Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

January 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 also completed on 29 November 2018, taking the monitoring into a post dredge phase. Continuing with the dredge phase monitoring report format, the monthly report includes comparisons of turbidity data collected during the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). Monitoring results collected during January 2019 are presented within this report. This includes KZ filtered data, which although not applicable to the post dredge phase of monitoring, was compared to compliance trigger values during dredging operations.

Climatic Conditions: Rainfall at Cashin Quay during January 2019 totalled 25.6 mm, slightly lower than that experienced the previous month. However, freshwater outflow from the Waimakariri River was notably greater than experienced during December, with a large peak in flow observed on 24 January. Daily averaged inshore wind speeds remained above 7 knots for the month, with peak mean daily winds speeds of 23.2 knots recorded on 14 January and maximum wind gusts of 60 knots recorded on 23 January.

Offshore, both wind speeds and wave heights remained variable over the month displaying similarly timed patterns. Maximum mean daily offshore wind speeds were recorded on 9 January, coinciding with peak offshore significant wave heights, yet displaying a temporal offset with inshore winds recorded at Cashin Quay.

Air temperatures continued the seasonal warming trend, with a monthly average of 18°C that was approximately 2°C warmer than December.

Currents: ADCP units at sites SG1 and SG3 remained offline during January 2019 and are currently undergoing 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 9 January 2019 and coincided with maximum offshore significant wave heights. Contrasting this apparent forcing, maximum near-seabed velocities were recorded several days later on 26 January, although elevated surface current speeds were also recorded at this time. Interestingly both offshore wind speeds and wave heights were relatively low at this time. Contrasting the typical results obtained from SG1 and SG3, current velocities at SG2a were reported to be greater at the near-seabed, displaying a slight dominance of easterly flows. Although the monthly mean current speed was slightly lower at the near-surface, current direction data indicated a strong dominance of flows towards the east during January.

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. Outside of the upper harbour, mean turbidity values and higher order percentile statistics for January 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. Turbidity at the inshore and nearshore monitoring sites all displayed a close relationship to inshore wind speeds, particularly on 24 January when wind gusts were recorded at 60 knots. Further offshore and at the spoil ground sites, turbidity appeared to be more stable, with increases correlating with increased wind speeds and/or wave heights as recorded by the WatchKeeper buoy. Offshore turbidity increased during the second half of the month, with a particularly rapid increase at SG2 and OS6 on 28 January in response to wave dynamics. Benthic turbidity units trended similarly to one another and displayed temporal variability similar to both offshore wind and wave conditions.

Other Physicochemical Parameters: Monthly mean surface water temperatures around Lyttelton Harbour continued the warming trend observed during the previous months. Reversing the spatial relationship between sites during austral winter, the warmest temperatures continued to be recorded in the shallow waters of the upper and central harbour. All monitoring locations indicated a brief period of cooling following 13.6 mm of rainfall on 14 January. Benthic temperatures were up to several degrees cooler than those of the surface; a pattern that has also been observed during previous summer months of the monitoring program. Sites OS1 and OS2 displayed relatively warmer benthic waters compared to the remaining sites, with a cooling signal also observed following rainfall on 14 January. Warming of nearshore benthic waters at OS3, OS4 and OS6 during the second half of the month eliminated this spatial difference.

Consistent with previous reports, pH during January did not display any particular spatial or temporal patterns across the monitoring network. Conductivity in January was also relatively stable, with some freshening at SG1, OS1 and OS5 on 8, 10 and 14 January that was likely associated with Waimakariri River outflow. Benthic waters were characterised by lower pH and higher conductivity values than the surface, with little impact from local rainfall events.

Dissolved oxygen (DO) concentrations displayed similar monthly mean values as recorded during December, however, diurnal fluctuations were particularly large at the northern sites within Lyttelton Harbour where concentrations dropped to as low as 50% saturation. Slight decreases in surface DO were also recorded after the rainfall event on 24 January. Mean monthly benthic DO concentrations displayed a high level of temporal variability over the month, with increases likely due to strong vertical mixing with high-oxygen surface waters during periods of increased wind and/or wave activity.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 15 and 16 January. Similar to profiles typically obtained during the monitoring program, the inner harbour and nearshore monitoring sites indicated a well-mixed water column. Slightly more saline surface waters were observed at site CH2, which contrasts the slight freshening signal that was observed during December 2018.

Further offshore, vertical profiling once again indicated warmer, fresher surface waters overlying the slightly cooler, more saline benthic environment. As commonly observed throughout the monitoring program, turbidity at OS6 and SG2 also increased towards the seabed. However, due to the greater water depth than within the harbour, such increases in benthic turbidity did not have a notable influence on the calculations of vertical light attenuation.

Turbidity and total suspended solids (TSS) measurements for surface waters were again elevated at inshore sites compared to the offshore areas, resulting in the shallowest estimations of the euphotic depth as typically recorded during the monitoring program. Euphotic depth at the spoil ground was relatively high; estimated to be at 18.6 m at SG3 (although lower than that calculated for December 2018). No exceedances of WQG were observed for sub-surface turbidity during the January sampling.

As commonly observed, total and dissolved reactive phosphorous concentrations were highest at the inshore sites and decreased further offshore. Concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites. Nitrogen oxides concentrations remained below LOR, however, total ammonia exceeded the applicable WQG at all inshore and nearshore sites except OS2. Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, slightly exceeded WQG at the upper harbour sites UH1 and UH3 indicating a slight increase from the previous month. An increase of available nutrients at the upper harbour sites is likely to have resulted in an increase in algal biomass, as confirmed by the highly fluctuating diurnal DO concentrations.

As typically observed, total aluminium concentrations exceeded designated WQG at all of the Lyttelton monitoring sites. Dissolved aluminium concentrations were lower, with only OS7 indicating levels greater than the 24 µg/L WQG. Total and dissolved copper concentrations were slightly elevated compared to December, however, WQGs were only exceeded at UH2, UH3 and CH1. Elevated levels of total mercury recorded at CH2 during December were not observed during the January sampling.

While no WQG are available for iron, concentrations were slightly elevated compared to the previous month, with values exceeding 100 µg/L at all upper and central harbour sites in addition to OS1 and OS6. Displaying a similar pattern to aluminium and a consistency with previous results, 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 January, with little spatial variability and a large component contained within the dissolved phase.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during January, both in terms of the monthly mean and the range, were greater than that experienced in December and this increase is clearly apparent within the benthic data.

The first week of the month was characterised by relatively low surface turbidity levels, resulting in little light attenuation through the water column. Maximum BPAR recorded at OS2 and OS3 during January were also some of the highest values recorded during the entire Lyttelton monitoring program, representing elevated incoming ambient PAR and low turbidity conditions through the water column. For the remainder of the month, BPAR at both monitoring sites remained relatively high, with variations reflecting the complex interplay between incoming ambient PAR and marine turbidity levels. As turbidity increased during the final days of the month, BPAR at OS2 declined to low values similar to those that have regularly been recorded in the past.

Sedimentation: During the first three days of January, bed level at the harbour entrance was relatively stable until a period of rapid sediment deposition resulted in a bed level increase of 22 mm by midnight 5 January. Following this increase, sediments at OS2

remained relatively stable once more till a second period of sedimentation from 21 January to the end of the month. The greatest period of sediment deposition during this second stage was observed between 27 and 28 January. During January 2019, there was a net deposition of 42 mm of sediment onto the seafloor at OS2.

Similar to previous observations, bed level in the upper harbour at UH3 was more stable than at OS2, varying within a range of approximately 10 mm and displaying little relationship with inshore wind speeds. Unfortunately, from 23 January both altimeters on site failed to read a return echo, and following equipment retrieval it appeared that the frame for UH3 had been lying on its site. A peak in surface turbidity at this site was also reported at the time of altimeter data loss. From 1 to 23 January, net bed level at UH3 increased by 7 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.

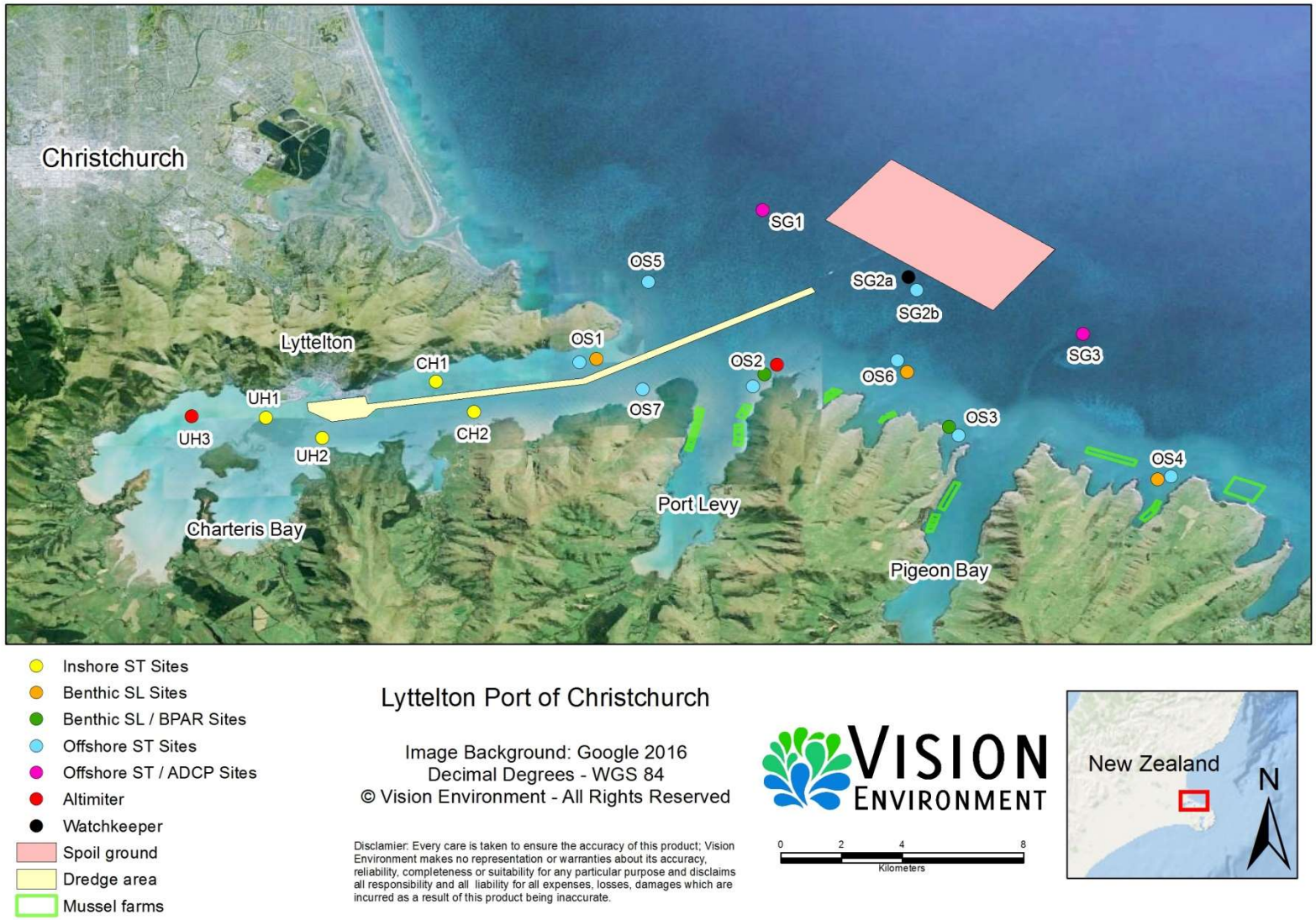

Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 31 January 2019 during post dredge operations. Monthly water sampling and depth profiling was conducted on 15 and 16 January 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 January 2019, Cashin Quay received 25.6 mm of rainfall over 10 days (Figure 2); slightly lower than that recorded during the previous month. Over half of this monthly total was recorded on 14 January (13.6 mm), during a period of elevated (23.2 knots) mean daily wind speeds. Daily rainfall above 1 mm was also recorded on 6, 7 and 23 January (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 notably greater than that recorded during December (when flow remained less than 340 m^3/s), with peak volumes of 717.6 m^3/s recorded on 24 January (Figure 3) (ECAN, 2019).

Mean daily inshore wind speeds in January remained above 7 knots for the duration of the month, with maximum mean daily wind speeds of 23.2 knots recorded on 14 January coming from the west-south-west. Maximum wind gusts of 60 knots were, however, recorded several days later during 23 January from a southwesterly direction. For the majority of the month, mean daily wind speeds greater than 14 knots were recorded from an east-north-easterly direction as typically observed (Figure 2) (Metconnect, 2018).

Daily mean air temperatures at Cashin Quay ranged from 14 to 23°C, resulting in a warmer monthly mean temperature of 18°C, 2°C warmer than the previous month (Metconnect, 2019).

Offshore significant wave heights peaked at 2.2 m on 9 January, travelling in a south-south-westerly direction, and remained quite variable during the majority of the month (Figure 3). Variability in mean daily offshore wind speeds displayed a similar pattern to wave height data, with a maximum daily mean wind speed of 16.3 knots also recorded on 9 January (Figure 3).

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.

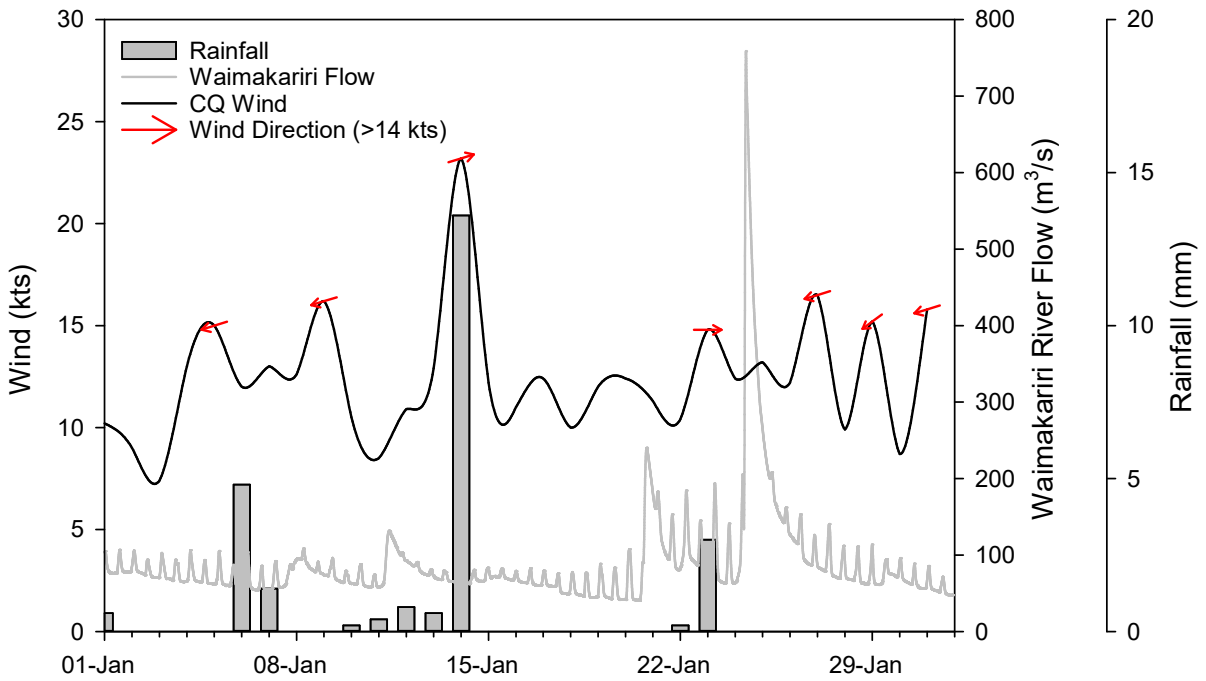

Figure 2 Inshore metocean conditions, including daily averaged wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during January 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

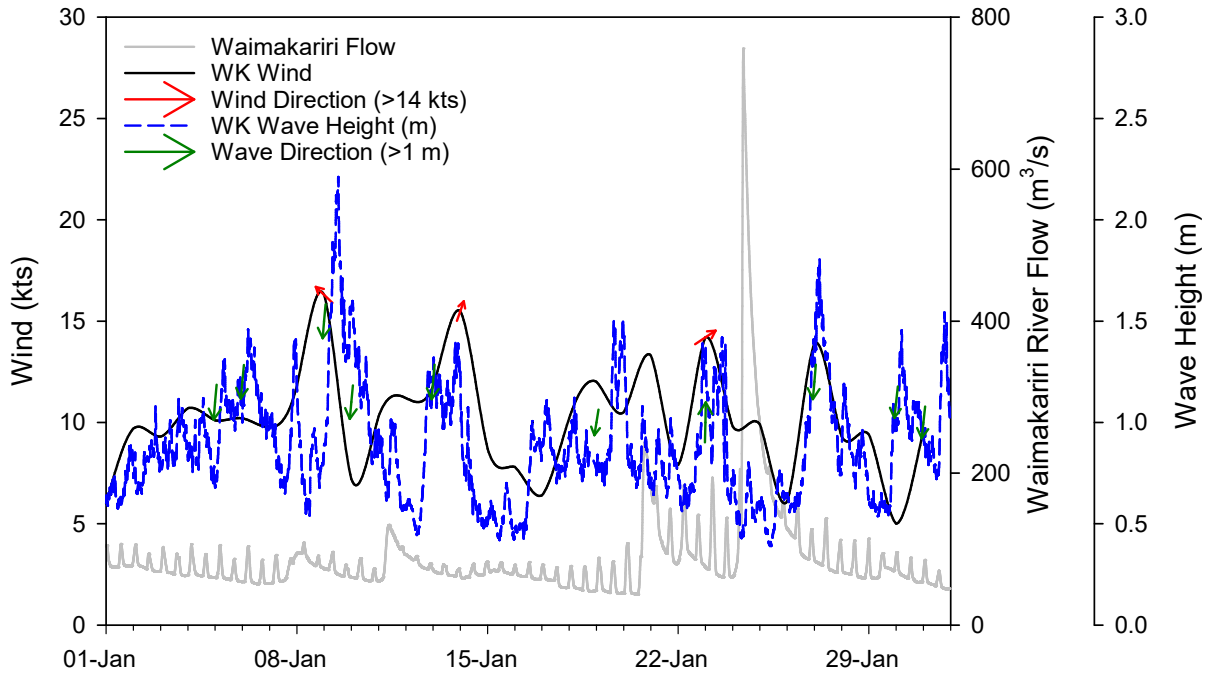

Figure 3 Offshore metocean conditions, including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during January 2019.
Note: Arrows indicate the direction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

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 9 January at 267 mm/s (Table 2), coinciding with maximum offshore significant wave heights that reached 2.2 m (Figure 3). Near the seabed, maximum current velocities of 456 mm/s were recorded several days later on 26 January when offshore wind speeds and wave heights were relatively low (Table 2, Figure 3). The monthly mean current speed for the near-seabed (97 mm/s) was greater than that recorded for the near surface (52 mm/s), contrasting typical observations from SG1 and SG3 and possibly reflecting benthic topography at SG2. Near-surface current velocities were slightly reduced compared to December, whereas near-seabed current speeds were slightly increased (Table 2).

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

Parameter	SG2a	
	Near-surface	*Near-seabed*
Minimum current speed (mm/s)	1	4
Maximum current speed (mm/s)	267	456
Mean current speed (mm/s)	52	97
Standard deviation of current speed (mm/s)	42	54
Current speed, 95th percentile (mm/s)	138	189

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).

Similar to data recorded from SG2a during December, currents during January displayed a strong dominance of surface flow to the east (33%) rather than bidirectional flow along an east-west axis as recorded during October and November (Figure 4). This change in movement may represent the influence of a mesoscale eddy in the area. Near-seabed current direction during January displayed a greater component of flow along the east-west axis, with a slight dominance of easterly flows (25.7% c.f. 16.2% to the west) (Figure 4).

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties (turbidity, temperature, conductivity [normalised to a reference temperature of 25°C], pH and DO) of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 15 and 16 January 2019. Further details regarding the methodology used can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017).

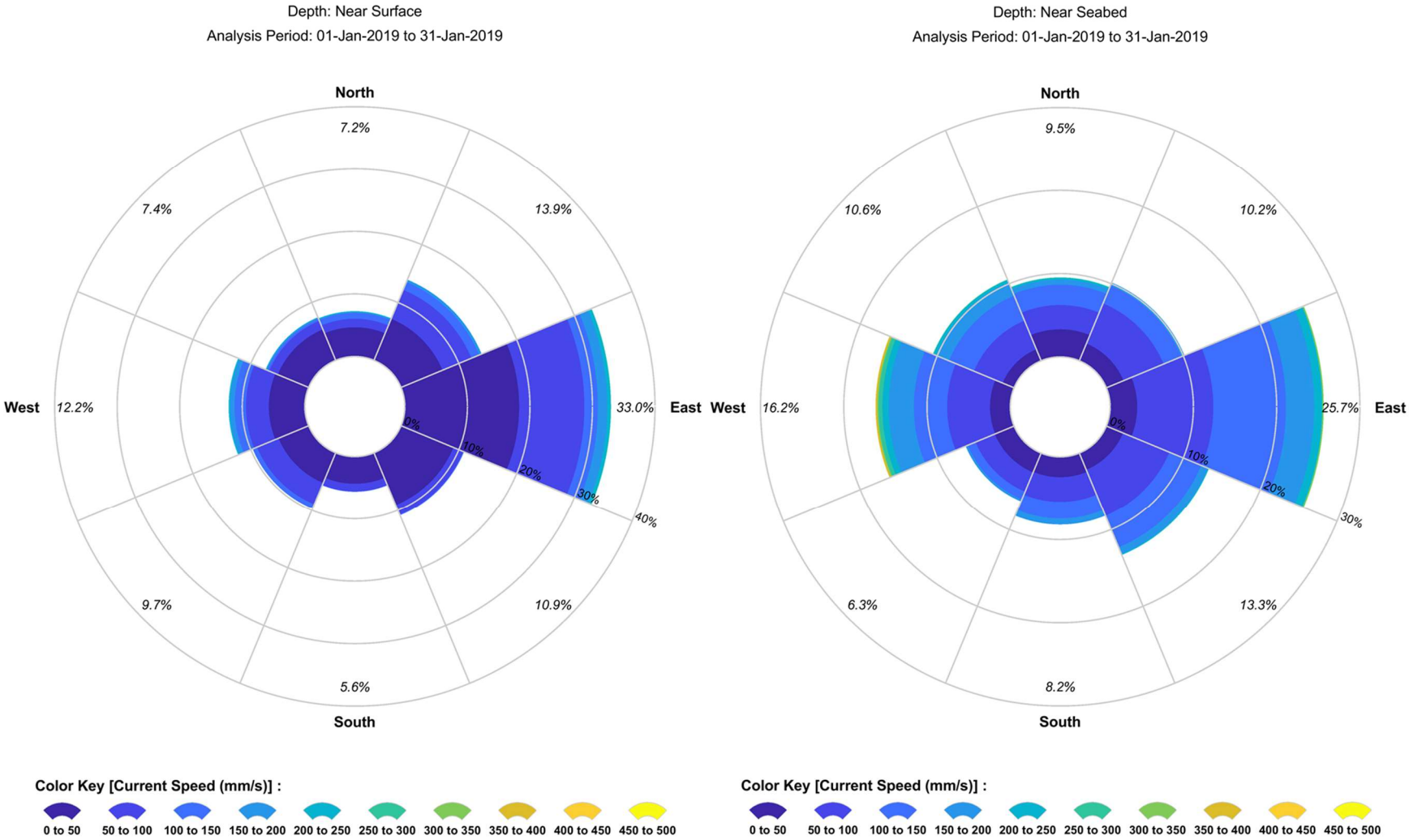

Figure 4 WatchKeeper near-surface and near-seabed current speed and direction during January 2019.
Speed intervals of 50 mm/s are used

Summary statistics for each physicochemical parameter recorded during January 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 January 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 4.8 to 14 NTU) at the inshore monitoring sites (Tables 3 to 5, Figure 5). Further offshore, the spoil ground sites exhibited lower (monthly means of 0.9 to 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 (1.4 to 3.3 NTU) during January (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.

Variations in turbidity at all inner harbour and nearshore sites displayed a similar variability as inshore wind speed; with increasing NTUs particularly apparent within the second half of the month (Figure 5). A large peak in surface turbidity was observed at the harbour head (Site UH1) on 24 January where 24 hour averaged turbidity increased from ~13 NTU to 42 NTU. Similarly timed peaks were also recorded at UH2 and CH1, although at a notably lower intensity and did not result in elevated turbidity for the remainder of the month. This large turbidity response was not the result of monthly maximum mean daily wind speeds (Figure 5), rather a result of wind gusts reaching 60 knots on 23 January (Metconnect, 2019).

The nearshore monitoring sites displayed a larger response to elevated mean daily wind speeds on 14 January, with northeasterly winds during the final week of January also acting to increase surface turbidity. All sites displayed a relatively coherent turbidity pattern throughout the month, with slightly elevated turbidity recorded at OS1 during the first week and final few days of January (Figure 5).

Further offshore at the spoil ground, OS5 and OS6, slight increases in surface turbidity were recorded on 11 and 15 January when offshore wind speeds were slightly elevated. Sites SG2 and OS6 also displayed an increase in surface turbidity during the second half of the month, with a particularly large increase on 28 January that may have been induced by a similar increase in offshore significant wave height at that time (Figure 5). Unfortunately,

data availability from SG1 and SG3 were limited as both buoys have been retrieved during January for manual ADCP data download and diagnostics

Table 3 Mean turbidity and statistics at inshore water quality logger sites during January 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for January are means ± se, range and percentiles (n = 2899 to 2971) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface January	Surface Baseline
UH1	Mean ± se	14 ± 0	12
	Range	2 – 214	-
	99th	45	39
	95th	29	22
	80th	19	15
UH2	Mean ± se	8.0 ± 0.1	10
	Range	<1 – 104	-
	99th	23	32
	95th	13	20
	80th	9.7	13
CH1	Mean ± se	7.2 ± 0.1	9
	Range	<1 – 33	-
	99th	19	29
	95th	14	18
	80th	9.2	12
CH2	Mean ± se	4.8 ± 0.0	8
	Range	<1 – 19	-
	99th	12	24
	95th	9.2	16
	80th	6.8	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during January 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for January are means ± se, range and percentiles (n = 1252 to 2959). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface January	Surface Baseline
SG1*	Mean ± se	1.3 ± 0.0	4.2
	Range	<1 – 9.9	-
	99th	4.9	14
	95th	2.8	10
	80th	1.7	6.2
SG2	Mean ± se	3.3 ± 0.0	4.6
	Range	<1 – 13	-
	99th	11	20
	95th	8.6	11
	80th	4.5	7.0
SG3*	Mean ± se	0.9 ± 0.0	3.6
	Range	<1 – 5.1	-
	99th	3.0	13
	95th	2.1	7.7
	80th	1.4	4.8

**Limited deployments for SG1 and SG3*

Table 5 Mean turbidity and statistics at offshore water quality logger sites during January 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for January are means ± se, range and percentiles (n = 2135 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface January	Surface Baseline	Benthic January
OS1	Mean ± se	3.3 ± 0.0	7.5	30 ± 0
	Range	<1 – 17	-	<1 – 167
	99th	11	24	106
	95th	8.1	16	69
	80th	4.4	10	40
OS2	Mean ± se	2.9 ± 0.0	6.4	32 ± 1
	Range	<1 – 14	-	3 – 176
	99th	10	18	123
	95th	6.2	13	85
	80th	4.1	9.0	48
OS3	Mean ± se	3.0 ± 0.0	6.6	26 ± 0
	Range	<1 – 13	-	1 – 130
	99th	7.7	27	86
	95th	5.5	15	60
	80th	3.9	8.9	38
OS4	Mean ± se	1.4 ± 0.0	5.9	17 ± 0
	Range	<1 – 11	-	2 – 110
	99th	7.3	20	85
	95th	3.9	13	53
	80th	2.0	8.3	27
OS5	Mean ± se	2.7 ± 0.0	4.6	–
	Range	<1 – 9.8	-	–
	99th	7.3	19	–
	95th	5.5	11	–
	80th	3.4	6.4	–
OS6	Mean ± se	1.5 ± 0.0	4.7	35 ± 1
	Range	<1 – 8.3	-	2 – 169
	99th	5.9	19	113
	95th	3.3	12	80
	80th	2.1	7.2	52
OS7	Mean ± se	3.0 ± 0.0	6.4	–
	Range	<1 – 16	-	–
	99th	9.9	23	–
	95th	6.5	14	–
	80th	4.1	9.2	–

Benthic:

Benthic data recovery for January was relatively high, with all five sites indicating similar patterns in turbidity across the month. As typically observed, increased offshore winds and significant wave heights corresponded well with increases in benthic turbidity, with much larger amplitude turbidity signals recorded at the benthos than in the surface waters (Figure 5). Mean monthly benthic turbidity was greatest at the exposed offshore site OS6 (35 NTU), and lowest at the reference site OS4 (17 NTU) (Tables 4 to 6).

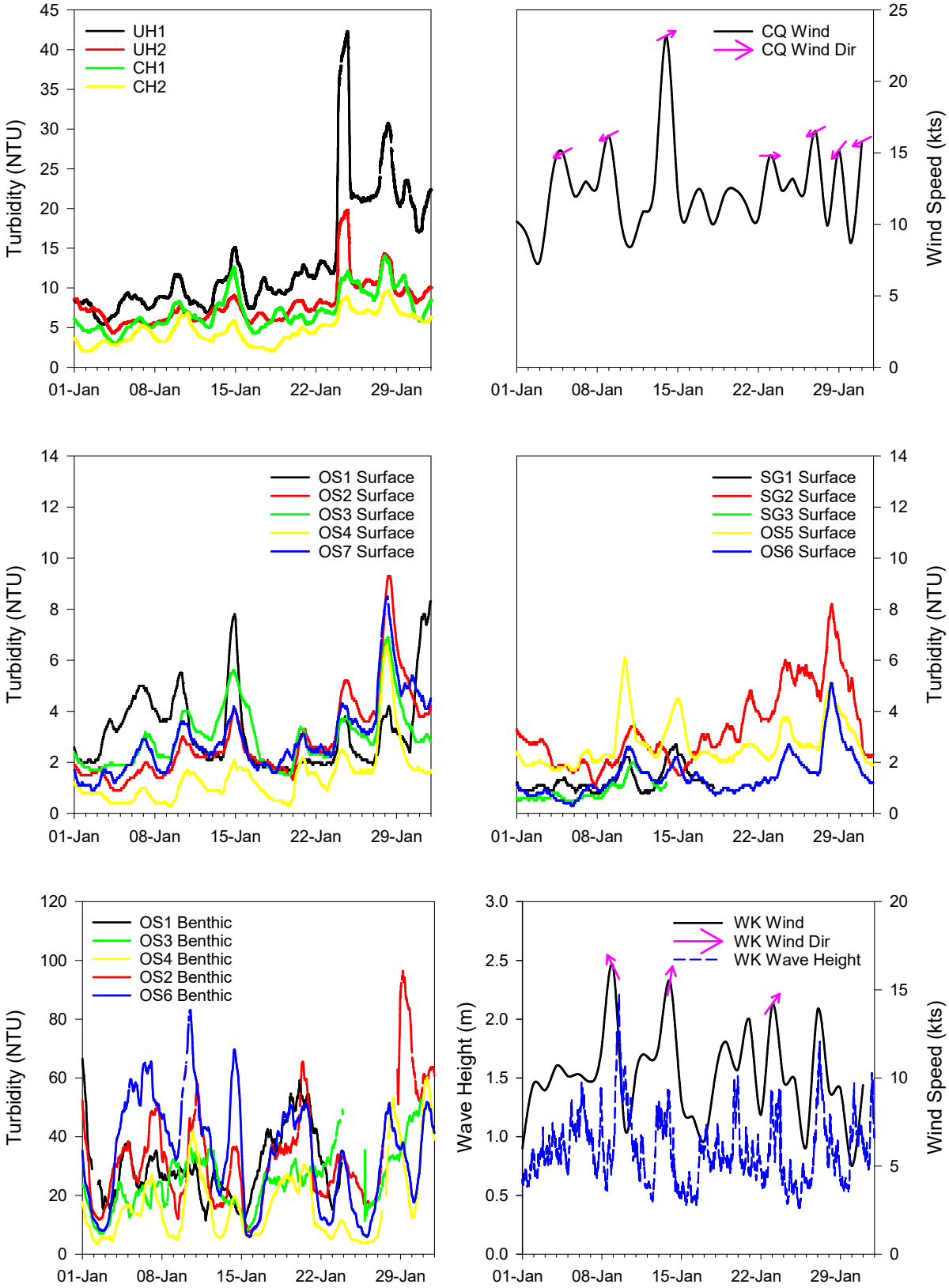

Figure 5 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

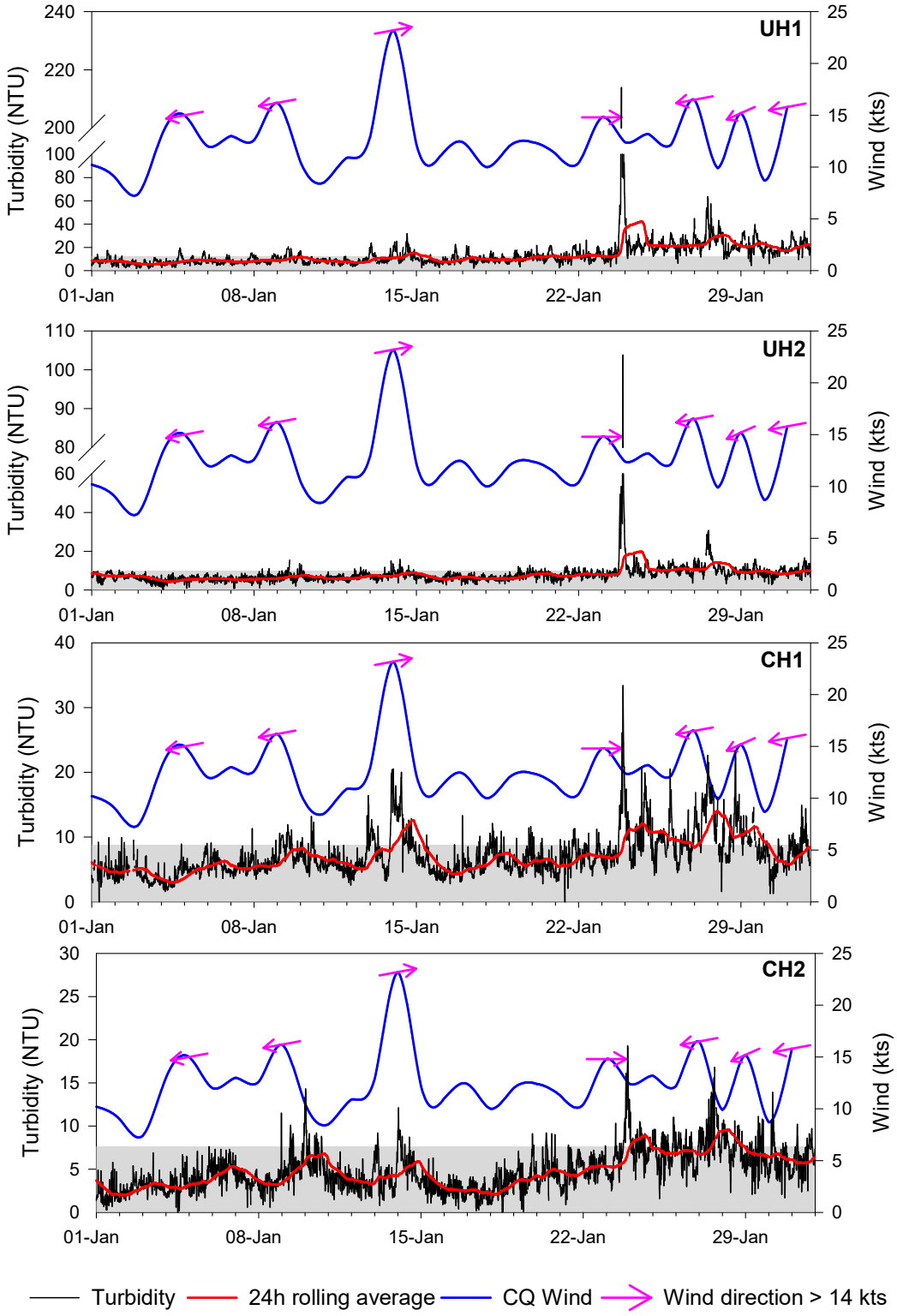

Figure 6 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

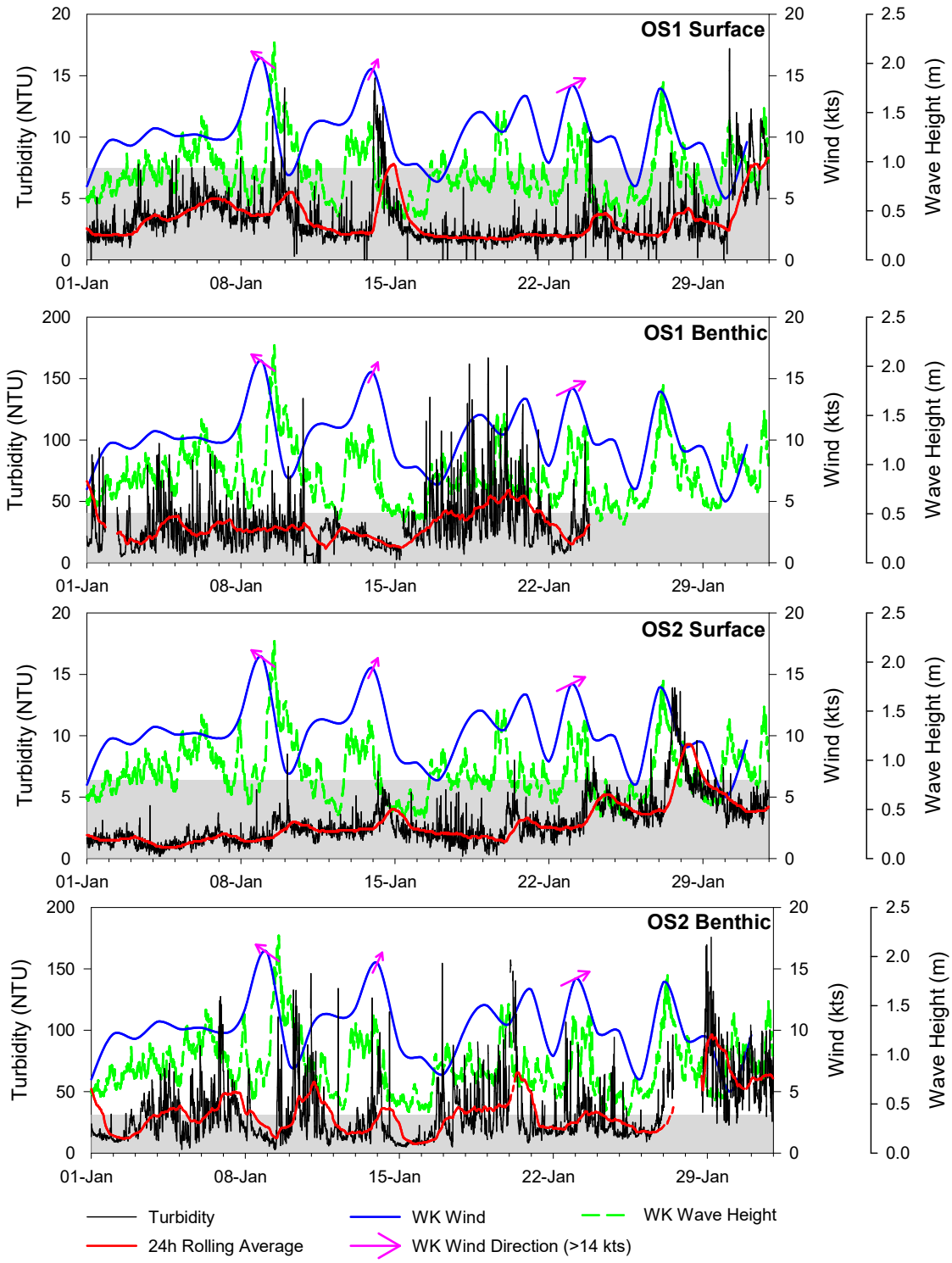

Figure 7 Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

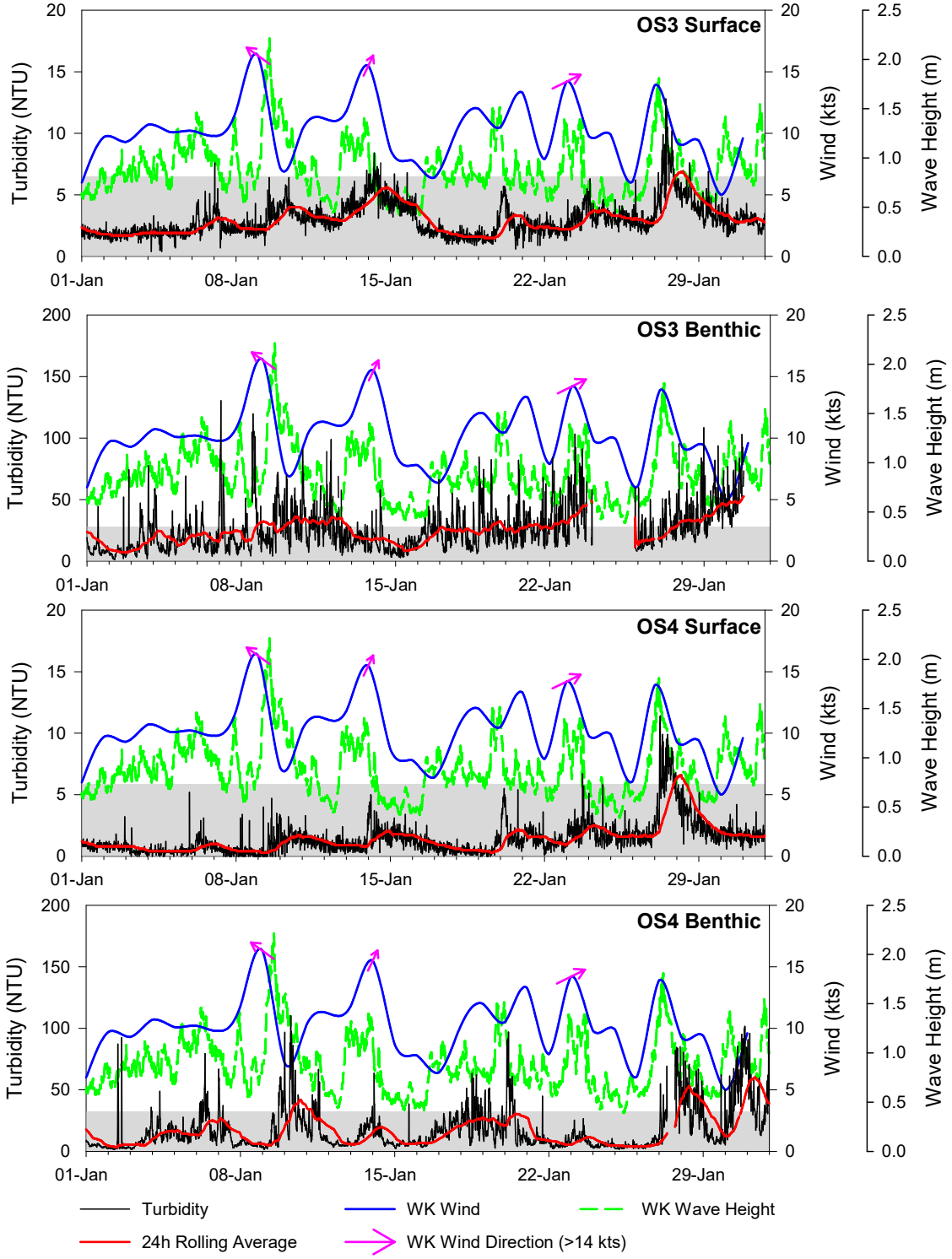

Figure 8 Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

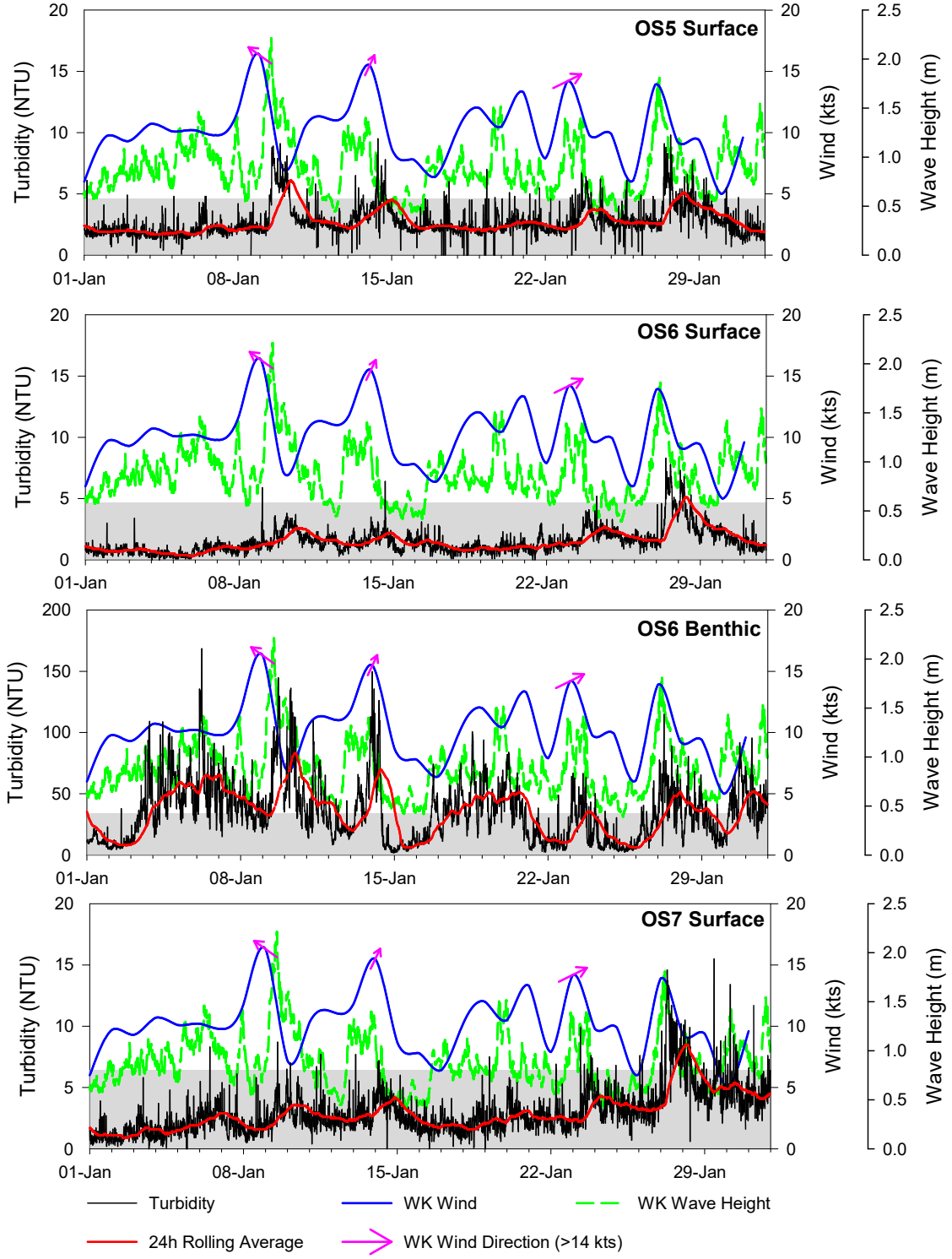

Figure 9 Surface turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

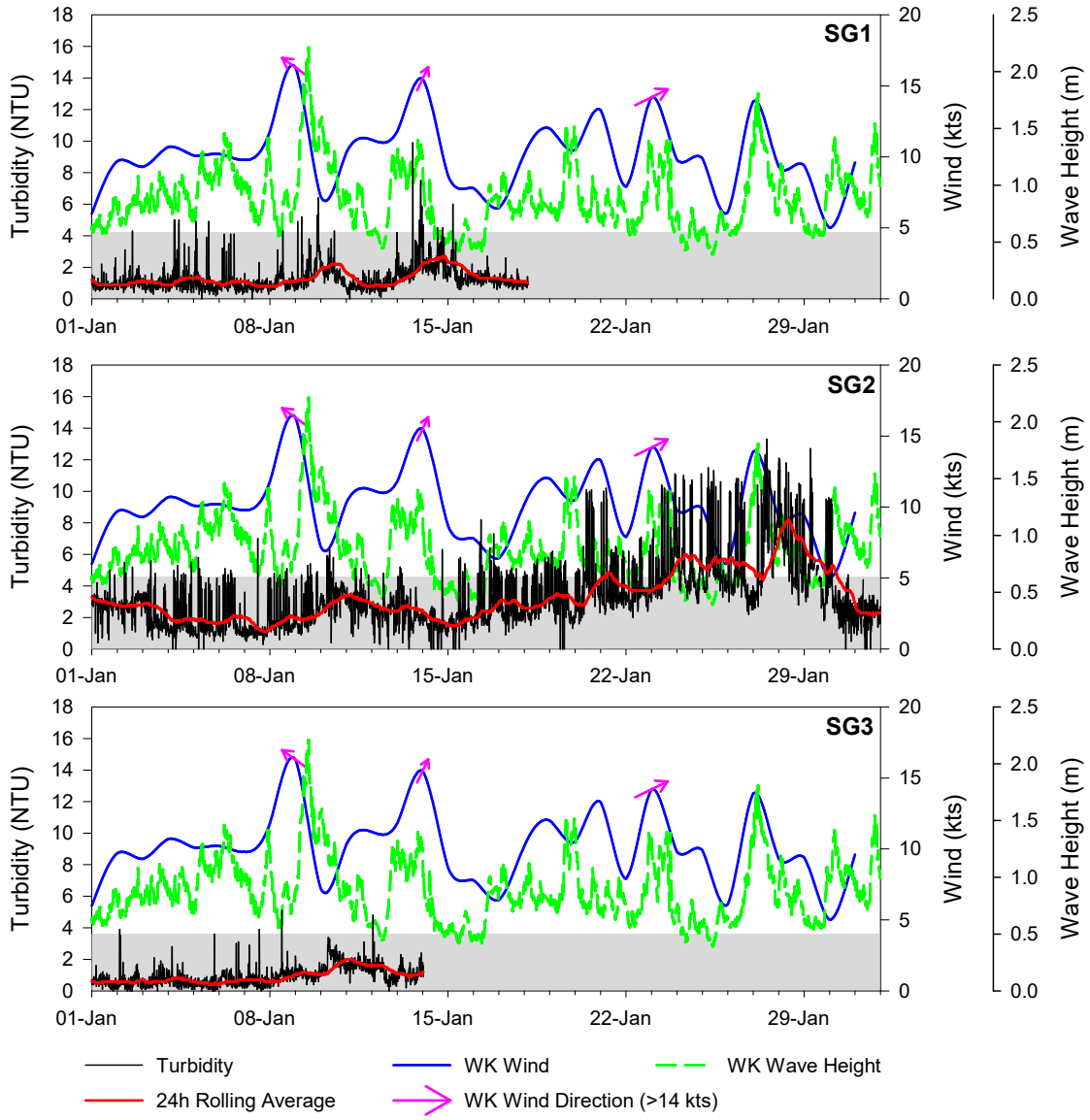

Figure 10 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.

Comparison to Baseline:

Mean surface turbidity and higher order percentile statistics from the upper harbour sites during January were similar to or greater than surface baseline conditions (Table 3), mostly due to elevated turbidity conditions on 24 January continuing for the remainder of the month (Figure 6). The remaining monitoring locations all indicate turbidity conditions typically below the baseline monitoring period average (Tables 4 and 5, Figures 7 to 10). Post-dredge data acquisition from CH1 had previously indicated elevated turbidity conditions at CH1, however, in a similar manner to the December report, mean surface turbidity and higher order percentile statistics from January were below average baseline conditions (Table 3).

3.2.2 Temperature

Warmer ambient air temperatures experienced during January resulted in further warming of the surface waters, with monthly means ranging from 18.1 to 19.9°C (Table 6), compared to 16.3 to 17.5°C in December. Similar to previous observations, the shallower waters of the upper and central harbour displayed the warmest mean temperatures with monthly means of over 19°C. Where data were available, all surface sites displayed cooling of up to 3°C on 14 January, coinciding with maximum monthly rainfall of 13.6 mm (Figures 11 and 12). This cooling was particularly notable at sites OS3, OS4 and OS6 (Figure 12). For the remainder of the month, all surface temperatures displayed a warming trend to values similar to, or above temperatures recorded at the beginning of the month.

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 once again several degrees 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). During the first half of January, benthic temperatures at OS1 and OS2 were up to 3°C warmer than at the more exposed sites at OS3, OS4 and OS6 (Figure 12). Interestingly these two sites also displayed cooling associated with the rainfall event on 14 January that may indicate strong vertical mixing within the water column at these sites. From 21 January, the rate of benthic warming at OS3, OS4 and OS6 increased and the spatial difference between these sites and OS1 and OS2 declined (Figure 12).

Table 6 Mean temperature at inshore, spoil ground and offshore water quality sites during January 2019.
Values are means ± se (n = 1252 to 2976).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	19.9 ± 0.0	–
UH2	19.6 ± 0.0	–
CH1	19.2 ± 0.0	–
CH2	19.2 ± 0.0	–
SG1*	18.2 ± 0.0	–
SG2	18.1 ± 0.0	–
SG3*	18.5 ± 0.0	–
OS1	19.0 ± 0.0	17.4 ± 0.0
OS2	18.7 ± 0.0	16.6 ± 0.0
OS3	18.2 ± 0.0	16.2 ± 0.0
OS4	18.1 ± 0.0	16.3 ± 0.0
OS5	18.4 ± 0.0	–
OS6	18.3 ± 0.0	15.8 ± 0.0
OS7	18.8 ± 0.0	–

**Limited deployments for SG1 and SG3*

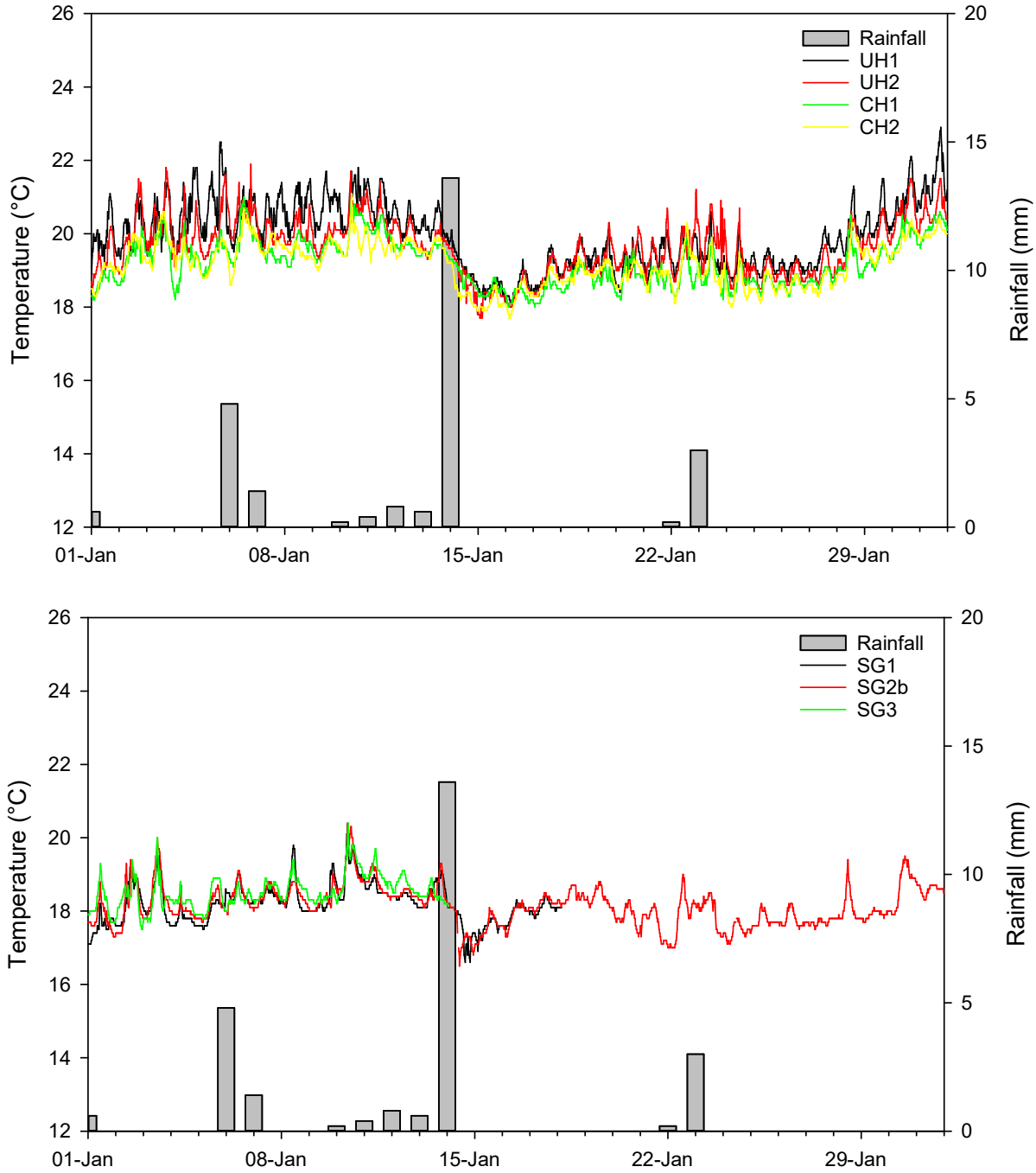

Figure 11 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during January 2019.

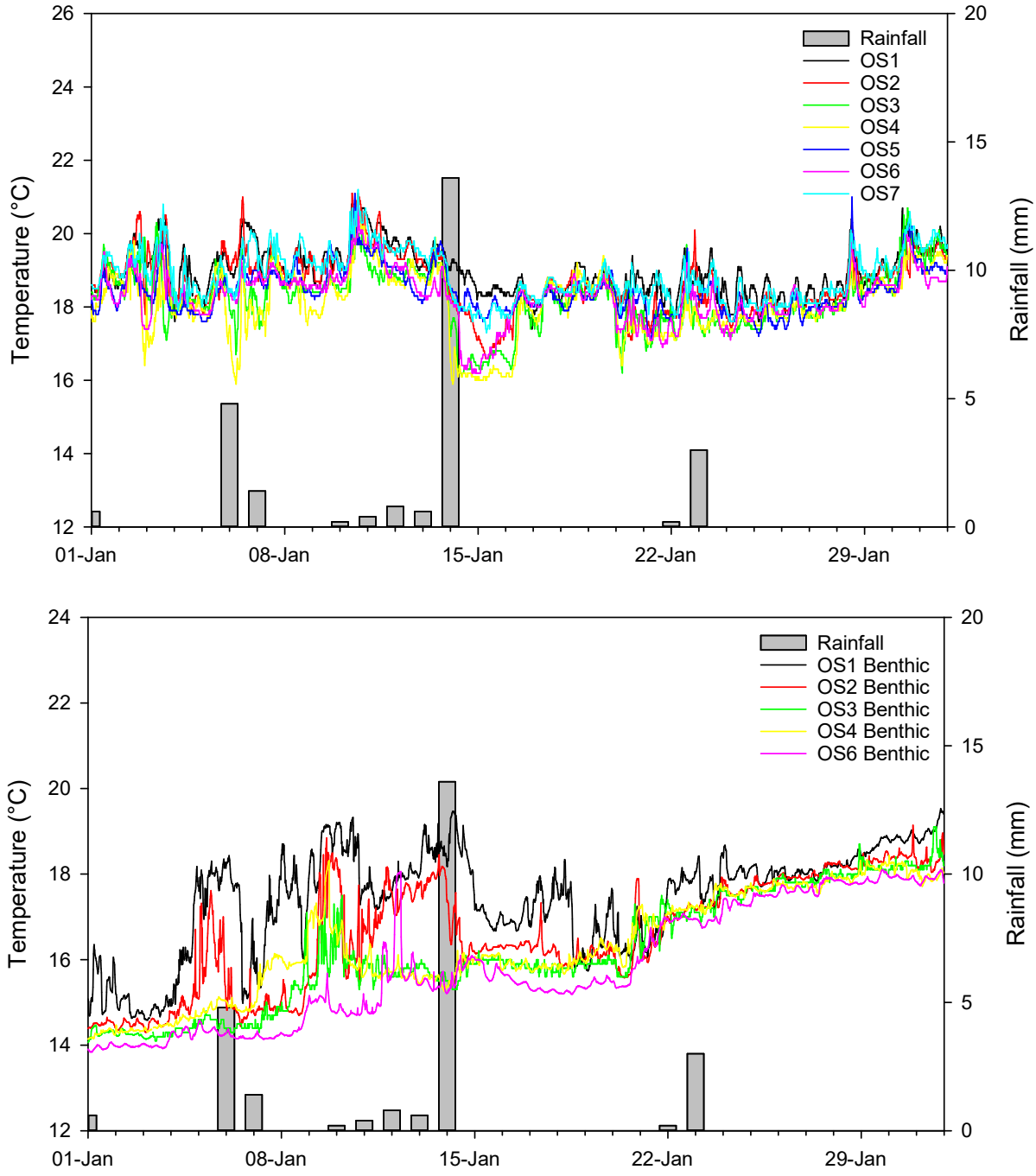

Figure 12 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites during January 2019.

3.2.3 pH

Surface pH data collected during January indicates slightly higher pH at the spoil ground and OS6 (8.1 to 8.2), with the remaining sites varying between 8.0 and 8.1 (Table 7). Temporally, surface pH did not appear to display any notable trends, with no strong impact of the month's rainfall events (Figures 13 and 14). Diurnal variations at CH2 did increase towards the end of the month which may be a reflection in the balance of photosynthesis (increases pH) and respiration (decreases pH) in the water column.

Benthic pH was lower than at the surface ranging from 7.8 to 8.1 (Table 7). As expected, benthic pH appeared relatively consistent across the month (Figure 14), due to the reduced influence of photosynthesis at depth. Interestingly, pH displayed a period of elevated values from 14 to 26 January, commencing at the same time as elevated inshore rainfall.

Table 7 Mean pH at inshore, spoil ground and offshore water quality sites during January 2019. *Values are means ± se (n = 1252 to 2975).*

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*	8.2 ± 0.0	–
SG2	8.2 ± 0.0	–
SG3*	8.1 ± 0.0	–
OS1	8.0 ± 0.0	7.9 ± 0.0
OS2	8.0 ± 0.0	7.9 ± 0.0
OS3	8.1 ± 0.0	7.9 ± 0.0
OS4	8.1 ± 0.0	7.8 ± 0.0
OS5	8.0 ± 0.0	–
OS6	8.2 ± 0.0	8.1 ± 0.0
OS7	8.1 ± 0.0	–

**Limited deployments for SG1 and SG3*

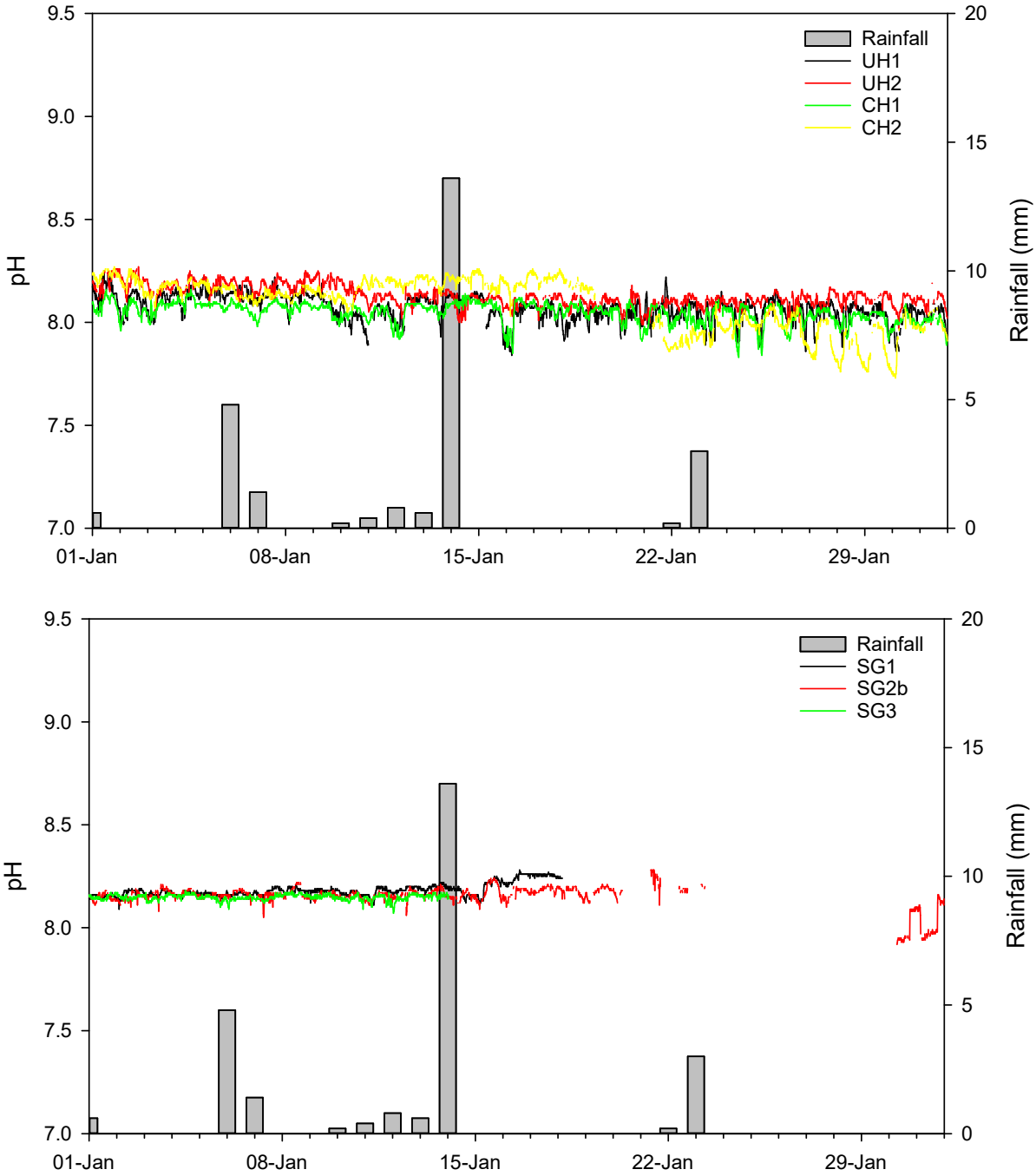

Figure 13 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during January 2019.

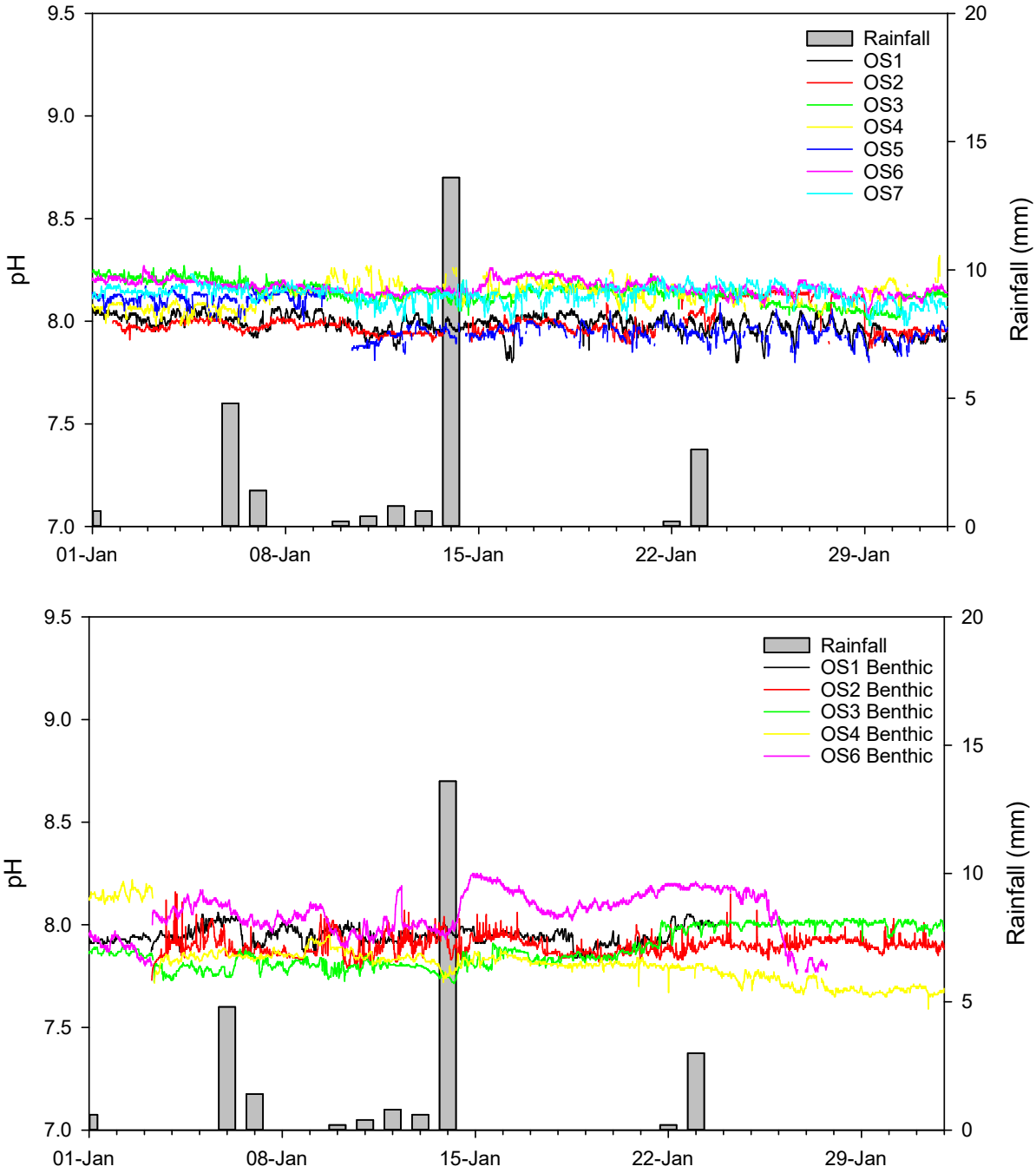

Figure 14 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at offshore water quality sites during January 2019.

3.2.4 Conductivity

Surface conductivity in January ranged from 51.7 mS/cm at OS1 to 54.7 mS/cm at SG2 (Table 8), notably higher than the monthly mean values calculated for December. Within the upper and central harbour, conductivity remained relatively stable throughout January, with no surface freshening recorded following rainfall events at Cashin Quay (Figure 15). At the northerly spoil ground monitoring site, SG1, declines in surface conductivity were recorded around 8, 10 and 14 January (Figure 15), with similar freshening events recorded at OS5 and OS1 (OS1 to a lesser extent) (Figure 16). This spatial pattern of reduced conductivity is indicative of freshwater outflow from the Waimakariri River being advected southwards towards Lyttelton Harbour, and potentially localised rainfall events.

Benthic waters 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. Rainfall events recorded at Cashin Quay did not result in declines in conductivity near the benthos, due to less dense fresh water being restricted to the surface (Figure 16).

Table 8 Mean conductivity at inshore, spoil ground and offshore water quality sites during January 2019.
Values are means ± se (n = 1252 to 2974).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	52.6 ± 0.0	–
UH2	52.8 ± 0.0	–
CH1	52.6 ± 0.0	–
CH2	53.1 ± 0.0	–
SG1*	54.0 ± 0.0	–
SG2	54.7 ± 0.0	–
SG3*	54.5 ± 0.0	–
OS1	51.7 ± 0.0	54.1 ± 0.0
OS2	53.5 ± 0.0	54.5 ± 0.0
OS3	53.8 ± 0.0	55.8 ± 0.0
OS4	54.6 ± 0.0	56.4 ± 0.0
OS5	52.9 ± 0.0	–
OS6	53.7 ± 0.0	54.8 ± 0.0
OS7	53.4 ± 0.0	–

**Limited deployments for SG1 and SG3*

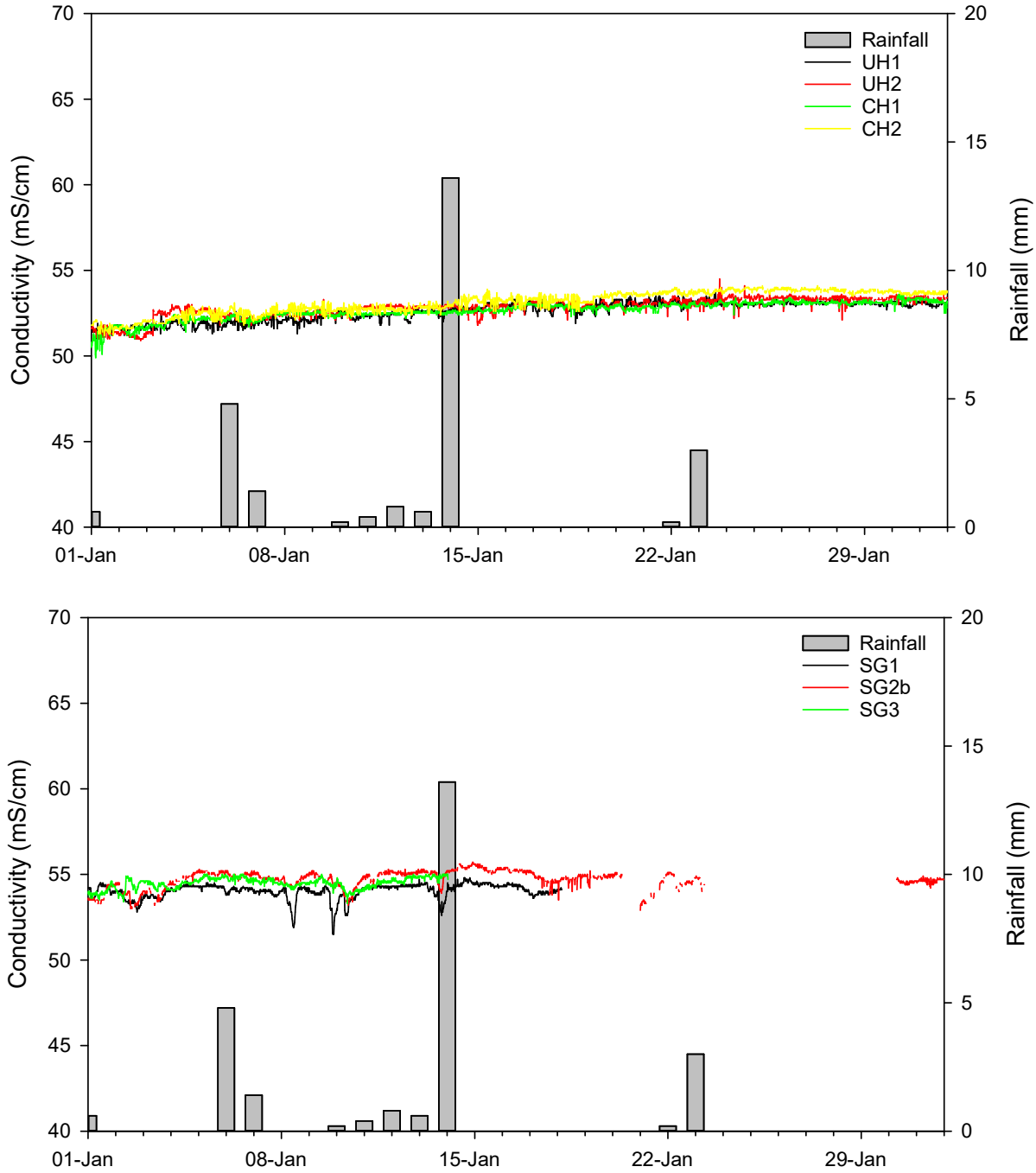

Figure 15 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during January 2019.

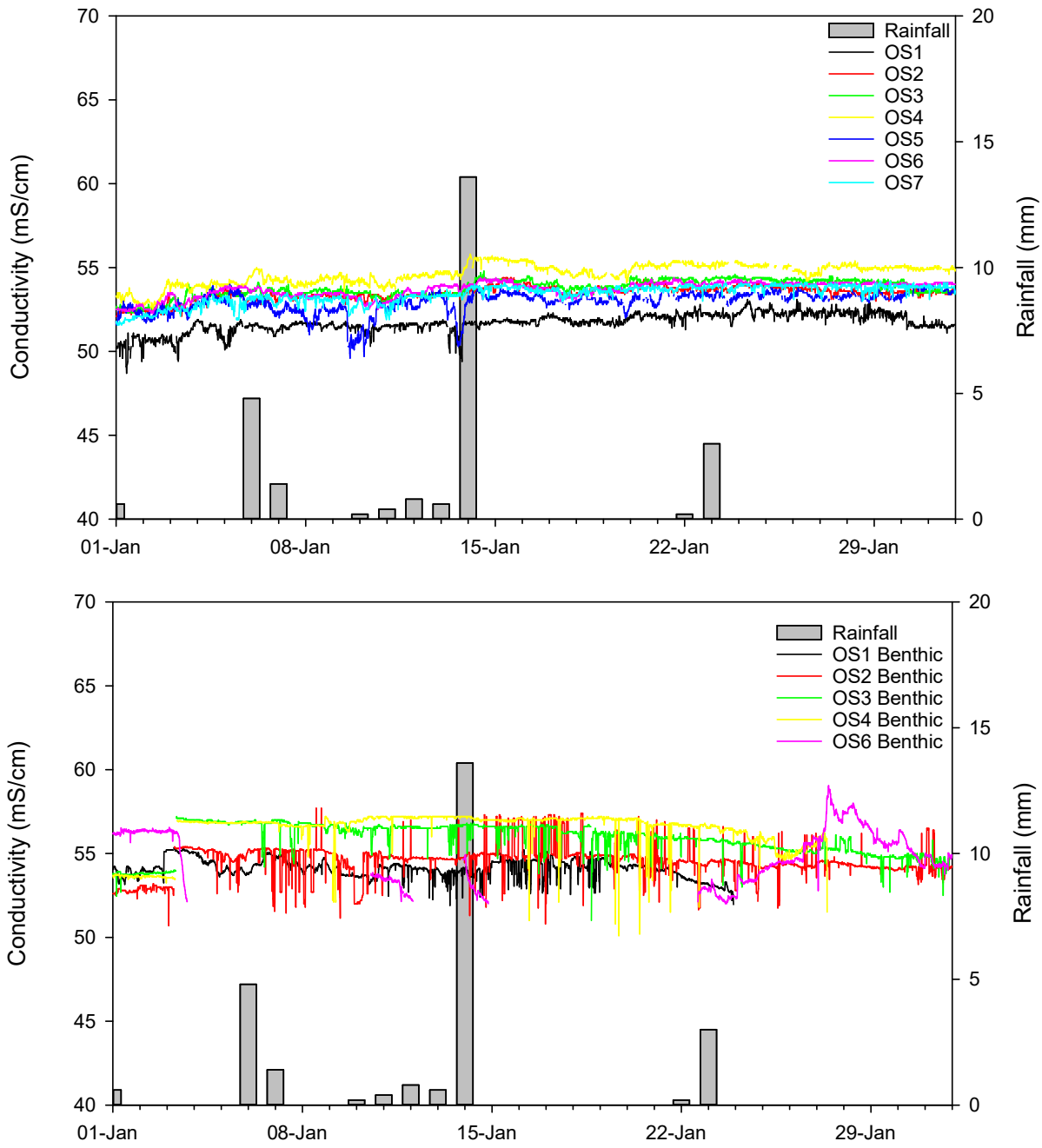

Figure 16 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites during January 2019.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in January ranged from 91 to 103% saturation (Table 9), similar to values recorded in December. Diurnal fluctuations in DO were particularly pronounced at the northern inner harbour sites, especially at UH1 where night time concentrations dropped to as low as 50% saturation (Figure 17). Diurnal variability was also high in the nearshore environment, with concentrations declining following rainfall on 14 January (Figure 18). Further offshore, diurnal variability was reduced with both SG1 and SG2 displaying slightly reduced DO concentrations following the 14 January rainfall event. Unfortunately, no data were available from SG3 during this time.

As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings ranging from 82 to 89% saturation (Table 9), due to reduced photosynthesis (producing less oxygen) occurring at depth. Temporal variability in benthic DO concentrations was high, with elevated benthic DO appearing to correlate well with periods of increased wind and/or wave activity. Additional energy provided by elevated winds and waves would allow strong vertical mixing to occur at the monitoring locations, resulting in high oxygen waters from the surface being intermixed with benthic waters and raising the overall benthic DO concentration. Temporal variations were particularly high at OS6 (Figure 18), which may be related to its more exposed, offshore location.

Table 9 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during January 2019.
Values are means ± se (n = 1252 to 2976).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	91 ± 0	–
UH2	96 ± 0	–
CH1	91 ± 0	–
CH2	96 ± 0	–
SG1*	100 ± 0	–
SG2	101 ± 0	–
SG3*	101 ± 0	–
OS1	94 ± 0	89 ± 0
OS2	99 ± 0	83 ± 0
OS3	103 ± 0	87 ± 0
OS4	101 ± 0	89 ± 0
OS5	100 ± 0	–
OS6	101 ± 0	82 ± 0
OS7	98 ± 0	–

**Limited deployments for SG1 and SG3*

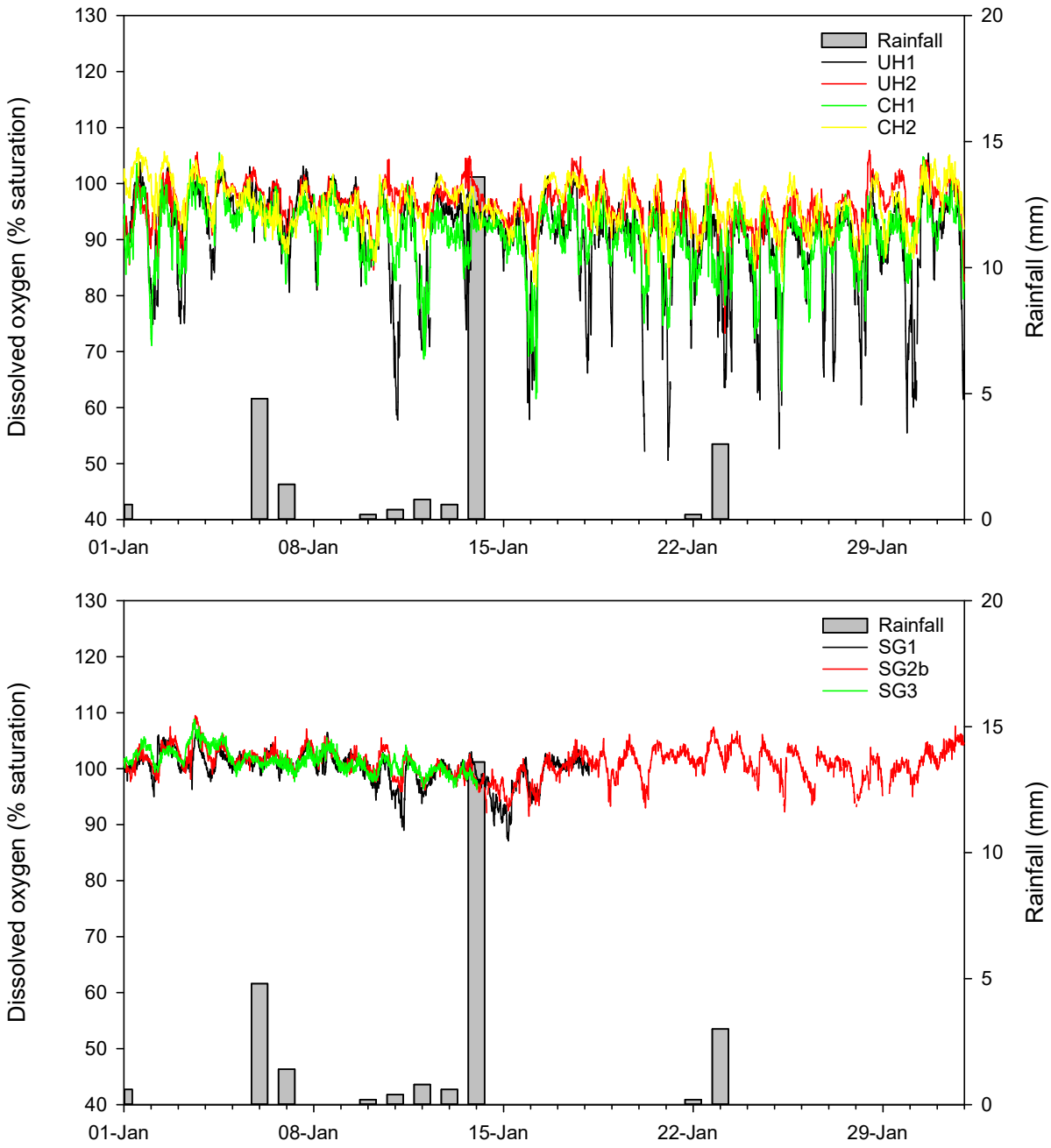

Figure 17 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during January 2019.

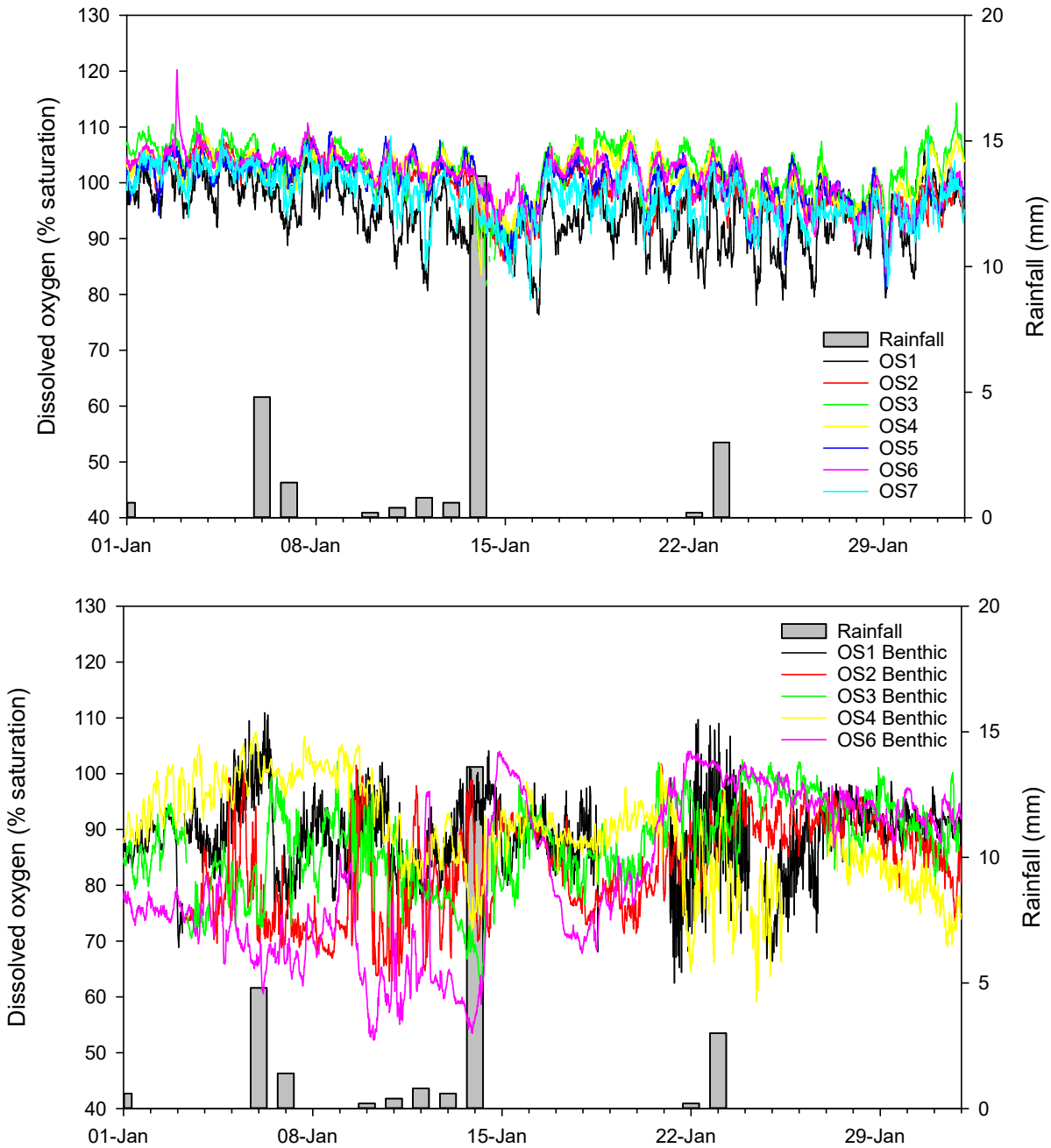

Figure 18 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites during January 2019.

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 15 and 16 January. 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 vertical water column. During December 2018, conductivity at the southern site of CH2 displayed a slight freshening in the surface 6 m that was not observed at the remaining inner harbour sites. This pattern was not repeated during the January sampling events, with conductivity at this site displaying the highest values within the upper and central harbour (Figure 19). 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 seabed) providing energy for sediment resuspension.

In a similar manner to temporal trends at CH2, the cooler, higher conductivity benthic waters reported at the nearshore sites during December 2018 were also absent from the January vertical profiles. Physicochemical data instead suggests that deep vertical mixing was occurring and thus surface-benthic differences were effectively eliminated (Figure 20). Turbidity at OS1 and OS3 were slightly elevated near the benthos, however, the absolute values remained within the range typically experienced around Lyttelton Harbour.

Further offshore, at OS5, OS6 and the spoil ground sites, benthic waters were characterised by slightly cooler temperatures and higher conductivity values (Figure 21). Spatially, surface waters at SG3 (the most southerly offshore monitoring station) were notably cooler than the remaining offshore locations, however, conductivity readings remained comparable (Figure 21, Table 12). Dissolved oxygen concentrations and pH also displayed slight declines towards the benthos, with slight increases in benthic turbidity at OS6 and SG2.

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). Across the spoil ground, euphotic depth ranged from 15.4 m to 18.6 m during the January sampling (Table 12), which is notably lower than that calculated for December. There were no exceedances of WQG for the sub-surface during the January sampling campaign.

Table 10 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the January 2019 sampling event.
Values are means ± se (n = 3 to 6 for sub-surface, n = 18 to 32 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	15/01/2019 08:33	Sub-surface	18.4 ± 0.0	8.0 ± 0.0	53.3 ± 0.0	96 ± 0	6.1 ± 0.1	19	1.1 ± 0.0	4.1
		Whole column	18.4 ± 0.0	8.0 ± 0.0	53.3 ± 0.0	95 ± 0	6.7 ± 0.2	–		
UH2	15/01/2019 08:43	Sub-surface	18.3 ± 0.0	8.0 ± 0.0	53.2 ± 0.0	95 ± 0	6.7 ± 0.2	6	1.0 ± 0.1	4.5
		Whole column	18.3 ± 0.0	8.0 ± 0.0	53.2 ± 0.0	95 ± 0	6.5 ± 0.1	–		
UH3	15/01/2019 08:16	Sub-surface	17.9 ± 0.0	8.0 ± 0.0	53.0 ± 0.0	97 ± 0	6.7 ± 0.1	18	1.2 ± 0.1	3.7
		Whole column	17.9 ± 0.0	8.0 ± 0.0	53.1 ± 0.0	97 ± 0	7.3 ± 0.1	–		
CH1	15/01/2019 09:08	Sub-surface	18.3 ± 0.0	8.0 ± 0.0	53.3 ± 0.0	97 ± 0	5.8 ± 0.9	10	0.9 ± 0.1	5.0
		Whole column	18.3 ± 0.0	8.0 ± 0.0	53.4 ± 0.0	96 ± 0	6.4 ± 0.8	–		
CH2	15/01/2019 09:00	Sub-surface	17.7 ± 0.0	8.0 ± 0.0	53.8 ± 0.0	97 ± 0	2.6 ± 0.1	5	0.6 ± 0.1	7.9
		Whole column	17.7 ± 0.0	8.1 ± 0.0	53.9 ± 0.0	95 ± 1	4.9 ± 1.9	–		
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 January 2019 sampling event. *Values are means ± se (n =0 to 6 for sub-surface, mid and benthos, n = 20 to 38 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	15/01/2019 09:24	Sub-surface	18.3 ± 0.0	8.0 ± 0.0	53.6 ± 0.0	96 ± 0	2.8 ± 0.0	7	0.6 ± 0.0	7.5
		Mid	17.9 ± 0.0	8.1 ± 0.0	53.7 ± 0.0	95 ± 0	2.3 ± 0.1	5		
		Benthos	17.0 ± 0.1	8.0 ± 0.0	54.1 ± 0.0	89 ± 1	17 ± 5	41		
		Whole column	17.9 ± 0.1	8.0 ± 0.0	53.7 ± 0.0	94 ± 1	5.3 ± 1.4	–		
OS2	16/01/2019 07:36	Sub-surface	17.3 ± 0.0	8.1 ± 0.0	53.9 ± 0.0	98 ± 0	0.7 ± 0.1	<3	0.4 ± 0.0	12.5
		Mid	–	–	–	–	–	<3		
		Benthos	16.2 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	94 ± 0	3.5 ± 0.8	4		
		Whole column	16.8 ± 0.1	8.1 ± 0.0	54.1 ± 0.0	96 ± 0	1.3 ± 0.3	–		
OS3	16/01/2019 07:14	Sub-surface	16.4 ± 0.0	8.1 ± 0.0	54.2 ± 0.0	100 ± 0	4.1 ± 1.6	<3	0.5 ± 0.0	10.1
		Mid	16.3 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	98 ± 1	0.8 ± 0.1	<3		
		Benthos	15.7 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	94 ± 0	14 ± 7	4		
		Whole column	16.2 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	97 ± 0	4.4 ± 1.3	–		
OS4	16/01/2019 06:46	Sub-surface	16.0 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	100 ± 0	0.3 ± 0.0	<3	0.3 ± 0.0	14.5
		Mid	15.9 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	98 ± 0	0.7 ± 0.0	4		
		Benthos	15.7 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	98 ± 0	2.2 ± 0.2	3		
		Whole column	15.9 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	98 ± 0	1.0 ± 0.1	-		
OS7	16/01/2019 07:49	Sub-surface	17.8 ± 0.0	8.1 ± 0.0	53.6 ± 0.0	98 ± 0	1.6 ± 0.0	5	0.5 ± 0.1	9.0
		Mid	17.4 ± 0.1	8.1 ± 0.0	54.0 ± 0.0	97 ± 1	1.2 ± 0.0	<3		
		Benthos	16.4 ± 0.0	8.1 ± 0.0	54.3 ± 0.0	92 ± 0	6.2 ± 0.3	4		
		Whole column	17.3 ± 0.1	8.1 ± 0.0	53.9 ± 0.0	96 ± 1	2.7 ± 0.4	–		
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 January 2019 sampling event.
Values are means ± se (n = 5 to 6 for sub-surface, mid and benthos, n = 36 to 46 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	15/01/2019 09:39	Sub-surface	17.6 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	99 ± 0	1.1 ± 0.1	4	0.4 ± 0.0	11.8
		Mid	17.5 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	98 ± 0	1.1 ± 0.1	3		
		Benthos	16.5 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	96 ± 0	1.5 ± 0.2	4		
		Whole column	17.3 ± 0.1	8.1 ± 0.0	54.0 ± 0.0	98 ± 0	1.1 ± 0.1	–		
OS6	16/01/2019 06:03	Sub-surface	17.4 ± 0.0	8.1 ± 0.0	53.8 ± 0.0	98 ± 0	0.8 ± 0.0	4	0.3 ± 0.0	13.7
		Mid	16.5 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	95 ± 0	0.4 ± 0.0	<3		
		Benthos	15.5 ± 0.0	8.0 ± 0.0	54.4 ± 0.0	90 ± 0	6.6 ± 1.2	7		
		Whole column	16.6 ± 0.1	8.1 ± 0.0	54.1 ± 0.0	96 ± 0	1.7 ± 0.4	–		
SG1	15/01/2019 10:10	Sub-surface	17.4 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	102 ± 0	0.0 ± 0.0	<3	0.3 ± 0.0	15.4
		Mid	16.5 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	97 ± 1	0.2 ± 0.1	<3		
		Benthos	15.4 ± 0.0	8.0 ± 0.0	54.4 ± 0.0	89 ± 0	9.9 ± 7.5	7		
		Whole column	16.6 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	97 ± 1	1.5 ± 0.9	–		
SG2b	15/01/2019 10:36	Sub-surface	17.3 ± 0.0	8.1 ± 0.0	54.0 ± 0.0	102 ± 0	0.0 ± 0.0	<3	0.2 ± 0.0	18.6
		Mid	16.8 ± 0.2	8.1 ± 0.0	54.2 ± 0.0	101 ± 0	0.0 ± 0.0	<3		
		Benthos	15.3 ± 0.0	8.1 ± 0.0	54.5 ± 0.0	97 ± 0	8.1 ± 3.9	9		
		Whole column	16.5 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	100 ± 0	1.2 ± 0.6	–		
SG3	16/01/2019 06:24	Sub-surface	16.8 ± 0.0	8.1 ± 0.0	54.1 ± 0.0	101 ± 0	0.2 ± 0.1	<3	0.3 ± 0.0	15.4
		Mid	16.6 ± 0.0	8.1 ± 0.0	54.2 ± 0.0	101 ± 0	0.1 ± 0.0	3		
		Benthos	15.3 ± 0.0	8.1 ± 0.0	54.5 ± 0.0	97 ± 0	2.3 ± 0.3	4		
		Whole column	16.4 ± 0.1	8.1 ± 0.0	54.2 ± 0.0	100 ± 0	0.5 ± 0.1	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

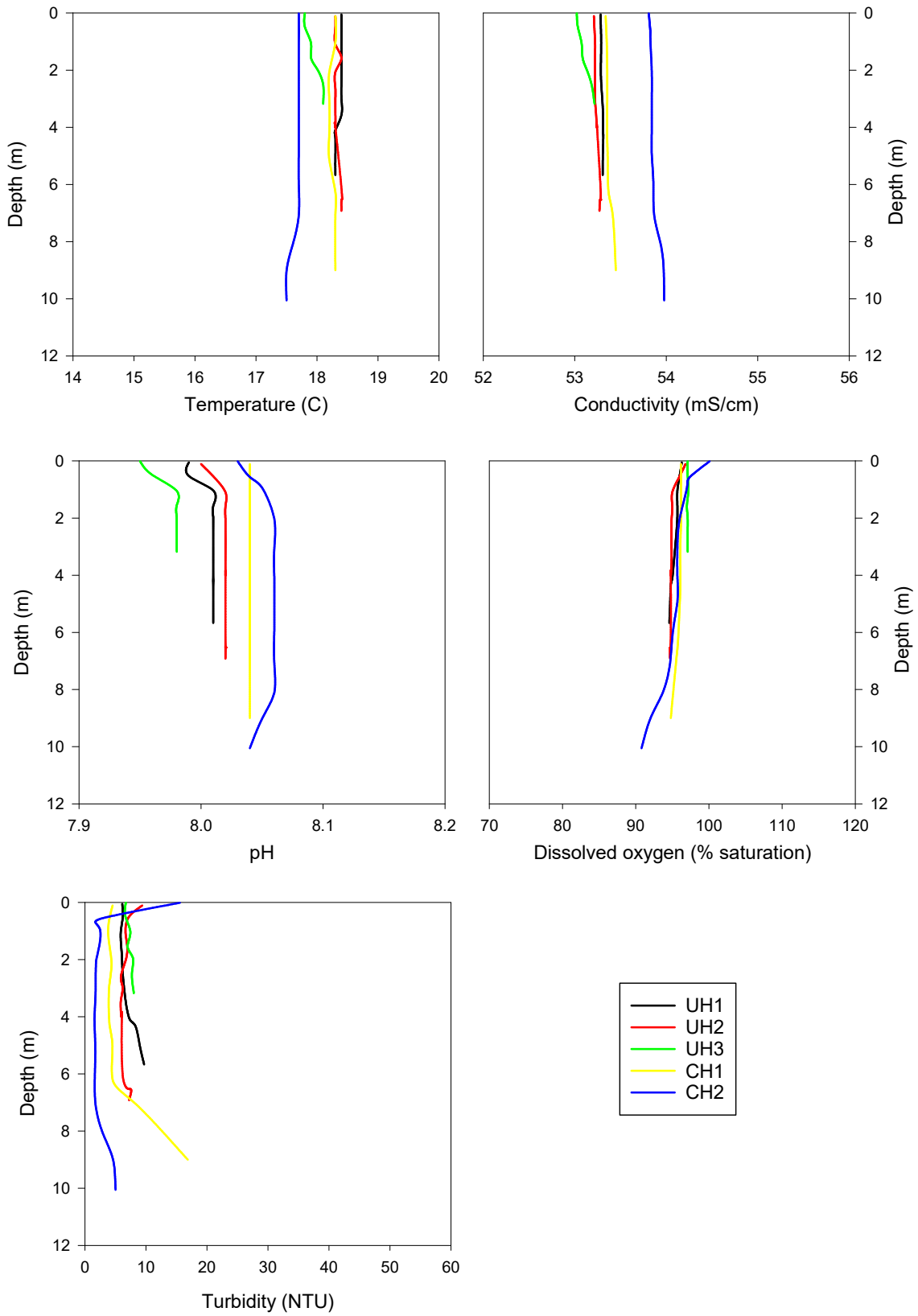

Figure 19 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 15 January 2019.

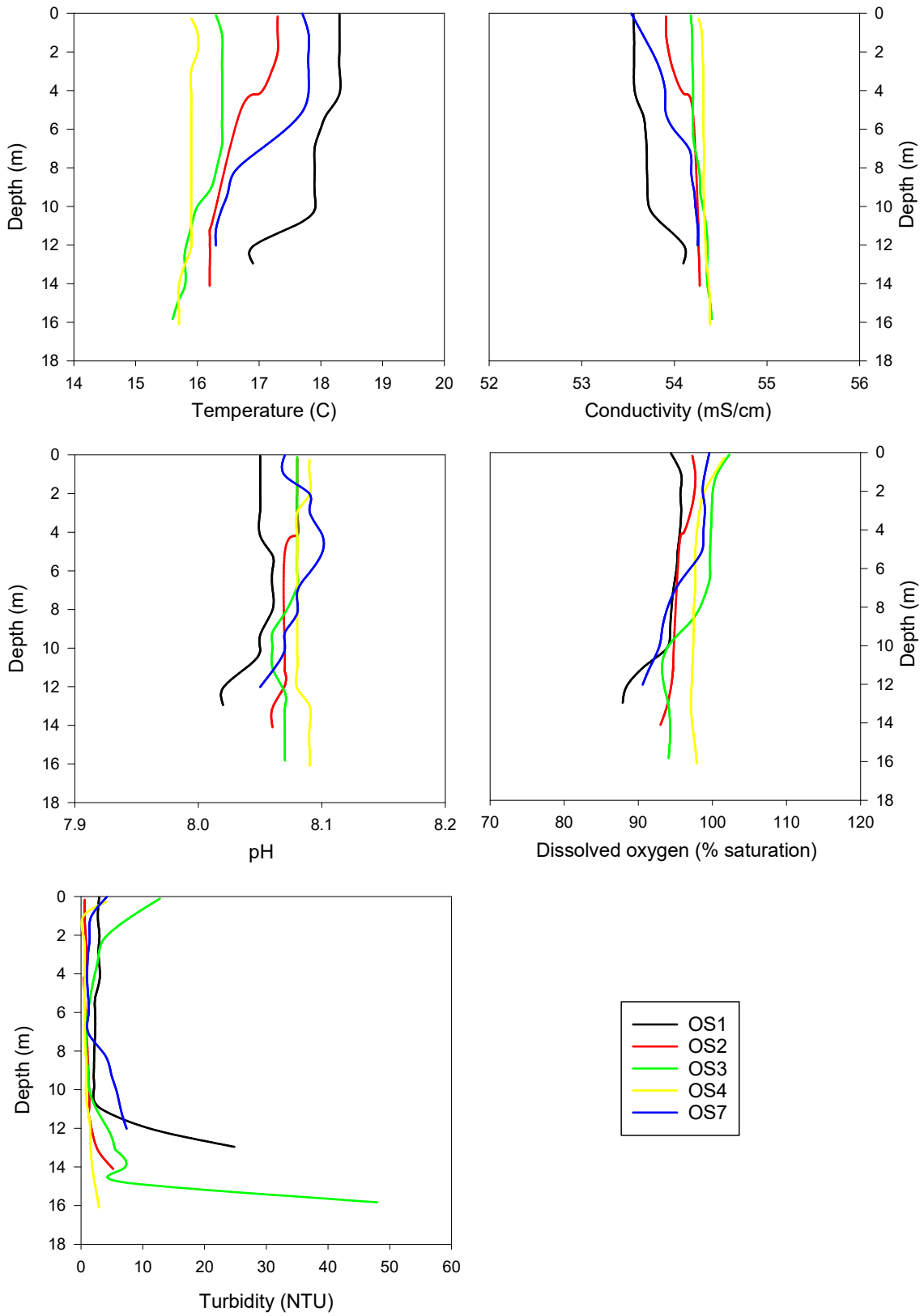

Figure 20 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 15 and 16 January 2019.

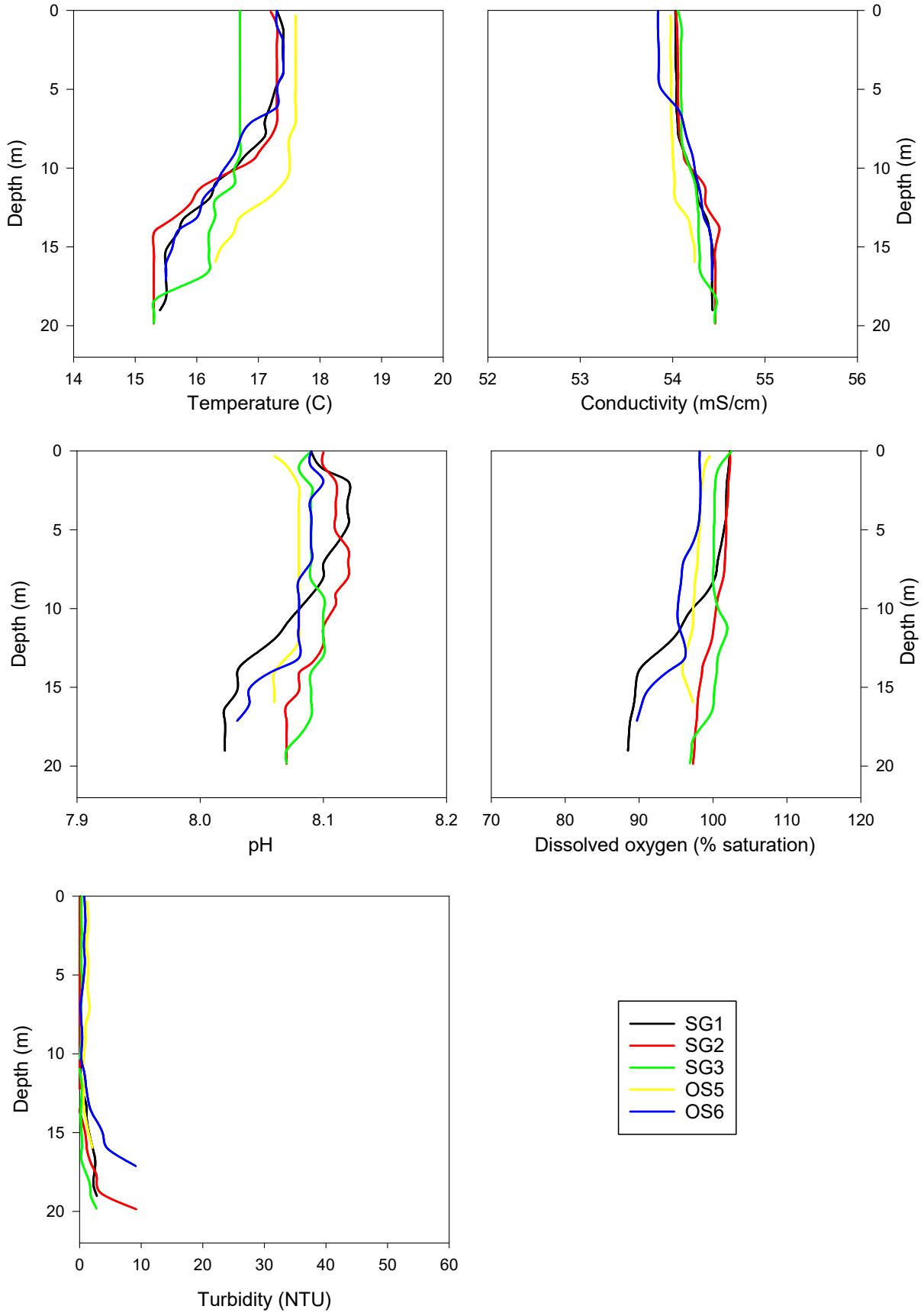

Figure 21 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 15 and 16 January 2019.

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 (3 January) 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 21,900 to 55,700 mmol/m^2/day (Table 13). This increase from December, particularly within the minimum recorded values, resulted in a January mean TDP of 41,606 mmol/m^2/day; notably larger than that recorded during December 2018 (31,010 mmol/m^2/day).

Surface turbidity levels at both OS2 and OS3 were relatively low during the first week of January, with these clear waters inducing little light attenuation through the water column and allowing correspondingly elevated PAR levels at the benthos. Large peaks in BPAR at both OS2 and OS3 were recorded on 4-5 January and 9 January 2019, reflecting elevated ambient PAR (as measured in Christchurch) and the aforementioned low turbidity levels within the water column (Figure 22). These maximum benthic light intensities of 142 mmol/m^2/day and 90 mmol/m^2/day recorded at OS2 and OS3, respectively (Table 13) are some of the greatest recorded during the monitoring program in Lyttelton Harbour.

During the remainder of the month, BPAR remained elevated compared to previous months, with peaks and troughs correlating with changes in surface turbidity and/or incoming solar radiation as measured in Christchurch. As surface turbidity at the end of the month exceeded 3 NTU, BPAR at OS2 declined, with a similar pattern observed at OS3. Slightly declining surface turbidity values at OS3 during the final few days of the month resulted in elevated BPAR readings of 36 mmol/m^2/day. This peak was not mirrored in the OS2 dataset, where surface turbidity remained around 4 NTU (Figure 22).

Table 13 Total Daily PAR (TDP) statistics during January 2019.
Values are means ± se (n = 30 to 31). Note data from the BPAR exchange day on 3 January 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	-	41,606 ± 1,739	42,000	21,900 – 55,700
OS2	17	18 ± 6	2.3	<0.01 – 142
OS3	14	22 ± 4	14	<0.01 – 90

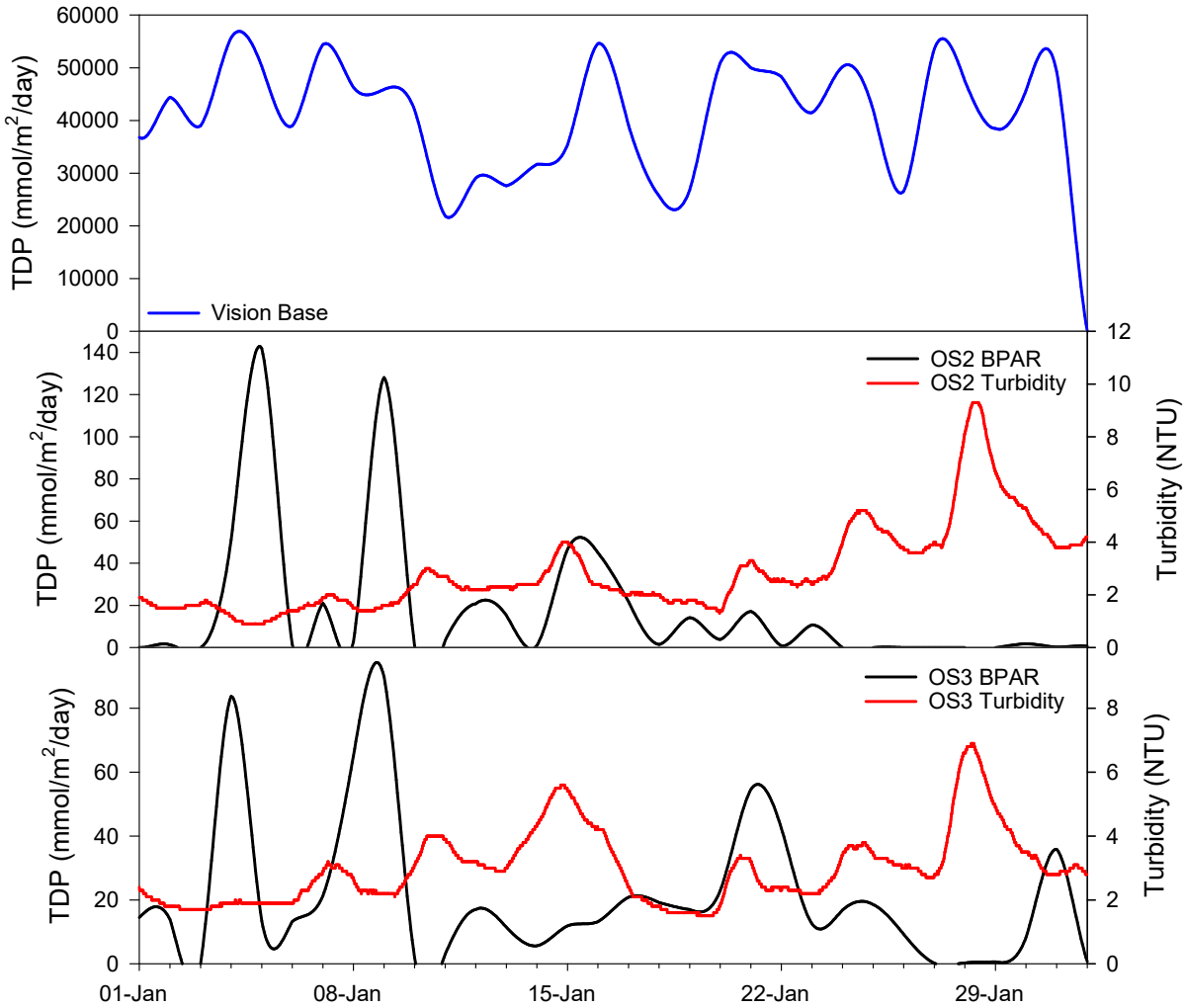

Figure 22 Total daily BPAR at OS2 and OS3 during January 2019 compared to ambient PAR and corresponding surface turbidity.
Note data from the BPAR exchange day on 3 January were not utilized in plots or statistics.

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 three days of the month, when offshore winds and significant wave heights were around 10 knots and 1 m respectively. By midnight on 5 January, rapid deposition had resulted in an elevated bed level of 22 mm under relatively stable wind conditions. This could be an anomaly with potential movement of the unit after exchange on the 3 January. Following this period of sedimentation, bed level then remained relatively stable for the majority of the month, until 21 January when notable sediment deposition once again occurred. Rapid deposition occurred on 27 and 28 January with bed level increasing from 29 mm to 44 mm and a large peak in surface turbidity was also recorded during this time (Figure 23). Over the course of January, bed level at OS2 increased by 42 mm (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, from the 23 January, both altimeters failed to record an echo and following equipment retrieval it is suggested that the frame at UH3 was lying on its site. Interestingly a large peak in surface turbidity was also observed at this time (Figure 23). From the data period available, net bed level at UH3 increased by 7 mm from 1 to 23 January (Table 14).

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

Site	December 2018 Net bed level change (mm)
OS2	+42
UH3	+7*

**Note that UH3 data were only available up until 23 January when both altimeters ceased to gain echo return from the sediment. Upon retrieval on 7 February, the UH3 altus frame was found to be tipped over.*

3.6 Water Samples

Discrete water sampling was conducted on 15 and 16 January 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 January 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 only slightly exceeded at UH1 where concentrations reached 31 µg/L. Dissolved phosphorous concentrations were notably higher during January than December, when the majority of the monitoring sites displayed concentrations below the laboratory limit of reporting. During the January monitoring, concentrations of dissolved reactive phosphorous exceeded the 5 µg/L WQG at all sites except SG1 and SG2b. In a similar manner to the measurements of total phosphorous, the highest concentrations of dissolved phosphorous were recorded in the upper harbour (Table 15).

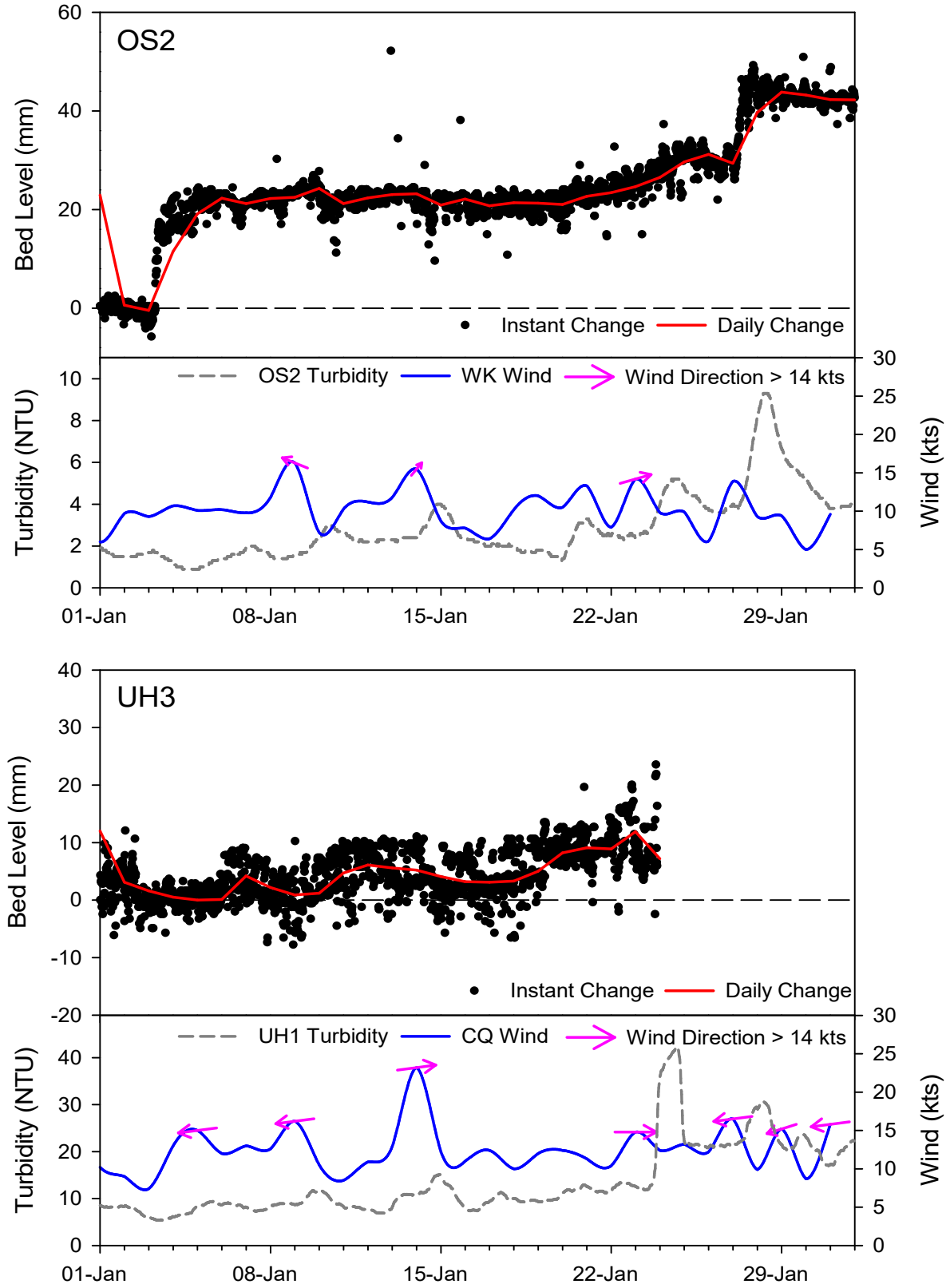

Figure 23 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during January 2019 compared to ambient surface turbidity (24 hour rolling average) wind speed and direction.
Note: Arrows indicate the direction of travel for winds greater than 14 knots. UH3 data from 1 to 23 January only due to underwater frame dislodgement.

Table 15 Concentrations of nutrients and chlorophyll *a* at monitoring sites during January 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	31	15	<300	<200	21	7.9	4.1
UH2	21	13	<300	<200	27	5.5	3.3
UH3	24	14	<300	<200	18	4.6	5.0
CH1	17	9.7	<300	<200	21	5.4	2.9
CH2	15	9.0	<300	<200	20	6.6	2.2
OS1	19	9.4	<300	<200	22	4.9	3.3
OS2	15	7.6	<300	<200	14	5.3	2.9
OS3	17	8.9	<300	<200	18	12	3.9
OS4	13	7.6	<300	<200	23	9.1	1.9
OS5	12	7.1	<300	<200	18	6.2	1.7
OS6	13	8.9	<300	<200	16	5.6	3.5
OS7	14	7.6	<300	<200	17	8.1	2.9
SG1	11	4.4	<300	<200	10	2.9	2.8
SG2	10	3.8	<300	<200	11	4.6	2.5
SG3	15	7.5	<300	<200	14	2.2	3.7
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

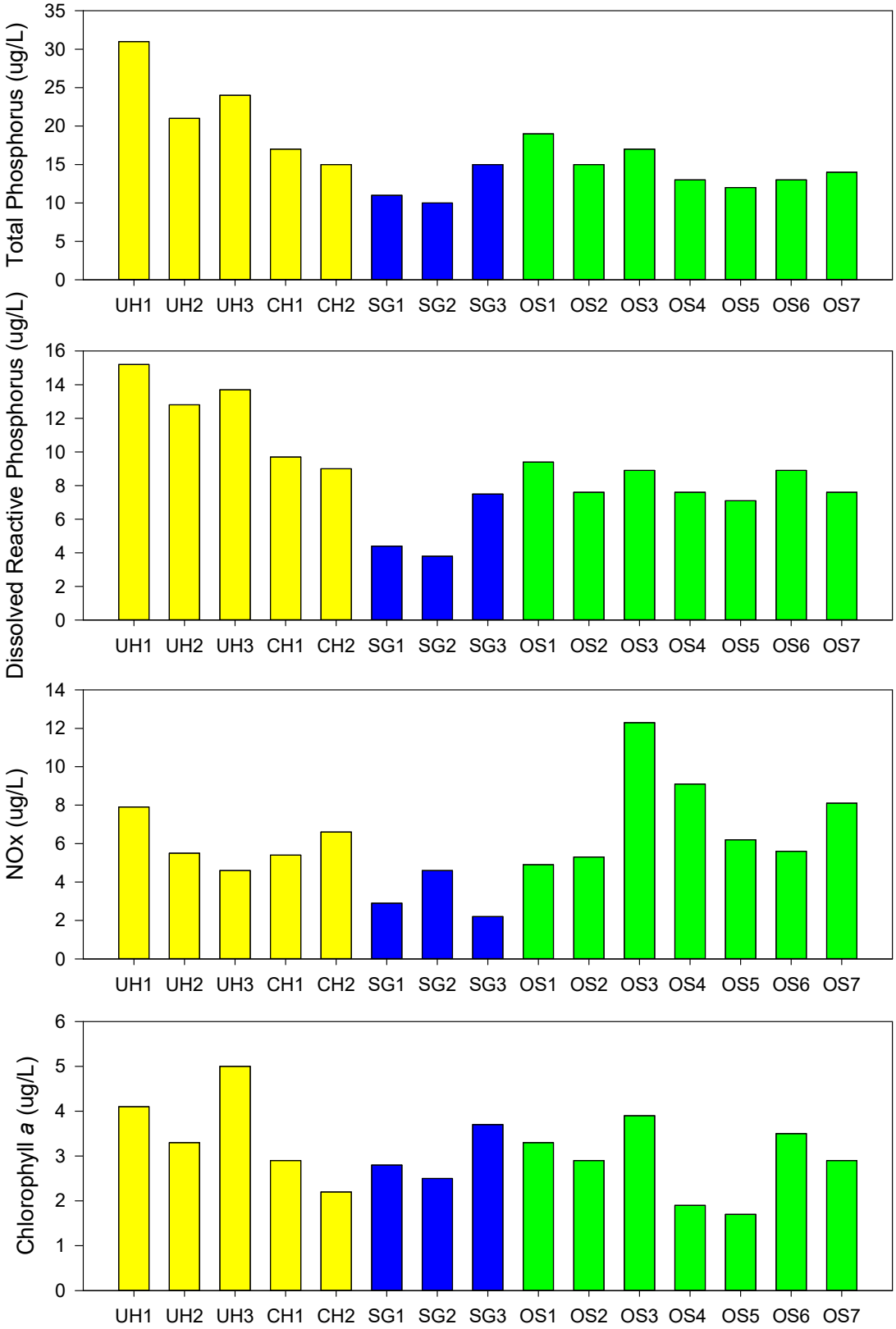

Figure 24 Nutrient and chlorophyll *a* concentrations at monitoring sites during January 2019.
Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN concentrations were not plotted as all or most sites were < LOR.

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 10 to 27 µg/L; concentrations that are greater than those recorded during the December sampling. The applicable WQG (15 µg/L) was exceeded at all the nearshore and inshore sites except OS2. Nitrogen oxides at all sites were below LOR, with concentrations of chlorophyll *a* exceeding the 4 µg/L WQG at the upper harbour sites UH1 and UH3. The increase in available nutrients in January is likely to have stimulated algal growth at the upper harbor sites, particularly UH1 which displayed large fluctuations in DO generally associated with algal blooms.

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) and tin (<5.3 µg/L). Total and dissolved copper concentrations were slightly elevated compared to December, with the WQG (1.3 µg/L) being exceeded at the harbour sites UH2, UH3 and CH1. Total mercury concentrations above LOR were recorded at CH2 during the December sampling, however, laboratory analysis conducted on the January water samples indicates concentrations below LOR at all monitoring sites around Lyttelton harbour, as typically observed (Tables 16 to 18).

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 January sampling, exceedances were recorded at all monitoring sites, indicating an increase in the spatial distribution of elevated concentrations since December. Concentrations of the more bioavailable dissolved fraction ranged between <LOR (12 µg/L) and 28 µg/L, exceeding WQG at the nearshore site OS7 just within the harbour entrance (Figures 25 and 26).

Of the remaining metals analysed that have assigned WQGs, no exceedances were reported during the January 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 January, concentrations of total iron exceeded 100 µg/L at all upper and central harbour sites, in addition to OS1 and OS6. These results indicate a notable increase in total iron at OS1 to OS7 from December, when concentrations remained below 49 µg/L. Similar to patterns in 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.

Total and dissolved manganese concentrations were above LOR (<1 µg/L) at all monitoring sites during January. 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 December 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 January 2019. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	16	12	13	12	18	24
	Total	390	320	350	230	122	
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	1.6	1.3	1.9	1.8	1.7	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.2	1.7	1.9	1.6	2.2	
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	1.3	1.6	1.4	2.5	<1.1	
Iron	Dissolved	7	5	<4	<4	<4	-
	Total	620	490	510	340	164	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	7.9	6.4	7.3	4.3	2.1	-
	Total	20	15.5	19.9	12.1	6.3	
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	12	11	11	11	-
	Total	12	12	12	12	11	
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	2.0	2.0	2.0	1.9	1.6	100
	Total	3.0	3.0	2.0	2.6	2.6	
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 January 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	19	28	24
	Total	177	29	36	58	74	69	90	
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	1.6	1.4	1.5	1.5	1.1	1.3	1.4	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.7	1.3	1.6	1.4	<1.1	1.2	1.4	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	8	<4	<4	<4	<4	-
	Total	240	35	42	86	62	106	87	
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	3.1	2.1	1.8	1.9	1.4	2.1	2.8	-
	Total	9.2	4.1	4.4	4.7	3.9	5.2	6.2	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11	11	11	11	11	11	12	-
	Total	11	12	12	12	12	12	12	
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	1.8	2.1	2.1	2.0	1.8	1.6	2.0	100
	Total	2.6	2.1	2.3	1.9	1.7	2.4	2.1	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	5.4	<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 January 2019.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	31	25	50	
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	1.3	1.2	1.6	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.3	<1.1	<1.1	
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	1.3	<1.1	<1.1	
Iron	Dissolved	<4	19	<4	-
	Total	35	37	36	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.2	1.7	1.2	-
	Total	3.6	2.7	3.6	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11	12	12	-
	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	1.4	1.9	100
	Total	1.9	2.0	1.9	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

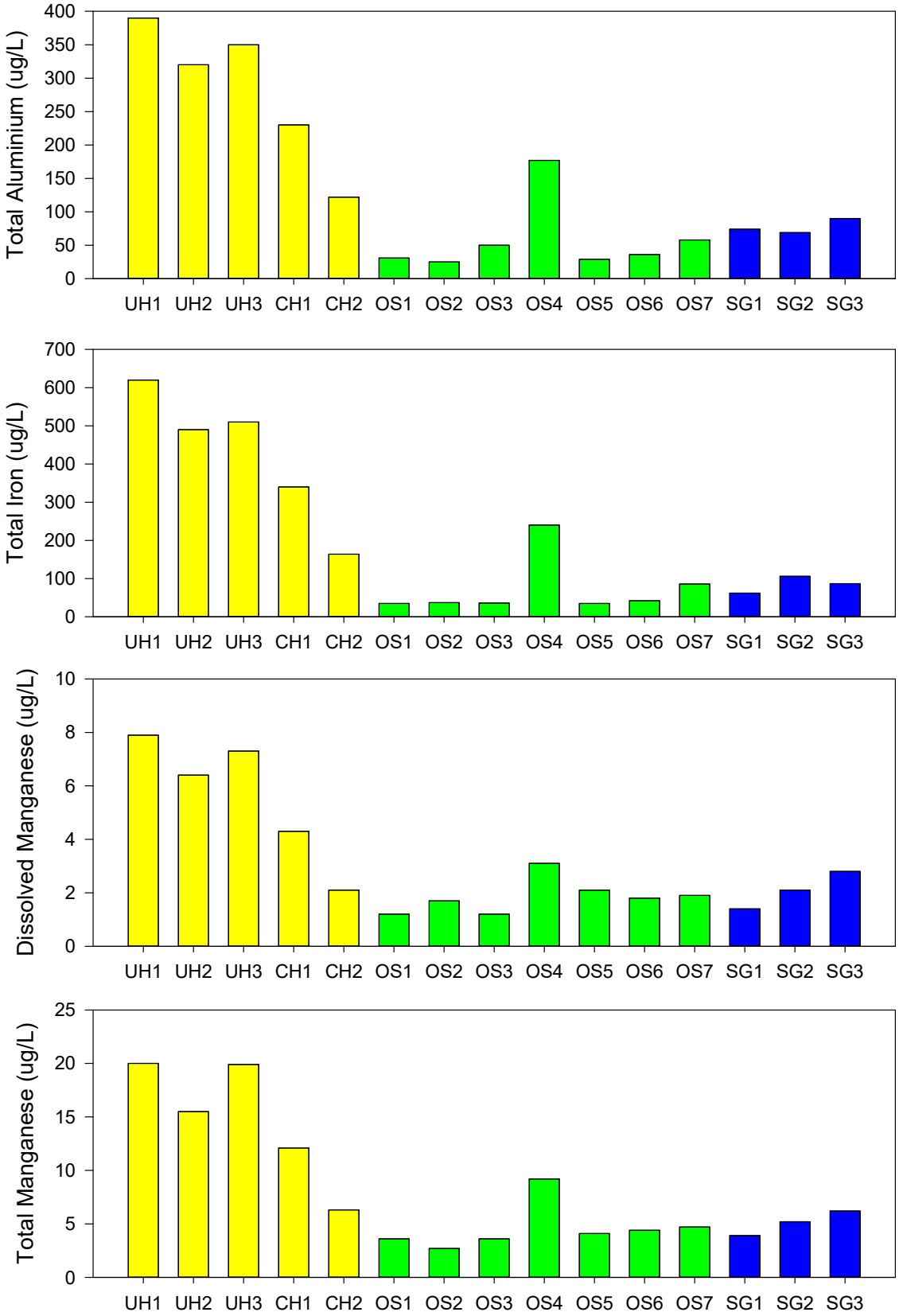

Figure 25 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during January 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

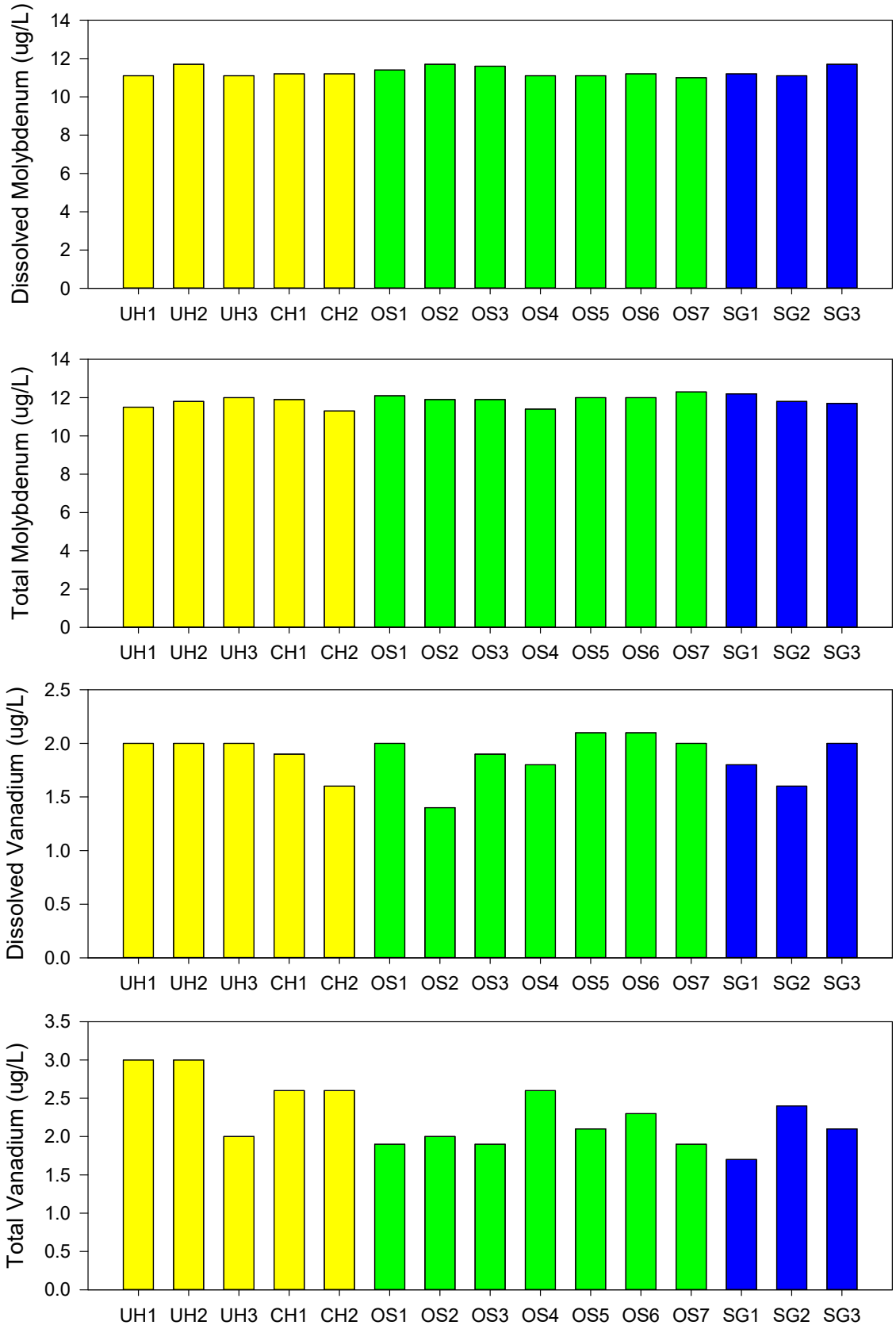

Figure 26 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during January 2019.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

4 REFERENCES

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5 APPENDIX

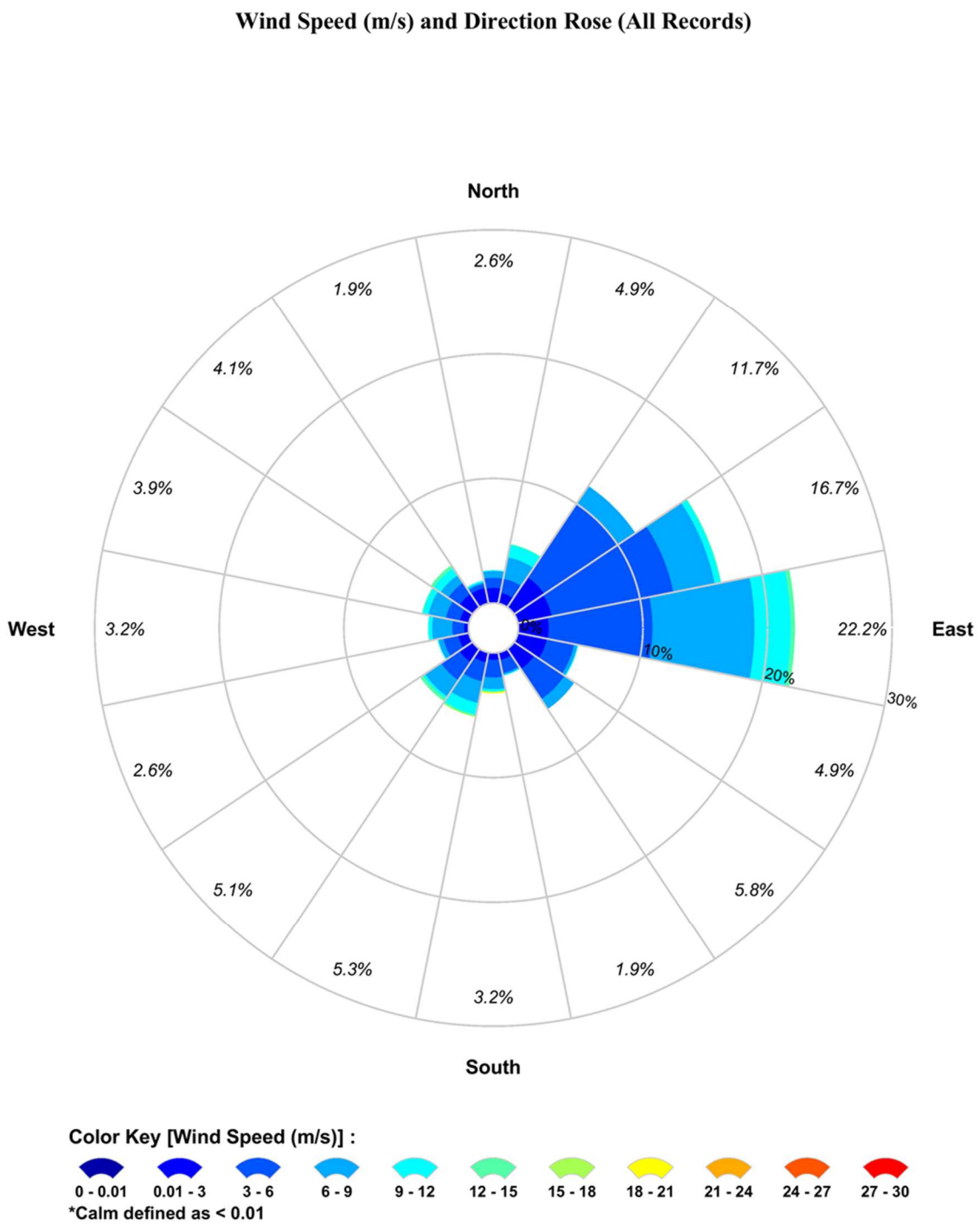

Figure 27 WatchKeeper wind speed (m/s) and direction rose (%) during January 2019.

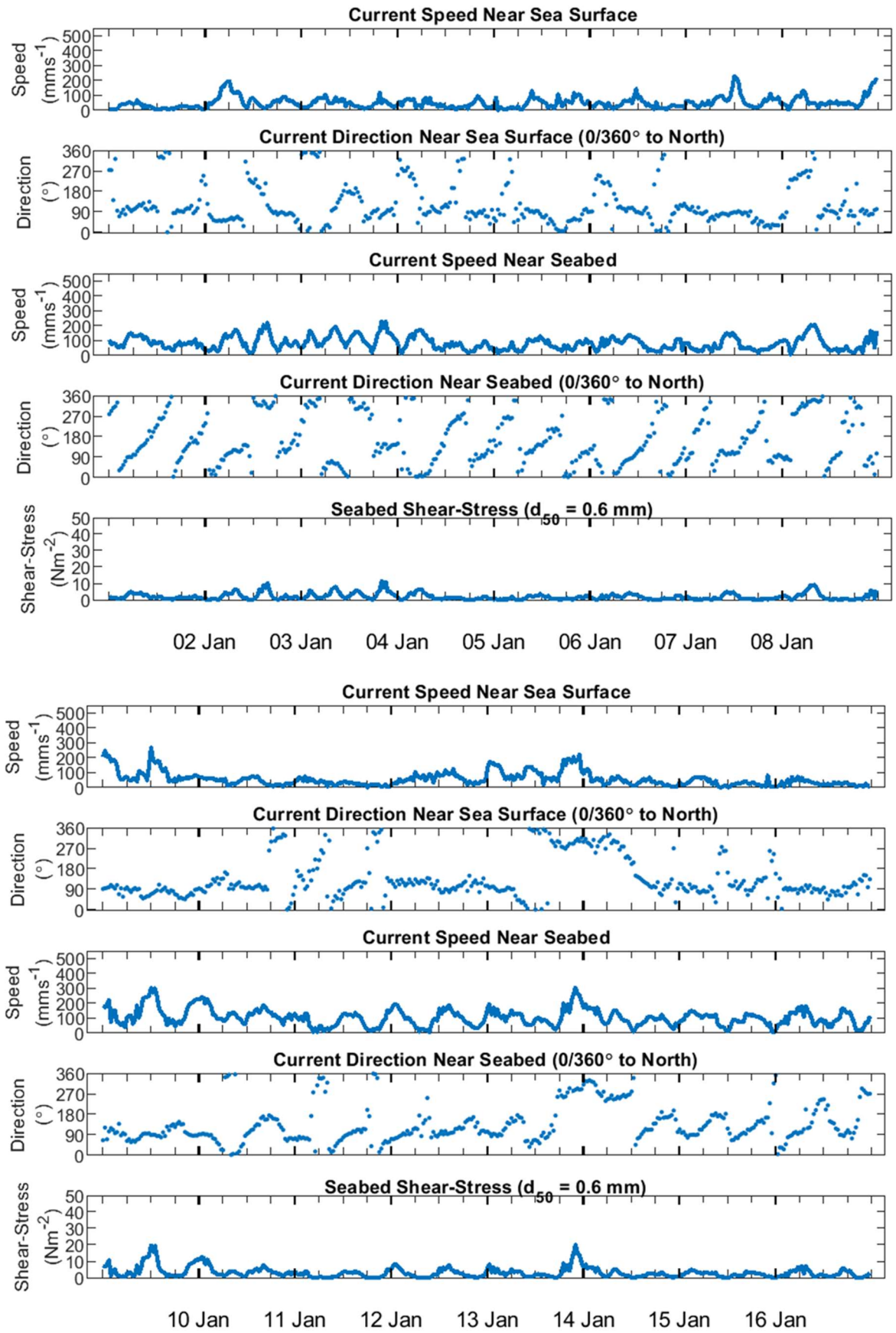

Figure 28 SG2a current speed, direction and shear bed stress 1 to 16 January 2019.

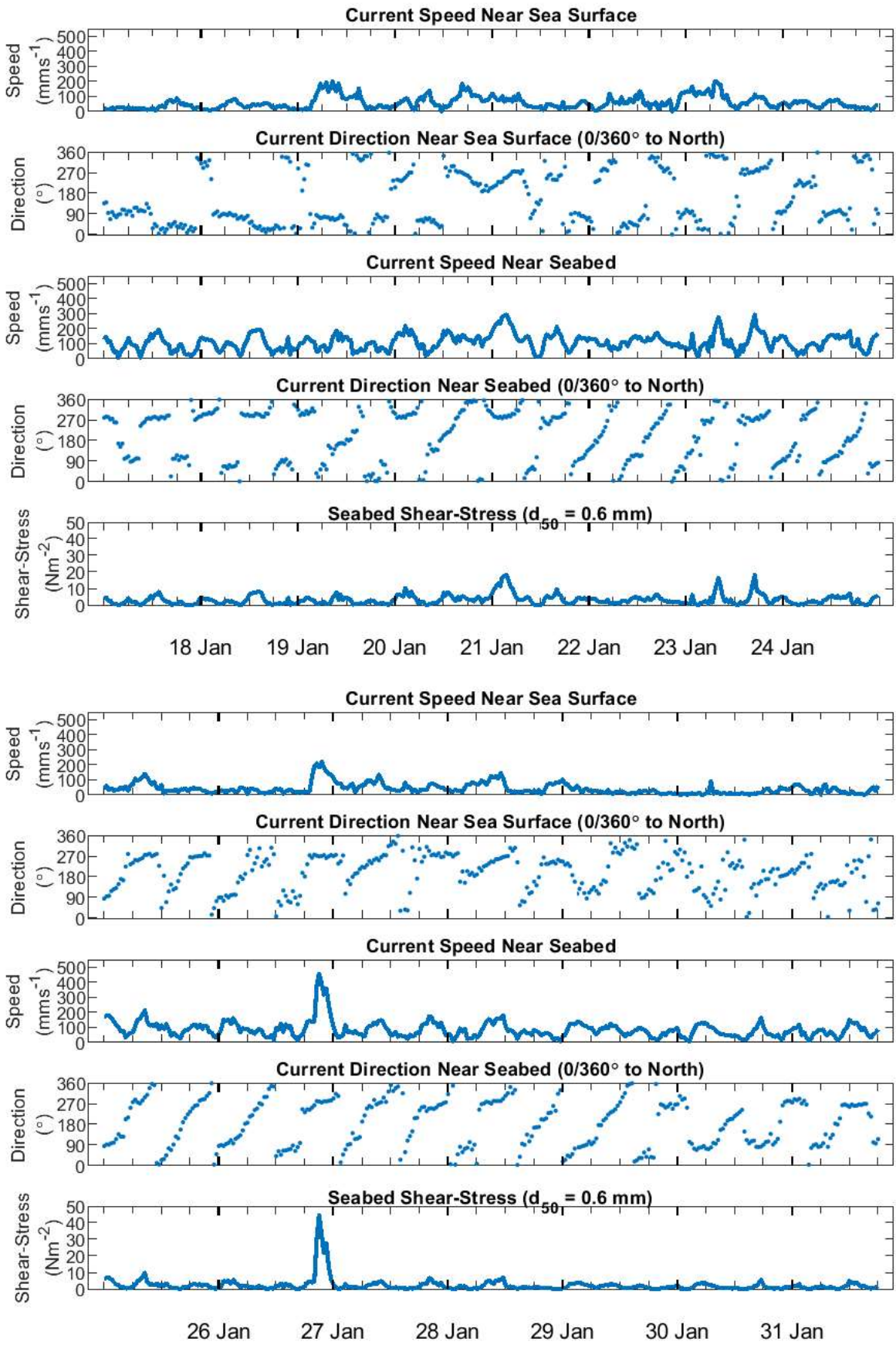

Figure 29 SG2a current speed, direction and shear bed stress 17 to 31 January 2019.

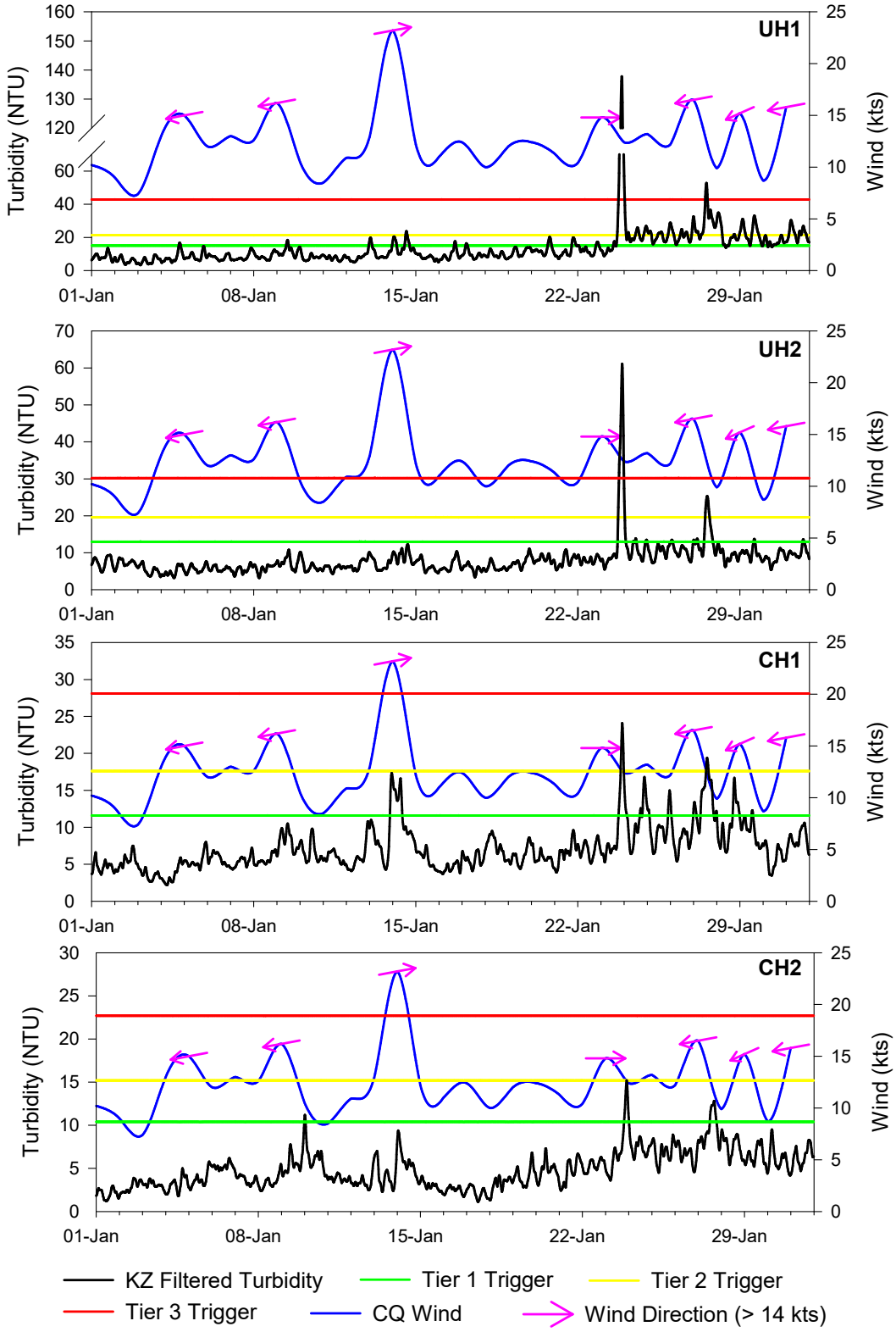

Figure 30 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier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

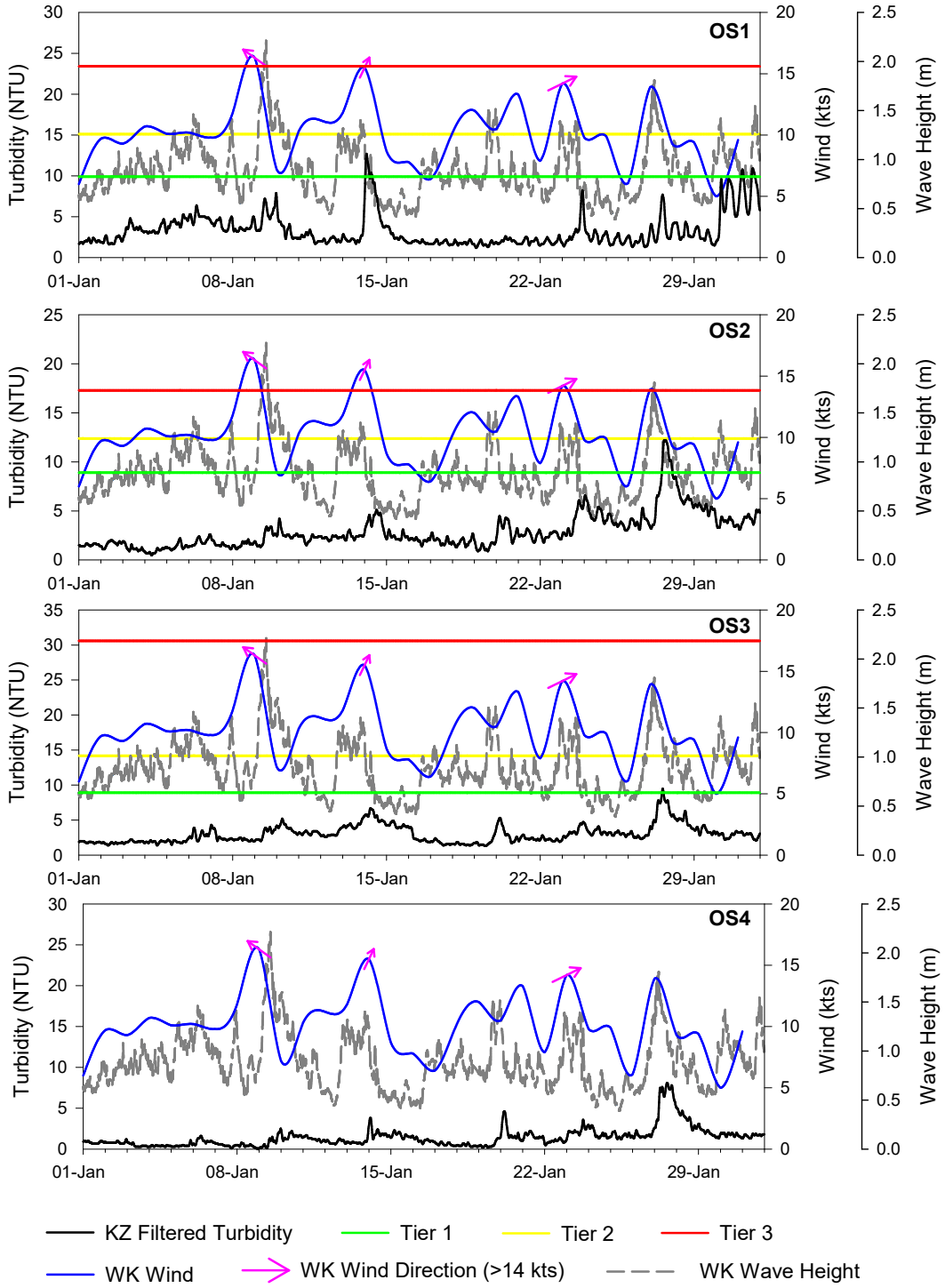

Figure 31 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

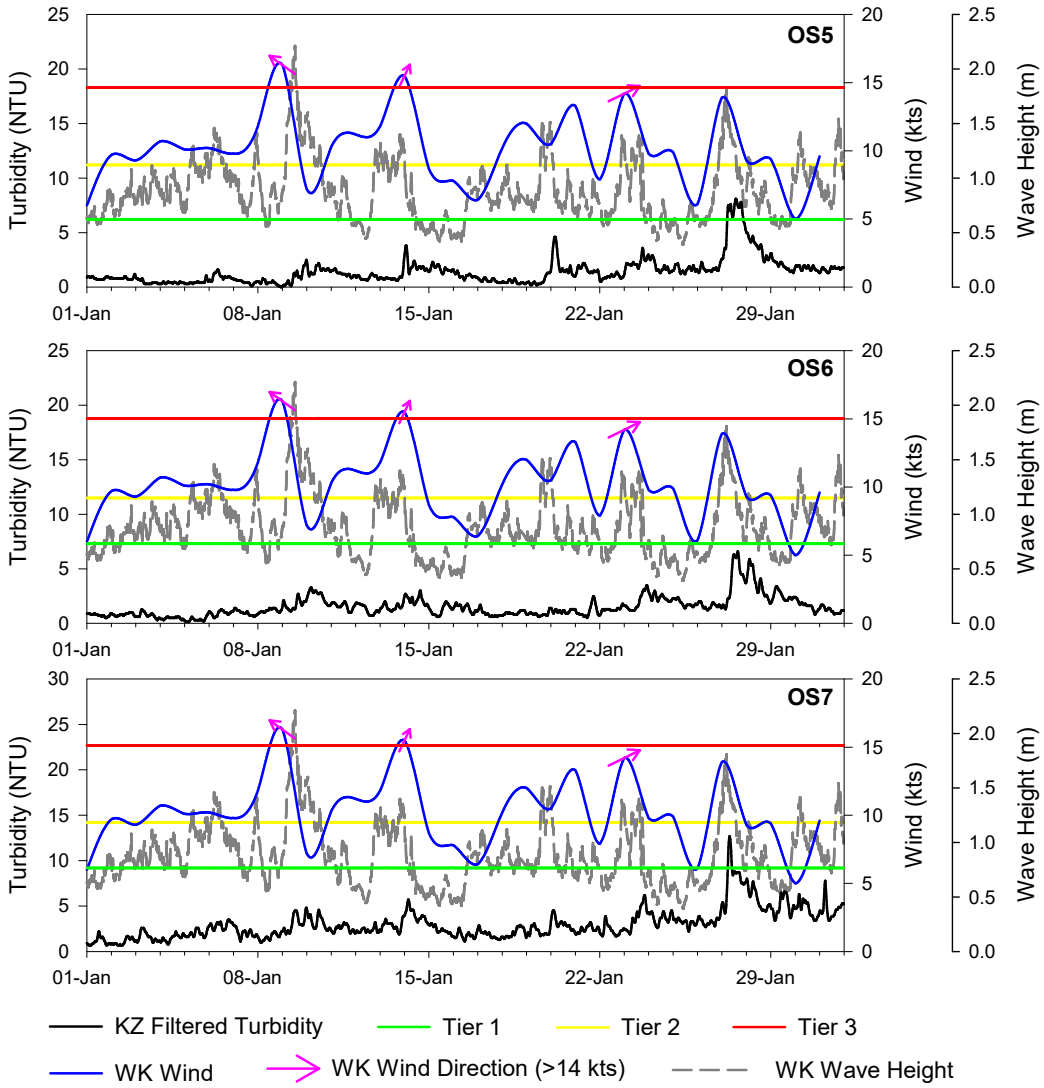

Figure 32 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

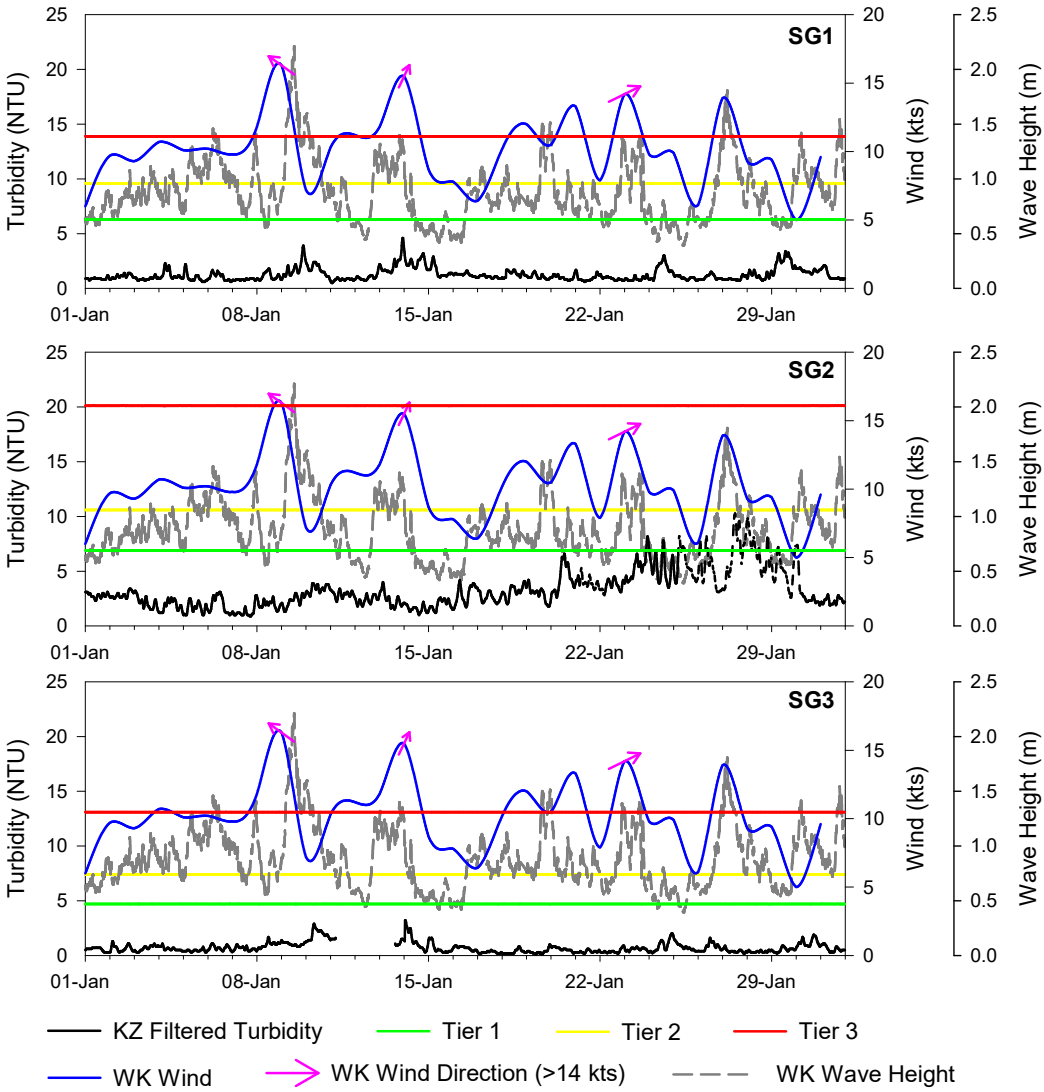

Figure 33 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during January 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 19 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during January 2019 and baseline period 1 November 2016 to 31 October 2017
Values for January are means ± se, range and percentiles (n = 2976). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface January	Surface Baseline
UH1	Mean ± se	14 ± 0	12
	Range	3 – 138	2 – 155
	99th	48	37
	95th	27	21
	80th	19	15
UH2	Mean ± se	8.0 ± 0.1	9.9
	Range	3 – 61	2 – 59
	99th	24	29
	95th	13	19
	80th	9.6	13
CH1	Mean ± se	7.2 ± 0.1	8.8
	Range	2 – 24	<1 – 50
	99th	17	27
	95th	14	17
	80th	9.2	12
CH2	Mean ± se	4.9 ± 0.0	7.6
	Range	1 – 15	<1 – 39
	99th	12	22
	95th	8.5	15
	80th	6.6	10

Table 20 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during January 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for January are means ± se, range and percentiles (n = 1021-2832). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface January	Surface Baseline
SG1	Mean ± se	1.3 ± 0.0	4.2
	Range	<1 – 4.6	<1 – 31
	99th	3.5	14
	95th	2.6	9.5
	80th	1.6	6.1
SG2	Mean ± se	3.2 ± 0.0	4.6
	Range	<1 – 10	<1 – 33
	99th	8.3	20
	95th	6.8	10
	80th	4.1	6.9
SG3	Mean ± se	0.9 ± 0.0	3.6
	Range	<1 – 2.9	<1 – 22
	99th	2.5	13
	95th	1.9	7.3
	80th	1.1	4.7

Table 21 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during January 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for January are means ± se, range and percentiles (n = 2976). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface January	Surface Baseline
OS1	Mean ± se	3.3 ± 0.0	7.5
	Range	1 – 13	<1 – 99
	99th	11	23
	95th	7.7	15
	80th	4.3	9.7
OS2	Mean ± se	2.9 ± 0.0	6.4
	Range	<1 – 12	<1 – 36
	99th	10	17
	95th	6.1	12
	80th	4.1	8.9
OS3	Mean ± se	3.0 ± 0.0	6.5
	Range	1 – 9.5	<1 – 110
	99th	7.7	27
	95th	5.4	14
	80th	3.9	8.9
OS4	Mean ± se	1.4 ± 0.0	5.9
	Range	<1 – 8.1	<1 – 35
	99th	7.4	18
	95th	3.7	13
	80th	1.9	8.1
OS5	Mean ± se	2.7 ± 0.0	4.6
	Range	1.2 – 8.0	<1 – 35
	99th	6.5	18
	95th	5.2	11
	80th	3.2	6.1
OS6	Mean ± se	1.5 ± 0.0	4.7
	Range	<1 – 6.6	<1 – 37
	99th	5.7	18
	95th	3.1	11
	80th	2.0	7.1
OS7	Mean ± se	3.0 ± 0.0	6.3
	Range	<1 – 13	<1 – 48
	99th	8.7	22
	95th	6.1	14
	80th	4.0	9.1

Table 22 Summary of Vision Environment quality control data for January 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		
			UH3 A (µg/L)	UH3 B (µg/L)	Variation (%)
TSS	<3	<3	18	17	6
Dissolved Aluminium (ug/l)	<3	<3	13	16	19
Total Aluminium (ug/l)	<3.2	<3.2	350	320	9
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)	<6000	<6000	1.9	1.6	16
Total Chromium (ug/l)	<0.53	<0.53	1.9	1.8	5
Dissolved Cobalt (ug/l)	<0.2	<0.2	FALSE	FALSE	ND
Total Cobalt (ug/l)	<0.21	<0.21	<0.63	<0.63	ND
Dissolved Copper (ug/l)	<19000	<19000	<1	<1	ND
Total Copper (ug/l)	<0.53	<0.53	1.4	1.2	14
Dissolved Iron (ug/l)	<20	<20	<4	<4	ND
Total Iron (ug/l)	<21	<21	510	520	2
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	7.3	7.2	1
Total Manganese (ug/l)	<0.53	<0.53	19.9	19.4	3
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	11.1	11	1
Total Molybdenum (ug/l)	<0.21	<0.21	12	11.8	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	1.8	10
Total Vanadium (ug/l)	<1.1	<1.1	2	3.2	38
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	24	27	11
Dissolved Reactive Phosphorus (ug/l)	<4	<4	13.7	14	2
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	18	17	6
Nitrate-N + Nitrite-N (ug/l)	<2	<2	4.6	5.6	18
Chlorophyll a (ug/L)	<0.2	<0.2	5	5.3	6