Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

May 2019

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Summary

Since September 2016, Vision Environment (VE) has been undertaking water quality monitoring for the Environmental Monitoring and Management Plan (EMMP) associated with the Lyttelton Port Company (LPC) Channel Deepening Project (CDP) (Envisor, 2018). Baseline datasets were acquired from three spoil ground sites (SG1, SG2 and SG3), seven offshore sites (OS1 to OS7) and five inshore sites (UH1 to UH3, CH1 and CH2) to assess potential impacts of the dredging project.

Dredging operations for the CDP, which commenced on 29 August 2018, were completed on 29 November 2018, taking the monitoring into a post dredge phase up until 11 March when a smaller dredging operation began for the reclamation works at Cashin Quay. Monitoring results collected during May 2019 are presented within this report. Continuing with the dredge phase monitoring report format, this monthly report includes comparisons of turbidity data collected during the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). KZ filtered data are also included within the Appendix are compared to compliance trigger values during reclamation dredging operations.

Climatic Conditions: During May, 18.0 mm of rainfall was recorded at Cashin Quay, approximately half that recorded in April. The rainfall was scattered fairly evenly across the month with heaviest falls during high wind speed events. Maximum daily inshore wind speeds (18.6 kts) and gusts (59 kts) were recorded on 13 May and continued for several days after. Maximum flow from the Waimakariri River (1244 m^3/s) was recorded on the 31 May and would not be expected to impact monitoring sites till early June. Monthly average temperature (12°C) was similar to that recorded in April.

Offshore, both wind speeds and wave heights displayed similar temporal variations over the month. Similar to the inshore environment, the offshore wind speeds were also elevated on 13 May with gusts reaching over 20kts and wave heights of 2.0 m. However, a second offshore wind speed event accompanied by elevated wave heights experienced on 30 May, did not affect the inshore area to any large degree.

Currents: ADCP data were available at all three spoil ground monitoring sites in May. Near-surface and near-seabed currents at SG1 were highest on 31 May corresponding with peak offshore wind speed and wave height events. Currents at this site, in addition to both near-surface and near-seabed at sites SG2a and SG3, also peaked on 12 may during the period of highest inshore wind speeds for the month. Similar to April the strongest flow was observed at SG3 near-surface, with near-seabed currents at SG1 and SG3 of a lower velocity than those at the surface, while near seabed currents were higher than near surface at SG2a. This site exhibited overall lower current velocities than the remaining sites as commonly found, and this has been previously attributed to varying topography across the spoil ground. Both SG1 and SG3 exhibited currents in a north-west/south-east direction in contrast to SG2a where currents were predominantly on an east-west axis.

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 for May were generally lower than April and those recorded during the baseline monitoring period.

Relatively high turbidity was recorded at all sites from 13 to 16 May in response to strong inshore wind speeds coming from a west-south-west direction. The strongest response was observed at site UH1 where the turbidity rolling average reached almost 30 NTU in comparison to other sites, which remained under 15 NTU. The elevated offshore wind speed event accompanied by increased wave heights towards the end of May, had little impact on inshore turbidity but resulted in elevated turbidity at offshore and spoil ground sites. Similarly a strong inshore wind event on 7 May in the opposite direction to that of 13 May, had little impact on turbidity at inshore sites.

Benthic turbidity at OS1 responded to both wind speed/wave height events in May, whereas remaining sites responded mainly to the end of month event, resulting in elevated turbidity.

Dredge Compliance Turbidity Trigger Values: During May, the Tier 3 intensity values were exceeded at site UH1 for 9.75 hours. This was attributed to the mid-month elevated wind speed event which had a large impact on turbidity at this site in particular which was most likely a result of specific wind direction.

Other Physicochemical Parameters: The trend for water cooling across all sites was consistent throughout May, with monthly means up to 2.4 ºC lower than April. Continuing the trend which commenced in April, cooler water temperatures were recorded in the upper and central harbour rather than the offshore sites. A rapid decrease in temperatures was recorded on 13 April in response to the mid-month wind speed and rain event. In contrast there was little temperature response to the wind speed event at the end of May. Benthic temperatures were consistent with those at the surface indicating a well-mixed water column.

Consistent with previous reports, pH during May was consistent across all sites, both surface and benthic. With limited rainfall and river flow events recorded during May, conductivity was also reasonably consistent at each site for the month of May.

Dissolved oxygen (DO) concentrations during May were similar to those in April, most likely due to continued cool temperatures restricting photosynthesis resulting in lower oxygen production. Large diurnal fluctuations in DO were observed at the majority of sites for the month of May. Low DO at the start of May, which was likely due to late April metocean conditions, demonstrated recovery until the mid-month weather event, at which DO declined at all sites. There was also little response in DO to the late May weather event. Benthic DO trended similarly to the surface although OS1 benthic exhibited larger diurnal fluctuations compared to other sites, coinciding with greater temperature fluctuations at this site.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 5 May 2019. Similar to profiles typically obtained during the monitoring program, inner harbour and nearshore monitoring sites indicated a well-mixed water column. Further offshore and at spoil ground sites, depth profiling indicated a continuation of vertically mixed conditions, with turbidity increasing near the benthos.

Turbidity and total suspended solids (TSS) measurements for surface waters were again elevated at inshore sites compared to the offshore areas, resulting in the shallowest estimations of euphotic depth as typically recorded during the monitoring program. Euphotic depths at the offshore monitoring locations were relatively high; estimated to be at 16.4 m at SG2. No exceedances of WQG were observed for sub-surface during the May 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 recorded at all sites.

Concentrations of total nitrogen and total kjeldahl nitrogen once again remained below detection limits at most sampling sites. Ammonia and nitrogen oxides (NOx) were elevated in May as they were in April, with most sites exceeding both the ammonia and NOx, WQG. This may be a result of continual degradation of organic material such as phytoplankton releasing nitrogenous products Chlorophyll *a*, an indicator of phytoplankton biomass, exceeded WQG at three sites throughout the harbour, as it did in April.

Several metals were reported as below the limit of reporting (LOR) at all sites as commonly found. As typically observed, total aluminium concentrations exceeded designated WQG at all of the monitoring sites. Dissolved aluminium concentrations, however, remained well below the WQG at all sites. A similar spatial pattern was observed for both total and dissolved iron, although no WQG are available for iron. Dissolved copper at UH3 slightly exceeded the WQG.

Detectable concentrations of manganese were once again recorded in the upper harbour, with a relatively even split between dissolved and particulate components and a decreasing gradient from inner to outer harbour. Chromium, vanadium and molybdenum were also reported above LOR during May at some sites with little spatial variability and a large component contained within the dissolved phase and therefore easily dispersed across the harbour.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight was fairly consistent during May but lower than that in April, and this was reflected in lower overall BPAR levels. Elevated turbidity from the end of month weather event resulted in negligible BPAR being recorded at both OS2 and OS3 for the remainder of the month.

Sedimentation: During May, bed level at OS2 displayed an overall increase of +46 mm, which was notable at the beginning and end of the month in relation to late April and late May weather events. Missing data for the middle of May prevented detailed interpretation. Sediment flux increased at UH3 in response to the 13 May weather event. This resulted in an overall accretion of +1.4 mm for the month of May.

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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 2018 with completion of works on 29 November 2018. Monitoring continued into a post-dredge phase up until 11 March 2019 when smaller scale dredging operations for the reclamation works commenced. The interpreted environmental data provided by VE supports the process of the Environmental Monitoring and Management Plan (EMMP) for the LPC CDP (Envisor, 2018) and will assist to ascertain the potential impacts of the project.

2 METHODOLOGY

2.1 Approach

An overview of the methodology for the baseline and operations phases of water quality monitoring is provided in this section. A more detailed description of the importance of the measured parameters and the specific methodology for the CDP data collection and processing protocols can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

2.1.1 Monitoring Locations and Equipment

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

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

The inshore monitoring area (including monitoring sites CH1 and CH2, and UH1 to UH3) is a shallow (<10 m depth) marine environment that, in addition to wind speeds and wave heights, is also influenced by tides (~ 0.2 m/s). The water column is well mixed at these sites, with little to no stratification. Therefore, surface loggers only have predominantly been utilised at these sites.

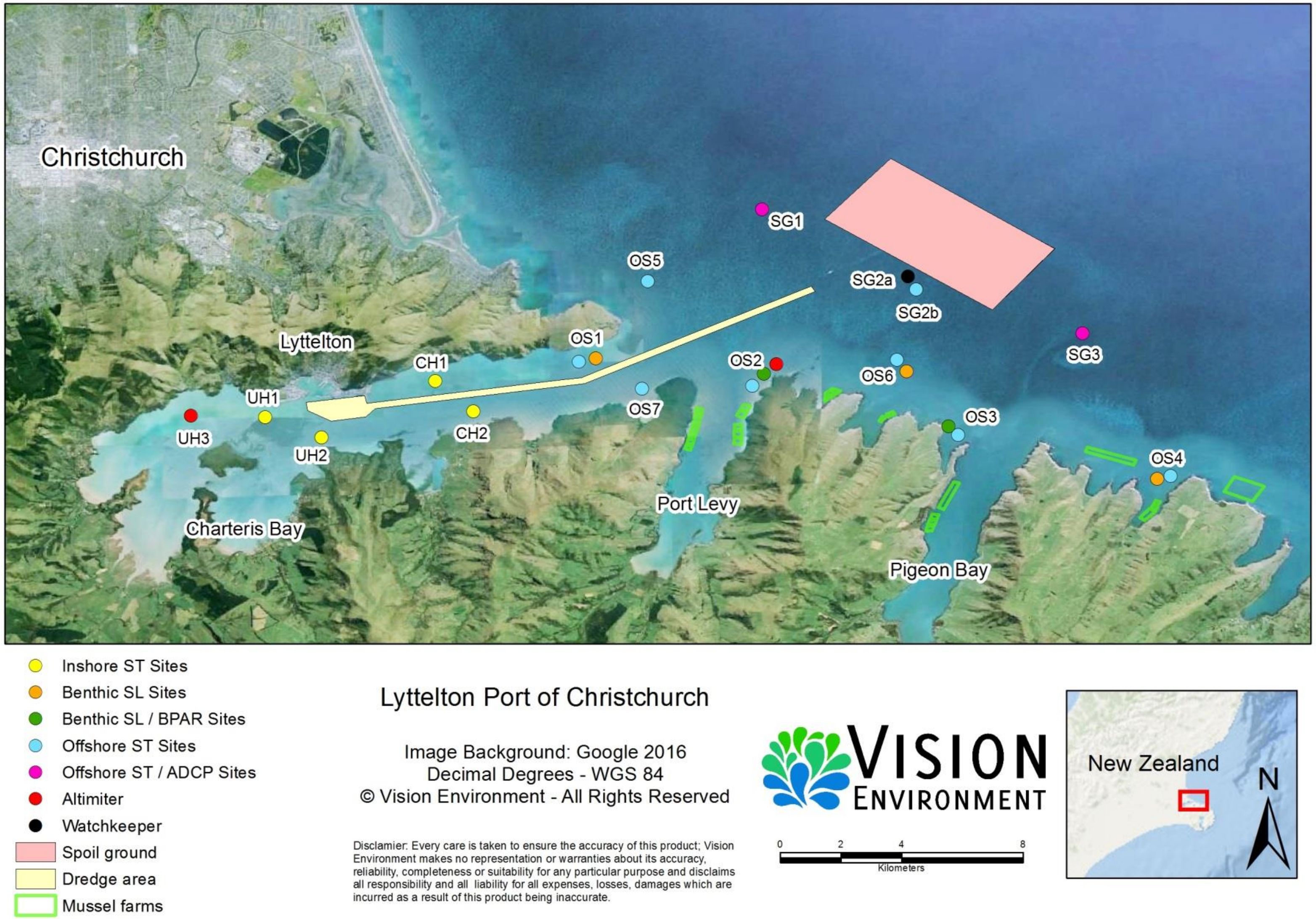


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

Table 1 Summary of monitoring sites and deployment equipment for the LPC Channel Deepening Project.
ST = subsurface telemetry, SL = self-logger, BSL = benthic self-logger, BPAR = benthic photosynthetically active radiation, and ADCP = Acoustic Doppler Current Profiler, WK = WatchKeeper telemetered weather station.

Site	WK	ST/ADCP	ST	BSL sonde	BSL sonde/BPAR	Altimeter
	WatchKeeper telemetered weather station with currents and waves	Subsurface telemetered dual physico-chemistry and currents	Subsurface telemetered dual physico-chemistry	Benthic self-logging dual physico-chemistry	Benthic self-logging dual physico-chemistry and self-logging BPAR	Benthic self-logging dual altimeter
SG2a	√					
SG2b			√			
SG1		√				
SG3		√				
OS1			√	√		
OS2			√		√	√
OS3			√		√	
OS4			√	√		
OS5			√			
OS6			√	√		
OS7			√			
CH1			√			
CH2			√			
UH1			√			
UH2			√			
UH3						√
Total	1	2	12	3	2	2

The comprehensive water quality component of the program involves the monitoring of:

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

This monthly report presents data collected from the 22 monitoring locations for May 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 5 May 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 several 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

A total of 18.0 mm of rainfall was recorded at Cashin Quay during May 2019, which was approximately half the precipitation that had been recorded in April (36.0 mm). Rainfall was spread across the month with the largest fall (5.2 mm) recorded on 13 May (Metconnect, 2019). Freshwater flows from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour several days post flow, remained below 230 m^3/s till 30 May. Flows then increased rapidly reaching a peak of 1244 m^3/s on 31 May (Figure 2), before declining (ECAN, 2019). Impacts to monitoring sites from this flow event are not expected to be observed until early June.

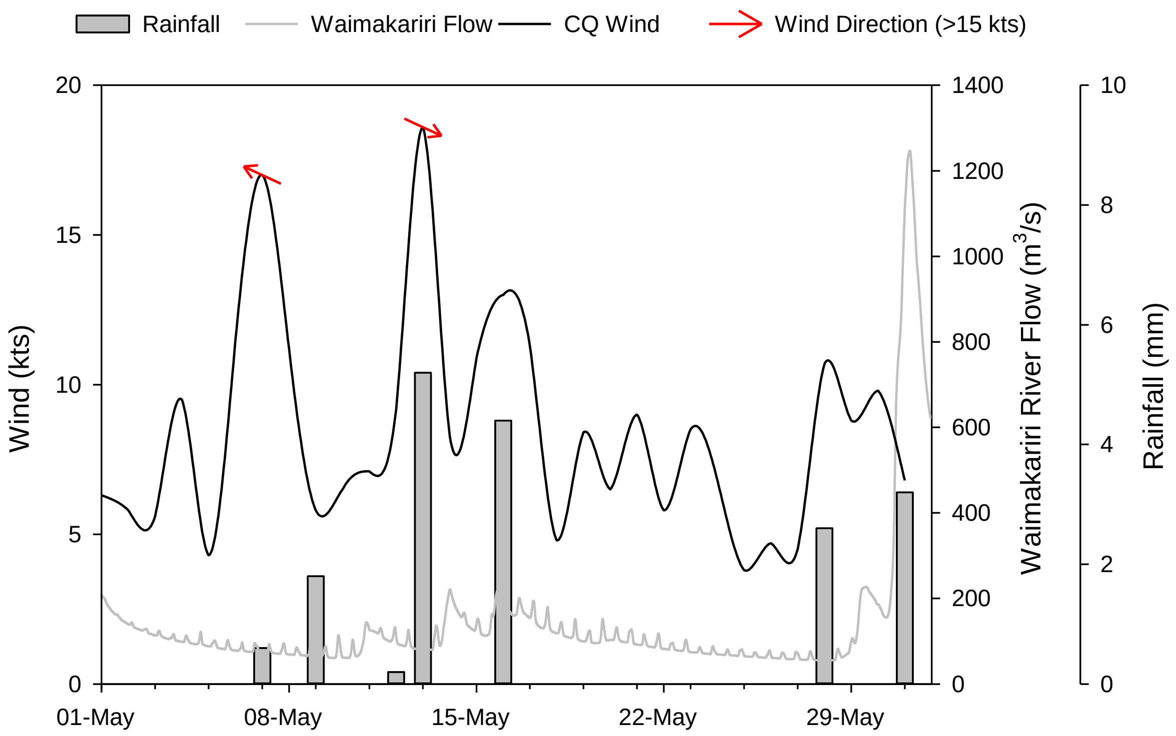


Figure 2 Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during May 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.

Inshore wind direction varied greatly throughout May, with east-north-east winds predominating for seven days of the month and average speeds peaking at 17 kts on 7 May. This compared with south-westerly winds that were prominent in April. Maximum average wind speeds (18.6 kts) however were experienced on 13 May in a west-south-west direction when maximum wind gusts up to 59 knots were also recorded during the heaviest rain period for the month (Metconnect, 2019). Wind gusts of 44 and 48 knots were also experienced on 15 and 16 May. Daily mean air temperatures at Cashin Quay ranged from 7 to 17°C, resulting in a monthly mean temperature of 12°C (Metconnect, 2019) and was similar to the April mean temperature of 13°C, despite the May maximum temperature being 8°C cooler.

Offshore significant wave heights were variable throughout May generally paralleling offshore wind speeds (Figure 3), with gusts reaching over 20 kts on 12 and 13 May (daily average 14.0 kts). Maximum significant wave heights of 2.0 m were recorded at this time. Peak wave heights of 2.1 m travelling in a northerly direction (Figure 3) were recorded on 28 May just prior to maximum daily wind speeds that were recorded on 30 May (15.6 kts).

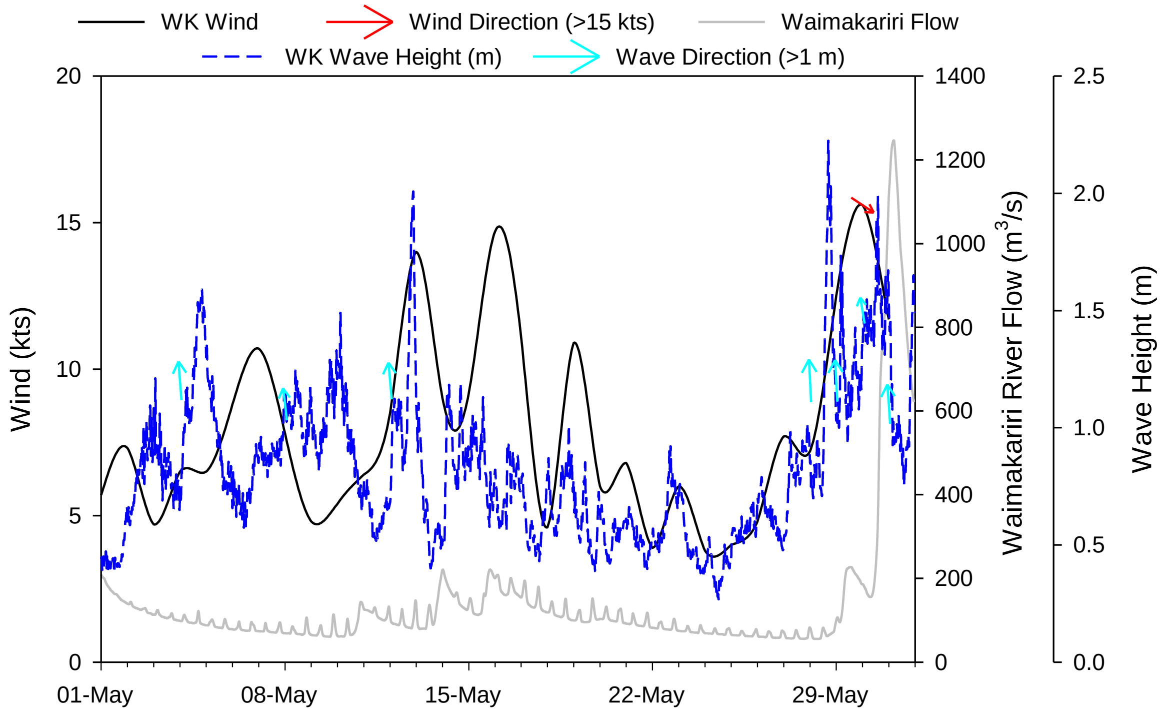


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during May 2019.

Note: Arrows indicate the direction of travel for offshore winds greater than 15 knots and offshore waves above 1 m significant wave height. Directions from the WatchKeeper buoy have not been corrected for magnetic declination.

3.1.2 Currents

Acoustic Doppler Current Profilers (ADCPs) are deployed at the spoil ground monitoring sites SG1, SG2a and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Summary ADCP statistics are presented within Figures 4 to 6 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 33 and 38 in the Appendix. Note that the ADCP data are presented in this report using the UTC time format.

Maximum currents at SG1 at the near-surface (430 mm/s) and near-seabed (367 mm/s) peaked on 31 May coinciding with peak wave height and wind speed events which occurred a few days prior. Currents > 300 mm/s also recorded on 12 May at both depths, also corresponding with high wind speed/wave height events. Highest near-surface currents were recorded at SG2a on 12 May (101 mm/s) while maximum near-seabed currents were recorded on 5 May (172 mm/s). At SG3 maximum currents were also recorded on 12 May (470 and 413 mm/s, respectively for near-surface and near-seabed), while second highest currents were recorded on 31 May. The similar timings between maximum near-surface and near-benthic current velocities across most of the spoil ground sites suggests that the increased wind speeds and wave heights resulted in a whole water column impact.

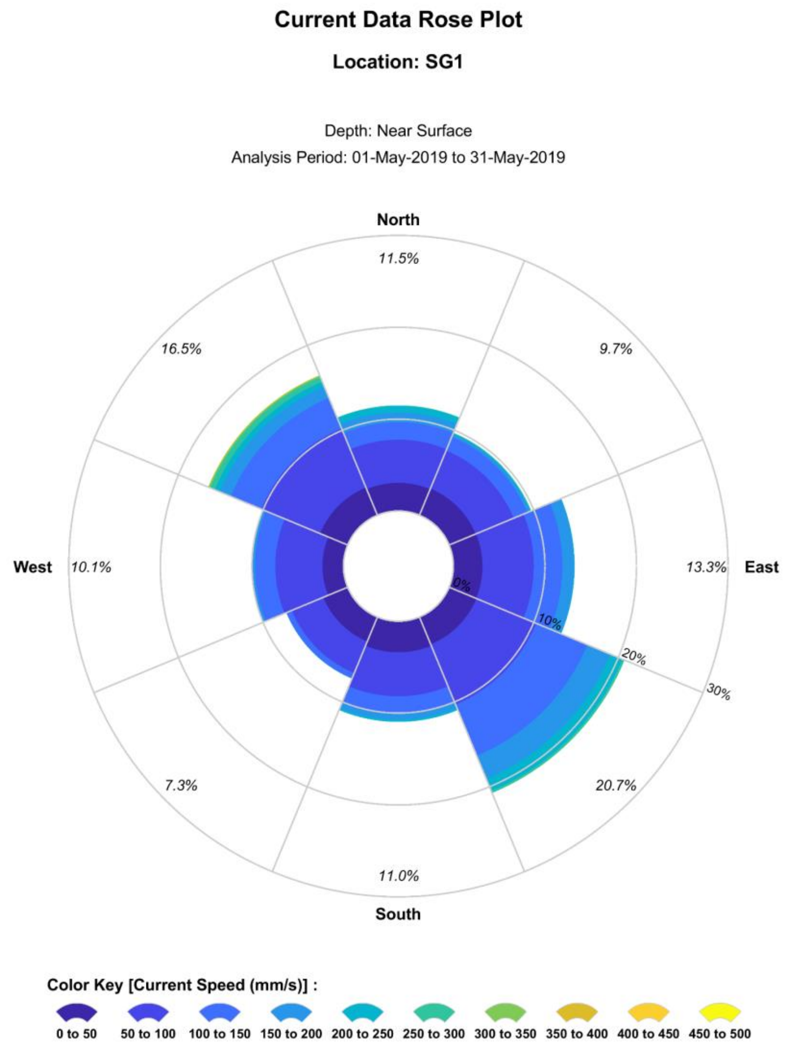
Table 2 Parameter statistics for spoil ground ADCPs during May 2019.

Parameter	Depth	Site		
		SG1	**SG2a**	**SG3**
Minimum current speed (mm/s)	*Near-surface*	1	0	0
	Near-seabed	2	0	2
Maximum current speed (mm/s)	*Near-surface*	430	101	470
	Near-seabed	367	172	413
Mean current speed (mm/s)	*Near-surface*	89	16	118
	Near-seabed	77	62	109
Standard deviation of current speed (mm/s)	*Near-surface*	53	13	71
	Near-seabed	43	28	60
Current speed, 95th percentile (mm/s)	*Near-surface*	194	42	251
	Near-seabed	155	111	217

Consistent with previous reports, current velocities at SG2 were considerably lower than those recorded at both SG1 and SG3. This has been attributed to varying topography across the spoil ground sites.

Minimum current velocities were low and varied only slightly across the month: SG1 near-surface and near-seabed recorded on the 6 and 23 May (1 mm/s) and 15 May (2 mm/s), respectively; SG2 near-surface (0 mm/s) recorded on 20, 23 and 26 May, and near-seabed (0 mm/s) recorded on 24 May; and SG3 near-surface and near-seabed on the 23 May (0 mm/s) and 13 May (2 mm/s), respectively.

The time-series plots (Figures 34 to 38 in Appendix) illustrate time-varying current direction, whilst the current rose diagrams (Figures 4 to 6) depict the distribution of current direction and velocity in the near-surface and near-seabed layers. When interpreting the current data, note that the convention for defining current direction is the direction in which the current flows *towards*, which is the reference used throughout the figures presented (the opposite is true for wind direction, where the reference is the direction from which the wind is coming from). Near-surface current direction at SG1 during May tended to flow towards the north-west (16.5%) and south-east (20.7%). These current flow directions were somewhat similar at the near-seabed (north-west: 17.1%; south-east 15.6%). Similar flow directions were evident at SG3 near-surface (north-west: 32.2%; south-east 16.1%) and near-seabed (north-west: 23.9%; south-east 17.9%). In contrast, current flow at SG2a tended to be along a more east (near-surface: 17.9%, near-seabed: 23.8%) and west (near-surface: 14.2%, near-seabed: 21.6%) axis.



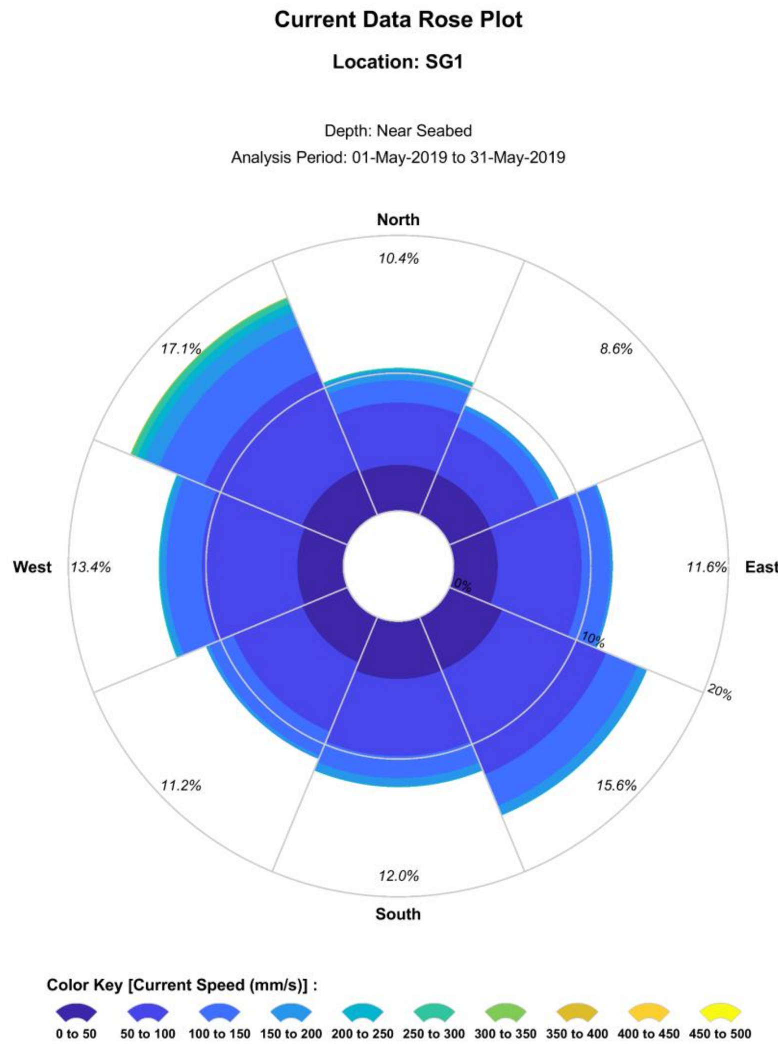


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during May 2019.
Speed intervals of 50 mm/s are used.

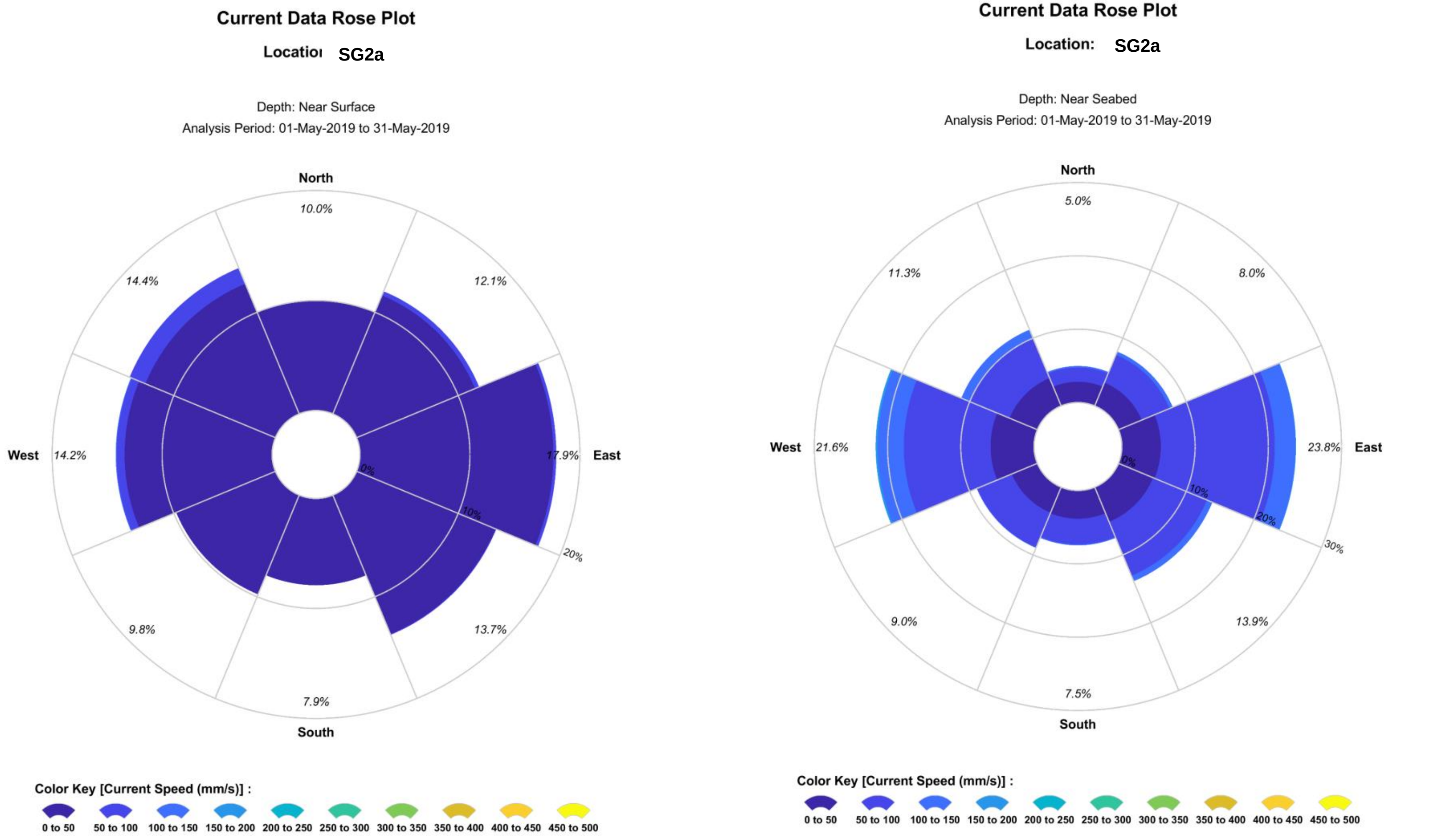
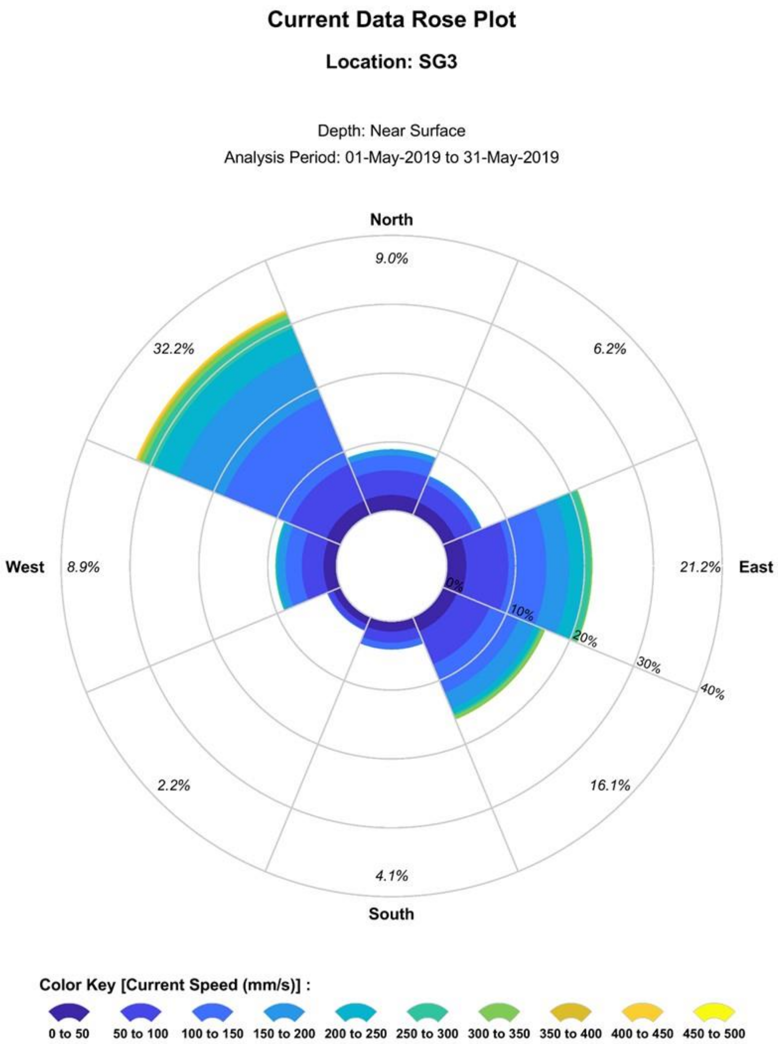


Figure 5 Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during May 2019.
Speed intervals of 50 mm/s are used.



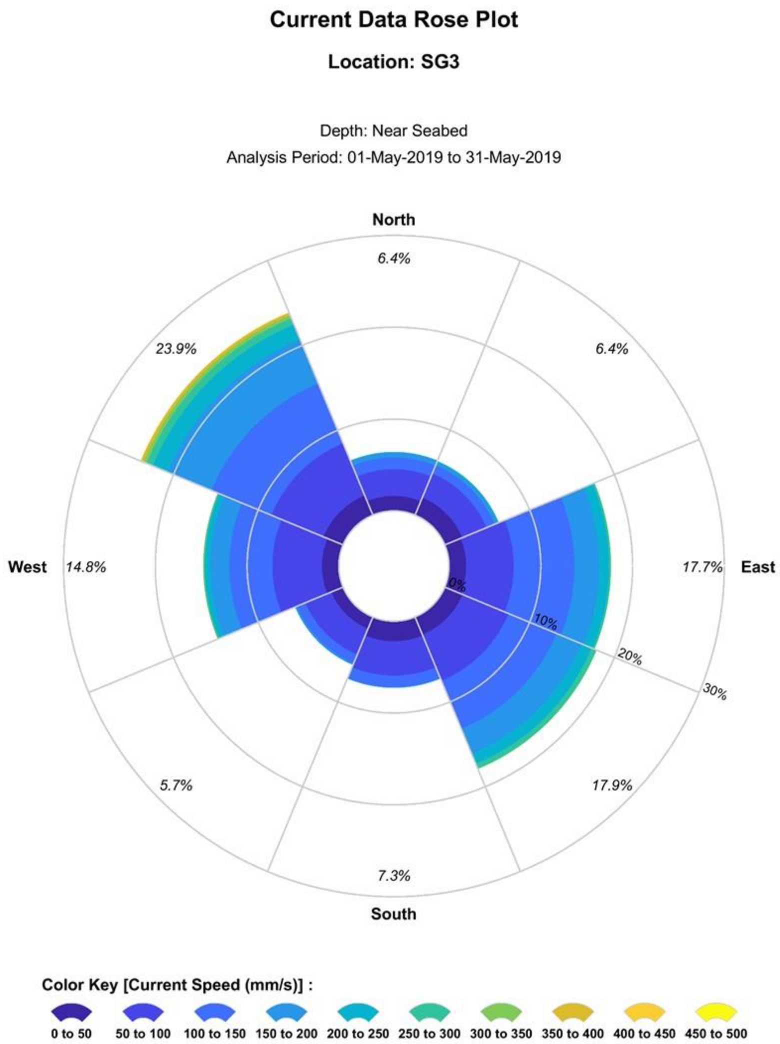


Figure 6 Near-surface and near-seabed current speed and direction at SG3 during May 2019.
Speed intervals of 50 mm/s are used.

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 5 May 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 May are presented in Tables 3 to 12. Validated datasets for surface and benthic measurements are also presented in Figures 7 to 23. Due to the inherent high level of variability in the turbidity datasets, a 24-hour rolling average has been calculated every 15 minutes to act as 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 May 2019 dredge data. Summary statistics for KZ filtered turbidity data, used for real time compliance monitoring during dredge operations, are also presented in Tables 22 to 24 in the Appendix. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 39 to 42 in the Appendix.

May Turbidity:

Consistent with the entire monitoring program, surface turbidity values were highest (monthly means of 3.4 to 8.7 NTU) at the inshore monitoring sites (Table 3, Figure 7). Further offshore, the spoil ground sites (Table 4) exhibited lower surface turbidity values (2.2 to 3.7 NTU), which are likely due to the deeper water column limiting expressions of seafloor sediment disturbance at the sub-surface. Nearshore sites experienced intermediate mean turbidity values (3.1 to 6.7 NTU) during May (Table 5), as typically observed. Turbidity across all monitoring sites was overall lower than it was in April. Surface turbidity at CH2 (5.3 NTU) on the southern side of the harbour, which had remained lower than the other three inner harbour sites for several months prior, was now aligned with its inner harbour counterparts.

Turbidity across the inner harbour was relatively stable for the entire month of May remaining below 10 NTU except for on 13 May when turbidity peaked at all sites in response to increased inshore wind speeds (Figure 7) that were from a west-south-west direction. Site UH1 displayed the highest response with the 24h rolling average reaching almost 30 NTU. This site also displayed a secondary turbidity peak two days later in response to elevated wind speeds also recorded on 15 and 16 May. Interestingly very little turbidity response was observed in relation to the similarly strong wind event that occurred on 7 May, but which was in the opposite direction.

Turbidity at nearshore sites of the monitoring program (OS1 to 4 and OS7) mimicked that of the inshore sites peaking on the 13 to 16 May albeit at lower levels (OS7 24h rolling average almost reaching 12 NTU). Unlike the inner harbour sites however, a large turbidity peak was also recorded at these sites as a result of the elevated offshore wind speeds recorded on 28

May. Very little response to this wind speed event was recorded at inshore sites where inshore wind speed remained below 11 knots.

Table 3 Mean turbidity and statistics at inshore water quality logger sites during May 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for May are means ± se, range and percentiles (n = 2960 to 2976) Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface May	Surface Baseline
UH1	Mean ± se	8.7 ± 0.1	12
	Range	3 – 109	-
	99th	33	39
	95th	16	22
	80th	10	15
UH2	Mean ± se	3.4 ± 0.1	10
	Range	<1 – 69	-
	99th	11	32
	95th	7.1	20
	80th	4.7	13
CH1	Mean ± se	6.2 ± 0.1	9
	Range	2 – 80	-
	99th	15	29
	95th	11	18
	80th	7.8	12
CH2	Mean ± se	5.3 ± 0.0	8
	Range	1 – 15	-
	99th	12	24
	95th	8.6	16
	80th	6.8	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during May 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for May are means ± se, range and percentiles (n =2930 to 2975). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU) Surface May	Surface Baseline
SG1	Mean ± se	3.7 ± 0.0	4.2
	Range	1 – 19	-
	99th	10	14
	95th	6.5	10
	80th	4.7	6.2
SG2	Mean ± se	3.3 ± 0.0	4.6
	Range	<1 – 14	-
	99th	7.2	20
	95th	6.3	11
	80th	5.1	7.0
SG3	Mean ± se	2.2 ± 0.0	3.6
	Range	<1 – 12	-
	99th	7.7	13
	95th	5.6	7.7
	80th	3.0	4.8

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks also followed the same trends as at the nearshore sites, although the 24h rolling average remained < 7 NTU at all times. Turbidity peaks occurred when increases in wind and wave heights were recorded (Figure 7), which coincided in the month of May.

Comparison to Baseline:
Mean surface turbidity values during May were overall lower to values calculated from the baseline monitoring period (Tables 3 to 5, Figures 8 to 12).

Benthic:

No valid turbidity data was able to be recovered for benthic sites OS4 for may but with good data recovered from remaining sites (Figure 7). Where data were available there was consistency between surface and benthic turbidity patterns. Variations in benthic turbidity displayed a high correspondence with wave heights, particularly at OS1, with periods of increased wave energy coinciding with elevated turbidity levels (Figure 7) both mid-month and towards the end of the month. Remaining sites tended to respond mainly to the end of the month weather event.

Table 5 Mean turbidity and statistics at offshore water quality logger sites during May 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for May are means ± se, range and percentiles (n = 2364 to 2975). Baseline values modified from Fox 2018. No valid turbidity data gained from OS4 benthic during May 2019.*

Site	Statistic	Turbidity (NTU)		
		Surface May	Surface Baseline	Benthic May
OS1	Mean ± se	4.8 ± 0.0	7.5	33 ± 0
	Range	<1 – 23	-	2 – 167
	99th	14	24	111
	95th	9.5	16	76
	80th	6.3	10	47
OS2	Mean ± se	3.8 ± 0.0	6.4	21 ± 0
	Range	<1 – 17	-	<1 – 121
	99th	11	18	92
	95th	8.4	13	65
	80th	5.3	9.0	35
OS3	Mean ± se	5.0 ± 0.1	6.6	20 ± 0
	Range	1 – 24	-	<1 – 122
	99th	15	27	76
	95th	11	15	51
	80th	6.8	8.9	30
OS4	Mean ± se	3.3 ± 0.0	5.9	*
	Range	<1 – 28	-	-
	99th	11	20	-
	95th	6.9	13	-
	80th	4.6	8.3	-
OS5	Mean ± se	3.5 ± 0.0	4.6	–
	Range	<1 – 17	-	–
	99th	9.4	19	–
	95th	6.9	11	–
	80th	4.5	6.4	–
OS6	Mean ± se	3.1 ± 0.0	4.7	29 ± 0
	Range	<1 – 32	-	<1 – 124
	99th	9.7	19	88
	95th	7.0	12	68
	80th	4.3	7.2	46
OS7	Mean ± se	6.7 ± 0.0	6.4	–
	Range	3 – 33	-	–
	99th	14	23	–
	95th	12	14	–
	80th	8.3	9.2	–

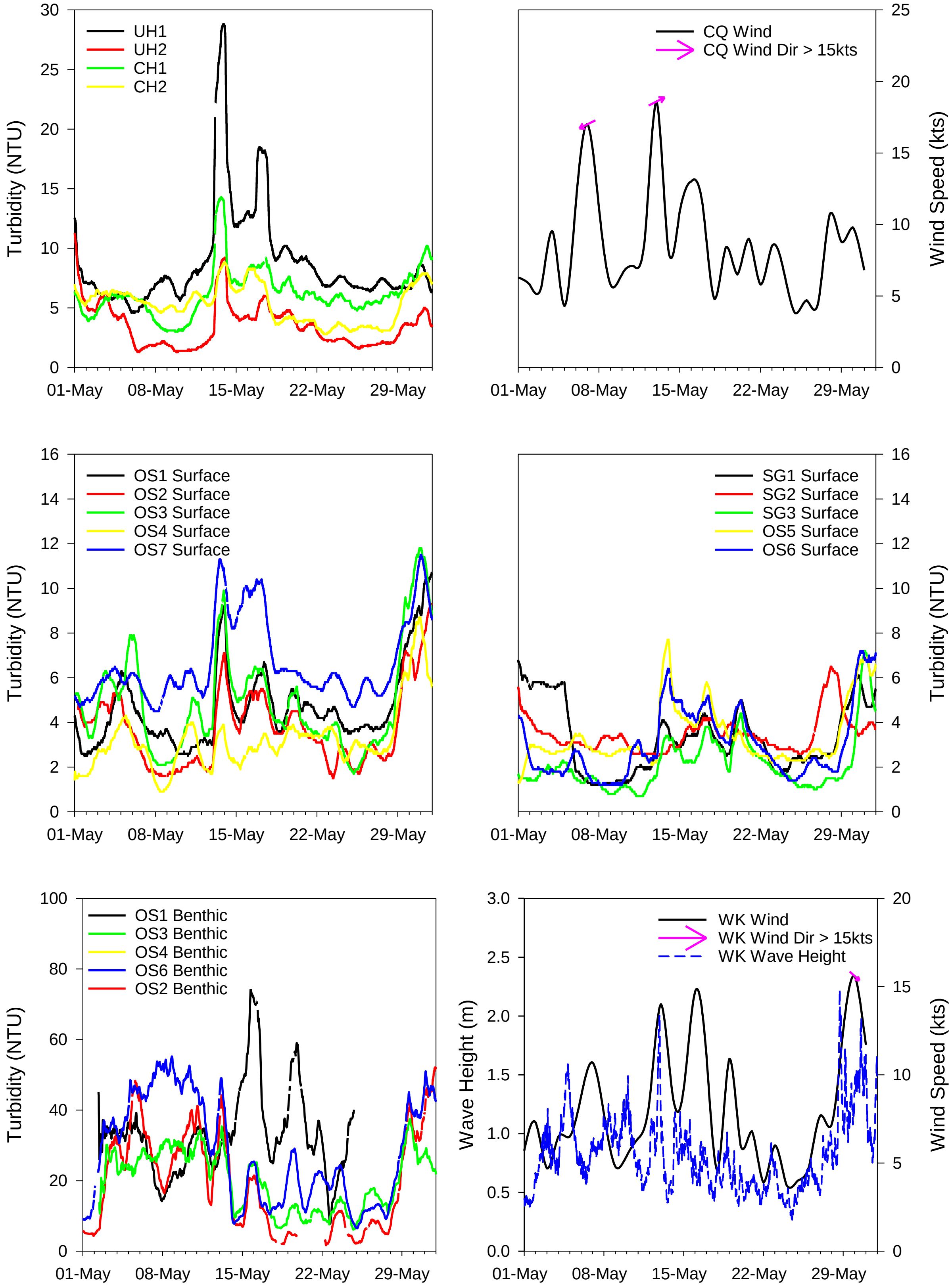


Figure 7 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots.

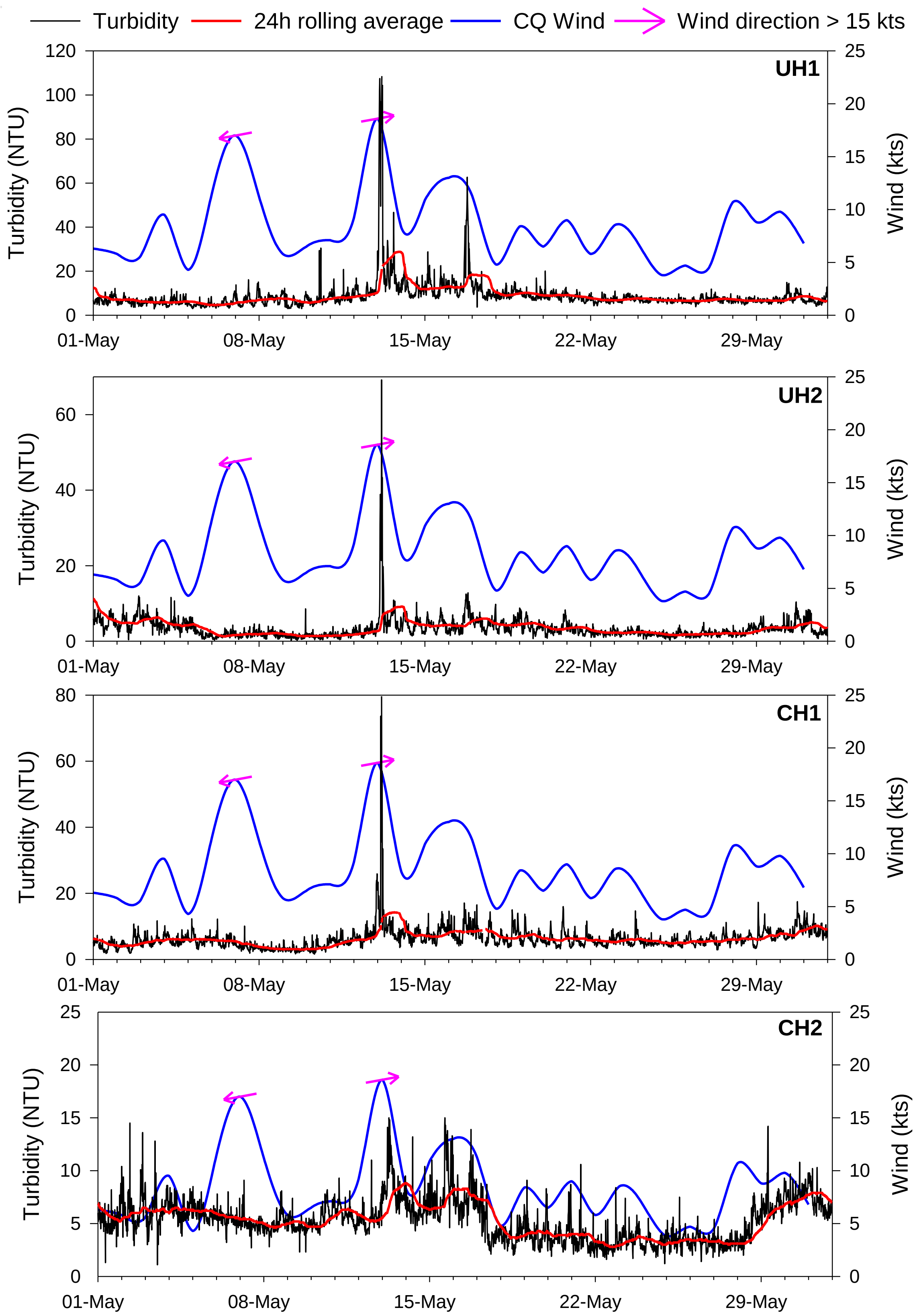


Figure 8 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during May 2019.
Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

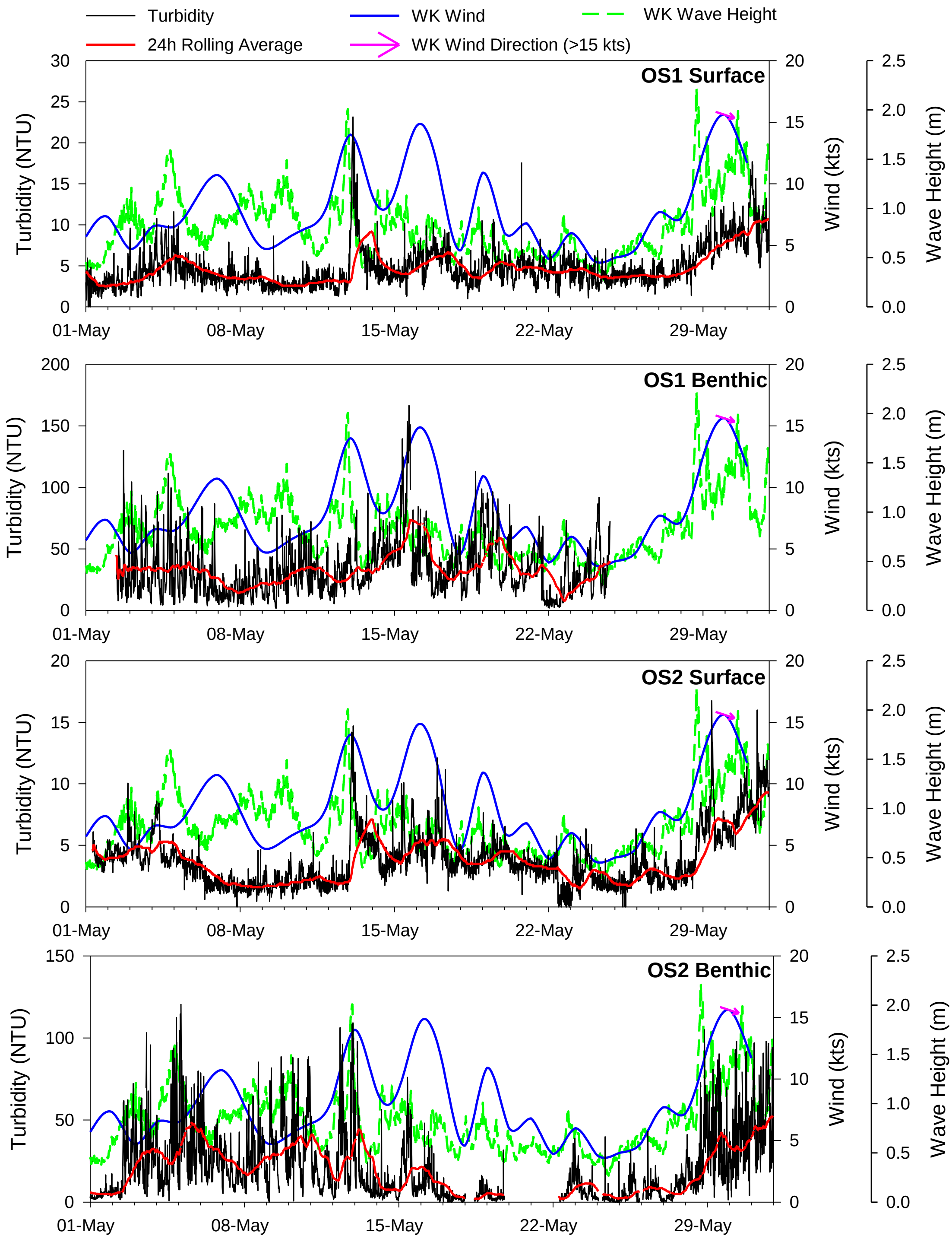


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

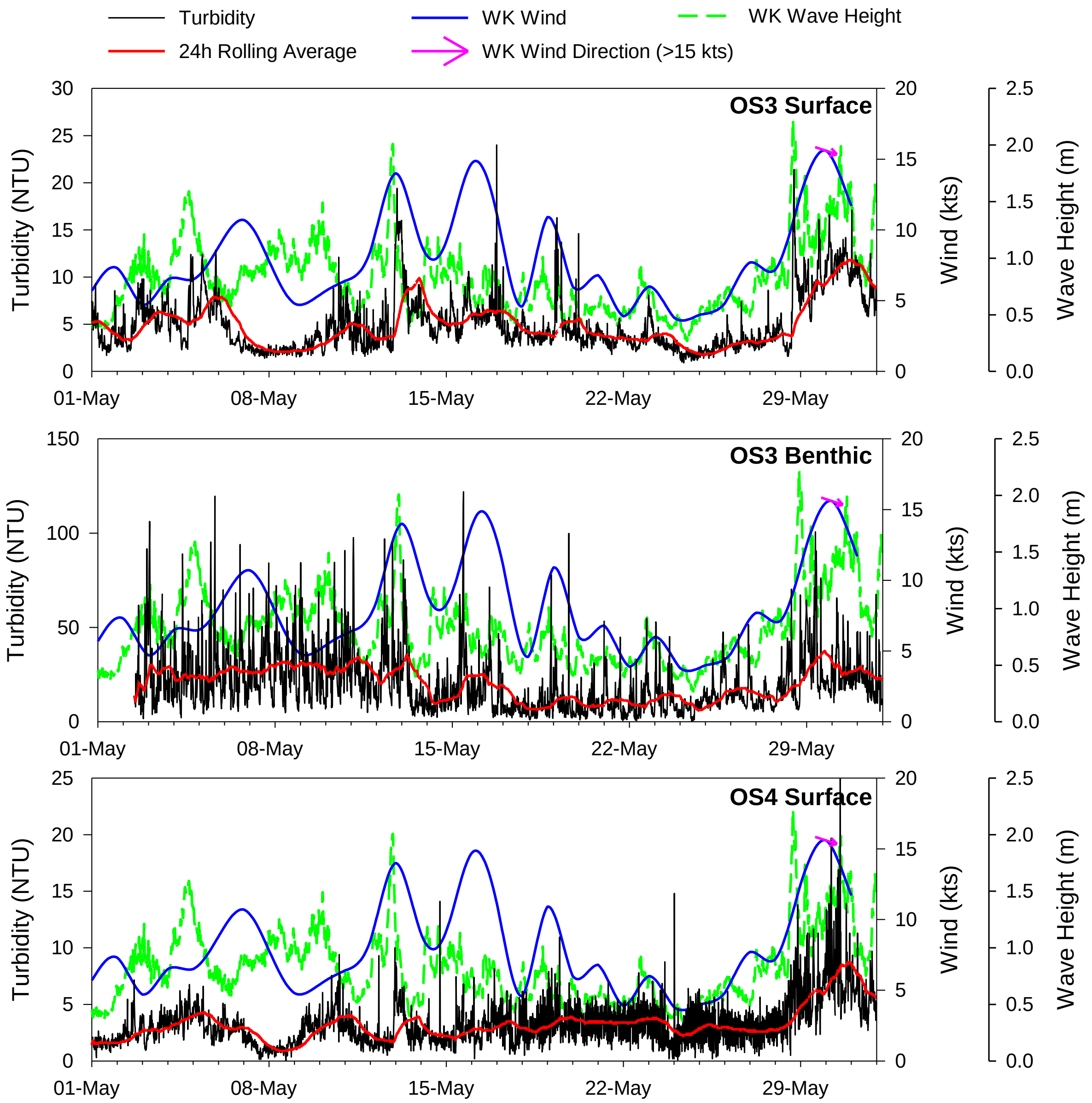


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during May 2019.
Note differing scales for each plot. *Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity. Note that no valid turbidity data was recorded at OS4 Benthic during May 2019.*

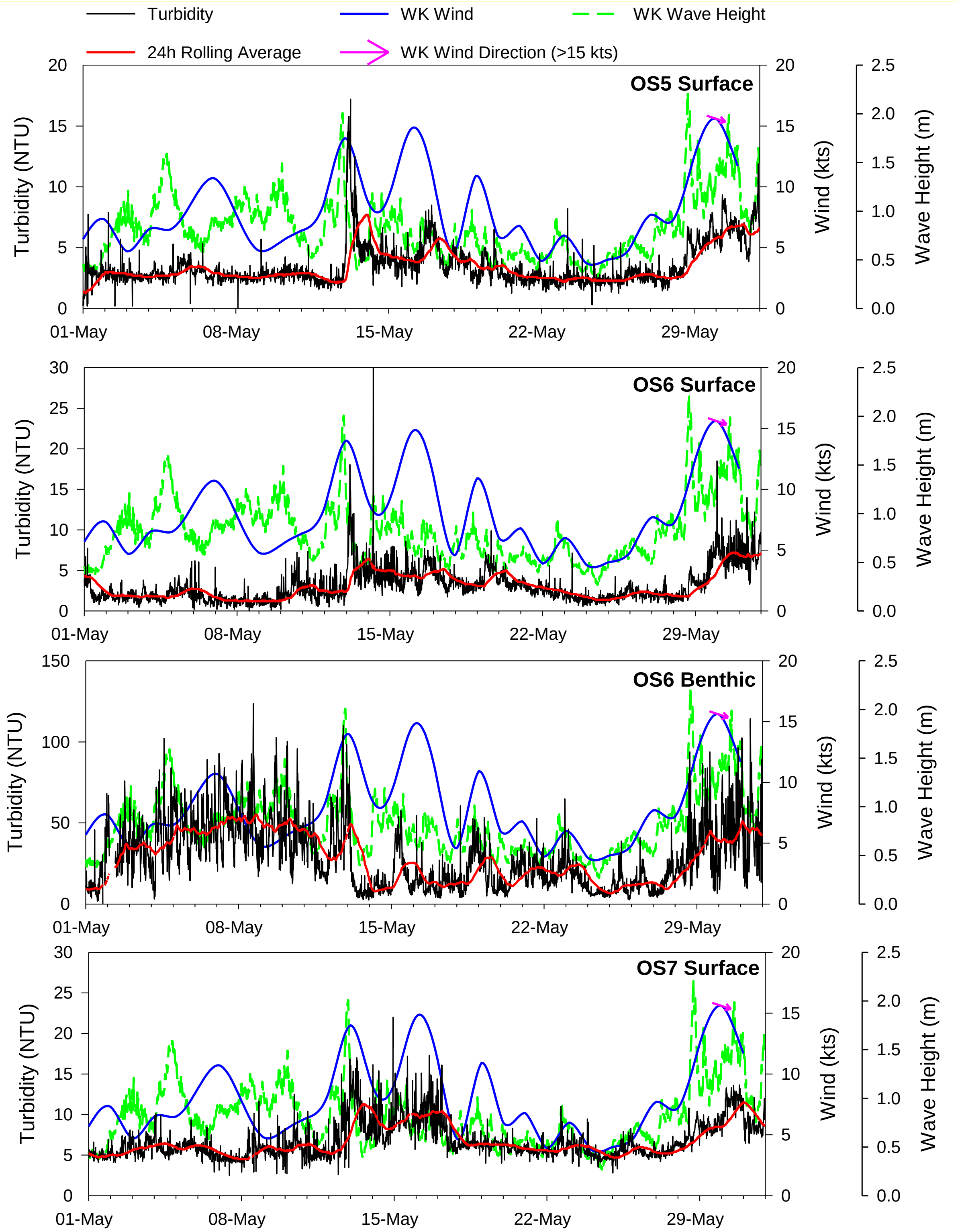


Figure 11 Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

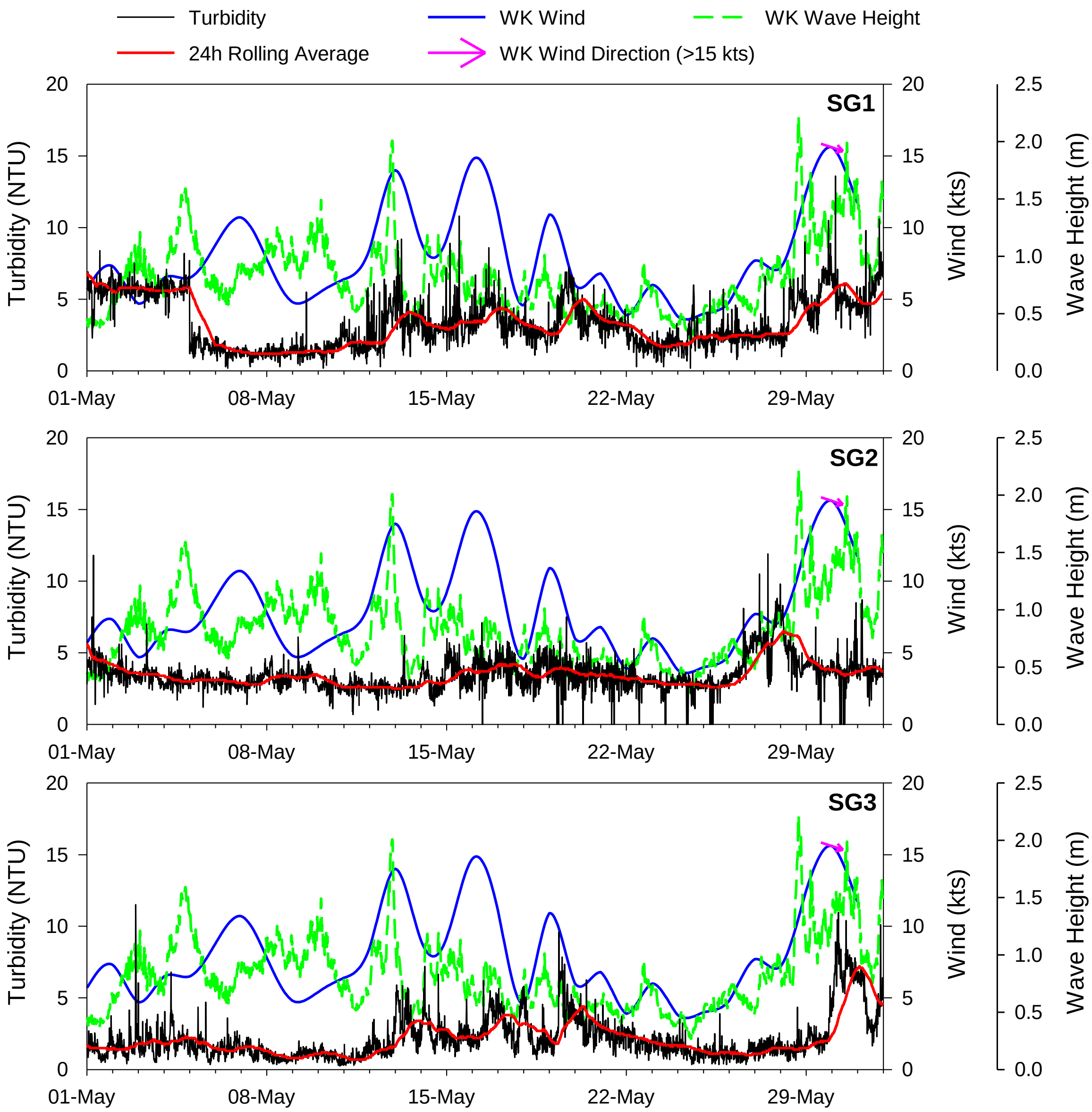


Figure 12 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

3.2.2 Dredge Compliance Trigger Values

Management of dredge operations was guided using three tier levels of turbidity trigger values based on the higher order percentiles of baseline data (refer Section 2.1.2). Tier 1 (80^{th} percentile) and Tier 2 (95^{th} percentile) intensity values are designated for LPC internal use and provide early warning mechanisms for elevated turbidity conditions. A compliance alert is 'tripped' if:

1) The current KZ smoothed turbidity reading is above the relevant Tier 3 (99^{th} percentile) intensity level; **and**
2) The cumulative time of exceedances defined in 1) during the current 30-day rolling window exceeds the allowable hours given.

The Tier 1 to 3 intensity levels for KZ smoothed data and allowable hours calculated for the project (Fox, 2018), are outlined in Table 6.

Table 6 Turbidity intensity values for each site and allowable hours of exceedance in rolling 30-day period.
Allowable hours for Tiers 1 and 2 are indicative only and non-binding as these are for internal LPC use only.

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

3.2.2.1 P99 Exceedance Counts

During May the Tier 3 intensity values within the monitoring network were exceeded at UH1 (Table 7) (Figure 13). This was attributed to elevated wind speeds (gusts 44 to 59 kts) predominantly in a west-south-west direction on 13 to 17 May, which had a maximum impact at this site in particular.

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

Site	P99 Count >7.2 Hours Start Time	P99 Count >7.2 Hours End Time	Maximum P99 Count (Hours)
UH1	13/05/19 04:30	29/05/19 17:45	9.75
UH2	–	–	4.25
CH1	–	–	2.25
CH2	–	–	0.00
OS1	–	–	0.00
OS2	–	–	0.00
OS3	–	–	1.25
OS4		Reference site	
OS5	–	–	0.00
OS6	–	–	0.00
OS7	–	–	2.75
SG1	–	–	0.00
SG2	–	–	0.00
SG3	–	–	0.00

3.2.2.2 P99 Exceedance Counts Consented Removal

Surface turbidity levels during May were largely below baseline conditions. Although site UH1 accumulated more than the allowable validated P99 exceedance counts (Table 7) this was attributed to natural conditions and no exceedance counts were required to be removed (Table 8).

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

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

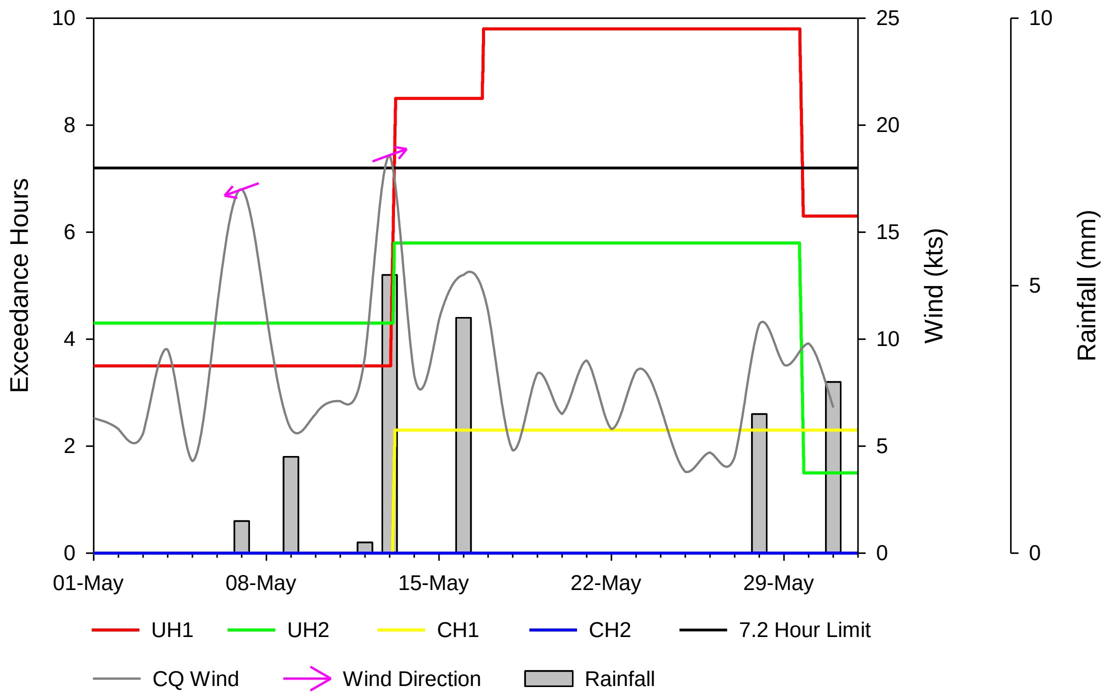


Figure 13 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during May 2019.

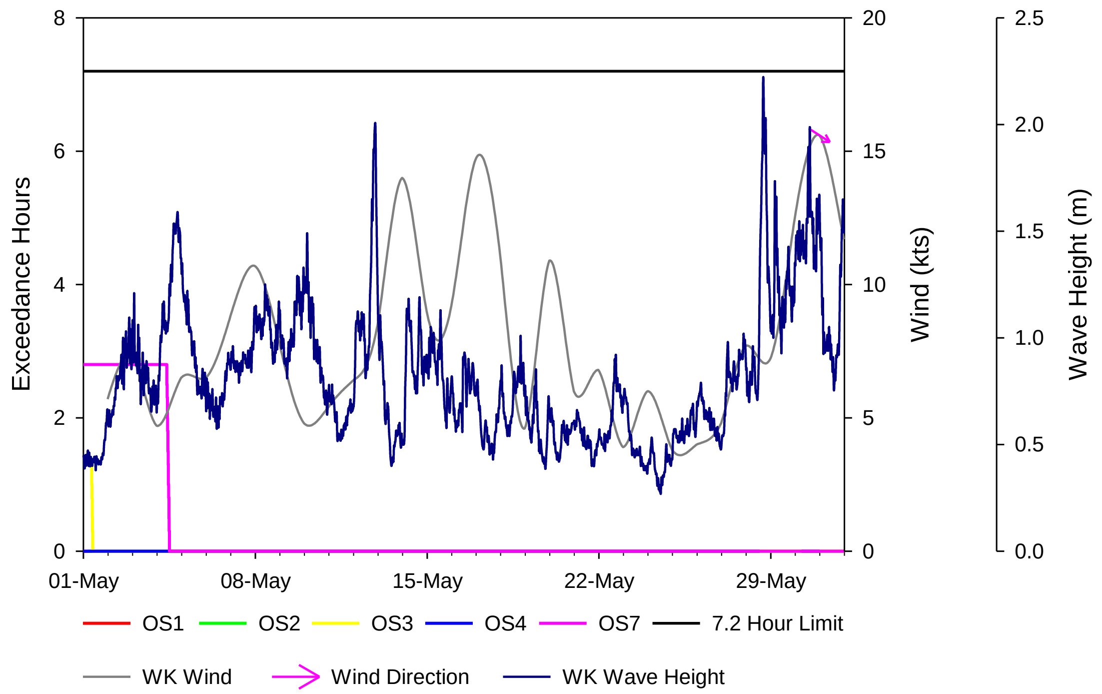


Figure 14 Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during May 2019.
Note there is no trigger value for the reference site OS4.

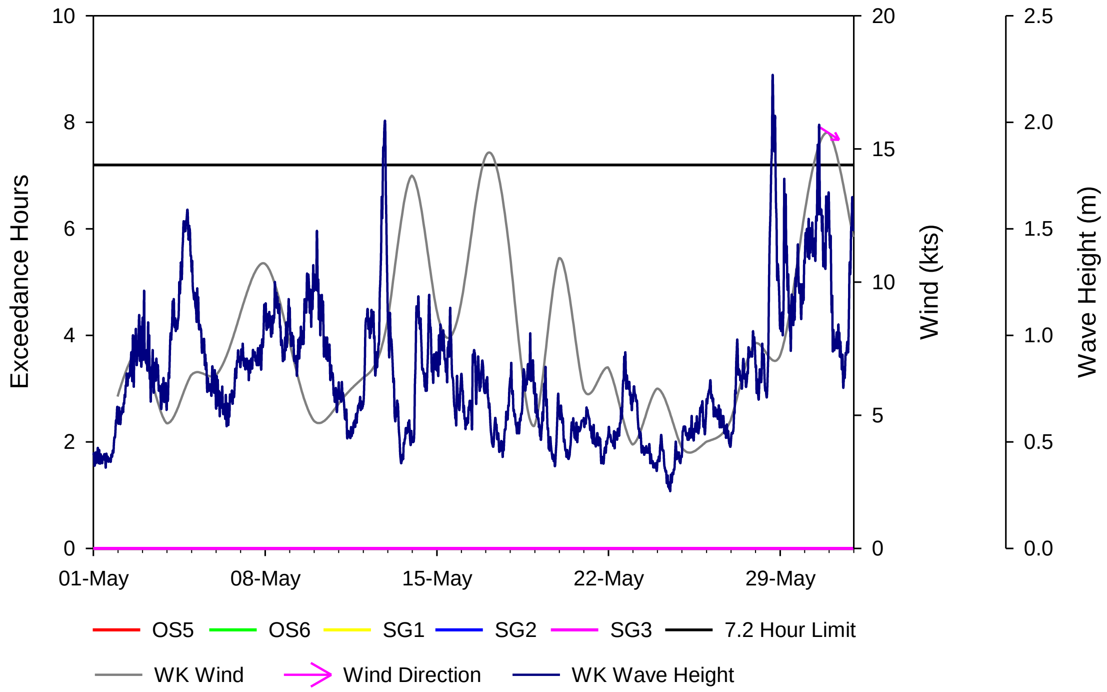


Figure 15 Tier 3 allowable hour counts at SG1, SG2b and SG3 after exceedance of the intensity values during May 2019.

3.2.3 Temperature

Mean monthly sea surface temperatures around Lyttelton Harbour were considerably cooler than those experienced during April, ranging from 12.4 to 13.8°C (Table 9) (c.f. 14.6 to 15.2°C in April) continuing the trend for seasonal cooling with the approaching winter months. Continuing trends for the previous month, slightly cooler temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites.

Water temperatures were fairly stable during the first half of the month until high wind speeds and rainfall on 13 May instigated a decline, which continued to 17 May, when wind speeds and rainfall abated. Water temperatures then remained stable at a lower baseline level for the remainder of the month (Table 9, Figure 16).

Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the surface temperature datasets, particularly at the inner harbour sites. This was also evident at site OS1. No impact to temperatures was detected at nearshore and offshore sites at the end of the month as a result the elevated offshore wind speed and wave height event. Benthic temperatures were similar to overlying surface waters (Table 9, Figure 17), again indicating a well-mixed water column.

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during May 2019. *Values are means ± se (n = 2799 to 2976).*

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	12.4 ± 0.0	–
UH2	12.6 ± 0.0	–
CH1	12.8 ± 0.0	–
CH2	13.1 ± 0.0	–
SG1	13.5 ± 0.0	–
SG2	13.5 ± 0.0	–
SG3	13.8 ± 0.0	–
OS1	13.2 ± 0.0	13.3 ± 0.0
OS2	13.3 ± 0.0	13.5 ± 0.0
OS3	13.5 ± 0.0	13.4 ± 0.0
OS4	13.4 ± 0.0	13.5 ± 0.0
OS5	13.5 ± 0.0	–
OS6	13.5 ± 0.0	13.5 ± 0.0
OS7	13.3 ± 0.0	–

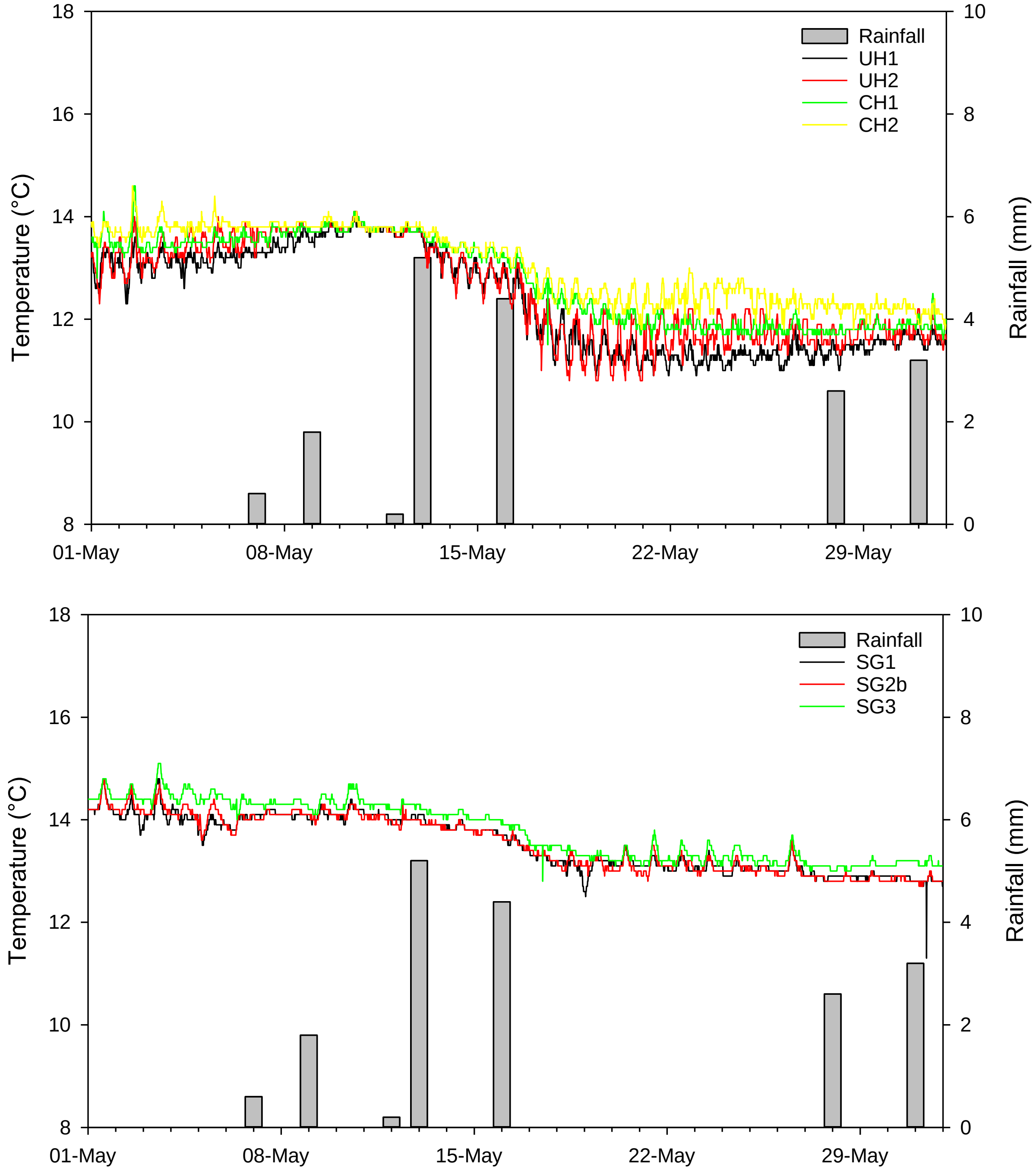
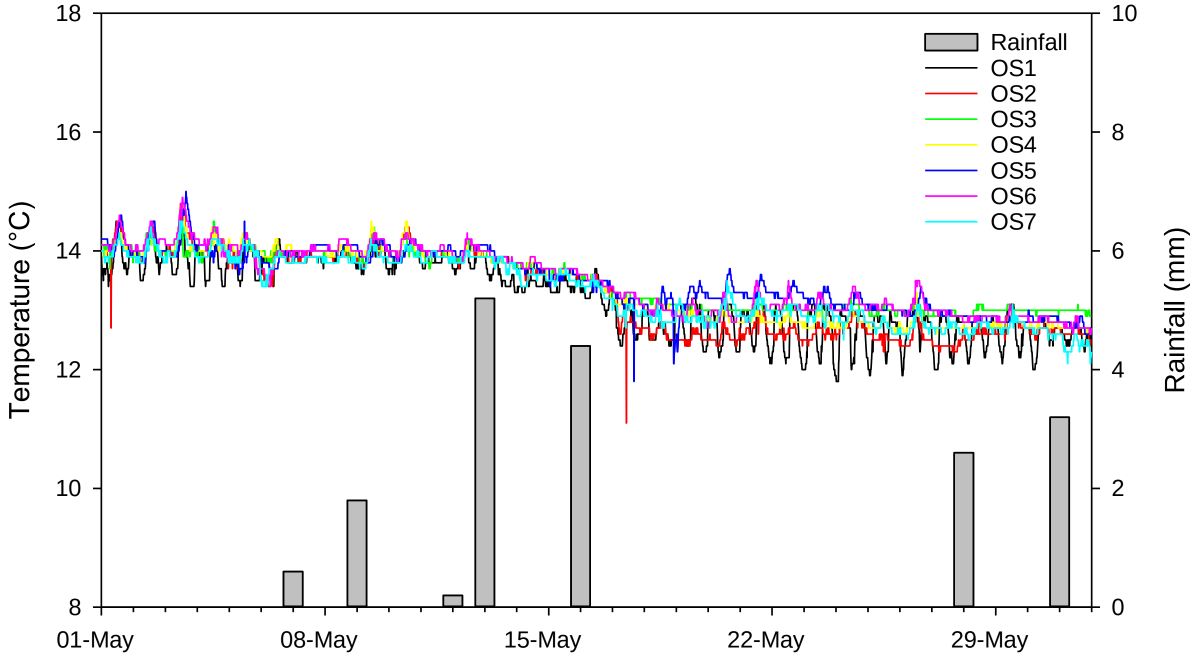


Figure 16 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during May 2019.



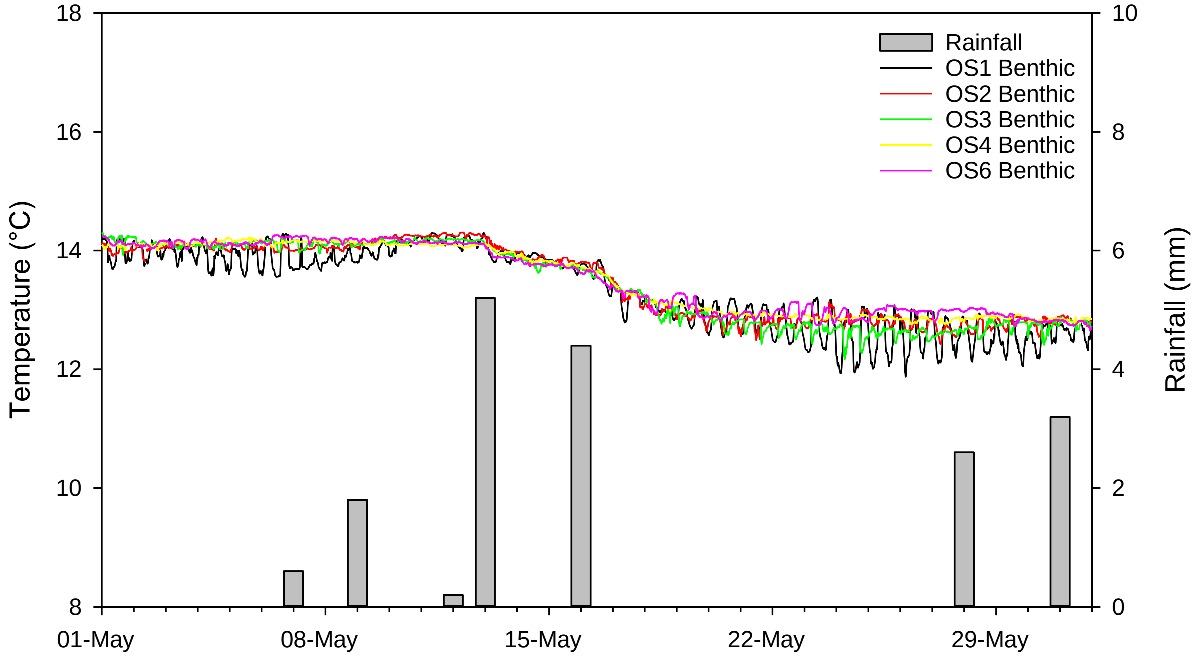


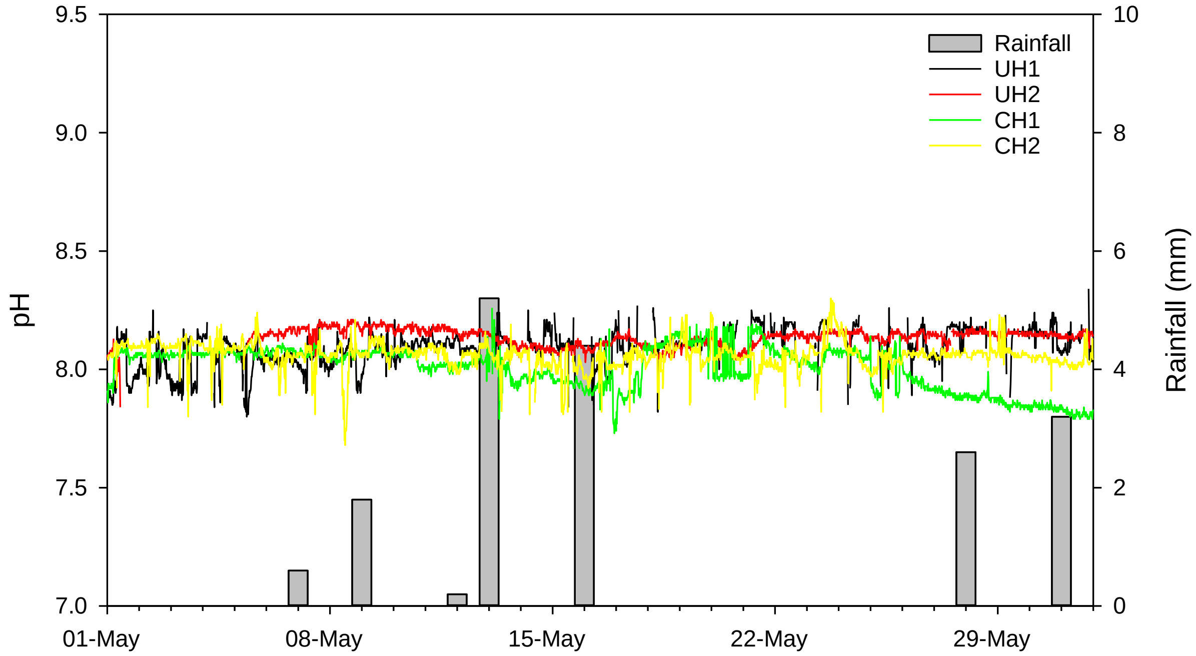
Figure 17 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during May 2019.

3.2.4 pH

The pH in May was consistent across all sites, both surface and benthic, with monthly means ranging between 8.0 and 8.1 (Table 10, Figures 18 and 19), as typically observed. Some post calibration issues have been encountered with pH probes during March to May which has resulted in some unacceptable data. Firmware updates and replacement probes are expected to resolve these issues in the near future. No notable temporal trends were observed across the month.

Table 10 Mean pH at inshore, spoil ground and offshore water quality sites during May 2019. *Values are means ± se (n = 1454 to 2976).*

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



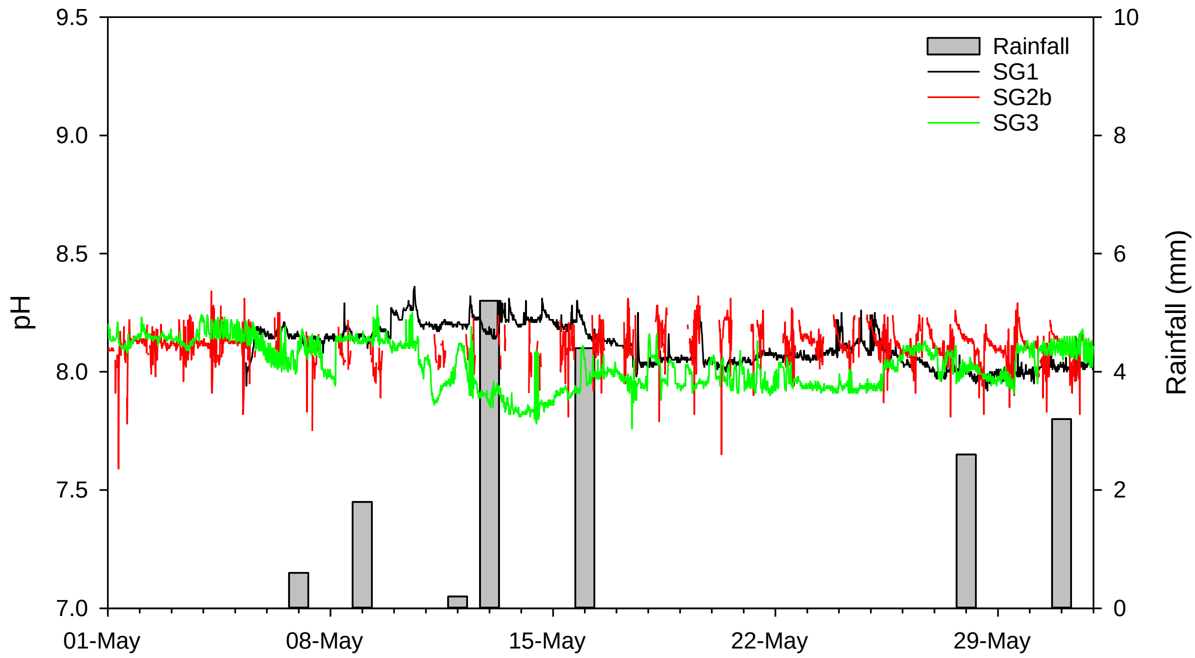
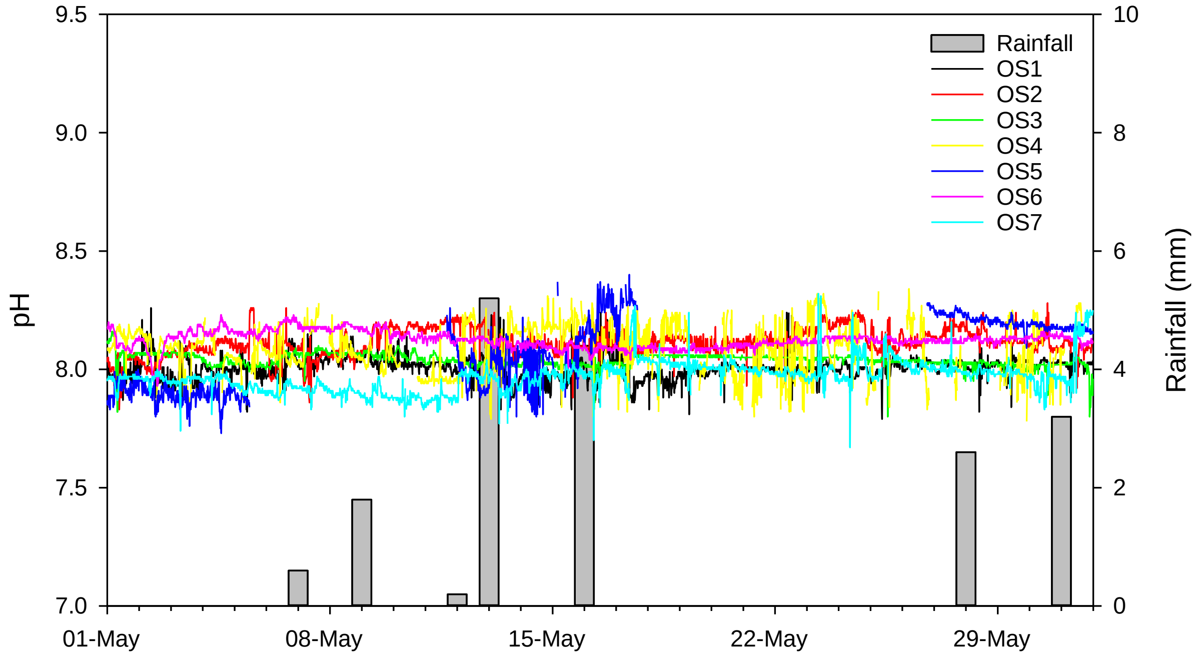


Figure 18 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during May 2019.



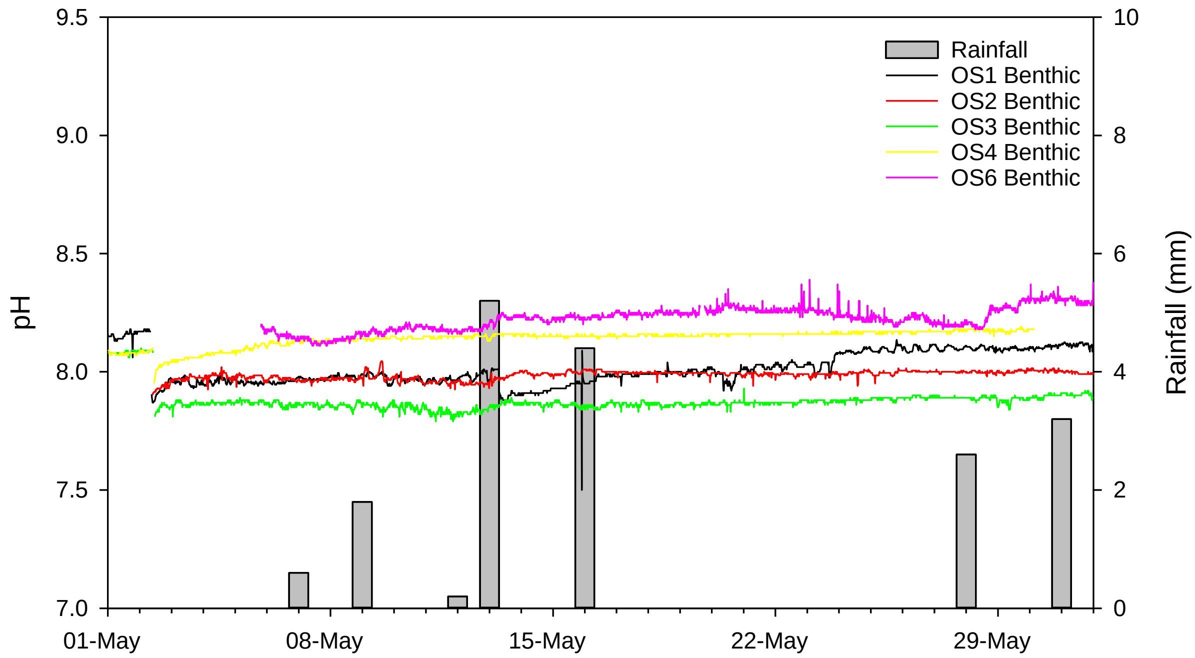


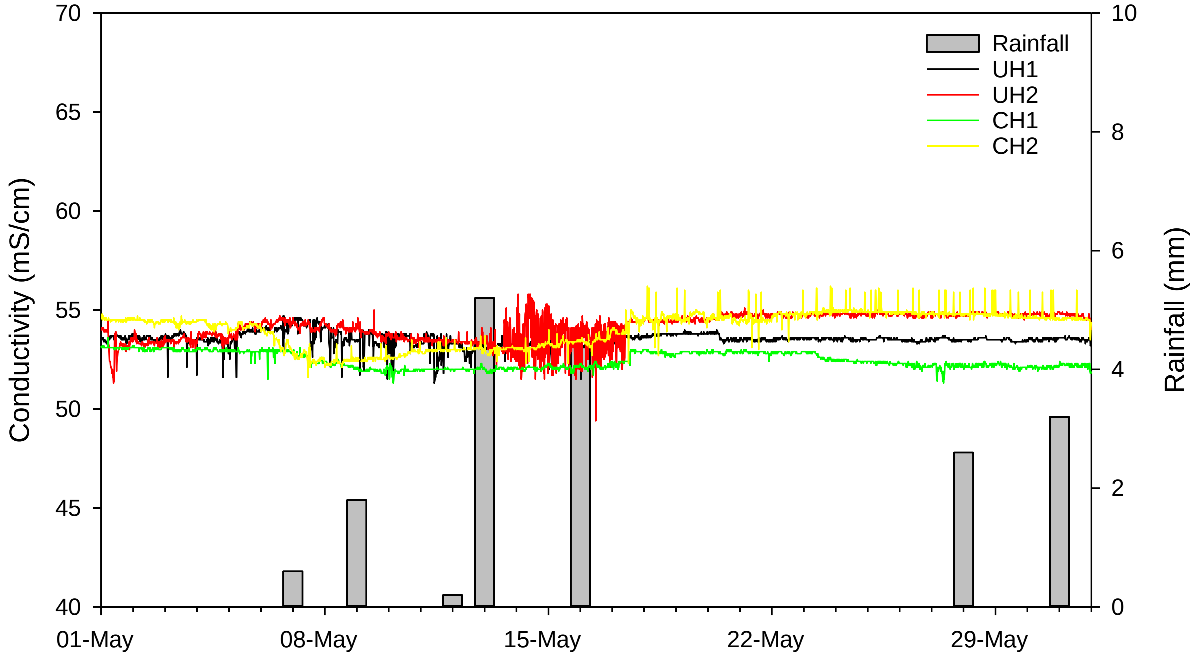
Figure 19 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at nearshore and offshore water quality sites during May 2019.

3.2.5 Conductivity

Surface conductivity in May ranged from 52.4 mS/cm to 56.0 mS/cm (Table 11, Figure 20 and 21), while benthic conductivity was slightly lower ranging from 50.1 mS/cm to 51.4 mS/cm, which were similar to monthly mean values calculated for April. Conductivity was fairly stable at all sites mainly due to precipitation being restricted to several small rainfall events and lack of flows from the Waimakariri River. A small decline in conductivity was recorded at SG1 and SG2b at the start of May most likely in response to the flow event which had occurred on 29 April. Small responses to this event were also recorded at some of the offshore sites including OS2. The large flow event towards the end of May would not be expected to influence sites until early June.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during May 2019. *Values are means ± se (n = 2735 to 2976).*

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	53.5 ± 0.0	–
UH2	54.1 ± 0.0	–
CH1	52.4 ± 0.0	–
CH2	54.0 ± 0.0	–
SG1	54.9 ± 0.0	–
SG2	54.3 ± 0.0	–
SG3	56.0 ± 0.0	–
OS1	52.9 ± 0.0	50.7 ± 0.0
OS2	54.0 ± 0.0	50.5 ± 0.0
OS3	54.3 ± 0.0	51.4 ± 0.0
OS4	55.3 ± 0.0	50.1 ± 0.0
OS5	53.3 ± 0.0	–
OS6	53.5 ± 0.0	54.1 ± 0.0
OS7	54.0 ± 0.0	–



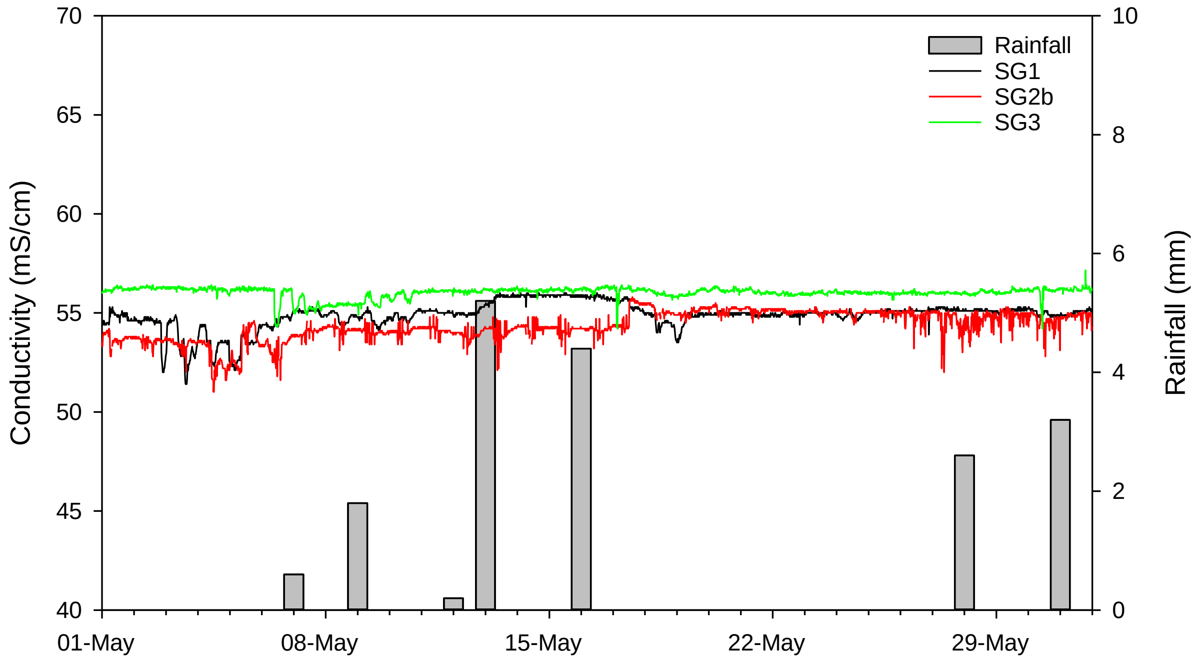
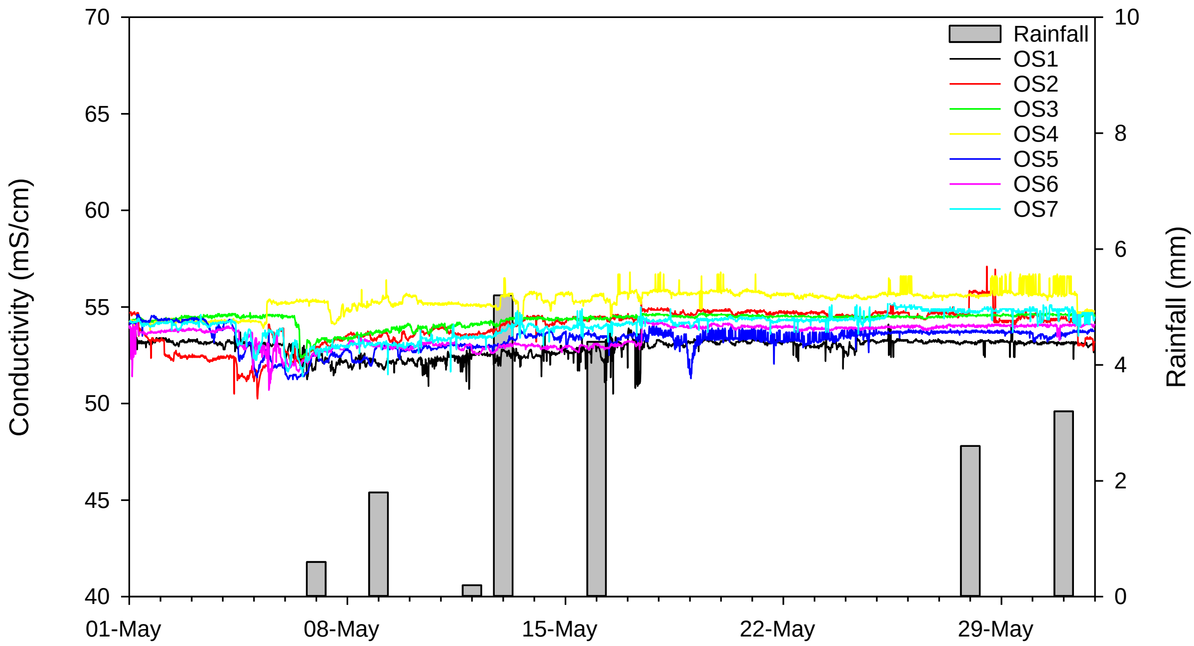


Figure 20 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during May 2019.



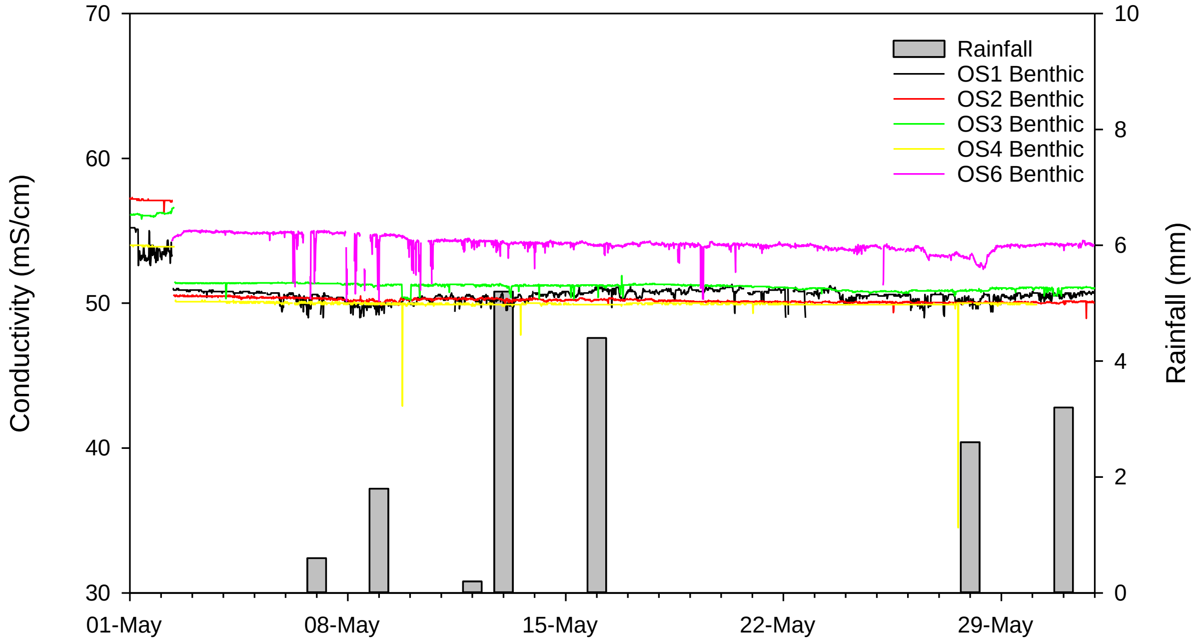


Figure 21 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during May 2019.

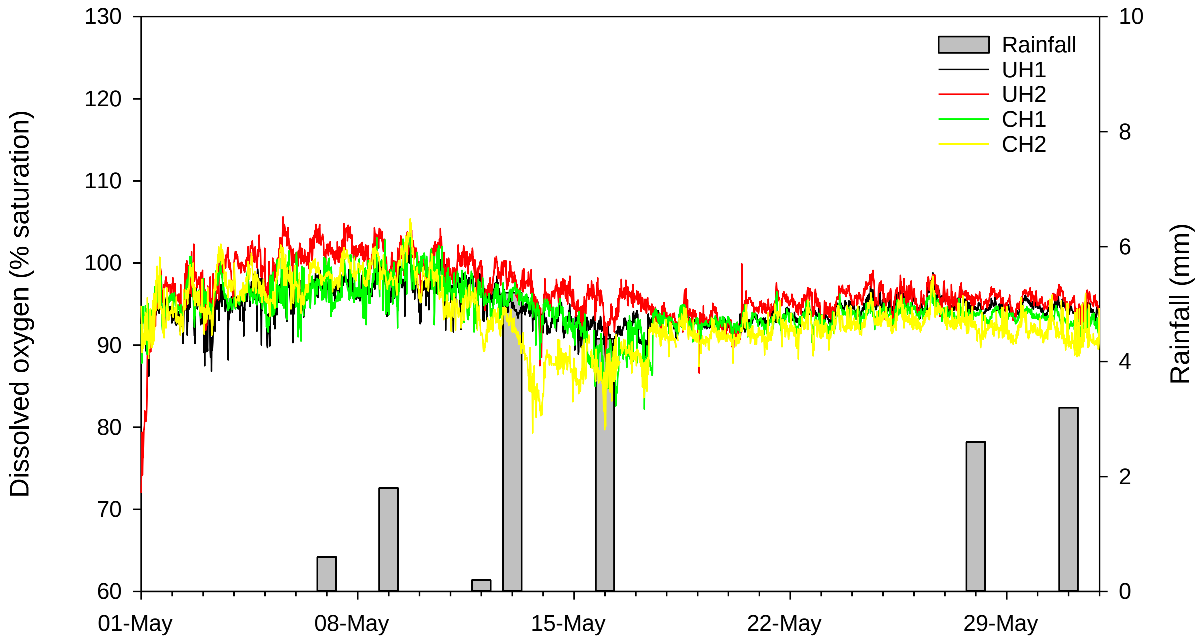
3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in May ranged from 93 to 98% saturation, similar overall to April values (91 to 99% saturation), which were lower than in March. The continuing decreasing water temperatures, in conjunction with decreased solar radiation, is likely to have resulted in reduced photosynthesis and thus lower oxygen production over the last two months. As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings ranging from 89 to 94% saturation (Table 12, Figures 22 and 23), due to reduced photosynthesis occurring at depth.

Large diurnal fluctuations in DO were recorded at all sites including the spoil ground for the entire month of May. DO was low at all sites at the start of the month most likely in response to the late April weather event but displayed a steady increase until the weather event of 13 May, which included precipitation and therefore cloud cover. DO declined at all sites during this period, particularly at site CH2, SG3 and OS6. Interestingly there appeared to be no impact to DO in response to the second large weather event at the end of May.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during May 2019.
Values are means ± se (n = 2836 to 2976).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	95 ± 0	–
UH2	97 ± 0	–
CH1	94 ± 0	–
CH2	93 ± 0	–
SG1	97 ± 0	–
SG2	98 ± 0	–
SG3	96 ± 0	–
OS1	95 ± 0	94 ± 0
OS2	94 ± 0	90 ± 0
OS3	93 ± 0	92 ± 0
OS4	95 ± 0	94 ± 0
OS5	96 ± 0	–
OS6	98 ± 0	89 ± 0
OS7	94 ± 0	–



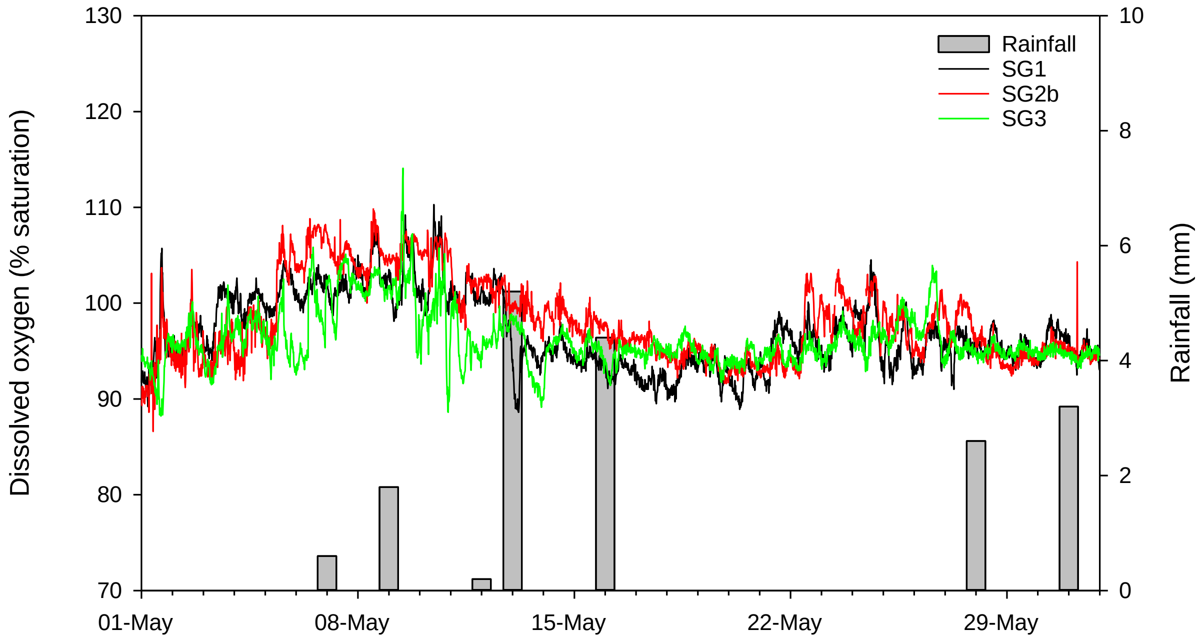
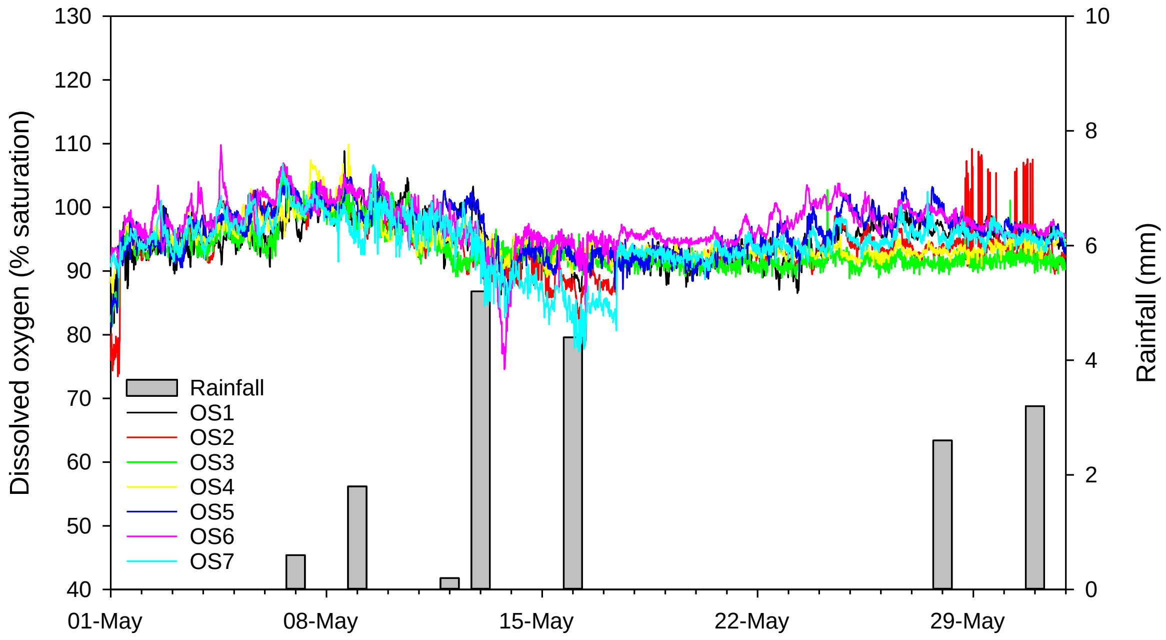


Figure 22 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during May 2019.

Benthic DO displayed a similar pattern to surface counterparts being quite variable at the beginning of May before declining similarly to surface sites just prior to the 13 May weather event. Benthic DO then recovered quite quickly and was relatively stable for the remainder of the month. OS1 benthic DO displayed larger diurnal fluctuations compared to other benthic sites. This is most likely related to benthic temperature at this site which also fluctuated by several degrees across a daily cycle.



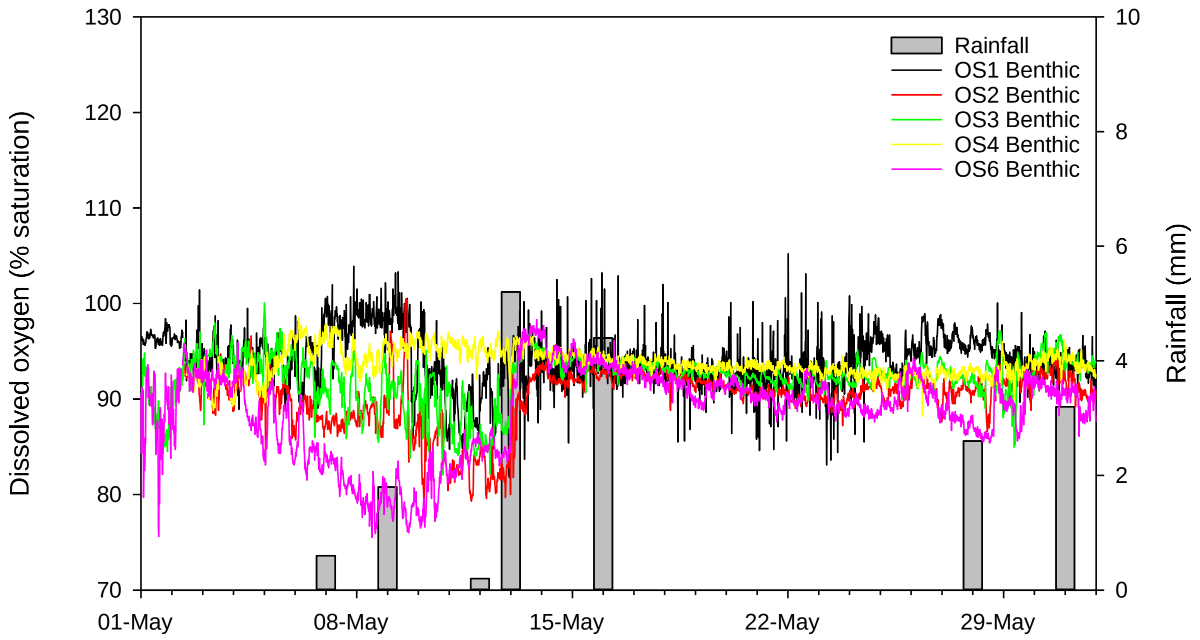


Figure 23 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during May 2019.

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

Water samples for the determination of TSS were also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, CH1 and CH2. Further information regarding the specific sampling methodology can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Statistical analyses of the resulting datasets are provided in Tables 13 to 15, with depth profile plots presented in Figures 24 to 26.

The relatively shallow sites of the upper and central harbour once again displayed well mixed conditions with little variability recorded in parameters through the water column (Figure 24). Similar to the continuous loggers, the uppermost harbour site UH3, displayed the lowest temperature and conductivity readings within the harbour, as was also observed in April. There appeared to be little benthic resuspension at inshore sites in May, with little change in turbidity at the benthos as is often observed.

Within the nearshore region, physicochemical data collected also indicated the persistence of strong vertical mixing, with little change in temperature, conductivity or pH through the water column. DO displayed a decreasing gradient from surface to benthos likely due to declining photosynthesis with depth. A sharper decline in DO was recorded at both OS7 and OS2 at 4 m depth (Figure 25). Turbidity was consistent through the water column at all sites until approximately 10 m depth when turbidity increased to the benthos. This is often observed due to shear forces (friction between the overlying moving water and the stationary seabed) providing energy for sediment resuspension.

Within the offshore region of the spoil ground, OS5 and OS6, the water column was once again recorded to be well mixed, with notably lower conductivity values in the surface waters at SG1, SG2 and OS5 (Figure 26). Conductivity at the remaining sites (OS6 and SG3) remained fairly stable through the water column. The large flow event from the Waimakariri River which occurred at the end of April may have been responsible for fresher surface waters at sites closest to the river discharge. Although pH remained relatively consistent through the water column at all sites, DO recorded a steady decreasing gradient at all sites except site SG3, furthest from the river flow. Benthic resuspension was observed at all sites, similar to that at nearshore sites.

The shallowest euphotic depths that ranged from 3.4 m to 8.4 m were calculated for upper and central harbour monitoring sites (Table 14), which reflects the typically higher levels of turbidity experienced (Figure 24). The deepest euphotic depth was calculated to be 16.4 m at SG2 (Table 15) where turbidity in the surface and mid-column was low. No exceedances of WQG were recorded for the sub-surface during the May vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the May 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 18 to 31 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	05/05/2019 08:00	Sub-surface	12.8 ± 0.0	8.2 ± 0.0	53.8 ± 0.0	100 ± 0	3.9 ± 0.0	8	0.7 ± 0.0	6.4
		Whole column	12.8 ± 0.0	8.2 ± 0.0	53.8 ± 0.0	100 ± 0	4.0 ± 0.0	–		
UH2	05/05/2019 08:34	Sub-surface	13.2 ± 0.0	8.3 ± 0.0	54.0 ± 0.0	102 ± 0	2.6 ± 0.1	5	0.6 ± 0.0	8.4
		Whole column	13.2 ± 0.0	8.3 ± 0.0	54.1 ± 0.0	102 ± 0	2.7 ± 0.0	–		
UH3	05/05/2019 08:13	Sub-surface	12.6 ± 0.0	8.2 ± 0.0	53.6 ± 0.0	100 ± 0	5.8 ± 0.3	10	1.3 ± 0.3	3.4
		Whole column	12.6 ± 0.0	8.2 ± 0.0	53.6 ± 0.0	100 ± 0	6.5 ± 0.2	–		
CH1	05/05/2019 09:10	Sub-surface	13.3 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	102 ± 0	4.6 ± 0.1	10	0.9 ± 0.0	5.0
		Whole column	13.3 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	101 ± 0	5.7 ± 0.3	–		
CH2	05/05/2019 08:57	Sub-surface	13.6 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	102 ± 0	3.9 ± 0.9	5	0.6 ± 0.0	7.6
		Whole column	13.6 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	101 ± 0	4.7 ± 0.5	–		
WQG			–	**7.0 – 8.5**	–	**80 – 110**	**10**	–	–	–

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the May 2019 sampling event.
Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 29 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	05/05/2019 09:26	Sub-surface	13.3 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	100 ± 0	4.8 ± 0.9	5	0.5 ± 0	9.5
		Mid	13.3 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	100 ± 0	3.0 ± 0.1	10		
		Benthos	13.4 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	99 ± 0	5.9 ± 0.5	5		
		Whole column	13.3 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	100 ± 0	4.2 ± 0.3	–		
OS2	05/05/2019 13:18	Sub-surface	14.0 ± 0.0	8.3 ± 0.0	54.0 ± 0.0	104 ± 0	2.2 ± 0.1	< 3	0.5 ± 0	9.5
		Mid	13.8 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	100 ± 0	2.6 ± 0.1	7		
		Benthos	13.8 ± 0.0	8.3 ± 0.0	54.4 ± 0.0	97 ± 0	6.5 ± 0.9	5		
		Whole column	13.9 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	101 ± 0	3.2 ± 0.3	–		
OS3	05/05/2019 12:28	Sub-surface	14.0 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	101 ± 0	5.7 ± 0.1	11	0.8 ± 0	5.7
		Mid	13.9 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	100 ± 0	6.1 ± 0.1	31		
		Benthos	13.9 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	100 ± 0	14 ± 4	10		
		Whole column	13.9 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	100 ± 0	7.4 ± 0.9	–		
OS4	05/05/2019 11:54	Sub-surface	14.2 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	101 ± 0	3.1 ± 0.1	4	0.6 ± 0	7.6
		Mid	14.0 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	100 ± 0	4.2 ± 0.3	19		
		Benthos	13.9 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	99 ± 0	6.0 ± 0.7	12		
		Whole column	14.0 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	100 ± 0	4.1 ± 0.2	-		
OS7	05/05/2019 13:40	Sub-surface	14.0 ± 0.0	8.3 ± 0.0	54.0 ± 0.0	106 ± 0	2.4 ± 0.1	6	0.8 ± 0.1	6.1
		Mid	13.8 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	100 ± 1	6.2 ± 0.2	41		
		Benthos	13.8 ± 0.0	8.3 ± 0.0	54.4 ± 0.0	98 ± 0	13 ± 2	11		
		Whole column	13.9 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	102 ± 1	5.8 ± 0.9	–		
WQG			–	**7.0 – 8.5**	–	**80 – 110**	**10**	–	–	

Table 15 Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during the May 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 34 to 43 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	05/05/2019 09:49	Sub-surface	13.7 ± 0.0	8.3 ± 0.0	53.0 ± 0.0	103 ± 0	2.0 ± 0.0	< 3	0.3 ± 0.1	16.1
		Mid	14.1 ± 0.0	8.3 ± 0.0	54.4 ± 0.0	99 ± 0	1.0 ± 0.0	13		
		Benthos	14.1 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	92 ± 1	4.6 ± 0.4	< 3		
		Whole column	13.9 ± 0.0	8.3 ± 0.0	53.9 ± 0.1	99 ± 1	2.1 ± 0.2	–		
OS6	05/05/2019 12:48	Sub-surface	14.0 ± 0.0	8.3 ± 0.0	54.0 ± 0.0	103 ± 0	2.2 ± 0.1	4	0.4 ± 0.0	11.9
		Mid	14.0 ± 0.0	8.3 ± 0.0	54.4 ± 0.0	99 ± 0	1.8 ± 0.1	6		
		Benthos	13.9 ± 0.0	8.3 ± 0.0	54.5 ± 0.0	94 ± 0	4.4 ± 0.6	5		
		Whole column	14.0 ± 0.0	8.3 ± 0.0	54.3 ± 0.0	99 ± 0	2.4 ± 0.2	–		
SG1	05/05/2019 10:21	Sub-surface	13.7 ± 0.0	8.3 ± 0.0	52.4 ± 0.0	103 ± 0	1.2 ± 0.0	< 3	0.3 ± 0.0	14.8
		Mid	14.0 ± 0.0	8.3 ± 0.0	54.2 ± 0.0	100 ± 0	0.9 ± 0.1	3		
		Benthos	14.2 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	92 ± 0	5.2 ± 0.5	< 3		
		Whole column	14.0 ± 0.0	8.3 ± 0.0	53.8 ± 0.1	99 ± 1	1.9 ± 0.3	–		
SG2	05/05/2019 10:53	Sub-surface	13.9 ± 0.0	8.3 ± 0.0	53.6 ± 0.0	104 ± 0	1.5 ± 0.1	4	0.3 ± 0.0	16.4
		Mid	14.1 ± 0.0	8.3 ± 0.0	54.4 ± 0.0	102 ± 0	1.2 ± 0.1	3		
		Benthos	14.1 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	96 ± 2	6.2 ± 2.1	< 3		
		Whole column	14.0 ± 0.0	8.3 ± 0.0	54.2 ± 0.1	102 ± 0	2.0 ± 0.4	–		
SG3	05/05/2019 11:24	Sub-surface	14.1 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	99 ± 0	1.8 ± 0.1	4	0.3 ± 0.0	13.2
		Mid	14.0 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	98 ± 0	2.1 ± 0.1	3		
		Benthos	14.0 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	98 ± 0	3.7 ± 0.9	4		
		Whole column	14.0 ± 0.0	8.3 ± 0.0	54.6 ± 0.0	99 ± 0	2.3 ± 0.1	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	

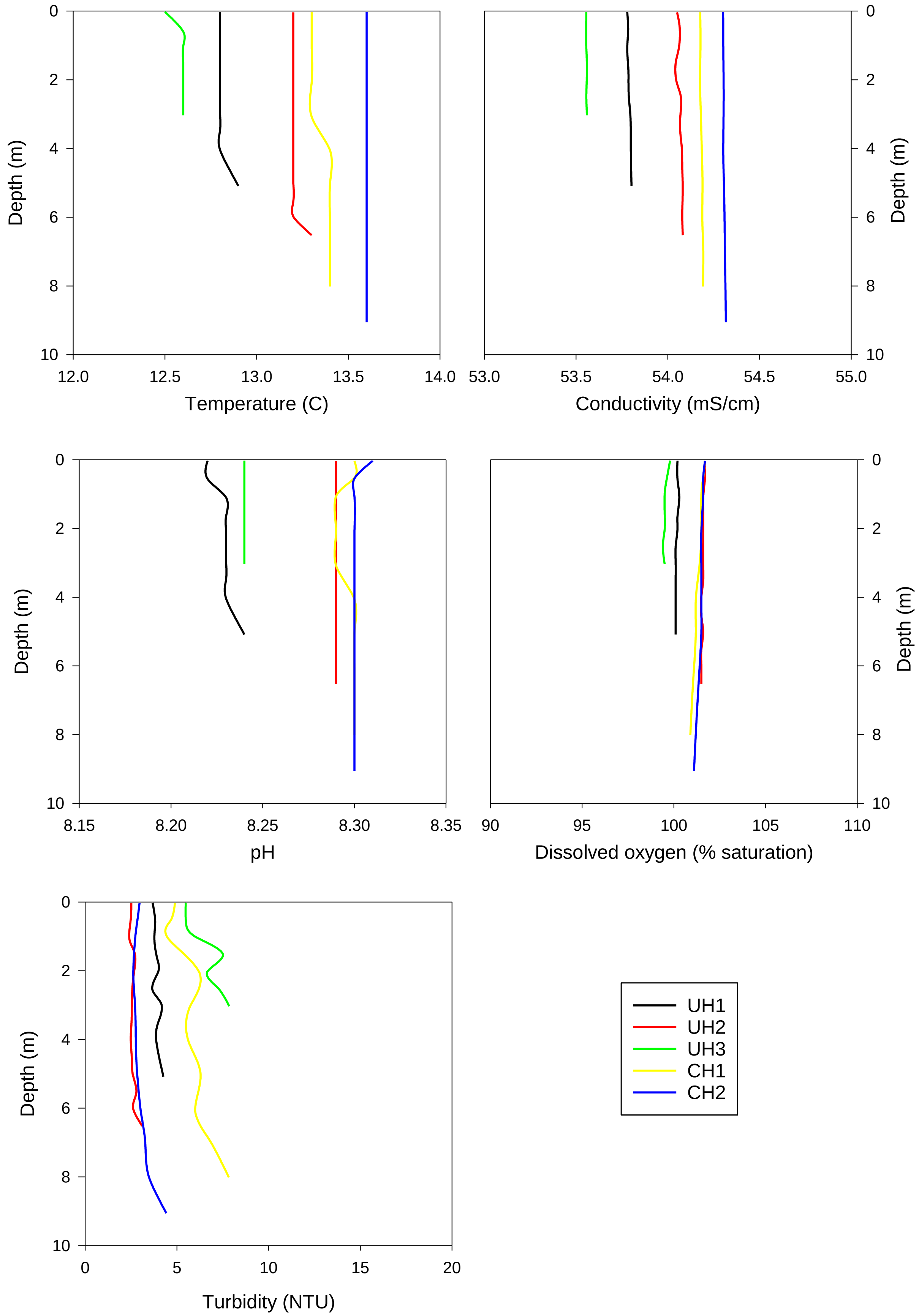


Figure 24 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 5 May 2019.

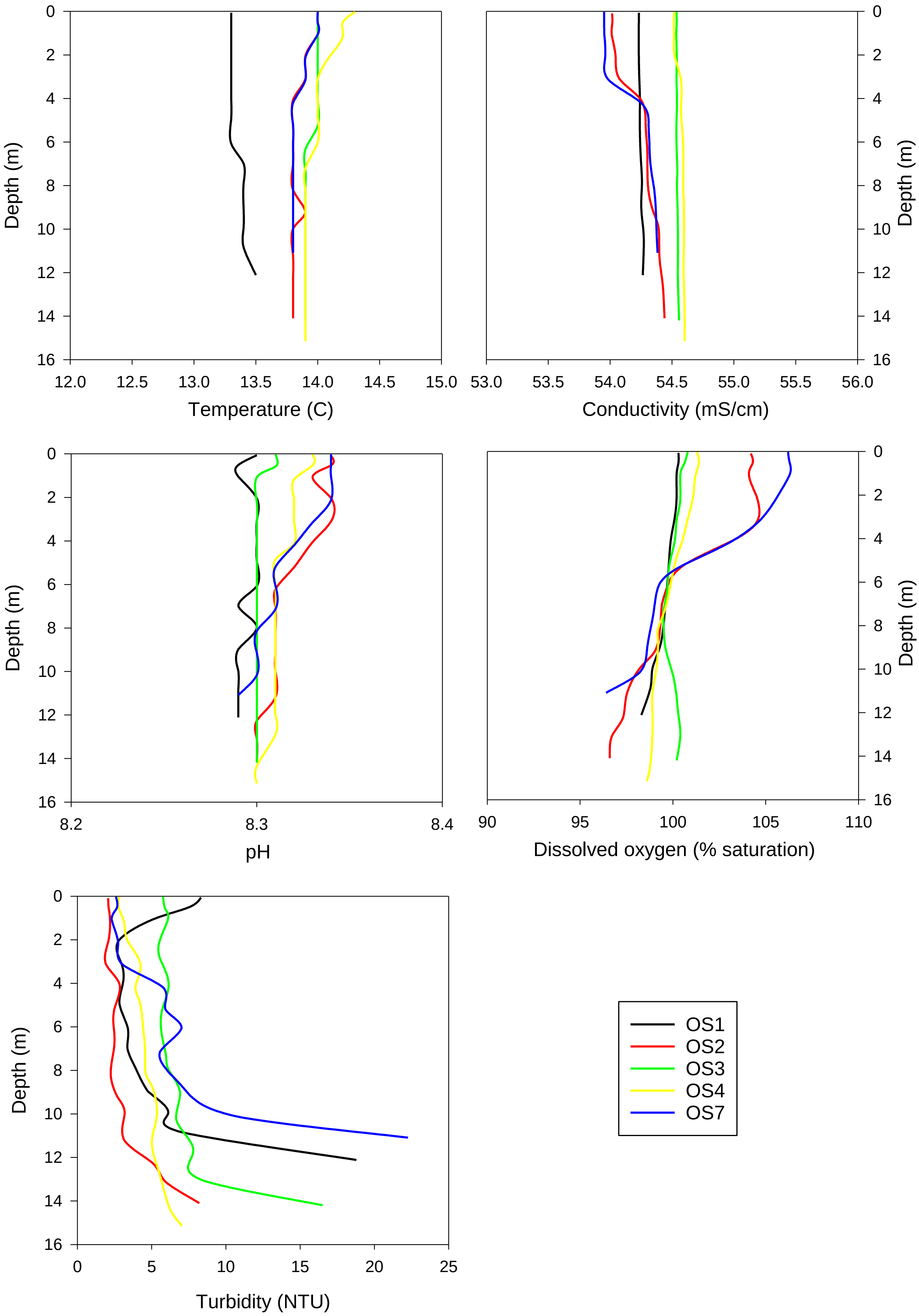


Figure 25 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 5 May 2019.

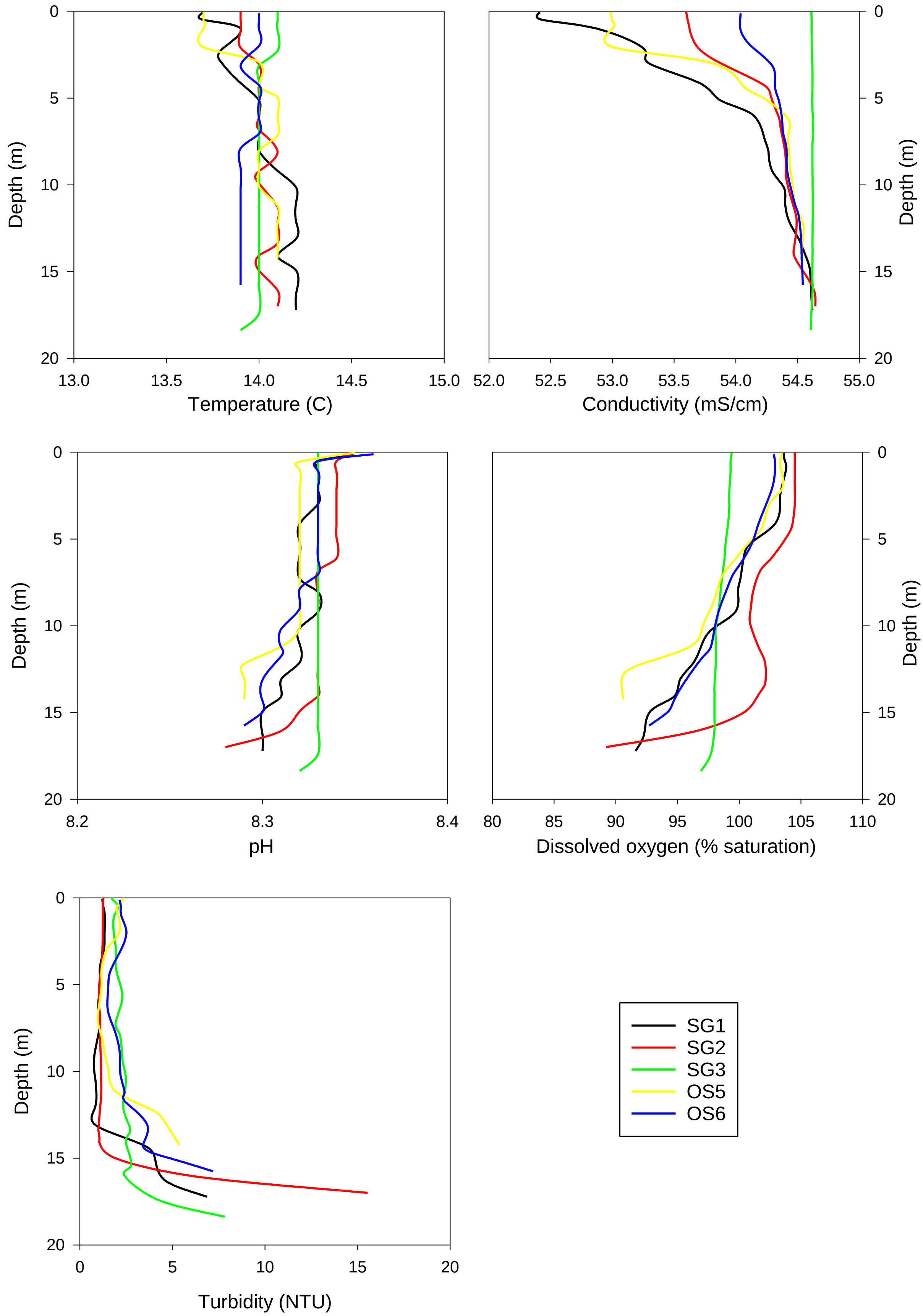


Figure 26 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 5 May 2019.

3.4 Continuous BPAR Loggers

Benthic PAR, or the amount of light reaching the benthos that can be utilised for photosynthesis, was measured at two offshore sites (OS2 and OS3) by autonomous dual PAR Odyssey loggers. Benthic PAR was compared to ambient PAR measured by telemetered loggers located at the Vision Environment office in Christchurch (Vision Base Christchurch, VBCC) in order to account for variations in daily light intensity such as those induced by cloud cover. Further information on the specific methodology used in BPAR measurements can be obtained from the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

Statistical analyses on the monthly BPAR datasets are presented in Table 16, with the collected data from benthic and VBCC sensors presented in Figure 27. Data from the logger exchange date (2 May) were removed from the analyses.

Table 16 Total Daily PAR (TDP) statistics during May 2019.
Values are means ± se (n = 30 to 31). Note data from the BPAR exchange day on 2 May were not utilized in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m²/day)		
		Mean ± se	Median	Range
Base	-	10,955 ± 674	11,100	3,300 – 18,400
OS2	17	25 ± 5	18	<0.01 – 92
OS3	14	14 ± 4	3	<0.01 – 94

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 3,300 to 18,400 mmol/m^2/day (Table 16). This range was somewhat lower than that observed during April (4,900 to 28,300 mmol/m^2/day). The decline in available light is apparent within the monthly mean TDP of only 10,955 mmol/m^2/day (Table 16) c.f. 17,460 mmol/m^2/day recorded during April and continues the trend of shorter daylight hours with the coming winter months.

The variability in TDP was fairly consistent across the month of May. Lower turbidity from 8 May resulted in a peak of BPAR at OS2 but not at OS3, despite this being the shallower site. Both sites displayed similar intermittent BPAR peaks in response to similarly low turbidity from 20 to 28 May prior to the extreme weather event on 29 May. After this time BPAR at both sites became negligible due to elevated turbidity and decreased water clarity (Figure 27). At OS2 mean BPAR intensity was recorded as 25 mmol/m^2/day, while mean BPAR at OS3 was slightly lower at 14 mmol/m^2/day.

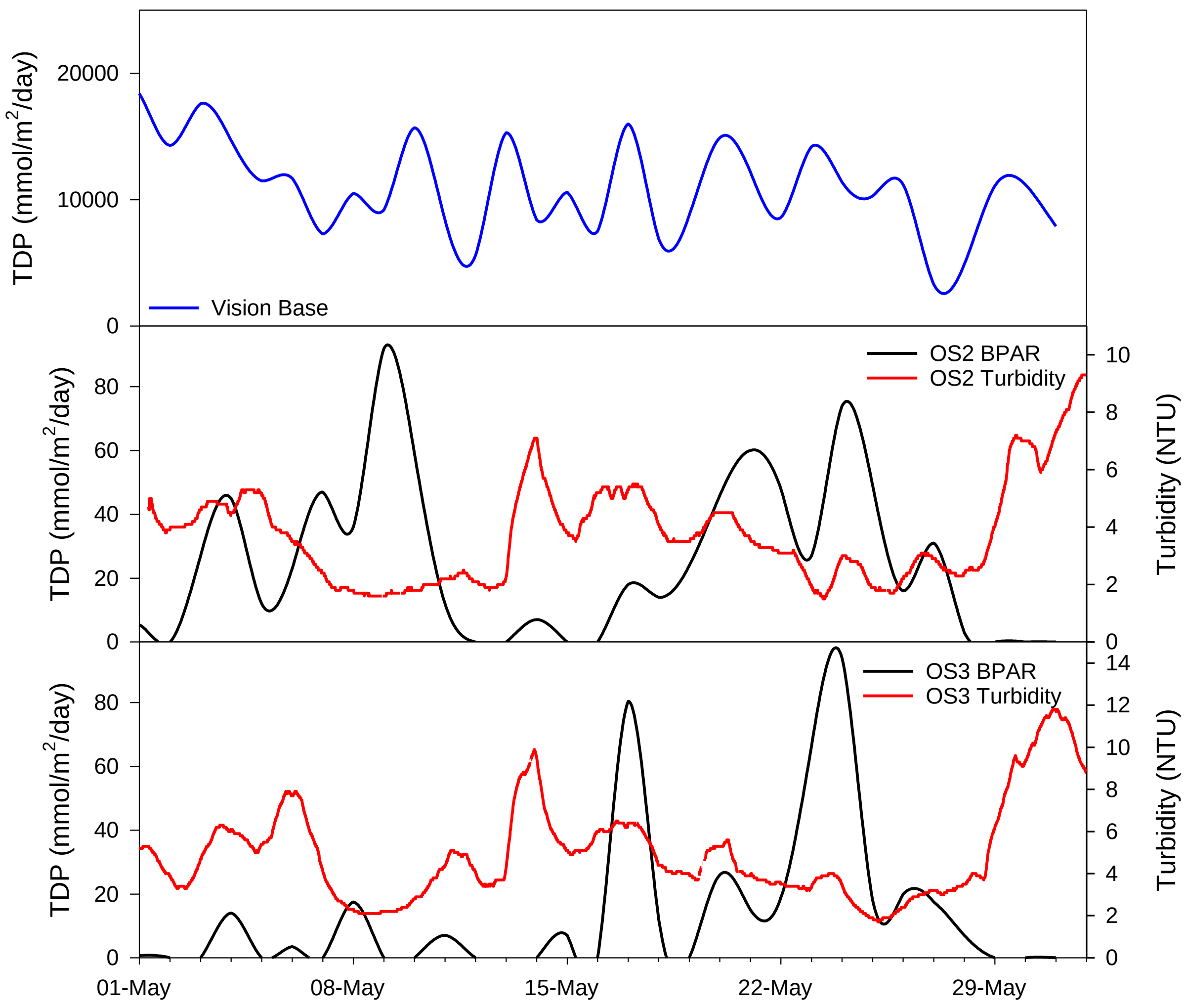


Figure 27 Total daily BPAR at OS2 and OS3 during May 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 2 May were not utilized in plots or statistics.

3.5 Continuous Sedimentation Loggers

Data on sediment deposition/erosion rates were collected at the inshore site UH3 and offshore site OS2, using ALTUS acoustic altimeters located approximately between 200 and 600 mm above the seabed in drop down frames. Further details on the specific methodology used can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Changes in energy from wind waves, currents and/or tidally induced flows can result in variations in sedimentation patterns, ranging from deposition of sediments originating from another location, resuspension of sediments with no net change in the seabed or the resuspension of sediments and transportation to another location. Altimeters provide two forms of information to help identify these processes:

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

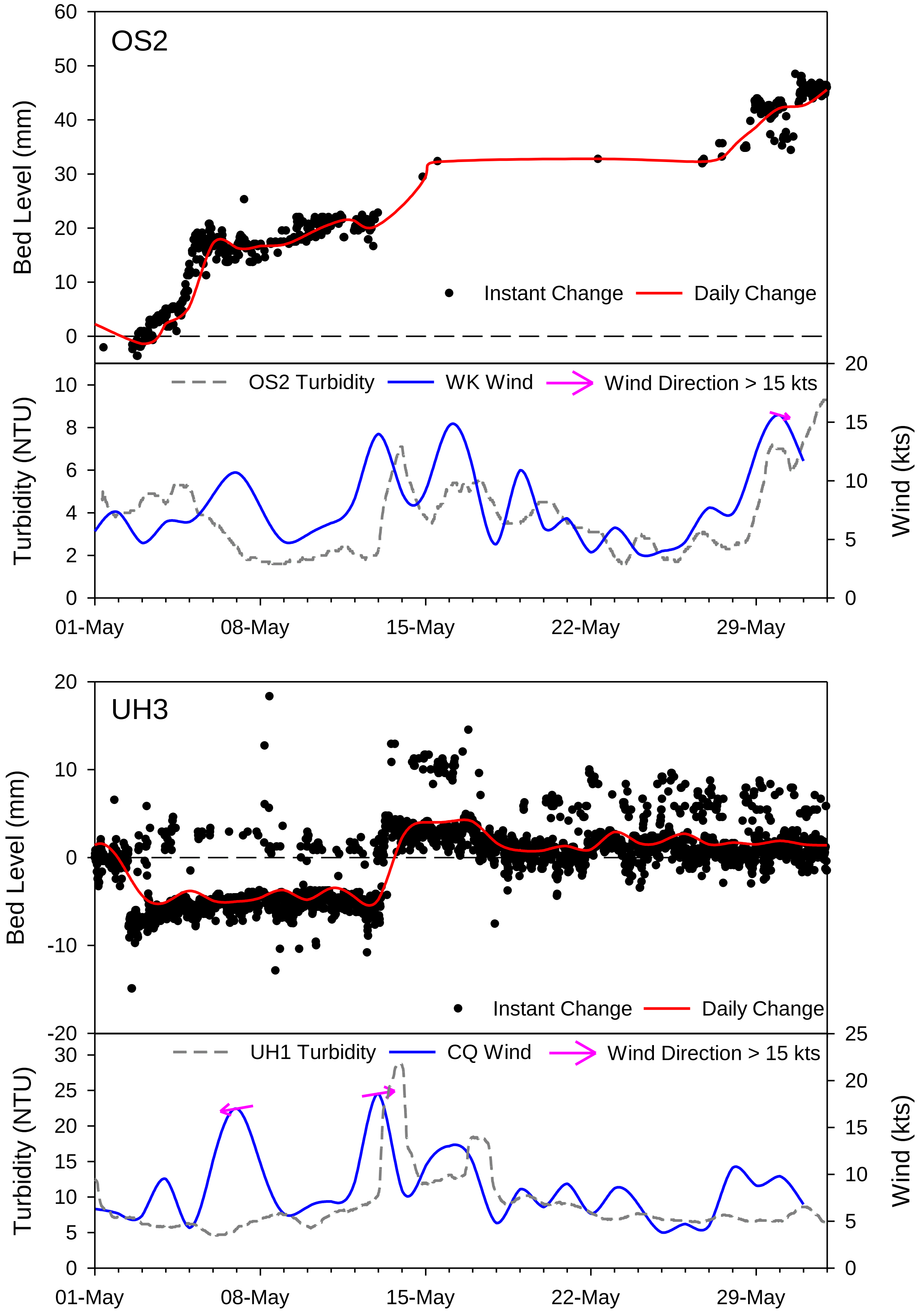


Figure 28 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during May 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction.
Note: Arrows indicate the direction of travel for winds greater than 15 knots.

Limited data was returned from altimeters at OS2 from 12 to 27 May and so interpretation of data for this period should be treated with caution. Bed level at the offshore site OS2 displayed an initial increase in the first week of May when already raised turbidity levels then declined and bed level then stabilised. Approximately 20 mm of sediment was deposited on the sea bed from 1 to 6 May 2019. Although the period from 12 to 27 may was not recorded, the new recorded bed level on 28 May suggests overall deposition of approximately 10 mm over this period (Figure 28). Bed level then displayed another period of rapid deposition in response to the elevated wind speed and wave height event at the end of May. This resulted in an overall accretion of +46 mm for the month of May (Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2, with little apparent impact of inshore wind speed on sediment movement (Figure 28). The exception to this was the wind speed event of 12 May which generated exceptionally high turbidity at UH1 compared to other sites. This resulted in rapid deposition of sediment at UH3 with an increase in bed level of approximately 10 mm over a two-day period. Bed level prior to this event was stable apart from a small period of erosion in the first few days of the month and bed level after this event demonstrated little change. There was no response to the offshore wind speed and wave event that impacted OS2 (Figure 27). These variations over May resulted in a net bed level change of only 1.4 mm (Table 17).

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

Site	May 2019 Net bed level change (mm)
OS2	+46
UH3	+1.4

3.6 Water Samples

Discrete water sampling was conducted on 5 May 2019, in conjunction with vertical physicochemical profiling through the water column. Quality assurance/quality control (QA/QC) procedures included a duplicate water sample collected at one site, in addition to a laboratory and field blank for each parameter. Further details on the specific sampling methodology can be found within the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Laboratory results associated with VE QA/QC procedures are presented in Table 25 of the Appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during May 2019 remained below the WQG of 30 µg/L at all sites, with the highest concentrations once again reported in the upper and central harbour (Table 18, Figure 29), as commonly found. Similar to the April sampling, dissolved reactive phosphorous was elevated across the monitoring network, with concentrations ranging from 7.3 to 16.4 µg/L at SG2 and UH3 respectively, in a commonly observed spatial pattern and with values notably above the designated 5 µg/L WQG.

Both total nitrogen and total kjeldahl nitrogen were < LOR at all sites. Total ammonia concentrations were elevated as they were the previous month, with exceedances of the 15 µg/L WQG recorded at all sites except the offshore sites SG1 and SG2. Concentrations of nitrogen oxides were also elevated as they were in April ranging from 13.6 to 33 µg/L, however, in contrast to April nearly all sites with the exception of UH2, CH1 and SG3 displayed concentrations above the 15 µg/L WQG.

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during May 2019.
Values outside recommended WQG are highlighted in blue.

Site	Parameter (µg/L)						
	Total Phosphorus	Dissolved Reactive Phosphorus	Total Nitrogen	Total Kjeldahl Nitrogen (TKN)	Total Ammonia	Nitrogen Oxides (NOx)	Chlorophyll *a*
UH1	22	13.8	<300	<200	20	17.9	3.9
UH2	21	11.7	<300	<200	20	13.6	2.8
UH3	27	16.4	<300	<200	22	22	2.8
CH1	22	11.4	<300	<200	22	14.3	5.2
CH2	16	11.4	<300	<200	20	18.8	4.3
OS1	21	12.3	<300	<200	25	16.9	3.3
OS2	20	11.2	<300	<200	19	21	3.0
OS3	24	13.9	<300	<200	31	23	1.5
OS4	18	11.9	<300	<200	32	33	1.0
OS5	16	12.5	<300	<200	28	33	2.3
OS6	15	11.6	<300	<200	24	19.2	2.5
OS7	20	11.7	<300	<200	21	21	5.2
SG1	16	8.5	<300	<200	15	27	2.5
SG2	18	7.3	<300	<200	10	17.6	3.1
SG3	14	8.3	<300	<200	28	13.9	1.2
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

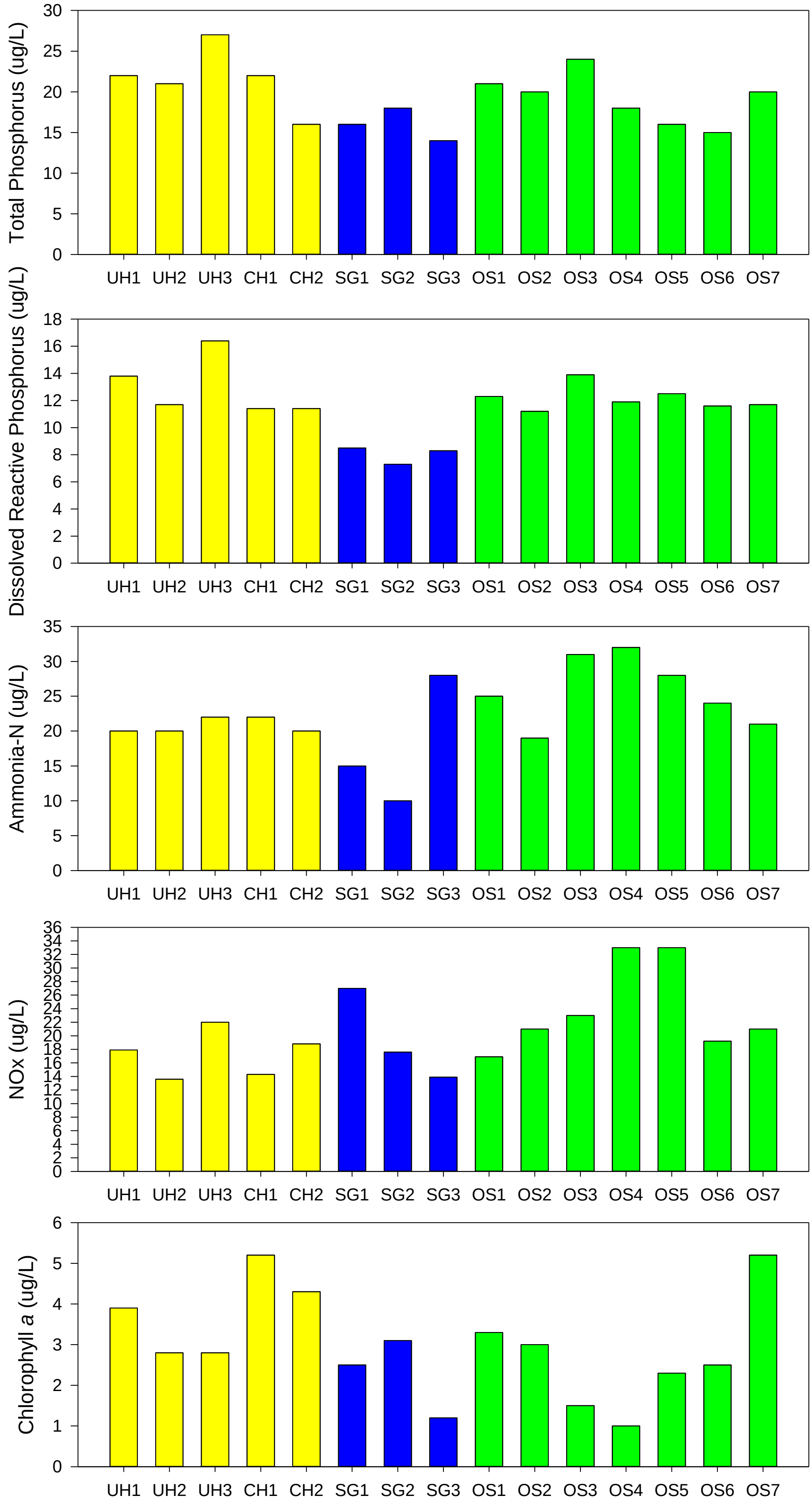


Figure 29 Nutrient and chlorophyll *a* concentrations at monitoring sites during May 2019.
Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were < LOR.

This may be a result of continual bacterial degradation of organic material such as phytoplankton releasing nitrogenous products. In contrast to previous months, nitrogen oxide concentrations not necessarily lower further offshore at the spoil ground monitoring sites (Figure 28).

Concentrations of chlorophyll a, an indicator of phytoplankton biomass were similar to April, ranging from 1.0 to 5.2 µg/L, with sites CH1, CH2 and OS7 displaying exceedances of the 4 µg/L WQG (Table 18).

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 (<1 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5 µg/L) and zinc (<4 µg/L). Contrasting previous months, concentrations of total mercury which had slightly exceeded the LOR of 0.08 µg/L at UH3 was once again below LOR (Tables 19 to 21). In a similar manner to mercury, concentrations of total zinc which exceeded LOR at SG1 in April was below LOR in May (Table 21).

As commonly observed, total aluminium concentrations were reported above the WQG of 24 µg/L (note that this WQG is designated for concentrations of the more readily available dissolved aluminium fraction) at all sites across the monitoring network. Concentrations of the more bioavailable dissolved fraction were mostly below LOR (<12 µg/L) with the highest concentrations of 15 µg/L reported (Tables 19 to 21, Figure 30). The only other exceedance during May was for dissolved copper (1.4 µg/L) at UH3, which was only slightly above the WQG (1.3 µg/L)(Tables 19 to 21).

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. The greatest concentrations of total iron were recorded in the central harbour and declined with increasing distance offshore with the lowest concentrations at the spoil ground (Figure 30). However during may the highest concentration of total iron was recorded at OS3. This spatial pattern in total iron displayed a high similarity to those of total aluminum including elevated concentrations at OS3. Dissolved iron concentrations were once again low (<4 µg/L) indicating that iron was predominantly present in the particulate phase, and thus not readily available for biological uptake (Tables 19 to 21).

Total chromium was above LOR at all sites with the exception of UH2, whereas dissolved chromium was only detected at some sites. Dissolved manganese concentrations were below LOR (<1 µg/L) at OS3, OS4, OS5, OS6 and the spoil ground monitoring sites (Tables 19 to 21) in a similar spatial trend to April. Higher concentrations of total manganese were reported at all sites with a decreasing gradient from the inner harbor to offshore and spoil ground sites as commonly observed (Figure 31).

Consistent with previous monitoring reports, molybdenum concentrations which were recorded at all sites during May, displayed little spatial variation across the inshore and offshore monitoring network (Figure 31). Given the similarity between the dissolved and total metal concentrations, molybdenum present in the dissolved phase (Tables 19 to 21 and Figure 31) would be readily dispersed across the region. Concentrations of total and dissolved vanadium displayed a similar pattern to that of molybdenum, with equal proportions of vanadium also present in the dissolved phase (Figure 31).

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

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	<12	<12	<12	<12	<12	24
	Total	119	79	182	152	88	
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	1.3	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.3	<1.1	2.5	2.3	2.3	
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	1.2	1.4	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	-
	Total	290	175	420	330	210	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	3.4	3	3.5	2.7	1.8	-
	Total	9.5	6.7	9.1	9.9	6.2	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	0.09	<0.08	
Molybdenum	Dissolved	10	10.3	9.9	10.3	10.4	-
	Total	10.4	10.8	10.9	11	11.1	
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	1.5	1.9	1.8	2.1	1.4	100
	Total	2.5	1.9	2	2.6	1.9	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 20 Total and dissolved metal concentrations at offshore monitoring sites during May 2019. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites							WQG
		OS1	OS2	OS3	OS4	OS5	OS6	OS7	
Aluminium	Dissolved	<12	15	12	<12	<12	<12	12	24
	Total	65	64	173	98	37	49	70	
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	1.4	<1	<1	<1	1.1	1.2	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.3	2.8	2.7	1.6	1.3	2.3	2.3	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	171	147	450	270	87	111	163	
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	1.1	1	<1	<1	<1	<1	1.5	-
	Total	6.2	5.1	7.4	4.3	3.1	3.5	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	10.7	10.5	10.9	10.9	10.5	10.4	10.2	-
	Total	11.3	11.2	10.9	11.2	10.5	11.5	11.2	
Nickel	Dissolved	<7	<7	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<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	2.1	1.7	1.5	1.9	1.5	2	1.6	100
	Total	2.2	2	2.6	2.4	2	2.2	2.3	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 21 Total and dissolved metal concentrations at spoil ground monitoring sites during May 2019. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	15	<12	<12	24
	Total	33	33	<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	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.4	2.1	1.2	
Cobalt	Dissolved	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	-
	Total	83	81	74	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	<1	<1	<1	-
	Total	2.5	2.5	2.3	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10	11.7	10.6	-
	Total	11.1	10.7	11.2	
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	1.7	1.7	1.8	100
	Total	2.1	2.2	2.2	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

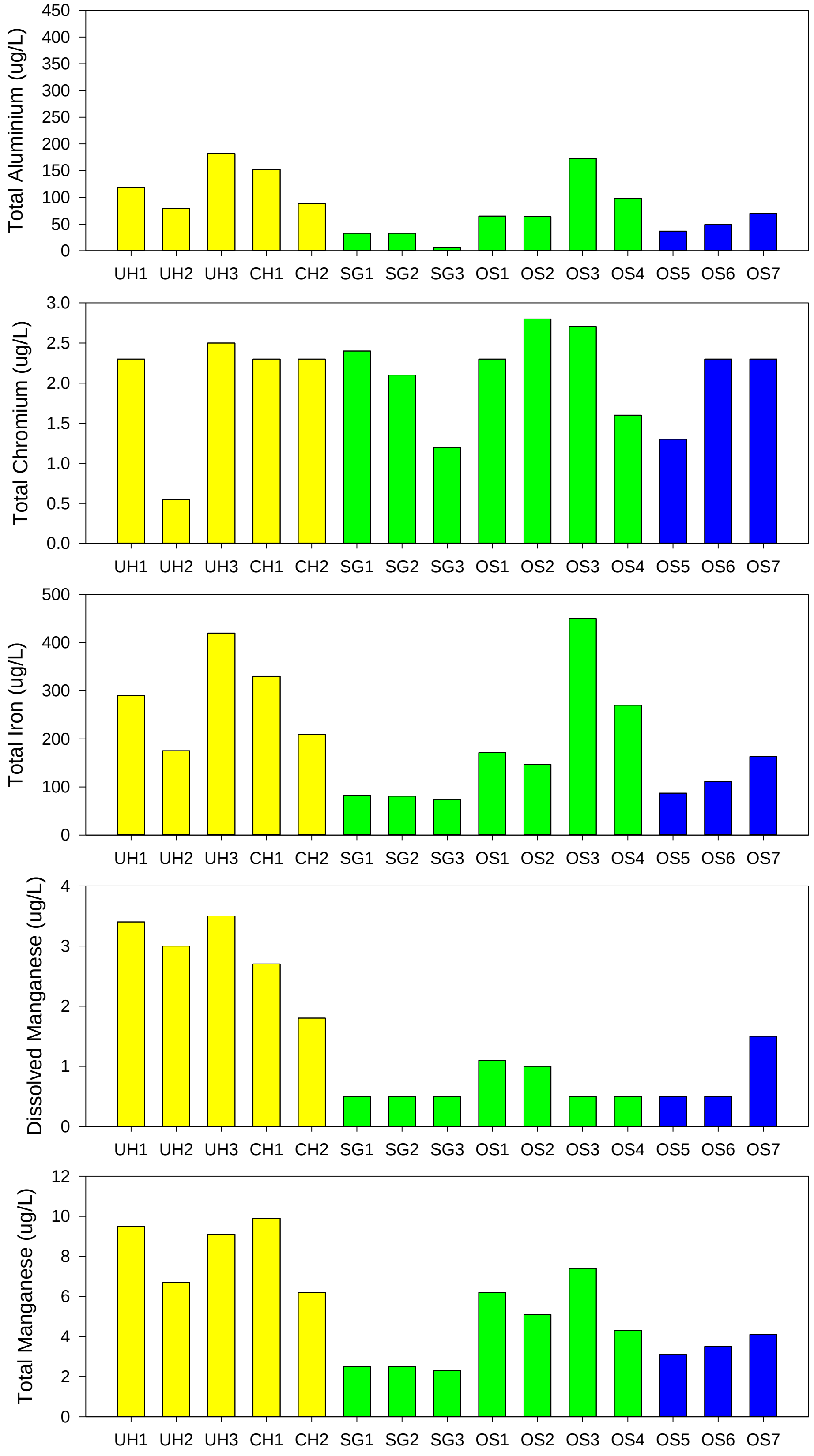


Figure 30 Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during May 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

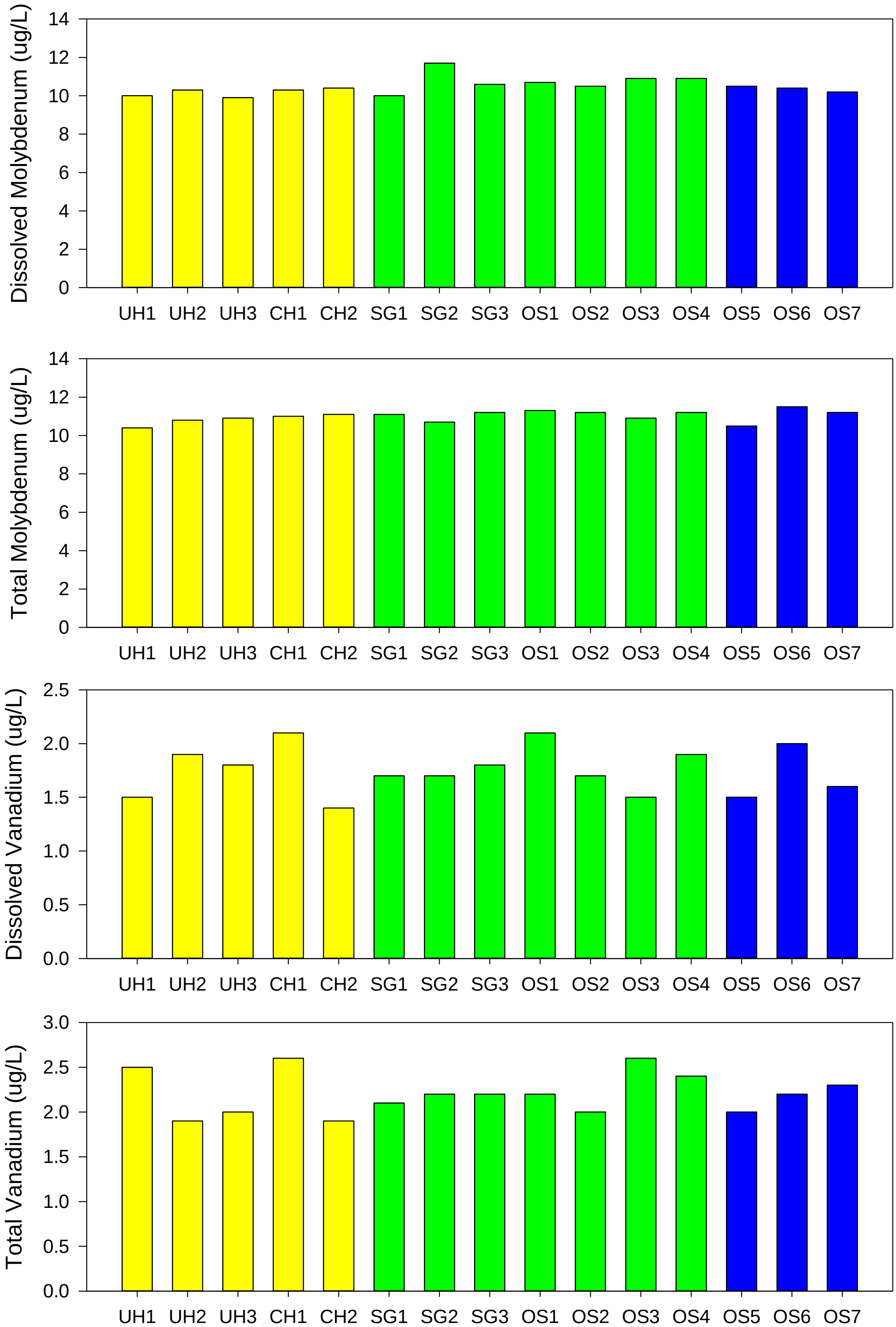


Figure 31 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during May 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

4 REFERENCES

ANZECC/ARMCANZ. 2000. National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting. Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand

APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. Port City Press, Baltimore, USA.

ECAN. 2019. Environment Canterbury Regional Council.http://data.ecan.govt.nz/Catalogue/Method?MethodId=79#tab-data

Envisor. 2018. Environmental Monitoring and Management Plan. LPC Channel Deepening Project: Stage 1.

Fox, D. R. 2018. Turbidity triggers for Lyttelton Port Company's Channel Deepening Project. Environmetrics Australia, Melbourne, Australia

Metconnect. 2019. Meteorological Service of New Zealand http://www.metconnect.co.nz

MetOcean. 2016a. Lyttelton Port Company Channel Deepening Project – Simulations of suspended sediment plumes generated from the deposition of spoil at the offshore capital disposal site. MetOcean Solutions Ltd, New Plymouth, New Zealand

MetOcean. 2016b. Lyttelton Port Company Channel Deepening Project – Simulations of Dredge Plumes from Dredging Activities in the Channel. MetOcean Solutions Ltd, New Plymouth, New Zealand

Vision Environment. 2017. Lyttelton Port Company Channel Deepening Project Water Quality Environmental Monitoring Methodology – August 2017. . Gladstone, Australia

5 APPENDIX

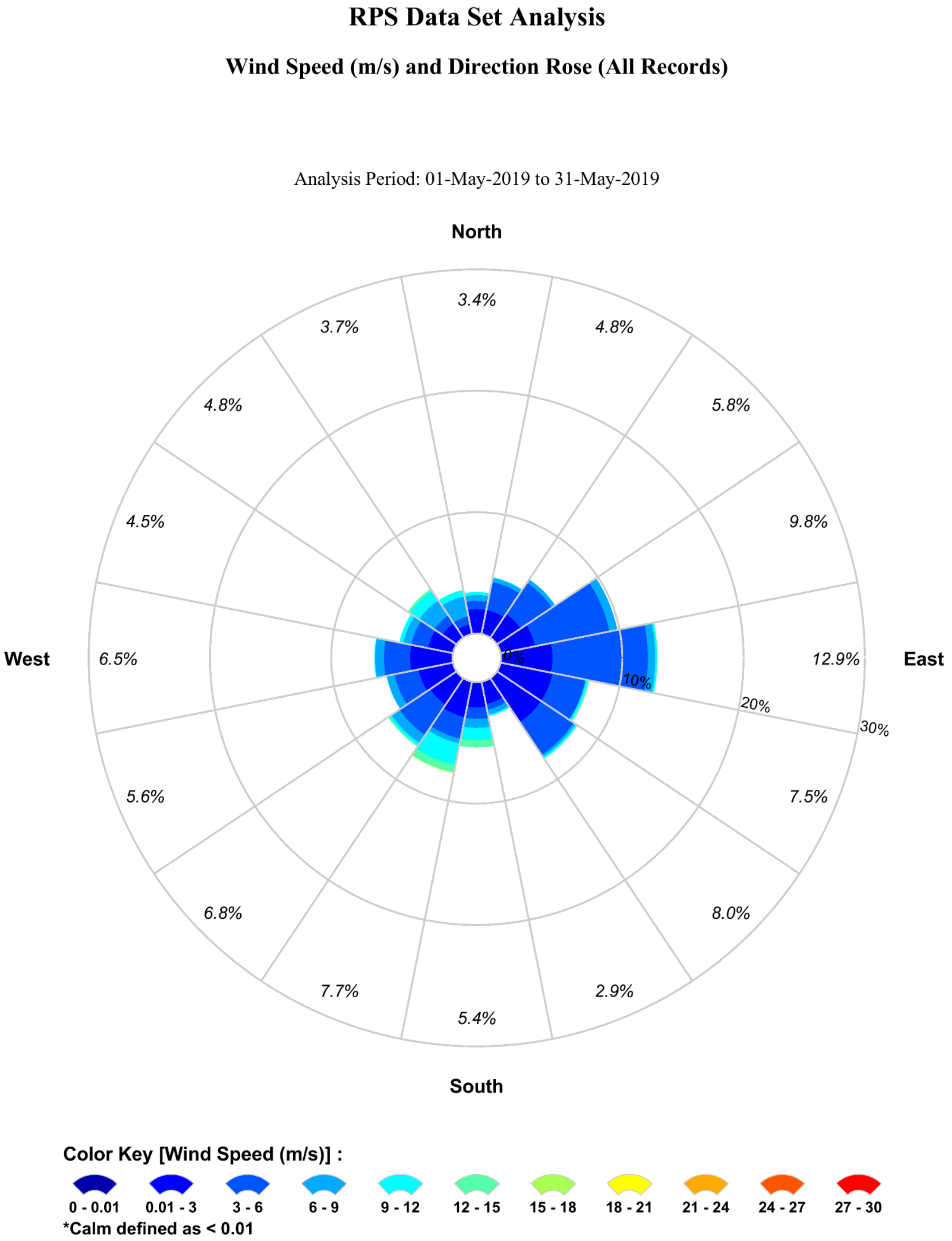


Figure 32 WatchKeeper wind speed (m/s) and direction rose (%) during May 2019.

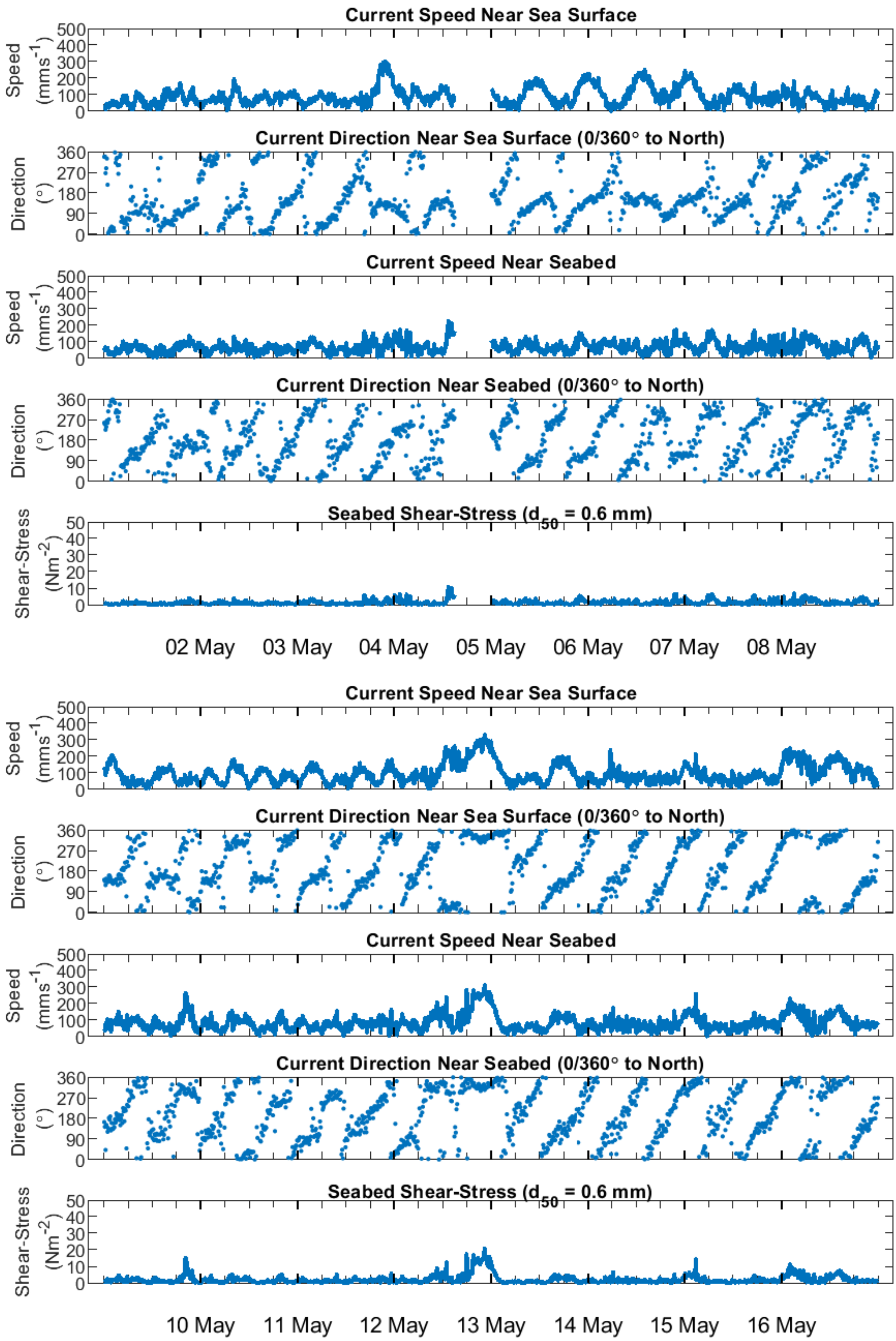


Figure 33 SG1 current speed, direction and shear bed stress 1 to 16 May 2019.

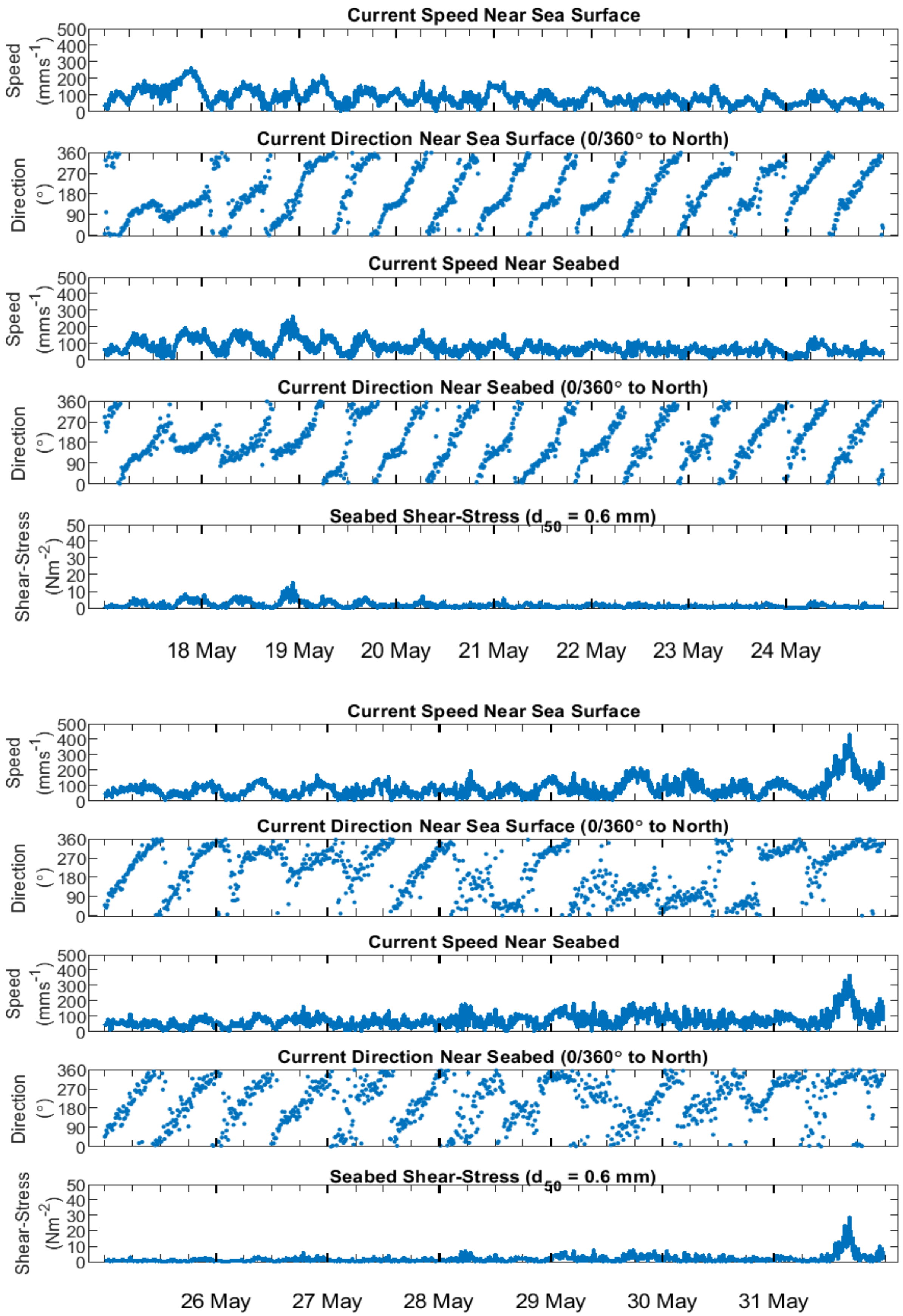


Figure 34 SG1 current speed, direction and shear bed stress 17 to 31 May 2019.

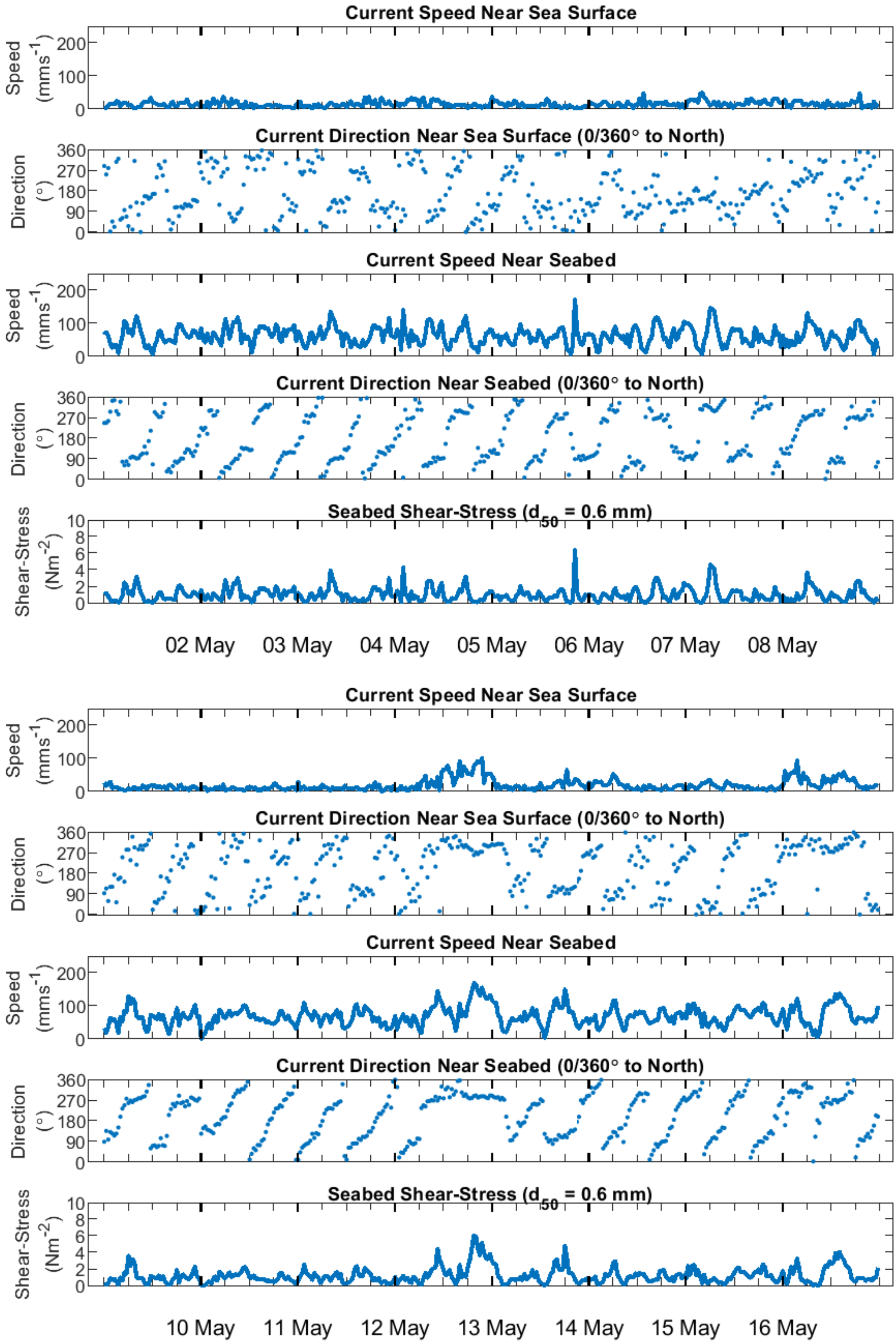
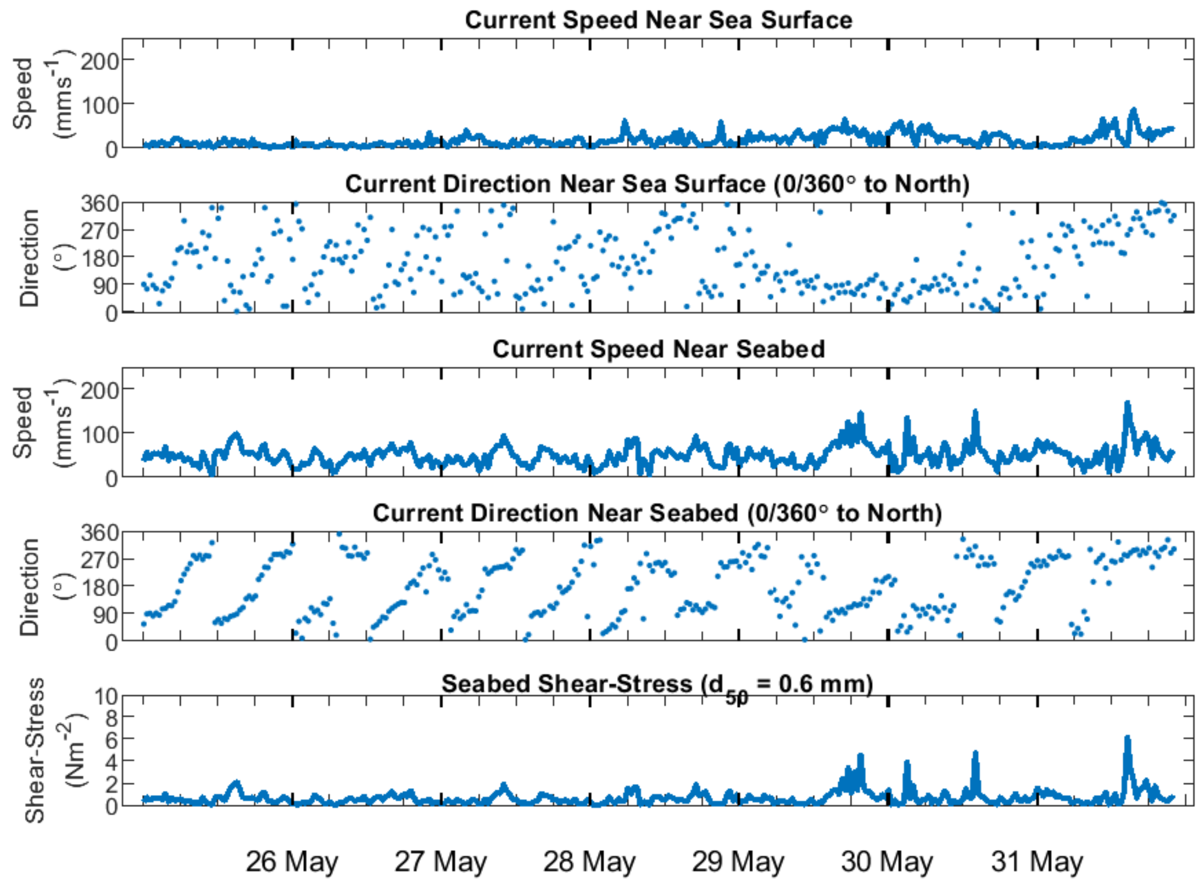


Figure 35 SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 May 2019.



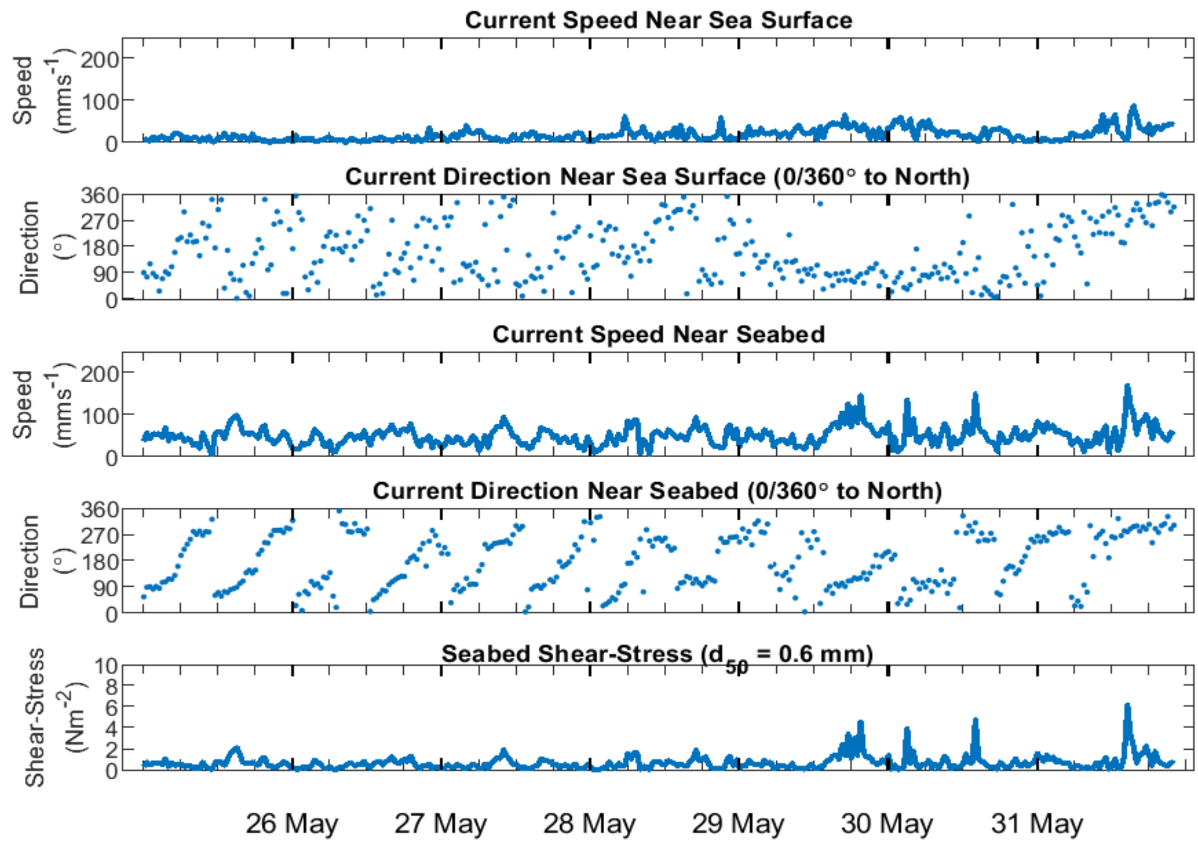


Figure 36 SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 31 May 2019.

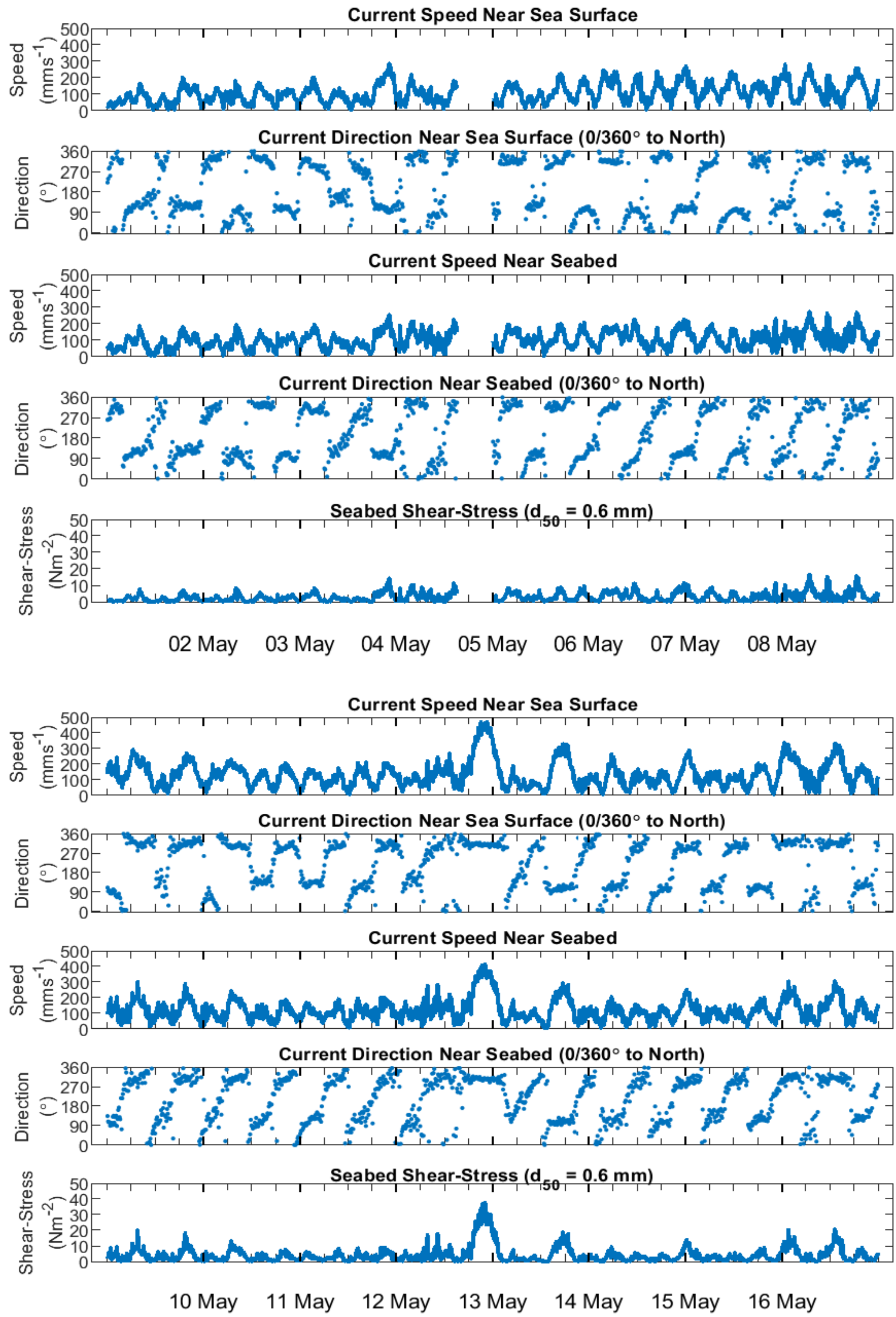
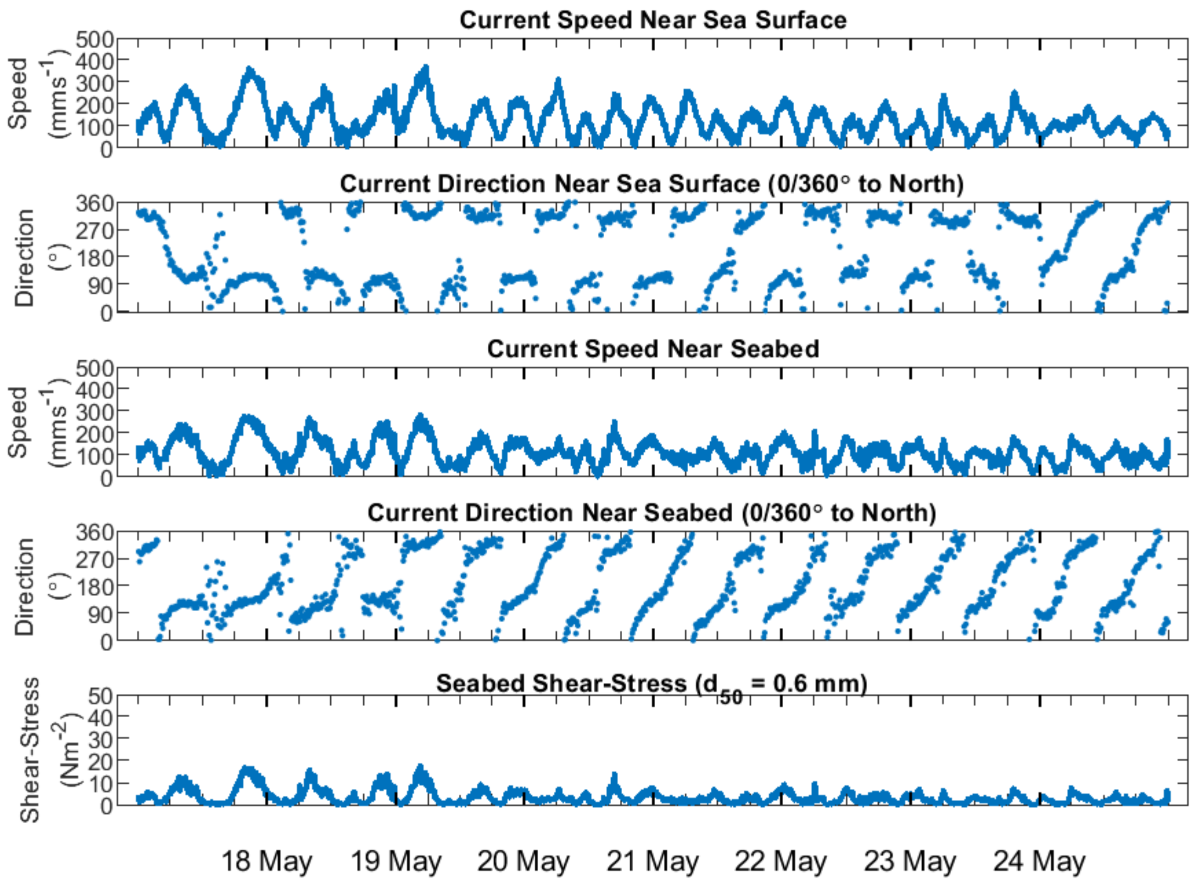


Figure 37 SG3 current speed, direction and shear bed stress 1 to 16 May 2019.



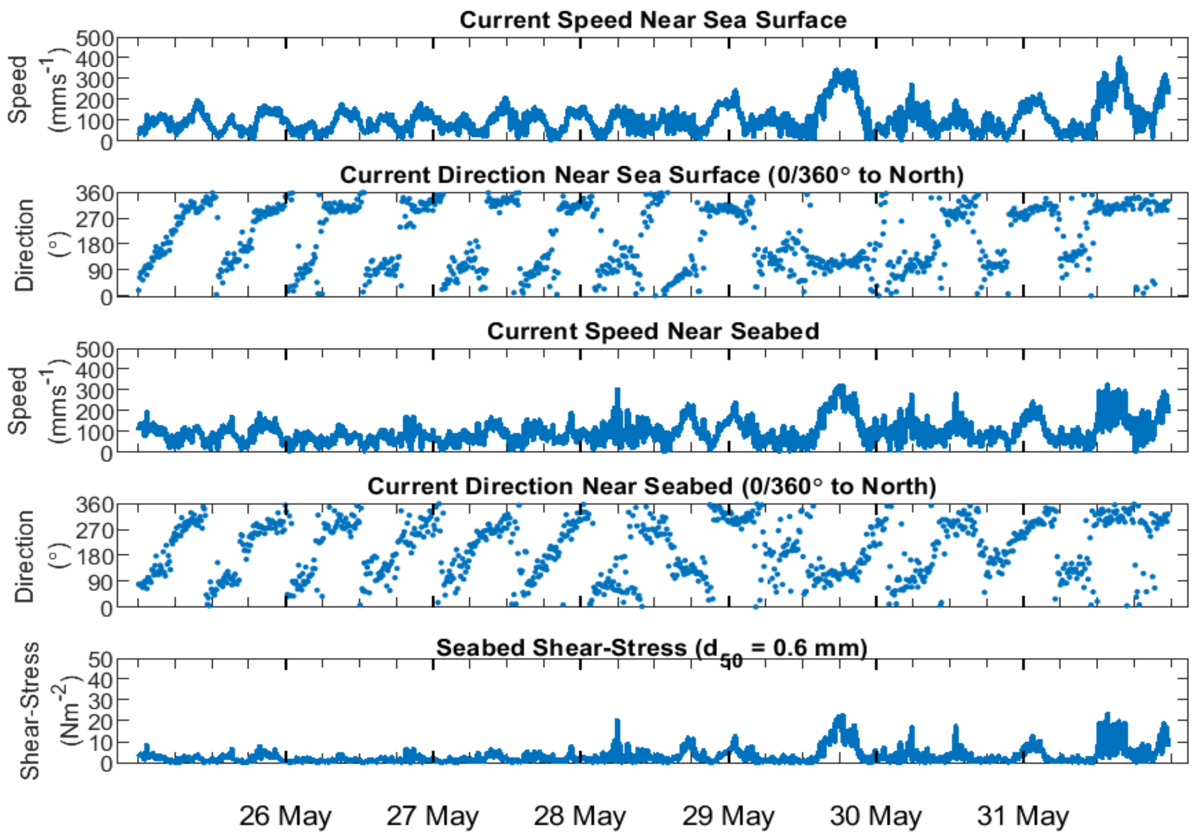


Figure 38 SG3 current speed, direction and shear bed stress 17 to 31 May 2019.

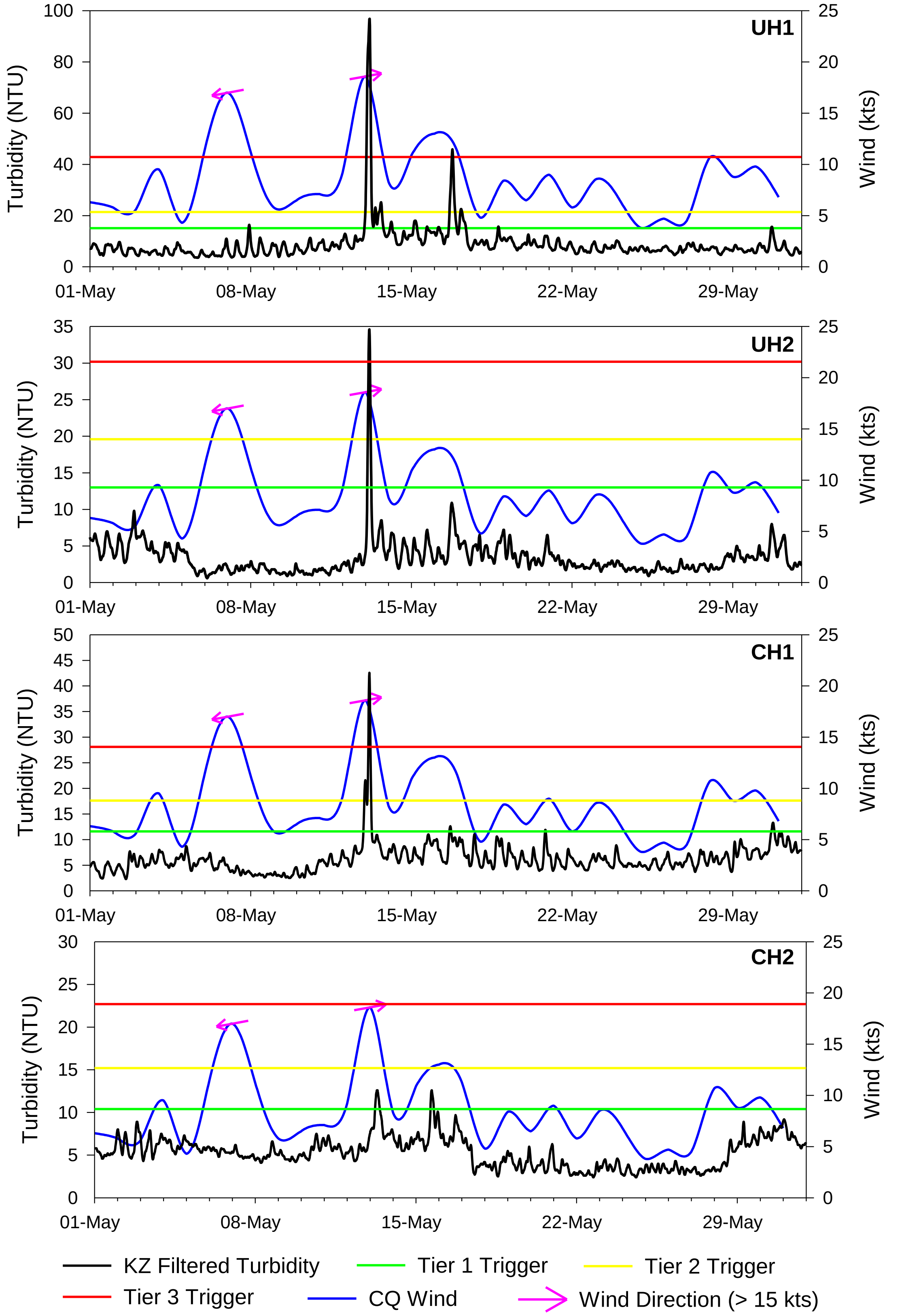


Figure 39 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

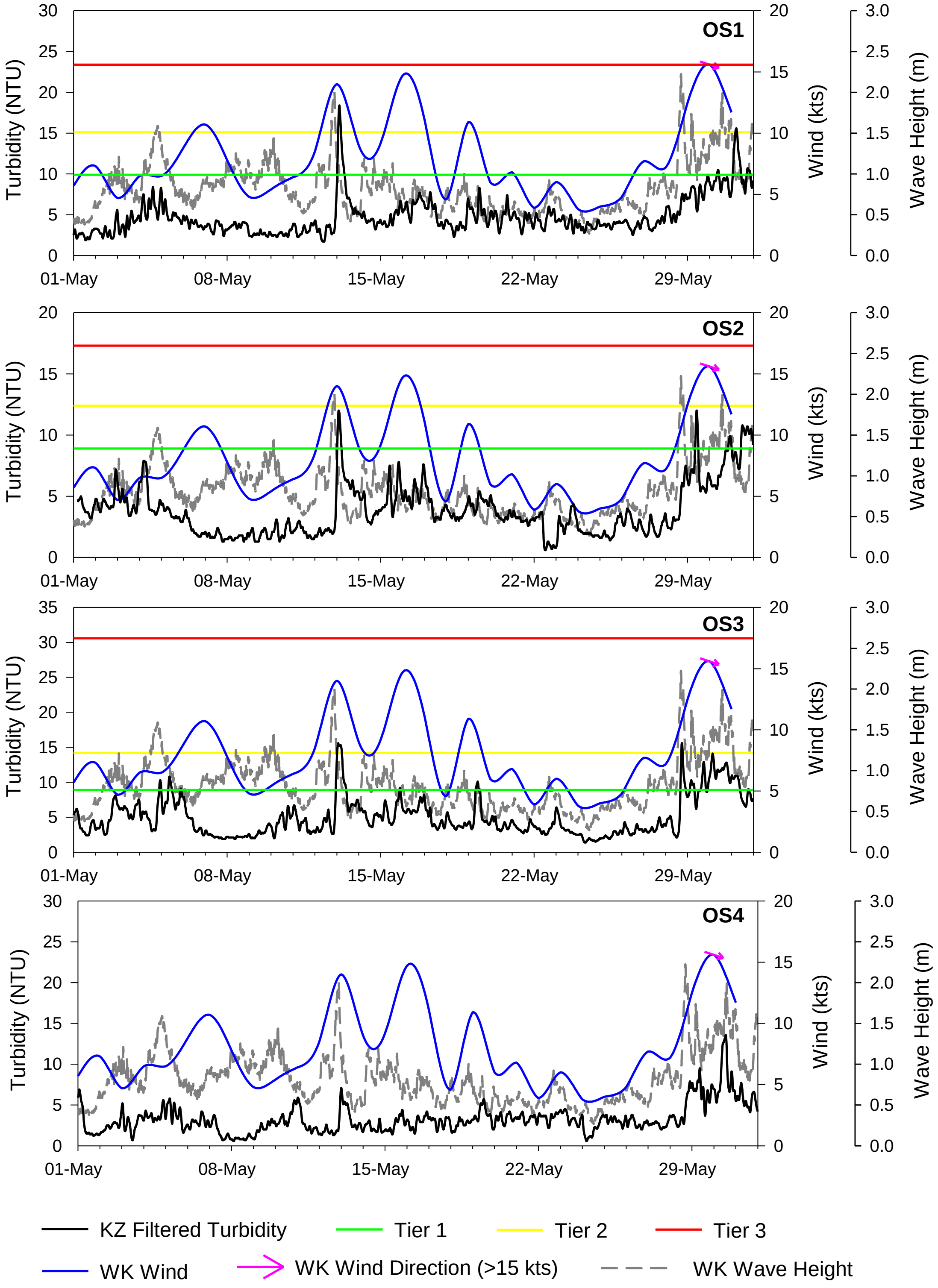


Figure 40 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

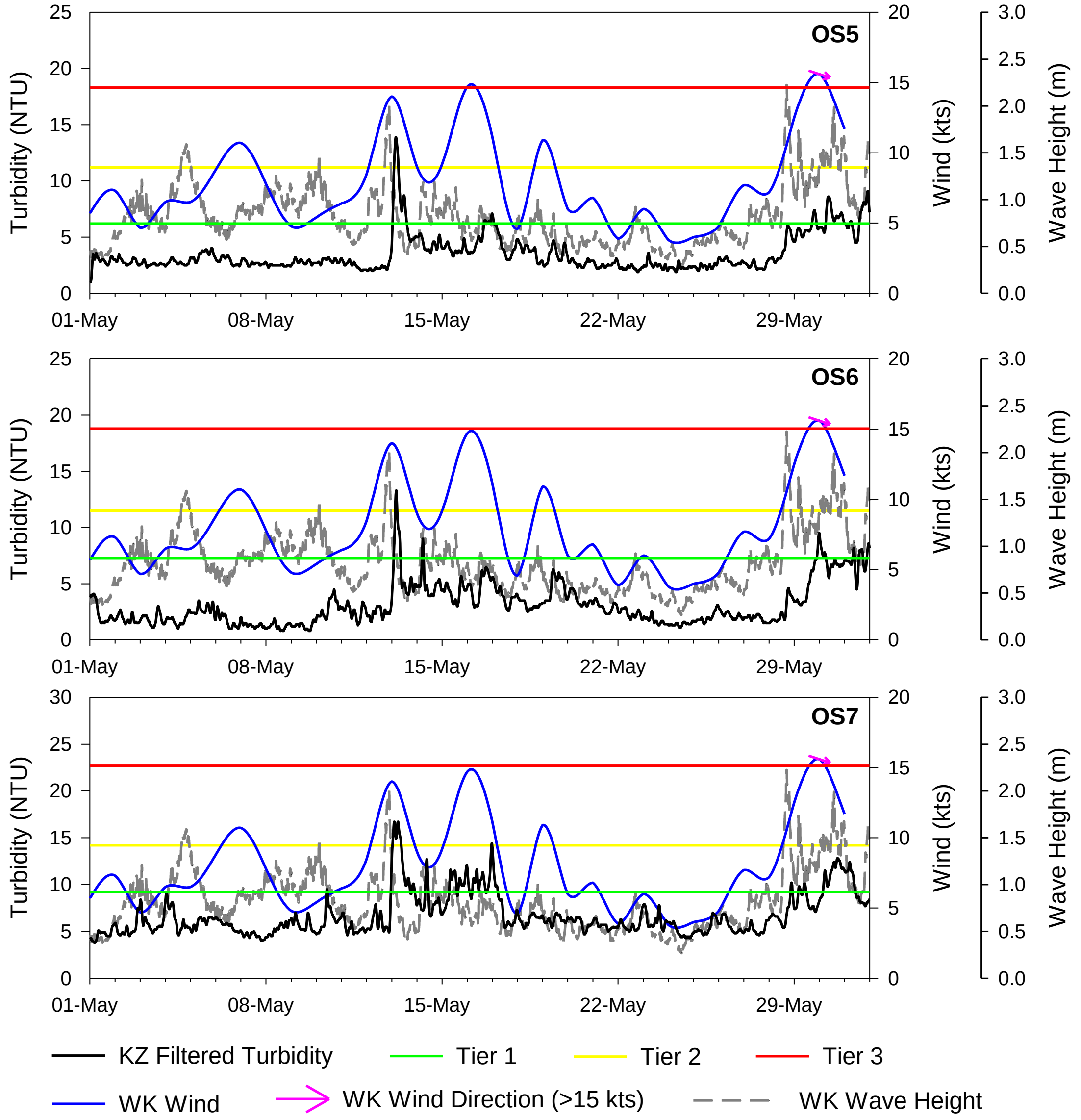


Figure 41 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during May 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

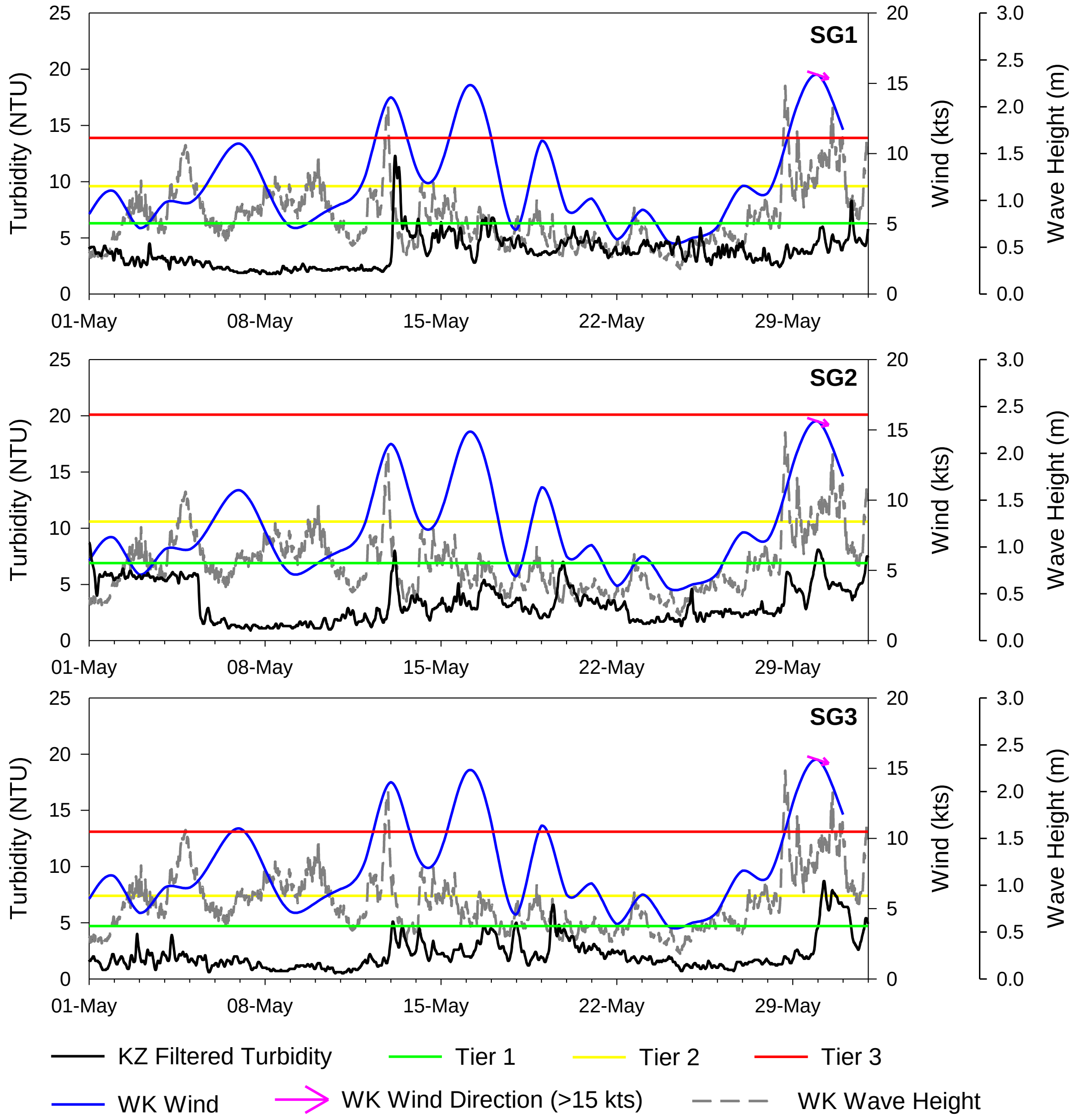


Figure 42 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during May 2019.
Note differing scales for each plot. *Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.*

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

Site	Statistic	KZ Filtered Turbidity (NTU) Surface May	Surface Baseline
UH1	Mean ± se	8.9 ± 0.1	12
	Range	4 – 97	2 – 155
	99th	37	37
	95th	16	21
	80th	10	15
UH2	Mean ± se	3.4 ± 0.0	9.9
	Range	<1 – 69	2 – 59
	99th	11	29
	95th	7.1	19
	80th	4.7	13
CH1	Mean ± se	6.3 ± 0.1	8.8
	Range	2 – 42	<1 – 50
	99th	16	27
	95th	10	17
	80th	7.7	12
CH2	Mean ± se	5.3 ± 0.0	7.6
	Range	2 – 13	<1 – 39
	99th	11	22
	95th	8.2	15
	80th	6.8	10

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

Site	Statistic	KZ Filtered Turbidity (NTU) Surface May	Surface Baseline
SG1	Mean ± se	3.7 ± 0.0	4.2
	Range	2 – 12	<1 – 31
	99th	8.2	14
	95th	5.9	9.5
	80th	4.7	6.1
SG2	Mean ± se	3.3 ± 0.0	4.6
	Range	<1 – 9	<1 – 33
	99th	7.6	20
	95th	6.0	10
	80th	5.1	6.9
SG3	Mean ± se	2.2 ± 0.0	3.6
	Range	<1 – 9	<1 – 22
	99th	7.5	13
	95th	5.1	7.3
	80th	2.8	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during May 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for May are means ± se, range and percentiles (n = 2959 to 2976). Baseline values modified from Fox 2018.

Site		KZ Filtered Turbidity (NTU)	
	Statistic	Surface May	Surface Baseline
OS1	Mean ± se	4.8 ± 0.0	7.5
	Range	2 – 18	<1 – 99
	99th	14	23
	95th	9.2	15
	80th	5.9	9.7
OS2	Mean ± se	3.8 ± 0.0	6.4
	Range	<1 – 12	<1 – 36
	99th	11	17
	95th	8.0	12
	80th	5.2	8.9
OS3	Mean ± se	5.0 ± 0.1	6.5
	Range	1 – 16	<1 – 110
	99th	14	27
	95th	11	14
	80th	6.8	8.9
OS4	Mean ± se	3.3 ± 0.0	5.9
	Range	<1 – 14	<1 – 35
	99th	9.1	18
	95th	6.7	13
	80th	4.0	8.1
OS5	Mean ± se	3.5 ± 0.0	4.6
	Range	1 – 14	<1 – 35
	99th	8.7	18
	95th	6.8	11
	80th	4.4	6.1
OS6	Mean ± se	3.1 ± 0.0	4.7
	Range	<1 – 13	<1 – 37
	99th	8.9	18
	95th	6.9	11
	80th	4.4	7.1
OS7	Mean ± se	6.7 ± 0.0	6.3
	Range	4 – 17	<1 – 48
	99th	15	22
	95th	11	14
	80th	8.1	9.1

Table 25 Summary of Vision Environment quality control data for May 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	8	6	29
Dissolved Aluminium (ug/l)	<3	<3	<12	<12	ND
Total Aluminium (ug/l)	<3.2	<3.2	119	119	0
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	2.3	2.7	16
Dissolved Cobalt (ug/l)	<0.2	<0.2	<0.6	<0.6	ND
Total Cobalt (ug/l)	<0.21	<0.21	<0.63	<0.63	ND
Dissolved Copper (ug/l)	<0.5	<0.5	<1	<1	ND
Total Copper (ug/l)	<0.53	<0.53	<1.1	<1.1	ND
Dissolved Iron (ug/l)	<20	<20	<4	<4	ND
Total Iron (ug/l)	<21	<21	290	320	10
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	3.4	3.6	6
Total Manganese (ug/l)	<0.53	<0.53	9.5	8	17
Dissolved Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Total Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum (ug/l)	<0.2	<0.2	10	9.7	3
Total Molybdenum (ug/l)	<0.21	<0.21	10.4	11.2	7
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	1.5	1.9	24
Total Vanadium (ug/l)	<1.1	<1.1	2.5	2.1	17
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	22	23	4
Dissolved Reactive Phosphorus (ug/l)	<4	<4	13.8	14	1
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	20	21	5
Nitrate-N + Nitrite-N (ug/l)	<2	<2	17.9	17.3	3
Chlorophyll a (ug/L)	<0.2	<0.2	3.9	3.6	8

** Slightly higher concentrations in the field blank compared to the lab blank, indicating potential sample contamination.*