# Lyttelton Port Company Channel Deepening Project Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

August 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 were undertaken from 29 August to 29 November 2018. Post-dredge monitoring was undertaken until 11 March 2019, when a smaller dredging operation began for the reclamation works at Cashin Quay.

Monitoring results collected during August 2019 are presented within this report. 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 and are compared to compliance trigger values.

***Climatic Conditions:*** During August lower rainfall was recorded at Cashin Quay (36.8 mm) than during July 2019 (60 mm), with highest daily rainfall recorded on 10 August (15 mm). Flows from the Waimakariri River were low during the month with a maximum of 212 $m^3/s$ recorded on 1 August. Monthly average air temperature (9.3°C) was slightly lower than that recorded in July (9.9°C). Inshore winds were generally westerly, including south-westerly and north-westerly, with mean daily wind speeds > 15 kts recorded on 1, 10 and 14 August. Offshore mean daily winds were highest (17 kts) on 10 August, with greatest mean daily significant wave heights recorded on 10 (1.5 m) and 20 (1.8 m) August.

***Currents:*** Near-surface and near-bed currents at SG1 and SG3 were highest on 2 August during a period of moderate to strong offshore winds from a south-westerly direction. At SG2a (Watchkeeper) maximum currents were recorded at near-surface on 16 August and near-seabed on 26 August, which did not correspond with any metocean events. There appeared to be little impact on current speeds from the high winds and waves on 10 and 20 August.

Near-surface and near-seabed predominant current movement for SG1 and SG3 tended to be in a northwest and southeast direction, somewhat similar to SG2a near-surface current directions. In contrast, near-seabed currents at SG2a, moved in an east and west direction.

***Turbidity:*** Consistent with previous results, turbidity was higher overall at the inshore monitoring sites of the central and upper harbour than at the offshore and spoilground monitoring locations. Mean turbidity values for August in addition to percentile statistics were similar to those recorded during the baseline monitoring period.

Elevated turbidity was recorded at all sites at the start of August, following on from the increased turbidity recorded in late July due to moderate to high inshore and offshore winds. Elevated turbidity at most sites was recorded again around 10 August following a period of high inshore and offshore winds, high rainfall and large wave heights. Surface turbidity peaks within the inner harbour reached up to 45 NTU, while a number of nearshore sites exhibited turbidity up to 20 NTU. Elevated wave heights recorded on 20 August resulted in an additional turbidity peak at several sites, particularly OS3, OS4 and OS7.

Benthic turbidity responded to both wind speed and wave height events in August with mean benthic turbidity being more elevated than their surface counterparts, as typically observed.

***Dredge Compliance Turbidity Trigger Values:*** During August, ongoing Tier 3 exceedances from late July were recorded at OS3 and SG3. Due to the 30-day rolling window, the Tier 3 exceedances were not cleared until late August.

***Other Physicochemical Parameters:*** While mean monthly temperatures were cooler in August than July, in late August water temperatures at all sites started to increase slightly. Benthic temperatures were consistent with those at the surface indicating a well-mixed water column.

Consistent with previous reports, surface and benthic pH during August was consistent across all sites, as was conductivity. Low flows from the Waimakariri River do not appear to have impacted conductivity at any sites.

Dissolved oxygen (DO) concentrations increased at all sites during late August. This increase is most likely due to warming sea temperatures stimulating microalgal populations thus increasing photosynthesis and therefore oxygen production. Diurnal fluctuations in DO were observed at most sites for the month of August as typically observed. Benthic DO trended similarly to surface counterparts becoming more variable in late August.

***Water Sample Analysis and Depth Profiling:*** Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 7 August 2019, and once again a well-mixed water column was indicated.

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 10.6 m at OS5. No exceedances of WQG were observed for sub-surface during the August 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, as commonly found.

Concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites, except for SG3 where total nitrogen exceeded the WQG. As typically recorded, ammonia and nitrogen oxides (NOx) concentrations exceeded WQG at all sites. Chlorophyll *a* concentrations remained low despite the high nutrient availability.

Several metals were reported as below the limit of reporting (LOR) at all sites as commonly found. Total aluminium concentrations exceeded designated WQG at all of the monitoring sites, but the dissolved and therefore readily bioavailable fraction, remained undetectable. Total and dissolved manganese, chromium, vanadium and molybdenum were also detected during August, with little spatial variability and a large component contained within the dissolved phase.

***Benthic Photosynthetically Active Radiation (BPAR):*** Levels of ambient sunlight were higher in August than July associated with the increased day lengths, in addition to the lower rainfall and associated cloud cover during the latter month. As such, BPAR at both OS2 and

OS3 also increased, peaking on 8 August when ambient PAR was reasonably high and water turbidity was low.

***Sedimentation:*** Overall accumulation of sediments at both OS2 and UH3 was evident in August. Periods of high sediment flux were evident at OS2 during periods of strong winds, elevated wave heights and therefore high turbidity, leading to an overall accumulation of 33 mm over the month. Sediment flux at UH3 was more stable with a period of minor erosion occurring in early August, and then slow and steady accumulation of sediments from mid to late August, resulting in an overall accumulation of 2.6 mm of sediments.

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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 program was designed.

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.

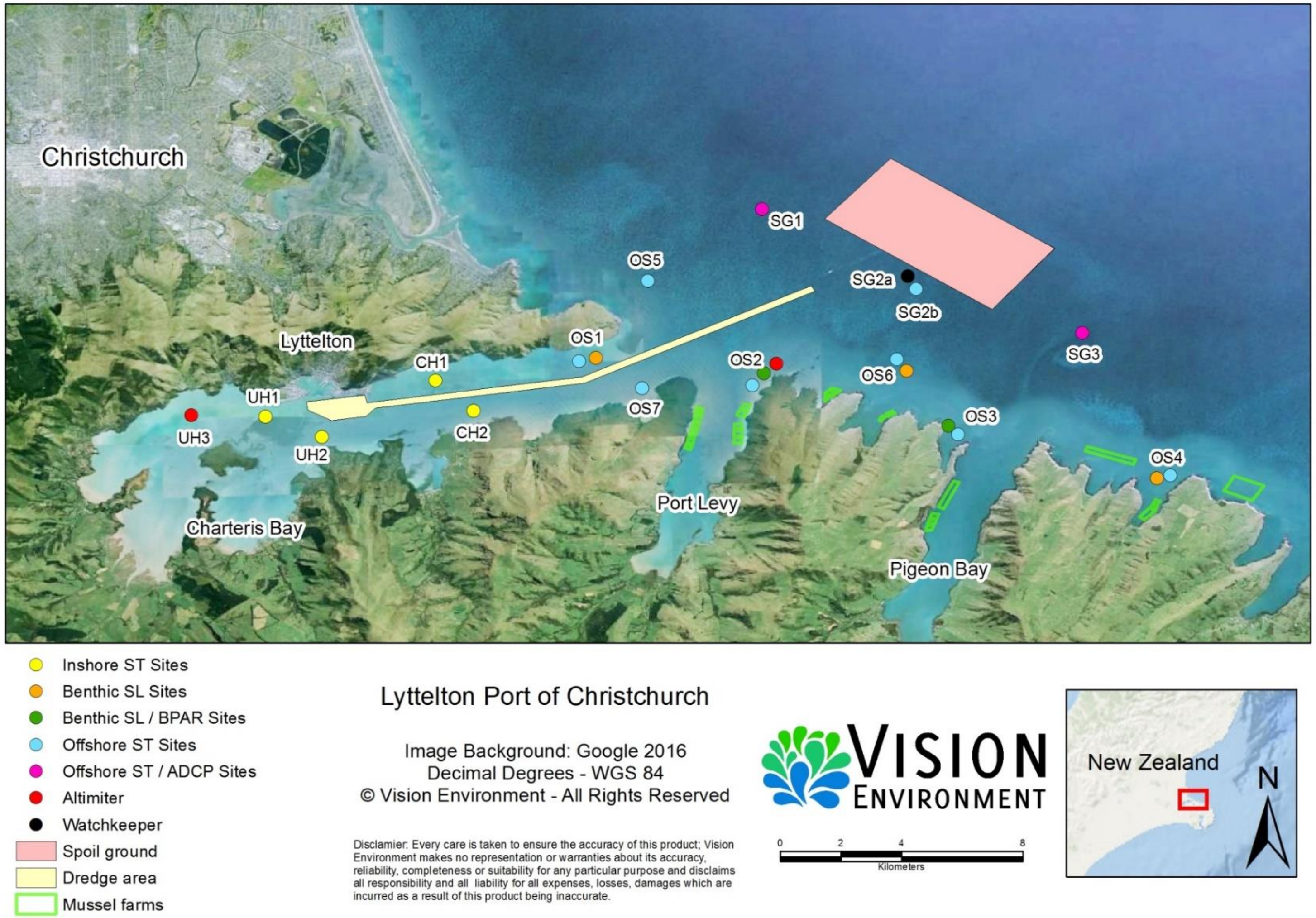



**Figure 1** Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
*ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler*

**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 August 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 7 August 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) default trigger values (ANZG, 2018). In the absence of specific trigger values for New Zealand estuarine or marine ecosystems, the WQG suggest the use of 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 (ANZG, 2018). 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 36.8 mm of rainfall was recorded at Cashin Quay during August 2019, a decrease from the precipitation recorded in July (60 mm). Highest rainfall (15.2 mm) was recorded on 10 August (Metconnect, 2019) (Figure 2). Freshwater flows from the Waimakariri River, can be transported south along the coastline and enter Lyttelton Harbour several days post flow. Flows for August ranged between 75 m$^3$/s and 212 m$^3$/s and were highest on 1 August (ECAN, 2019). Flows at this low level have historically not induced any noticeable impacts on the harbour sites.

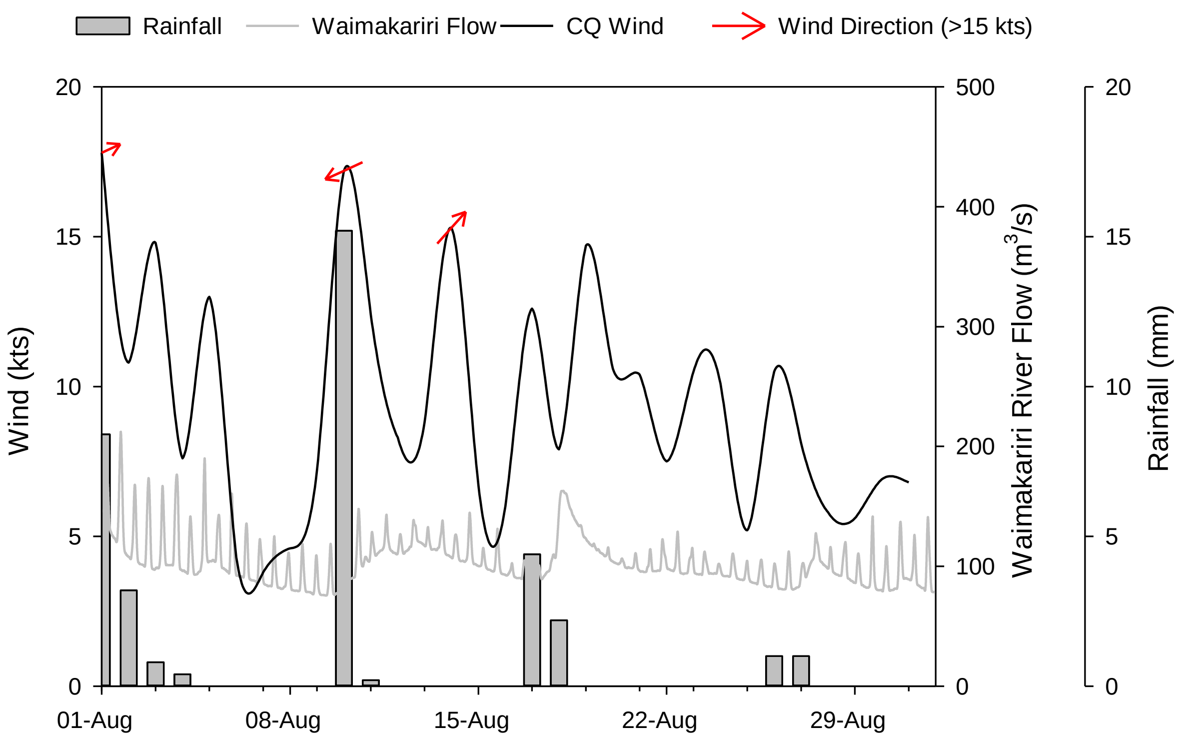



**Figure 2** Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during August 2019.
*Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.*

Inshore winds during August were generally from a westerly direction, including south-westerly and north-westerly (Metconnect, 2019). Highest mean winds speeds (17.8 kts) were recorded on 1 August from a south-westerly direction, while south-westerly wind gusts > 40 kts were recorded from 1 to 3 August. Daily mean wind speeds > 15 kts were also recorded on 10 (from north-easterly) and 14 (from south-westerly) August.

Daily mean air temperatures at Cashin Quay ranged from 6°C to 12°C, resulting in a monthly mean temperature of 9.3°C, slightly lower than the July mean temperature of 9.9°C (Metconnect, 2019).

Offshore significant wave height peaked at 2.6 m at 4:30pm on 10 August, leading to a mean daily significant wave height of 1.5 m. Highest mean daily offshore wind speeds (17 kts) were also recorded from a south-easterly direction on this day (Figure 3), although offshore winds during August were generally from a south-westerly direction.

Wave heights of up to 2.3 m were also recorded on 20 August, with a mean daily significant wave height of 1.8 m gained. Mean daily offshore winds of 11.7 kts from a southerly direction were recorded on this day.

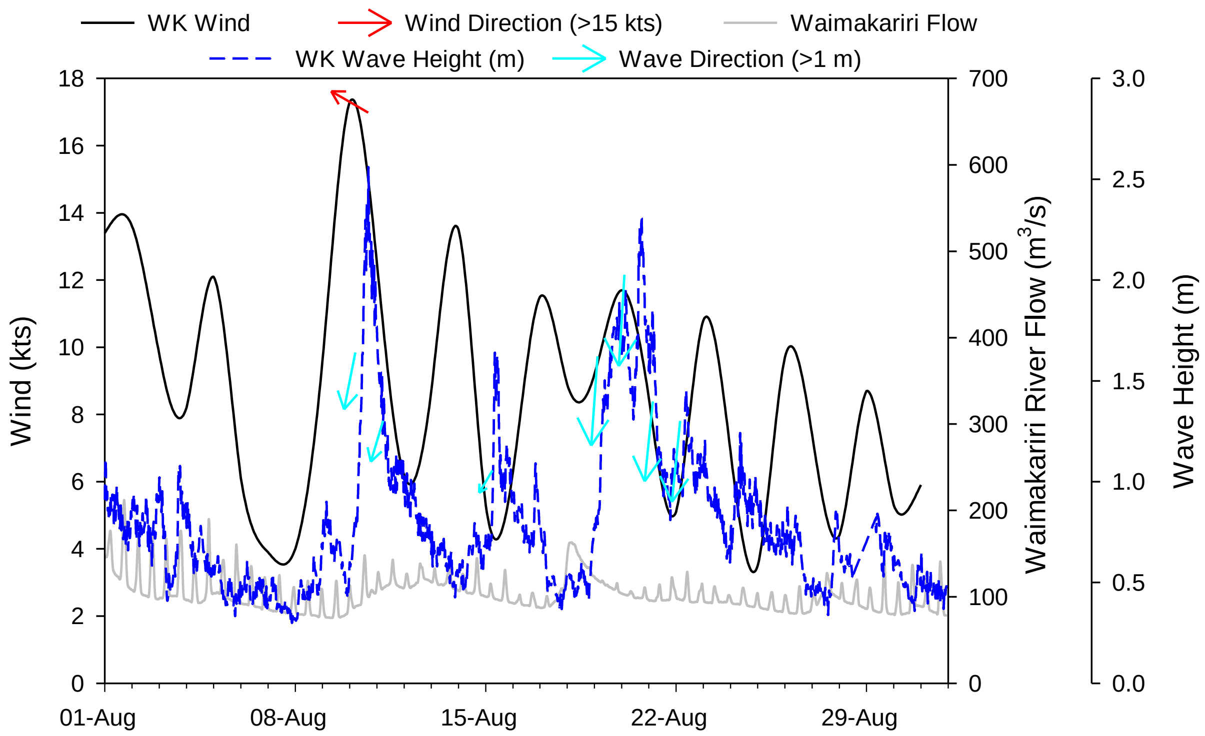



**Figure 3** Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during August 2019.
*Note: Arrows indicate the direction 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 (Watchkeeper) and SG3, reporting the speed and direction of currents in a profile from the sea surface to seabed. Summary ADCP statistics are presented within Table 2, and

Figures 4 to 6. 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.

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

| Parameter | Depth | Site | | |
|---|---|---|---|---|
| | | SG1 | SG2a | SG3 |
| Minimum current speed (mm/s) | *Near-surface* | 2 | 0 | 0 |
| | *Near-seabed* | 0 | 1 | 1 |
| Maximum current speed (mm/s) | *Near-surface* | 346 | 394 | 572 |
| | *Near-seabed* | 326 | 485 | 527 |
| Mean current speed (mm/s) | *Near-surface* | 108 | 48 | 133 |
| | *Near-seabed* | 88 | 86 | 121 |
| Standard deviation of current speed (mm/s) | *Near-surface* | 61 | 49 | 78 |
| | *Near-seabed* | 44 | 58 | 67 |
| Current speed, 95$^{th}$ percentile (mm/s) | *Near-surface* | 222 | 153 | 275 |
| | *Near-seabed* | 167 | 183 | 245 |

Maximum current speeds at SG1 (346 mm/s and 326 mm/s, respectively for near-surface and near-seabed) and SG3 (572 mm/s and 527 mm/s, respectively for near-surface and near-seabed) were recorded on 2 August, during a period of moderate to strong offshore winds (daily mean of 14 kts and gusts of up to 43 kts) from a south-westerly direction.

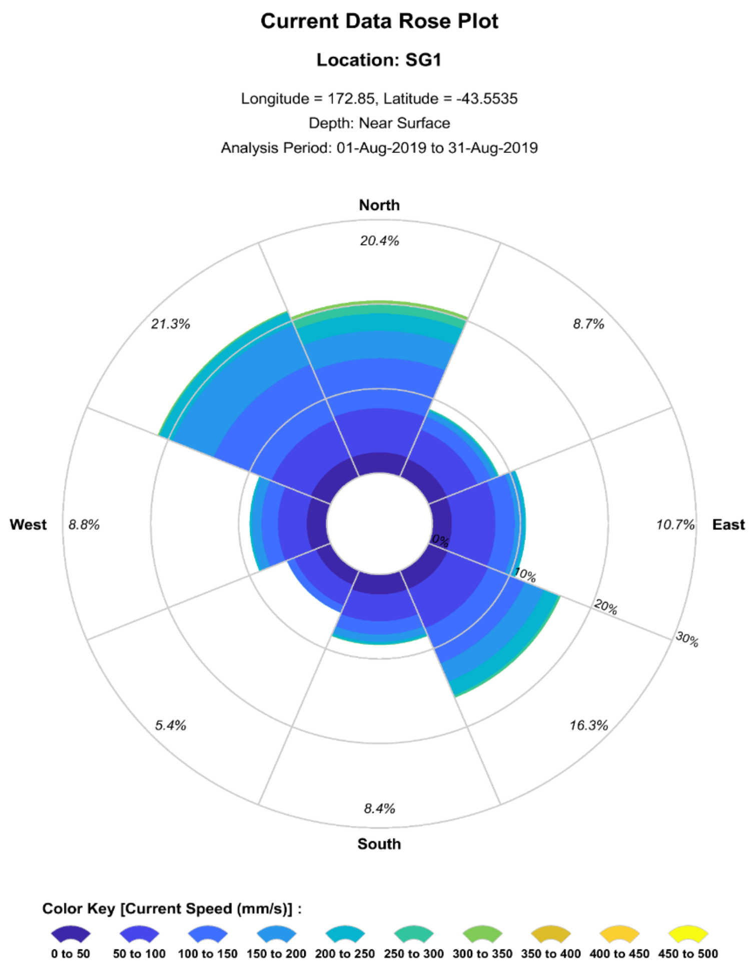
As typically found, maximum currents at SG2a did not align with the SG1 or SG3, with maximum near-surface currents (394 mm/s) on 16 August, and maximum near-seabed currents (485 mm/s) on 26 August. Daily wind speeds of < 10 kts from a southerly direction were recorded on these two dates.

There appeared to be no impact on current speed at any site during the period of high offshore winds and waves on 10 and 20 August.

The time-series plots (Figures 33 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.

Similar to July 2019, currents at SG1 near-surface during August tended to move in a north-northwest (41.7 %) and southeast (16.3%) direction, as did the near sea-bed currents (northwest: 18.8%, southeast 15.5%). A similar pattern was evident at SG3, with near-surface current moving in a northwest (31.5%) and southeast (19.4%) direction, and near-seabed currents moving in a west-northwest (36.8%) and east-southeast (39%) direction.

Current movements at SG2a were found to be in a more east/west direction, similar to July 2019. Near-surface currents moved in a west-northwest (36.8%) and east-southeast (30.1%) direction, while near-seabed currents moved in a west (21.6%) and east (19.4%) direction.



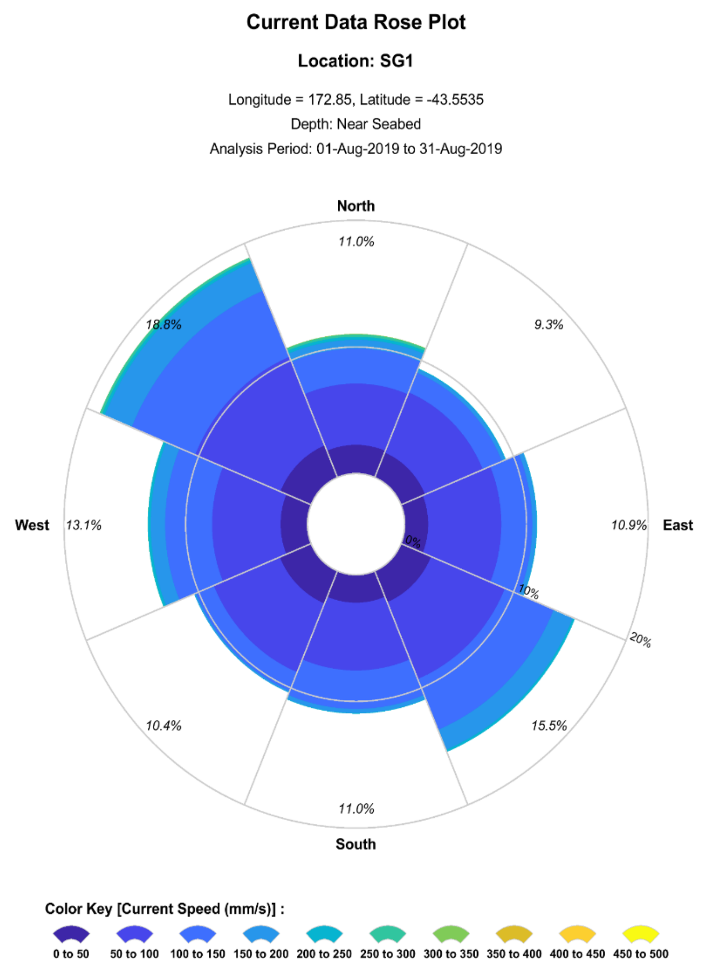




**Figure 4** Near-surface and near-seabed current speed and direction at SG1 during August 2019.
*Speed intervals of 50 mm/s are used.*

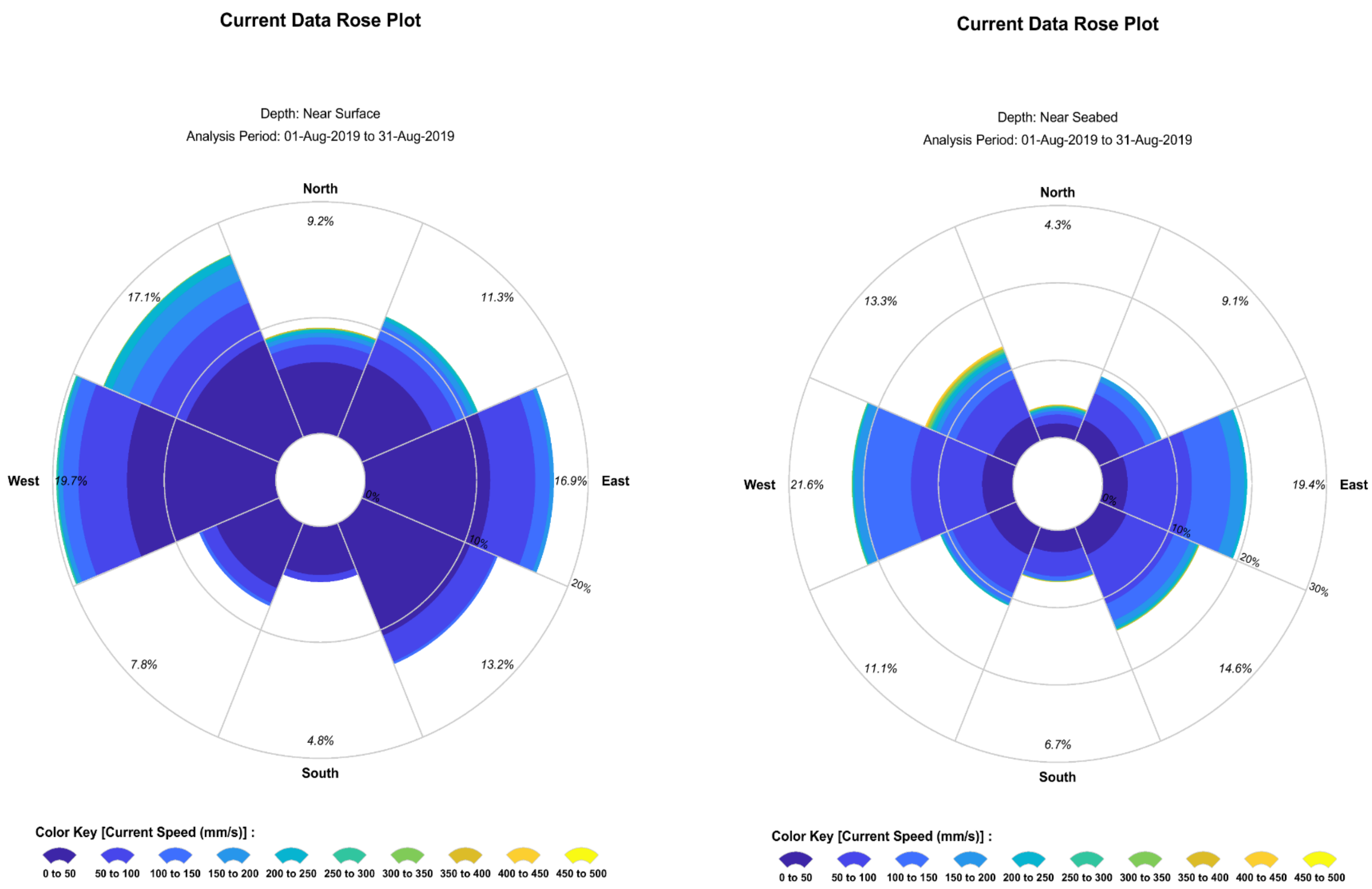
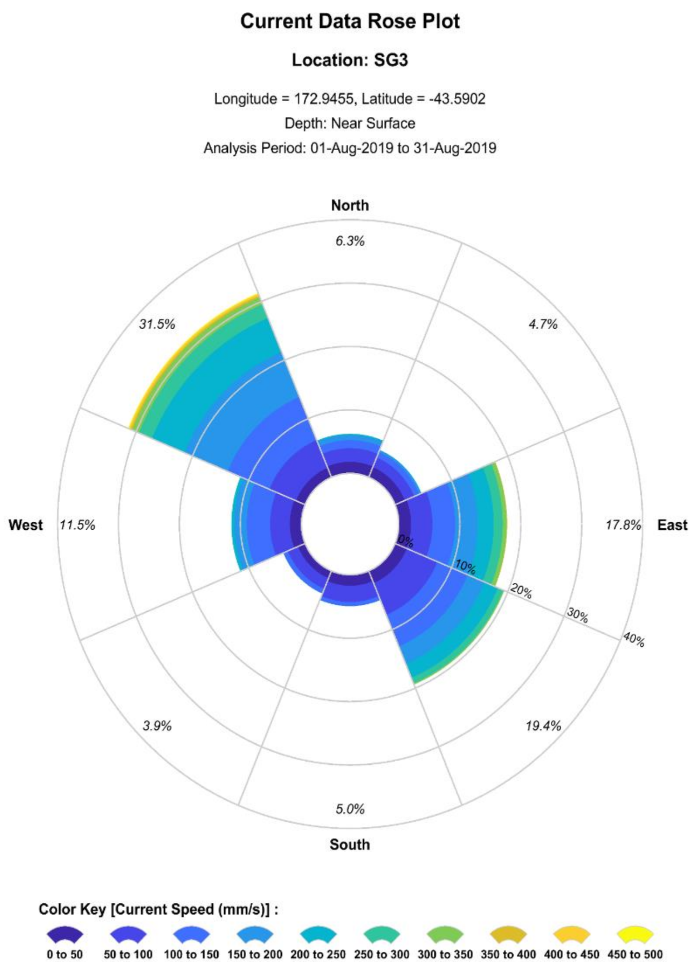



**Figure 5** Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during August 2019.
*Speed intervals of 50 mm/s are used.*



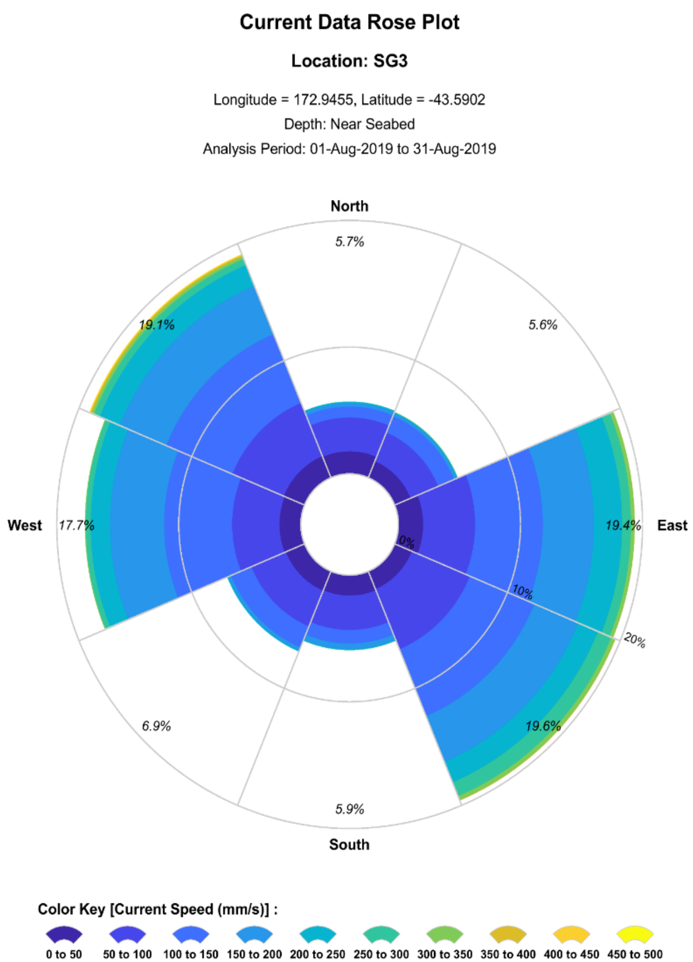




**Figure 6** Near-surface and near-seabed current speed and direction at SG3 during August 2019.
*Speed intervals of 50 mm/s are used.*

## 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 7 August 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 August 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 a 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 August 2019 dredge monitoring 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.

**August Turbidity:**

Consistent with previous monitoring months, mean surface turbidity values were typically highest (monthly means of 4.4 to 6.8 NTU) at the inshore monitoring sites (Table 3 and Figure 7). Further offshore, the spoil ground sites (Table 4) exhibited lower surface turbidity values (2.8 to 4.0 NTU), which are likely due to the deeper water column limiting expressions of seafloor sediment resuspension at the sub-surface. As typically observed, nearshore sites experienced intermediate mean turbidity values (3.8 to 5.6 NTU) during August (Table 5).

During August turbidity across the inner harbour was relatively low (~ 5 NTU) with exception of turbidity peaks on 1, 3 and 10 August in response to increased inshore winds (Figure 8). On 10 August during the period of highest rainfall for the month, maximum turbidity peaks were recorded at all four inshore sites: ~ 45 NTU at UH1 and UH2, and ~ 15 NTU at CH1 and CH2.

Surface turbidity at the nearshore sites (OS1 to 4 and OS7) peaked during 1 to 3 August and 11 and 12 August, immediately following periods of high inshore and offshore winds, with large wave heights also recorded during this latter period. Elevated wave heights were also recorded on 20 August, with sites OS3, OS4 and OS7 responding with increased turbidity on the following day. Similar to the July 2019 findings, it is likely that benthic resuspension at these sites adjacent to the north facing coastline is highly influenced by the northerly driven long swell events in addition to strong coastal wind events.

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks were also evident in early and mid-August, although less pronounced than at the inshore sites (Figures 11 and 12) most likely due to their greater depths with less movement of benthic sediments during periods higher winds and waves.

**Table 3** Mean turbidity and statistics at inshore water quality logger sites during August 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for August are means ± se, range and percentiles (n = 2967 to 2976) Baseline values modified from Fox 2018.*

| Site | Turbidity (NTU) | | |
|---|---|---|---|
| | Statistic | Surface August | Surface Baseline |
| UH1 | Mean ± se | 6.8 ± 0.1 | 12 |
| | Range | 2.2 – 45 | - |
| | 99th | 21.1 | 39 |
| | 95th | 13.3 | 22 |
| | 80th | 8.2 | 15 |
| UH2 | Mean ± se | 5.7 ± 0.1 | 10 |
| | Range | 1.5 – 46 | - |
| | 99th | 22.2 | 32 |
| | 95th | 11.6 | 20 |
| | 80th | 6.5 | 13 |
| CH1 | Mean ± se | 5.1 ± 0.0 | 9 |
| | Range | 2.4 – 18 | - |
| | 99th | 11.6 | 29 |
| | 95th | 8.6 | 18 |
| | 80th | 6.4 | 12 |
| CH2 | Mean ± se | 4.4 ± 0.0 | 8 |
| | Range | 2.5 – 13.5 | - |
| | 99th | 9.6 | 24 |
| | 95th | 7.3 | 16 |
| | 80th | 5.3 | 10 |

**Table 4** Mean turbidity and statistics at spoil ground water quality logger sites during August 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for August are means ± se, range and percentiles (n = 2953 to 2975). Baseline values modified from Fox 2018.*

| Site | Turbidity (NTU) | | |
|---|---|---|---|
| | Statistic | Surface August | Surface Baseline |
| SG1 | Mean ± se | 3.2 ± 0.0 | 4.2 |
| | Range | <1 – 15.3 | - |
| | 99th | 7.7 | 14 |
| | 95th | 6.0 | 10 |
| | 80th | 4.3 | 6.2 |
| SG2 | Mean ± se | 2.8 ± 0.0 | 4.6 |
| | Range | <1 – 15.4 | - |
| | 99th | 9.6 | 20 |
| | 95th | 6.4 | 11 |
| | 80th | 4.1 | 7.0 |
| SG3 | Mean ± se | 4.0 ± 0.0 | 3.6 |
| | Range | <1 – 17.4 | - |
| | 99th | 11.3 | 13 |
| | 95th | 8.3 | 7.7 |
| | 80th | 5.7 | 4.8 |

**Table 5** Mean turbidity and statistics at offshore water quality logger sites during August 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for August are means ± se, range and percentiles (n = 2816 to 2976). Baseline values modified from Fox 2018. *Note that no benthic turbidity data available for OS2 due to sonde malfunction.*

| Site | Statistic | Turbidity (NTU) | | |
|---|---|---|---|---|
| | | Surface August | Surface Baseline | Benthic August |
| OS1 | Mean ± se | 3.8 ± 0.0 | 7.5 | 24 ± 0.4 |
| | Range | <1 – 15.3 | - | 1.4 – 170 |
| | 99th | 13.1 | 24 | 94.4 |
| | 95th | 9.2 | 16 | 71.2 |
| | 80th | 4.9 | 10 | 42.1 |
| OS2 | Mean ± se | 5.1 ± 0.0 | 6.4 | –* |
| | Range | 1.1 – 32.5 | - | – |
| | 99th | 14.5 | 18 | – |
| | 95th | 9.1 | 13 | – |
| | 80th | 6.4 | 9.0 | – |
| OS3 | Mean ± se | 5.4 ± 0.1 | 6.6 | 21 ± 0.4 |
| | Range | <1 – 23 | - | 1.5 – 174 |
| | 99th | 17.5 | 27 | 89 |
| | 95th | 13 | 15 | 68 |
| | 80th | 6.8 | 8.9 | 31 |
| OS4 | Mean ± se | 4.9 ± 0.1 | 5.9 | 22 ± 0.4 |
| | Range | <1 – 23 | - | <1 – 188 |
| | 99th | 13.4 | 20 | 106 |
| | 95th | 10.3 | 13 | 66.6 |
| | 80th | 6.9 | 8.3 | 35.6 |
| OS5 | Mean ± se | 3.8 ± 0.0 | 4.6 | – |
| | Range | <1 – 19 | - | – |
| | 99th | 11.6 | 19 | – |
| | 95th | 8.2 | 11 | – |
| | 80th | 5.2 | 6.4 | – |
| OS6 | Mean ± se | 4.5 ± 0.0 | 4.7 | 30 ± 0.5 |
| | Range | <1 – 22 | - | 2 – 152 |
| | 99th | 13.1 | 19 | 113 |
| | 95th | 9.4 | 12 | 80.2 |
| | 80th | 6.1 | 7.2 | 46.8 |
| OS7 | Mean ± se | 5.6 ± 0.1 | 6.4 | – |
| | Range | 1 – 19 | - | – |
| | 99th | 14.7 | 23 | – |
| | 95th | 11.7 | 14 | – |
| | 80th | 7.2 | 9.2 | – |

**Comparison to Baseline:**
Mean surface turbidity values during August were similar (± 1 NTU) to values calculated from the baseline monitoring period (Tables 3 to 5, Figures 8 to 12).

**Benthic:**
Data return was gained for the majority of benthic sites during August. However, turbidity data was not able to be gained from OS2 benthic due to sonde malfunction. For the remaining sites,

benthic turbidity data corresponded with surface measurements, with increased turbidity evident during early and mid-August during periods of high winds and waves (Figure 7).

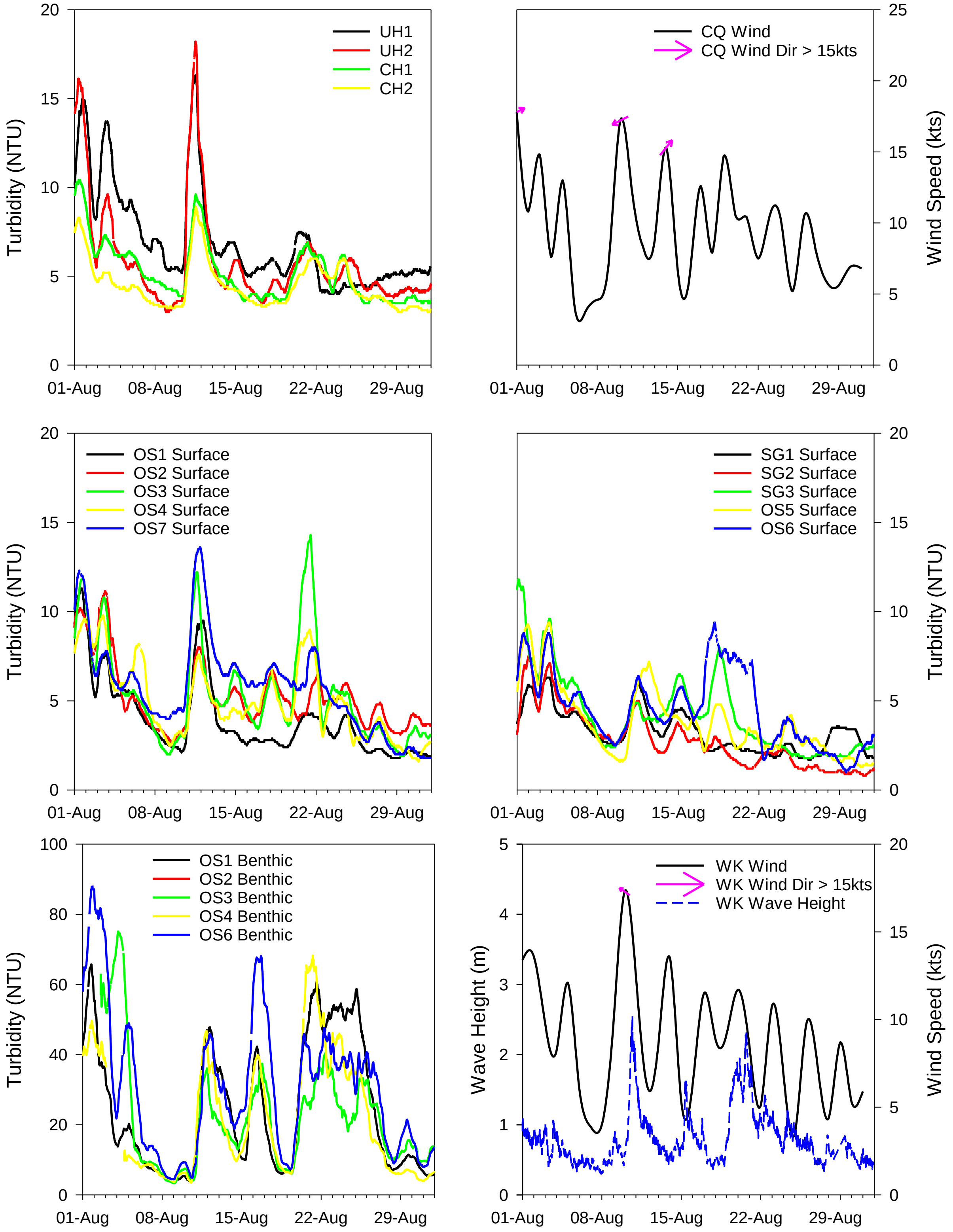



**Figure 7** 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
*Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots. *Note that no benthic turbidity data available for OS2 due to sonde malfunction.*

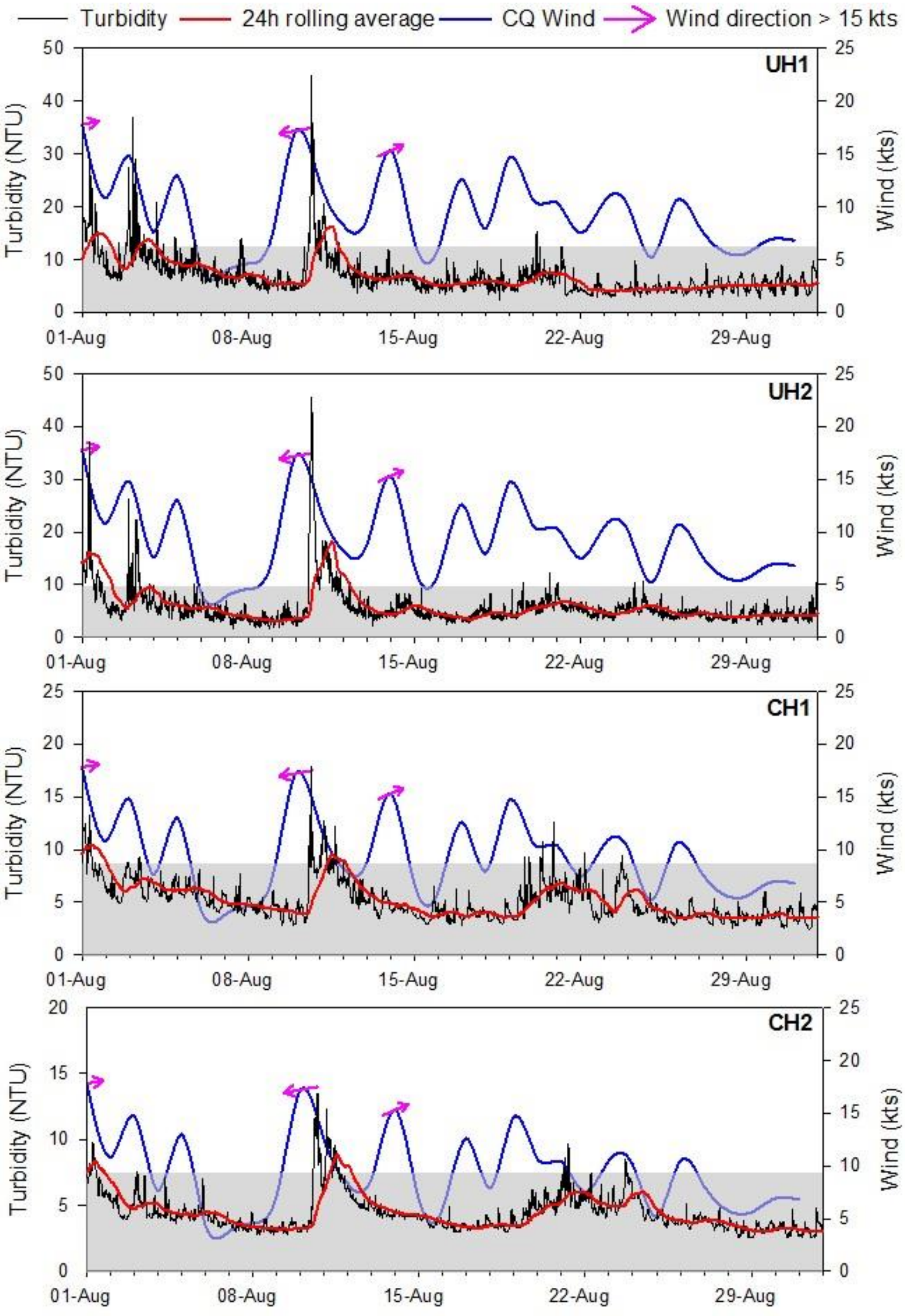



**Figure 8** Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during August 2019.
*Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

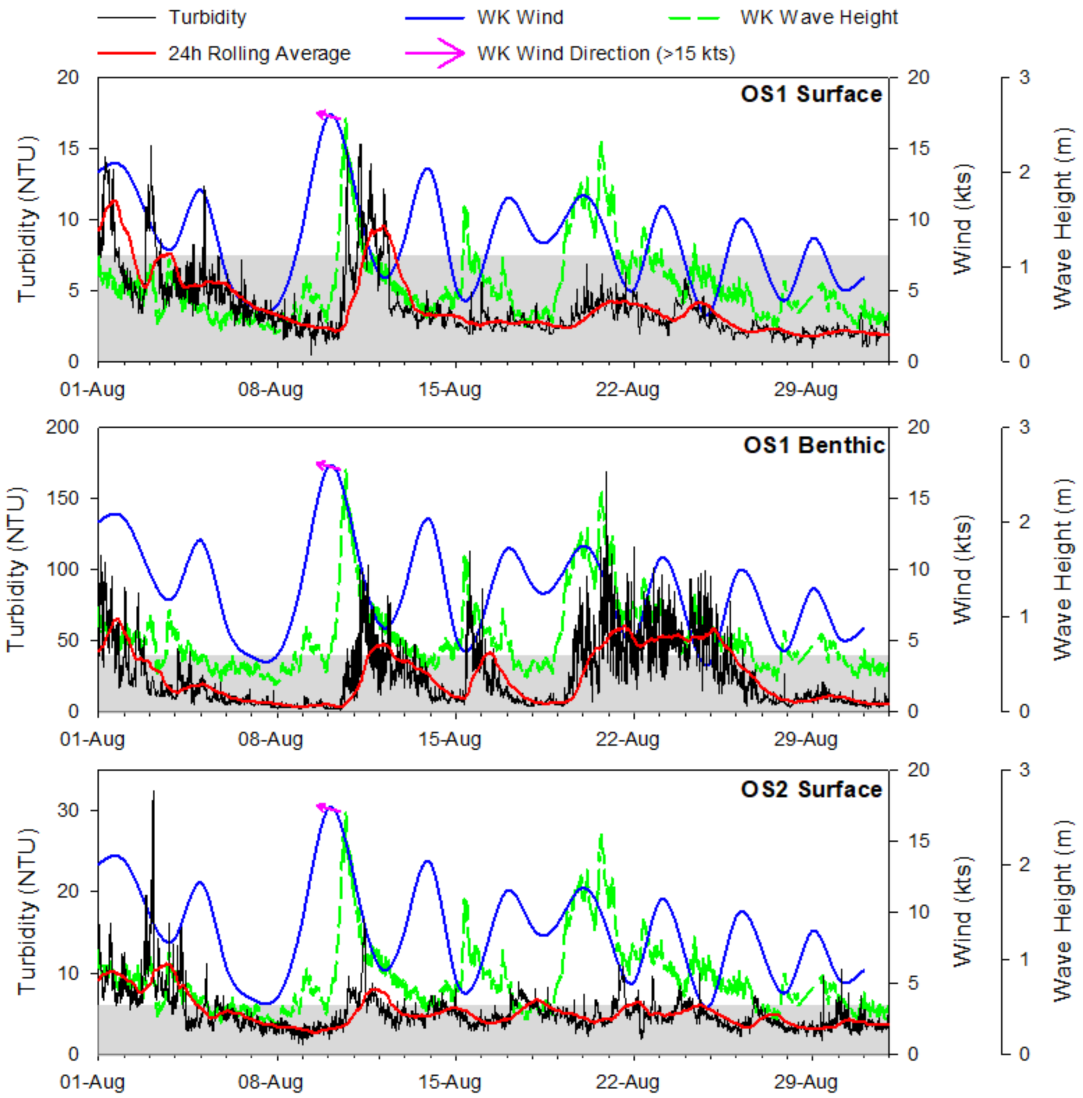



**Figure 9** Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity. *Note that no benthic turbidity data available for OS2.*

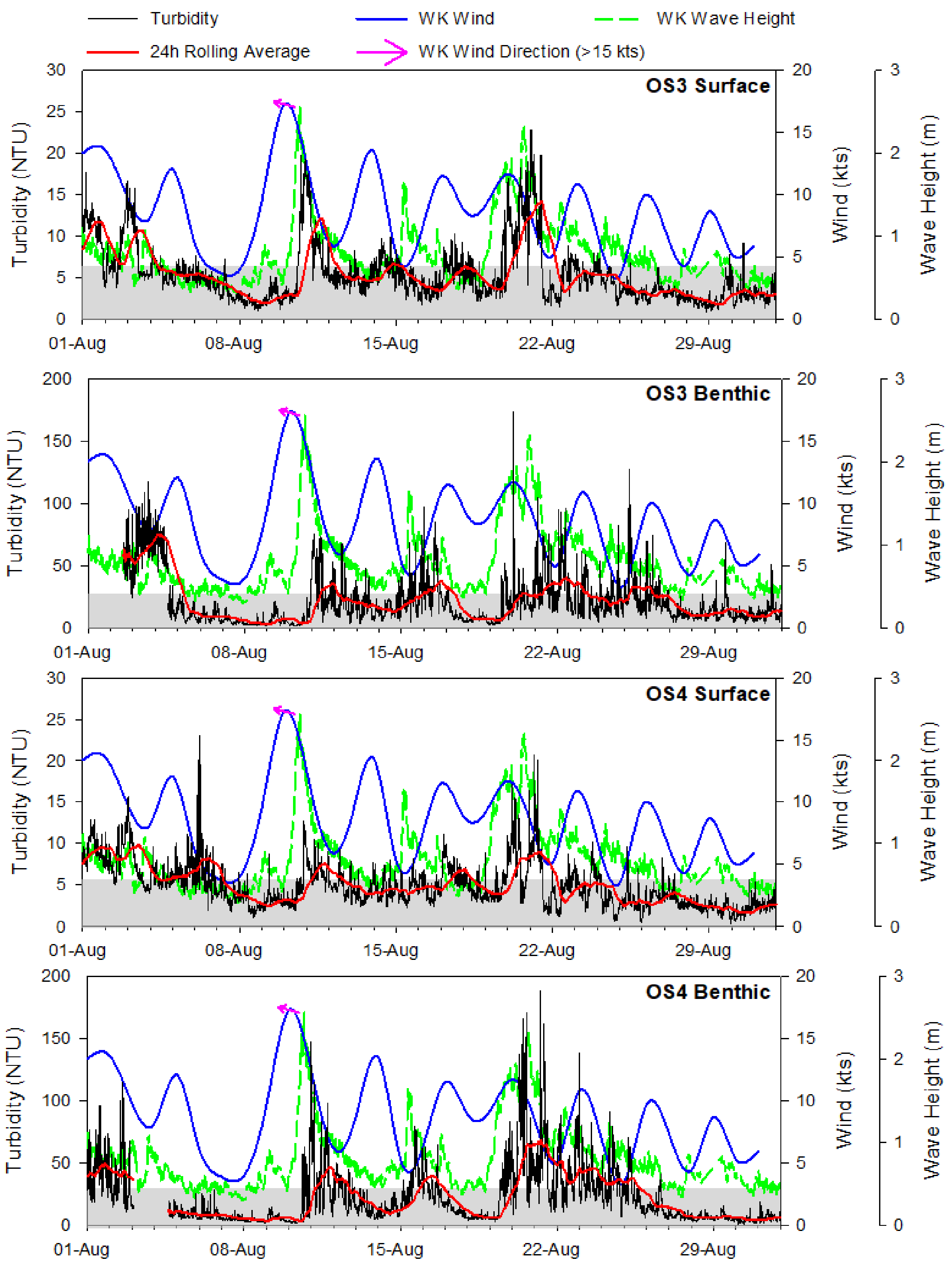



**Figure 10** Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

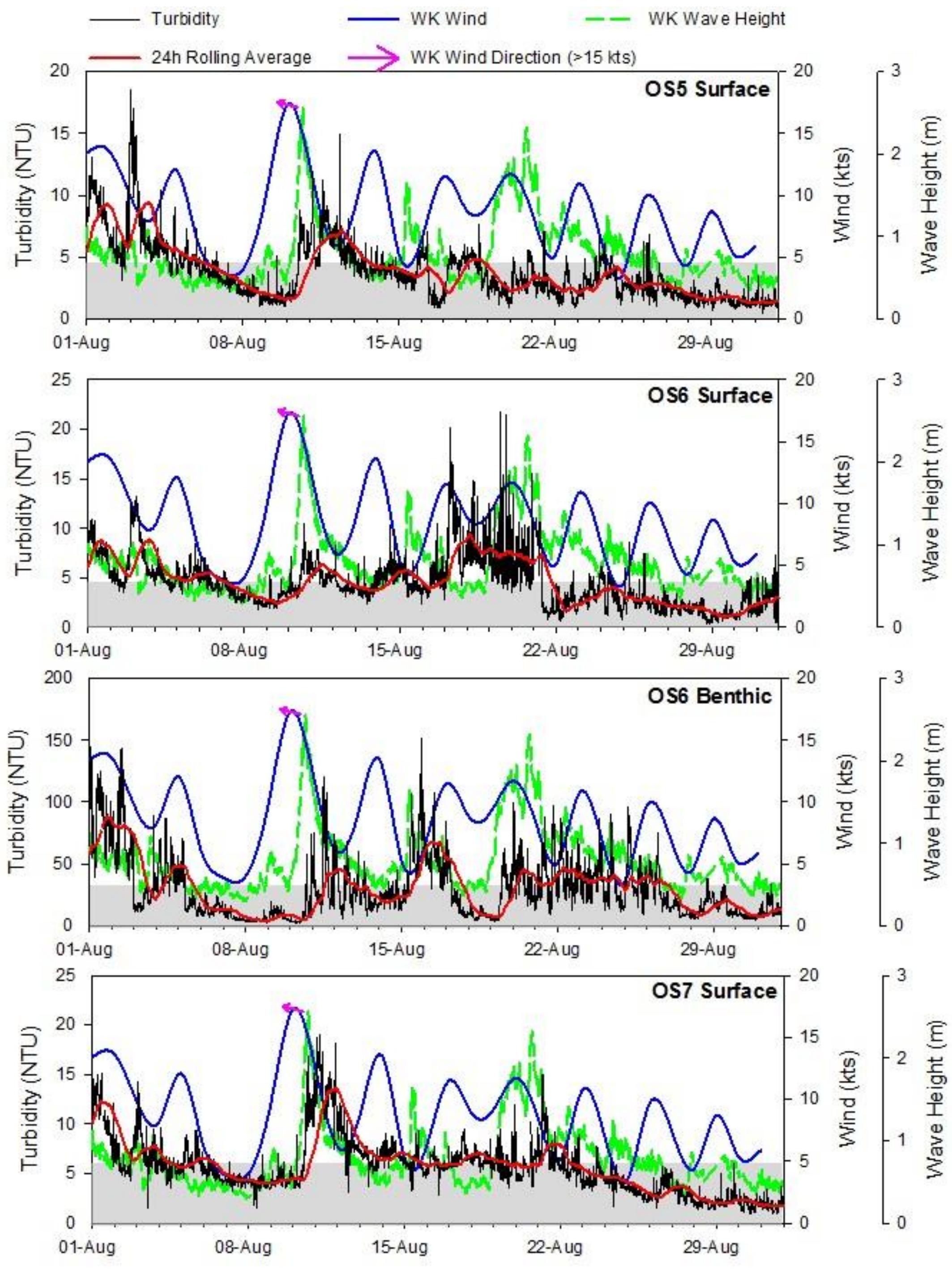



**Figure 11** Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean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

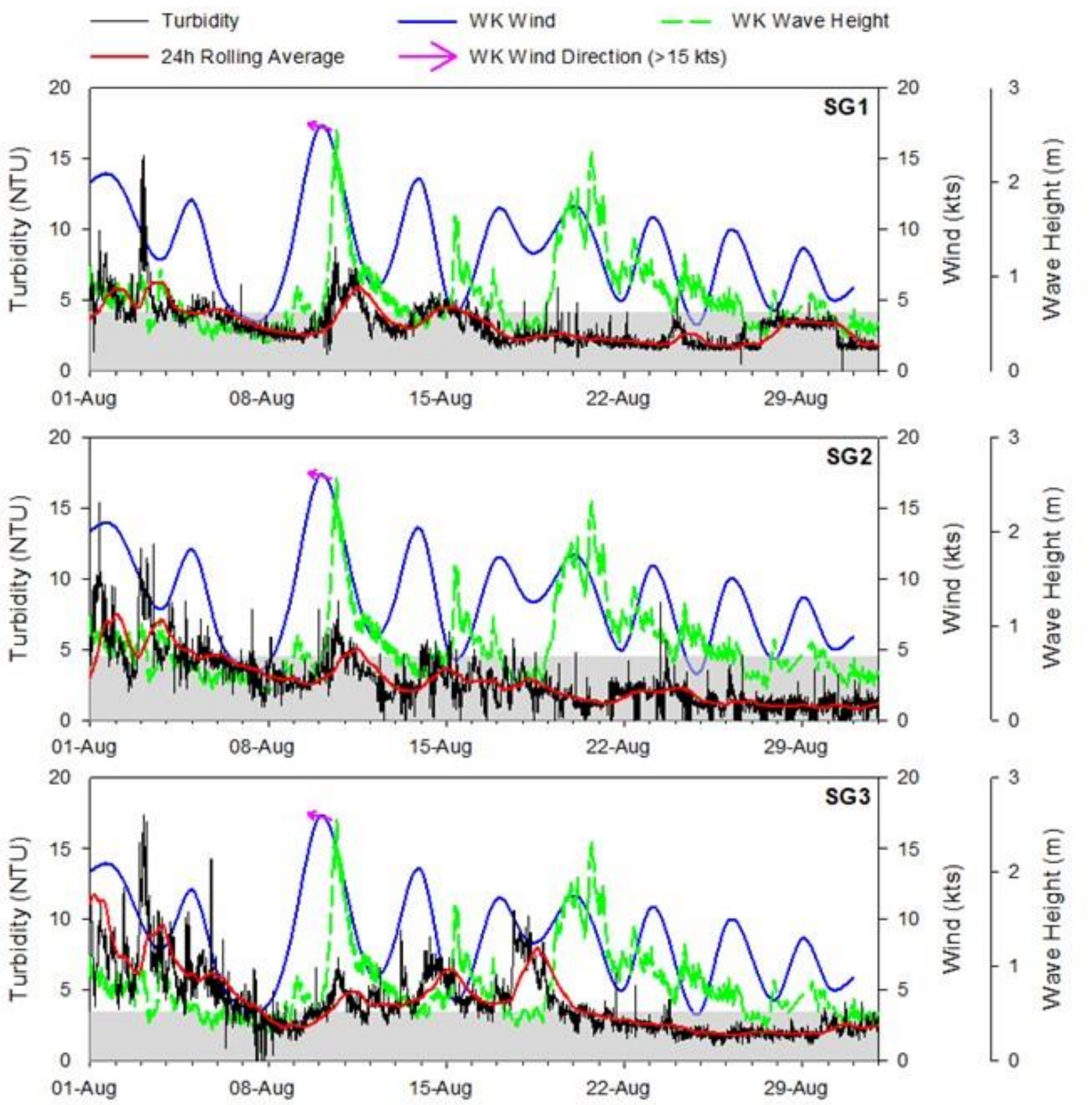



**Figure 12** Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

### *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** Site turbidity intensity values 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 August the Tier 3 intensity values were exceeded at two sites within the monitoring network (Table 7). At both sites (OS3 and SG3) the exceedances were initiated in late July during elevated swell (> 3.5 m), with the counts continuing into August due to the 30-day rolling window delaying the clearance of exceedance hours. The exceedance hour count returned to below 7.2 on 25 August at OS3 and 30 August at SG3 (Figures 14 and 15).

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

| Site | P99 Count >7.2 Hours Start Time | P99 Count >7.2 Hours End Time | Maximum P99 Count (Hours) |
|---|---|---|---|
| UH1 | - | - | 0.00 |
| UH2 | – | – | 3.3 |
| CH1 | – | – | 0.00 |
| CH2 | – | – | 0.00 |
| OS1 | – | – | 0.00 |
| OS2 | – | – | 3.3 |
| OS3 | 1/8/2019 00:00 | 24/8/19 16:45 | 26.5 |
| OS4 | Reference site | | |
| OS5 | – | – | 0.00 |
| OS6 | – | – | 0.00 |
| OS7 | – | – | 0.5 |
| SG1 | – | – | 0.00 |
| SG2 | – | – | 0.00 |
| SG3 | 1/8/2019 00:00 | 30/8/19 19:15 | 12.5 |

#### 3.2.2.2 P99 Exceedance Counts Consented Removal

No validated P99 exceedance counts were removed during August 2019 (Table 8).

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

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

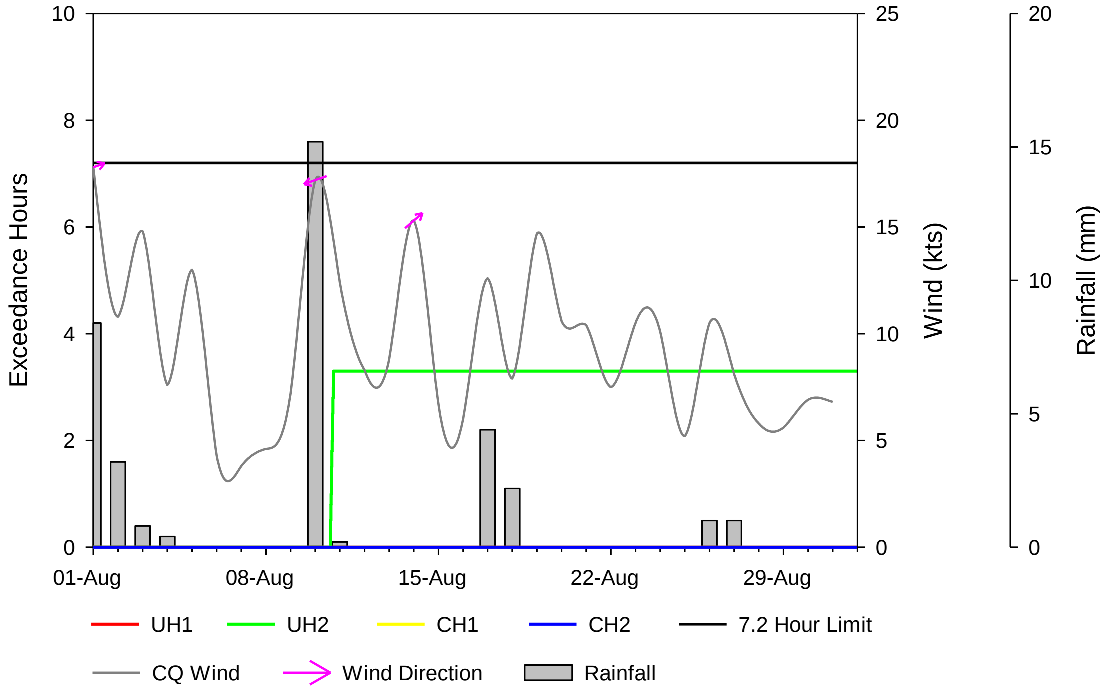



**Figure 13** Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during August 2019.

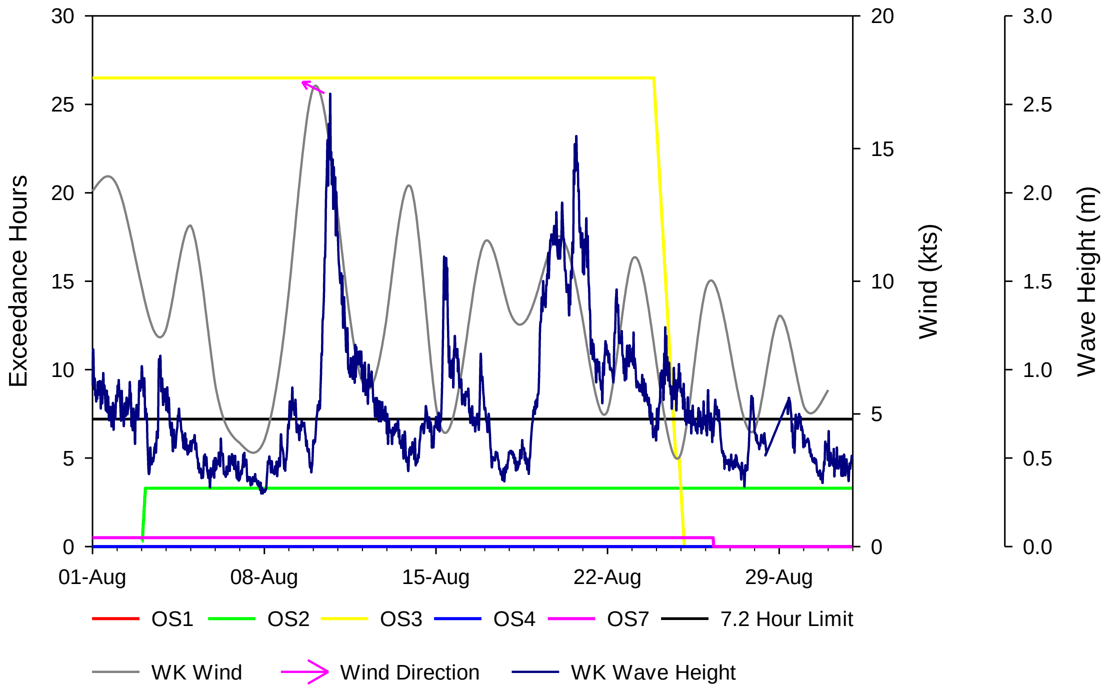



**Figure 14** Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during August 2019.
*Note there is no trigger value for the reference site OS4.*

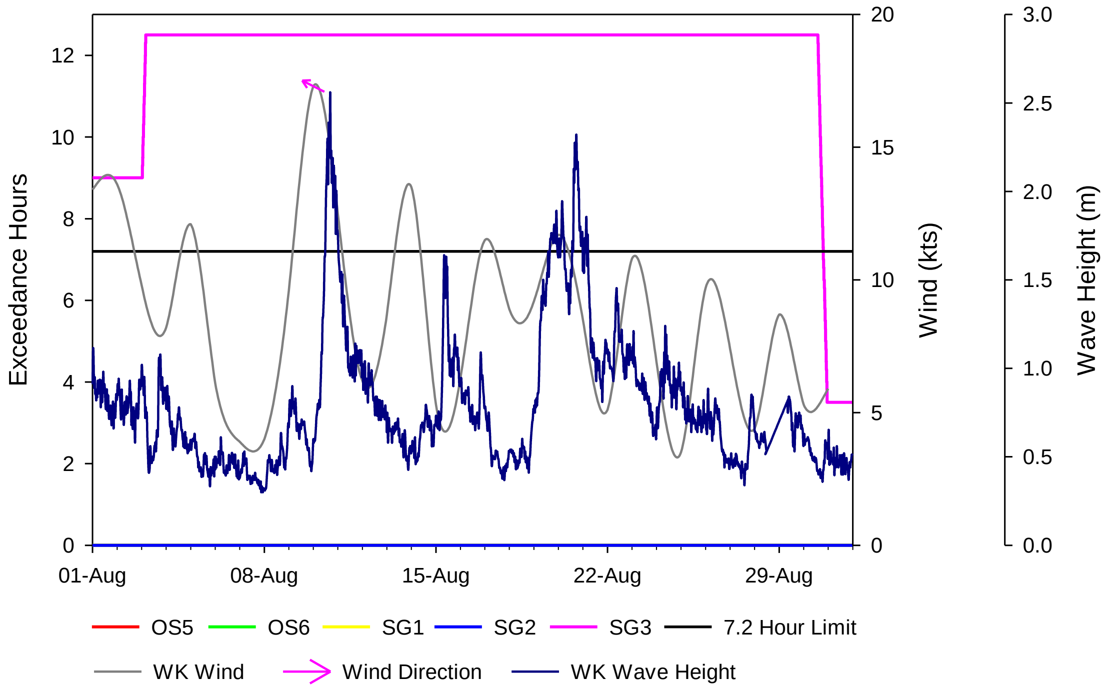



**Figure 15** Tier 3 allowable hour counts at OS5, OS6, SG1, SG2b and SG3 after exceedance of the intensity values during August 2019.

### *3.2.3 Temperature*

Mean monthly sea surface temperatures during August (8.7 to 9.7 °C) were slightly cooler than those experienced during July (8.8 to 10.8°C) indicating continued seasonal cooling (Table 9). However, slightly increasing temperatures at all sites were apparent during the last week of August (Figures 16 and 17).

**Table 9** Mean temperature at inshore, spoil ground and offshore water quality sites during August 2019. *Values are means ± se (n = 2827 to 2976).*

| Site | Temperature (°C) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 8.7 ± 0.0 | – |
| UH2 | 8.8 ± 0.0 | – |
| CH1 | 9.0 ± 0.0 | – |
| CH2 | 9.1 ± 0.0 | – |
| SG1 | 9.4 ± 0.0 | – |
| SG2 | 9.5 ± 0.0 | – |
| SG3 | 9.7 ± 0.0 | – |
| OS1 | 9.1 ± 0.0 | 9.3 ± 0.0 |
| OS2 | 9.3 ± 0.0 | 9.5 ± 0.0 |
| OS3 | 9.4 ± 0.0 | 9.4 ± 0.0 |
| OS4 | 9.4 ± 0.0 | 9.4 ± 0.0 |
| OS5 | 9.3 ± 0.0 | – |
| OS6 | 9.4 ± 0.0 | 9.5 ± 0.0 |
| OS7 | 9.2 ± 0.0 | – |

Similar to July, slightly cooler temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites during August. Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed, particularly at the inner harbour and spoil ground sites.

Benthic temperatures were slightly higher than the overlying surface waters and displayed the same surface trends indicating a well-mixed water column.

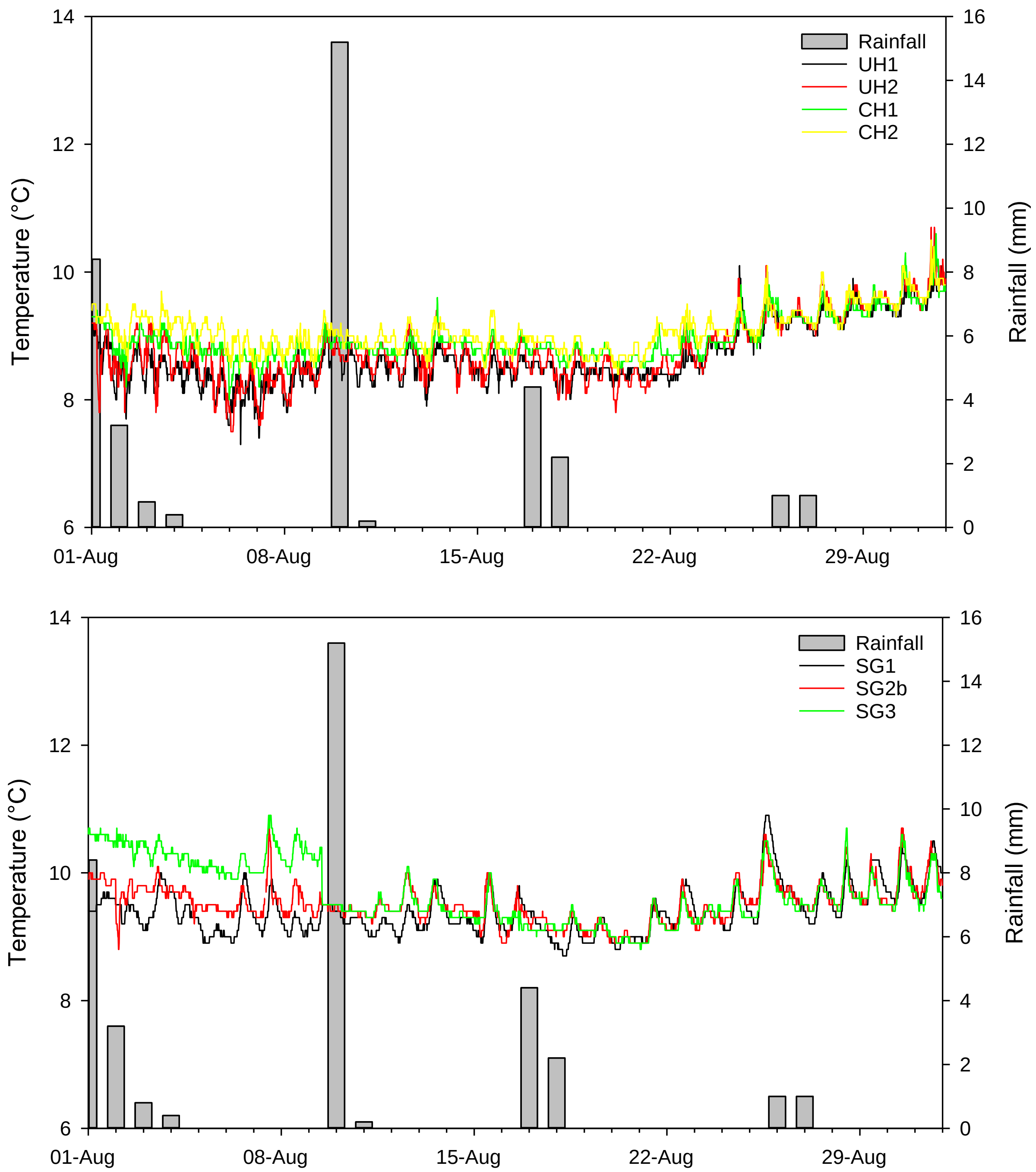



**Figure 16** Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during August 2019.

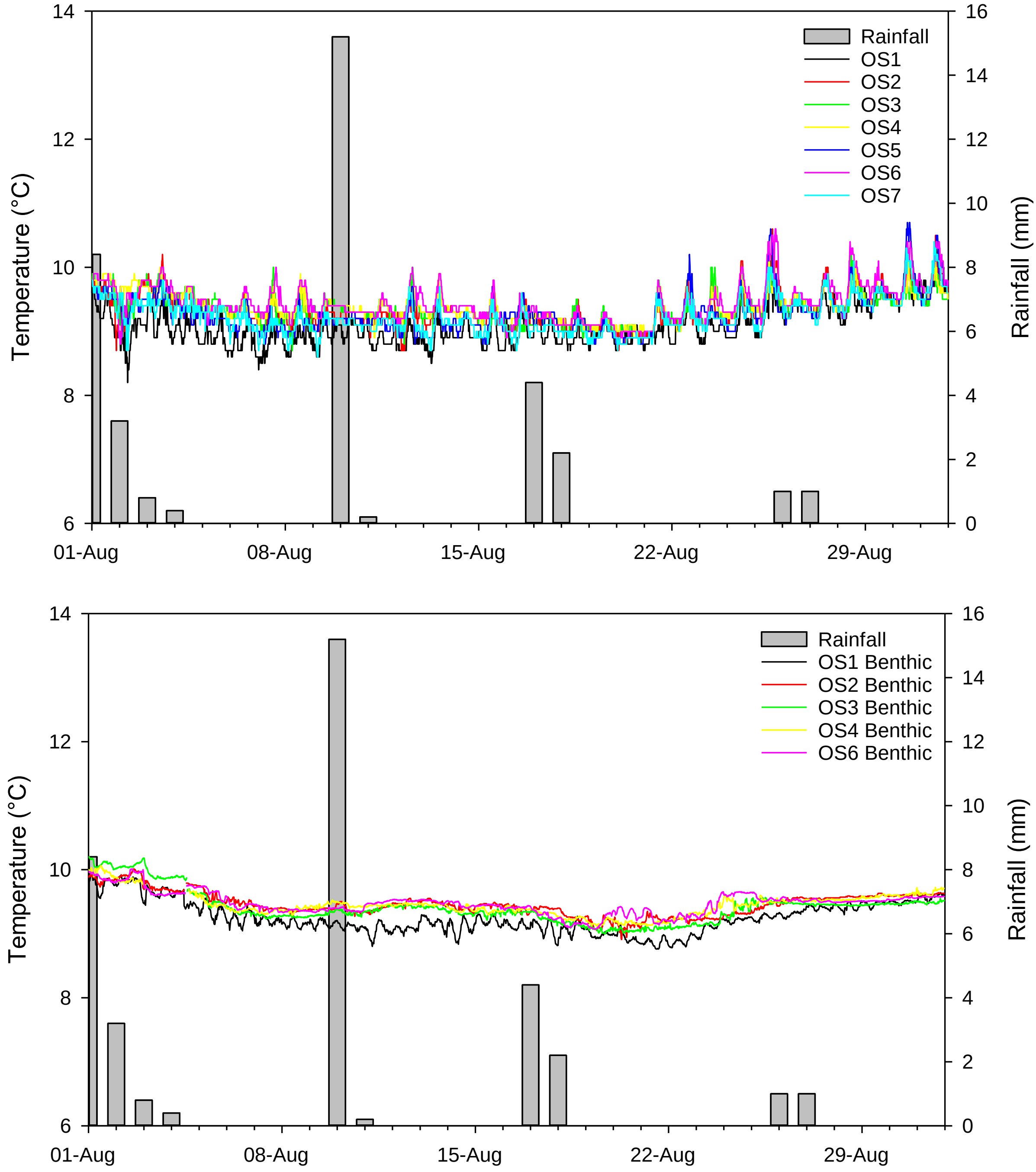



**Figure 17** Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during August 2019.

### 3.2.4 pH

The pH remained reasonably consistent across surface and benthic sites, with monthly means ranging between 8.0 and 8.2 (Table 10, Figures 18 and 19).

Some post calibration issues have been encountered with pH probes during March to August which has resulted in some unacceptable data. Troubleshooting has included the replacement of pH probes and associated hardware and firmware updates. Replacement sondes are now being rolled out across a number of sites.

**Table 10** Mean pH at inshore, spoil ground and offshore water quality sites during August 2019. *Values are means ± se (n = 334 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 | 8.2 ± 0.0 | – |
| SG2 | 8.0 ± 0.0 | – |
| SG3 | 8.1 ± 0.0 | – |
| OS1 | 8.1 ± 0.0 | 8.0 ± 0.0 |
| OS2 | 8.1 ± 0.0 | 8.2 ± 0.0 |
| OS3 | 8.0 ± 0.0 | 8.1 ± 0.0 |
| OS4 | 8.1 ± 0.0 | 8.0 ± 0.0 |
| OS5 | 8.2 ± 0.0 | – |
| OS6 | 8.1 ± 0.0 | 8.0 ± 0.0 |
| OS7 | 8.1 ± 0.0 | – |

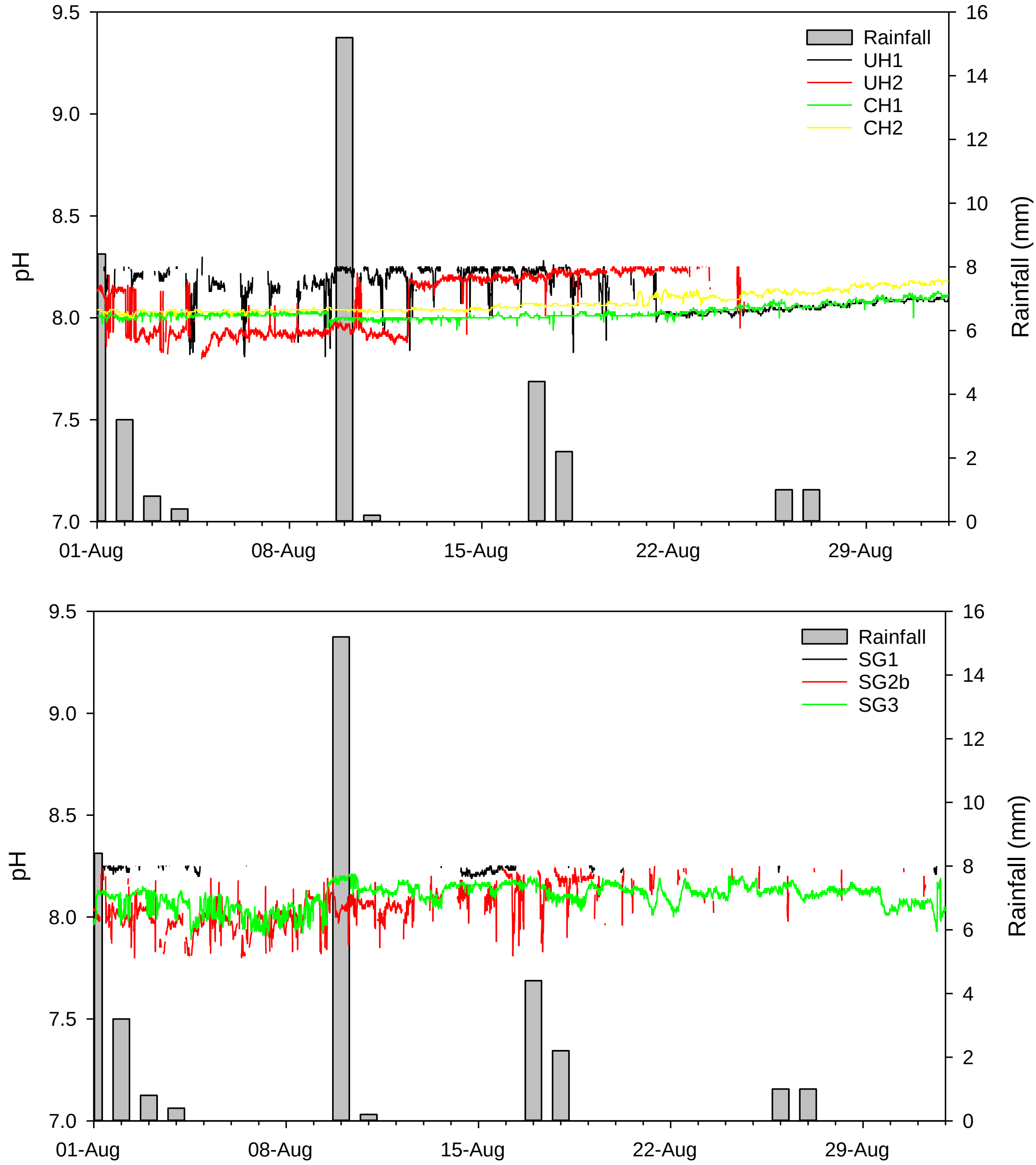



**Figure 18** Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during August 2019.

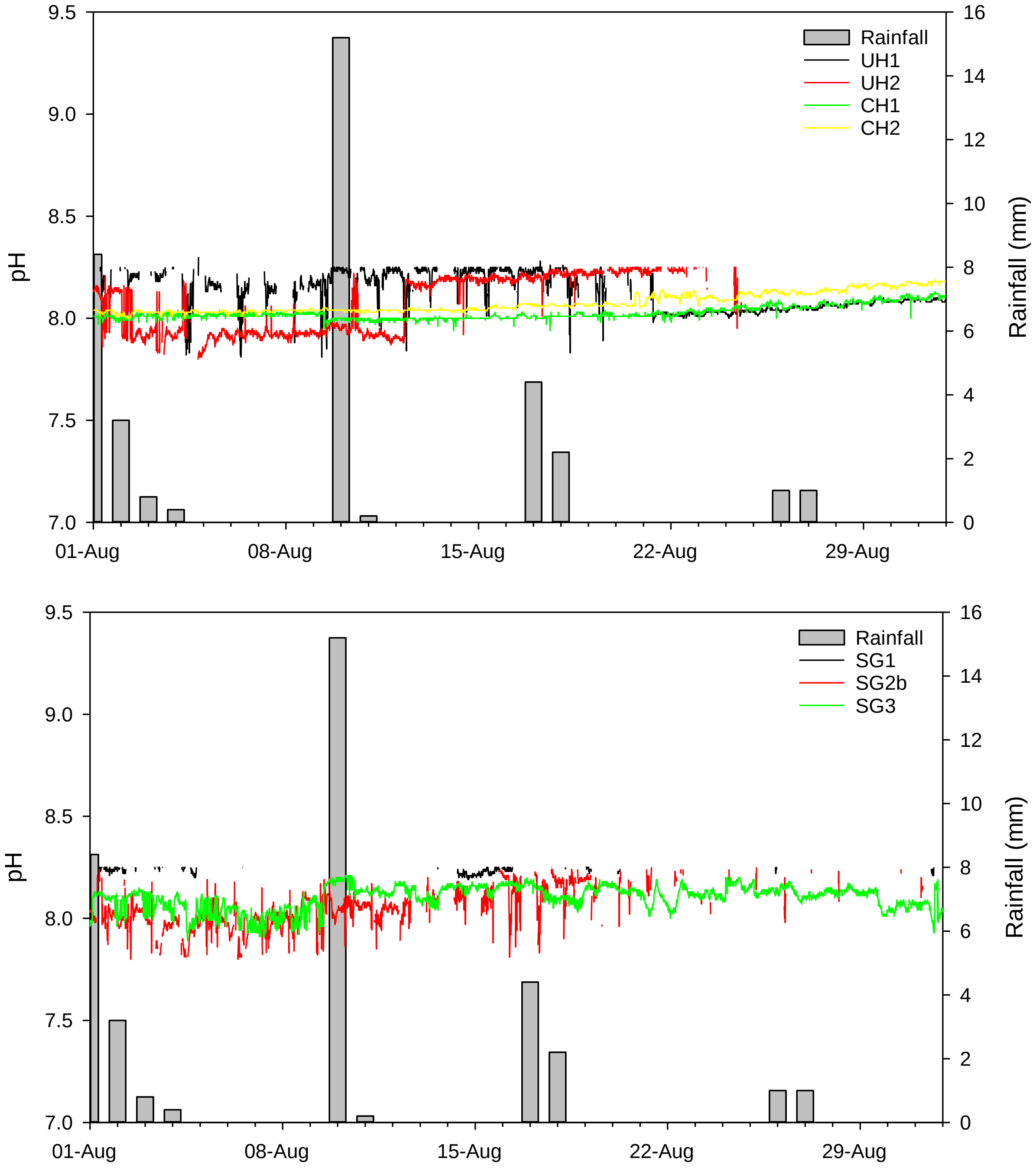



**Figure 19** Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at nearshore and offshore water quality sites during August 2019.

### 3.2.5 Conductivity

Surface conductivity in August ranged from 51.4 mS/cm to 54.0 mS/cm (Table 11, Figure 20 and 21), with benthic conductivity at similar levels, ranging from 50.7 mS/cm to 54.2 mS/cm.

Inner harbour sites recorded slightly lower mean conductivity values than offshore and spoil ground sites, which may reflect localised runoff. Low flows from the Waimakariri River were recorded during August and did not appear to have impacted conductivity at any sites.

**Table 11** Mean conductivity at inshore, spoil ground and offshore water quality sites during August 2019.
*Values are means ± se (n = 2633 to 2976).*

| Site | Conductivity (mS/cm) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 51.6 ± 0.0 | – |
| UH2 | 52.7 ± 0.0 | – |
| CH1 | 51.4 ± 0.0 | – |
| CH2 | 51.5 ± 0.0 | – |
| SG1 | 53.6 ± 0.0 | – |
| SG2 | 54.0 ± 0.0 | – |
| SG3 | 53.9 ± 0.0 | – |
| OS1 | 51.8 ± 0.0 | 54.2 ± 0.0 |
| OS2 | 53.3 ± 0.0 | 50.7 ± 0.0 |
| OS3 | 53.2 ± 0.0 | 52.8 ± 0.0 |
| OS4 | 54.0 ± 0.0 | 53.8 ± 0.0 |
| OS5 | 53.3 ± 0.0 | – |
| OS6 | 53.1 ± 0.0 | 53.8 ± 0.0 |
| OS7 | 53.3 ± 0.0 | – |

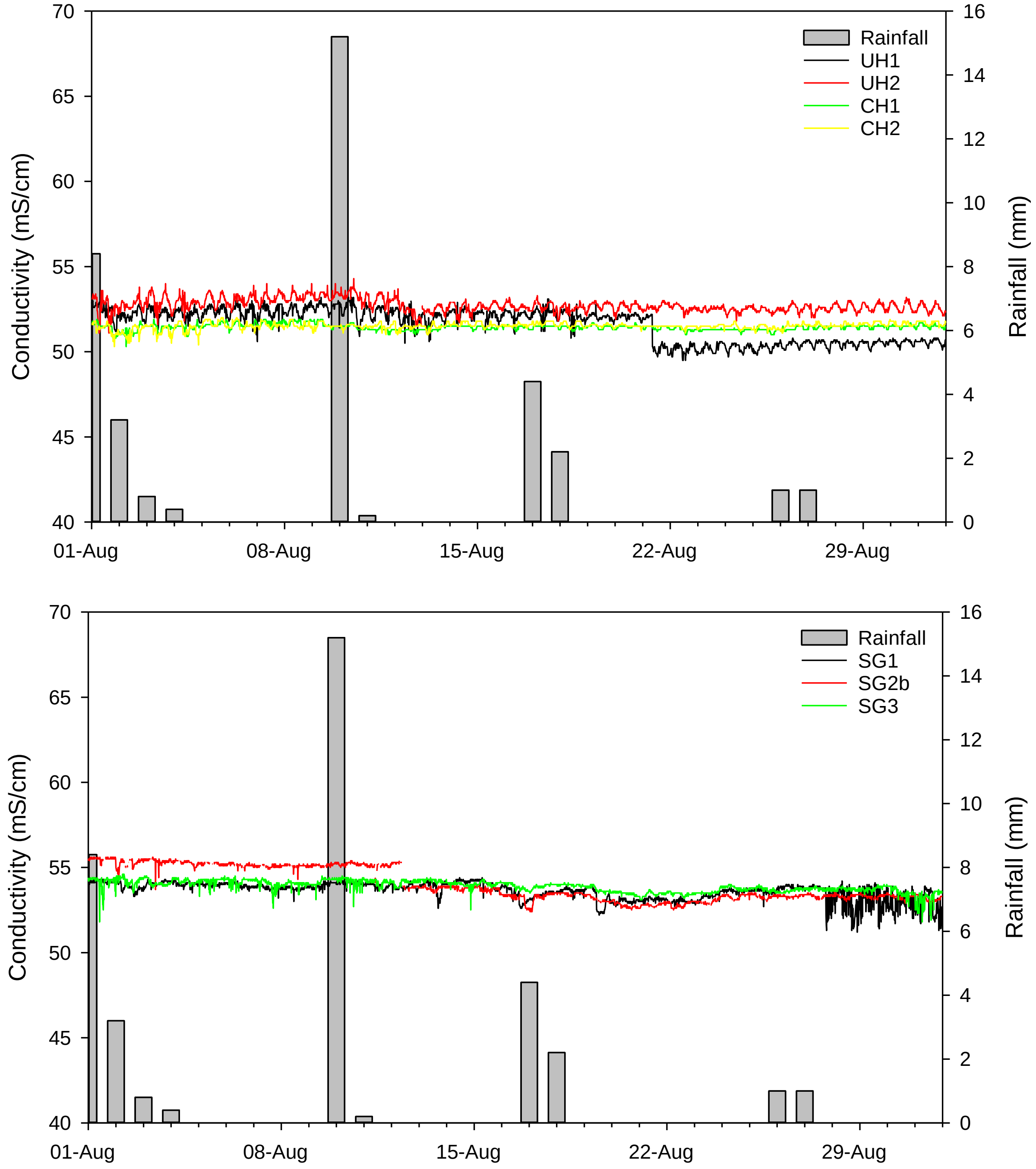



**Figure 20** Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during August 2019.

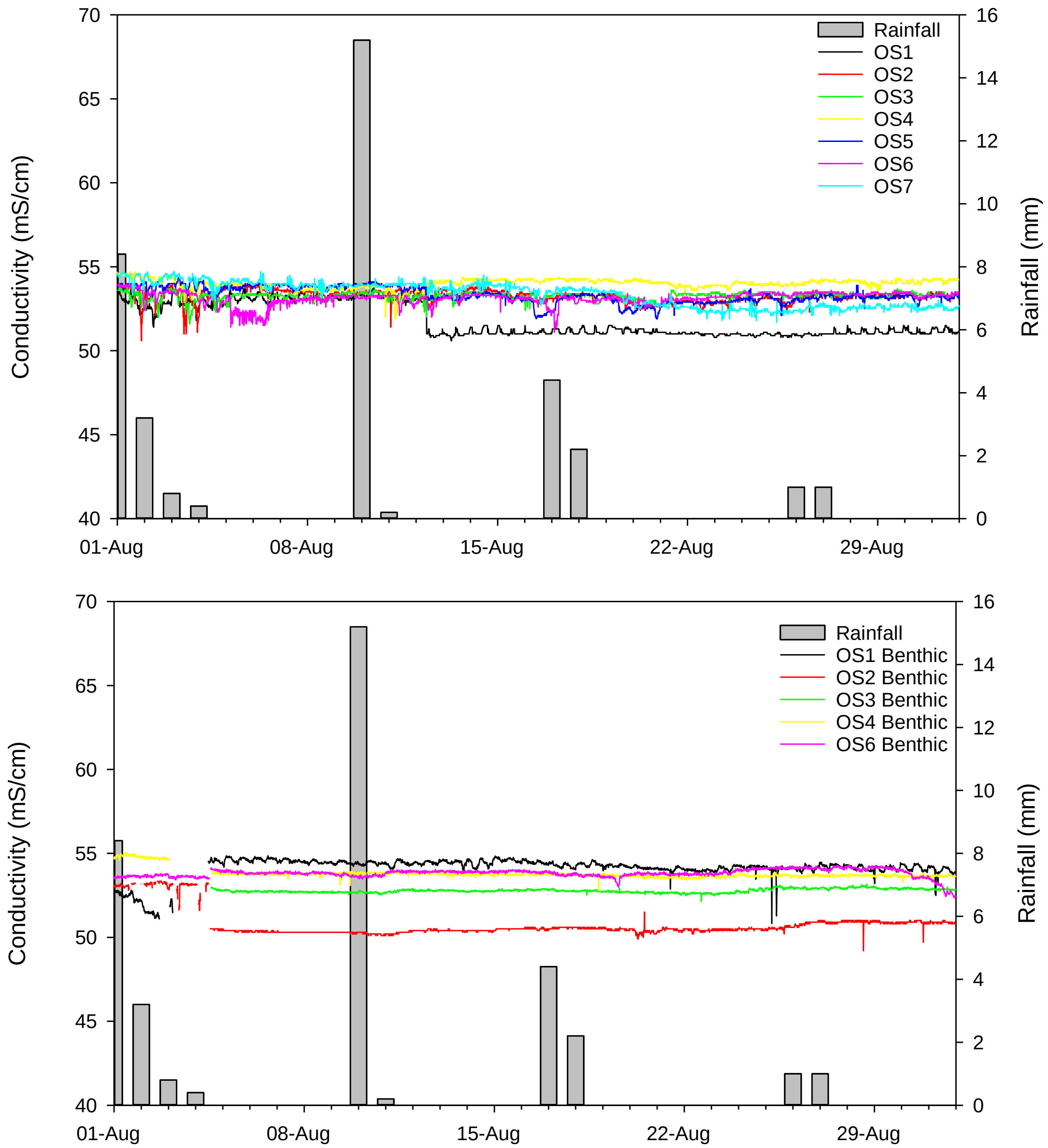



**Figure 21** Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during August 2019.

### 3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in August ranged from 94 to 104% saturation. Concentrations increased during mid to late August concurrently with the increasing temperatures. The increased temperatures likely stimulated microalgal growth, leading to increased photosynthesis and therefore increased DO concentrations.

Mean monthly benthic DO concentrations were lower than corresponding surface readings ranging from 93 to 98% saturation (Table 12, Figures 22 and 23), indicative of lower photosynthesis at the benthos. Benthic DO displayed a similar pattern to the surface counterparts with a relatively stable saturation until mid to late August where DO became more variable, likely due to increased photosynthesis and respiration.

**Table 12** Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during August 2019.
*Values are means ± se (n = 2663 to 2976).*

| Site | Dissolved oxygen (% saturation) | |
|---|---|---|
| | Surface loggers | Benthic loggers |
| UH1 | 100 ± 0 | – |
| UH2 | 100 ± 0 | – |
| CH1 | 101 ± 0 | – |
| CH2 | 104 ± 0 | – |
| SG1 | 99 ± 0 | – |
| SG2 | 101 ± 0 | – |
| SG3 | 99 ± 0 | – |
| OS1 | 99 ± 0 | 98 ± 0 |
| OS2 | 96 ± 0 | 94 ± 0 |
| OS3 | 94 ± 0 | 95 ± 0 |
| OS4 | 97 ± 0 | 96 ± 0 |
| OS5 | 97 ± 0 | – |
| OS6 | 99 ± 0 | 93 ± 0 |
| OS7 | 99 ± 0 | – |

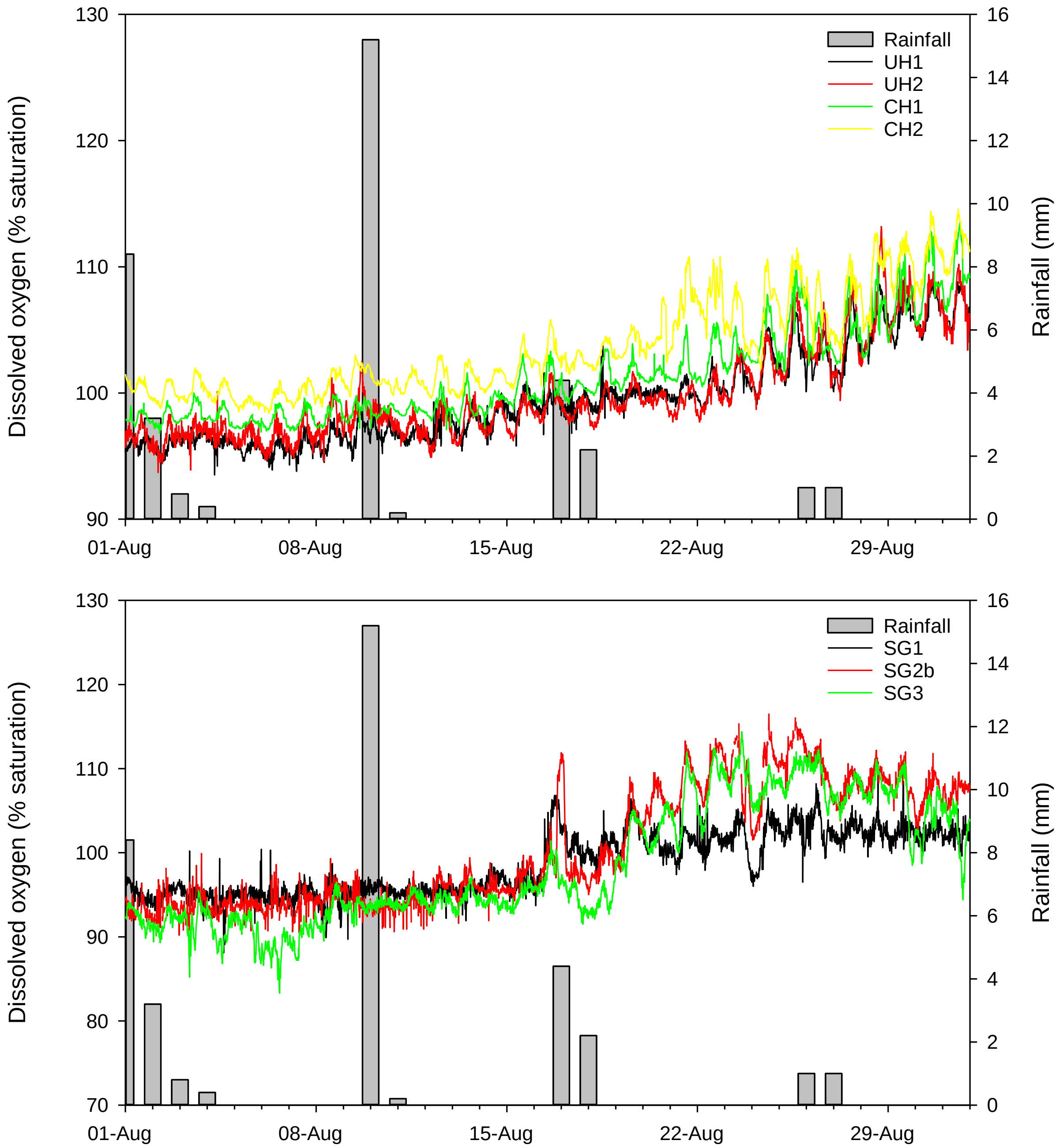



**Figure 22** Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during August 2019.

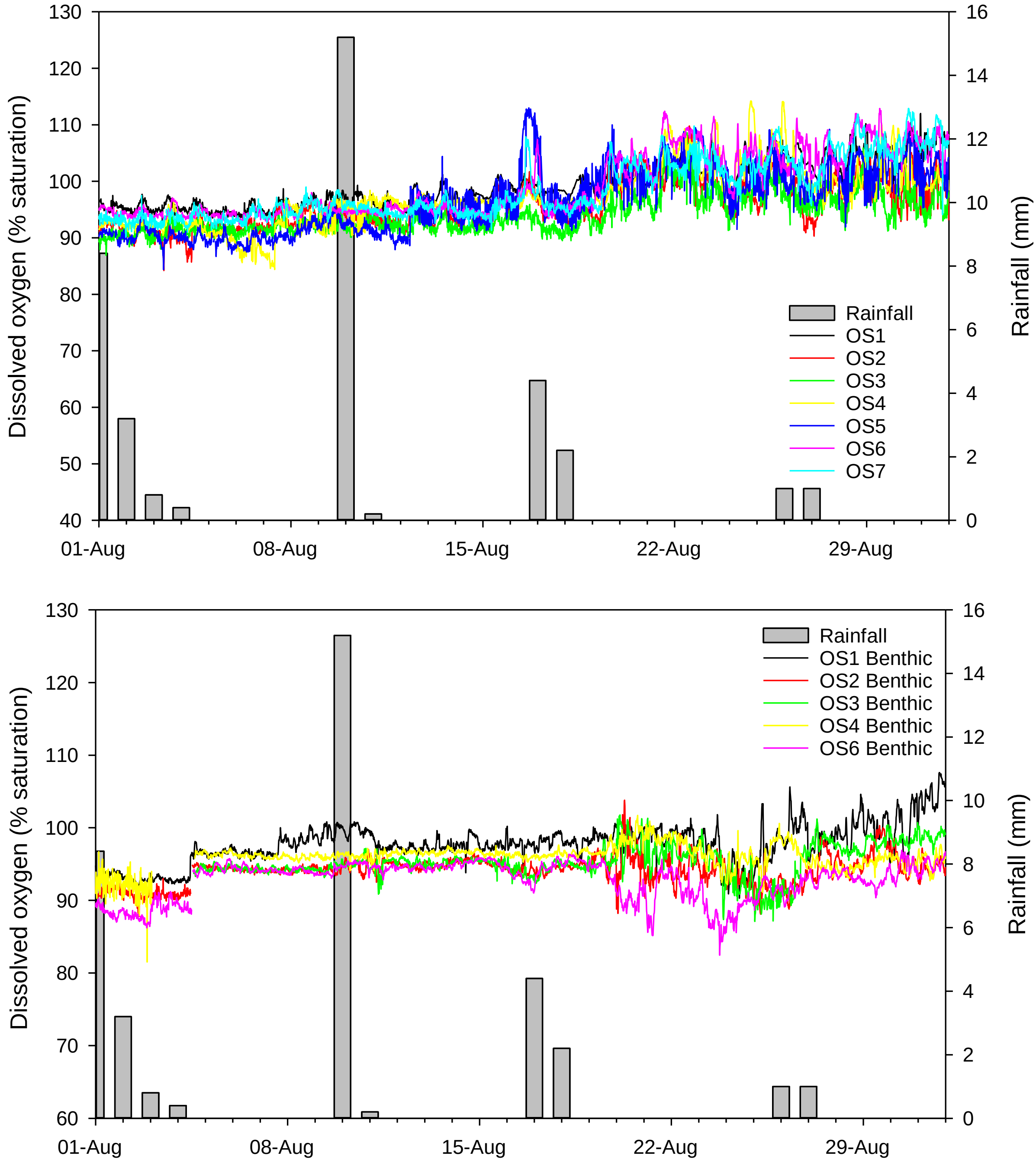



**Figure 23** Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during August 2019.

## 3.3 Physicochemistry Depth Profiling & TSS

Vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling on 7 August 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 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 at the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, UH3, 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 sites of UH3 and UH1 exhibited the lowest temperature and conductivity within the harbour. Increased turbidity near the benthos was also recorded at these sites, which is often 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 indicated vertical mixing, with little change in temperature, conductivity or pH through the water column (Figure 25). DO declined slightly from the surface to benthos, most likely due to decreasing photosynthesis with depth. Turbidity was consistent through the water column until the benthos where turbidity increased, similar to the inshore sites.

Within the offshore region of the spoil ground, OS5 and OS6, the water column also appeared to be well-mixed (Figure 26). Similar to the nearshore sites, DO decreased slightly with depth, and increased turbidity due to benthic resuspension was recorded at a number of sites at depths >15m.

The shallowest euphotic depth of 3.9 m occurred at the furthest upper harbour monitoring site UH3 (Table 14), which reflects the typically higher levels of turbidity experienced in this area (Figure 24). The deepest euphotic depth was calculated to be 10.6 m at OS5 (Table 15) where turbidity in the surface and mid-column was low. No exceedances of WQG were recorded at the sub-surface during the August vertical profiling.

**Table 13** Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the August 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 24 to 42 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

| Site | Sample date/time | Depth | Temperature (ºC) | pH | Conductivity (mS/cm) | Dissolved oxygen (% saturation) | Turbidity (NTU) | TSS (mg/L) | $K_d$ | Euphotic Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| UH1 | 07/08/2019 15:41 | Sub-surface | 8 ± 0 | 7.9 ± 0 | 49.9 ± 0 | 98 ± 0 | 5.5 ± 0.1 | 9 | 1 ± 0 | 4.6 |
| | | Whole column | 8 ± 0 | 7.9 ± 0 | 50 ± 0 | 97 ± 0 | 7.1 ± 1 | – | | |
| UH2 | 07/08/2019 14:58 | Sub-surface | 8.2 ± 0 | 7.9 ± 0 | 50.4 ± 0 | 99 ± 0 | 3.5 ± 0 | 7 | 0.8 ± 0 | 6.0 |
| | | Whole column | 8.1 ± 0 | 7.9 ± 0 | 50.4 ± 0 | 98 ± 0 | 4.4 ± 0.1 | – | | |
| UH3 | 07/08/2019 15:21 | Sub-surface | 7.5 ± 0 | 7.9 ± 0 | 49.5 ± 0 | 98 ± 0 | 5.7 ± 0.1 | 10 | 1.2 ± 0 | 3.9 |
| | | Whole column | 7.5 ± 0 | 7.9 ± 0 | 49.5 ± 0 | 98 ± 0 | 6.3 ± 0.3 | – | | |
| CH1 | 07/08/2019 09:09 | Sub-surface | 8.5 ± 0 | 7.9 ± 0 | 51.1 ± 0 | 96 ± 0 | 3.7 ± 0 | 6 | 0.7 ± 0 | 6.7 |
| | | Whole column | 8.6 ± 0.1 | 7.9 ± 0 | 51.2 ± 0 | 96 ± 0 | 5 ± 0.8 | – | | |
| CH2 | 07/08/2019 14:35 | Sub-surface | 8.9 ± 0 | 8 ± 0 | 51 ± 0 | 98 ± 0 | 2.9 ± 0 | 4 | 0.6 ± 0 | 8.1 |
| | | Whole column | 8.7 ± 0.1 | 8 ± 0 | 51.2 ± 0 | 97 ± 0 | 3.4 ± 0.1 | – | | |
| **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 August 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 34 to 42 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

| Site | Sample date/time | Depth | Temperature (ºC) | pH | Conductivity (mS/cm) | Dissolved oxygen (% saturation) | Turbidity (NTU) | TSS (mg/L) | $K_d$ | Euphotic Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| OS1 | 07/08/2019 09:31 | Sub-surface | 8.6 ± 0 | 7.9 ± 0 | 51.3 ± 0 | 96 ± 0 | 3 ± 0 | 4 | 0.6 ± 0 | 7.7 |
| | | Mid | 9.1 ± 0 | 7.9 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.9 ± 0.1 | 21 | | |
| | | Benthos | 9.1 ± 0 | 7.9 ± 0 | 51.7 ± 0 | 96 ± 0 | 20 ± 13 | 6 | | |
| | | Whole column | 8.9 ± 0.1 | 7.9 ± 0 | 51.5 ± 0 | 96 ± 0 | 6.3 ± 2.2 | – | | |
| OS2 | 07/08/2019 13:41 | Sub-surface | 9.3 ± 0 | 8 ± 0 | 51.6 ± 0 | 98 ± 0 | 2.7 ± 0 | 4 | 0.5 ± 0 | 9.0 |
| | | Mid | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.5 ± 0.2 | 32 | | |
| | | Benthos | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 95 ± 0 | 4.6 ± 0.2 | 5 | | |
| | | Whole column | 9.1 ± 0.1 | 8 ± 0 | 51.7 ± 0 | 97 ± 0 | 3.4 ± 0.1 | – | | |
| OS3 | 07/08/2019 12:39 | Sub-surface | 9.3 ± 0 | 8 ± 0 | 51.7 ± 0 | 97 ± 0 | 3.1 ± 0 | 4 | 0.5 ± 0 | 9.3 |
| | | Mid | 9.2 ± 0 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.4 ± 0.1 | 6 | | |
| | | Benthos | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 95 ± 0 | 4.1 ± 0.2 | 3 | | |
| | | Whole column | 9.2 ± 0.1 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.5 ± 0.1 | – | | |
| OS4 | 07/08/2019 12:06 | Sub-surface | 9.3 ± 0 | 8 ± 0 | 51.7 ± 0 | 97 ± 0 | 3.2 ± 0.1 | 4 | 0.5 ± 0 | 8.5 |
| | | Mid | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 4.2 ± 0.1 | 7 | | |
| | | Benthos | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 5.9 ± 1.2 | 8 | | |
| | | Whole column | 9.2 ± 0.1 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 4.2 ± 0.2 | - | | |
| OS7 | 07/08/2019 14:05 | Sub-surface | 9.1 ± 0.1 | 8 ± 0 | 51.2 ± 0 | 99 ± 0 | 2.6 ± 0 | 3 | 0.5 ± 0 | 9.3 |
| | | Mid | 8.8 ± 0 | 8 ± 0 | 51.5 ± 0 | 98 ± 0 | 2.8 ± 0.1 | 6 | | |
| | | Benthos | 8.8 ± 0 | 8 ± 0 | 51.5 ± 0 | 98 ± 0 | 4.7 ± 1 | 6 | | |
| | | Whole column | 8.9 ± 0.1 | 8 ± 0 | 51.4 ± 0 | 98 ± 0 | 3.1 ± 0.2 | – | | |
| **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 August 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 43 to 51 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

| Site | Sample date/time | Depth | Temperature (ºC) | pH | Conductivity (mS/cm) | Dissolved oxygen (% saturation) | Turbidity (NTU) | TSS (mg/L) | $K_d$ | Euphotic Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| OS5 | 07/08/2019 09:55 | Sub-surface | 8.8 ± 0 | 7.9 ± 0 | 51.5 ± 0 | 97 ± 0 | 2.7 ± 0 | <3 | 0.4 ± 0 | 10.6 |
| | | Mid | 8.9 ± 0 | 7.9 ± 0 | 51.6 ± 0 | 97 ± 0 | 2.5 ± 0 | 6 | | |
| | | Benthos | 9.2 ± 0 | 7.9 ± 0 | 51.8 ± 0 | 96 ± 0 | 7.4 ± 1.5 | 5 | | |
| | | Whole column | 8.9 ± 0.1 | 7.9 ± 0 | 51.6 ± 0 | 97 ± 0 | 3.3 ± 0.3 | – | | |
| OS6 | 07/08/2019 13:12 | Sub-surface | 9.4 ± 0.1 | 8 ± 0 | 51.7 ± 0 | 97 ± 0 | 2.8 ± 0 | 5 | 0.5 ± 0 | 9.7 |
| | | Mid | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.4 ± 0 | 15 | | |
| | | Benthos | 9.1 ± 0 | 8 ± 0 | 51.8 ± 0 | 95 ± 0 | 5 ± 0.5 | 5 | | |
| | | Whole column | 9.2 ± 0.1 | 8 ± 0 | 51.7 ± 0 | 96 ± 0 | 3.5 ± 0.1 | – | | |
| SG1 | 07/08/2019 10:21 | Sub-surface | 9.1 ± 0 | 8 ± 0 | 51.7 ± 0 | 98 ± 0 | 2.5 ± 0 | 4 | 0.5 ± 0 | 10.0 |
| | | Mid | 9.2 ± 0 | 8 ± 0 | 51.8 ± 0 | 97 ± 0 | 2.8 ± 0 | 23 | | |
| | | Benthos | 9.3 ± 0 | 8 ± 0 | 51.9 ± 0 | 94 ± 0 | 10 ± 1 | <3 | | |
| | | Whole column | 9.1 ± 0.1 | 8 ± 0 | 51.8 ± 0 | 97 ± 0 | 3.8 ± 0.4 | – | | |
| SG2 | 07/08/2019 10:51 | Sub-surface | 9.2 ± 0 | 8 ± 0 | 51.8 ± 0 | 98 ± 0 | 2.6 ± 0 | 4 | 0.4 ± 0 | 10.5 |
| | | Mid | 9.1 ± 0 | 8 ± 0 | 51.8 ± 0 | 97 ± 0 | 2.9 ± 0 | 10 | | |
| | | Benthos | 9.2 ± 0 | 8 ± 0 | 51.9 ± 0 | 96 ± 0 | 8.3 ± 1.9 | 4 | | |
| | | Whole column | 9.2 ± 0.1 | 8 ± 0 | 51.9 ± 0 | 97 ± 0 | 3.9 ± 0.3 | – | | |
| SG3 | 07/08/2019 11:23 | Sub-surface | 9.3 ± 0 | 8 ± 0 | 51.7 ± 0 | 98 ± 0 | 2.5 ± 0 | 4 | 0.5 ± 0 | 9.3 |
| | | Mid | 9.2 ± 0 | 8 ± 0 | 51.9 ± 0 | 97 ± 0 | 3.3 ± 0.2 | 13 | | |
| | | Benthos | 9.3 ± 0 | 8 ± 0 | 52 ± 0 | 96 ± 0 | 15 ± 5 | 8 | | |
| | | Whole column | 9.2 ± 0.1 | 8 ± 0 | 51.9 ± 0 | 97 ± 0 | 4.8 ± 0.8 | – | | |
| **WQG** | | | **–** | **7.0 – 8.5** | **–** | **80 – 110** | **10** | **–** | **–** | |

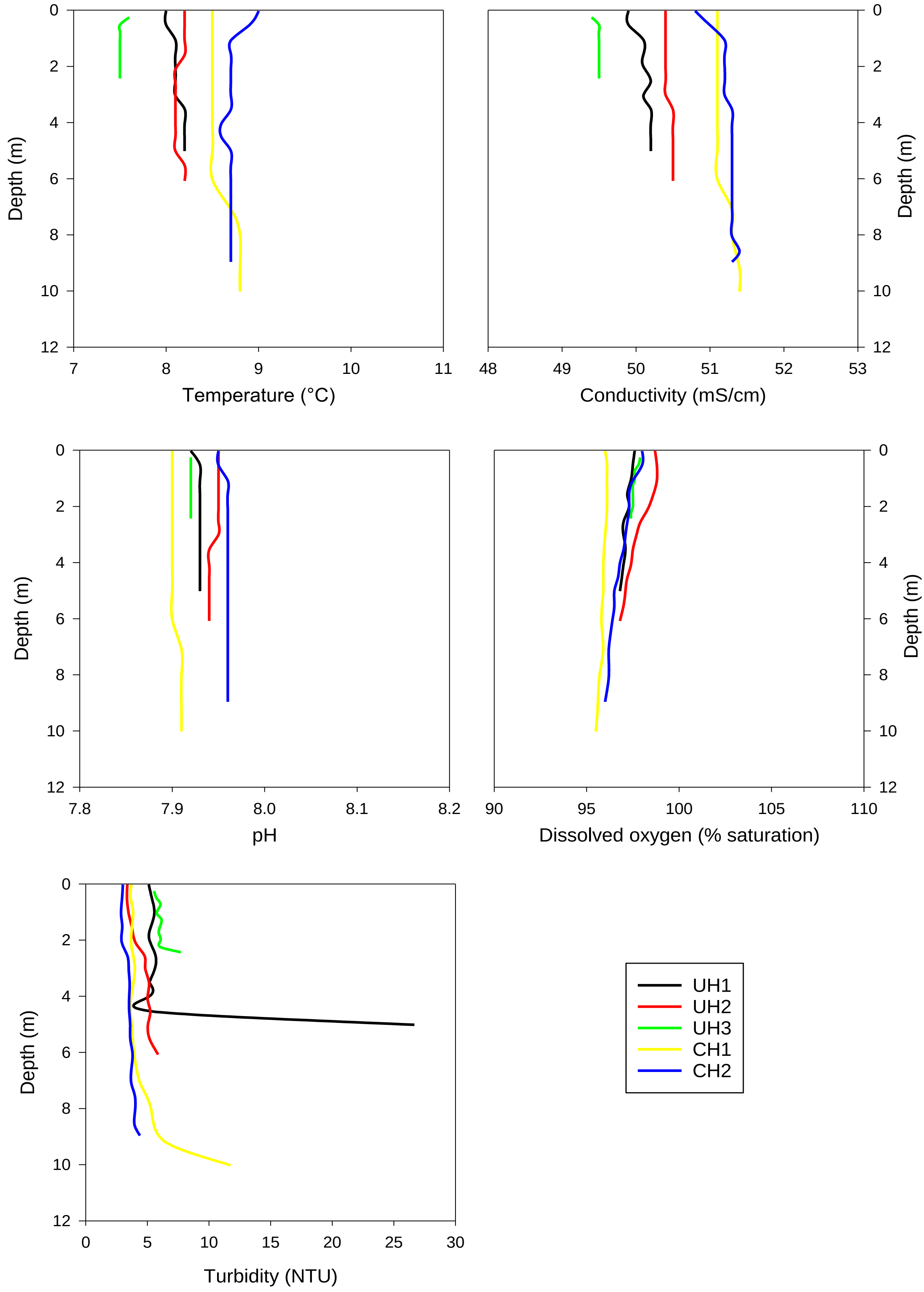



**Figure 24** Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 7 August 2019.

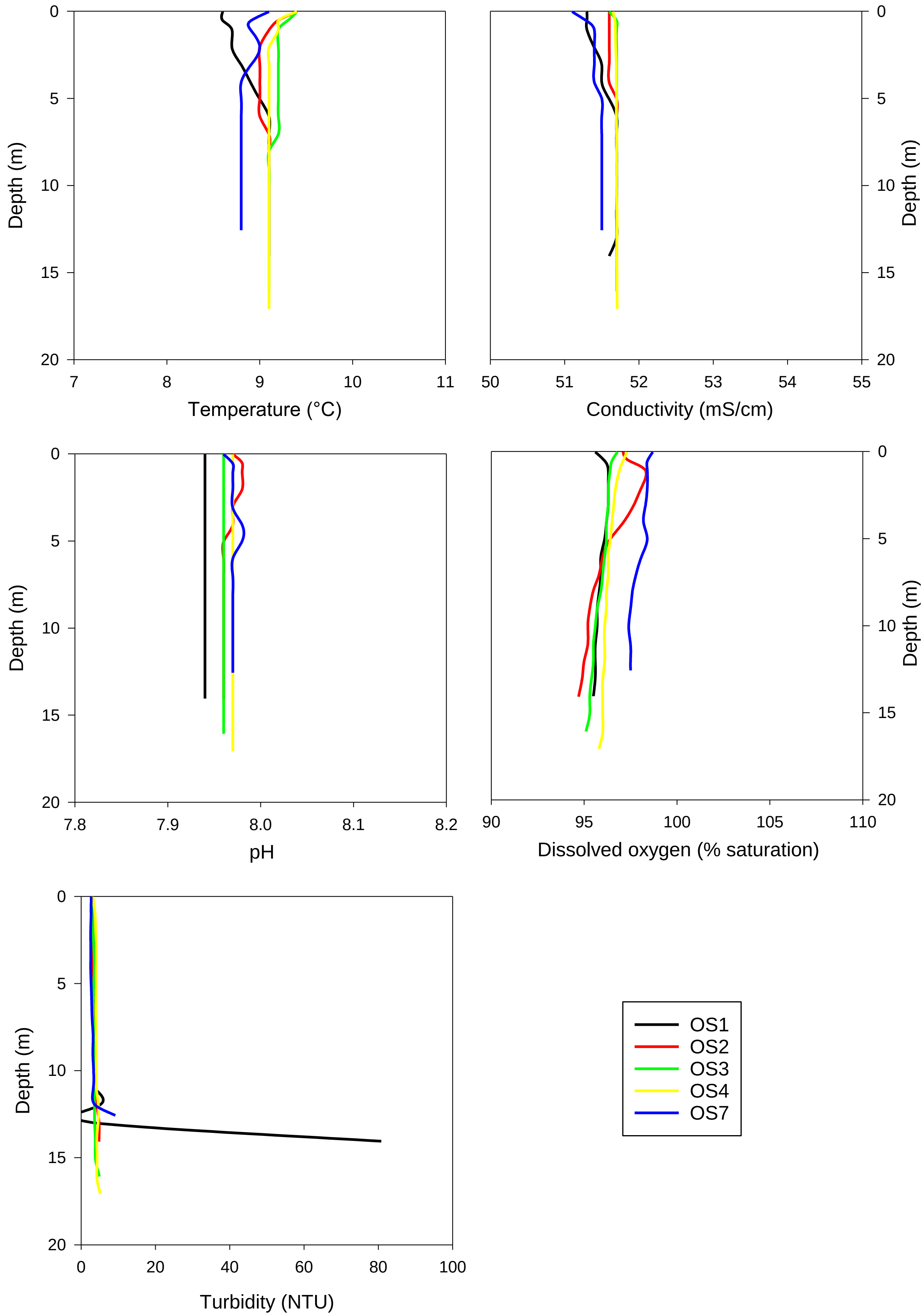



**Figure 25** Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 7 August 2019.

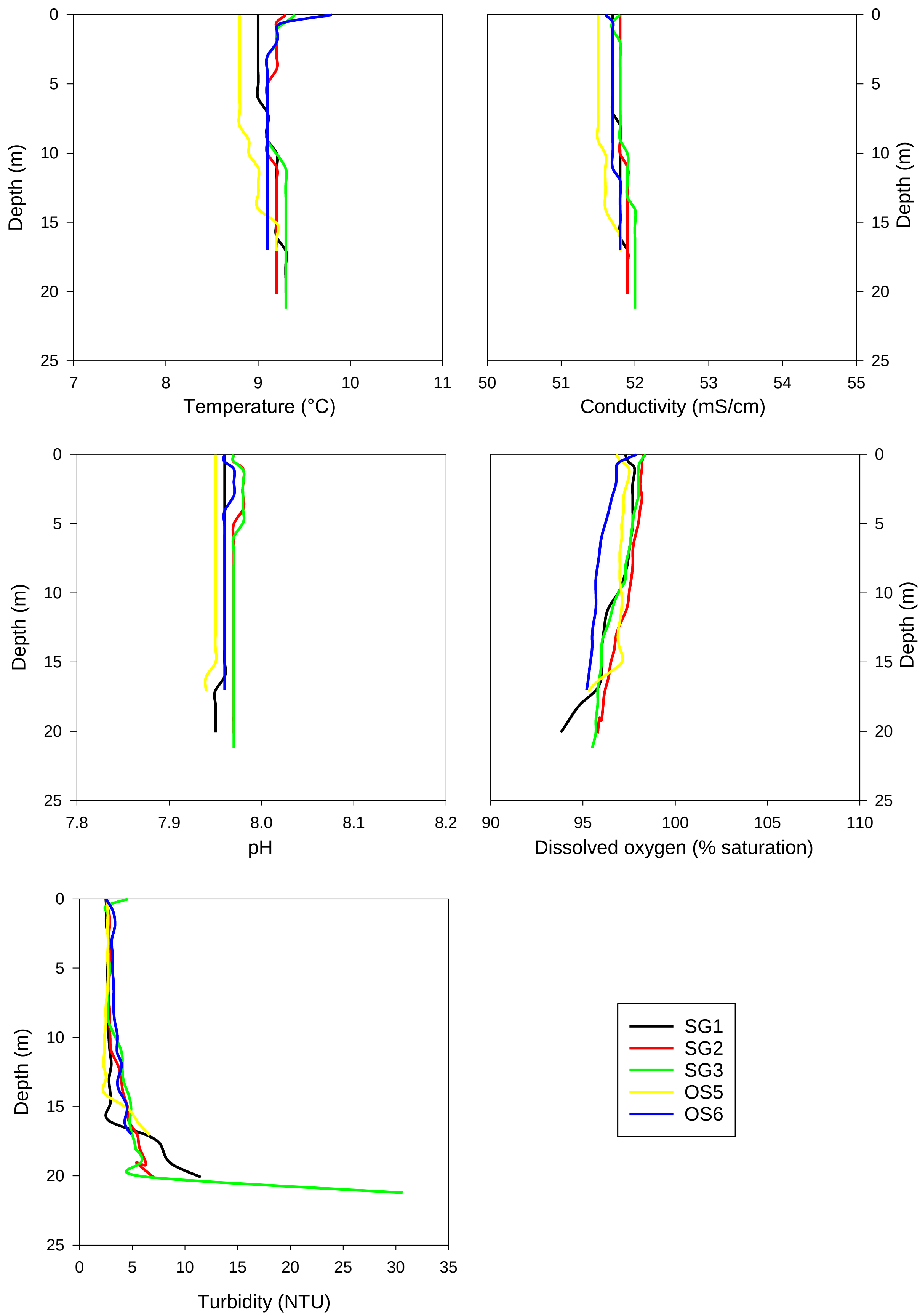



**Figure 26** Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 7 August 2019.

## 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 (4 August) were removed from the analyses.

**Table 16** Total Daily PAR (TDP) statistics during August 2019.
*Values are means ± se (n = 30 to 31). Note data from the BPAR exchange day on 4 August 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 | - | 13,484 ± 664 | 13,300 | 3,700 – 20,600 |
| OS2 | 17 | 194 ± 61 | 47 | <0.01 – 1447 |
| OS3 | 14 | 138 ± 62 | 21 | <0.01 – 1826 |

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 was variable, ranging from 3,700 to 20,600 mmol/m$^2$/day (Table 16), higher than the range recorded during July (2,500 to 13,800 mmol/m$^2$/day). The increase in ambient TDP is likely associated with the increased day lengths from July to August, in addition to the lower rainfall and associated cloud cover during the latter month.

Mean BPAR at both OS2 and OS3 also increased in August (194 and 138 mmol/m$^2$/day respectively) from July (8.9 and 1.1 mmol/m$^2$/day, respectively), most likely due to increased ambient PAR. BPAR at both OS2 and OS3 peaked on 8 August (1447 mmol/m$^2$/day and 1826 mmol/m$^2$/day, respectively), when ambient PAR was reasonably high and water turbidity was low (< 5 NTU).

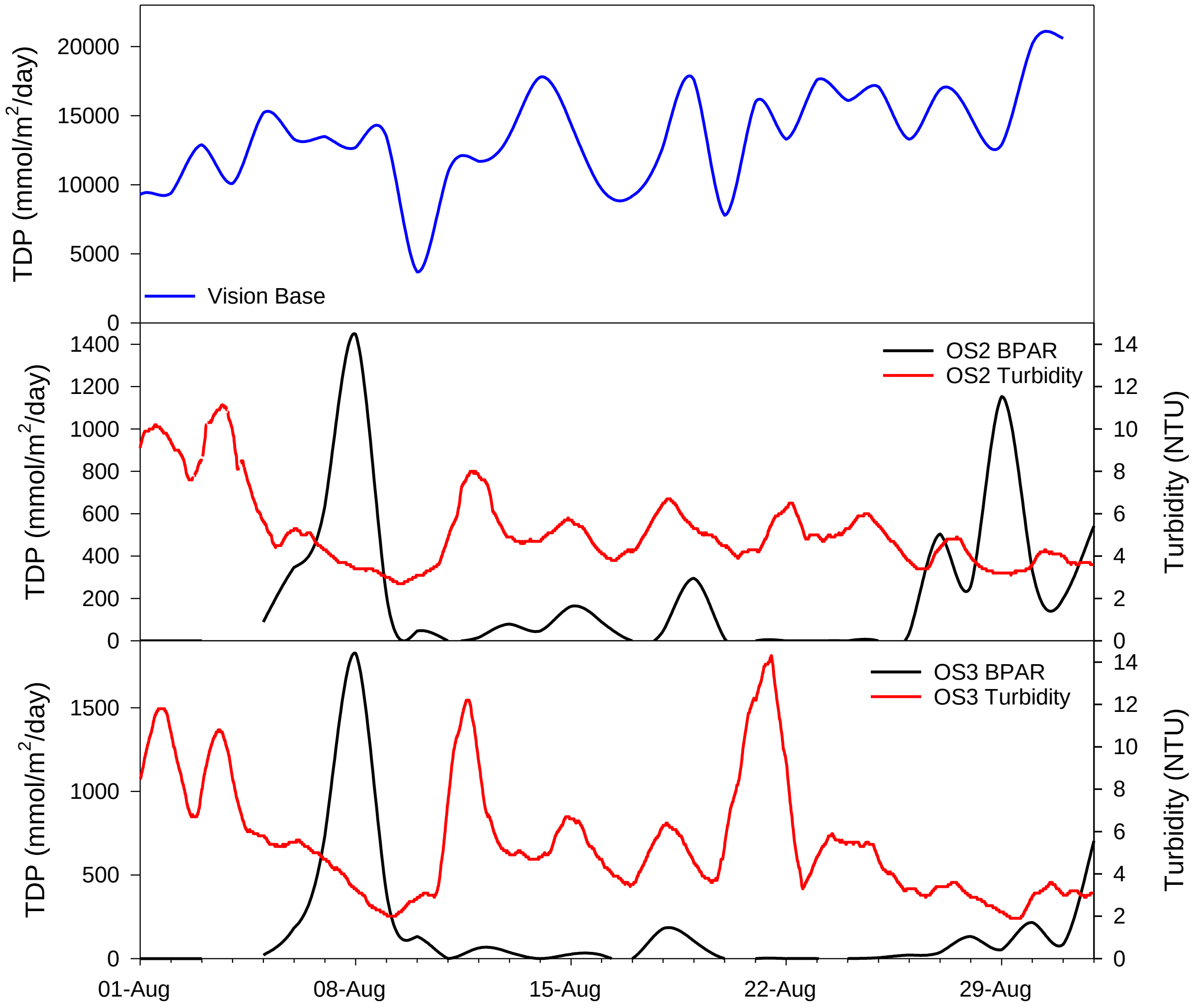



**Figure 27** Total daily BPAR at OS2 and OS3 during August 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
*Note data from the BPAR exchange day on 4 August were not utilized in plots or statistics.*

## 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.

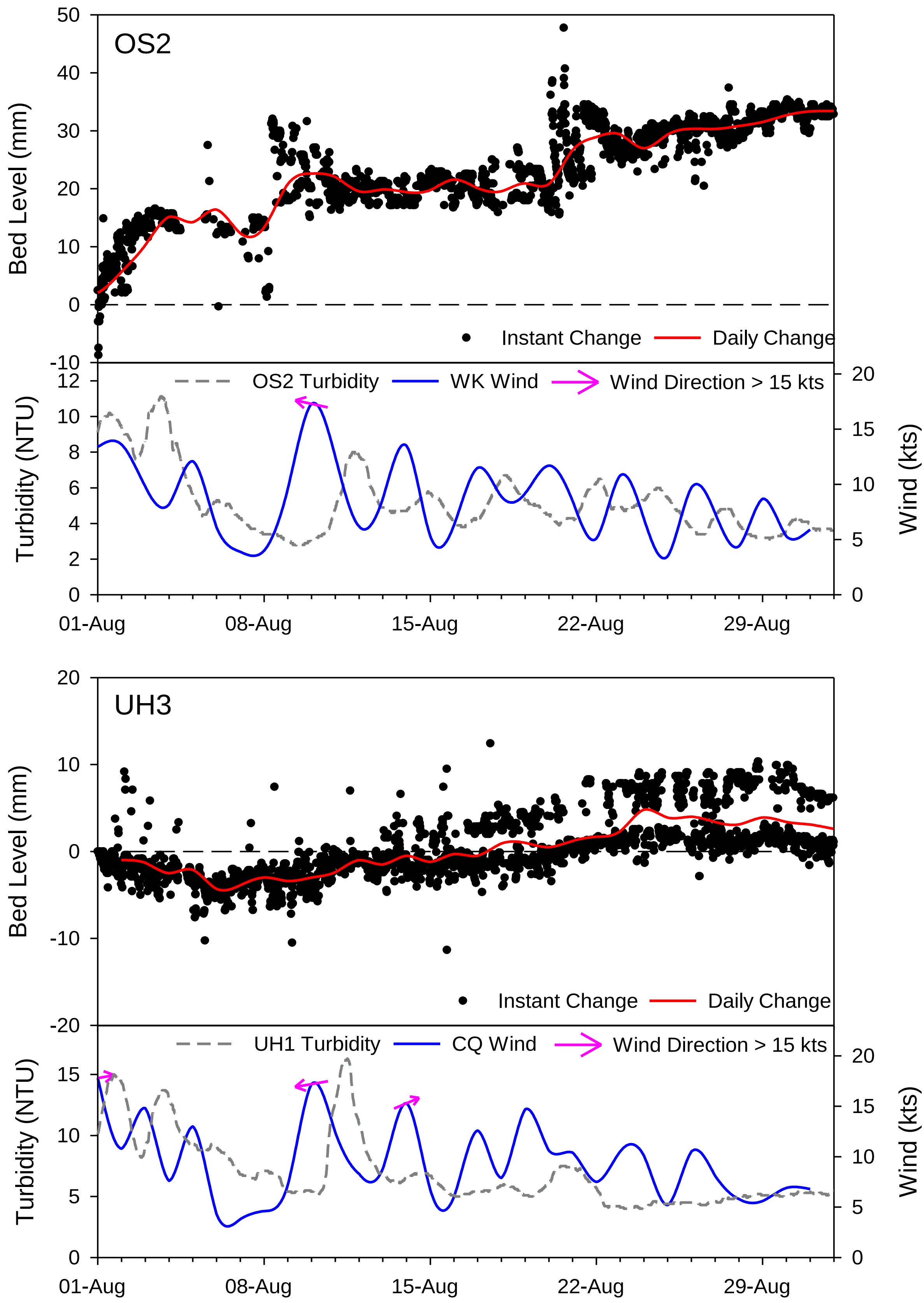



**Figure 28** Mean instantaneous and daily averaged bed level change at OS2 and UH3 during August 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction. *Note: Arrows indicate the direction of travel for winds greater than 15 knots.*

Overall, sediment accumulation was evident at the offshore site OS2 during early August, with approximately 20 mm accumulated from 1 to 8 August during a period of light to moderate offshore winds (4 to 14 kts) from a southwest direction. Bed level then remained reasonably stable until deposition again became evident from 20 August onwards, where an additional 13 mm of sediment was accumulated leading to an overall accumulation of 33 mm of sediment during August 2019 (Table 17). Periods of high sediment flux were evident on 10 and 20 August when strongest winds and largest wave heights of the month were recorded. Highest turbidity at OS2 was also recorded on 10 August.

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2. Slight erosion (- 3.4 mm) was apparent at UH3 following on from a period of moderate to strong inshore winds (11 to 18 kts) from a south-westerly direction, up until 8 August when slow sediment accumulation occurred for the remainder of the month, with an overall accumulation of 2.6 mm in August 2019 (Table 17). No periods of high sediment flux associated with wind, rainfall or high turbidity were evident at UH3.

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

| Site | August 2019 Net bed level change (mm) |
|---|---|
| OS2 | +33 |
| UH3 | +2.6 |

## 3.6 Water Samples

Discrete water sampling was conducted on 7 August 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 exhibited the typical spatial pattern with higher concentrations within the inner harbour and lowest concentrations at the spoil ground. Total phosphorous remained below the WQG of 30 µg/L at all sites, except for UH3 (31 µg/L). Similar to July, dissolved reactive phosphorous concentrations exceeded the WQG of 5 µg/L at all sites, ranging from 8.3 µg/L at SG3 to 16.8 µg/L at UH3.

Both total nitrogen and total kjeldahl nitrogen (TKN) were < LOR at all sites, except for site SG3, where concentrations of total nitrogen (500 µg/L) exceeded the WQG.

The readily bioavailable nitrogen forms of ammonia and nitrogen oxides (NOx) exceeded their respective WQG (15 µg/L) at all sites, similar to July 2019. As typically found, concentrations at the inshore sites (30 to 44 µg/L and 55 to 80 µg/L, for ammonia and NOx, respectively) were higher than offshore and spoilground sites (23 to 34 µg/L and 47 to 54 µg/L, for ammonia and NOx, respectively).

Despite the available nutrients, concentrations of chlorophyll *a*, an indicator of phytoplankton biomass remained low (0.4 to 1.4 µg/L) and below the WQG (4 µg/L) at all sites (Table 18).

**Table 18** Concentrations of nutrients and chlorophyll *a* at monitoring sites during August 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 | 27 | 15.8 | <300 | <200 | 44 | 67 | 1.2 |
| UH2 | 21 | 13.6 | <300 | <200 | 33 | 62 | 0.7 |
| UH3 | 31 | 16.8 | <300 | <200 | 41 | 80 | 1 |
| CH1 | 20 | 12.9 | <300 | <200 | 41 | 55 | 1.4 |
| CH2 | 23 | 12.4 | <300 | <200 | 30 | 57 | 0.9 |
| OS1 | 24 | 12 | <300 | <200 | 32 | 54 | 1.1 |
| OS2 | 20 | 10.2 | <300 | <200 | 25 | 50 | 0.8 |
| OS3 | 20 | 10 | <300 | <200 | 32 | 54 | 0.5 |
| OS4 | 18 | 9.5 | <300 | <200 | 34 | 50 | 0.4 |
| OS5 | 22 | 10.5 | <300 | <200 | 30 | 50 | 1.7 |
| OS6 | 19 | 10 | <300 | <200 | 31 | 54 | 0.6 |
| OS7 | 18 | 10.6 | <300 | <200 | 26 | 50 | 1 |
| SG1 | 14 | 9.9 | <300 | <200 | 23 | 52 | 1.3 |
| SG2 | 12 | 8.5 | <300 | <200 | 23 | 47 | 0.5 |
| SG3 | 20 | 8.3 | 500 | 400 | 23 | 48 | 0.4 |
| **WQG** | **30** | **5** | **300** | **-** | **15** | **15** | **4** |

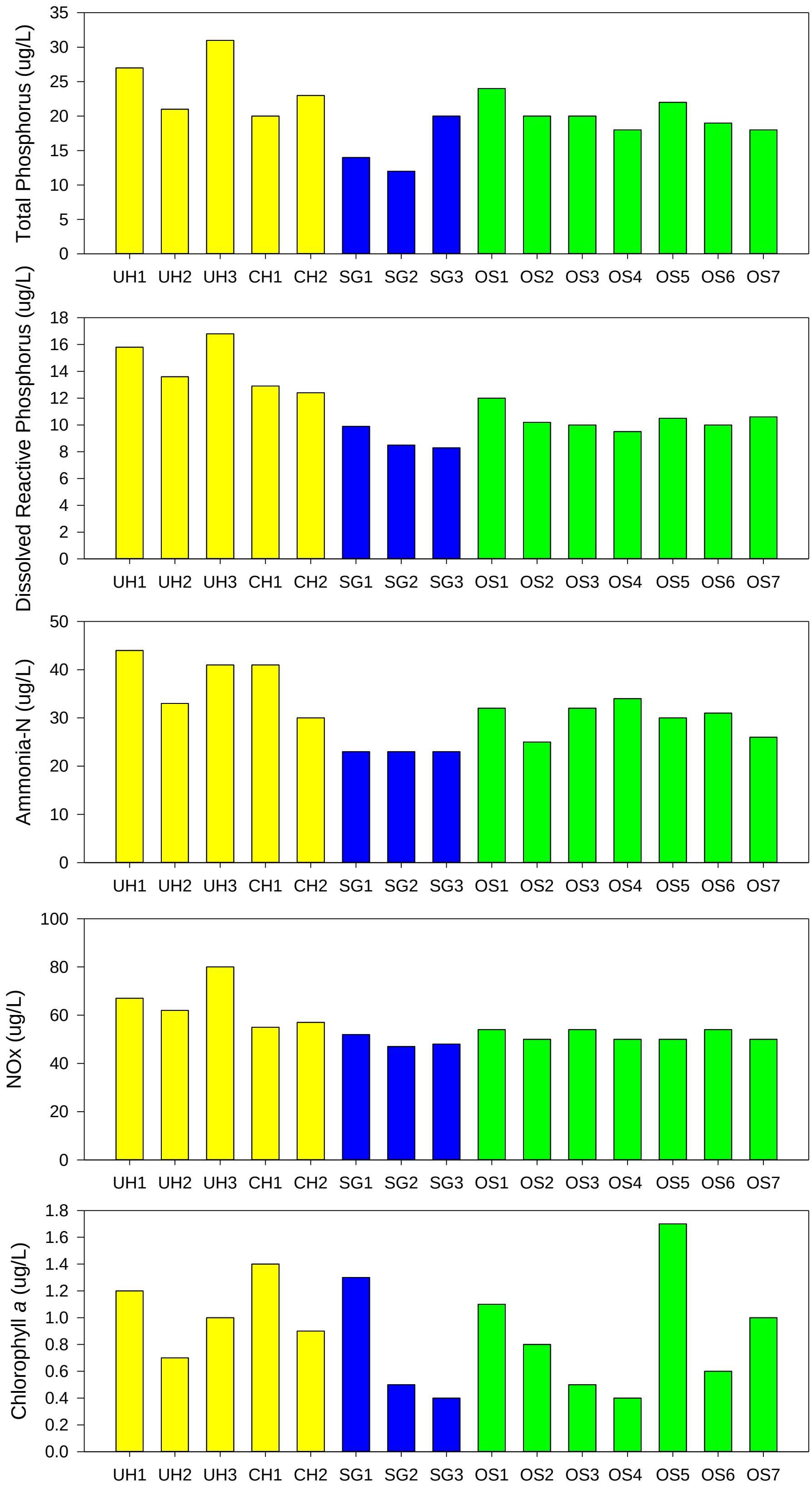



**Figure 29** Nutrient and chlorophyll *a* concentrations at monitoring sites during August 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were <LOR.*

### 3.6.2 Total and Dissolved Metals

Concentrations of several metals (Tables 19 to 21) 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), mercury (<0.08 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5 µg/L) and zinc (<4 µg/L).

While concentrations of total aluminium and iron were detected, dissolved concentrations of these metals were < LOR, indicating limited bioavailability. Concentrations of total aluminium at all sites (46 to 156 µg/L) were higher than the designated 95% species protection trigger value of 24 µg/L. However, as the WQG is applicable to the dissolved fraction only (ANZG, 2018),no exceedances were recorded. As typically recorded, both aluminium and iron were found to be higher at the inshore sites (58 to 156 µg/L and 59 to 200 µg/L, for aluminium, respectively) were higher than offshore and spoilground sites (46 to 75 µg/L and 42 to 95 µg/L).

Chromium, manganese, molybdenum and vanadium were recorded at the majority of sites in both total and dissolved forms. Chromium concentrations across the sites (<1 to 2.4 µg/L) were well below the 95% species protection trigger value of 4.4 µg/L from CrVI and 27.4 µg/L for CrIII. Similarly, recorded vanadium concentrations (1.3 to 2.2 µg/L) were well below the 95% species protection trigger value of 100 µg/L.

No trigger values are available for either manganese or molybdenum. Total and dissolved manganese concentrations ranged from 2.8 to 9.0 µg/L at inshore sites and were lower at offshore and spoilground sites (<1 to 3.6 µg/L). Total and dissolved molybdenum concentrations exhibited little spatial variation, ranging from 10.1 to 11.5 µg/L, similar to previous monitoring results.

**Table 19** Total and dissolved metal concentrations at inshore monitoring sites during August 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 | 156 | 80 | 144 | 100 | 58 | |
| 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 | 1.7 | 1.2 | 1.7 | Cr(III) 27.4<br>Cr(VI) 4.4 |
| | Total | 1.9 | <1.1 | 1.2 | 1.7 | <1.1 | |
| 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 | <4 | <4 | <4 | <4 | <4 | - |
| | Total | 200 | 106 | 192 | 121 | 59 | |
| Lead | Dissolved | <1 | <1 | <1 | <1 | <1 | 4.4 |
| | Total | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | |
| Manganese | Dissolved | 4.8 | 3.8 | 4.3 | 2.8 | 2.8 | - |
| | Total | 9 | 5.1 | 8 | 5.2 | 3.7 | |
| Mercury | Dissolved | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | 0.4 |
| | Total | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | |
| Molybdenum | Dissolved | 10.2 | 10.4 | 10.1 | 11.2 | 10.7 | - |
| | Total | 10.3 | 10.8 | 10.3 | 10.6 | 10.6 | |
| 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 | 1.4 | 2.1 | 1.8 | 1.9 | 1.9 | 100 |
| | Total | 2.1 | 1.9 | 1.8 | 1.3 | 2 | |
| 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 August 2019. *Values outside recommended WQG are highlighted in blue.*

| Metal (µg/L) | | Sites | | | | | | | WQG |
|---|---|---|---|---|---|---|---|---|---|
| | | OS1 | OS2 | OS3 | OS4 | OS5 | OS6 | OS7 | |
| Aluminium | Dissolved | <12 | <12 | <12 | <12 | <12 | <12 | <12 | 24 |
| | Total | 62 | 50 | 74 | 51 | 53 | 66 | 48 | |
| Arsenic | Dissolved | <4 | <4 | <4 | <4 | <4 | <4 | <4 | - |
| | Total | <4.3 | <4.3 | <4.3 | <4.3 | <4.3 | <4.3 | <4.3 | |
| Cadmium | Dissolved | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 5.5 |
| | Total | <0.21 | <0.21 | <0.21 | <0.21 | <0.21 | <0.21 | <0.21 | |
| Chromium | Dissolved | 1.1 | 1.3 | 2.2 | <1 | <1 | 1 | <1 | Cr(III) 27.4<br>Cr(VI) 4.4 |
| | Total | 2 | 2.2 | <1.1 | 2.1 | 1.9 | 1.2 | 2.4 | |
| Cobalt | Dissolved | <0.6 | <0.6 | <0.6 | <0.6 | <0.6 | <0.6 | <0.6 | 1.0 |
| | Total | <0.63 | <0.63 | <0.63 | <0.63 | <0.63 | <0.63 | <0.63 | |
| Copper | Dissolved | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 1.3 |
| | Total | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | |
| Iron | Dissolved | <4 | <4 | <4 | <4 | <4 | <4 | <4 | - |
| | Total | 60 | 95 | 83 | 48 | 64 | 71 | 44 | |
| 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 | 1.8 | 1.3 | <1 | <1 | 1.9 | <1 | 1.8 | - |
| | Total | 3.6 | 3 | 2.8 | 1.7 | 2.6 | 2.2 | 2.8 | |
| 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 | 10.6 | 10.4 | 11 | 10.8 | 10.8 | 10.6 | 10.5 | - |
| | Total | 10.8 | 11 | 11.5 | 11.1 | 10.9 | 10.9 | 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 | 1.5 | 2 | 2 | 1.8 | 1.9 | 1.6 | 1.5 | 100 |
| | Total | 1.9 | 2 | 2 | 2.1 | 2.2 | 2.1 | 1.7 | |
| 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 August 2019. *Values outside recommended WQG are highlighted in blue.*

| Metal (µg/L) | | Sites | | | WQG |
|---|---|---|---|---|---|
| | | SG1 | SG2b | SG3 | |
| Aluminium | Dissolved | <12 | <12 | <12 | 24 |
| | Total | 75 | 58 | 46 | |
| 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 | 1.2 | 1.5 | Cr(III) 27.4<br>Cr(VI) 4.4 |
| | Total | 1.4 | 1.3 | <1.1 | |
| Cobalt | Dissolved | <0.6 | <0.6 | <0.6 | 1.0 |
| | Total | <0.63 | <0.63 | <0.63 | |
| Copper | Dissolved | <1 | <1 | <1 | 1.3 |
| | Total | <1.1 | <1.1 | <1.1 | |
| Iron | Dissolved | <4 | <4 | <4 | - |
| | Total | 88 | 65 | 42 | |
| Lead | Dissolved | <1 | <1 | <1 | 4.4 |
| | Total | <1.1 | <1.1 | <1.1 | |
| Manganese | Dissolved | 1.1 | <1 | <1 | - |
| | Total | 3 | 2.5 | 1.6 | |
| Mercury | Dissolved | <0.08 | <0.08 | <0.08 | 0.4 |
| | Total | <0.08 | <0.08 | <0.08 | |
| Molybdenum | Dissolved | 11 | 11.2 | 10.6 | - |
| | Total | 11.2 | 11.1 | 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 | 1.5 | 1.5 | 2 | 100 |
| | Total | 2.2 | 1.8 | 2 | |
| Zinc | Dissolved | <4 | <4 | <4 | 15 |
| | Total | <4.2 | <4.2 | <4.2 | |

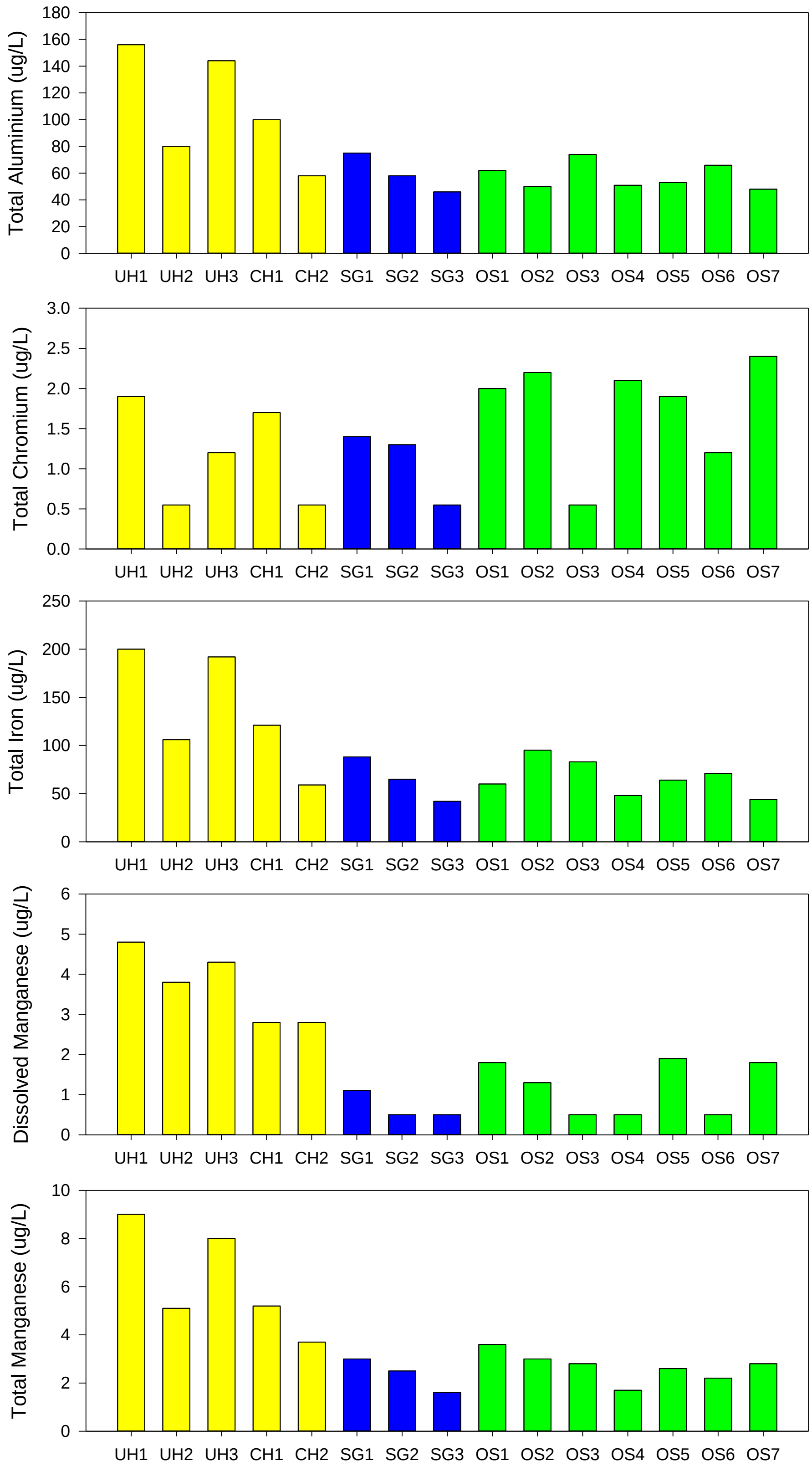



**Figure 30** Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during August 2019.
*Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.*

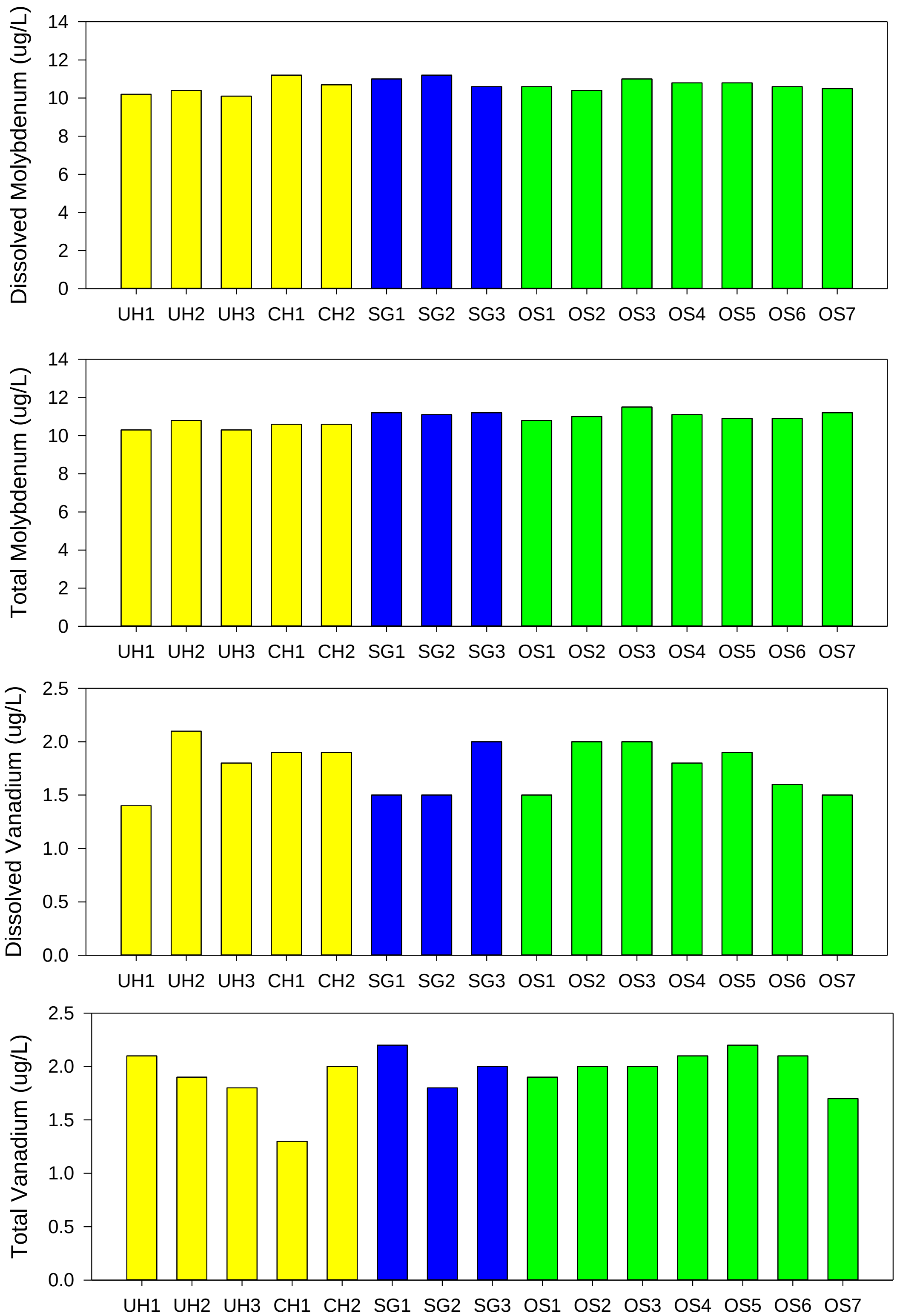



**Figure 31** Total and dissolved molybdenum and vanadium concentrations at monitoring sites during August 2019.
*Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.*

# 4 REFERENCES

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# 5 APPENDIX

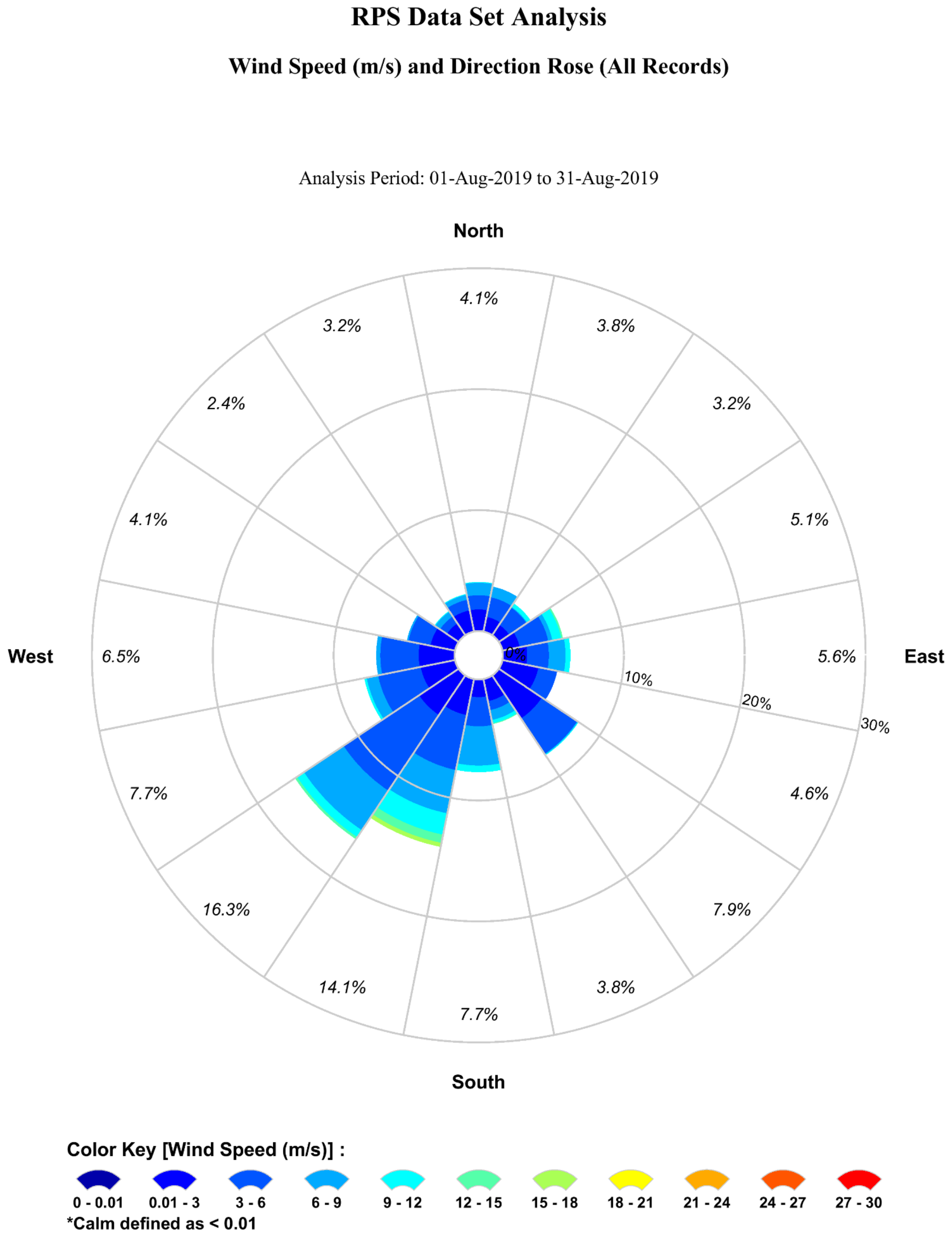



**Figure 32** WatchKeeper wind speed (m/s) and direction rose (%) during August 2019.

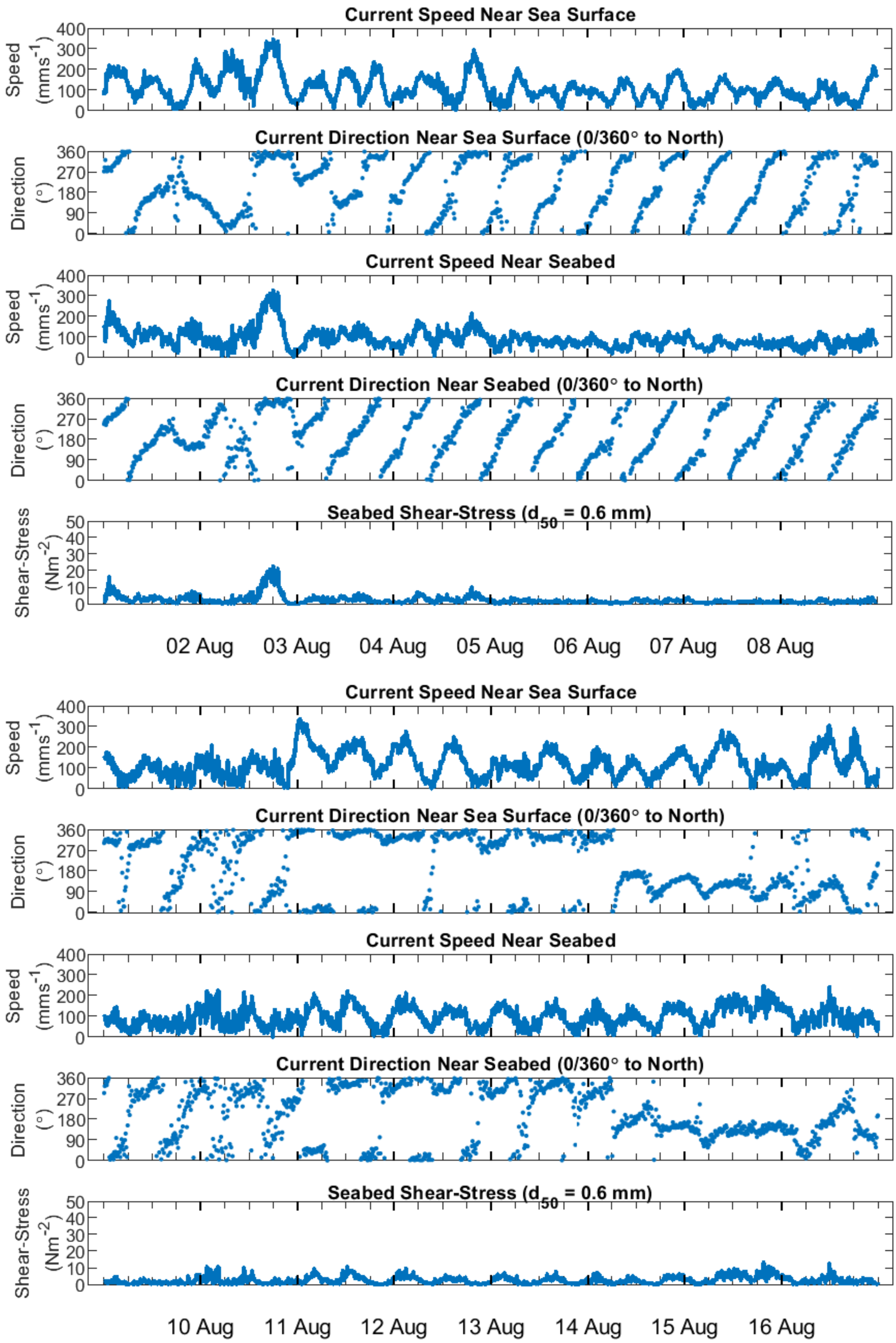



**Figure 33** SG1 current speed, direction and shear bed stress 1 to 16 August 2019.

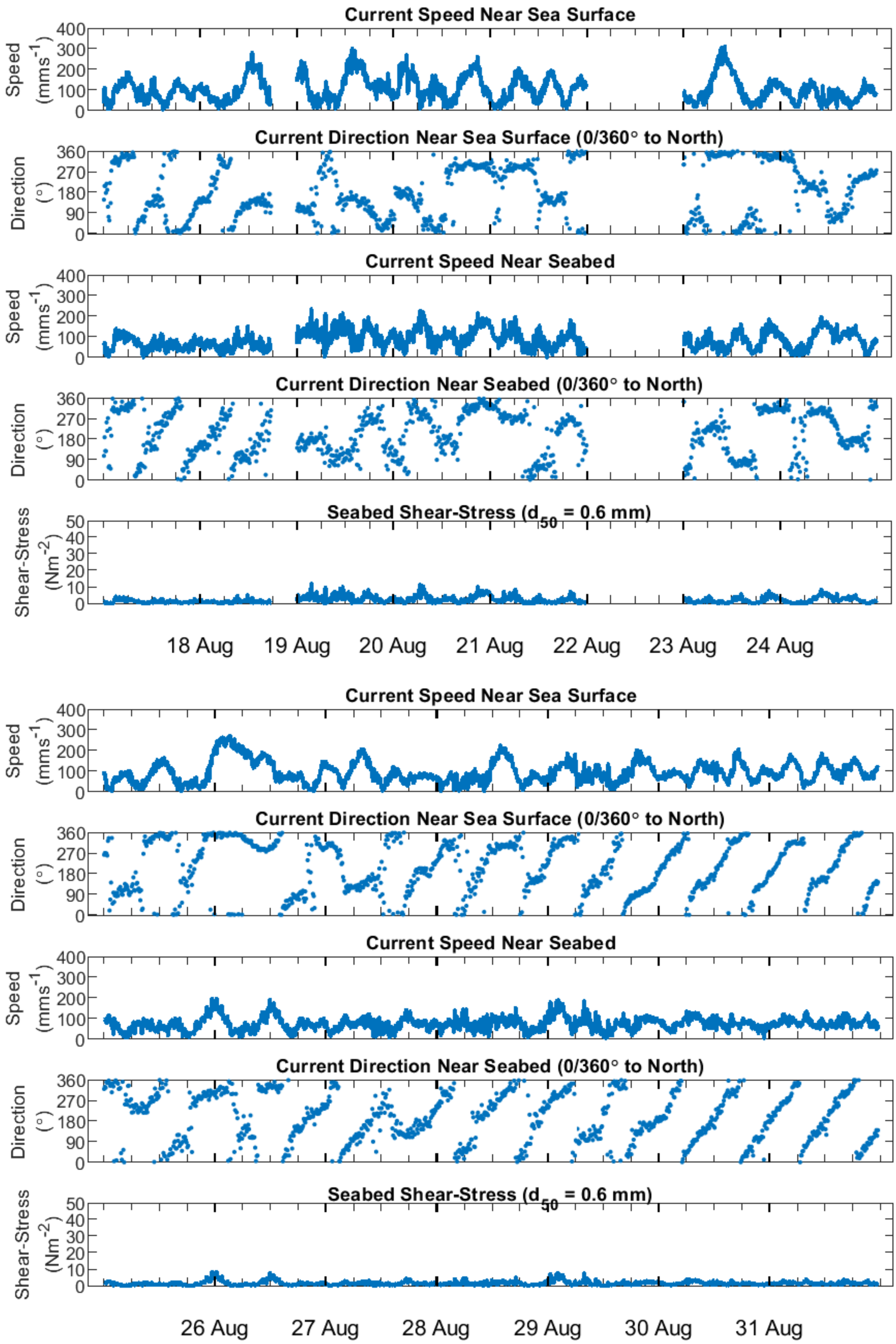
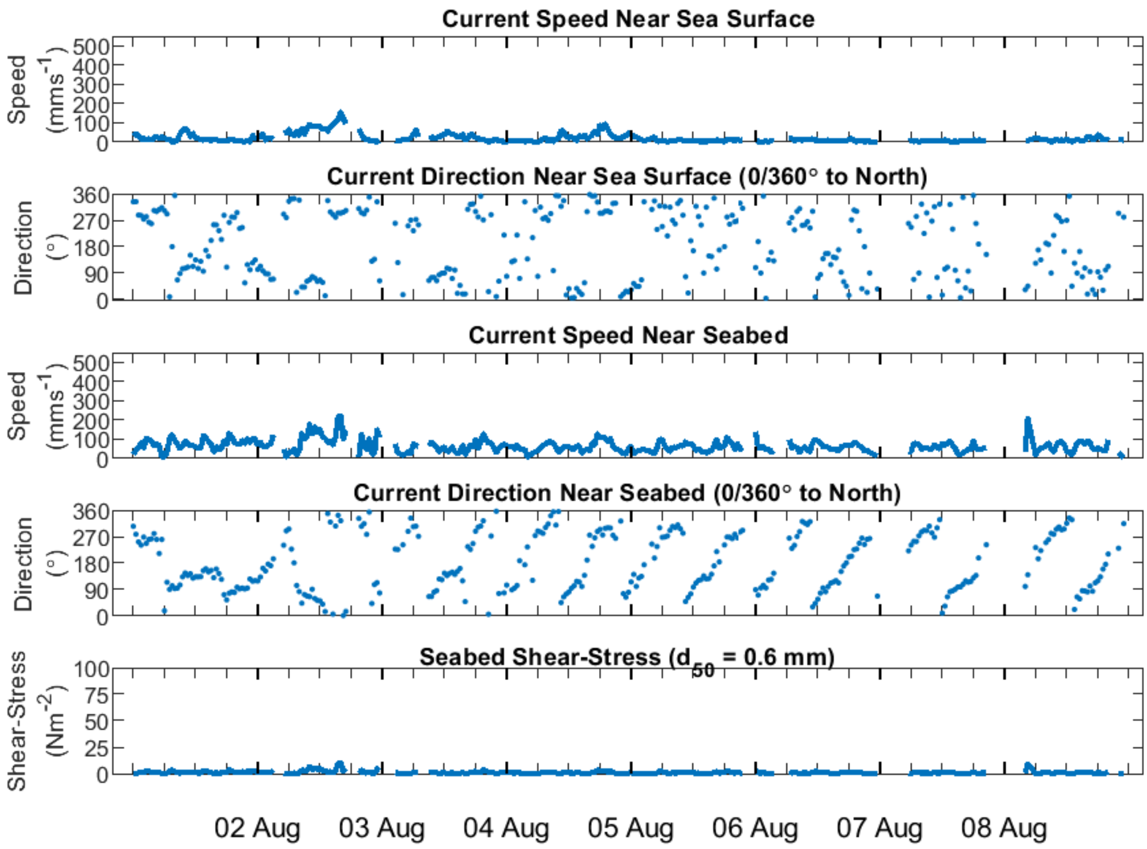



**Figure 34** SG1 current speed, direction and shear bed stress 17 to 31 August 2019.



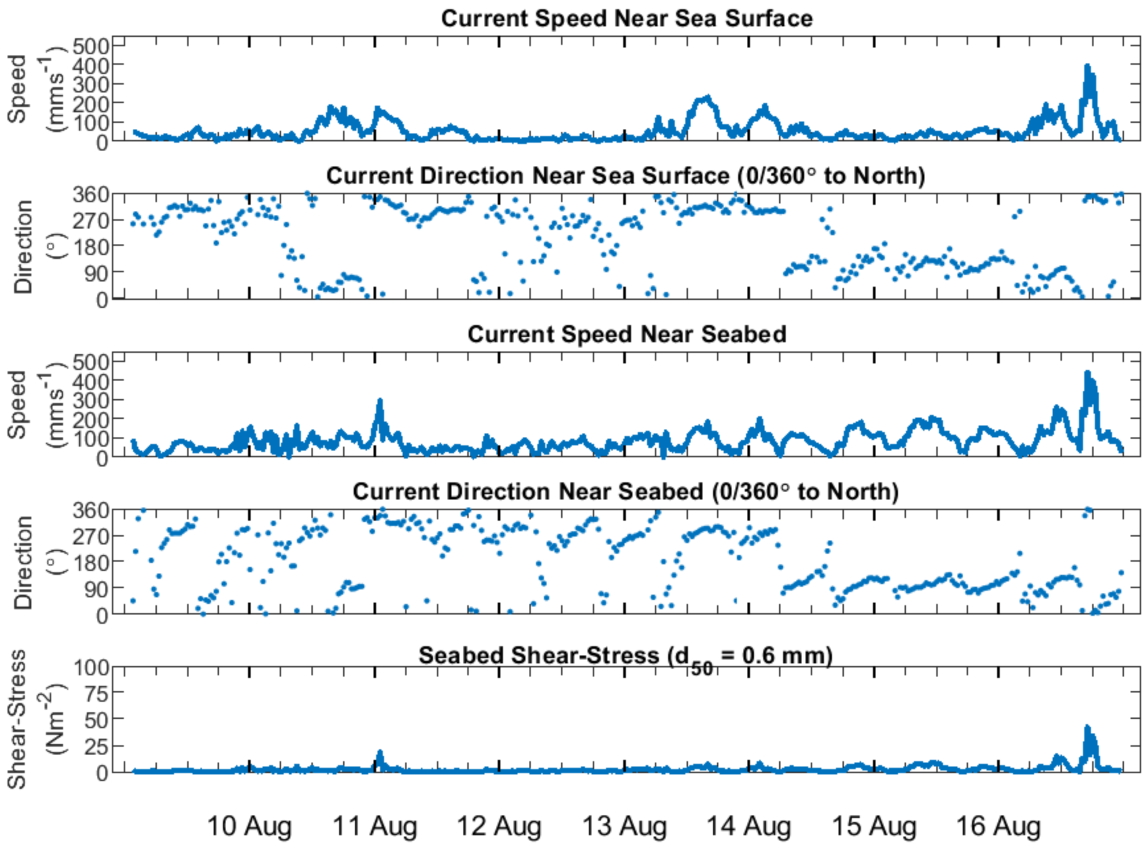
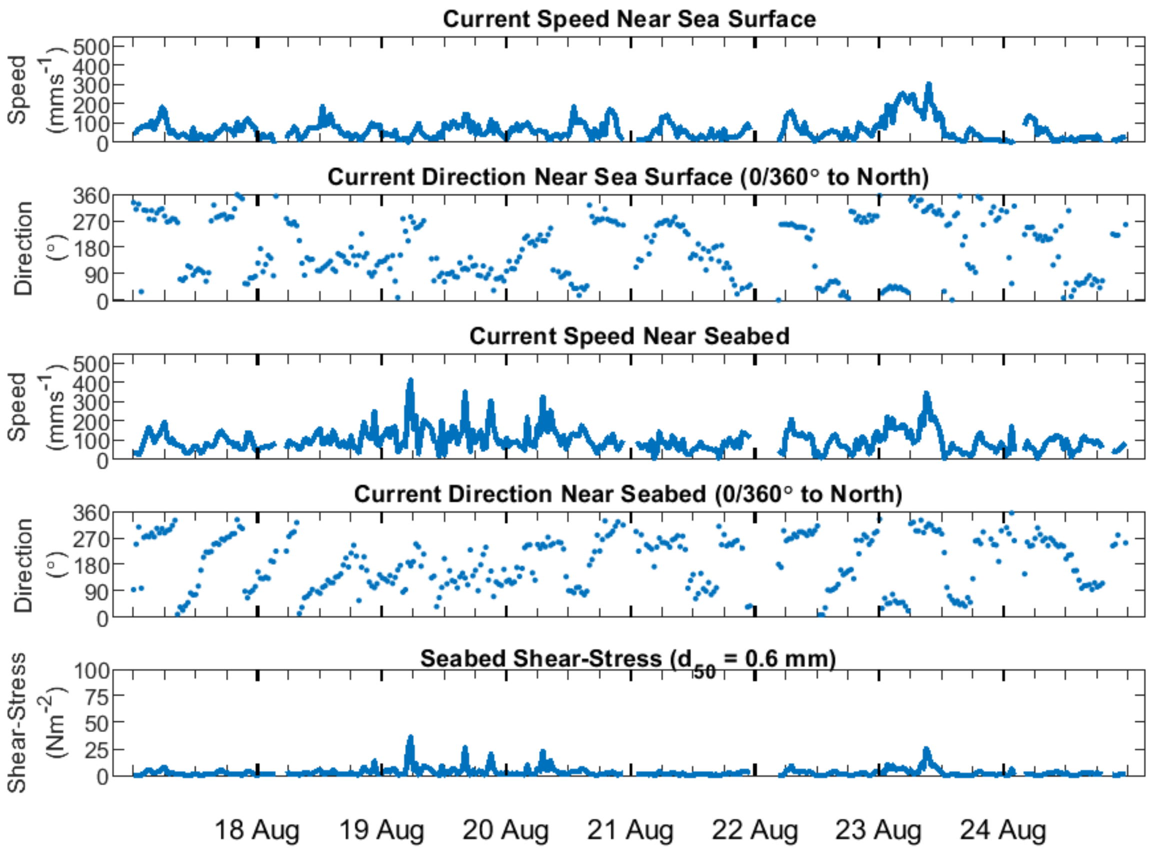




**Figure 35** SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 August 2019.



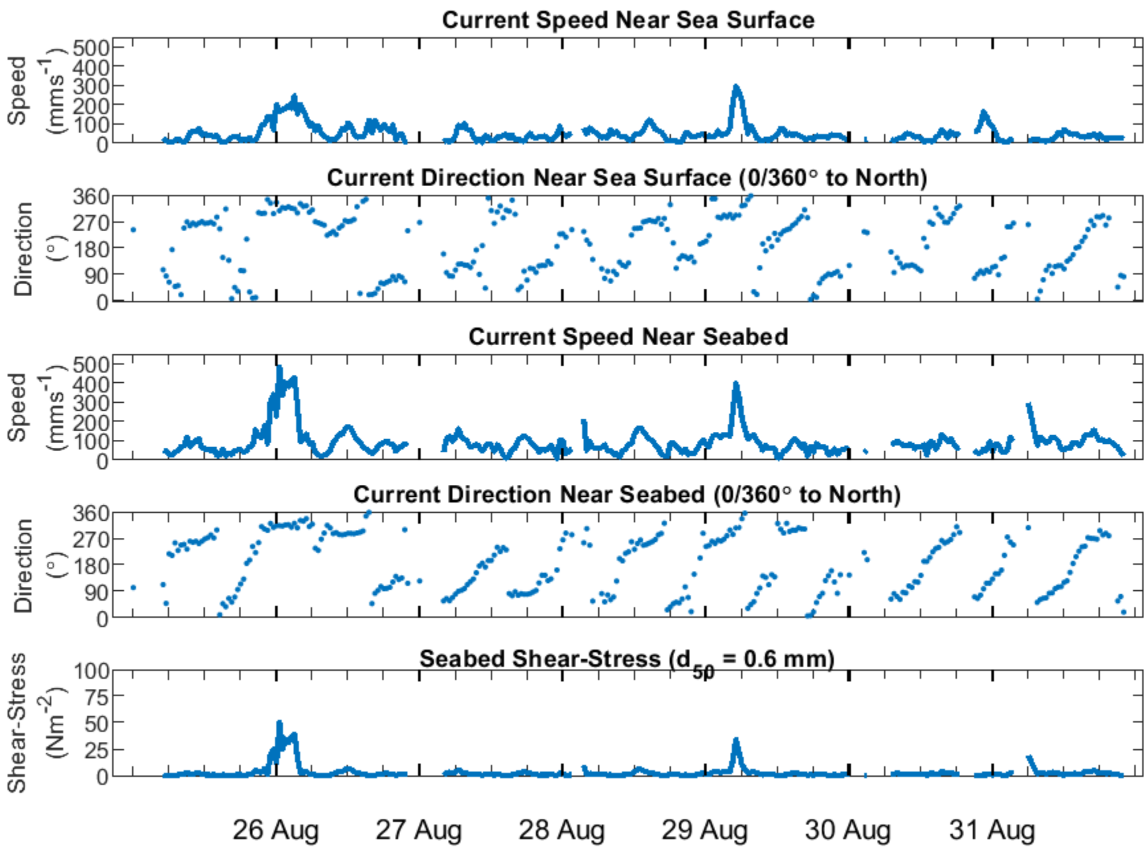




**Figure 36** SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 31 August 2019.

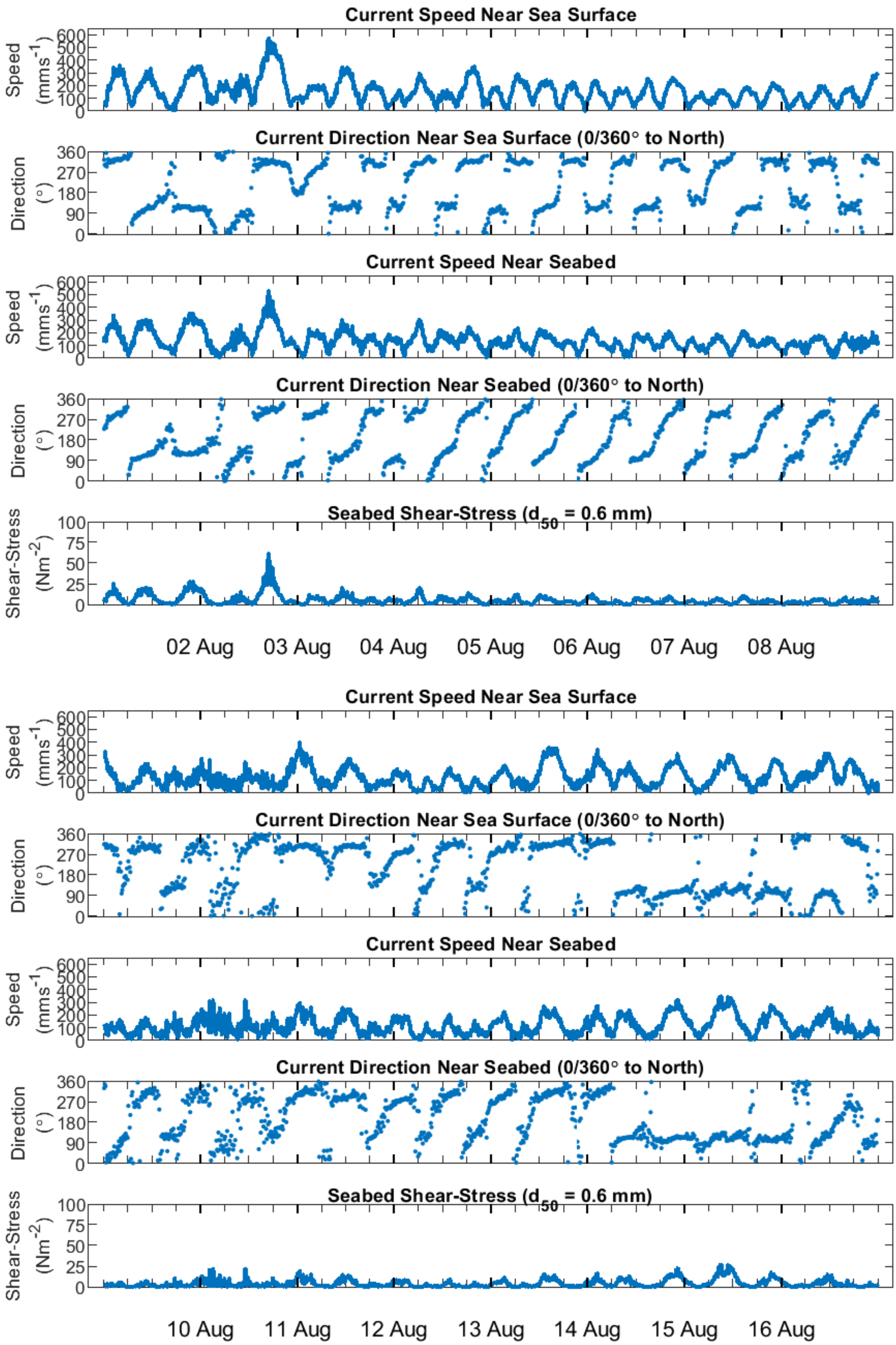



**Figure 37** SG3 current speed, direction and shear bed stress 1 to 16 August 2019.

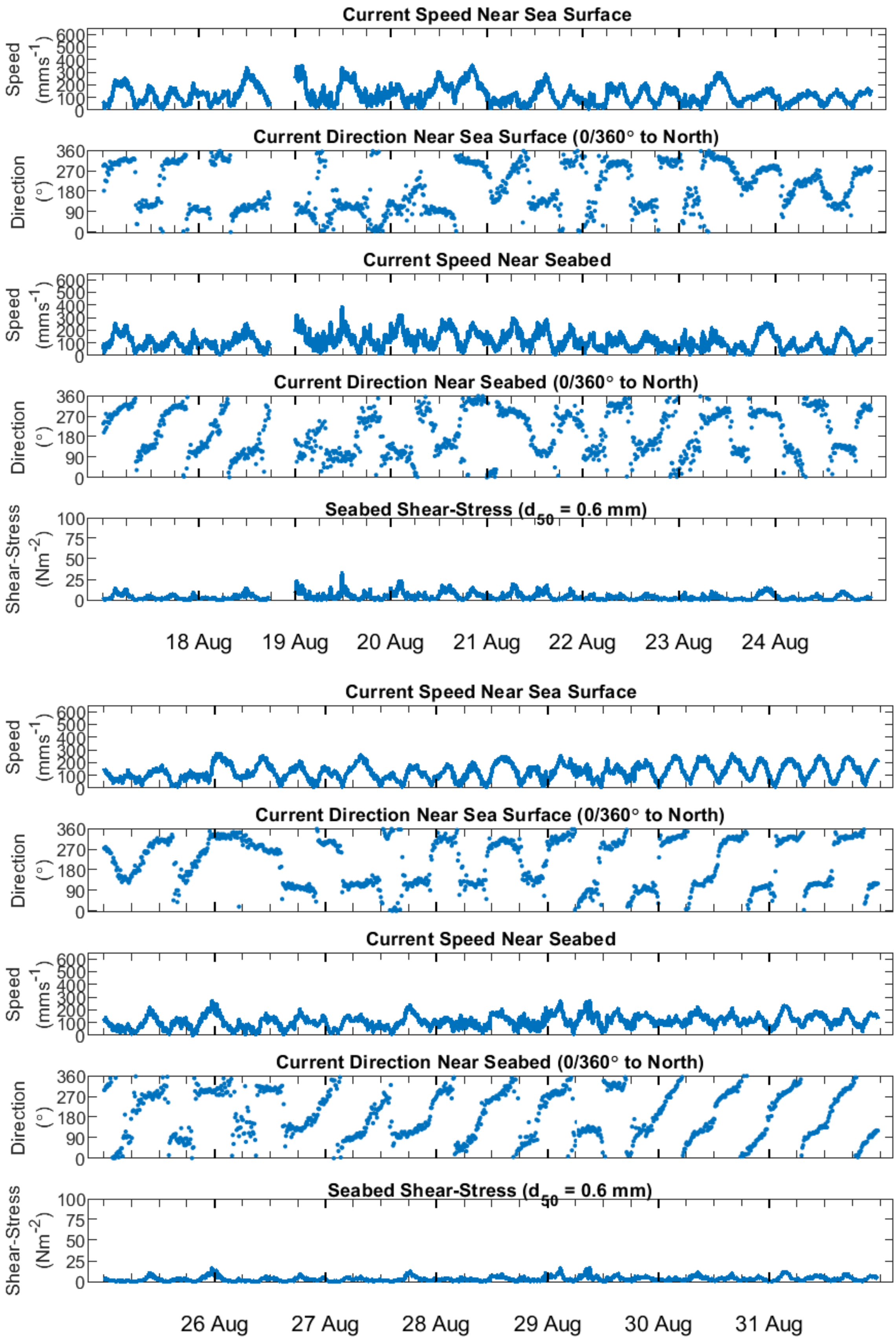



**Figure 38** SG3 current speed, direction and shear bed stress 17 to 31 August 2019.

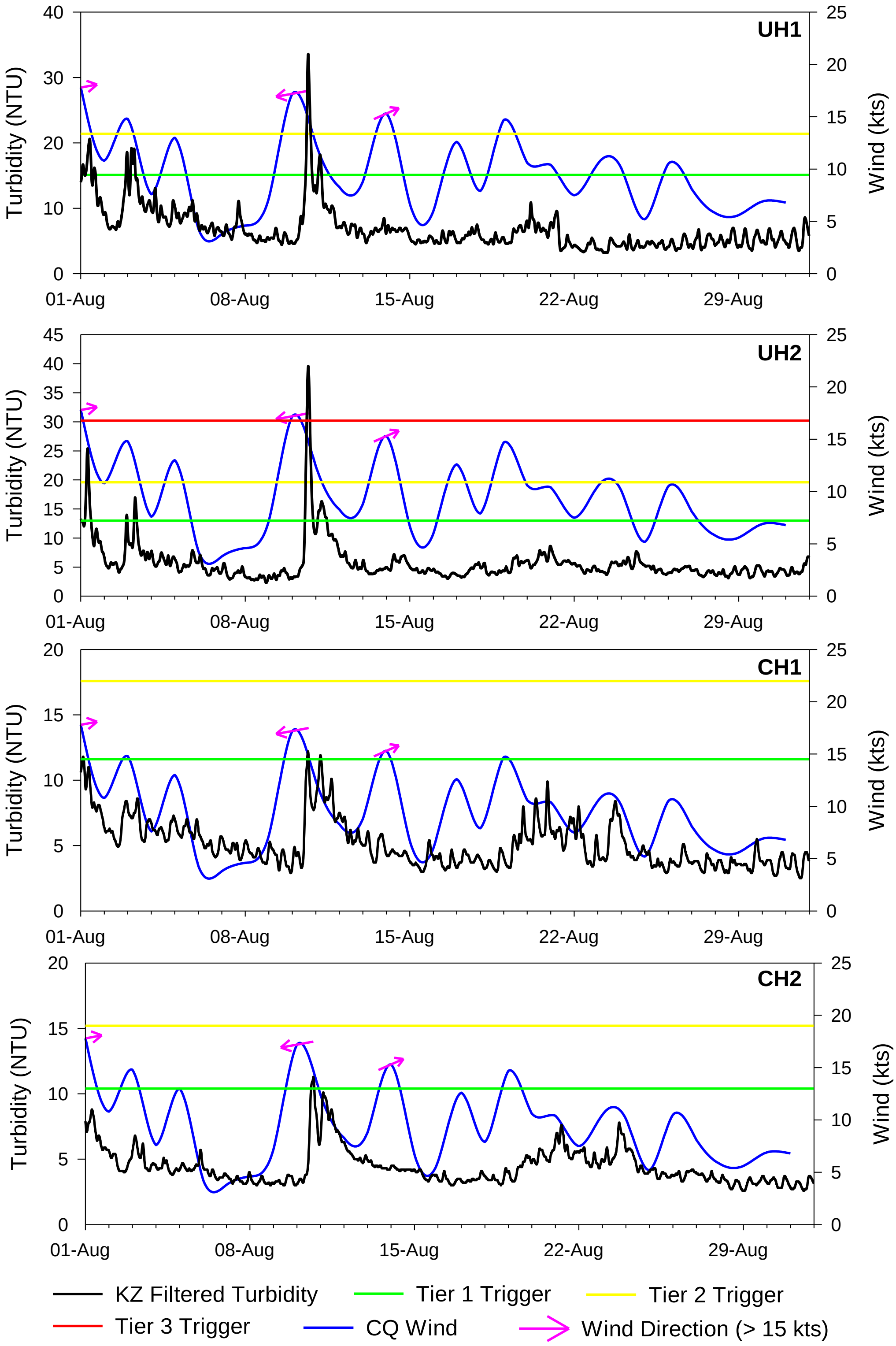



**Figure 39** Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity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

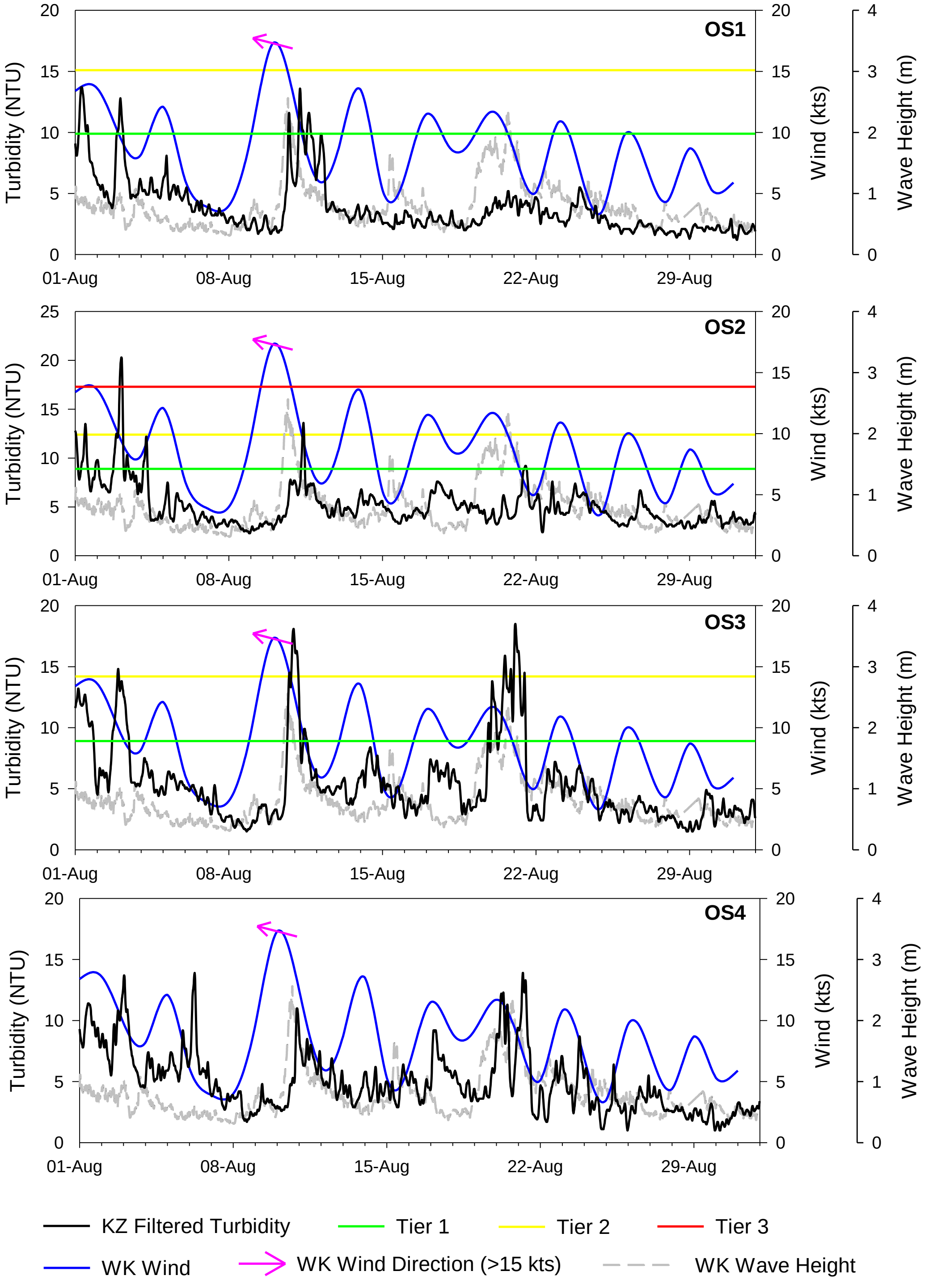



**Figure 40** Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.*

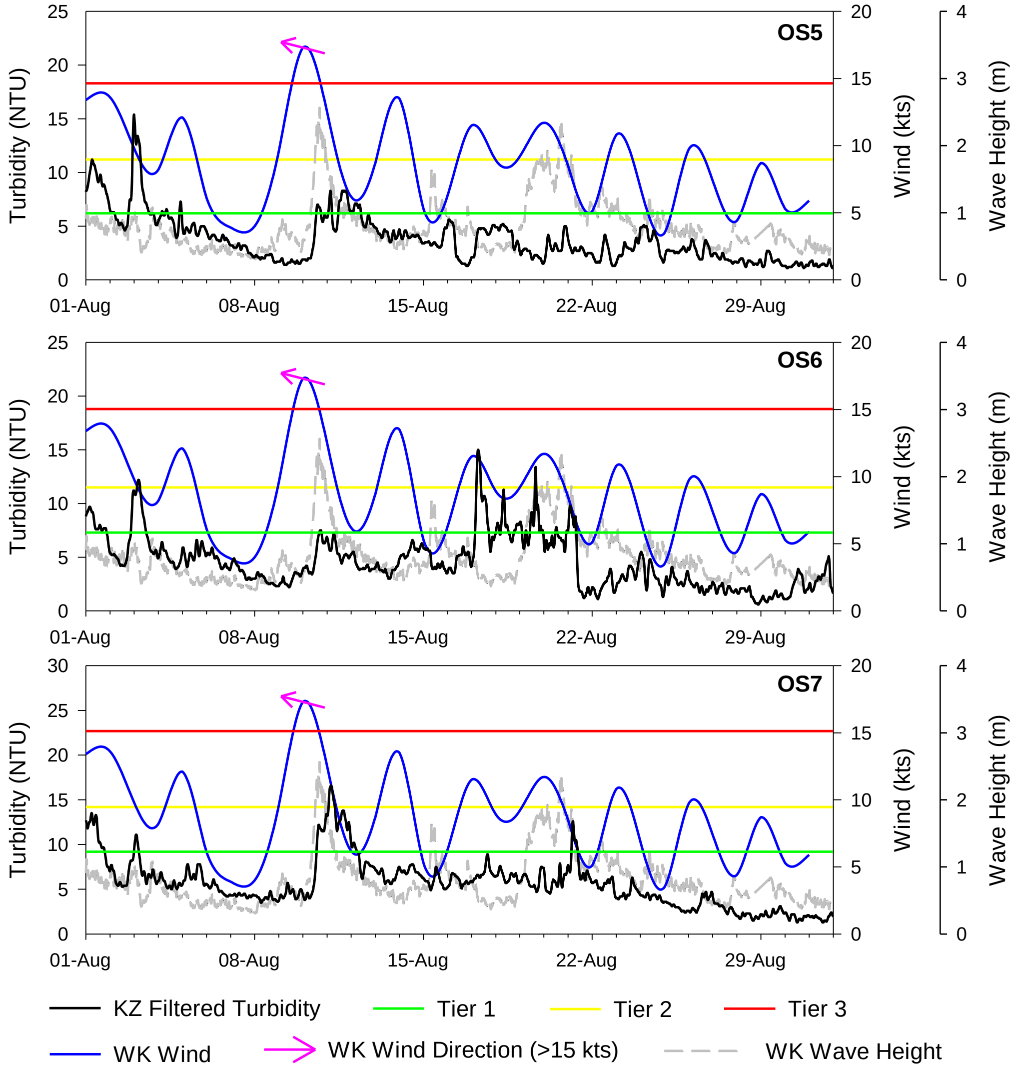



**Figure 41** Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.*

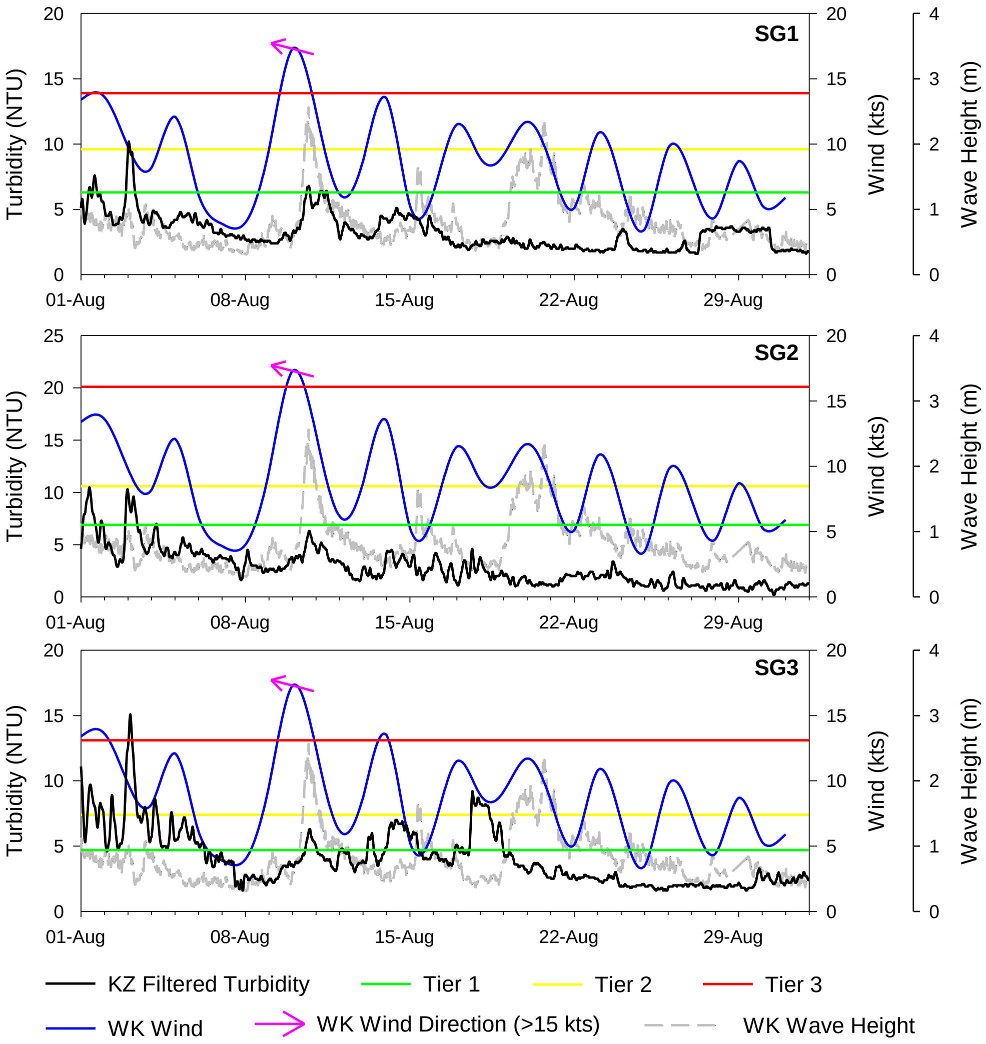



**Figure 42** Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during August 2019.
*Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.*

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

| Site | | KZ Filtered Turbidity (NTU) | |
|---|---|---|---|
| | Statistic | Surface August | Surface Baseline |
| UH1 | Mean ± se | 6.8 ± 0.1 | 12 |
| | Range | 3 – 34 | 2 – 155 |
| | 99th | 19 | 37 |
| | 95th | 14 | 21 |
| | 80th | 8 | 15 |
| UH2 | Mean ± se | 5.7 ± 0.1 | 9.9 |
| | Range | 2.3 – 40 | 2 – 59 |
| | 99th | 21.2 | 29 |
| | 95th | 11.6 | 19 |
| | 80th | 6.4 | 13 |
| CH1 | Mean ± se | 5.1 ± 0.0 | 8.8 |
| | Range | 2.5 – 12.2 | <1 – 50 |
| | 99th | 11 | 27 |
| | 95th | 8.5 | 17 |
| | 80th | 6.3 | 12 |
| CH2 | Mean ± se | 4.4 ± 0.0 | 7.6 |
| | Range | 3 – 11 | <1 – 39 |
| | 99th | 9.7 | 22 |
| | 95th | 7.2 | 15 |
| | 80th | 5.2 | 10 |

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

| Site | | KZ Filtered Turbidity (NTU) | |
|---|---|---|---|
| | Statistic | Surface August | Surface Baseline |
| SG1 | Mean ± se | 3.2 ± 0.0 | 4.2 |
| | Range | 1.6 – 10.2 | <1 – 31 |
| | 99th | 7.5 | 14 |
| | 95th | 5.9 | 9.5 |
| | 80th | 4.2 | 6.1 |
| SG2 | Mean ± se | 2.8 ± 0.0 | 4.6 |
| | Range | <1 – 10.5 | <1 – 33 |
| | 99th | 9.4 | 20 |
| | 95th | 6.3 | 10 |
| | 80th | 4 | 6.9 |
| SG3 | Mean ± se | 4.0 ± 0.0 | 3.6 |
| | Range | 1.6 – 15 | <1 – 22 |
| | 99th | 11.3 | 13 |
| | 95th | 8.1 | 7.3 |
| | 80th | 5.7 | 4.7 |

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

| Site | Statistic | KZ Filtered Turbidity (NTU) | |
|---|---|---|---|
| | | Surface August | Surface Baseline |
| OS1 | Mean ± se | 3.8 ± 0.0 | 7.5 |
| | Range | 1.2 – 14 | <1 – 99 |
| | 99th | 12.2 | 23 |
| | 95th | 9.3 | 15 |
| | 80th | 4.9 | 9.7 |
| OS2 | Mean ± se | 5.1 ± 0.0 | 6.4 |
| | Range | 2.3 – 20.3 | <1 – 36 |
| | 99th | 13 | 17 |
| | 95th | 9.1 | 12 |
| | 80th | 6.4 | 8.9 |
| OS3 | Mean ± se | 5.4 ± 0.1 | 6.5 |
| | Range | 1.5 – 18.5 | <1 – 110 |
| | 99th | 16.3 | 27 |
| | 95th | 13.1 | 14 |
| | 80th | 6.6 | 8.9 |
| OS4 | Mean ± se | 4.9 ± 0.0 | 5.9 |
| | Range | 1 – 14 | <1 – 35 |
| | 99th | 12.7 | 18 |
| | 95th | 10.2 | 13 |
| | 80th | 6.7 | 8.1 |
| OS5 | Mean ± se | 3.8 ± 0.0 | 4.6 |
| | Range | 1.1 – 15 | <1 – 35 |
| | 99th | 12 | 18 |
| | 95th | 8.2 | 11 |
| | 80th | 5.1 | 6.1 |
| OS6 | Mean ± se | 4.5 ± 0.0 | 4.7 |
| | Range | <1 – 15 | <1 – 37 |
| | 99th | 12 | 18 |
| | 95th | 9.2 | 11 |
| | 80th | 6.3 | 7.1 |
| OS7 | Mean ± se | 5.6 ± 0.1 | 6.3 |
| | Range | 1.3 – 17 | <1 – 48 |
| | 99th | 14 | 22 |
| | 95th | 12 | 14 |
| | 80th | 7 | 9.1 |

**Table 25** Summary of Vision Environment quality control data for August 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.*
** Slightly higher concentrations in the field and lab blank, indicating potential sample contamination.*

| Parameter | VE Field Blank (µg/L) | VE Lab Blank (µg/L) | Duplicate | | |
|---|---|---|---|---|---|
| | | | CH1 (A) (µg/L) | CH1 (B) (µg/L) | Variation (%) |
| TSS | <3 | <3 | 6 | 8 | 29 |
| Dissolved Aluminium (µg/l) | <3 | <3 | <12 | <12 | ND |
| Total Aluminium (µg/l) | <3.2 | <3.2 | 100 | 99 | 1 |
| Dissolved Arsenic (µg/l) | <1 | <1 | <4 | <4 | ND |
| Total Arsenic (µg/l) | <1.1 | <1.1 | <4.2 | <4.2 | ND |
| Dissolved Cadmium (µg/l) | <0.05 | <0.05 | <0.2 | <0.2 | ND |
| Total Cadmium (µg/l) | <0.053 | <0.053 | <0.21 | <0.21 | ND |
| Dissolved Chromium (µg/l) | <0.5 | <0.5 | 1.2 | 1.4 | 15 |
| Total Chromium (µg/l) | <0.53 | <0.53 | 1.7 | 1.2 | 34 |
| Dissolved Cobalt (µg/l) | <0.2 | <0.2 | <0.6 | <0.6 | ND |
| Total Cobalt (µg/l) | <0.21 | <0.21 | <0.63 | <0.63 | ND |
| Dissolved Copper (µg/l) | <0.5 | <0.5 | <1 | <1 | ND |
| Total Copper (µg/l) | <0.53 | <0.53 | <1.1 | <1.1 | ND |
| Dissolved Iron (µg/l) | <20 | <20 | <4 | <4 | ND |
| Total Iron (µg/l) | <21 | <21 | 121 | 134 | 10 |
| Dissolved Lead µg/l) | <0.1 | <0.1 | <1 | <1 | ND |
| Total Lead (µg/l) | <0.11 | <0.11 | <1.1 | <1.1 | ND |
| Dissolved Manganese (µg/l) | <0.5 | <0.5 | 2.8 | 2.2 | 24 |
| Total Manganese (µg/l) | <0.53 | <0.53 | 5.2 | 5.3 | 2 |
| Dissolved Mercury (µg/l) | <0.08 | <0.08 | <0.08 | <0.08 | ND |
| Total Mercury (µg/l) | <0.08 | <0.08 | <0.08 | <0.08 | ND |
| Dissolved Molybdenum (µg/l) | <0.2 | <0.2 | 11.2 | 10.6 | 6 |
| Total Molybdenum (µg/l) | <0.21 | <0.21 | 10.6 | 10.8 | 2 |
| Dissolved Nickel (µg/l) | <0.5 | <0.5 | <7 | <7 | ND |
| Total Nickel (µg/l) | <0.53 | <0.53 | <7 | <7 | ND |
| Dissolved Selenium (µg/l) | <1 | <1 | <4 | <4 | ND |
| Total Selenium (µg/l) | <1.1 | <1.1 | <4.2 | <4.2 | ND |
| Dissolved Silver (µg/l) | <0.1 | <0.1 | <0.4 | <0.4 | ND |
| Total Silver (µg/l) | <0.11 | <0.11 | <0.43 | <0.43 | ND |
| Dissolved Tin (µg/l) | <0.5 | <0.5 | <5 | <5 | ND |
| Total Tin (µg/l) | <0.53 | <0.53 | <5.3 | <5.3 | ND |
| Dissolved Vanadium (µg/l) | <1 | <1 | 1.9 | 1.8 | 5 |
| Total Vanadium (µg/l) | <1.1 | <1.1 | 1.3 | 2.2 | 51 |
| Dissolved Zinc (µg/l) | 1.1* | <1 | <4 | <4 | ND |
| Total Zinc (µg/l) | <1.1 | <1.1 | <4.2 | <4.2 | ND |
| Total Phosphorus (µg/l) | <4 | <4 | 20 | 24 | 18 |
| Dissolved Reactive Phosphorus (µg/l) | <4 | <4 | 12.9 | 12.8 | 1 |
| Total Nitrogen (µg/l) | <110 | <110 | <300 | <300 | ND |
| Total Kjeldahl Nitrogen (TKN) (µg/l) | <100 | <100 | <200 | <200 | ND |
| Total Ammonia (µg/l)* | <10 | 13 | 41 | 35 | 16 |
| Nitrate-N + Nitrite-N (µg/l) | <2 | <2 | 55 | 55 | 0 |
| Chlorophyll *a* (µg/L) | <0.2 | <0.2 | 1.4 | 1.2 | 15 |