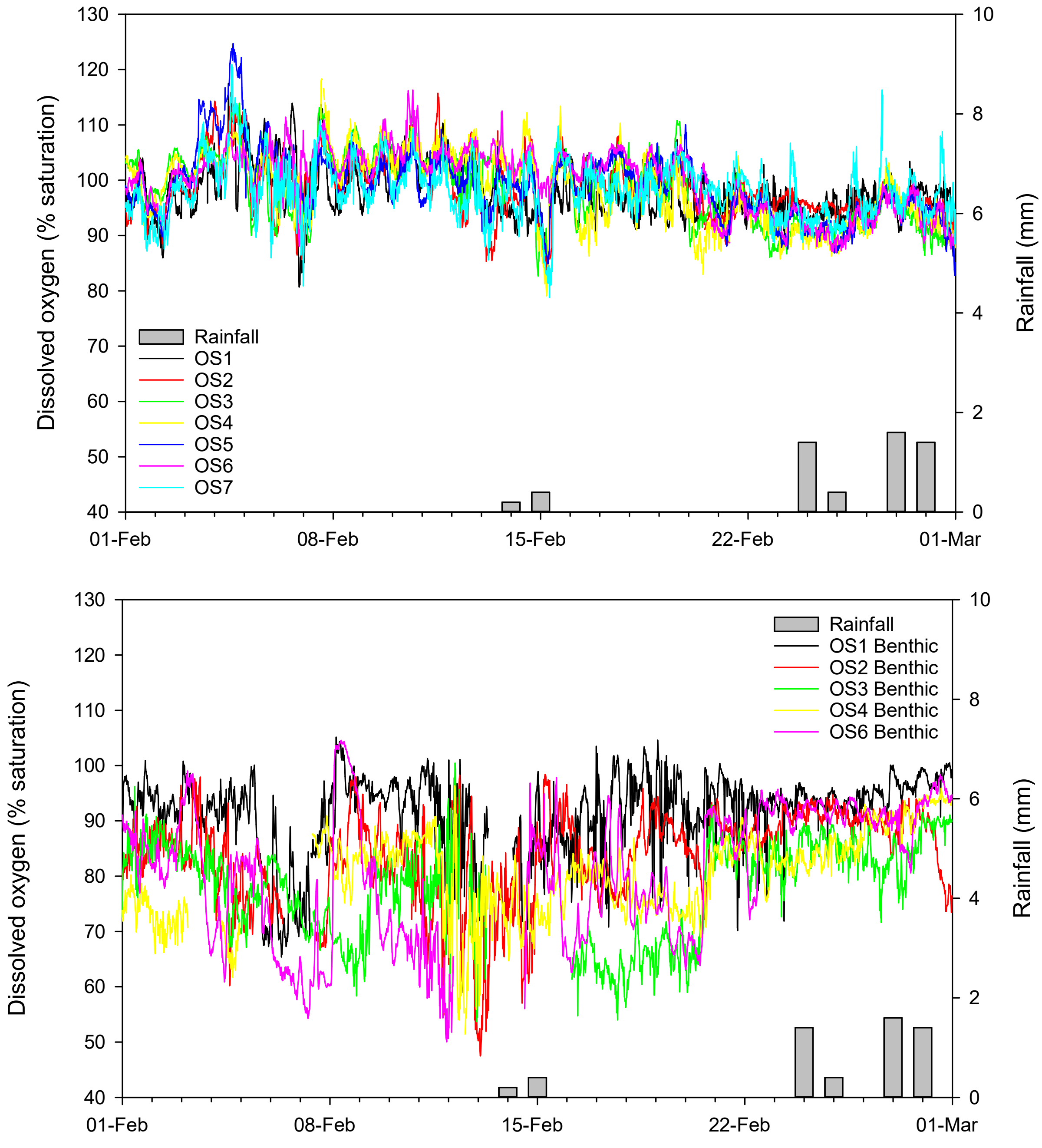


Figure 18 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites during February 2019.

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 11 February 2019. In addition to the previously discussed physicochemical parameters, the light attenuation rate (K_d, the rate at which light or PAR diminishes with depth through the water column) and resultant euphotic depth (the optical depth to which photosynthesis can occur/where light levels are ~1% of those at the surface) were also calculated.

Water samples for the determination of TSS were also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, CH1 and CH2. Further information regarding the specific sampling methodology can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Statistical analyses of the resulting datasets are provided in Tables 10 to 12, with depth profile plots presented in Figures 19 to 21.

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 upper most 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. Interestingly, deeper waters at CH2 displayed slightly warmer temperatures and higher salinity than the surface (Figure 19), with a corresponding decrease in pH and DO concentration. Several sites indicated slightly increased turbidity at the seabed, which would be typically 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 from OS1 indicate the persistence of strong vertical mixing within the water column. Relatively rapid declines in pH and DO concentration were apparent in close proximity to the benthos, however, these changes are likely related to the elevated turbidity induced by sediment resuspension from the seafloor (Figure 20). The remaining nearshore monitoring locations all displayed slightly declining temperature, pH and DO concentration with depth. Surface waters within the harbour (OS1, OS2 and OS7) were slightly fresher than those at OS3 and OS4, however, conductivity at OS2 and OS7 increased with depth and eliminated this spatial variation.

Within the offshore region of the spoil ground, OS5 and OS6, temperature also displayed a steady decline with increasing depth (Figure 21). Surface and mid-depth waters at OS5 were warmer and fresher than the remaining offshore sites, similar to the spatial pattern observed within the nearshore region. Variability within the vertical profiles of pH and DO was high, with subsurface maxima (~10 m) in both parameters recorded at OS6 and SG2. The similarly in pH and DO may be indicative of phytoplankton growth where photosynthesis consumes dissolved carbon dioxide (thus increasing pH) and releases oxygen. Increases in benthic turbidity were once again observed in many of the profiles, as typically experienced during the monitoring program.

As previously observed throughout the baseline and dredge monitoring, the clearest waters were observed within the offshore environment and the spoil ground. Low levels of turbidity and TSS throughout the water column resulted in limited vertical light attenuation and thus the greatest calculations of euphotic depth at these sites (Tables 10 to 12). Euphotic depth was calculated to be 34.2 m at OS6 during the February sampling (Table 12), which was notably higher than that calculated for January. There were no exceedances of WQG for the sub-surface during the February sampling campaign.

Table 10 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the February 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 20 to 28 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	11/02/2019 07:03	Sub-surface	19.9 ± 0.0	8.1 ± 0.0	53.9 ± 0.0	104 ± 0	2.9 ± 0.1	3	0.6 ± 0.0	7.3
		Whole column	19.9 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	103 ± 0	3.1 ± 0.1	–		
UH2	11/02/2019 07:31	Sub-surface	19.9 ± 0.0	8.2 ± 0.0	53.7 ± 0.0	105 ± 0	3.1 ± 0.1	6	0.8 ± 0.0	5.8
		Whole column	19.9 ± 0.0	8.2 ± 0.0	53.7 ± 0.0	105 ± 0	3.7 ± 0.2	–		
UH3	11/02/2019 07:17	Sub-surface	20.3 ± 0.0	8.1 ± 0.0	54.5 ± 0.0	102 ± 0	4.8 ± 0.1	7	1.1 ± 0.1	4.3
		Whole column	20.3 ± 0.0	8.1 ± 0.0	54.5 ± 0.0	101 ± 0	5.3 ± 0.2	–		
CH1	11/02/2019 07:47	Sub-surface	19.8 ± 0.0	8.2 ± 0.0	54.0 ± 0.0	103 ± 0	3.7 ± 0.1	5	0.8 ± 0.0	5.4
		Whole column	19.8 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	103 ± 0	6.7 ± 1.7	–		
CH2	11/02/2019 08:02	Sub-surface	19.7 ± 0.0	8.2 ± 0.0	53.6 ± 0.0	107 ± 0	1.4 ± 0.0	3	0.5 ± 0.0	8.4
		Whole column	19.7 ± 0.0	8.2 ± 0.0	53.5 ± 0.2	106 ± 0	2.3 ± 0.3	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	–

Table 11 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the February 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 33 to 42 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS1	11/02/2019 08:43	Sub-surface	19.5 ± 0.0	8.2 ± 0.0	53.7 ± 0.0	108 ± 0	1.0 ± 0.0	3	0.5 ± 0.0	8.4
		Mid	19.4 ± 0.0	8.2 ± 0.0	53.8 ± 0.0	107 ± 0	0.9 ± 0.1	4		
		Benthos	19.2 ± 0.0	8.2 ± 0.0	53.9 ± 0.0	105 ± 2	30 ± 13	4		
		Whole column	19.4 ± 0.0	8.2 ± 0.0	53.8 ± 0.0	107 ± 0	6.1 ± 2.9	–		
OS2	11/02/2019 12:33	Sub-surface	19.7 ± 0.0	8.2 ± 0.0	53.8 ± 0.0	107 ± 1	1.1 ± 0.1	<3	0.5 ± 0.0	8.6
		Mid	19.0 ± 0.0	8.2 ± 0.0	53.9 ± 0.0	103 ± 1	1.8 ± 0.1	5		
		Benthos	17.8 ± 0.0	8.1 ± 0.0	54.2 ± 0.0	85 ± 1	3.8 ± 0.4	24		
		Whole column	18.9 ± 0.1	8.2 ± 0.0	54.0 ± 0.0	101 ± 2	2.1 ± 0.2	–		
OS3	11/02/2019 11:42	Sub-surface	19.4 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	108 ± 0	0.3 ± 0.1	5	0.4 ± 0.1	11.6
		Mid	19.0 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	108 ± 0	<1 ± 0.0	<3		
		Benthos	17.9 ± 0.2	8.1 ± 0.0	54.3 ± 0.0	95 ± 2	10 ± 3	<3		
		Whole column	18.8 ± 0.1	8.2 ± 0.0	54.2 ± 0.0	105 ± 1	1.9 ± 0.7	–		
OS4	11/02/2019 11:12	Sub-surface	19.4 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	107 ± 0	<1 ± 0.0	<3	0.5 ± 0.0	8.9
		Mid	18.6 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	103 ± 1	2.1 ± 0.5	6		
		Benthos	17.6 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	92 ± 1	4.6 ± 0.6	8		
		Whole column	18.6 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	102 ± 1	1.8 ± 0.3	-		
OS7	11/02/2019 08:20	Sub-surface	19.5 ± 0.0	8.2 ± 0.0	53.6 ± 0.0	106 ± 0	1.4 ± 0.0	3	0.7 ± 0.0	6.6
		Mid	19.5 ± 0.0	8.2 ± 0.0	53.7 ± 0.0	105 ± 1	1.8 ± 0.2	4		
		Benthos	18.4 ± 0.1	8.1 ± 0.0	54.1 ± 0.0	83 ± 1	12 ± 3	4		
		Whole column	19.2 ± 0.1	8.2 ± 0.0	53.8 ± 0.0	100 ± 2	4.0 ± 0.9	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 12 Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during the February 2019 sampling event.
Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 42 to 48 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	11/02/2019 09:11	Sub-surface	19.6 ± 0.0	8.2 ± 0.0	53.9 ± 0.0	110 ± 0	<1 ± 0.0	<3	0.4 ± 0.0	12.3
		Mid	19.4 ± 0.0	8.2 ± 0.0	53.9 ± 0.0	108 ± 0	0.2 ± 0.0	3		
		Benthos	17.4 ± 0.1	8.0 ± 0.0	54.3 ± 0.0	81 ± 3	29 ± 16	4		
		Whole column	19.1 ± 0.1	8.2 ± 0.0	54.0 ± 0.0	103 ± 2	4.5 ± 2.6	–		
OS6	11/02/2019 12:10	Sub-surface	19.2 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	107 ± 0	<1 ± 0.0	<3	0.1 ± 0.0	34.2
		Mid	18.6 ± 0.1	8.2 ± 0.0	54.2 ± 0.0	109 ± 1	<1 ± 0.0	<3		
		Benthos	17.5 ± 0.1	8.1 ± 0.0	54.4 ± 0.0	99 ± 4	0.6 ± 0.2	<3		
		Whole column	18.6 ± 0.1	8.2 ± 0.0	54.2 ± 0.0	108 ± 1	<1 ± 0.0	–		
SG1	11/02/2019 09:39	Sub-surface	18.6 ± 0.0	8.2 ± 0.0	54.0 ± 0.0	110 ± 0	<1 ± 0.0	<3	0.2 ± 0.0	24.3
		Mid	18.2 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	106 ± 0	<1 ± 0.0	<3		
		Benthos	17.2 ± 0.1	8.2 ± 0.0	54.4 ± 0.0	104 ± 1	1.2 ± 0.7	7		
		Whole column	18.1 ± 0.1	8.2 ± 0.0	53.9 ± 0.3	107 ± 0	<1 ± 0.0	–		
SG2b	11/02/2019 10:20	Sub-surface	19.0 ± 0.0	8.2 ± 0.0	54.1 ± 0.0	108 ± 0	<1 ± 0.0	3	0.3 ± 0.0	18.4
		Mid	18.1 ± 0.1	8.2 ± 0.0	54.3 ± 0.0	111 ± 1	<1 ± 0.0	<3		
		Benthos	17.0 ± 0.0	8.0 ± 0.0	54.4 ± 0.0	87 ± 3	25 ± 13	7		
		Whole column	18.1 ± 0.1	8.2 ± 0.0	54.2 ± 0.0	103 ± 1	3.1 ± 2.1	–		
SG3	11/02/2019 10:44	Sub-surface	18.5 ± 0.0	8.2 ± 0.0	54.2 ± 0.0	108 ± 0	<1 ± 0.0	<3	0.2 ± 0.0	22.0
		Mid	18.0 ± 0.1	8.2 ± 0.0	54.3 ± 0.0	109 ± 0	<1 ± 0.0	3		
		Benthos	16.8 ± 0.1	8.1 ± 0.0	54.4 ± 0.0	91 ± 3	7.4 ± 3.4	<3		
		Whole column	17.9 ± 0.1	8.2 ± 0.0	54.3 ± 0.0	105 ± 1	0.4 ± 0.6	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

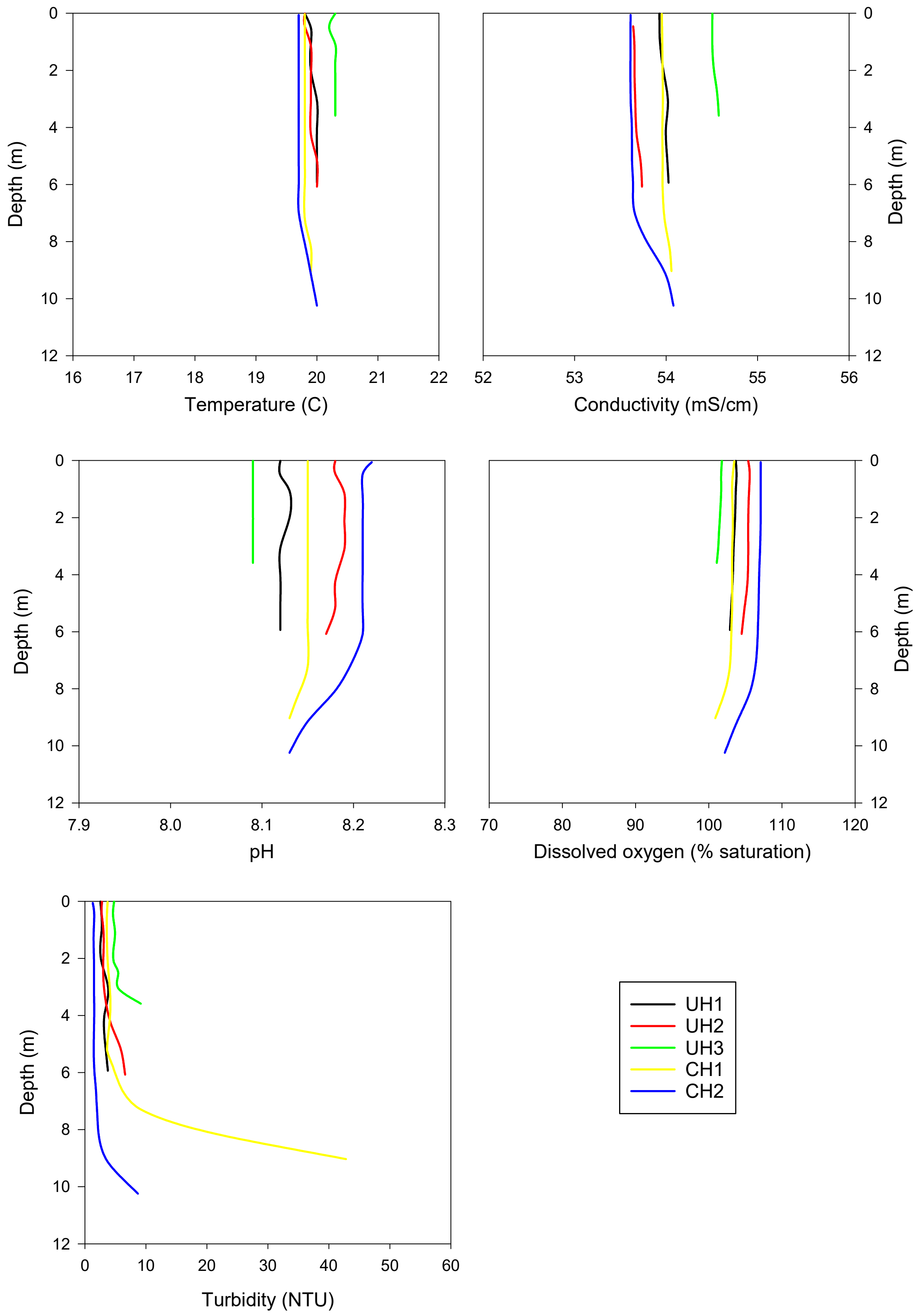


Figure 19 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 11 February 2019.

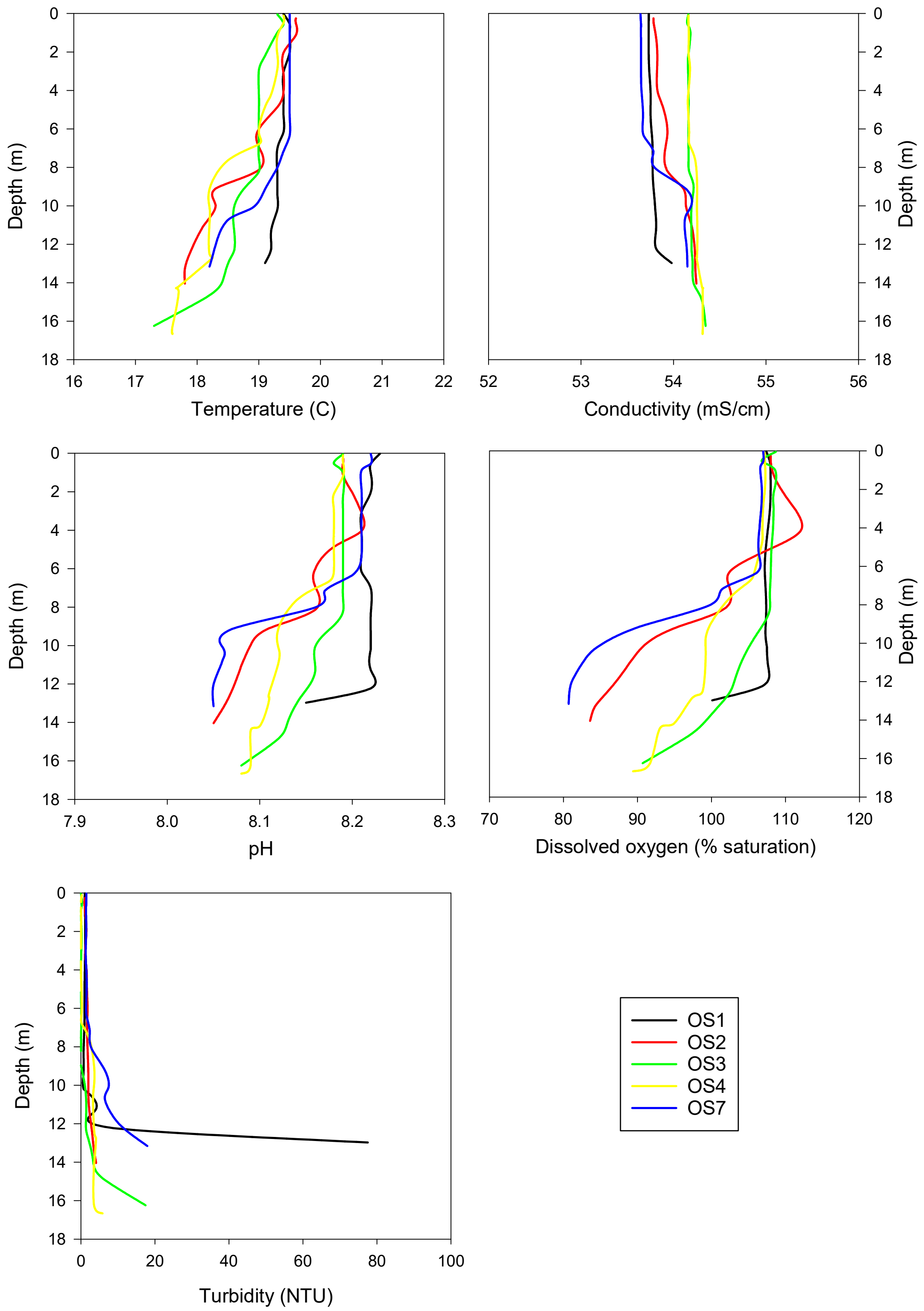


Figure 20 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 11 February 2019.

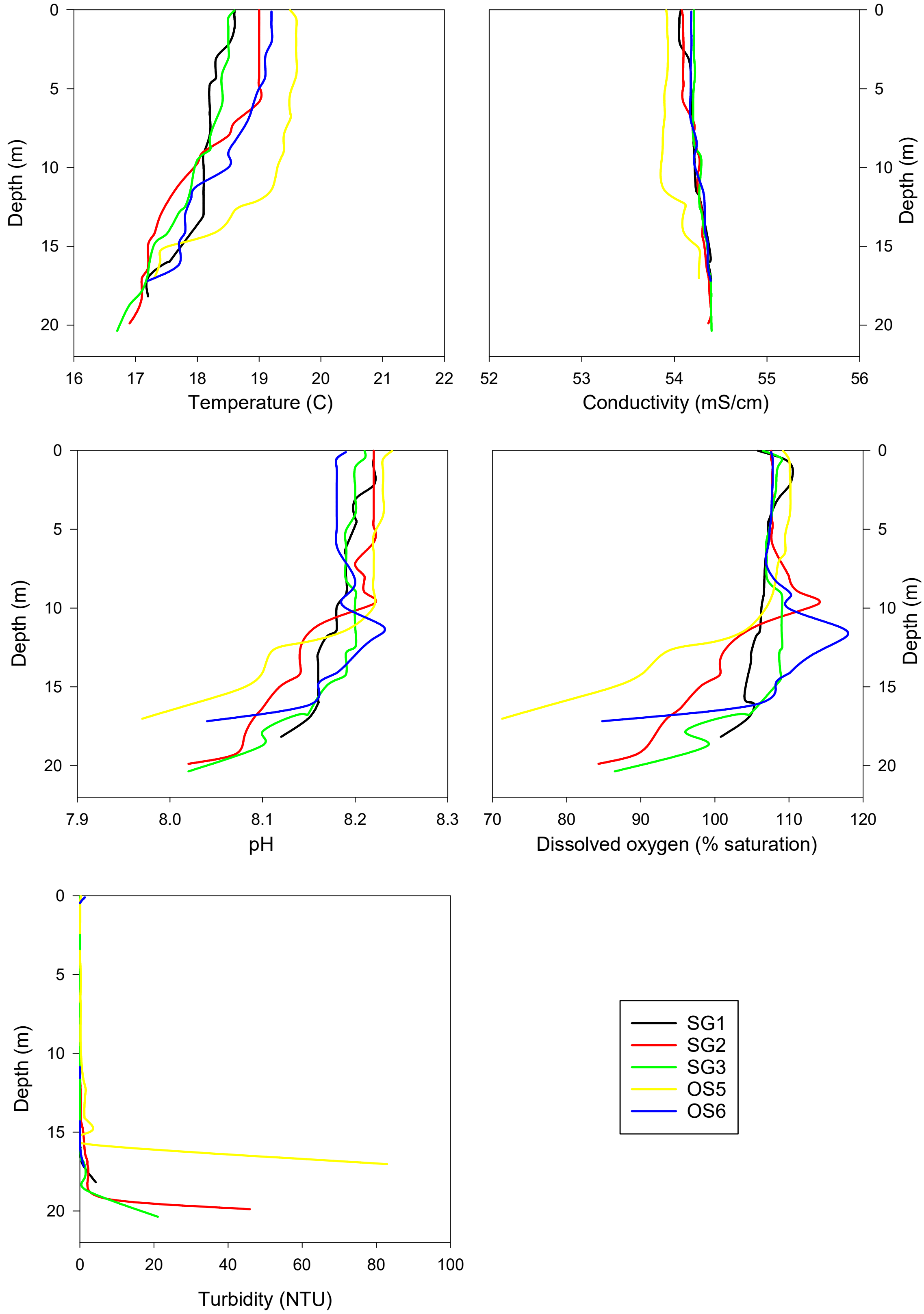


Figure 21 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 11 February 2019.

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 13, with the collected data from benthic and VBCC sensors presented in Figure 22. Data from the logger exchange date (7 February) 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 13). This range is wider than that observed during January, particularly within the minimum recorded values, however, the February mean TDP of 41,754 mmol/m^2/day was similar to that recorded during January (41,606 mmol/m^2/day).

Increases in ambient PAR, as recorded at the Vision base, on 3 February resulted in increases in BPAR at both sites. Despite the deeper water depth, the greatest values in BPAR were recorded at OS2, which is likely a reflection of the higher surface turbidity experienced at OS3 at this time (Figure 22). The greatest benthic light intensities, however, were recorded on the 10 and 11 February at OS2 (19.13 mmol/m^2/day) and OS3 (47.28 mmol/m^2/day), respectively. As commonly observed throughout the monitoring program, maximum BPAR values were associated with high levels of incoming ambient PAR, and low levels of surface turbidity.

For the remainder of the month, surface turbidity at both sites increased, therefore low BPAR values were recorded by the benthic sensors. Three days of elevated BPAR were recorded on the 17 to 19 February at OS2, yet these daily values remained below 15 mmol/m^2/day. Greater levels of surface turbidity at OS3 prevented any similar peaks in BPAR at this location (Figure 22).

Table 13 Total Daily PAR (TDP) statistics during February 2019.
Values are means ± se (n = 27 to 28). Note data from the BPAR exchange day on 7 February were not utilized in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m^2/day)		
		Mean ± se	Median	Range
Base	-	41,754 ± 1,709	41,900	13,200 – 53,800
OS2	17	3.7 ± 0.9	1.3	<0.01 – 19
OS3	14	3.1 ± 1.9	<0.01	<0.01 – 47

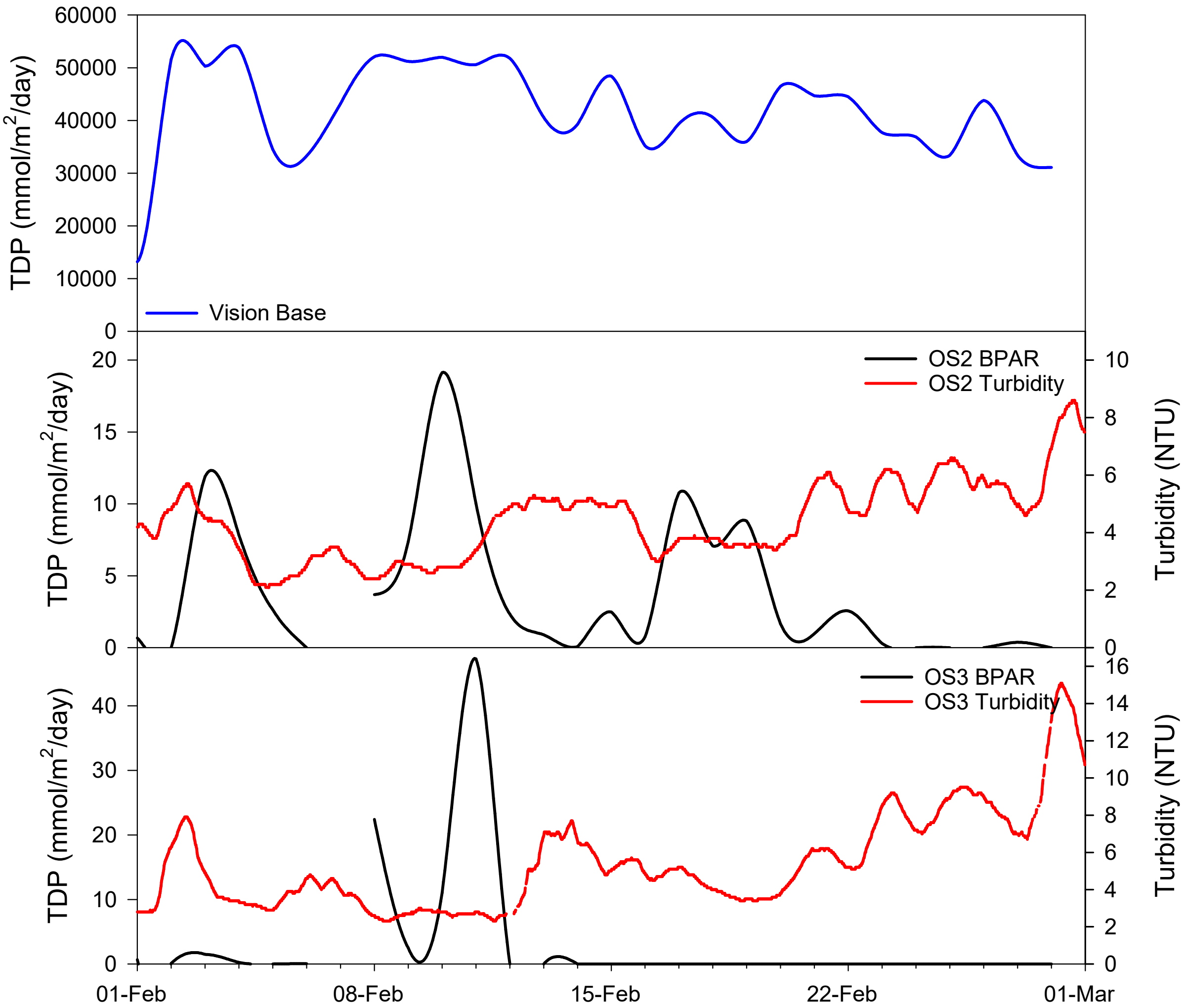


Figure 22 Total daily BPAR at OS2 and OS3 during February 2019 compared to ambient PAR and corresponding surface turbidity.
Note data from the BPAR exchange day on 7 February were not utilized in plots or statistics.

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 remained relatively stable during the first 10 days of the month, with slight sediment erosion following a decline in surface turbidity on 4 February. A large shift in seabed dynamics was then observed on between 10 and 12 February where sediment deposition resulted in a bed level increase of 146 mm (Figure 23). Offshore winds during this time remained relatively low (~10 knots), however, significant wave heights measured at the spoil ground increased to a maximum of 2.76 m on 12 February (Figure 3). Surface turbidity at OS2 also increased during this period of time, indicating that suspended material was transported towards OS2 where it settled out of the water column onto the seabed. A rapid bed level drop of 57.4 mm was observed between 13 and 15 February as wave heights and surface turbidity declined and the system reached a new equilibrium. This stability extended to 19 February and was followed by a slight decline to 21 February as offshore winds increased. For the remainder of the month, bed level increased once more, resulting in a net bed level change of 124 mm (Figure 23, Table 14).

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 23). Unfortunately, altimeter data to 7 February were unavailable due to the frame likely lying on its side. When available, bed level indicated relatively stable conditions to 24 February despite a slight disparity between the absolute heights of the dual sensors. Following a slight period of sedimentation between 24 and 25 February this difference between altimeters was reduced and bed level stabilised once more for the remainder of the month (Figure 23). From the data available, net bed level at UH3 increased by 16 mm from 7 to 28 February (Table 14).

Table 14 Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 during February 2019.

Site	February 2019 Net bed level change (mm)
OS2	+124
UH3	+16

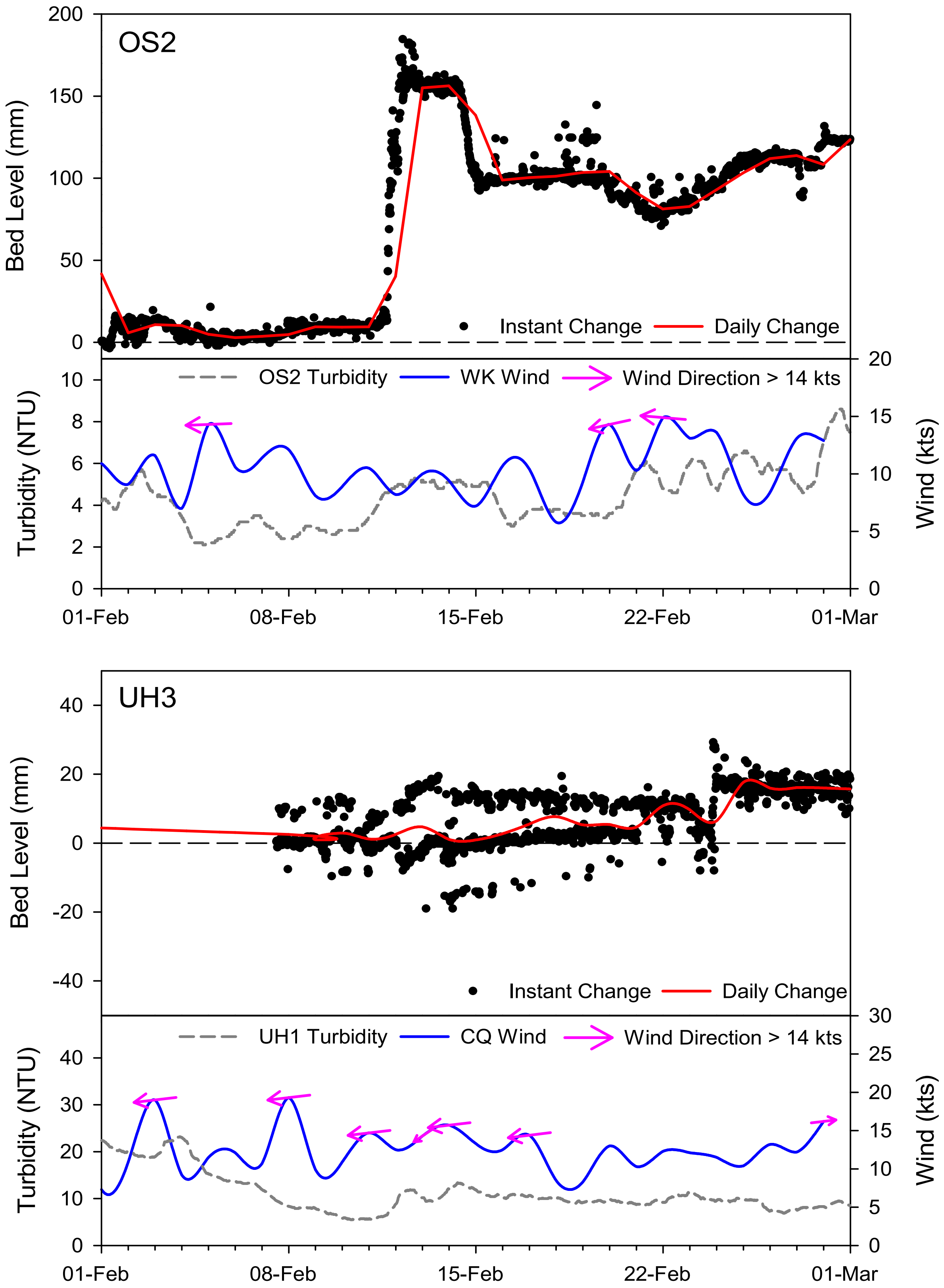


Figure 23 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during February 2019 compared to ambient surface turbidity (24 hour rolling average) wind speed and direction.

Note: Arrows indicate the direction of travel for winds greater than 14 knots. UH3 data from 7 February onwards due to prior underwater frame dislodgement.

3.6 Water Samples

Discrete water sampling was conducted on 11 February 2019, in conjunction with vertical physicochemical profiling through the water column. Quality assurance/quality control (QA/QC) procedures included a duplicate water sample collected at one site, in addition to a laboratory and field blank for each parameter. Further details on the specific sampling methodology can be found within the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Laboratory results associated with VE QA/QC procedures are presented in Table 22 of the appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during February 2019 displayed a similar spatial pattern to previous months, with higher concentrations reported in the shallower upper and central harbour sites decreasing further offshore (Table 15, Figure 24). The water quality guideline (WQG) for total phosphorous (30 µg/L) was not exceeded at any sites during the month. Elevated dissolved reactive phosphorous concentrations reported during January had generally declined, with exceedances of the 5 µg/L WQG at only UH3 and CH1 (Table 15). Spatial variations in dissolved reactive phosphorous displayed no particular pattern, as commonly observed with dissolved analytes.

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 13 to 16 µg/L; lower than those recorded during the January sampling. In a similar manner to dissolved reactive phosphorous, the applicable WQG (15 µg/L) for total ammonia was only exceeded UH3 and CH1. Nitrogen oxides concentrations at many sites were above LOR, with elevated concentrations of 34 and 45 µg/L reported at UH1 and OS7. These high concentrations may be a result of sample contamination as nitrogen oxide concentration in the duplicate sample was below LOR (Table 22). Chlorophyll *a* concentrations ranged from 0.5 µg/L at the spoil ground to 4.8 µg/L at OS2. Exceedances of the 4 µg/L WQG were recorded at UH3, OS2 and OS7 (Table 15).

Table 15 Concentrations of nutrients and chlorophyll *a* at monitoring sites during February 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	20	1.1	<300	<200	15	34	2.6
UH2	12	2.9	<300	<200	13	<1	2.5
UH3	28	8.4	<300	<200	16	2.7	4.5
CH1	18	6.1	<300	<200	16	1.5	2.5
CH2	11	2.0	<300	<200	13	<1	2.1
OS1	21	3.2	<300	<200	13	1.9	2.4
OS2	16	4.5	<300	<200	13	2.9	4.8
OS3	6	2.9	<300	<200	13	1.7	1.6
OS4	9	3.9	<300	<200	13	<1	1.4
OS5	8	2.8	<300	<200	15	2.7	1.8
OS6	7	2.4	<300	<200	13	<1	1.2
OS7	13	3.4	<300	<200	13	45	4.7
SG1	5	<1	<300	<200	15	4.4	1.3
SG2	<4	<1	<300	<200	13	<1	0.6
SG3	13	<1	<300	<200	15	<1	0.5
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

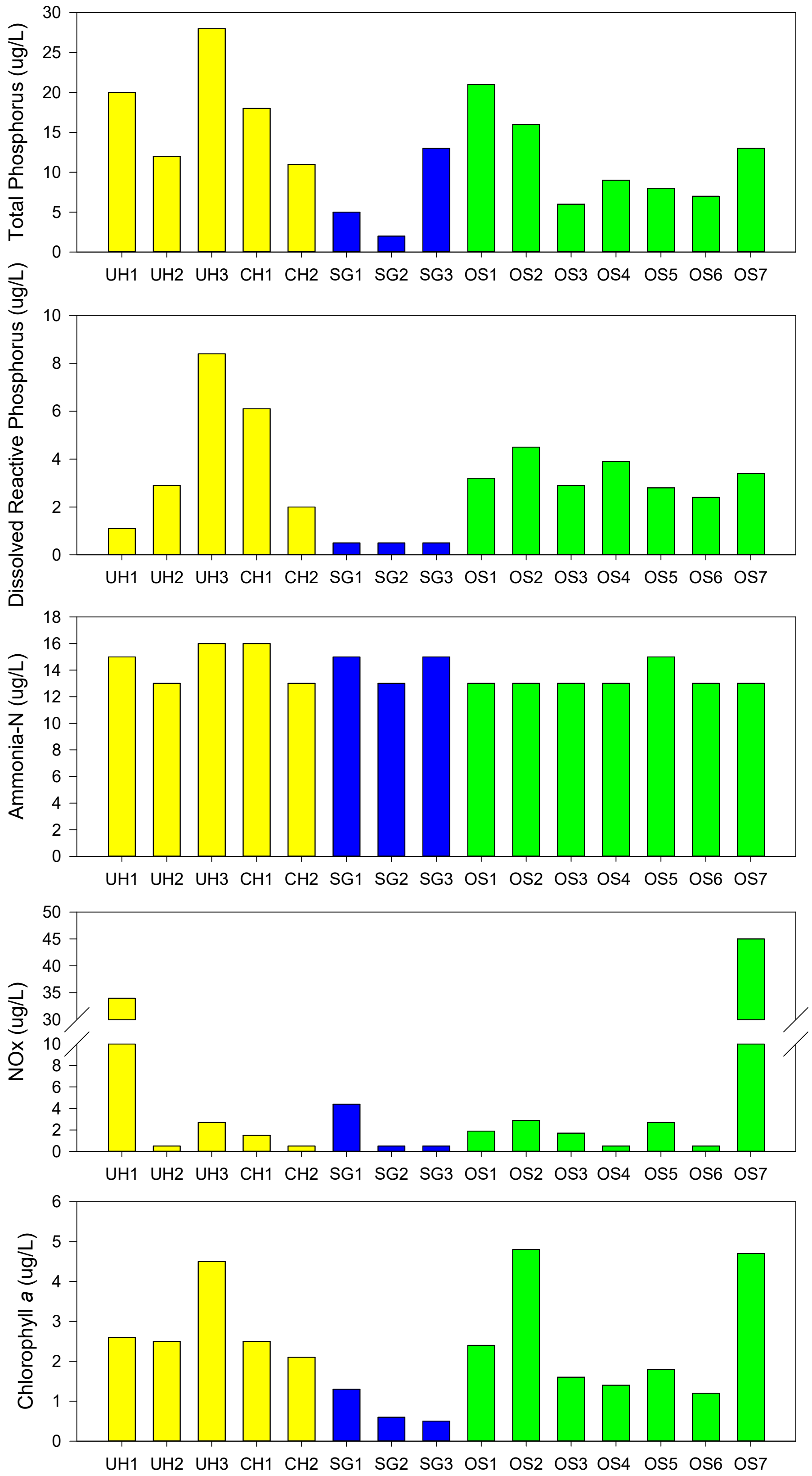


Figure 24 Nutrient and chlorophyll *a* concentrations at monitoring sites during February 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were < LOR.*

3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (LOR) at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), cobalt (<0.6 µg/L), lead (<1 µg/L), mercury (<0.08 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5.3 µg/L) and zinc (<4.2 µg/L). Total copper concentrations were above LOR at UH3, OS5 and SG1, with the WQG (1.3 µg/L) being slightly exceeded at the spoil ground site SG1 (Tables 16 to 18). Low concentrations of total copper were reported within the field blank, which may be an indication of sample contamination as copper is a very ubiquitous metal (Table 22). However, dissolved copper concentrations were all below LOR.

Total aluminium concentrations are generally 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, with occasional exceptions at spoil ground sites. During the February sampling, exceedances were recorded at all inshore and nearshore monitoring sites, reflecting a similar pattern as during January. Concentrations of the more bioavailable dissolved fraction were below LOR (12 µg/L) at all sites except UH1 (Tables 16 to 18, Figures 25 to 26). However, duplicate samples from UH1 indicated dissolved concentrations also below LOR (Table 22), suggesting that the original reading may be a result of sample contamination.

Of the remaining metals analysed that have assigned WQGs, no further exceedances were reported during the February 2019 water quality sampling campaign (Tables 16 to 18).

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. During February, concentrations of total iron were largely reduced (except at OS2 where concentrations slightly increased) from values reported during the January sampling event. Similar to patterns in aluminum, dissolved concentrations of iron were once again low (<16 µg/L) indicating that iron was predominantly present in the particulate phase, and thus not readily available for biological uptake (Tables 16 to 18).

Total and dissolved manganese concentrations were above LOR (<1 µg/L) at all monitoring sites during February. 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 25).

Consistent with previous monitoring reports, molybdenum concentrations during February displayed little spatial variation across the inshore and offshore monitoring network (Figure 26). Given the similarity between the dissolved and total metal concentrations, the majority of the molybdenum present appeared to be in the dissolved phase (Tables 16 to 18 and Figure 26). 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 26).

Table 16 Total and dissolved metal concentrations at inshore monitoring sites during February 2019. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	28	<12	<12	<12	<12	24
	Total	75	79	197	108	80	
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	<1	<1	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	1.4	1.1	<1.1	1.2	
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	<1.1	1.3	<1.1	<1.1	
Iron	Dissolved	16	<4	5	<4	<4	-
	Total	89	107	280	181	136	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	4.2	2.5	8.3	3.1	2.2	-
	Total	5.3	5.8	14.5	7.4	4.2	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11.4	11.6	11.6	11.4	11.6	-
	Total	12.2	11.6	12.1	11.6	12.1	
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	1.9	1.9	2	1.9	1.9	100
	Total	1.8	1.9	2.4	2.2	2.1	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 17 Total and dissolved metal concentrations at offshore monitoring sites during February 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	54	42	27	38	38	27	52	
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	<1	<1	<1	<1	1	1.1	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.4	<1.1	1.4	<1.1	1.3	1.1	<1.1	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	1.3	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	112	124	45	51	32	38	66	
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	1.7	1.7	1.2	1.5	1.5	1.1	1.7	-
	Total	5.1	3.2	2.5	2.5	2.6	2.9	4.1	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	12.6	11.6	11.7	11.7	11.5	11.5	11.4	-
	Total	11.7	12.1	12.1	12	12.1	12.1	11.6	
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	1.7	2.1	1.8	1.9	1.9	1.5	100
	Total	1.9	2.1	2.4	2.0	1.6	2.0	2.1	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 18 Total and dissolved metal concentrations at spoil ground monitoring sites during February 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	21	<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	1.1	1.2	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	1.3	1.3	
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	1.4	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	-
	Total	21	11.6	7.2	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.1	1.1	1.1	-
	Total	3.0	2.3	1.8	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11.8	11.9	11.9	-
	Total	12.3	11.7	12.3	
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	1.8	1.9	2.1	100
	Total	1.7	1.9	2.0	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

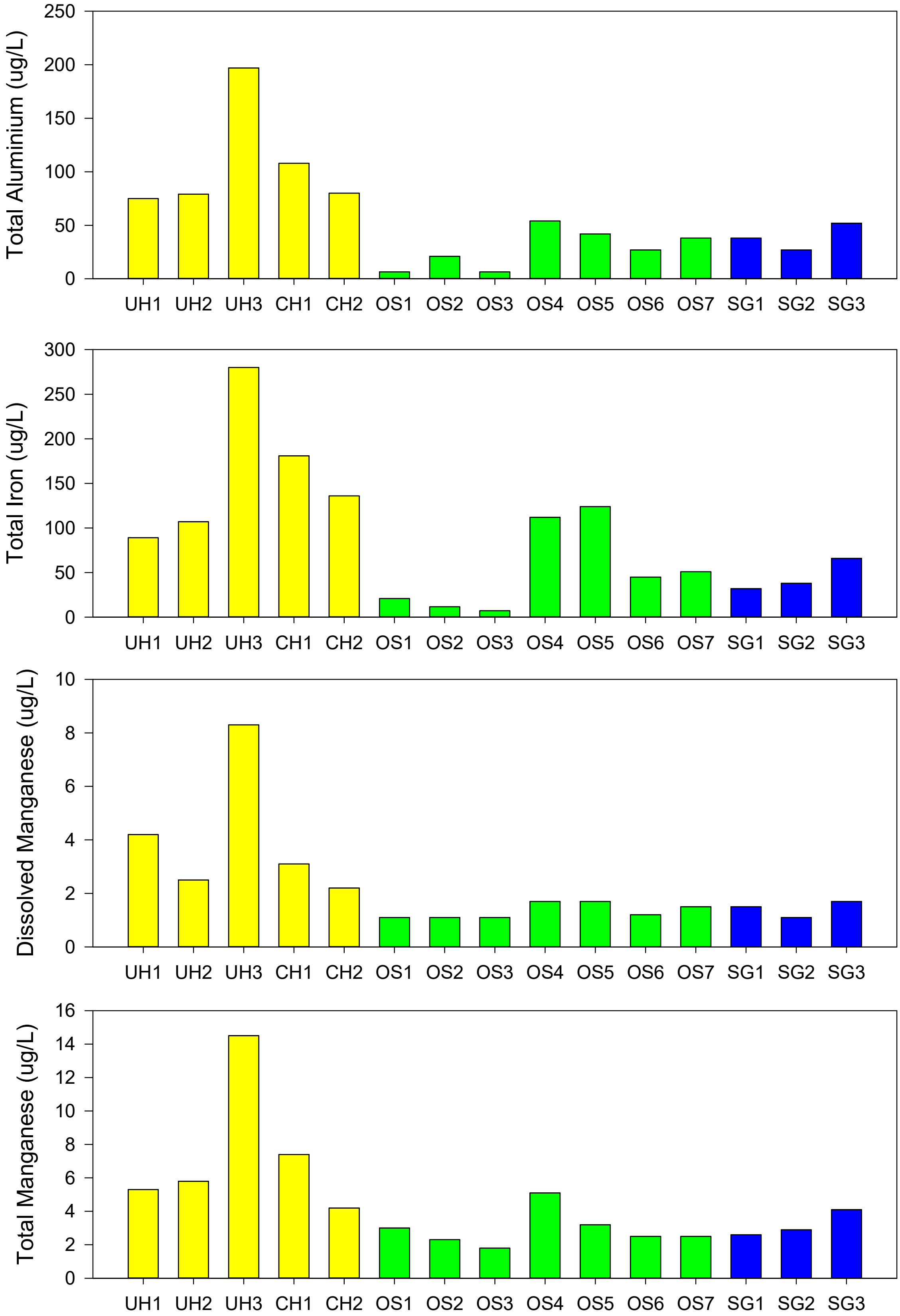


Figure 25 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during February 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

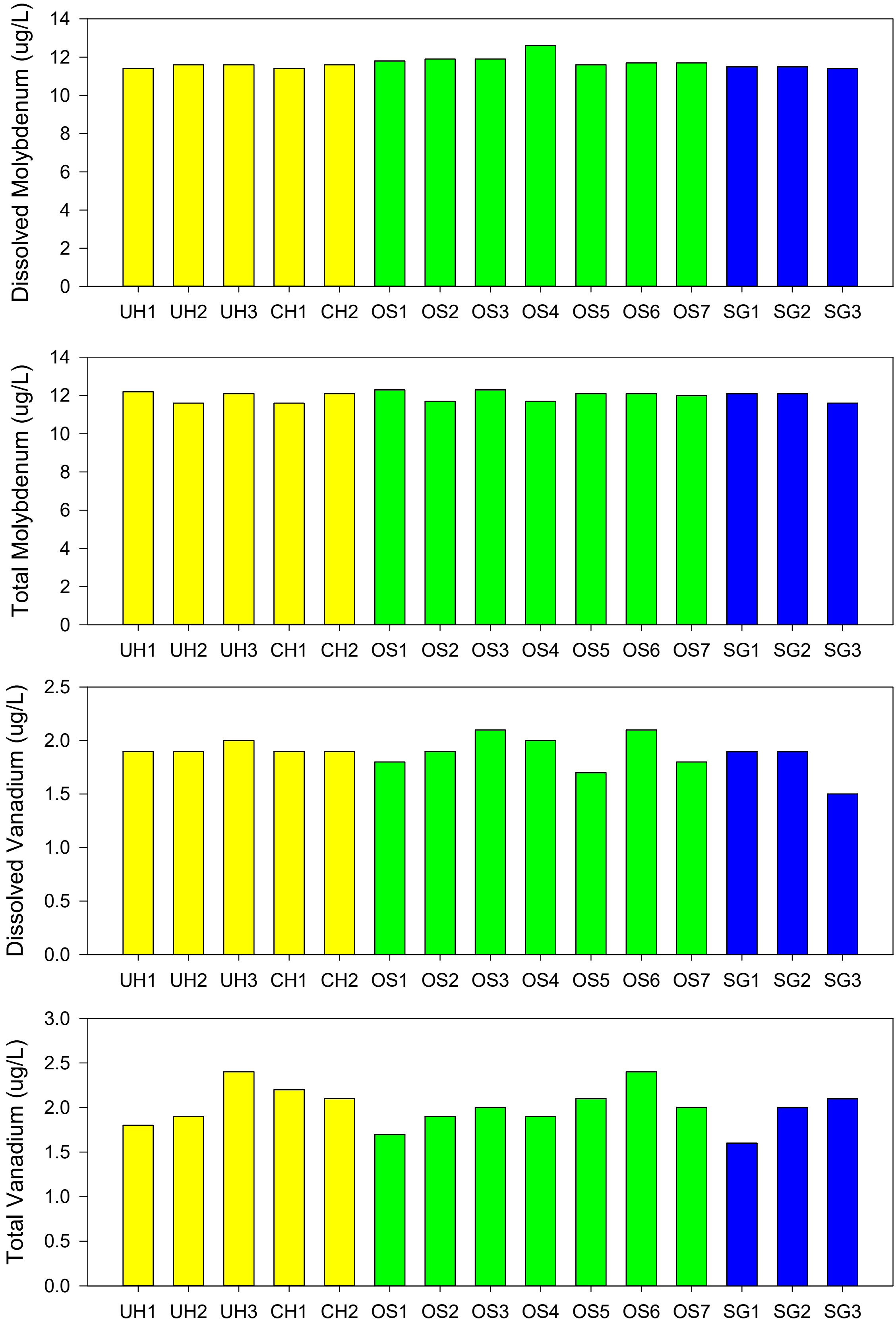


Figure 26 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during February 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

4 REFERENCES

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5 APPENDIX

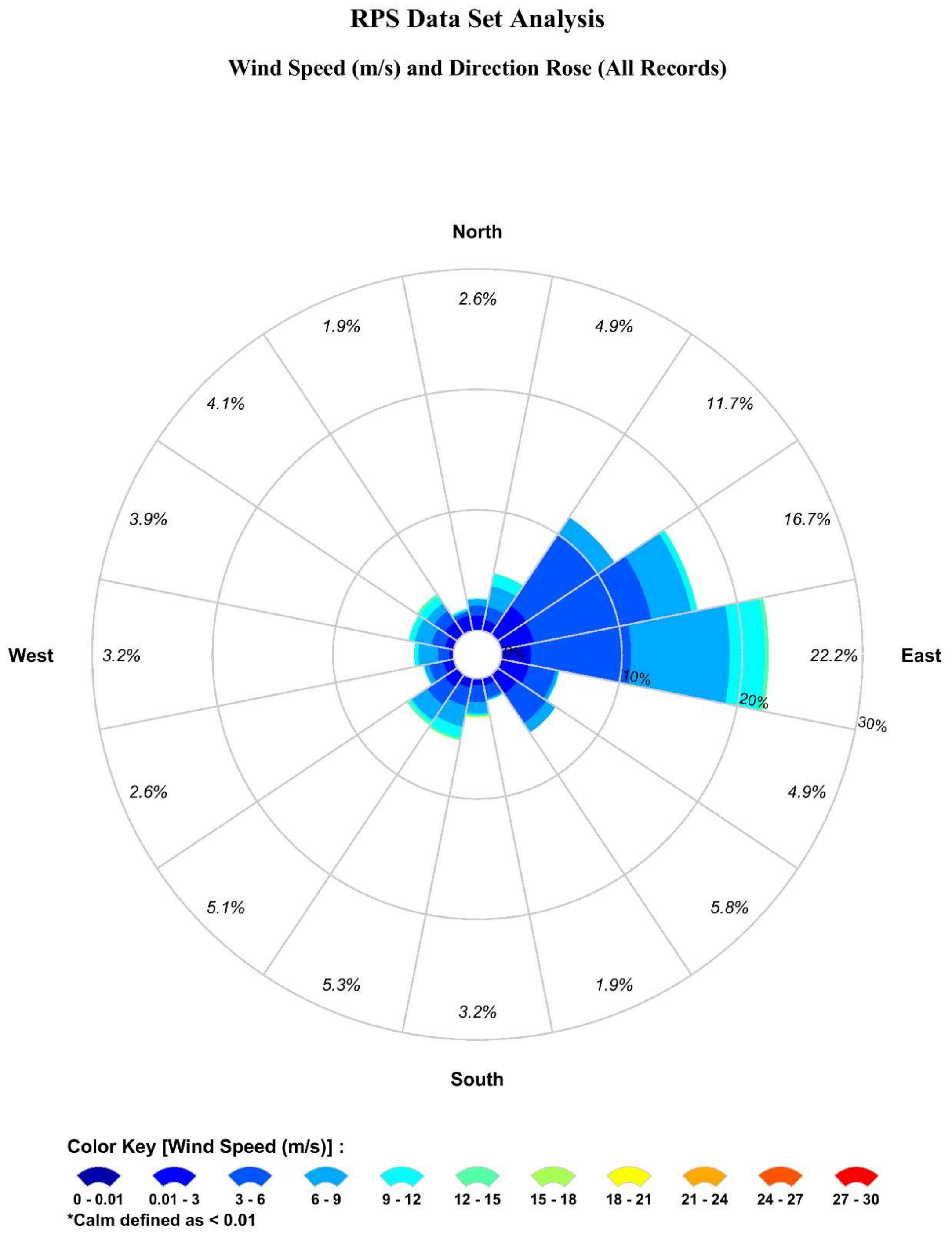

Figure 27 WatchKeeper wind speed (m/s) and direction rose (%) during February 2019.

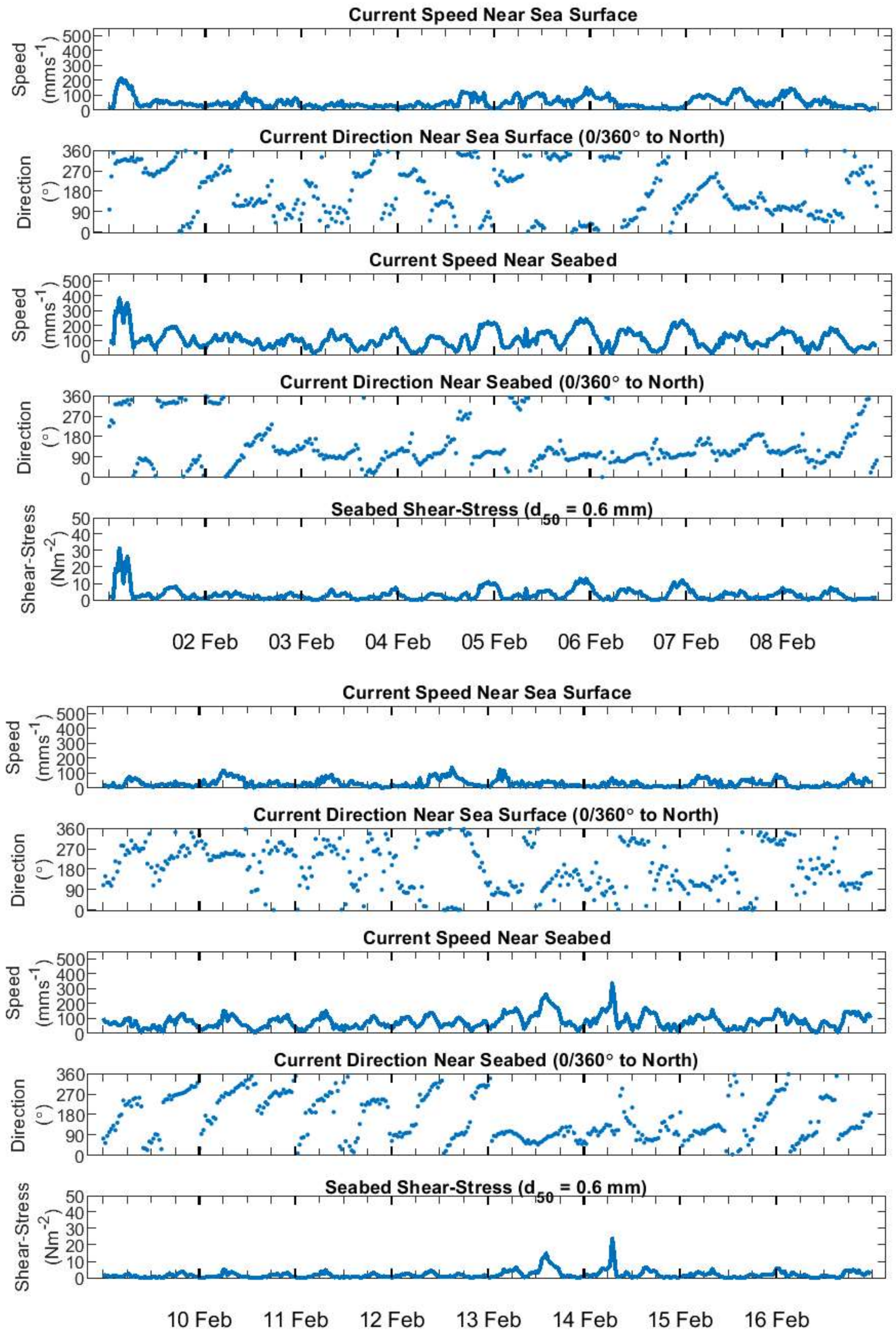

Figure 28 SG2a current speed, direction and shear bed stress 1 to 16 February 2019.

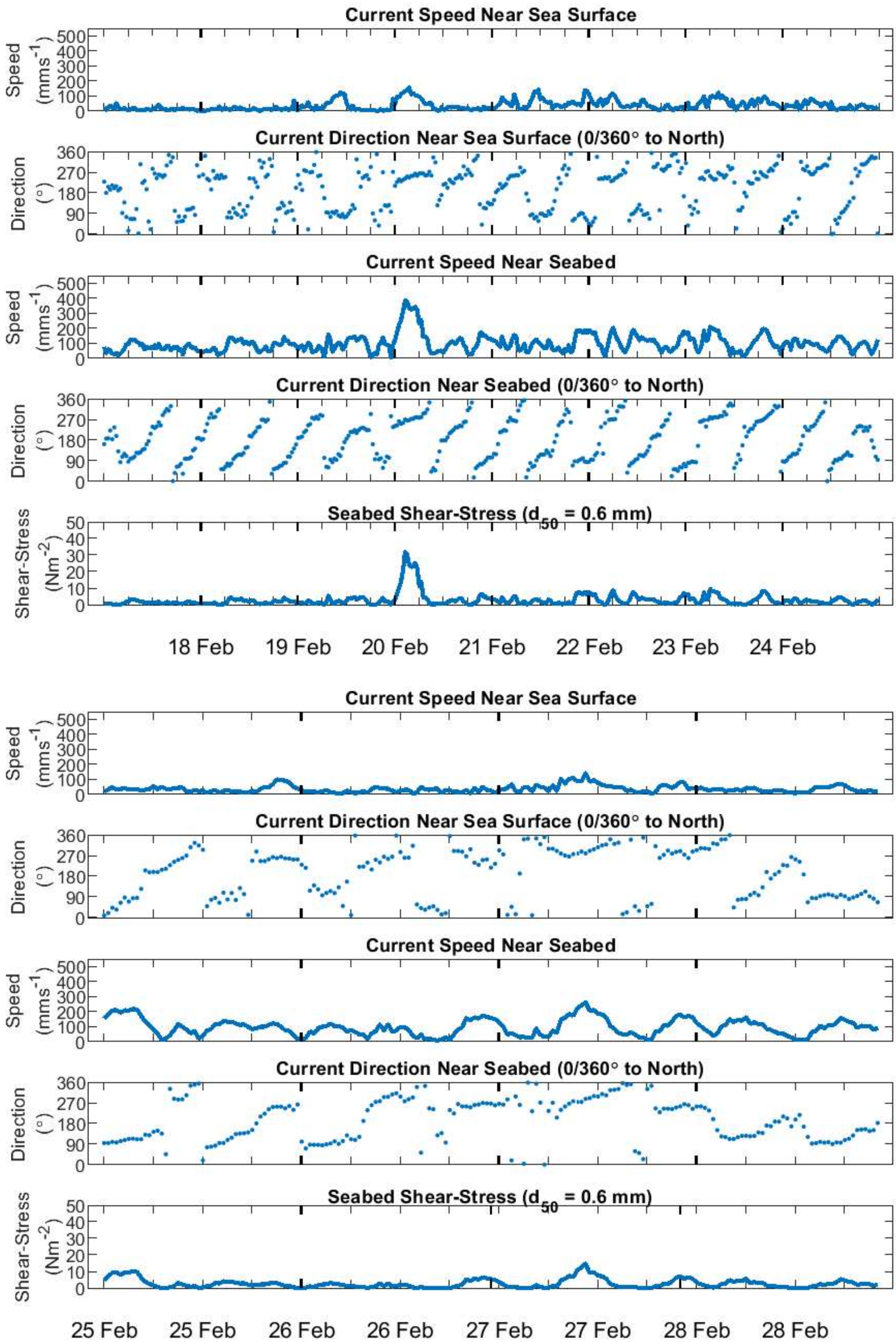

Figure 29 SG2a current speed, direction and shear bed stress 17 to 28 February 2019.

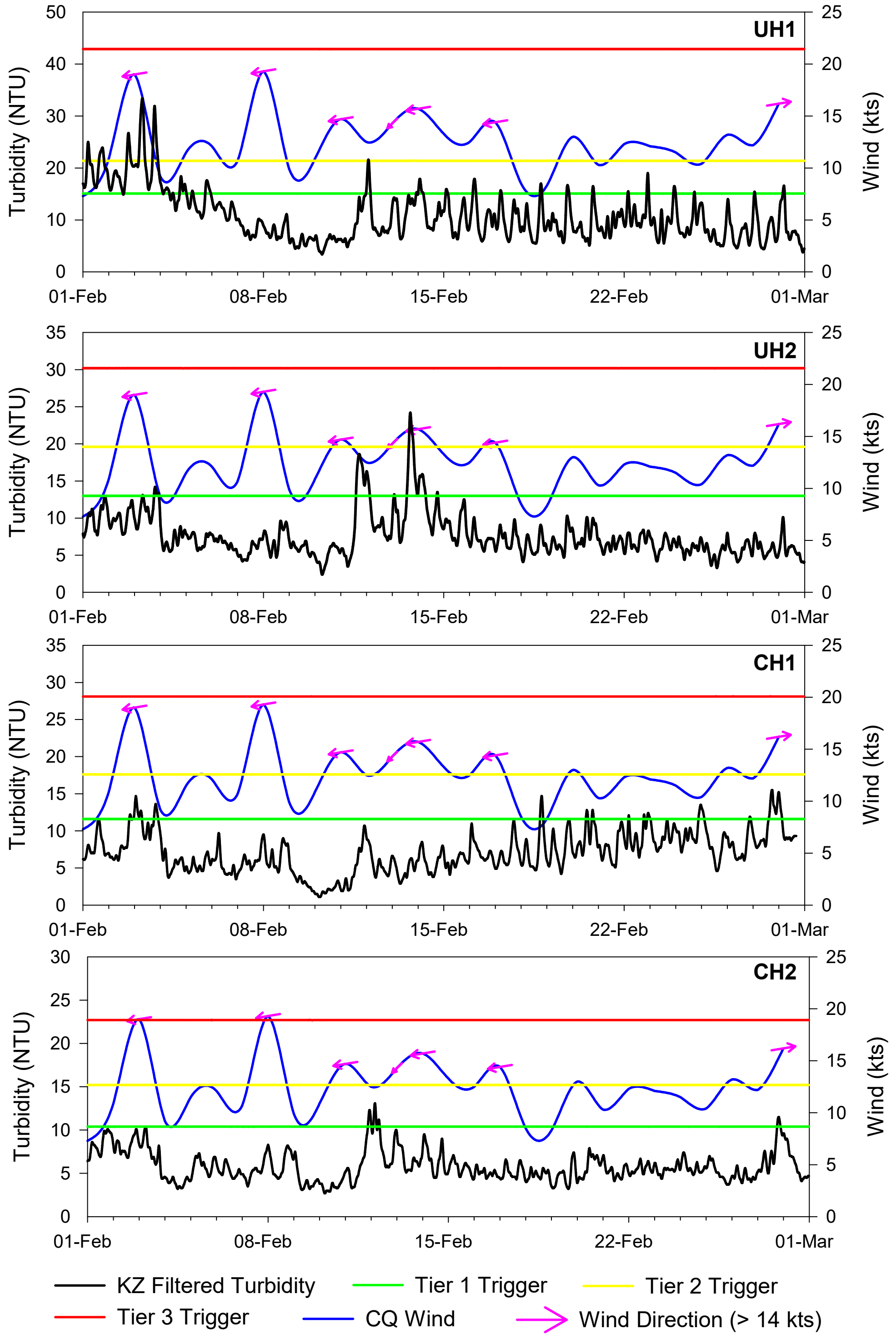

Figure 30 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

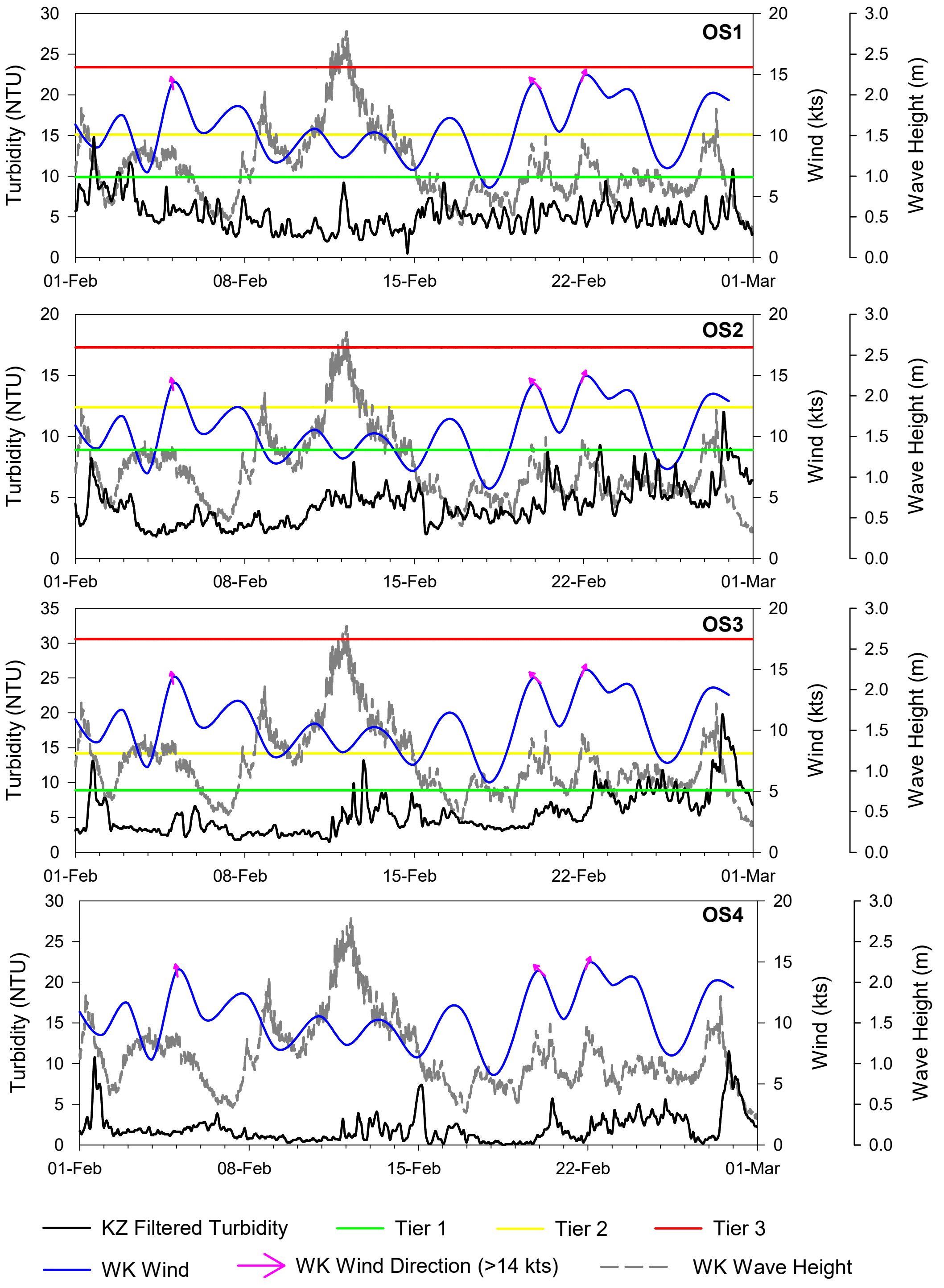

Figure 31 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

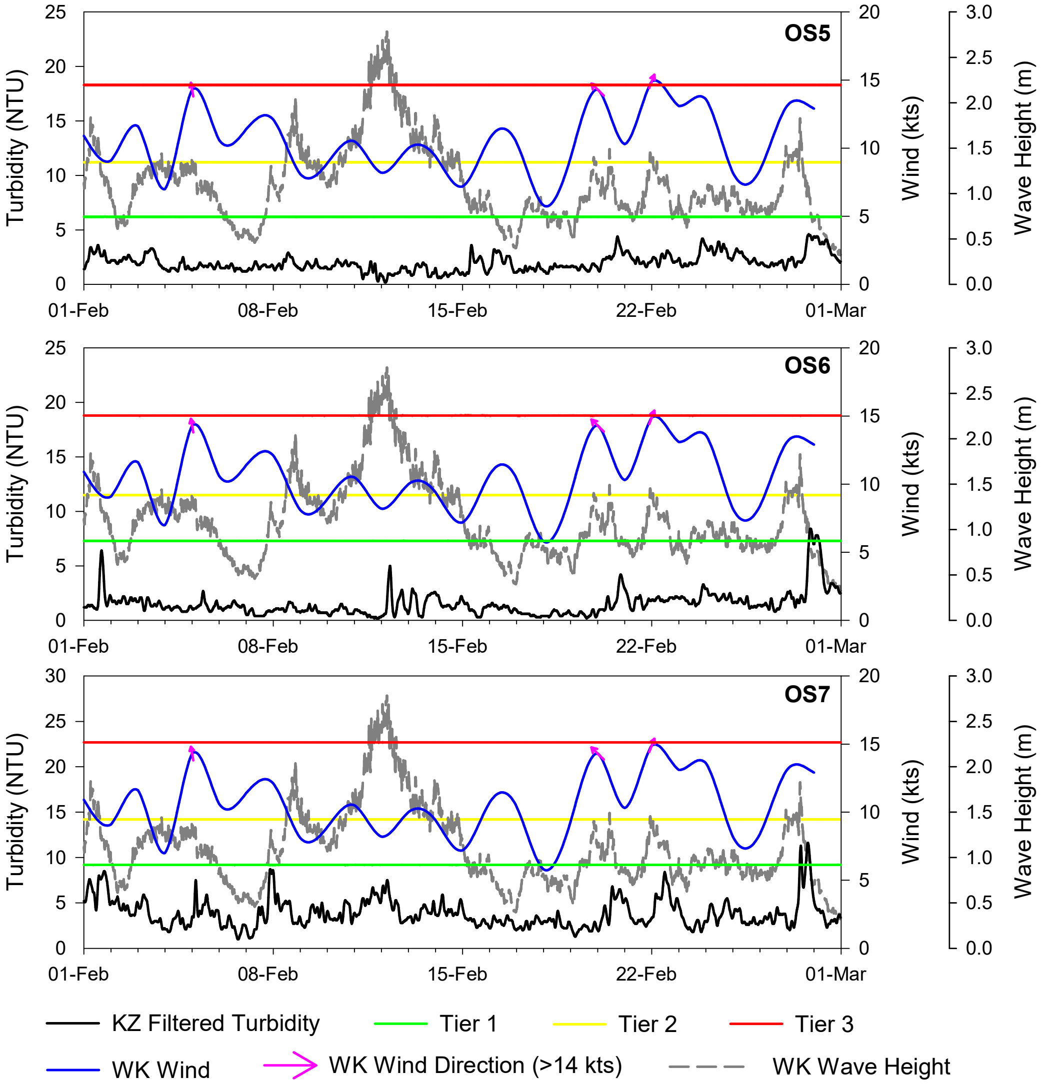

Figure 32 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during February 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

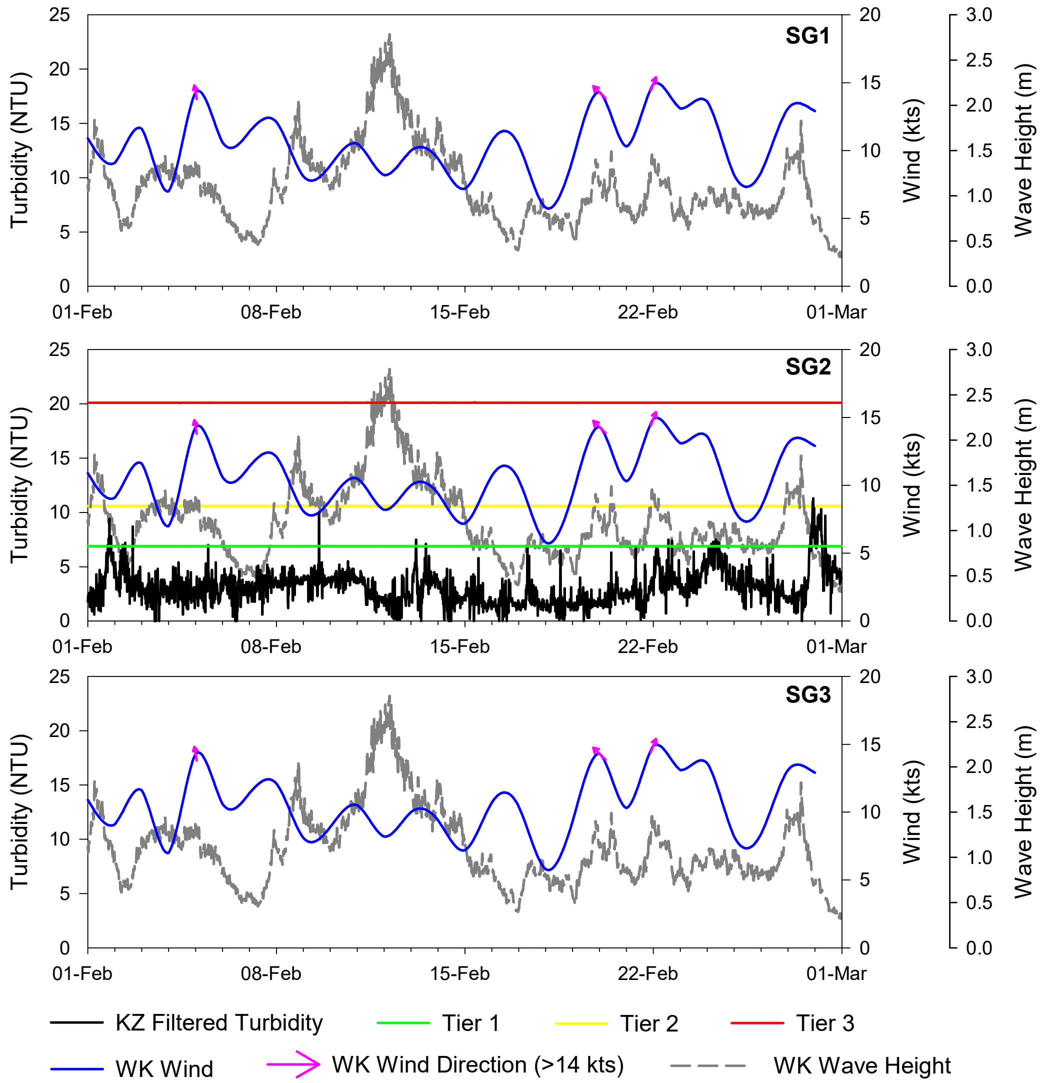

Figure 33 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during February 2019.

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 19 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during February 2019 and baseline period 1 November 2016 to 31 October 2017
Values for February are means ± se, range and percentiles (n = 2658 – 2688). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface February	Surface Baseline
UH1	Mean ± se	11 ± 0	12
	Range	3 – 33	2 – 155
	99th	27	37
	95th	20	21
	80th	15	15
UH2	Mean ± se	7.6 ± 0.1	9.9
	Range	2 – 24	2 – 59
	99th	18	29
	95th	13	19
	80th	9.2	13
CH1	Mean ± se	7.1 ± 0.1	8.8
	Range	1 – 16	<1 – 50
	99th	14	27
	95th	12	17
	80th	9.3	12
CH2	Mean ± se	5.8 ± 0.0	7.6
	Range	3 – 13	<1 – 39
	99th	11	22
	95th	9.5	15
	80th	7.0	10

Table 20 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during February 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for February are means ± se, range and percentiles (n = 0 – 2688). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface February	Surface Baseline
SG1	Mean ± se	–	4.2
	Range	–	<1 – 31
	99th	–	14
	95th	–	9.5
	80th	–	6.1
SG2	Mean ± se	3.1 ± 0.0	4.6
	Range	1.1 – 9.4	<1 – 33
	99th	8.1	20
	95th	5.5	10
	80th	3.8	6.9
SG3	Mean ± se	–	3.6
	Range	–	<1 – 22
	99th	–	13
	95th	–	7.3
	80th	–	4.7

Table 21 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during February 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for February are means ± se, range and percentiles (n = 2688). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface February	Surface Baseline
OS1	Mean ± se	5.2 ± 0.0	7.5
	Range	<1 – 15	<1 – 99
	99th	11	23
	95th	8.8	15
	80th	6.5	9.7
OS2	Mean ± se	4.4 ± 0.0	6.4
	Range	2 – 12	<1 – 36
	99th	9.0	17
	95th	7.8	12
	80th	5.5	8.9
OS3	Mean ± se	5.5 ± 0.1	6.5
	Range	2 – 20	<1 – 110
	99th	16	27
	95th	11	14
	80th	7.7	8.9
OS4	Mean ± se	2.0 ± 0.0	5.9
	Range	<1 – 12	<1 – 35
	99th	8.5	18
	95th	5.9	13
	80th	3.0	8.1
OS5	Mean ± se	2.0 ± 0.0	4.6
	Range	<1 – 4.6	<1 – 35
	99th	4.3	18
	95th	3.5	11
	80th	2.5	6.1
OS6	Mean ± se	1.5 ± 0.0	4.7
	Range	<1 – 8.4	<1 – 37
	99th	7.4	18
	95th	3.1	11
	80th	2.0	7.1
OS7	Mean ± se	3.9 ± 0.0	6.3
	Range	1 – 12	<1 – 48
	99th	8.7	22
	95th	7.0	14
	80th	5.0	9.1

Table 22 Summary of Vision Environment quality control data for February 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		
			UH1 A (µg/L)	UH1 B (µg/L)	Variation (%)
TSS	<3	<3	3	4	29
Dissolved Aluminium (ug/l)	<3	<3	28	<12	ND
Total Aluminium (ug/l)	<3.2	<3.2	75	120	46
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	<1	ND
Total Chromium (ug/l)	<0.53	<0.53	<1.1	1.2	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)	1.04	<0.53	<1.1	<1.1	ND
Dissolved Iron (ug/l)	<20	<20	16	<4	ND
Total Iron (ug/l)	<21	<21	89	260	98
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	4.2	4.5	7
Total Manganese (ug/l)	<0.53	<0.53	5.3	7.7	37
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	11.4	11.7	3
Total Molybdenum (ug/l)	<0.21	<0.21	12.2	11.9	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	1.9	2	5
Total Vanadium (ug/l)	<1.1	<1.1	1.8	2	11
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	20	13	42
Dissolved Reactive Phosphorus (ug/l)	<4	<4	1.1	3.1	95
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	15	13	14
Nitrate-N + Nitrite-N (ug/l)	23	<2	34	<1	ND
Chlorophyll a (ug/L)	<0.2	<0.2	2.6	2.4	8

Note: Slight presence of total copper and NOx compounds within the Field Blank that were not present in the Lab Blank.