# Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

April 2019

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## FILE REFERENCE

20190515_LPC Water Quality Environmental Monitoring April 2019_VE

## 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 April 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 April, 38.6 mm of rainfall was recorded at Cashin Quay, almost triple that recorded in March. Most of the rainfall was recorded on 29 April during the period of highest winds of the month (21.8 knot gusts in a south-westerly direction). Maximum flow from the Waimakariri River (472 $m^3/s$) was recorded the day after the rainfall on 30 April, with high flows expected to continue into May.

Offshore, both wind speeds and wave heights displayed similar temporal variations over the month. Maximum significant wave heights of 3.31 m were recorded on 1 April, following a period of increased wave heights in late March. Monthly average temperature dropped 4 °C in April to 13°C.

***Currents:*** ADCP data were available at all three spoil ground monitoring sites in April. While near-surface currents at SG1 were highest on 1 April, near-seabed currents at this site, in addition to both near-surface and near-seabed at sites SG2a and SG3, peaked on 29 April during the period of highest wind speeds for the month. 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. Both sites exhibited currents in a north-west/south-east direction.

In contrast, near-seabed currents were faster than near-surface currents at SG2a, with all currents following an east-west axis. Velocities at this site were considerably lower than SG1 and SG3, which has been attributed to varying topography across the spoil ground.

***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 April were similar to those recorded during the baseline monitoring period.

Relatively high turbidity was recorded at all sites at the start of April, following on from turbidity increases recorded in late March. Turbidity then decreased at all sites prior to increasing at inshore and nearshore sites from 8 to 11 April, in response to minor rainfall and an increase in wind speeds. While inshore sites exhibited a rapid increase in turbidity on 30 April in response to the high rainfall and winds experienced the day prior, a peak was not observed at nearshore sites suggesting the inshore peaks were a direct response of the rainfall and local runoff in the inner harbour.

At the offshore sites, several turbidity increases were recorded throughout the month corresponding with increases in wave heights. However, the turbidity 24h rolling average at all sites remained < 10 NTU at all times. Benthic turbidity, where available, corresponded with surface data, and appeared to vary in response to wave height variation.

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

***Other Physicochemical Parameters:*** Cooling across all sites was consistent throughout April, with monthly means up to 3 ºC lower than March. In contrast to previous month, cooler water temperatures were recorded in the upper and central harbour rather than the offshore sites. A rapid decrease in temperatures was recorded on 30 April, a day after the high rainfall and winds were recorded and were most pronounced at the inshore sites of UH1 and UH2.

Consistent with previous reports, pH during April was consistent across all sites, both surface and benthic. Conductivity was variable at most sites during the first week of April, likely due to prolonged effects from the late March Waimakariri River outflow. From April onwards conductivity remained reasonably consistent at each site for the remainder of the month.

Dissolved oxygen (DO) concentrations during April were slightly lower than March, most likely due to cooler temperatures causing a decrease in photosynthesis and thus lower oxygen production. Large fluctuations in DO were observed at the majority of sites in early April, likely in response to late March conditions and also on 30 April, one day after the high rainfall and winds. These fluctuations were not observed at spoil ground sites, which exhibited peaks in DO around the 5 and 25 April, which did not appear to coincide with any specific metocean condition.

***Water Sample Analysis and Depth Profiling:*** Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 11 April 2019. Similar to profiles typically obtained during the monitoring program, inner harbour and nearshore monitoring sites indicated a well-mixed water column with turbidity increasing near the benthos. Further offshore and at spoil ground sites, depth profiling indicated a continuation of vertically mixed conditions,

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 15.2 m at SG3. No exceedances of WQG were observed for sub-surface during the April 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 higher in April than during March, with most sites exceeding the ammonia WQG, and two inner harbour sites exceeding the NOx WQG. Chlorophyll *a*, an indicator of phytoplankton biomass, exceeded WQG at three sites throughout the harbour.

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.

Detectable concentrations of manganese were once again recorded in the upper harbour, with a relatively even split between dissolved and particulate components. Vanadium and molybdenum were also reported above LOR during April, with little spatial variability and a large component contained within the dissolved phase.

***Benthic Photosynthetically Active Radiation (BPAR):*** Levels of ambient sunlight during April decreased from March, as did BPAR levels. Highest BPAR was recorded around 22 April at both OS2 and OS3 when turbidity was at some of its lowest levels for the month.

***Sedimentation:*** During early April, bed level at OS2 displayed a rapid decline, most likely due to ongoing impacts of late March conditions. Following the erosion, gradual deposition occurred until the end of the month, resulting in an overall deposition of 4 mm in April.

Similar to previous observations, bed level in the upper harbour at UH3 was more stable. A period of erosion (~ 6 mm) was recorded in mid-April prior to gradual deposition until late April where rapid erosion occurred on 29 April during the high rainfall and wind period. Recovery was equally rapid, however, resulting in overall deposition of 1 mm in April.

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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.

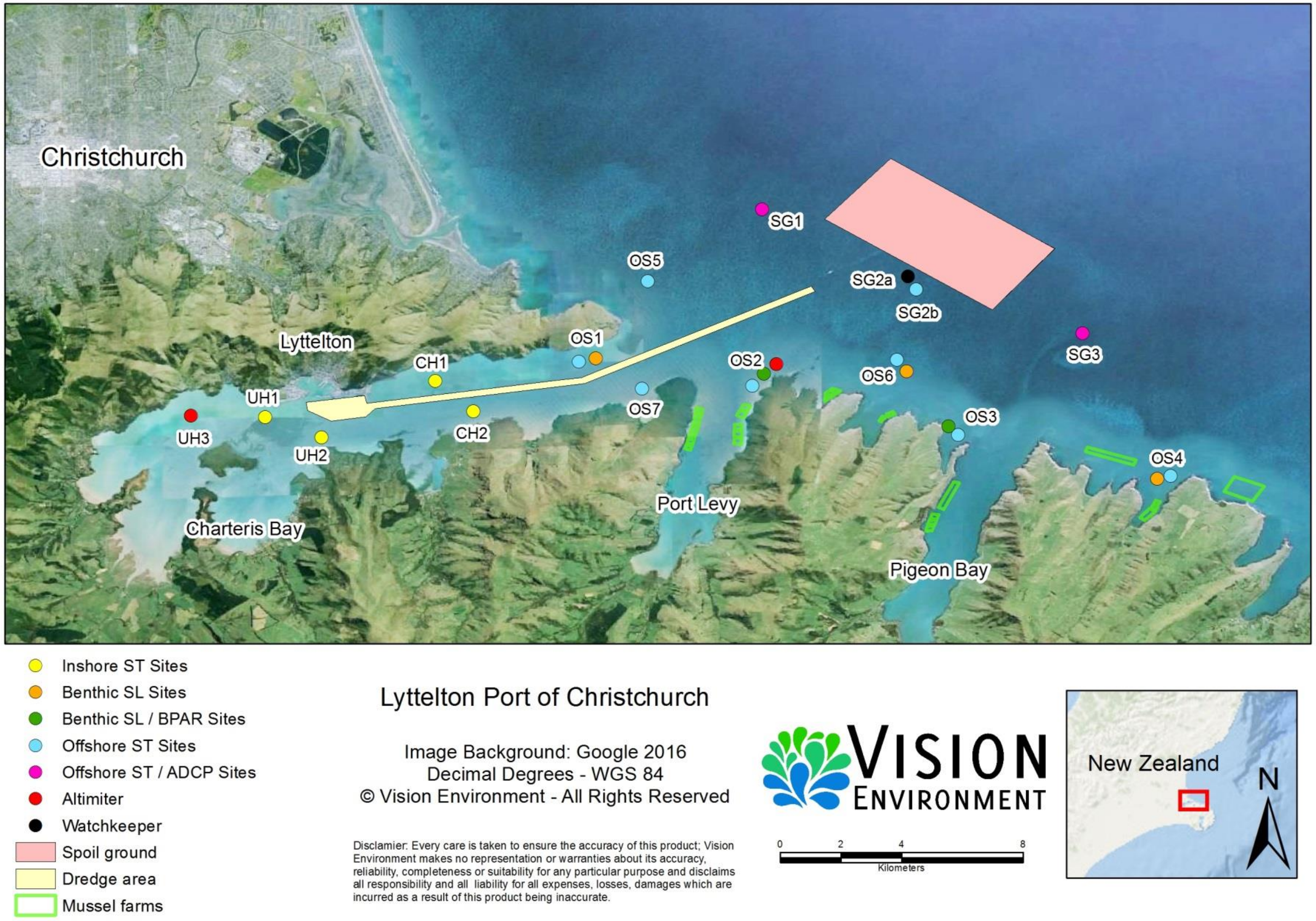



**Figure 1** Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
*ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler*

**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 during April 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 11 April 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*

During April 2019, Cashin Quay received 38.6 mm of rainfall, almost triple that recorded in March (13.2 mm). The majority of the rainfall (28 mm) was recorded on 29 April (Metconnect, 2019). Freshwater flows from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour post-rain, displayed a peak on 30 April (Figure 2), with a maximum outflow of 472 m$^3$/s (ECAN, 2019). High flows are expected to continue into May.

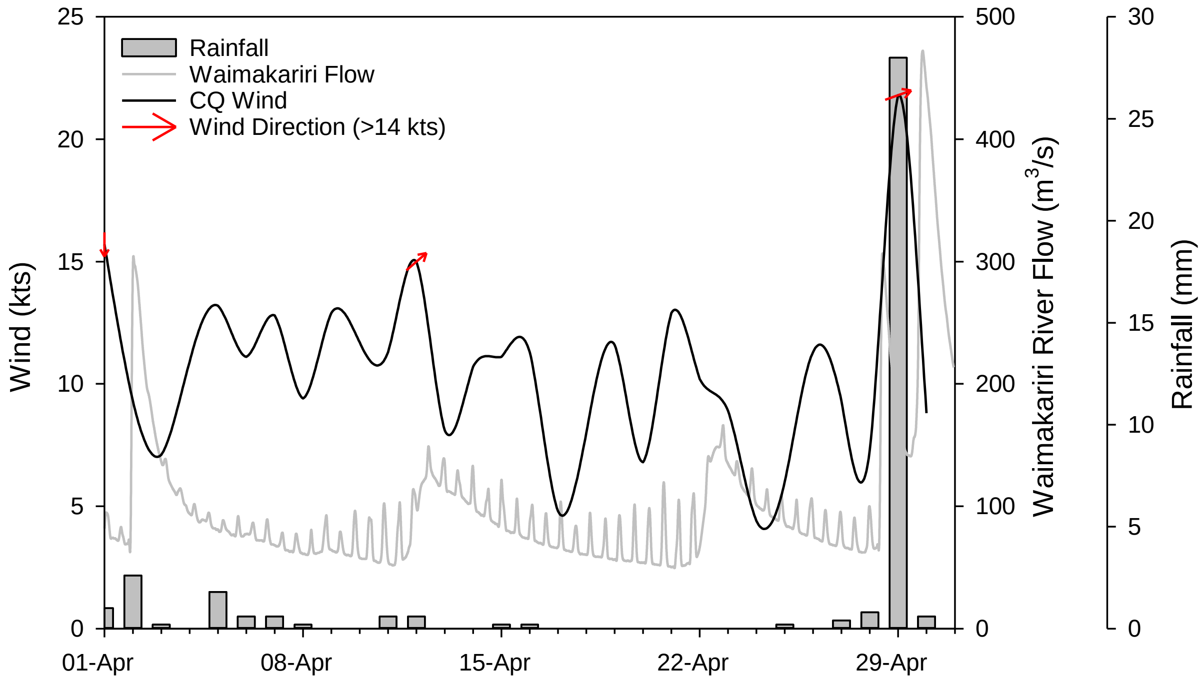



**Figure 2** Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during April 2019.
*Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.*

Inshore wind directionality varied throughout April, with south-westerly winds experienced on 12 days of the months, with gusts up to 21.8 knots recorded in this direction. Winds in a north-easterly direction were recorded during 11 days in April with gusts up to 12.9 knots recorded. The greatest maximum wind gusts (21.8 knots) were experienced on 29 April during the heavy rain period (Metconnect, 2019). Daily mean air temperatures at Cashin Quay ranged from 8 to 25°C, resulting in a monthly mean temperature of 13°C (Metconnect, 2019), considerably lower than the March mean temperature of 17°C.

Offshore significant wave heights were variable throughout April paralleling offshore wind speeds (Figure 3). Maximum significant wave heights were recorded at 3.31 m on 1 April, travelling in a south-westerly direction (Figure 3), following a period of increased wave heights in late March 2019.

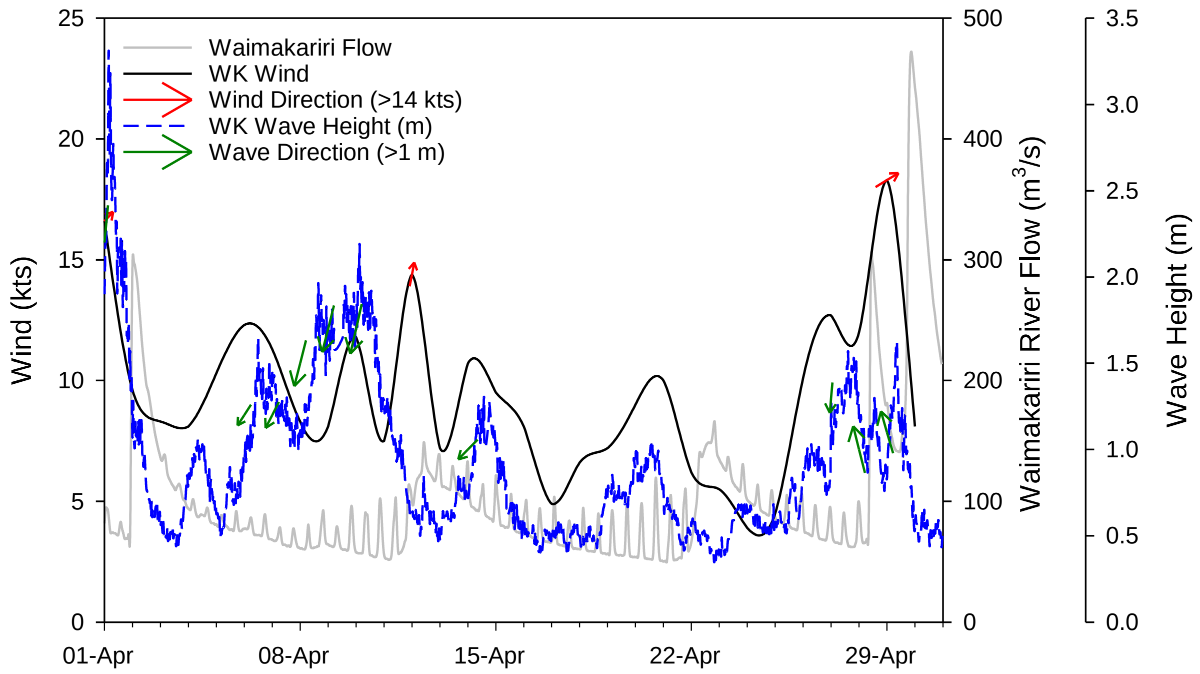



**Figure 3** Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during April 2019.
*Note: Arrows indicate the direction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

### 3.1.2 Currents

Acoustic Doppler Current Profilers (ADCPs) are deployed at the spoil ground monitoring sites SG1, SG2a and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Summary ADCP statistics are presented within Figures 4 to 6 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 30 and 35 in the Appendix. Note that the ADCP data are presented in this report using the UTC time format.

Maximum near-surface currents at SG1 (394 mm/s) reached their peak on 4 April, with currents > 300 mm/s also recorded on 1 and 29 April. However, near-seabed currents at SG1 (291 mm/s) in addition to near-surface and near-seabed currents at SG2a (130 and 240 mm/s, respectively) and SG3 (474 and 433 mm/s, respectively) peaked on 29 April during the period of highest wind speeds for the month. The similar timings between maximum near-surface and near-benthic current velocities across most of the spoil ground sites suggests that the increased winds resulted in a whole water column impact.

**Table 2** Parameter statistics for spoil ground ADCPs during April 2019.

| Parameter | Depth | Site | | |
|---|---|---|---|---|
| | | SG1 | SG2a | SG3 |
| Minimum current speed (mm/s) | *Near-surface* | 0 | 0 | 1 |
| | *Near-seabed* | 1 | 5 | 2 |
| Maximum current speed (mm/s) | *Near-surface* | 394 | 130 | 474 |
| | *Near-seabed* | 291 | 240 | 433 |
| Mean current speed (mm/s) | *Near-surface* | 94 | 20 | 120 |
| | *Near-seabed* | 81 | 78 | 113 |
| Standard deviation of current speed (mm/s) | *Near-surface* | 57 | 15 | 70 |
| | *Near-seabed* | 42 | 36 | 60 |
| Current speed, 95$^{th}$ percentile (mm/s) | *Near-surface* | 160 | 44 | 248 |

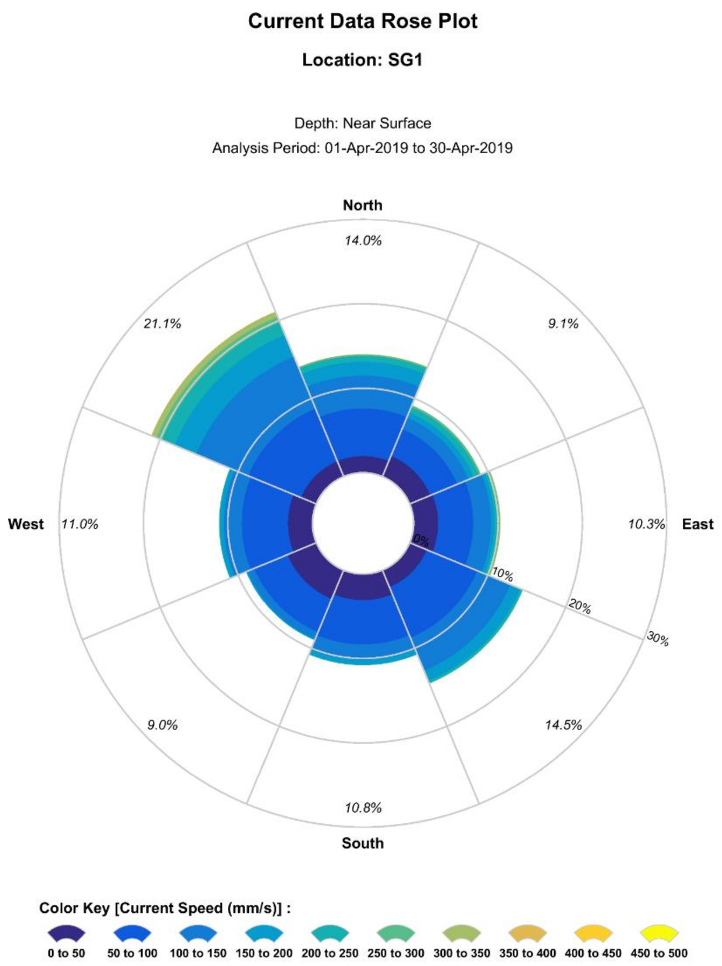
Maximum near-surface currents at SG1 (394 mm/s) reached their peak on 4 April, with currents > 300 mm/s also recorded on 1 and 29 April. However, near-seabed currents at SG1 (291 mm/s) in addition to near-surface and near-seabed currents at SG2a (130 and 240 mm/s, respectively) and SG3 (474 and 433 mm/s, respectively) peaked on 29 April during the period of highest wind speeds for the month. The similar timings between maximum near-surface and near-benthic current velocities across most of the spoil ground sites suggests that the increased winds resulted in a whole water column impact.

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 varied across the month: SG1 near-surface and near-seabed recorded on the 18 April (0 mm/s) and 12 April (1 mm/s), respectively; SG2 near-surface (0 mm/s) and near-seabed (5 mm/s) recorded on 4 April; and SG3 near-surface and near-seabed on the 9 April (1 mm/s) and 28 April (2 mm/s), respectively.

The time-series plots (Figures 30 to 35 in Appendix) illustrate time-varying current direction, whilst the current rose diagrams (Figures 4 to 6) depict the distribution of current direction and velocity in the near-surface and near-seabed layers. When interpreting the current data, 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 April tended to flow towards the north-west (21.1%) and south-east (14.5%). These current flow directions were somewhat similar at the near-seabed (north-west: 17.2%; south-east 14.6%). Similar flow directions were evident at SG3 near-surface (north-west: 29.8%; south-east 21.4%) and near-seabed (north-west: 21.8%; south-east 23,0%). In contrast, current flow at SG2a tended to be along a more east (near-surface: 20.4%, near-seabed: 24.2%) and west (near-surface: 18.0%, near-seabed: 21.6%) axis.



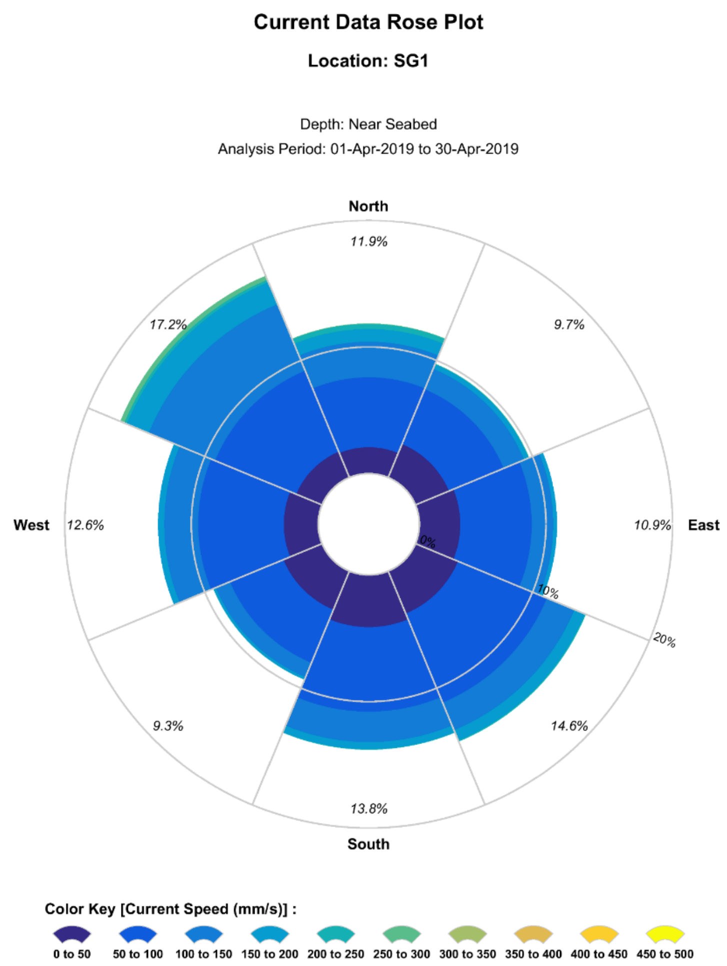
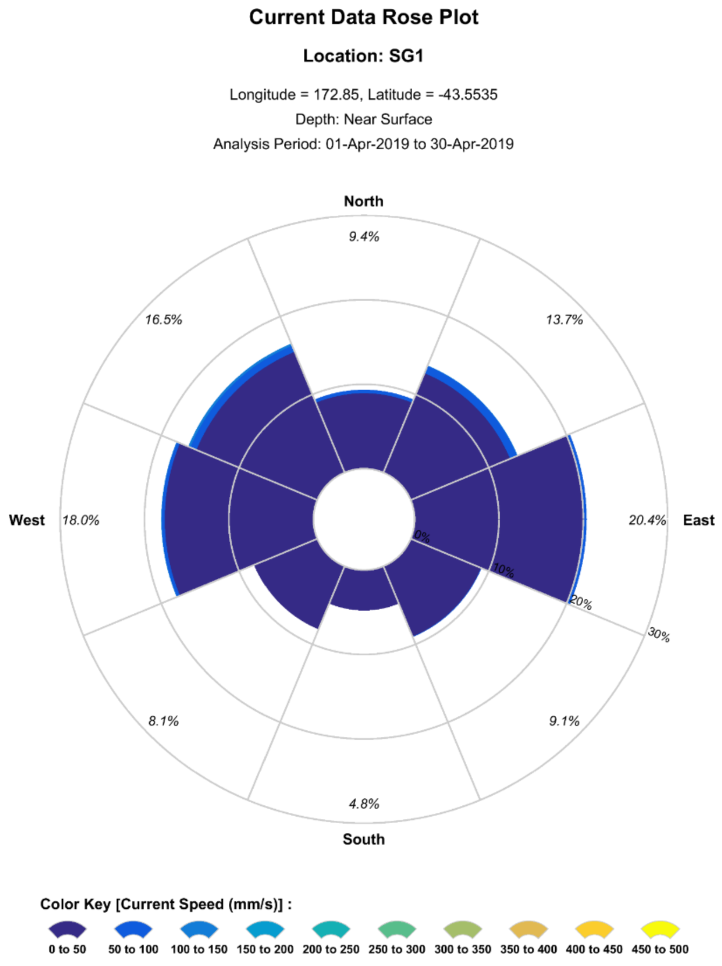




**Figure 4** Near-surface and near-seabed current speed and direction at SG1 during April 2019.
*Speed intervals of 50 mm/s are used.*



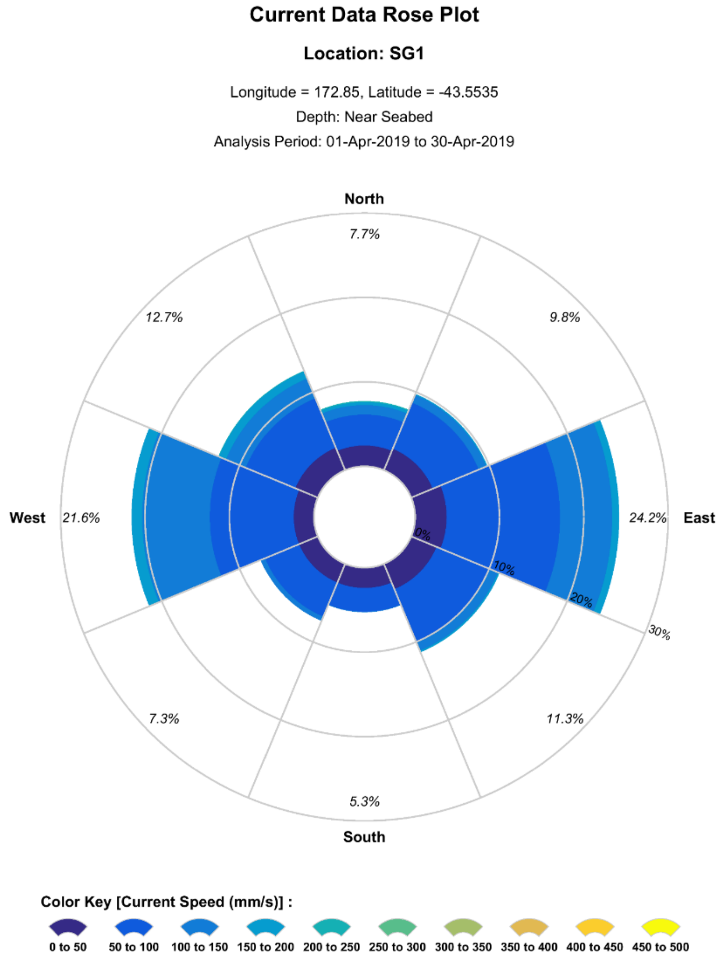
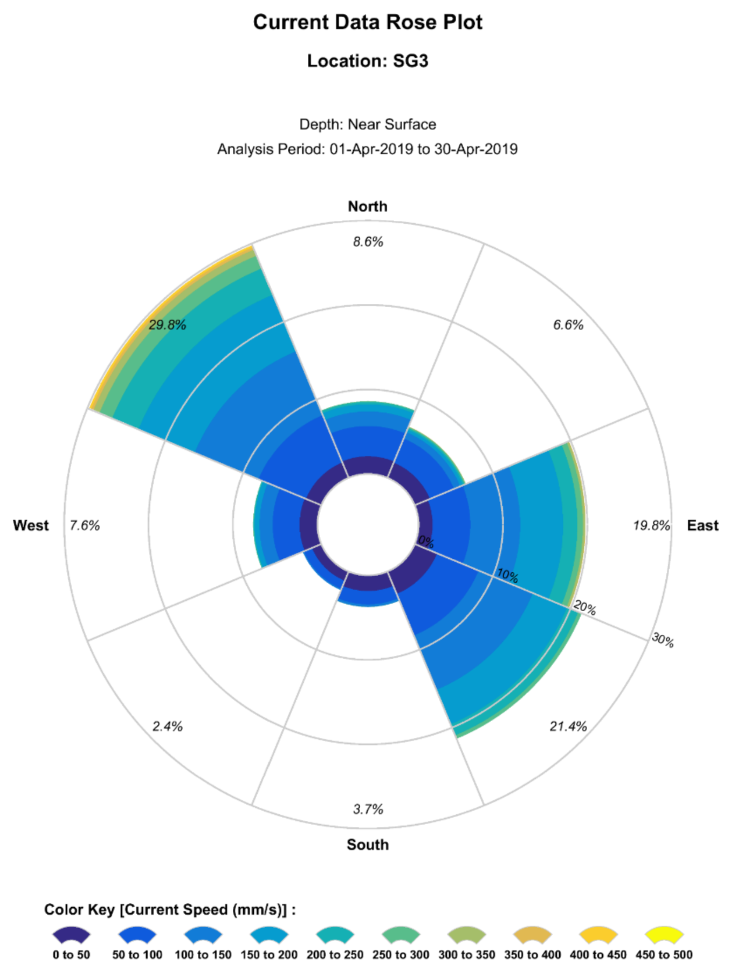




**Figure 5** Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during April 2019. *Speed intervals of 50 mm/s are used*



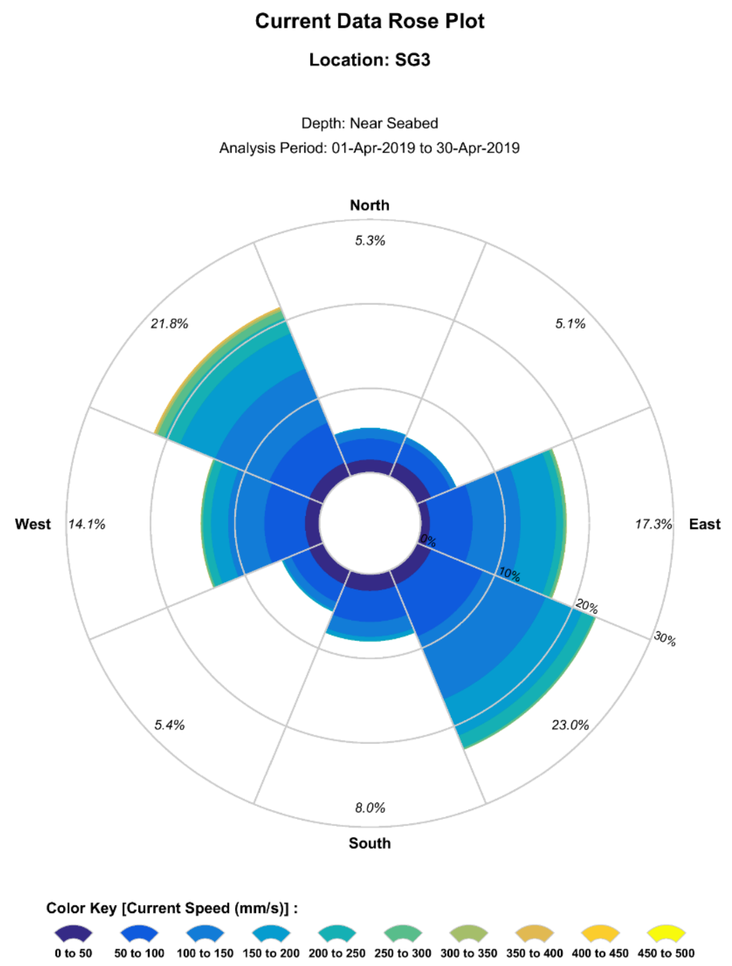




**Figure 6** Near-surface and near-seabed current speed and direction at SG3 during April 2019.
*Speed intervals of 50 mm/s are used*

## 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 11 April 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 April are presented in Tables 3 to 12. Validated datasets for surface and benthic measurements are also presented in Figures 7 to 20. Due to the inherent high level of variability in the turbidity datasets, a 24-hour rolling average has been calculated every 15 minutes to act as an interim smoothing technique and aid in data interpretation.

### *3.2.1 Turbidity*

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

**April Turbidity:**

Consistent with previous monitoring months, surface turbidity values were highest (monthly means of 6.9 to 10 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 5.5 NTU), 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 mean turbidity values (3.1 to 7.3 NTU) during April (Table 5). As per previous months, surface turbidity at CH2 (6.9 NTU) on the southern side of the harbour remained lower than the remaining three inner harbour sites (8.3 to 10 NTU), likely reflecting tidal movements within the harbour where the southern edge is dominated by the incoming flood tide.

Turbidity across the inner harbour was relatively high during the first few days of April following on from turbidity increases in late March (Figure 7). Turbidity then decreased prior to increasing slightly between 8 and 11 April in response to minor rainfall and an increase in wind speeds. By mid-April turbidity had again declined and remained reasonably consistent at the sites prior to increasing rapidly on 30 April in response to the high rainfall and winds experienced the day prior.

The nearshore sites of the monitoring program (OS1 to 4 and OS7) also exhibited early April peaks on 1, 8 and 11 prior to decreasing slightly and remaining reasonably stable from mid-April onwards. Unlike the inner harbour sites, a large turbidity peak was not recorded at the end of April, suggesting that the late April turbidity peak in the inner harbour was likely to be a direct response of rainfall and local runoff as opposed to high winds recorded over the region.

**Table 3** Mean turbidity and statistics at inshore water quality logger sites during April 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for April are means ± se, range and percentiles (n = 2693 to 2876) Baseline values modified from Fox 2018.*

| Site | Statistic | Turbidity (NTU) Surface April | Surface Baseline |
|---|---|---|---|
| UH1 | Mean ± se | 10 ± 0 | 12 |
| | Range | 5 – 107 | - |
| | 99th | 32 | 39 |
| | 95th | 16 | 22 |
| | 80th | 12 | 15 |
| UH2 | Mean ± se | 8.3 ± 0.1 | 10 |
| | Range | 3 – 164 | - |
| | 99th | 23 | 32 |
| | 95th | 14 | 20 |
| | 80th | 10 | 13 |
| CH1 | Mean ± se | 8.8 ± 0.1 | 9 |
| | Range | 3 – 26 | - |
| | 99th | 18 | 29 |
| | 95th | 14 | 18 |
| | 80th | 11 | 12 |
| CH2 | Mean ± se | 6.9 ± 0.1 | 8 |
| | Range | <1 – 20 | - |
| | 99th | 16 | 24 |
| | 95th | 12 | 16 |
| | 80th | 8.6 | 10 |

**Table 4** Mean turbidity and statistics at spoil ground water quality logger sites during April 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for April are means ± se, range and percentiles (n = 2590 to 2877). Baseline values modified from Fox 2018.*

| Site | Statistic | Turbidity (NTU) Surface April | Surface Baseline |
|---|---|---|---|
| SG1 | Mean ± se | 5.1 ± 0.0 | 4.2 |
| | Range | <1 – 13 | - |
| | 99th | 9.6 | 14 |
| | 95th | 8.2 | 10 |
| | 80th | 6.4 | 6.2 |
| SG2 | Mean ± se | 5.5 ± 0.0 | 4.6 |
| | Range | <1 – 15 | - |
| | 99th | 11 | 20 |
| | 95th | 9.1 | 11 |
| | 80th | 7.2 | 7.0 |
| SG3 | Mean ± se | 2.2 ± 0.0 | 3.6 |
| | Range | <1 – 12 | - |
| | 99th | 7.6 | 13 |
| | 95th | 5.2 | 7.7 |
| | 80th | 3.3 | 4.8 |

Further offshore at OS5, OS6 and the spoil ground sites, several turbidity peaks were recorded during the month on 2, 8, 15, 22 and 29 April, although the 24h rolling average remained < 10 NTU at these times. Turbidity peaks occurred when increases in wave heights were recorded (Figure 7).

**Comparison to Baseline:**

Mean surface turbidity values during April were similar (± 1.5 NTU) to values calculated from the baseline monitoring period (Tables 3 to 5, Figures 8 to 12).

**Benthic:**

No turbidity data was able to be recovered for benthic sites OS1 and OS3, with limited data recovery at site OS4 (Figure 7). However, where data are available there was consistency between surface and benthic turbidity patterns. Variations in benthic turbidity displayed a high correspondence with wave heights, particularly at OS6, with periods of increased wave energy coinciding with elevated turbidity levels (Figure 7).

**Table 5** Mean turbidity and statistics at offshore water quality logger sites during April 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for April are means ± se, range and percentiles (n =235 to 2870). Baseline values modified from Fox 2018. *Note that no benthic turbidity data available for OS1 and OS3 due to sonde malfunction.*

| Site | Statistic | Turbidity (NTU) | | |
|---|---|---|---|---|
| | | Surface April | Surface Baseline | Benthic April |
| OS1 | Mean ± se | 4.8 ± 0.0 | 7.5 | –* |
| | Range | <1 – 22 | - | – |
| | 99th | 14 | 24 | – |
| | 95th | 9.5 | 16 | – |
| | 80th | 6.5 | 10 | – |
| OS2 | Mean ± se | 7.3 ± 0.0 | 6.4 | 14 ± 0 |
| | Range | 3 – 20 | - | 1 – 100 |
| | 99th | 14 | 18 | 74 |
| | 95th | 11 | 13 | 49 |
| | 80th | 9.0 | 9.0 | 20 |
| OS3 | Mean ± se | 6.8 ± 0.1 | 6.6 | -* |
| | Range | 1 – 39 | - | - |
| | 99th | 24 | 27 | - |
| | 95th | 13 | 15 | - |
| | 80th | 8.7 | 8.9 | - |
| OS4 | Mean ± se | 4.8 ± 0.0 | 5.9 | 44 ± 1 |
| | Range | <1 – 21 | - | <1 – 107 |
| | 99th | 15 | 20 | 100 |
| | 95th | 9.5 | 13 | 80 |
| | 80th | 26.4 | 8.3 | 62 |
| OS5 | Mean ± se | 3.1 ± 0.0 | 4.6 | – |
| | Range | <1 – 15 | - | – |
| | 99th | 8.2 | 19 | – |
| | 95th | 5.8 | 11 | – |
| | 80th | 4.3 | 6.4 | – |
| OS6 | Mean ± se | 5.3 ± 0.0 | 4.7 | 31 ± 1 |
| | Range | <1 – 18 | - | <1 – 230 |
| | 99th | 12 | 19 | 121 |
| | 95th | 10 | 12 | 84 |
| | 80th | 7.0 | 7.2 | 52 |
| OS7 | Mean ± se | 6.7 ± 0.0 | 6.4 | – |
| | Range | <1 – 19 | - | – |
| | 99th | 14 | 23 | – |
| | 95th | 11 | 14 | – |
| | 80th | 8.4 | 9.2 | – |

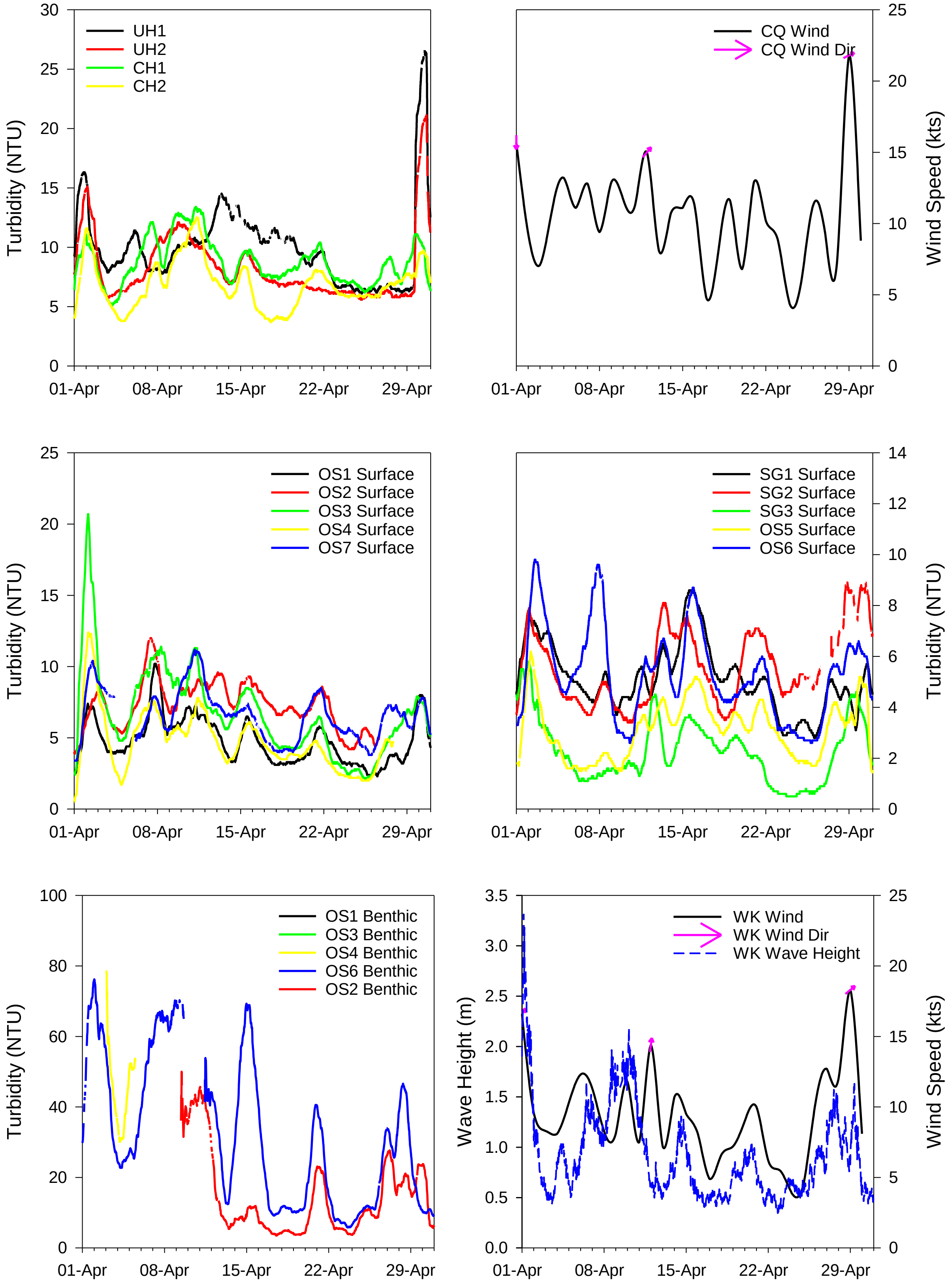



**Figure 7** 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
*Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.*

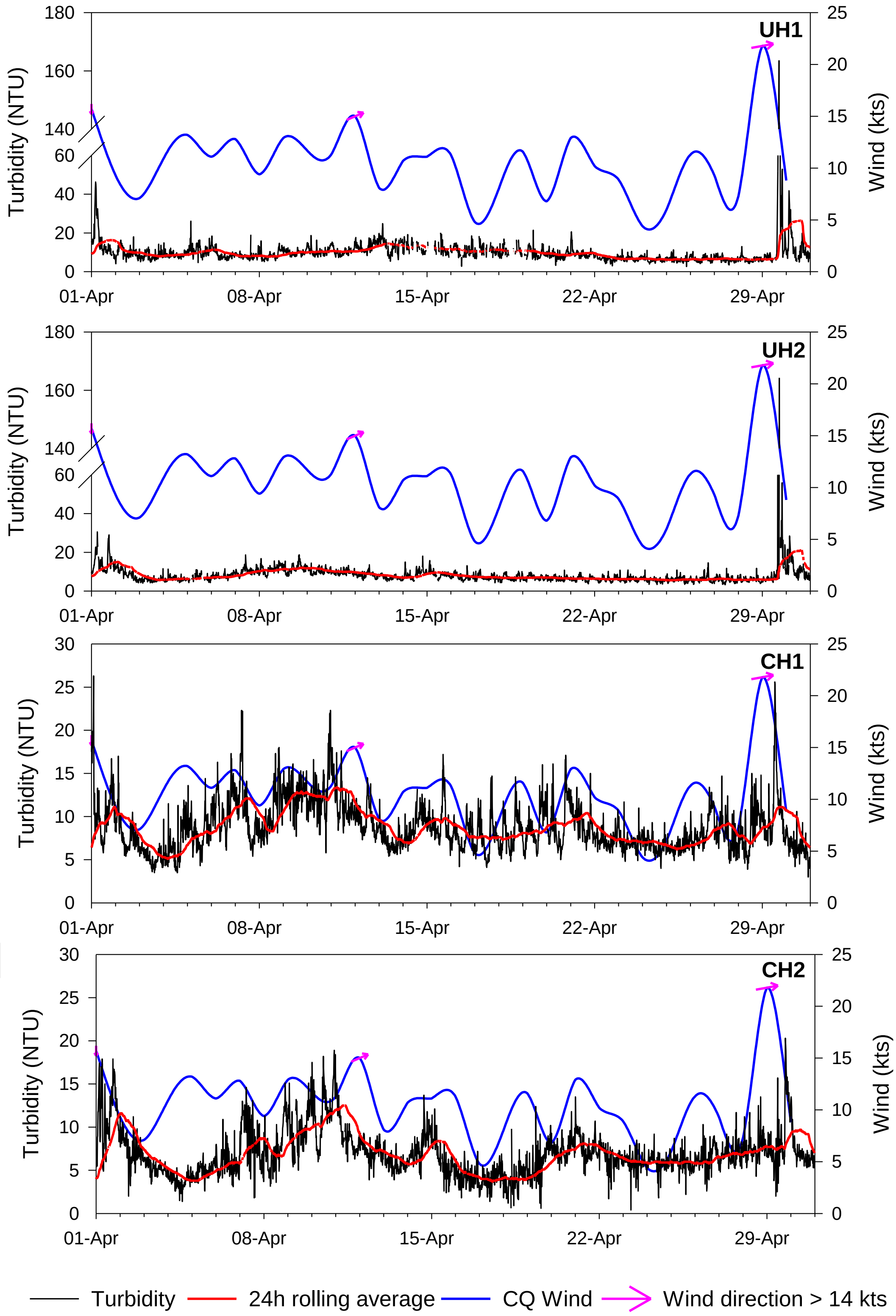



**Figure 8** Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during April 2019.
*Arrows indicate the direction of travel for inshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.*

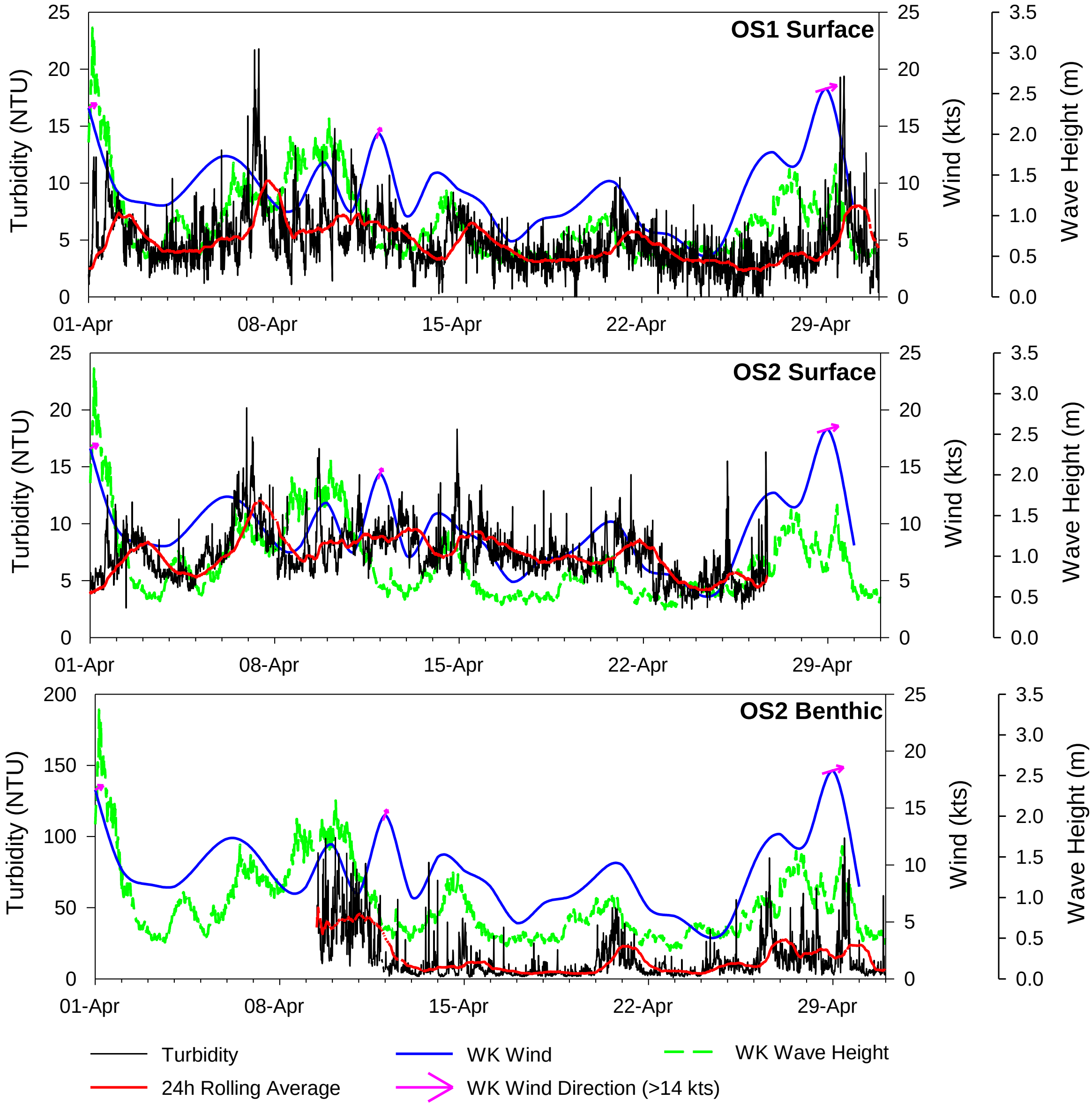



**Figure 9** Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during April 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity. *Note that no benthic turbidity data available for OS1 due to sonde malfunction.*

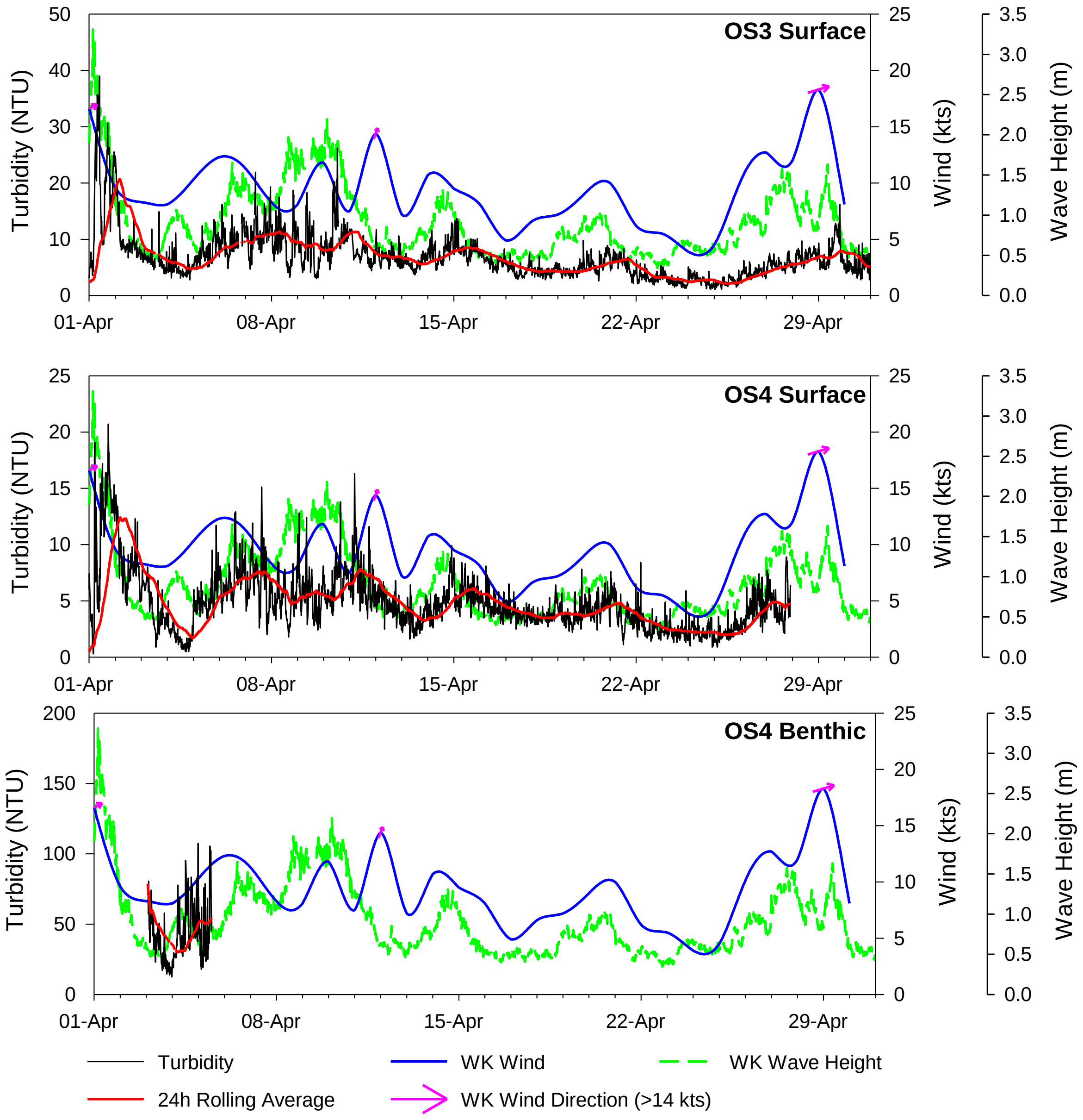



**Figure 10** Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during April 2019.

*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. *Note that no benthic turbidity data available for OS3 due to sonde malfunction.*

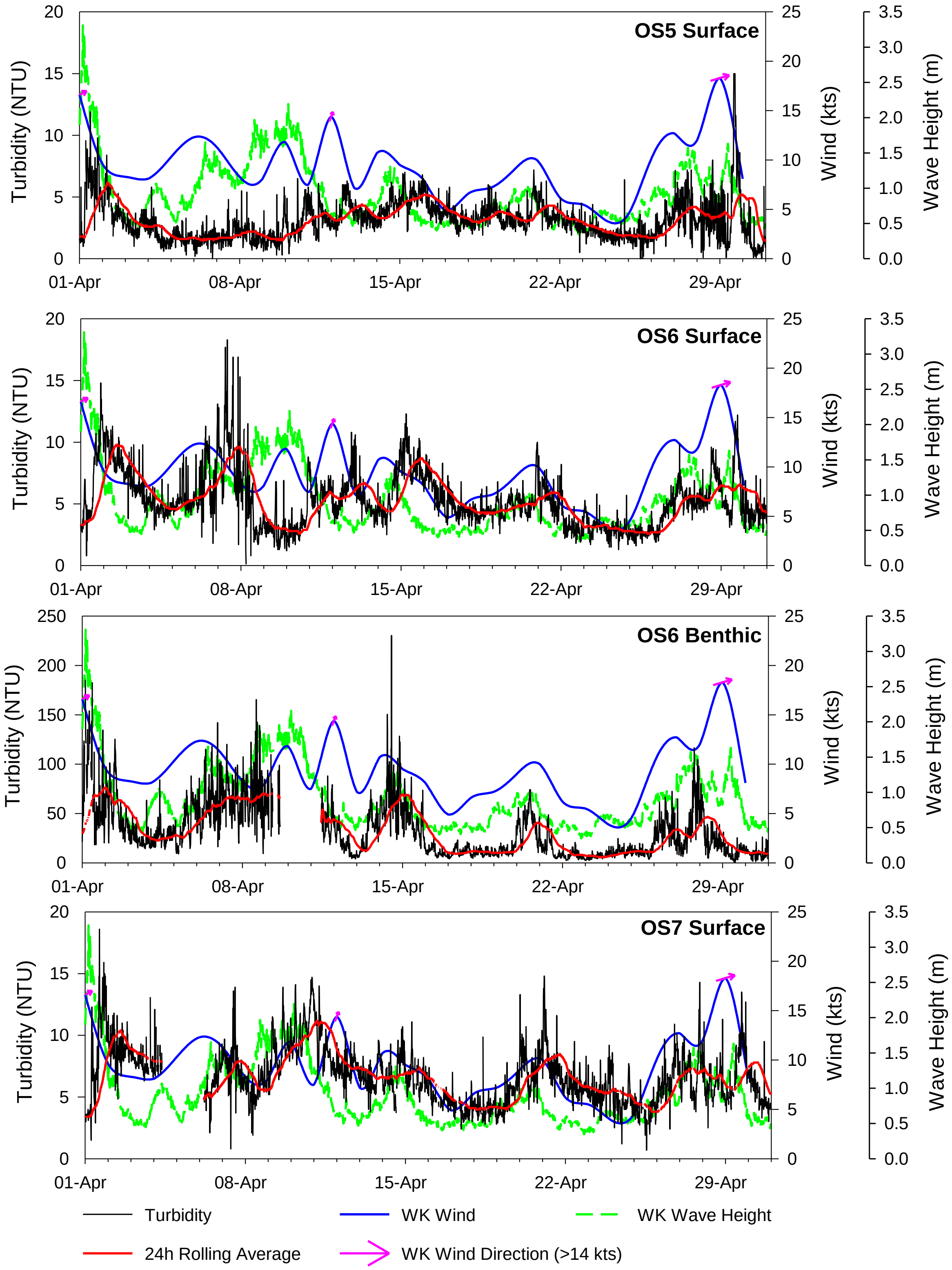



**Figure 11** Surface turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during April 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.*

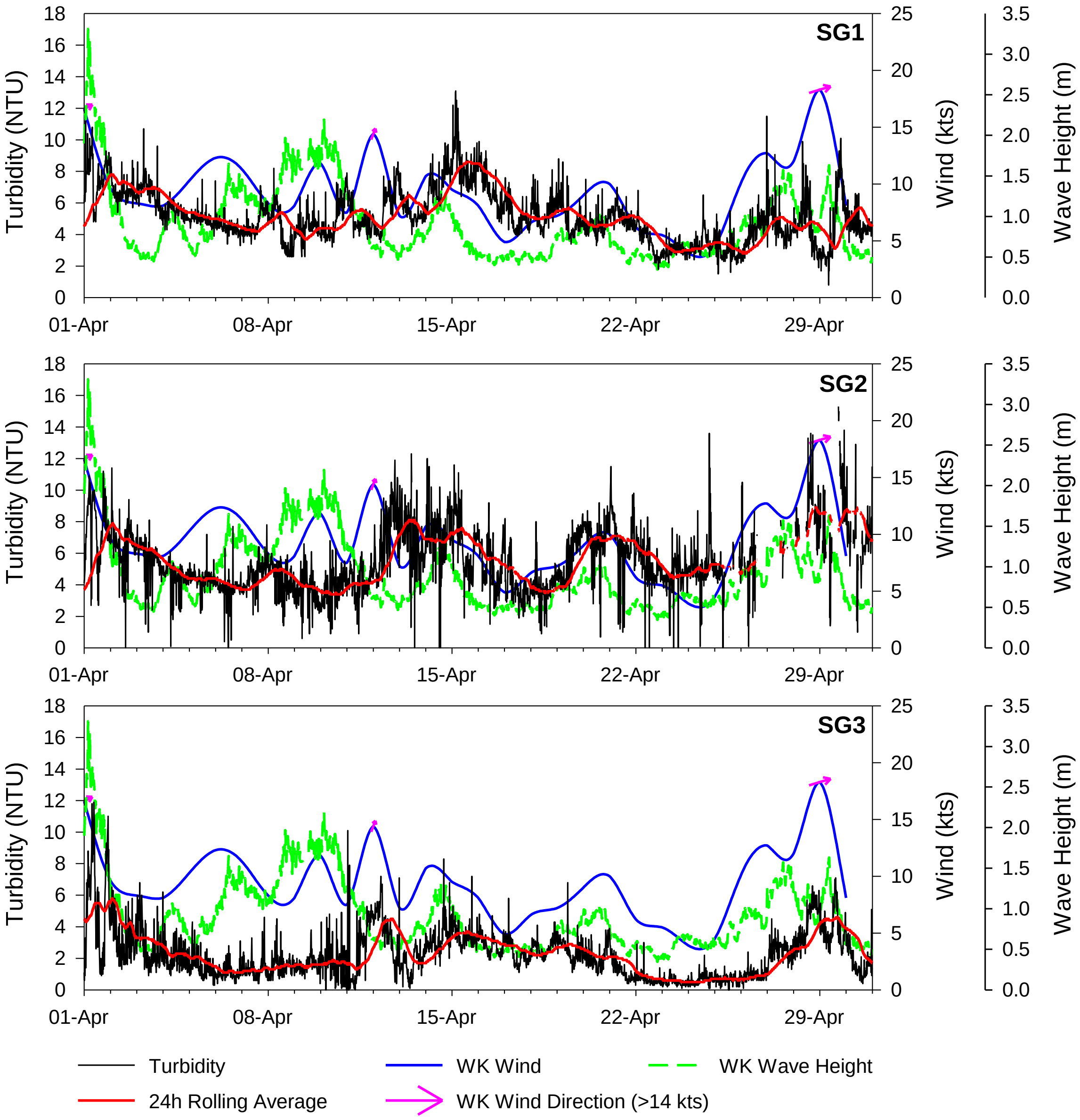



**Figure 12** Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during April 2019. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Grey shading indicates the baseline mean turbidity.*

### *3.2.2 Dredge Compliance Trigger Values*

Management of dredge operations 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 April the Tier 3 intensity values were not exceeded at any site within the monitoring network (Table 7).

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

| Site | P99 Count >7.2 Hours Start Time | P99 Count >7.2 Hours End Time | Maximum P99 Count (Hours) |
|---|---|---|---|
| UH1 | – | – | 3.50 |
| UH2 | – | – | 4.25 |
| CH1 | – | – | 0.00 |
| 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 April were largely similar to or below baseline conditions, and as such no validated P99 exceedance counts were accumulated (Table 7) nor removed (Table 8).

**Table 8** Hour counts removed from monitoring statistics during April 2019.

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

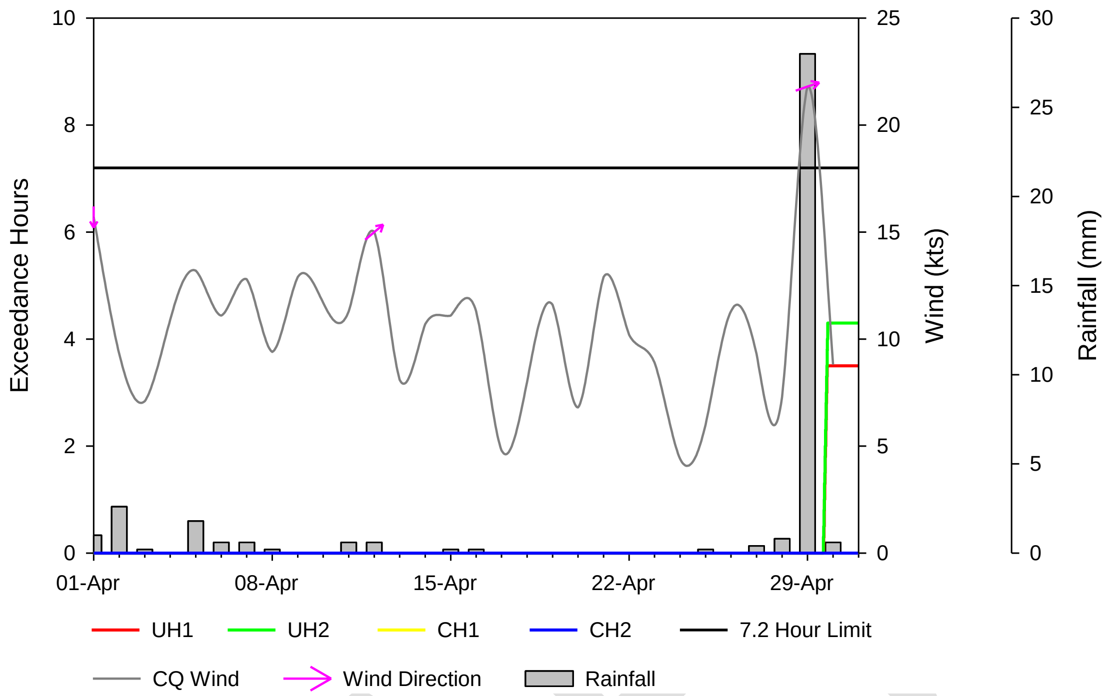



**Figure 13** Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values from 1 to 30 April 2019.

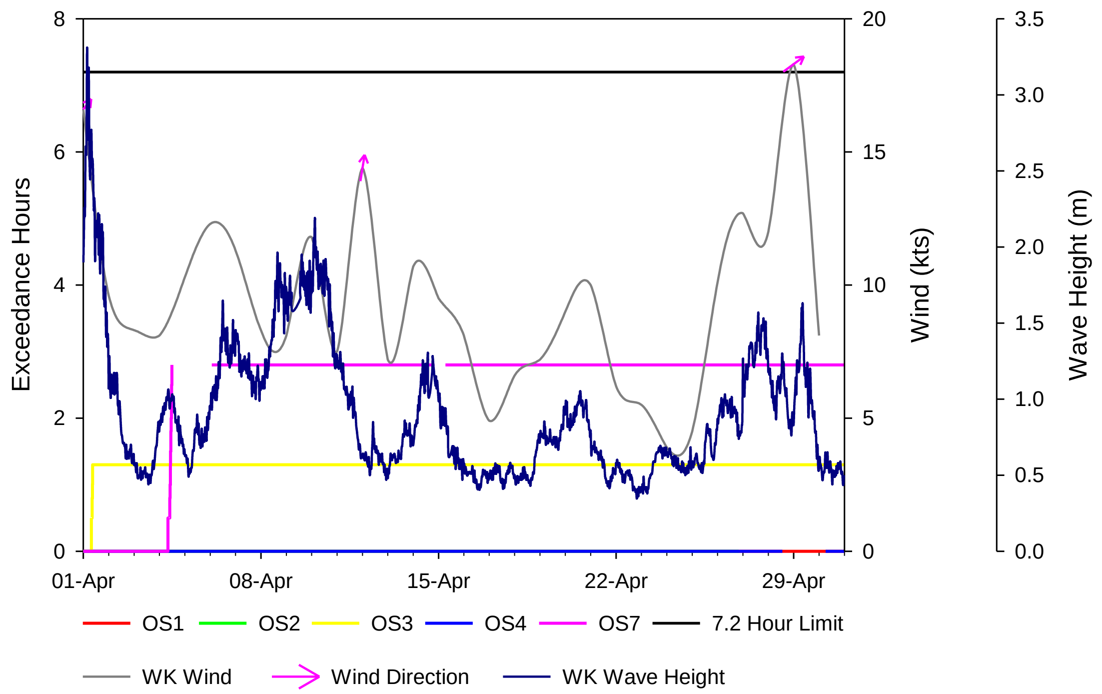



**Figure 14** Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values from 1 to 30 April 2019.
*Note there is no trigger value for the reference site OS4.*

### *3.2.3 Temperature*

Mean monthly sea surface temperatures around Lyttelton Harbour were considerably cooler than those experienced during March, ranging from 14.6 to 15.2°C (Table 9) (c.f. 17.3 to 18.3°C in March). In contrast to previous months, slightly cooler temperatures were recorded in the upper and central harbour in comparison with offshore sites.

Cooling across all sites was consistent throughout April, with a rapid decrease at the majority of sites observed on 29 and 30 April during and immediately after the high rain and wind event. Rapid cooling was most pronounced at inshore sites UH1 and UH2, which also exhibited cooler temperatures during the minor rain periods in early April. Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the surface temperature datasets, particularly at the inner harbour sites. Benthic temperatures were similar to overlying surface waters (Table 9), again indicating a well-mixed water column.

**Table 9** Mean temperature at inshore, spoil ground and offshore water quality sites during April 2019. *Values are means ± se (n = 2867 to 2880).*

| Site | Temperature (°C) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 14.6 ± 0.0 | – |
| UH2 | 14.6 ± 0.0 | – |
| CH1 | 14.8 ± 0.0 | – |
| CH2 | 14.9 ± 0.0 | – |
| SG1 | 15.2 ± 0.0 | – |
| SG2 | 15.2 ± 0.0 | – |
| SG3 | 15.2 ± 0.0 | – |
| OS1 | 15.0 ± 0.0 | 15.1 ± 0.0 |
| OS2 | 15.1 ± 0.0 | 15.2 ± 0.0 |
| OS3 | 15.2 ± 0.0 | 15.3 ± 0.0 |
| OS4 | 15.2 ± 0.0 | 15.2 ± 0.0 |
| OS5 | 15.2 ± 0.0 | – |
| OS6 | 15.1 ± 0.0 | 15.1 ± 0.0 |
| OS7 | 15.1 ± 0.0 | – |

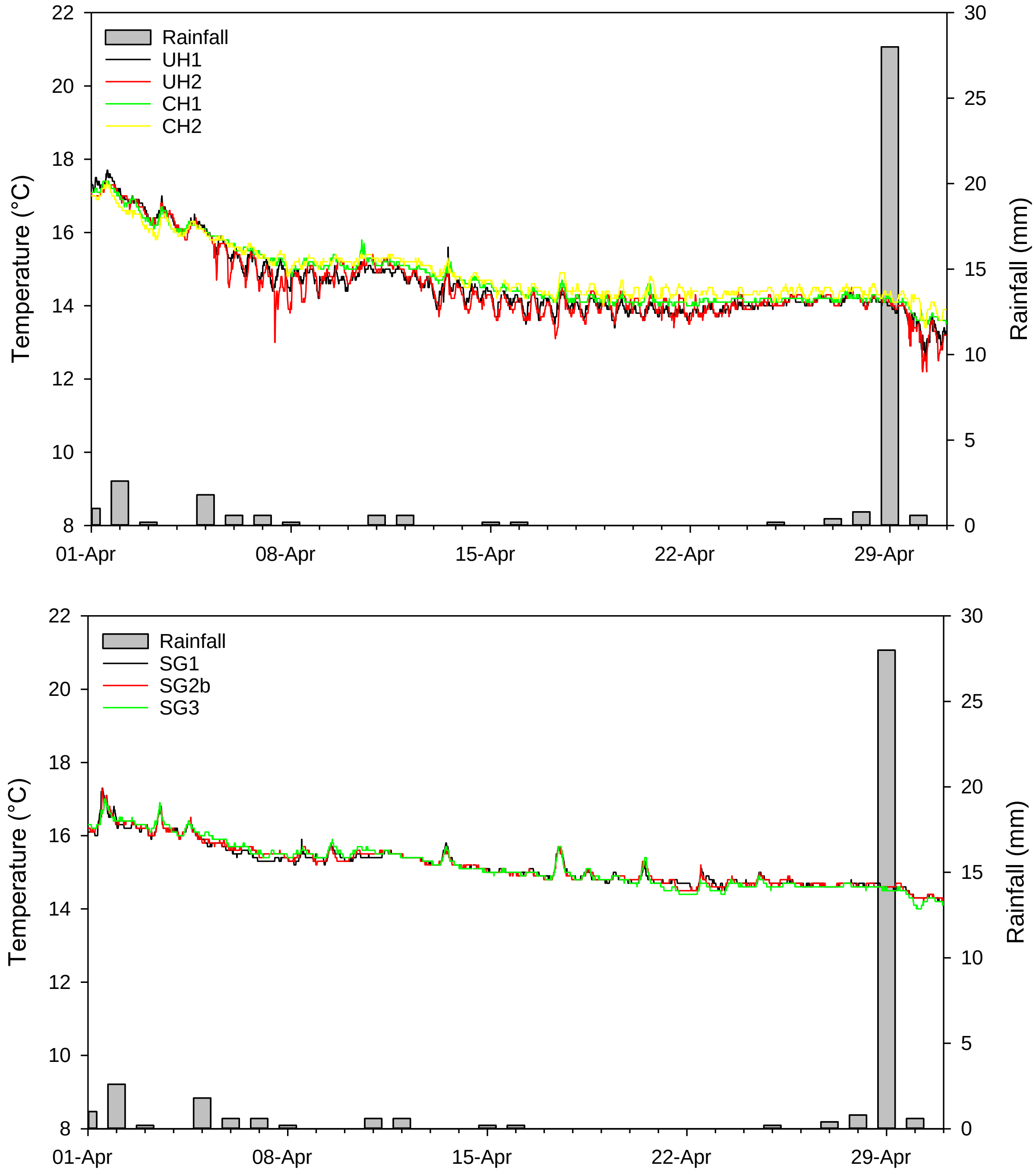



**Figure 15** Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during April 2019.

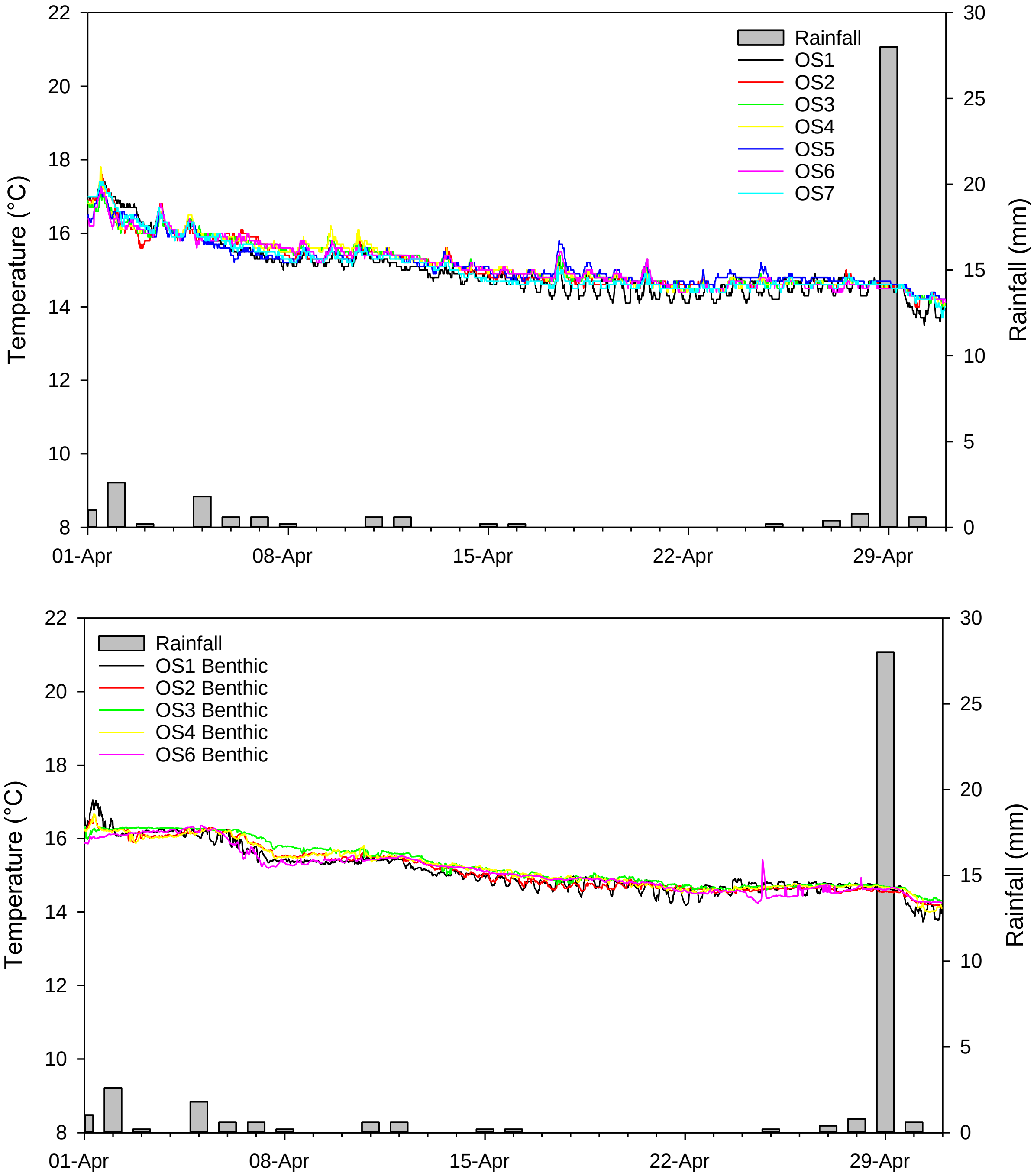


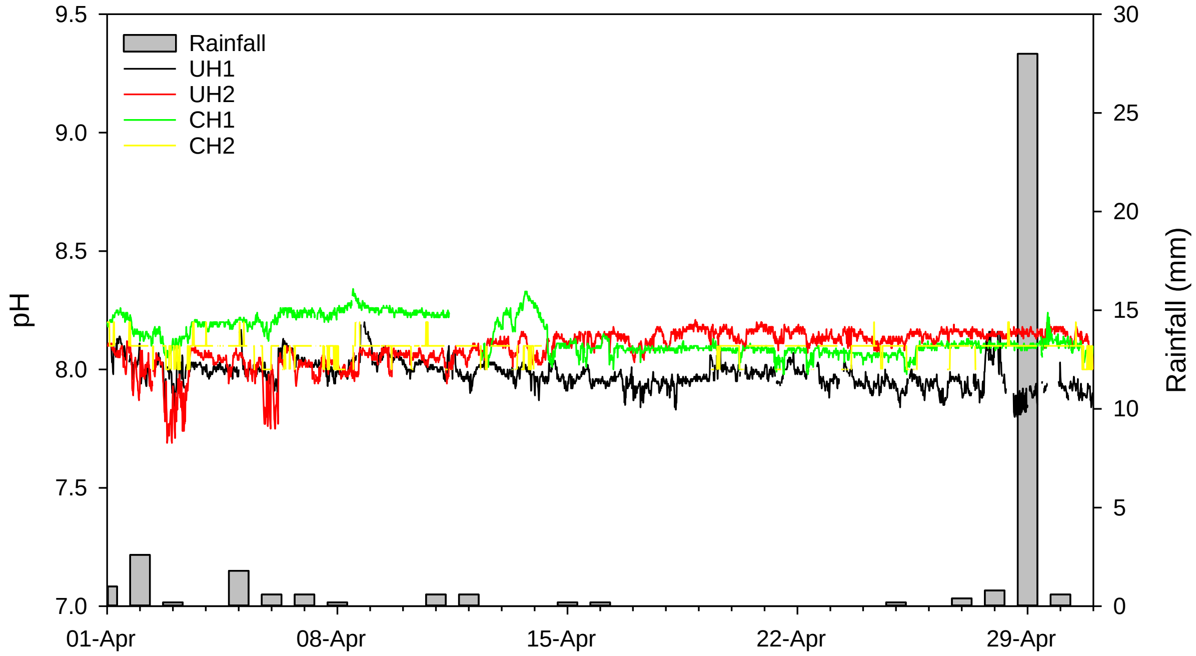

**Figure 16** Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during April 2019.

### 3.2.4 pH

The pH in April was consistent across all sites, both surface and benthic, with monthly means ranging between 8.0 and 8.2 (Table 10, Figures 17 and 18). Some post calibration issues have been encountered with pH probes during March and April 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 April 2019. *Values are means ± se (n = 355 to 2865).*

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



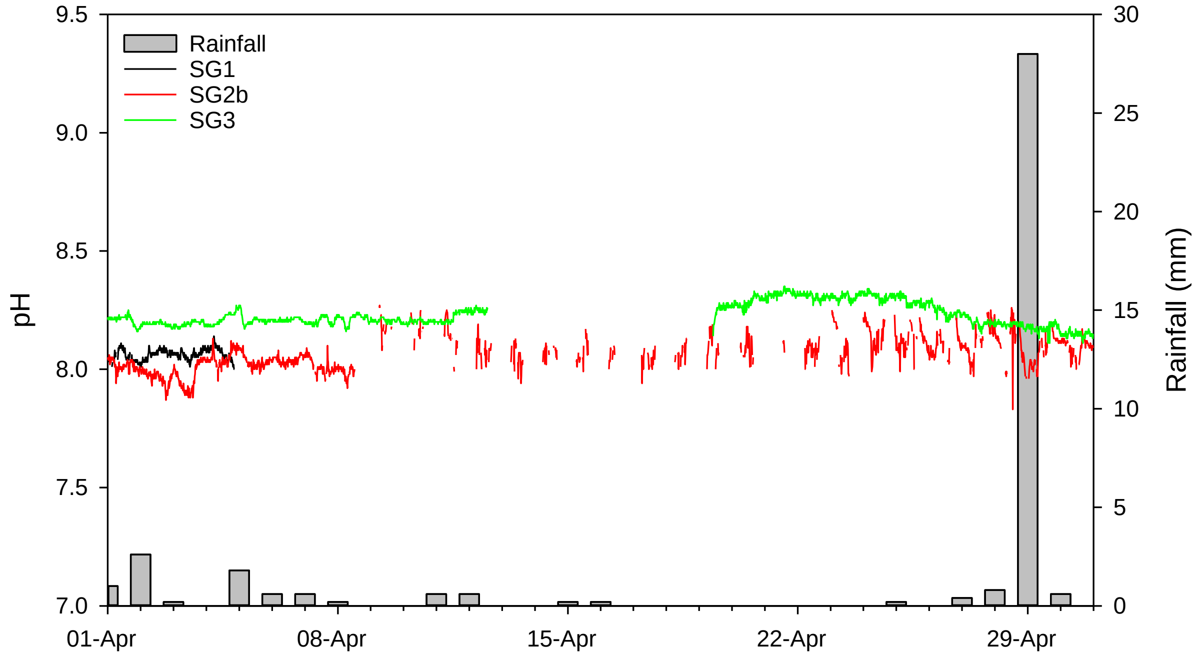
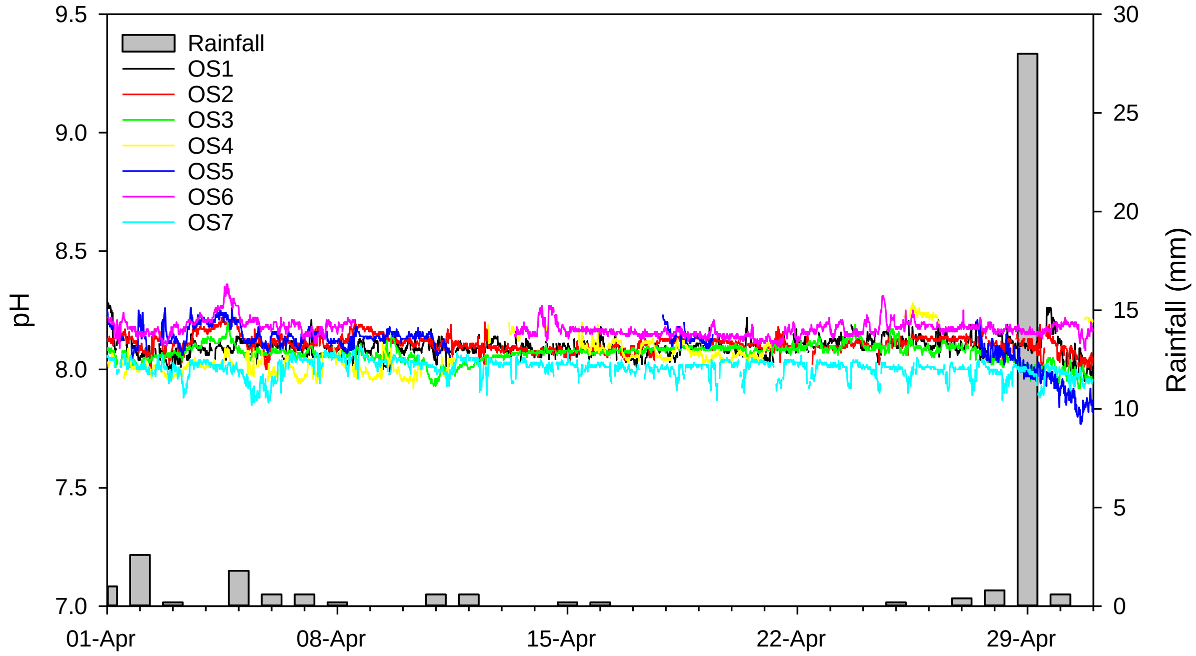




**Figure 17** Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during April 2019.



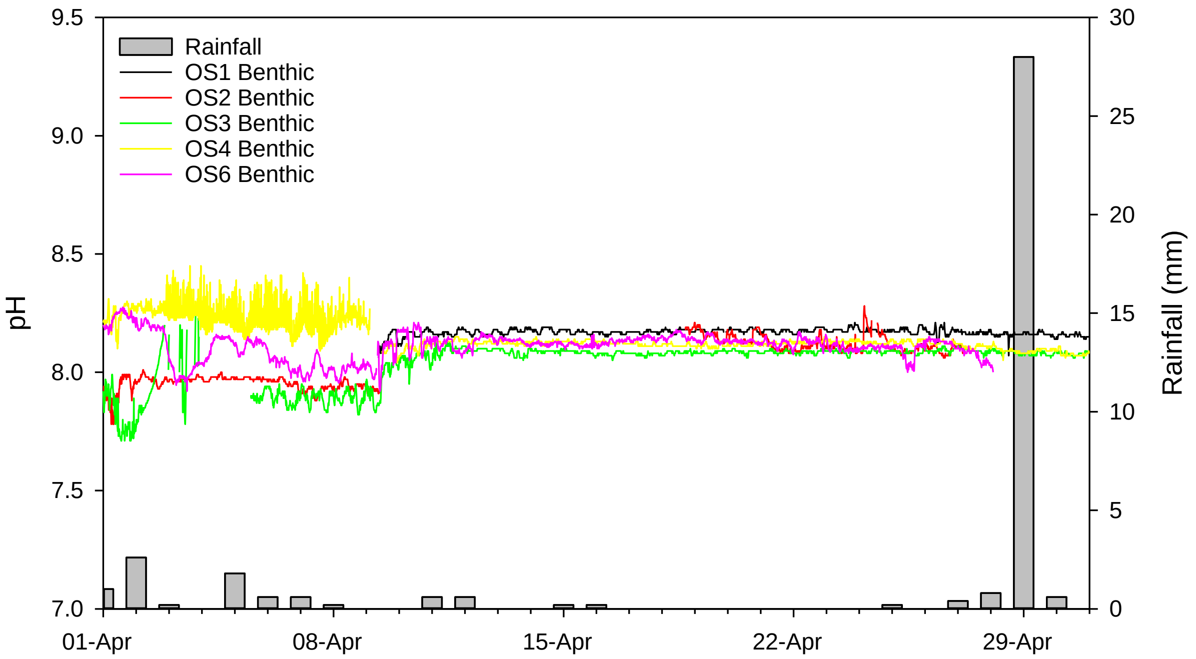



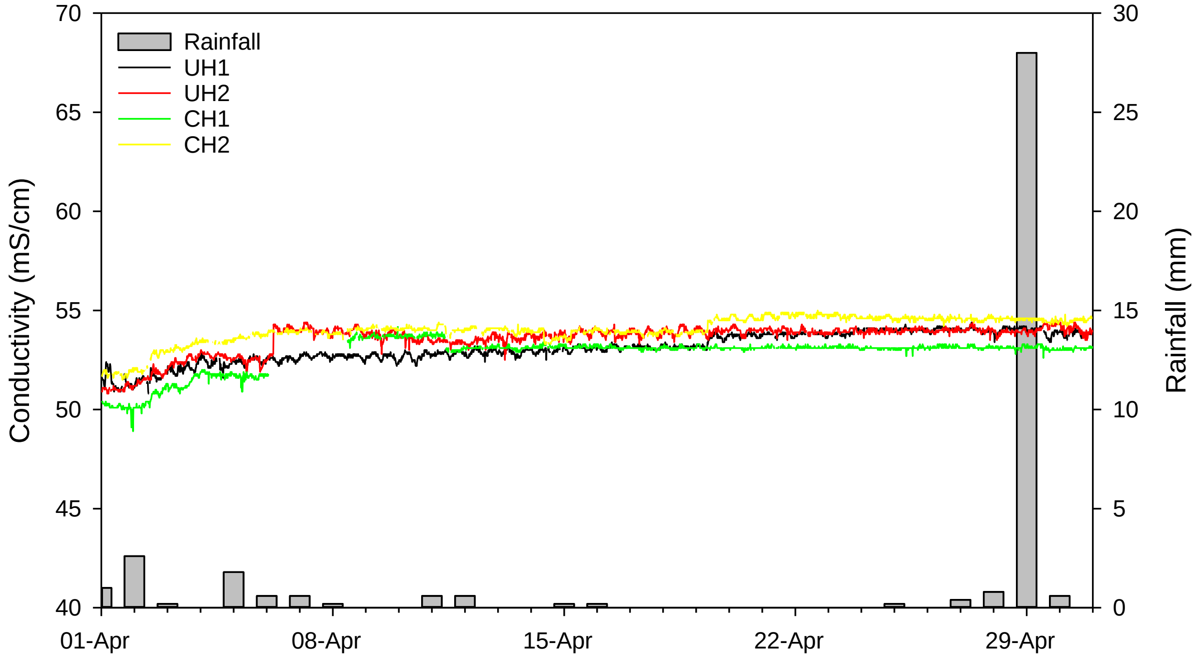

**Figure 18** Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at nearshore and offshore water quality sites during April 2019.

### 3.2.5 Conductivity

Surface conductivity in April ranged from 52.8 mS/cm to 55.3 mS/cm (Table 11), while benthic conductivity ranged from 53.6 mS/cm to 56.2 mS/cm, similar to monthly mean values calculated for March. Conductivity was more variable at the start of April, most likely due to prolonged effects from the Waimakariri River outflow which peaked at 957 $m^3/s$ on 27 March 2019. However, from 8 April onwards, conductivity remained reasonably consistent at each site for the remainder of the month, with no notable impact evident during April from the high rainfall recorded on 29 April, or resultant flows from the Waimakariri River. The latter impacts are likely to be observed in May.

**Table 11** Mean conductivity at inshore, spoil ground and offshore water quality sites during April 2019.
*Values are means ± se (n = 978 to 2879).*

| Site | Conductivity (mS/cm) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 53.1 ± 0.0 | – |
| UH2 | 53.6 ± 0.0 | – |
| CH1 | 52.8 ± 0.0 | – |
| CH2 | 54.1 ± 0.0 | – |
| SG1 | 54.4 ± 0.0 | – |
| SG2 | 54.1 ± 0.0 | – |
| SG3 | 55.3 ± 0.0 | – |
| OS1 | 53.4 ± 0.0 | 53.6 ± 0.0 |
| OS2 | 54.3 ± 0.0 | 55.7 ± 0.0 |
| OS3 | 53.9 ± 0.0 | 56.2 ± 0.0 |
| OS4 | 54.2 ± 0.0 | 54.3 ± 0.0 |
| OS5 | 53.8 ± 0.0 | – |
| OS6 | 54.0 ± 0.0 | 55.5 ± 0.0 |
| OS7 | 53.7 ± 0.0 | – |



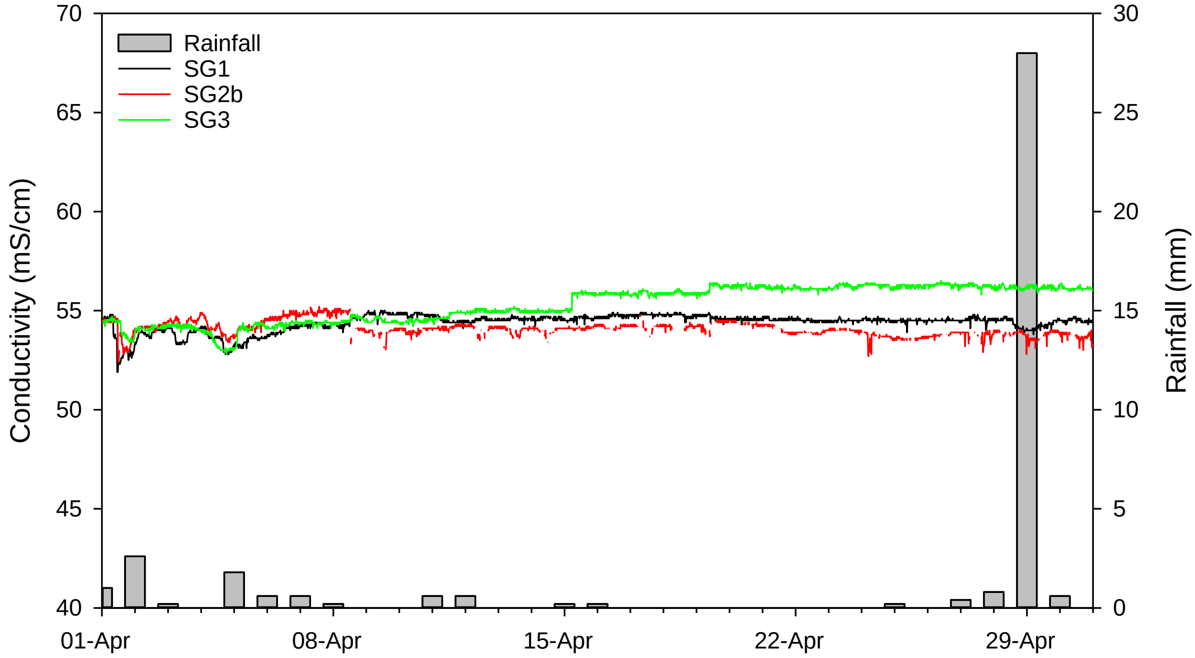




**Figure 19** Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during April 2019.

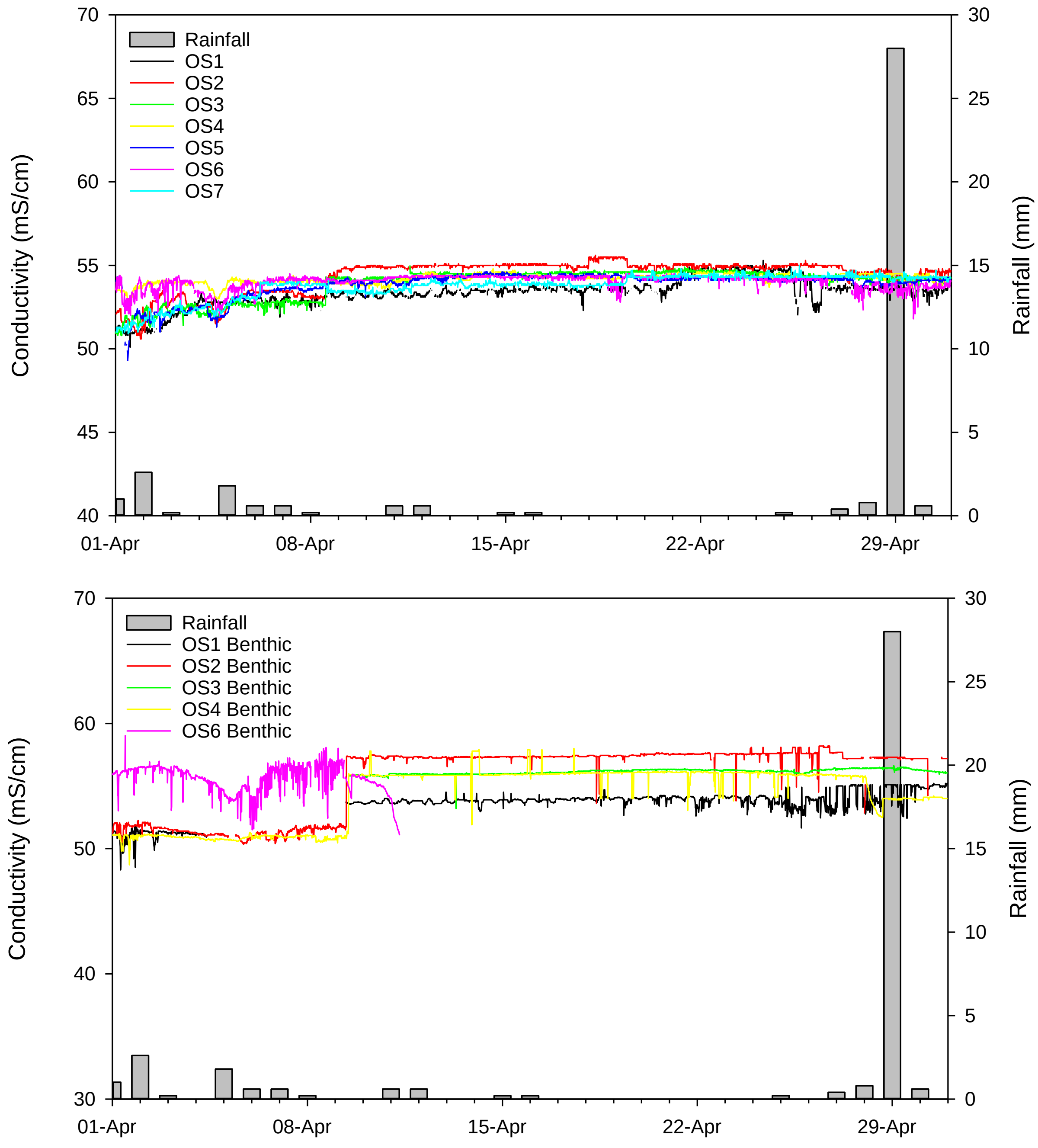



**Figure 20** Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during April 2019.

### 3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in April ranged from 91 to 99% saturation, slightly lower overall than the March values (95 to 104% saturation). The decreased water temperatures during April, in conjunction with the decreased solar radiation, is likely to have resulted in reduced photosynthesis and thus lower oxygen production. As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings ranging from 88 to 93% saturation (Table 12), due to reduced photosynthesis occurring at depth.

Large diurnal fluctuations in DO were recorded at all sites except the spoil ground during early April, most likely due to continuing impacts from late March conditions. DO fluctuations were also recorded on 30 April, one day after the high rainfall and winds. Early May data is likely to show the full extent of the rainfall and wind event on DO.

In contrast with the other sites, the spoil ground sites exhibited peaks in DO around the 5 and 25 April, which did not appear to coincide with any specific metocean condition.  No declines in dissolved oxygen were observed at these sites during both the early and late April events.

**Table 12** Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during April 2019.
*Values are means ± se (n = 2722 to 2879).*

| Site | Dissolved oxygen (% saturation) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 95 ± 0 | – |
| UH2 | 94 ± 0 | – |
| CH1 | 96 ± 0 | – |
| CH2 | 94 ± 0 | – |
| SG1 | 99 ± 0 | – |
| SG2 | 97 ± 0 | – |
| SG3 | 99 ± 0 | – |
| OS1 | 94 ± 0 | 93 ± 0 |
| OS2 | 91 ± 0 | 90 ± 0 |
| OS3 | 91 ± 0 | 91 ± 0 |
| OS4 | 94 ± 0 | 91 ± 0 |
| OS5 | 93 ± 0 | – |
| OS6 | 95 ± 0 | 88 ± 0 |
| OS7 | 95 ± 0 | – |

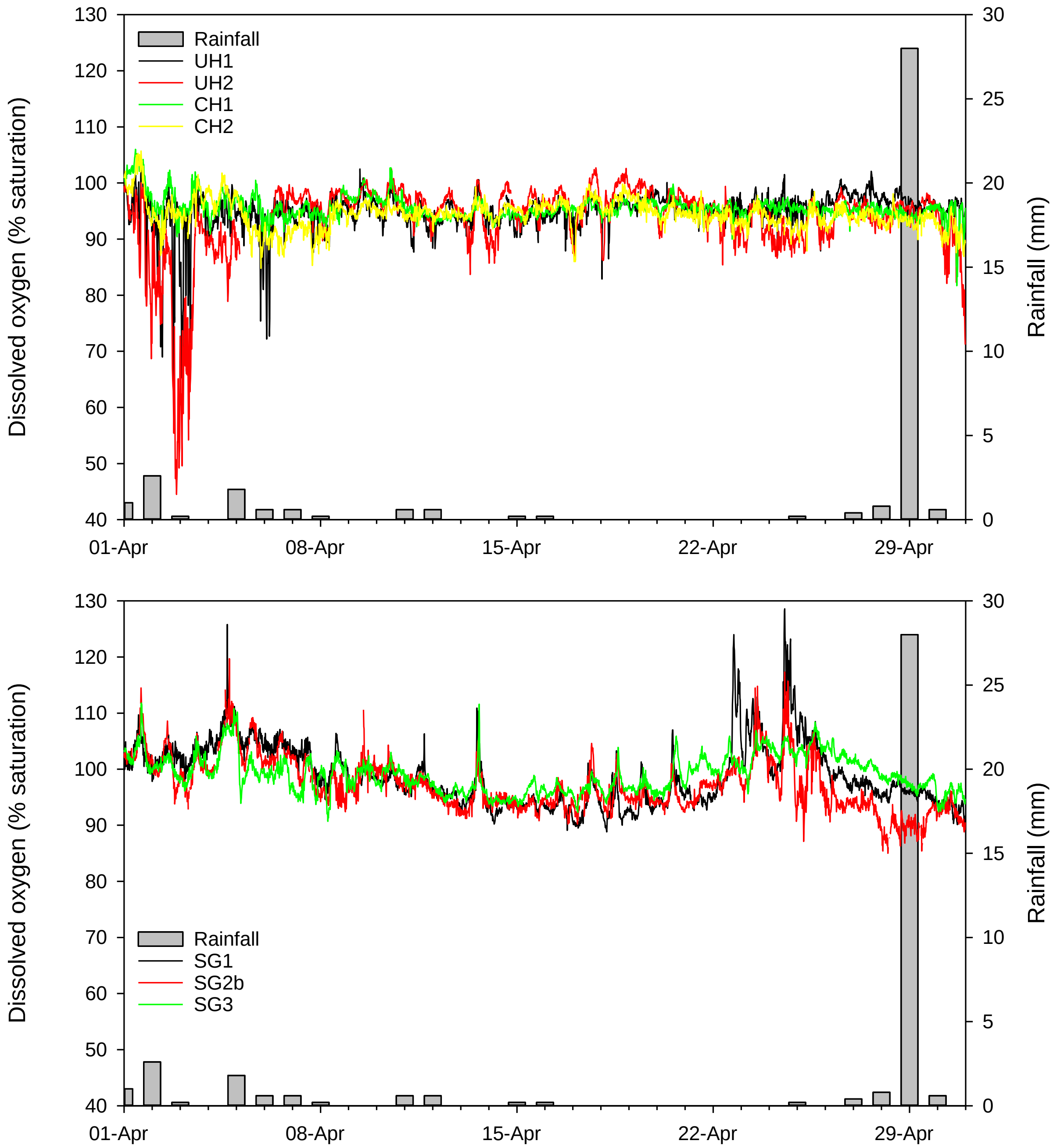



**Figure 21** Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during April 2019.

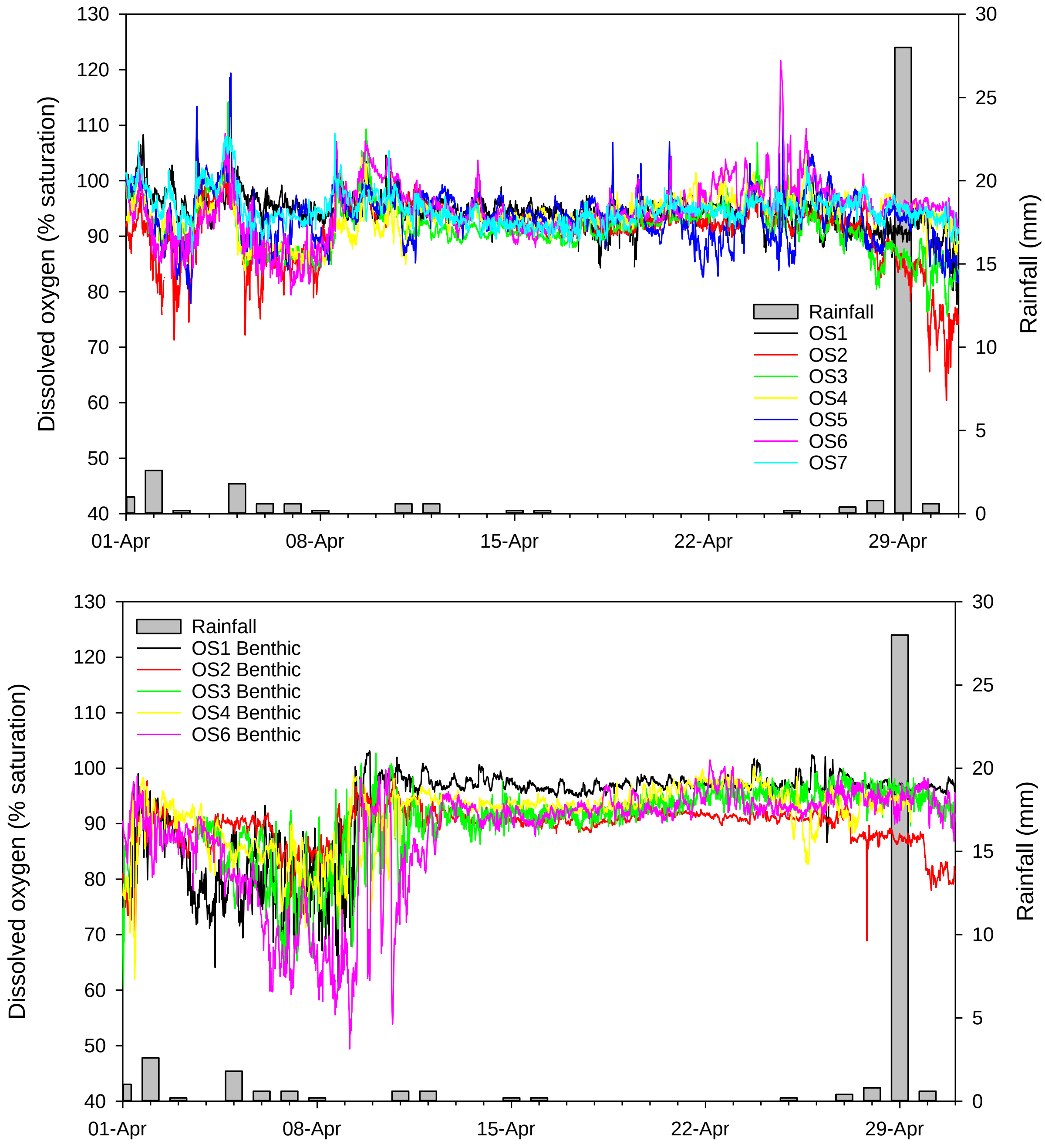



**Figure 22** Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during April 2019.

## 3.3 Physicochemistry Depth Profiling & TSS

Vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling on 11 April 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 21 to 23.

The relatively shallow sites of the upper and central harbour once again displayed well mixed conditions with a slight variability recorded in several parameters through the water column at UH2 (Figure 21). Similar to the continuous loggers, the uppermost harbour site UH3, displayed the lowest temperature and conductivity readings within the harbour. Several sites once again exhibited slightly increased turbidity at the seabed, which would typically be observed due to shear forces (friction between the overlying moving water and the stationary seabed) providing energy for sediment resuspension.

Within the nearshore region, physicochemical data collected also indicate the persistence of strong vertical mixing within the water column, however slightly warmer temperatures were recorded near the benthos at OS1 and OS7. These increases in temperature were counteracted by similar increases in conductivity with depth that would have maintained a vertically stable water column at these harbour mouth locations. The pH profiles displayed some variability within the surface 50 cm and remained relatively stable throughout deeper depths until further slight variations were observed near the benthos as turbidity increased (Figure 22).

Within the offshore region of the spoil ground, OS5 and OS6, the water column was once again recorded to be well mixed, with notably higher conductivity values in the surface waters at SG2 and SG3 (Figure 23). Conductivity at the remaining sites (OS5, OS6 and SG1) increased with depth to values similar to those observed at SG2 and SG3, indicating that this spatial variability was restricted to the surface water. Interestingly, sites SG1 and OS6 displayed similarly lower pH and DO conditions through the water column than those observed at SG2, SG3 and OS6 (Figure 23). This may be a reflection of either locally reduced rates of *in situ* photosynthesis or increased rates of *in situ* respiration at SG1 and OS6.

The shallowest euphotic depths that ranged from 2.7 m and 5.3 m were calculated for upper and central harbour monitoring sites (Table 14), which reflect the typically higher levels of turbidity experienced (Figure 22). The deepest euphotic depth was calculated to be 15.2 m at SG3 (Table 15) where turbidity in the surface and mid-column was low. No exceedances of WQG were recorded for the sub-surface during the April vertical profiling.

**Table 13** Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the April 2019 sampling event.
*Values are means ± se (n = 6 for sub-surface, n = 20 to 35 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

| Site | Sample date/time | Depth | Temperature (ºC) | pH | Conductivity (mS/cm) | Dissolved oxygen (% saturation) | Turbidity (NTU) | TSS (mg/L) | $K_d$ | Euphotic Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| UH1 | 11/04/2019 11:50 | Sub-surface | 14.8 ± 0.0 | 8.2 ± 0.0 | 53.7 ± 0.0 | 98 ± 0 | 5.4 ± 0.1 | 12 | 0.9 ± 0.0 | 5.1 |
| | | Whole column | 14.8 ± 0.0 | 8.2 ± 0.0 | 53.7 ± 0.0 | 98 ± 0 | 5.7 ± 0.1 | – | | |
| UH2 | 11/04/2019 12:19 | Sub-surface | 15.0 ± 0.0 | 8.2 ± 0.0 | 53.7 ± 0.0 | 100 ± 0 | 5.2 ± 0.0 | 9 | 1.0 ± 0.0 | 4.8 |
| | | Whole column | 15.0 ± 0.0 | 8.2 ± 0.0 | 53.7 ± 0.0 | 98 ± 0 | 6.2 ± 0.2 | – | | |
| UH3 | 11/04/2019 12:04 | Sub-surface | 14.7 ± 0.0 | 8.2 ± 0.0 | 53.4 ± 0.0 | 98 ± 0 | 7.4 ± 0.3 | 14 | 1.2 ± 0.0 | 3.8 |
| | | Whole column | 14.7 ± 0.0 | 8.2 ± 0.0 | 53.4 ± 0.0 | 98 ± 0 | 7.8 ± 0.2 | – | | |
| CH1 | 11/04/2019 13:11 | Sub-surface | 15.0 ± 0.0 | 8.2 ± 0.0 | 53.9 ± 0.0 | 96 ± 0 | 11 ± 0.5 | 14 | 1.7 ± 0.1 | 2.7 |
| | | Whole column | 15.0 ± 0.0 | 8.2 ± 0.0 | 53.9 ± 0.0 | 96 ± 0 | 13 ± 1 | – | | |
| CH2 | 11/04/2019 12:44 | Sub-surface | 15.2 ± 0.0 | 8.2 ± 0.0 | 54.1 ± 0.0 | 98 ± 0 | 5.8 ± 0.2 | 8 | 0.9 ± 0.1 | 5.3 |
| | | Whole column | 15.2 ± 0.0 | 8.2 ± 0.0 | 54.2 ± 0.0 | 98 ± 0 | 8.8 ± 1.3 | – | | |
| **WQG** | | | – | **7.0 – 8.5** | – | **80-110** | **10** | – | – | – |

**Table 14** Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the April 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 32 to 40 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

| Site | Sample date/time | Depth | Temperature (ºC) | pH | Conductivity (mS/cm) | Dissolved oxygen (% saturation) | Turbidity (NTU) | TSS (mg/L) | $K_d$ | Euphotic Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| OS1 | 11/04/2019 13:27 | Sub-surface | 15.1 ± 0.0 | 8.2 ± 0.0 | 54.0 ± 0.0 | 99 ± 0 | 5.9 ± 0.5 | 6 | 0.9 ± 0.0 | 5.0 |
| | | Mid | 15.1 ± 0.0 | 8.2 ± 0.0 | 54.0 ± 0.0 | 98 ± 0 | 6.2 ± 0.3 | 13 | | |
| | | Benthos | 15.2 ± 0.0 | 8.2 ± 0.0 | 54.3 ± 0.1 | 98 ± 0 | 11 ± 1 | 37 | | |
| | | Whole column | 15.1 ± 0.0 | 8.2 ± 0.0 | 54.1 ± 0.0 | 98 ± 0 | 7.2 ± 0.5 | – | | |
| OS2 | 11/04/2019 17:18 | Sub-surface | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.4 ± 0.0 | 102 ± 0 | 2.4 ± 0.1 | 4 | 0.6 ± 0.0 | 7.3 |
| | | Mid | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 100 ± 0 | 4.5 ± 0.2 | 10 | | |
| | | Benthos | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 100 ± 0 | 6.2 ± 0.8 | 10 | | |
| | | Whole column | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 101 ± 0 | 3.9 ± 0.3 | – | | |
| OS3 | 11/04/2019 16:35 | Sub-surface | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 98 ± 0 | 5.1 ± 0.1 | 8 | 0.7 ± 0.0 | 6.2 |
| | | Mid | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 97 ± 0 | 5.6 ± 0.1 | 13 | | |
| | | Benthos | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 96 ± 0 | 15 ± 4 | 43 | | |
| | | Whole column | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 97 ± 0 | 7.0 ± 0.8 | – | | |
| OS4 | 11/04/2019 16:02 | Sub-surface | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 97 ± 0 | 5.6 ± 0.1 | 8 | 0.7 ± 0.1 | 6.4 |
| | | Mid | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 97 ± 0 | 4.4 ± 0.1 | 8 | | |
| | | Benthos | 15.3 ± 0.0 | 8.2 ± 0.0 | 54.7 ± 0.0 | 95 ± 0 | 28 ± 8 | 29 | | |
| | | Whole column | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 97 ± 0 | 9.3 ± 1.7 | - | | |
| OS7 | 11/04/2019 17:38 | Sub-surface | 15.2 ± 0.0 | 8.3 ± 0.0 | 54.3 ± 0.0 | 101 ± 0 | 4.8 ± 0.3 | 7 | 0.8 ± 0.0 | 5.7 |
| | | Mid | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.4 ± 0.0 | 100 ± 0 | 6.0 ± 0.5 | 10 | | |
| | | Benthos | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 98 ± 0 | 24 ± 4 | 34 | | |
| | | Whole column | 15.2 ± 0.0 | 8.3 ± 0.0 | 54.4 ± 0.0 | 100 ± 0 | 9.6 ± 1.5 | – | | |
| **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 April 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 38 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 | 11/04/2019 13:57 | Sub-surface | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.3 ± 0.0 | 103 ± 0 | 3.2 ± 0.3 | 7 | 0.5 ± 0.1 | 8.6 |
| | | Mid | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.4 ± 0.0 | 102 ± 0 | 3.1 ± 0.2 | 4 | | |
| | | Benthos | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 100 ± 0 | 12 ± 6 | 4 | | |
| | | Whole column | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.4 ± 0.0 | 102 ± 0 | 4.5 ± 1 | – | | |
| OS6 | 11/04/2019 16:58 | Sub-surface | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 101 ± 0 | 3.4 ± 0.0 | 7 | 0.7 ± 0.0 | 7.1 |
| | | Mid | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.5 ± 0.0 | 99 ± 0 | 3.7 ± 0.1 | 5 | | |
| | | Benthos | 15.4 ± 0.0 | 8.2 ± 0.0 | 54.6 ± 0.0 | 96 ± 0 | 4.7 ± 0.2 | 9 | | |
| | | Whole column | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 99 ± 0 | 3.7 ± 0.1 | – | | |
| SG1 | 11/04/2019 14:22 | Sub-surface | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.5 ± 0.0 | 103 ± 0 | 2.0 ± 0.0 | 4 | 0.5 ± 0.0 | 9.5 |
| | | Mid | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 98 ± 0 | 2.2 ± 0.1 | 8 | | |
| | | Benthos | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.7 ± 0.0 | 97 ± 0 | 15 ± 2 | 32 | | |
| | | Whole column | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 99 ± 0 | 4.5 ± 0.7 | – | | |
| SG2b | 11/04/2019 14:51 | Sub-surface | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 102 ± 0 | 1.4 ± 0.0 | 4 | 0.3 ± 0.0 | 14.6 |
| | | Mid | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 101 ± 0 | 1.1 ± 0.0 | 6 | | |
| | | Benthos | 15.3 ± 0.0 | 8.3 ± 0.0 | 54.7 ± 0.0 | 96 ± 1 | 7.7 ± 1.9 | 9 | | |
| | | Whole column | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 101 ± 0 | 2.2 ± 0.4 | – | | |
| SG3 | 11/04/2019 15:21 | Sub-surface | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.6 ± 0.0 | 102 ± 0 | 1.3 ± 0.0 | <3 | 0.3 ± 0.0 | 15.2 |
| | | Mid | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.7 ± 0.0 | 102 ± 0 | 1.1 ± 0.0 | 4 | | |
| | | Benthos | 15.3 ± 0.0 | 8.2 ± 0.0 | 54.7 ± 0.0 | 90 ± 0 | 9.1 ± 0.6 | 7 | | |
| | | Whole column | 15.4 ± 0.0 | 8.3 ± 0.0 | 54.7 ± 0.0 | 100 ± 1 | 2.5 ± 0.4 | – | | |
| **WQG** | | | **–** | **7.0 – 8.5** | **–** | **80-110** | **10** | **–** | **–** | |

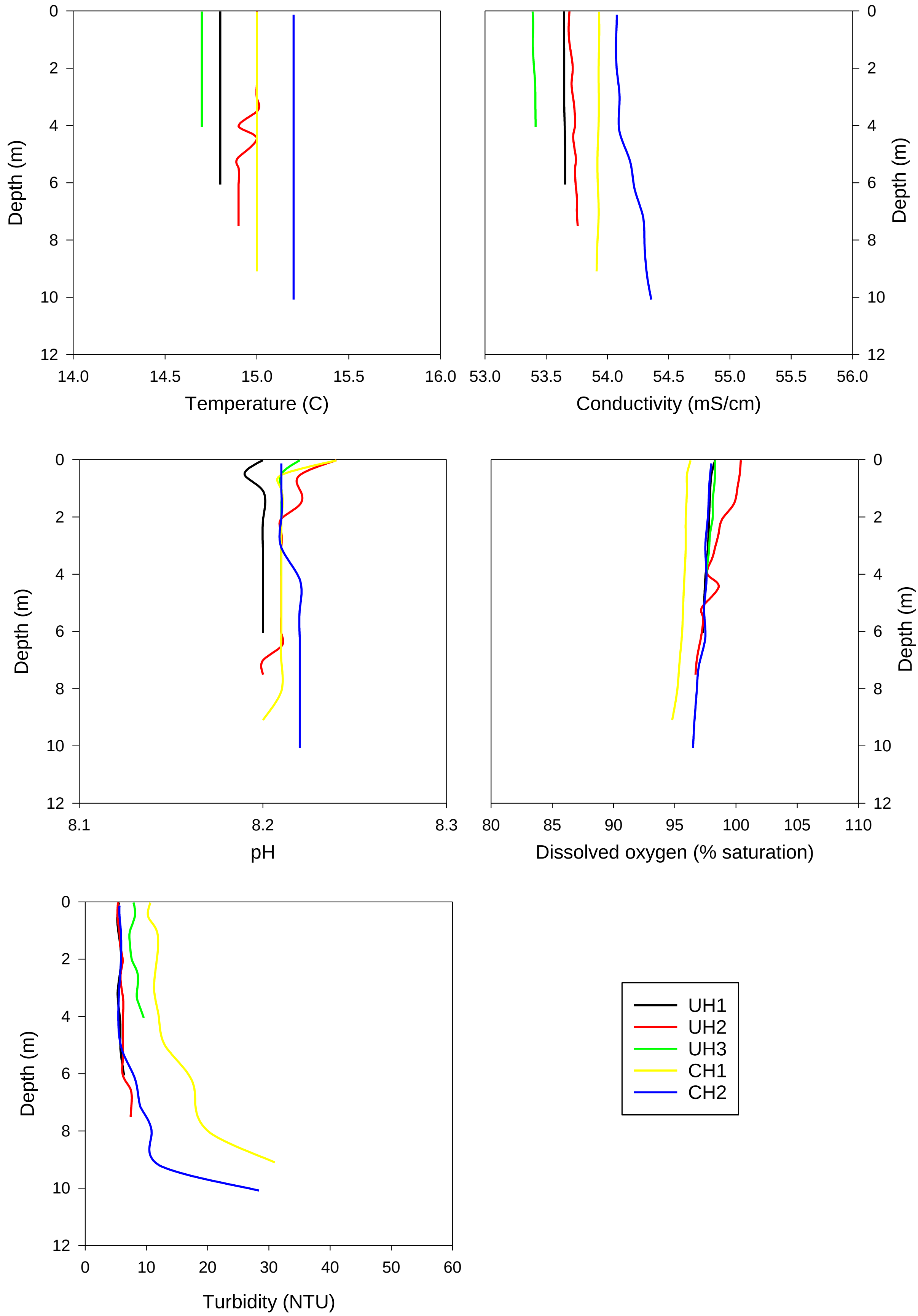



**Figure 23** Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 11 April 2019.

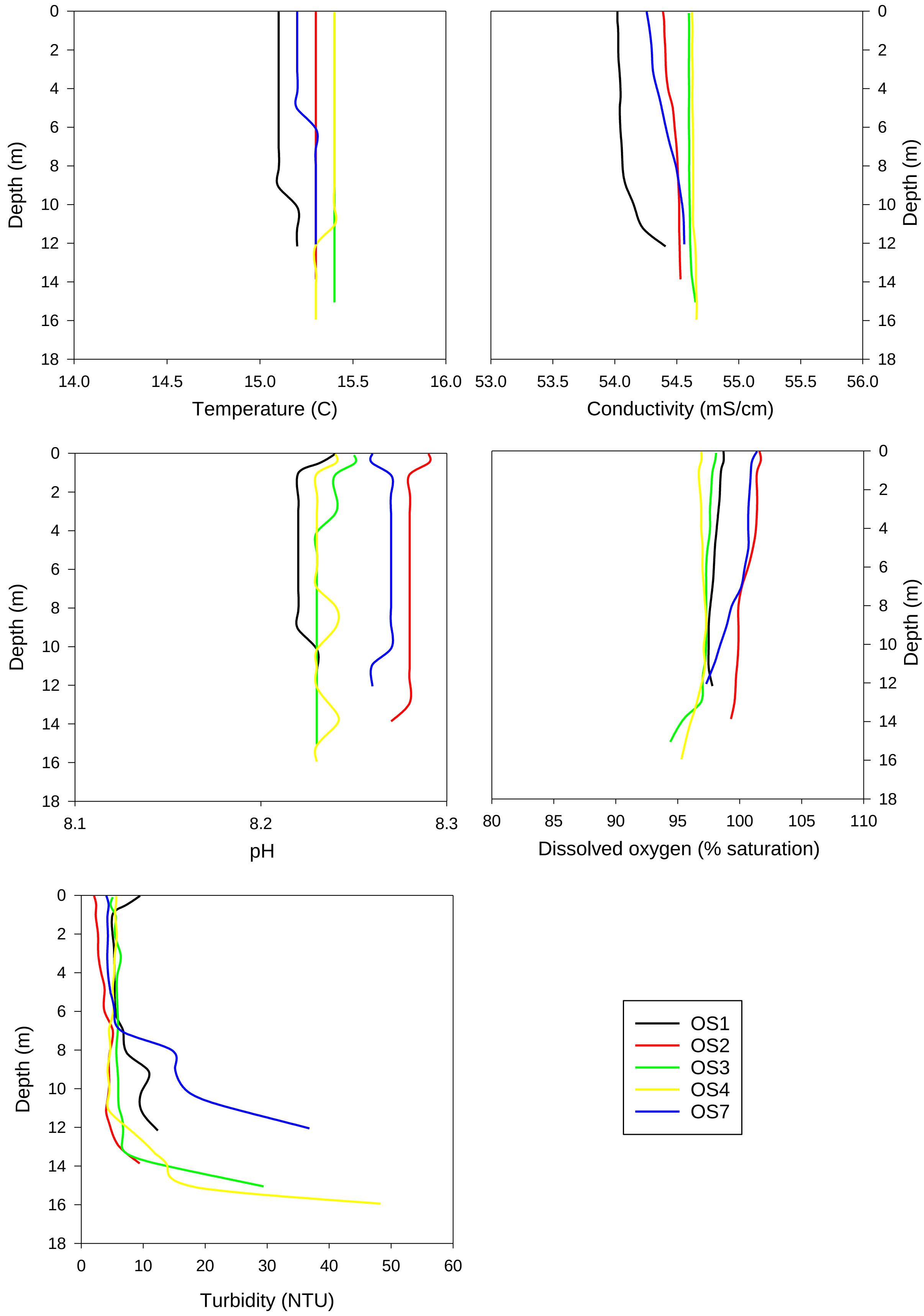



**Figure 24** Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 11 April 2019.

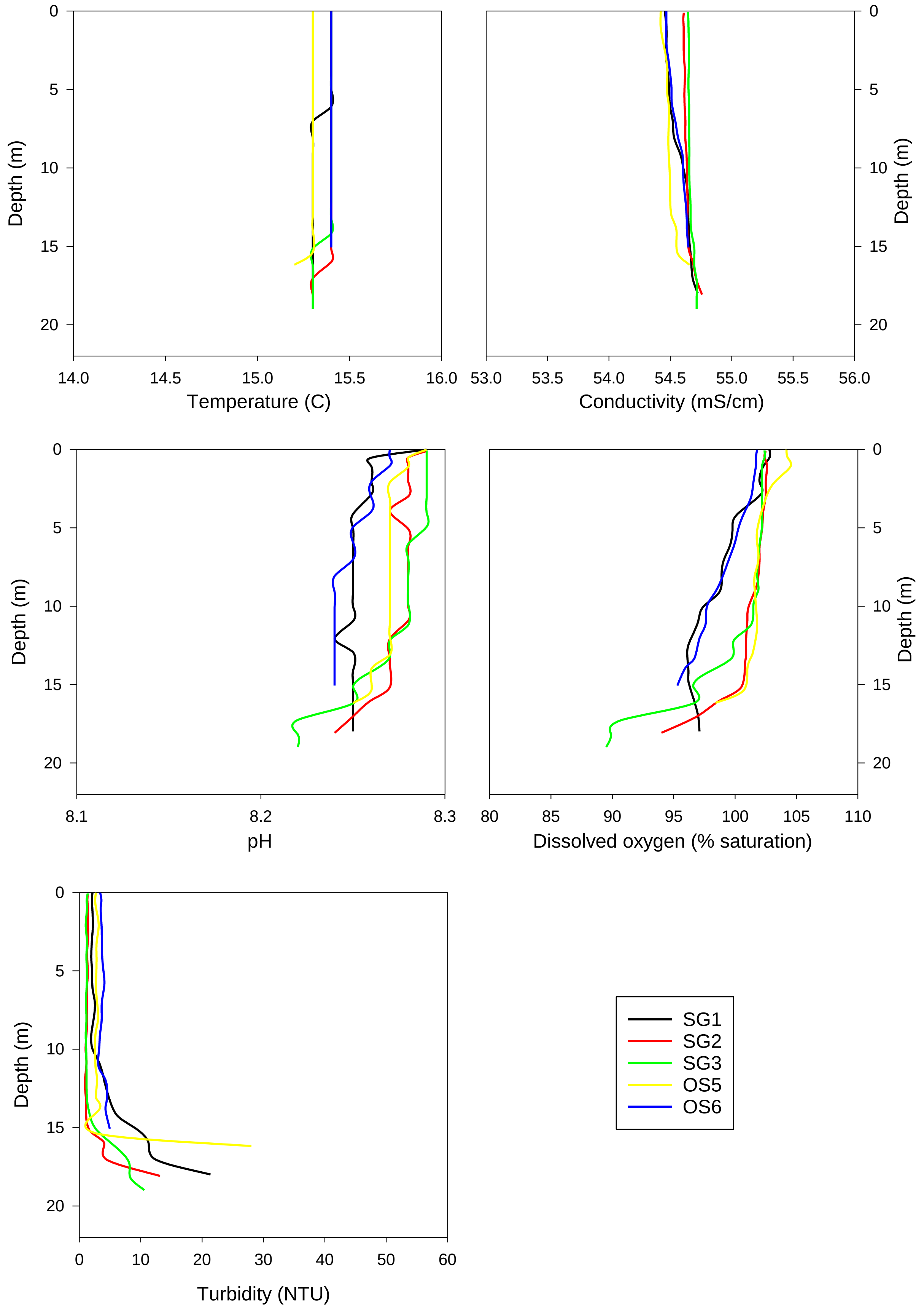



**Figure 25** Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 11 April 2019.

## 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 26. Data from the logger exchange date (10 April) were removed from the analyses.

**Table 16** Total Daily PAR (TDP) statistics during April 2019.
*Values are means ± se (n = 29 to 30). Note data from the BPAR exchange day on 10 April 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 | - | 17,460 ± 1,145 | 18550 | 4,900 – 28,300 |
| OS2 | 17 | 0.8 ± 0.3 | <0.01 | <0.01 – 5.5 |
| OS3 | 14 | 0.4 ± 0.2 | <0.01 | <0.01 – 6.1 |

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 4,900 to 28,300 $mmol/m^2/day$ (Table 16). This range was considerably lower than that observed during March (13,200 to 53,800 $mmol/m^2/day$). This decline in available light is apparent within the monthly mean TDP of only 17,460 $mmol/m^2/day$ (Table 16) c.f. 26,603 $mmol/m^2/day$ recorded during March.

Despite the slightly higher TDP during the first half of April, BPAR at both OS2 and OS3 peaked around the 22 April, when turbidity was lower at both sites (Figure 26). At OS2 maximum BPAR intensity was recorded as 5.5 $mmol/m^2/day$, while maximum BPAR at OS3 was slightly higher at 6.1 $mmol/m^2/day$.

## 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).

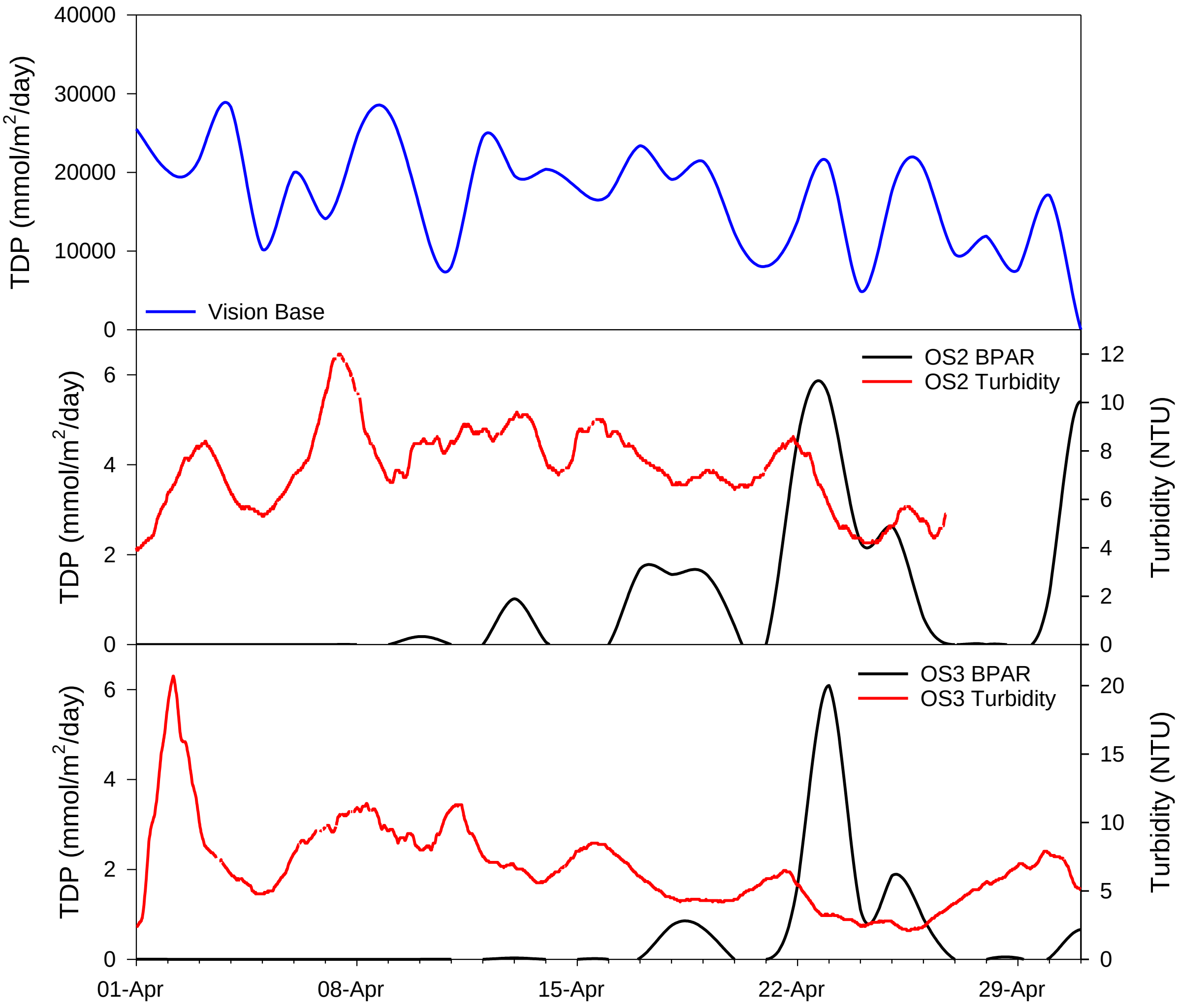



**Figure 26** Total daily BPAR at OS2 and OS3 during April 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
*Note data from the BPAR exchange day on 10 April were not utilized in plots or statistics.*

Changes in energy from wind waves, currents and/or tidally induced flows can result in variations in sedimentation patterns, ranging from deposition of sediments originating from another location, resuspension of sediments with no net change in the seabed or the resuspension of sediments and transportation to another location. Altimeters provide two forms of information to help identify these processes:

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

Bed level at the offshore site OS2 displayed an initial rapid decline, with approximately 30 mm of sediment removed from the sea bed from 1 to 2 April 2019. This erosion was likely a result of elevated wind speeds, with surface turbidity increasing as a response to sea bed sediment resuspension (Figure 27). Following this erosion, the altimeters deployed at OS2 indicate a slow and variable recovery towards the end of the month, resulting in a net bed level change of only +4 mm over the course of April (Table 17). It should, however, be noted that the return signals from the altimeters were weak from approximately 13 April to the end of the month, therefore these trends should be interpreted with caution.

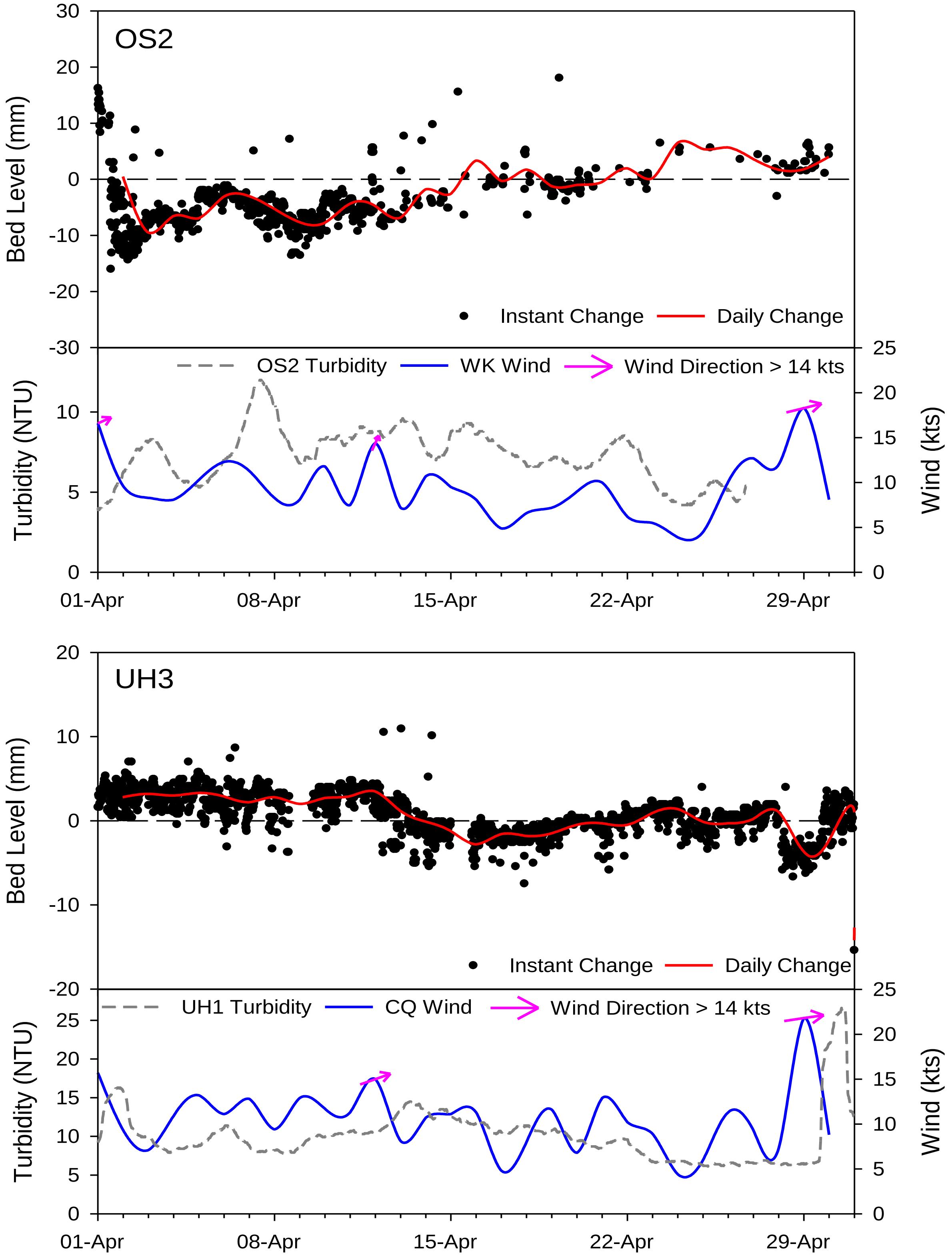



**Figure 27** Mean instantaneous and daily averaged bed level change at OS2 and UH3 during April 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction.
*Note: Arrows indicate the direction of travel for winds greater than 14 knots.*

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 27). Contrasting the sediment dynamics recorded at OS2, daily averaged bed level remained stable through to 11 April, with 6 mm of sediment eroded from 11 to 15 April. This erosion did not correlate with any apparent trends in inshore wind speeds, with the system displaying a period of recovery deposition to 27 April. Elevated inshore wind speeds reaching 21.8 knots on 29 April resulting in a period of rapid sediment erosion, with an equally rapid recovery at the end of the month as surface turbidity at UH1 increased (Figure 27). These variations over April resulted in a net bed level change of only 1 mm (Table 17).

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

| Site | April 2019 Net bed level change (mm) |
|---|---|
| OS2 | +4 |
| UH3 | +1 |

## 3.6 Water Samples

Discrete water sampling was conducted on 11 April 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 April 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 28). However, dissolved reactive phosphorous was elevated across the monitoring network, with concentrations ranging from 6.8 to 15 µg/L at SG3 and UH1 respectively; notably above the designated 5 µg/L WQG.

Both total nitrogen and total kjeldahl nitrogen were < LOR at all sites, except for site CH2, where concentrations of total nitrogen (400 µg/L) exceeded the WQG of 300 µg/L. Total ammonia concentrations were elevated compared to March 2019, with exceedances of the 15 µg/L WQG recorded at all sites except the offshore sites OS5, SG2 and SG3. Concentrations of nitrogen oxides were also elevated compared to the previous month, however, only sites UH1 and CH1 (those on the northern edge of the inner harbour) displayed concentrations above the 15 µg/L WQG. This may be a result of bacterial degradation of organic material such as phytoplankton releasing nitrogenous products. As typically expected, nitrogen oxide concentrations were lower further offshore at the spoil ground monitoring sites (Figure 28).

Concentrations of chlorophyll a, an indicator of phytoplankton biomass, ranged from 1.4 to 5.2 µg/L, with sites UH2, OS7 and SG1 displaying exceedances of the 4 µg/L WQG (Table 18).

**Table 18** Concentrations of nutrients and chlorophyll *a* at monitoring sites during April 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 | 26 | 15 | <300 | <200 | 34 | 17 | 3.2 |
| UH2 | 26 | 13 | <300 | <200 | 21 | 10 | 4.3 |
| UH3 | 27 | 14 | <300 | <200 | 26 | 11 | 2.5 |
| CH1 | 24 | 15 | <300 | <200 | 32 | 19 | 2.2 |
| CH2 | 23 | 13 | 400 | 300 | 23 | 11 | 2.0 |
| OS1 | 18 | 13. | <300 | <200 | 27 | 15 | 1.6 |
| OS2 | 18 | 9.9 | <300 | <200 | 20 | 2.8 | 3.1 |
| OS3 | 20 | 12 | <300 | <200 | 24 | 12 | 1.4 |
| OS4 | 19 | 13 | <300 | <200 | 24 | 15 | 1.7 |
| OS5 | 15 | 8.7 | <300 | <200 | 15 | 9.1 | 2.3 |
| OS6 | 20 | 11 | <300 | <200 | 20 | 5.9 | 3.9 |
| OS7 | 17 | 11 | <300 | <200 | 23 | 8.3 | 5.2 |
| SG1 | 16 | 9.4 | <300 | <200 | 16 | 4.2 | 4.3 |
| SG2 | 16 | 7.9 | <300 | <200 | 13 | 4.1 | 1.5 |
| SG3 | 17 | 6.8 | <300 | <200 | 15 | 2.0 | 1.5 |
| **WQG** | **30** | **5** | **300** | **-** | **15** | **15** | **4** |

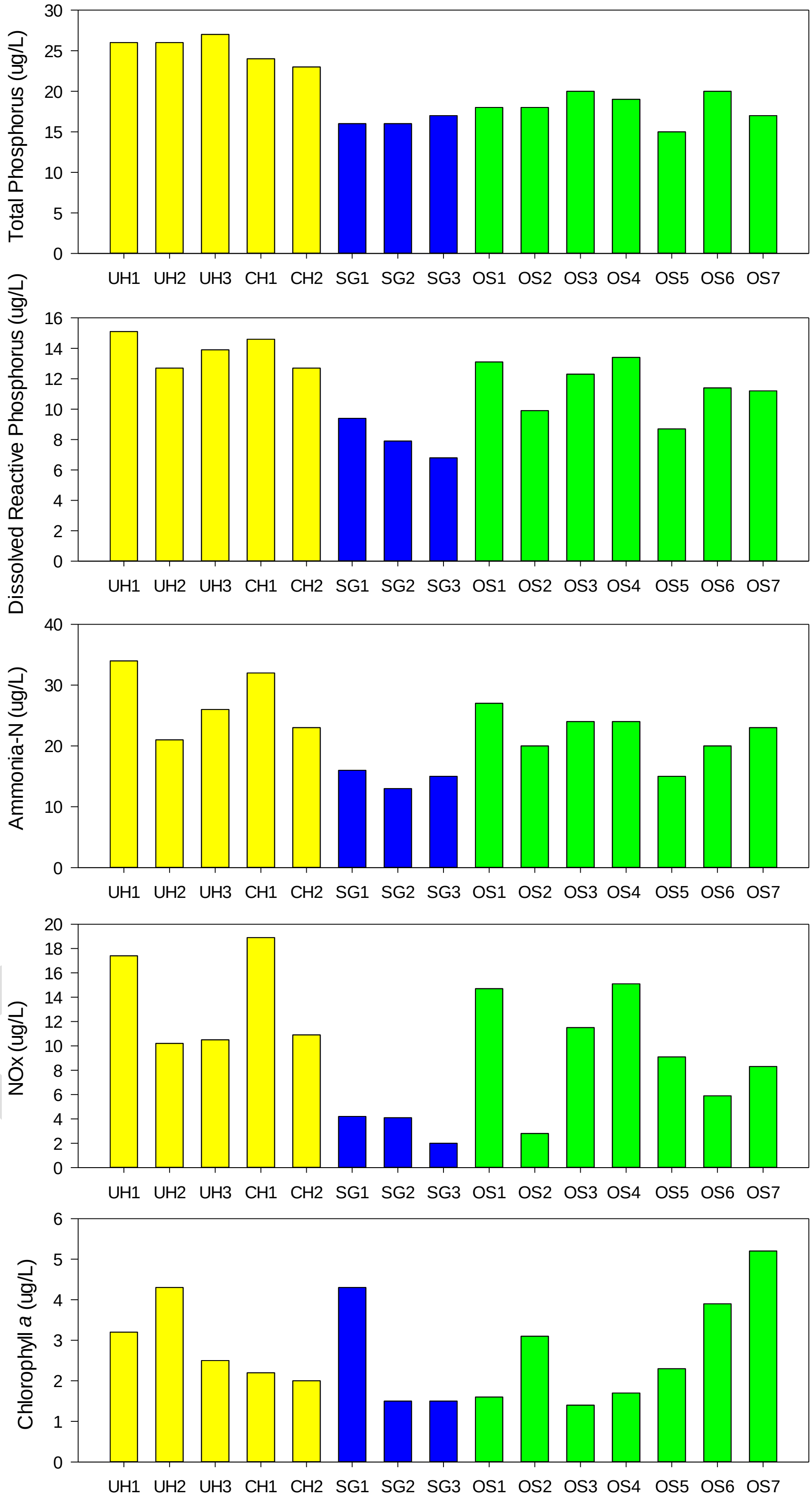



**Figure 28** Nutrient and chlorophyll *a* concentrations at monitoring sites during April 2019.
*Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were < LOR.*

### 3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (LOR) at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), cobalt (<0.6 µg/L), copper (<1 µg/L), lead (<1 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L) and tin (<5 µg/L). Contrasting previous months, concentrations of total mercury exceeded the LOR of 0.08 µg/L at UH3 where concentrations were reported at 0.12 µg/L. Dissolved mercury concentrations, for which WQG are derived, remained below LOR at all monitoring locations (Tables 19 to 21). In a similar manner to mercury, concentrations of zinc have been commonly reported as below LOR, however total zinc at SG1 was reported at 10 µg/L (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 ranged from below LOR (12 µg/L) to 17 µg/L, with the highest concentrations reported in the upper harbour (Tables 19 to 21, Figure 29). No further exceedances were reported during the April 2019 water quality sampling campaign (Tables 19 to 21).

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. The greatest concentrations of total iron were recorded in the central harbour at CH1 and declined with increasing distance offshore with the lowest concentrations at the spoil ground site SG3 (Figure 29). This spatial pattern in total iron displayed a high similarity to those of total aluminum. Dissolved iron concentrations were once again low (≤7 µg/L) indicating that iron was predominantly present in the particulate phase, and thus not readily available for biological uptake (Tables 19 to 21).

Dissolved manganese concentrations were below LOR (<1 µg/L) at OS3, OS4, OS5 and the spoil ground monitoring sites (Tables 19 to 21) during April, with higher concentrations reported for the total components. As commonly observed with the metals analyses, the highest concentrations of total and dissolved manganese were once again observed within the upper and central harbour (Figure 29).

Consistent with previous monitoring reports, molybdenum concentrations during April displayed little spatial variation across the inshore and offshore monitoring network (Figure 30). Given the similarity between the dissolved and total metal concentrations, the majority of the molybdenum present appeared to be in the dissolved phase (Tables 19 to 21 and Figure 30) and thus readily dispersed across the region. Concentrations of total and dissolved vanadium displayed a similar pattern to that of molybdenum, with a large proportion of vanadium also present in the dissolved phase (Figure 30).

It should be noted that total chromium, total zinc and nitrogen oxides were detected in the field blank at concentrations slightly above the laboratory LOR, with blank results for these analytes remaining below LOR (Table 25).

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

| Metal (µg/L) | | Sites | | | | | WQG |
|---|---|---|---|---|---|---|---|
| | | UH1 | UH2 | UH3 | CH1 | CH2 | |
| Aluminium | Dissolved | <12 | 17 | 14 | 15 | <12 | 24 |
| | Total | 154 | 194 | 260 | 430 | 220 | |
| 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 | 1.5 | 1.8 | 3.0 | 3.2 | 1.5 | Cr(III) 27.4<br>Cr(VI) 4.4 |
| | Total | 2.5 | 3.9 | 3.2 | 3.8 | 2.8 | |
| Cobalt | Dissolved | <0.6 | <0.6 | <0.6 | <0.6 | <0.6 | 1.0 |
| | Total | <0.63 | <0.63 | <0.63 | <0.63 | <0.63 | |
| Copper | Dissolved | <1 | <1 | <1 | <1 | <1 | 1.3 |
| | Total | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | |
| Iron | Dissolved | 6.0 | <4 | <4 | <4 | <4 | - |
| | Total | 260 | 280 | 360 | 640 | 320 | |
| Lead | Dissolved | <1 | <1 | <1 | <1 | <1 | 4.4 |
| | Total | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | |
| Manganese | Dissolved | 2.6 | 1.9 | 3.4 | 1.5 | 1.1 | - |
| | Total | 9.0 | 8.3 | 12 | 14 | 7.1 | |
| Mercury | Dissolved | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | 0.4 |
| | Total | <0.08 | <0.08 | 0.12 | <0.08 | <0.08 | |
| Molybdenum | Dissolved | 11 | 11 | 10 | 11 | 11 | - |
| | Total | 11 | 11 | 11 | 11 | 10 | |
| Nickel | Dissolved | <7 | <7 | <7 | <7 | <7 | 70 |
| | Total | <7 | <7 | <7 | <7 | <7 | |
| Selenium | Dissolved | <4 | <4 | <4 | <4 | <4 | - |
| | Total | <4.2 | <4.2 | <4.2 | <4.2 | <4.2 | |
| Silver | Dissolved | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | 1.4 |
| | Total | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | |
| Tin | Dissolved | <5 | <5 | <5 | <5 | <5 | - |
| | Total | <5.3 | <5.3 | <5.3 | <5.3 | <5.3 | |
| Vanadium | Dissolved | 1.9 | 1.9 | 1.5 | 1.8 | 1.7 | 100 |
| | Total | 2.4 | 2.6 | 2.2 | 2.5 | 2.4 | |
| 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 April 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 | 13 | <12 | 24 |
| | Total | 123 | 79 | 240 | 210 | 84 | 115 | 147 | |
| 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 | 2.5 | 2.6 | <1 | 2.0 | 2.6 | <1 | 3.0 | Cr(III) 27.4<br>Cr(VI) 4.4 |
| | Total | 2.5 | 2.6 | 2.7 | 2.5 | 2.5 | 2.9 | 2.5 | |
| 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 | 7 | <4 | <4 | 6 | <4 | <4 | - |
| | Total | 176 | 120 | 300 | 300 | 124 | 159 | 187 | |
| Lead | Dissolved | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 4.4 |
| | Total | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | |
| Manganese | Dissolved | 1.6 | 1.5 | <1 | <1 | <1 | 1.1 | 1.1 | - |
| | Total | 5.4 | 3.5 | 6.5 | 6.3 | 3.1 | 4.1 | 5.3 | |
| 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 | 11 | - |
| | Total | 11 | 11 | 11 | 11 | 11 | 11 | 11 | |
| Nickel | Dissolved | <7 | <7 | <7 | <7 | <7 | <7 | <7 | 70 |
| | Total | <7 | <7 | <7 | <7 | <7 | <7 | <7 | |
| Selenium | Dissolved | <4 | <4 | <4 | <4 | <4 | <4 | <4 | - |
| | Total | <4.2 | <4.2 | <4.2 | <4.2 | <4.2 | <4.2 | <4.2 | |
| Silver | Dissolved | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | 1.4 |
| | Total | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | |
| Tin | Dissolved | <5 | <5 | <5 | <5 | <5 | <5 | <5 | - |
| | Total | <5.3 | <5.3 | <5.3 | <5.3 | <5.3 | <5.3 | <5.3 | |
| Vanadium | Dissolved | 2.1 | 2.0 | 1.8 | 1.8 | 2.3 | 1.9 | 1.9 | 100 |
| | Total | 2.4 | 2.3 | 2.8 | 2.8 | 2.9 | 2.1 | 2.5 | |
| 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 April 2019. *Values outside recommended WQG are highlighted in blue.*

| Metal (µg/L) | | SG1 | SG2b | SG3 | WQG |
|---|---|---|---|---|---|
| Aluminium | Dissolved | <12 | <12 | <12 | 24 |
| | Total | 61 | 50 | 38 | |
| 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 | 1.9 | 1.7 | 1.9 | Cr(III) 27.4 Cr(VI) 4.4 |
| | Total | 1.9 | 2.3 | 2.3 | |
| Cobalt | Dissolved | <0.6 | <0.6 | <0.6 | 1.0 |
| | Total | <0.63 | <0.63 | <0.63 | |
| Copper | Dissolved | <1 | <1 | <1 | 1.3 |
| | Total | <1.1 | <1.1 | <1.1 | |
| Iron | Dissolved | <4 | 6.0 | <4 | - |
| | Total | 89 | 66 | 44 | |
| Lead | Dissolved | <1 | <1 | <1 | 4.4 |
| | Total | <1.1 | <1.1 | <1.1 | |
| Manganese | Dissolved | <1 | <1 | <1 | - |
| | Total | 2.6 | 2.2 | 1.7 | |
| Mercury | Dissolved | <0.08 | <0.08 | <0.08 | 0.4 |
| | Total | <0.08 | <0.08 | <0.08 | |
| Molybdenum | Dissolved | 11 | 11 | 11 | - |
| | Total | 11 | 11 | 11 | |
| 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 | 1.9 | 1.8 | 1.7 | 100 |
| | Total | 2.0 | 2.3 | 1.9 | |
| Zinc | Dissolved | <4 | <4 | <4 | 15 |
| | Total | 10 | <4.2 | <4.2 | |

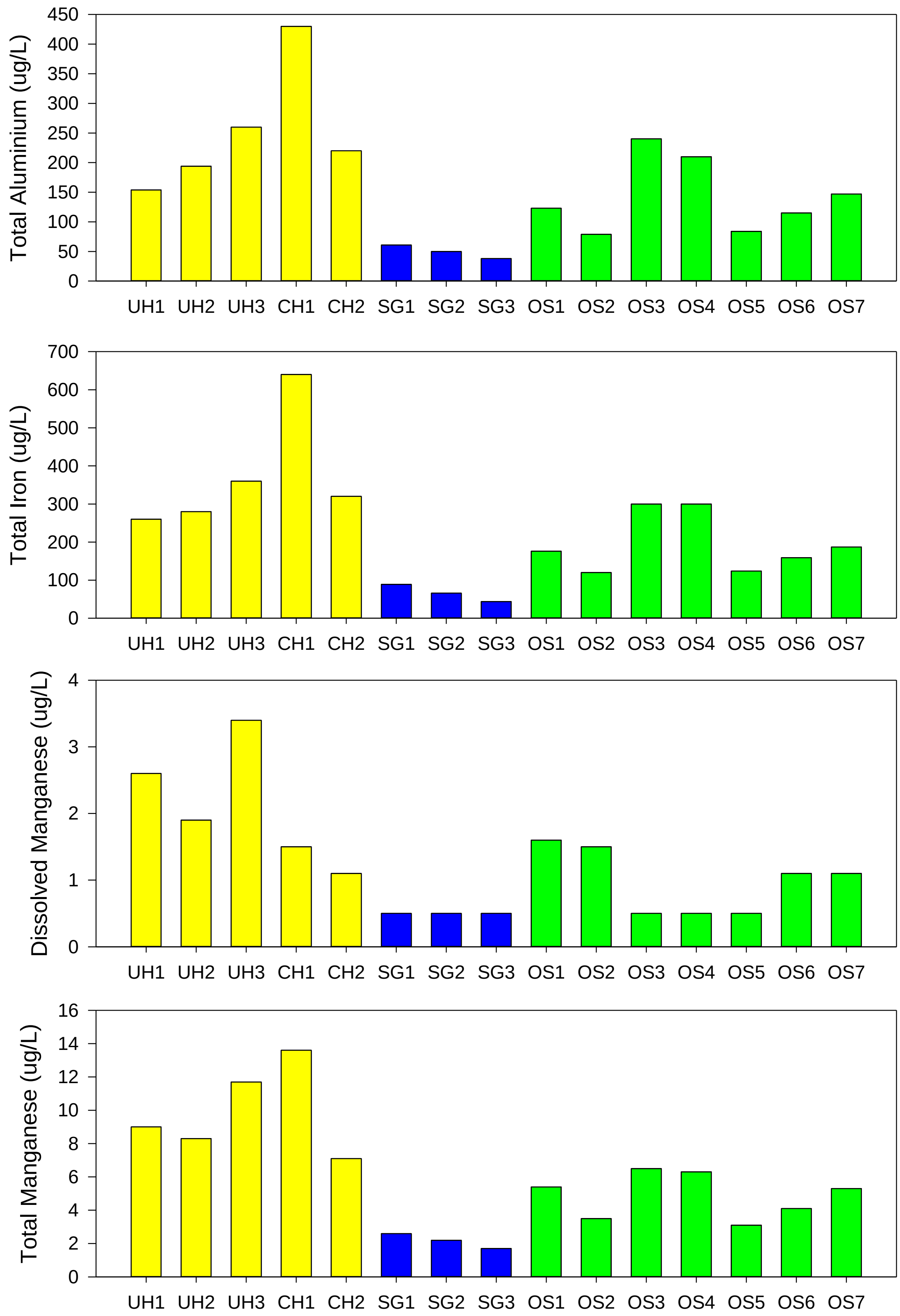



**Figure 29** Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during April 2019.
*Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.*

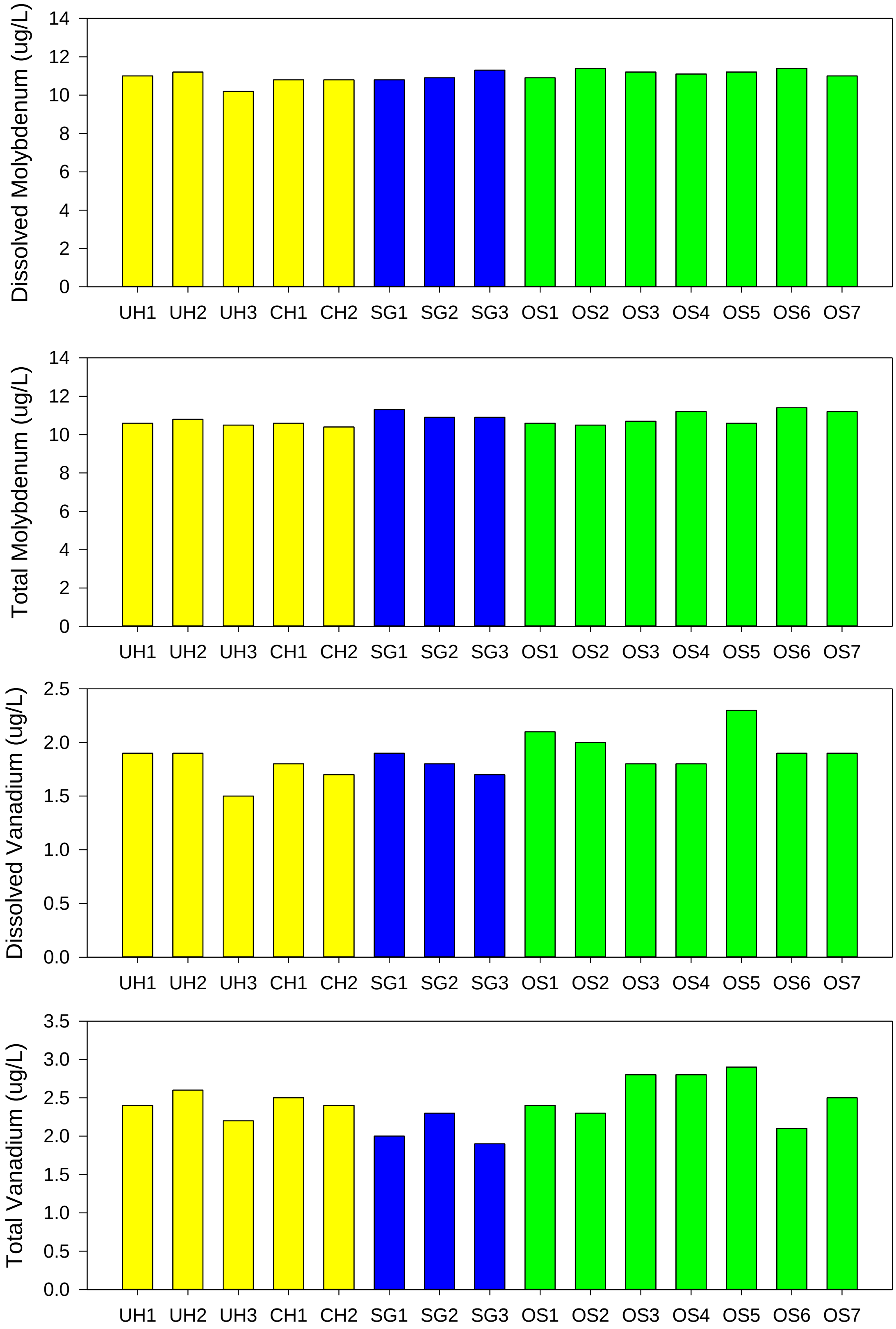



**Figure 30** Total and dissolved molybdenum and vanadium concentrations at monitoring sites during April 2019.
*Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.*

# 4 REFERENCES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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

**RPS Data Set Analysis**

**Wind Speed (m/s) and Direction Rose (All Records)**

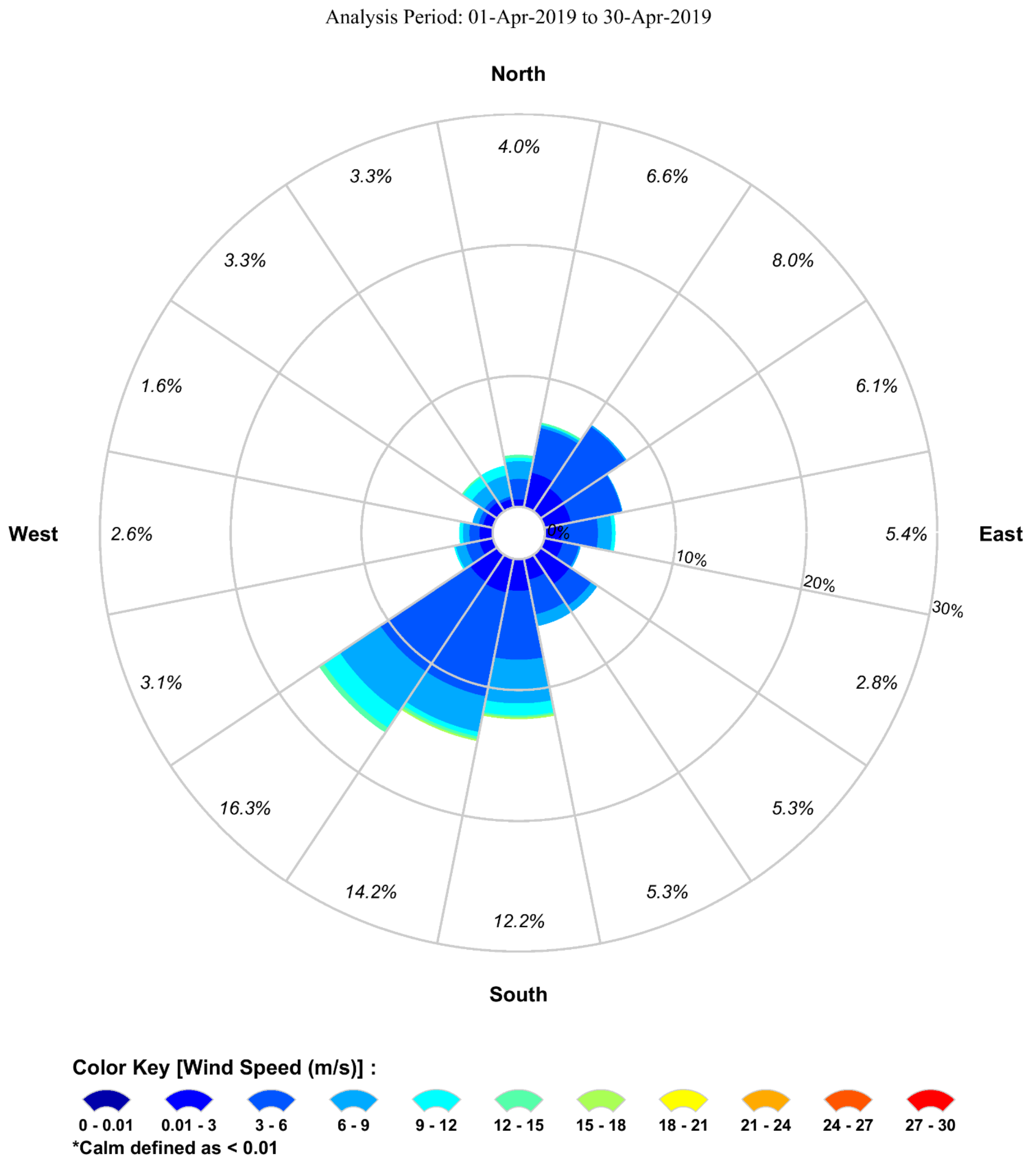



**Figure 31** WatchKeeper wind speed (m/s) and direction rose (%) during April 2019.

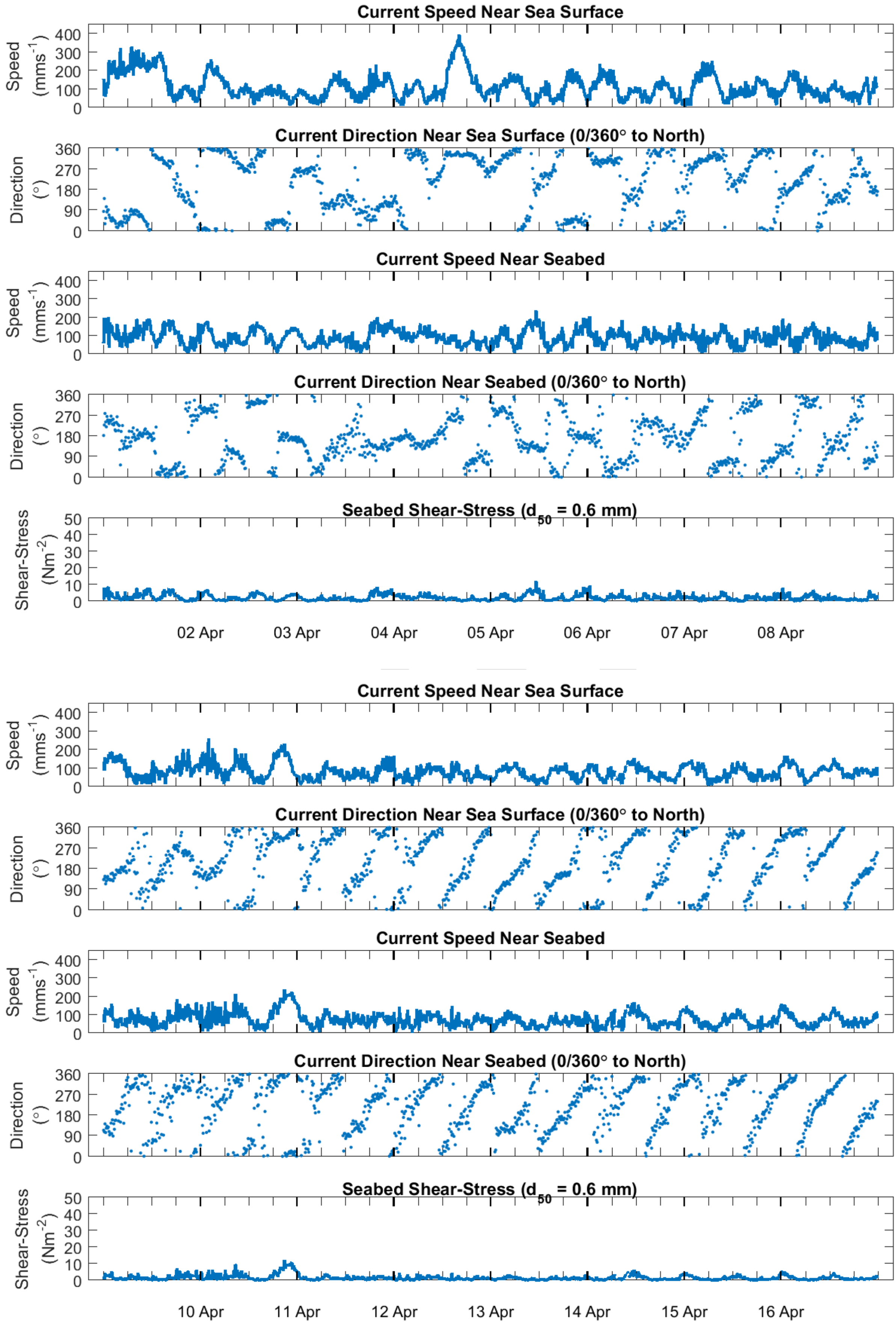
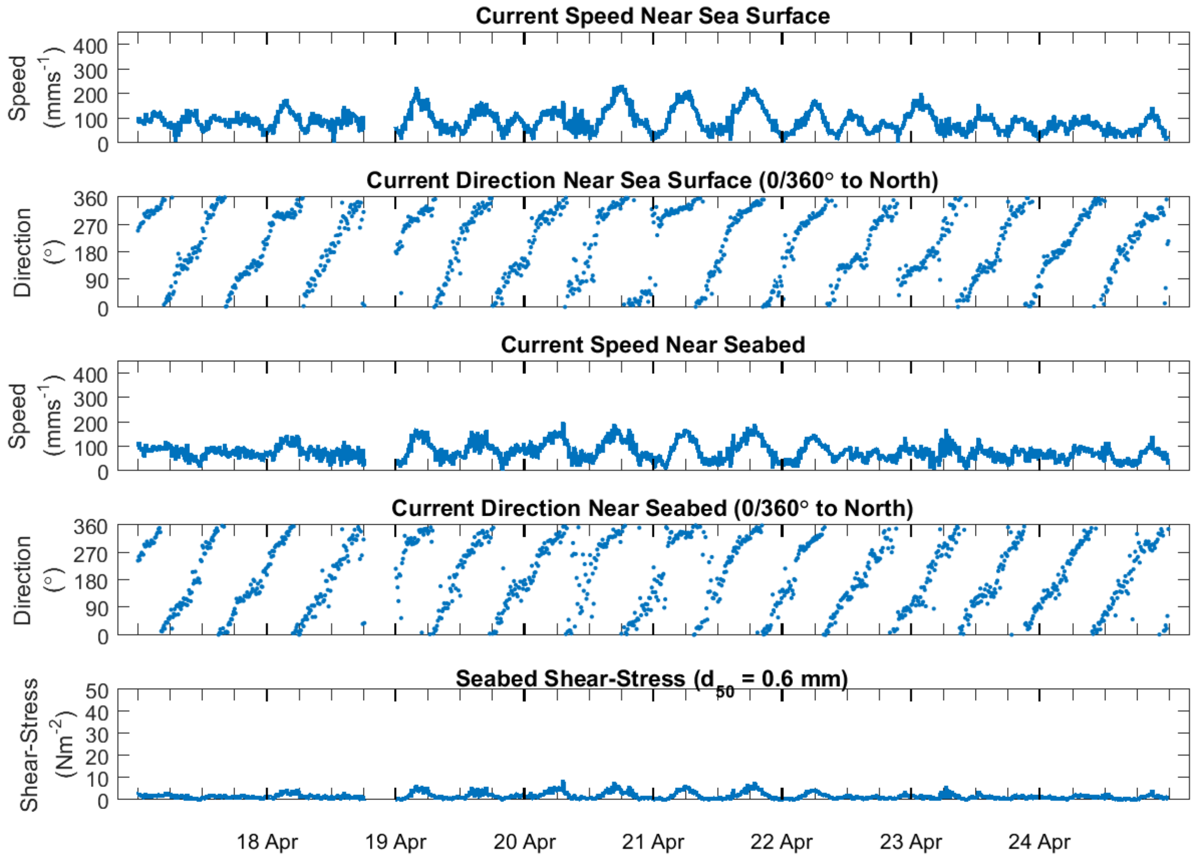



**Figure 32** SG1 current speed, direction and shear bed stress 1 to 16 April 2019.



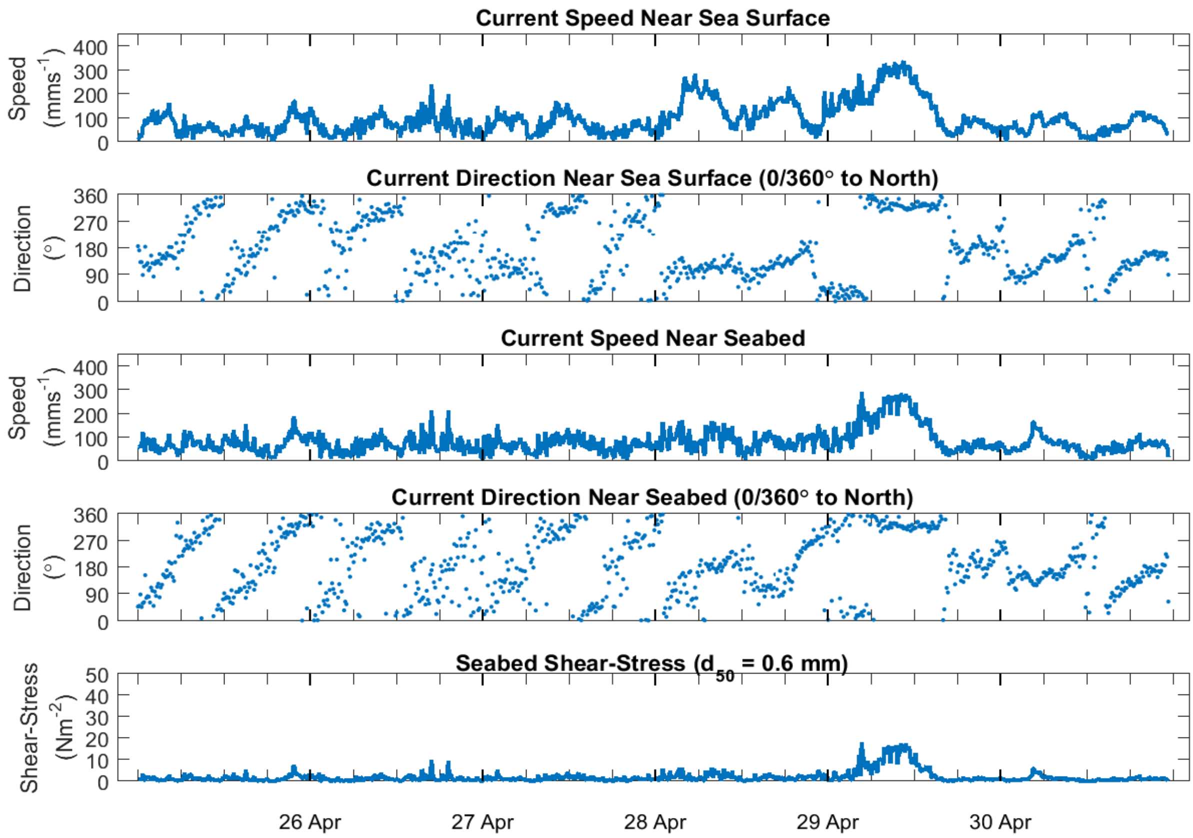
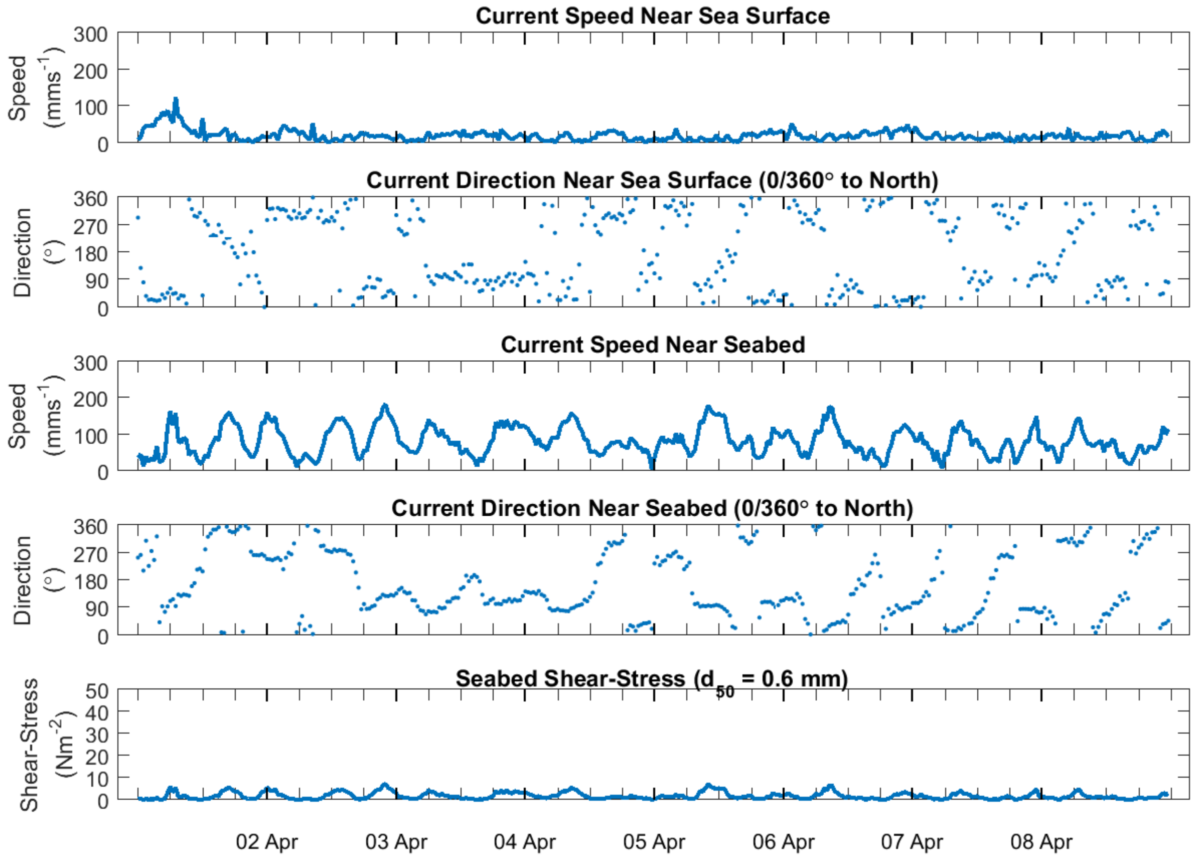




**Figure 33** SG1 current speed, direction and shear bed stress 17 to 30 April 2019.



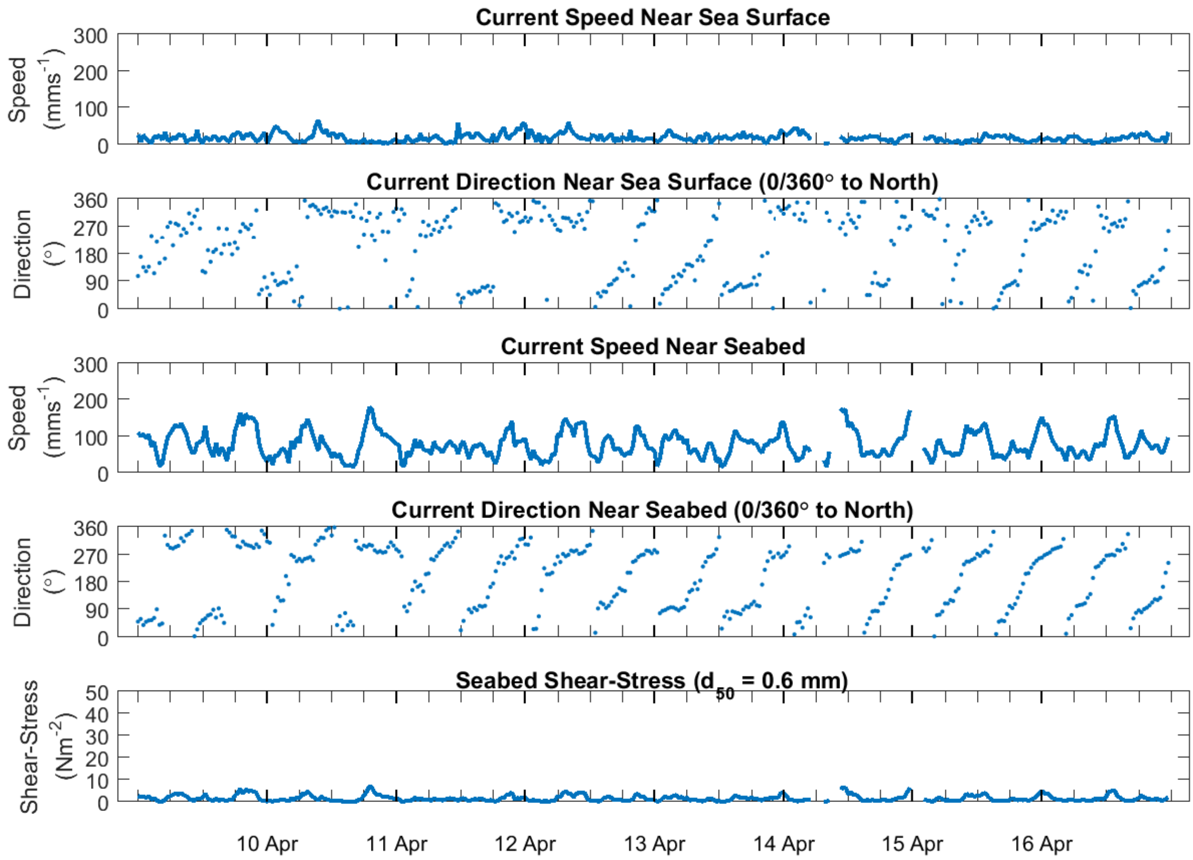




**Figure 34** SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 April 2019.

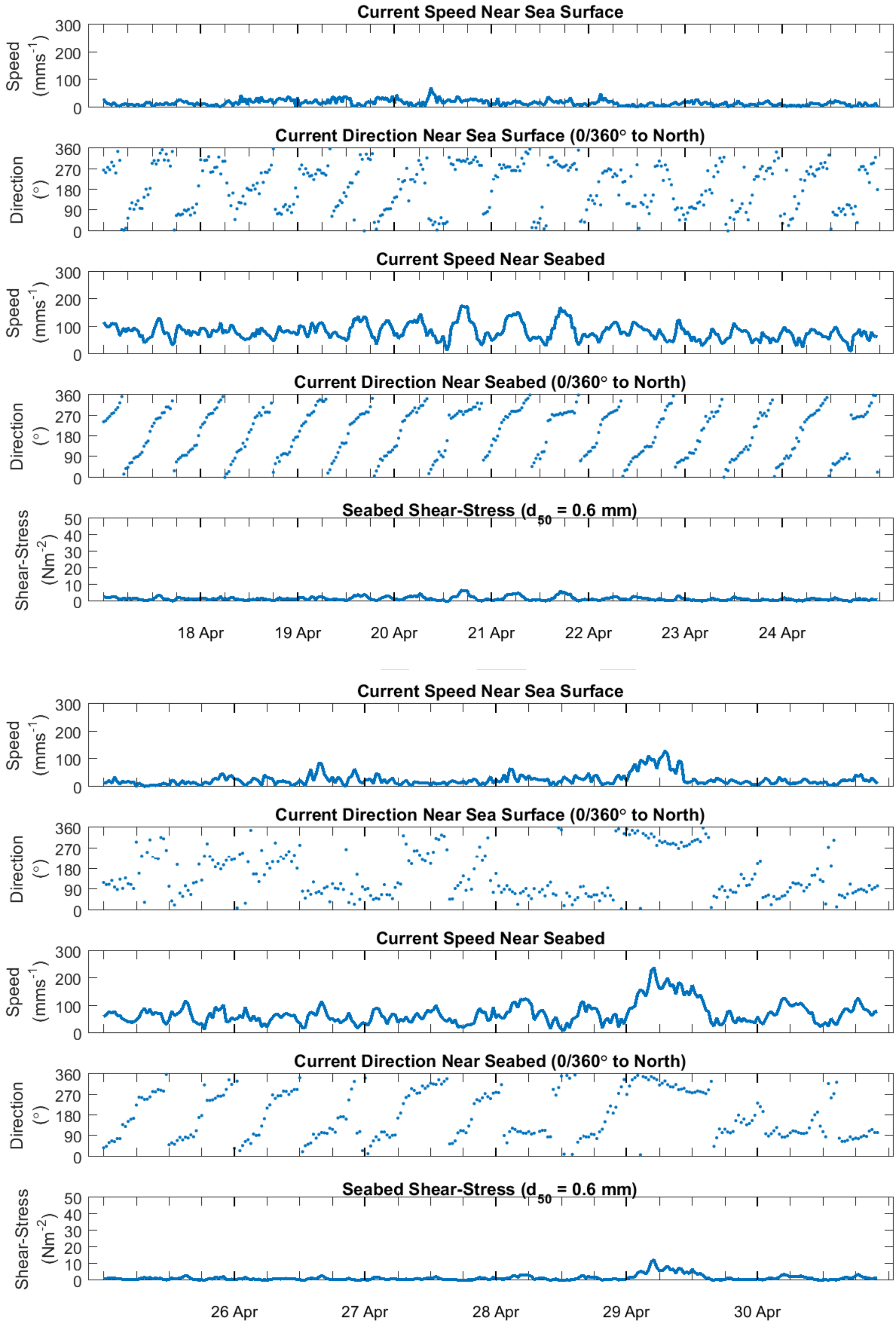
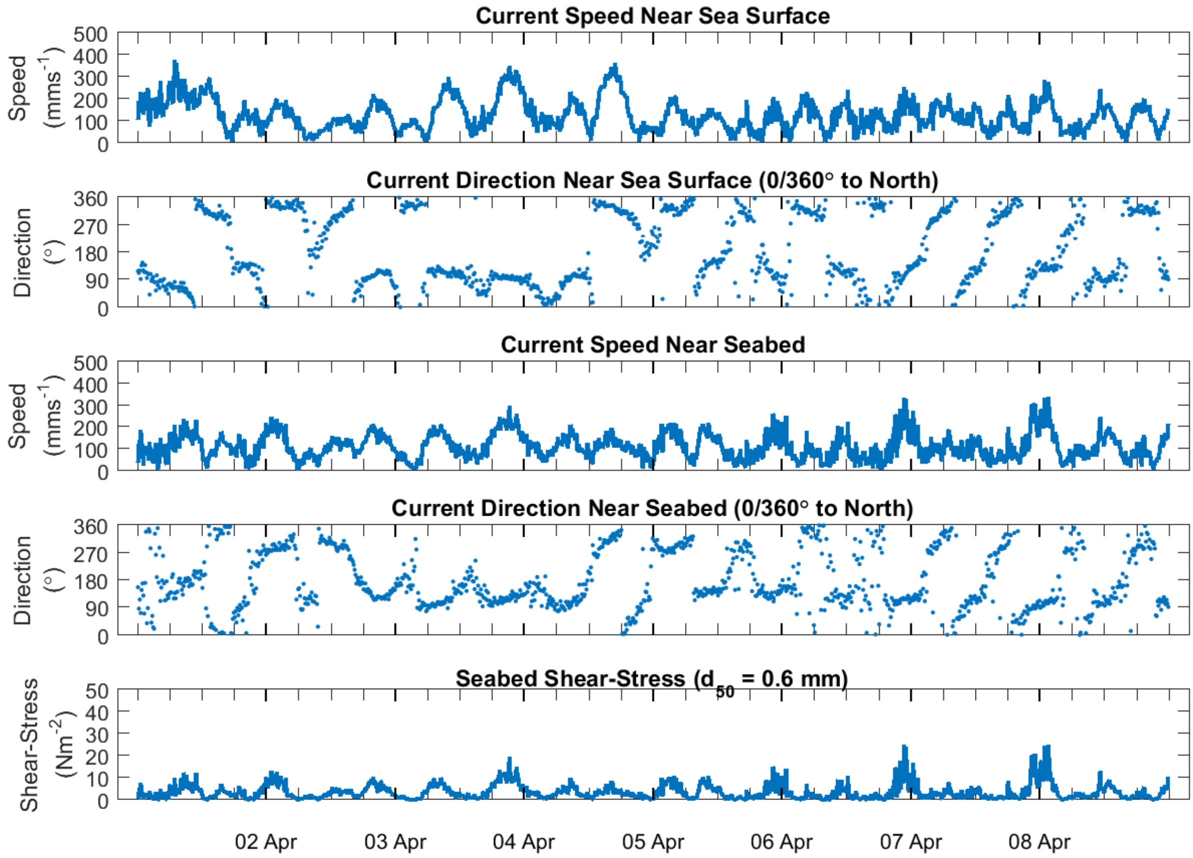



**Figure 35** SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 30 April 2019.



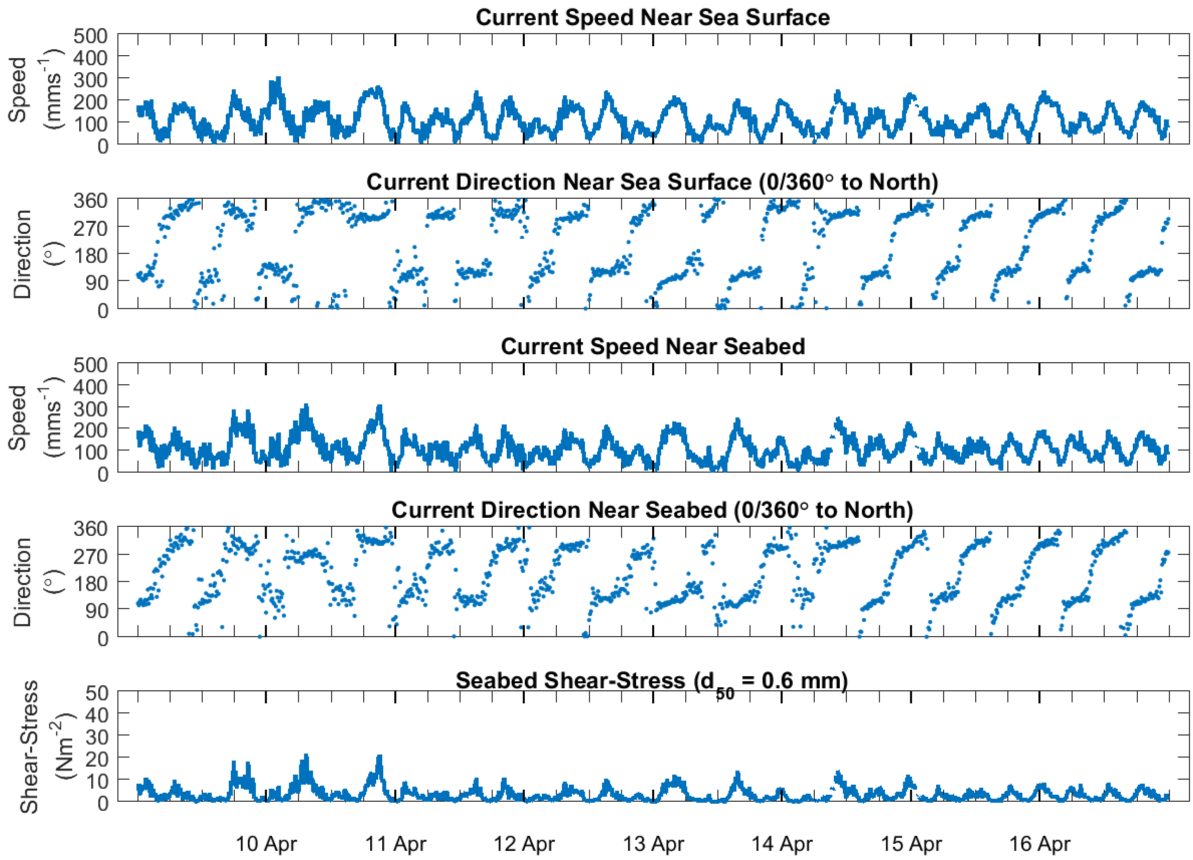




**Figure 36** SG3 current speed, direction and shear bed stress 1 to 16 April 2019.

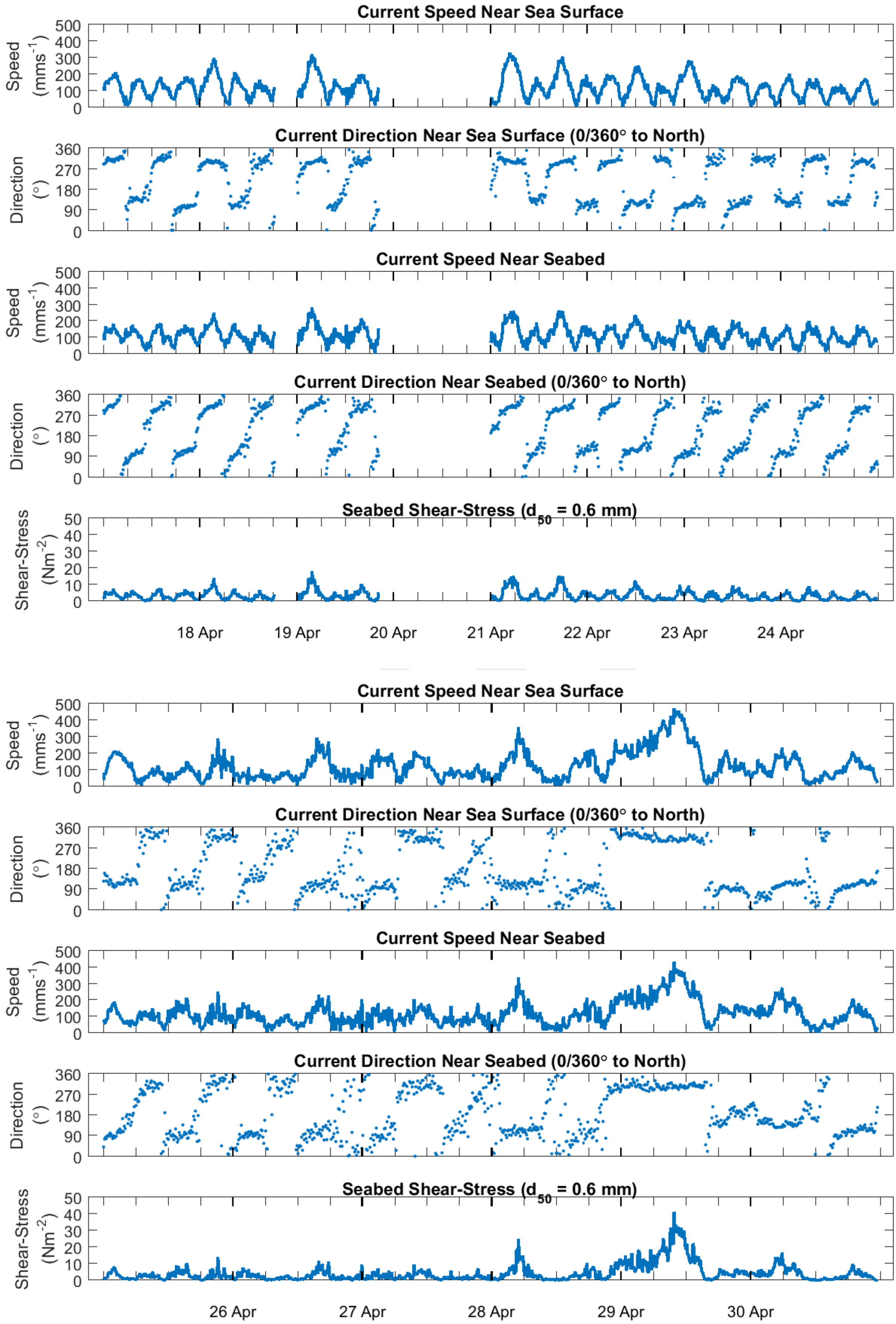



**Figure 37** SG3 current speed, direction and shear bed stress 17 to 30 April 2019.

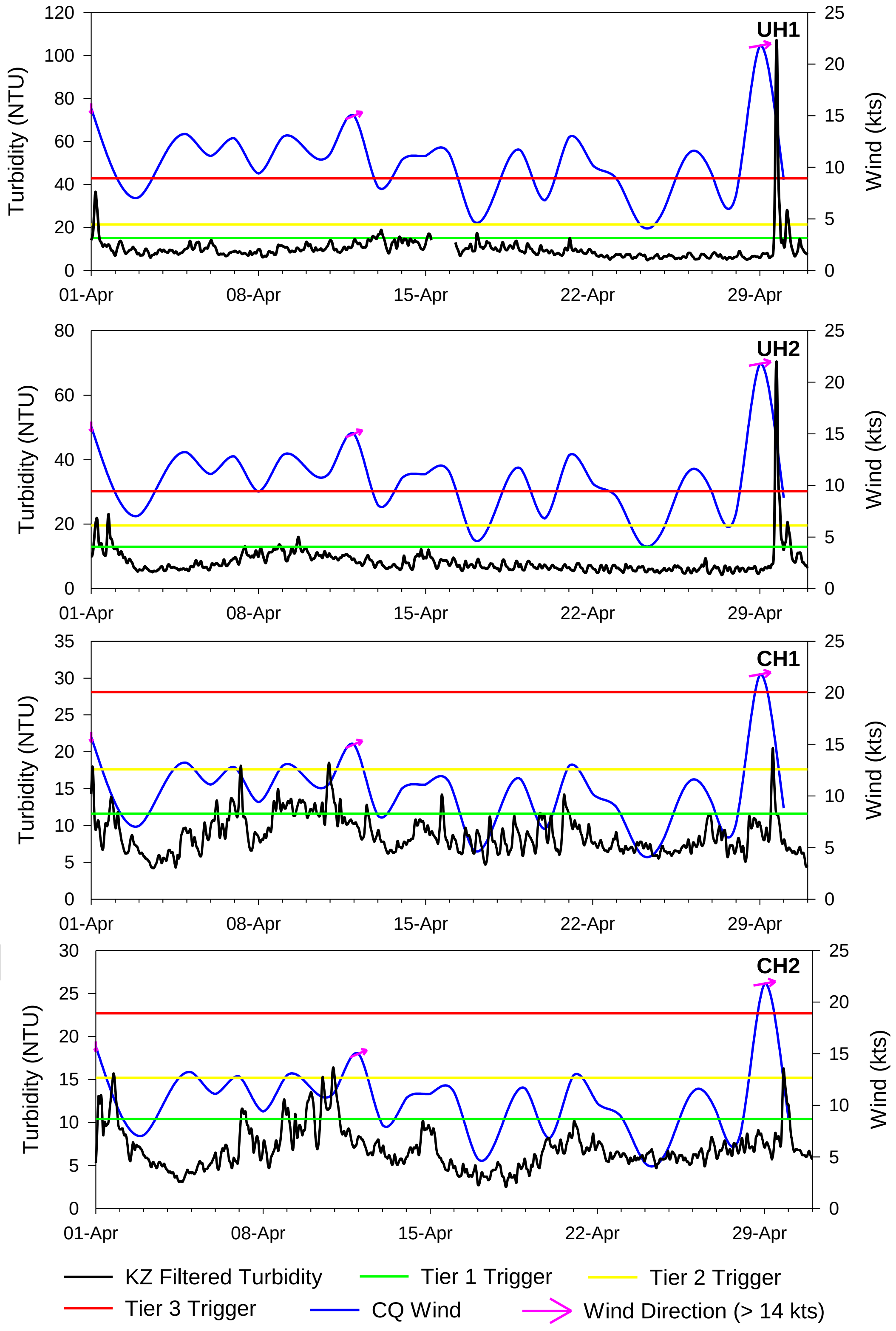



**Figure 38** Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during April 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.*

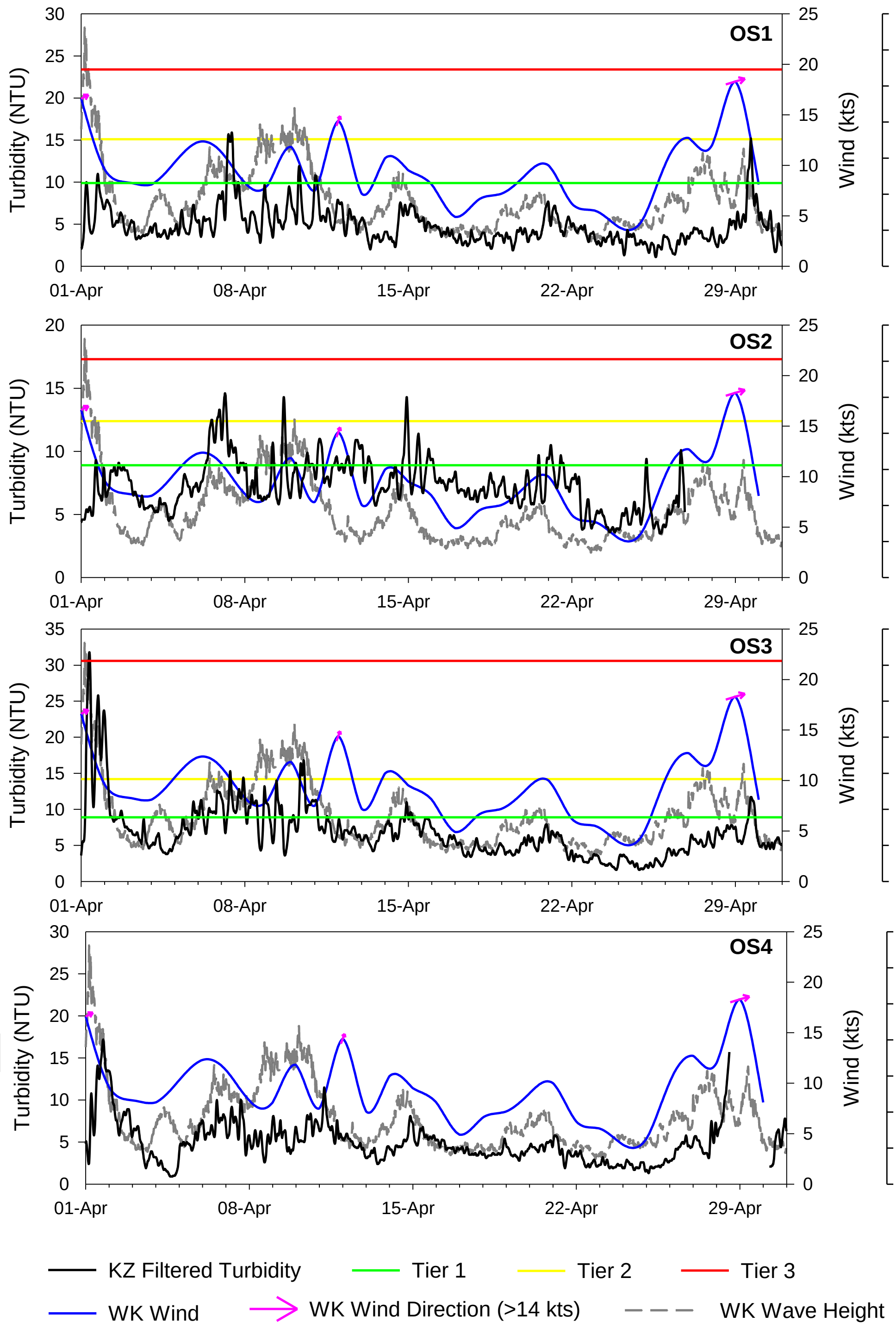



**Figure 39** Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during April 2019.

*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.*

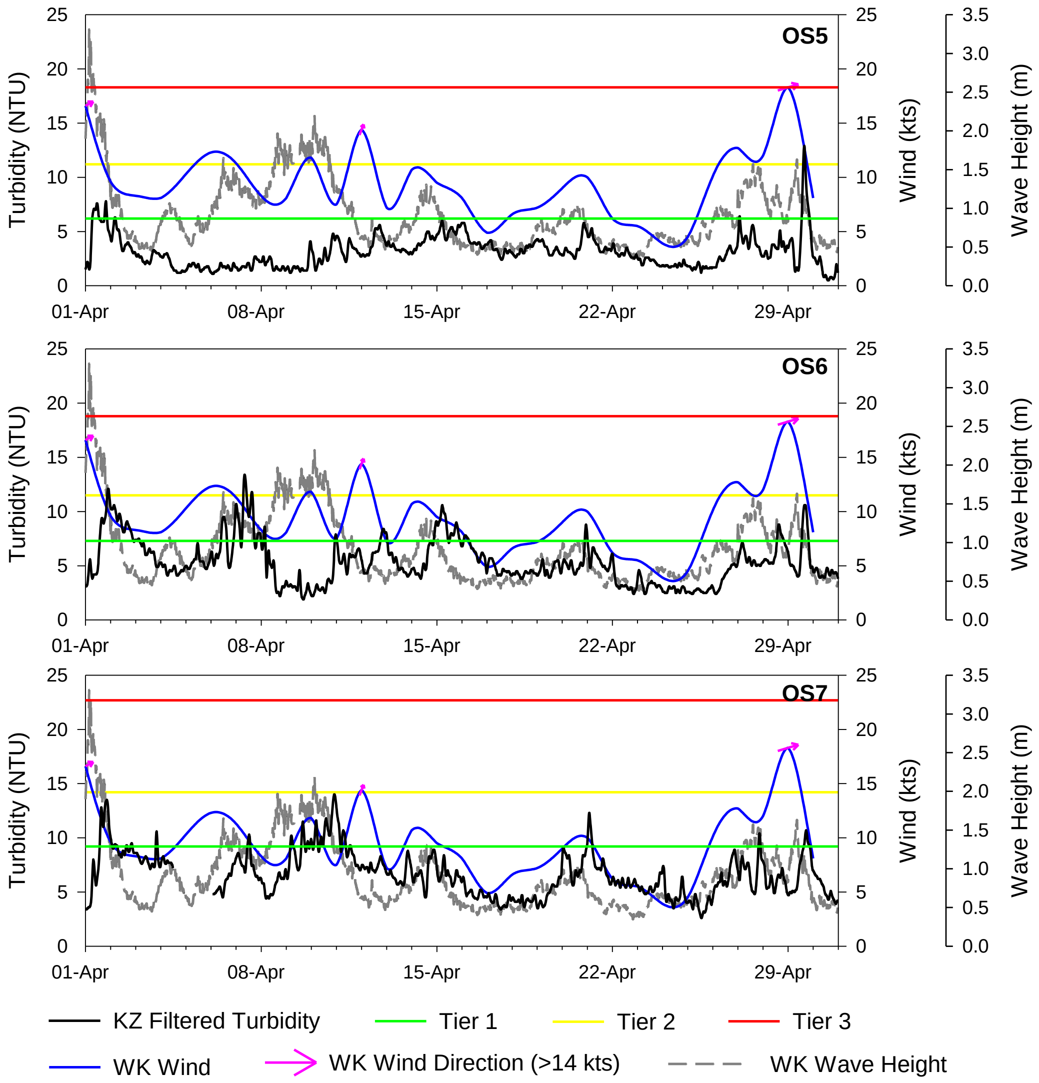



**Figure 40** Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during April 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.*

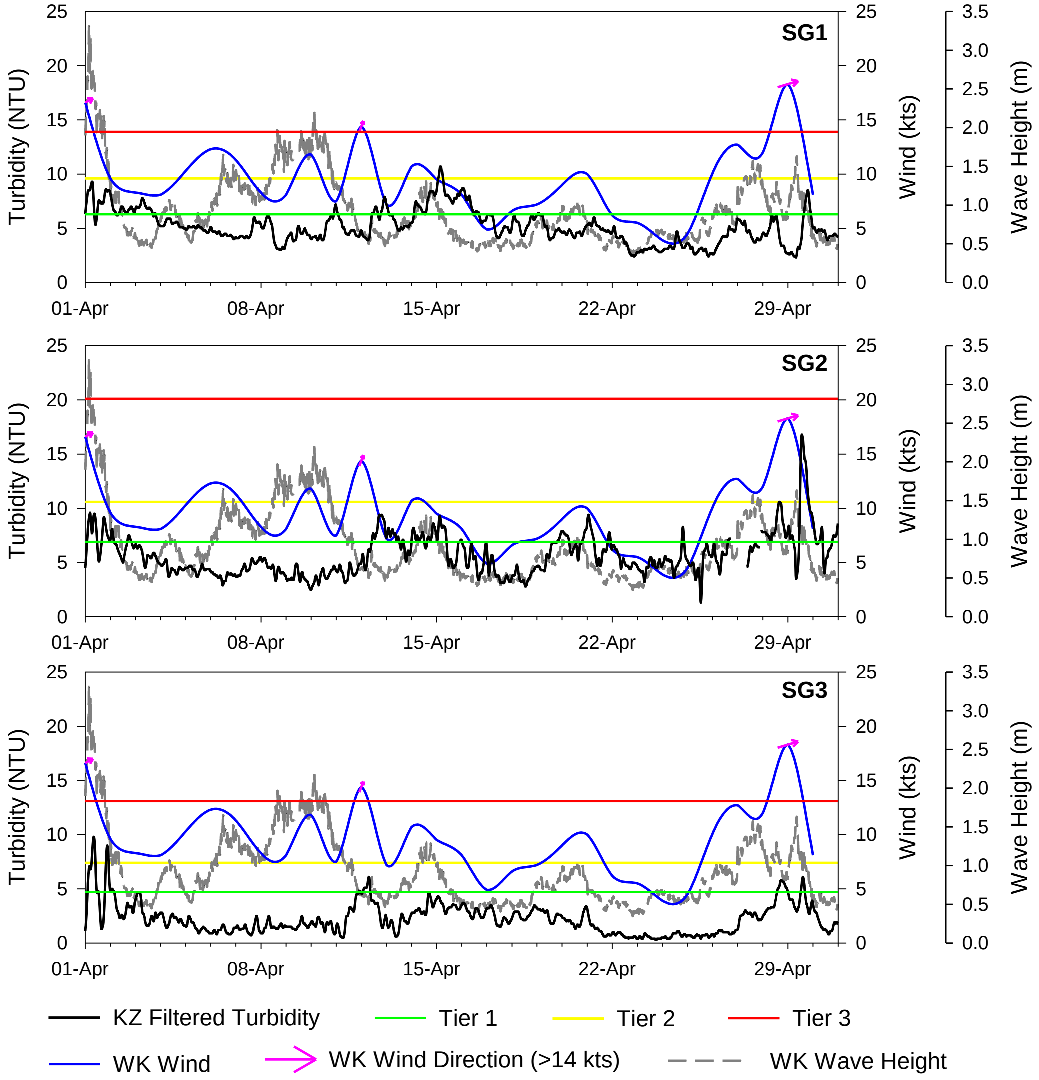



**Figure 41** Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during April 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.*

**Table 22** Mean KZ filtered turbidity and statistics at inshore water quality logger sites during April 2019 and baseline period 1 November 2016 to 31 October 2017
*Values for April are means ± se, range and percentiles (n = 2784 – 2880). Baseline values modified from Fox 2018.*

| Site | | KZ Filtered Turbidity (NTU) | |
|---|---|---|---|
| | Statistic | Surface April | Surface Baseline |
| UH1 | Mean ± se | 10 ± 0 | 12 |
| | Range | 5 – 107 | 2 – 155 |
| | 99th | 31 | 37 |
| | 95th | 15 | 21 |
| | 80th | 12 | 15 |
| UH2 | Mean ± se | 8.3 ± 0.1 | 9.9 |
| | Range | 4 – 70 | 2 – 59 |
| | 99th | 22 | 29 |
| | 95th | 13 | 19 |
| | 80th | 10 | 13 |
| CH1 | Mean ± se | 8.8 ± 0.0 | 8.8 |
| | Range | 4 – 21 | <1 – 50 |
| | 99th | 17 | 27 |
| | 95th | 13 | 17 |
| | 80th | 11 | 12 |
| CH2 | Mean ± se | 6.9 ± 0.0 | 7.6 |
| | Range | 3 – 16 | <1 – 39 |
| | 99th | 15 | 22 |
| | 95th | 12 | 15 |
| | 80th | 9 | 10 |

**Table 23** Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites during April 2019 and baseline period 1 November 2016 to 31 October 2017.
*Values for April are means ± se, range and percentiles (n = 2818 – 2880). Baseline values modified from Fox 2018.*

| Site | | KZ Filtered Turbidity (NTU) | |
|---|---|---|---|
| | Statistic | Surface April | Surface Baseline |
| SG1 | Mean ± se | 5.1 ± 0.0 | 4.2 |
| | Range | 2.3 – 11 | <1 – 31 |
| | 99th | 9.1 | 14 |
| | 95th | 8.1 | 9.5 |
| | 80th | 6.4 | 6.1 |
| SG2 | Mean ± se | 5.7 ± 0.0 | 4.6 |
| | Range | 1 – 17 | <1 – 33 |
| | 99th | 12 | 20 |
| | 95th | 8.8 | 10 |
| | 80th | 7.2 | 6.9 |
| SG3 | Mean ± se | 2.2 ± 0.0 | 3.6 |
| | Range | <1 – 9.8 | <1 – 22 |
| | 99th | 7.1 | 13 |
| | 95th | 4.8 | 7.3 |
| | 80th | 3.2 | 4.7 |

**Table 24** Mean KZ filtered turbidity and statistics at offshore water quality logger sites during April 2019 and baseline period 1 November 2016 to 31 October 2017.
*Values for April are means ± se, range and percentiles (n = 2481 – 2880). Baseline values modified from Fox 2018.*

| Site | Statistic | KZ Filtered Turbidity (NTU) Surface April | Surface Baseline |
|---|---|---|---|
| OS1 | Mean ± se | 4.8 ± 0.0 | 7.5 |
| | Range | 1 – 16 | <1 – 99 |
| | 99th | 14 | 23 |
| | 95th | 8.8 | 15 |
| | 80th | 6.1 | 9.7 |
| OS2 | Mean ± se | 7.3 ± 0.0 | 6.4 |
| | Range | 4 – 15 | <1 – 36 |
| | 99th | 13 | 17 |
| | 95th | 11 | 12 |
| | 80th | 8.9 | 8.9 |
| OS3 | Mean ± se | 6.8 ± 0.1 | 6.5 |
| | Range | 2 – 32 | <1 – 110 |
| | 99th | 23 | 27 |
| | 95th | 13 | 14 |
| | 80th | 8.8 | 8.9 |
| OS4 | Mean ± se | 4.9 ± 0.0 | 5.9 |
| | Range | 1 – 17 | <1 – 35 |
| | 99th | 14 | 18 |
| | 95th | 9.1 | 13 |
| | 80th | 6.4 | 8.1 |
| OS5 | Mean ± se | 3.1 ± 0.0 | 4.6 |
| | Range | <1 – 13 | <1 – 35 |
| | 99th | 7.5 | 18 |
| | 95th | 5.6 | 11 |
| | 80th | 4.1 | 6.1 |
| OS6 | Mean ± se | 5.3 ± 0.0 | 4.7 |
| | Range | 2 – 13 | <1 – 37 |
| | 99th | 11 | 18 |
| | 95th | 9.4 | 11 |
| | 80th | 6.9 | 7.1 |
| OS7 | Mean ± se | 6.7 ± 0.0 | 6.3 |
| | Range | 3 – 14 | <1 – 48 |
| | 99th | 13 | 22 |
| | 95th | 10 | 14 |
| | 80th | 8.3 | 9.1 |

**Table 25** Summary of Vision Environment quality control data for April 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 | 12 | 8 | 40 |
| Dissolved Aluminium (ug/l) | <3 | <3 | <12 | <12 | ND |
| Total Aluminium (ug/l) | <3.2 | <3.2 | 154 | 124 | 22 |
| 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 | 1.5 | 2.3 | 42 |
| Total Chromium (ug/l)* | 1.31 | <0.53 | 2.5 | 2.5 | 0 |
| 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 | 6 | <4 | ND |
| Total Iron (ug/l) | <21 | <21 | 260 | 171 | 41 |
| 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 | 2.6 | 2.6 | 0 |
| Total Manganese (ug/l) | <0.53 | <0.53 | 9 | 7.3 | 21 |
| 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 | 10.8 | 2 |
| Total Molybdenum (ug/l) | <0.21 | <0.21 | 10.6 | 10.5 | 1 |
| Dissolved Nickel (ug/l) | <0.5 | <0.5 | <7 | <7 | ND |
| Total Nickel (ug/l) | <0.53 | <0.53 | <7 | <7 | ND |
| Dissolved Selenium (ug/l) | <1 | <1 | <4 | <4 | ND |
| Total Selenium (ug/l) | <1.1 | <1.1 | <4.2 | <4.2 | ND |
| Dissolved Silver (ug/l) | <0.1 | <0.1 | <0.4 | <0.4 | ND |
| Total Silver (ug/l) | <0.11 | <0.11 | <0.43 | <0.43 | ND |
| Dissolved Tin (ug/l) | <0.5 | <0.5 | <5 | <5 | ND |
| Total Tin (ug/l) | <0.53 | <0.53 | <5.3 | <5.3 | ND |
| Dissolved Vanadium (ug/l) | <1 | <1 | 1.9 | 1.7 | 11 |
| Total Vanadium (ug/l) | <1.1 | <1.1 | 2.4 | 2.3 | 4 |
| Dissolved Zinc (ug/l) | <1 | <1 | <4 | <4 | ND |
| Total Zinc (ug/l)* | 2.5 | <1.1 | <4.2 | <4.2 | ND |
| Total Phosphorus (ug/l) | <4 | <4 | 26 | 23 | 12 |
| Dissolved Reactive Phosphorus (ug/l) | <4 | <4 | 15.1 | 14.1 | 7 |
| 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 | 34 | 30 | 13 |
| Nitrate-N + Nitrite-N (ug/l)* | 4 | <2 | 17.4 | 9.1 | 63 |
| Chlorophyll a (ug/L) | <0.2 | <0.2 | 3.2 | 3.1 | 3 |

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