Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

September 2019

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Document draft	***Originated by***	***Edit and review***	***Date***
Draft for Client review	AS, FM	LA	14/10/2019
Final submitted to Client	FM	LA	18/03/2020

CITATION

This report should be cited as:

Vision Environment (2019). *Lyttelton Port Company Channel Deepening Project Water Quality Environmental Monitoring - Monthly Report – September 2019.* Vision Environment, Gladstone, QLD, Australia.

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FILE REFERENCE

18032020 Final LPC Water Quality Environmental Monitoring September 2019_VE

Summary

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

Dredging operations for the CDP 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 September 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 September lower rainfall was recorded at Cashin Quay (29.4 mm) than during August 2019 (36.8 mm), with highest daily rainfall recorded on 4 September (8.2 mm). Flows from the Waimakariri River were moderate (<100 m^3/s) during the month with maximum flows occurring on the 17 (459 m^3/s) and 30 September (463 m^3/s). Monthly average air temperature (10.3°C) was slightly higher than that recorded in August (9.3°C). Inshore winds were generally westerly, including south-westerly and north-westerly, with mean daily wind speeds > 15 kts recorded on 5, 6 and 26 September. Offshore mean daily winds were highest (14 kts) on 6 September, with greatest mean daily significant wave heights recorded on 7 September (1.6 m).

Currents: Near-surface currents at SG1 and SG3 were highest on 10 September during a period of moderate offshore winds from a north-easterly direction. Near-bed currents at SG1 and SG3 were highest on 5 and 7 September respectively, during a period of moderate offshore wind speeds from a southerly direction. At SG2a (Watchkeeper) maximum currents were recorded at near-surface on 10 September, similar to SG1 and SG3, and near-seabed on 24 September, which corresponded to 1.5 m significant wave event from a north-easterly direction.

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 spoil ground monitoring locations. Mean turbidity values for September in addition to percentile statistics were similar to those recorded during the baseline monitoring period.

Elevated turbidity was recorded at all sites from 4 to 8 September (< 20 NTU), due to moderate to high inshore and offshore winds. Elevated turbidity at most offshore sites was recorded again around 23 to 24 September following a period of large wave heights.

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

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

Other Physicochemical Parameters: Mean monthly temperatures were warmer in September than August with all sites displaying a seasonal increase. In contrast to August, warmer temperatures were recorded in the upper and central harbour than the offshore sites. Benthic temperatures were consistent with those at the surface indicating a well-mixed water column.

Consistent with previous reports, surface and benthic pH during September 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 fluctuated at all sites during September, with higher concentrations at the start of September and 20 to 22 September. These fluctuations are 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 September as typically observed. Benthic DO trended similarly to surface DO throughout September.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 5 September 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 12.3 m at SG1 and SG2. Turbidity at CH1 within the sub-surface layer (10.3 NTU) slightly exceeded the WQG (10 NTU) and this was reflected within the high TSS sample (20 mg/L). No other exceedances of WQG were observed for sub-surface during the September 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 UH2 where total nitrogen exceeded the WQG. As typically recorded, ammonia concentrations exceeded WQG at all sites, while nitrogen oxides reduced in concentrations with the majority of sites below WQG. Chlorophyll *a* concentrations were elevated across all sites with many sites exceeding the WQG. This was likely due to the presence of an algal bloom.

Several metals were reported as below the limit of reporting (LOR) at all sites as commonly found. Dissolved copper exceeded the designated WQG at UH1. Total aluminium concentrations exceeded designated WQG at all of the monitoring sites, but the dissolved and therefore readily bioavailable fraction, remained undetectable. Total aluminium, iron and manganese displayed a strong spatial difference with elevated concentrations found in the inshore and offshore locations, whereas spoil ground sites reported the lowest concentrations. Total and dissolved chromium, vanadium and molybdenum were also detected during September, 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 September than August associated with the increased day lengths, in addition to the lower rainfall and associated cloud cover during the month. As such, BPAR at both OS2 and OS3 also increased with many peaks occurring after 15 September, when ambient PAR was reasonably high and water turbidity was low.

Sedimentation: Overall accumulation of sediments at both OS2 and UH3 was evident in September. 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 10 mm over the month. Sediment flux at UH3 was more stable with a period of minor erosion occurring in early to mid-September, and then slow and steady accumulation of sediments from mid to late September, resulting in an overall accumulation of 9.8 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.

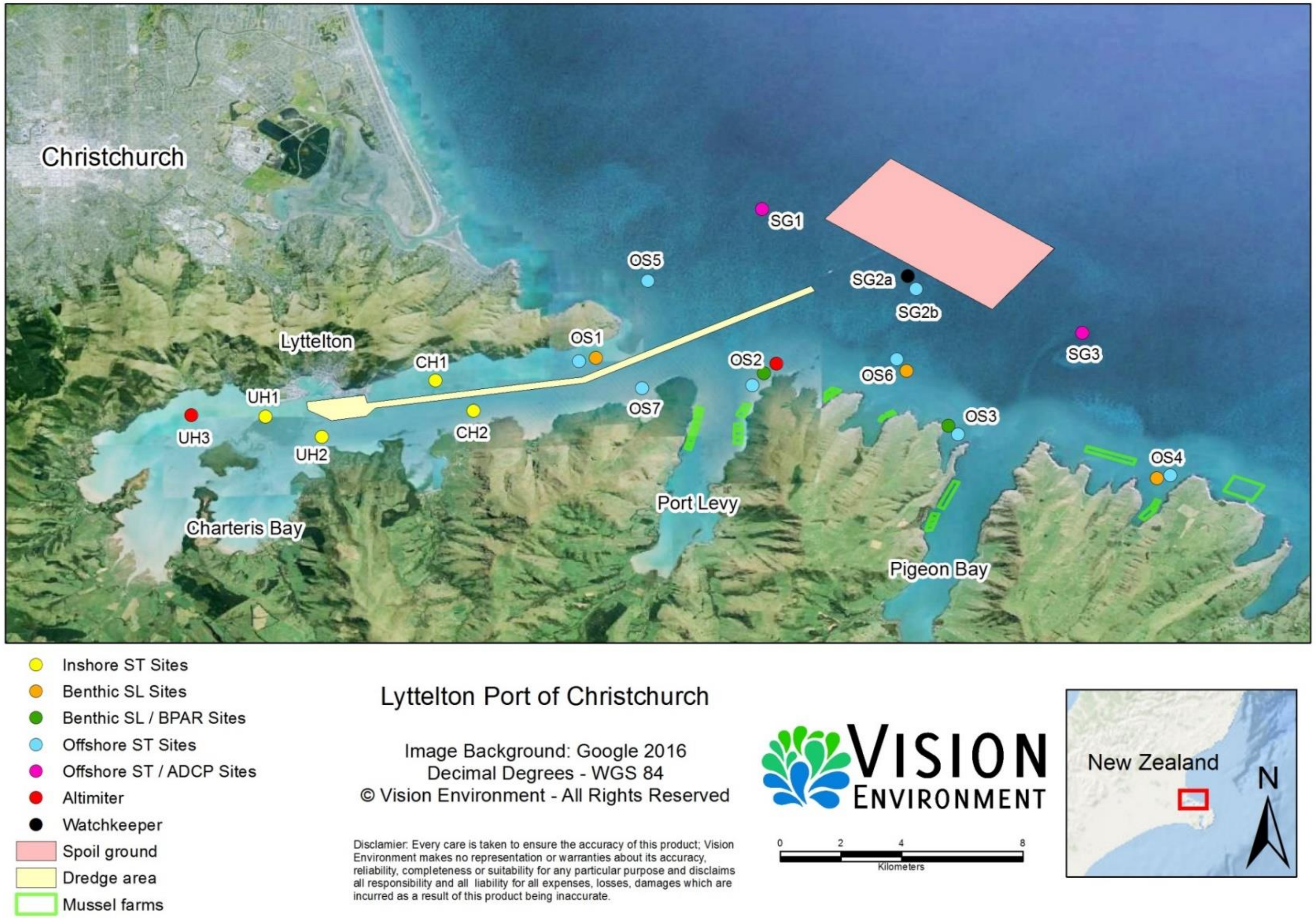


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 September 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 5 September 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 29.4 mm of rainfall was recorded at Cashin Quay during September 2019, a slight decrease from the precipitation recorded in August (37 mm). Highest rainfall (8.2 mm) was recorded on 4 September, followed by 7.8 mm on 14 September (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 September ranged between 54 m^3/s and 463 m^3/s with peaks recorded on the 30 September (463 m^3/s), and the 17 September (459 m^3/s), (ECAN, 2019). However flows in September appeared to have little impact on harbour parameters.

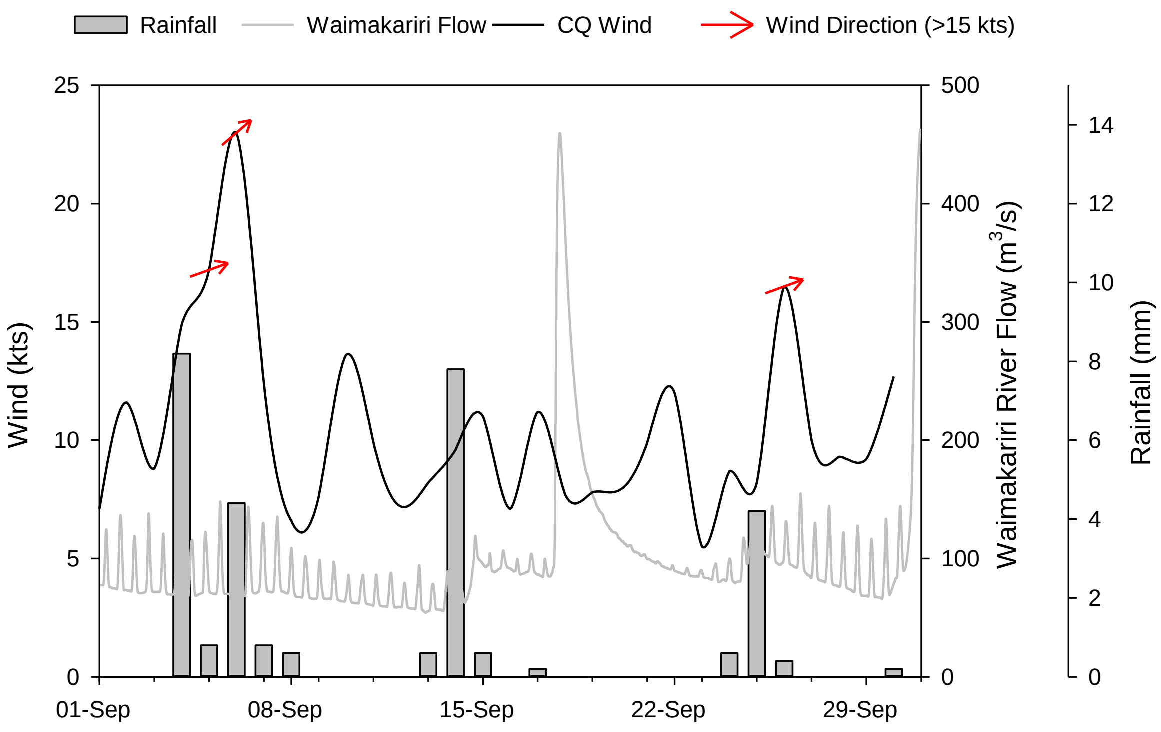


Figure 2 Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during September 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.

Inshore winds during September were generally from a westerly direction, including south-westerly and north-westerly (Metconnect, 2019). Highest mean winds speeds (23 kts) were recorded on 6 September from a south-westerly direction, while south-westerly wind gusts > 40 kts were recorded on the 6 and 16 September. Daily mean wind speeds > 15 kts were also recorded on the 5 (from west-south-westerly) and 26 (from west-south-westerly) September.

Daily mean air temperatures at Cashin Quay ranged from 6°C to 17°C, resulting in a monthly mean temperature of 10.3°C, slightly higher than the August mean temperature of 9.3°C (Metconnect, 2019).

Offshore significant wave height peaked at 2.21 m at 11:00 pm on 4 September, with other significant waves >2m occurring until 3:00am on 5 September leading to mean daily significant wave heights of 1.3 m and 1.4 m, respectively. Mean daily offshore wind speeds were generally <15 kts, however elevated offshore wind speeds of 12 to 14 kts occurred from a south-westerly direction on 5 to 6, 13 and 26 September (Figure 3).

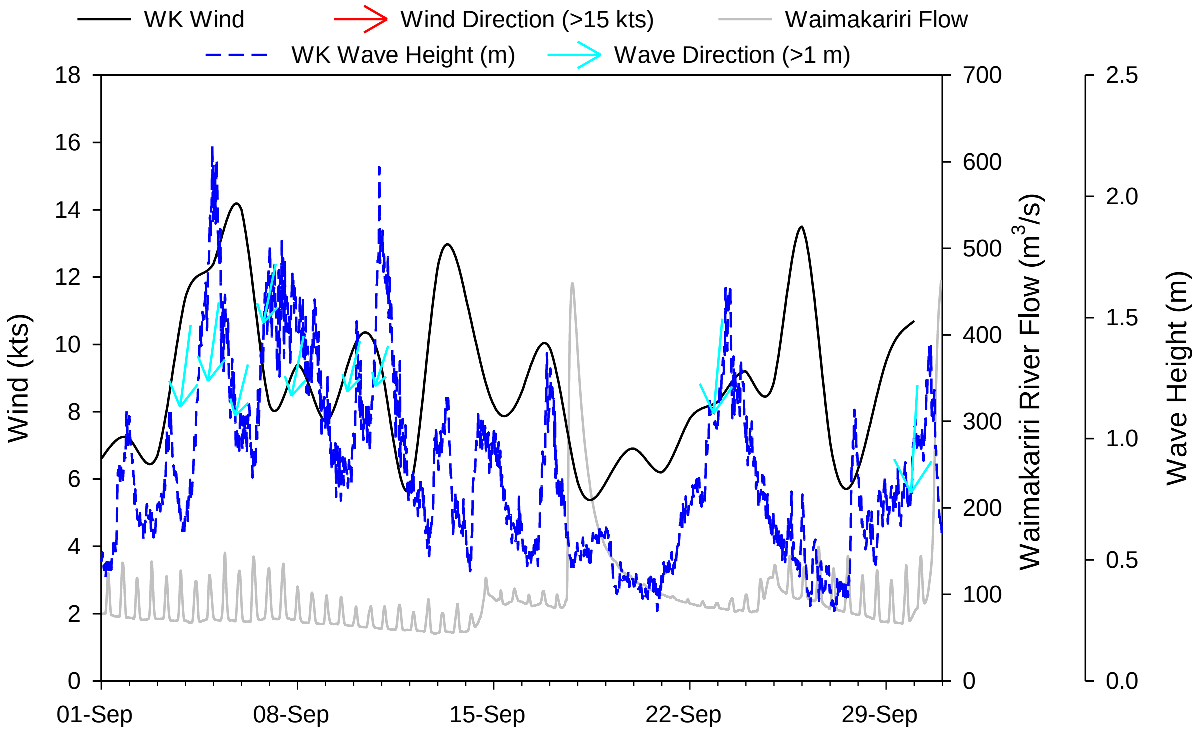


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during September 2019.
Note: Arrows indicate the direction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

Parameter	Depth	Site		
		SG1	SG2a	SG3
Minimum current speed (mm/s)	*Near-surface*	2	1	3
	Near-seabed	1	2	1
Maximum current speed (mm/s)	*Near-surface*	373	317	395
	Near-seabed	283	578	377
Mean current speed (mm/s)	*Near-surface*	104	75	128
	Near-seabed	89	132	116
Standard deviation of current speed (mm/s)	*Near-surface*	60	62	75
	Near-seabed	47	97	63
Current speed, 95th percentile (mm/s)	*Near-surface*	221	209	270
	Near-seabed	177	337	236

Maximum near-surface current speeds at SG1 (373 mm/s), SG3 (395 mm/s) and SG2a (317 mm/s) were recorded on 10 September during a period of moderate offshore winds (daily mean of 9.9 kts with gusts >15kts) from a north-easterly direction and inshore winds (daily mean 13.6 kts with maximum gusts of 28 kts) from an east-north-easterly direction.

Maximum near-seabed current speeds at SG1 (283 mm/s), SG3 (377 mm/s) and SG2a (578 mm/s) were recorded on different days to near-surface current speeds with maximums recorded on 5, 7 and 24 September respectively. Daily offshore wind speeds of 8 to 12 kts from a southerly direction and maximum significant wave heights >1.3 m could explain the increased near-seabed currents on these dates.

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 August 2019, currents at SG1 near-surface during September tended to move in a north-northwest (43%) and southeast (25.1%) direction, as did the near sea-bed currents (northwest: 34.9%, southeast 24.6%). A similar pattern was evident at SG3, with near-surface current moving in a northwest (30.4%) and southeast (35.6%) direction, and near-seabed currents moving in a west-northwest (40.7%) and east-southeast (35%) direction.

Current movements at SG2a were found to be in a more east/west direction, similar to August 2019. Near-surface currents moved in a north-northwest (35.9%) and east (17.0%) direction, while near-seabed currents moved in a west (22.7%) and east (16.0%) direction.

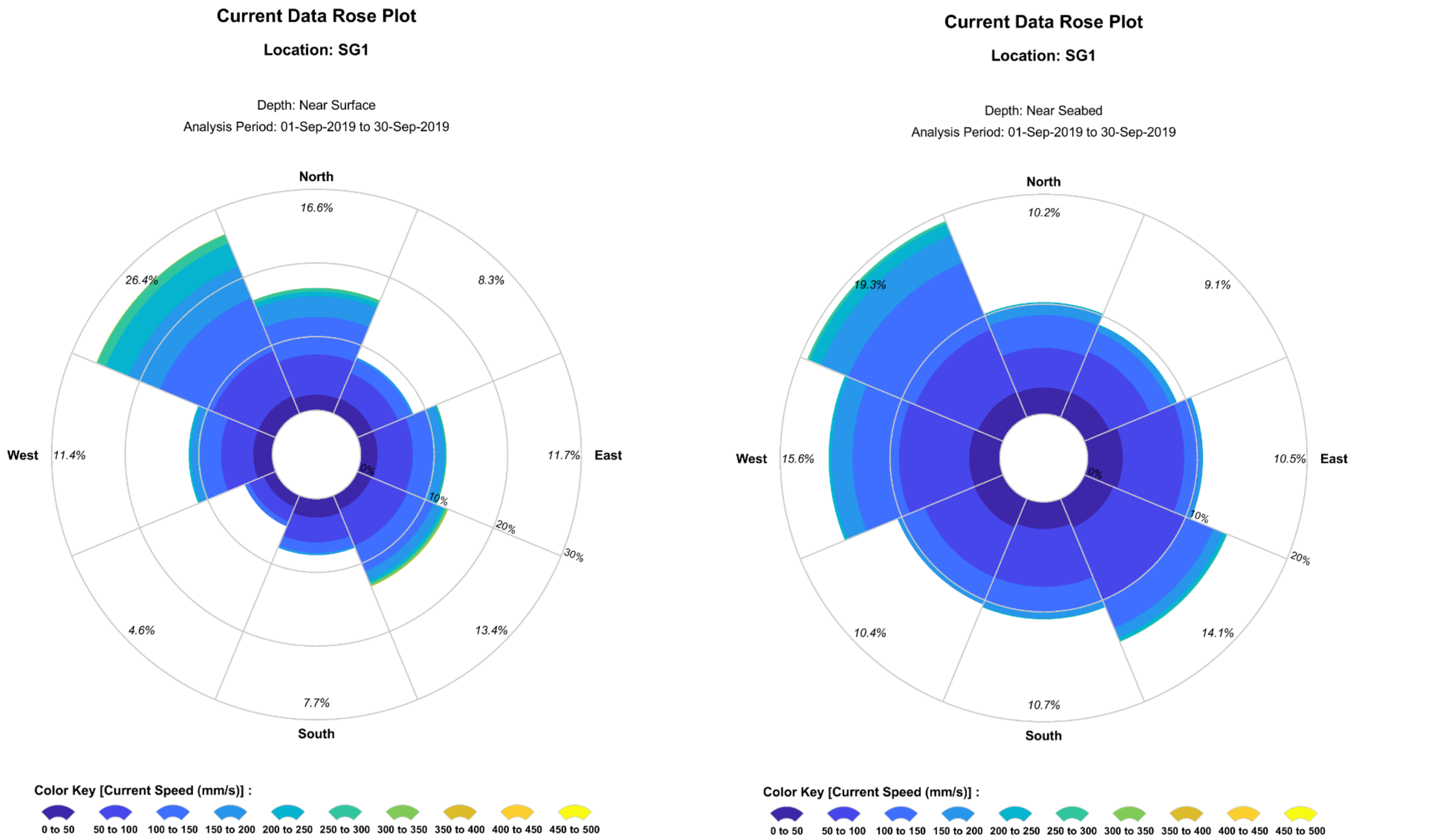
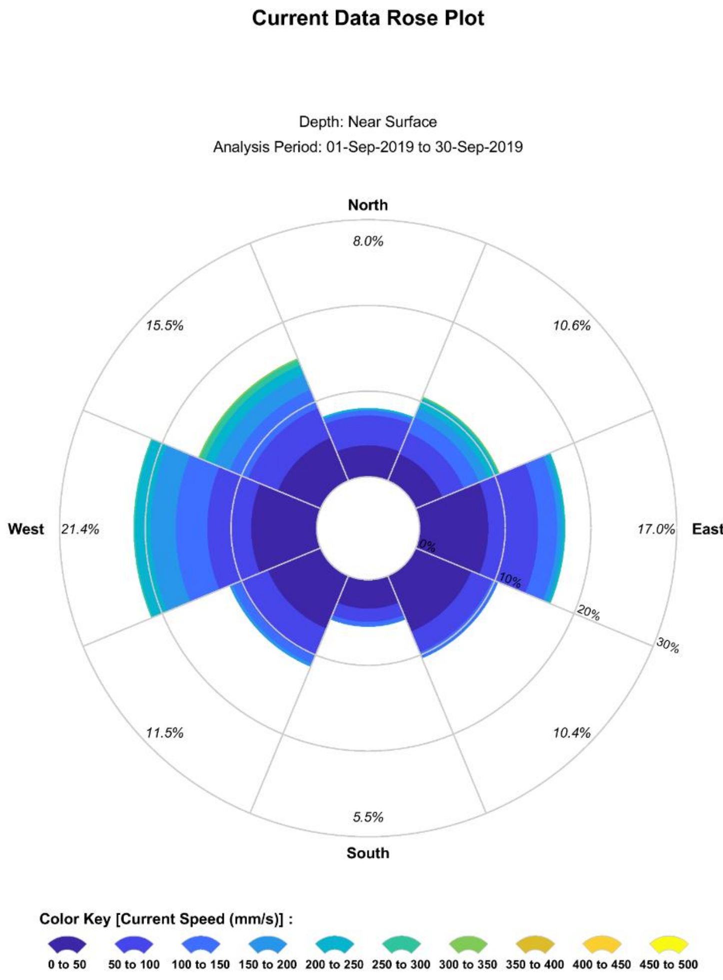


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during September 2019.
Speed intervals of 50 mm/s are used.



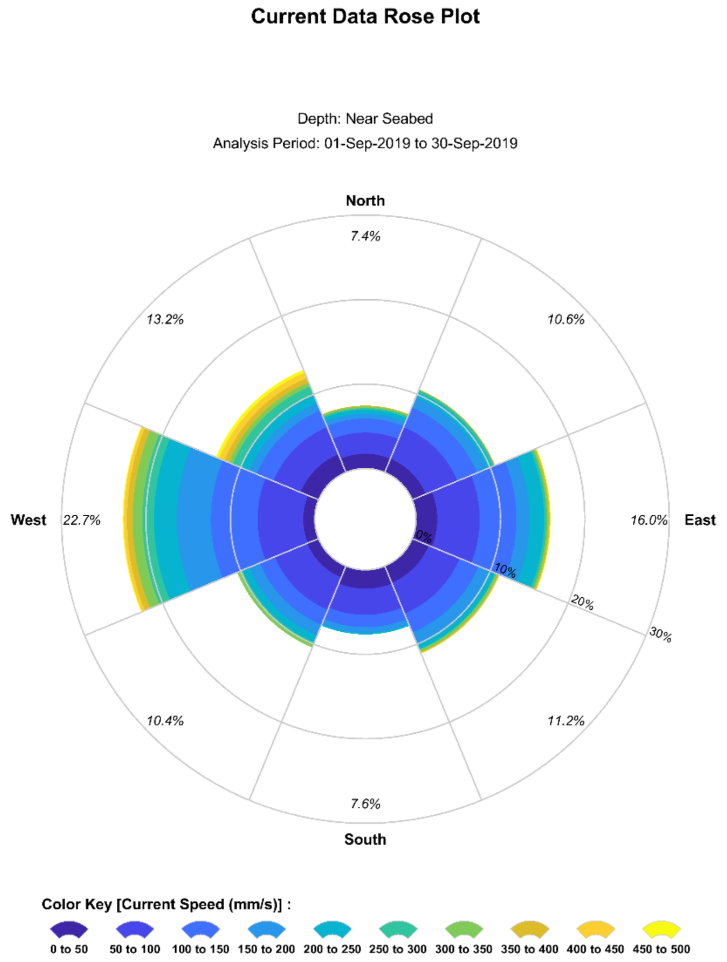
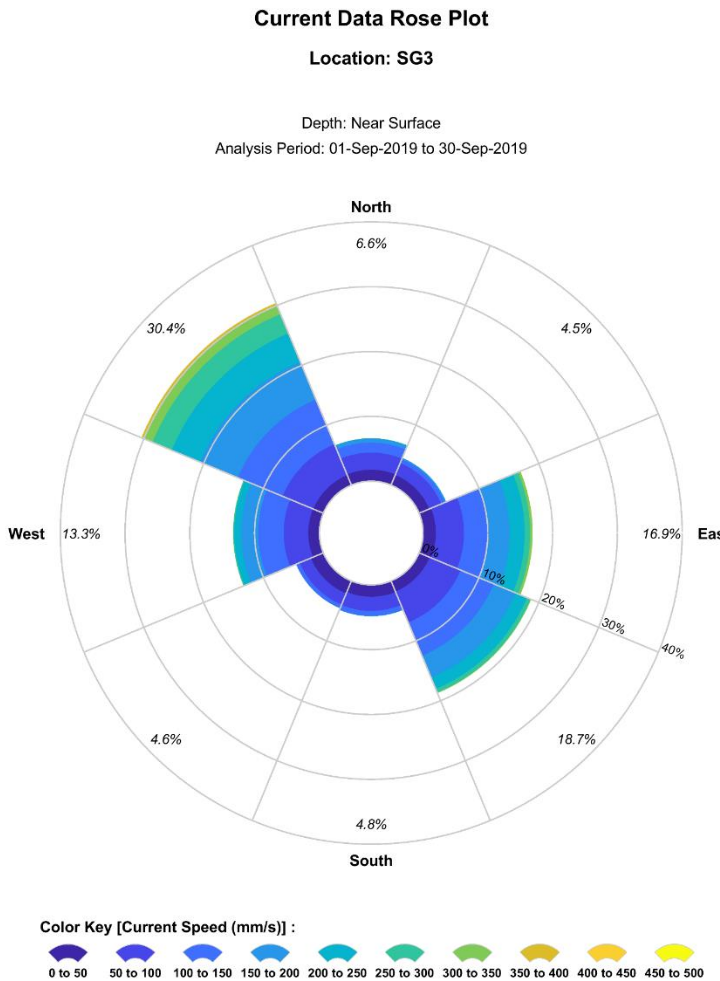


Figure 5 Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during September 2019.
Speed intervals of 50 mm/s are used.



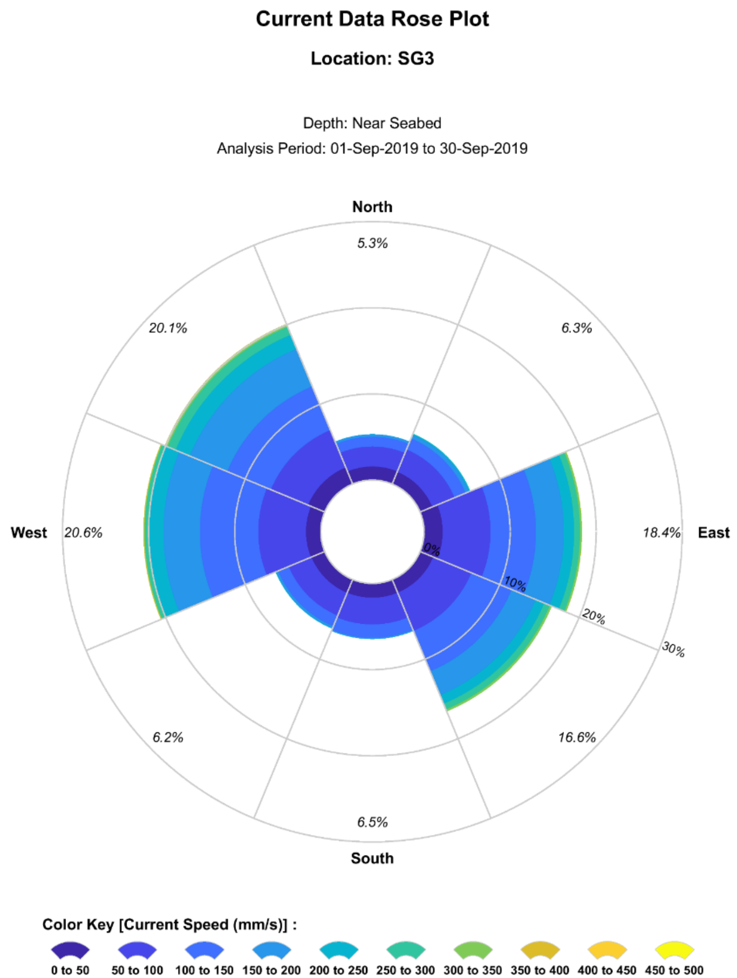


Figure 6 Near-surface and near-seabed current speed and direction at SG3 during September 2019. *Speed intervals of 50 mm/s are used.*

3.2 Continuous Physicochemistry Loggers

Physical and chemical properties of the water column are measured at monitoring sites every 15 minutes by dual telemetered surface loggers. Additional dual sets of benthic loggers have also been deployed at five offshore sites (OS1 to OS4 and OS6). In conjunction with the continuous loggers, discrete depth profiles of all physicochemical parameters were also conducted at all 15 monitoring sites on 5 September 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 September 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 September 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.

September Turbidity:

Consistent with previous monitoring months, mean surface turbidity values were typically highest (monthly means of 4.1 to 7.0 NTU) at the inshore monitoring sites (Table 3 and Figure 7). Further offshore, the spoil ground sites (Table 4) exhibited lower surface turbidity values (1.7 to 2.5 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 (2.4 to 5.4 NTU) during September (Table 5).

During September turbidity across the inner harbour was relatively low (~ 5 NTU) with exception of turbidity peaks between 4 to 8 September in response to increased inshore winds and localised period of higher rainfall (Figure 8).

Surface turbidity at the nearshore sites (OS1 to 4 and OS7) peaked during 4 to 8 September and 23 and 24 September, immediately following periods of high inshore and offshore winds, and increased wave heights.

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks were also evident between 5 to 8 September, 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.

Benthic:

Data return was gained for the majority of benthic sites during September. However, turbidity data was not able to be gained from OS6 benthic due to sonde malfunction. For the remaining sites, benthic turbidity data corresponded with surface measurements, with increased turbidity evident during early and late September, during periods of high winds and waves (Figure 7).

Table 3 Mean turbidity and statistics at inshore water quality logger sites during September 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for September are means ± se, range and percentiles (n = 2869 to 2880) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface September	Surface Baseline
UH1	Mean ± se	5.4 ± 0.0	12
	Range	2.3 – 13	-
	99th	10.1	39
	95th	8	22
	80th	6.1	15
UH2	Mean ± se	7.0 ± 0.0	10
	Range	1.9 – 23.4	-
	99th	16	32
	95th	12.7	20
	80th	8.5	13
CH1	Mean ± se	4.5 ± 0.0	9
	Range	2.2 – 15	-
	99th	10.8	29
	95th	8.3	18
	80th	5.5	12
CH2	Mean ± se	4.1 ± 0.0	8
	Range	2.5 – 10.3	-
	99th	8.6	24
	95th	7.2	16
	80th	4.6	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during September 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for September are means ± se, range and percentiles (n = 2874 to 2880). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface September	Surface Baseline
SG1	Mean ± se	2.5 ± 0.0	4.2
	Range	<1 – 10.5	-
	99th	8.5	14
	95th	5.3	10
	80th	3.4	6.2
SG2	Mean ± se	2.0 ± 0.0	4.6
	Range	<1 – 8.9	-
	99th	5.5	20
	95th	3.9	11
	80th	2.7	7.0
SG3	Mean ± se	1.7 ± 0.0	3.6
	Range	<1 – 6.8	-
	99th	5.1	13
	95th	4.0	7.7
	80th	2.6	4.8

Table 5 Mean turbidity and statistics at offshore water quality logger sites during September 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for September are means ± se, range and percentiles (n = 138 to 2881). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface September	Surface Baseline	Benthic September
OS1	Mean ± se	3.8 ± 0.0	7.5	33 ± 0.9
	Range	1.3 – 12.5	-	<1 – 207
	99th	9.8	24	171.9
	95th	7.0	16	124.1
	80th	4.7	10	58.8
OS2	Mean ± se	5.4 ± 0.0	6.4	30.8 ± 0.6
	Range	1 – 30.9	-	2.5 – 185
	99th	14.4	18	143.3
	95th	10.2	13	100.4
	80th	6.8	9.0	53.7
OS3	Mean ± se	5.4 ± 0.1	6.6	26 ± 0.5
	Range	1.4 – 29	-	<1 – 154
	99th	17.2	27	103.4
	95th	11.1	15	77.1
	80th	7	8.9	39.5
OS4	Mean ± se	4.6 ± 0.0	5.9	24 ± 0.5
	Range	1.1 – 21.6	-	<1 – 160
	99th	12.8	20	117.5
	95th	10.1	13	81.36
	80th	6	8.3	40.3
OS5	Mean ± se	2.4 ± 0.0	4.6	–
	Range	<1 – 12.3	-	–
	99th	8.6	19	–
	95th	6.1	11	–
	80th	3.4	6.4	–
OS6	Mean ± se	3.4 ± 0.0	4.7	28 ± 1.3
	Range	<1 – 11.5	-	10 – 69
	99th	8.6	19	66.1
	95th	6.3	12	55.6
	80th	4.3	7.2	40.5
OS7	Mean ± se	3.9 ± 0.1	6.4	–
	Range	<1 – 16.1	-	–
	99th	11.6	23	–
	95th	8.6	14	–
	80th	5.3	9.2	–

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

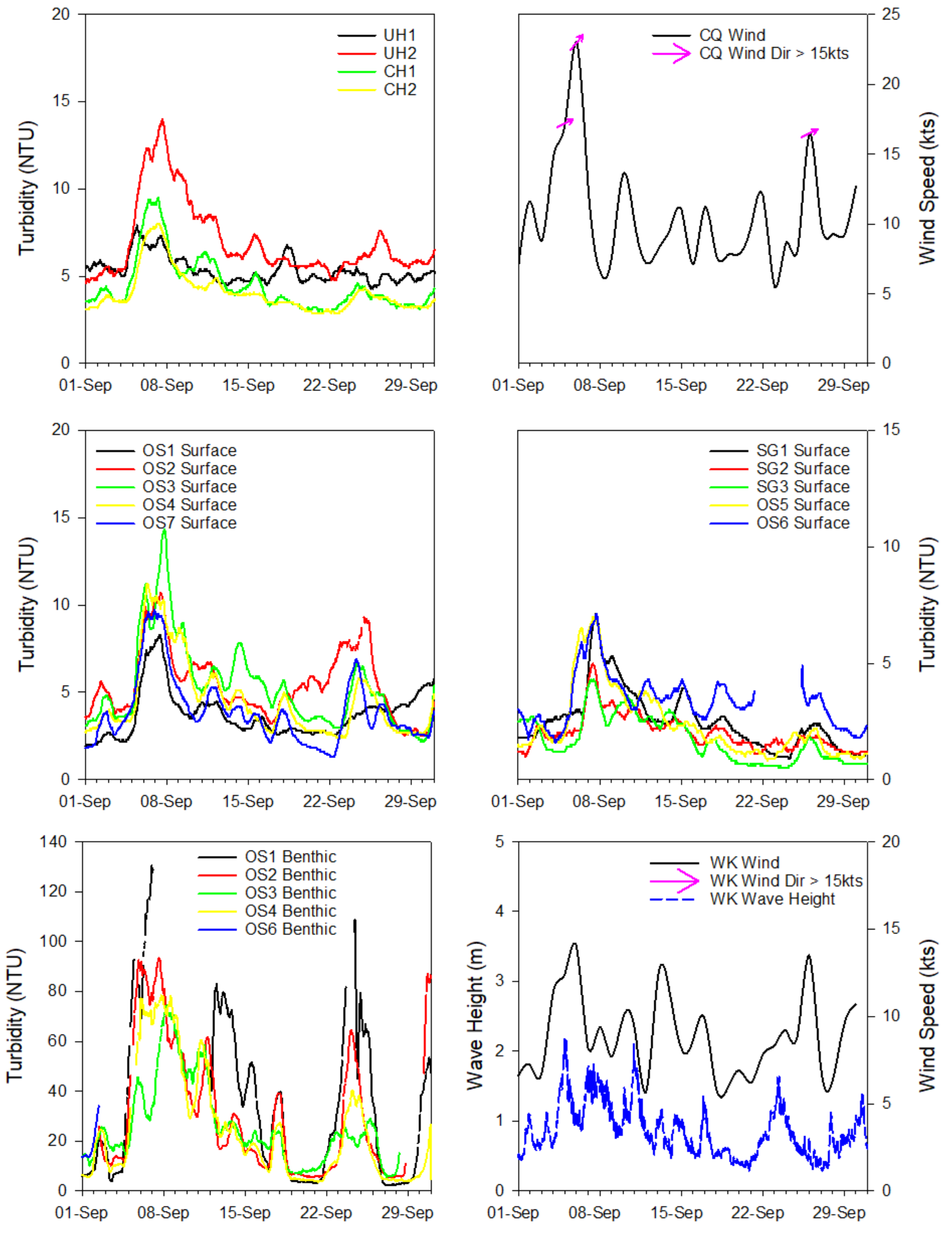


Figure 7 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots.

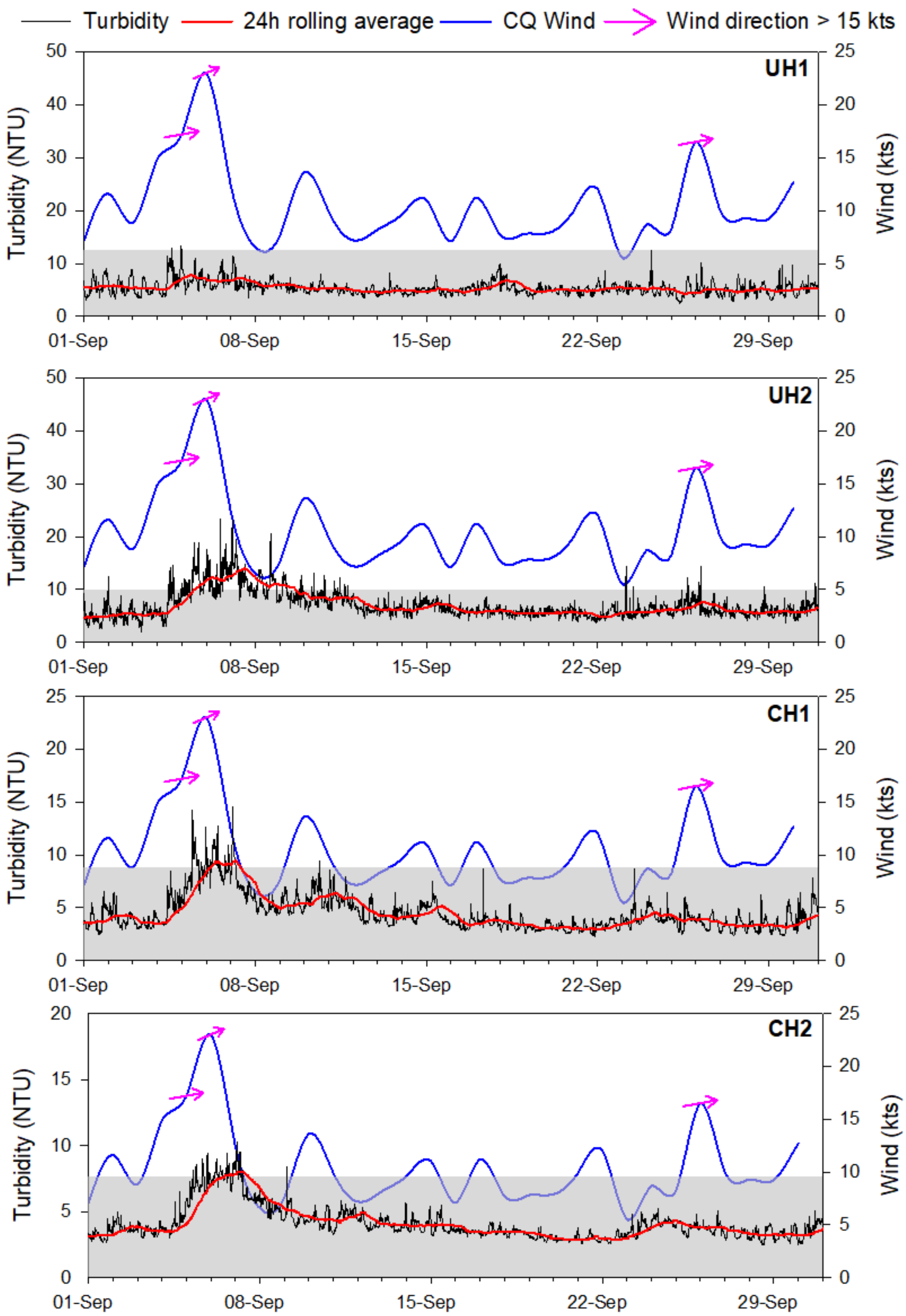


Figure 8 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during September 2019.
Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

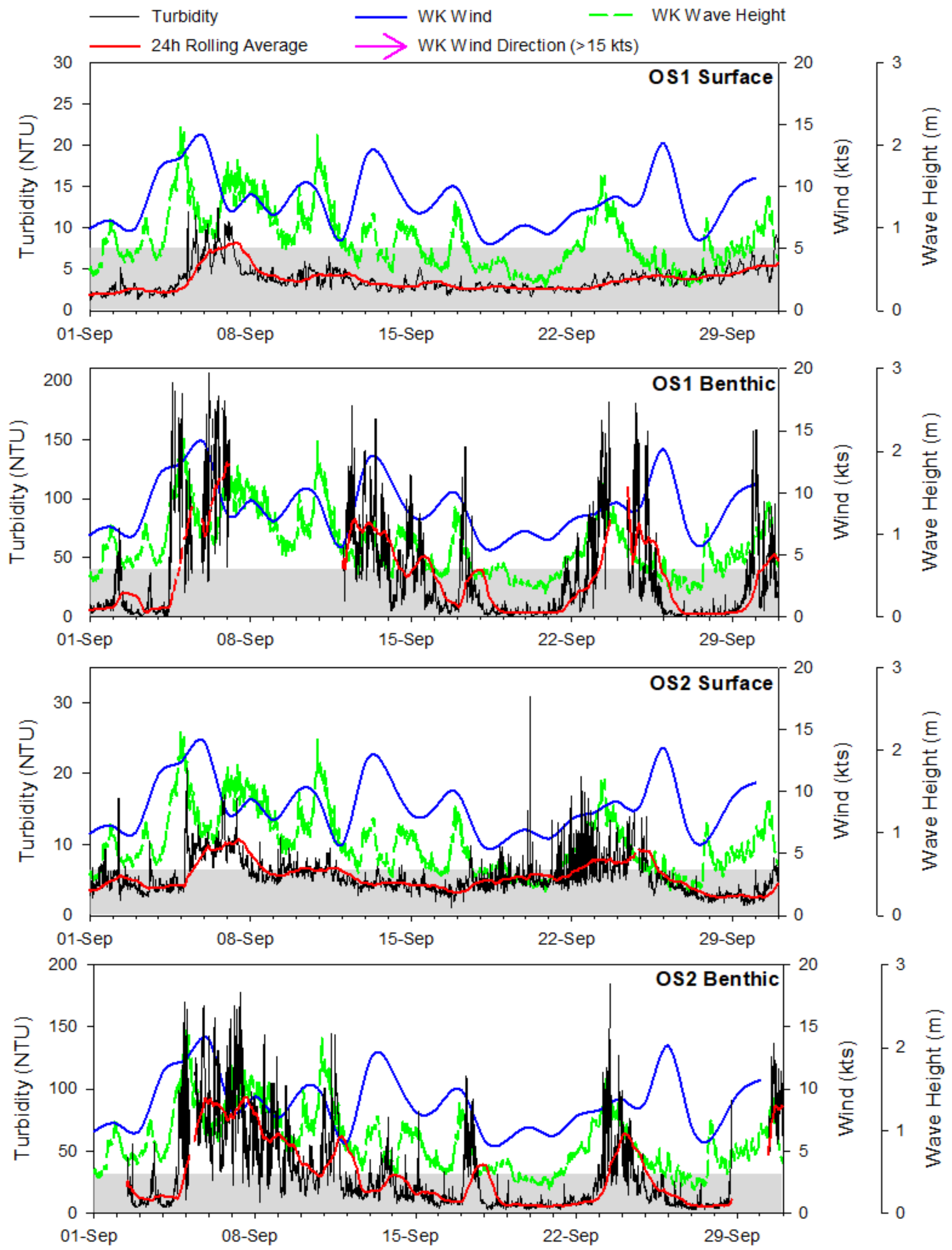


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

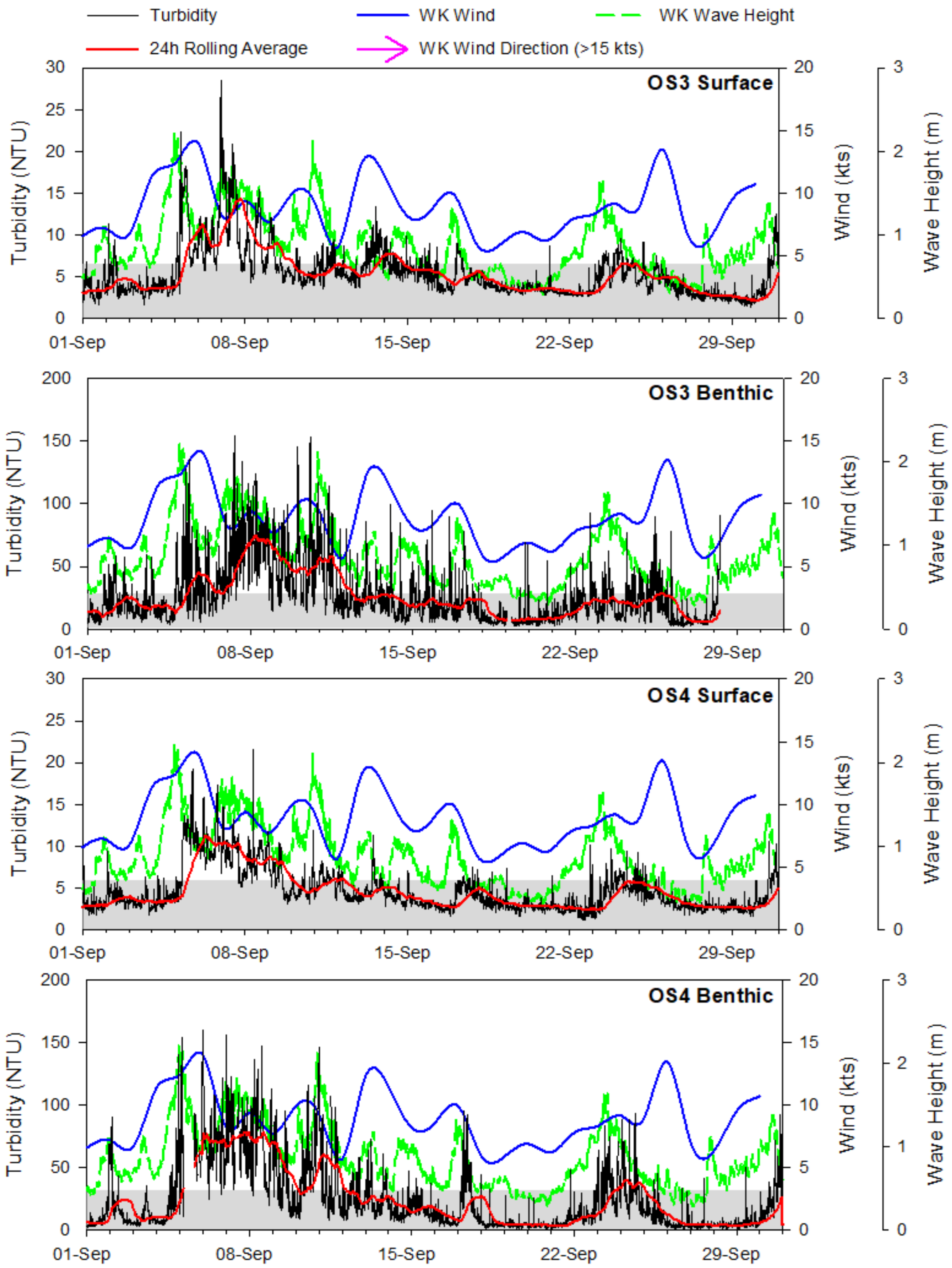


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

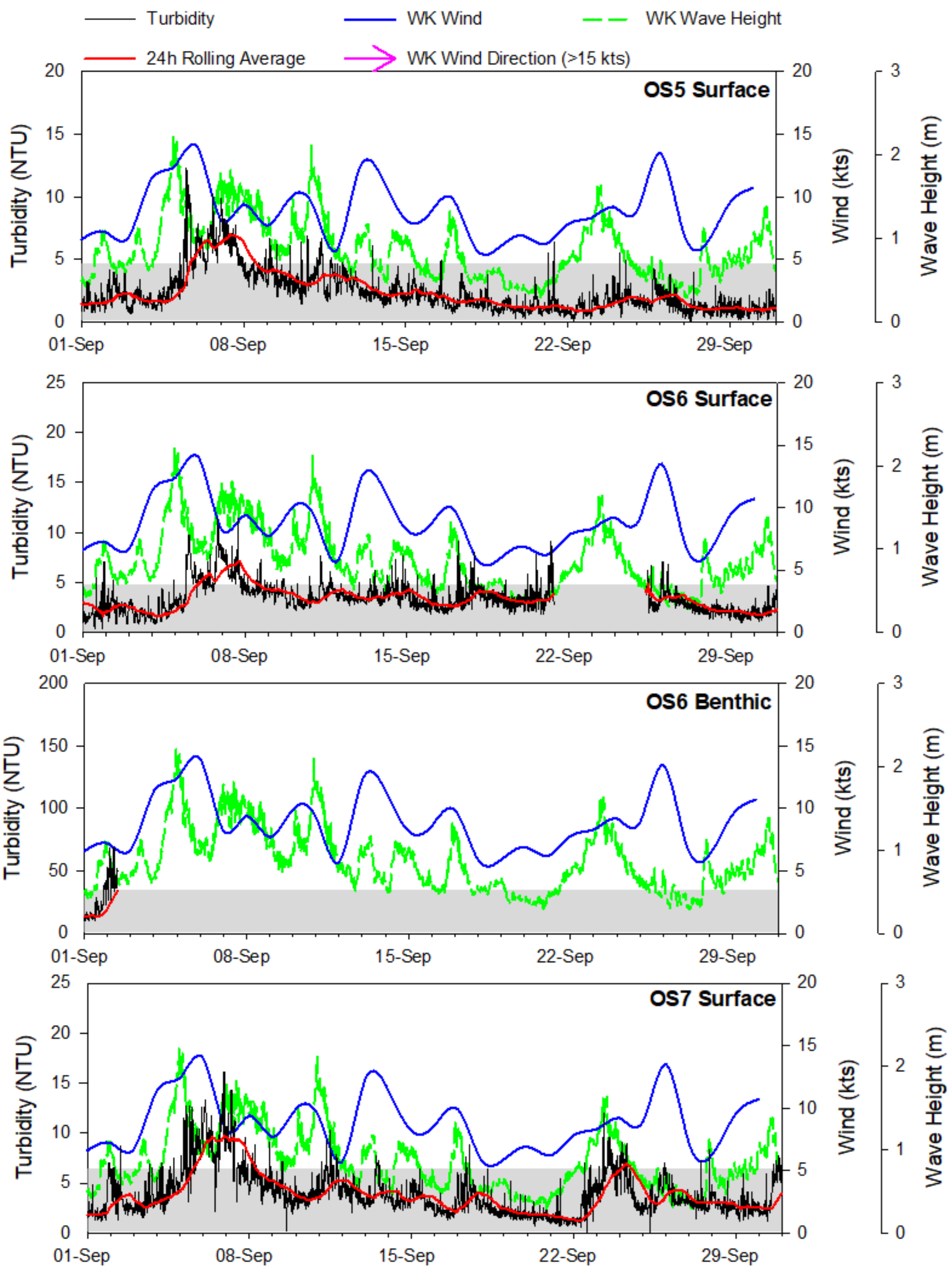


Figure 11 Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity. No data available for OS6.

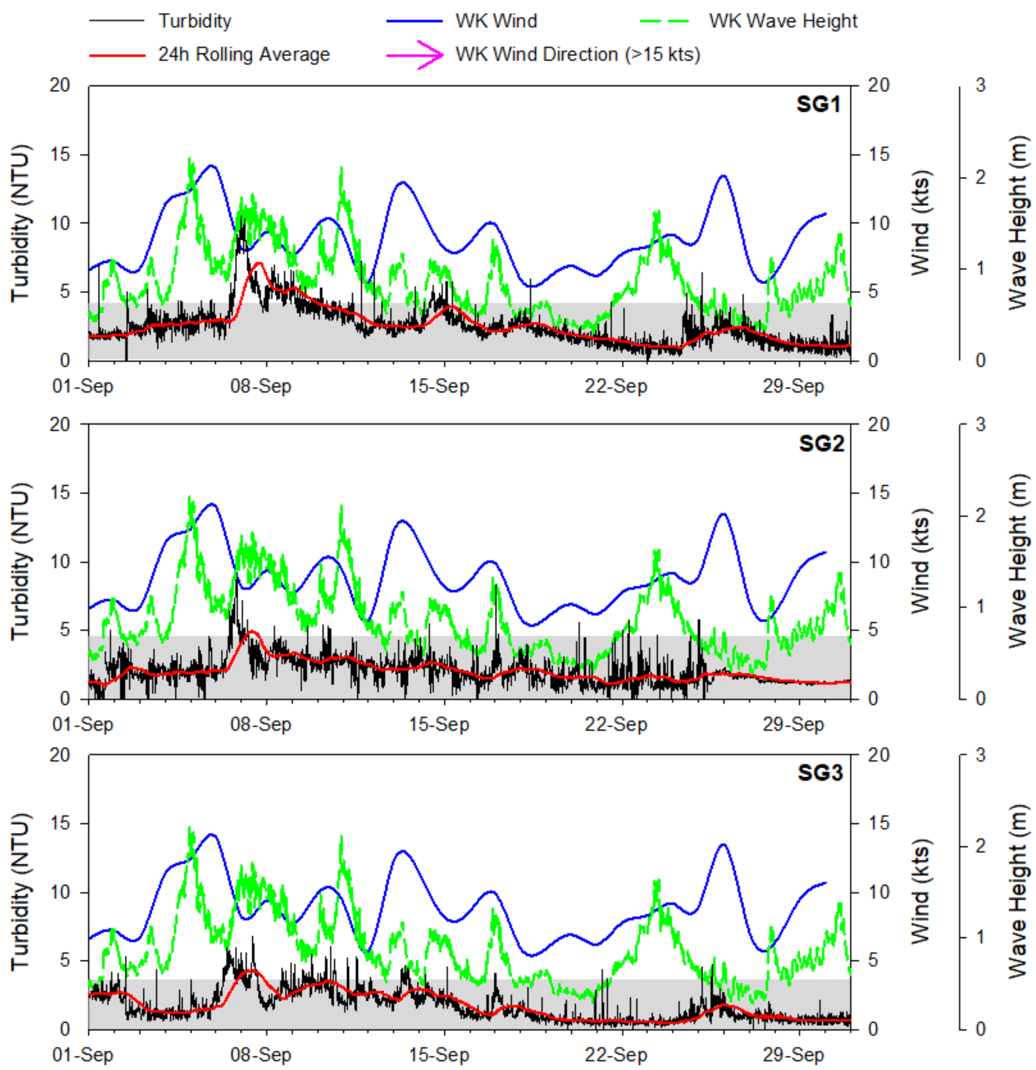


Figure 12 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during September 2019. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.*

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 (80th percentile) and Tier 2 (95th 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 (99th 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 September the Tier 3 intensity values were not exceeded at any site within the monitoring network (Table 7, Figures 13 to 15).

Table 7 Tier 3 intensity value exceedances and maximum hour counts during September 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	–	–	0.00
OS4	Reference site		
OS5	–	–	0.00
OS6	–	–	0.00
OS7	–	–	0.00
SG1	–	–	0.00
SG2	–	–	0.00
SG3	–	–	3.5

3.2.2.2 P99 Exceedance Counts Consented Removal

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

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

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

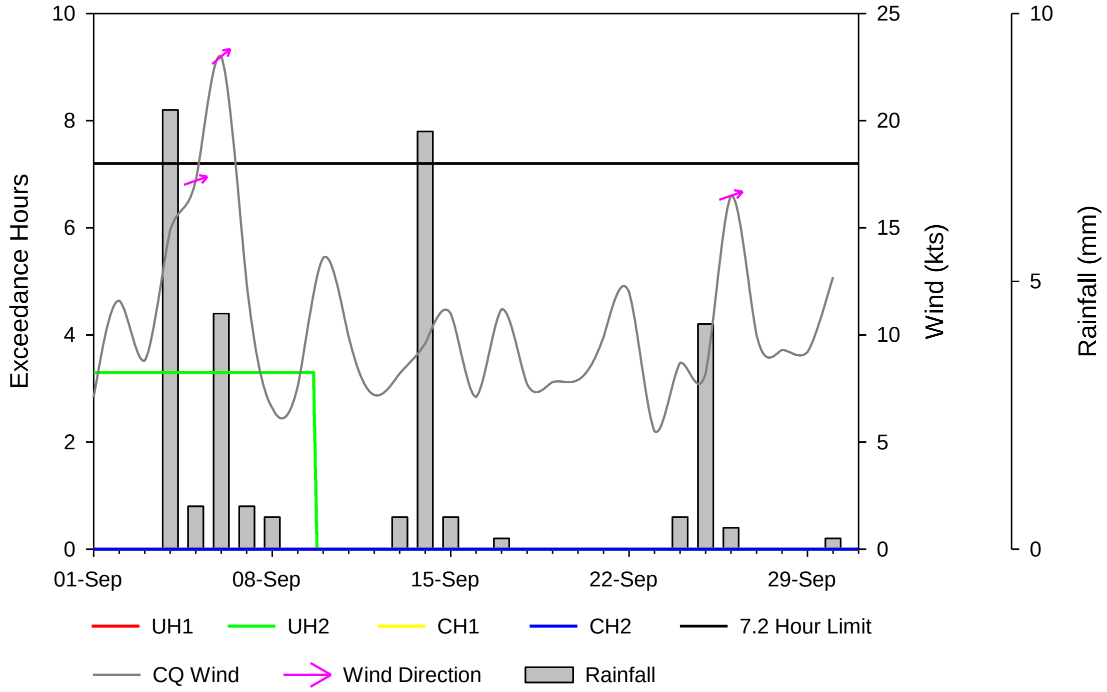


Figure 13 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during September 2019.

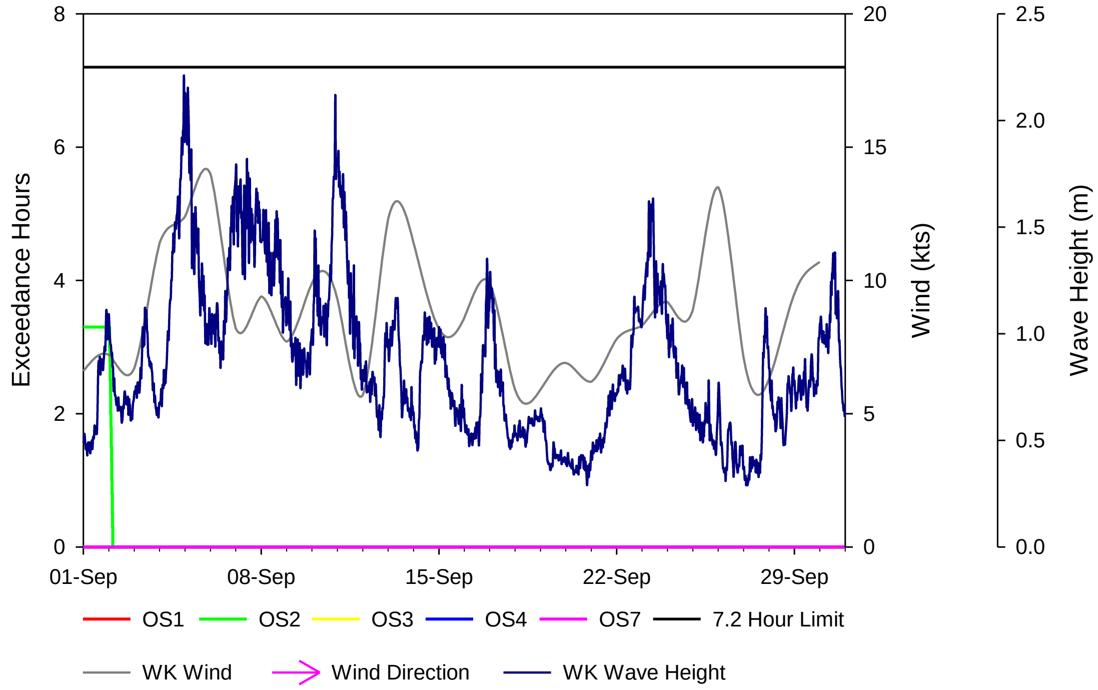


Figure 14 Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during September 2019.
Note there is no trigger value for the reference site OS4.

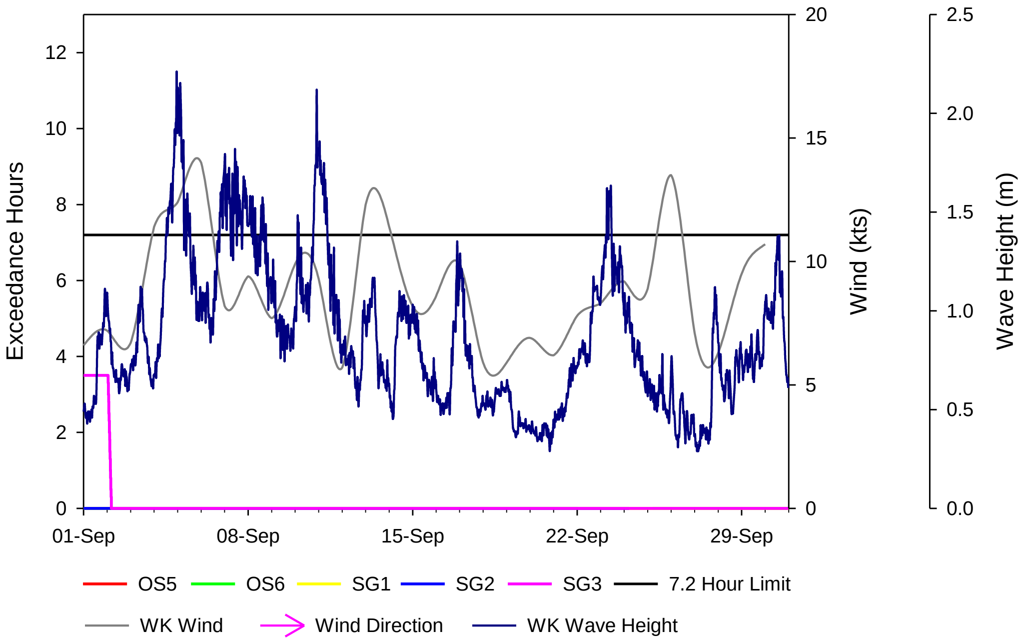


Figure 15 Tier 3 allowable hour counts at OS5, OS6, SG1, SG2b and SG3 after exceedance of the intensity values during September 2019.

3.2.3 Temperature

Mean monthly sea surface temperatures during September (10.1 to 10.6 °C) were slightly warmer than those experienced during August (8.7 to 9.7°C) indicating the continuation of seasonal warming noted in late August (Table 9). The temperature trend for September was an overall increase at all sites particularly during the last two weeks of September (Figures 16 and 17).

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during September 2019.
Values are means ± se (n = 138 to 2881).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	10.6 ± 0.0	–
UH2	10.5 ± 0.0	–
CH1	10.5 ± 0.0	–
CH2	10.4 ± 0.0	–
SG1	10.3 ± 0.0	–
SG2	10.3 ± 0.0	–
SG3	10.3 ± 0.0	–
OS1	10.4 ± 0.0	10.3 ± 0.0
OS2	10.3 ± 0.0	10.1 ± 0.0
OS3	10.2 ± 0.0	10.0 ± 0.0
OS4	10.1 ± 0.0	10.0 ± 0.0
OS5	10.3 ± 0.0	–
OS6	10.3 ± 0.0	9.6 ± 0.0
OS7	10.3 ± 0.0	–

In contrast to August and the previous winter trend, slightly warmer temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites during September. 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 lower than the overlying surface waters and displayed the same surface trends indicating a well-mixed water column.

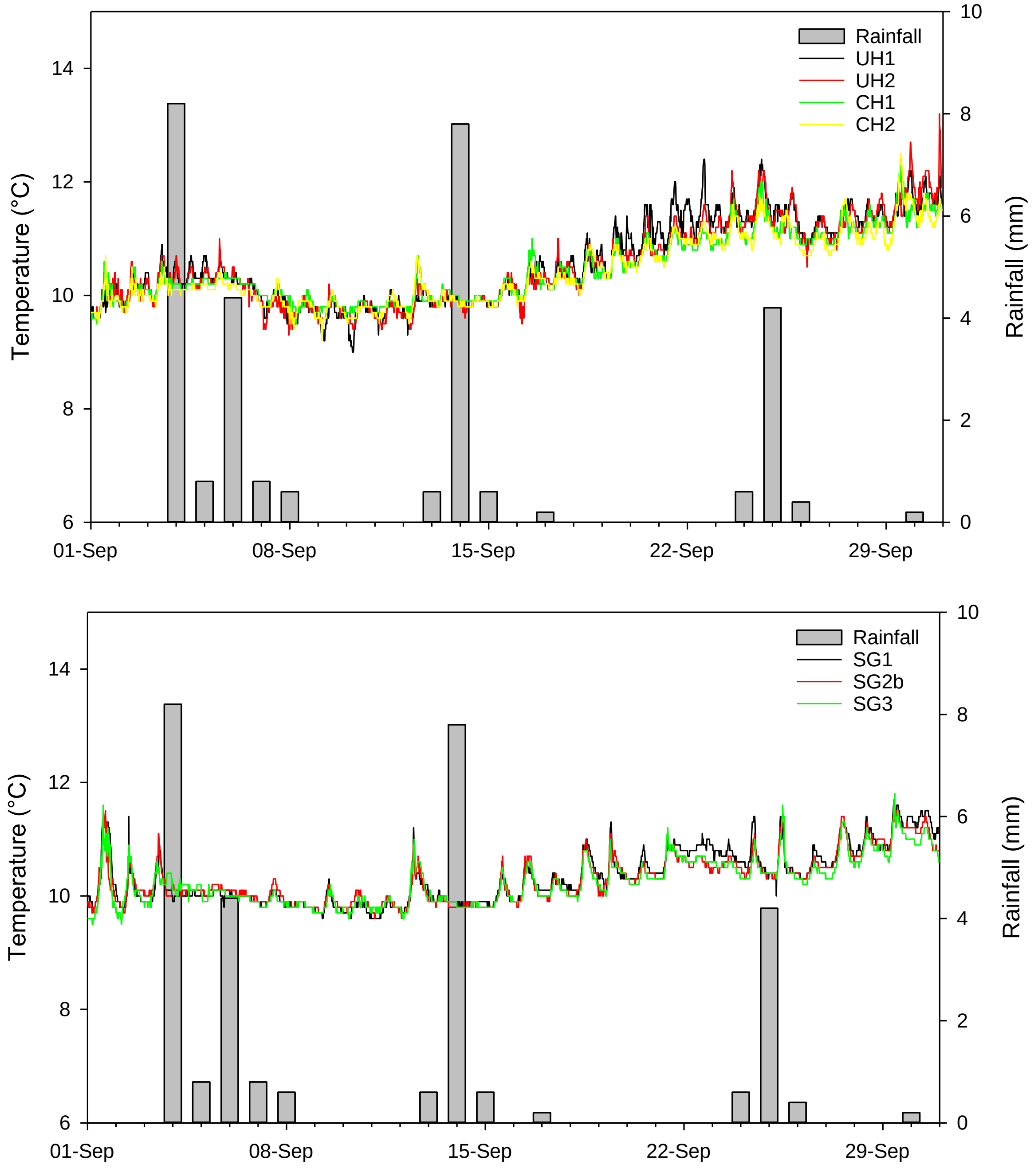


Figure 16 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during September 2019.

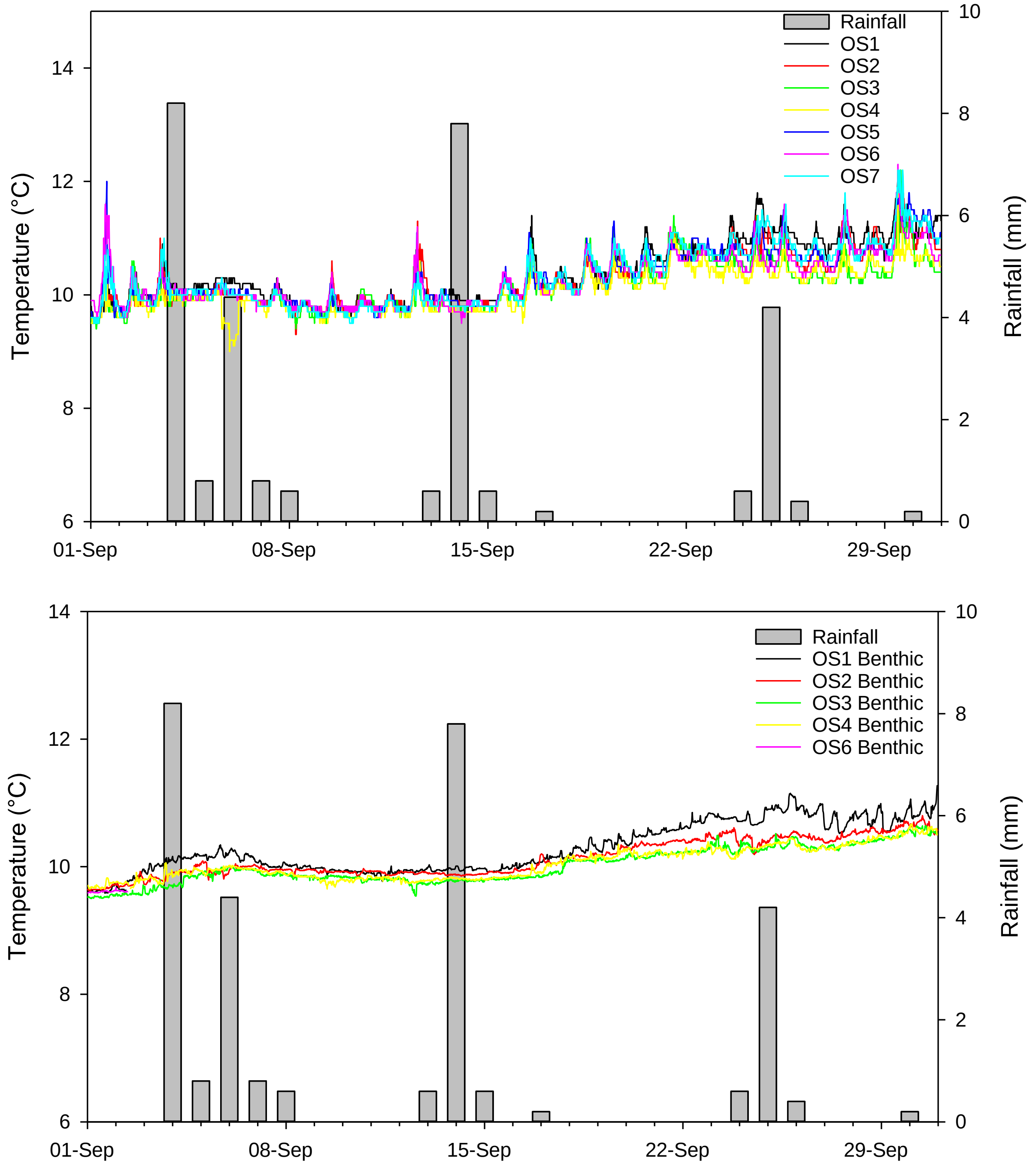


Figure 17 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during September 2019.

3.2.4 pH

The pH remained reasonably consistent across surface and benthic sites, with monthly means ranging between 7.8 and 8.2 (Table 10, Figures 18 and 19).

Some post calibration issues have been encountered with pH probes during March to September 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 September 2019. *Values are means ± se (n = 138 to 2881).*

Site	pH	
	Surface loggers	Benthic loggers
UH1	8.0 ± 0.0	–
UH2	8.2 ± 0.0	–
CH1	8.0 ± 0.0	–
CH2	8.1 ± 0.0	–
SG1	8.2 ± 0.0	–
SG2	8.2 ± 0.0	–
SG3	8.1 ± 0.0	–
OS1	8.1 ± 0.0	7.8 ± 0.0
OS2	8.1 ± 0.0	8.2 ± 0.0
OS3	8.0 ± 0.0	8.1 ± 0.0
OS4	8.2 ± 0.0	8.1 ± 0.0
OS5	8.1 ± 0.0	–
OS6	8.2 ± 0.0	8.0 ± 0.0
OS7	8.2 ± 0.0	–

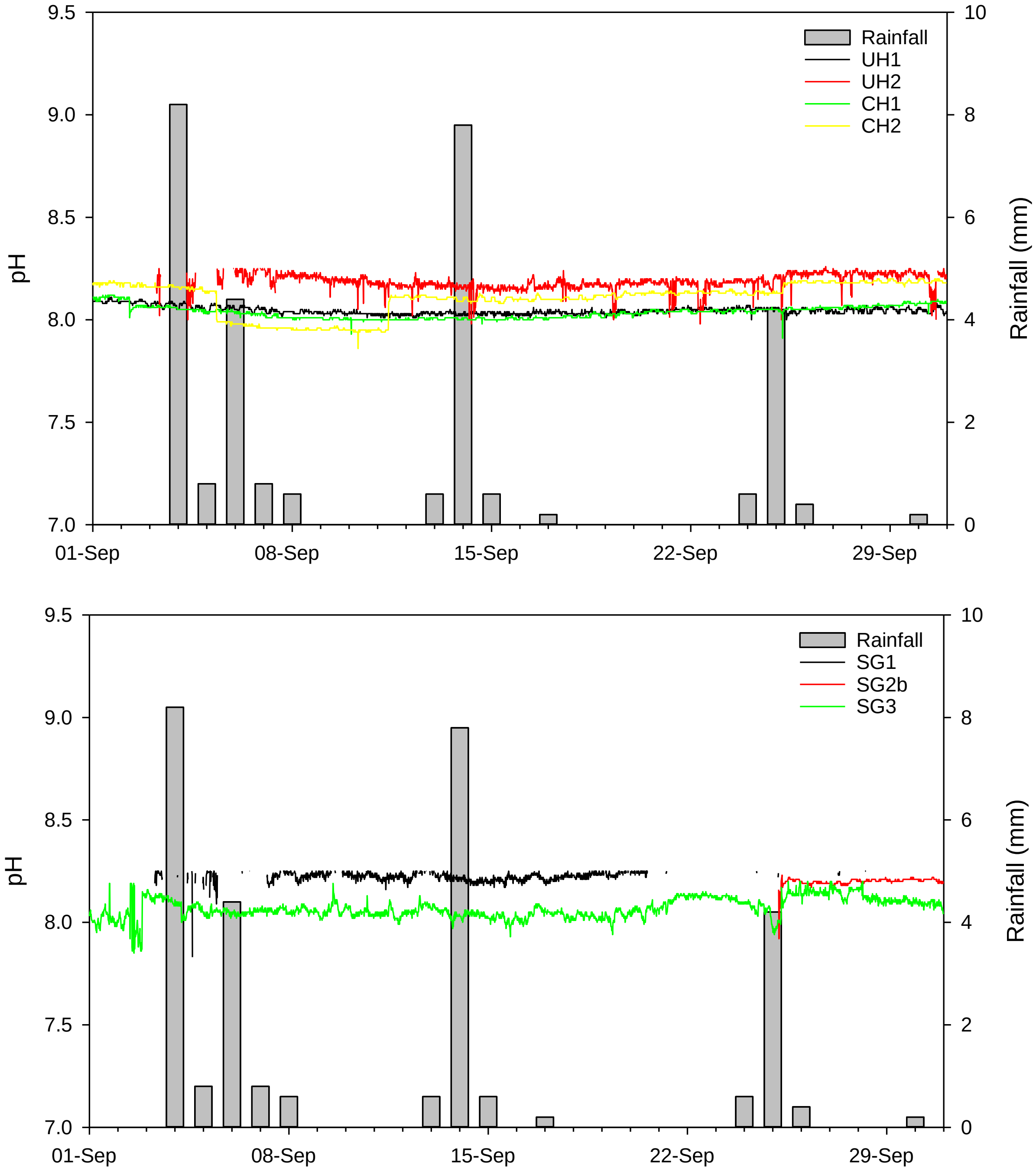


Figure 18 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during September 2019.

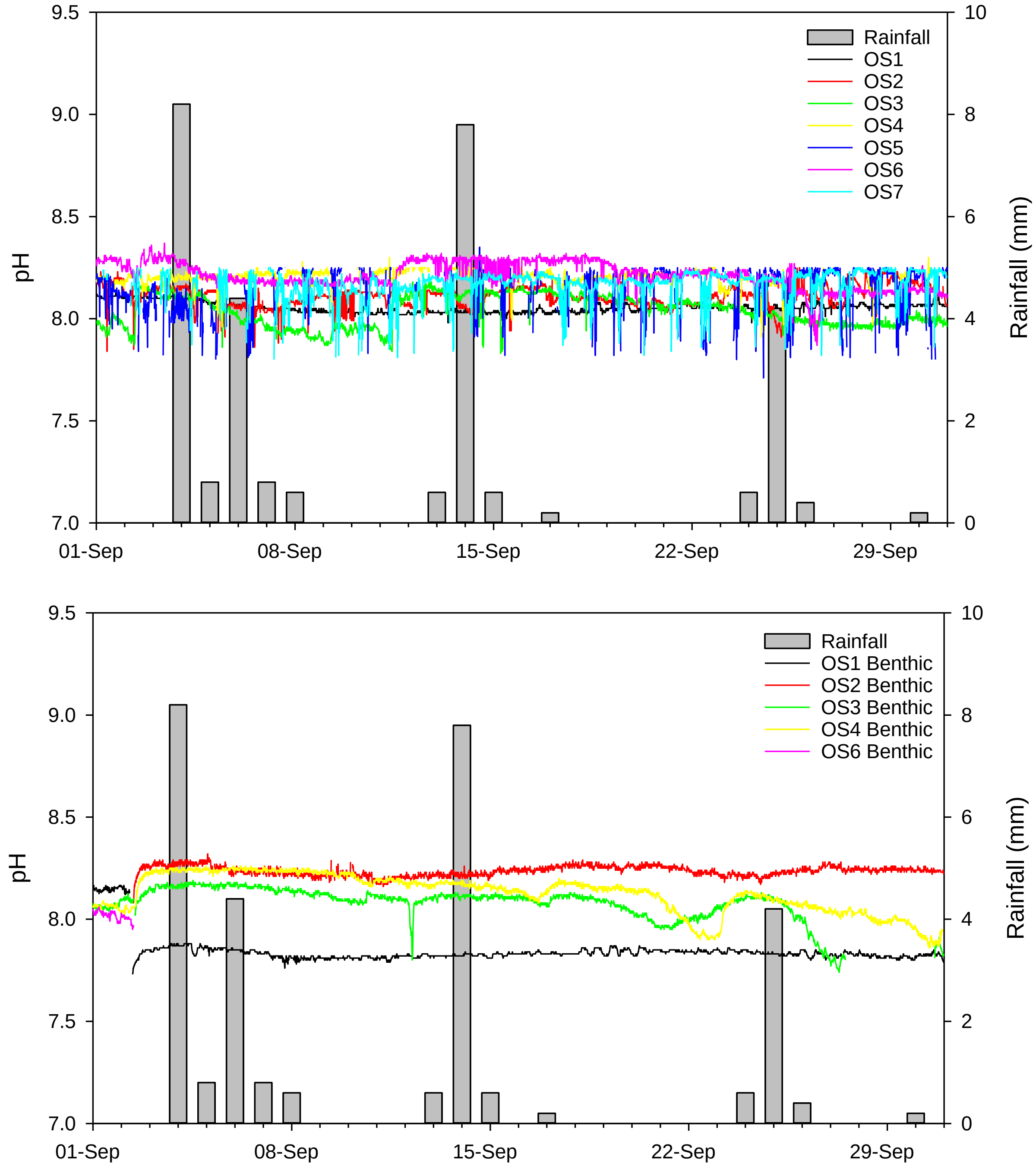


Figure 19 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during September 2019.

3.2.5 Conductivity

Surface conductivity in September ranged from 50.8 mS/cm to 54.9 mS/cm (Table 11, Figure 20 and 21), with benthic conductivity at similar levels, ranging from 51.4 mS/cm to 55.1 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 September 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 September 2019.
Values are means ± se (n = 138 to 2881).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	50.8 ± 0.0	–
UH2	52.5 ± 0.0	–
CH1	51.5 ± 0.0	–
CH2	52.0 ± 0.0	–
SG1	54.8 ± 0.0	–
SG2	52.9 ± 0.0	–
SG3	54.1 ± 0.0	–
OS1	51.4 ± 0.0	54.0 ± 0.0
OS2	53.5 ± 0.0	53.5 ± 0.0
OS3	54.1 ± 0.0	55.1 ± 0.0
OS4	54.9 ± 0.0	54.2 ± 0.0
OS5	53.9 ± 0.0	–
OS6	53.8 ± 0.0	51.4 ± 0.0
OS7	53.2 ± 0.0	–

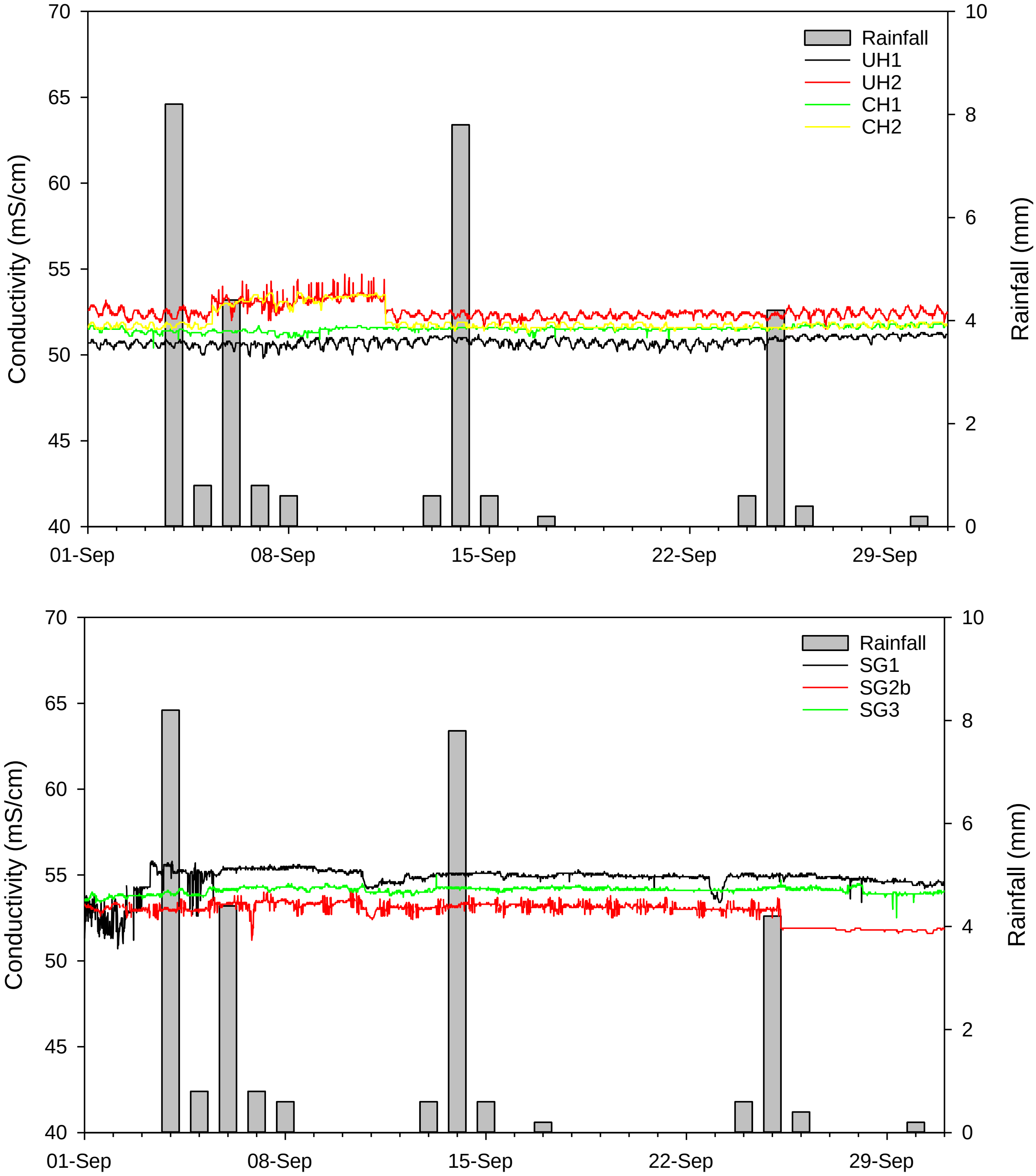


Figure 20 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during September 2019.

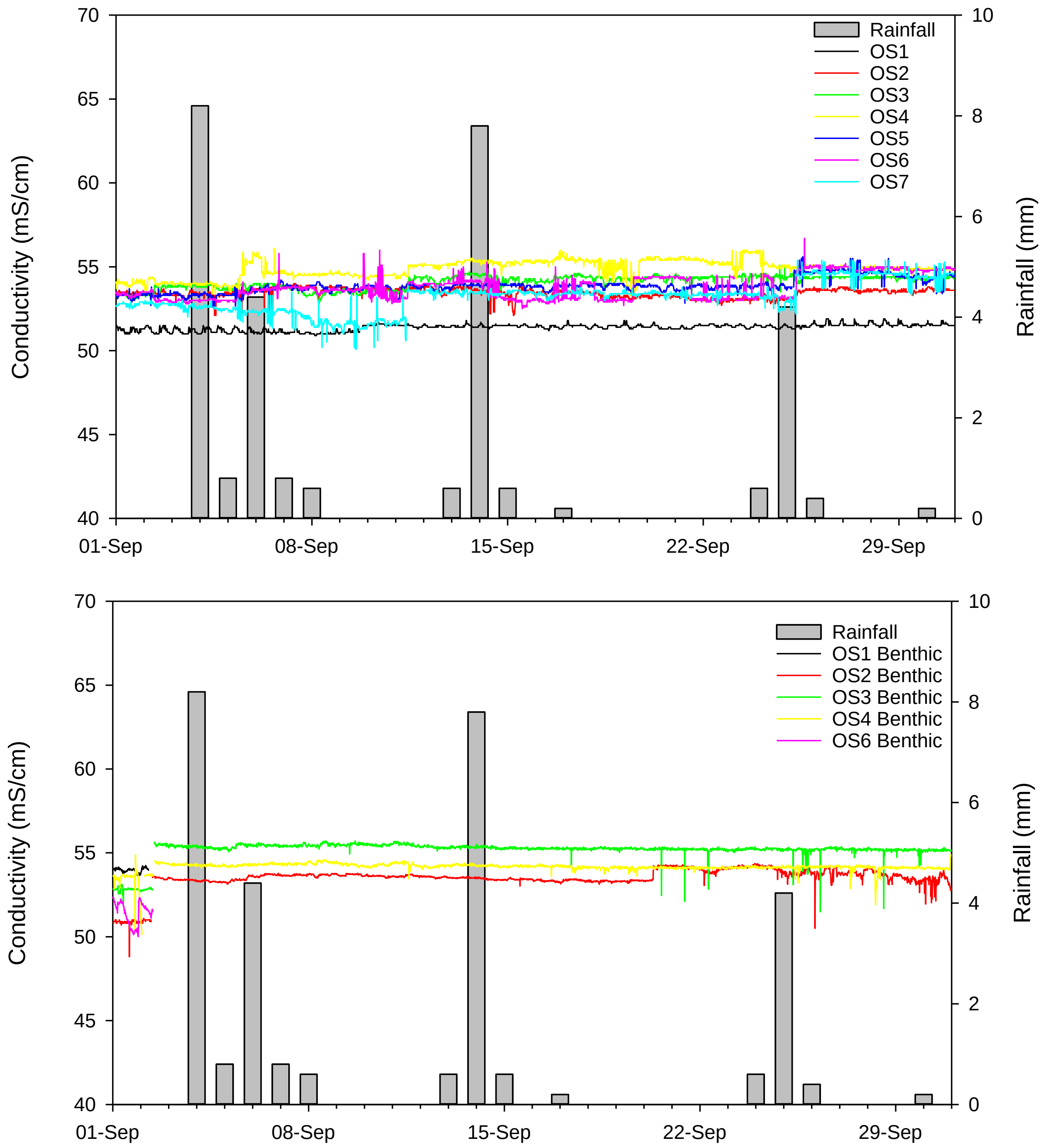


Figure 21 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during September 2019.

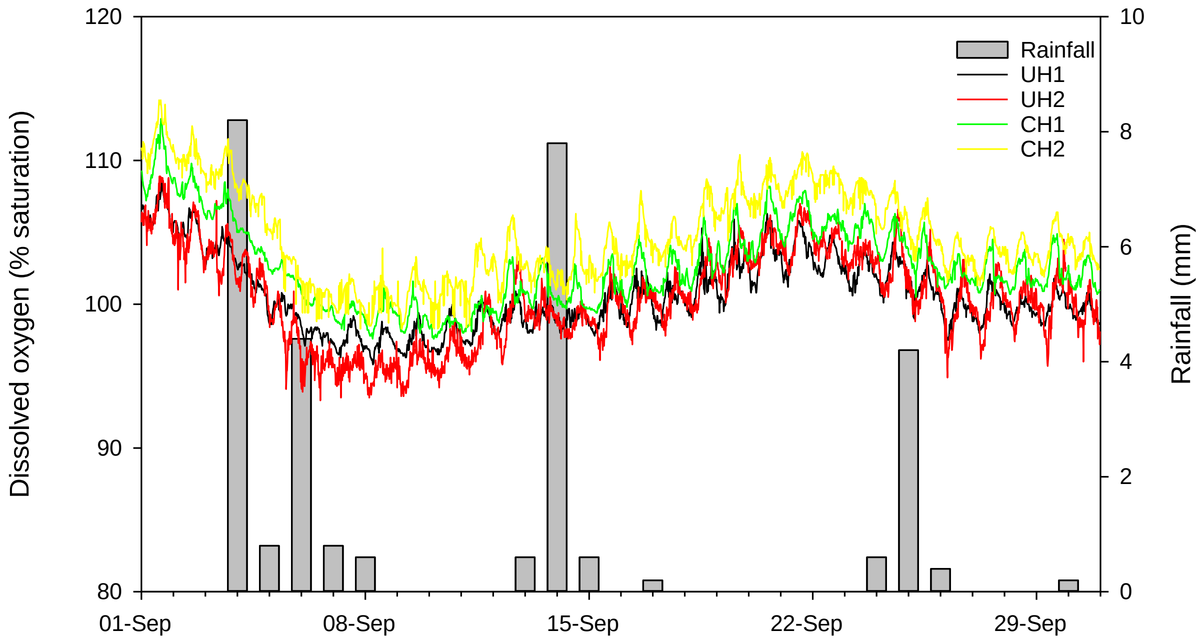
3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in September ranged from 97 to 107% saturation. Concentrations decreased from the previous months higher DO concentrations until the 8 September where concentrations then gradually regained to 22 September before declining again in concentrations for the remainder of September, concurrently with water 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 96 to 98% saturation (Table 12, Figures 22 and 23), indicative of lower photosynthesis at the benthos. Benthic DO however displayed a similar pattern to surface cohorts.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during September 2019.
Values are means ± se (n = 138 to 2881).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	101 ± 0	–
UH2	100 ± 0	–
CH1	103 ± 0	–
CH2	105 ± 0	–
SG1	107 ± 0	–
SG2	105 ± 0	–
SG3	102 ± 0	–
OS1	102 ± 0	98 ± 0
OS2	97 ± 0	96 ± 0
OS3	102 ± 0	98 ± 0
OS4	99 ± 0	98 ± 0
OS5	101 ± 0	–
OS6	103 ± 0	96 ± 0
OS7	103 ± 0	–



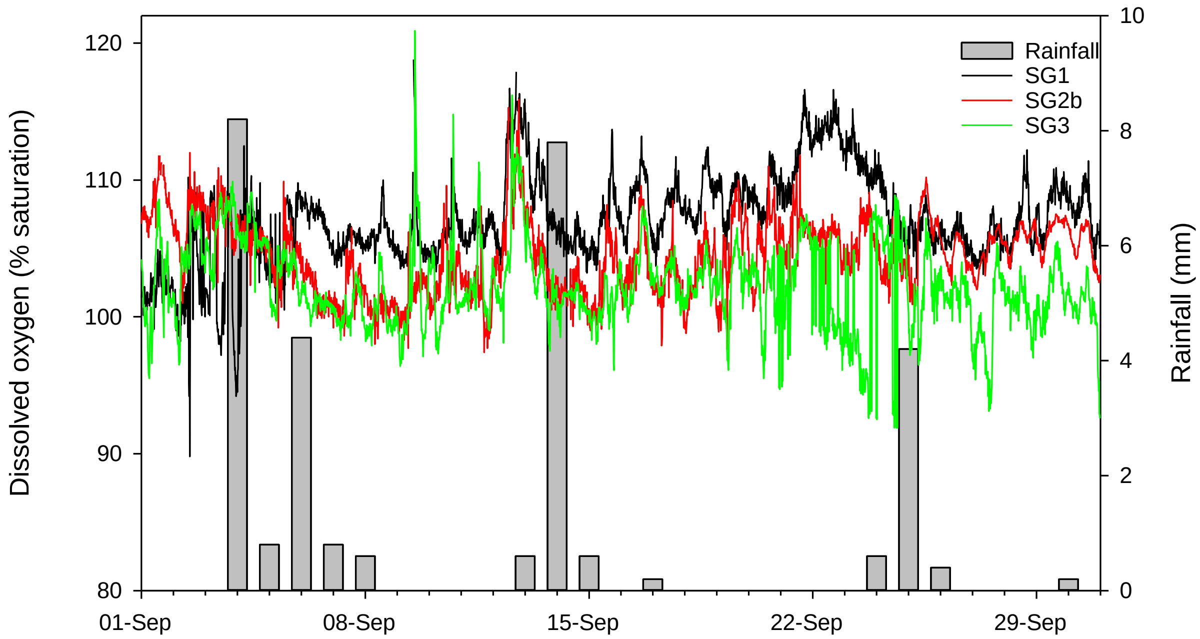
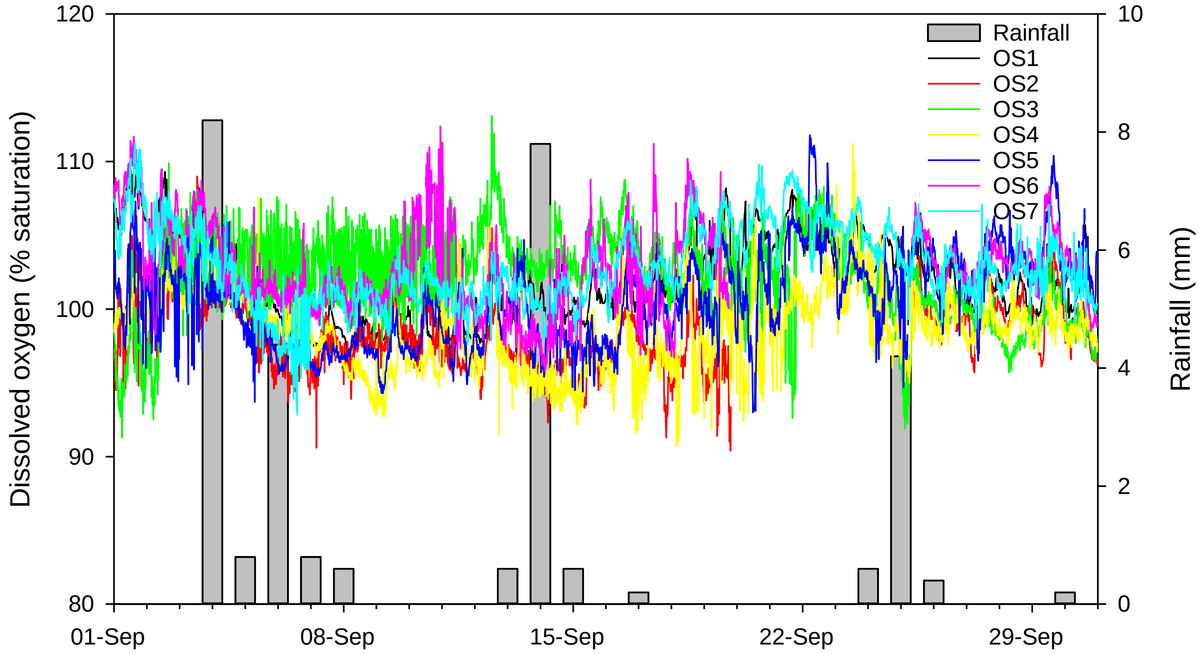


Figure 22 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during September 2019.



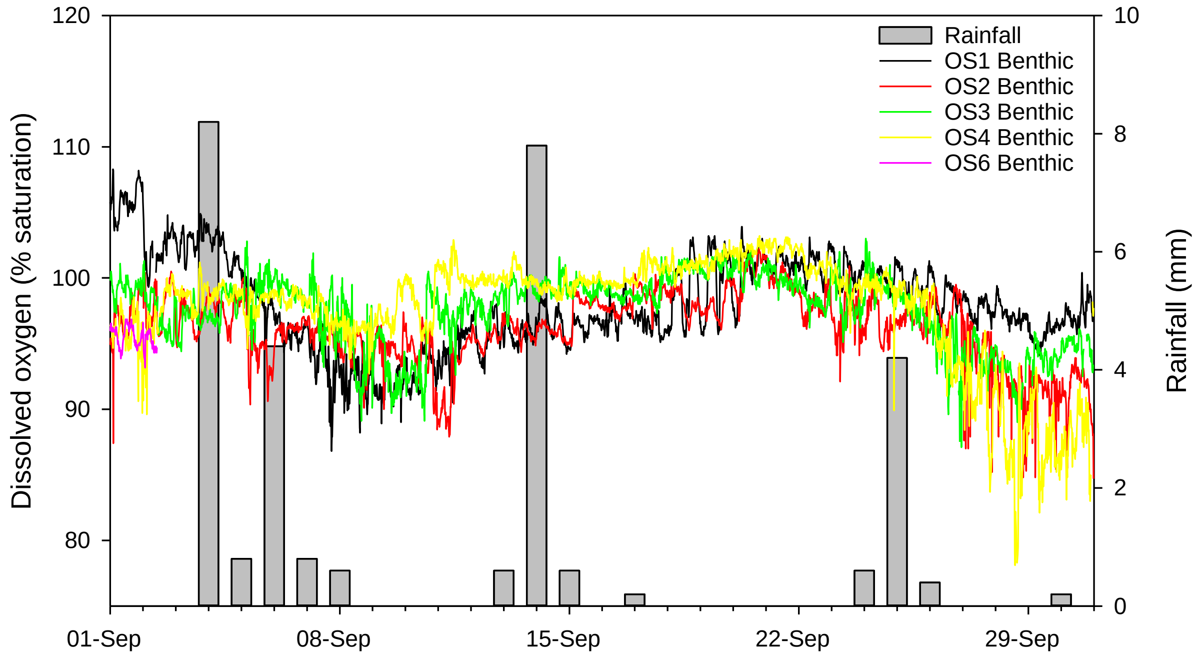


Figure 23 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during September 2019.

3.3 Physicochemistry Depth Profiling & TSS

Vertical depth profiling of the whole water column at each monitoring site was conducted in conjunction with monthly discrete water sampling on 5 September 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 conductivity, pH and dissolved oxygen within the harbour and higher temperature. 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. In contrast OS3 displayed an increase in DO and a decrease in turbidity at 7m then reversed concentrations again at 14 m, suggesting a different body of water at this 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 4.3 m occurred within upper harbour monitoring sites UH1 and UH2 (Table 13), which reflects the typically higher levels of turbidity experienced in this area (Figure 24). No K_d or euphotic depth is reported for CH1 due to data being deemed unacceptable (Table 13). The deepest euphotic depth was calculated to be 12.3 m at SG1 and SG2 (Table 15) where turbidity in the surface and mid-column was low. Turbidity slightly exceeded the WQG (10 NTU) at CH1 within the sub-surface layer (10.3 NTU) and is reflected within the high TSS sample (20 mg/L), possibly due to the sample being taken later in the day after wind speeds increased, in comparison to the other inshore sites that were sampled in the morning (Table 13). No other exceedances of WQG were recorded at the sub-surface during the September vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the September 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, n = 22 to 40 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.* Note no K_d or euphotic depth available due to meter malfunction.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
UH1	05/09/2019 09:02	Sub-surface	10.2 ± 0	8 ± 0	50.7 ± 0	100 ± 0	6.8 ± 0.1	10	1.1 ± 0.1	4.3
		Whole column	10.1 ± 0.2	8 ± 0	50.8 ± 0	100 ± 0	7.9 ± 0.3	–		
UH2	05/09/2019 09:39	Sub-surface	10 ± 0	8 ± 0	51.1 ± 0	101 ± 0	7.6 ± 0.1	3	1.1 ± 0	4.3
		Whole column	10 ± 0.2	8 ± 0	51.1 ± 0	101 ± 0	7.7 ± 0.1	–		
UH3	05/09/2019 09:19	Sub-surface	10.1 ± 0	8 ± 0	50.8 ± 0.1	100 ± 0	6 ± 0.2	13	0.9 ± 0.1	5.0
		Whole column	10.1 ± 0.2	8 ± 0	50.8 ± 0	100 ± 0	6 ± 0.1	–		
CH1	05/09/2019 15:29	Sub-surface	10.1 ± 0	8.1 ± 0	51 ± 0	101 ± 0	10.3 ± 0.1	20	–*	–*
		Whole column	10.1 ± 0.2	8.1 ± 0	51 ± 0	101 ± 0	13.1 ± 1.2	–		
CH2	05/09/2019 10:07	Sub-surface	9.9 ± 0	8.1 ± 0	51.4 ± 0	103 ± 0	6.3 ± 0	12	1 ± 0	4.8
		Whole column	9.9 ± 0.1	8.1 ± 0	51.4 ± 0	103 ± 0	7.3 ± 0.3	–		
WQG			–	**7.0 – 8.5**	–	**80 – 110**	**10**	–	–	–

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the September 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 31 to 40 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS1	05/09/2019 15:01	Sub-surface	10.1 ± 0	8.1 ± 0	51.3 ± 0	102 ± 0	9 ± 0.1	12	0.7 ± 0.1	6.6
		Mid	10.1 ± 0	8.1 ± 0	51.3 ± 0	102 ± 0	9.7 ± 0.2	22		
		Benthos	10 ± 0	8.1 ± 0	51.3 ± 0	102 ± 0	22.9 ± 5.2	43		
		Whole column	10.1 ± 0.2	8.1 ± 0	51.3 ± 0	102 ± 0	12.1 ± 1.4	–		
OS2	05/09/2019 10:53	Sub-surface	9.9 ± 0	8 ± 0	51.6 ± 0	100 ± 0	5.5 ± 0.1	6	0.9 ± 0	5.1
		Mid	9.8 ± 0	8 ± 0	51.6 ± 0	101 ± 0	9.6 ± 0.3	8		
		Benthos	9.7 ± 0	8 ± 0	51.8 ± 0	99 ± 0	24.4 ± 1.2	11		
		Whole column	9.8 ± 0.2	8 ± 0	51.6 ± 0	100 ± 0	11.8 ± 1.3	–		
OS3	05/09/2019 11:37	Sub-surface	9.9 ± 0	8 ± 0	51.8 ± 0	101 ± 0	11.5 ± 0.1	24	0.9 ± 0.1	5.1
		Mid	9.8 ± 0	8 ± 0	51.9 ± 0	102 ± 0	8 ± 1.2	27		
		Benthos	9.9 ± 0	8 ± 0	52.1 ± 0	105 ± 0	5.5 ± 2.8	5		
		Whole column	9.8 ± 0.2	8 ± 0	51.9 ± 0	102 ± 0	8.4 ± 0.7	–		
OS4	05/09/2019 12:13	Sub-surface	9.9 ± 0	8 ± 0	51.9 ± 0	102 ± 0	9.2 ± 0.2	5	1 ± 0.1	4.7
		Mid	9.8 ± 0	8 ± 0	52 ± 0	101 ± 0	8.7 ± 0.1	7		
		Benthos	9.8 ± 0	8 ± 0	52 ± 0	100 ± 0	36.2 ± 13.1	< 3		
		Whole column	9.9 ± 0.1	8 ± 0	52 ± 0	101 ± 0	13.6 ± 2.4	-		
OS7	05/09/2019 10:33	Sub-surface	9.9 ± 0	8.1 ± 0	51.6 ± 0	102 ± 0	4.1 ± 0.1	7	0.7 ± 0	6.3
		Mid	9.8 ± 0	8.1 ± 0	51.6 ± 0	102 ± 0	4.2 ± 0.1	8		
		Benthos	9.8 ± 0	8 ± 0	51.6 ± 0	101 ± 0	11.3 ± 2.8	< 3		
		Whole column	9.8 ± 0.2	8.1 ± 0	51.6 ± 0	102 ± 0	5.6 ± 0.6	–		
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 September 2019 sampling event.
Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 36 to 44 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS5	05/09/2019 14:34	Sub-surface	10 ± 0	8.1 ± 0	51.4 ± 0	102 ± 0	7 ± 0.1	11	1 ± 0.1	4.7
		Mid	9.9 ± 0	8.1 ± 0	51.5 ± 0	102 ± 0	5.8 ± 0.1	< 3		
		Benthos	9.9 ± 0	8.1 ± 0	51.7 ± 0	102 ± 0	4.1 ± 0.1	4		
		Whole column	9.9 ± 0.2	8.1 ± 0	51.5 ± 0	102 ± 0	6 ± 0.2	–		
OS6	05/09/2019 11:16	Sub-surface	9.9 ± 0	8 ± 0	51.9 ± 0	103 ± 0	2.4 ± 0.1	5	0.4 ± 0	11.0
		Mid	9.8 ± 0	8 ± 0	51.9 ± 0	102 ± 0	2.1 ± 0	8		
		Benthos	9.5 ± 0	8 ± 0	52.1 ± 0	95 ± 1	29.2 ± 14	4		
		Whole column	9.8 ± 0.1	8 ± 0	51.9 ± 0	101 ± 0	6.1 ± 2.3	–		
SG1	05/09/2019 13:56	Sub-surface	9.9 ± 0	8.1 ± 0	51.7 ± 0	104 ± 0	2 ± 0	< 3	0.4 ± 0	12.3
		Mid	9.8 ± 0	8.1 ± 0	51.8 ± 0	104 ± 0	2.1 ± 0	31		
		Benthos	9.6 ± 0	8 ± 0	51.9 ± 0	99 ± 1	17.9 ± 13	25		
		Whole column	9.8 ± 0.1	8.1 ± 0	51.8 ± 0	103 ± 0	4.5 ± 1.9	–		
SG2	05/09/2019 13:22	Sub-surface	10 ± 0	8.1 ± 0	52 ± 0	106 ± 0	1.7 ± 0	< 3	0.4 ± 0	12.3
		Mid	9.9 ± 0	8 ± 0	52.1 ± 0	105 ± 0	1.9 ± 0.1	101		
		Benthos	9.5 ± 0	8 ± 0	52.1 ± 0	94 ± 0	17.2 ± 3.9	37		
		Whole column	9.8 ± 0.1	8 ± 0	52.1 ± 0	103 ± 1	4.3 ± 0.9	–		
SG3	05/09/2019 12:51	Sub-surface	9.9 ± 0	8.1 ± 0	52.1 ± 0	106 ± 0	1.6 ± 0	< 3	0.4 ± 0	10.9
		Mid	9.8 ± 0	8 ± 0	52.2 ± 0	105 ± 0	1.8 ± 0.1	33		
		Benthos	9.8 ± 0	8 ± 0	52.2 ± 0	102 ± 0	10.2 ± 3.6	11		
		Whole column	9.8 ± 0.1	8 ± 0	52.2 ± 0	105 ± 0	3.7 ± 0.7	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	

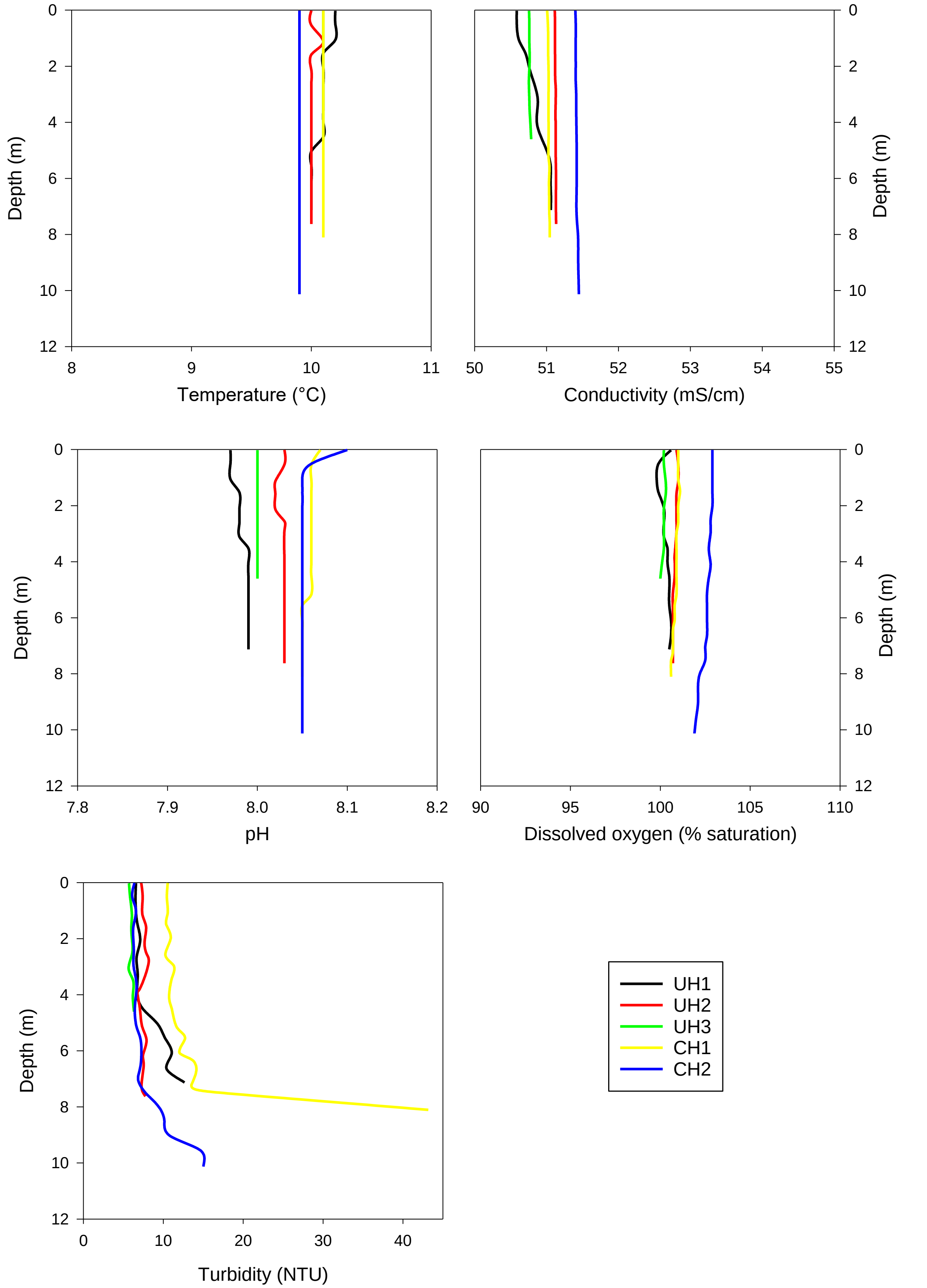


Figure 24 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 5 September 2019.

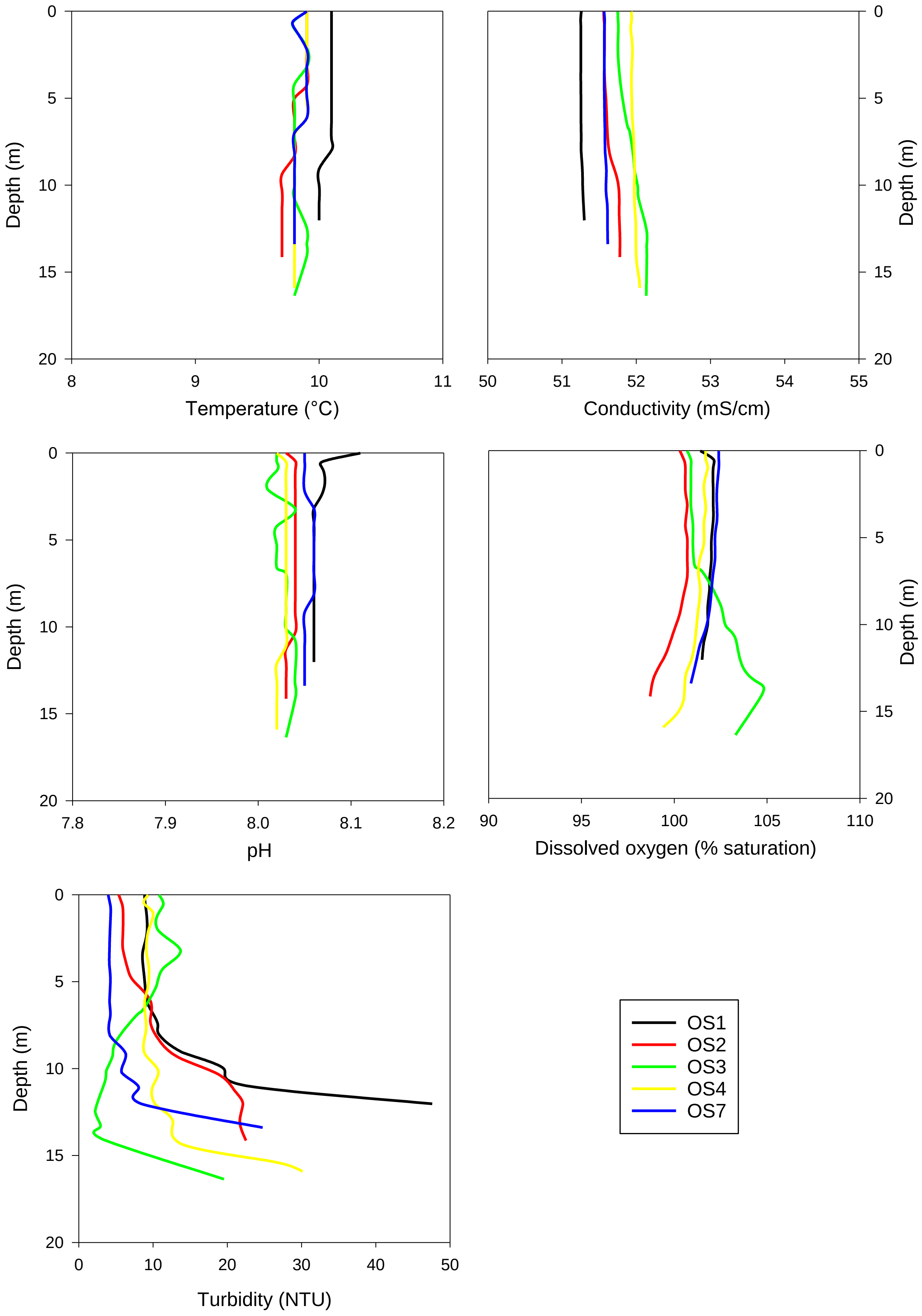


Figure 25 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 5 September 2019.

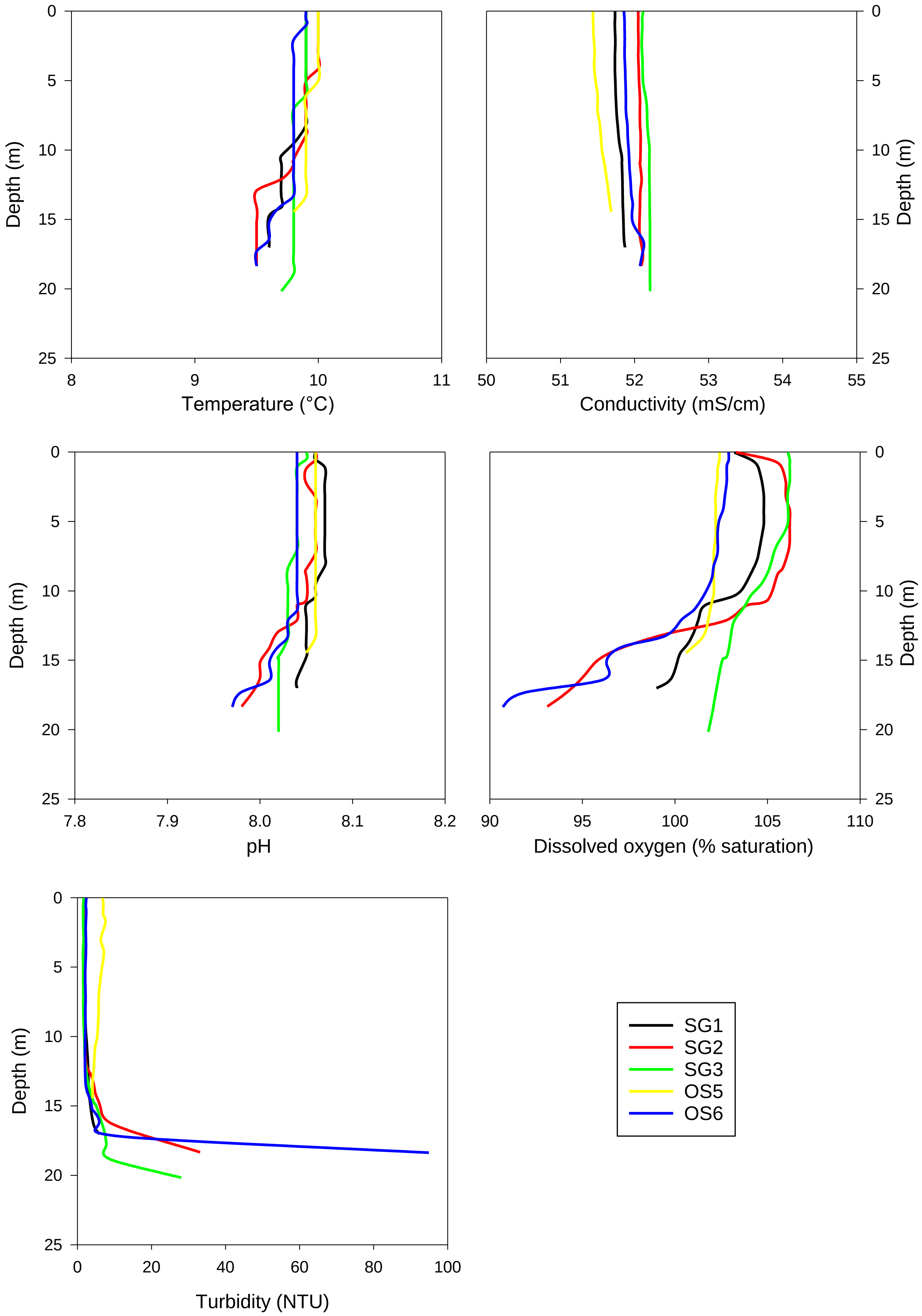


Figure 26 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 5 September 2019.

3.4 Continuous BPAR Loggers

Benthic PAR, or the amount of light reaching the benthos that can be utilised for photosynthesis, was measured at two offshore sites (OS2 and OS3) by autonomous dual PAR Odyssey loggers. Benthic PAR was compared to ambient PAR measured by telemetered loggers located at the Vision Environment office in Christchurch (Vision Base Christchurch, VBCC) in order to account for variations in daily light intensity such as those induced by cloud cover.

Further information on the specific methodology used in BPAR measurements can be obtained from the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

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

Table 16 Total Daily PAR (TDP) statistics during September 2019.
Values are means ± se (n = 29 to 30). Note data from the BPAR exchange day on 2 September were not utilised in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m^2/day)		
		Mean ± se	Median	Range
Base	-	18,813 ± 1,143	19,350	4,600 – 29,600
OS2	17	1,324 ± 348	205	<0.01 – 6342
OS3	14	1,305 ± 342	653	<0.01 – 6400

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 4,600 to 29,600 mmol/m^2/day (Table 16), higher than the range recorded during August (3,700 to 20,600 mmol/m^2/day). The increase in ambient TDP is likely associated with the increased day lengths from August to September, in addition to the slightly lower rainfall and associated cloud cover during the latter month.

Mean BPAR at both OS2 and OS3 also increased in September (1,324 and 1,305 mmol/m^2/day respectively) from August (194 and 138 mmol/m^2/day, respectively), most likely due to increased ambient PAR. BPAR at both OS2 and OS3 recorded a number of peaks > 2000 mmol/m^2/day in the latter half of the month when ambient PAR was reasonably high and water turbidity was low (< 5 NTU).

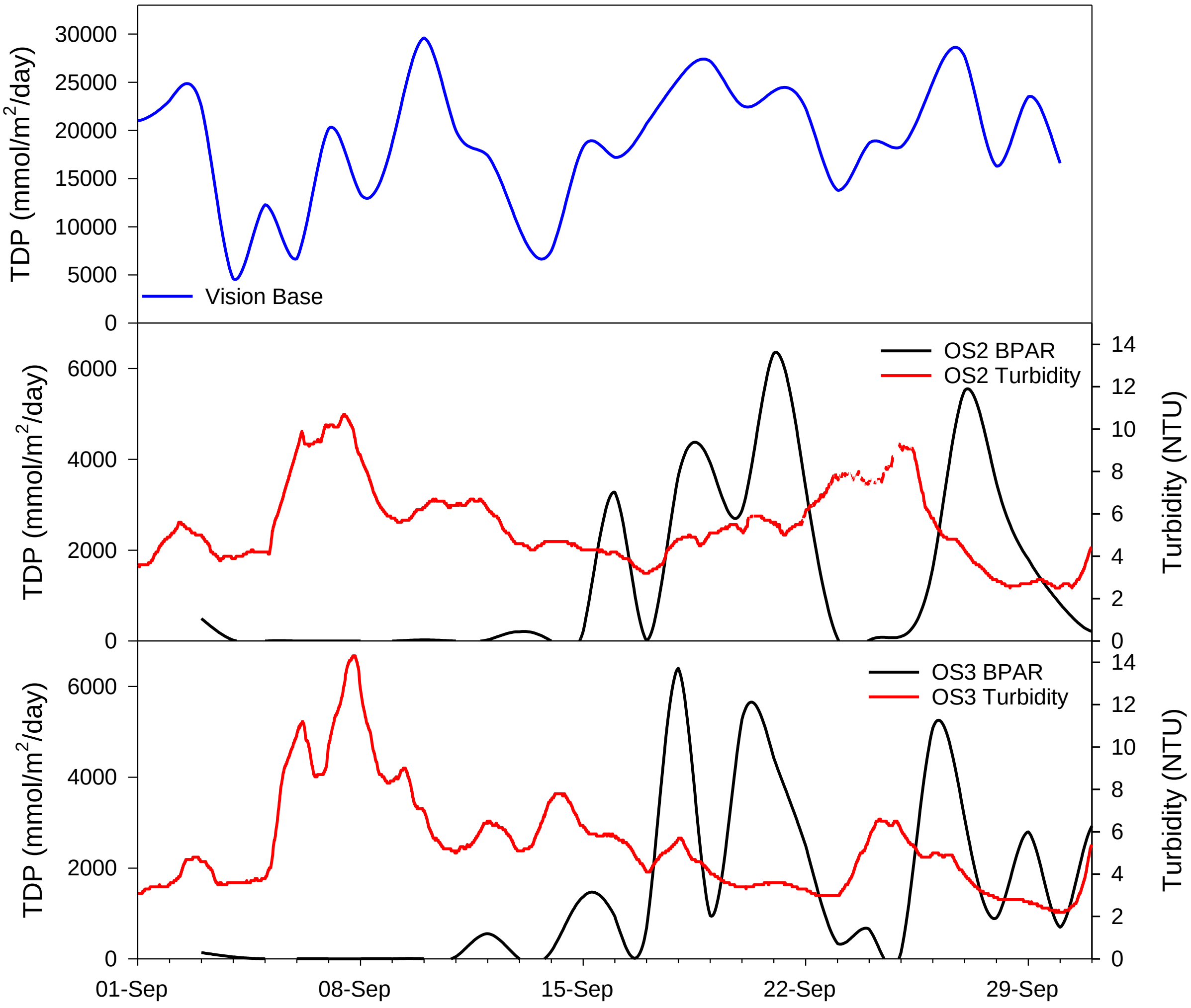


Figure 27 Total daily BPAR at OS2 and OS3 during September 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 2 September were not utilized in plots or statistics.

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.

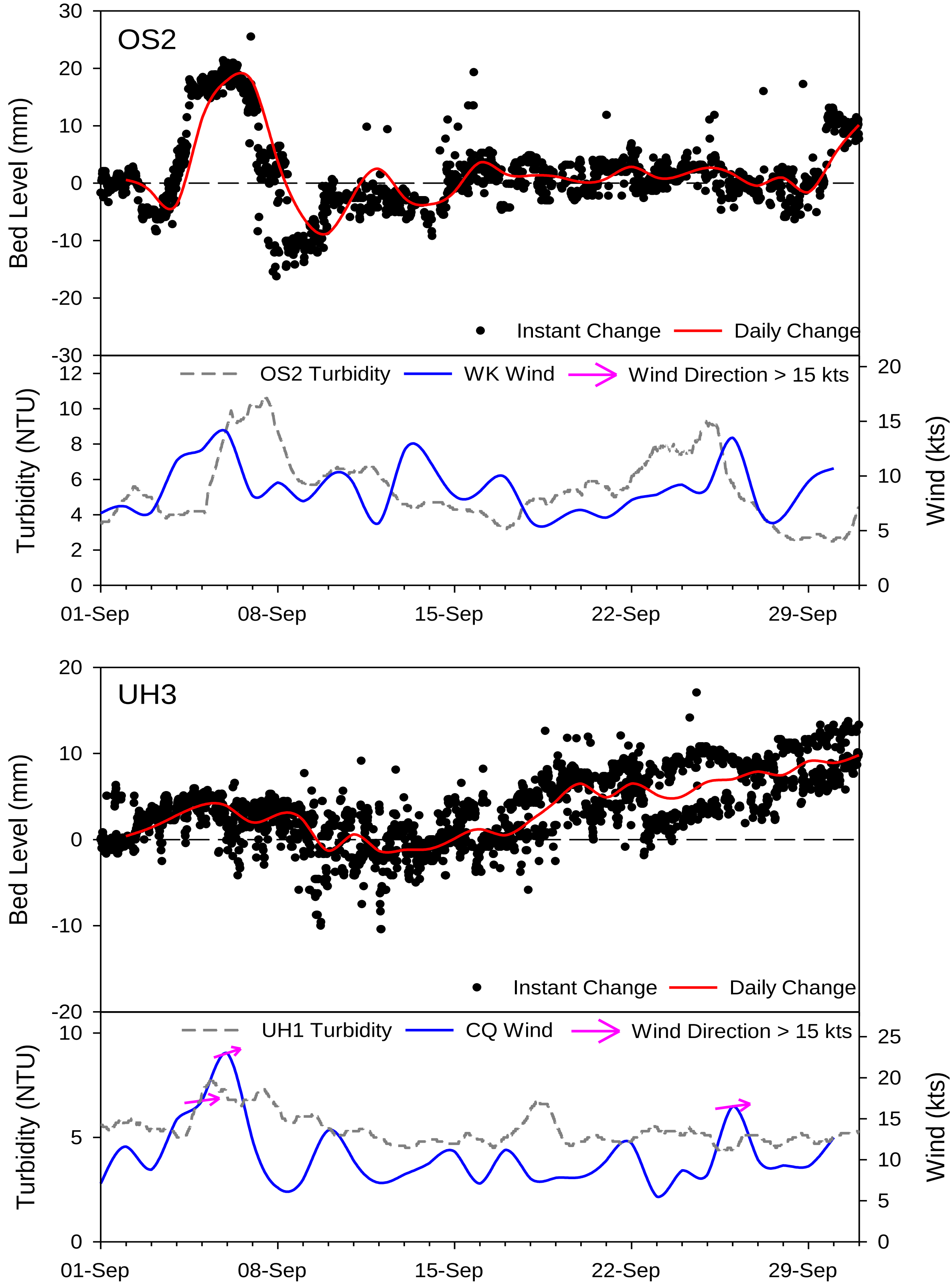


Figure 28 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during September 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction. *Note: Arrows indicate the direction of travel for winds greater than 15 knots.*

Overall, sediment accumulation was evident at the offshore site OS2 during early September, with approximately 20 mm accumulated from 3 to 6 September which was quickly followed by a period of erosion of 30 mm from 8 to 10 September following a period of moderate to high offshore winds (8 to 14 kts) from a southwest direction. Bed level then remained relatively stable until another deposition event from 29 September onwards, where an additional 13 mm of sediment was accumulated leading to an overall accumulation of 10 mm of sediment during September 2019 (Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2. Slight erosion (~ 5 mm) was apparent at UH3 following on from a period of moderate to strong inshore winds (15 to 23 kts) from a south-westerly direction, up until 13 September when slow sediment accumulation occurred for the remainder of the month. An overall accumulation of 9.8 mm was recorded in September 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 September 2019.

Site	September 2019 Net bed level change (mm)
OS2	+10
UH3	+9.8

3.6 Water Samples

Discrete water sampling was conducted on 5 September 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 a 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. Continuing on from last month, dissolved reactive phosphorous concentrations at the majority of sites were slightly above the WQG of 5 µg/L, with only SG1 reporting a value below the WQG (4.1 µg/L).

Both total nitrogen and total kjeldahl nitrogen (TKN) were < LOR at all sites, except for site UH2, where concentrations of total nitrogen (400 µg/L) exceeded the WQG.

Total ammonia ranged from 17 to 25 µg/L and like previous months all sites exceeded the WQG (15 µg/L). Within the previous months of June to August nitrogen oxide (NOx) values were high (>47 µg/L) and constantly exceeding the WQG (15 µg/L). September is the first month to see NOx values below the WQG (15 µg/L) within the inner harbor and a number of offshore sites. The spoil ground sites reported the maximum values (15.3 to 28 µg/L).

Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, was elevated at all sites ranging from 3.4 at UH2 to 7.7 at SG2, with the majority of sites exceeding the WQG (4 µg/L) (Table 18). Anecdotal evidence confirmed that a wide-reaching algal bloom was present during sampling. This is further supported by the decline in NOx likely due to being utilised by reproducing algal populations.

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during September 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	24	7.5	<300	<200	20	1.2	3.9
UH2	17	5.9	400	400	23	1.4	3.4
UH3	20	8.5	<300	<200	24	5.1	4.2
CH1	24	7.5	<300	<200	19	5.2	4.4
CH2	18	4.9	<300	<200	17	1.1	4.4
OS1	20	5.8	<300	<200	18	<1	4.3
OS2	18	6.8	<300	<200	23	4.5	3.5
OS3	26	8.4	<300	<200	24	18.3	3.5
OS4	21	8.7	<300	<200	25	26	4
OS5	21	5.3	<300	<200	17	2	4.5
OS6	18	6.4	<300	<200	18	15.8	5.6
OS7	15	5.1	<300	<200	18	7.3	4.9
SG1	15	4.1	<300	<200	17	28	5.4
SG2	18	6.2	<300	<200	18	15.3	7.7
SG3	15	7.6	<300	<200	18	23	5.7
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

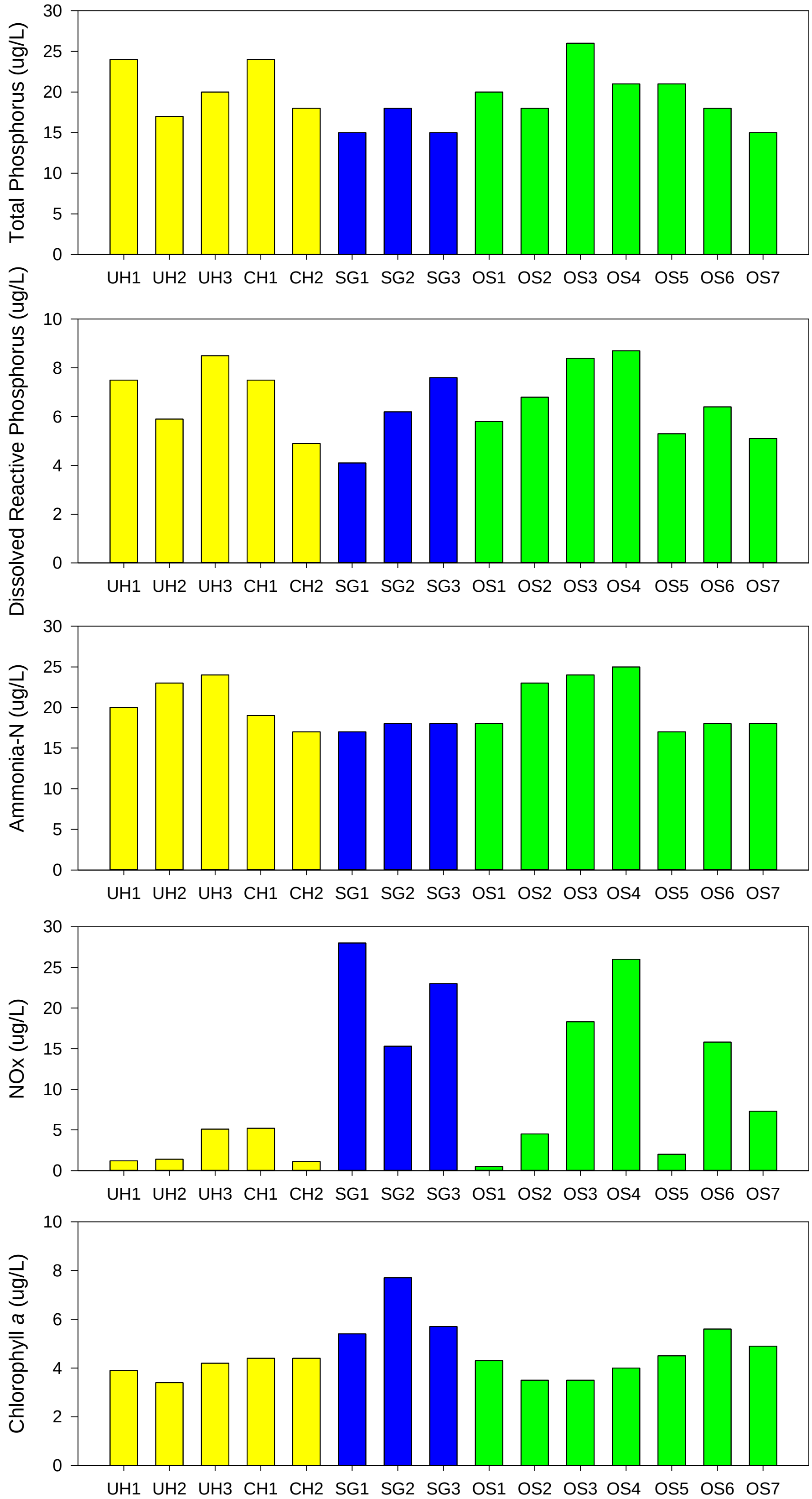


Figure 29 Nutrient and chlorophyll *a* concentrations at monitoring sites during September 2019. *Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were <LOR.*

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), lead (<1 µg/L), mercury (<0.08 µg/L), nickel (<7 µg/L), silver (<0.4 µg/L) and tin (<5 µg/L). Total and dissolved selenium was below LOR at all sites, except at OS1 where the dissolved portion reported an LOR value of 4 µg/L. Total and dissolved zinc was below LOR at all sites, except for total zinc at UH1 reporting 4.5 µg/L which was slightly above the LOR (4.2 µg/L) but below the WQG (15 µg/L). Total and dissolved copper was below the LOR at all sites, except at UH1 where dissolved copper 1.5 µg/L slightly exceeded the WQG (1.3 µg/L), however, the total fraction remained LOR.

While concentrations of total aluminium and iron were detected, dissolved concentrations of these metals were < LOR or close to the LOR, indicating limited bioavailability. Concentrations of total aluminium at all sites (27 to 490 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. Unlike previous months where offshore and spoil ground concentrations are typically similar, both total aluminium and iron appeared to be generally higher at the inshore and offshore sites (66 to 490 µg/L and 92 to 720 µg/L, respectively) with minimum concentrations at the spoil ground sites (27 to 35 µg/L and 47 to 51 µg/L, respectively). This pattern could have been exacerbated in September due to the higher concentrations of phytoplankton at the spoil ground sites absorbing the metals potentially even in their total forms.

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 3.6 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 (1.4 to 2.5 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 1.1 to 15.4 µg/L at inshore and offshore sites and were lower at spoil ground sites (<1 to 2.5 µg/L). Total and dissolved molybdenum concentrations exhibited little spatial variation, ranging from 10.3 to 11.9 µg/L, similar to previous monitoring results.

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during September 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	230	260	195	420	210	
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	2.2	2.7	3.3	2.4	1.7	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1.1	1.4	1.5	1.9	2	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	1.5	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	5	<4	7	-
	Total	380	440	310	730	340	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	4.7	3.4	5.2	4.1	2.2	-
	Total	11.9	10.5	10	15.4	8.1	
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	10.8	11	10.4	10.4	10.6	-
	Total	11.2	11.1	10.7	11.3	11	
Nickel	Dissolved	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	1.6	1.8	1.7	1.6	1.4	100
	Total	2.2	2.3	2	2.5	1.6	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	4.5	<4.2	<4.2	<4.2	<4.2	

Table 20 Total and dissolved metal concentrations at offshore monitoring sites during September 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	400	200	490	360	290	66	141	
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	1.2	1.8	2.4	1.5	1.9	2	1.9	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.4	2.2	3.6	3.2	3.2	1.8	2	
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	6	11	5	<4	<4	<4	4	-
	Total	630	280	720	570	420	92	187	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	2.7	2.3	1.5	1.1	2.3	1.3	1.9	-
	Total	13.1	6.2	12.4	9.9	9.9	2.9	5.2	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	10.3	10.8	11	11.2	10.8	10.8	11.3	-
	Total	11.6	11.2	11.7	11.1	10.7	11.7	11.3	
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	1.6	1.8	1.9	1.7	1.7	1.7	1.4	100
	Total	2.5	2.3	2.3	2.3	2.1	2	2.1	
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 September 2019.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	<12	<12	24
	Total	31	35	27	
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	1.6	1.5	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.6	2.2	1.7	
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	5	<4	-
	Total	47	51	47	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.2	<1	<1	-
	Total	2.5	1.5	<1	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	11	10.9	11.2	-
	Total	11.9	11.5	11.7	
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	1.6	1.8	1.6	100
	Total	1.5	1.8	2	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

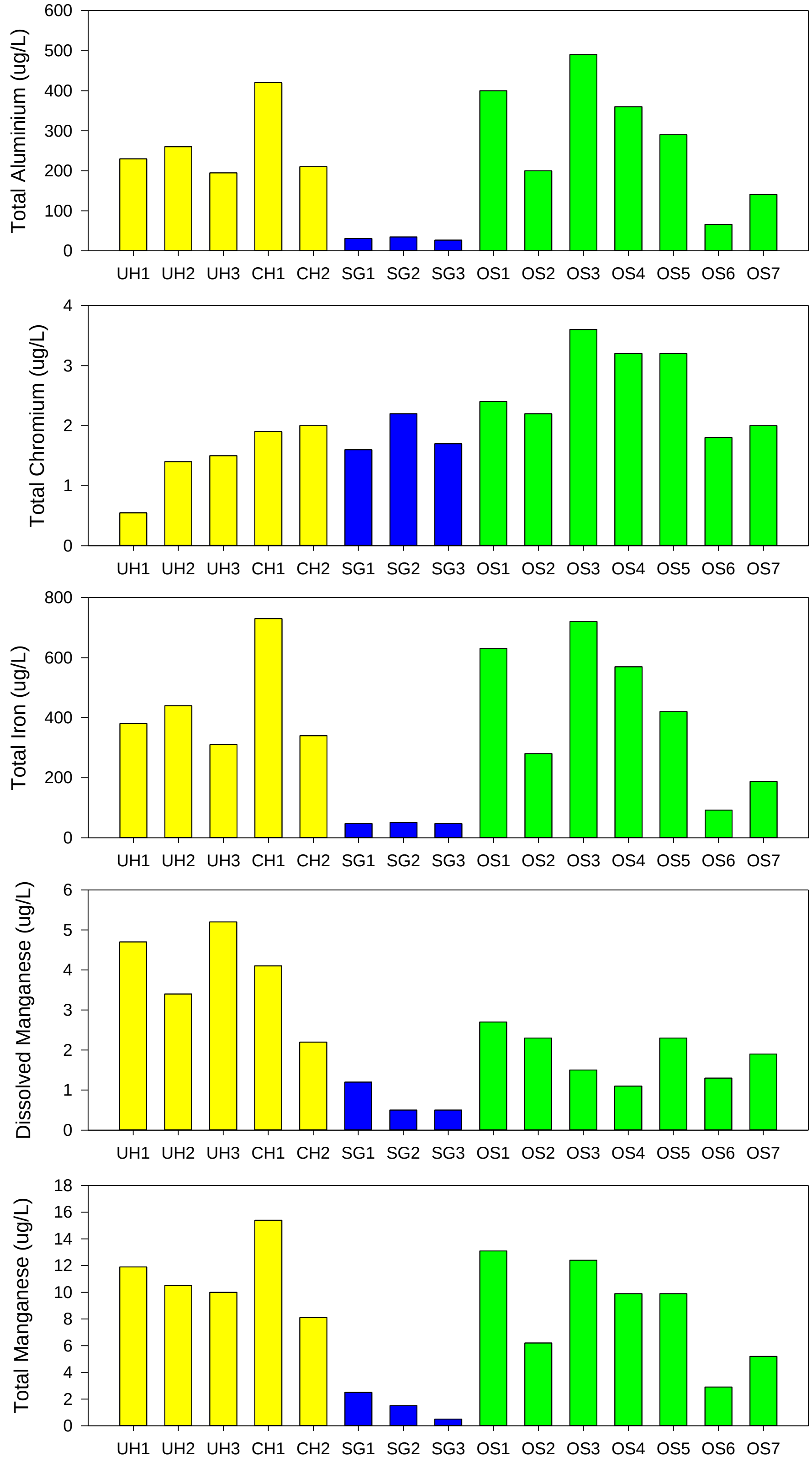


Figure 30 Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during September 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

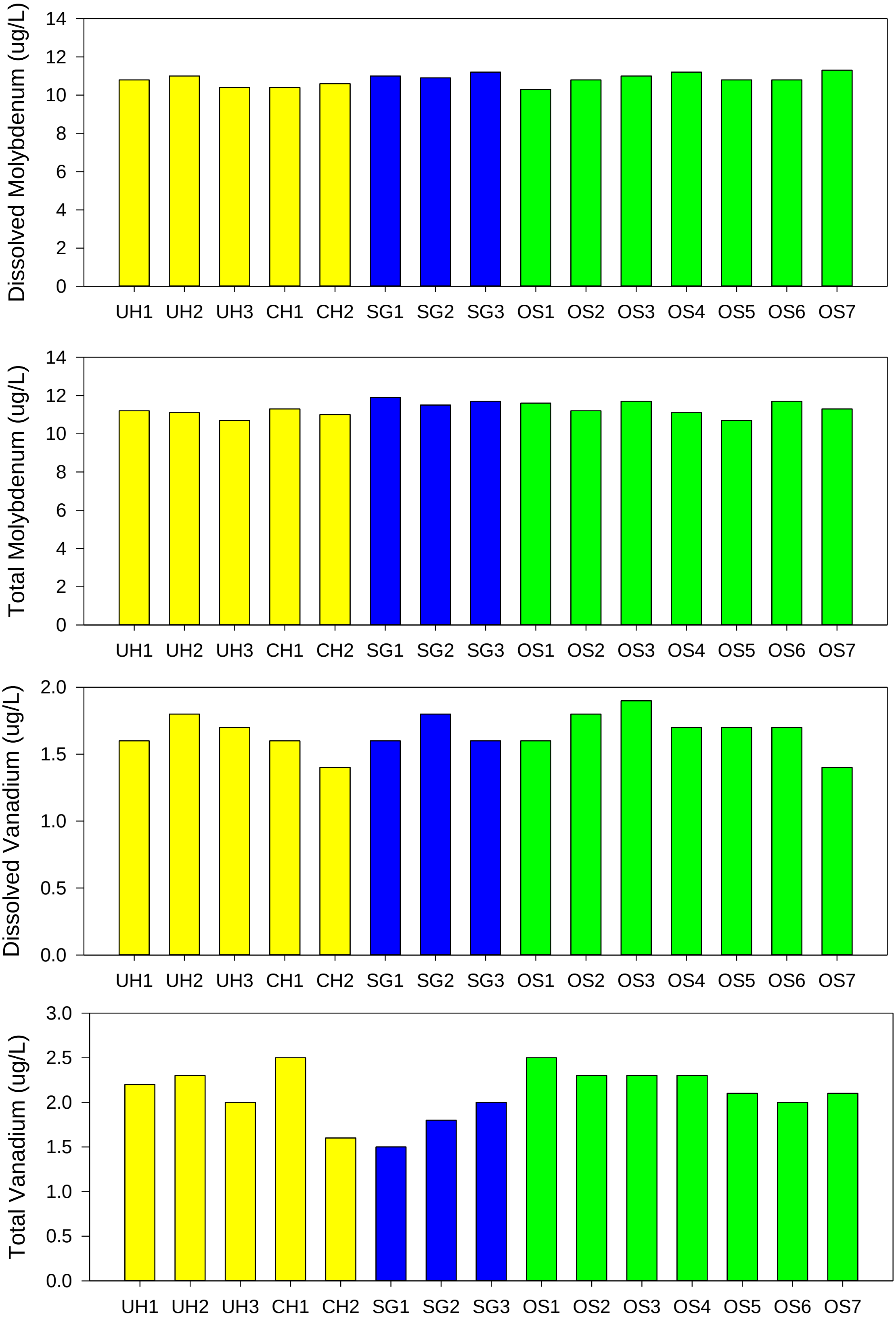


Figure 31 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during September 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

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5 APPENDIX

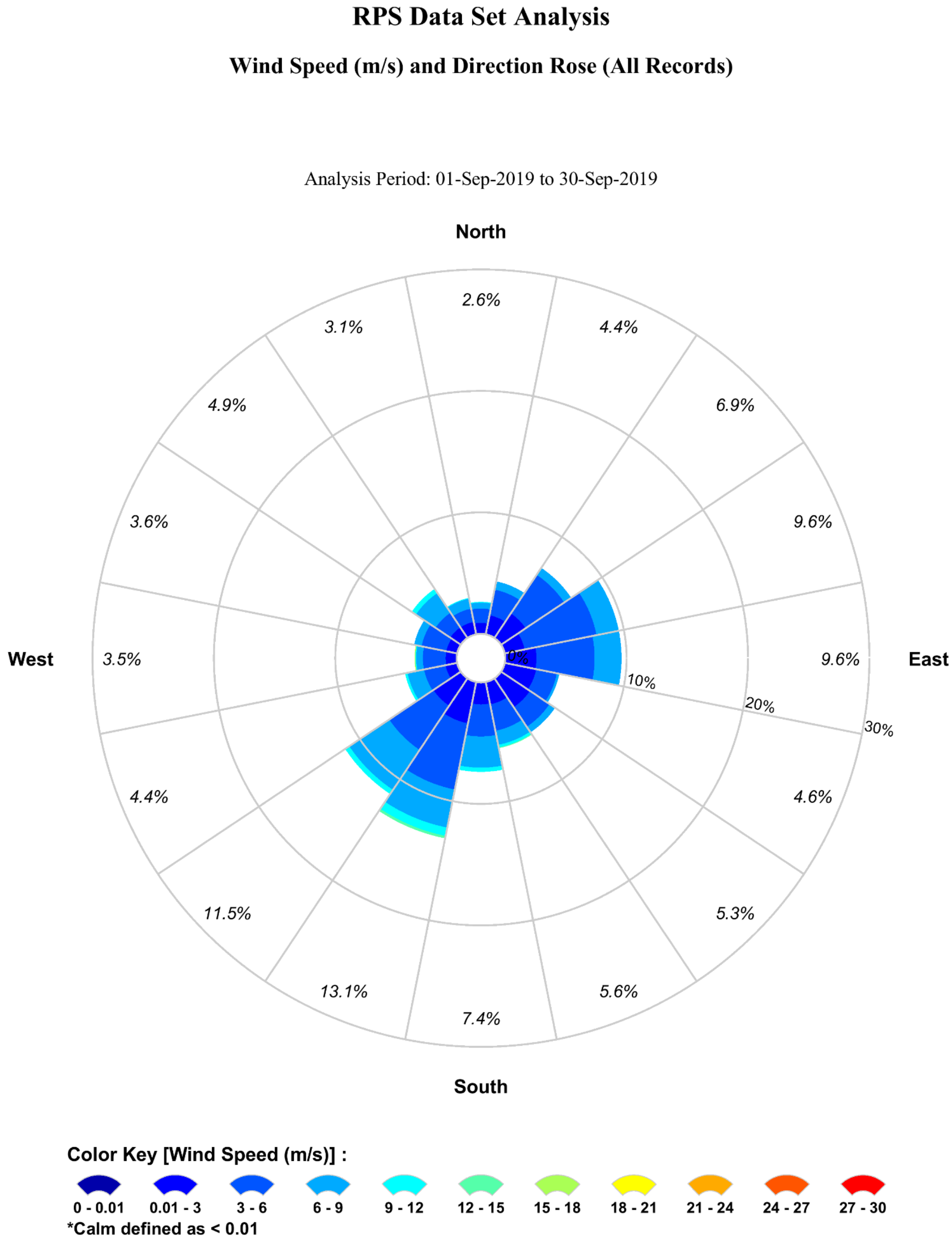

Figure 32 WatchKeeper wind speed (m/s) and direction rose (%) during September 2019.

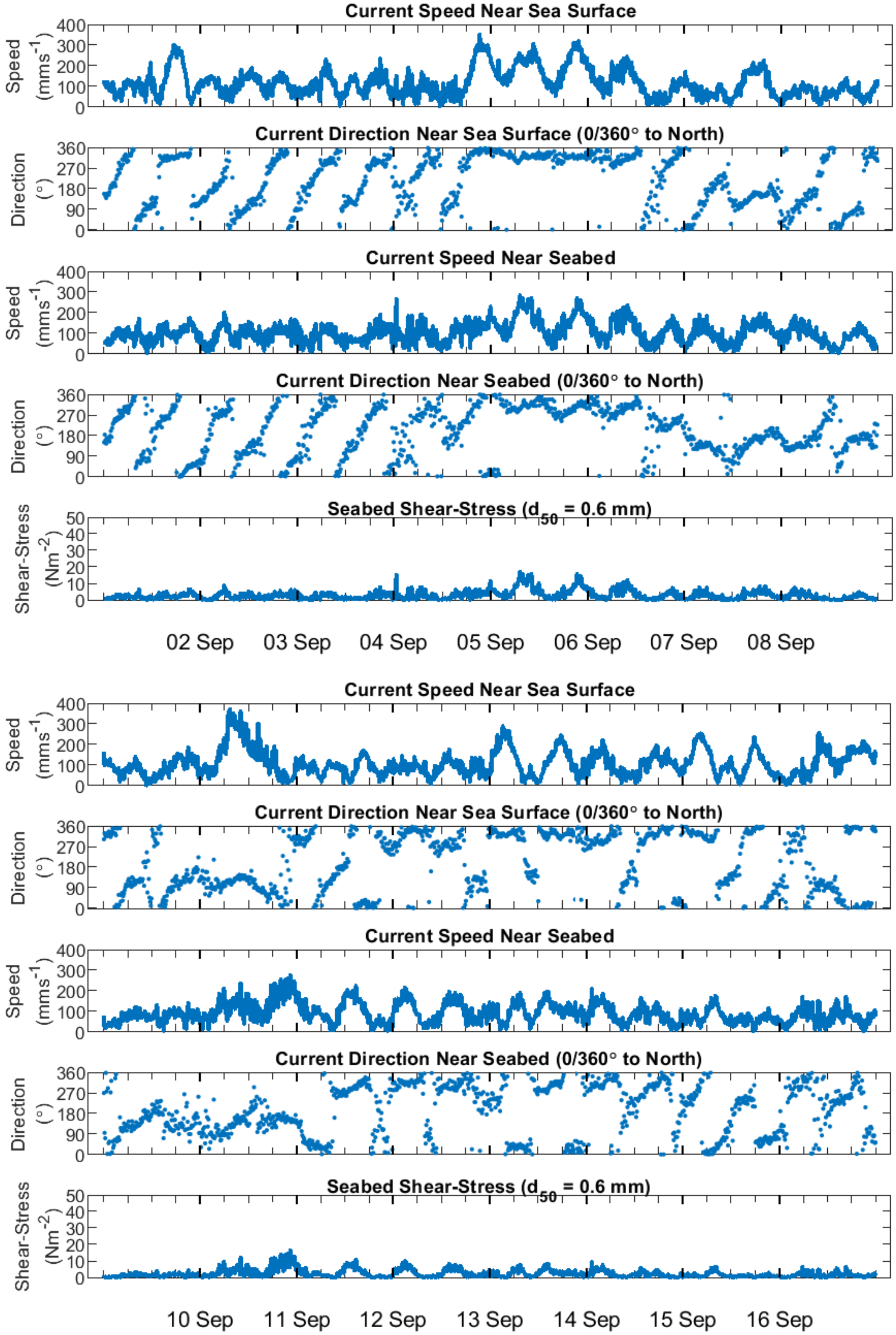

Figure 33 SG1 current speed, direction and shear bed stress 1 to 16 September 2019.

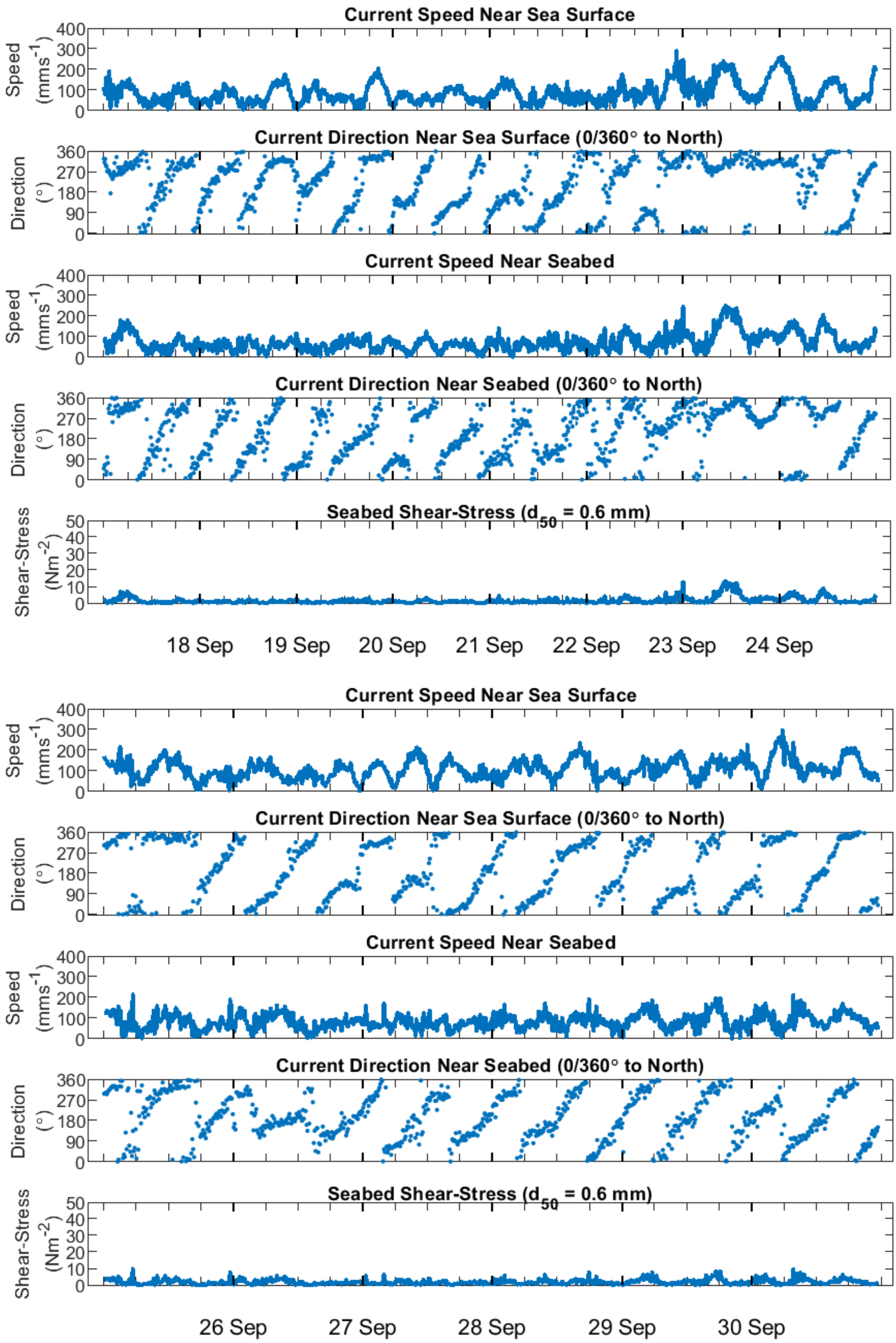

Figure 34 SG1 current speed, direction and shear bed stress 17 to 31 September 2019.

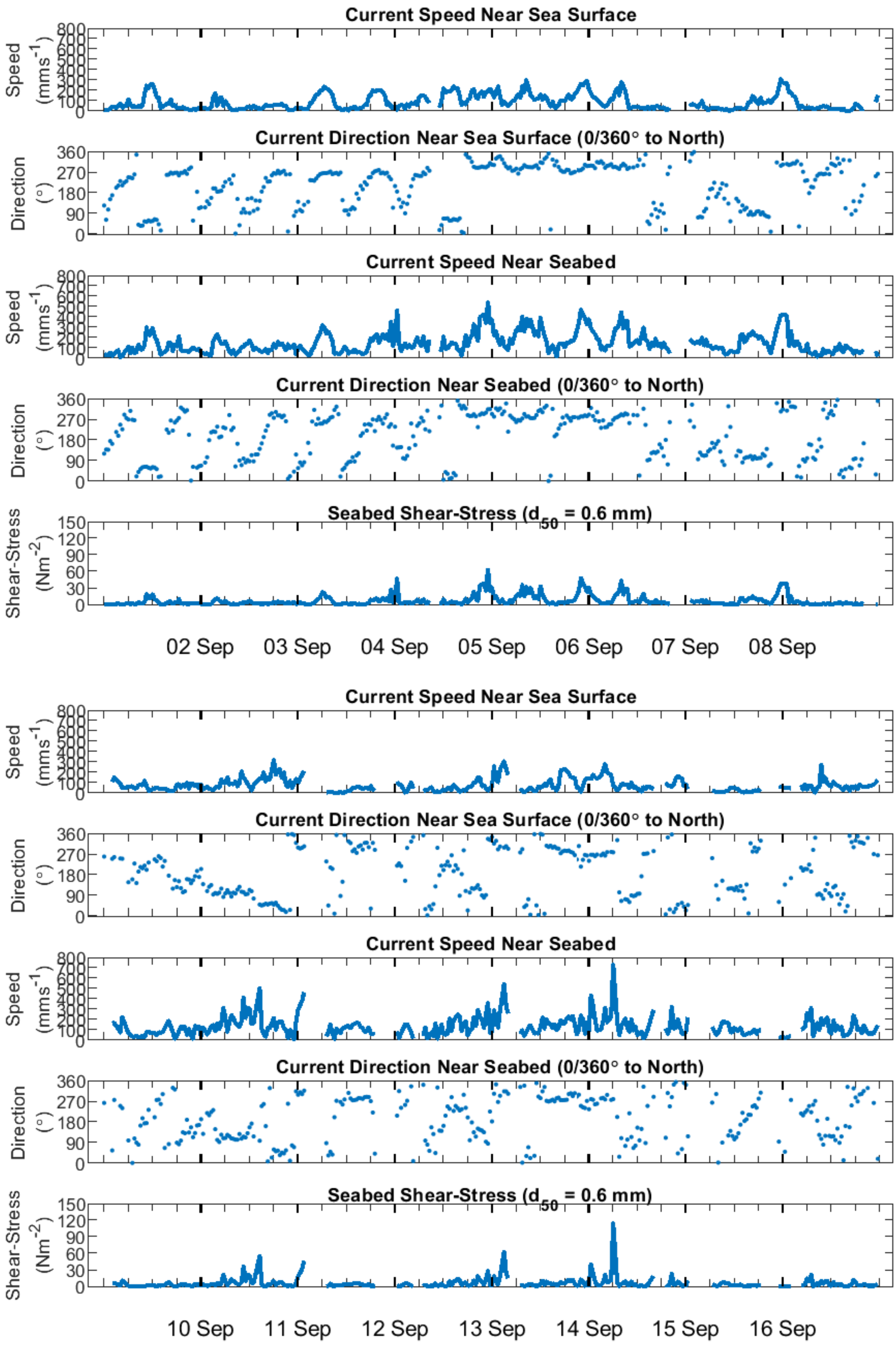

Figure 35 SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 September 2019.

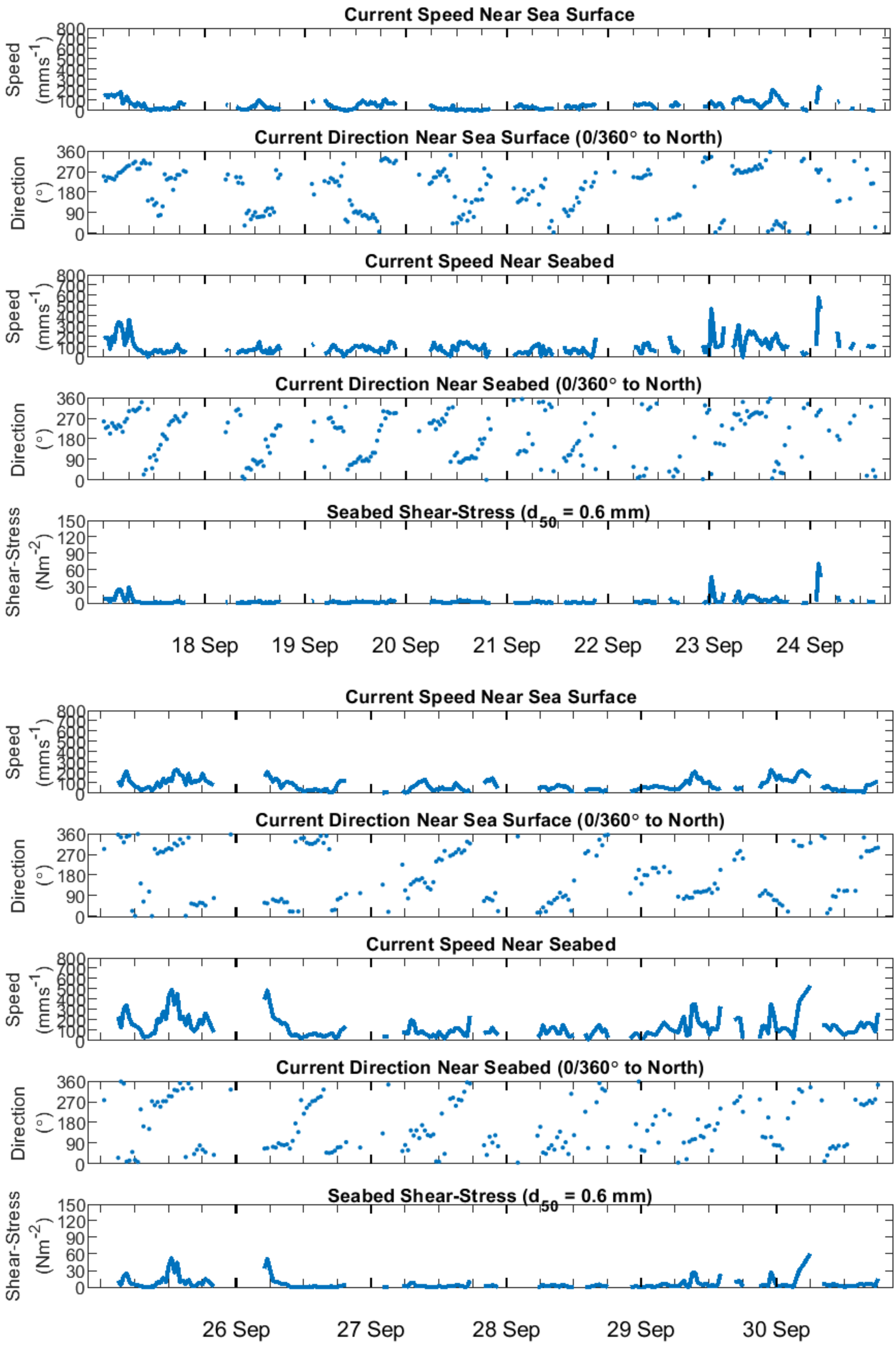

Figure 36 SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 31 September 2019.

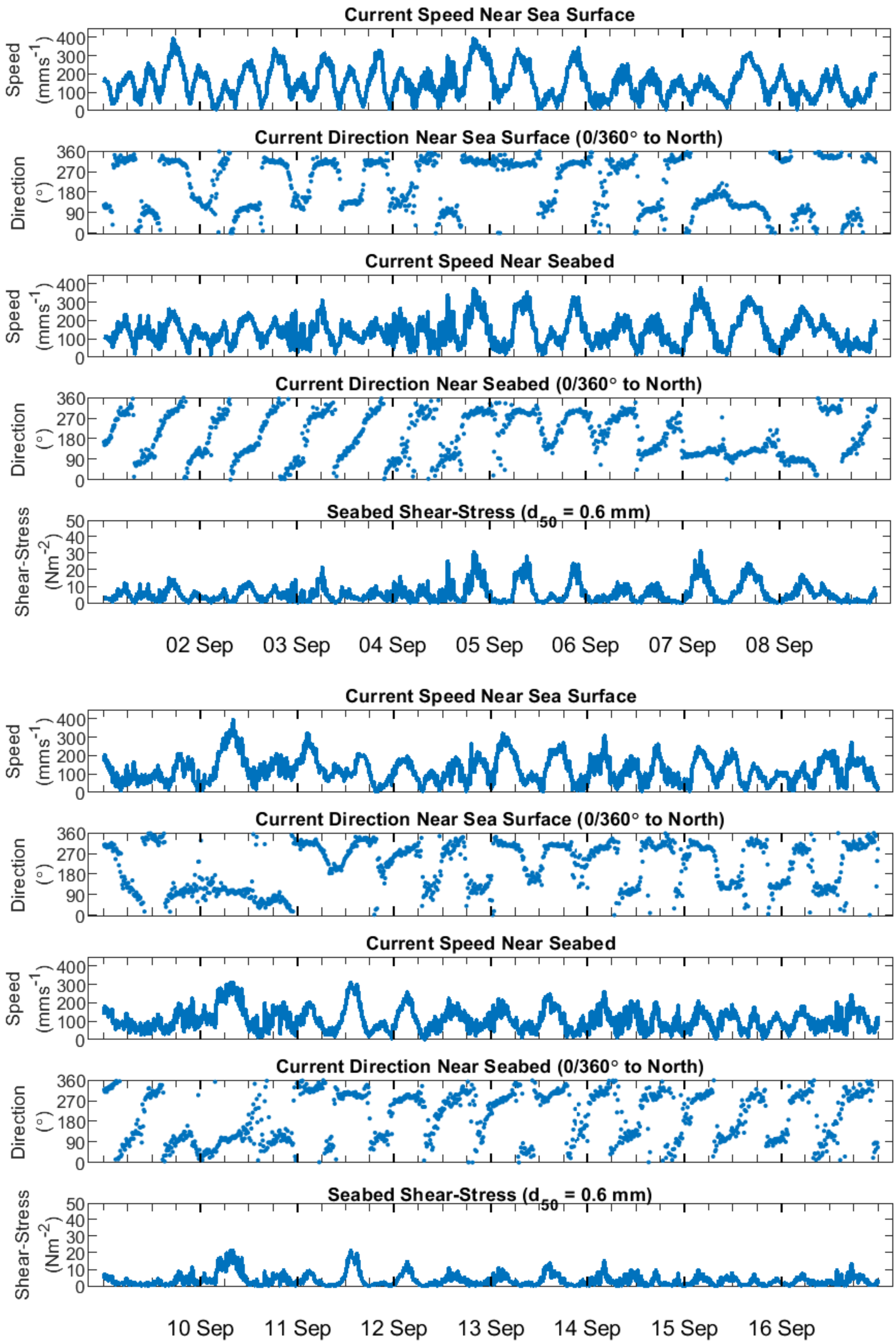

Figure 37 SG3 current speed, direction and shear bed stress 1 to 16 September 2019.

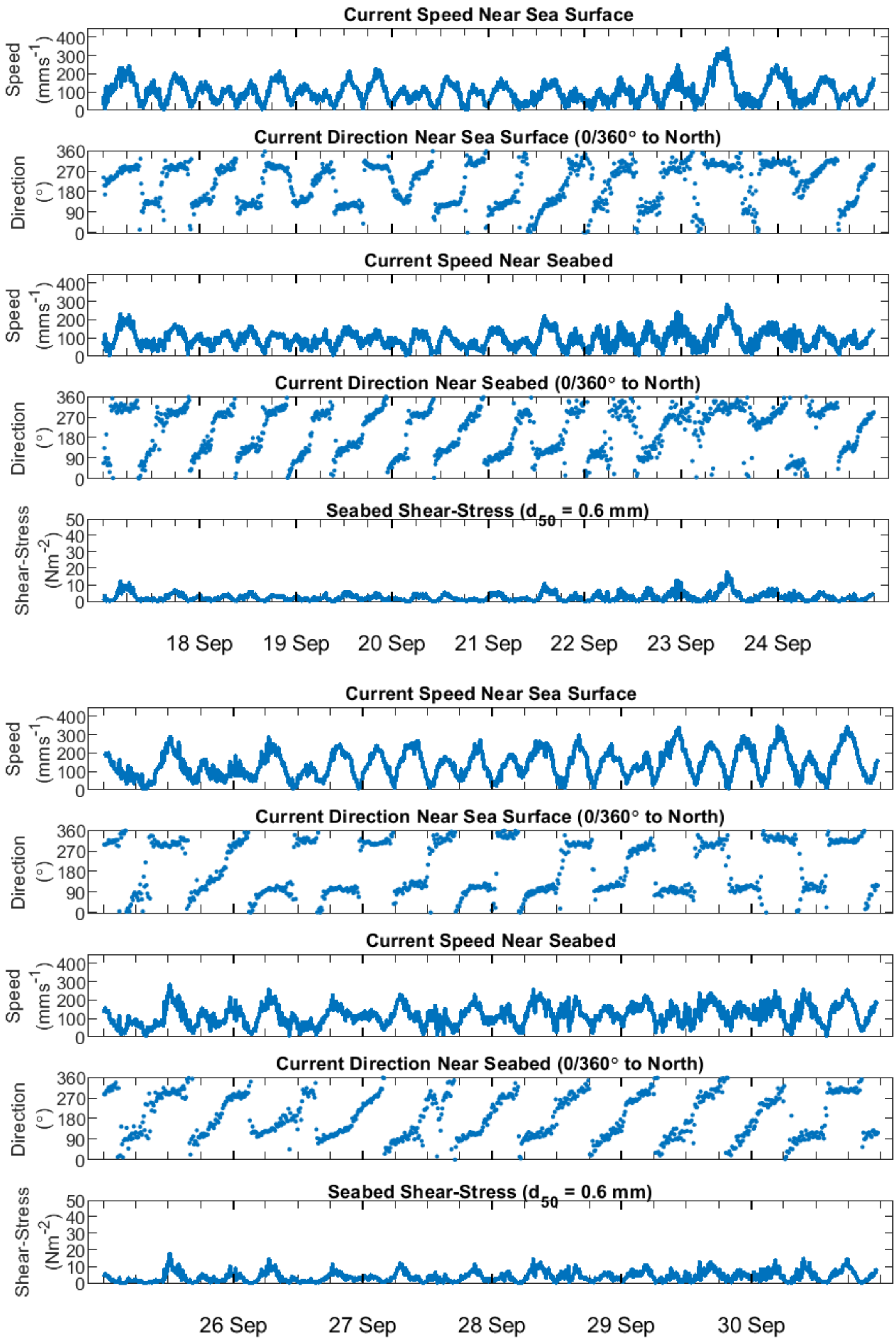

Figure 38 SG3 current speed, direction and shear bed stress 17 to 31 September 2019.

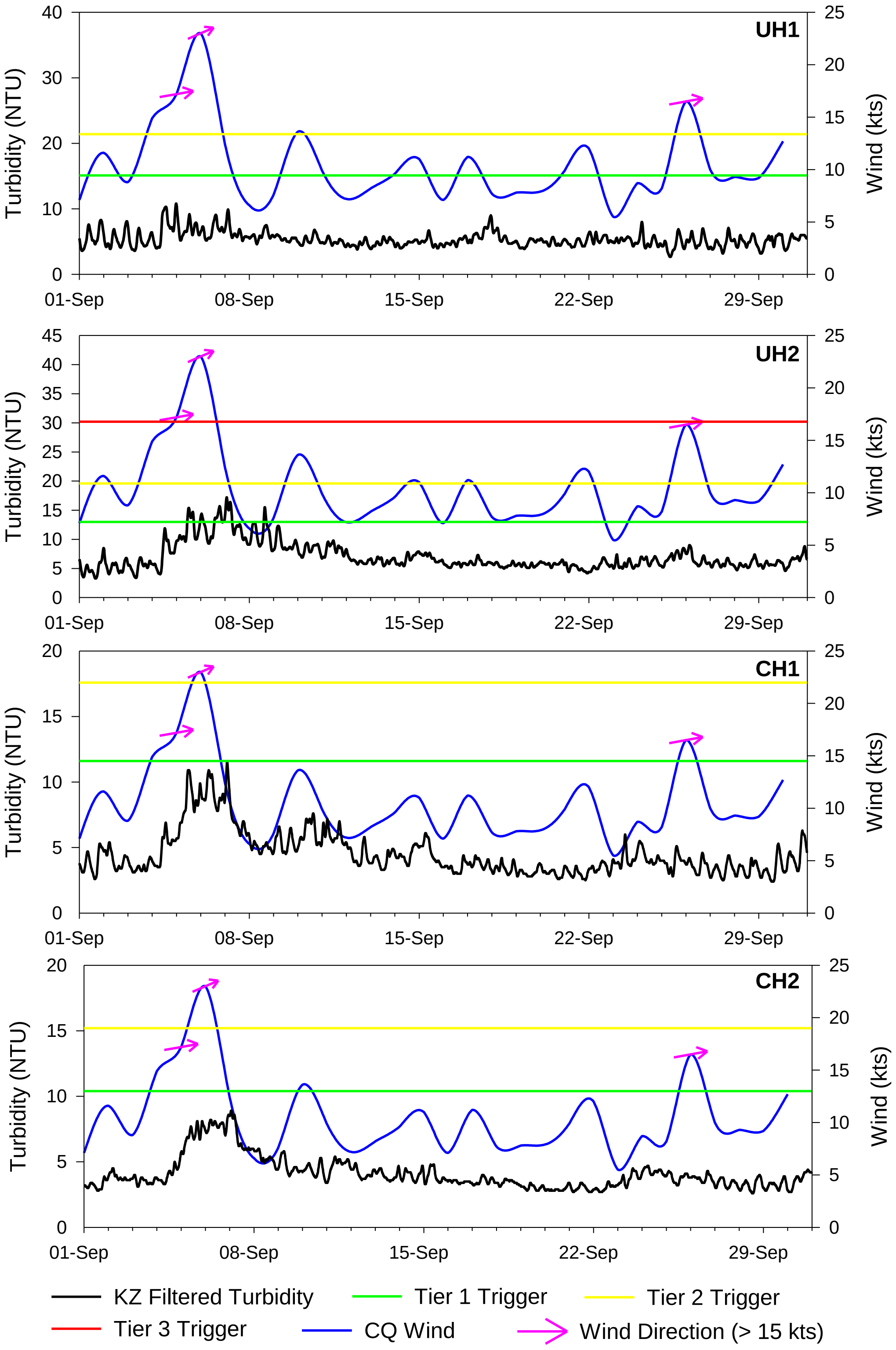

Figure 39 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity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

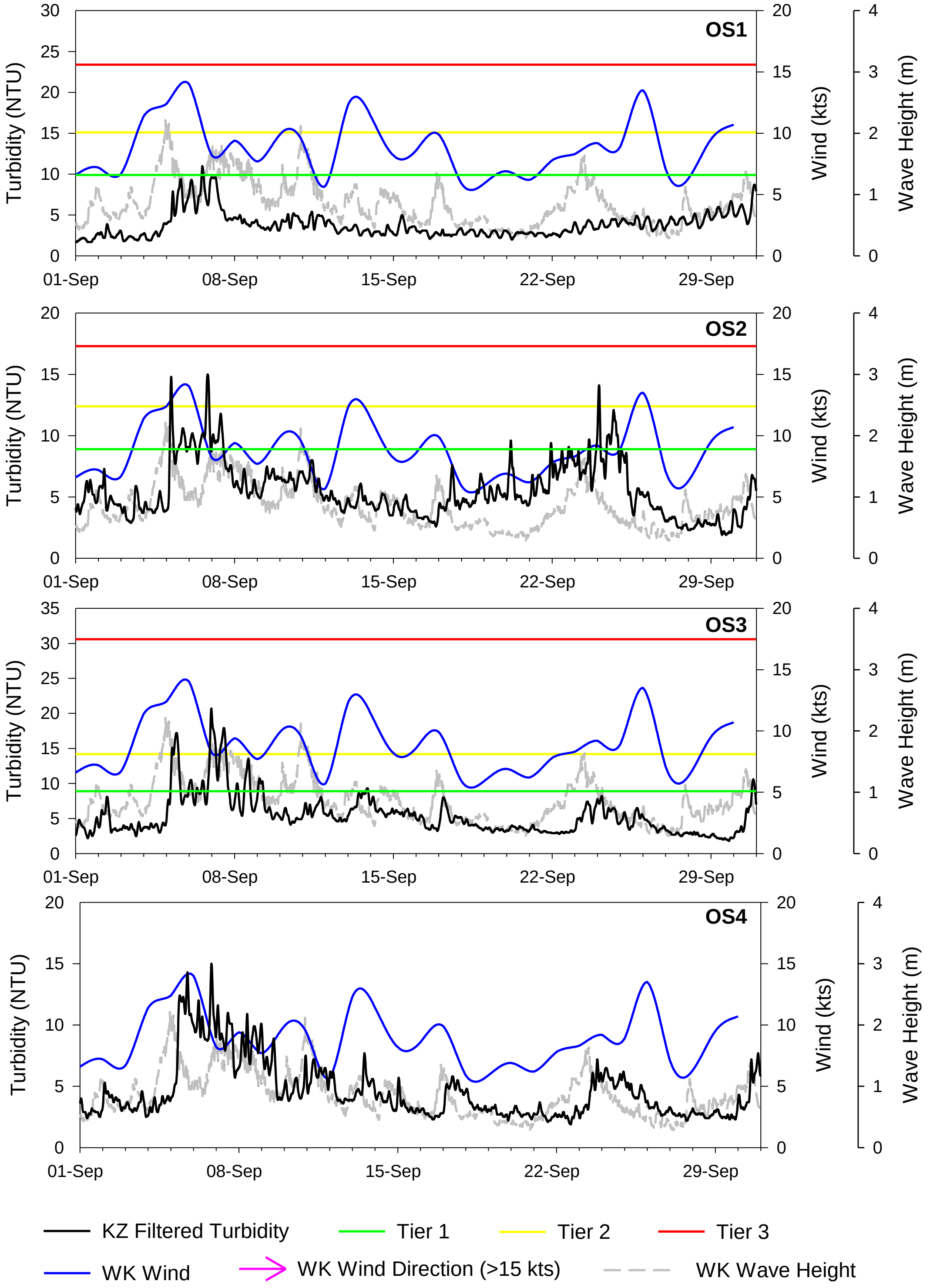

Figure 40 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

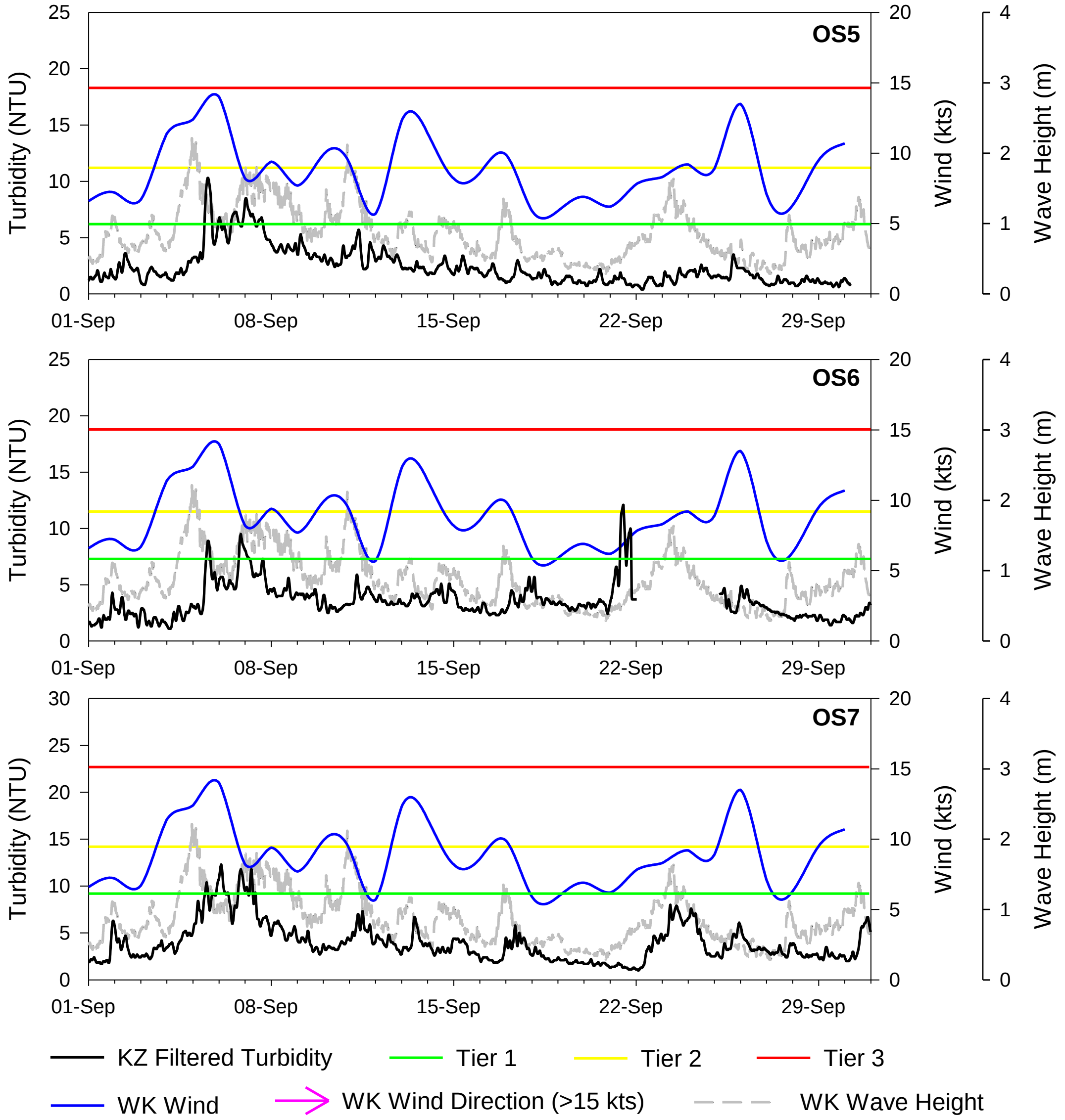

Figure 41 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

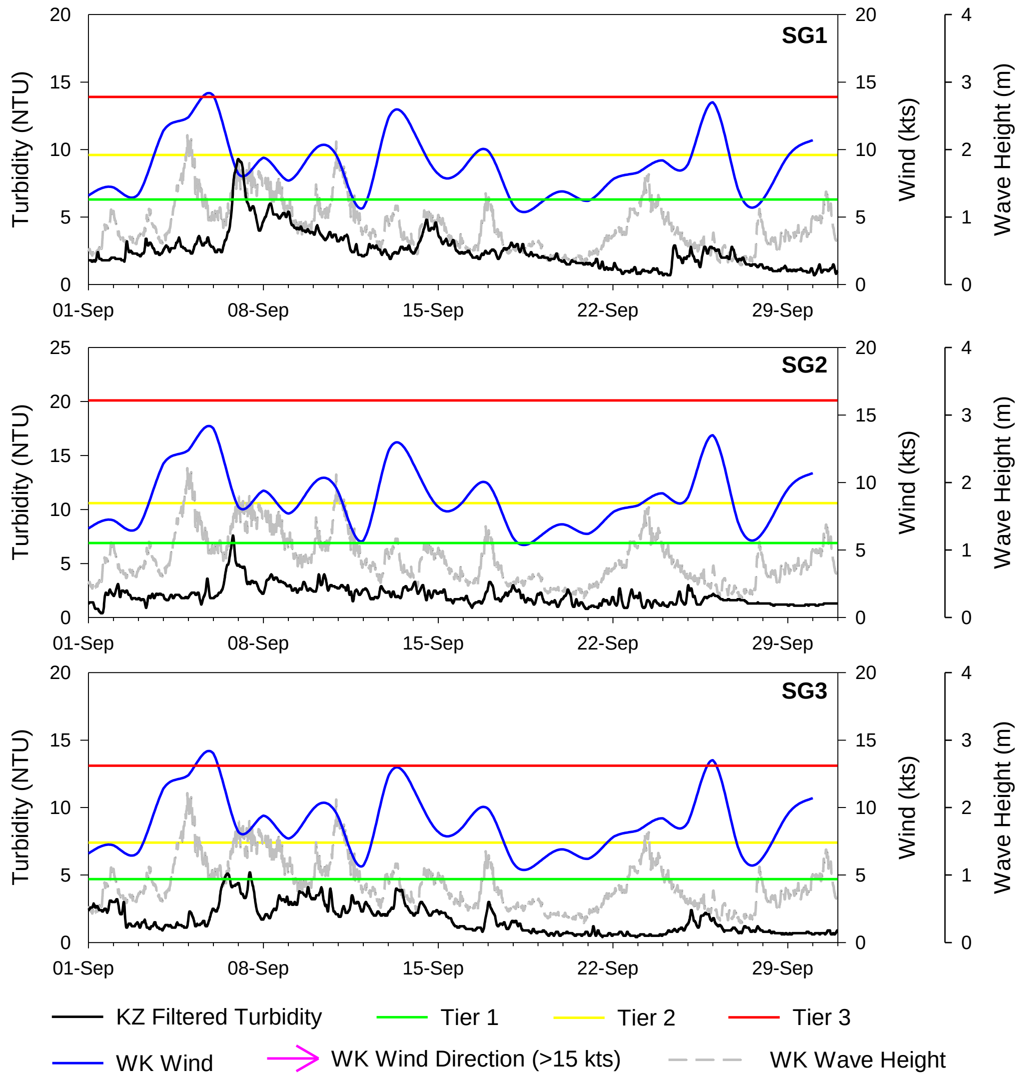

Figure 42 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during September 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

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

Site	Statistic	KZ Filtered Turbidity (NTU) Surface September	Surface Baseline
UH1	Mean ± se	5.4 ± 0.1	12
	Range	2.7 – 10.8	2 – 155
	99th	9.6	37
	95th	7.5	21
	80th	6	15
UH2	Mean ± se	7.0 ± 0.0	9.9
	Range	3.3 – 17.2	2 – 59
	99th	15.2	29
	95th	12.5	19
	80th	8.5	13
CH1	Mean ± se	4.5 ± 0.0	8.8
	Range	2.2 – 14.6	<1 – 50
	99th	10.8	27
	95th	8.3	17
	80th	5.5	12
CH2	Mean ± se	4.1 ± 0.0	7.6
	Range	2.5 – 10.3	<1 – 39
	99th	8.6	22
	95th	7.2	15
	80th	4.6	10

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

Site	Statistic	KZ Filtered Turbidity (NTU) Surface September	Surface Baseline
SG1	Mean ± se	2.5 ± 0.0	4.2
	Range	<1 – 9.3	<1 – 31
	99th	8.4	14
	95th	5.2	9.5
	80th	3.3	6.1
SG2	Mean ± se	2.0 ± 0.0	4.6
	Range	<1 – 7.6	<1 – 33
	99th	5.0	20
	95th	3.5	10
	80th	2.6	6.9
SG3	Mean ± se	1.7 ± 0.0	3.6
	Range	<1 – 5.2	<1 – 22
	99th	4.7	13
	95th	3.8	7.3
	80th	2.6	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during September 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for September are means ± se, range and percentiles (n = 2575 to 2880). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface September	Surface Baseline
OS1	Mean ± se	3.8 ± 0.0	7.5
	Range	1.7 – 11	<1 – 99
	99th	9.5	23
	95th	7.0	15
	80th	4.6	9.7
OS2	Mean ± se	5.5 ± 0.0	6.4
	Range	1.9 – 15	<1 – 36
	99th	12.3	17
	95th	9.9	12
	80th	7.2	8.9
OS3	Mean ± se	5.4 ± 0.1	6.5
	Range	1.8 – 20.7	<1 – 110
	99th	17.1	27
	95th	10.5	14
	80th	6.8	8.9
OS4	Mean ± se	4.6 ± 0.0	5.9
	Range	1.9 – 15	<1 – 35
	99th	12.2	18
	95th	10	13
	80th	5.9	8.1
OS5	Mean ± se	2.4 ± 0.0	4.6
	Range	<1 – 10.3	<1 – 35
	99th	8.1	18
	95th	6.2	11
	80th	3.3	6.1
OS6	Mean ± se	3.5 ± 0.0	4.7
	Range	1.1 – 12.1	<1 – 37
	99th	9.4	18
	95th	6.5	11
	80th	4.3	7.1
OS7	Mean ± se	4.0 ± 0.0	6.3
	Range	1 – 12.3	<1 – 48
	99th	11.1	22
	95th	8.6	14
	80th	5.3	9.1

Table 25 Summary of Vision Environment quality control data for September 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		
			UH1 (A) (µg/L)	UH1 (B) (µg/L)	Variation (%)
TSS	<3	<3	10	34	109
Dissolved Aluminium (µg/l)	<3	<3	<12	<12	ND
Total Aluminium (µg/l)	<3.2	<3.2	230	199	14
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	2.2	2	10
Total Chromium (µg/l)*	<0.53	0.58	<1.1	1.8	ND
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	1.5	<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	380	340	11
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	4.7	4.4	7
Total Manganese (µg/l)	<0.53	<0.53	11.9	11.1	7
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	10.8	10.8	0
Total Molybdenum (µg/l)	<0.21	<0.21	11.2	10.7	5
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	1.6	1.7	6
Total Vanadium (µg/l)	<1.1	<1.1	2.2	2.1	5
Dissolved Zinc (µg/l)	<1	<1	<4	<4	ND
Total Zinc (µg/l)	<1.1	<1.1	4.5	<4.2	ND
Total Phosphorus (µg/l)	<4	<4	24	21	13
Dissolved Reactive Phosphorus (µg/l)	<4	<4	7.5	7.3	3
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	<10	20	21	5
Nitrate-N + Nitrite-N (µg/l)	<2	<2	1.2	2.1	55
Chlorophyll *a* (µg/L)	<0.2	<0.2	3.9	4.1	5