



## Lyttelton Port Company Channel Deepening Project Environmental Monitoring

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Water Quality Environmental Monitoring  
Services – Monthly Report

August 2018

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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
DRP	Dissolved Reactive Phosphorus
EMMP	Environmental Monitoring and Management Plan
$K_d$	Light attenuation coefficient
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

## 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) (Tonkin & Taylor, 2016). Baseline datasets are acquired from three spoil ground sites (SG1, SG2 and SG3), seven offshore sites (OS1–OS7) and five inshore sites (UH1–UH3, CH1–CH2) to assess potential impacts of the dredging project. Results collected between the 1 and 31 August 2018, are presented within this monthly report. It should be noted that during the August monitoring period, construction works as part of the ‘Lyttelton Harbour wastewater scheme’ continued in the upper harbour, and dredging operations for the Channel Deepening Project commenced on 29 August.

**Climatic Conditions:** Rainfall measured at Cashin Quay during August was limited, with only 14 mm experienced over 11 days. Freshwater additions to the region through the southerly transported Waimakariri River outflow were also limited, with river flow at the Old Harbour Bridge below 210 m<sup>3</sup>/s for the duration of the month. Mean daily inshore wind speeds greater than 14 knots were recorded on 12, 20, 24 and 31 August.

Offshore, significant wave heights peaked at 2.4 m on 20 August. Air temperatures remained low, with a monthly average of 9°C.

**Currents:** Similar to previous months, current speeds recorded at SG3 were greater than those at SG1, with data from both the near-surface and near-seabed indicating maximum velocities on 31 August. Further north at SG1, near-surface and near-seabed current velocities peaked on 9 and 6 August, respectively. Sub-maximal increases in current velocity were also observed at SG1 at the end of the month, coinciding with strong currents at SG3.

Current direction data indicate a strong dominance of northwesterly flows at SG1, and a strong east-west flow directionality further south at SG3.

**Physicochemical Parameters:** Consistent with previous reports of the baseline monitoring, turbidity was once again elevated at the inshore monitoring sites of the central and upper harbour. The remaining nearshore and offshore monitoring locations displayed lower mean turbidity levels that typically decreased with increasing distance offshore.

Three of the four inner harbour sites displayed a peak in surface turbidity on 12 to 13 August, with the highest turbidity recorded at the northern upper harbour (site UH1). Interestingly, turbidity at CH2 declined at this period in time, which may be an indication of construction induced turbidity elevations. Elevated offshore significant wave heights resulted in increased turbidity within the nearshore region around 8 August, followed by a slight declining trend that was superimposed with higher frequency variability. Notably higher surface turbidity was recorded at OS1 towards the end of the month, when compared to the remaining nearshore sites.

Further offshore at the spoil ground and sites OS5 and OS6, turbidity levels remained more stable over the course of the month. Surface turbidity levels initially declined at the beginning of the month, followed by slight increases at SG1, SG2 and OS5.

Benthic data recovery was limited for OS1, however, sites OS2 and OS6 provided a high percent return for August. Initially, benthic turbidity declined at the beginning of the month, followed by notable increases at OS2 and OS4 as offshore wave heights increased.



Interestingly, the relatively exposed sites OS3 and OS6 did not display a large benthic turbidity response to this forcing. During the second half of the month, benthic turbidity at all monitoring sites displayed concomitant variability that correlated well with short term changes in offshore wind and waves.

Monthly mean surface water temperatures around Lyttelton Harbour indicated slight warming; breaking the long term cooling trend reported over recent months. The lowest temperatures were once again recorded in the shallow waters of the upper and central harbour. All surface datasets indicated a warming trend throughout the month, with a brief phase of cooling at SG1 on 21 August. Benthic temperatures were up to 0.3°C warmer than those of the surface, and also displayed a similar cooling signal.

Consistent with previous reports, mean conductivity for August did not display any particular spatial pattern across the monitoring network. Temporally, however, surface conductivity declined at OS5, SG1 and SG2 on 12 August, in a pattern that typically occurs due to the presence of freshwater outflow from the Waimakariri River, although volumes around this time were quite low (<210 m<sup>3</sup>/s). A second, smaller amplitude, decline in conductivity was also observed at SG1 on 21 August, coinciding with a period of cooler temperatures at this location.

Dissolved oxygen concentration and pH data did not display any notable spatial or temporal patterns during August. Both parameters continued to display a diurnal signal that reflects variations in the balance of photosynthesis and respiration. Benthic conductivity, DO and pH conditions also remained relatively stable over August.

**Water Sample Analysis and Depth Profiling:** Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 9 August 2018. Similar to the profiles obtained during July, the harbour and nearshore monitoring sites indicated a well-mixed water column. Benthic waters at these sites were characterised by increases in turbidity near the seabed. In a similar manner to July, notably lower temperature and conductivity values were recorded at the northern edge of the harbour mouth (site OS1).

Further offshore at the spoil ground and sites OS5 and OS6, temperature and conductivity data also indicated well mixed conditions. However, declines in DO and pH were observed at depth. Corresponding increases in benthic turbidity suggest that sediment resuspension may have been a driving factor for these changes.

Turbidity and total suspended solids (TSS) measurements for surface waters were once again elevated at inshore sites compared to the offshore areas, resulting in the shallowest estimations of the euphotic depth, as typically recorded during the baseline monitoring. Near-seabed data at the spoil ground and offshore sites displayed greater levels of turbidity and TSS concentrations than at the sub-surface, most likely due to resuspension of sediments by near-seabed currents. Euphotic depth at the spoil ground was high; estimated to be between 11.4 and 15.6 m. No exceedances of WQG were observed for sub-surface turbidity during the August sampling.

Total phosphorous concentrations only exceeded WQG at the upper harbour monitoring site UH3, with the more bioavailable dissolved reactive fraction once again reported above WQGs at multiple sites across the monitoring network. Elevated concentrations of total kjeldahl nitrogen resulted in WQQ exceedances of both total nitrogen and total kjeldahl nitrogen at UH2. Concentrations of dissolved ammonia and nitrogen oxides were both

reduced from July, with exceedances of dissolved ammonia occurring at similar sites to those of dissolved reactive phosphorous. Exceedances of WQG for nitrogen oxides occurred at monitoring sites located along the northern edge of Lyttelton harbour, and at OS5 located to the north of the harbour mouth.

Despite the high availability of nutrients, chlorophyll a concentrations remained low ( $\leq 3.5$   $\mu\text{g/L}$ ). This may change with seasonal warming.

As typically observed, total aluminium concentrations exceeded designated WQG at all sites except SG3. Concentrations of dissolved aluminium were below the 24  $\mu\text{g/L}$  WQG at all sites; indicating that the majority of aluminium present was associated with particulate matter and thus deemed less biologically available. Of the remaining metals that have associated WQG, no further exceedances were recorded during the August WQ sampling.

No WQG have been derived for iron concentrations, yet high concentrations of total iron were once again recorded in the upper harbour during August. Similar to previous months, the total iron concentrations displayed a decreasing trend in a seawards direction. As with the aluminium data, iron was predominately present in the particulate phase, and is thus not deemed to have been particularly biologically available.

**Benthic Photosynthetically Active Radiation (BPARG):** Levels of ambient sunlight during August displayed a slightly greater range than reported during July, resulting in an increase in the monthly mean ambient PAR. Benthic PAR intensities were greater at OS3 than at OS2, with values reaching up to 2.2  $\text{mmol/m}^2/\text{day}$ , c.f. a maximum of 0.9  $\text{mmol/m}^2/\text{day}$  at OS2.

**Sedimentation:** Altimeter data from site OS2, near the mouth of Lyttelton Harbour indicated relatively stable bed level conditions during the first 6 days of the month, followed by a period of erosion till 18 August. Approximately 28 mm of material was removed from the seafloor, which may have been induced by slightly elevated offshore significant wave heights at this time. For the remainder of the month, sediment deposition resulted in a monthly net bed level change of -8 mm.

Bed level at the upper harbour site UH3 increased by 15 mm during the first 14 days of August, with elevated surface turbidity recorded at the nearby monitoring site UH1. This may be an indication that externally sourced materials were settling out in the lower energy environment of UH3. A brief period of erosion was experienced between 14 and 22 August, followed by a second period of deposition towards the end of the month. These varying periods of deposition and erosion resulted in a net bed level increase of 16 mm at UH3 during August, with little correlation between sediment dynamics and inshore wind speed/direction.

## 1 INTRODUCTION

Water quality monitoring and data collection undertaken by Vision Environment (VE) for Lyttelton Port of Christchurch (LYT), the South Island's largest port, commenced in September 2016. Lyttelton Port Company (LPC) is proposing a Channel Deepening Project (CDP) to extend the existing navigational channel to allow larger vessels access to the Port. The marine water quality environmental monitoring services undertaken by VE will provide interpreted baseline data to support the process of the Environmental Monitoring and Management Plan (EMMP) for the LPC CDP (Tonkin & Taylor, 2016) and assist to ascertain the potential impacts of the project.

The aim of the CDP is to deepen, widen and lengthen the existing approach channel and turning basin, to accommodate increasing cargo capacity requirements and ensure LPC continues to provide efficient shipping services for the local and regional economy. LPC is committed to environmentally responsible and safe port operations and development, and in particular, ensuring the protection of mahinga kai values and the health of Lyttelton Harbour/Whakaraupō and Port Levy/Koukourārata. Utilising background information provided by LPC and advice from the Technical Advisory Group (TAG) in relation to ambient conditions, location of sensitive habitats and dredge impact hydrodynamic modelling scenarios, a water quality monitoring design was proposed for the initial 12 month baseline monitoring phase, which has continued into a second year. Note this report only covers the water quality and metocean monitoring, and other forms of monitoring are outlined in the EMMP.

## 2 METHODOLOGY

### 2.1 Approach

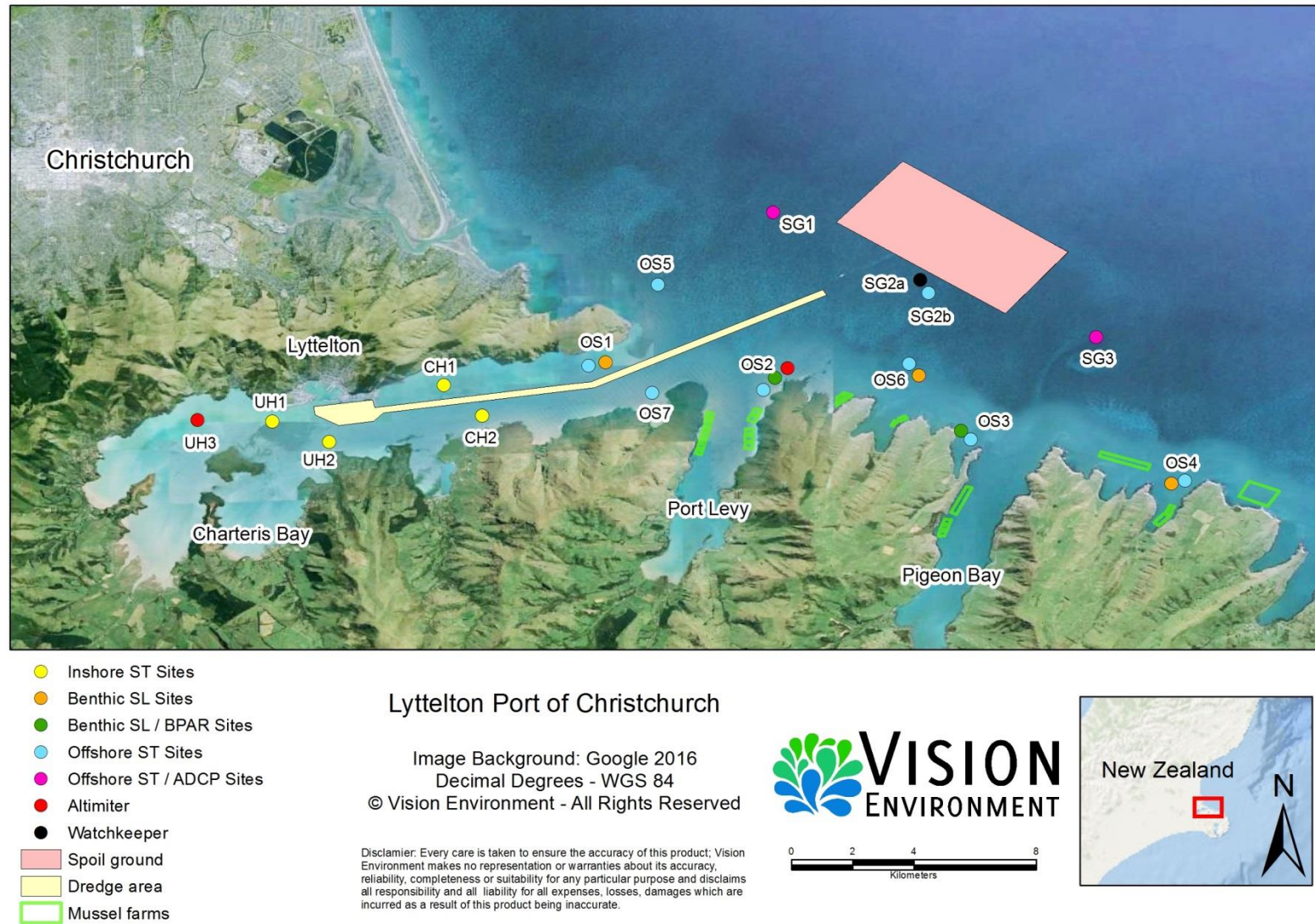
An overview of the methodology for baseline water quality monitoring is provided in this section. A more detailed description of the importance of the measured parameters and the specific methodology for the CDP data collection and processing protocols, can be found in the Channel Deepening Project Water 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 monitoring sites were located outside the area of predicted direct impact (i.e. dredge footprint and offshore disposal ground), 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). At 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 has been utilised at a number of offshore locations.





**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

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 appears to be well mixed at these sites, with little to no stratification. Therefore, surface loggers only have predominantly been utilised at these sites.

**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						√
<b>Total</b>	1	2	12	3	2	2

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

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

This monthly report presents data collected from the 22 monitoring locations from 1 to 31 August 2018. A summary of climatic conditions during this period is provided, in addition to the results of continuous and discrete water sampling.

### 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 are 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 those which pass through a 0.45 µm membrane filter (APHA, 2005). Trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived for a number of metals. The guidelines refer to dissolved metals as these are considered to be the potential 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

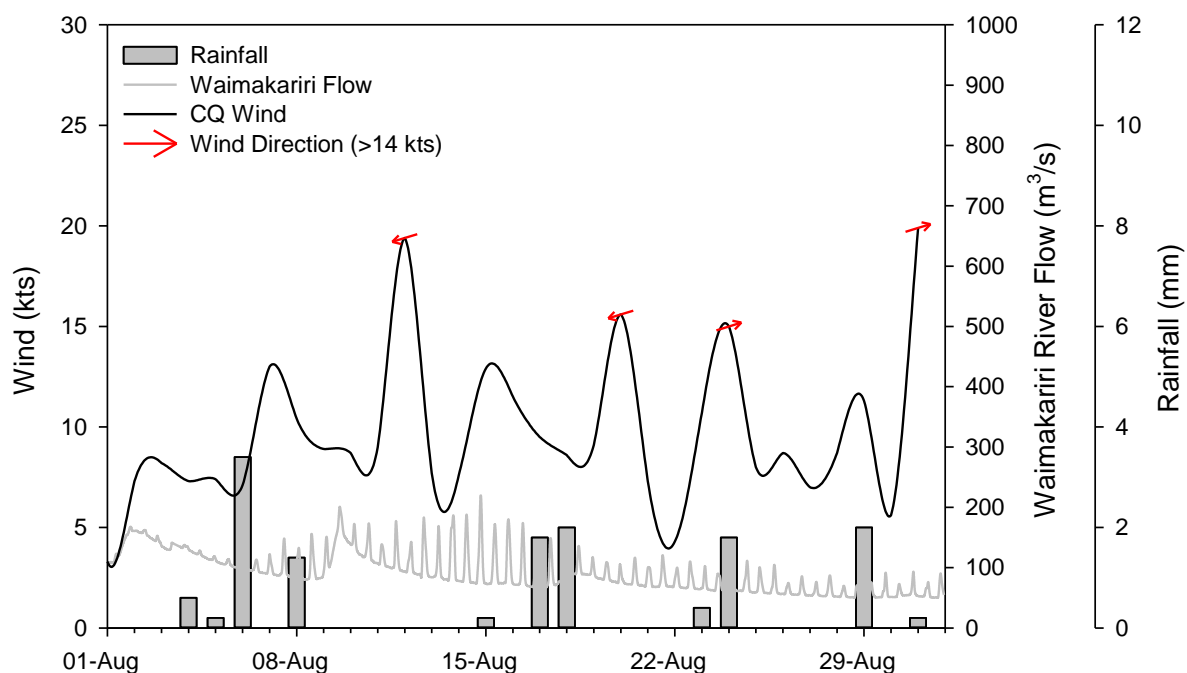
#### 3.1.1 Wind and precipitation

Only 14 mm of rainfall was received at Cashin Quay during August, which was relatively evenly spread throughout the month over 11 rain days (Figure 2) (Metconnect, 2018). Freshwater flows from the Waimakariri River, which can be transported south along the coastline and enter Lyttelton Harbour several days later, were also limited, with flows remaining below 210 m<sup>3</sup>/s (Figure 2) (ECAN, 2018). Maximum daily mean inshore average wind speeds measured at Cashin Quay were recorded at 19.9 knots on 31 August, blowing from a west-south-westerly direction. Elevated inshore winds greater than 14 knots were also recorded on 12, 20 and 24 August (Figure 2).

Offshore significant wave height peaked at 2.4 m on 20 August (Figure 3) occurring shortly after a period of increased offshore wind speeds (>14 knots). Monthly mean air temperature remained low during austral winter. Daily mean air temperatures at Cashin Quay ranged from 4 to 17°C, resulting in a monthly mean temperature of 9°C (Metconnect, 2018).

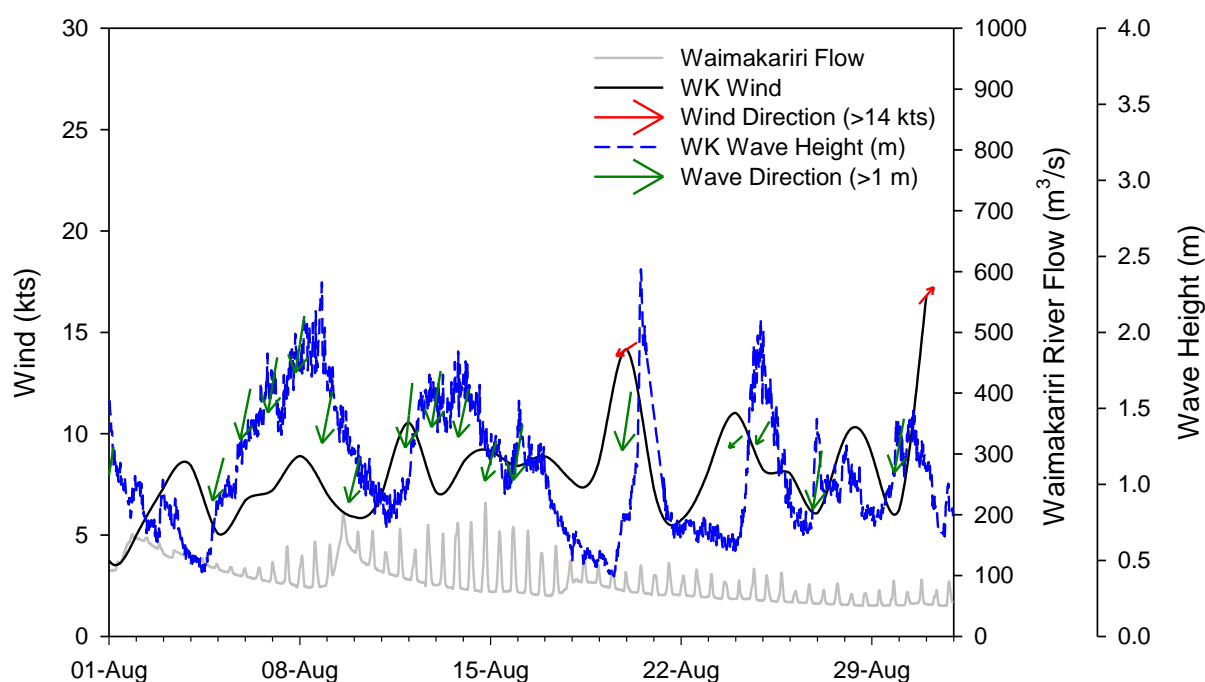
#### 3.1.2 Currents

Acoustic Doppler Current Profilers (ADCPs) are deployed at the spoil ground monitoring sites SG1 and SG3, reporting the speed and direction of currents in close proximity to the sea surface and seabed. Summary statistics from these two monitoring sites are presented within Table 2 and Figures 4 and 5. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 28 to 31, located within the report appendix.



**Figure 2** Inshore meteocean conditions, including daily averaged wind speed, daily averaged wind direction and rainfall measured at Cashin Quay; combined with Waimakariri River flow at the Old Harbour Bridge station, from 1 to 31 August 2018.

*Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.*



**Figure 3** Offshore meteocean conditions, including wind speed, wind direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a; combined with Waimakariri River flow measurements at the Old Harbour Bridge station, from 1 to 31 August 2018.

*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.*



Similar to observations during previous months of monitoring, mean current speeds at SG3 in August were once again higher than those at SG1 (Table 2), with reduced monthly mean current velocities observed at the near-seabed. Mean near-surface current speeds were calculated at 93 mm/s (SG1) and 114 mm/s (SG3), whereas mean near-seabed current speeds were slightly lower at 90 mm/s at SG1 and 112 mm/s at SG3.

The maximum near-surface current velocity at SG1 was recorded on 9 August at 358 mm/s, coinciding with a sustained increase in maximum significant wave heights as measured by the WatchKeeper Buoy (Figure 3). Maximum near-seabed velocities of 298 mm/s were observed three days earlier, on 6 August, however benthic currents were also elevated on 9 August, with daily maximum speeds of 266 mm/s.

Further south at SG3, maximum current velocities were greater than those experienced at SG1. Currents reached maximum velocities of 429 mm/s (near-surface) and 430 mm/s (near-seabed) on 31 August, with a trend of increasing current speeds also recorded at SG1 at the end of the month.

**Table 2** Parameter statistics for ADCP at SG1 and SG3 during August 2018.

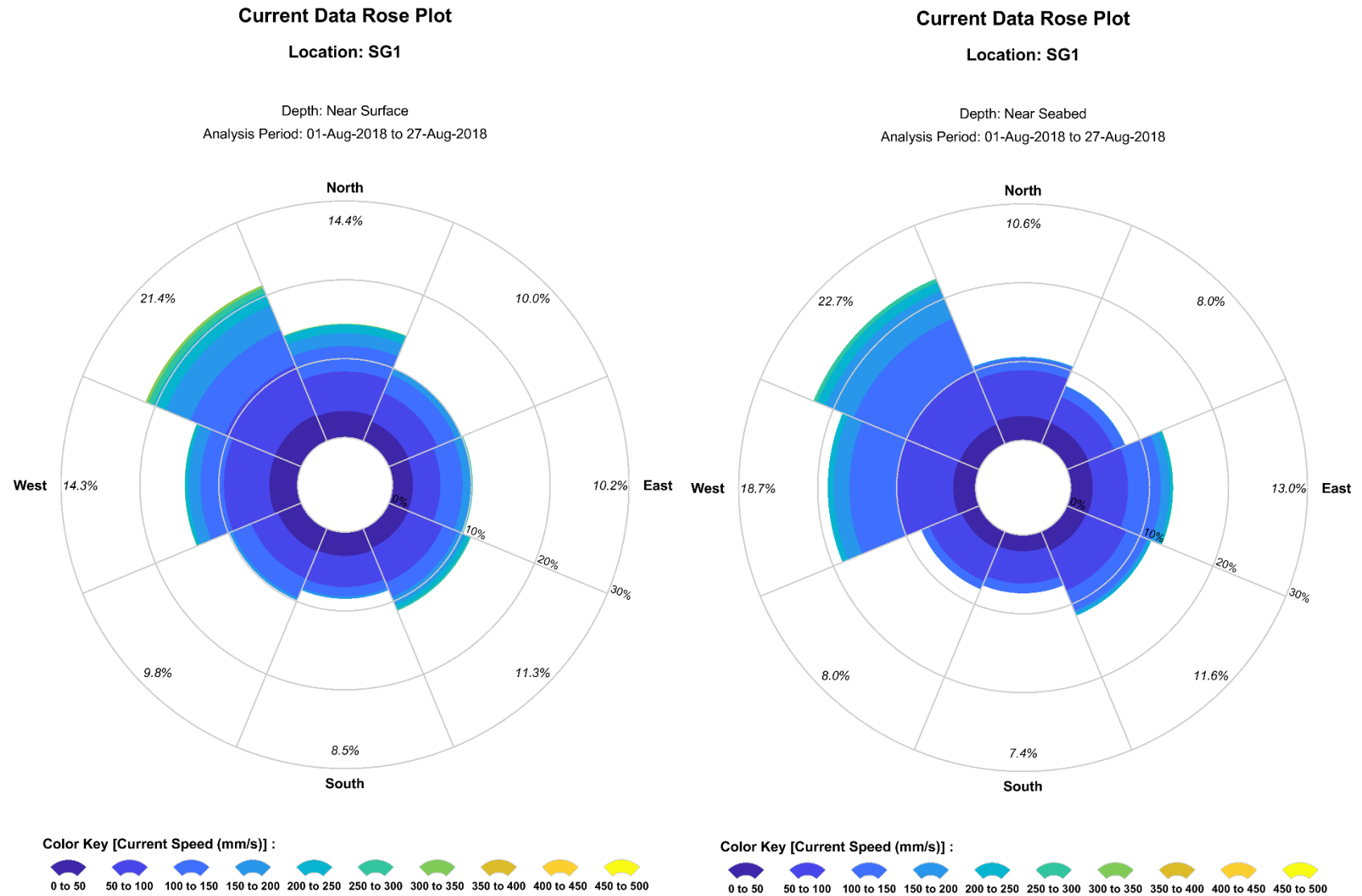
Parameter	Depth	Site	
		SG1	SG3
Minimum current speed (mm/s)	<i>Near-surface</i>	1	2
	<i>Near-seabed</i>	<1	2
Maximum current speed (mm/s)	<i>Near-surface</i>	358	429
	<i>Near-seabed</i>	298	430
Mean current speed (mm/s)	<i>Near-surface</i>	93	114
	<i>Near-seabed</i>	90	112
Standard deviation of current speed (mm/s)	<i>Near-surface</i>	58	69
	<i>Near-seabed</i>	48	67
Current speed, 95 <sup>th</sup> percentile (mm/s)	<i>Near-surface</i>	205	245
	<i>Near-seabed</i>	183	235

*Note: Data from SG1 were only available from 1 to 27 August.*

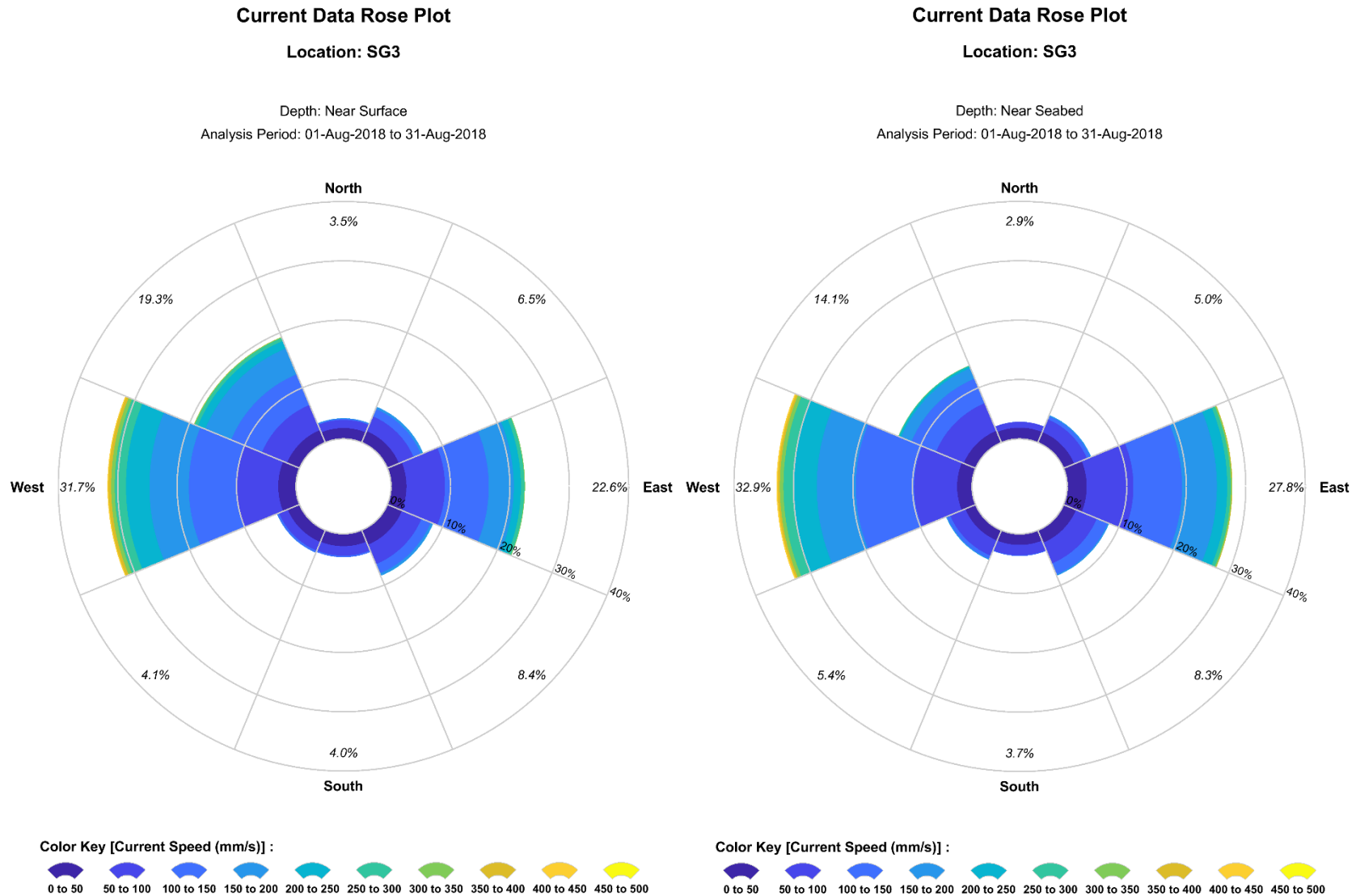
The time-series plots (Figures 28 to 31 in the appendix) illustrate time-varying current direction, whilst current rose diagrams (Figures 4 and 5) depict the distribution of current direction and velocity in the near-surface and near-seabed layers. When interpreting the current data, please note that the convention for defining current direction is the direction in which the current flows *towards*, which is the reference used throughout the figures presented (the opposite is true for wind direction, where the reference is the direction from which the wind is coming from).

Current direction data from SG1 during August displayed a strong dominance of flow to the northwest at both the near-surface and near-seabed (Figure 4). ADCP data from SG3 once again indicated a strong east-west flow directionality at both the near-surface and near-seabed (Figure 5). Contrasting patterns observed during July, both depths indicate a dominance of westerly flows. The apparent reversal of flows across an approximate 180° axis observed at both locations represent the influence of semi-diurnal tides on the local currents, which can also be observed in the weekly current flow plots in Figures 28 to 31 of the Appendix.





**Figure 4** SG1 near-surface and near-seabed current speed and direction 1 to 31 August 2018.  
 Speed intervals of 50 mm/s are used



**Figure 5** SG3 near-surface and near-seabed current speed and direction 1 to 31 August 2018.  
 Speed intervals of 50 mm/s are used

## 3.2 Continuous Physicochemistry Loggers

Physical and chemical properties (turbidity, temperature, conductivity [normalised to a reference temperature of 25°C], pH and DO) of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 9 August 2018. 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 are presented in Tables 3 to 9 in the form of monthly means, standard error of the mean, and 99<sup>th</sup>, 95<sup>th</sup> and 80<sup>th</sup> percentiles. Validated datasets for surface and benthic measurements are also presented in Figures 6 to 19. 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.

Of note during August is the continuation of construction works associated with the Lyttelton Harbour wastewater scheme in the upper harbour, and the commencement of Channel Deepening Project operations on 29 August.

### 3.2.1 Turbidity

Of key importance within the parameters recorded during the baseline monitoring period are the surface turbidity measurements, due to their use in the generation of trigger values for dredge operations monitoring. Statistical analyses of surface and benthic (where available) data are provided within Tables 3 to 5 and summary plots of 24 hour rolling average turbidity values for all sites are provided in Figure 6. High temporal resolution turbidity data averaged over both loggers for each site are presented in Figures 7 to 11.

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 8.2 to 11 NTU) at the inshore monitoring sites (Tables 3 to 5, Figure 6), particularly at the northern sites UH1 and CH1, where the finer seafloor sediments are more readily resuspended following a disturbance. Further offshore, the spoil ground sites exhibited lower (monthly means of 1.2 to 4.4 NTU) surface turbidity values (Table 4), which are likely due to the deeper water column limiting disturbance expressions at the sub-surface. As typically observed, nearshore sites experienced intermediate turbidity values during August (Table 5). Notably higher mean monthly surface turbidity values had been reported for OS3 and OS7 during the July monitoring, however, this was not apparent within the August data (Table 5).

Both upper harbour sites and the central harbour site CH1 displayed a rapid increase in surface turbidity, peaking on 12 to 13 August 2018 (Figure 6) as inshore winds speeds increased (Figure 2). Interestingly, turbidity at CH2 declined while the remaining inner harbour sites reached monthly maxima. This difference may be an indication of construction related influences in the upper harbour. Similar to upper harbour turbidity trends recorded during previous months, higher temporal resolution plots in Figure 7 also indicate a cyclic variation of higher and lower turbidity, which are likely to reflect the forces of tidal movements on patches of increased surface turbidity and the notable residence time of harbour waters.

Within the nearshore environment, turbidity at all sites displayed a declining trend during the first week of August, followed by a rapid increase in turbidity induced by elevated offshore significant wave heights. Lower amplitude variability in surface turbidity was superimposed on a slight declining trend from 10 to 22 August, once again following variations in offshore wave heights. Within these nearshore sites, OS2 and OS1 displayed elevated turbidity on 20 to 21 August and 25 to 31 August, respectively. This may in part be due to their location at the mouth of Lyttelton Harbour, although equally high turbidity concentrations would typically be expected at the exposed sites OS3 and OS4.

Further offshore, the spoil ground sites, OS5 and OS6 presented a similar pattern of declining turbidity at the beginning of the month, albeit at a lower absolute intensity than the inshore and nearshore sites. Following the monthly minima around 8 to 10 August, surface turbidity at SG1, SG2 and OS5 displayed a slight increasing trend to the end of the month. Relatively stable turbidity levels were recorded at the southerly offshore sites SG3 and OS6 for the remainder of the month.

Benthic data recovery from the continuous loggers at OS1 was intermittent during August, with a particularly high level of data recovery from benthic sites OS2 and OS6. As offshore wave heights declined at the start of the month, benthic turbidity at OS1, OS2 and OS4 declined as particulate matter settled out of the water column. Increasing wave heights between 5 and 17 August resulted in elevated turbidity at OS2 and OS4 from <20 NTU to >60 NTU. Unfortunately no benthic data were recovered from OS1 at this time, however, benthic turbidity at OS3 and OS6 did not display a particularly large response to this external forcing. As the period of sustained elevated wave energy passed, concomitant variability in benthic turbidity at all sites appears to reflect shorter term changes in offshore winds and waves.

**Table 3** Mean turbidity at inshore water quality logger sites from 1 to 31 August 2018.  
*Values are means  $\pm$  se, range and percentiles (n = 2965 to 2975)*

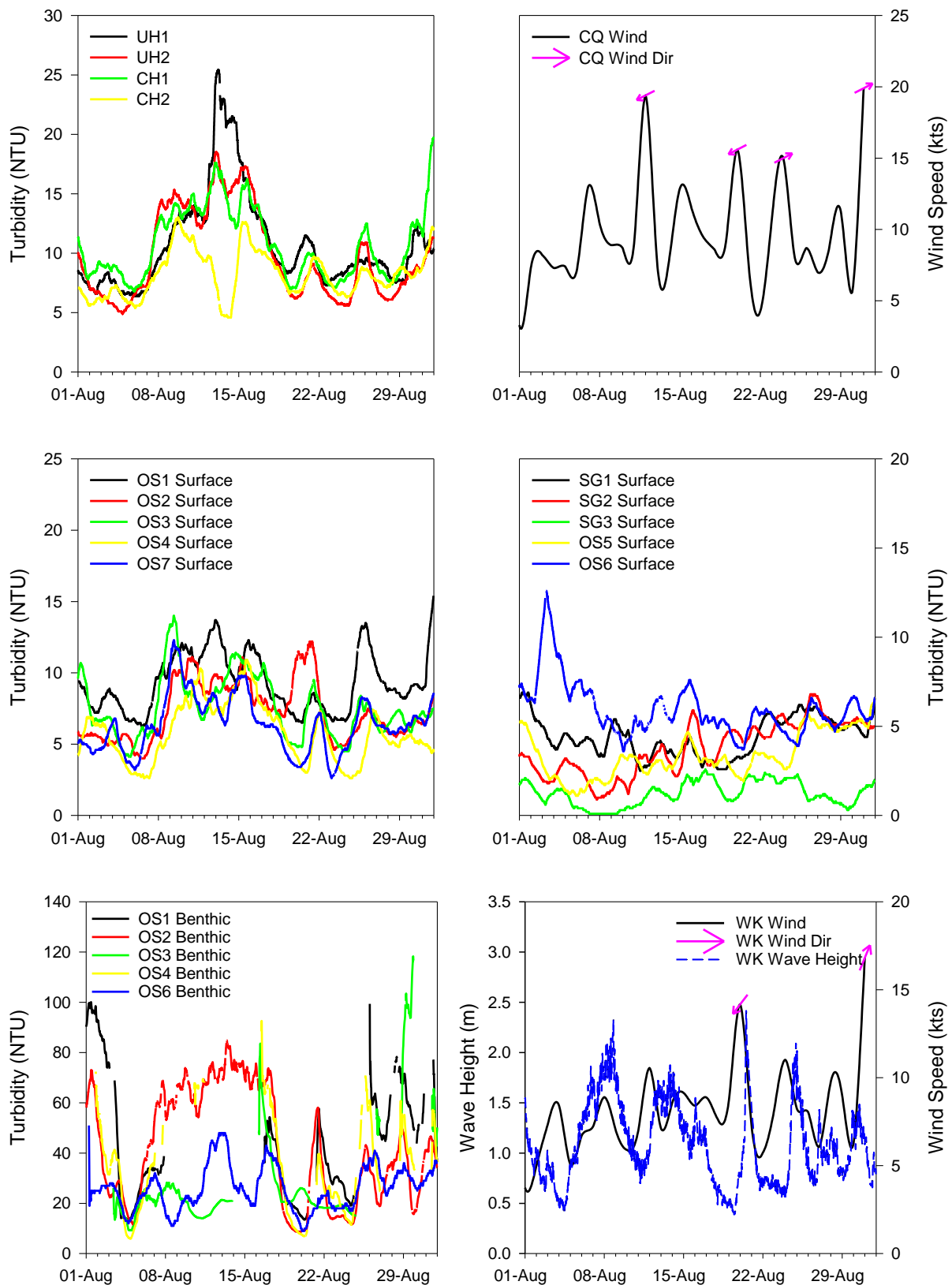
Site	Turbidity (NTU)	
	Statistic	Surface
UH1	Mean $\pm$ se	10 $\pm$ 0
	Range	<1 – 71
	99 <sup>th</sup>	38
	95 <sup>th</sup>	19
	80 <sup>th</sup>	13
UH2	Mean $\pm$ se	9.8 $\pm$ 0.1
	Range	3 – 45
	99 <sup>th</sup>	25
	95 <sup>th</sup>	19
	80 <sup>th</sup>	13
CH1	Mean $\pm$ se	11 $\pm$ 0
	Range	3 – 61
	99 <sup>th</sup>	24
	95 <sup>th</sup>	19
	80 <sup>th</sup>	14
CH2	Mean $\pm$ se	8.2 $\pm$ 0.1
	Range	1 – 24
	99 <sup>th</sup>	17
	95 <sup>th</sup>	13
	80 <sup>th</sup>	10

**Table 4** Mean turbidity at spoil ground water quality logger sites from 1 to 31 August 2018.  
*Values are means  $\pm$  se, range and percentiles (n = 2962 to 2976)*

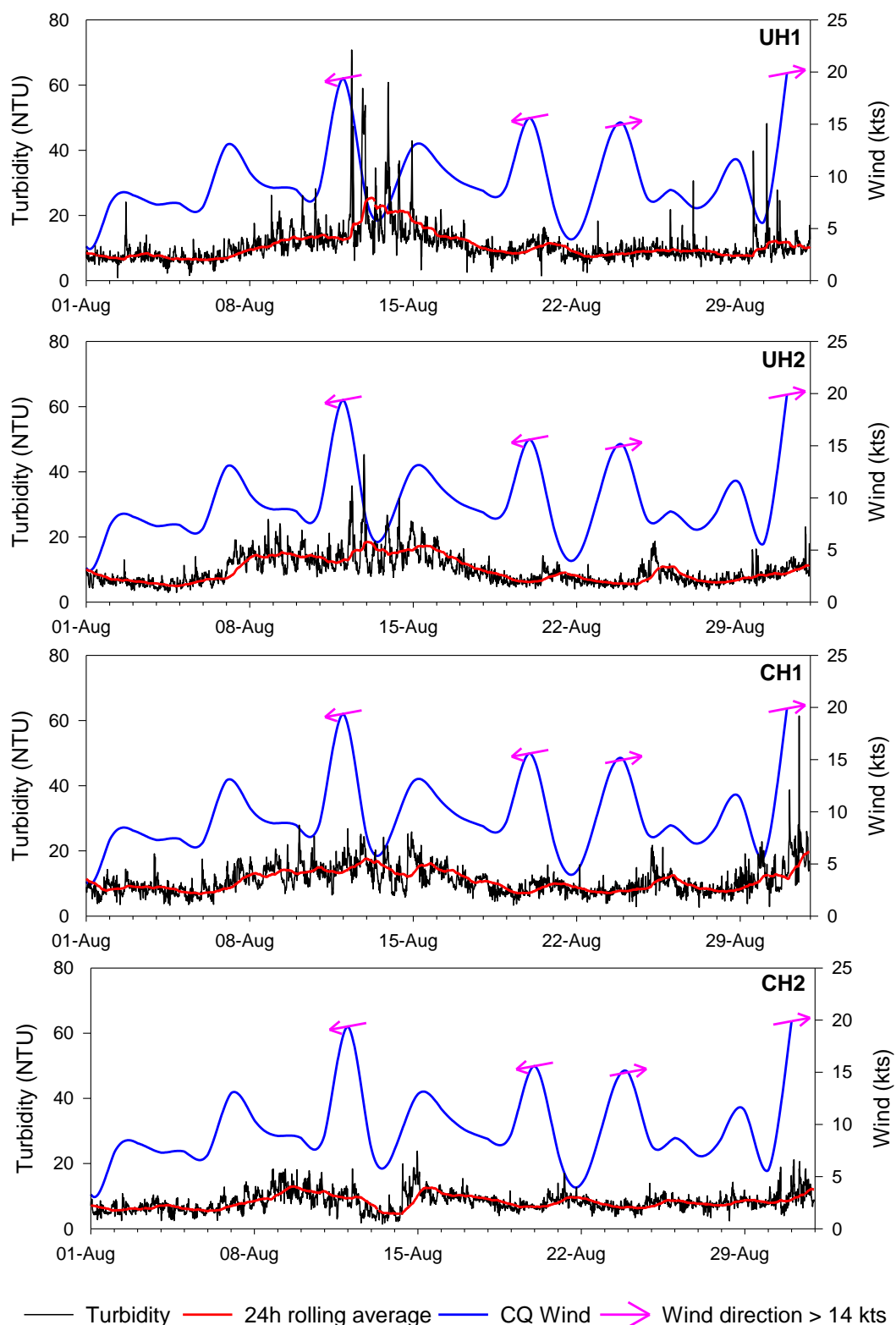
Site	Turbidity (NTU)	
	Statistic	Surface
SG1	Mean $\pm$ se	4.4 $\pm$ 0.0
	Range	<1 – 10
	99 <sup>th</sup>	8.3
	95 <sup>th</sup>	6.6
	80 <sup>th</sup>	5.5
SG2	Mean $\pm$ se	3.8 $\pm$ 0.0
	Range	<1 – 11
	99 <sup>th</sup>	7.6
	95 <sup>th</sup>	6.3
	80 <sup>th</sup>	5.3
SG3	Mean $\pm$ se	1.2 $\pm$ 0.0
	Range	<1 – 7.8
	99 <sup>th</sup>	4.2
	95 <sup>th</sup>	3.0
	80 <sup>th</sup>	2.0

**Table 5** Mean turbidity at offshore water quality logger sites from 1 to 31 August 2018.  
 Values are means  $\pm$  se, range and percentiles ( $n = 1490$  to  $2975$ )

Site	Statistic	Turbidity (NTU)	
		Surface	Benthic
OS1	Mean $\pm$ se	$9.4 \pm 0.1$	$41 \pm 1$
	Range	3 – 38	5 – 159
	99 <sup>th</sup>	19	123
	95 <sup>th</sup>	16	95
	80 <sup>th</sup>	12	63
OS2	Mean $\pm$ se	$7.3 \pm 0.1$	$41 \pm 1$
	Range	1 – 31	6 – 181
	99 <sup>th</sup>	18	142
	95 <sup>th</sup>	13	107
	80 <sup>th</sup>	9.1	65
OS3	Mean $\pm$ se	$7.5 \pm 0.1$	$27 \pm 1$
	Range	2 – 23	2 – 190
	99 <sup>th</sup>	17	169
	95 <sup>th</sup>	13	80
	80 <sup>th</sup>	9.6	28
OS4	Mean $\pm$ se	$5.8 \pm 0.1$	$28 \pm 1$
	Range	<1 – 28	4 – 127
	99 <sup>th</sup>	14	102
	95 <sup>th</sup>	11	80
	80 <sup>th</sup>	7.9	46
OS5	Mean $\pm$ se	$3.4 \pm 0.0$	–
	Range	<1 – 13	–
	99 <sup>th</sup>	8.6	–
	95 <sup>th</sup>	6.0	–
	80 <sup>th</sup>	4.8	–
OS6	Mean $\pm$ se	$6.0 \pm 0.0$	$26 \pm 0$
	Range	<1 – 17	2 – 115
	99 <sup>th</sup>	14	77
	95 <sup>th</sup>	11	56
	80 <sup>th</sup>	7.3	35
OS7	Mean $\pm$ se	$6.4 \pm 0.0$	–
	Range	<1 – 26	–
	99 <sup>th</sup>	15	–
	95 <sup>th</sup>	11	–
	80 <sup>th</sup>	8.2	–

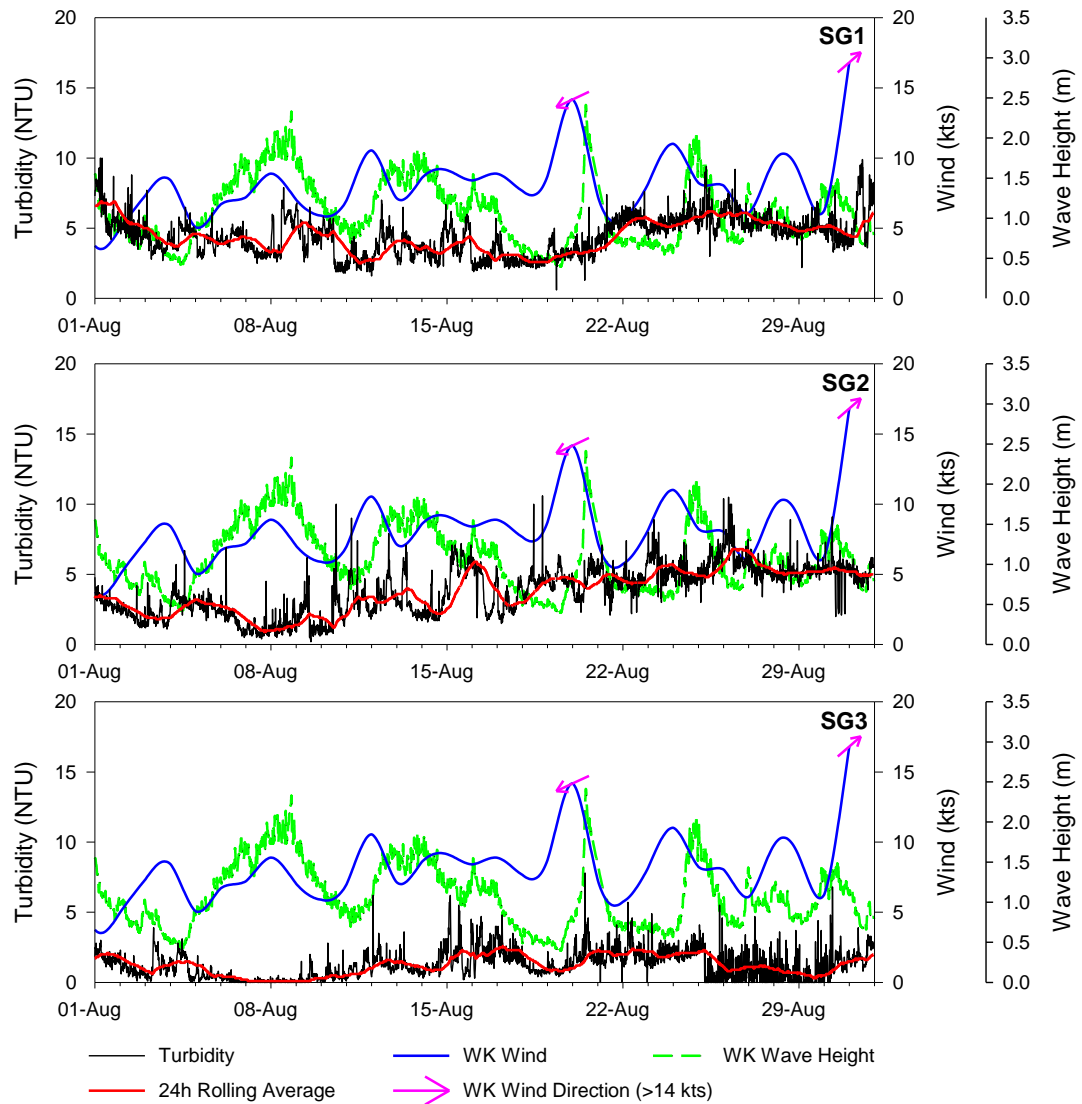


**Figure 6** 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.  
 Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

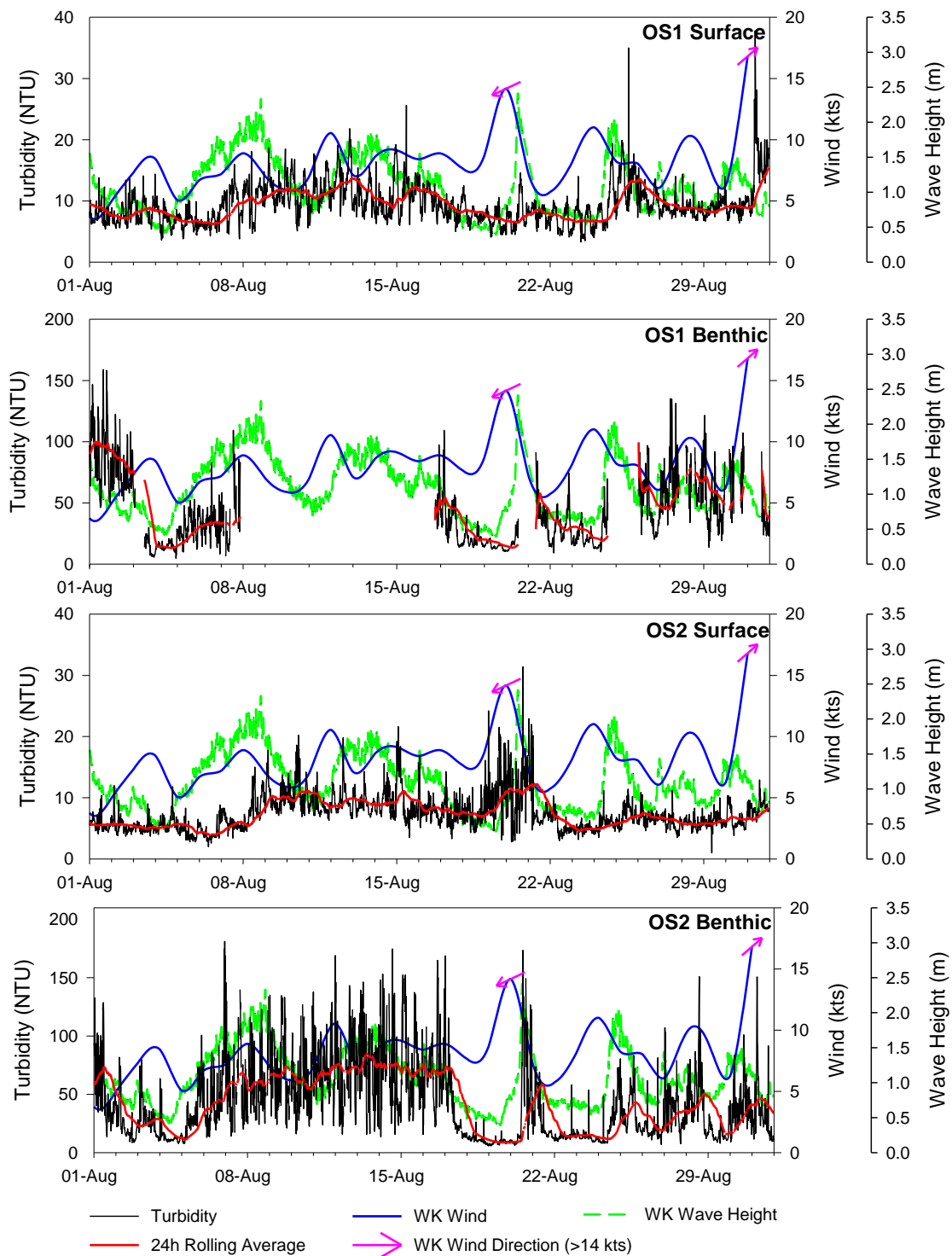


**Figure 7** Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) from 1 to 31 August 2018. Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots.

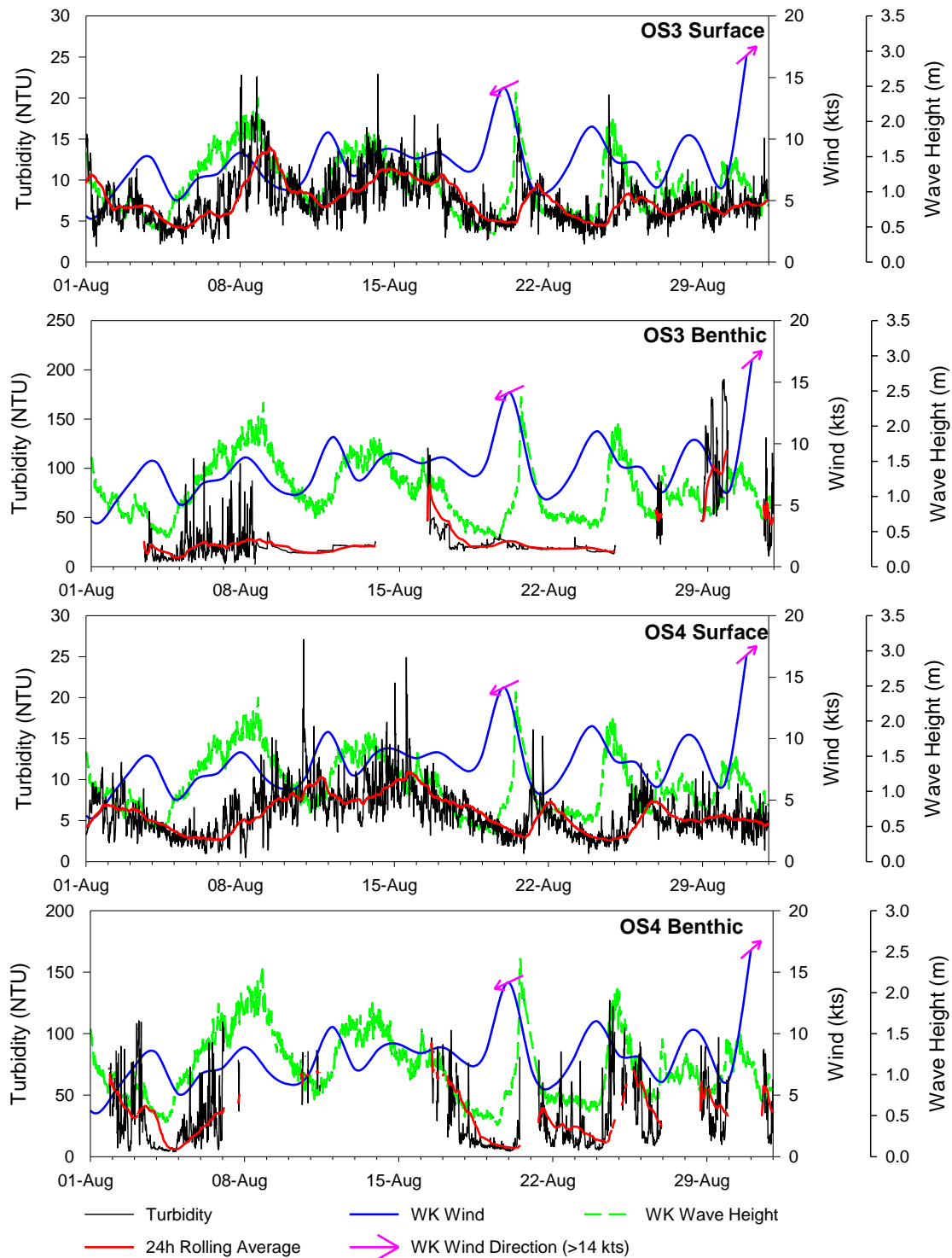




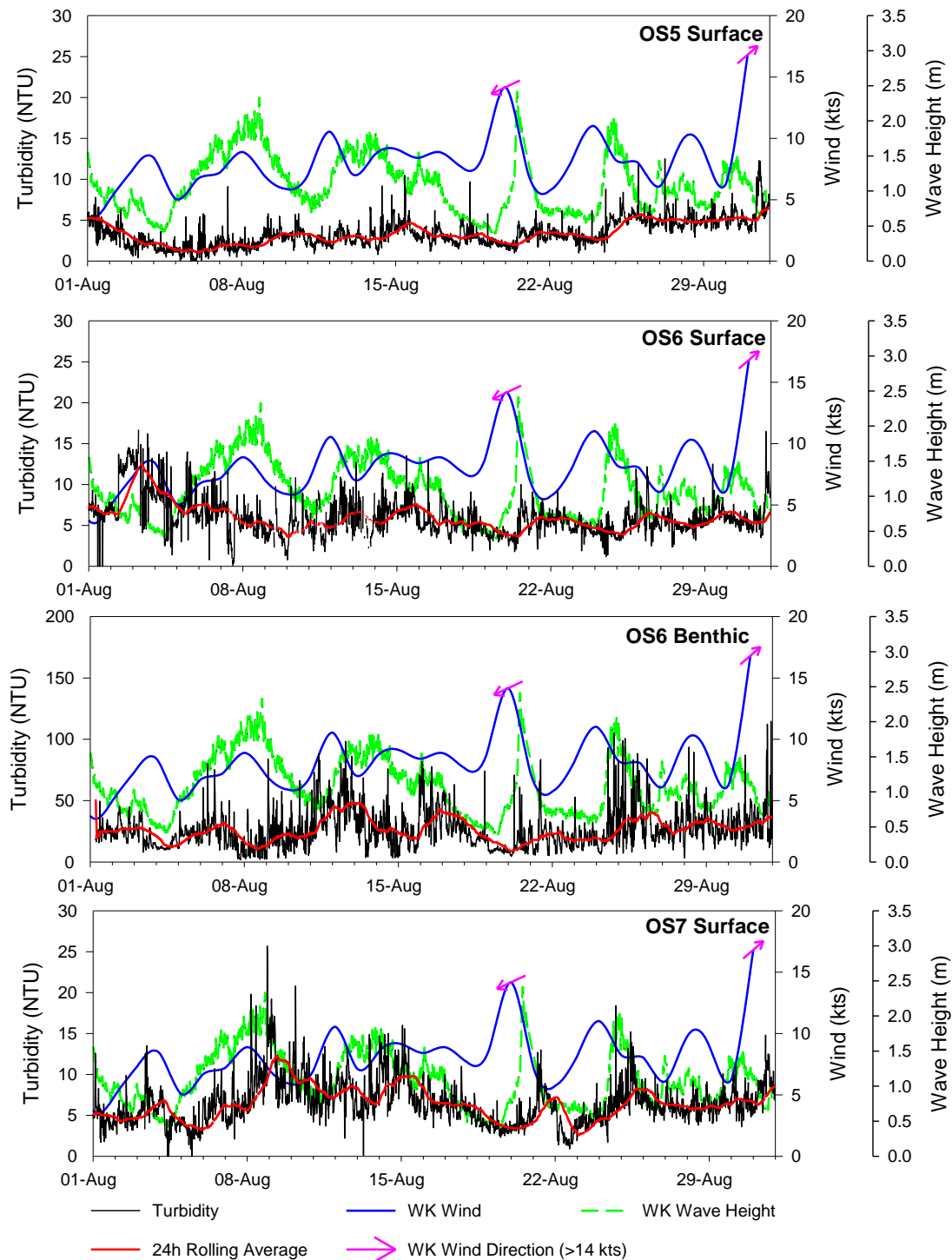
**Figure 8** Surface turbidity at spoil ground sites (SG1, SG2b and SG3) from 1 to 31 August 2018. Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots.



**Figure 9** Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) from 1 to 31 August 2018.  
 Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots



**Figure 10** Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) from 1 to 31 August 2018.  
*Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots*



**Figure 11** Surface and benthic turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) from 1 to 31 August 2018. Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots

### 3.2.2 Temperature

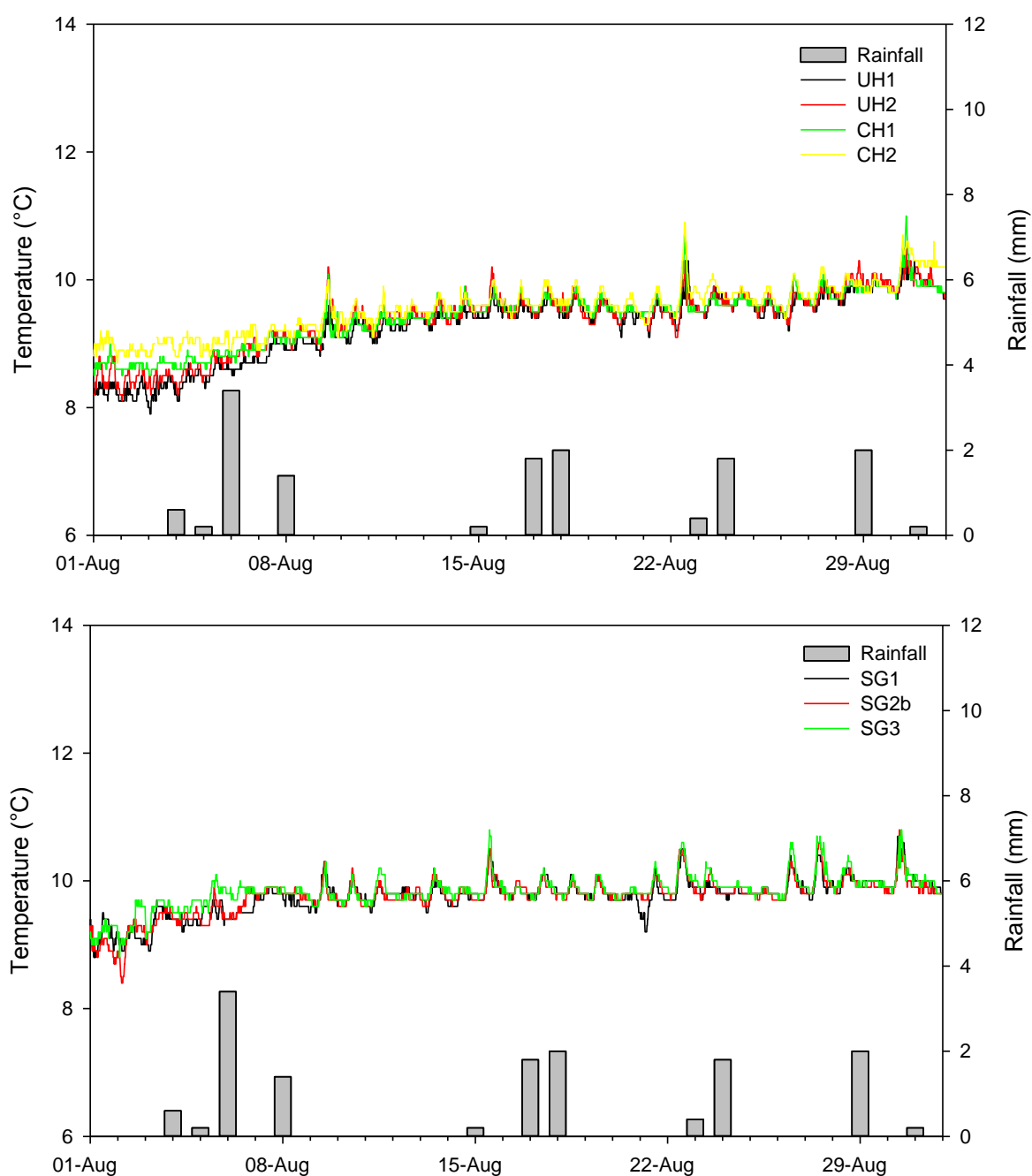
Average surface water temperatures during August were slightly warmer than those experienced during July, ranging from 9.3 to 9.8°C (Table 6), c.f. 8.5 to 9.8°C in July. Similar to the previous month, the coolest temperatures were recorded in the shallow waters of the upper and central harbour. All sites displayed a warming trend across the month, with peaks in temperature occurring around the same time as periods of rainfall (Figures 12 and 13). Semidiurnal variability (associated with tidal water movements and solar radiation) was once again observed within the datasets, particularly at site OS1. One notable anomaly to the warming trend was the cooling of surface temperatures at SG1 on 21 August, when temperatures were ~0.6 °C cooler than at SG2B and SG3.

**Table 6** Mean temperature at inshore, spoil ground and offshore water quality sites from 1 to 31 August 2018.

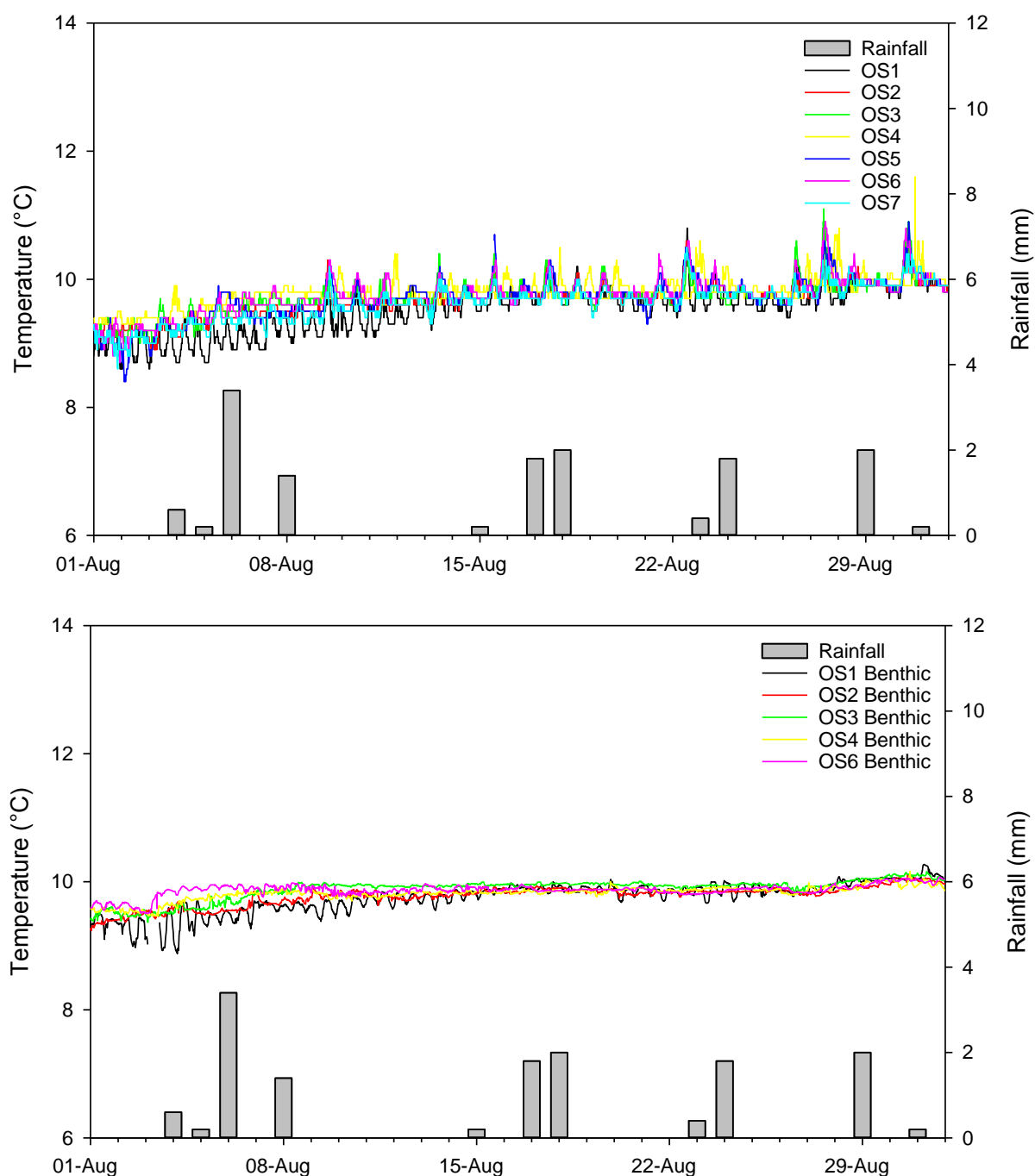
*Values are means  $\pm$  se ( $n = 2936$  to  $2976$ ).*

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	9.3 $\pm$ 0.0	–
UH2	9.4 $\pm$ 0.0	–
CH1	9.4 $\pm$ 0.0	–
CH2	9.6 $\pm$ 0.0	–
SG1	9.8 $\pm$ 0.0	–
SG2	9.8 $\pm$ 0.0	–
SG3	9.8 $\pm$ 0.0	–
OS1	9.5 $\pm$ 0.0	9.8 $\pm$ 0.0
OS2	9.7 $\pm$ 0.0	9.8 $\pm$ 0.0
OS3	9.7 $\pm$ 0.0	9.9 $\pm$ 0.0
OS4	9.8 $\pm$ 0.0	9.8 $\pm$ 0.0
OS5	9.7 $\pm$ 0.0	–
OS6	9.7 $\pm$ 0.0	9.9 $\pm$ 0.0
OS7	9.6 $\pm$ 0.0	–

Benthic monthly mean temperatures were up to 0.3°C warmer than those of the surface waters, and displayed a slight warming trend similar to those of the surface waters (Table 6, Figure 13). Interestingly, benthic temperatures at site OS1, displayed a cyclic variation of warming and cooling, particularly within the first week of August (Figure 13).



**Figure 12** Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall from 1 to 31 August 2018.



**Figure 13** Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 31 August 2018.

### 3.2.3 pH

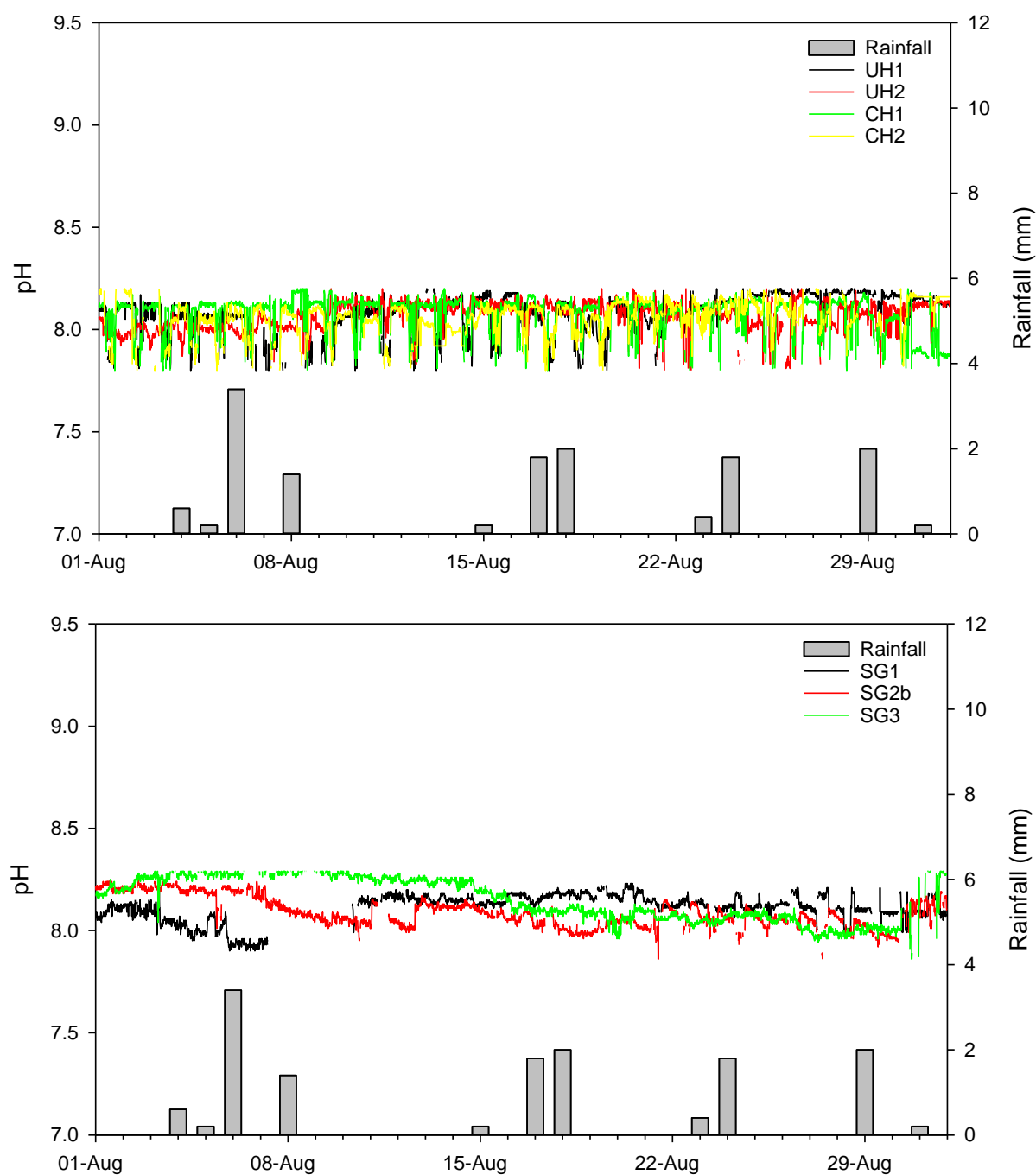
Once again the pH data collected from surface sondes did not demonstrate any particularly strong spatial patterns, with mean monthly surface pH for August ranging from 8.0 to 8.1 (Table 7). Temporally, surface pH did not appear to display any trends associated with rainfall events or freshwater run off (Figures 14 and 15). However, marked variability in pH was observed over the diurnal cycle, with declining pH and increased variance observed during daylight hours, particularly at the inshore and nearshore monitoring sites.

As expected, benthic pH displayed greater stability than that of the surface waters (Figure 15), due to the reduced influence of biological photosynthesis and respiration at depth. Interestingly, benthic pH at the reference site OS4, increased between 4 and 9 August, with a similar timing to increased offshore significant wave heights.

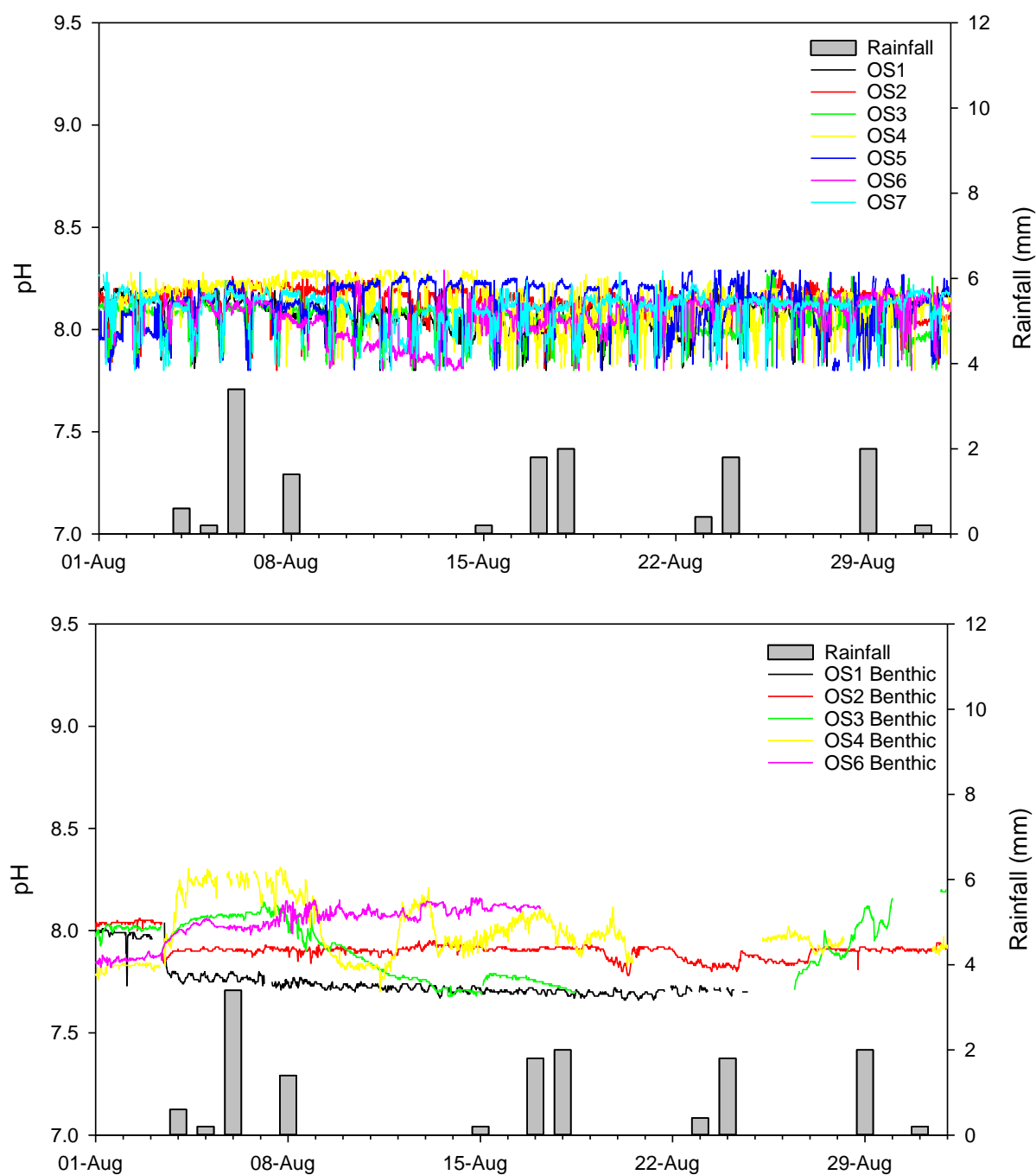
**Table 7** Mean pH at inshore, spoil ground and offshore water quality sites from 1 to 31 August 2018. Values are means  $\pm$  se ( $n = 1560$  to  $2972$ ).

Site	pH	
	Surface loggers	Benthic loggers
UH1	8.1 $\pm$ 0.0	–
UH2	8.1 $\pm$ 0.0	–
CH1	8.1 $\pm$ 0.0	–
CH2	8.1 $\pm$ 0.0	–
SG1	8.1 $\pm$ 0.0	–
SG2	8.1 $\pm$ 0.0	–
SG3	8.1 $\pm$ 0.0	–
OS1	8.1 $\pm$ 0.0	7.7 $\pm$ 0.0
OS2	8.1 $\pm$ 0.0	7.9 $\pm$ 0.0
OS3	8.0 $\pm$ 0.0	7.9 $\pm$ 0.0
OS4	8.1 $\pm$ 0.0	8.0 $\pm$ 0.0
OS5	8.1 $\pm$ 0.0	–
OS6	8.1 $\pm$ 0.0	8.0 $\pm$ 0.0
OS7	8.1 $\pm$ 0.0	–





**Figure 14** Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 31 August 2018.



**Figure 15** Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 31 August 2018.

### 3.2.4 Conductivity

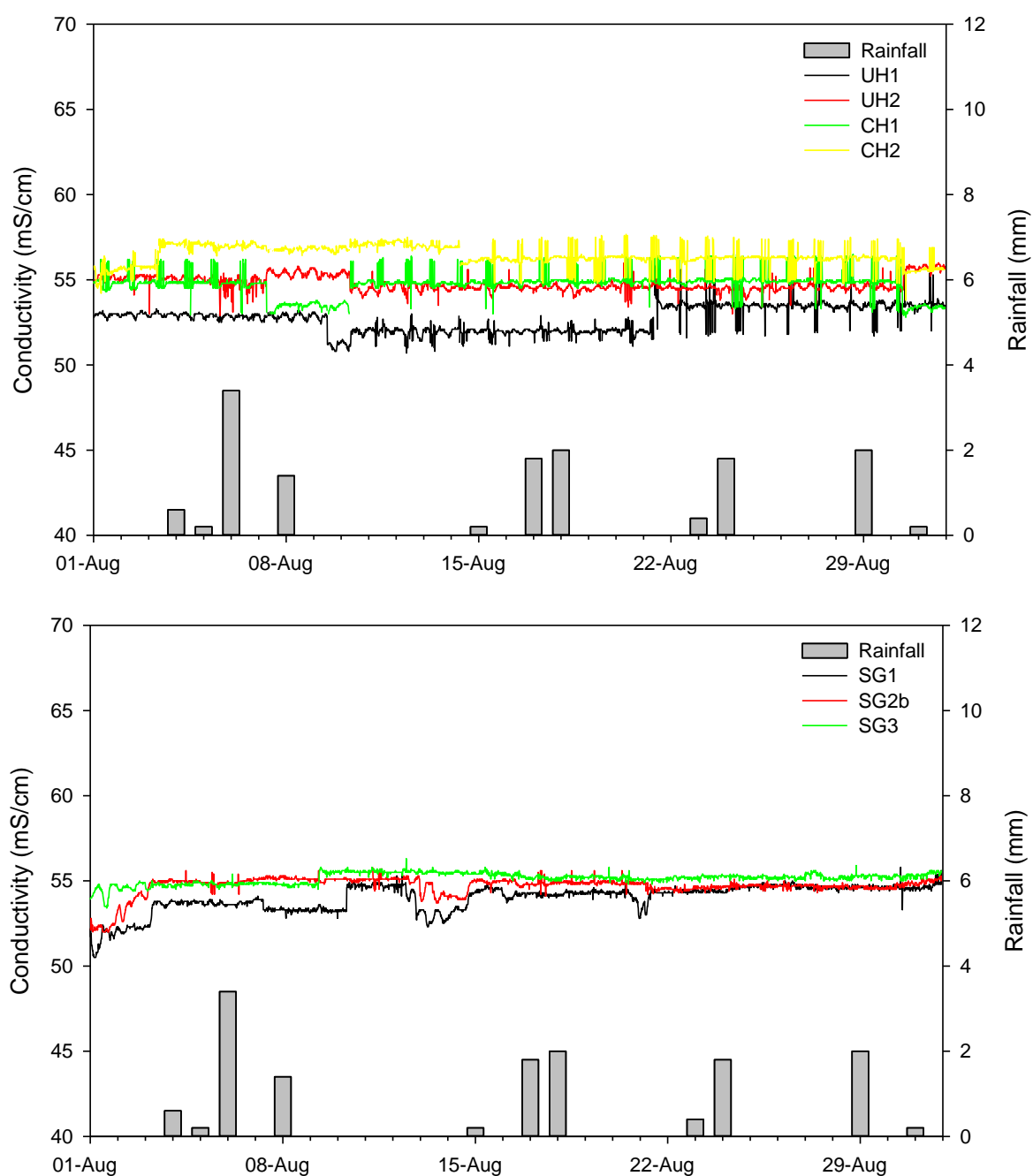
Similar to the previous months, mean conductivity for August did not reveal any significant spatial patterns across the monitoring sites (Table 8). Conductivity at CH1 displayed a slight decline from 7 to 10 August, which may be a reflection of surface runoff, however no other inner harbour sites displayed a similar trend (Figure 16). Conductivity also declined at OS5 around 12 August, with lower magnitude declines also recorded at the northern spoil ground sites SG1 and SG3. This pattern of freshening is commonly an indication of the presence of freshwater riverine outflow sourced from the Waimakariri River north of Lyttelton, although flows were quite low at the time. A smaller decline in conductivity was also recorded at SG1 on 21 August, coinciding with reduced sea surface temperatures at this site.

Benthic data for August also appeared to remain relatively stable. Periods of increased variability do not correlate with periods of local rainfall, which is to be expected as lower density freshwater additions would remain at the surface of the water column.

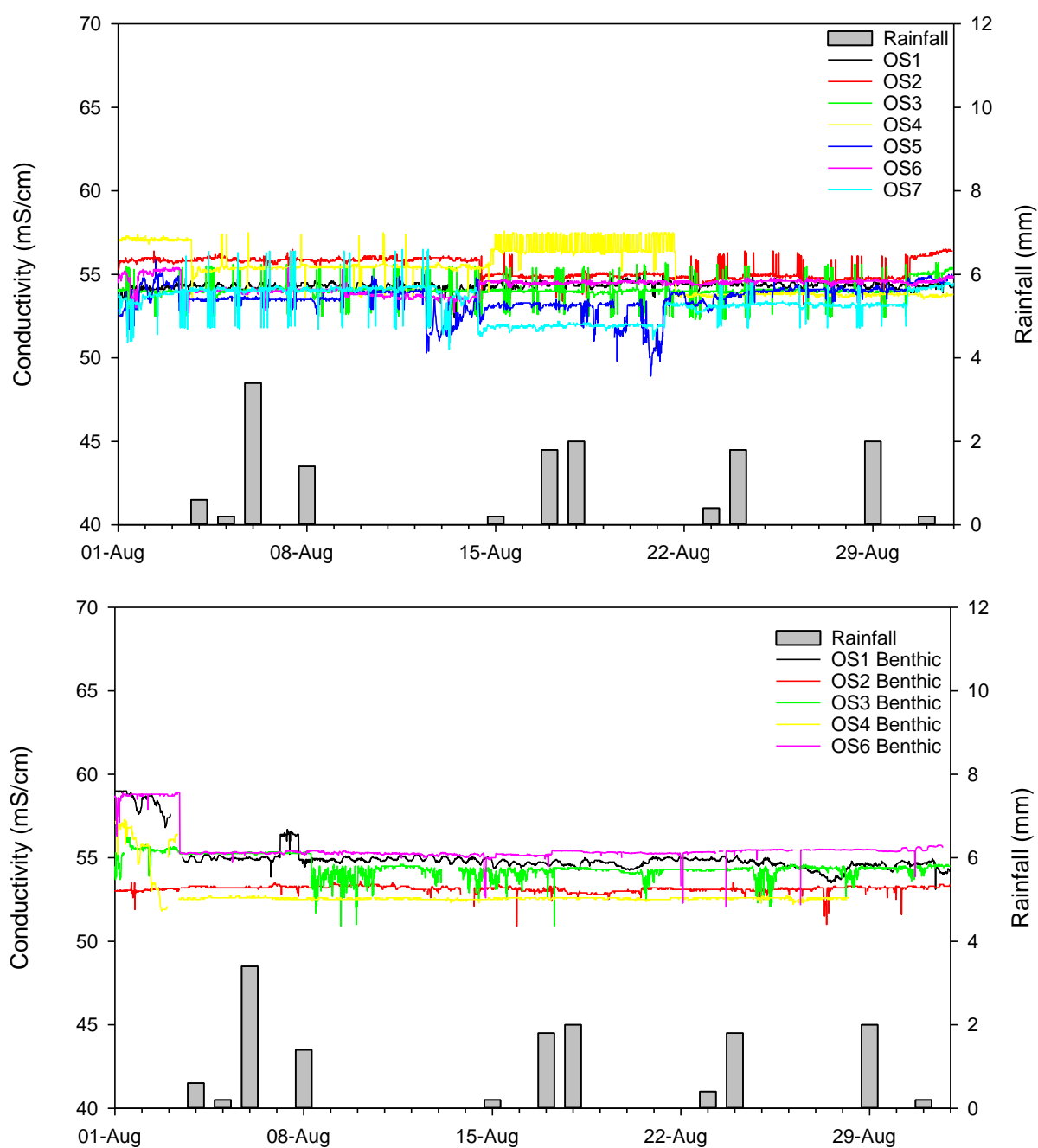
**Table 8** Mean conductivity at inshore, spoil ground and offshore water quality sites from 1 to 31 August 2018.

*Values are means  $\pm$  se ( $n = 2611$  to  $2976$ ).*

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	52.7 $\pm$ 0.0	—
UH2	54.8 $\pm$ 0.0	—
CH1	54.7 $\pm$ 0.0	—
CH2	56.4 $\pm$ 0.0	—
SG1	54.0 $\pm$ 0.0	—
SG2	54.7 $\pm$ 0.0	—
SG3	55.1 $\pm$ 0.0	—
OS1	54.3 $\pm$ 0.0	55.0 $\pm$ 0.0
OS2	55.4 $\pm$ 0.0	53.1 $\pm$ 0.0
OS3	54.1 $\pm$ 0.0	54.5 $\pm$ 0.0
OS4	55.3 $\pm$ 0.0	52.8 $\pm$ 0.0
OS5	53.5 $\pm$ 0.0	—
OS6	54.3 $\pm$ 0.0	55.6 $\pm$ 0.0
OS7	53.2 $\pm$ 0.0	—



**Figure 16** Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 31 August 2018.



**Figure 17** Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 31 August 2018.

### 3.2.1 Dissolved oxygen

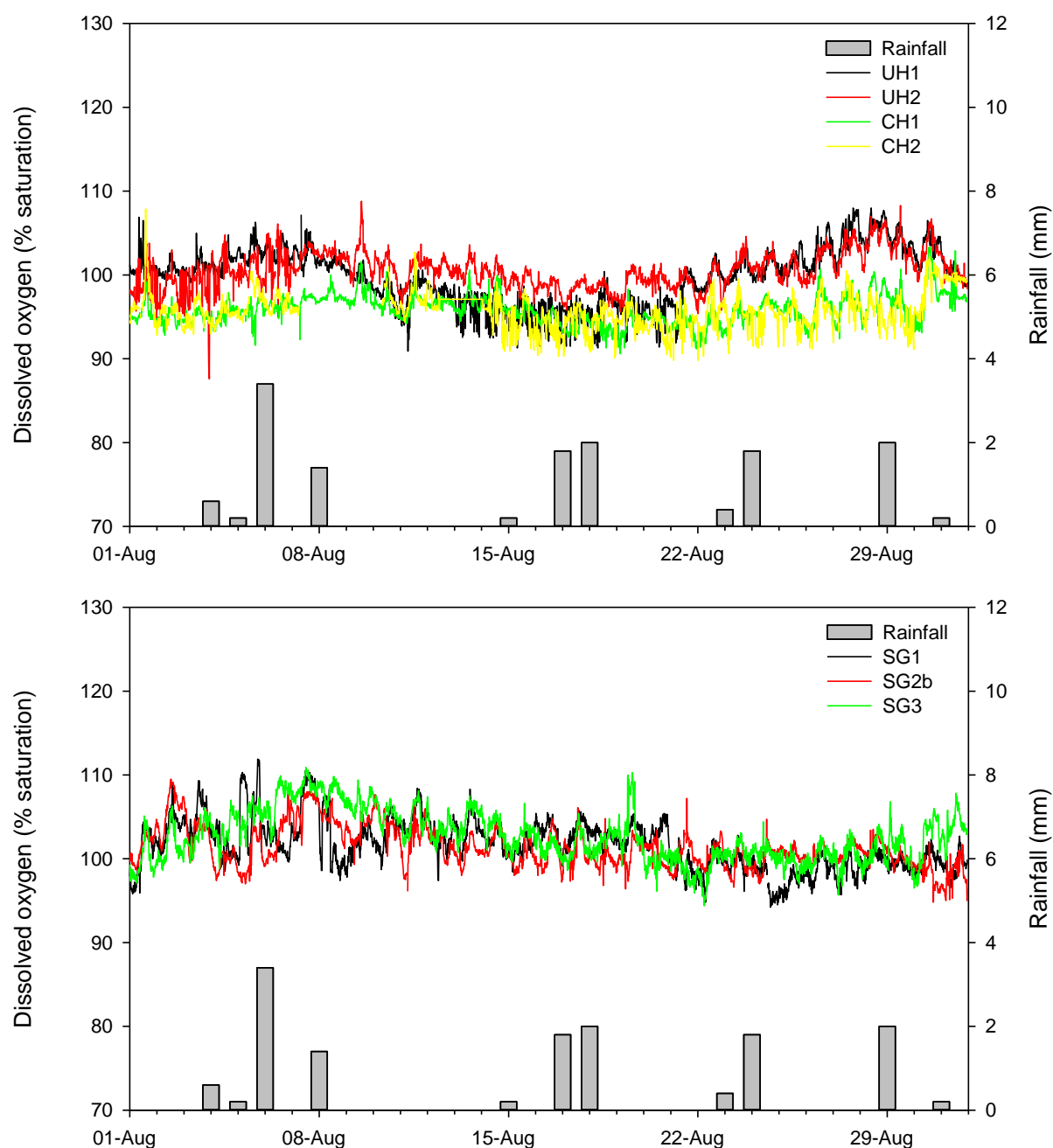
Mean monthly surface DO concentrations ranged from 96 to 103% saturation, with no apparent spatial patterns across the sites (Table 9), nor any notable temporal patterns through the month (Figures 18 and 19). Dissolved oxygen concentrations in the surface waters once again displayed a component of diurnal variability at all sites. This pattern represents the balance between photosynthesis and respiration occurring during the day; and the sole influence of respiration reducing DO during the night (Figures 18 and 19).

Benthic data recovery for dissolved oxygen was relatively high for the majority of sites. Mean monthly benthic DO were slightly lower than surface readings, due to reduced photosynthesis (releasing oxygen) occurring at depth. In a similar manner to the surface dataset, benthic DO concentrations did not appear to display any notable temporal trends.

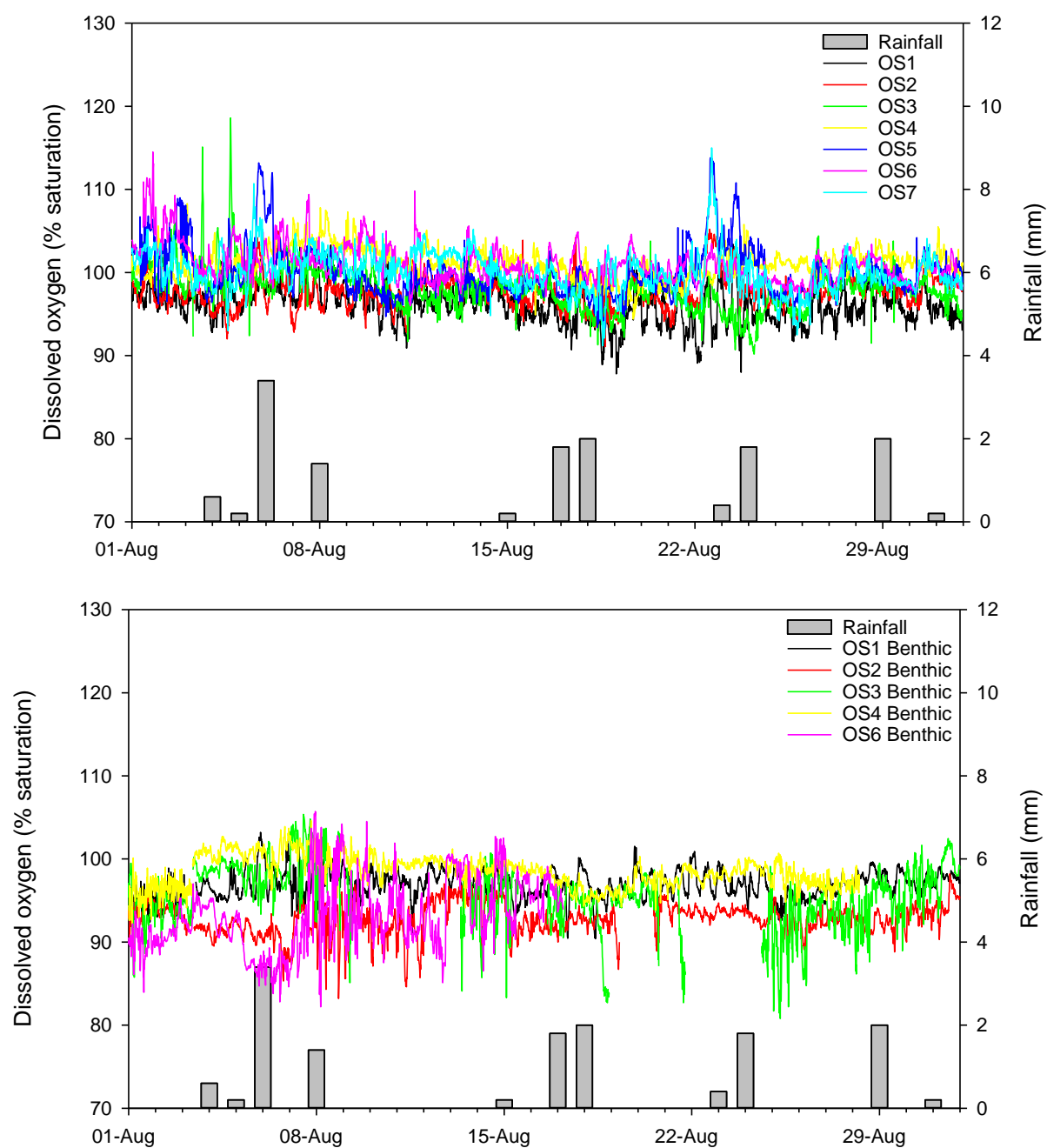
**Table 9** Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites from 1 to 31 August 2018.

Values are means  $\pm$  se ( $n = 1560$  to  $2976$ ).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	100 $\pm$ 0	–
UH2	101 $\pm$ 0	–
CH1	96 $\pm$ 0	–
CH2	96 $\pm$ 0	–
SG1	102 $\pm$ 0	–
SG2	101 $\pm$ 0	–
SG3	103 $\pm$ 0	–
OS1	96 $\pm$ 0	97 $\pm$ 0
OS2	98 $\pm$ 0	93 $\pm$ 0
OS3	98 $\pm$ 0	95 $\pm$ 0
OS4	101 $\pm$ 0	98 $\pm$ 0
OS5	100 $\pm$ 0	–
OS6	101 $\pm$ 0	93 $\pm$ 0
OS7	100 $\pm$ 0	–



**Figure 18** Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 31 August 2018.



**Figure 19** Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites from 1 to 31 August 2018.



### 3.3 Physicochemistry Depth Profiling & TSS

On 9 August 2018, vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling. 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 theoretical depth to which photosynthesis can occur/where light levels are ~1% of those at the surface) were also calculated.

Water samples for the determination of TSS were also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, CH1 and CH2. Further information regarding the specific sampling methodology can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Statistical analyses of the resulting datasets are provided in Tables 10 to 12, with depth profile plots presented in Figures 20 to 22.

The relatively shallow sites of the upper and central harbour were once again vertically well mixed. Benthic waters within the central harbour were also characterised by slight increases in turbidity (Figure 20, Table 10). The highest levels of sub-surface turbidity and TSS were recorded at the upper harbour site UH3 (11 NTU, 26 mg/L TSS, Table 10).

Within the nearshore environment, vertical profiles also indicated a high level of vertical mixing, with benthic waters characterised by slight increases in turbidity in close proximity to the sea floor (Figure 21). Similar to patterns observed in July, site OS1, located at the northern edge of the harbour mouth, displayed notably cooler temperatures and slightly lower conductivity than the remaining sites. This pattern may be a reflection of the cyclonic (clockwise) tidal flows within Lyttelton Harbour [where the flood tide dominates the southern side of the harbour, and the ebb tide dominates the northern side (Tonkin & Taylor, 2016)] that brings cooler, fresher waters from the upper and central harbour (Figure 20) to the northern side of the entrance. Benthic turbidity was noted to have increased at OS7 at depths greater than 8 m, with a corresponding decrease in benthic DO concentrations. These two patterns are likely related, with increased turbidity reducing light available for benthic photosynthesis, and the potential for lower oxygen pore waters to be released as seafloor sediments were resuspended.

Similar to the inshore and nearshore vertical profiles, temperature and conductivity data from the spoil ground and sites OS5 and OS6 also indicated generally well mixed conditions during August (Figure 22). However, notable declines in pH and DO were observed near the benthos at all sites. These changes in environmental conditions are likely associated with sediment resuspension, as indicated by the corresponding increases in benthic turbidity, particularly at the spoil ground sites. As previously observed during the baseline monitoring, the clearest waters were observed at the deeper offshore spoil ground sites, with the calculated euphotic depth extending down to 11.4 – 15.6 m at these three sites (Table 12). No exceedances of WQG were observed for sub-surface turbidity during the August sampling.

**Table 10** Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during August 2018 sampling event. Values are means  $\pm$  se ( $n = 4$  to  $6$  for sub-surface,  $n = 26$  to  $40$  for whole column). Sub-surface values outside recommended WQG are highlighted in blue.

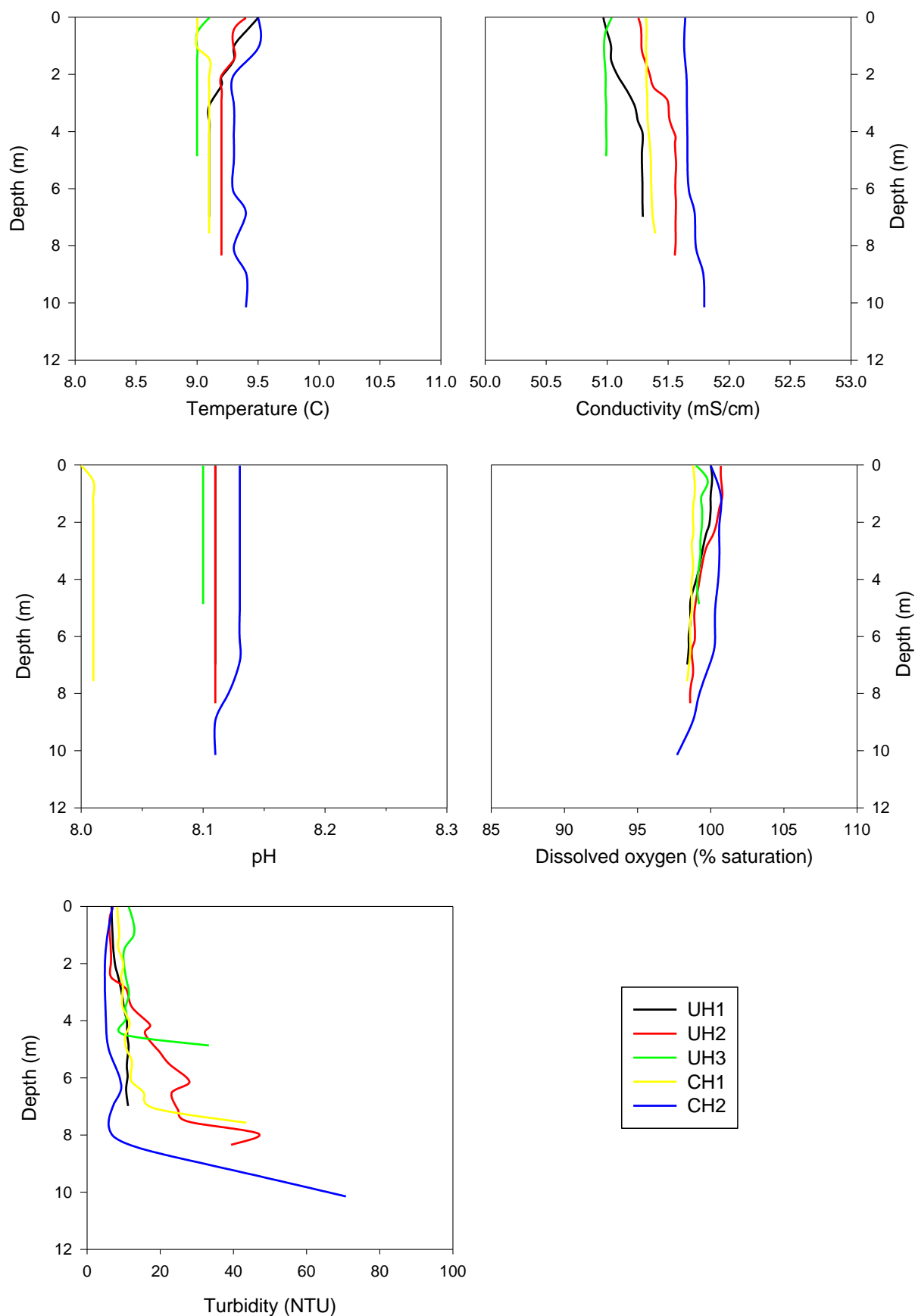
Site	Sample date/time	Depth	Temperature (°C)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K <sub>d</sub>	Euphotic Depth (m)
UH1	09/08/2018 13:51	Sub-surface	9.4 ± 0.0	8.1 ± 0.0	51.0 ± 0.0	100 ± 0	7.0 ± 0.2	15	1.4 ± 0.0	3.3
		Whole column	9.2 ± 0.0	8.1 ± 0.0	51.2 ± 0.0	99 ± 0	10 ± 1	–		
UH2	09/08/2018 13:00	Sub-surface	9.4 ± 0.0	8.1 ± 0.0	51.3 ± 0.0	101 ± 0	6.4 ± 0.1	15	1.7 ± 0.0	2.7
		Whole column	9.2 ± 0.0	8.1 ± 0.0	51.5 ± 0.0	100 ± 0	17 ± 2	–		
UH3	09/08/2018 13:14	Sub-surface	9.0 ± 0.0	8.1 ± 0.0	51.0 ± 0.0	100 ± 0	11 ± 1	26	1.3 ± 0.2	3.6
		Whole column	9.0 ± 0.0	8.1 ± 0.0	51.0 ± 0.0	99 ± 0	12 ± 1	–		
CH1	09/08/2018 07:57	Sub-surface	9.0 ± 0.0	8.0 ± 0.0	51.3 ± 0.0	99 ± 0	8.6 ± 0.1	18	1.5 ± 0.0	3.1
		Whole column	9.1 ± 0.0	8.0 ± 0.0	51.3 ± 0.0	99 ± 0	11 ± 1	–		
CH2	09/08/2018 12:38	Sub-surface	9.4 ± 0.0	8.1 ± 0.0	51.6 ± 0.0	101 ± 0	5.3 ± 0.1	14	1.0 ± 0.0	4.7
		Whole column	9.4 ± 0.0	8.1 ± 0.0	51.7 ± 0.0	100 ± 0	13 ± 3	–		
WQG			–	7.0 – 8.5	–	80-110	10	–	–	

**Table 11** Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during August 2018 sampling event. Values are means  $\pm$  se ( $n = 6$  for sub-surface, mid and benthos,  $n = 28$  to  $38$  for whole column). Sub-surface values outside recommended WQG are highlighted in blue.

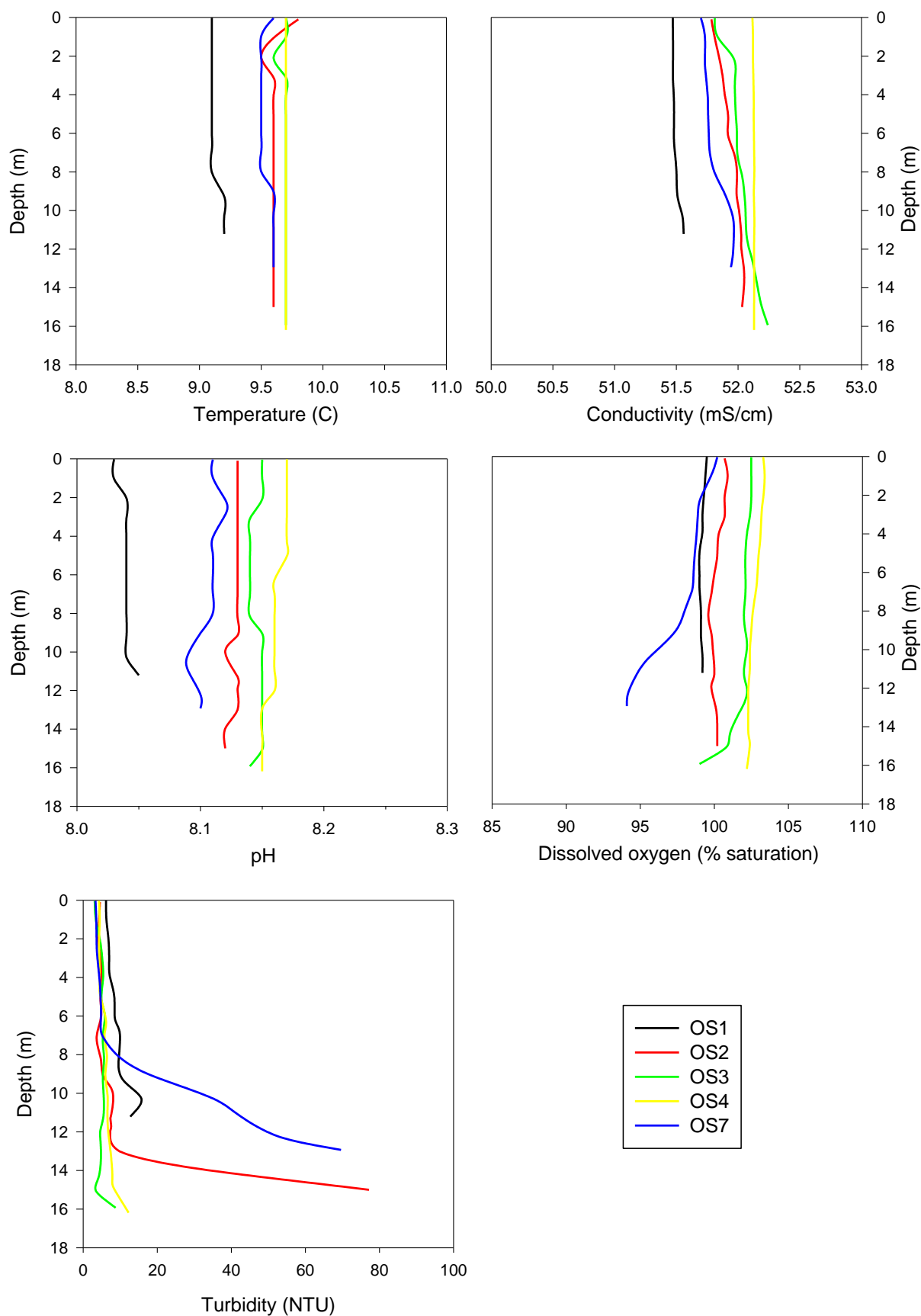
Site	Sample date/time	Depth	Temperature (°C)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K <sub>d</sub>	Euphotic Depth (m)
OS1	09/08/2018 08:21	Sub-surface	9.1 ± 0.0	8.0 ± 0.0	51.5 ± 0.0	99 ± 0	6.4 ± 0.1	11	1.5 ± 0.0	3.2
		Mid	9.1 ± 0.0	8.0 ± 0.0	51.5 ± 0.0	99 ± 0	8.4 ± 0.4	20		
		Benthos	9.2 ± 0.0	8.0 ± 0.0	51.5 ± 0.0	99 ± 0	13 ± 1	24		
		Whole column	9.1 ± 0.0	8.0 ± 0.0	51.5 ± 0.0	99 ± 0	8.7 ± 0.6	–		
OS2	09/08/2018 12:01	Sub-surface	9.6 ± 0.0	8.1 ± 0.0	51.8 ± 0.0	101 ± 0	4.1 ± 0.1	8	0.7 ± 0.0	6.3
		Mid	9.6 ± 0.0	8.1 ± 0.0	52.0 ± 0.0	100 ± 0	5.8 ± 0.7	19		
		Benthos	9.6 ± 0.0	8.1 ± 0.0	52.0 ± 0.0	100 ± 0	35 ± 11	111		
		Whole column	9.6 ± 0.0	8.1 ± 0.0	51.9 ± 0.0	100 ± 0	10 ± 3	–		
OS3	09/08/2018 11:20	Sub-surface	9.6 ± 0.0	8.2 ± 0.0	51.9 ± 0.0	102 ± 0	3.7 ± 0.1	9	0.8 ± 0.0	5.8
		Mid	9.7 ± 0.0	8.1 ± 0.0	52.0 ± 0.0	102 ± 0	5.3 ± 0.1	12		
		Benthos	9.7 ± 0.0	8.1 ± 0.0	52.2 ± 0.0	101 ± 0	6.8 ± 2.2	10		
		Whole column	9.7 ± 0.0	8.1 ± 0.0	52.0 ± 0.0	102 ± 0	5.0 ± 0.4	–		
OS4	09/08/2018 10:54	Sub-surface	9.8 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 0	4.4 ± 0.1	10	0.8 ± 0.0	5.6
		Mid	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 0	6.2 ± 0.1	10		
		Benthos	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	102 ± 0	10 ± 1	17		
		Whole column	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 0	6.3 ± 0.4	-		
OS7	09/08/2018 12:19	Sub-surface	9.5 ± 0.0	8.1 ± 0.0	51.7 ± 0.0	99 ± 0	3.4 ± 0.1	8	1.0 ± 0.0	4.7
		Mid	9.5 ± 0.0	8.1 ± 0.0	51.8 ± 0.0	98 ± 0	6.3 ± 0.7	14		
		Benthos	9.6 ± 0.0	8.1 ± 0.0	52.0 ± 0.0	94 ± 0	57 ± 4	29		
		Whole column	9.5 ± 0.0	8.1 ± 0.0	51.1 ± 0.7	98 ± 0	17 ± 4	–		
WQG			–	7.0 – 8.5	–	80-110	10	–	–	

**Table 12** Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during August 2018 sampling event. Values are means  $\pm$  se ( $n = 6$  for sub-surface, mid and benthos,  $n = 36$  to  $46$  for whole column). Sub-surface values outside recommended WQG are highlighted in blue.

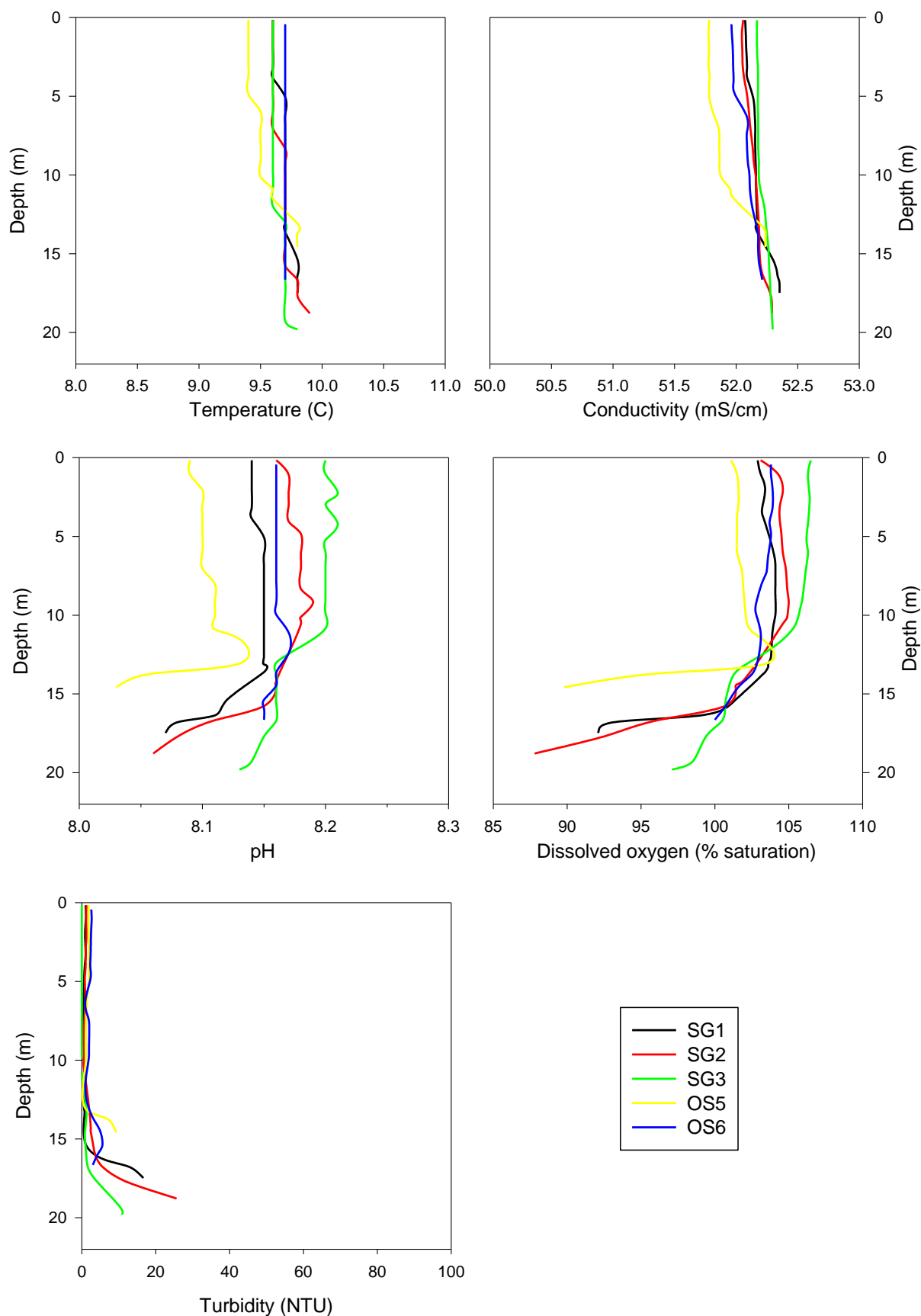
Site	Sample date/time	Depth	Temperature (°C)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K <sub>d</sub>	Euphotic Depth (m)
OS5	09/08/2018 08:43	Sub-surface	9.4 ± 0.0	8.1 ± 0.0	51.8 ± 0.0	101 ± 0	1.9 ± 0.0	4	0.4 ± 0.0	11.4
		Mid	9.5 ± 0.0	8.1 ± 0.0	51.9 ± 0.0	102 ± 0	1.1 ± 0.0	7		
		Benthos	9.8 ± 0.0	8.1 ± 0.0	52.2 ± 0.0	97 ± 2	6.7 ± 2.6	2		
		Whole column	9.5 ± 0.0	8.1 ± 0.0	51.9 ± 0.0	101 ± 0	2.3 ± 0.5	–		
OS6	09/08/2018 11:43	Sub-surface	9.8 ± 0.0	8.2 ± 0.0	52.0 ± 0.0	104 ± 0	2.5 ± 0.0	6	0.5 ± 0.0	9.9
		Mid	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 0	1.8 ± 0.1	5		
		Benthos	9.7 ± 0.0	8.2 ± 0.0	52.2 ± 0.0	101 ± 0	2.8 ± 0.8	10		
		Whole column	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 0	2.2 ± 0.2	–		
SG1	09/08/2018 09:07	Sub-surface	9.6 ± 0.0	8.1 ± 0.0	52.1 ± 0.0	103 ± 0	1.0 ± 0.0	<3	0.3 ± 0.0	13.2
		Mid	9.7 ± 0.0	8.2 ± 0.0	52.2 ± 0.0	104 ± 0	0.4 ± 0.0	4		
		Benthos	9.8 ± 0.0	8.1 ± 0.0	52.3 ± 0.0	97 ± 2	9.1 ± 2.5	16		
		Whole column	9.7 ± 0.0	8.1 ± 0.0	52.2 ± 0.0	102 ± 0	1.9 ± 0.6	–		
SG2	09/08/2018 09:31	Sub-surface	9.6 ± 0.0	8.2 ± 0.0	52.0 ± 0.0	104 ± 0	1.2 ± 0.0	6	0.4 ± 0.0	11.4
		Mid	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	105 ± 0	0.6 ± 0.0	3		
		Benthos	9.8 ± 0.0	8.1 ± 0.0	52.3 ± 0.0	95 ± 2	12 ± 3	10		
		Whole column	9.7 ± 0.0	8.2 ± 0.0	52.1 ± 0.0	103 ± 1	2.7 ± 0.7	–		
SG3	09/08/2018 10:31	Sub-surface	9.6 ± 0.0	8.2 ± 0.0	52.2 ± 0.0	106 ± 0	<1	<3	0.3 ± 0.0	15.6
		Mid	9.6 ± 0.0	8.2 ± 0.0	52.2 ± 0.0	106 ± 0	<1	5		
		Benthos	9.7 ± 0.0	8.1 ± 0.0	52.3 ± 0.0	99 ± 0	6.5 ± 1.4	7		
		Whole column	9.6 ± 0.0	8.2 ± 0.0	52.2 ± 0.0	104 ± 0	1.1 ± 0.4	–		
WQG			–	7.0 – 8.5	–	80-110	10	–	–	



**Figure 20** Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 9 August 2018.



**Figure 21** Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 9 August 2018.



**Figure 22** Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 9 August 2018.

### 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 PAR loggers located at the Vision Environment office in Christchurch (Vision Base Christchurch, VBCC), in order to account for variations in daily light intensity such as those induced by cloud cover. Further information on the specific methodology used in BPAR measurements can be obtained from the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

Statistical analyses on the monthly BPAR datasets are presented in Table 13, with the collected data from benthic and VBCC sensors presented in Figure 23. Data from the logger exchange date (3 August) were removed from the analyses.

**Table 13** Total Daily PAR (TDP) statistics from 1 to 31 August 2018.

*Values are means  $\pm$  se ( $n = 30$ ). Note data from the BPAR exchange day on 3 August were not utilized in plots or statistics for sites OS2 and OS3.*

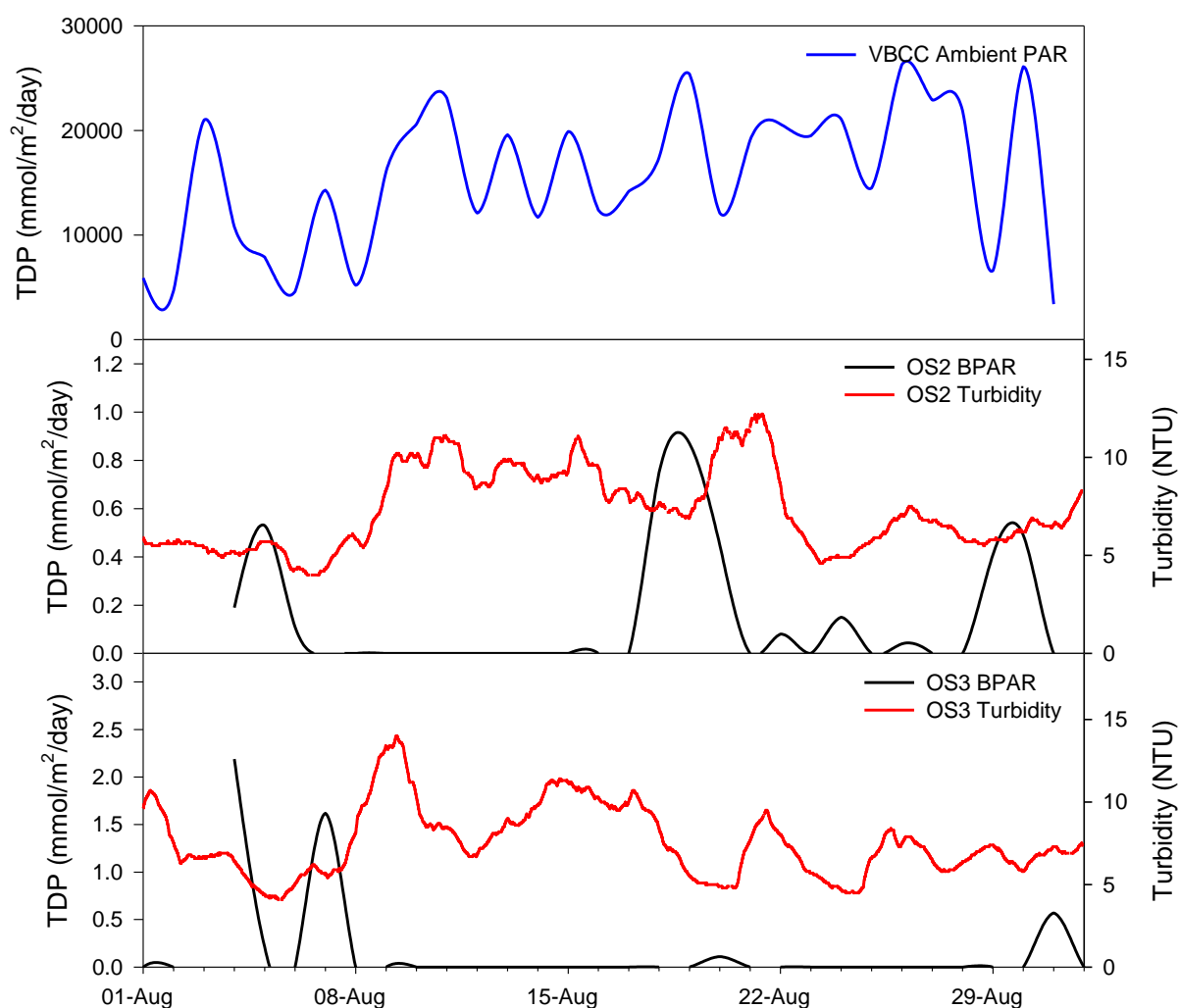
Site	Depth (m)	TDP (mmol/m <sup>2</sup> /day)		
		Mean $\pm$ se	Median	Range
Base	-	15,516 $\pm$ 1250	16,100	3,400 – 26,300
OS2	17	0.2 $\pm$ 0.1	<0.01	<0.01 – 0.9
OS3	14	0.2 $\pm$ 0.1	<0.01	<0.01 – 2.2

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 associated with high levels of cloud cover, the amount of incoming solar radiation at VBCC displayed significant variation, with values ranging from 3,400 to 26,300 mmol/m<sup>2</sup>/day (Table 13). Maximum TDP was slightly higher than that observed during July (19,400 mmol/m<sup>2</sup>/day), and multiple days of non-zero BPAR readings were recorded (Figure 23).

Three notable peaks in benthic PAR were recorded at OS2 during August, centred on 5, 19 and 30 August. These events typically correlated with periods of elevated incoming solar radiation and/or reduced surface turbidity; resulting in readings up to 0.9 mmol/m<sup>2</sup>/day (Figure 23). Smaller, variable non-zero values in benthic PAR were recorded between 19 and 30 August, however these remained below 0.2 mmol/m<sup>2</sup>/day.

Benthic PAR intensities at OS3 were greater than those at OS2, with a light intensity of 2.2 mmol/m<sup>2</sup>/day recorded on 4 August. A secondary peak at 1.6 mmol/m<sup>2</sup>/day was recorded on 8 August. Additional non-zero BPAR values were recorded on 20 August and 30 August under low turbidity and high ambient light intensity conditions, respectively (Figure 23).





**Figure 23** Total daily BPAR at OS2 and OS3 from 1 to 31 August 2018 compared to ambient PAR and corresponding surface turbidity.

*Note data from the BPAR exchange day on 3 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 derived 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:

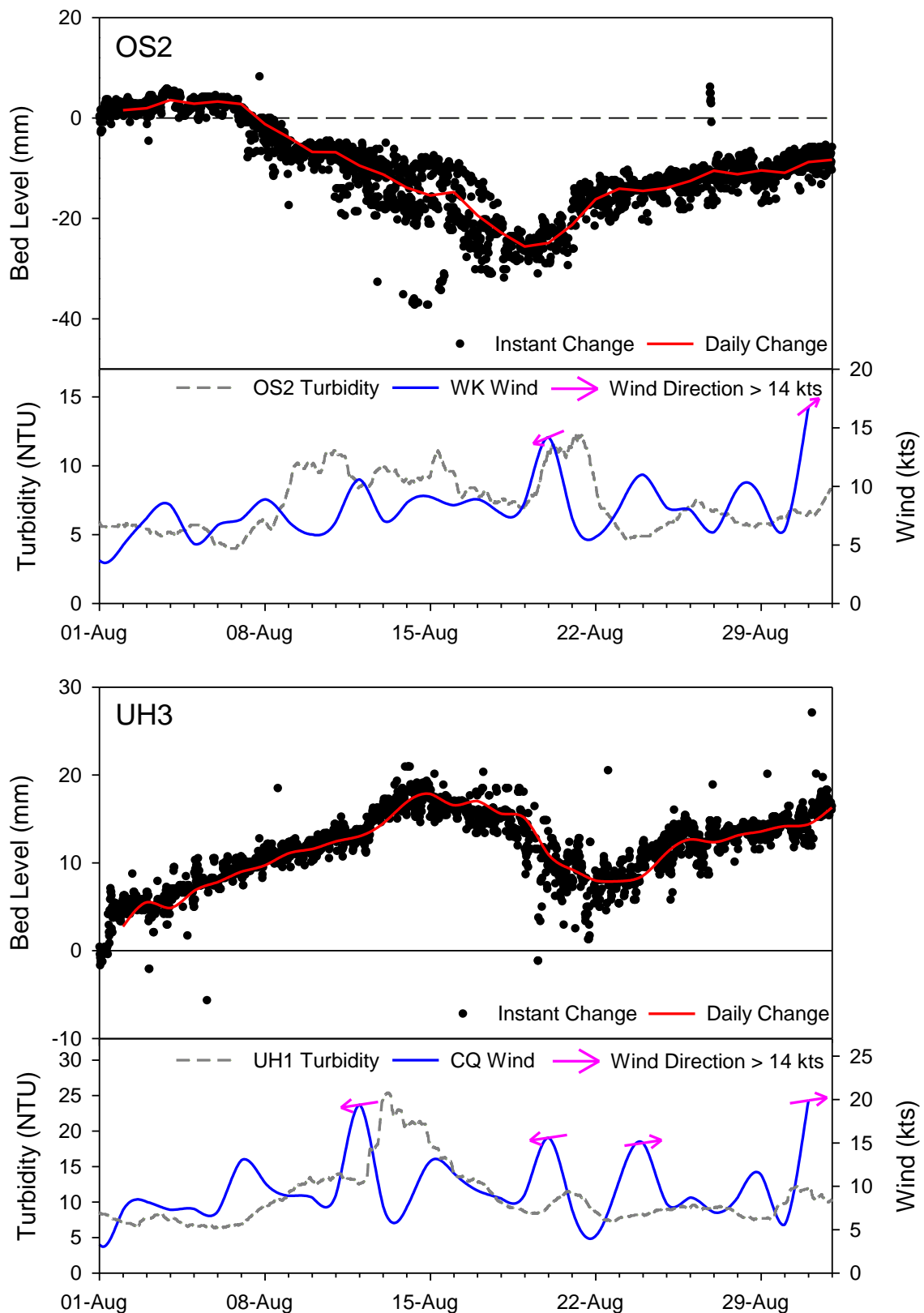
- Instantaneous bed level change calculated every 15 minutes indicating the level of sediment flux occurring at a set point in time; and
- Net cumulative change in bed level over a given period.

Daily averaged altimeter readings at the entrance of Lyttelton Harbour (site OS2) indicated a period of relatively stable bed level from 1 to 6 August, followed by a phase of seabed erosion till 18 August. This erosional phase resulted in bed level dropping by 28 mm, and surface turbidity at OS2 increasing by approximately 5 NTU (Figure 24). Despite WatchKeeper wind speeds displaying a slight increasing trend at this time, the shift in sediment dynamics to deposition for the duration of the month does not appear to correlate with changes in offshore wind direction and/or speed. However, offshore significant wave heights were slightly elevated during the erosional period, and thus are likely to have provided the external energy required to resuspend seafloor sediments as evidenced by the large increase in benthic turbidity (Figure 9). Sediment deposition during the last two weeks of the month was at a lower rate than the previously experienced erosion, resulting in a net bed level change of -8 mm during August 2018 (Table 14).

Altimeter data presented in previous reports has typically indicated stable seafloor conditions at the inshore, relatively protected waters of the harbour head (site UH3). Contrasting this general trend, data collected during August 2018 indicates ~15 mm of sediment deposition over the first 14 days of the month. Surface turbidity at the nearby monitoring site UH1 also displayed an increasing trend over this period of time, suggesting that externally sourced materials may have been settling out in the lower energy environment at UH3. From 14 to 22 August, bed level decreased by approximately 10 mm, followed by a period of recovery to the end of the month. As with the offshore bed level data, sediment dynamics at UH3 do not appear to correlate well with local winds. During August, bed level at UH3 increased by 16 mm (Table 14).

**Table 14** Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 from 1 to 31 August 2018.

Site	August 2018 Net bed level change (mm)
OS2	-8
UH3	+16



**Figure 24** Mean instantaneous and daily averaged bed level change at OS2 and UH3 from 1 to 31 August 2018 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.*

### 3.6 Water Samples

Discrete water sampling was conducted on 9 August 2018, 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 19 of the appendix.

#### 3.6.1 Nutrients

Total phosphorous concentrations reported during the August water quality monitoring campaign displayed a similar spatial variability to previous months, with higher concentrations reported in the shallower upper and central harbour sites that typically decreased further offshore. Water quality guidelines for total phosphorous (30 µg/L) were only slightly exceeded at the upper harbour site UH3, where concentrations reached 32 µg/L (Table 15, Figure 25). Concentrations of the more bioavailable dissolved reactive phosphorous were lower than those observed during July, with WQG exceeded at UH2, CH1, OS1, OS3-5 and SG1. A comparison between the total and dissolved concentrations indicates that phosphorous was largely present in the dissolved phase.

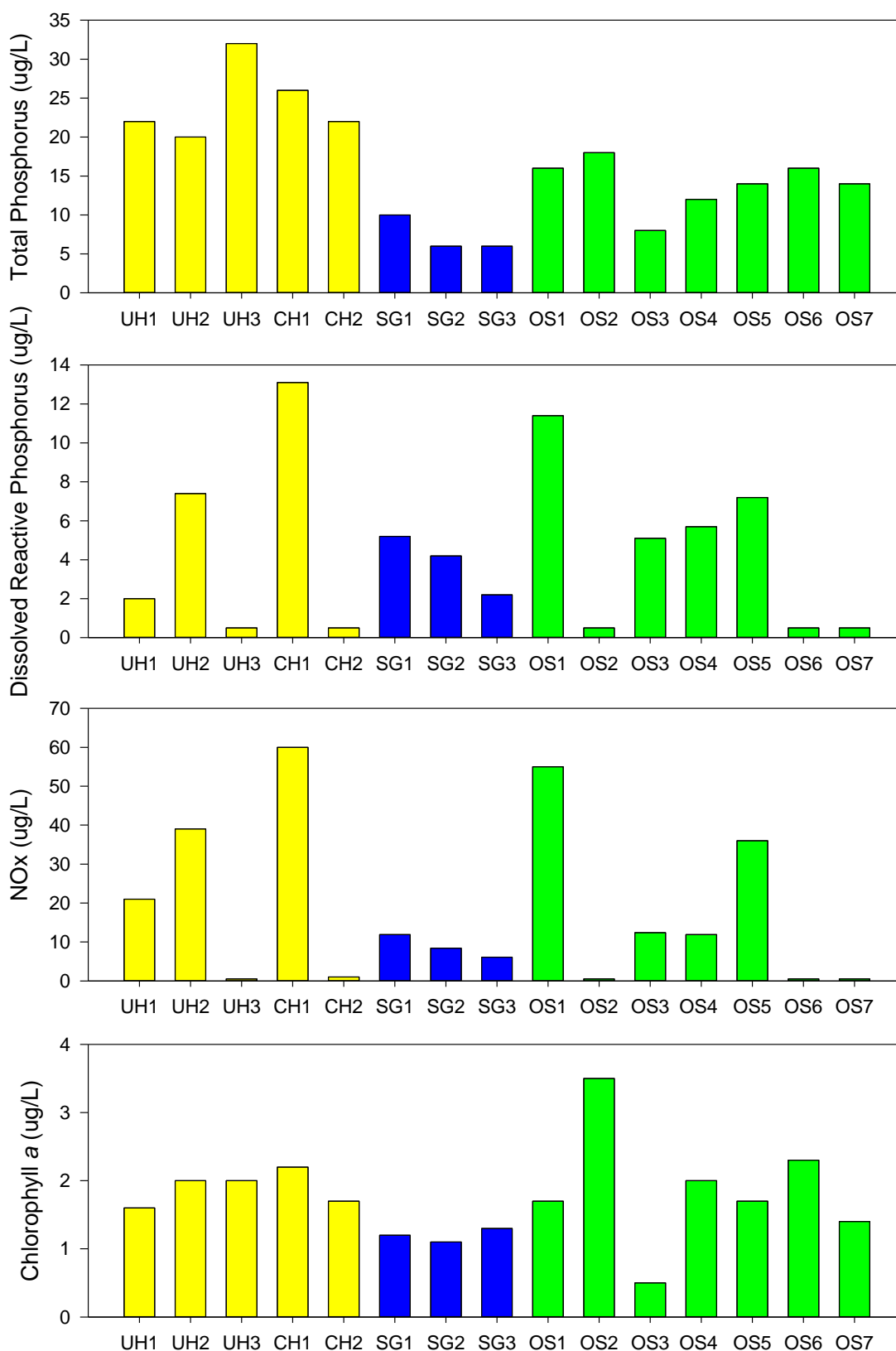
Contrasting previous baseline monitoring reports, concentrations of total nitrogen exceeded the WQG of 300 µg/L at UH2, due to the elevated concentration of total kjeldahl nitrogen (400 µg/L). At all of the remaining monitoring sites, concentrations of total nitrogen and total kjeldahl nitrogen were either at, or below laboratory LOR (300 µg/L and 200 µg/L, respectively).

Concentrations of total ammonia and nitrogen oxides had largely declined from those recorded in July. Exceedances of the total ammonia WQG were recorded at CH1, OS1, OS3-OS5, SG1 and SG2; displaying a similar pattern to exceedances of dissolved reactive phosphorous concentrations. Exceedances of nitrogen oxides were recorded at UH1, UH2, CH1, OS1 and OS5; i.e., monitoring sites located along the northern edge of Lyttelton Harbour (Figure 1).

Phytoplankton biomass, as indicated by chlorophyll *a* concentration, remained relatively low at all sites ( $\leq 3.5$  µg/L), representing minimal growth during the deep mixing and low light conditions of austral winter/spring (Table 15, Figure 25), despite the presence of bioavailable nutrients.

**Table 15** Concentrations of nutrients and chlorophyll *a* at monitoring sites during August 2018.*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 oxide (NOx)	Chlorophyll <i>a</i>
UH1	22	2.0	<300	<200	11	21	1.6
UH2	20	7.4	400	400	10	39	2.0
UH3	32	<1	<300	<200	11	<1	2.0
CH1	26	13	200	<200	23	60	2.2
CH2	22	<1	<300	<200	11	1	1.7
OS1	16	11	<300	<200	20	55	1.7
OS2	18	<1	<300	<200	10	<1	3.5
OS3	8	5.1	<300	<200	23	12	0.5
OS4	12	5.7	<300	<200	19	12	2.0
OS5	14	7.2	<300	<200	21	36	1.7
OS6	16	<1	<300	<200	11	<1	2.3
OS7	14	<1	<300	<200	11	<1	1.4
SG1	10	5.2	<300	<200	19	12	1.2
SG2	6	4.2	<300	<200	17	8.4	1.1
SG3	6	2.2	<300	<200	13	6.1	1.3
<b>WQG</b>	<b>30</b>	<b>5</b>	<b>300</b>	<b>-</b>	<b>15</b>	<b>15</b>	<b>4</b>



**Figure 25** Nutrient and chlorophyll a concentrations at monitoring sites during August 2018. Values which were <LOR, were plotted as half LOR. Total nitrogen, TKN and ammonia concentrations 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 LOR at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), lead (<1 µg/L), mercury (<0.08 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5.3 µg/L) and zinc (<4 µg/L). Note that the analysing laboratory have increased the LOR for tin to 5.0 and 5.3 µg/L for the dissolved and total fractions, respectively.

As typically reported, total aluminium concentrations were once again 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 except SG3. Concentrations of the more bioavailable dissolved fraction only exceeded the 12 µg/L LOR at UH1-UH3, CH2 and OS7, with no recorded concentrations above the 24 µg/L WQG (Tables 16 to 18). These low dissolved concentrations across the monitoring network indicates that the majority of the total aluminium present was associated with the particulate phase, and thus is not considered readily available for biological uptake.

No further exceedances of WQG were observed at any location during the August 2018 water quality sampling campaign.

Of the metals analysed that do not have assigned WQG, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour. During the August monitoring, high concentrations of total iron were once again observed within the upper harbour, with 540 µg/L recorded at UH3 (Table 16). As observed during previous months, there was a general spatial pattern of decreasing concentrations with distance from the harbour head, with total iron concentrations of 13 to 52 µg/L at the spoil ground sites (Table 18, Figure 26). Similar to the patterns in aluminum, dissolved concentrations of iron were relatively low (≤ 20 µg/L) and therefore iron within Lyttelton Harbour and the surrounds was predominantly present in the particulate phase, and thus not readily available for biological uptake.

Dissolved manganese concentrations were above LOR at UH1, UH3, CH1 and OS1, with a notable reduction in concentration at UH3 compared with water samples collected in July. Total manganese concentrations were highest in the upper harbour with reduced concentrations reported at the spoil ground sampling sites (Figure 26). The majority of the total manganese in Lyttelton Harbour was present in the particulate phase. Consistent with previous monitoring reports, molybdenum and vanadium concentrations during August displayed little spatial variation across the monitoring network (Figure 27). Given the similarity between the dissolved and total metal concentrations, the majority of molybdenum and vanadium appeared to be present in the dissolved phase, allowing efficient mixing and therefore a lack of spatial variation across the monitoring sites (Tables 16 to 18 and Figure 27).

**Table 16** Total and dissolved metal concentrations at inshore monitoring sites during August 2018. Values above recommended WQG are highlighted in blue.

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	23	17	22	<12	13	24
	Total	76	190	290	181	163	
Arsenic	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	<0.2	<0.2	
Chromium	Dissolved	<1	1.4	<1	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	<1	<1	<1	1.3	
Cobalt	Dissolved	0.6	<0.6	0.6	<0.6	<0.6	1.0
	Total	<0.6	0.7	0.8	<0.6	0.66	
Copper	Dissolved	<1	<1	1.1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	
Iron	Dissolved	20	10	14	<4	9	-
	Total	141	340	540	220	270	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	
Manganese	Dissolved	2.2	<1	2.4	1.2	<1	-
	Total	5.9	7.3	13	6.2	5.7	
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	12	12	13	12	12	-
	Total	11	12	11	12	12	
Nickel	Dissolved	<6	<6	<6	<6	<6	70
	Total	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	
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	<1.6	<1.6	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	<1.7	<1.7	
Vanadium	Dissolved	1.6	1.4	1.4	2.0	1.6	100
	Total	1.6	2.2	2.4	2.1	2.0	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4	<4	<4	<4	<4	

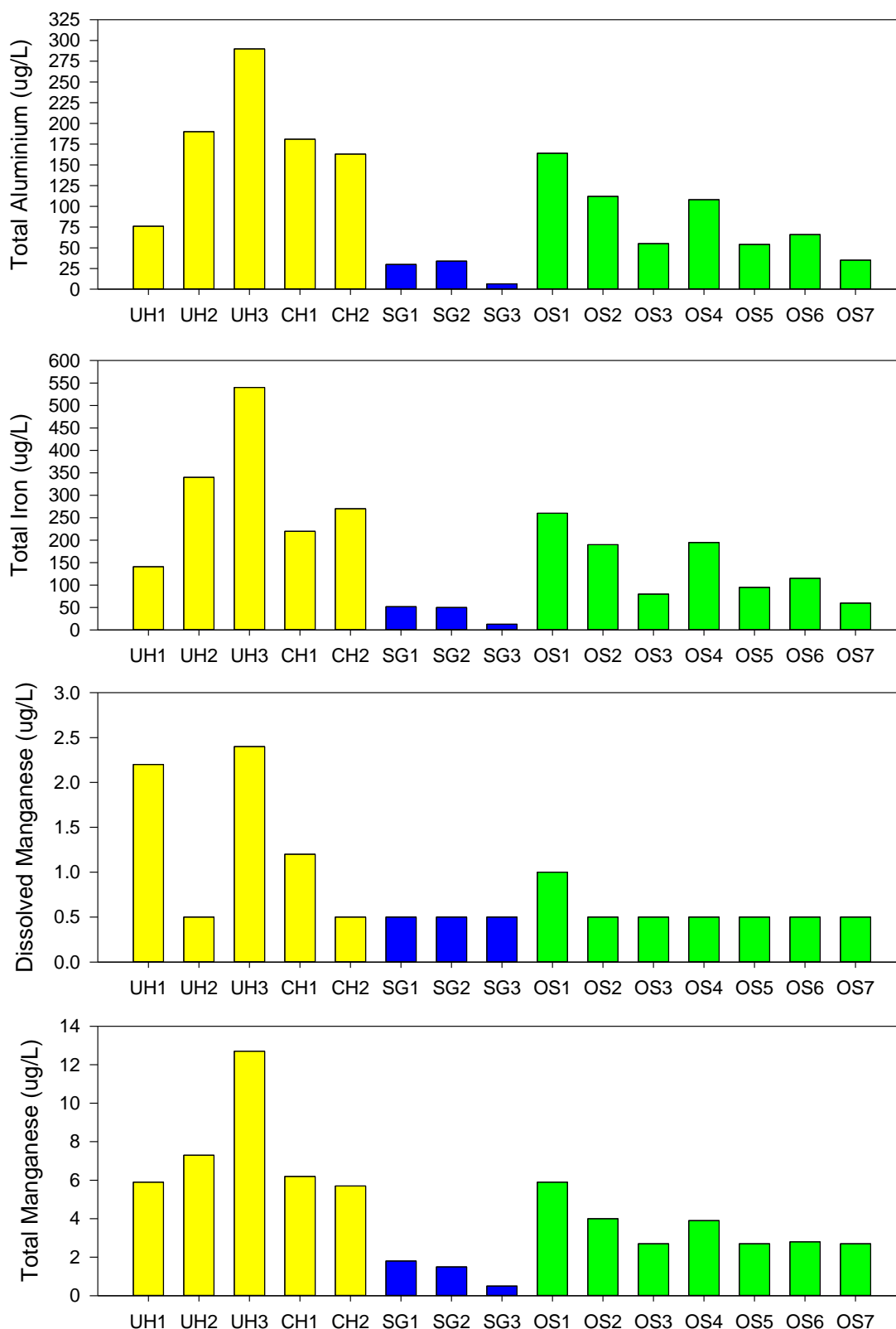


**Table 17** Total and dissolved metal concentrations at offshore monitoring sites during August 2018.  
*Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites							WQG
		OS1	OS2	OS3	OS4	OS5	OS6	OS7	
Aluminium	Dissolved	<12	<12	<12	<12	<12	<12	16	24
	Total	164	112	55	108	54	66	35	
Arsenic	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Chromium	Dissolved	<1	<1	<1	1.8	1.1	<1	1.3	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	1.4	<1	<1	<1	1.3	1.3	
Cobalt	Dissolved	<0.6	0.7	<0.6	0.7	<0.6	0.8	<0.6	1.0
	Total	0.7	0.6	<0.6	<0.6	<0.6	<0.6	<0.6	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	<1	<1	
Iron	Dissolved	<4	6	<4	<4	<4	6	10	-
	Total	260	190	80	195	95	115	60	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	<1	<1	
Manganese	Dissolved	1.0	<1	<1	<1	<1	<1	<1	-
	Total	5.9	4.0	2.7	3.9	2.7	2.8	2.7	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	12	12	12	12	12	12	12	-
	Total	12	12	12	12	12	12	11	
Nickel	Dissolved	<6	<6	<6	<6	<6	<6	<6	70
	Total	<7	<7	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4	<4	<4	<4	<4	<4	<4	
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	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	
Vanadium	Dissolved	1.8	1.8	1.9	1.6	1.4	1.8	1.9	100
	Total	2.0	2.0	1.6	2.2	1.7	1.7	1.7	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	6	15
	Total	<4	<4	<4	<4	<4	<4	<4	

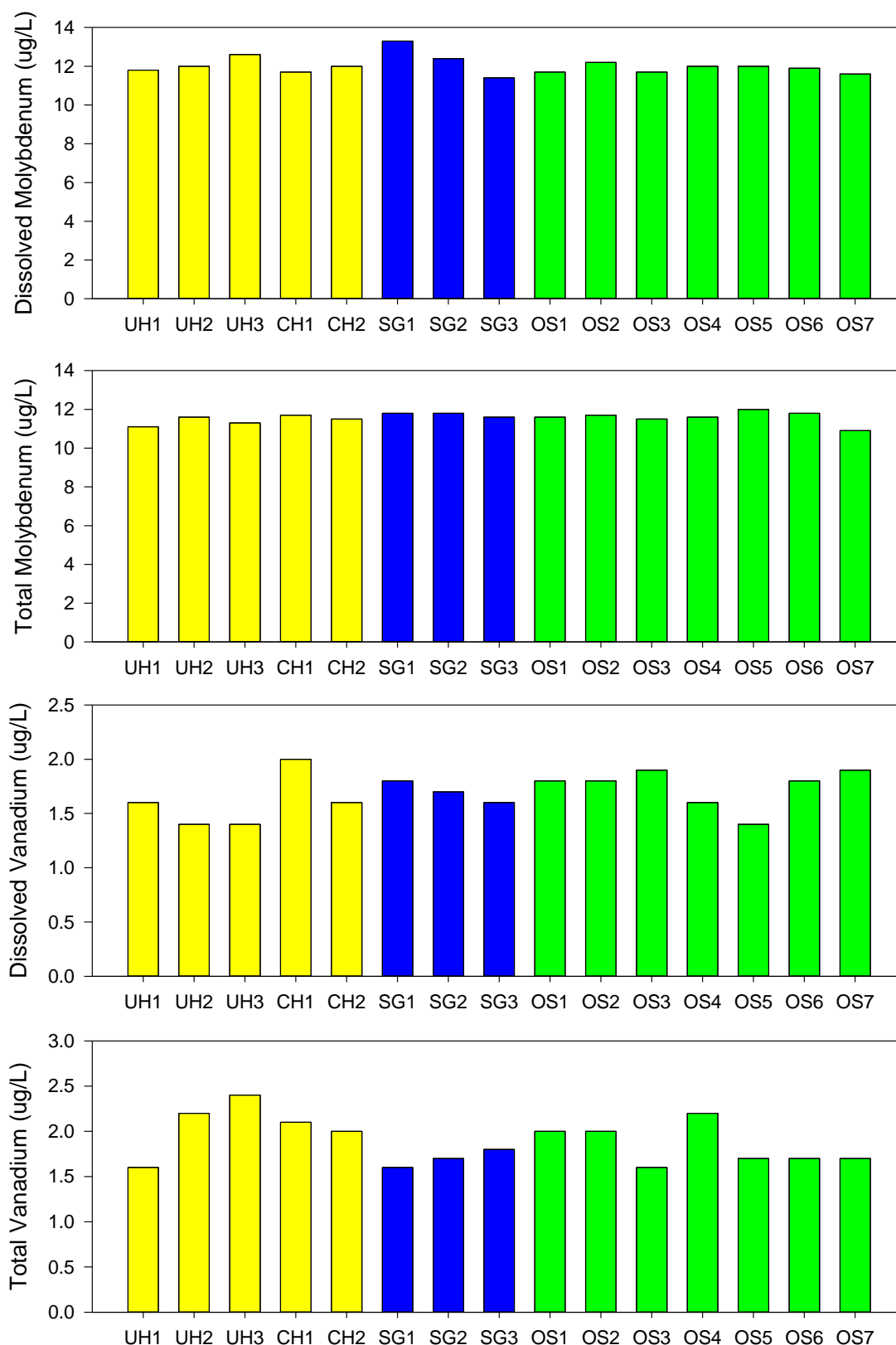
**Table 18** Total and dissolved metal concentrations at spoil ground monitoring sites during August 2018. Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	30	34	<13	
Arsenic	Dissolved	<4	<4	<4	-
	Total	<4	<4	<4	
Cadmium	Dissolved	<0.2	<0.2	<0.2	5.5
	Total	<0.2	<0.2	<0.2	
Chromium	Dissolved	<1	<1	1.4	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	<1	1.3	
Cobalt	Dissolved	<0.6	<0.6	<0.6	1.0
	Total	<0.6	<0.6	<0.6	
Copper	Dissolved	<1	<1	<1	1.3
	Total	<1	<1	<1	
Iron	Dissolved	<4	<4	<4	-
	Total	52	50	13	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1	<1	<1	
Manganese	Dissolved	<1	<1	<1	-
	Total	1.8	1.5	<1	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	13	12	11	-
	Total	12	12	12	
Nickel	Dissolved	<6	<6	<6	70
	Total	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	-
	Total	<4	<4	<4	
Silver	Dissolved	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	
Tin	Dissolved	<1.6	<1.6	<1.6	-
	Total	<1.7	<1.7	<1.7	
Vanadium	Dissolved	1.8	1.7	1.6	100
	Total	1.6	1.7	1.8	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4	<4	<4	



**Figure 26** Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during August 2018.

Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

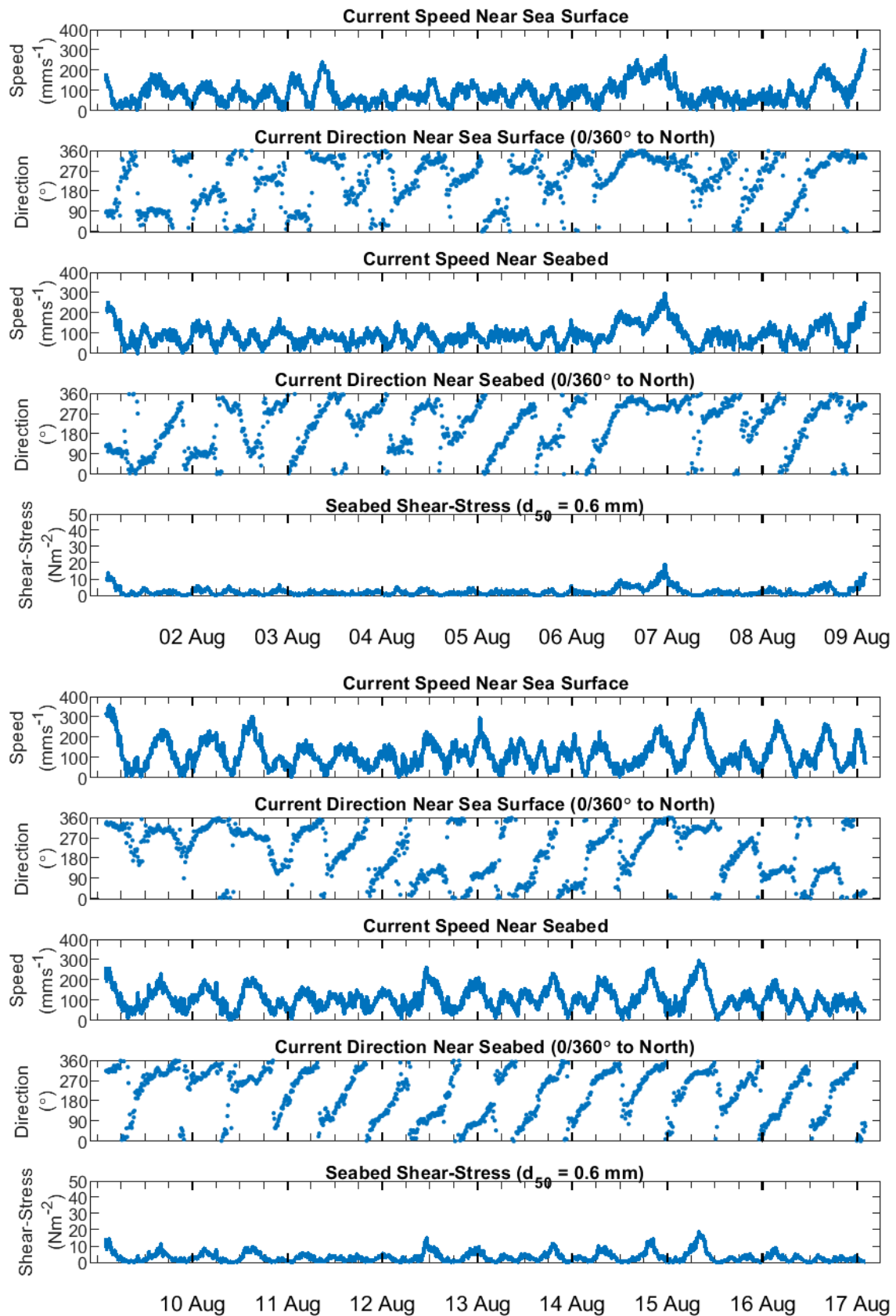


**Figure 27** Total and dissolved molybdenum and vanadium concentrations at monitoring sites during August 2018.  
 Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

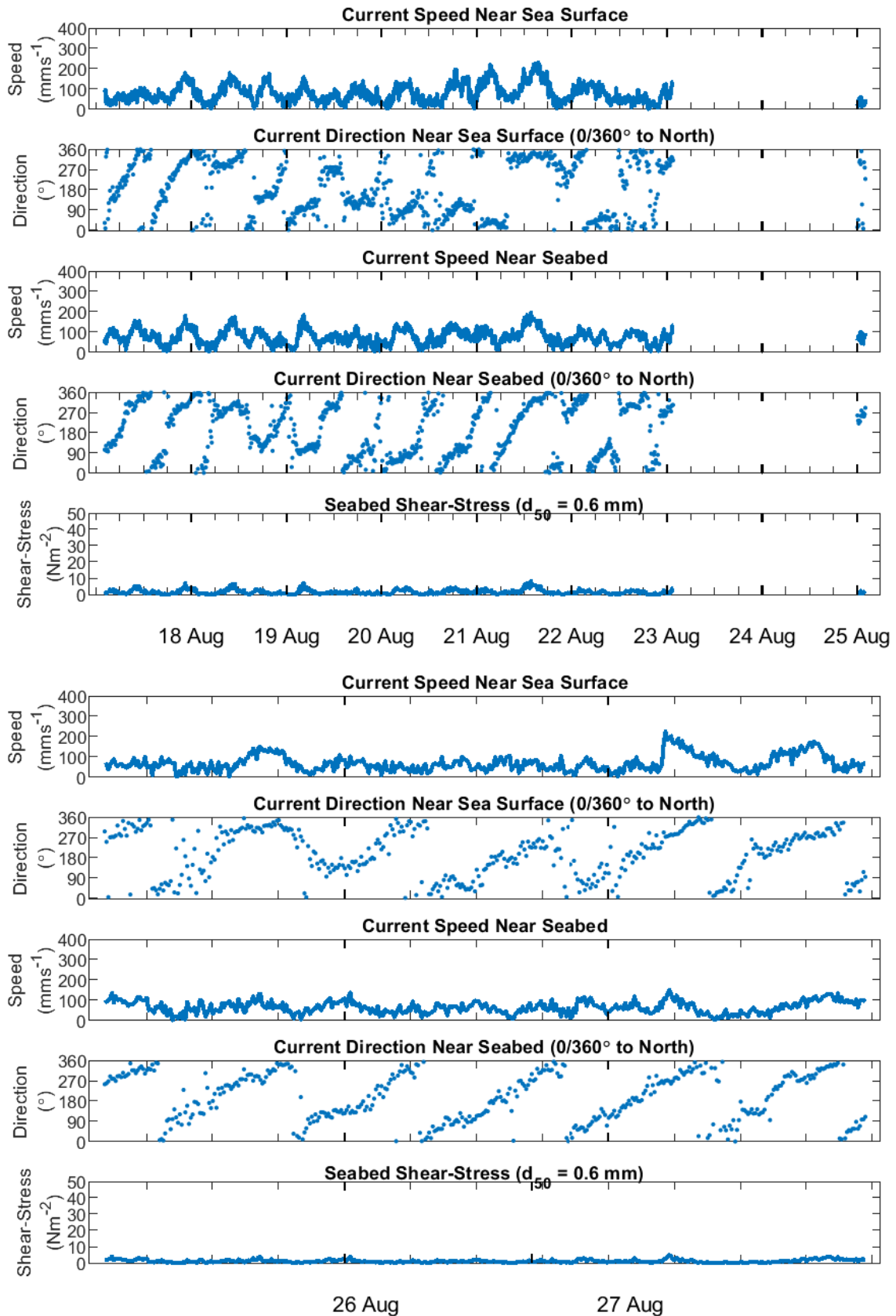
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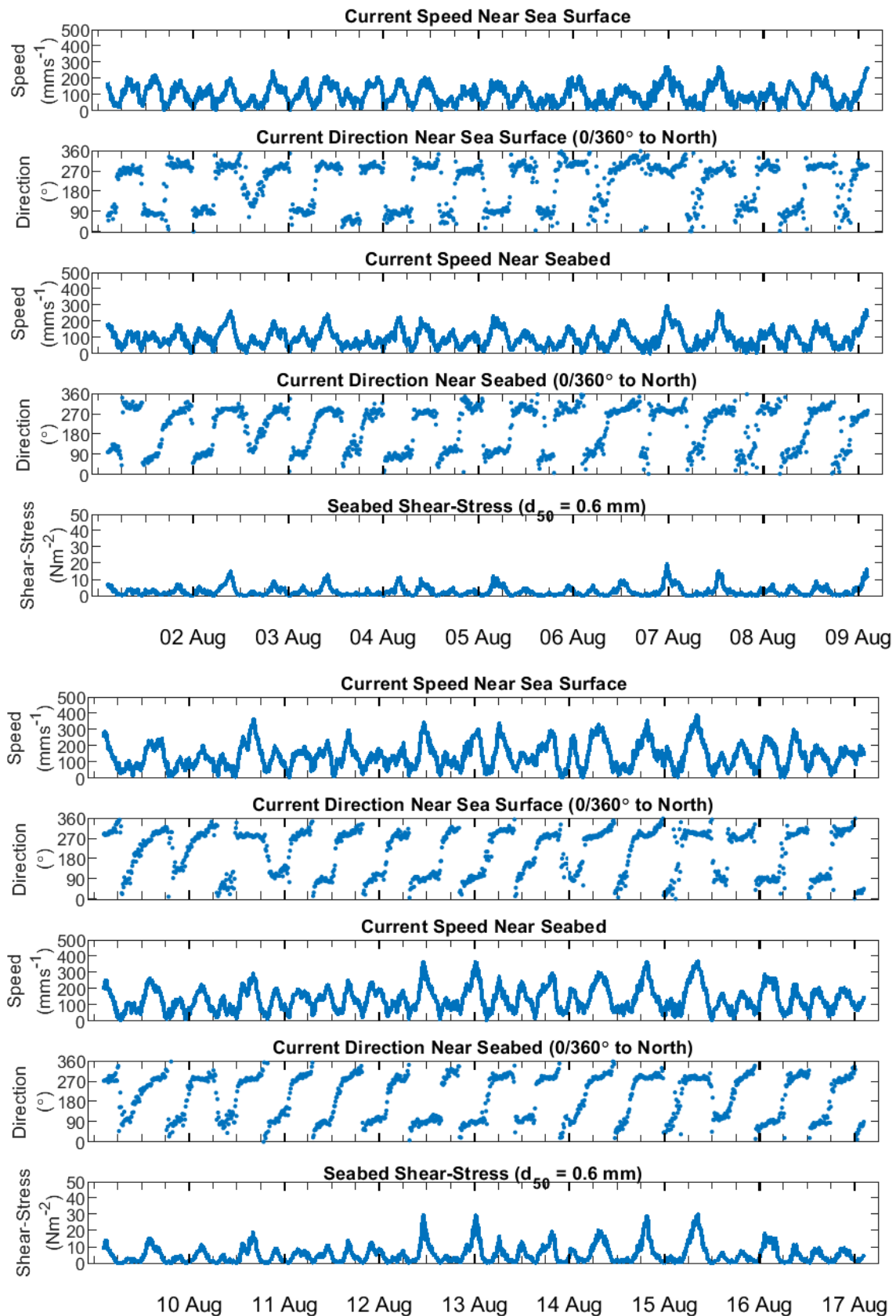
## 5 APPENDIX



**Figure 28** SG1 current speed, direction and shear bed stress 1 to 9 and 9 to 17 August 2018.

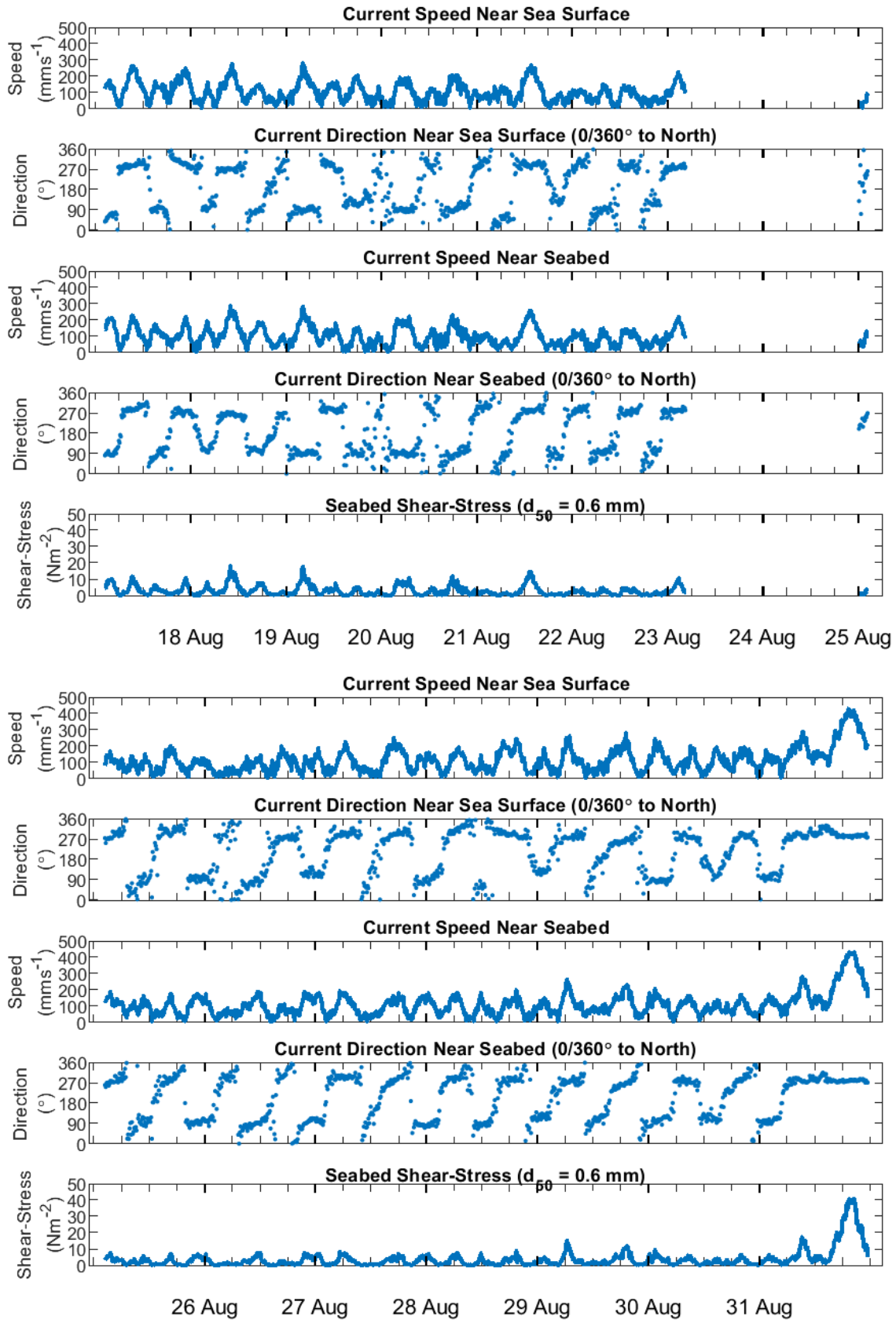


**Figure 29** SG1 current speed, direction and shear bed stress 17 to 25 and 25 to 27 August 2018.



**Figure 30** SG3 current speed, direction and shear bed stress 1 to 9 and 9 to 17 August 2018.





**Figure 31** SG3 current speed, direction and shear bed stress 17 to 25 and 25 to 31 August 2018.

**Table 19** Summary of Vision Environment quality control data for August 2018 water sampling.  
*ND = not determined as one or more samples was below LOR. Variation between duplicate field samples  $\geq 50\%$  has been highlighted in blue. High variation indicates heterogeneity within the water column.*

Parameter	VE Field Blank ( $\mu\text{g/l}$ )	Duplicate		
		CH1 A ( $\mu\text{g/L}$ )	CH1 B ( $\mu\text{g/L}$ )	Variation (%)
Total Suspended Solids	<3	18	18	0
Dissolved Aluminium	<3	<12	<12	ND
Total Aluminium	<3.2	181	330	45
Dissolved Arsenic	<1	<4	<4	ND
Total Arsenic	<1.1	<4.2	<4.2	ND
Dissolved Cadmium	<0.05	<0.2	<0.2	ND
Total Cadmium	<0.053	<0.21	<0.21	ND
Dissolved Chromium	<0.5	<1	<1	ND
Total Chromium	<0.53	<1.1	1.2	ND
Dissolved Cobalt	<0.2	FALSE	FALSE	ND
Total Cobalt	<0.21	<0.63	0.64	ND
Dissolved Copper	<0.5	<1	<1	ND
Total Copper	<0.53	<1.1	<1.1	ND
Dissolved Iron	<20	<4	<4	ND
Total Iron	<21	220	400	45
Dissolved Lead	<0.1	<1	<1	ND
Total Lead	<0.11	<1.1	<1.1	ND
Dissolved Manganese	<0.5	1.2	1.1	8
Total Manganese	<0.53	6.2	9	31
Dissolved Mercury	<0.08	<0.08	<0.08	ND
Total Mercury	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum	<0.2	11.7	11.6	1
Total Molybdenum	<0.21	11.7	11.1	5
Dissolved Nickel	<0.5	<7	<7	ND
Total Nickel	<0.53	<7	<7	ND
Dissolved Selenium	<1	<4	<4	ND
Total Selenium	<1.1	<4.2	<4.2	ND
Dissolved Silver	<0.1	<0.4	<0.4	ND
Total Silver	<0.11	<0.43	<0.43	ND
Dissolved Tin	<0.5	<5	<5	ND
Total Tin	<0.53	<5.3	<5.3	ND
Dissolved Vanadium	<1	2	1.7	15
Total Vanadium	<1.1	2.1	2.7	22
Dissolved Zinc	<1	<4	<4	ND
Total Zinc	<1.1	<4.2	<4.2	ND
Total Phosphorus	<4	26	26	0
Dissolved Reactive Phosphorus	<4	13	12	6
Total Nitrogen	<110	200	<300	ND
Total Kjeldahl Nitrogen (TKN)	<100	<200	<200	ND
Total Ammonia	<10	23	21	9
Nitrate + Nitrite	<2	60	59	2
Chlorophyll <i>a</i>	<0.2	2.2	2	9