Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

September 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
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

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–OS7) and five inshore sites (UH1–UH3, CH1–CH2) to assess potential impacts of the dredging project.

During the September monitoring period, construction works as part of the 'Lyttelton Harbour wastewater scheme' which commenced in July 2018 were ongoing. Of note, however was the continuation of dredging operations for the CDP, which commenced on 29 August 2018, thus transitioning from the baseline to dredge phase of reporting. As such, the monthly report has been expanded to include comparisons of turbidity data collected during the baseline period of monitoring from 1 November 2016 to 31 October 2017 (Fox, 2018) with that observed in September 2018 during dredging activities. Information in regards to the dredge trigger value exceedances and management has also been included. Results collected between the 1 and 30 September 2018, are presented within this monthly report.

Climatic Conditions: 39.2 mm of rainfall was experienced over five days during September, as recorded at Cashin Quay. Anecdotal evidence suggests that during this period rainfall on the southern side of the Harbour was significantly higher. Freshwater additions to the region through the southerly transported Waimakariri River outflow remained limited, with river flow at the Old Harbour Bridge below 200 m^3/s for the duration of the month. Mean daily inshore wind speeds greater than 14 knots were recorded on 19, 21, 23, 25 and 26 September.

Offshore, significant wave heights peaked at 3.6 m on 7 September, which would be considered in the upper range of typical wave heights experienced during the baseline period. Air temperatures displayed a slight warming trend, with a monthly average of 10°C.

Currents: Unfortunately, both ADCP units at sites SG1 and SG3 were offline during September, however current data is being received from the Watchkeeper buoy at SG2a and is yet to be reported. It should be noted that although the telemetry system is not receiving ADCP data from SG1 and SG3, it is likely that the units are internally logging and that the data may be acquired through a manual download at a later date.

Turbidity: Consistent with previous reports during 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. Mean turbidity for September at all sites were similar to those recorded for the baseline period; although slightly elevated concentrations were reported at UH1 and CH1.

All inner harbour and nearshore sites displayed a peak in surface turbidity on 3 and 4 September following elevated inshore wind speeds and notable rainfall. Following this event, two secondary peaks in turbidity were recorded on 7 and 10 September that were likely induced by increased offshore significant wave heights in a south west direction providing increased energy for sediment resuspension as they funnelled into the harbour. Turbidity at site CH1 then retained slightly higher residual baseline turbidity than the remaining three inner harbour sites, for the duration of the month. The higher order percentiles (80^{th} and 95^{th})

for CH1 were also slightly raised compared to baseline, suggesting a raised background turbidity level.

Further offshore, surface turbidity at sites OS5 and OS6 also displayed an increase on 3 September following elevated rainfall and wind speeds. However, only site OS6 appeared to display increased turbidity in response to greater significant wave heights. OS3 located at Pigeon Bay displayed elevated turbidity trends similar to OS1 at the harbour entrance in the first half of September, suggesting that elevated turbidity was weather related, although there were no similarities for the remainder of the month. Turbidity at the spoil ground did not appear to correlate particularly well with the local metocean conditions and remained fairly stable across the month.

Limited benthic data were available from sites OS3 and OS6, with intermittent turbidity values from OS1. However, within the remaining sites, benthic turbidity increased on 8-12, 14, 17-18 and 24-25 September, with consistency across the monitoring network. The greatest levels of benthic turbidity were recorded at the reference site OS4, and at the northern side of Lyttelton Harbour entrance at OS1. It is anticipated that OS3 benthic would have displayed similar turbidity trends in response to the extreme weather events. Offshore waves and winds were likely the driving forces behind the temporal variations in benthic turbidity.

Dredge Compliance Turbidity Trigger Values:

There were several exceedances of the turbidity intensity component of the Tier 3 trigger level for several sites during the month of September; namely UH2, CH1, OS1 and OS2. However, the compliance trigger, the Tier 3 allowable hours (7.2 hours), was only exceeded at OS1. Due to the anomalous elevated wind and rain conditions experienced on 2 and 3 September, hour counts of turbidity threshold exceedances were removed from UH2, OS1 and OS2 to reflect the 'extraordinary' nature of this meteorological event as consented by Environment Canterbury (ECan).

Other Physicochemical Parameters: Monthly mean surface water temperatures around Lyttelton Harbour continued the slight warming trend observed during August. Reversing the spatial relationship between sites, the warmest temperatures were recorded in the shallow waters of the upper and central harbour, which typically exhibit the coolest temperatures during winter. Brief periods of cooling were observed within the monthly warming trend, following rainfall events on 3 and 25 September. A brief phase of cooling was also recorded at SG1 on 21 September. Benthic temperatures were up to 0.2°C lower than those of the surface and also displayed a warming signal, particularly during the latter half of the month.

Consistent with previous reports, mean conductivity for September did not display any particular spatial pattern across the monitoring network. Temporally, conductivity within the inner harbour and at OS2 declined following heavy and sustained rainfall on 3 September. Several drops in conductivity were also reported at OS1, OS5 and SG1 during September that did not correlate with either local rainfall or riverine runoff.

Dissolved oxygen concentration and pH data did not display any notable spatial and/or few temporal patterns during September. Both parameters continued to display a diurnal signal that reflects variations in the balance of photosynthesis and respiration. Slightly elevated DO concentrations in the inner harbour from 15 to 24 September may be an indication of a phytoplankton bloom. Benthic conductivity, DO and pH conditions remained relatively stable over September.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 11 September. Similar to the profiles obtained during August, the harbour and nearshore monitoring sites indicated a well-mixed water column. Benthic waters at these sites were characterised by slight increases in turbidity near the seabed. In a similar manner to August, notably lower 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, with slight warming having occurred in the surface waters. Notable declines in DO concentration were recorded near the benthos at sites SG2b and SG3 that may be a reflection of *in situ* oxygen consumption.

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 at 11.2 m at SG2b. A shallower than expected euphotic depth of only 5.1 m was calculated for SG3, which likely reflects increased particulate matter within the water column. No exceedances of WQG were observed for sub-surface turbidity during the September sampling.

Nutrient concentrations in September were not indifferent to those recorded during the baseline period. Total phosphorous concentrations (slightly) exceeded WQG at all three upper harbour monitoring sites and CH2. Exceedances of WQG for the more bioavailable dissolved reactive fraction were once again reported at multiple nearshore and offshore sites across the monitoring network, coinciding with WQG exceedances of total ammonia and elevated concentrations of nitrogen oxides. WQG exceedances of dissolved reactive phosphorous and nitrogen oxide were also reported at UH3, however the duplicate samples from this site did not reveal concentrations above the laboratory limit of reporting.

As has been previously observed during baseline monitoring, concentrations of total nitrogen and total kjeldahl nitrogen remained below detection limits at all sampling sites. Despite elevated concentrations of phosphorous, ammonia and nitrogen oxides, concentrations of chlorophyll *a* remained low. This suggests that despite increased nutrient availability, phytoplankton growth had not yet been stimulated at the time of sampling.

Metal concentrations were mostly similar to the baseline period with a few exceptions. As typically observed, total aluminium concentrations exceeded designated WQG at all sites, with higher concentrations reported for UH1, OS5-OS7 and the spoil ground sites compared to the August sampling. Concentrations of dissolved aluminium were below the 24 µg/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, only slight exceedances were reported for total cobalt at UH1, UH3 and OS1.

In an ongoing trend, elevated concentrations of total iron were recorded in the upper harbour during September. Similar to previous months, total iron concentrations displayed a decreasing trend in a seawards direction. No WQG have been derived for iron concentrations. As with the aluminium data, iron was predominately present in the particulate phase, and is thus not deemed to have been particularly biologically available. However dissolved iron concentrations were notably more elevated than concentrations recorded in August. Sampling conducted during September also indicated an increase in dissolved manganese concentrations across the network and increased total vanadium concentrations within the inshore and nearshore environments. These two metals have occasionally been detected during the baseline period.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight during September displayed a greater range than reported during August, resulting in an increase in the monthly mean ambient PAR. Contrasting previous months, benthic PAR intensities were greater at OS2 than at OS3, with values reaching up to 7.2 mmol/m^2/day, c.f. a maximum of 1.9 mmol/m^2/day at OS3. This change in the spatial relationship of BPAR measurements was most likely due to the elevated turbidity experienced at OS3 during September.

Sedimentation: Altimeter data from site OS2, near the mouth of Lyttelton Harbour indicated relatively dynamic seafloor conditions, with three distinct periods of rapid bed level increase and subsequent erosion recorded during September, associated with weather/wave events. Relatively rapid sediment deposition during the final two days of the month, however, minimised the monthly net bed level change to -11 mm.

Bed level at the head of the upper harbour was once again relatively stable during September, with a brief period of sedimentation and erosion at the start of the month coinciding with extreme weather events. Following these events, bed level data indicated a slight, yet steady accretion of sediments for the remainder of the month. Over the course of the month, bed level at UH3 increased by 4 mm.

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, 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. Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016 continuing into a second year that now extends into the current phase of dredge operations. 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.

As per the Resource Consent (CRC172522) conditions and the EMMP, trigger values were developed from the extensive baseline data sets, to allow adaptive dredge management based on real time turbidity monitoring. The Tier 1 to Tier 3 trigger levels based on higher order percentiles (80^{th}, 95^{th} and 99^{th}) of the collected background (baseline) turbidity data, allow management and mitigation measures to be undertaken in order to manage dredging operations in an environmentally sustainable way.

2 METHODOLOGY

2.1 Approach

An overview of the methodology for baseline and operations phase 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), 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.

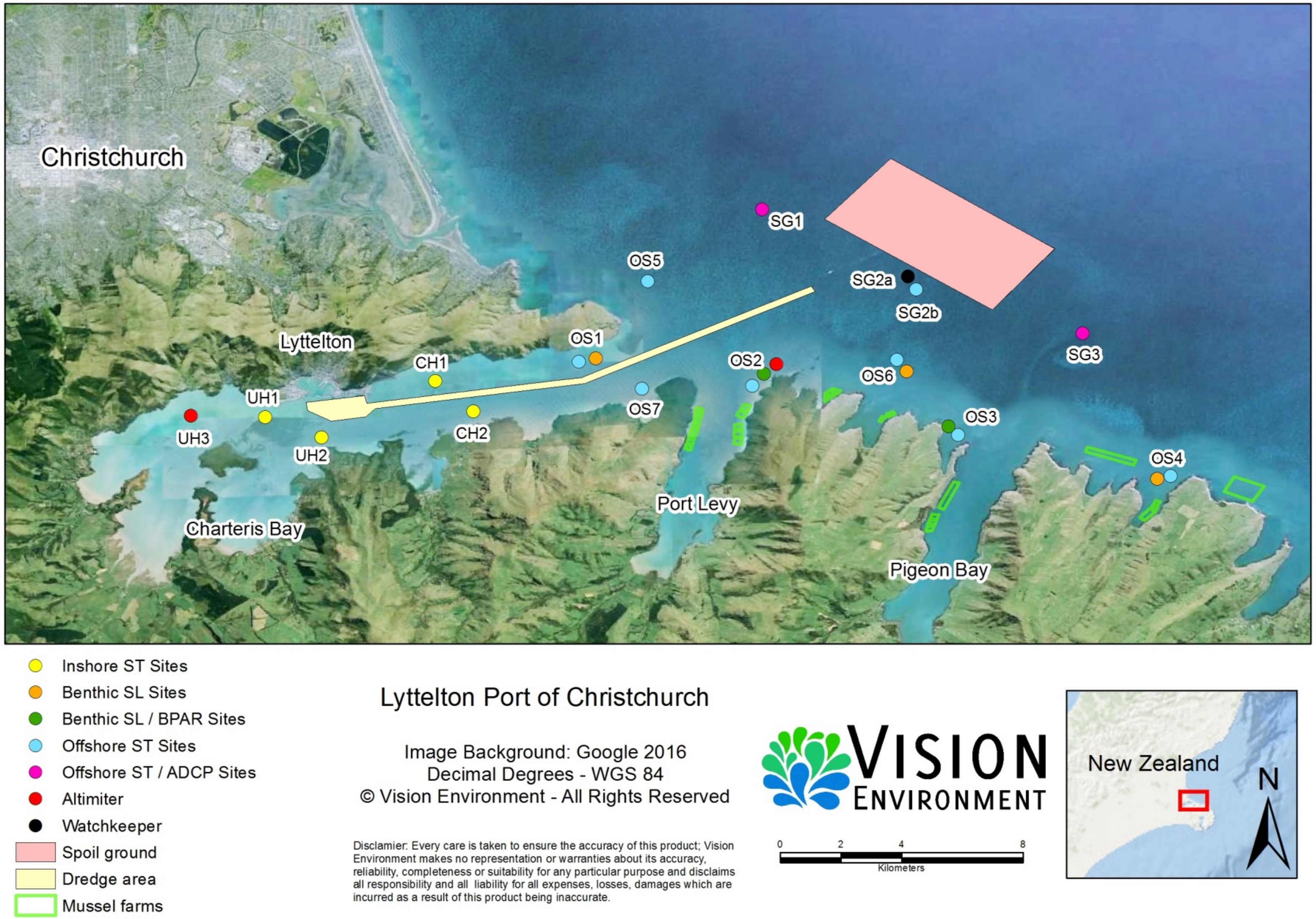


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

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 is 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						√
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 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 30 September 2018 during dredging operations. 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 Dredge Compliance Triggers

As per the Resource Consent (CRC172522) conditions, there are two turbidity triggers (Tier 1 and Tier 2) and one compliance level tier (Tier 3), based on the 80th, 95th and 99th percentiles of smoothed Kolmogorov-Zurbenko (KZ) filtered baseline data, respectively. Each monitoring location has been assigned an individual, unique allowable turbidity intensity and duration (Fox, 2018). The turbidity intensity is a measure of the absolute turbidity following smoothing with the KZ filter, while the allowable duration represents the amount of time in a 30 day rolling window that the turbidity at any given monitoring site may exceed the turbidity intensity value. Once the turbidity intensity has been exceeded for the allowable duration, a trigger event occurs, requiring management actions that are dependent on the level of turbidity experienced. The trigger event ceases when either the turbidity drops below the allowable intensity, the allowable hours are no longer in exceedance or the event is considered an extraordinary natural event. The Tier 1 and Tier 2 turbidity triggers are internal triggers, alerting the Consent Holder Project Team and Dredging Operator that the turbidity at the monitoring location has increased (either dredging or natural cause related). The Tier 3 Compliance Level trigger requires dredging at the location of the trigger event to cease (Envisor, 2018).

Turbidity data collected in September during dredging operations have been compared to turbidity statistics calculated for the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). Additionally, KZ filtered data collected during September have been compared to established Tier 1 to Tier 3 trigger values in a similar manner to the procedure for real time dredge management.

2.1.3 Water Quality Guidelines

Water quality monitoring data from LYT were compared to the Australian and New Zealand Water Quality Guidelines (WQG) (ANZECC/ARMCANZ, 2000) default interim trigger values. In the absence of specific default trigger values for estuarine or marine ecosystems, which are yet to be developed in New Zealand, the WQG suggest the use of interim trigger values for south-east Australian estuarine and marine ecosystems.

Total metals represent the concentration of metals determined in an unfiltered sample (those bound to sediments or colloidal particles in addition to dissolved metals), while dissolved metals are defined as those which pass through a 0.45 µm membrane filter (APHA, 2005). Specific trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived for a number of metals. These guidelines refer to the dissolved fraction, as they are considered to be the potentially bioavailable fraction (ANZECC/ARMCANZ, 2000). The LYT coastal environment could be described as slightly-to-moderately disturbed, therefore the 95% WQG trigger value was considered appropriate for comparison.

3 RESULTS & DISCUSSION

3.1 Metocean Conditions

3.1.1 Wind and precipitation

A large deep low pressure system crossed Canterbury on 3 and 4 September, before heading slowly northwards and becoming slow moving of the east coast of the North Island. This generated very strong southerly winds and significant local rainfall in Lyttelton Harbour on 3 and 4 September, and large ocean swells as the low moved northwards.

A total of 39.2 mm rainfall was received at Cashin Quay over 5 days during September. The majority of this precipitation (21.6 mm) occurred on 3 September, with notable rainfall of 5.2 and 10 mm experienced on 24 and 25 September, respectively (Figure 2) (Metconnect, 2018). Niwa's Daimond Harbour rain gauge (station 40985) recorded 54.2mm over the event on 3 and 4 September. The same gauge calculated that only 30% of the rainfall would have been absorbed, with the remaining 70% becoming runoff.

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 200 m^3/s for the duration of the month (Figure 2) (ECAN, 2018). Maximum daily mean inshore average wind speeds measured at Cashin Quay were recorded at 21.7 knots on 3 September (10 min mean of 33 knots, gusts of 47 knots), blowing from a west-south-westerly direction and coinciding with the maximum daily rainfall during the month. Elevated inshore winds greater than 14 knots were also recorded on 19, 21, 23, 25 and 26 September (Figure 2).

Offshore significant wave heights peaked at 3.6 m on 7 September, travelling in a south west direction, despite offshore wind speeds declining since 3 September (Figure 3). This would be considered in the upper range for wave heights, which typically peak at <2.5 m. Maximum monthly offshore wind speeds occurred on 17 September at 15.1 knots, however, they did not appear to result in a significant change in offshore significant wave heights. Daily mean air temperatures at Cashin Quay ranged from 6 to 15°C, resulting in a slightly warmer monthly mean temperature of 10°C (Metconnect, 2018).

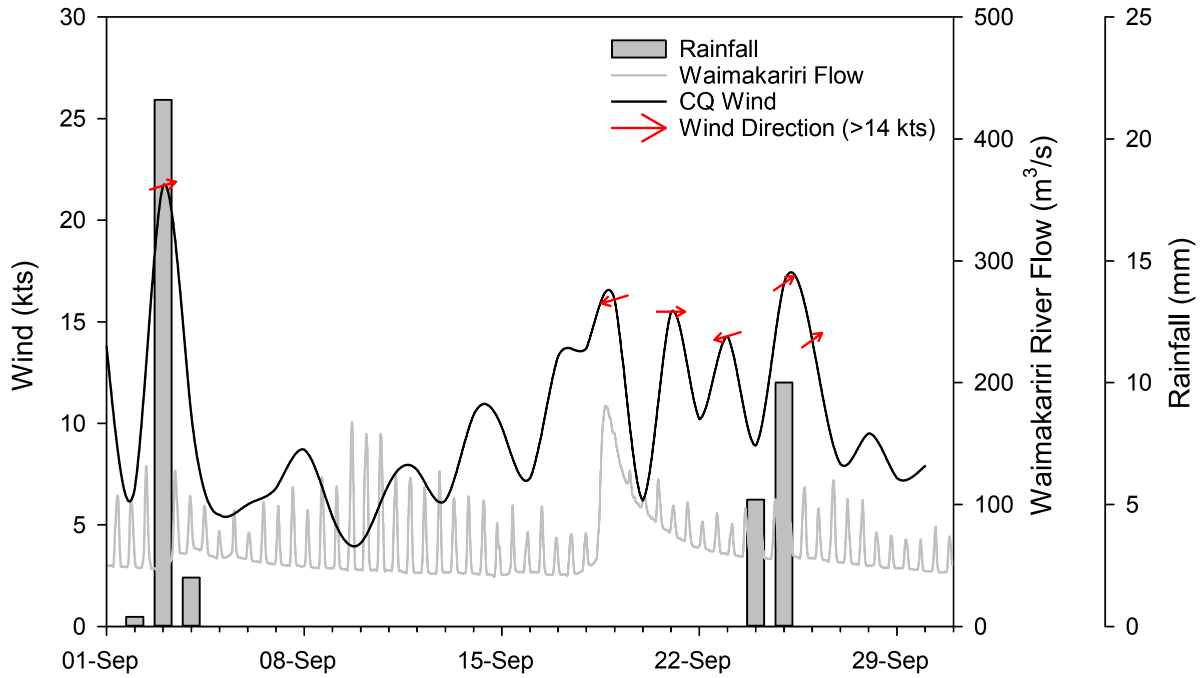


Figure 2 Inshore metocean conditions, including daily averaged wind speed, daily averaged wind direction and rainfall measured at Cashin Quay; combined with Waimakariri River flow at the Old Harbour Bridge station, from 1 to 30 September 2018.
Note: Arrows indicate the direction of travel for inshore winds greater than 14 knots.

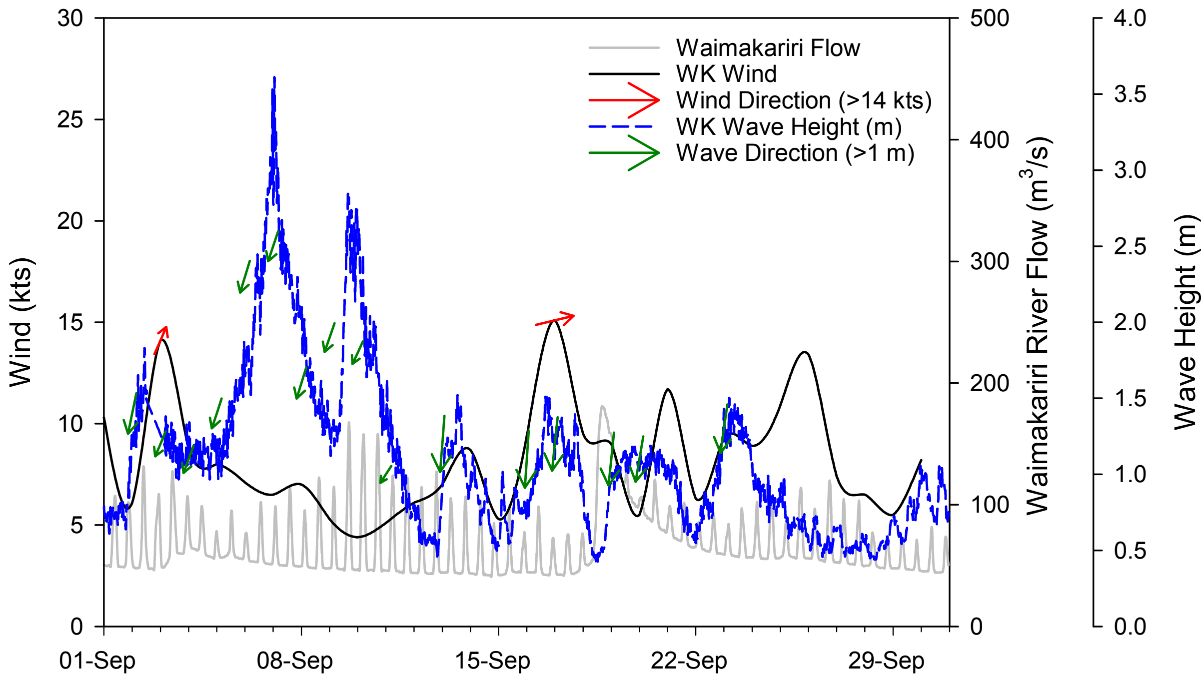


Figure 3 Offshore metocean conditions, including wind speed, wind direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a; combined with Waimakariri River flow measurements at the Old Harbour Bridge station, from 1 to 30 September 2018.
Note: 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.

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. Unfortunately, both ADCP units stopped sending data in late August and early September and have not been removed from the spoil ground due to the requirement for turbidity monitoring at those sites. Additional ADCP data collected from the WatchKeeper Buoy at SG2a is currently being processed.

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 11 September 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 recorded during September are presented in Tables 2 to 11. Validated datasets for surface and benthic measurements are also presented in Figures 4 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.

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 dredge operations management. As such, summary turbidity statistics for the baseline period of monitoring from 1 November 2016 to 31 October 2017 (Fox, 2018) are also presented in Tables 2 to 4 to allow a comparison with the September data. Summary statistics for KZ filtered turbidity data, used for real time compliance monitoring, are also presented in Tables 21 to 23 within the appendix. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 29 to 32 of the appendix.

September Turbidity:

Consistent with previous monitoring months, surface turbidity values were typically highest (monthly means of 8.8 to 13 NTU) at the inshore monitoring sites (Tables 2 to 4, Figure 4). Further offshore, the spoil ground sites exhibited lower (monthly means of 2.5 to 5.0 NTU) surface turbidity values (Table 3), 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 (5.0 to 8.8 NTU) during September (Table 4).

All central and upper harbour monitoring sites displayed large increases in surface turbidity on 3 and 4 September, following elevated inshore wind speeds of 21.7 knots (daily averaged) and heavy rainfall. As wind speeds declined, surface turbidity also displayed a short lived decrease, with two further periods of elevated surface turbidity around 7 and 10 September (Figure 4 and Figure 5). Inshore winds remained relatively low during this period, however significant wave heights measured at SG2a recorded a phase of increased wave energy with peak wave heights coinciding with peak turbidity at both central and upper harbour sites (Figure 4). Waves were travelling in a south-south-easterly direction at this time (Figure 3) and thus wave energy would have been funnelled into the harbour towards the upper harbour sites. CH1 displayed slightly elevated turbidity levels for the remainder of the month compared to the other sites (Figure 4) and tracked well with inshore wind speed changes. The remaining central and upper harbour sites all displayed lower turbidity values that declined towards the end of the month.

Nearshore sites also indicated elevated surface turbidity levels on 3 September, likely associated with elevated local wind speeds and rainfall. In a similar manner to the harbour monitoring sites, increased significant wave action on 7 and 10 September coincided with further increases in surface turbidity, particularly at OS1 (Figure 6) and OS3 (Figure 7). OS3, which is located south of the harbour entrance at Pigeon Bay, displayed a more elevated turbidity response to increased wave action than OS1, located at the harbour entrance (Figure 4). For the remainder of the month, turbidity patterns displayed a long term declining trend, with a superimposed cyclicity that appeared to be induced by increased wind speeds and/or offshore wave heights (Figure 3). From 20 September turbidity, declined and recovered to mean baseline levels at OS3 (Figure 7) but continued to peak at OS1 in reaction to wind speeds (Figure 6); perhaps due to the resuspension of residual sediments at OS1.

Further offshore, surface turbidity at OS5 and OS6 displayed a slight increase following elevated wind speeds on 3 September. A slightly greater increase in turbidity was observed within the surface dataset of OS6, located south of the spoil ground, in relation to elevated significant wave heights recorded at SG2a on 7 and 10 September. In contrast, 24 hour rolling average turbidity at OS5, located west of the spoil ground, remained relatively stable over this period of time (Figure 8). For the remainder of the month, both OS5 and OS6 displayed increased surface turbidity on 18 and 26 September, correlating with offshore wind speeds greater than 12 knots.

Turbidity at the spoil ground sites did not appear to correlate particularly well with local metocean conditions. Elevated offshore winds speeds on 3 September coincided with a slight increase in turbidity at SG1, while 24 hour rolling average turbidity at SG2 and SG3 remained largely unaffected. In a similar manner, elevated offshore significant wave heights on 7 and 10 September did not appear to result in increased surface turbidity (Figure 9).

Comparison to Baseline:

Mean surface turbidity in the upper and central harbour sites for September were similar to those of the baseline monitoring period, however, the September mean for CH1 was 4 NTU greater than the baseline mean (Table 2). The higher order percentiles were also raised for CH1 in September (Table 2, Figure 5), potentially due to this site maintaining raised background turbidity after the early September extreme weather events and not recovering as quickly as the other sites. Turbidity at the spoil ground sites was overall similar or slightly lower in September compared to baseline conditions (Table 3). At the offshore sites, only mean turbidity from the reference site OS4 was lower than that recorded during the baseline monitoring period. All other offshore sites displayed higher turbidity values for the September mean (Table 4).

Benthic:

Benthic data recovery from the continuous loggers at OS1 was intermittent during September but with a particularly high level of data recovery from benthic sites OS2 and OS4. Limited data were available from OS6, as the marker buoy was discovered detached from the frame (which could not be located), thus requiring a replacement frame in early October. Limited turbidity data were also available for benthic site OS3. Where data were available, benthic turbidity increased on 8-12, 14, 17-18 and 24-25 September, with some apparent consistency across the monitoring sites (Figure 4). Peaks in 24 hour rolling averaged benthic turbidity measured at OS2 remained at a similar intensity throughout the month, however, variability within the initial 15 minute readings was notably increased from 19 to 25 September (Figure 6). The highest overall levels of benthic turbidity were recorded at the reference site OS4 and the northern harbour site OS1, with rolling averaged values regularly greater than 100 NTU. Turbidity at the benthos and sea surface of OS4 displayed a similar pattern over the month. This relationship suggests that wind and wave driven sediment resuspension from the seafloor was a main driver of surface turbidity, as low density particulate matter was mixed vertically throughout the water column. Limited data recovery during September from the benthic units at OS3, also located outside of the harbour, limited data interpretation. However, the relatively exposed location may have allowed offshore winds and wave action to induce sediment resuspension in a similar manner to that of OS4.

Table 2 Mean turbidity and statistics at inshore water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017
Values for September are means ± se, range and percentiles (n = 2864 to 2872) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface September	Surface Baseline
UH1	Mean ± se	10 ± 0	12
	Range	<1– 60	-
	99th	31	39
	95th	21	22
	80th	13	15
UH2	Mean ± se	10 ± 0	10
	Range	3 – 67	-
	99th	31	32
	95th	22	20
	80th	13	13
CH1	Mean ± se	13 ± 0	9
	Range	3 – 54	-
	99th	32	29
	95th	24	18
	80th	16	12
CH2	Mean ± se	8.8 ± 0.1	8
	Range	1 – 61	-
	99th	23	24
	95th	18	16
	80th	12	10

Table 3 Mean turbidity and statistics at spoil ground water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for September are means ± se, range and percentiles (n = 2838 to 2880). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface September	Surface Baseline
SG1	Mean ± se	3.7 ± 0.0	4.2
	Range	<1 – 13	-
	99th	9.2	14
	95th	6.5	10
	80th	4.9	6.2
SG2	Mean ± se	5.0 ± 0.0	4.6
	Range	<1 – 12	-
	99th	9.3	20
	95th	7.7	11
	80th	6.1	7.0
SG3	Mean ± se	2.5 ± 0.0	3.6
	Range	<1 – 9.4	-
	99th	6.3	13
	95th	5.0	7.7
	80th	3.5	4.8

Table 4 Mean turbidity and statistics at offshore water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for are means ± se, range and percentiles (n = 69 to 2877). Baseline values modified from Fox 2018.

Site	Statistic	Turbidity (NTU)		
		Surface September	Surface Baseline	Benthic September
OS1	Mean ± se	8.8 ± 0.1	7.5	71 ± 1
	Range	<1 – 31	-	4 – 388
	99th	26	24	312
	95th	17	16	217
	80th	12	10	115
OS2	Mean ± se	7.5 ± 0.1	6.4	54 ± 1
	Range	2 – 24	-	8 – 298
	99th	18	18	187
	95th	12	13	127
	80th	9.3	9.0	78
OS3	Mean ± se	8.5 ± 0.1	6.6	85 ± 2*
	Range	1 – 46	-	27 – 194
	99th	28	27	189
	95th	18	15	159
	80th	11	8.9	120
OS4	Mean ± se	5.4 ± 0.1	5.9	60 ± 1
	Range	<1– 27	-	4 – 198
	99th	15	20	261
	95th	11	13	191
	80th	8.0	8.3	103
OS5	Mean ± se	5.0 ± 0.0	4.6	–
	Range	<1 – 16	-	–
	99th	11	19	–
	95th	8.7	11	–
	80th	6.3	6.4	–
OS6	Mean ± se	6.2 ± 0.0	4.7	48 ± 2*
	Range	1 – 21	-	10 – 188
	99th	12	19	179
	95th	9.9	12	110
	80th	7.7	7.2	65
OS7	Mean ± se	6.5 ± 0.0	6.4	–
	Range	<1 – 26	-	–
	99th	15	23	–
	95th	11	14	–
	80th	8.5	9.2	–

** Limited data available for OS3 and OS6 benthic turbidity*

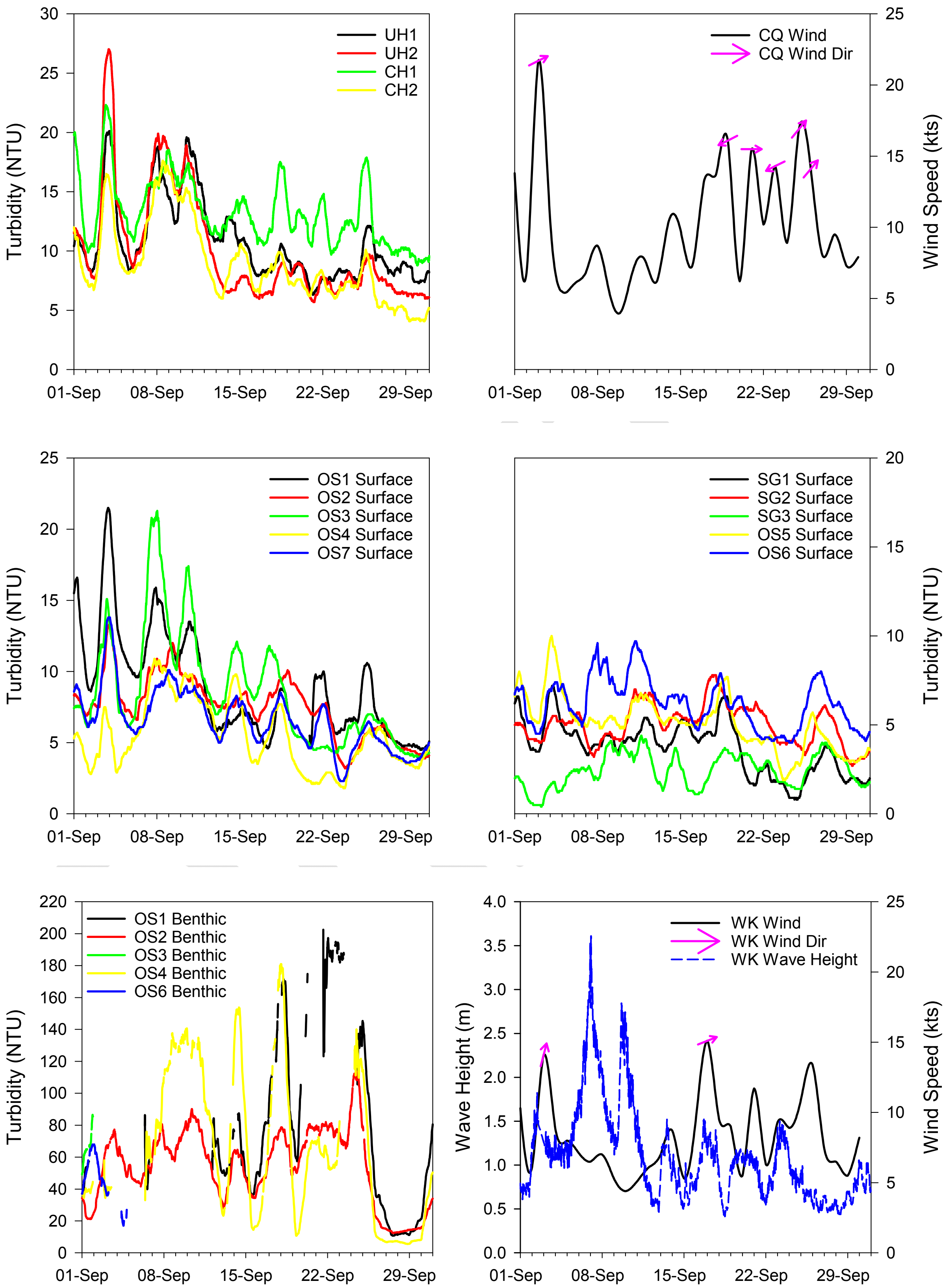


Figure 4 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 14 knots.

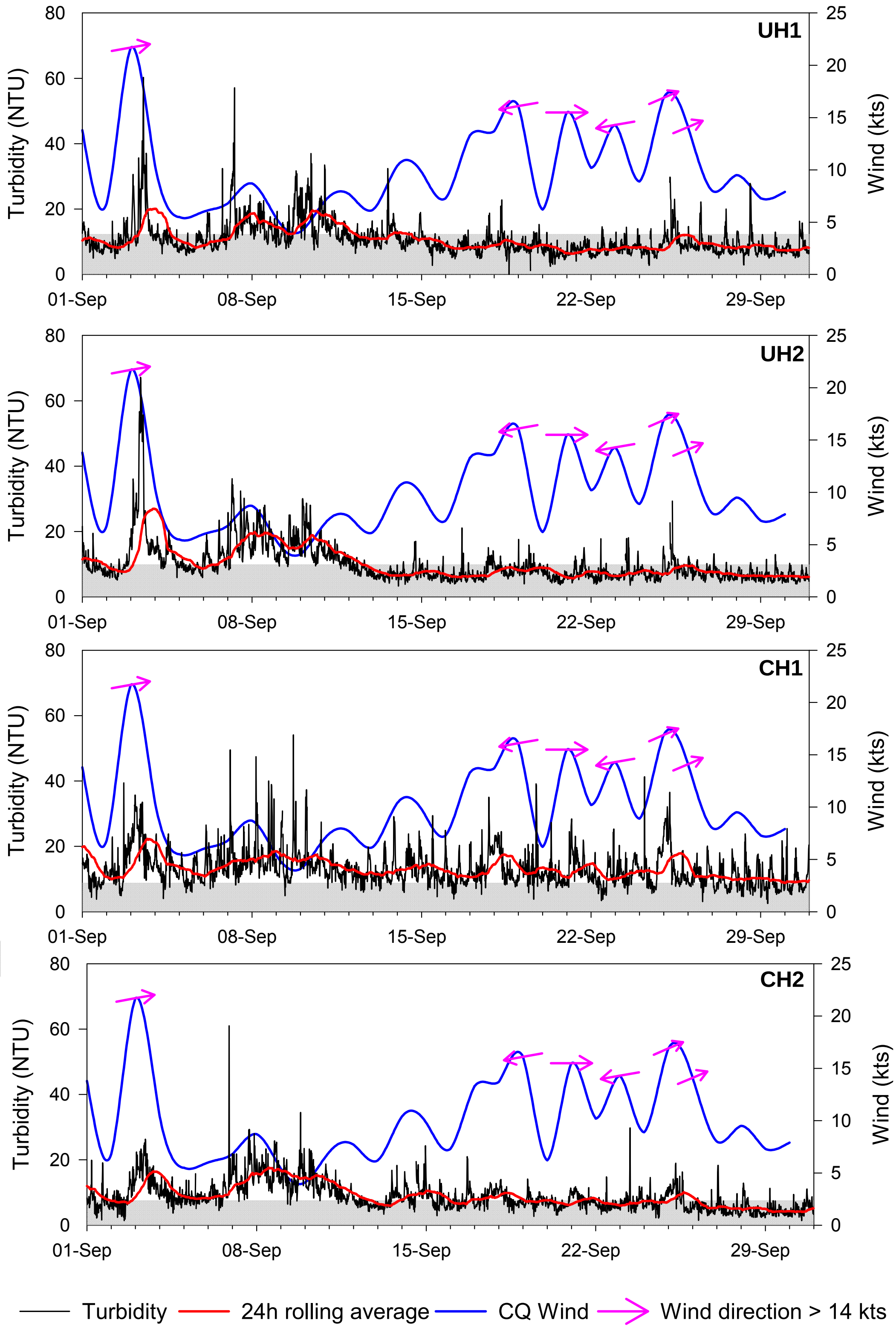


Figure 5 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Baseline mean shaded in grey.

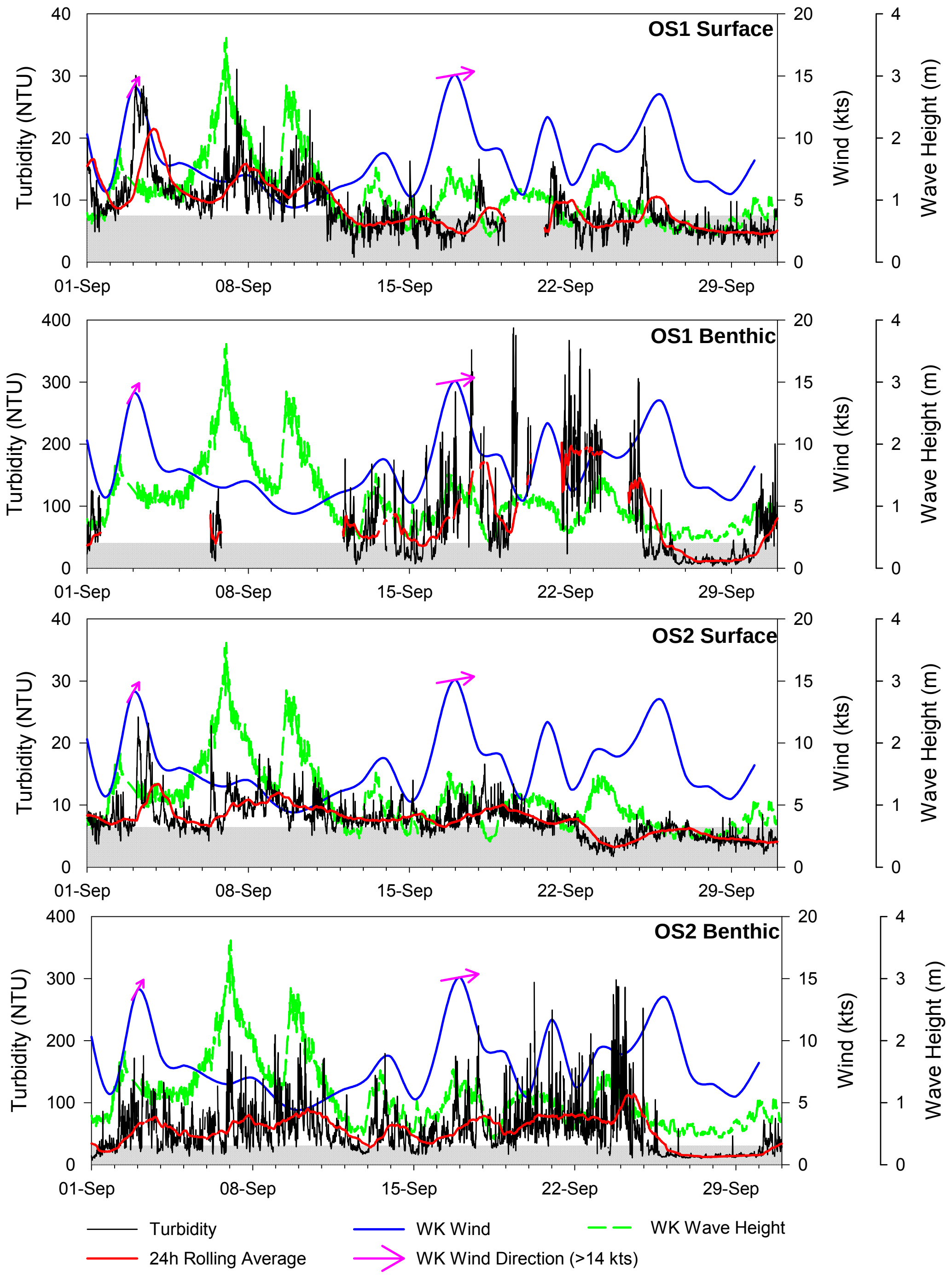


Figure 6 Surface and benthic turbidity and daily averaged winds at offshore sites (OS1 and OS2) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Baseline mean shaded in grey.

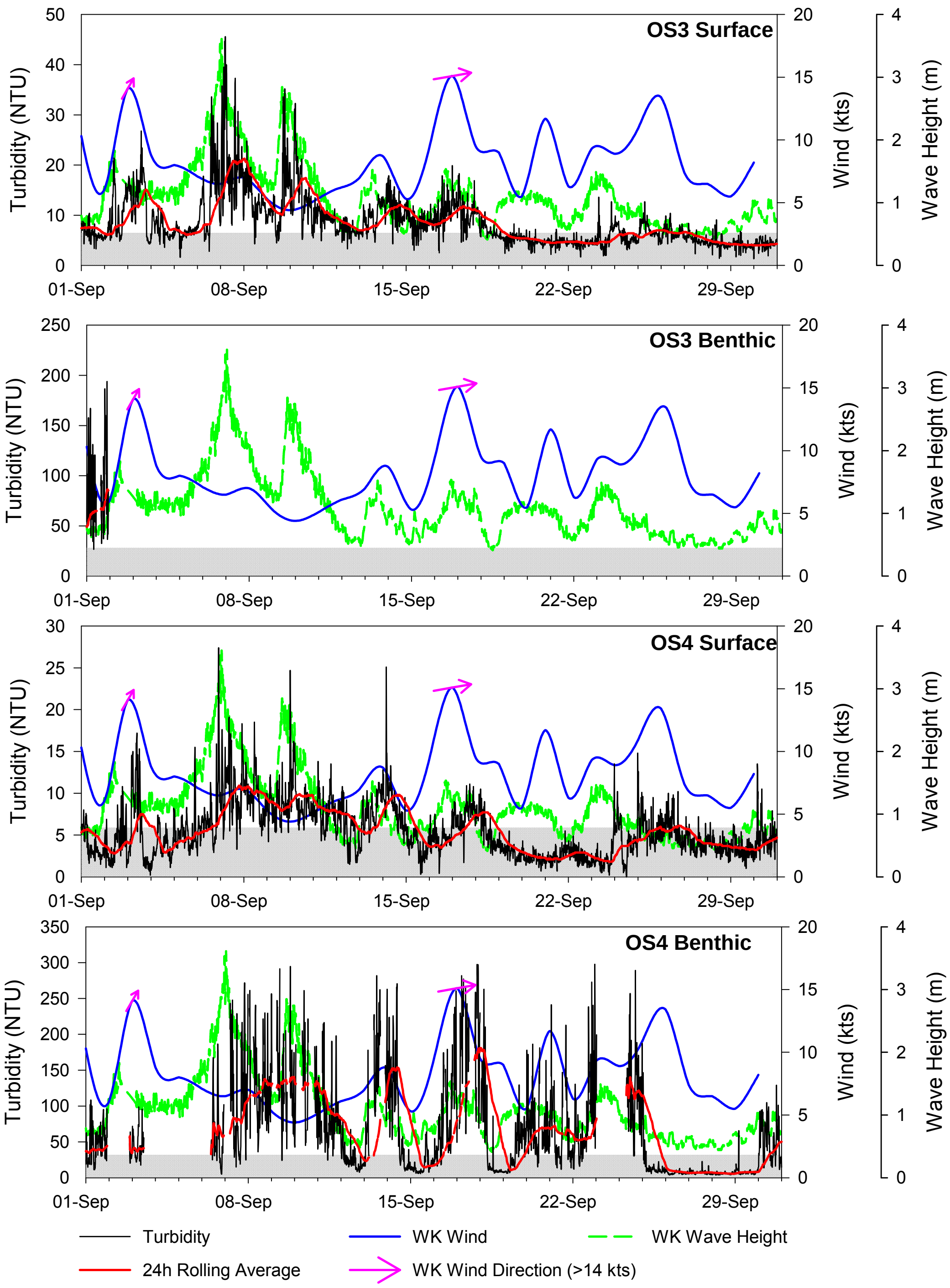


Figure 7 Surface and benthic turbidity and daily averaged winds at offshore sites (OS3 and OS4) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Baseline mean shaded in grey.

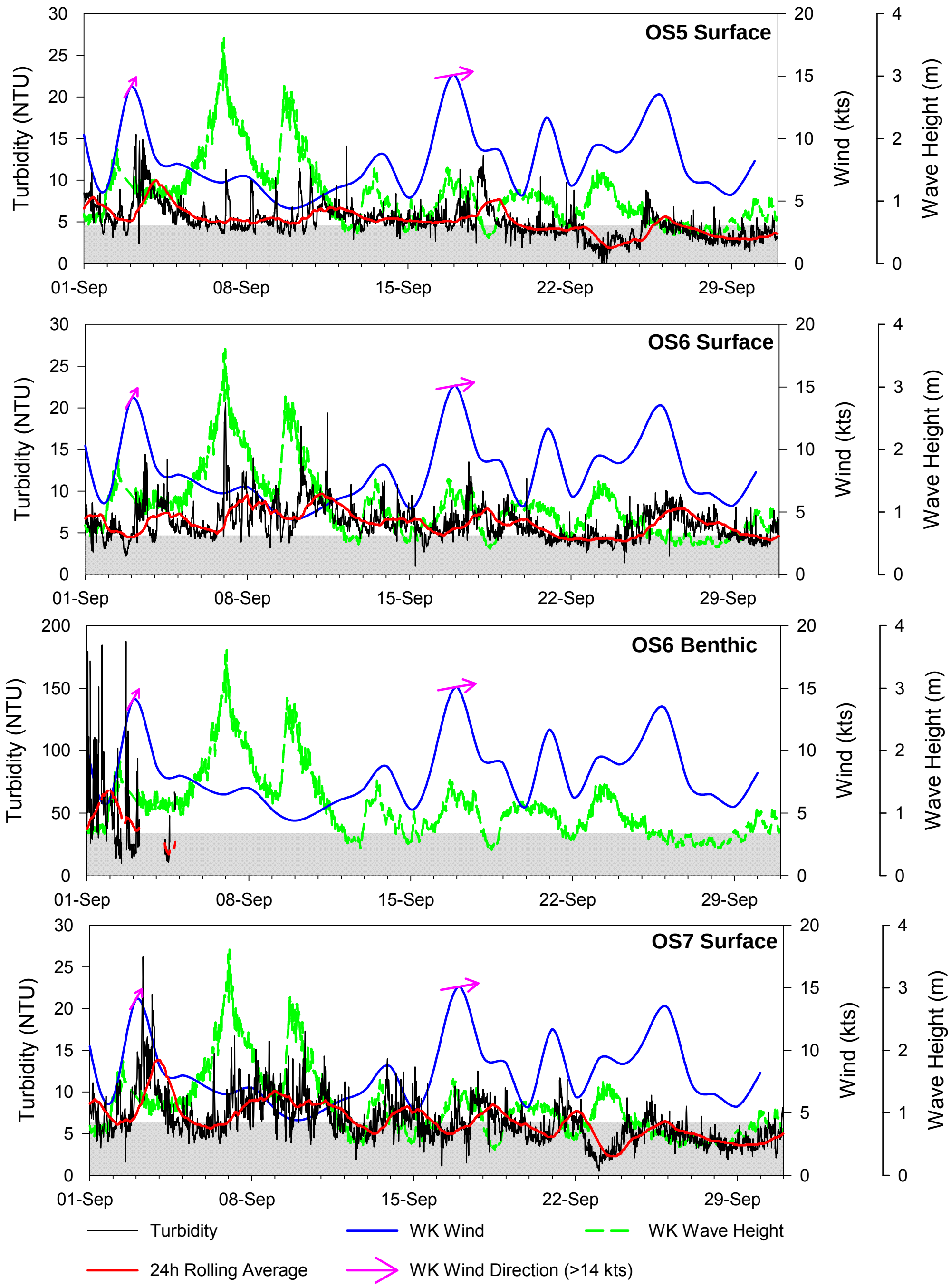


Figure 8 Surface and benthic turbidity and daily averaged winds at offshore sites (OS5, OS6 and OS7) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Baseline mean shaded in grey.

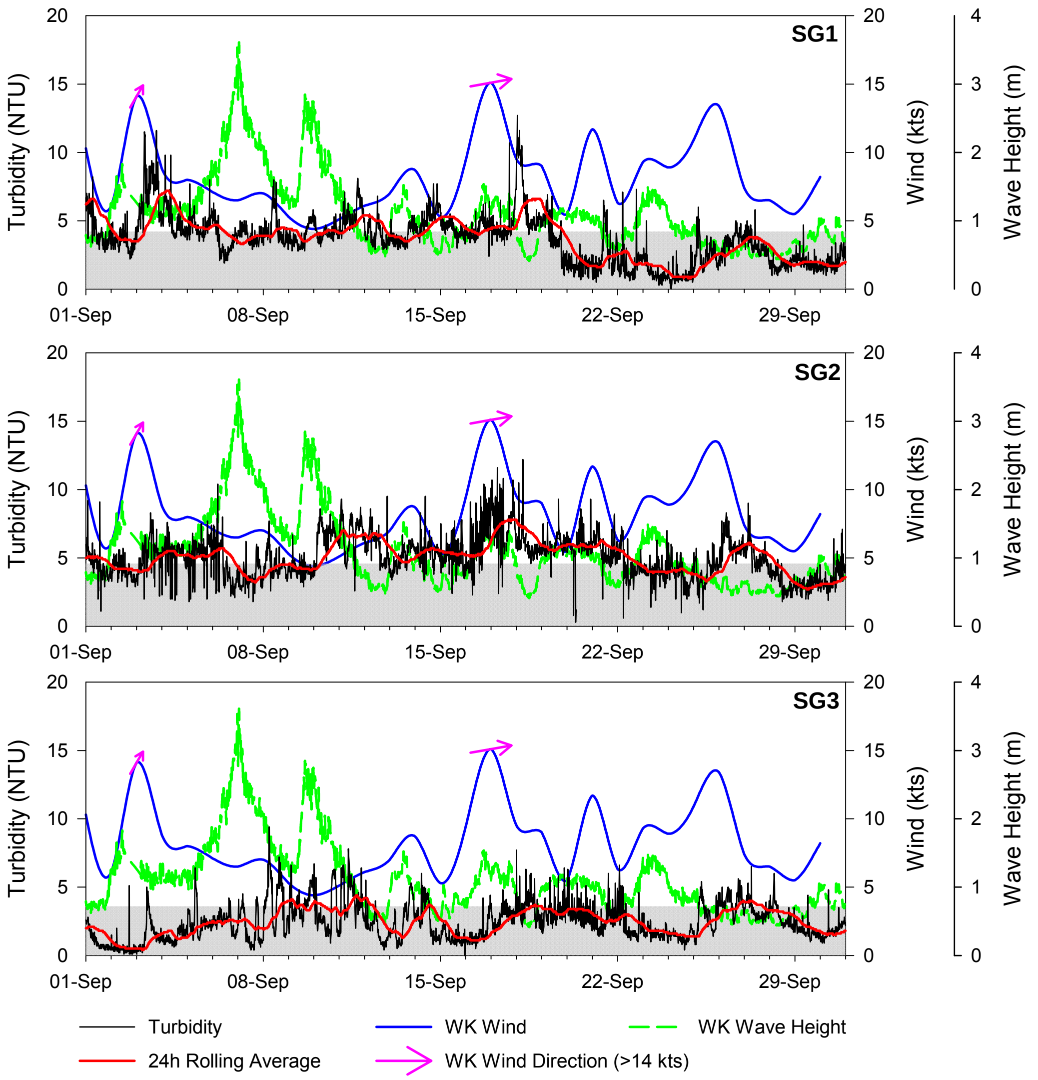


Figure 9 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) from 1 to 30 September 2018. *Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 14 knots. Baseline mean shaded in grey.*

3.2.2 Dredge Compliance Trigger Values

Management of dredge operations from commencement of the works on the 29 August 2018 was guided by the use of three tier levels of turbidity trigger values based on the higher order percentiles (refer 2.1.2). Tier 1 (80^{th} percentile) and Tier 2 (95^{th} percentile) intensity values are for LPC internal use and provide early warning mechanisms of elevated turbidity conditions. A compliance alert is 'tripped' if:

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

The Tier 1 to 3 intensity levels for KZ smoothed data and allowable hours calculated for the project (Fox, 2018), are outlined in Table 5.

Table 5 Turbidity intensity values for each site and allowable hours of exceedance in rolling 30 day period.
Allowable hours for tiers 1 and 2 are indicative only and non-binding as these are for internal LPC use only.

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

3.2.2.1 P99 Exceedance Counts

During September the Tier 3 intensity values were exceeded at inner and central harbour sites UH2, CH1 and CH2 (Table 6, Figure 10), but not UH1. Despite the elevated turbidity, none of the sites exceeded the allowable hour count of 7.2 hours in the rolling 30 day window. Site UH2 displayed the greatest number of hour counts in the inner harbour, reaching 6.25 hours on 3 September. Tier 3 intensity values were also exceeded for nearshore sites OS1, OS2 and OS3 (Table 6, Figure 11). There is no trigger value for reference site OS4. Allowable hours were also exceeded for OS1 which reached a peak of 13 h during the extreme wind and rain event from 2 September. Remaining sites did not exceed the allowable hours during this time (Table 6, Figure 11). Tier 3 intensity values were not exceeded at any time at the spoil ground sites or OS5 and OS6 during the month of September.

Table 6 Tier 3 intensity value exceedances and allowable hour counts from 1 to 30 September 2018.

Site	P99 Count >7.2 Hours Start Time	P99 Count >7.2 Hours End Time	Maximum P99 Count (Hours)
UH1			0.00
UH2			6.25
CH1			3.00
CH2			3.00
OS1	3/09/2018 08:15	6/09/2018 05:00*	13.0
OS2			6.00
OS3			2.25
OS4		Reference site	
OS5			0.00
OS6			0.00
OS7			0.00
SG1			0.00
SG2			0.00
SG3			0.00

* Counts manually removed after application to ECan approved.

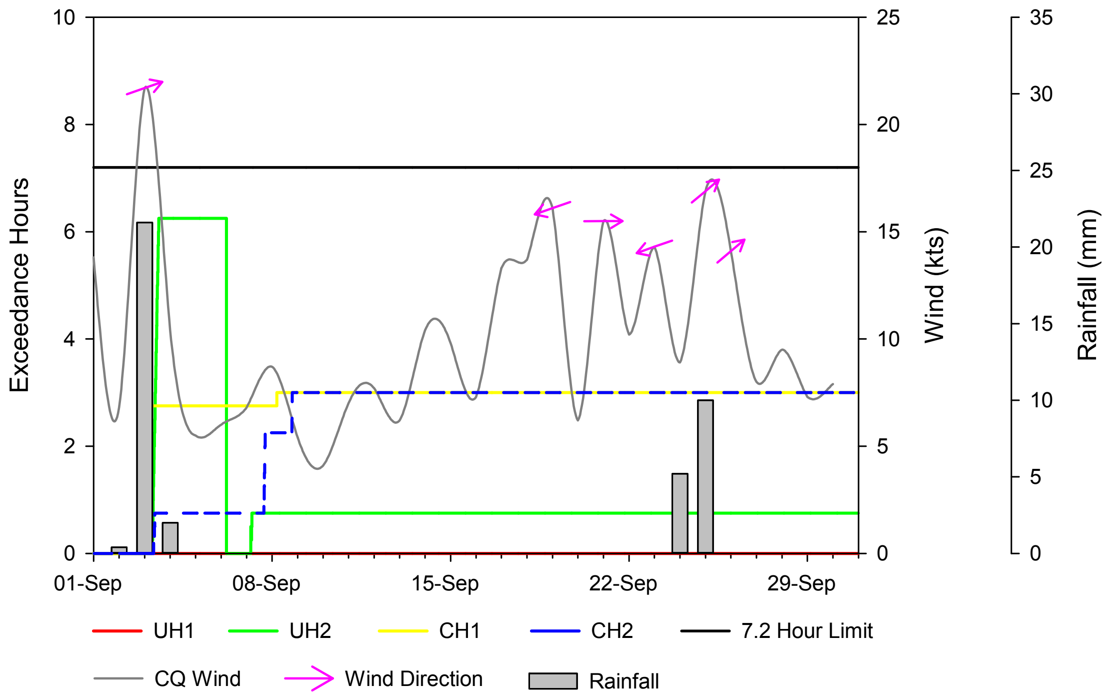


Figure 10 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH3 after exceedance of the intensity value from 1 to 30 September 2018.

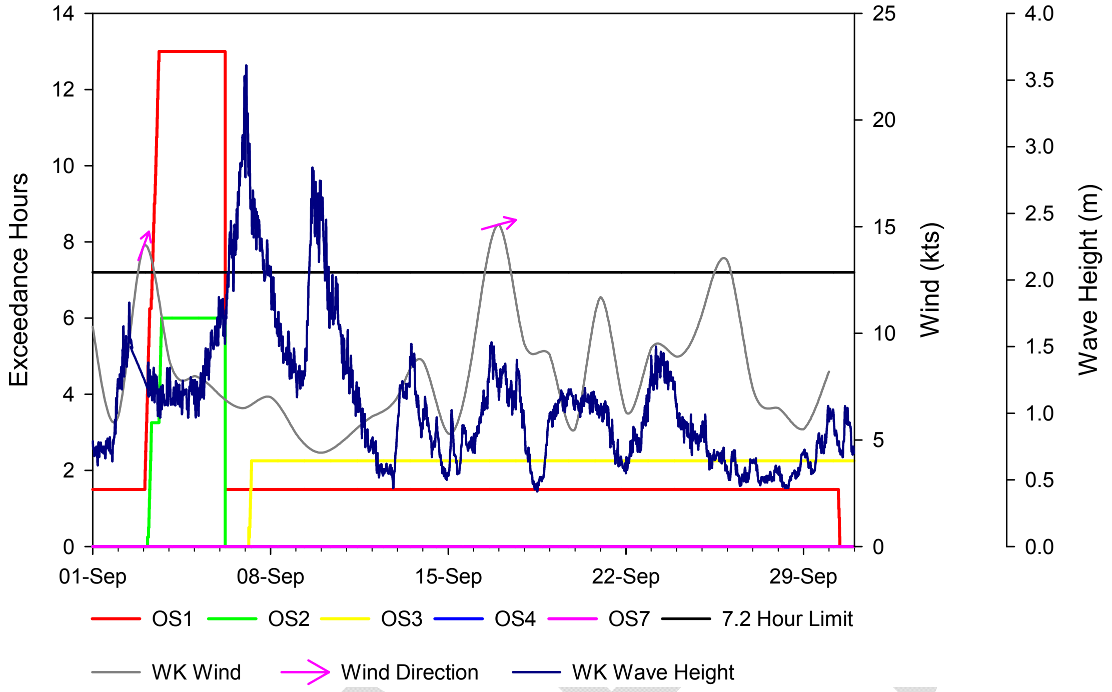


Figure 11 Tier 3 allowable hour counts at OS1, OS2, OS3 and OS7 after exceedance of the intensity value from 1 to 30 September 2018.
Note there is no trigger value for reference site OS4.

3.2.2.2 P99 Exceedance Counts Consented Removal

Following strong winds and heavy localised rainfall from 2 to 3 September, several monitoring stations exceeded the Tier 3 turbidity triggers for both intensity and/or duration. A report was submitted to ECan following this event, which was subsequently classed an 'extraordinary event'. On 6 September, turbidity hour counts for sites OS1, OS2 and UH2 during this period of anomalous weather conditions were removed from the monitoring statistics (Table 7), resulting in a drop in hour counts for these sites at this time (Figures 10 and 11).

Table 7 Hour counts removed from monitoring statistics during September 2018.

Site	Start Time (NZST)	End Time (NZST)
UH2	3 September 2018 0316	3 September 2018 1640
OS1	3 September 2018 0609	3 September 2018 1923
OS2	3 September 2018 0854	3 September 2018 1525

3.2.3 Temperature

Average surface water temperatures during September were slightly warmer than those experienced during August, ranging from 10.4 to 10.9°C (Table 8), c.f. 9.3 to 9.8°C in August. Contrasting previous winter months, the shallow waters of the upper and central harbour displayed the warmest mean temperatures. All sites displayed a warming trend across the month, with cooler temperatures occurring during periods of rainfall on 3 and 25 September (Figures 12 and 13). Semidiurnal variability (associated with tidal water movements and solar radiation) was once again observed within the datasets.

Benthic monthly mean temperatures were up to 0.1 to 0.2°C cooler than those of the surface waters, with the exception of OS6 where limited data were available for statistical analysis. Benthic temperatures remained relatively stable during the first two weeks of September, with warming occurring during the latter two weeks of the month. The exception to this was at OS1, where benthic temperatures rose from 11 September and displayed a spatial heterogeneity from the remaining benthic sites (Table 8, Figure 13).

Table 8 Mean temperature at inshore, spoil ground and offshore water quality sites from 1 to 30 September 2018.
Values are means ± se (n = 522 to 2880).

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	10.9 ± 0.0	–
UH2	10.9 ± 0.0	–
CH1	10.6 ± 0.0	–
CH2	10.6 ± 0.0	–
SG1	10.5 ± 0.0	–
SG2	10.4 ± 0.0	–
SG3	10.5 ± 0.0	–
OS1	10.5 ± 0.0	10.4 ± 0.0
OS2	10.4 ± 0.0	10.2 ± 0.0
OS3	10.4 ± 0.0	10.2 ± 0.0
OS4	10.4 ± 0.0	10.2 ± 0.0
OS5	10.5 ± 0.0	–
OS6	10.4 ± 0.0	9.9 ± 0.0*
OS7	10.5 ± 0.0	–

**Limited benthic data are available for OS6.*

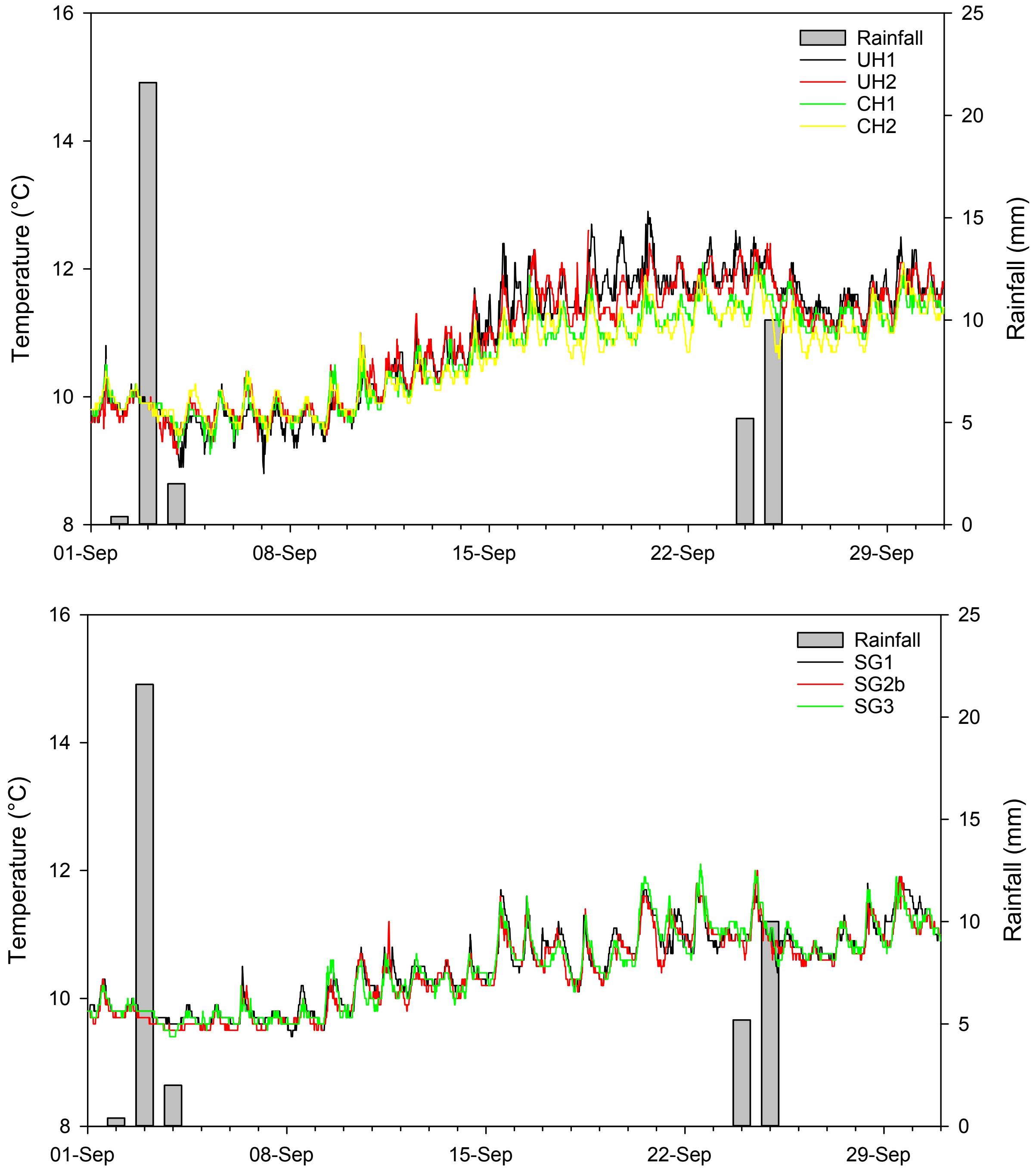
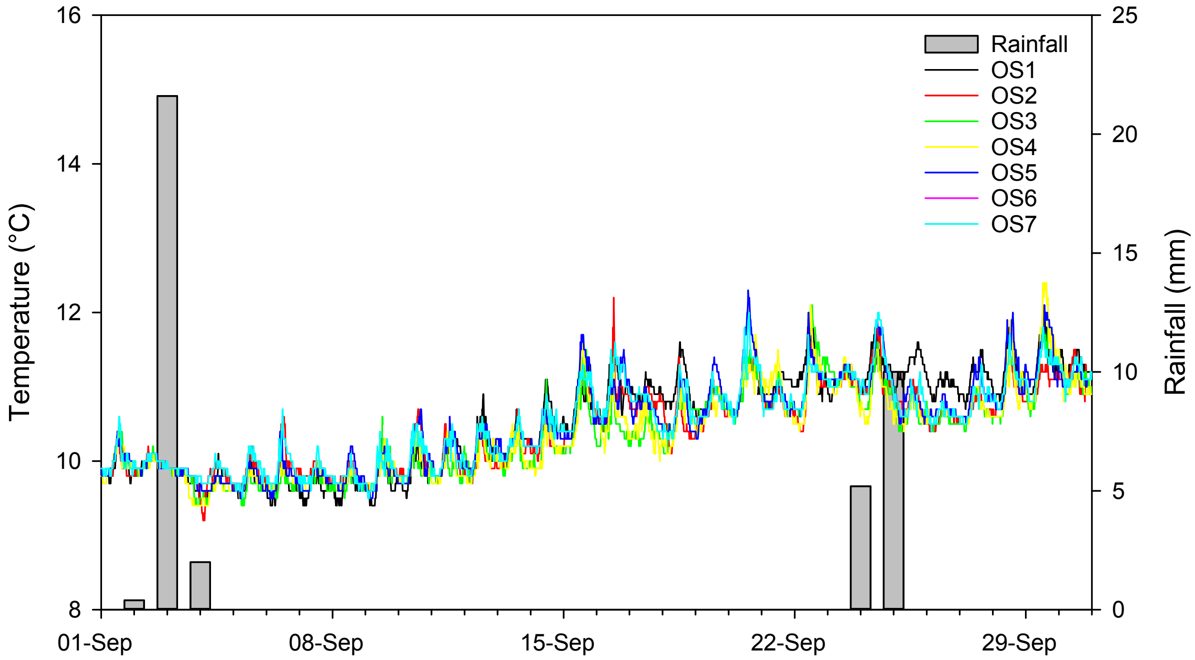


Figure 12 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall from 1 to 30 September 2018.



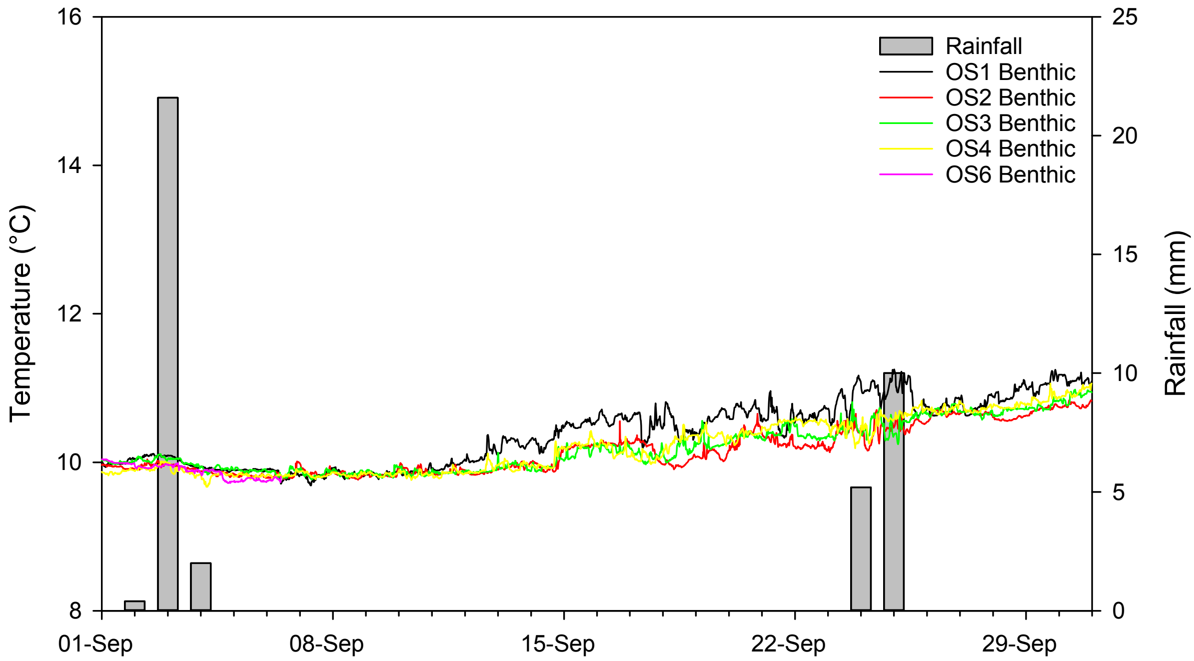


Figure 13 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 30 September 2018.

3.2.4 pH

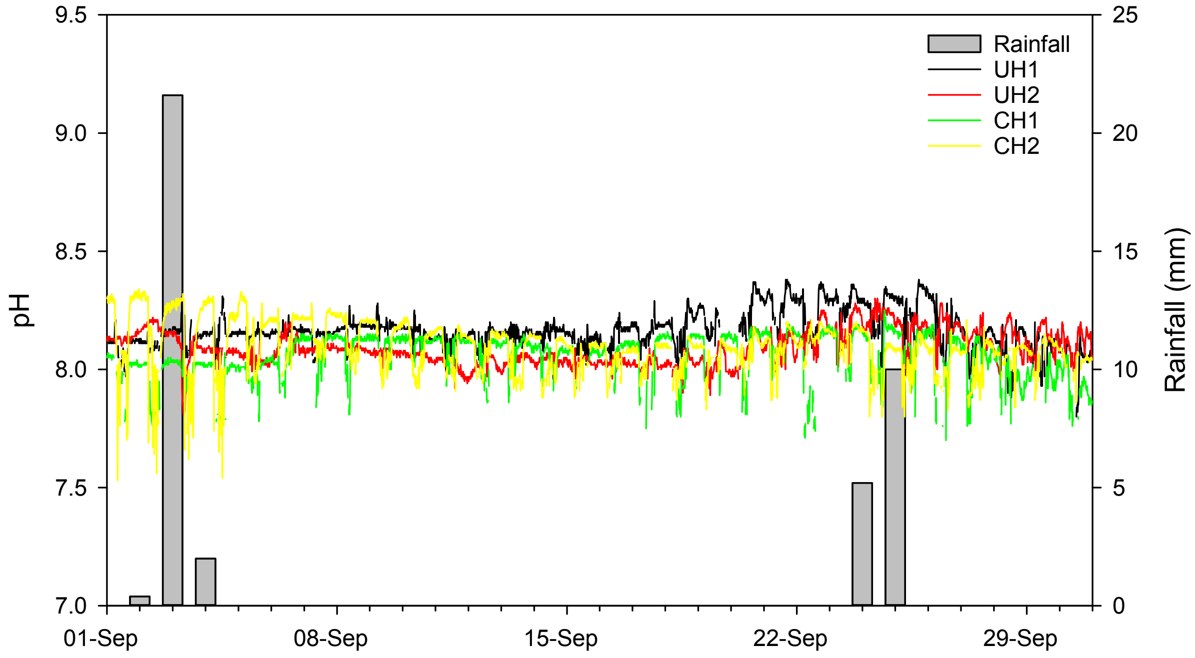
Once again, pH data collected from surface sondes did not demonstrate any particularly strong spatial patterns, with mean monthly surface pH for September ranging from 8.0 to 8.3 (Table 9). Temporally, surface pH did not appear to display any trends associated with the month's rainfall events or potential freshwater runoff (Figures 14 and 15) with the exception of CH1 which displayed larger cyclical declines in pH during the rainfall event in the first week of September. However, marked variability in pH was observed over the diurnal cycle at all sites (with the exception of SG1 and SG3), with declining pH and increased variance observed during daylight hours, particularly at the inshore and nearshore monitoring sites, and SG2.

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. During August, benthic pH at the reference site OS4 was observed to increase during periods of increased significant wave heights. No such similarity in timing was observed during September, despite elevated significant wave heights earlier in the month.

Table 9 Mean pH at inshore, spoil ground and offshore water quality sites from 1 to 30 September 2018.
Values are means ± se (n = 2366 to 2880).

Site	pH	
	Surface loggers	Benthic loggers
UH1	8.2 ± 0.0	–
UH2	8.1 ± 0.0	–
CH1	8.1 ± 0.0	–
CH2	8.1 ± 0.0	–
SG1	8.2 ± 0.0	–
SG2	8.3 ± 0.0	–
SG3	8.2 ± 0.0	–
OS1	8.1 ± 0.0	7.7 ± 0.0
OS2	8.1 ± 0.0	8.1 ± 0.0
OS3	8.0 ± 0.0	8.1 ± 0.0
OS4	8.1 ± 0.0	7.9 ± 0.0
OS5	8.1 ± 0.0	–
OS6	8.0 ± 0.0	–*
OS7	8.1 ± 0.0	–

**No benthic data are available for OS6.*



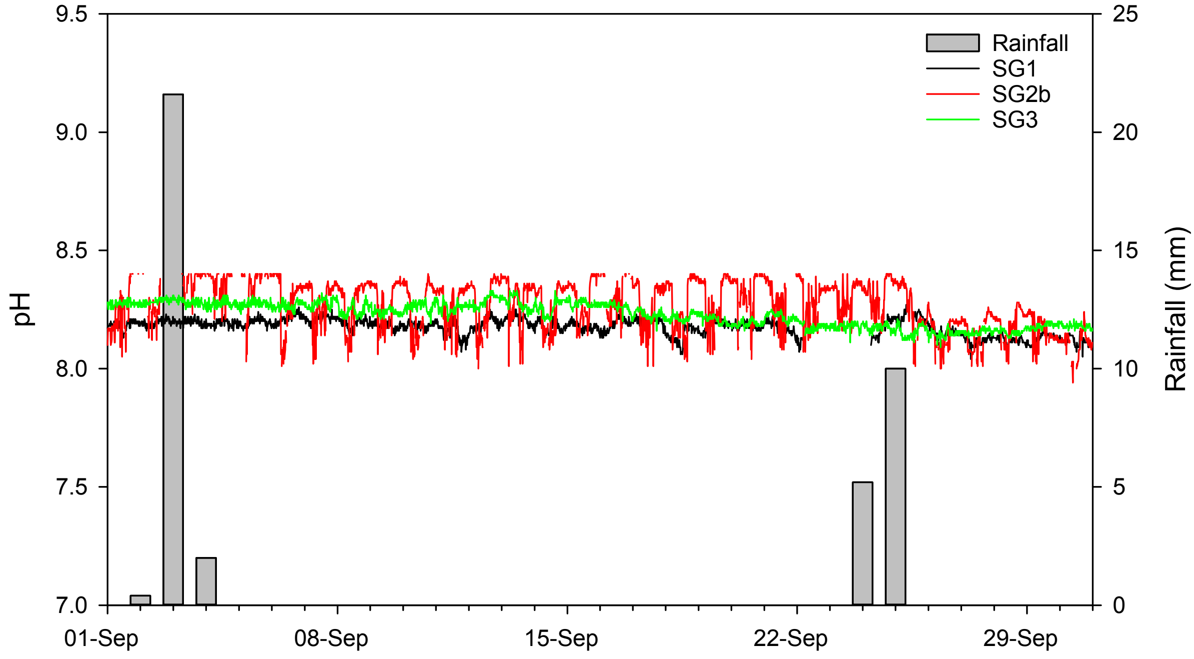
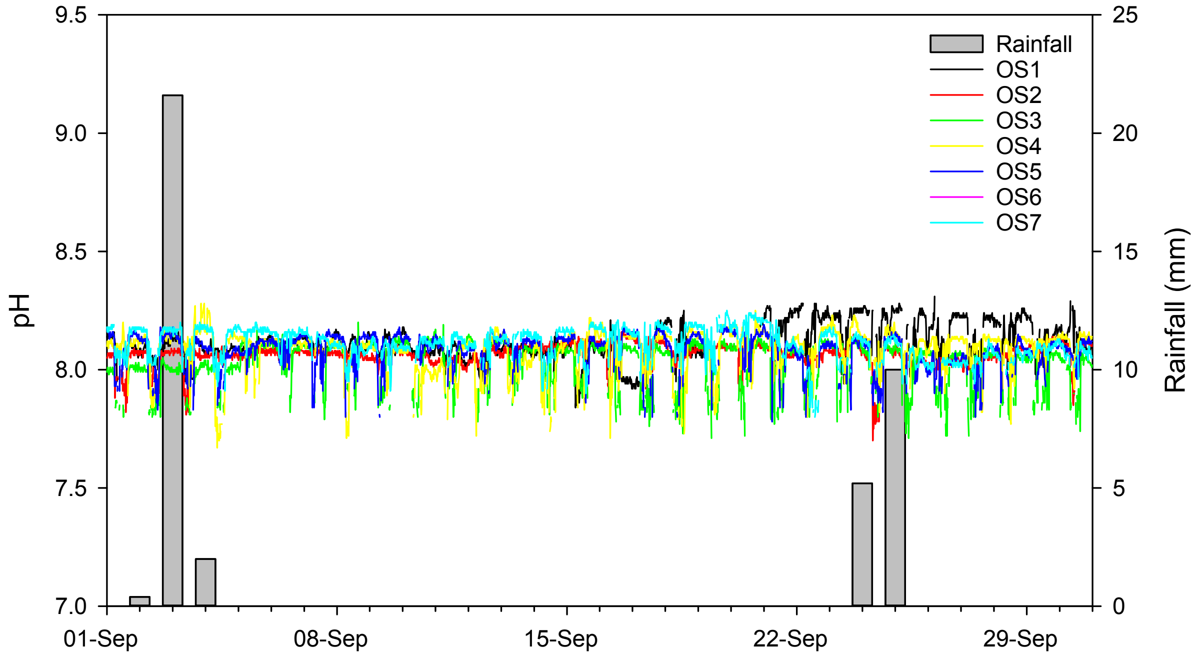


Figure 14 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 30 September 2018.



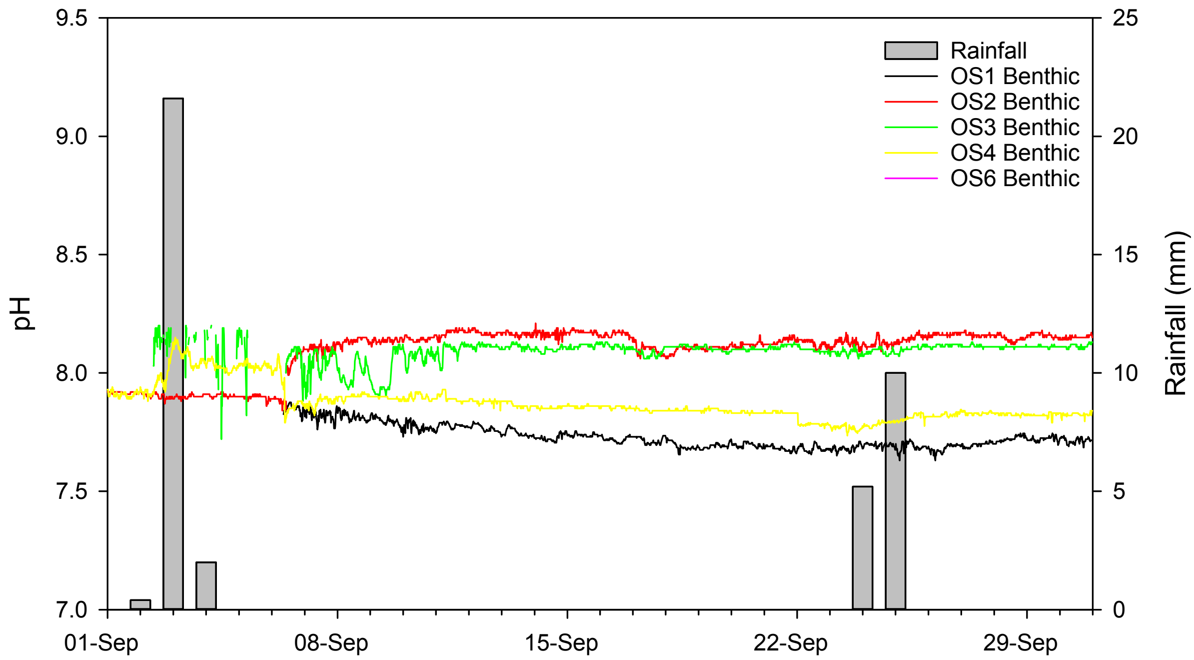


Figure 15 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 30 September 2018.

3.2.5 Conductivity

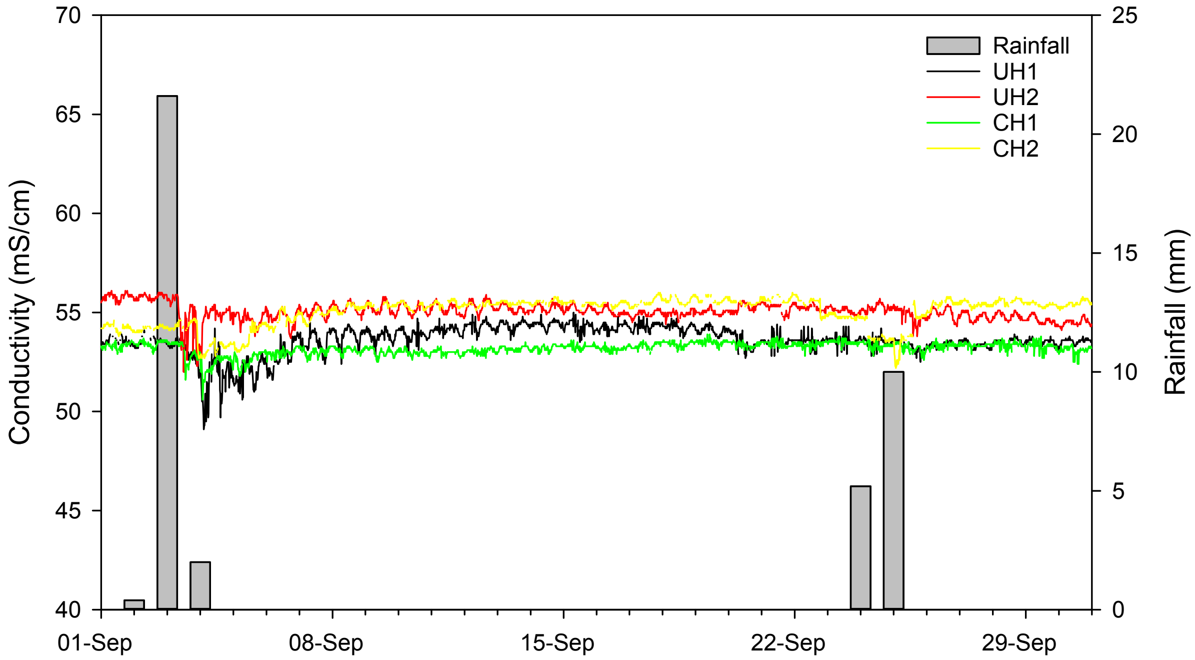
In a similar manner to previous months, mean conductivity for September did not reveal any significant spatial patterns across the monitoring sites (Table 10). Conductivity at UH2 displayed a drop following 21.6 mm of rainfall on 3 September, with the remaining central and upper harbour sites responding approximately a day later (Figure 16). Within the nearshore environment, surface conductivity at OS2 also declined on 4 September due to the significant rainfall event on 3 September. Conductivity at the remaining nearshore surface sites remained relatively stable during the month, with the exception of slight freshening at OS1 from 11 to 16 September and OS5 from 19 to 20 September (Figure 17). As typically observed, conductivity at the spoil ground sites also remained relatively stable throughout September. Three distinct drops in conductivity were observed on 8, 9 and 10 September at SG1, however, they do not correlate with rainfall measured at Cashin Quay nor any temperature anomalies at SG1.

Benthic data for September also appeared to remain relatively stable, with slightly greater variability observed at OS3 (Figure 17). Periods of localised rainfall did not result in variability in benthic conductivity, as lower density freshwater additions would remain at the surface of the water column.

Table 10 Mean conductivity at inshore, spoil ground and offshore water quality sites from 1 to 30 September 2018.
Values are means ± se (n = 299 to 2880).

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	53.6 ± 0.0	–
UH2	55.0 ± 0.0	–
CH1	53.2 ± 0.0	–
CH2	55.0 ± 0.0	–
SG1	54.5 ± 0.0	–
SG2	54.9 ± 0.0	–
SG3	55.0 ± 0.0	–
OS1	53.9 ± 0.0	54.3 ± 0.0
OS2	56.5 ± 0.0	53.6 ± 0.0
OS3	55.0 ± 0.0	55.9 ± 0.0
OS4	53.7 ± 0.0	55.8 ± 0.0
OS5	54.2 ± 0.0	–
OS6	54.3 ± 0.0	55.6 ± 0.0*
OS7	54.0 ± 0.0	–

**Limited benthic data are available for OS6.*



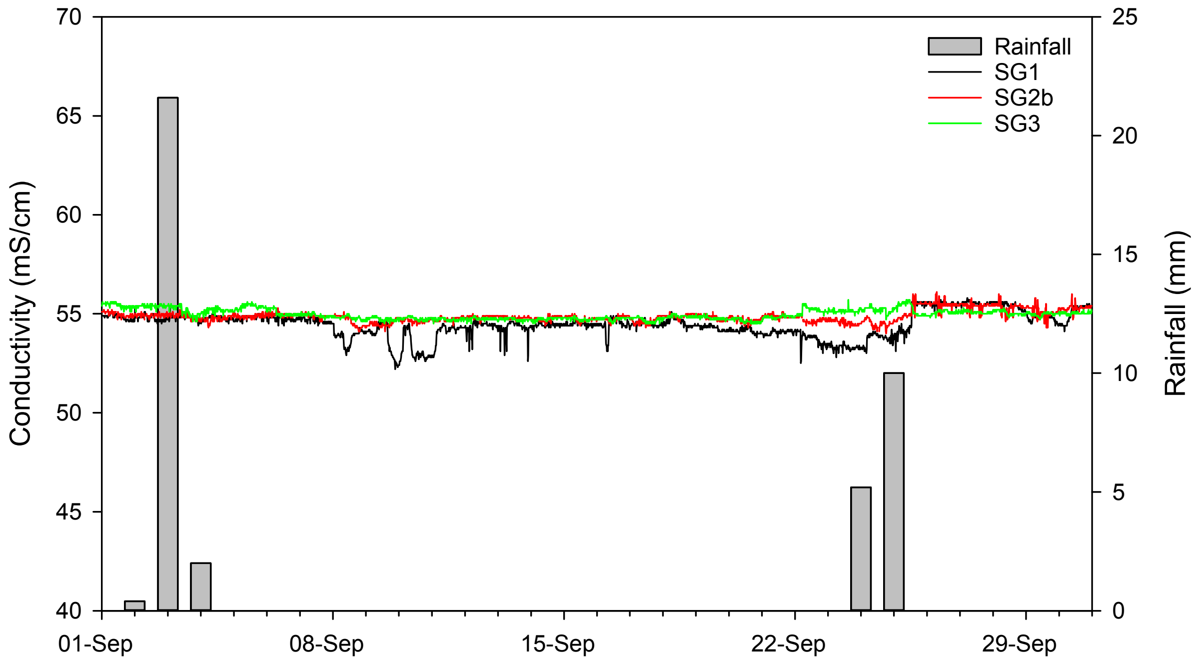
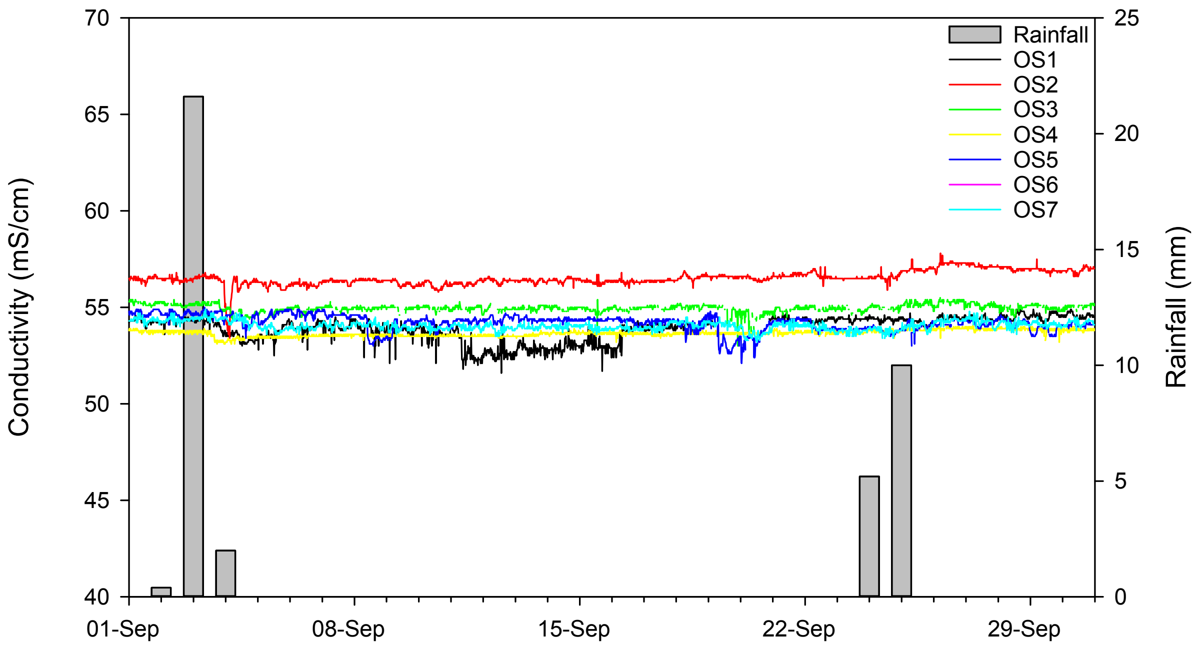


Figure 16 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 30 September 2018.



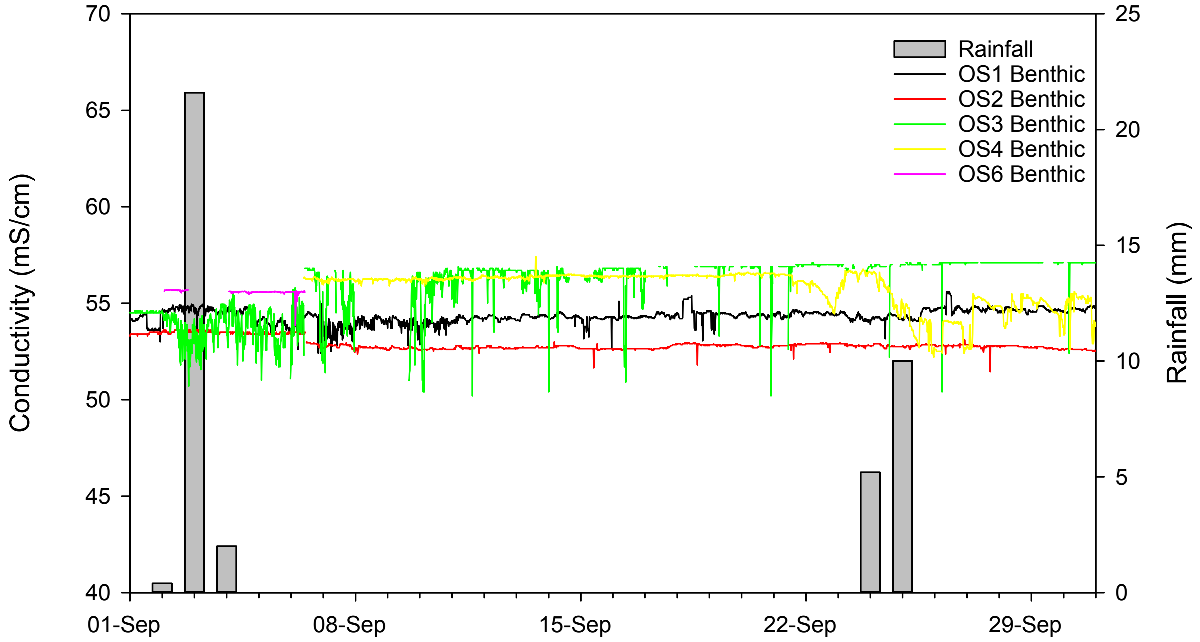


Figure 17 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at offshore water quality sites from 1 to 30 September 2018.

3.2.1 Dissolved oxygen

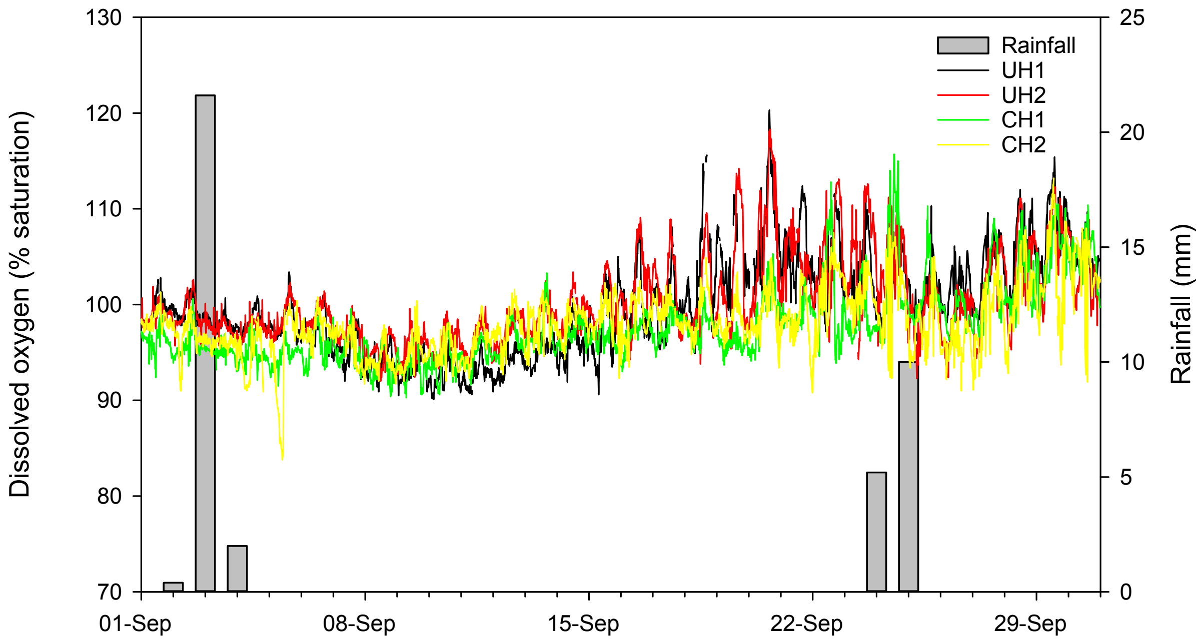
Mean monthly surface DO concentrations ranged from 96 to 104% saturation, with no apparent spatial patterns across the sites (Table 11). Within the central and upper harbour, DO concentrations displayed a slight declining trend during the first week of September, followed by a notable increase in both concentration and diurnal variation that may be indicative of increased phytoplankton concentrations. A slight decline in DO was also observed at both the harbour and nearshore monitoring stations around 25 and 26 September, following a brief period of rainfall (Figures 18 and 19). Dissolved oxygen concentrations at the spoil ground sites remained relatively stable throughout September, with the largest variability occurring as a drop in DO concentration at both SG1 and SG2b on 18 September (Figure 18), which does not appear to be related to metocean conditions.

Benthic data recovery for dissolved oxygen was relatively high for the majority of sites. As typically observed, mean monthly benthic DO concentrations were slightly lower than the corresponding surface readings, due to reduced photosynthesis (producing less oxygen) occurring at depth. Variability in benthic DO concentration was particularly enhanced around 7 and 10 October (Figure 19), coinciding with elevated offshore significant wave heights. This additional energy within the water column would have enhanced vertical mixing, bringing higher DO surface waters to the benthic environment.

Table 11 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites from 1 to 30 September 2018.
Values are means ± se (n = 2362 to 2880).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	100 ± 0	–
UH2	100 ± 0	–
CH1	98 ± 0	–
CH2	98 ± 0	–
SG1	101 ± 0	–
SG2	100 ± 0	–
SG3	104 ± 0	–
OS1	96 ± 0	96 ± 0
OS2	98 ± 0	92 ± 0
OS3	97 ± 0	94 ± 0
OS4	100 ± 0	97 ± 0
OS5	100 ± 0	–
OS6	99 ± 0	–*
OS7	99 ± 0	–

**No benthic data are available for OS6.*



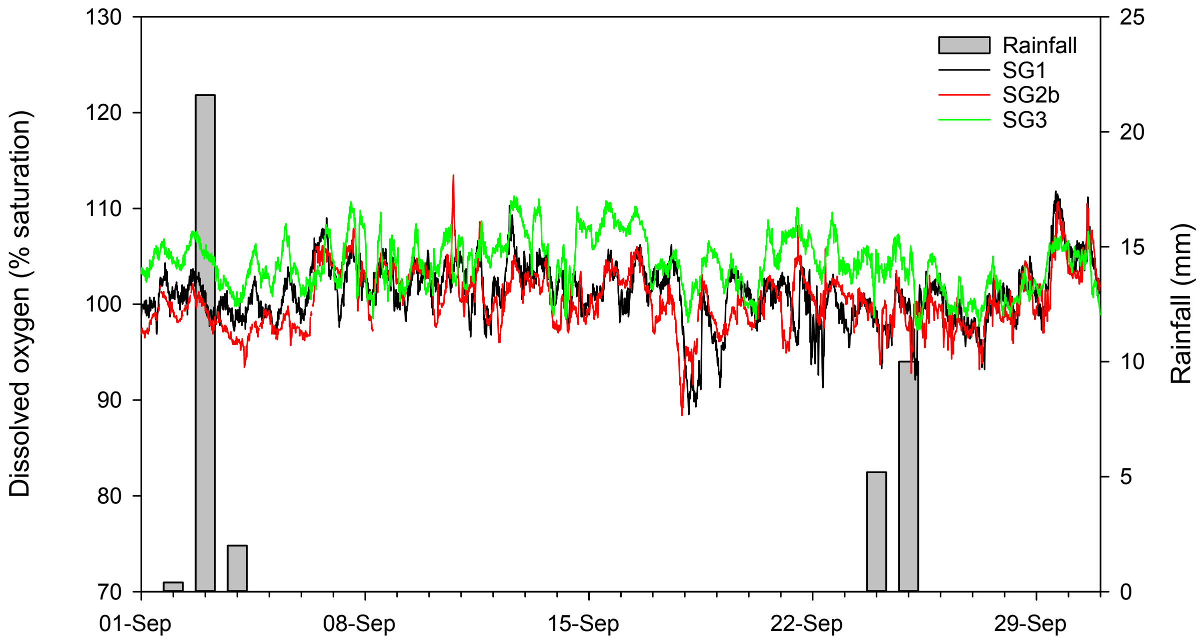


Figure 18 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites from 1 to 30 September 2018.

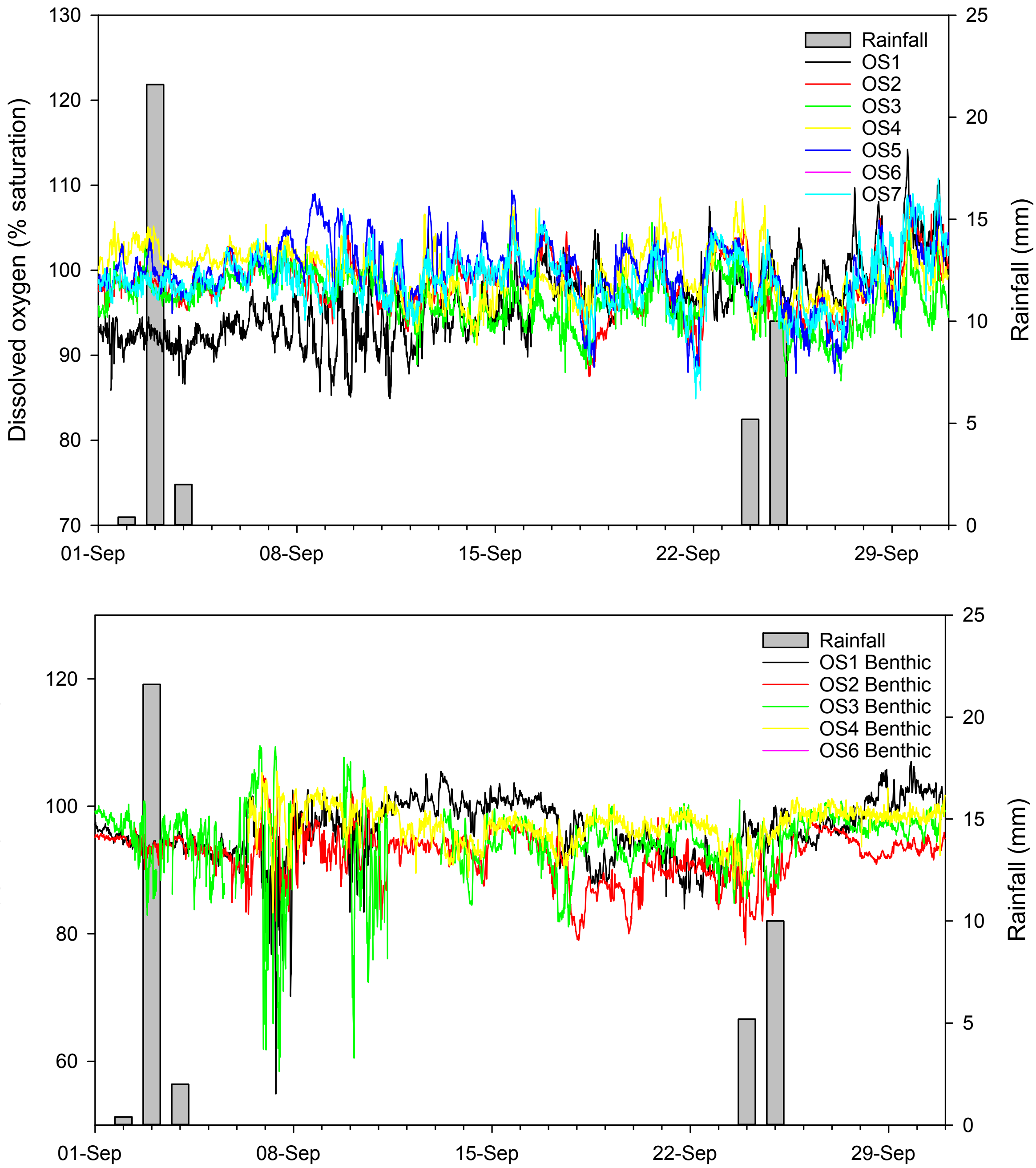


Figure 19 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at offshore water quality sites from 1 to 30 September 2018.

3.3 Physicochemistry Depth Profiling & TSS

On 11 September 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 12 to 14, with depth profile plots presented in Figures 20 to 22.

Unfortunately, the YSI ProDSS used to collect data through vertical water profiling displayed connectivity issues during the monthly sampling, causing intermittent loss of sensor parameters (predominately pH). The unit has since been repaired at Xylem Analytics for the October sampling. The spare VE instrument was on loan to Boskalis during the field operations thus was not available for use during the field sampling event.

The relatively shallow sites of the upper and central harbour were once again vertically well mixed. Benthic waters within the harbour were also characterised by slight increases in turbidity (Figure 20, Table 12). The highest levels of sub-surface turbidity and TSS were recorded at the upper harbour site UH1 (10 NTU, 23 mg/L TSS, Table 12), with measured turbidity on the limit of reported WQGs.

Within the nearshore environment, vertical profiles also indicated a high level of vertical mixing, with slightly warmer surface waters at all sites (Figure 21). As previously observed, benthic waters were also characterised by increases in turbidity, particularly at sites OS1 and OS7 (Figure 21). During the July and August monitoring, vertical profiles at OS1 were characterised by lower temperature and conductivity characteristics when compared to the remaining nearshore sampling sites. Temperature at OS1 during September was within the range expected from the nearby sites, however, conductivity remained slightly fresher.

Similar to the inshore and nearshore vertical profiles, conductivity data from the spoil ground sites, OS5 and OS66 indicate a well-mixed water column (Figure 22). Surface temperatures also displayed slight warming, most likely due to solar insolation as the seasons progress towards summer. Of note, however, were the reduced oxygen concentrations near the seafloor at sites SG2b and SG3 (Figure 22). These notable declines in DO near the benthos were not observed at other sites. These reductions in benthic DO are likely induced by *in situ* consumption of dissolved oxygen.

As previously observed during baseline monitoring, the clearest waters were observed at the deeper offshore spoil ground sites, with the calculated euphotic depth extending down to 11.2 m at SG2b (Table 14). Elevated concentrations of particulate matter within the water column did however increase light attenuation at SG3, resulting in a shallower than expected euphotic depth of only 5.1 m. No exceedances of WQG were observed for sub-surface turbidity during the September sampling.

Table 12 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during September 2018 sampling event. *Values are means ± se (n =5 to 6 for sub-surface, n = 22 to 38 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
UH1	11/09/2018 08:26	Sub-surface	9.9 ± 0.0	–	51.4 ± 0.0	94 ± 0	10 ± 0	23	1.8 ± 0.0	2.6
		Whole column	9.9 ± 0.0	–	51.4 ± 0.0	93 ± 0	11 ± 0	–		
UH2	11/09/2018 08:36	Sub-surface	10.0 ± 0.0	–	51.7 ± 0.0	96 ± 0	8.5 ± 0.1	16	1.5 ± 0.0	3.0
		Whole column	10.0 ± 0.0	–	51.7 ± 0.0	95 ± 0	14 ± 2	–		
UH3	11/09/2018 07:48	Sub-surface	10.0 ± 0.0	–	50.9 ± 0.1	95 ± 0	8.7 ± 0.2	15	1.7 ± 0.1	2.7
		Whole column	10 ± 0.0	–	51.2 ± 0.1	94 ± 0	15.± 3	–		
CH1	11/09/2018 09:38	Sub-surface	9.9 ± 0.0	–	51.7 ± 0.0	95 ± 0	6.3 ± 0.1	17	1.3 ± 0.0	3.4
		Whole column	9.8 ± 0.0	–	51.9 ± 0.0	94 ± 0	14 ± 2	–		
CH2	11/09/2018 09:04	Sub-surface	9.9 ± 0.0	–	52.0 ± 0.0	96 ± 0	7.3 ± 0.1	15	1.6 ± 0.4	3.0
		Whole column	9.8 ± 0.0	–	52.1 ± 0.0	96 ± 0	17 ± 3	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during September 2018 sampling event. *Values are means ± se (n = 3 to 6 for sub-surface, mid and benthos, n = 23 to 36 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS1	11/09/2018 10:03	Sub-surface	9.9 ± 0.0	–	51.9 ± 0.0	96 ± 0	4.8 ± 0.1	11	0.9 ± 0.0	5.4
		Mid	9.8 ± 0.0	–	52.3 ± 0.1	97 ± 0	4.5 ± 0.1	9		
		Benthos	9.8 ± 0.0	–	52.4 ± 0.0	99 ± 0	31 ± 24	9		
		Whole column	9.8 ± 0.0	–	52.1 ± 0.0	97 ± 0	8.2 ± 3.2	–		
OS2	11/09/2018 13:17	Sub-surface	10.0 ± 0.1	–	52.5 ± 0.0	100 ± 0	4.0 ± 0.2	8	0.9 ± 0.0	5.3
		Mid	9.7 ± 0.0	–	52.6 ± 0.0	97 ± 0	6.5 ± 0.2	12		
		Benthos	9.8 ± 0.0	–	52.7 ± 0.0	95 ± 0	13 ± 1	34		
		Whole column	9.8 ± 0.0	–	52.6 ± 0.0	97 ± 0	6.6 ± 0.5	–		
OS3	11/09/2018 12:42	Sub-surface	9.9 ± 0.0	–	52.8 ± 0.0	101 ± 0	5.7 ± 0.1	13	0.9 ± 0.1	5.3
		Mid	9.7 ± 0.0	–	52.8 ± 0.0	100 ± 0	7.0 ± 0.2	14		
		Benthos	9.7 ± 0.0	–	52.8 ± 0.0	98 ± 0	16 ± 2	133		
		Whole column	9.8 ± 0.0	–	52.8 ± 0.0	100 ± 0	8.1 ± 0.7	–		
OS4	11/09/2018 12:14	Sub-surface	10.1 ± 0.0	–	52.8 ± 0.0	103 ± 0	3.8 ± 0.1	9	0.8 ± 0.1	5.8
		Mid	9.8 ± 0.0	–	52.8 ± 0.0	101 ± 0	5.9 ± 0.1	12		
		Benthos	9.7 ± 0.0	–	52.8 ± 0.0	100 ± 0	8.8 ± 1.3	16		
		Whole column	9.9 ± 0.0	–	52.8 ± 0.0	101 ± 0	5.7 ± 0.4	-		
OS7	11/09/2018 10:27	Sub-surface	9.9 ± 0.0	–	52.5 ± 0.0	100 ± 0	6.5 ± 0.1	15	1.5 ± 0.0	3.1
		Mid	9.7 ± 0.0	–	52.6 ± 0.0	100 ± 0	16 ± 1	39		
		Benthos	9.7 ± 0.0	–	52.6 ± 0.0	100 ± 0	30 ± 5	44		
		Whole column	9.8 ± 0.0	–	52.6 ± 0.0	100 ± 0	17 ± 1.9	–		
WQG			–	**7.0 – 8.5**	–	**80-110**	**10**	–	–	

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore and spoil ground sites during September 2018 sampling event.
Values are means ± se (n =0 to 6 for sub-surface, mid and benthos, n = 24 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_d	Euphotic Depth (m)
OS5	11/09/2018 10:44	Sub-surface	9.9 ± 0.0	–	52.4 ± 0.0	101 ± 0	4.6 ± 0.1	11	0.7 ± 0.0	6.3
		Mid	9.8 ± 0.0	–	52.5 ± 0.0	100 ± 0	3.5 ± 0.1	6		
		Benthos	9.8 ± 0.0	–	52.9 ± 0.0	96 ± 1	13 ± 7	10		
		Whole column	9.8 ± 0.0	–	52.6 ± 0.0	100 ± 0	5.5 ± 1.2	–		
OS6	11/09/2018 12:59	Sub-surface	10.1 ± 0.0	–	52.6 ± 0.0	99 ± 0	4.9 ± 0.1	9	0.7 ± 0.0	6.2
		Mid	9.7 ± 0.0	–	52.7 ± 0.0	100 ± 0	4.1 ± 0.1	7		
		Benthos	9.7 ± 0.0	–	52.9 ± 0.0	101 ± 0	2.9 ± 0.8	6		
		Whole column	9.8 ± 0.0	–	52.7 ± 0.0	99 ± 0	4.2 ± 0.2	–		
SG1	11/09/2018 11:03	Sub-surface	10.3 ± 0.0	–	52.7 ± 0.0	106 ± 0	1.8 ± 0.1	4	0.4 ± 0.0	10.4
		Mid	9.8 ± 0.0	–	52.9 ± 0.0	103 ± 0	1.6 ± 0.1	3		
		Benthos	9.8 ± 0.0	–	53.1 ± 0.0	98 ± 2	6.3 ± 3.2	10		
		Whole column	9.9 ± 0.0	–	52.9 ± 0.0	103 ± 1	2.4 ± 0.6	–		
SG2b	11/09/2018 11:27	Sub-surface	10.2 ± 0.0	–	52.8 ± 0.0	107 ± 0	2.0 ± 0.0	<3	0.4	11.2
		Mid	9.6 ± 0.0	–	52.9 ± 0.0	103 ± 0	1.2 ± 0.0	<3		
		Benthos	9.7 ± 0.0	–	52.9 ± 0.0	89 ± 4	–	7		
		Whole column	9.8 ± 0.0	–	52.9 ± 0.0	103 ± 1	1.5 ± 0.1	–		
SG3	11/09/2018 11:48	Sub-surface	10.3 ± 0.0	–	52.8 ± 0.0	103 ± 0	3.7 ± 0.1	6	0.9 ± 0.0	5.1
		Mid	9.7 ± 0.0	–	52.9 ± 0.0	95 ± 1	8.5 ± 0.6	11		
		Benthos	9.7 ± 0.0	–	53.0 ± 0.0	57 ± 18	14 ± 1	32		
		Whole column	9.9 ± 0.0	–	52.9 ± 0.0	95 ± 1	7.0 ± 0.5	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80-110**	**10**	**–**	**–**	

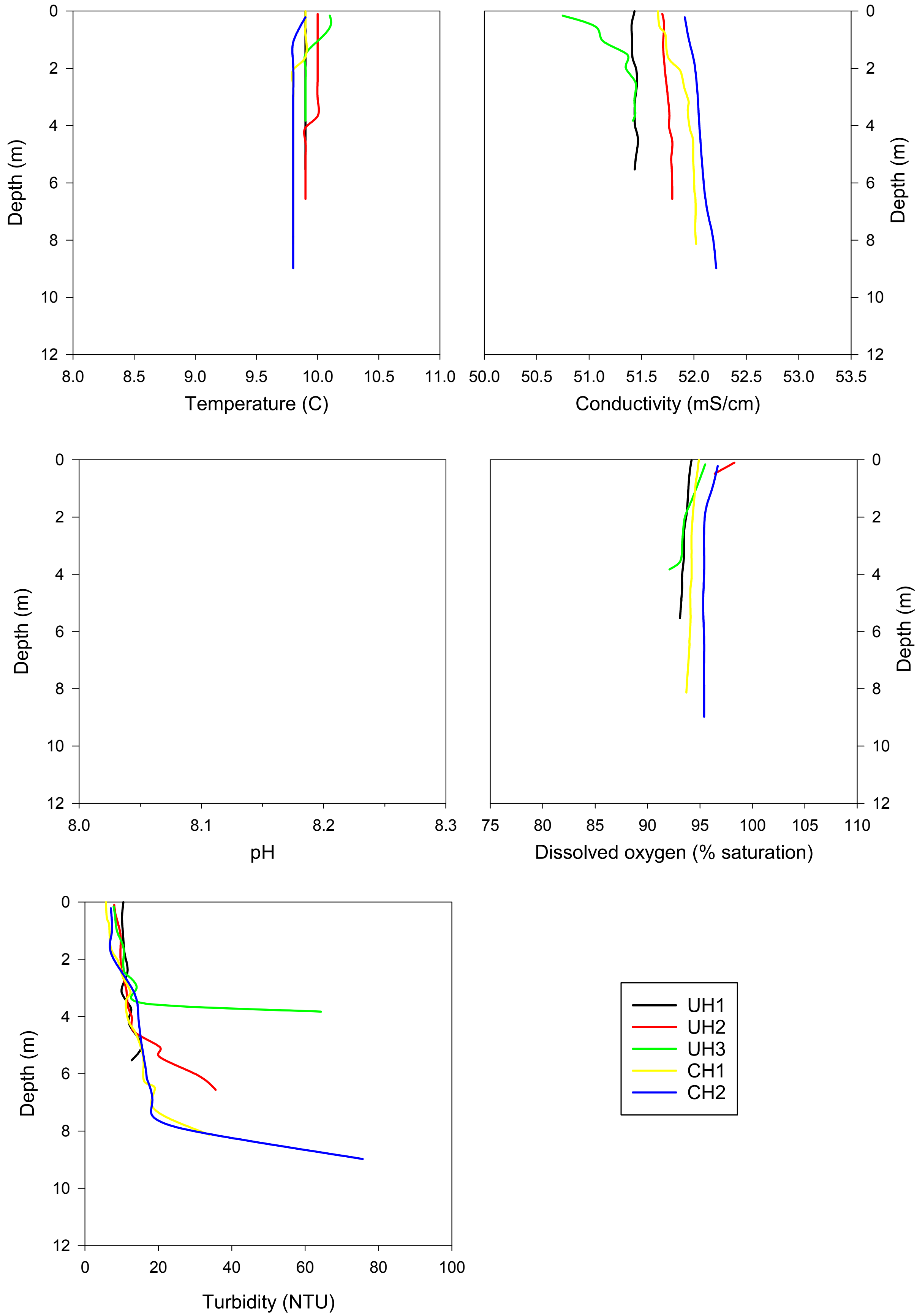


Figure 20 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 11 September 2018.

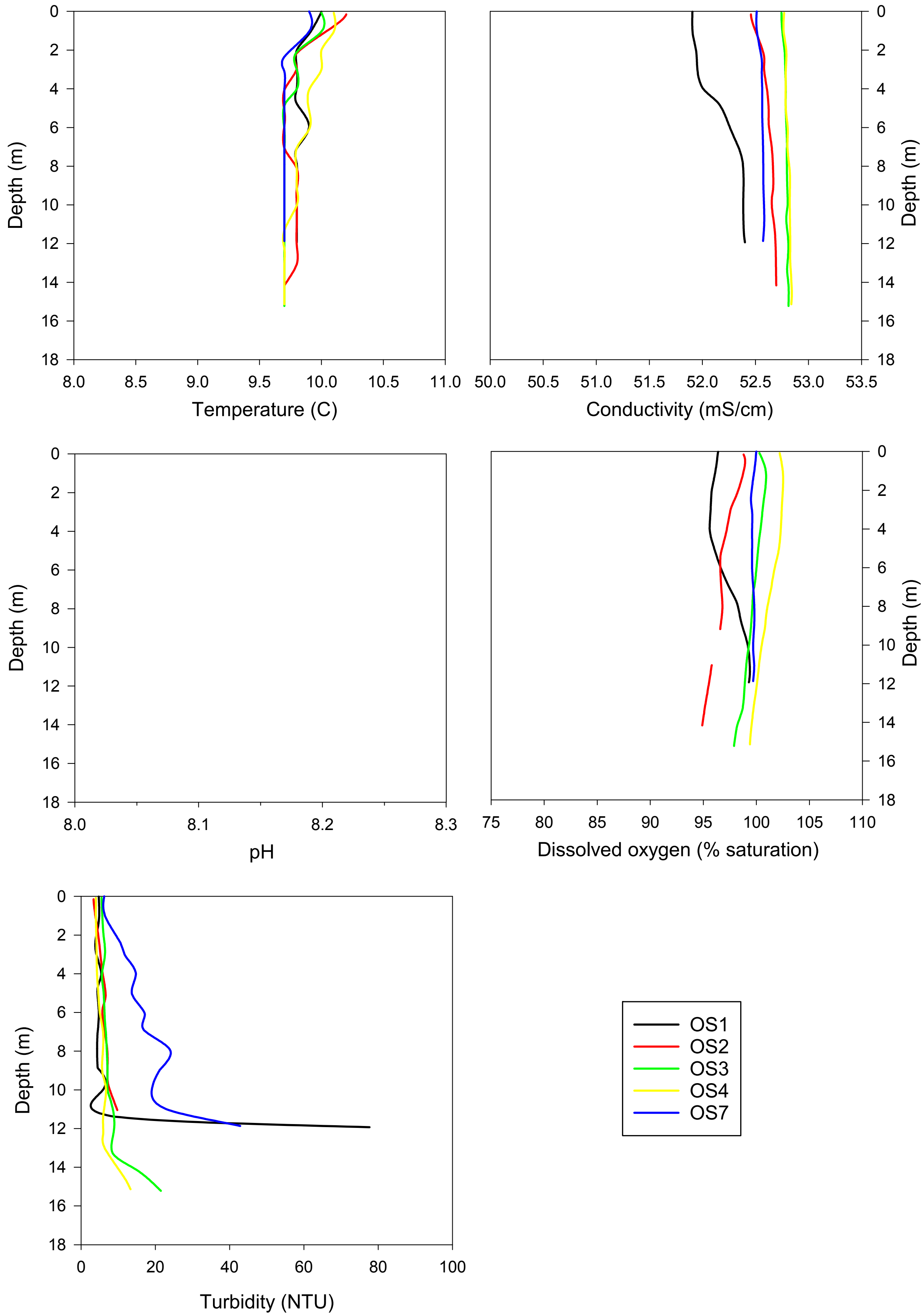


Figure 21 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 11 September 2018.

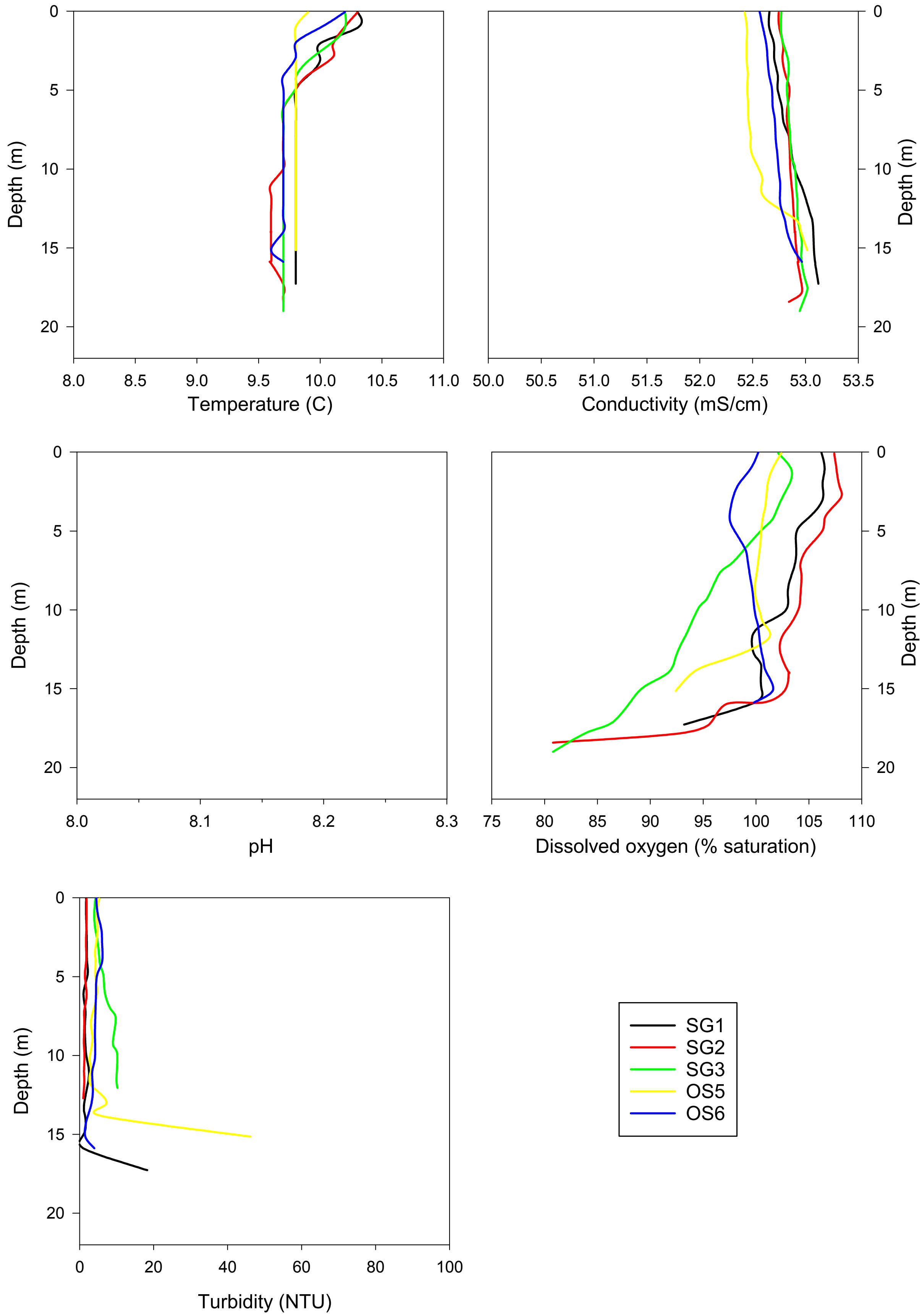


Figure 22 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 11 September 2018.

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 15, with the collected data from benthic and VBCC sensors presented in Figure 23. Data from the logger exchange date (6 September) were removed from the analyses.

Table 15 Total Daily PAR (TDP) statistics from 1 to 30 September 2018.
Values are means ± se (n = 29). Note data from the BPAR exchange day on 6 September were not utilized in plots or statistics for sites OS2 and OS3.

Site	Depth (m)	TDP (mmol/m^2/day)		
		Mean ± se	**Median**	**Range**
Base	-	26,307 ± 1,469	26,900	6,000 – 39,100
OS2	17	1.1 ± 0.4	<0.01	<0.01 – 7.2
OS3	14	0.1 ± 0.1	<0.01	<0.01 – 1.9

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 6,000 to 39,100 mmol/m^2/day (Table 15). Maximum TDP was slightly higher than that observed during August (26,300 mmol/m^2/day), and multiple days of non-zero BPAR readings were recorded (Figure 23).

Benthic PAR from OS2 remained low during the first two weeks of September, due to relatively low ambient PAR and elevated surface turbidity levels associated with extreme weather events. As turbidity declined and ambient solar radiation increased towards the end of the month, four peaks in BPAR were recorded on 15, 20, 23 and 27 September. Maximum total daily BPAR measurements reached 7.6 mmol/m^2/day on 27 September, when ambient solar insolation recorded at VBCC was also reaching the monthly maximum.

Temporally, BPAR data collected from OS3 presented similarly timed peaks as those at OS2, with non-zero values recorded on 15, 20 and 27 September. Contrasting the spatial relationship in BPAR observed during August, benthic light intensities recorded at OS3 were lower than those at OS2, reaching a monthly maximum of only 1.9 mmol/m^2/day on 27 September.

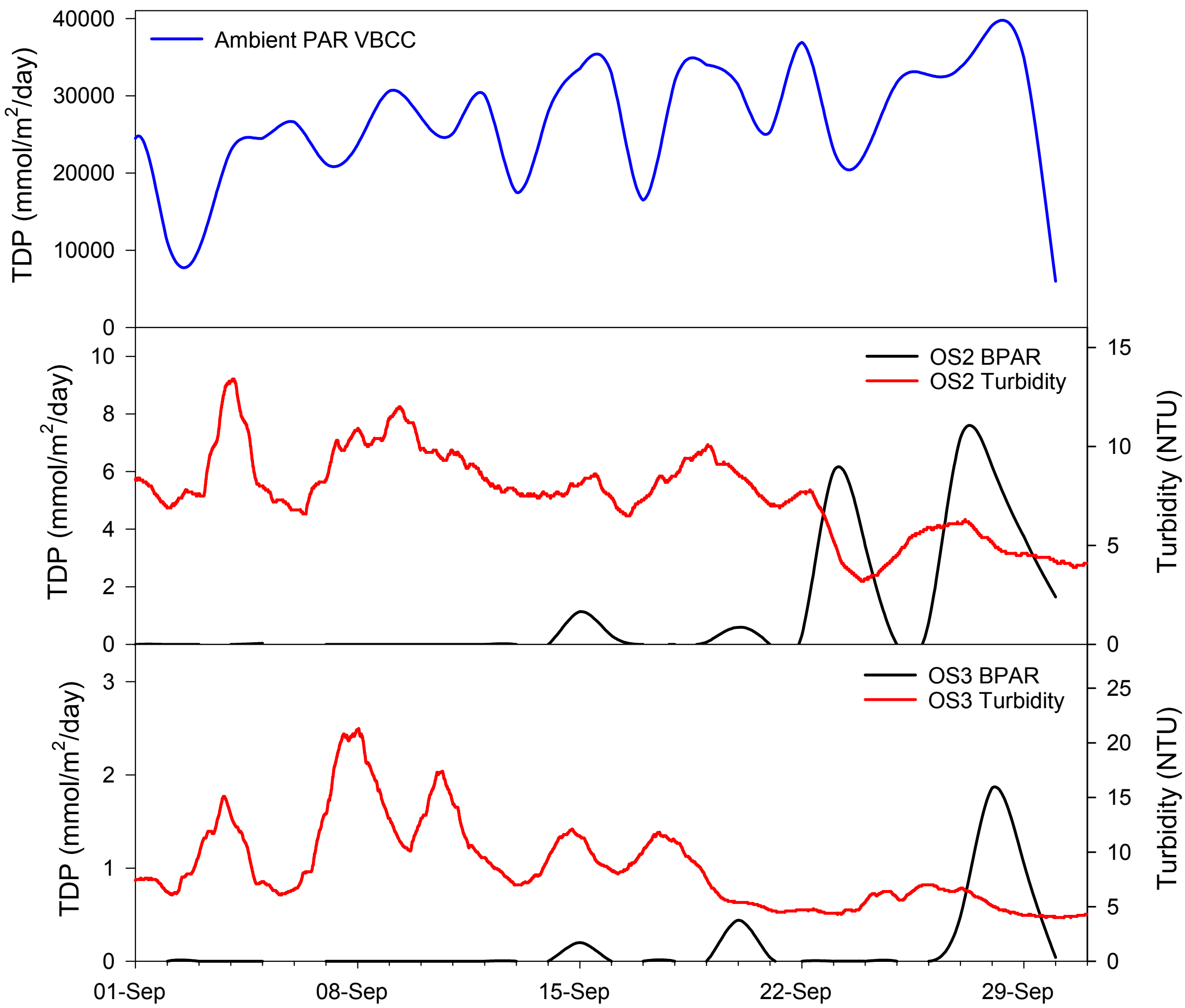


Figure 23 Total daily BPAR at OS2 and OS3 from 1 to 30 September 2018 compared to ambient PAR and corresponding surface turbidity.
Note data from the BPAR exchange day on 6 September were not utilized in plots or statistics.

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 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 September despite the extreme wind and rain event of 3 September resulting in elevated turbidity at OS2. This was followed by three distinct periods of rapid bed level increase and subsequent erosion. The first period of deposition followed by erosion occurred from 8 September and was associated with a period of elevated turbidity. Although wind speeds at the time were low, wave heights reached a peak and were considered a driving force for turbidity in the harbour at that time. Subsequent alterations in bed level were associated with elevated wind speed events from 15 to 21 September. Following these rapid alterations, daily averaged bed level displayed a steady decline as 17 mm of sediment was removed from the sea floor between 21 and 28 September, also associated with elevated wind speed but in the opposite direction. Within the final two days of September, almost 20 mm of sediment accreted under the altimeter, resulting in a monthly net bed level change of -11 mm (Figure 24, Table 16).

Contrasting the highly altered sea floor dynamics experienced at OS2 in September, altimeter readings at UH3 once more indicated a relatively stable environment at the harbour head. Following an initial period of sediment deposition and subsequent erosion during the first week of September, daily averaged bed level data indicate a relatively steady accretion of sediments over the remainder of the month. Slight variability in the rate of deposition was observed over this period in time however, the long term monthly trend recorded a net bed level change of +4 mm during September (Figure 24, Table 16).

Table 16 Net Bed Level Change statistics from data collected from altimeters deployed at OS2 and UH3 from 1 to 30 September 2018.

Site	September 2018 Net bed level change (mm)
OS2	-11
UH3	+4

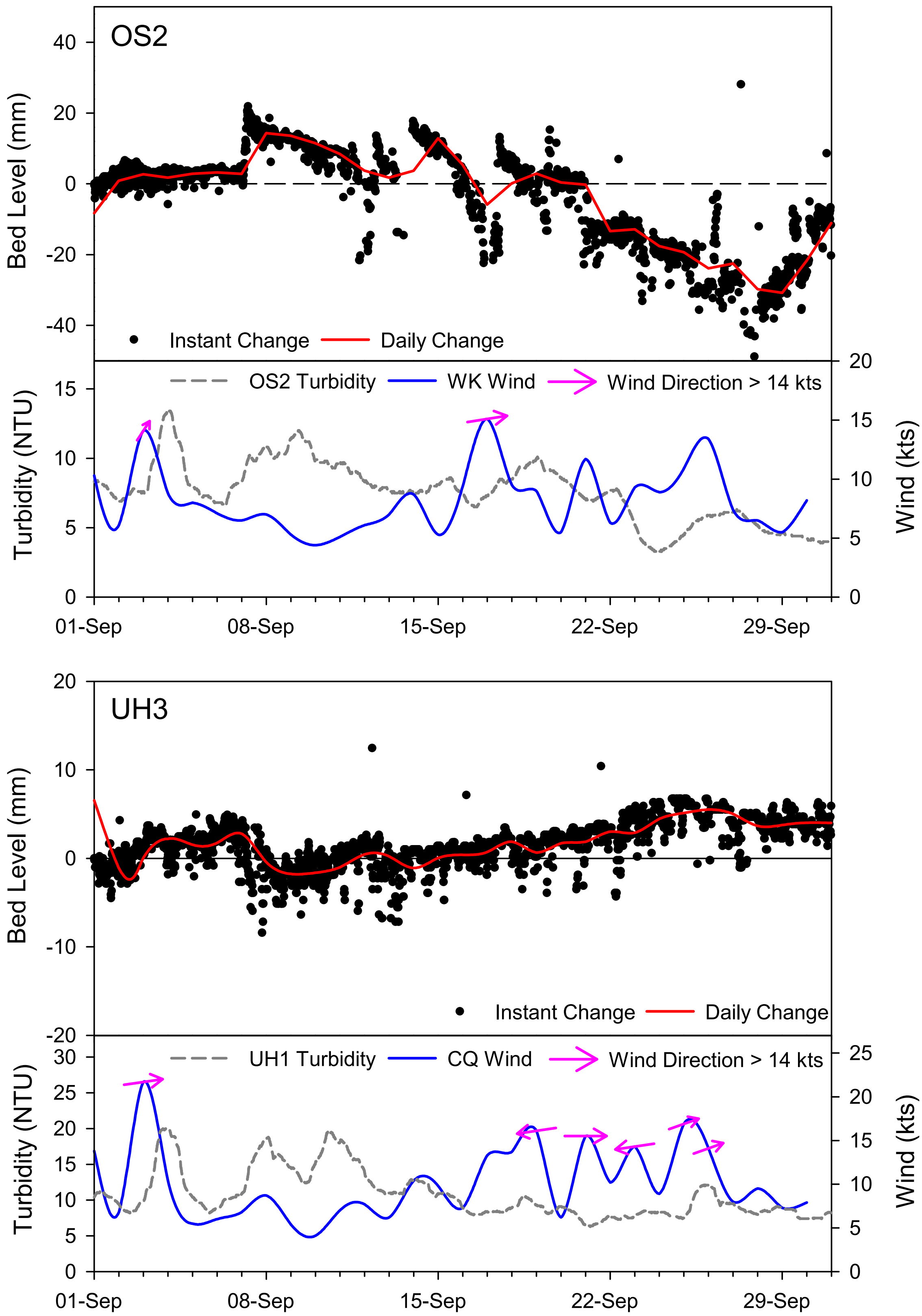


Figure 24 Mean instantaneous and daily averaged bed level change at OS2 and UH3 from 1 to 30 September 2018 compared to ambient surface turbidity (24 hour rolling average) wind speed and direction.

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

3.6 Water Samples

Discrete water sampling was conducted on 11 September 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 24 of the appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during the September 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 (WQG) for total phosphorous (30 μg/L) were only slightly exceeded at all three upper harbour sites and CH2, with concentrations reaching 37 μg/L (Table 17, Figure 25).

Of the remaining nutrients analysed, exceedances of the WQG were reported for dissolved reactive phosphorous and total ammonia at the nearshore sites OS2 and OS3, and the offshore sites OS5, OS6 and SG3. Exceedances of total ammonia WQG (15 μg/L) were also reported for the reference site OS4. Elevated concentrations of nitrogen oxides were also reported at the same six sites where total ammonia was observed to exceed WQG (OS2 to OS6 and SG3), although they remained within the reported guideline limits (Table 17). Additional exceedances of dissolved reactive phosphorous and nitrogen oxide WQG were also reported for the initial samples at UH3 (Table 17) yet remained below detection limits in the duplicate analyses (Table 24). This difference between samples suggests that the elevated concentrations within the primary samples may have been the result of contamination.

As typically observed, concentrations of both total nitrogen and total kjeldahl nitrogen remained below detection limits across the monitoring network. Concentrations of chlorophyll *a*, an indicator of phytoplankton biomass, remained below 2.6 μg/L during September. The lowest concentrations were recorded at the three spoil ground locations and the offshore site OS6 (Table 17). Increased concentrations of dissolved reactive phosphorous, total ammonia and nitrogen oxides observed during September, do not appear to have resulted in increased phytoplankton growth at the time of water quality sampling.

Table 17 Concentrations of nutrients and chlorophyll *a* at monitoring sites during September 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 *a*
UH1	37	<1	<300	<200	9	6.4	2.6
UH2	31	<1	<300	<200	8	<1	2.0
UH3	35	6.6	<300	<200	9	24	1.7
CH1	30	<1	<300	<200	9	5.5	1.6
CH2	34	<1	<300	<200	8	<1	1.8
OS1	28	<1	<300	<200	9	<1	1.1
OS2	18	8.6	<300	<200	26	15	1.3
OS3	20	7.3	<300	<200	28	15	2.1
OS4	14	3.3	<300	<200	20	6.2	1.8
OS5	24	7.5	<300	<200	30	6.9	1.4
OS6	17	7.7	<300	<200	25	10	1.2
OS7	20	<1	<300	<200	7	<1	1.3
SG1	12	3.1	<300	<200	14	3.9	1.0
SG2	12	3.2	<300	<200	10	3.3	1.2
SG3	13	5.4	<300	<200	20	7.6	1.3
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

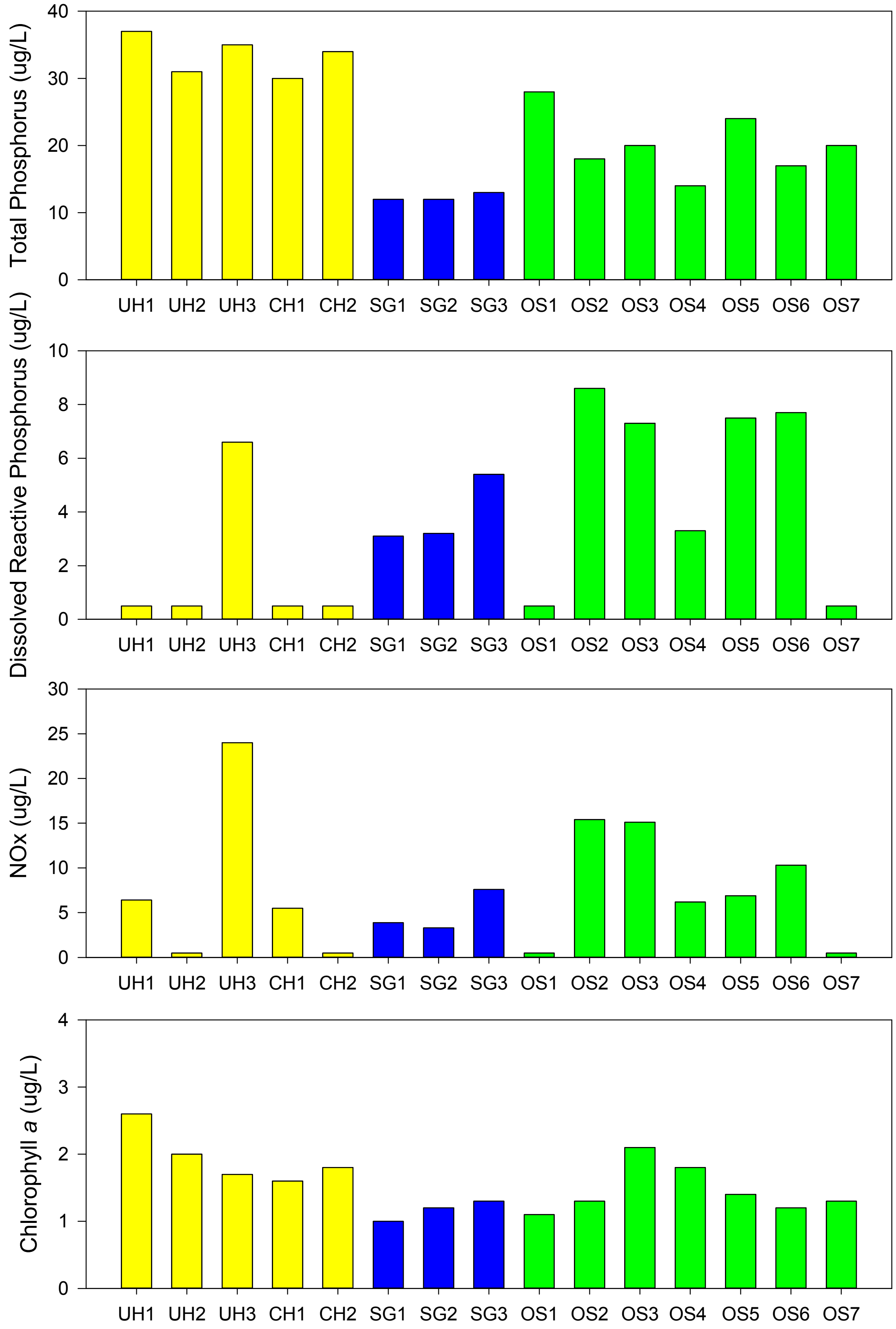


Figure 25 Nutrient and chlorophyll *a* concentrations at monitoring sites during September 2018. *Values which were <LOR, were plotted as half LOR. Total nitrogen, TKN and ammonia concentrations were not plotted as all or most sites were < LOR.*

3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (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) (Tables 18 to 20). Note that the analysing laboratory have recently 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. Concentrations of the more bioavailable dissolved fraction only exceeded the 12 µg/L LOR at UH1-UH3, CH1-CH2 and SG1, with no recorded concentrations above the 24 µg/L WQG (Tables 18 to 20). 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.

Of the remaining metals analysed that have assigned WQGs, only slight exceedances were reported for total cobalt at UH1, UH3, and OS1 (1.1-1.2 µg/L, c.f. 1.0 µg/L WQG) during the September 2018 water quality sampling campaign (Tables 18 and 19).

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. During September, elevated concentrations of total iron were observed within the upper harbour, with 700 µg/L recorded at UH1 (Table 18). 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 52 to 198 µg/L at the spoil ground sites (Table 20, Figure 26). Similar to the patterns in aluminum, dissolved concentrations of iron were relatively low (≤ 41 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. However, concentrations were notably greater than those reported during the August monitoring.

Providing further indication of a shift in environmental conditions since August, all monitoring sites except SG2b reported dissolved manganese concentrations above laboratory LOR. Similar to the previously discussed metals, concentrations of both dissolved and total manganese were greatest in the upper and central harbour, and site OS1, with reduced concentrations reported at the spoil ground sites (Figure 26).

Consistent with previous monitoring reports, molybdenum concentrations during September displayed little spatial variation across the monitoring network (Figure 27). Given the similarity between the dissolved and total metal concentrations, the majority of appeared to be present in the dissolved phase, allowing efficient mixing and therefore a lack of spatial variation across the monitoring sites (Tables 18 to 20 and Figure 27). Concentrations of total vanadium in the inshore and nearshore monitoring sites were slightly elevated compared to values recorded during August, which is likely a reflection of increased turbidity and TSS measurements.

Table 18 Total and dissolved metal concentrations at inshore monitoring sites during September 2018. *Values above recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites					WQG
		UH1	UH2	UH3	CH1	CH2	
Aluminium	Dissolved	19	15	15	14	14	24
	Total	360	230	270	200	185	
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	1.4	1.8	<1	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	1.4	1.8	1.5	<1	
Cobalt	Dissolved	0.9	0.9	0.8	0.9	0.8	1.0
	Total	1.1	1.0	1.2	1.0	0.9	
Copper	Dissolved	<1	<1	<1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	
Iron	Dissolved	14	41	14	16	11	-
	Total	700	440	500	400	370	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	
Manganese	Dissolved	11	6.1	6.2	11	6.6	-
	Total	23	13	15	19	14	
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	11	11	11	12	11	-
	Total	12	12	12	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	1.7	1.8	1.8	2.1	2.1	100
	Total	3.7	2.5	3.0	2.1	2.3	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4	<4	<4	<4	<4	

Table 19 Total and dissolved metal concentrations at offshore monitoring sites during September 2018.
Values outside recommended WQG are highlighted in blue.

Metal (µg/L)		**Sites**							**WQG**
		OS1	**OS2**	**OS3**	**OS4**	**OS5**	**OS6**	**OS7**	
Aluminium	Dissolved	16	<12	<12	<12	<12	<12	<12	24
	Total	118	98	169	104	172	143	220	
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	1.0	<1	1.1	1.5	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	1.8	<1	<1	1.2	1.3	<1	
Cobalt	Dissolved	0.9	0.7	0.9	0.8	0.7	0.7	1.0	1.0
	Total	1.1	0.9	0.8	0.9	0.9	0.8	1.0	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1	<1	<1	<1	<1	<1	1.2	
Iron	Dissolved	10	6	<4	5	<4	<4	18	-
	Total	198	184	330	220	350	240	400	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1	<1	<1	<1	<1	<1	<1	
Manganese	Dissolved	11	3.2	1.0	1.0	3.9	1.6	2.7	-
	Total	15	6.1	6.1	4.5	12	6.0	10	
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	13	12	12	
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	1.6	1.7	1.5	1.4	1.5	1.7	1.5	100
	Total	2.1	1.9	2.4	2.7	2.7	2.1	2.2	
Zinc	Dissolved	<4	<4	<4	<4	<4	<4	<4	15
	Total	<4	<4	<4	<4	<4	<4	<4	

Table 20 Total and dissolved metal concentrations at spoil ground monitoring sites during September 2018. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	15	<12	<12	24
	Total	59	60	94	
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	1.6	Cr(III) 27.4 Cr(VI) 4.4
	Total	<1	<1	1.4	
Cobalt	Dissolved	0.8	0.9	0.7	1.0
	Total	0.9	0.8	0.9	
Copper	Dissolved	<1	<1	<1	1.3
	Total	<1	<1	1.2	
Iron	Dissolved	6	<4	6	-
	Total	123	52	198	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1	<1	<1	
Manganese	Dissolved	1.4	<1	1.7	-
	Total	3.8	2.4	4.7	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	
Molybdenum	Dissolved	12	12	12	-
	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	1.7	1.2	1.5	100
	Total	1.8	1.5	2.2	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4	<4	<4	

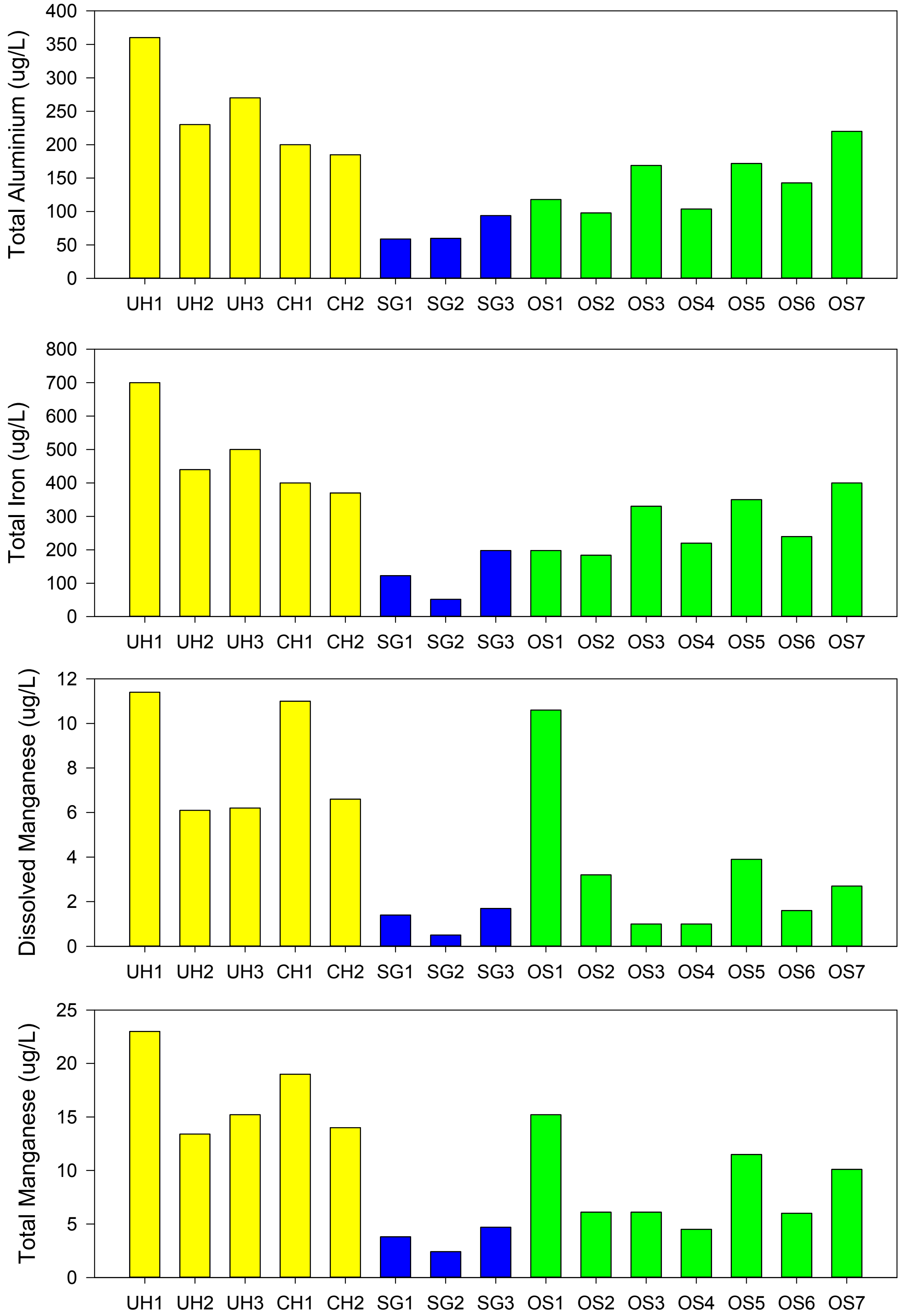


Figure 26 Total aluminium, total iron, and total and dissolved manganese concentrations at monitoring sites during September 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

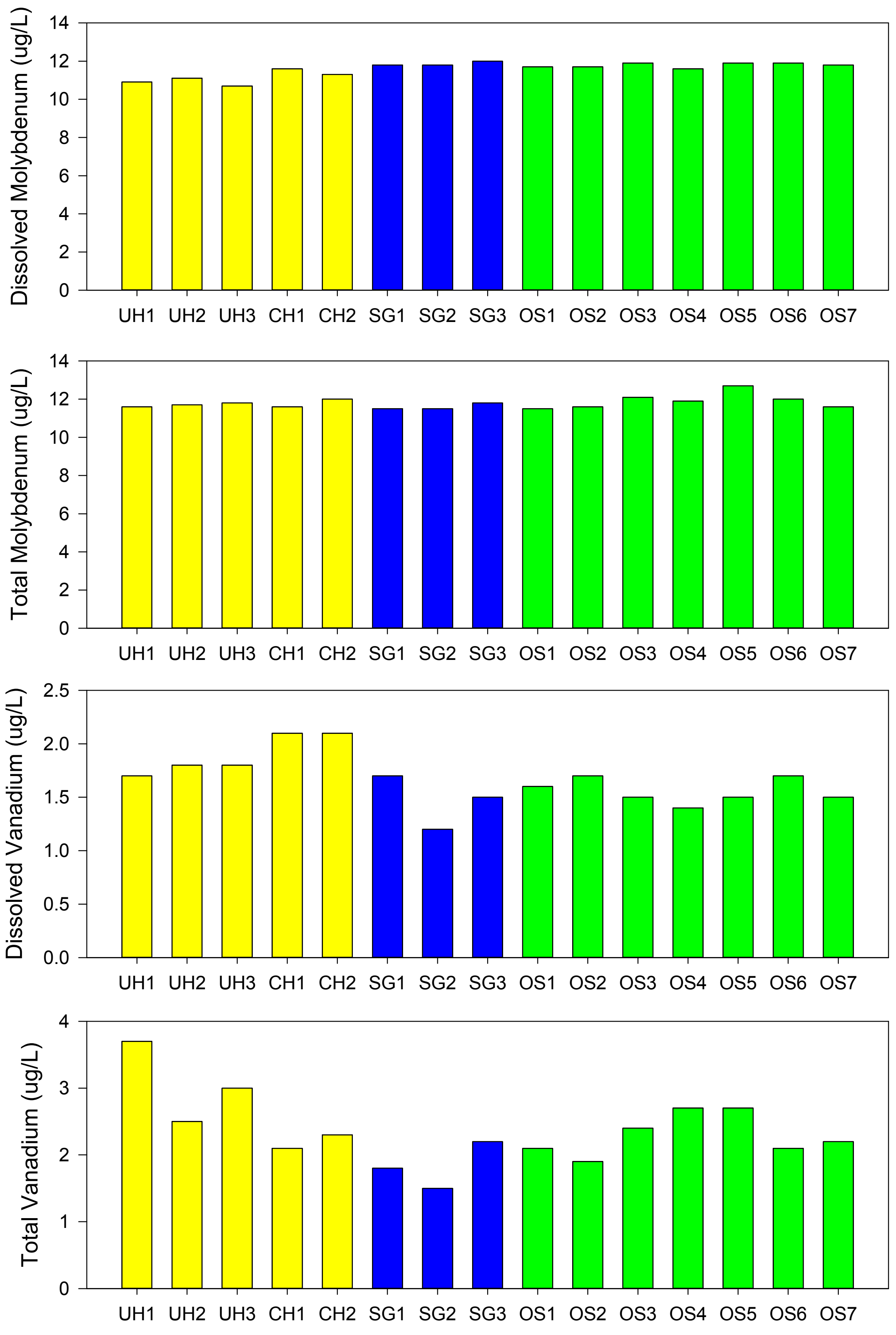


Figure 27 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during September 2018.
Values which were <LOR, were plotted as half LOR. Metals which were below LOR at all sites were not plotted.

4 REFERENCES

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5 APPENDIX

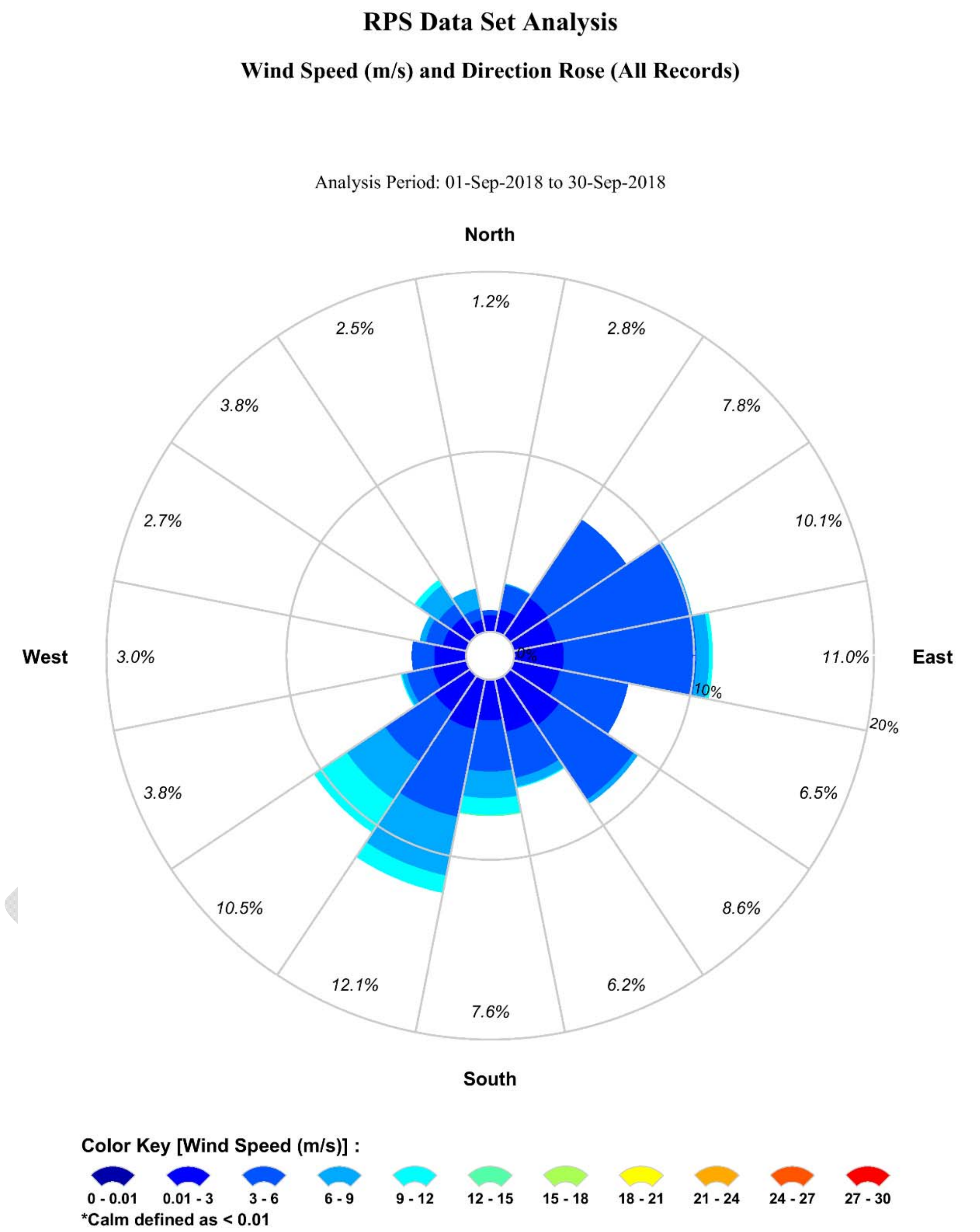

Figure 28 WatchKeeper wind speed (m/s) and direction rose (%) during September 2018.

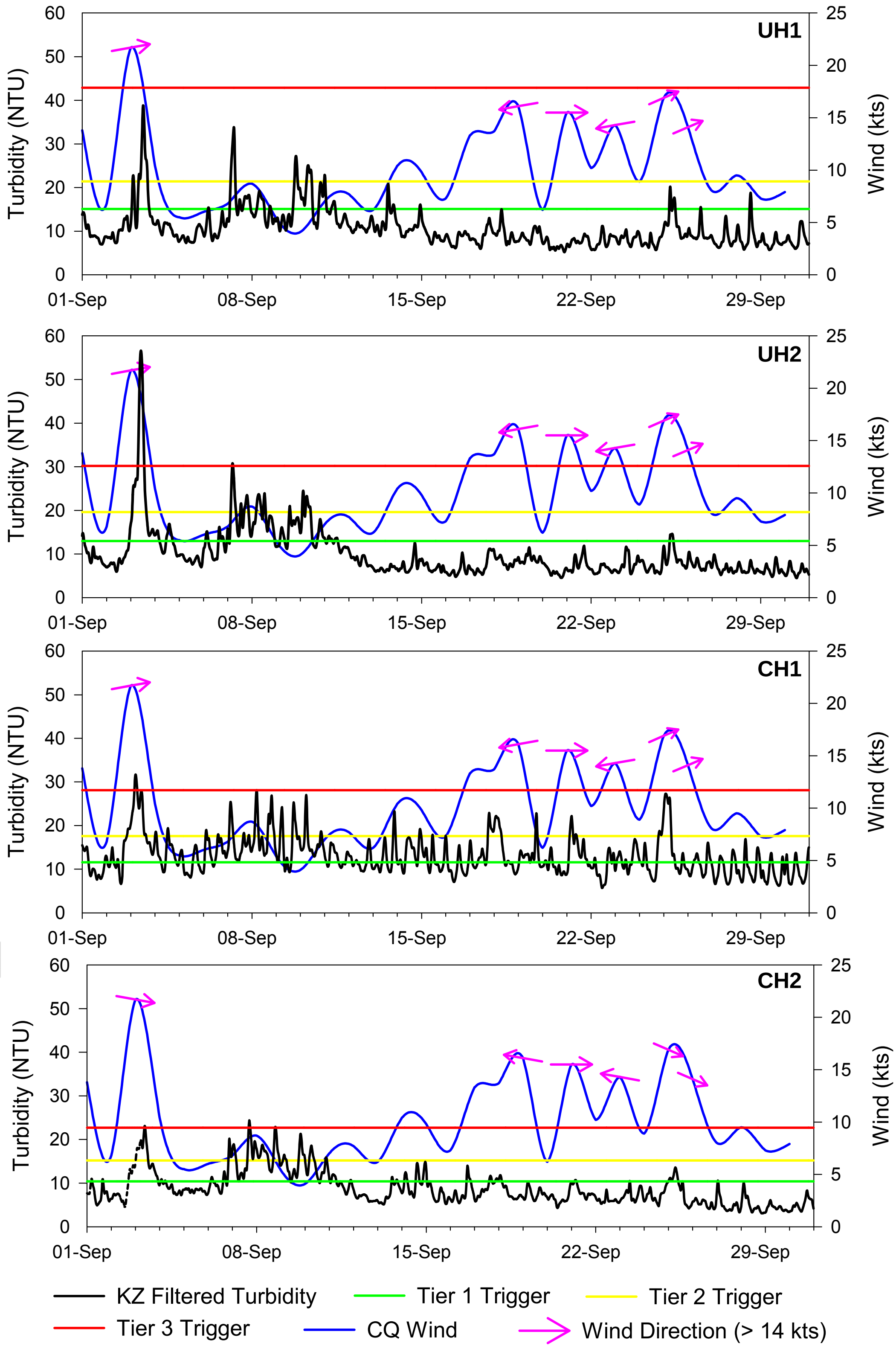

Figure 29 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

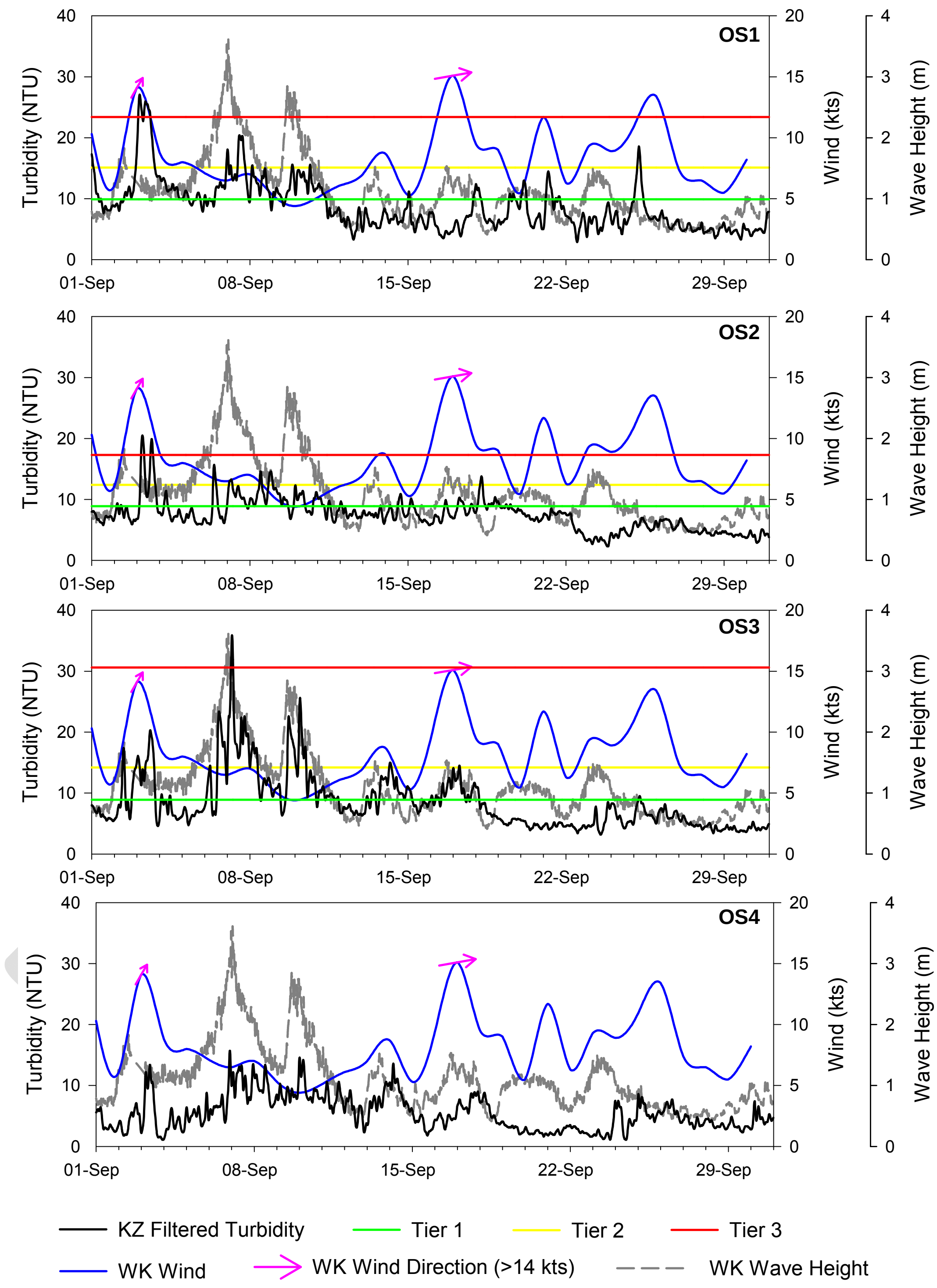

Figure 30 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

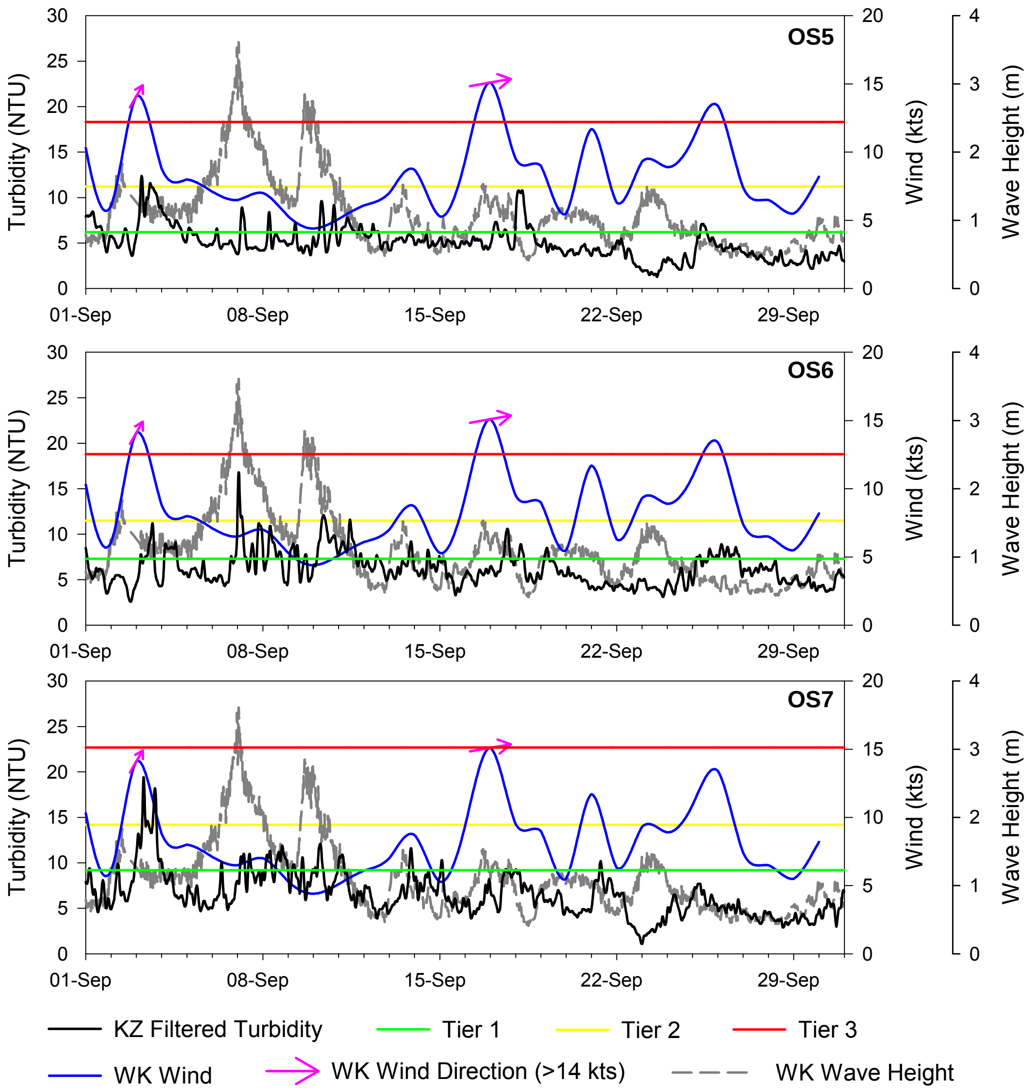

Figure 31 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

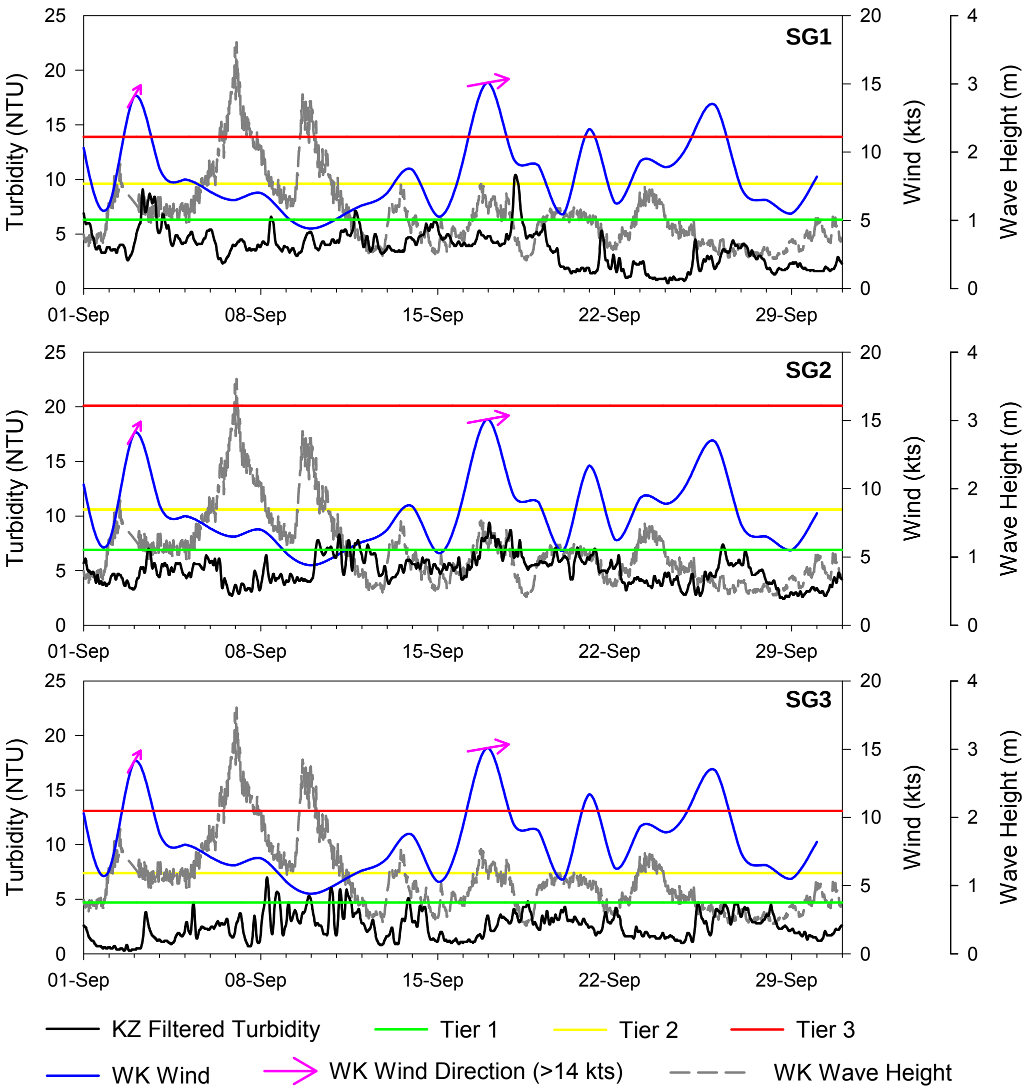

Figure 32 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) from 1 to 30 September 2018.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 14 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 21 Mean KZ filtered turbidity and statistics at inshore water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017
Values for September are means ± se, range and percentiles (n = 2864 to 2872) Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface September	Surface Baseline
UH1	Mean ± se	11 ± 0	12
	Range	5 – 39	2 – 155
	99th	27	37
	95th	19	21
	80th	13	15
UH2	Mean ± se	10 ± 0	9.9
	Range	5 – 57	2 – 59
	99th	30	29
	95th	21	19
	80th	13	13
CH1	Mean ± se	13 ± 0	8.8
	Range	6 – 32	<1 – 50
	99th	27	27
	95th	22	17
	80th	16	12
CH2	Mean ± se	8.8 ± 0.1	7.6
	Range	3 – 24	<1 – 39
	99th	21	22
	95th	17	15
	80th	11	10

Table 22 Mean KZ filtered turbidity and statistics at spoil ground water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for September are means ± se, range and percentiles (n = 2838 to 2880). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU) Surface September	Surface Baseline
SG1	Mean ± se	3.7 ± 0.0	4.2
	Range	<1 – 10	<1 – 31
	99th	8.7	14
	95th	6.3	9.5
	80th	4.9	6.1
SG2	Mean ± se	5.0 ± 0.0	4.6
	Range	2.4 – 9.4	<1 – 33
	99th	8.2	20
	95th	7.4	10
	80th	6.0	6.9
SG3	Mean ± se	2.5 ± 0.0	3.6
	Range	<1 – 7.0	0.2 – 22
	99th	5.7	13
	95th	4.6	7.3
	80th	3.5	4.7

Table 23 Mean KZ filtered turbidity and statistics at offshore water quality logger sites from 1 to 30 September 2018 and Baseline period 1 November 2016 to 31 October 2017.
Values for are means ± se, range and percentiles (n = 69 to 2877). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface September	Surface Baseline
OS1	Mean ± se	8.7 ± 0.1	7.5
	Range	3 – 27	<1 – 99
	99th	25	23
	95th	16	15
	80th	12	9.7
OS2	Mean ± se	7.5 ± 0.0	6.4
	Range	2 – 21	<1 – 36
	99th	16	17
	95th	12	12
	80th	9.2	8.9
OS3	Mean ± se	8.5 ± 0.1	6.5
	Range	3 – 36	<1 – 110
	99th	23	27
	95th	18	14
	80th	11	8.9
OS4	Mean ± se	5.4 ± 0.1	5.9
	Range	1 – 16	<1 – 35
	99th	13	18
	95th	11	13
	80th	7.8	8.1
OS5	Mean ± se	5.0 ± 0.0	4.6
	Range	1 – 12	<1 – 35
	99th	11	18
	95th	8.4	11
	80th	6.2	6.1
OS6	Mean ± se	6.2 ± 0.0	4.7
	Range	3 – 17	<1 – 37
	99th	12	18
	95th	9.4	11
	80th	7.6	7.1
OS7	Mean ± se	6.5 ± 0.0	6.3
	Range	1 – 19	<1 – 48
	99th	15	22
	95th	11	14
	80th	8.4	9.1

Table 24 Summary of Vision Environment quality control data for September 2018 water sampling. *ND = not determined as one or more samples was below LOR. Variation between duplicate field samples ≥ 50% has been highlighted in blue. High variation indicates heterogeneity within the water column.*

Parameter	VE Field Blank (µg/l)	Duplicate		
		UH3 A (µg/L)	UH3 B (µg/L)	Variation (%)
Total Suspended Solids	<3	15	15	0
Dissolved Aluminium	<0.05	15	26	42
Total Aluminium	<3.2	270	230	15
Dissolved Arsenic	<7000	<4	<4	ND
Total Arsenic	<1.1	<4.2	<4.2	ND
Dissolved Cadmium	<0.2	<0.2	<0.2	ND
Total Cadmium	<0.053	<0.21	<0.21	ND
Dissolved Chromium	<0.5	<1	1.1	ND
Total Chromium	<0.53	1.8	<1.1	ND
Dissolved Cobalt	<20	0.8	0.8	0
Total Cobalt	<0.21	1.2	0.85	29
Dissolved Copper	<0.1	<1	<1	ND
Total Copper	<0.53	<1.1	<1.1	ND
Dissolved Iron	<0.5	14	20	30
Total Iron	<21	500	470	6
Dissolved Lead	<0.08	<1	<1	ND
Total Lead	<0.11	<1.1	<1.1	ND
Dissolved Manganese	<0.2	6.2	6.3	2
Total Manganese	<0.53	15.2	14.9	2
Dissolved Mercury	<0.5	<0.08	<0.08	ND
Total Mercury	<1	<0.08	<0.08	ND
Dissolved Molybdenum	<1	10.7	11	3
Total Molybdenum	<0.21	11.8	11.4	3
Dissolved Nickel	<0.1	<7	<7	ND
Total Nickel	<0.53	<7	<7	ND
Dissolved Selenium	<0.5	<4	<4	ND
Total Selenium	<1.1	<4.2	<4.2	ND
Dissolved Silver	<1	<0.4	<0.4	ND
Total Silver	<0.11	<0.43	<0.43	ND
Dissolved Tin	<1	<5	<5	ND
Total Tin	<0.53	<5.3	<5.3	ND
Dissolved Vanadium	<2	1.8	1.9	5
Total Vanadium	<1.1	3	2.9	3
Dissolved Zinc	<2	<4	<4	ND
Total Zinc	<1.1	<4.2	<4.2	ND
Total Phosphorus	<4	35	34	3
Dissolved Reactive Phosphorus	<3	6.6	<1	ND
Total Nitrogen	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN)	<100	<200	<200	ND
Total Ammonia	<10	9	7	22
Nitrate + Nitrite	<0.08	24	<1	ND
Chlorophyll *a*	<0.2	1.7	1.7	0