Lyttelton Port Company
Channel Deepening Project
Environmental Monitoring

Water Quality Environmental Monitoring Services – Monthly Report

July 2019

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Summary

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

Dredging operations for the CDP, which commenced on 29 August 2018, were completed on 29 November 2018, taking the monitoring into a post dredge phase up until 11 March when a smaller dredging operation began for the reclamation works at Cashin Quay. Monitoring results collected during July 2019 are presented within this report. Continuing with the dredge phase monitoring report format, this monthly report includes comparisons of turbidity data collected during the initial baseline monitoring period from 1 November 2016 to 31 October 2017 (Fox, 2018). KZ filtered data are also included within the Appendix are compared to compliance trigger values during reclamation dredging operations.

Climatic Conditions: During July, 60.0 mm of rainfall was recorded at Cashin Quay, which was approximately the same as recorded in June. Falls of <13 mm occurred throughout the whole month although >24 mm was recorded over a two-day period. Maximum daily inshore wind speeds (18.5 kts) and gusts (46 kts) were recorded on 31 July, with slightly lower wind speeds and gusts also recorded on 5/6 July. Flows from the from the Waimakariri River were low during July with a maximum of 611 m^3/s being recorded on the 14 July. Monthly average temperature (9.9°C) was only slightly higher (1°C) than that recorded in June.

Offshore, both wind speeds and wave heights displayed similar temporal variations over the month. Similar to the inshore environment, the offshore wind speeds were also elevated on 5, 20 and 31 July, with gusts reaching over 20 kts on the 31 July. A significant wave height event (maximum 3.6 m) recorded on 25 July did not correspond to offshore winds at the time, which were recorded at 6 kts. Increased wave heights were likely a result of swell waves induced from further offshore.

Currents: ADCP data were available at all three spoil ground monitoring sites in July. Near-surface and near-seabed currents at SG1 and SG2a (Watchkeeper) were highest on 31 July during the period of highest wind speeds for the month. SG3 near-surface highest currents were also observed on 31 July, however near-seabed highest currents occurred on the 20 July, during a smaller wind event. The highest mean current flow followed the same previous patterns of SG1 and SG3 having higher velocities at the near-surface than SG2a which are consistently lower. These site differences are attributed to the varying topography across the spoil ground. There appeared to be little impact on current speeds from the increased swell height of 25 July.

Near-surface and near-seabed predominant current direction for July was similar for SG1 and SG3 with exhibited currents tending towards the north-north-west. While, SG2a had dominant near-surface and near-seabed flows tending towards the west-north-west.

Turbidity: Consistent with previous results, turbidity was overall more elevated at the inshore monitoring sites of the central and upper harbour than at the offshore monitoring locations. However, a number of nearshore surface sites (OS3, OS4 and OS7) displayed some of the

highest recorded NTU values for July, which corresponded to increased significant wave heights of 25 July. Mean turbidity values for July were generally similar to June and also to those recorded during the baseline monitoring period, except for OS3 where mean turbidity was 3.4 NTU more elevated than the baseline value due to the unusual increased wave height event.

Turbidity peaks were recorded at all sites at multiple times from 4 to 6, 27 and 31 July in response to strong inshore wind speeds coming from a south-south-westerly direction. Gusts of over 40 kts were recorded on two occasions, which is considered high compared to typical values. Surface turbidity peaks within the inner harbour reached up to 28 NTU, with the remainder of July displaying low turbidity values (<15 NTU). A number of nearshore sites (OS1, OS3 and OS4) displayed pronounced turbidity peaks >20 NTU in response to the significant wave height event of 25 July. Turbidity peaks observed at the offshore and spoil ground sites were generally below 10 NTU, except for SG3 which recorded a 20 NTU turbidity peak on 31 July, in response to the strong offshore south-westerly winds of the time.

Benthic turbidity at all sites responded to both wind speed and wave height events in July with mean benthic turbidity being more elevated than their surface counterparts, as typically observed. Turbidity values during the significant wave height event of 25 July often >1000 NTU may have been at the limit of the instruments accurate recording range.

Dredge Compliance Turbidity Trigger Values: During July, there were two exceedances of the Tier 3 intensity values. These were at site OS3 for 26.5 hours and at SG3 for 9 hours. OS3 exceedance was attributed to the increased wave height event and SG3 exceedance was attributed to increased offshore winds towards the end of July, which were the highest recorded for the month.

Other Physicochemical Parameters: The trend for water cooling across all sites was consistent throughout July, with monthly means up to 1°C lower than June, despite ambient temperatures being slightly higher. Continuing the trend which commenced in April, cooler water temperatures were recorded in the upper and central harbour rather than the offshore sites. Sea surface temperatures were consistent across the month with a brief period of warming displayed within the inner harbour from the 15 to 23 July occurring after the larger rainfall event of 19/20 July. Benthic temperatures were consistent with those at the surface indicating a well-mixed water column.

Consistent with previous reports, the pH during July was consistent across all sites, both surface and benthic. Conductivity was reasonably consistent at each site for July, with a slight decrease on the 20 July within the inner harbour sites and OS1, due to the preceding high rainfall.

Dissolved oxygen (DO) concentrations during July were higher than those in June and were temporally stable across the month at offshore sites. Fluctuations at UH1 and at all spoil ground sites at various times through the month were likely related to localised increases in photosynthetic organisms. Diurnal fluctuations in DO were observed at the majority of sites for the month of July as typically observed. Benthic DO trended similarly to surface counterparts and remained stable until 24 July where increased wave heights proceeded to produce highly variable DO concentrations for the remainder of the month, likely due to increased turbulence resulting in oxygenation of the water column to the benthos.

Water Sample Analysis and Depth Profiling: Discrete water sampling was conducted in conjunction with vertical profiling of the water column on 9 July 2019. Similar to profiles typically obtained during the monitoring program, inner harbour monitoring sites indicated a well-mixed water column. Nearshore, offshore and at spoil ground sites, depth profiling indicated a continuation of vertically mixed conditions, with turbidity increasing near the benthos due to resuspension.

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 12.9 m at SG3. No exceedances of WQG were observed for sub-surface during the June sampling.

As commonly observed, total and dissolved reactive phosphorous concentrations were highest at the inshore sites and decreased further offshore at the spoil ground sites. 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 equalled the WQG value of 300 µg/L. Ammonia and nitrogen oxides (NOx) were elevated in July as they were in June, with the majority of sites exceeding both the ammonia and NOx, WQG. Chlorophyll *a* concentrations remained low and below the WQG (4 µg/L) at all sites, despite the high nutrient availability, suggesting low photosynthetic activity likely associated with low temperatures and lack of sunlight.

Several metals were reported as below the limit of reporting (LOR) at all sites as commonly found. However, total mercury and total copper reported values above the LOR at sites within the inner harbour and the spoil ground. However, no WQG exceedances were recorded. As typically observed, total aluminium concentrations exceeded designated WQG at all of the monitoring sites. Dissolved aluminium concentrations, however, remained well below the WQG at all sites as commonly found. A similar spatial pattern was observed for total iron, although no WQG are available for iron. No other exceedances occurred for metals.

Detectable concentrations of manganese were once again recorded in the upper harbour, with a relatively even split between dissolved and particulate components and a decreasing gradient from inner to outer harbour. Chromium, vanadium and molybdenum were also reported above LOR during July, with little spatial variability and a large component contained within the dissolved phase and therefore easily dispersed across the harbour.

Benthic Photosynthetically Active Radiation (BPAR): Levels of ambient sunlight were fairly consistent during July but similar to those in June. In contrast BPAR levels were much lower as a reflection of elevated turbidity recorded in July. Both sites displayed similar low intermittent BPAR peaks corresponding with intermittent periods of low turbidity during July.

Sedimentation: During July, bed level at OS2 despite being quite dynamic throughout the month displayed an overall increase of only +2 mm. While bed level incrementally increased over July in response to the intermittent weather events, rapid erosion occurred in response to increased swell. Sediment flux at UH3 was stable for July with an overall deposition occurring over July. This resulted in an overall accretion of +11 mm for the month of July.

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Acronyms

ADCP	Acoustic Doppler Current Profiler
BPAR	Benthic Photosynthetically Active Radiation
BSL	Benthic self-logging sonde
CDP	Channel Deepening Project
DO	Dissolved oxygen
ECan	Environment Canterbury
EMMP	Environmental Monitoring and Management Plan
K_d	Light attenuation coefficient
KZ filter	Kolmogorov-Zurbenko filter
LOR	Limits of Reporting
LPC	Lyttelton Port Company
LYT	Lyttelton Port of Christchurch
NTU	Nephelometric Turbidity Units
PAR	Photosynthetically Active Radiation
QA/QC	Quality Assurance/Quality Control
SL	Self-Logger
ST	Subsurface telemetry
ST/ADCP	Subsurface telemetry/Acoustic Doppler Current Profiler
TAG	Technical Advisory Group
TDP	Total daily PAR
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
VBCC	Vision Base Christchurch
VE	Vision Environment
WK	WatchKeeper telemetered weather station
WQG	Water Quality Guidelines

1 INTRODUCTION

Lyttelton Port Company (LPC) is undertaking a Channel Deepening Project (CDP) to extend the existing navigational channel to allow larger vessels access to the Lyttelton Port of Christchurch (LYT), the South Island's largest port. Utilising background information provided by LPC and advice from the Technical Advisory Group (TAG) in relation to ambient conditions, locations of sensitive habitats and dredge impact hydrodynamic modelling scenarios, a water quality monitoring design was proposed for the initial 12-month baseline monitoring phase. Baseline water quality monitoring and data collection undertaken by Vision Environment (VE) commenced in September 2016, progressing into dredge operations monitoring from 29 August 2018 with completion of works on 29 November 2018. Monitoring continued into a post-dredge phase up until 11 March 2019 when smaller scale dredging operations for the reclamation works commenced. The interpreted environmental data provided by VE supports the process of the Environmental Monitoring and Management Plan (EMMP) for the LPC CDP (Envisor, 2018) and will assist to ascertain the potential impacts of the project.

2 METHODOLOGY

2.1 Approach

An overview of the methodology for the baseline and operations phases of water quality monitoring is provided in this section. A more detailed description of the importance of the measured parameters and the specific methodology for the CDP data collection and processing protocols can be found in the Channel Deepening Project Water Quality Environmental Monitoring Methodology (Vision Environment, 2017).

2.1.1 Monitoring Locations and Equipment

Guided by the results of preliminary hydrodynamic modelling (MetOcean, 2016a, b) in addition to advice from the TAG, baseline and dredge operations, monitoring sites were located outside the area of predicted direct impact (i.e. dredge footprint and offshore disposal ground), but within the zone of dredging and dredge material placement influence, in addition to being in the vicinity of sensitive receptors (e.g. mussels farms and important mahinga kai sites). For ease of identification the harbour was divided into four areas: spoil ground (SG); offshore (OS); central harbour (CH); and upper harbour (UH), in which 15 locations were selected for monitoring (Figure 1). In each area, one to three monitoring sites were selected for the deployment of the various individual types of equipment, which are identified in Table 1. A total of 22 monitoring units were deployed across the 15 locations.

The offshore monitoring area (encompassing monitoring sites SG1 to SG3 and OS1 to OS7) is a deep water (generally >15 m) oceanic environment, where turbidity appears to be mostly driven by wind speeds and wave heights, resulting in resuspension of material from the benthos. A combination of both surface loggers and benthic loggers have been utilised at several offshore locations.

The inshore monitoring area (including monitoring sites CH1 and CH2, and UH1 to UH3) is a shallow (<10 m depth) marine environment that, in addition to wind speeds and wave heights, is also influenced by tides (~ 0.2 m/s). The water column is well mixed at these sites, with little to no stratification. Therefore, surface loggers only have predominantly been utilised at these sites.

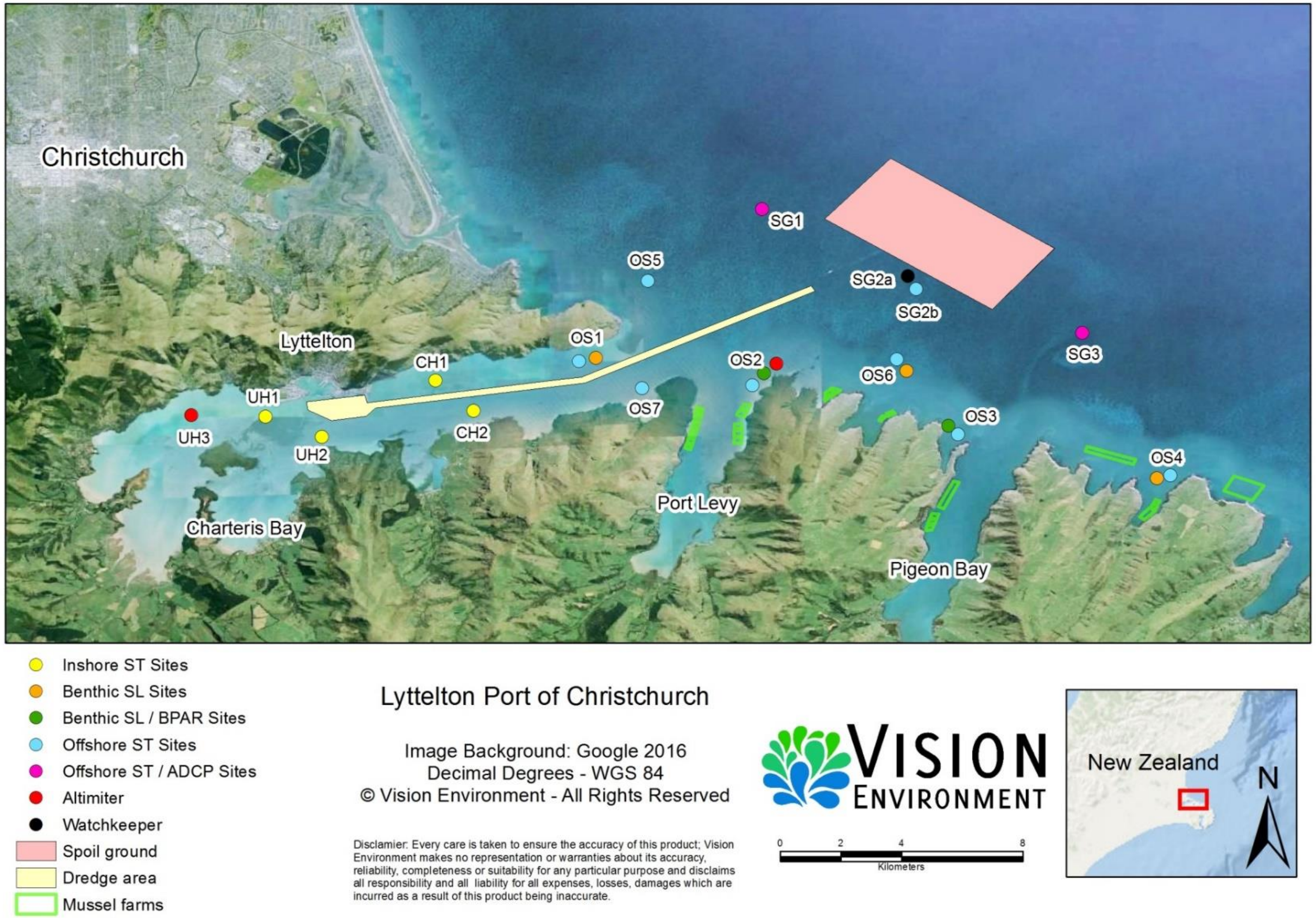


Figure 1 Monitoring locations for the LPC Channel Deepening Project, displaying sites within each location.
ST = subsurface telemetry, SL = self-logger, BPAR = benthic photosynthetically active radiation, ADCP = Acoustic Doppler Current Profiler

Table 1 Summary of monitoring sites and deployment equipment for the LPC Channel Deepening Project.
ST = subsurface telemetry, SL = self-logger, BSL = benthic self-logger, BPAR = benthic photosynthetically active radiation, and ADCP = Acoustic Doppler Current Profiler, WK = WatchKeeper telemetered weather station.

Site	WK	ST/ADCP	ST	BSL sonde	BSL sonde/BPAR	Altimeter
	WatchKeeper telemetered weather station with currents and waves	Subsurface telemetered dual physico-chemistry and currents	Subsurface telemetered dual physico-chemistry	Benthic self-logging dual physico-chemistry	Benthic self-logging dual physico-chemistry and self-logging BPAR	Benthic self-logging dual altimeter
SG2a	√					
SG2b			√			
SG1		√				
SG3		√				
OS1			√	√		
OS2			√		√	√
OS3			√		√	
OS4			√	√		
OS5			√			
OS6			√	√		
OS7			√			
CH1			√			
CH2			√			
UH1			√			
UH2			√			
UH3						√
Total	1	2	12	3	2	2

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

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

This monthly report presents data collected from the 22 monitoring locations for July 2019 during dredge operations. Monthly water sampling and depth profiling was conducted on 9 July 2019. A summary of climatic conditions during this period is provided, in addition to the results of continuous and discrete water sampling with comparisons to the baseline monitoring period.

2.1.2 Water Quality Guidelines

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

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

3 RESULTS & DISCUSSION

3.1 Metocean Conditions

3.1.1 Wind and precipitation

A total of 60 mm of rainfall was recorded at Cashin Quay during July 2019, which was similar to the precipitation recorded in June (69.0 mm). Rainfall was recorded at various times throughout July with the highest fall (13.4 mm) recorded on 31 July, but with two days of consecutive higher rainfall (24.8 mm) on 19/20 July (Metconnect, 2019). Freshwater flows from the Waimakariri River, can be transported south along the coastline and enter Lyttelton Harbour several days post flow. Flows were lowest (60 m^3/s) at the beginning of July, with peak volumes of 612 m^3/s and 459 m^3/s occurring on the 14 and 22 July, respectively (Figure 2)(ECAN, 2019). Flows at this low level have historically not induced any noticeable impacts on the harbour sites.

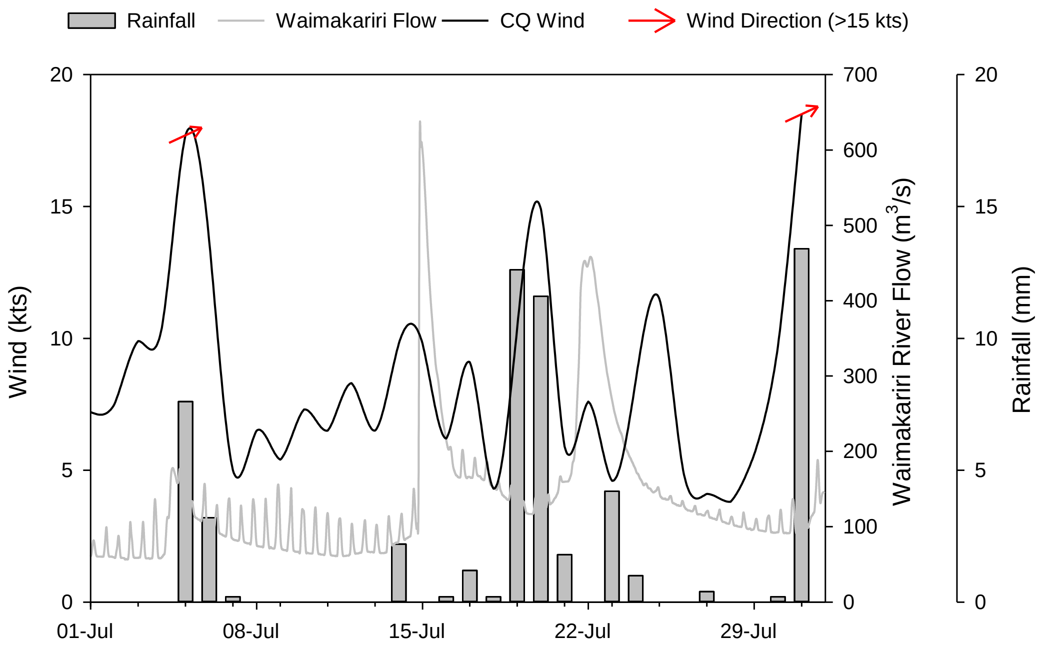


Figure 2 Inshore metocean conditions including wind speed and direction, rainfall measured at Cashin Quay, and Waimakariri River flow at the Old Harbour Bridge station, during July 2019.
Note: Arrows indicate the direction of travel for inshore winds greater than 15 knots.

Inshore wind direction varied greatly throughout July, with greater west-south-westerly to westerly winds predominating for ten days throughout July. Wind speeds ranged from 3.8 kts on 28 July to 18.5 kts on 31 July, which also observed the maximum wind gust of 46 kts from a west-south-westerly direction (Metconnect, 2019). A second slightly smaller wind event was also recorded on 5/6 July with gusts of up to 42 kts in a similar direction. Daily mean air temperatures at Cashin Quay ranged from 6°C to 16°C, resulting in a monthly mean temperature of 10°C (Metconnect, 2019), which was slightly higher than the June mean temperature of 9°C.

Offshore significant wave heights were predominant and variable throughout July with waves flowing in a south-westerly direction (Figure 3). The maximum significant wave height was recorded at 3.6 m on 25 July and did not correspond to strong offshore winds, suggesting increased wave heights were swell waves sourced further offshore. Offshore winds were predominantly from the south-west and were for the majority <10 kts (Figure 32). Offshore wind speeds and gusts recorded a peak of 17 kts on the 31 July (Figure 3), similar to maximum inshore wind speeds.

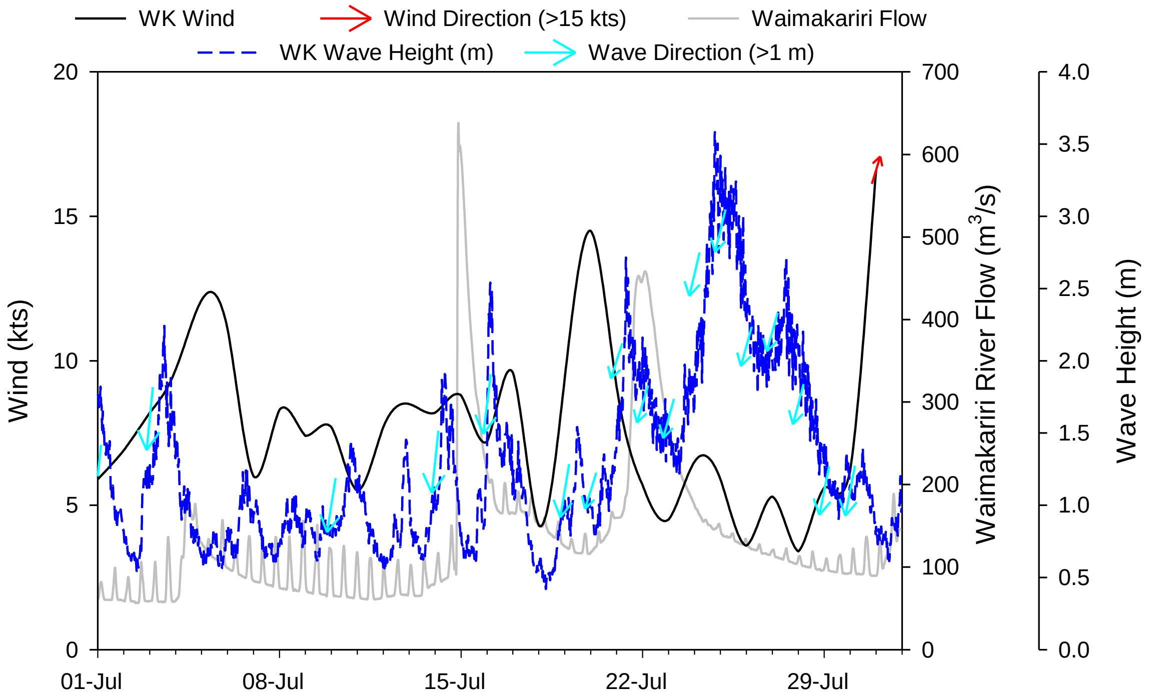


Figure 3 Offshore metocean conditions including wind speed and direction, significant wave height and daily averaged wave direction as measured by the WatchKeeper Buoy at site SG2a, and Waimakariri River flow at the Old Harbour Bridge station, during July 2019.
Note: Arrows indicate the direction of 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 Figures 4 to 6 and Table 2. Additional current information in the form of weekly current speed, direction and associated shear stress plots are provided in Figures 33 and 38 in the Appendix. Note that the ADCP data are presented in this report using the UTC time format.

Maximum currents at SG1 coincided with currents at SG2a, with near-surface currents (408 mm/s and 179 mm/s, respectively) and near-seabed (321 mm/s and 324 mm/s, respectively) currents peaking on 31 July, coinciding with maximum offshore wind speeds (Table 2). Near-surface maximum currents at SG3 (584 mm/s) also peaked on 31 July, while the near-seabed maximum current (401 mm/s) occurred on 20 July. The latter event coincided with increased offshore winds from a south-westerly direction. Differences in mean current flows were also noted within the strength of the current with velocity at SG2a being consistently lower than the those recorded at SG1 and SG3 (Table 2). These differences have been attributed to varying topography across the spoil ground sites. There appeared to be no impact on current speed from the increased wave heights recorded on 25 July.

Table 2 Parameter statistics for spoil ground ADCPs during July 2019.

Parameter	**Depth**	**Site**		
		SG1	**SG2a**	**SG3**
Minimum current speed (mm/s)	*Near-surface*	3	<1	2
	Near-seabed	2	2	<1
Maximum current speed (mm/s)	*Near-surface*	408	179	584
	Near-seabed	321	324	401
Mean current speed (mm/s)	*Near-surface*	100	19	123
	Near-seabed	86	57	118
Standard deviation of current speed (mm/s)	*Near-surface*	63	18	78
	Near-seabed	46	28	66
Current speed, 95^{th} percentile (mm/s)	*Near-surface*	228	52	270
	Near-seabed	169	106	238

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 (the opposite is true for wind direction, where the reference is the direction from which the wind is coming from).

Current direction at SG1 during July tended to flow towards the north-northwest at the near-surface (41.6%) and near-seabed (34.9%), with smaller components from the east-southeast (23.9% and 23.2% respectively). Flow directions at SG3 were similar to SG1 and also to those in June, with dominant flows at the near-surface and near-seabed tending to the north-west (30.9% and 25.9% respectively) and east-southeast (37% and 36.1 % respectively). Current flow at SG2a was also similar to that in June but was slightly different to the other sites with dominant current flow at both the near-surface and near-seabed tending towards the west-northwest (38.4% and 37.2%, respectively) and to the east-northeast (24.3% and 29.2%, respectively).

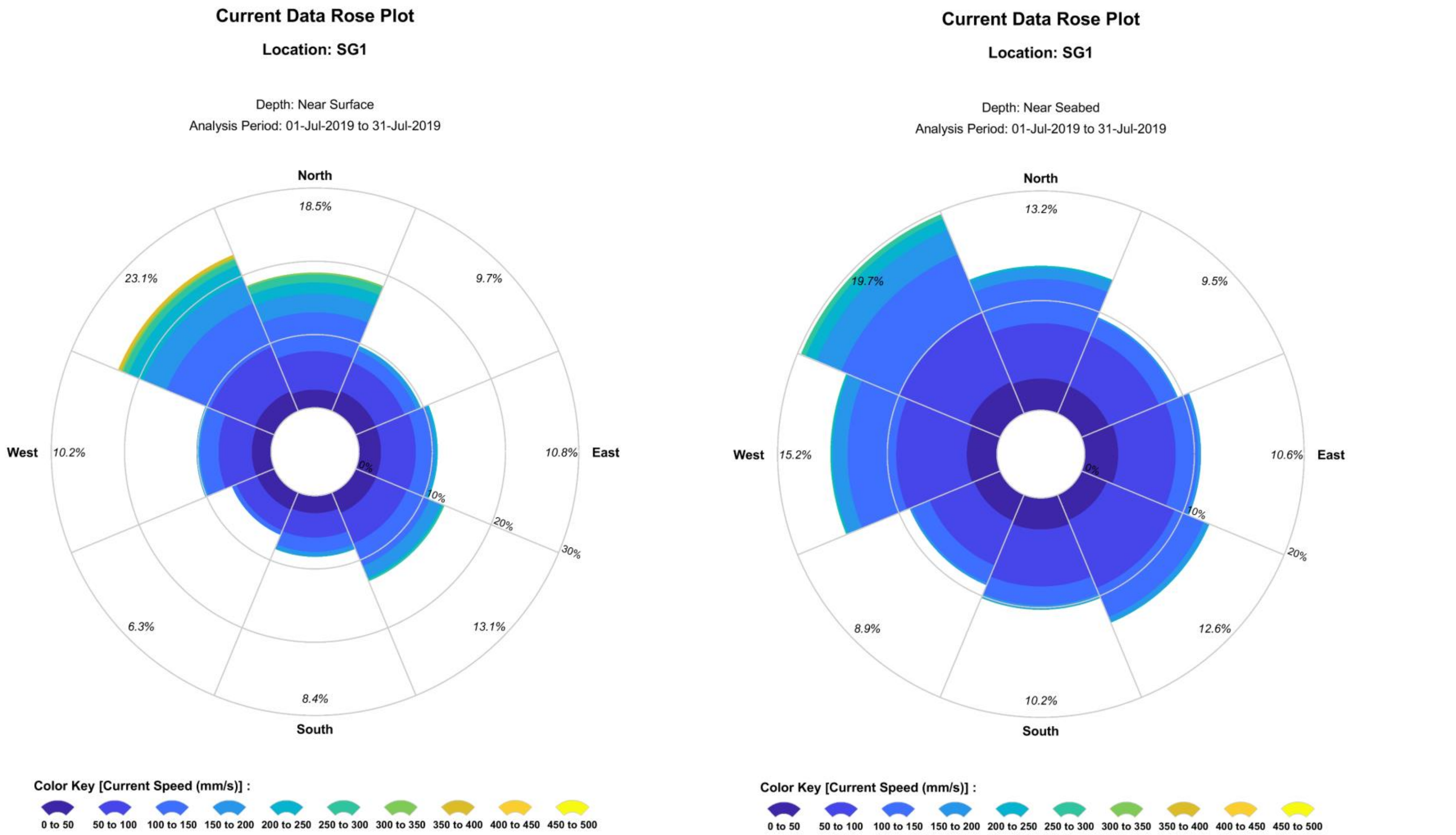
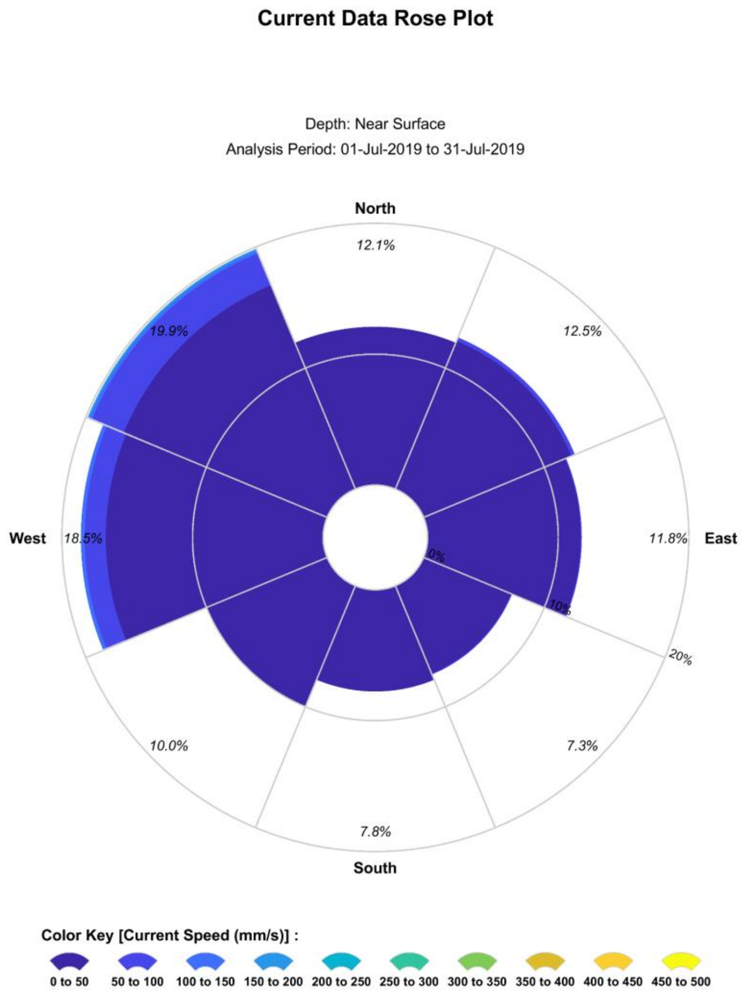


Figure 4 Near-surface and near-seabed current speed and direction at SG1 during July 2019.
Speed intervals of 50 mm/s are used.



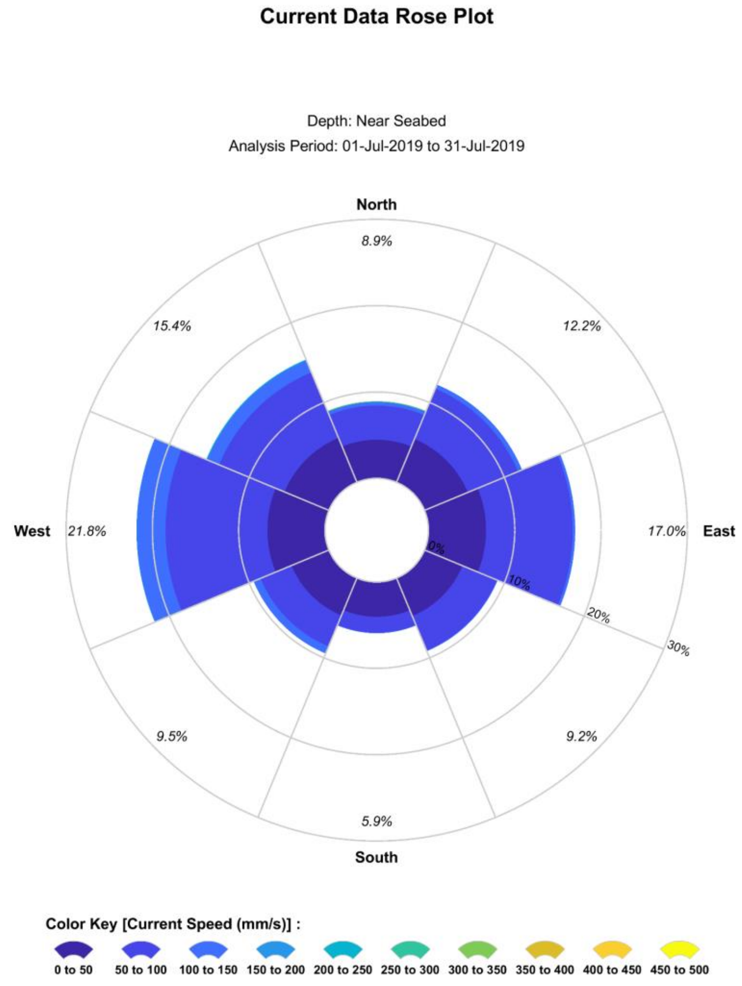


Figure 5 Near-surface and near-seabed current speed and direction at SG2a (Watchkeeper) during July 2019.
Speed intervals of 50 mm/s are used.

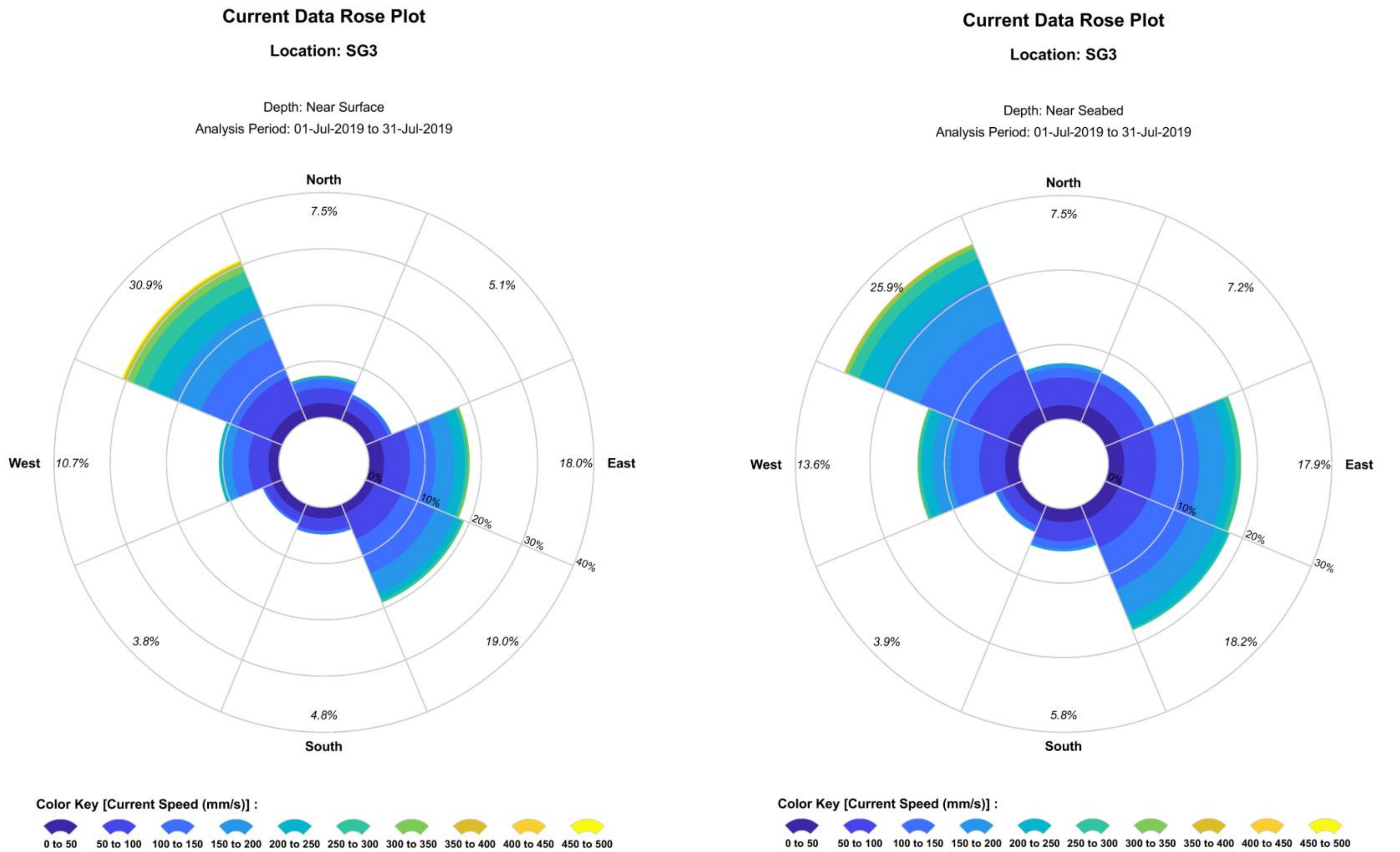


Figure 6 Near-surface and near-seabed current speed and direction at SG3 during July 2019.
Speed intervals of 50 mm/s are used.

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 9 July 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 July 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 July 2019 dredge data. Summary statistics for KZ filtered turbidity data, used for real time compliance monitoring during dredge operations, are also presented in Tables 22 to 24 in the Appendix. Similarly, plots of KZ filtered turbidity data with site specific trigger values are also presented within Figures 39 to 42 in the Appendix.

July Turbidity:

As commonly reported, surface turbidity values were higher (monthly means of 5.7 to 7.3 NTU) at the inshore monitoring sites than the spoil ground sites (2.6 to 3.4 NTU) in July (Tables 3 and 4). In contrast to historical data, some of the nearshore surface sites (OS3, OS4 and OS7) displayed a higher range and some of the highest recorded mean NTU values for July (6.4 to 10 NTU), compared to remaining nearshore sites (OS1-2 and OS5-6, Table 5, Figure 7), where turbidity was recorded at more typical ranges (3.2 to 5.7 NTU). This was attributed to some unusual weather events which occurred in July.

Turbidity overall across the inner harbour was relatively low for July except for a number of peaks of up to 28 NTU, which occurred in response to the inshore strong west-south-westerly winds on the 4 to 6, 27 and 31 July (Figure 8). Turbidity peaks particularly at UH2 on the 26 July were potentially influenced by significant increased wave heights of the 25 July, that may have been funnelled into the harbour, as wind speeds at this time were <13 kts.

Turbidity at nearshore sites of the monitoring program (OS1 to 4 and OS7) mimicked that of the inshore sites with turbidity peaks and levels similar to the inner harbour. The notable exception was at site OS3 where raw turbidity reached 108 NTU (Figure 10) on 25 July. The 24 h rolling average was >40 NTU compared to other offshore sites which remained <10 NTU (Figure 7). This peak strongly aligns with the elevated significant wave height on the 25 July from a north-easterly direction. The influence of this strong swell on the 25 July was also seen to a much lesser degree at OS1 and OS7. Anecdotal observations at the time suggest a back wash of swell waves against the coastline was responsible for the elevated turbidity at OS3, as dredge disposal operations were not occurring between 20 to 29 July. The strong offshore wind event on the 20 July did not produce any significant peaks within the surface nearshore sites.

Table 3 Mean turbidity and statistics at inshore water quality logger sites during July 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for June are means ± se, range and percentiles (n = 2828 to 2976) Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface July	Surface Baseline
UH1	Mean ± se	7.3 ± 0.1	12
	Range	2.2 – 22	-
	99th	17	39
	95th	13	22
	80th	9.5	15
UH2	Mean ± se	5.7 ± 0.1	10
	Range	0.6 – 28	-
	99th	19.4	32
	95th	14	20
	80th	8.1	13
CH1	Mean ± se	7.0 ± 0.0	9
	Range	3.6 – 27	-
	99th	13.1	29
	95th	9.9	18
	80th	8.2	12
CH2	Mean ± se	5.9 ± 0.0	8
	Range	2.7 – 16	-
	99th	11.1	24
	95th	9.1	16
	80th	7.1	10

Table 4 Mean turbidity and statistics at spoil ground water quality logger sites during July 2019 and Baseline period (1 November 2016 to 31 October 2017).
Values for June are means ± se, range and percentiles (n = 2969 to 2976). Baseline values modified from Fox 2018.

Site	Turbidity (NTU)		
	Statistic	Surface July	Surface Baseline
SG1	Mean ± se	3.4 ± 0.0	4.2
	Range	<1 – 10.5	-
	99th	8.3	14
	95th	6.8	10
	80th	5	6.2
SG2	Mean ± se	2.6 ± 0.0	4.6
	Range	<1 – 11.3	-
	99th	8.2	20
	95th	5.8	11
	80th	4.2	7.0
SG3	Mean ± se	3.4 ± 0.0	3.6
	Range	<1 – 20	-
	99th	13.8	13
	95th	7.2	7.7
	80th	5	4.8

Further offshore at OS5, OS6 and the spoil ground sites, turbidity peaks also followed the same trends as at the nearshore sites with peaks on the 4 to 6 and 31 July (Figures 11 and 12). Another peak was noted on the 21 July at OS5, SG1, SG2 and SG3 and was most likely in response to the increased wind speeds on the 20 July from a south-westerly direction.

Turbidity at SG3 from 31 July also displayed a greater response to the highest wind speed event of the month compared to other offshore sites. Turbidity peaks occurred when increases in either wind speed and/or wave heights were recorded (Figure 7) during the month of July.

Table 5 Mean turbidity and statistics at offshore water quality logger sites during July 2019 and Baseline period (1 November 2016 to 31 October 2017).
*Values for June are means ± se, range and percentiles (n = 1962 to 2976). Baseline values modified from Fox 2018**

Site	Statistic	Turbidity (NTU)		
		Surface July	Surface Baseline	Benthic July
OS1	Mean ± se	5.3 ± 0.1	7.5	35 ± 0.5
	Range	<1 – 28	-	5 – 190
	99th	15	24	139
	95th	10	16	92.4
	80th	7	10	51.1
OS2	Mean ± se	5.7 ± 0.0	6.4	43 ± 0.5
	Range	2.2 – 14	-	5 – 168
	99th	12	18	123
	95th	10	13	96.5
	80th	7	9.0	65
OS3	Mean ± se	10 ± 0.2	6.6	26 ± 0.4
	Range	2.5 – 108	-	3.1 – 142
	99th	53	27	79
	95th	22	15	56
	80th	11.5	8.9	36.4
OS4	Mean ± se	6.4 ± 0.1	5.9	36 ± 0.5
	Range	1.3 – 30	-	1.8 – 151
	99th	15	20	109
	95th	11.4	13	84.3
	80th	8.4	8.3	55
OS5	Mean ± se	3.2 ± 0.0	4.6	–
	Range	<1 – 12	-	–
	99th	8.8	19	–
	95th	6.8	11	–
	80th	4.8	6.4	–
OS6	Mean ± se	3.9 ± 0.0	4.7	36 ± 0.3
	Range	<1 – 14	-	2.3 – 125
	99th	10	19	93.4
	95th	7.8	12	73
	80th	5.2	7.2	49.4
OS7	Mean ± se	7.3 ± 0.1	6.4	–
	Range	2.2 – 21.7	-	–
	99th	17	23	–
	95th	13	14	–
	80th	9.5	9.2	–

Comparison to Baseline:
Mean surface turbidity values during July were overall lower to values calculated from the baseline monitoring period, except for OS3, OS4 and OS7 where mean turbidity was higher

than the calculated baseline values (Tables 3 to 5, Figures 8 to 12). This is attributed to the unusual weather events of increased significant wave heights and stronger than typical wind gusts experienced in July.

Benthic:

Benthic data recovery was good with all sites reporting values for the majority of July, except for the period of increased wave height (Figure 7). Although data was received from some sondes during this period the majority of values were >1000 NTU and were deemed too variable and outside normal measurable values to include in the data set. However potentially turbidity at this time may have reached the extreme limits of the instruments. There was consistency between surface and benthic turbidity patterns for the most part of July, however departures occurred within the benthic turbidity data during the significant wave height event, returning to expected values towards the end of the month. (Figure 7).

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 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

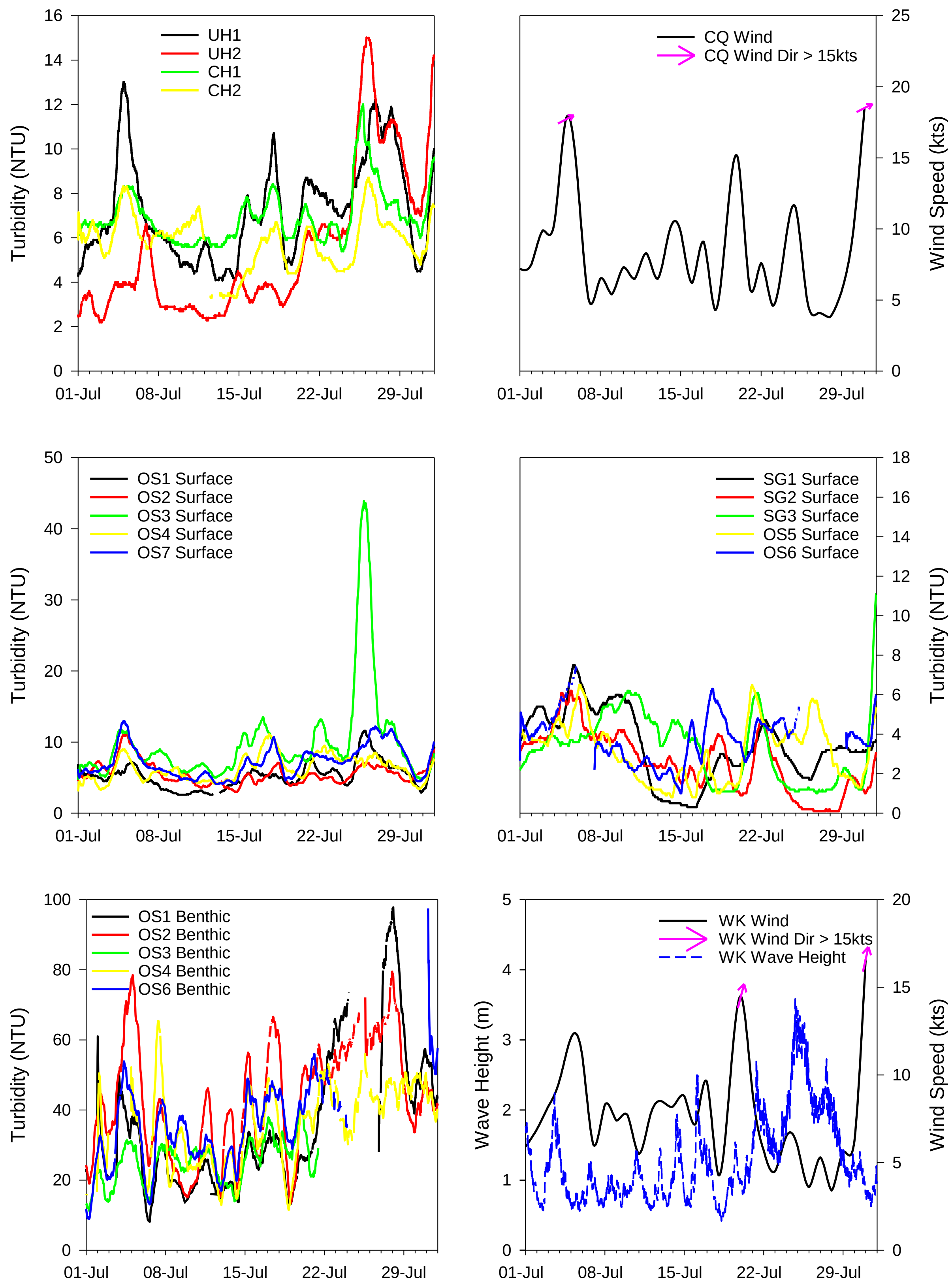


Figure 7 24 hour rolling average turbidity and metocean data for inshore, nearshore, offshore and benthic monitoring stations.
Note differing scales between plots. Arrows indicate the direction of travel for inshore/offshore winds greater than 15 knots.

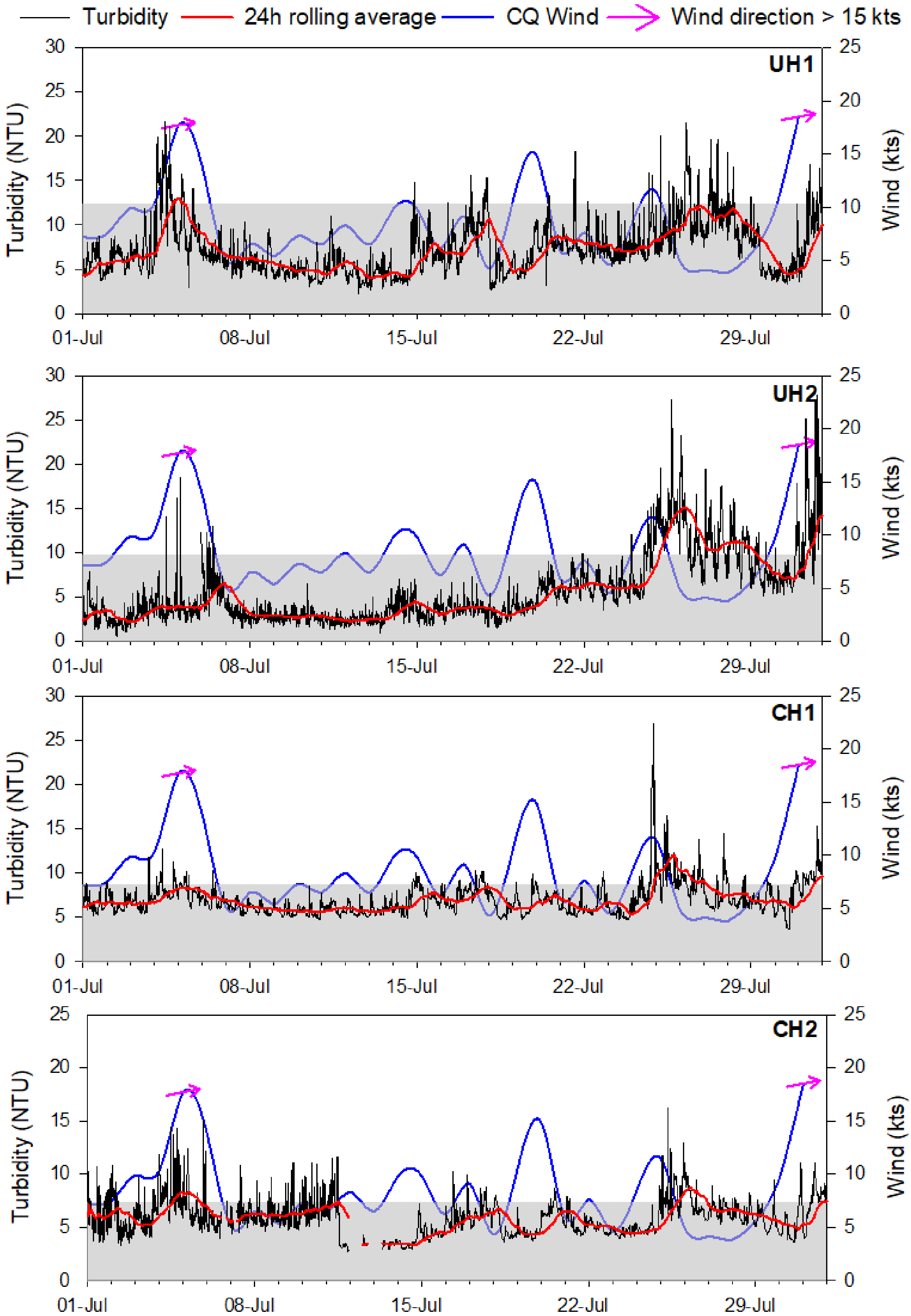


Figure 8 Surface turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during July 2019.
Arrows indicate the direction of travel for inshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

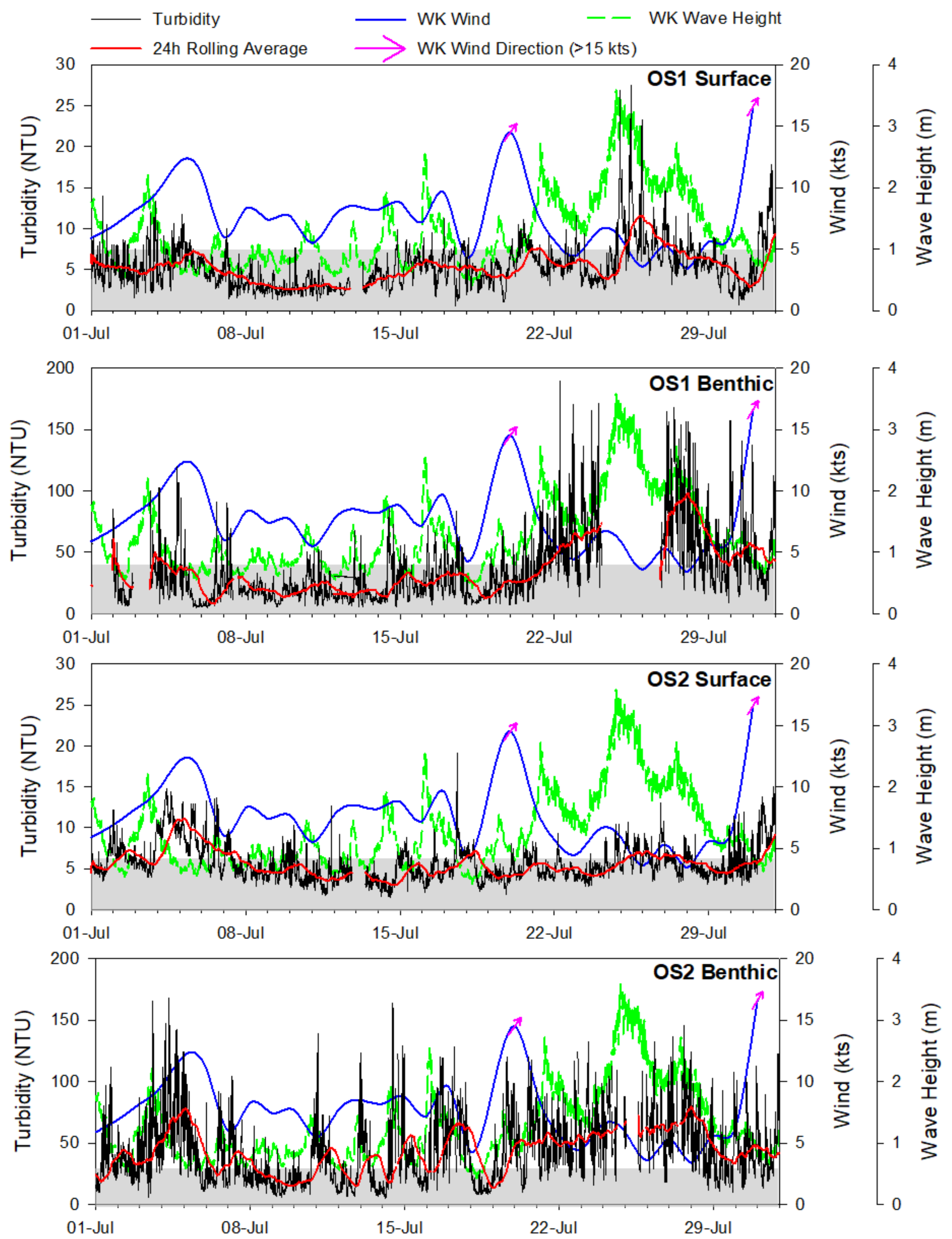


Figure 9 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS1 and OS2) during July 2019.

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.

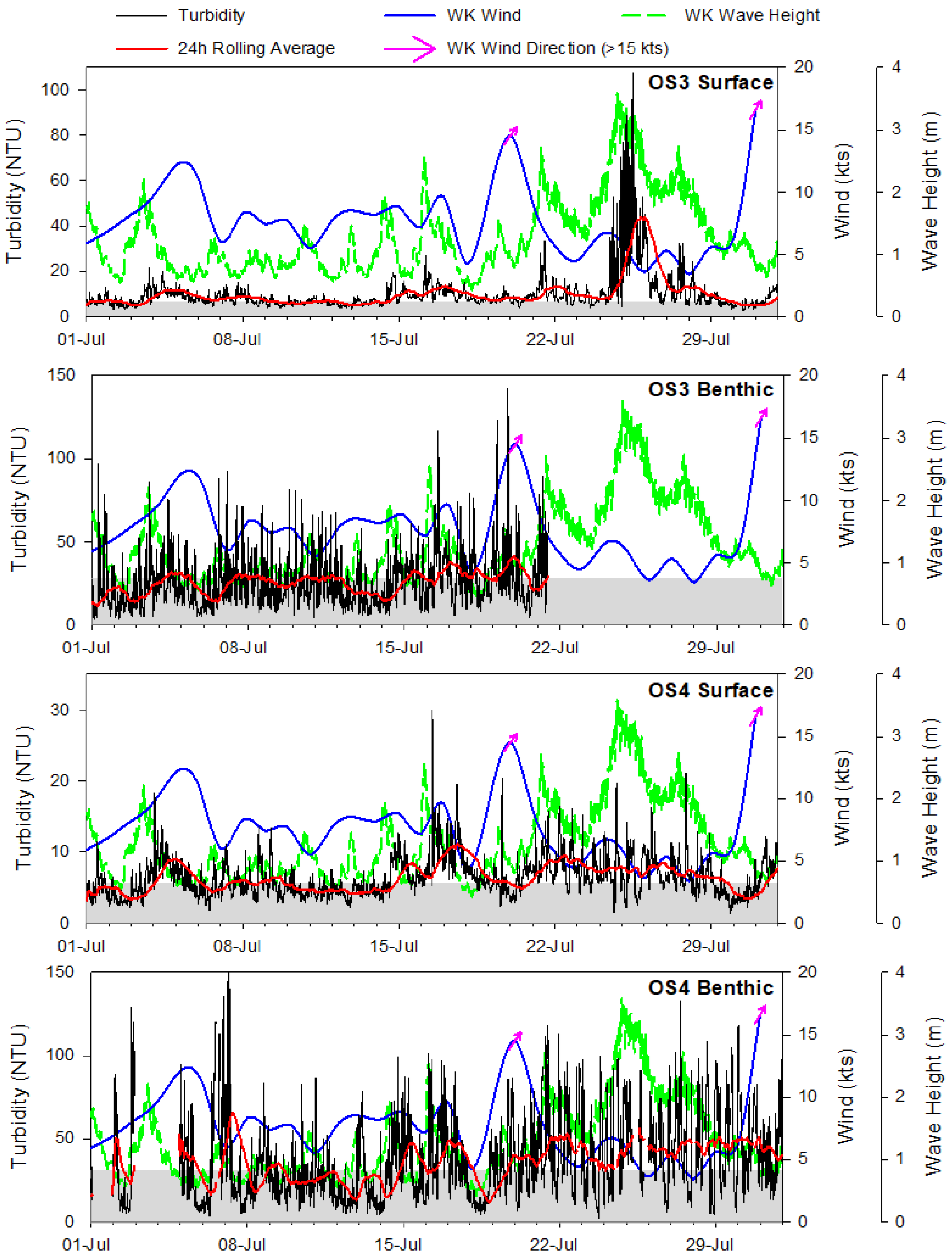


Figure 10 Surface and benthic turbidity and daily averaged winds at nearshore sites (OS3 and OS4) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

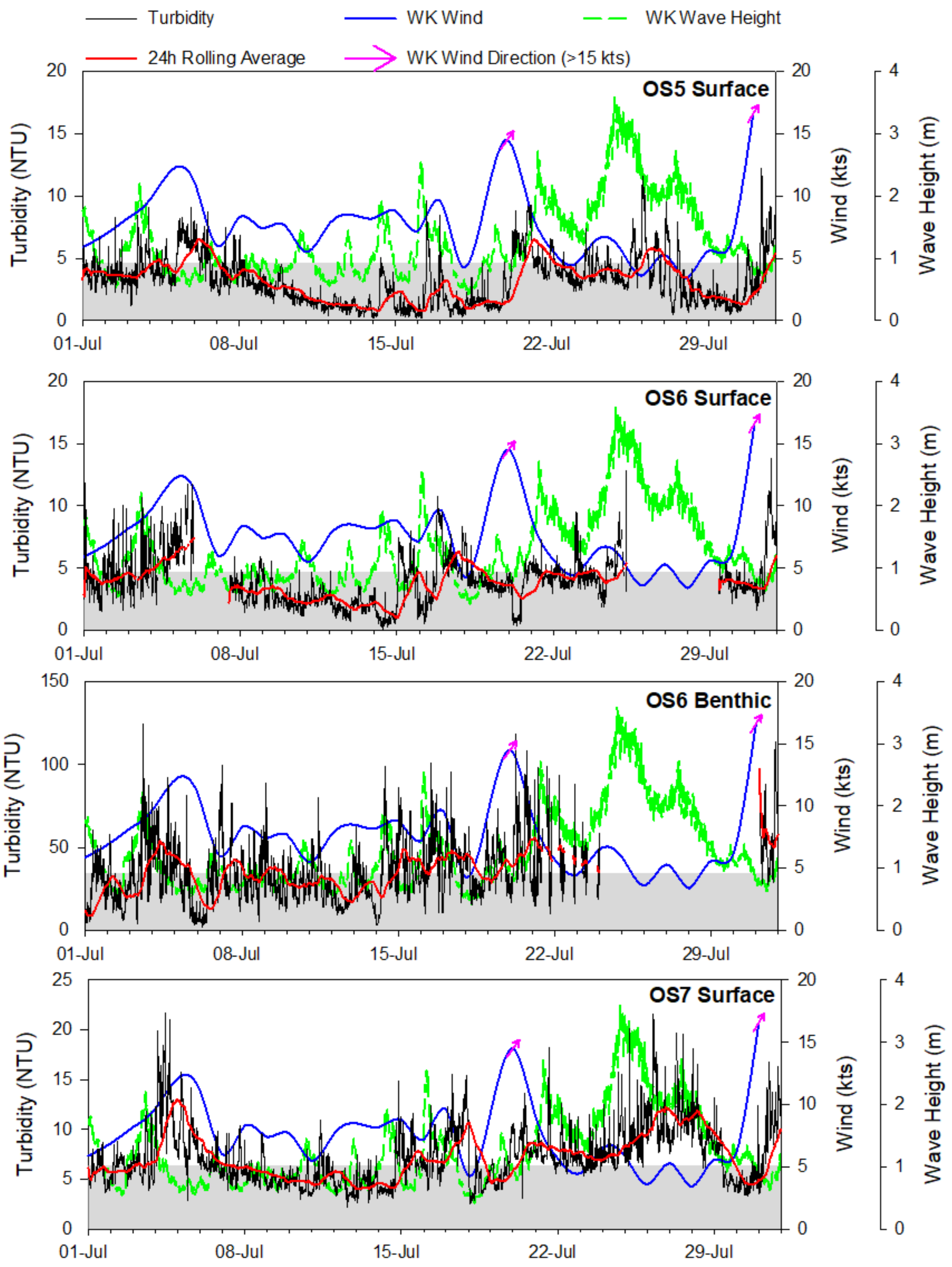


Figure 11 Surface and benthic turbidity and daily averaged winds at nearshore and offshore sites (OS5, OS6 and OS7) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

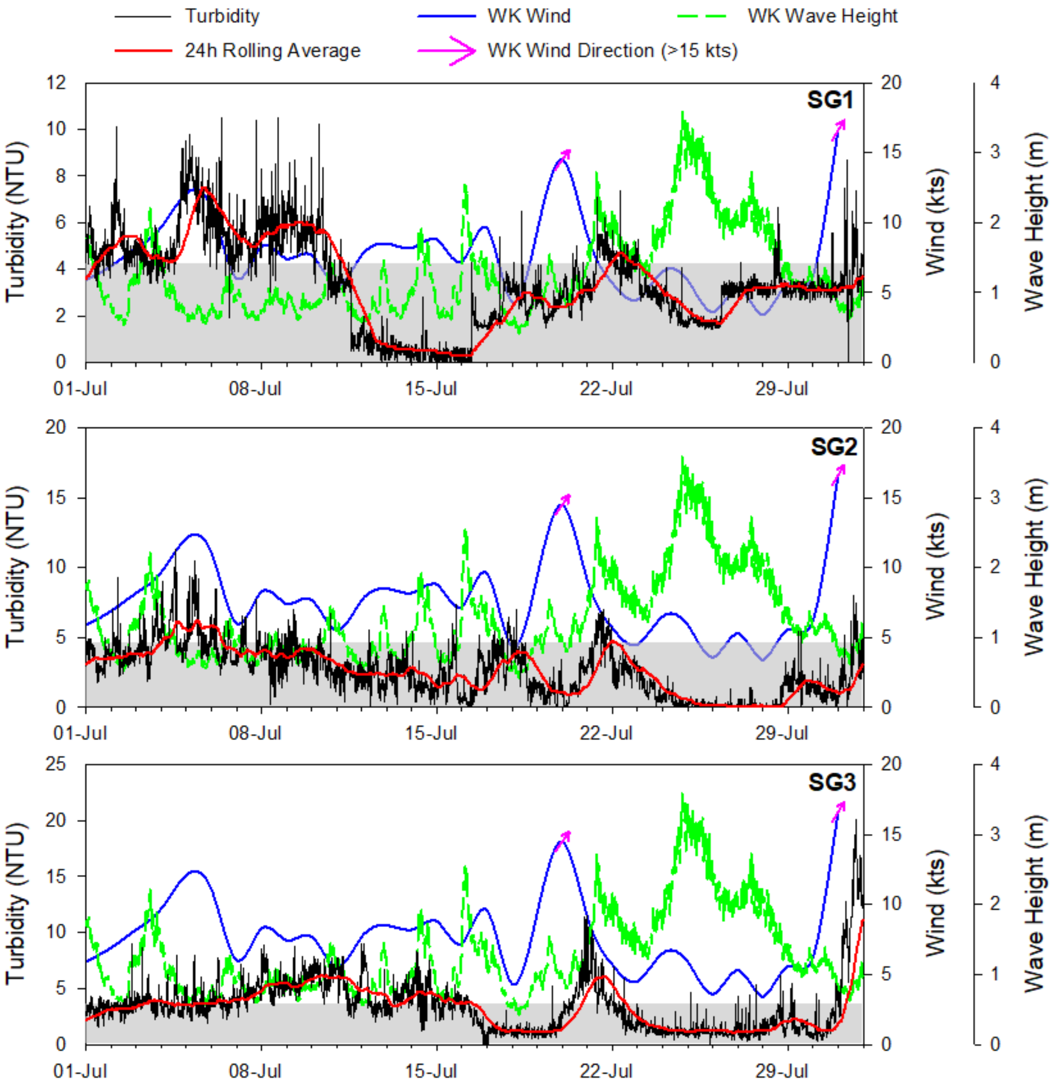


Figure 12 Surface turbidity at spoil ground sites (SG1, SG2b and SG3) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Grey shading indicates the baseline mean turbidity.

3.2.2.1 P99 Exceedance Counts

During July the Tier 3 intensity values were exceeded at two sites within the monitoring network (Table 7). The first exceedance occurred at OS3 and was attributed to the elevated swell waves (>3.5 m) which occurred on the 24 to 25 July from a north-easterly direction. No dredge disposal activities occurred between 20 to 29 July. The second exceedance occurred at SG3 and at the same time as elevated offshore southerly winds which were the highest recorded for the month, including wind gusts >40 kts.

Table 7 Tier 3 intensity value exceedances and maximum hour counts during July 2019.
* still continuing

Site	P99 Count >7.2 Hours Start Time	P99 Count >7.2 Hours End Time	Maximum P99 Count (Hours)
UH1	-	-	0.5
UH2	–	–	0.00
CH1	–	–	0.00
CH2	–	–	0.00
OS1	–	–	0.00
OS2	–	–	0.00
OS3	25/7/2019 04:00	31/7/19 23:45*	26.5
OS4	Reference site		
OS5	–	–	0.00
OS6	–	–	0.00
OS7	–	–	0.5
SG1	–	–	0.00
SG2	–	–	0.00
SG3	31/7/2019 20:45	31/7/19 23:45*	9.00

3.2.2.2 P99 Exceedance Counts Consented Removal

Despite exceedances of intensity values and exceedance hours at OS3 and SG3, the increased surface turbidity was deemed to be weather related. No validated P99 exceedance counts (Table 7) were removed (Table 8) on this occasion.

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

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

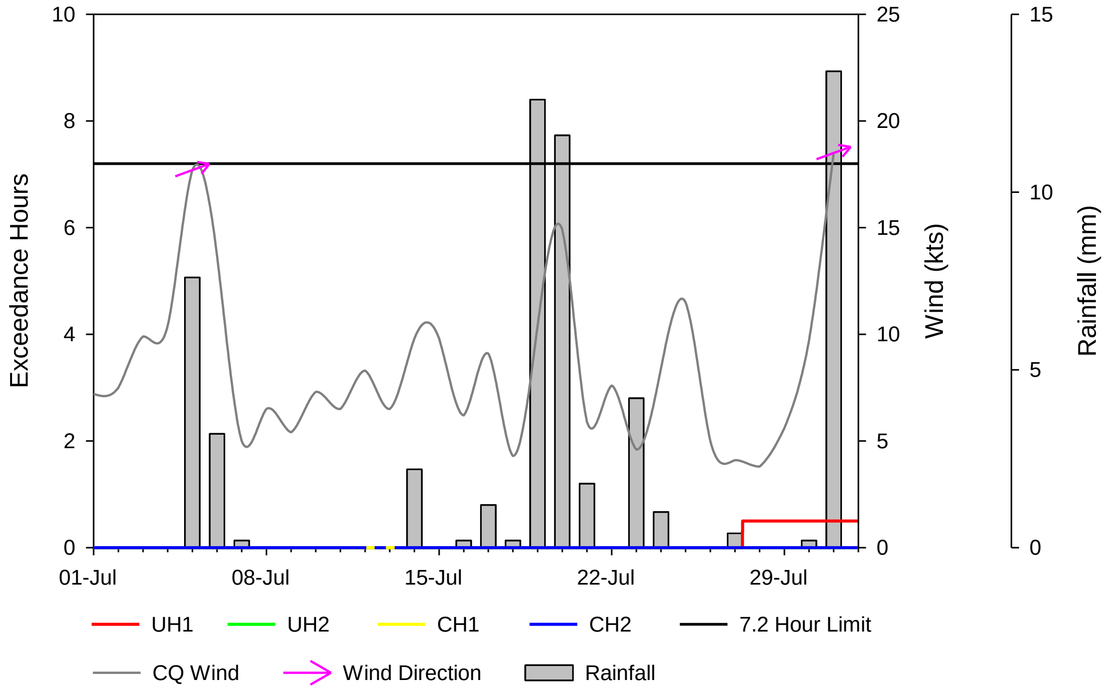


Figure 13 Tier 3 allowable hour counts at UH1, UH2, CH1 and CH2 after exceedance of the intensity values during July 2019.

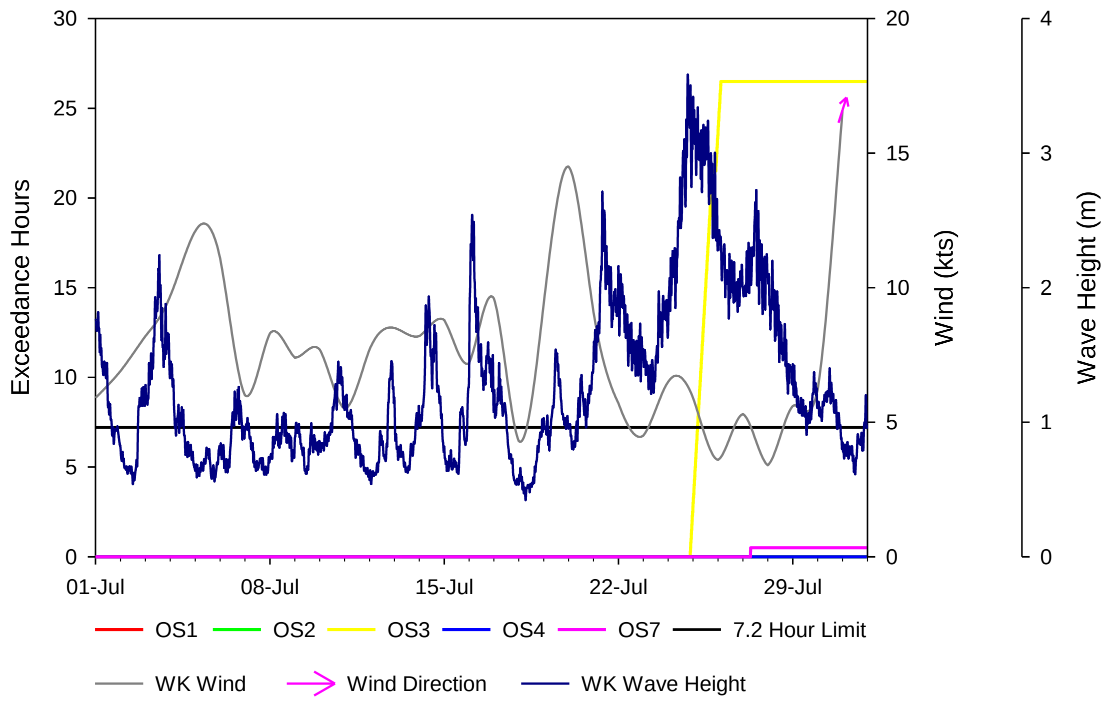


Figure 14 Tier 3 allowable hour counts at OS1-OS3, and OS7 after exceedance of the intensity values during July 2019.

Note there is no trigger value for the reference site OS4.

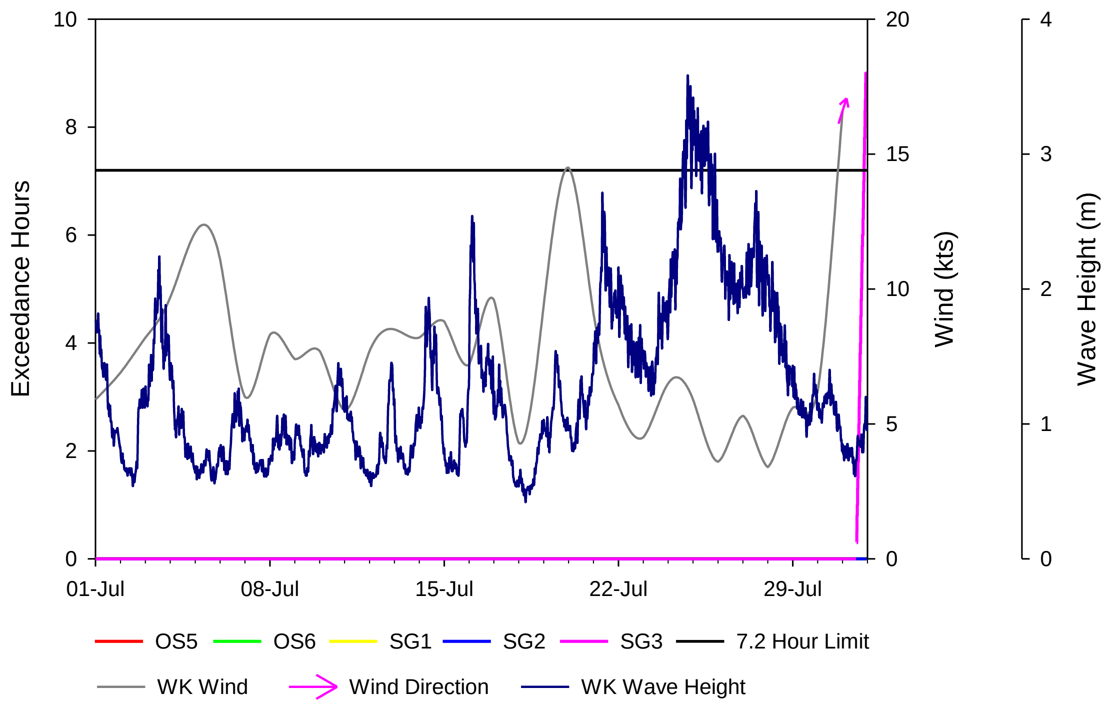


Figure 15 Tier 3 allowable hour counts at OS5, OS6, SG1, SG2b and SG3 after exceedance of the intensity values during July 2019.

3.2.3 Temperature

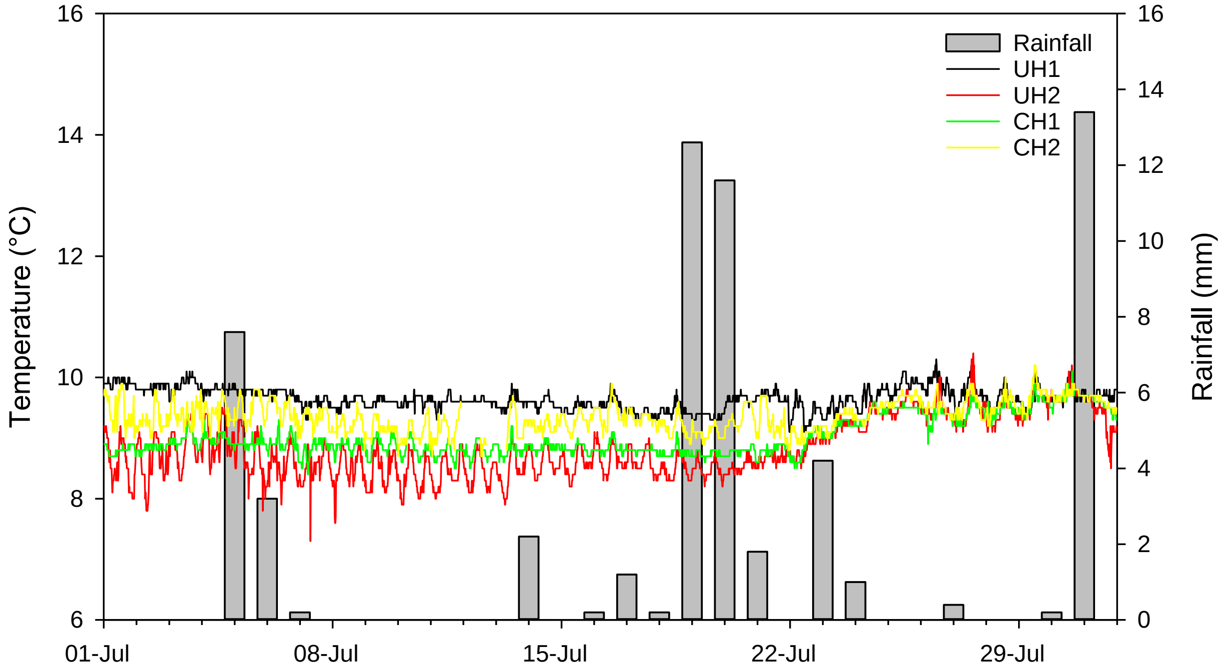
Mean monthly sea surface temperatures around Lyttelton Harbour were slightly cooler than those experienced during June, ranging from 8.8 to 10.8°C (Table 9) (c.f. 9.5 to 11.8°C in June) continuing the trend for cooler waters associated with the winter months. This is despite mean ambient temperatures slightly increasing in July. Continuing trends for the previous month, slightly cooler temperatures were recorded in the shallower waters of the upper and central harbour in comparison with offshore sites.

All sites displayed a relatively consistent trend across the month, with a period of warming within the inner harbour occurring after the rainfall event from the 15 to 23 July (Table 9, Figure 16).

Semidiurnal variability (associated with tidal water movements and solar radiation) was again observed within the surface temperature datasets, particularly at the inner harbour sites and at site OS1 at the harbour entrance. Benthic temperatures were slightly higher than the overlying surface waters (Table 9, Figure 17), and displayed the same surface trends indicating a well-mixed water column.

Table 9 Mean temperature at inshore, spoil ground and offshore water quality sites during July 2019. *Values are means ± se (n = 2863 to 2976).*

Site	Temperature (°C)	
	Surface loggers	Benthic loggers
UH1	9.6 ± 0.0	–
UH2	8.8 ± 0.0	–
CH1	9.0 ± 0.0	–
CH2	9.4 ± 0.0	–
SG1	9.9 ± 0.0	–
SG2	10.0 ± 0.0	–
SG3	10.7 ± 0.0	–
OS1	9.4 ± 0.0	9.8 ± 0.0
OS2	9.8 ± 0.0	10.0 ± 0.0
OS3	9.9 ± 0.0	10.1 ± 0.0
OS4	9.9 ± 0.0	10.0 ± 0.0
OS5	9.8 ± 0.0	–
OS6	9.9 ± 0.0	10.1 ± 0.0
OS7	9.6 ± 0.0	–



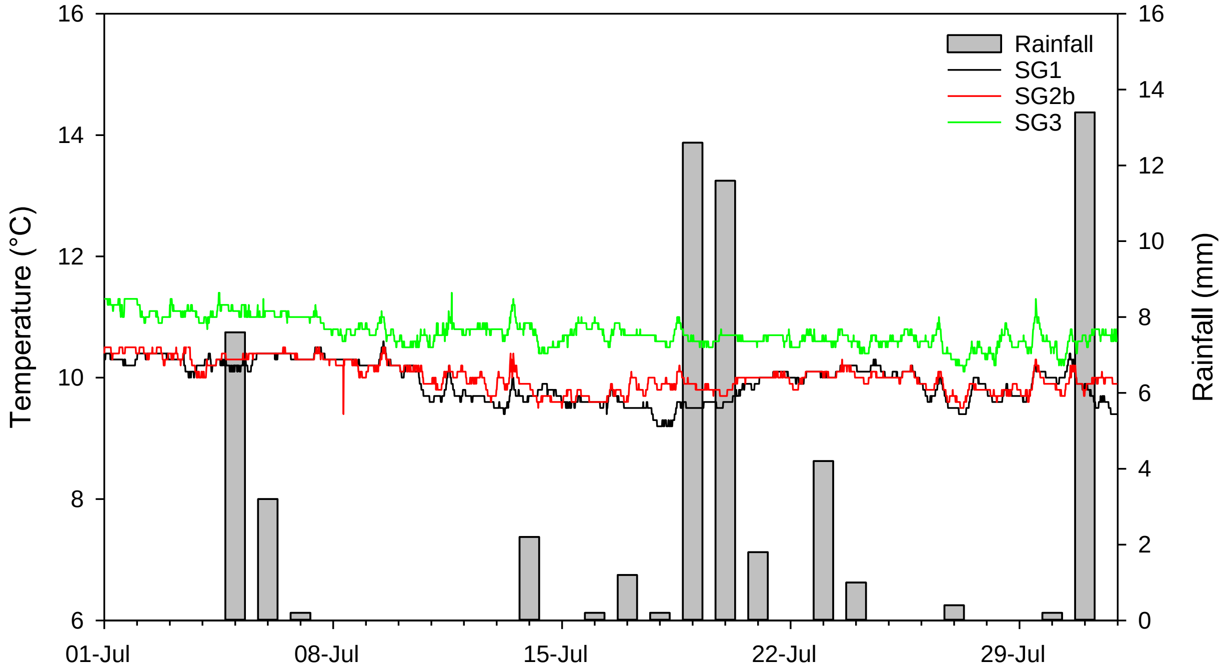


Figure 16 Surface temperature at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites and rainfall during July 2019.

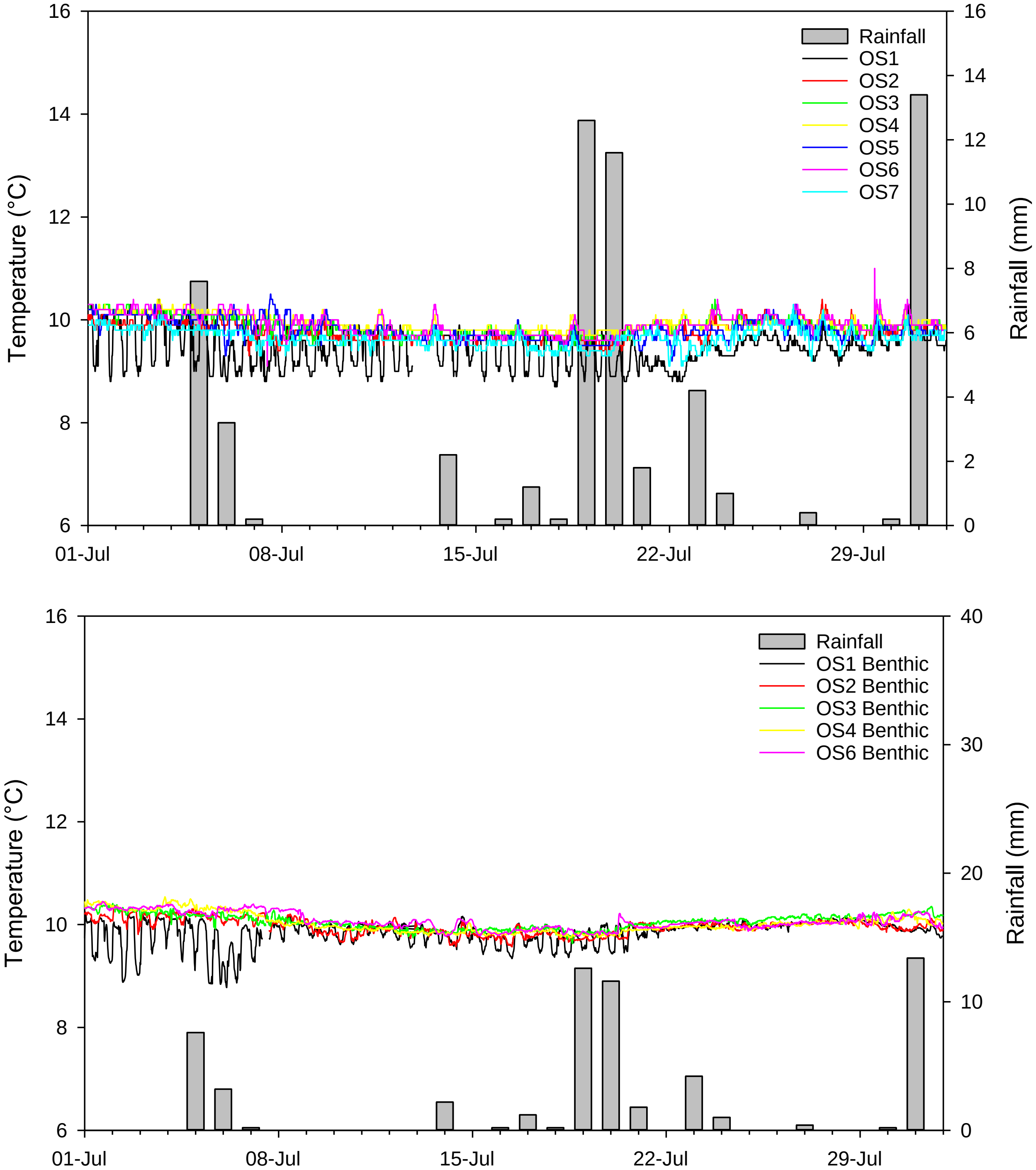


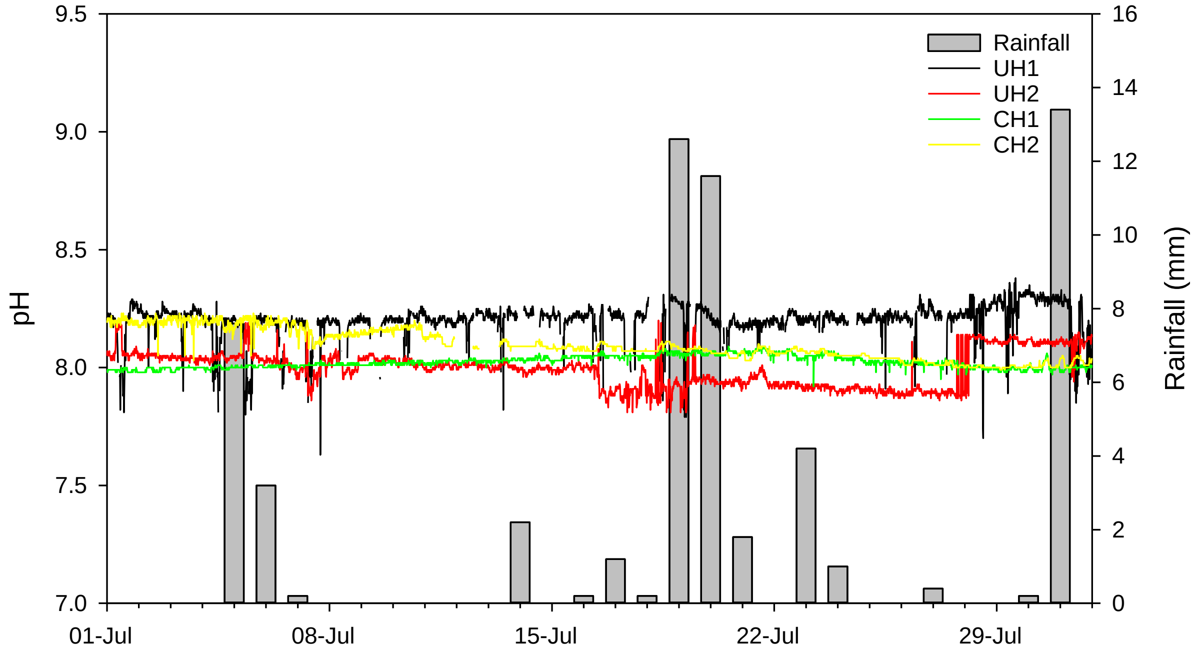
Figure 17 Surface temperature (OS1 to OS7) and benthic temperature (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during July 2019.

3.2.4 pH

The pH in July was temporally consistent across all sites, both surface and benthic, with monthly means ranging between 8.0 and 8.2 (Table 10, Figures 18 and 19). Some post calibration issues have been encountered with pH probes during March to July which has resulted in some unacceptable data. Replacement probes and firmware updates have not completely resolved the issue. 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 July 2019. *Values are means ± se (n = 1569 to 2976).*

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



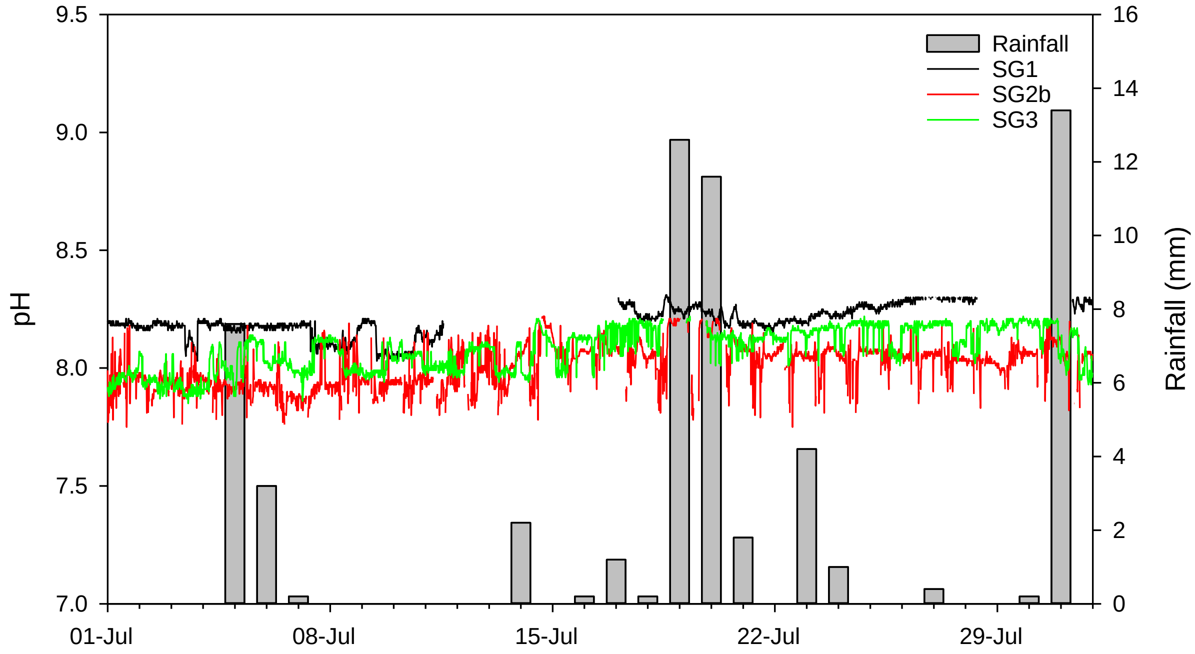
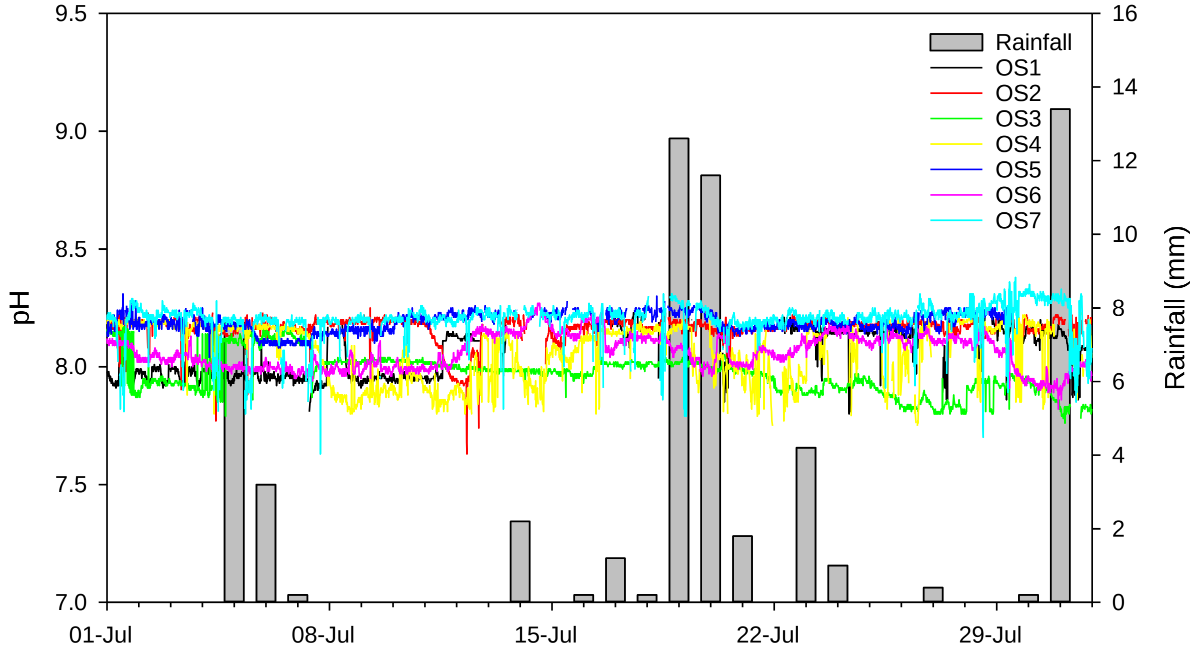


Figure 18 Surface pH at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during July 2019.



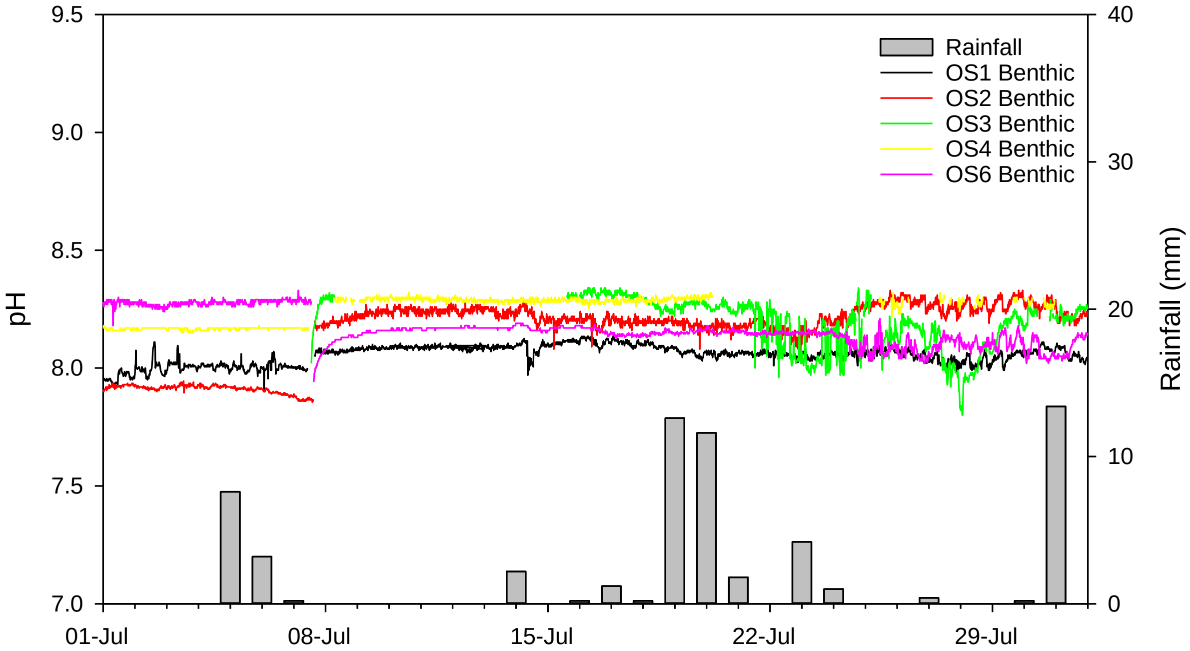


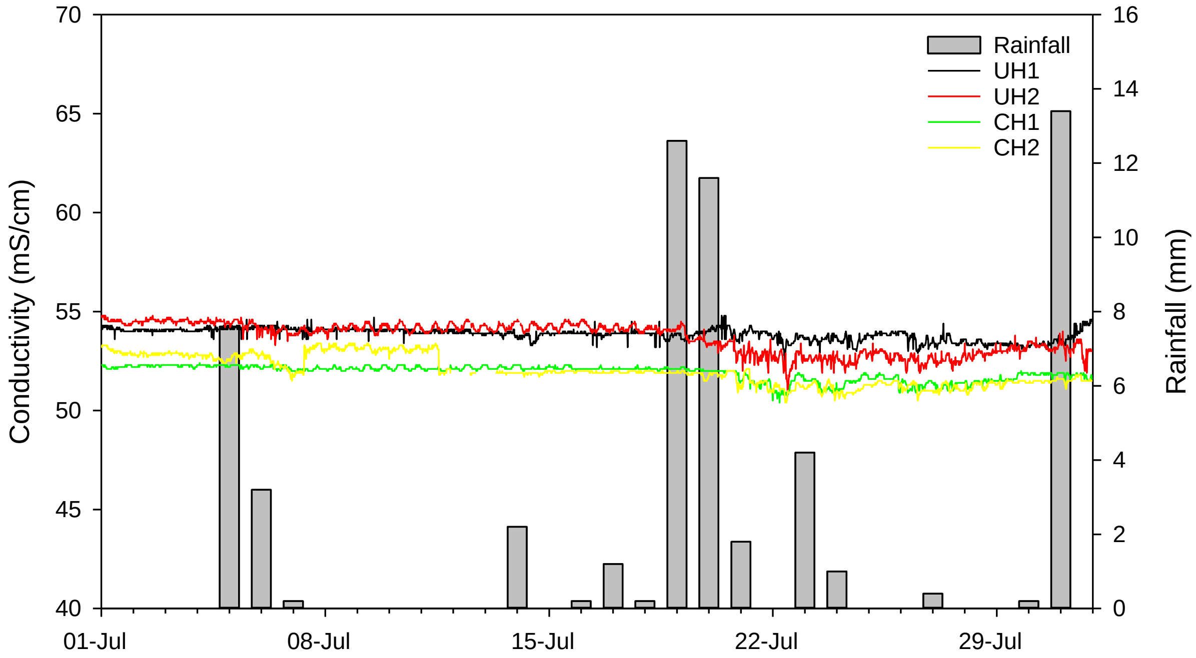
Figure 19 Surface pH (OS1 to OS7) and benthic pH (OS1 to OS4) at nearshore and offshore water quality sites during July 2019.

3.2.5 Conductivity

Surface conductivity in July ranged from 51.9 mS/cm to 55.0 mS/cm (Table 11, Figure 20 and 21), while benthic conductivity was similar or slightly lower, ranging from 52.9 mS/cm to 53.6 mS/cm. Monthly mean values were similar to those calculated for June. Surface conductivity was noted to slightly decline on the 20 July within the inner harbour and OS1, due to the preceding rainfall (>24 mm). Conductivity then returned to stable values for the remainder of the month at all sites. Low flows from the Waimakariri River are unlikely to have impacted conductivity at any sites.

Table 11 Mean conductivity at inshore, spoil ground and offshore water quality sites during July 2019. *Values are means ± se (n = 2057 to 2976).*

Site	Conductivity (mS/cm)	
	Surface loggers	Benthic loggers
UH1	53.9 ± 0.0	–
UH2	53.7 ± 0.0	–
CH1	51.9 ± 0.0	–
CH2	52.0 ± 0.0	–
SG1	54.0 ± 0.0	–
SG2	55.0 ± 0.0	–
SG3	54.2 ± 0.0	–
OS1	53.4 ± 0.0	53.4 ± 0.0
OS2	53.8 ± 0.0	52.9 ± 0.0
OS3	53.8 ± 0.0	54.5 ± 0.0
OS4	54.3 ± 0.0	53.6 ± 0.0
OS5	53.9 ± 0.0	–
OS6	53.8 ± 0.0	53.5 ± 0.0
OS7	53.9 ± 0.0	–



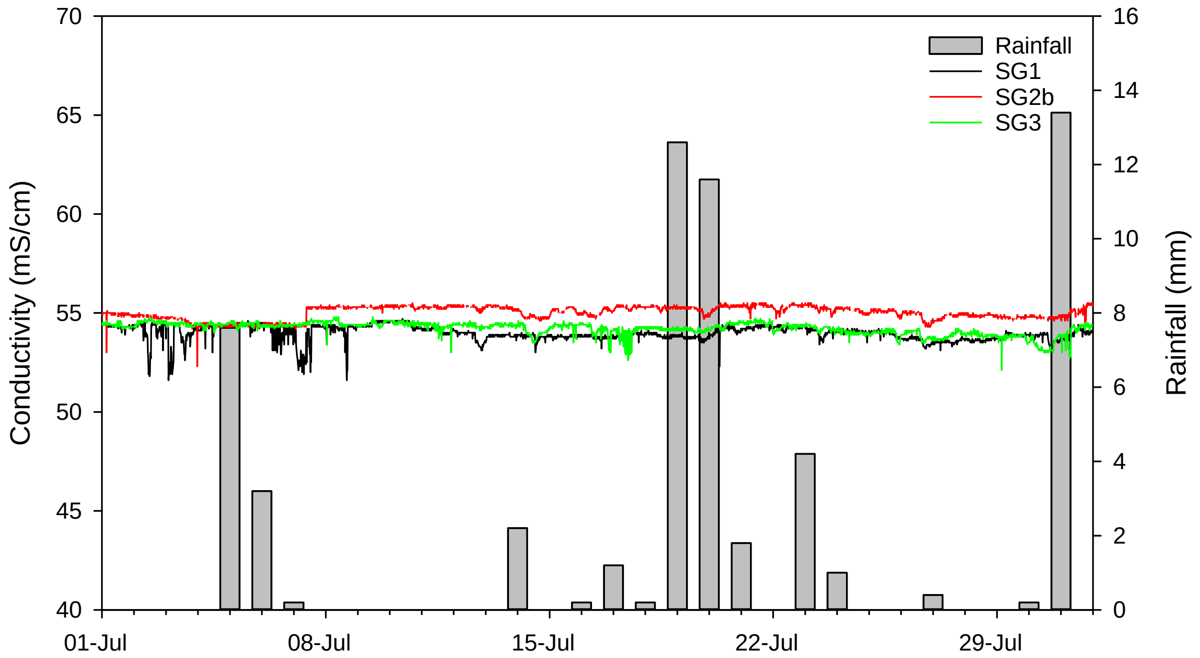
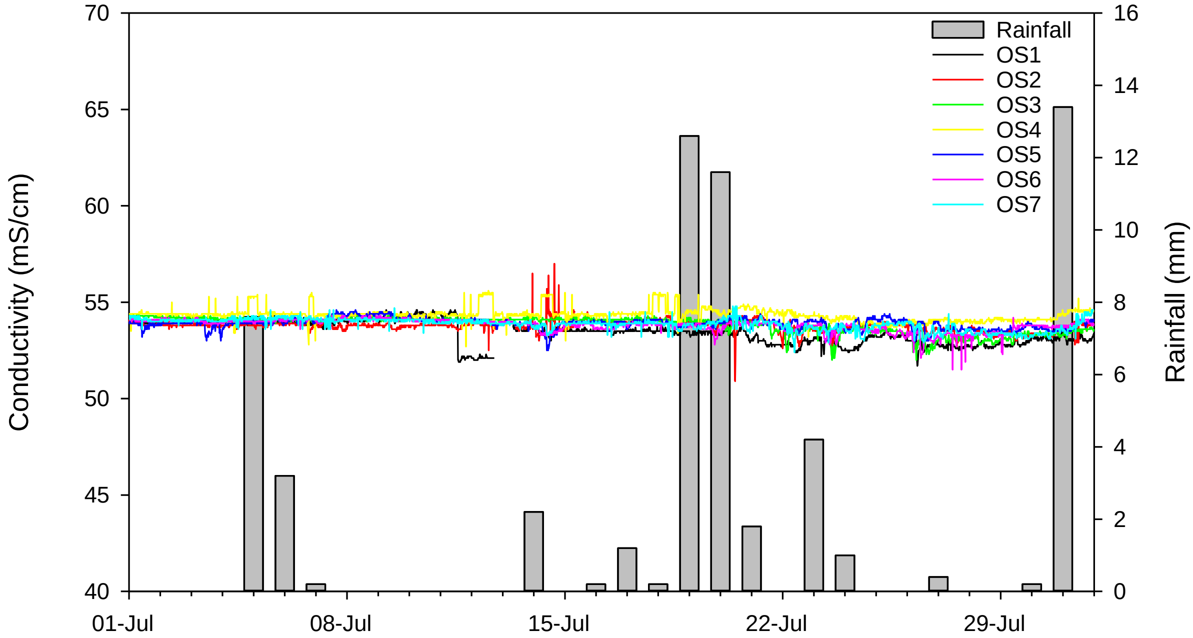


Figure 20 Surface conductivity at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during July 2019.



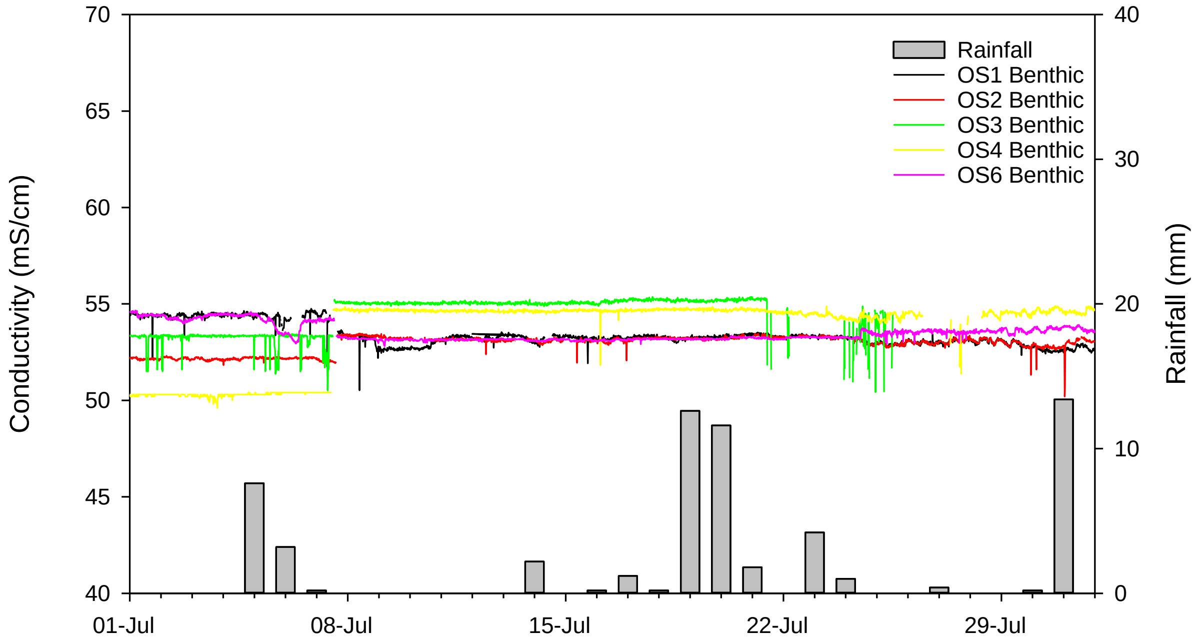


Figure 21 Surface conductivity (OS1 to OS7) and benthic conductivity (OS1 to OS4 and OS6) at nearshore and offshore water quality sites during July 2019.

3.2.1 Dissolved oxygen

Mean monthly surface DO concentrations in July ranged from 96 to 101% saturation, which was higher than June values (93 to 97% saturation). DO concentrations fluctuated somewhat in July with peaks generally not coinciding with any specific metocean condition (Figure 22 and 23). Lower DO at UH1 during the heavier rainfall period may have been related to a reduction of light and thus photosynthesis at this shallow site. Fluctuating elevations of DO at all three spoil ground sites from 11 July may have been indicative of localised offshore algal blooms but did not appear temperature related. However, DO did increase slowly towards the end of the month likely in response to temperature and increased photosynthesis. In contrast DO at offshore sites remained fairly stable. Large diurnal fluctuations in DO were recorded at all sites including the spoil ground for the entire month of July.

Table 12 Mean dissolved oxygen at inshore, spoil ground and offshore water quality sites during July 2019.
Values are means ± se (n = 2778 to 2976).

Site	Dissolved oxygen (% saturation)	
	Surface loggers	Benthic loggers
UH1	97 ± 0	–
UH2	96 ± 0	–
CH1	101 ± 0	–
CH2	101 ± 0	–
SG1	99 ± 0	–
SG2	99 ± 0	–
SG3	98 ± 0	–
OS1	99 ± 0	94 ± 0
OS2	96 ± 0	92 ± 0
OS3	96 ± 0	95 ± 0
OS4	97 ± 0	94 ± 0
OS5	98 ± 0	–
OS6	99 ± 0	90 ± 0
OS7	97 ± 0	–

Mean monthly benthic DO concentrations were lower than corresponding surface readings ranging from 90 to 95% saturation (Table 12, Figures 22 and 23), indicative of lower photosynthesis at the benthos. Benthic DO displayed a similar pattern to the surface counterparts with a relatively stable saturation until 24 July. After the 24 July benthic DO became extremely variable ranging from 62 to 109% saturation (Figure 23). This variability aligns with the increase in swell waves over this time period, which increased turbidity and therefore reduced light penetration for photosynthesis to occur at the seafloor. However, increased turbulence from wave action introducing highly oxygenated waters from the surface down to the benthos, would most likely explain the highly fluctuating DO that was recorded at all benthic sites.

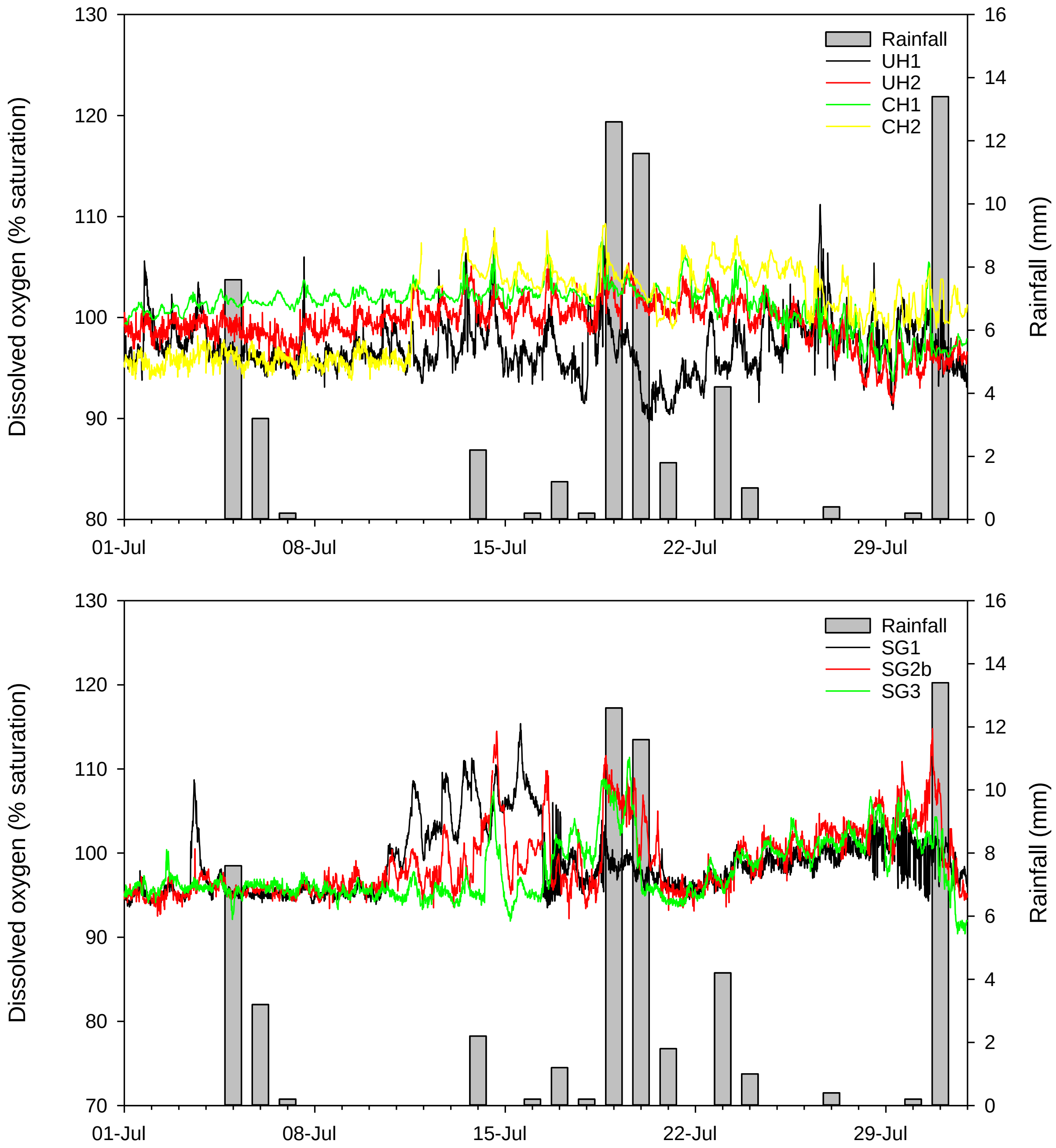


Figure 22 Surface DO at inshore (UH1, UH2, CH1 and CH2) and spoil ground (SG1, SG2b and SG3) water quality sites during July 2019.

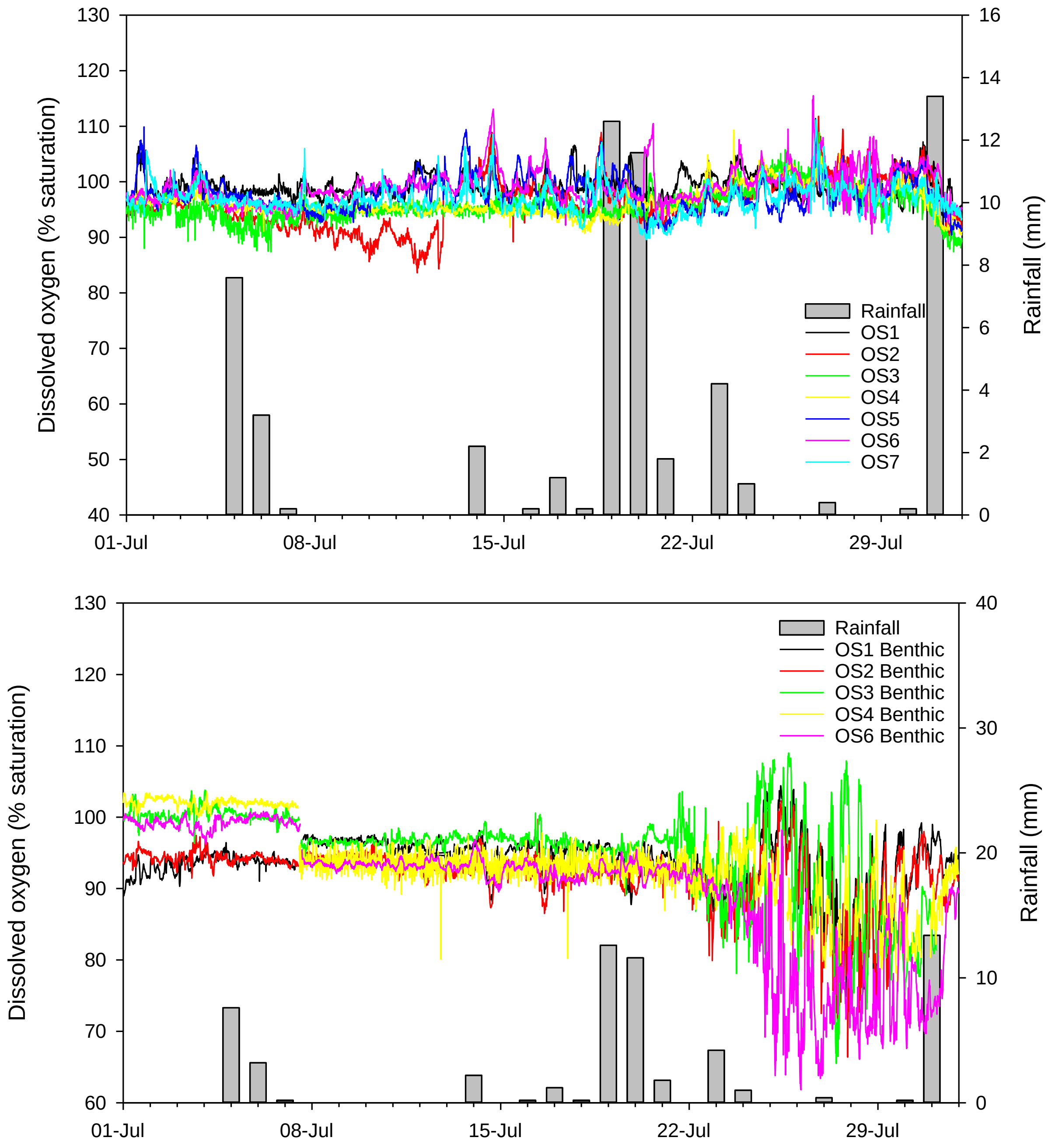


Figure 23 Surface DO (OS1 to OS7) and benthic DO (OS1 to OS 4 and OS6) at nearshore and offshore water quality sites during July 2019.

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 9 July 2019. In addition to the previously discussed physicochemical parameters, the light attenuation rate (K_d, the rate at which light or PAR diminishes with depth through the water column) and resultant euphotic depth (the depth to which net photosynthesis can occur/where light levels are ~1% of those at the surface) were also calculated.

Water samples for the determination of TSS were also collected from three different depths (sub-surface, mid-column and approximately 1 m above the benthos) at the ten offshore and spoil ground sites. Due to the shallow water depths associated with the inshore monitoring sites, only surface TSS samples were collected from sites UH1, UH2, 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, displayed the lowest temperature and conductivity readings within the harbour, as was also observed in June. UH3 exhibited slightly increased turbidity at 2 m, most likely associated with a transient plume at this shallow site.

Within the nearshore region, physicochemical data collected also indicated the persistence of strong vertical mixing, with little change in temperature, conductivity or pH through the water column. (Figure 25). DO displayed a slight decreasing gradient from surface to benthos likely due to declining photosynthesis with depth. Turbidity was consistent through the water column until the benthos where turbidity increased. This is often observed due to shear forces (friction between the overlying moving water and the stationary seabed) providing energy for sediment resuspension.

Within the offshore region of the spoil ground, OS5 and OS6, the water column was once again recorded to be well mixed (Figure 26) and very similar in trends to the nearshore region. DO recorded a steady decreasing gradient at all sites with OS6 displaying a sharper decline. Benthic resuspension was also observed at a number of sites.

The shallowest euphotic depth of 5.6 m occurred at the furthest upper harbour monitoring site UH3 (Table 14), which reflects the typically higher levels of turbidity experienced (Figure 24). The deepest euphotic depth was calculated to be 12.9 m at OS5 (Table 15) where turbidity in the surface and mid-column was low. No exceedances of WQG were recorded for the sub-surface during the July vertical profiling.

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at inshore sites during the July 2019 sampling event. *Values are means ± se (n = 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	09/07/2019 09:23	Sub-surface	7.9 ± 0	8 ± 0	51.5 ± 0	99 ± 0	3.2 ± 0	9	0.7 ± 0	6.3
		Whole column	8 ± 0	8 ± 0	51.5 ± 0	99 ± 0	3.1 ± 0	–		
UH2	09/07/2019 10:06	Sub-surface	8.6 ± 0	8.1 ± 0	51.8 ± 0	101 ± 0	2.2 ± 0	6	0.4 ± 0.1	10.3
		Whole column	8.7 ± 0	8.1 ± 0	51.9 ± 0	100 ± 0	2.4 ± 0.2	–		
UH3	09/07/2019 09:45	Sub-surface	7.9 ± 0	8.1 ± 0	51.5 ± 0	100 ± 0	4 ± 0.1	9	0.8 ± 0	5.6
		Whole column	7.9 ± 0	8.1 ± 0	51.5 ± 0	100 ± 0	4.2 ± 0.3	–		
CH1	09/07/2019 11:01	Sub-surface	9 ± 0	8.1 ± 0	52 ± 0	102 ± 0	2.3 ± 0	6	0.6 ± 0	7.6
		Whole column	9 ± 0	8.1 ± 0	52 ± 0	101 ± 0	2.5 ± 0	–		
CH2	09/07/2019 10:37	Sub-surface	9.2 ± 0	8.1 ± 0	52.2 ± 0	100 ± 0	1.8 ± 0	4	0.4 ± 0	11.0
		Whole column	9.3 ± 0	8.1 ± 0	52.2 ± 0	100 ± 0	2.1 ± 0.1	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	**–**

Table 14 Discrete physicochemical statistics from depth-profiling of the water column at offshore sites during the July 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 30 to 42 for whole column). Sub-surface values outside recommended WQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	TSS (mg/L)	K_d	Euphotic Depth (m)
OS1	09/07/2019 11:28	Sub-surface	9.3 ± 0	8.1 ± 0	52.2 ± 0	101 ± 0	2 ± 0.1	5	0.6 ± 0	7.6
		Mid	9.5 ± 0	8.1 ± 0	52.3 ± 0	100 ± 0	2.2 ± 0.1	9		
		Benthos	9.6 ± 0	8.1 ± 0	52.4 ± 0	99 ± 0	4.8 ± 0.4	7		
		Whole column	9.5 ± 0	8.1 ± 0	52.3 ± 0	100 ± 0	2.9 ± 0.2	–		
OS2	09/07/2019 16:10	Sub-surface	9.8 ± 0	8.1 ± 0	52.2 ± 0	103 ± 0	1.7 ± 0	5	0.5 ± 0	8.8
		Mid	9.5 ± 0	8.1 ± 0	52.3 ± 0	100 ± 0	2.3 ± 0	14		
		Benthos	9.7 ± 0	8.1 ± 0	52.3 ± 0	99 ± 0	14.8 ± 7	7		
		Whole column	9.6 ± 0	8.1 ± 0	52.3 ± 0	101 ± 0	4.2 ± 1.3	–		
OS3	09/07/2019 15:06	Sub-surface	9.9 ± 0	8.1 ± 0	52.4 ± 0	100 ± 0	2.8 ± 0.1	5	0.6 ± 0	7.6
		Mid	9.7 ± 0	8.1 ± 0	52.4 ± 0	99 ± 0	3.8 ± 0.1	12		
		Benthos	9.7 ± 0	8.1 ± 0	52.4 ± 0	98 ± 0	4.7 ± 0.2	9		
		Whole column	9.8 ± 0	8.1 ± 0	52.4 ± 0	99 ± 0	3.6 ± 0.1	–		
OS4	09/07/2019 14:32	Sub-surface	9.9 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	3.1 ± 0.1	6	0.5 ± 0	9.2
		Mid	9.8 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	3.8 ± 0.1	15		
		Benthos	9.8 ± 0	8.1 ± 0	52.5 ± 0	98 ± 0	23.5 ± 7.3	11		
		Whole column	9.8 ± 0	8.1 ± 0	52.4 ± 0.1	99 ± 0	6.6 ± 1.5	-		
OS7	09/07/2019 16:37	Sub-surface	9.5 ± 0	8.1 ± 0	52.2 ± 0	102 ± 0	1.7 ± 0	4	0.5 ± 0	9.4
		Mid	9.4 ± 0	8.1 ± 0	52.2 ± 0	101 ± 0	1.8 ± 0	6		
		Benthos	9.4 ± 0	8.1 ± 0	52.2 ± 0	100 ± 0	5.6 ± 3	6		
		Whole column	9.4 ± 0	8.1 ± 0	52.2 ± 0	101 ± 0	3.4 ± 1.1	–		
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 July 2019 sampling event. *Values are means ± se (n = 6 for sub-surface, mid and benthos, n = 39 to 48 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	09/07/2019 12:07	Sub-surface	9.7 ± 0	8.1 ± 0	52.3 ± 0	101 ± 0	1.4 ± 0	3	0.4 ± 0	12.9
		Mid	9.7 ± 0	8.1 ± 0	52.4 ± 0	100 ± 0	1.4 ± 0	6		
		Benthos	9.9 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	2.3 ± 0.3	5		
		Whole column	9.7 ± 0	8.1 ± 0	52.4 ± 0	100 ± 0	1.6 ± 0.1	–		
OS6	09/07/2019 15:34	Sub-surface	9.9 ± 0	8.1 ± 0	52.3 ± 0	103 ± 0	1.9 ± 0.2	3	0.5 ± 0	9.0
		Mid	9.8 ± 0	8.1 ± 0	52.4 ± 0	100 ± 0	5.7 ± 2.1	49		
		Benthos	9.9 ± 0	8.1 ± 0	52.4 ± 0	99 ± 0	15.1 ± 3.9	5		
		Whole column	9.8 ± 0	8.1 ± 0	52.3 ± 0.1	101 ± 0	5.9 ± 1.1	–		
SG1	09/07/2019 12:39	Sub-surface	10.2 ± 0	8.1 ± 0	52.5 ± 0	100 ± 0	2.3 ± 0.1	4	0.4 ± 0	10.9
		Mid	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	2.3 ± 0	17		
		Benthos	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	16.8 ± 8.8	8		
		Whole column	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	4.5 ± 1.3	–		
SG2	09/07/2019 13:15	Sub-surface	10.2 ± 0	8.1 ± 0	52.4 ± 0	100 ± 0	2.4 ± 0	6	0.5 ± 0	9.4
		Mid	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	4 ± 0.2	12		
		Benthos	10 ± 0	8.1 ± 0	52.5 ± 0	98 ± 0	9.8 ± 1.4	7		
		Whole column	10 ± 0	8.1 ± 0	52.4 ± 0	99 ± 0	4.4 ± 0.4	–		
SG3	09/07/2019 13:52	Sub-surface	10.2 ± 0	8.1 ± 0	52.5 ± 0	101 ± 0	2.1 ± 0	32	0.4 ± 0	10.2
		Mid	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	2.7 ± 0.1	16		
		Benthos	10 ± 0	8.1 ± 0	52.5 ± 0	98 ± 0	20.2 ± 9	8		
		Whole column	10 ± 0	8.1 ± 0	52.5 ± 0	99 ± 0	5.3 ± 1.3	–		
WQG			**–**	**7.0 – 8.5**	**–**	**80 – 110**	**10**	**–**	**–**	

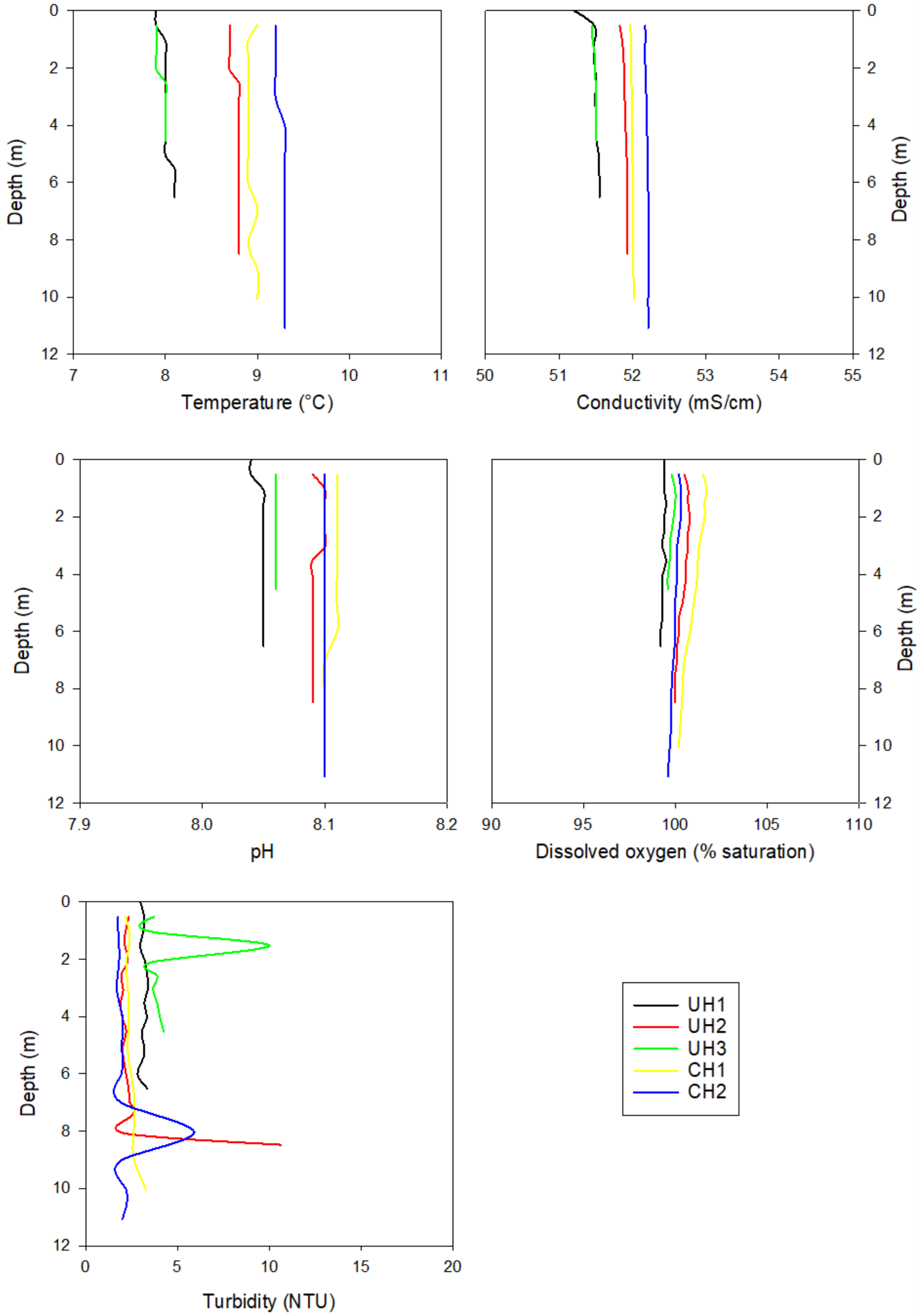


Figure 24 Depth-profiled physicochemical parameters at sites UH1, UH2, UH3, CH1 and CH2 on 9 July 2019.

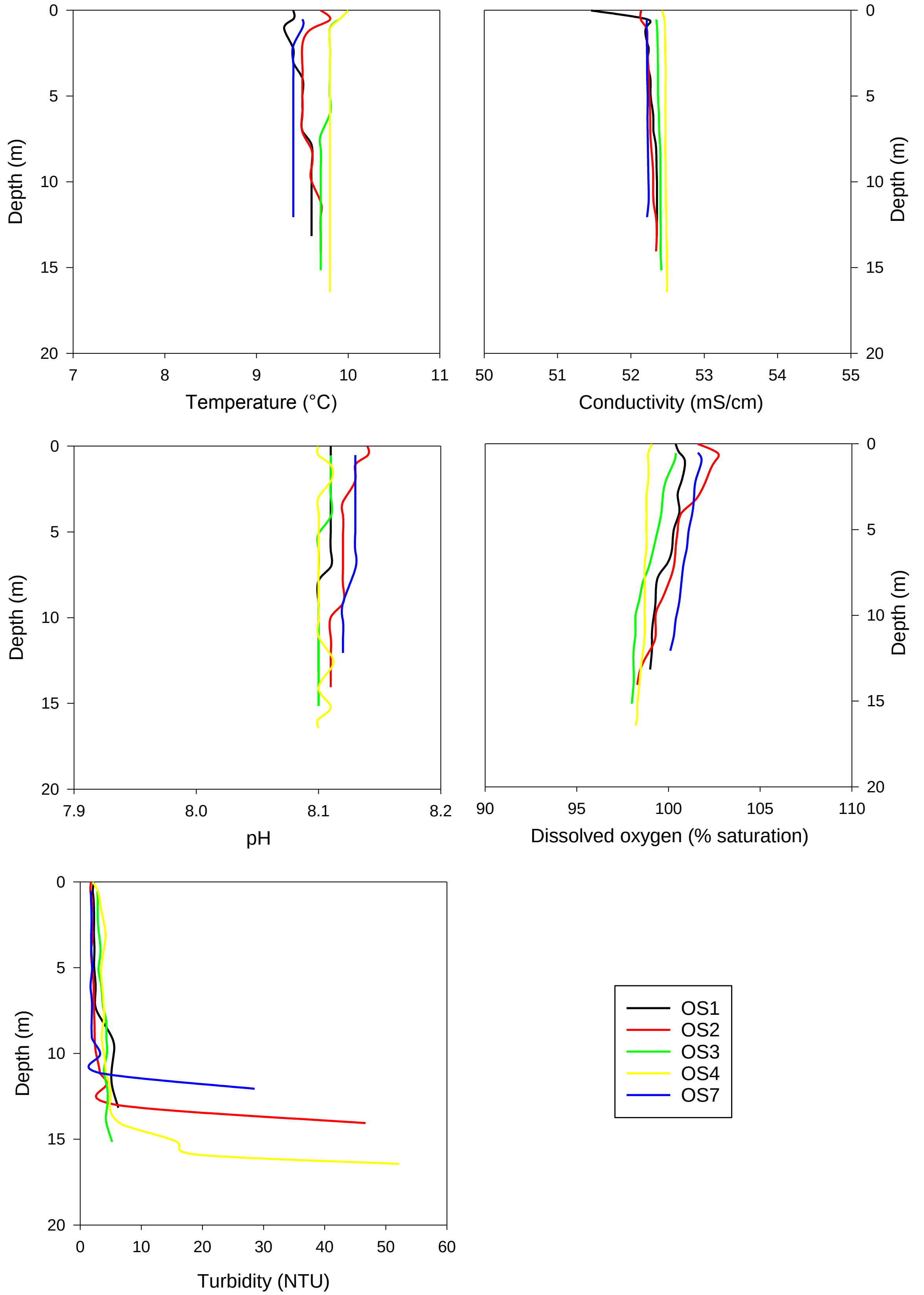


Figure 25 Depth-profiled physicochemical parameters at sites OS1, OS2, OS3, OS4 and OS7 on 9 July 2019.

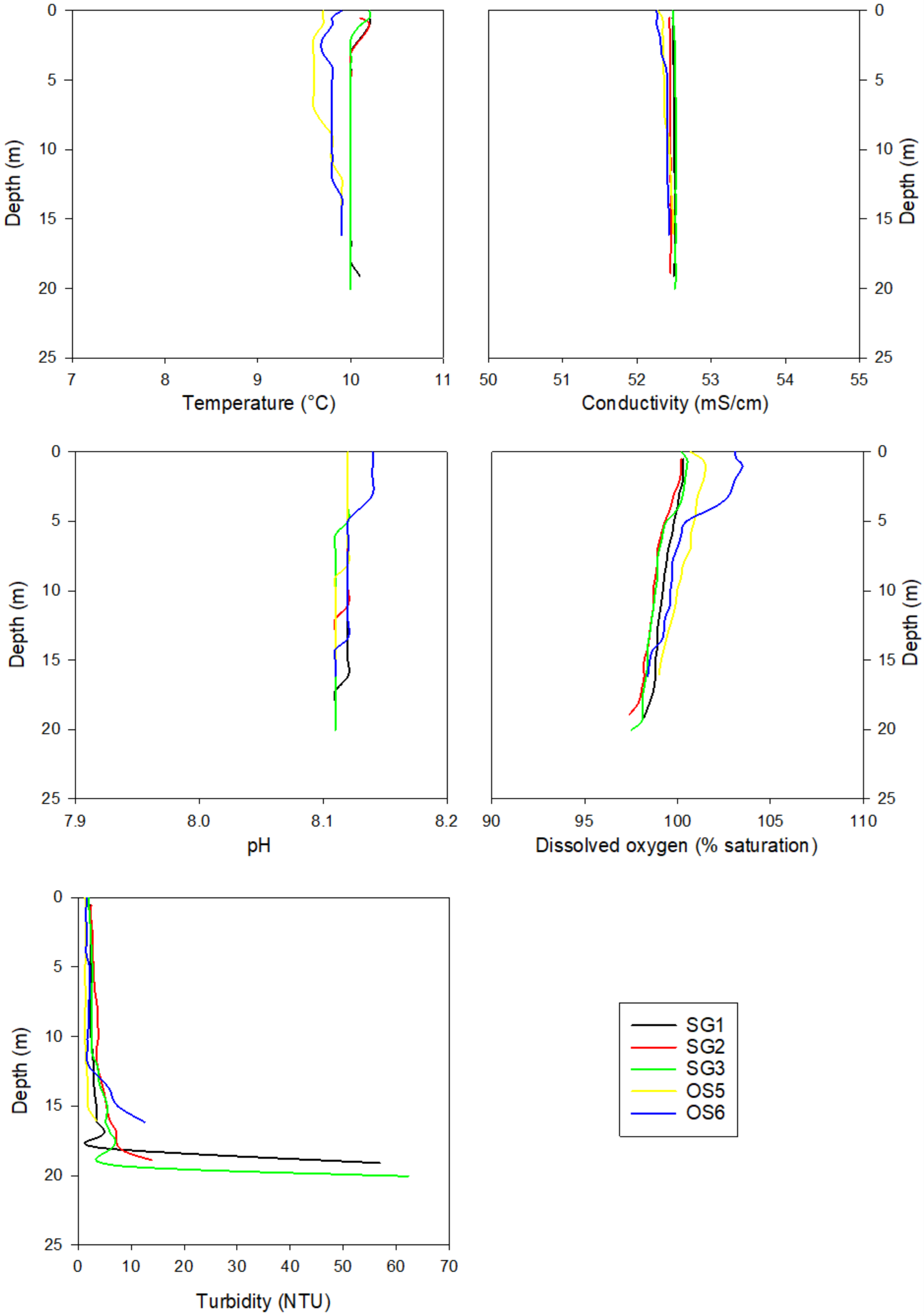


Figure 26 Depth-profiled physicochemical parameters at sites SG1, SG2, SG3, OS5 and OS6 on 9 July 2019.

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 (7 July) were removed from the analyses.

Table 16 Total Daily PAR (TDP) statistics during July 2019.
Values are means ± se (n = 30 to 31). Note data from the BPAR exchange day on 7 July 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	-	8,416 ± 527	7,900	2,500 – 13,800
OS2	17	8.9 ± 1.1	<0.01	<0.01 – 132
OS3	14	1.1 ± 0.8	<0.01	<0.01 – 21

Ambient PAR/total daily PAR (TDP, i.e., the amount of sunlight available to enter the water column), turbidity and the depth of the water column, all have a controlling factor on BPAR measurements. As typically observed in temperate regions with high levels of cloud cover, the amount of incoming solar radiation at VBCC displayed significant variation with values ranging from 2,500 to 13,800 mmol/m^2/day (Table 16). This range was similar to that observed during June (2,100 to 12,900 mmol/m^2/day). Available light was slightly lower with a monthly mean TDP of 8,416 mmol/m^2/day (Table 16) c.f. 9,060 mmol/m^2/day recorded during June and continues the trend of shorter daylight hours with the continuing winter months.

Mean BPAR was consistently low for both sites in July (8.9 and 1.1 mmol/m^2/day, Table 16) in comparison to June means of 144 and 179 mmol/m^2/day. This is due to the increased precipitation (increased cloud cover), and turbidity experienced in July. Turbidity decreased at OS2 and resulted in a BPAR peak on 9 July of 132 mmol/m^2/day (Figure 27). Whereas at OS3 mean BPAR intensity was much lower. Peaks of 11 and 21 mmol/m^2/day were recorded earlier in the month on 6 and 13 July, respectively.

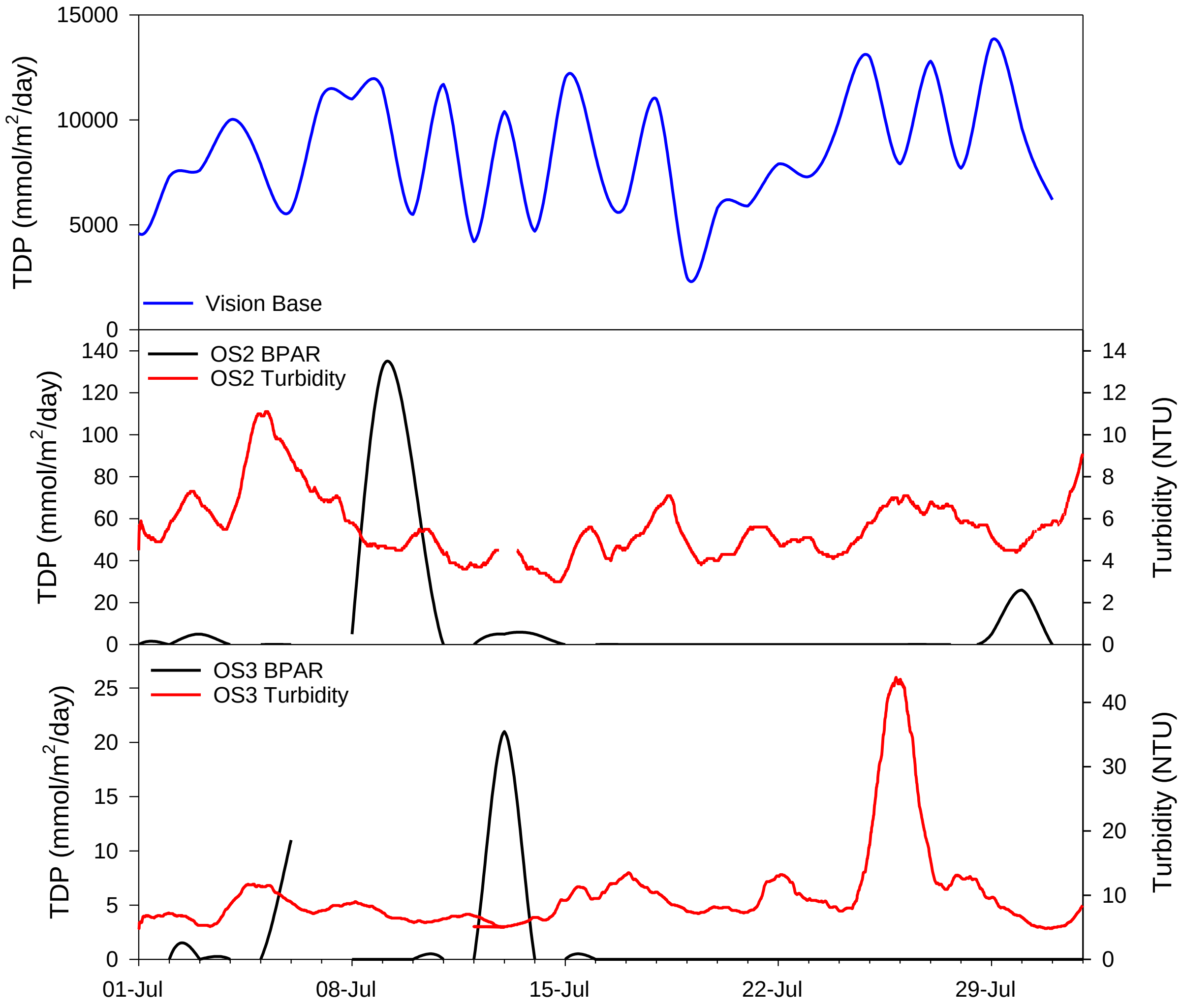


Figure 27 Total daily BPAR at OS2 and OS3 during July 2019 compared to ambient PAR and corresponding surface turbidity (24 hour rolling average).
Note data from the BPAR exchange day on 7 July were not utilized in plots or statistics.

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.

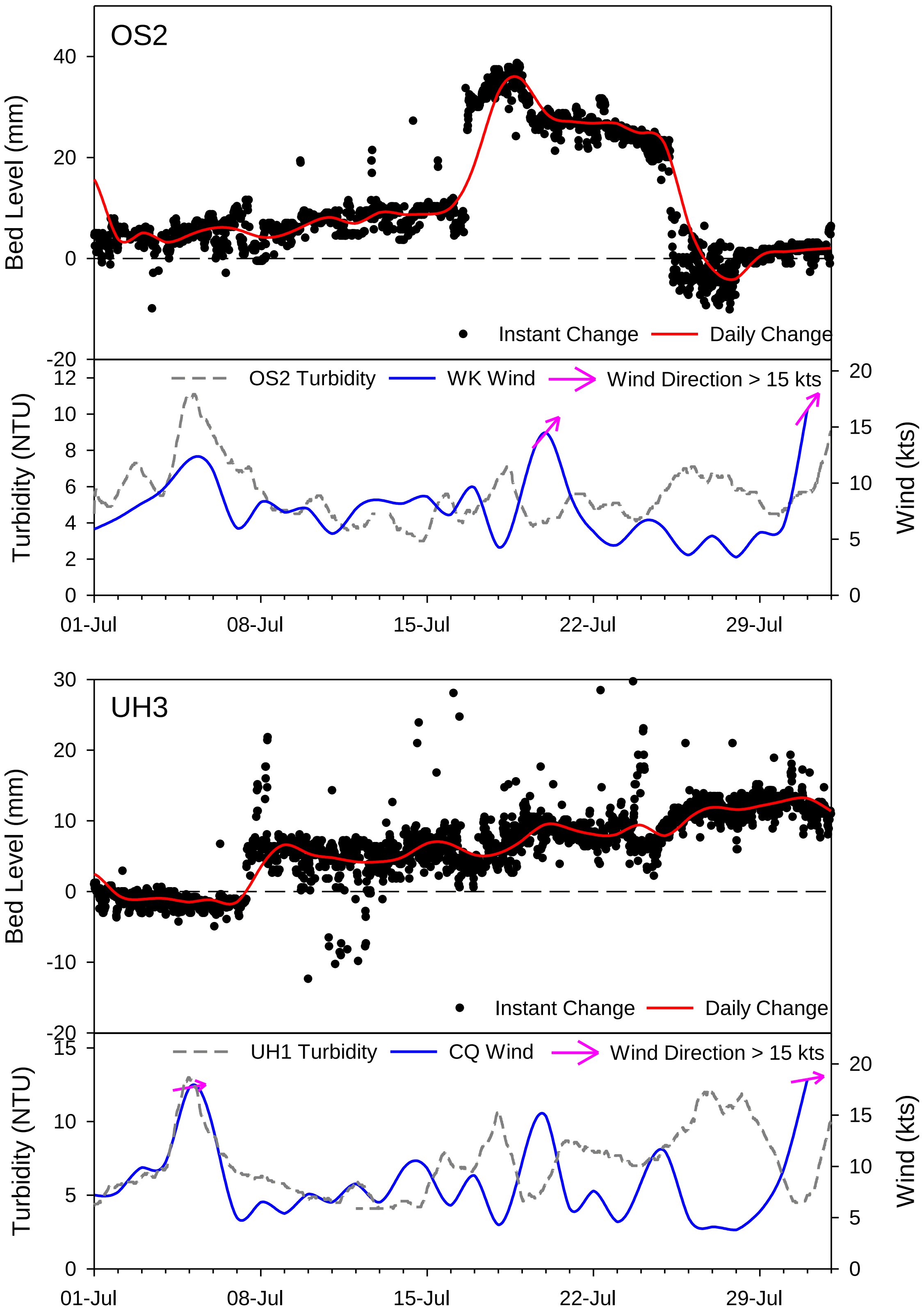


Figure 28 Mean instantaneous and daily averaged bed level change at OS2 and UH3 during July 2019 compared to ambient surface turbidity (24 hour rolling average), wind speed and direction.
Note: Arrows indicate the direction of travel for winds greater than 15 knots.

Bed level at the offshore site OS2 was quite dynamic in July. There was a gradual increase in bed level until the 16 July where significant deposition of approximately 25 mm occurred between 16 and 25 July. The accretion corresponded to a period of increased offshore wind speeds >15 kts. Rapid erosion (approximately 20 mm) then occurred during the significant wave height event over a couple of days from 25 July, before bed level stabilised to the end of the month (Figure 28). The overall result for the month of July was accretion of only +2 mm (Table 17).

As typically observed, bed level within the sheltered upper harbour at UH3 was more stable than that at OS2, with little apparent impact of inshore wind speed on sediment movement (Figure 28). Bed level was stable until 7 July when a period of deposition was recorded following the decline of the strong south westerly wind event of 5/6 July. UH3 bed level gently increased due to gentle sediment deposition for the rest of July (Figure 27). These variations over July resulted in a net bed level change of +11 mm (Table 17).

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

Site	July 2019 Net bed level change (mm)
OS2	+2.0
UH3	+11

3.6 Water Samples

Discrete water sampling was conducted on 9 July 2019, in conjunction with vertical physicochemical profiling through the water column. Quality assurance/quality control (QA/QC) procedures included a duplicate water sample collected at one site, in addition to a laboratory and field blank for each parameter. Further details on the specific sampling methodology can be found within the Channel Deepening Project Water Quality Environmental Monitoring Methodology report (Vision Environment, 2017). Laboratory results associated with VE QA/QC procedures are presented in Table 25 of the Appendix.

3.6.1 Nutrients

Total phosphorous concentrations reported during July 2019 remained below the WQG of 30 µg/L at all sites, with the highest concentrations reported in the upper harbour and offshore sites (Table 18, Figure 29). Similar to the June sampling, dissolved reactive phosphorous was elevated across the monitoring network, with concentrations ranging from 10.2 to 15.5 µg/L at OS5 and UH1 respectively, and with values notably above the designated 5 µg/L WQG, as commonly found.

Both total nitrogen and total kjeldahl nitrogen were < LOR at all sites, except for site UH2, where concentrations of total nitrogen equaled the WQG of 300 µg/L. Total ammonia concentrations were elevated as they were the previous month, with exceedances of the 15 µg/L WQG recorded at all sites except for OS5 and OS7. Concentrations of nitrogen oxides were similar to those previously recorded in June, with results ranging from 54 to 149 µg/L, and with all sites exceeding the 15 µg/L WQG. As per the previous month this suggests the breakdown of nitrogenous material contained in detritus releasing bioavailable nutrients into the system. Despite the available nutrients, concentrations of chlorophyll a, an indicator of phytoplankton biomass remained low and below the WQG (4 µg/L) at all sites (Table 18), with higher concentrations at offshore locations.

Table 18 Concentrations of nutrients and chlorophyll *a* at monitoring sites during July 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	20	15.5	<300	<200	24	65	0.7
UH2	20	13.9	300	200	19	63	0.9
UH3	28	15.4	<300	<200	24	65	0.6
CH1	18	14.3	<300	<200	16	64	1
CH2	16	15	<300	<200	16	64	0.7
OS1	22	14.1	<300	<200	18	65	1.4
OS2	22	14.2	<300	<200	15	62	2
OS3	23	15.2	<300	<200	23	73	3
OS4	28	15.2	<300	<200	18	68	0.6
OS5	29	10.2	<300	<200	10	54	1.9
OS6	18	13.3	<300	<200	16	63	2
OS7	20	13.7	<300	<200	14	67	2
SG1	14	12.6	<300	<200	15	149	1
SG2	14	12.8	<300	<200	15	67	0.6
SG3	20	13.7	<300	<200	15	68	0.6
WQG	**30**	**5**	**300**	**-**	**15**	**15**	**4**

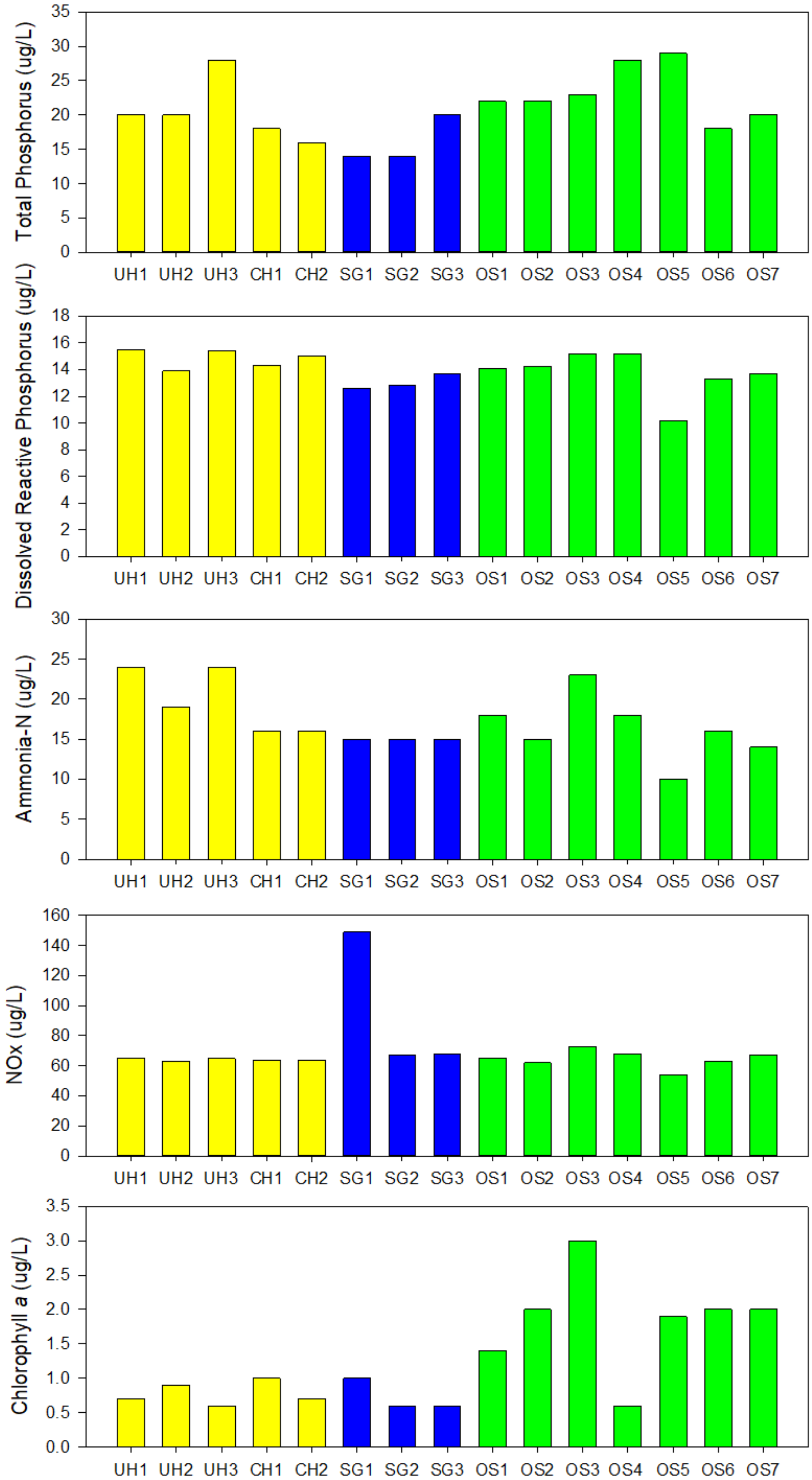


Figure 29 Nutrient and chlorophyll *a* concentrations at monitoring sites during July 2019.
Values which were <LOR, were plotted as half LOR. Total nitrogen and TKN were not plotted as all or most sites were <LOR.

3.6.2 Total and Dissolved Metals

Concentrations of several metals were reported as below the limit of reporting (LOR) at all sites, including total and dissolved arsenic (<4 µg/L), cadmium (<0.2 µg/L), cobalt (<0.6 µg/L), lead (<1 µg/L), nickel (<7 µg/L), selenium (<4 µg/L), silver (<0.4 µg/L), tin (<5 µg/L) and zinc (<4 µg/L). Contrasting previous months, concentrations of total mercury exceeded the LOR of 0.08 µg/L at UH2, UH3, CH1 and SG2b where concentrations ranged from 0.1 to 0.12 µg/L. Dissolved mercury concentrations, for which WQG are derived, remained below LOR at all monitoring locations (Tables 19 to 21). Similarly, total copper reported values above the LOR of 1.1 µg/L at UH1, UH3, CH1 and SG1 where concentrations ranged from 1.2 to 19 µg/L. Dissolved copper concentrations for which WQG are derived, remained below LOR at all monitoring locations (Tables 19 to 20).

As commonly observed, total aluminium concentrations were reported above the WQG of 24 µg/L at all sites across the monitoring network (note that this WQG is designated for concentrations of the more readily available dissolved aluminium fraction). Concentrations of the more bioavailable dissolved aluminium fraction were all below LOR (<12 µg/L) (Tables 19 to 21, Figure 30). No other metal exceedances occurred during June 2019.

Despite not having assigned WQGs, particulate iron has regularly been reported at elevated concentrations within Lyttelton Harbour during the baseline monitoring. The greatest concentrations of total iron were recorded in the upper harbour (230 µg/L) and declined with increasing distance offshore with the lower concentrations (50 µg/L) at offshore sites (Figure 30). Dissolved iron concentrations were once again low (<11 µg/L) indicating that iron was predominantly present in the particulate phase, and thus not readily available for biological uptake (Tables 19 to 21).

Total and dissolved chromium was above LOR at all sites, except CH2, OS7 and SG1 where dissolved chromium was below LOR (<1 µg/L). Dissolved manganese concentrations were below LOR (<1 µg/L) at SG1 (Tables 19 to 21) in a similar spatial trend to June. Higher concentrations of total manganese were reported at all sites with a decreasing gradient from the inner harbor to offshore and spoil ground sites as commonly observed (Figure 31).

Consistent with previous monitoring reports, molybdenum concentrations which were recorded at all sites during June displayed little spatial variation across the inshore and offshore monitoring network (Figure 31). Given the similarity between the dissolved and total metal concentrations, molybdenum present in the dissolved phase (Tables 19 to 21 and Figure 31) would be readily dispersed across the region. Concentrations of total and dissolved vanadium displayed a similar pattern to that of molybdenum, with equal or higher proportions of vanadium also present in the dissolved phase (Figure 31), as typically observed.

It should be noted that total chromium was detected in the field and laboratory blank at concentrations above the laboratory LOR, suggesting contamination of the laboratory supplied water (Table 25). Concentrations of dissolved vanadium and dissolved molybdenum were slightly higher than total vanadium and molybdenum at a number of sites suggesting sample water heterogeneity (Tables 19 to 21).

Table 19 Total and dissolved metal concentrations at inshore monitoring sites during July 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	136	61	149	79	59	
Arsenic	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.3	<4.3	<4.3	<4.3	<4.3	
Cadmium	Dissolved	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Total	<0.21	<0.21	<0.21	<0.21	<0.21	
Chromium	Dissolved	1.2	1.1	1.2	2.1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	2.3	3.1	1.2	2.5	1.9	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	1.3
	Total	1.2	<1.1	1.2	1.6	<1.1	
Iron	Dissolved	4	8	5	9	<4	-
	Total	230	74	210	100	83	
Lead	Dissolved	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	4	2.8	6.1	2.4	1.6	-
	Total	8.2	4.5	8.8	4.6	3.3	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	0.12	0.13	0.1	<0.08	
Molybdenum	Dissolved	11.3	11.3	11.1	11	10.8	-
	Total	10.9	10.7	10.5	11	11.6	
Nickel	Dissolved	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	1.8	1.8	1.2	1.6	1.8	100
	Total	1.9	1.9	2.3	1.6	1.9	
Zinc	Dissolved	<4	<4	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	

Table 20 Total and dissolved metal concentrations at offshore monitoring sites during July 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	63	56	79	61	47	62	60	
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	1.6	1.5	1.4	2	1.7	2	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.6	1.9	1.8	1.5	2.1	3.3	1.8	
Cobalt	Dissolved	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.0
	Total	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	<0.63	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Iron	Dissolved	<4	<4	<4	<4	<4	<4	7	-
	Total	80	71	99	60	50	56	78	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	
Manganese	Dissolved	1.9	1.1	1.3	1.1	1.2	2	2	-
	Total	2.9	3	3.2	1.9	2.1	2.5	3.1	
Mercury	Dissolved	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.4
	Total	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.08	
Molybdenum	Dissolved	11.2	11.1	11.9	12	11.4	11.6	11.4	-
	Total	11.4	10.8	11.2	10.9	11	11.1	11.2	
Nickel	Dissolved	<7	<7	<7	<7	<7	<7	<7	70
	Total	<7	<7	<7	<7	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	<4	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2	
Silver	Dissolved	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	<5	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	<5.3	<5.3	<5.3	<5.3	
Vanadium	Dissolved	2	2.5	1.6	2.3	1.8	1.8	1.6	100
	Total	2.2	2.2	1.9	2.1	1.9	1.7	2	
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 July 2019. *Values outside recommended WQG are highlighted in blue.*

Metal (µg/L)		Sites			WQG
		SG1	SG2b	SG3	
Aluminium	Dissolved	<12	17	<12	24
	Total	77	78	65	
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	1.7	2	Cr(III) 27.4 Cr(VI) 4.4
	Total	1.9	2.6	2.2	
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	19	<1.1	<1.1	
Iron	Dissolved	<4	11	<4	-
	Total	107	117	147	
Lead	Dissolved	<1	<1	<1	4.4
	Total	<1.1	<1.1	<1.1	
Manganese	Dissolved	<1	1	1.1	-
	Total	2.4	2.1	2.6	
Mercury	Dissolved	<0.08	<0.08	<0.08	0.4
	Total	<0.08	0.1	<0.08	
Molybdenum	Dissolved	12	11.5	11.7	-
	Total	11.2	11.2	11.2	
Nickel	Dissolved	<7	<7	<7	70
	Total	<7	<7	<7	
Selenium	Dissolved	<4	<4	<4	-
	Total	<4.2	<4.2	<4.2	
Silver	Dissolved	<0.4	<0.4	<0.4	1.4
	Total	<0.4	<0.4	<0.4	
Tin	Dissolved	<5	<5	<5	-
	Total	<5.3	<5.3	<5.3	
Vanadium	Dissolved	2	2.2	2.1	100
	Total	2.1	2.4	2.4	
Zinc	Dissolved	<4	<4	<4	15
	Total	<4.2	<4.2	<4.2	

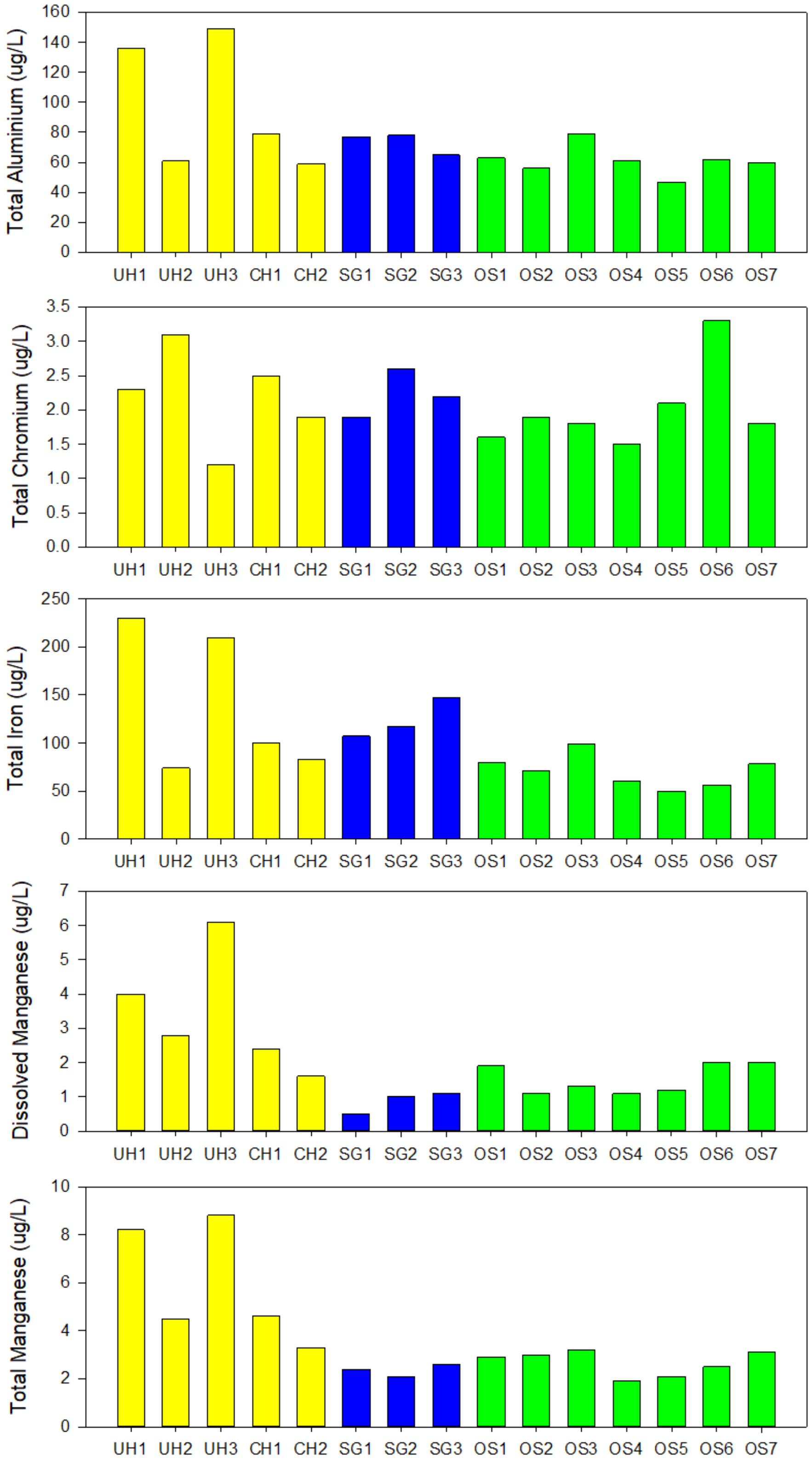


Figure 30 Total aluminium, total chromium, total iron, and total and dissolved manganese concentrations at monitoring sites during July 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

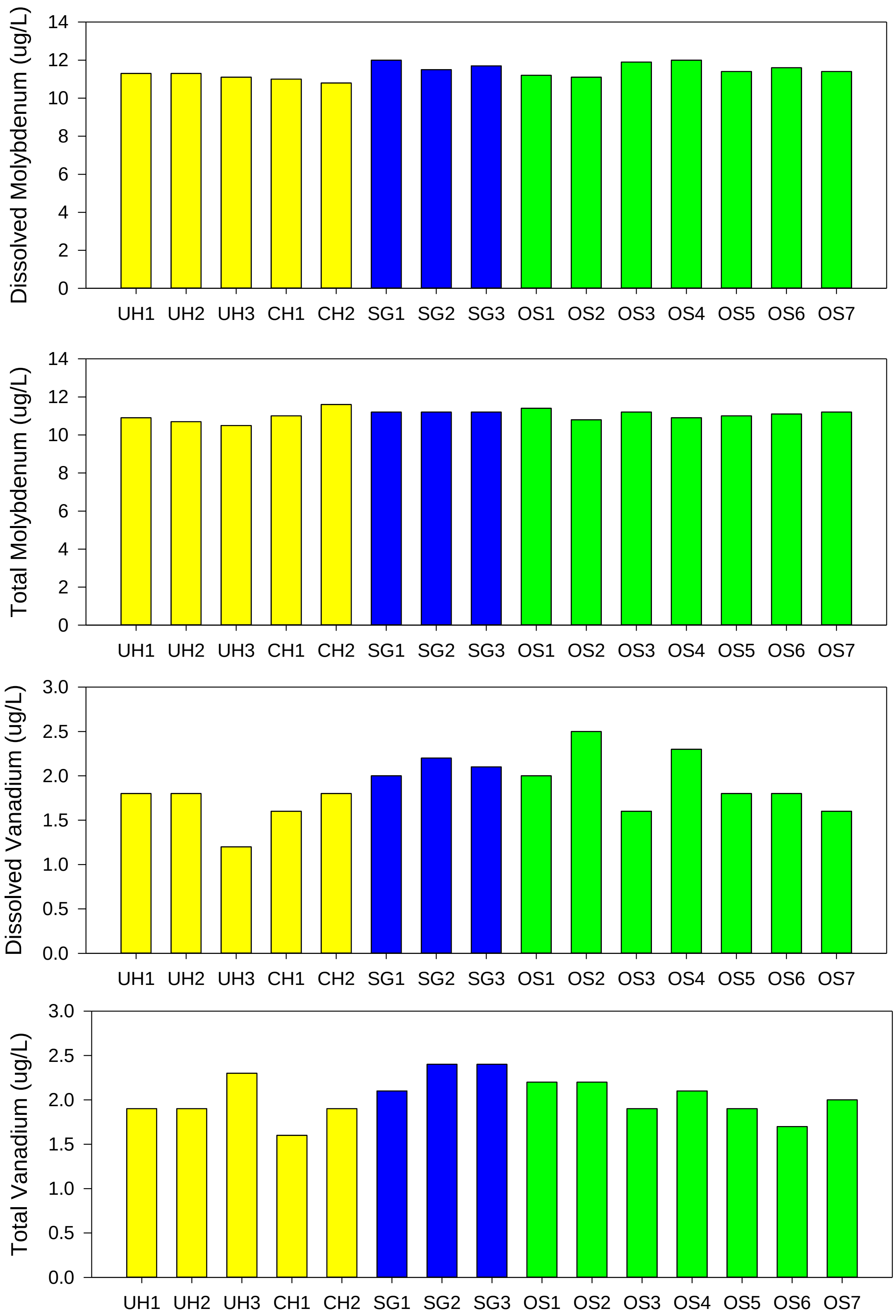


Figure 31 Total and dissolved molybdenum and vanadium concentrations at monitoring sites during July 2019.
Values which were <LOR, were plotted as half LOR. Metals that were below LOR at most sites were not plotted.

4 REFERENCES

ANZECC/ARMCANZ. 2000. National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting. Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand

APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. Port City Press, Baltimore, USA.

ECAN. 2019. Environment Canterbury Regional Council.http://data.ecan.govt.nz/Catalogue/Method?MethodId=79#tab-data

Envisor. 2018. Environmental Monitoring and Management Plan. LPC Channel Deepening Project: Stage 1.

Fox, D. R. 2018. Turbidity triggers for Lyttelton Port Company's Channel Deepening Project. Environmetrics Australia, Melbourne, Australia

Metconnect. 2019. Meteorological Service of New Zealand http://www.metconnect.co.nz

MetOcean. 2016a. Lyttelton Port Company Channel Deepening Project – Simulations of suspended sediment plumes generated from the deposition of spoil at the offshore capital disposal site. MetOcean Solutions Ltd, New Plymouth, New Zealand

MetOcean. 2016b. Lyttelton Port Company Channel Deepening Project – Simulations of Dredge Plumes from Dredging Activities in the Channel. MetOcean Solutions Ltd, New Plymouth, New Zealand

Vision Environment. 2017. Lyttelton Port Company Channel Deepening Project Water Quality Environmental Monitoring Methodology – August 2017. . Gladstone, Australia

5 APPENDIX

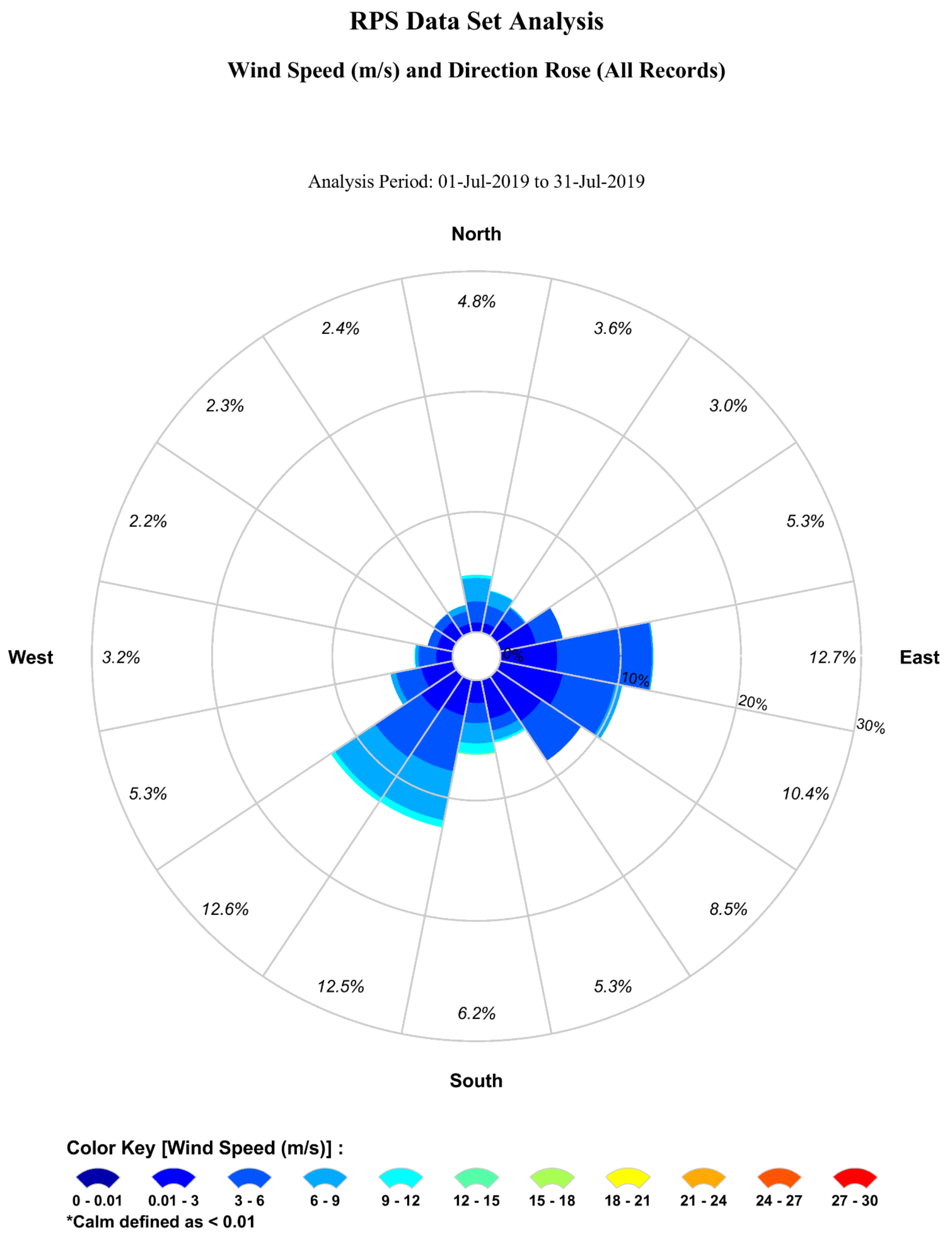


Figure 32 WatchKeeper wind speed (m/s) and direction rose (%) during July 2019.

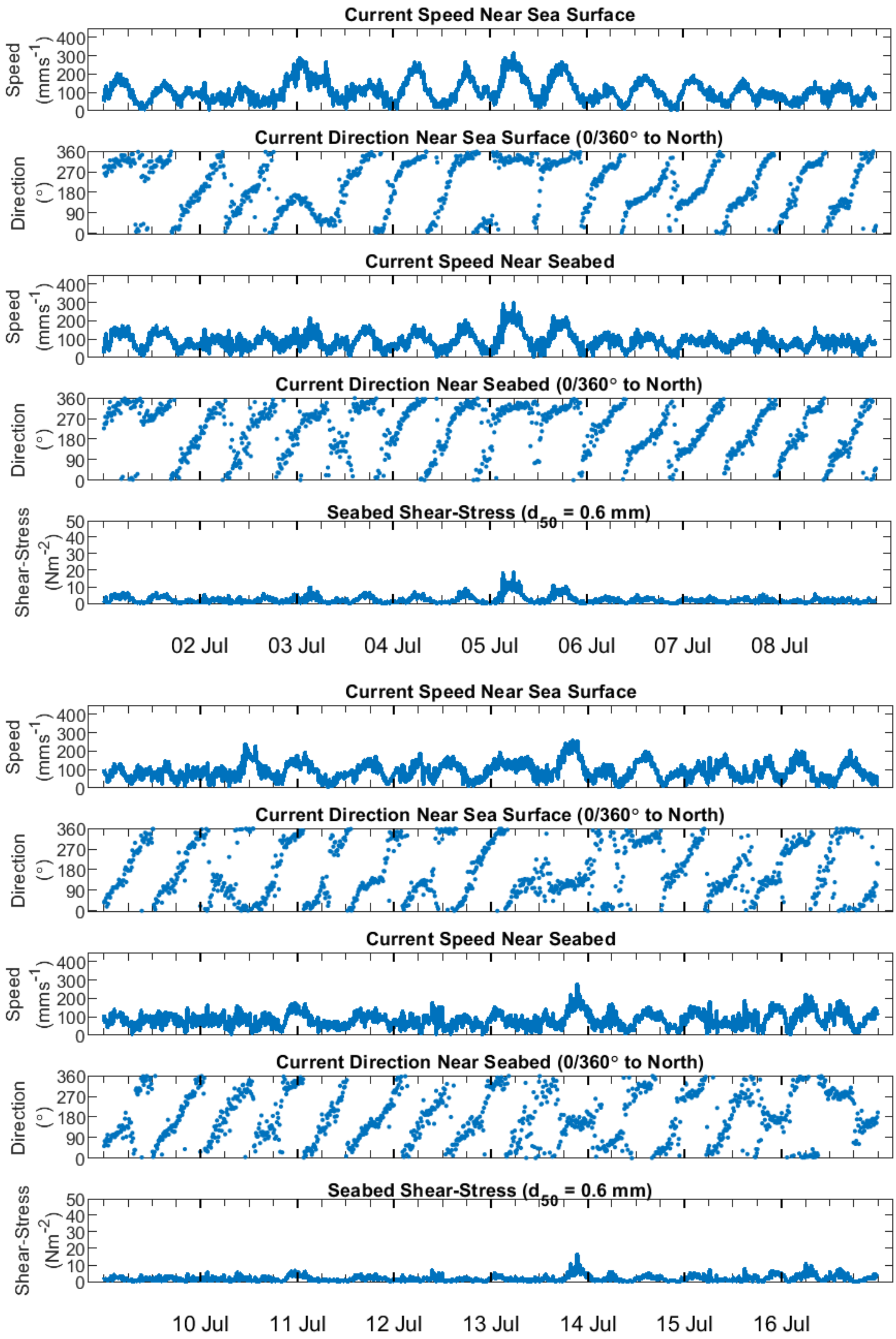


Figure 33 SG1 current speed, direction and shear bed stress 1 to 16 July 2019.

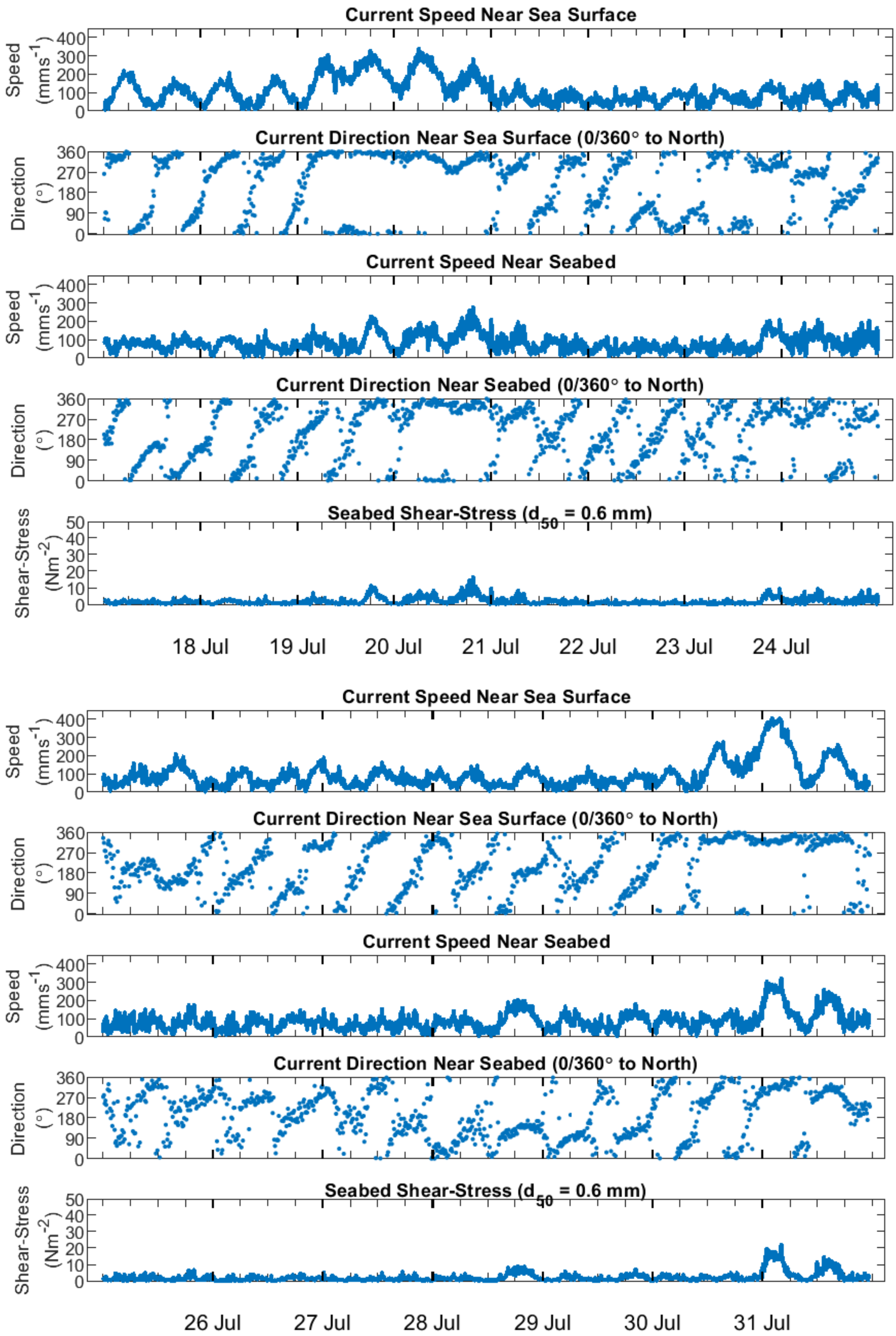


Figure 34 SG1 current speed, direction and shear bed stress 17 to 31 July 2019.

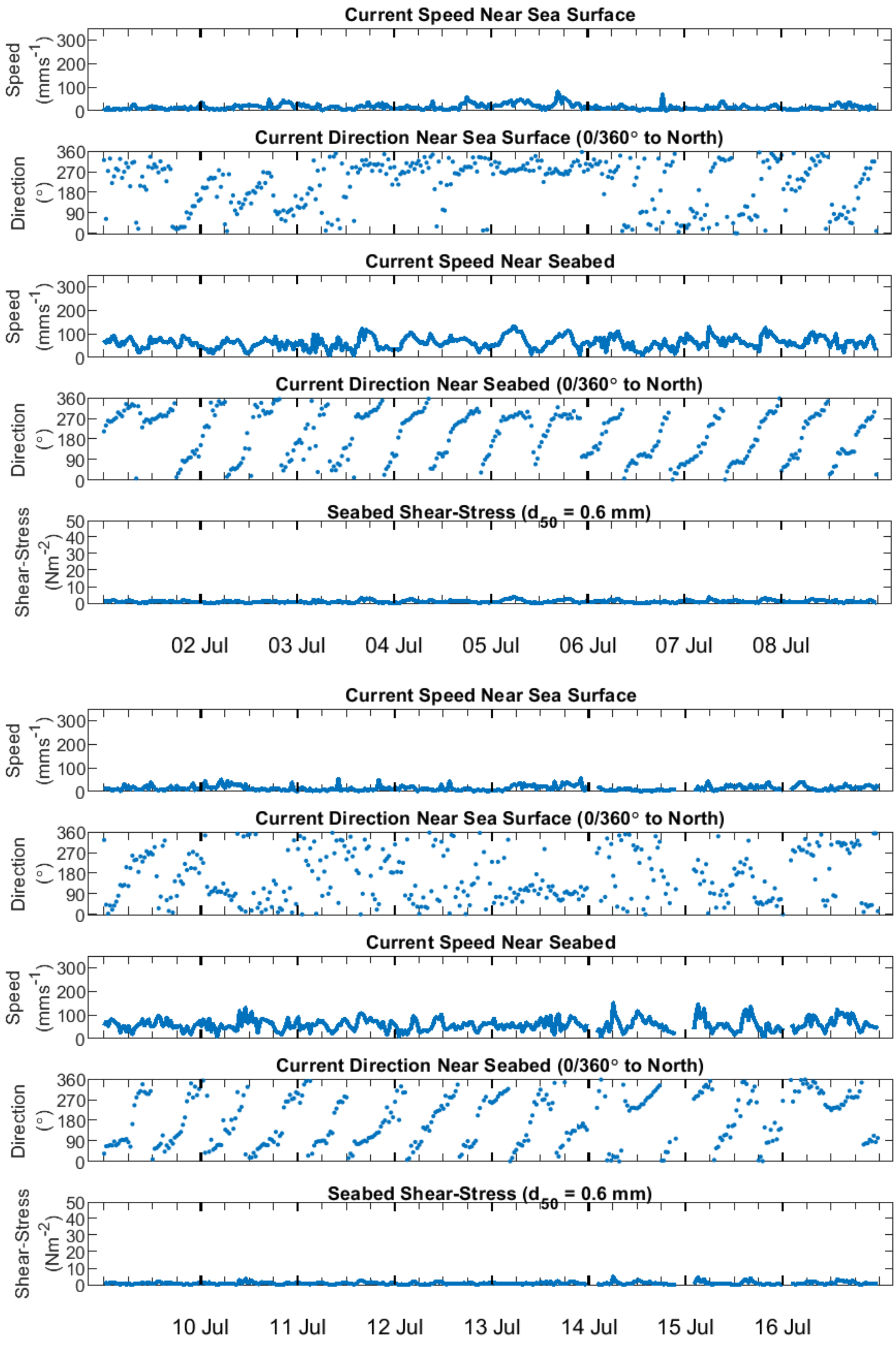


Figure 35 SG2a (WatchKeeper) current speed, direction and shear bed stress 1 to 16 July 2019.

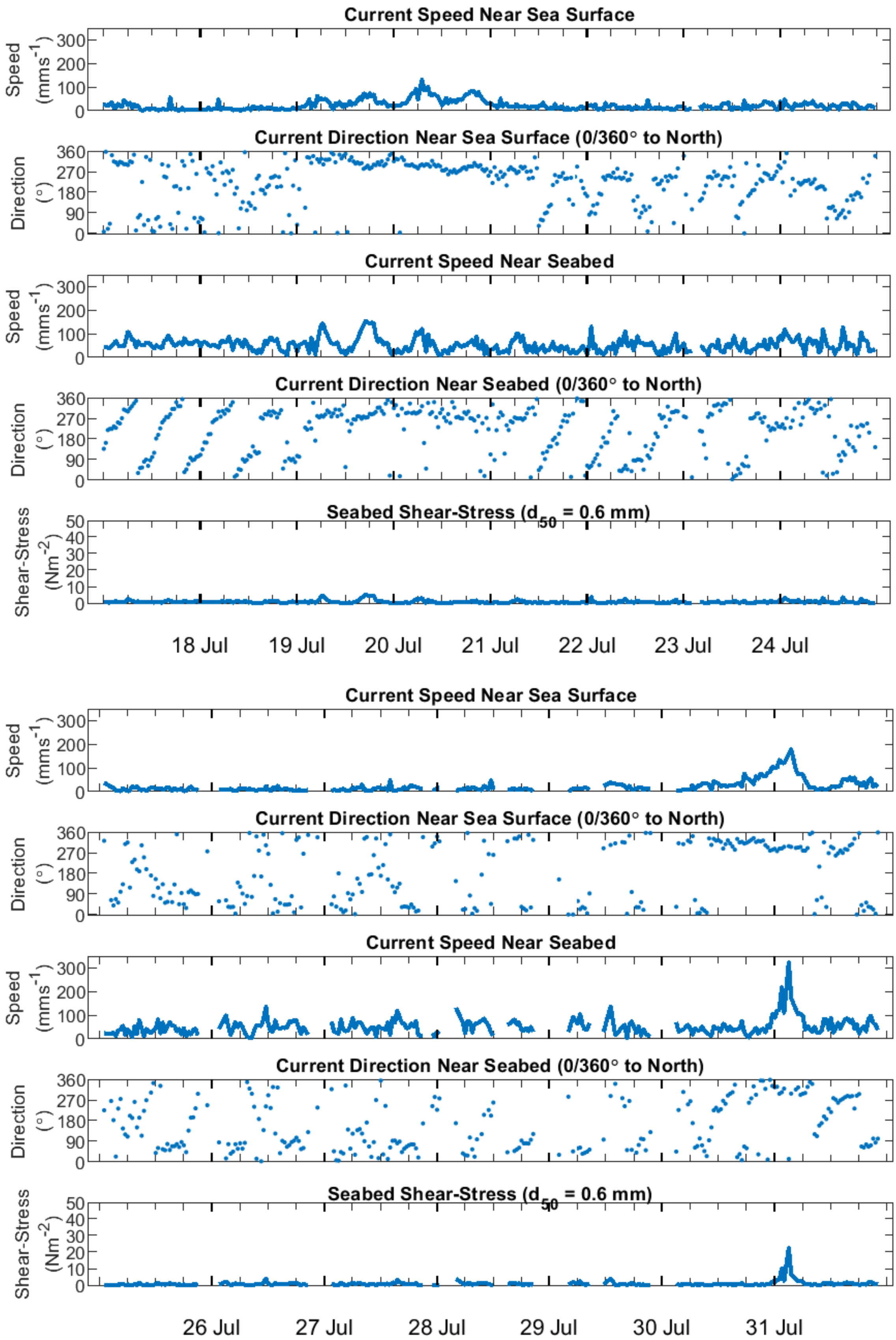
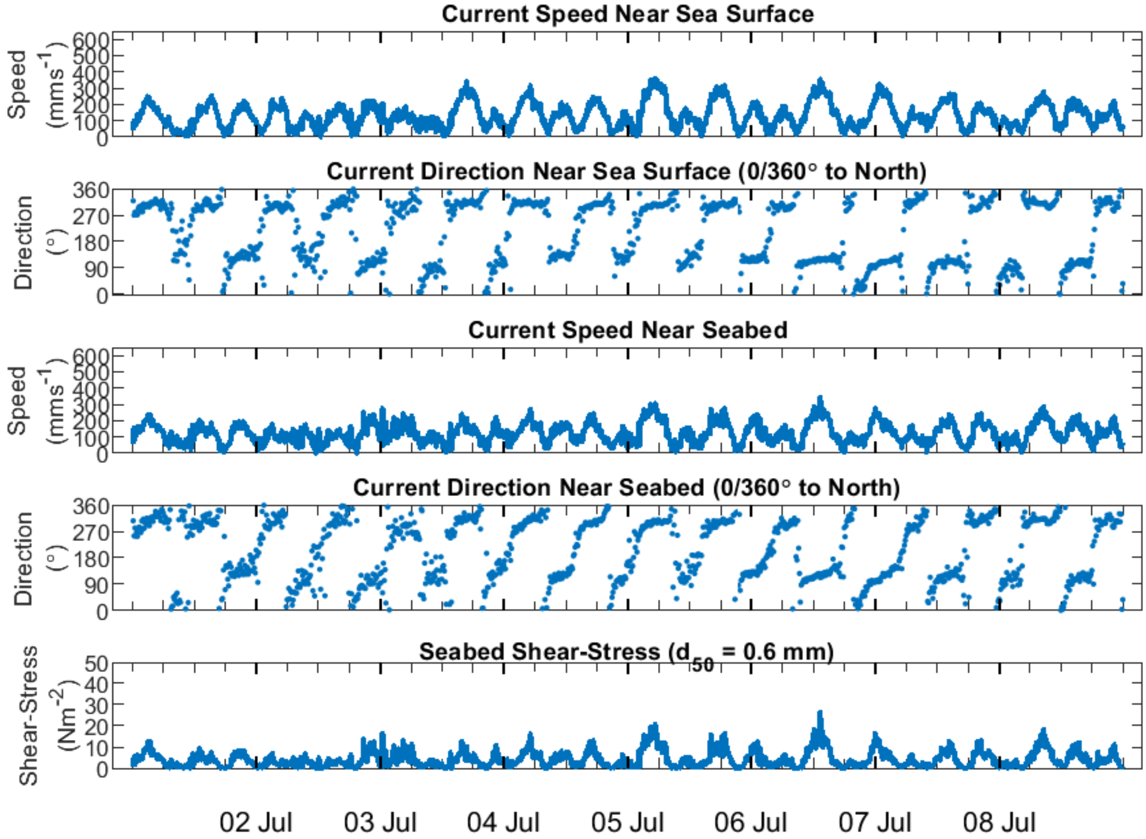


Figure 36 SG2a (WatchKeeper) current speed, direction and shear bed stress 17 to 31 July 2019.



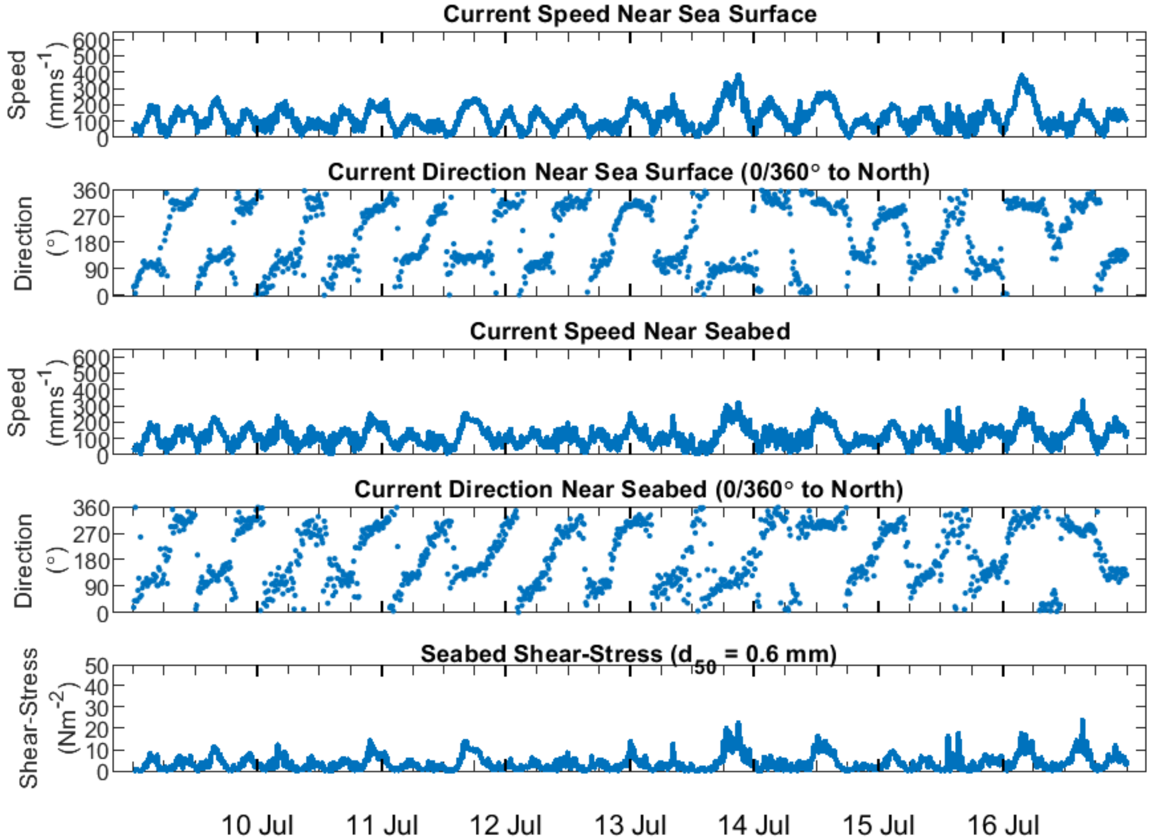


Figure 37 SG3 current speed, direction and shear bed stress 1 to 16 July 2019.

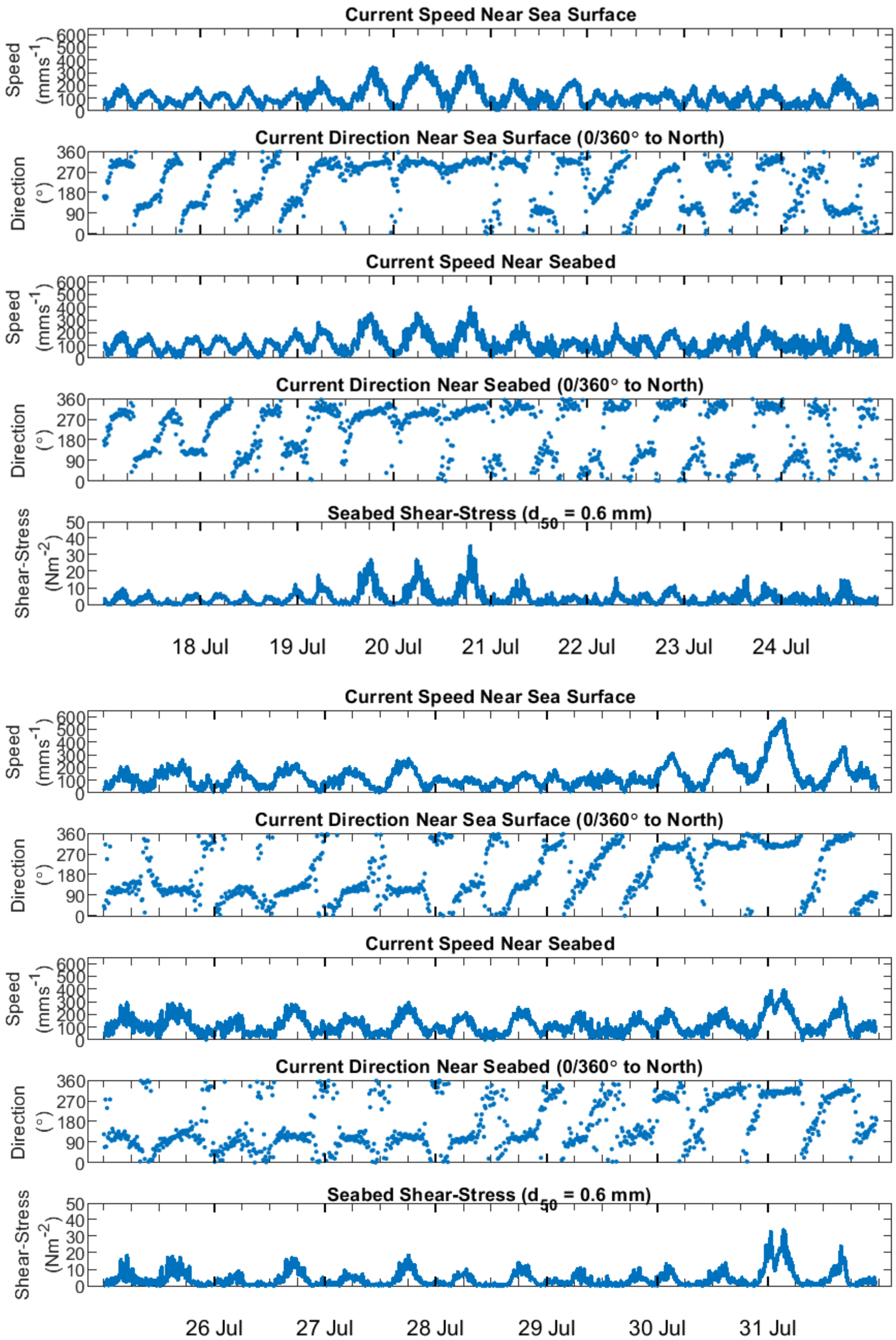


Figure 38 SG3 current speed, direction and shear bed stress 17 to 31 July 2019.

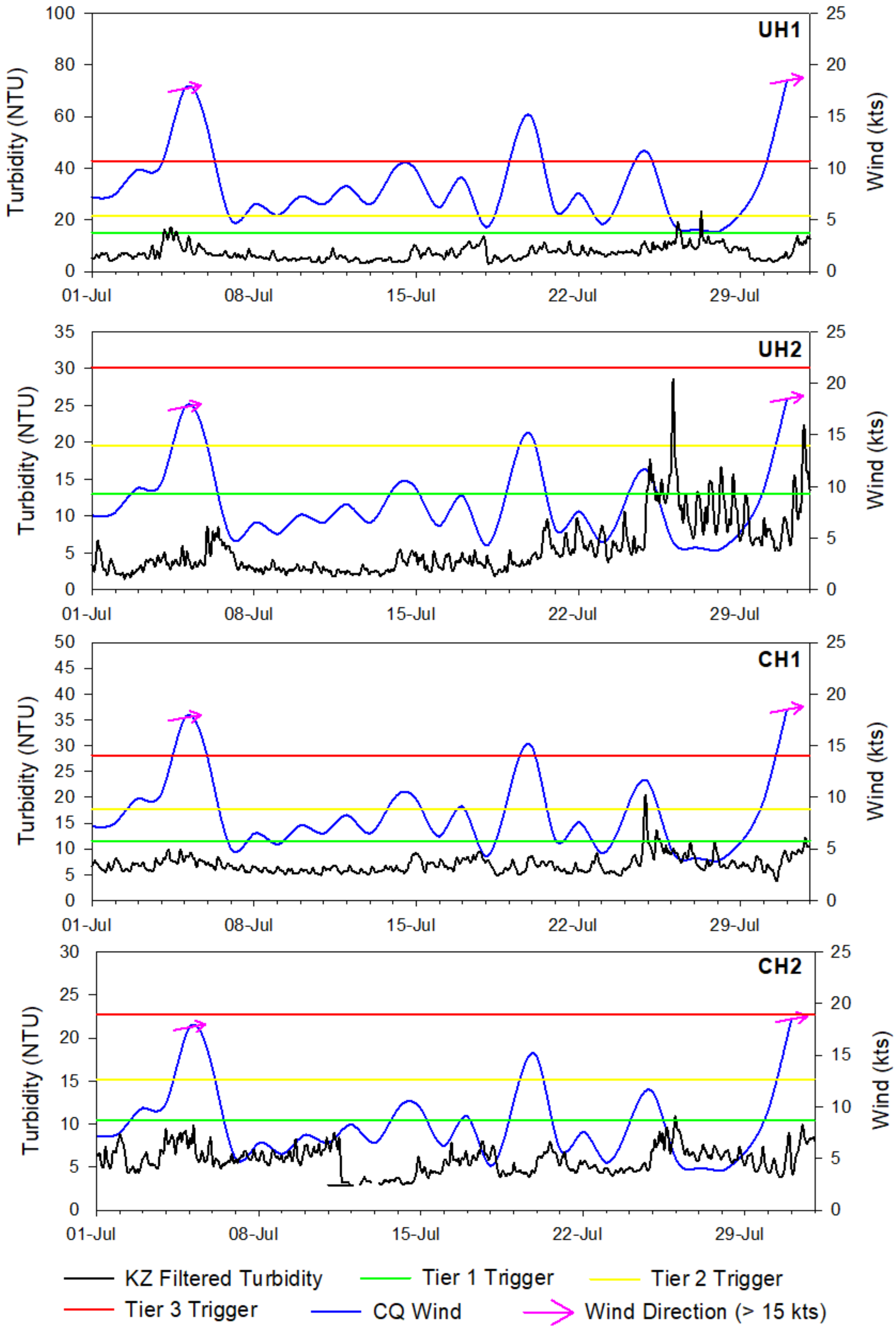


Figure 39 Surface KZ filtered turbidity and inshore daily averaged winds at inshore sites (UH1, UH2, CH1 and CH2) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for inshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier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

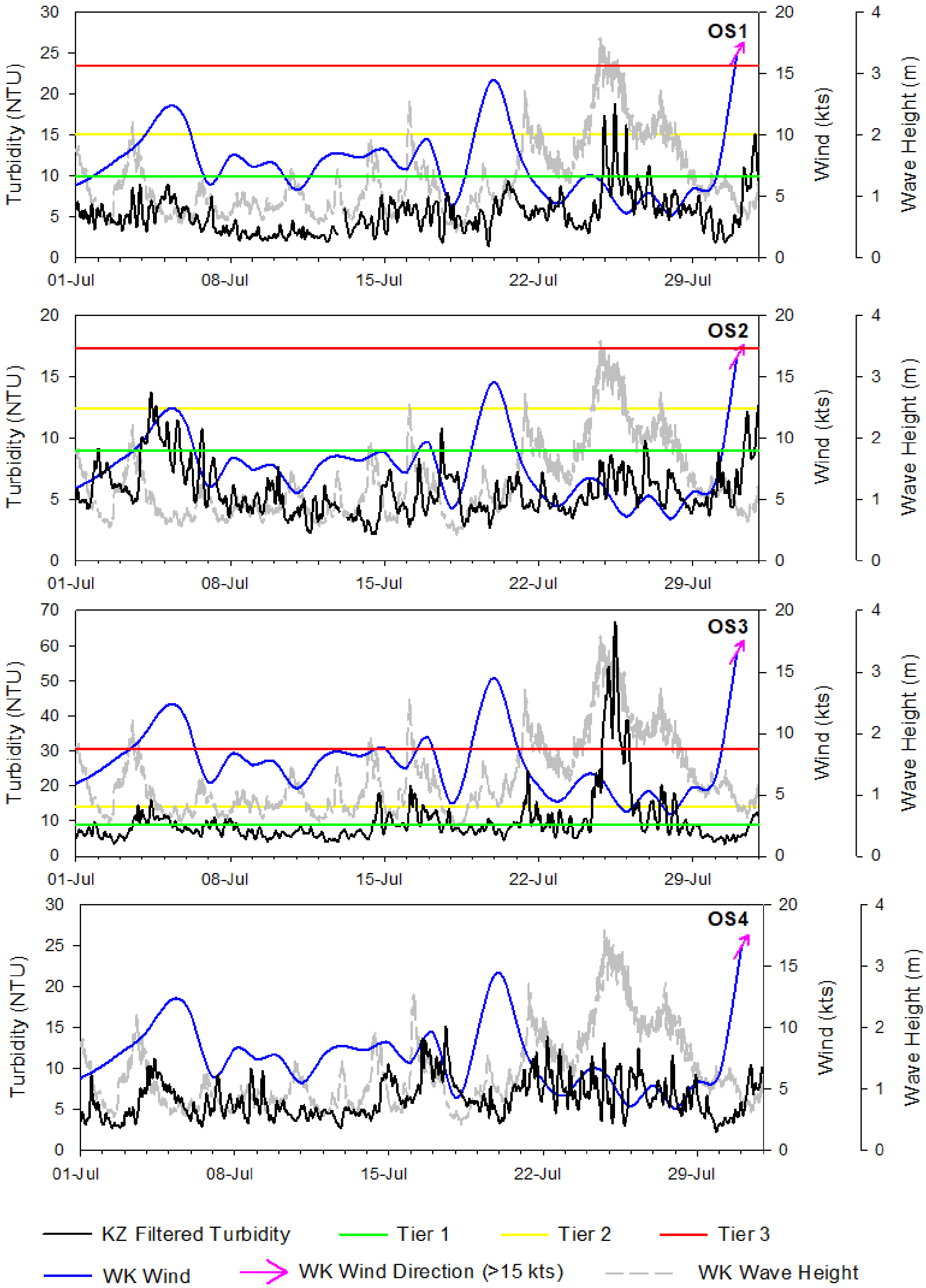


Figure 40 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS1 to OS4) during July 2019.

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.

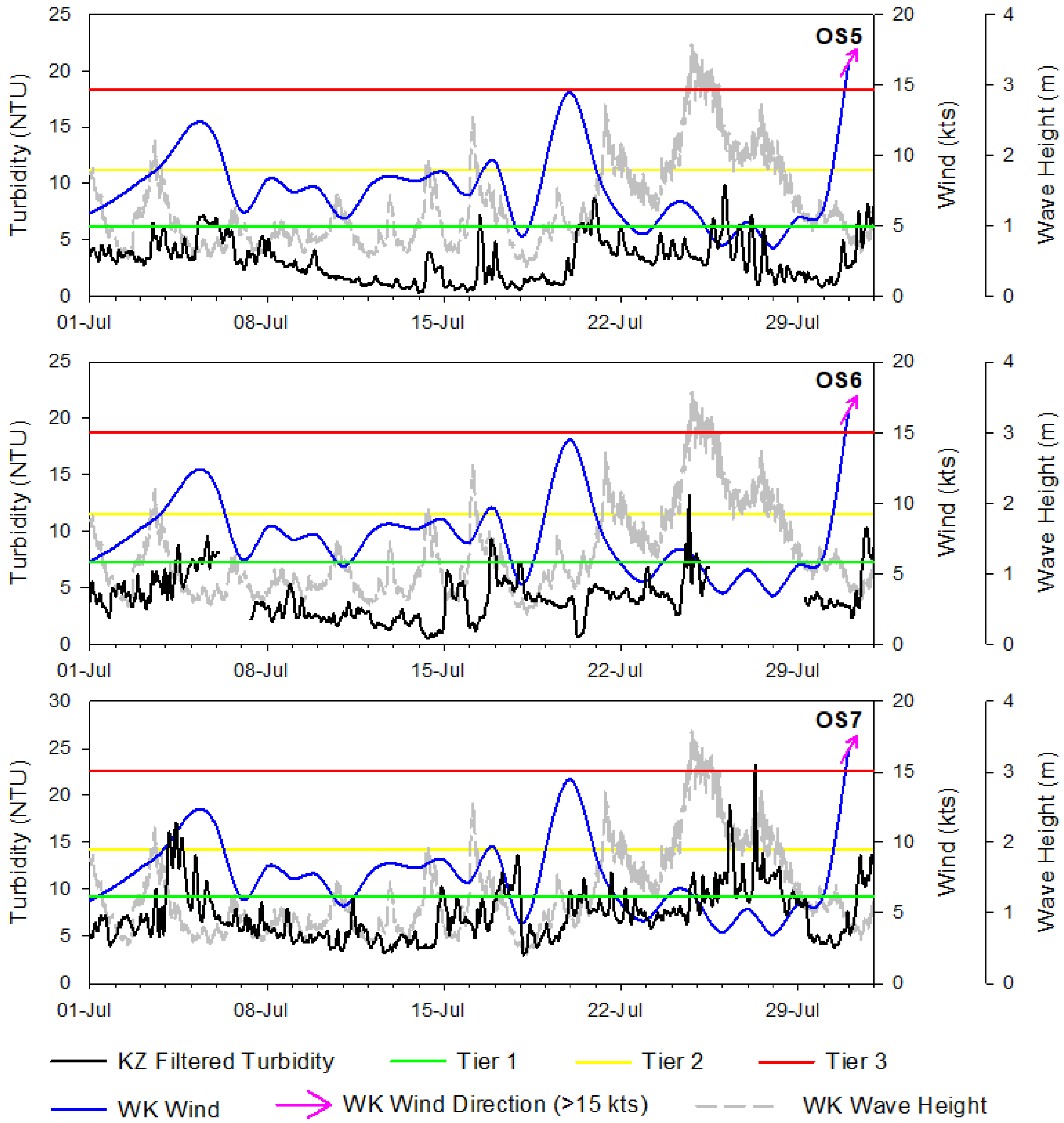


Figure 41 Surface KZ filtered turbidity and daily averaged winds at offshore sites (OS5 to OS7) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

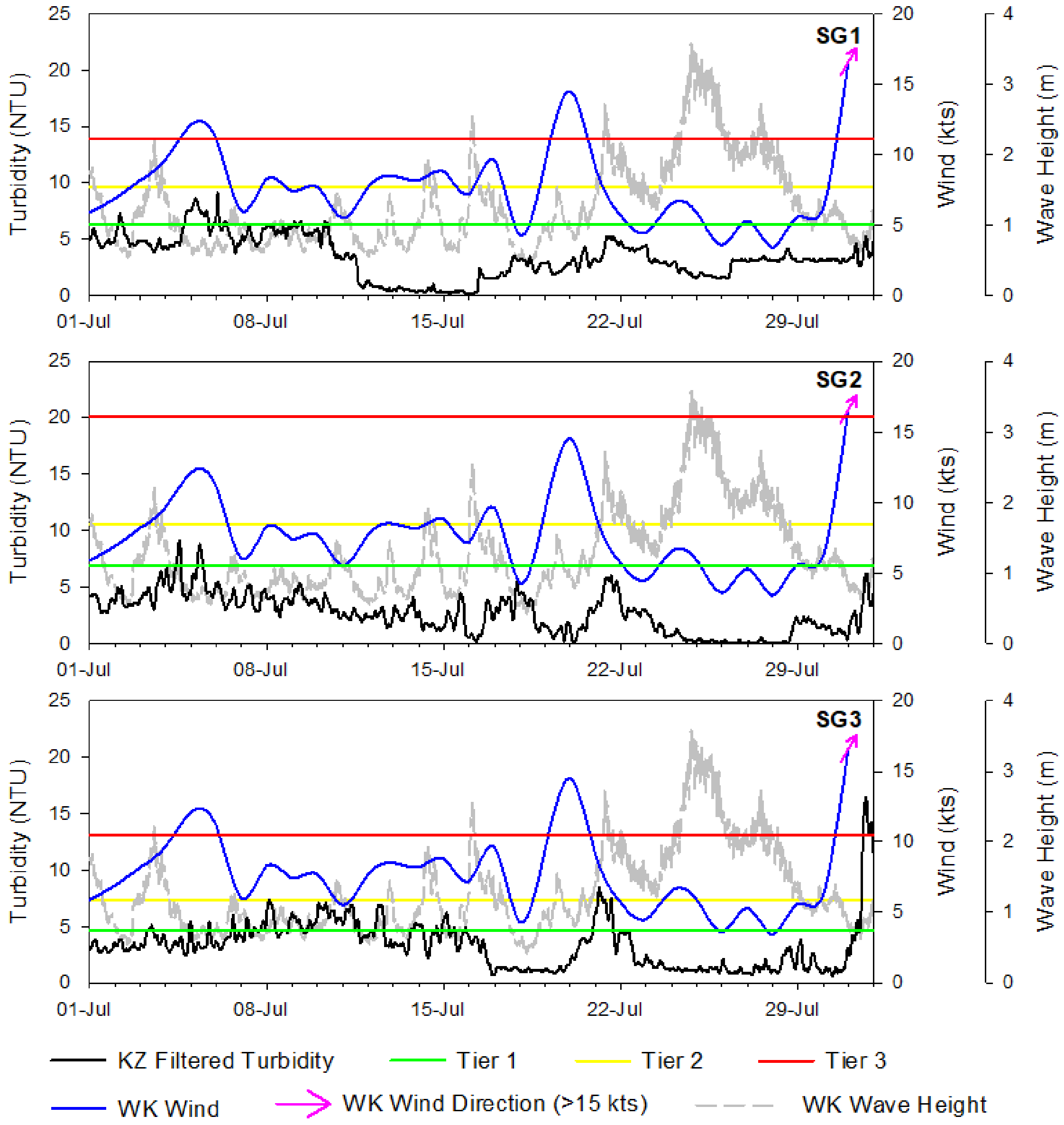


Figure 42 Surface KZ filtered turbidity and daily averaged winds at the spoil ground sites (SG1 to SG3) during July 2019.
Note differing scales for each plot. Arrows indicate the direction of travel for offshore winds greater than 15 knots. Horizontal lines indicate turbidity intensity tier levels.

Table 22 Mean KZ filtered turbidity and statistics at inshore water quality logger sites during July 2019 and baseline period 1 November 2016 to 31 October 2017
Values for July are means ± se, range and percentiles (n = 2912 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface July	Surface Baseline
UH1	Mean ± se	7.4 ± 0.1	12
	Range	3 – 23	2 – 155
	99th	16	37
	95th	12	21
	80th	9	15
UH2	Mean ± se	5.6 ± 0.1	9.9
	Range	1.5 – 29	2 – 59
	99th	17.7	29
	95th	14	19
	80th	7.9	13
CH1	Mean ± se	7.0 ± 0.0	8.8
	Range	4 – 20	<1 – 50
	99th	12	27
	95th	10	17
	80th	8	12
CH2	Mean ± se	5.8 ± 0.0	7.6
	Range	3 – 11	<1 – 39
	99th	9.5	22
	95th	8.5	15
	80th	7	10

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

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface July	Surface Baseline
SG1	Mean ± se	3.4 ± 0.0	4.2
	Range	<1 – 9	<1 – 31
	99th	8	14
	95th	7	9.5
	80th	5	6.1
SG2	Mean ± se	2.6 ± 0.0	4.6
	Range	<1 – 9	<1 – 33
	99th	7.5	20
	95th	5.5	10
	80th	4.1	6.9
SG3	Mean ± se	3.4 ± 0.0	3.6
	Range	<1 – 16	<1 – 22
	99th	13.4	13
	95th	6.7	7.3
	80th	4.8	4.7

Table 24 Mean KZ filtered turbidity and statistics at offshore water quality logger sites during July 2019 and baseline period 1 November 2016 to 31 October 2017.
Values for June are means ± se, range and percentiles (n = 2493 to 2976). Baseline values modified from Fox 2018.

Site	Statistic	KZ Filtered Turbidity (NTU)	
		Surface July	Surface Baseline
OS1	Mean ± se	5.3 ± 0.0	7.5
	Range	<1 – 19	<1 – 99
	99th	15	23
	95th	9.5	15
	80th	6.9	9.7
OS2	Mean ± se	5.7 ± 0.0	6.4
	Range	2.2 – 14	<1 – 36
	99th	12	17
	95th	10	12
	80th	7.1	8.9
OS3	Mean ± se	10 ± 0.1	6.5
	Range	3 – 67	<1 – 110
	99th	48	27
	95th	21	14
	80th	11	8.9
OS4	Mean ± se	6.4 ± 0.0	5.9
	Range	2.4 – 15	<1 – 35
	99th	13	18
	95th	10.6	13
	80th	8.4	8.1
OS5	Mean ± se	3.2 ± 0.0	4.6
	Range	<1 – 10	<1 – 35
	99th	8	18
	95th	6.5	11
	80th	4.7	6.1
OS6	Mean ± se	4.1 ± 0.0	4.7
	Range	<1 – 13	<1 – 37
	99th	9.5	18
	95th	7.8	11
	80th	5.4	7.1
OS7	Mean ± se	7.4 ± 0.1	6.3
	Range	3 – 23	<1 – 48
	99th	16	22
	95th	12.4	14
	80th	9.4	9.1

Table 25 Summary of Vision Environment quality control data for July 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	9	11	20
Dissolved Aluminium (ug/l)	<3	<3	<12	<12	ND
Total Aluminium (ug/l)	<3.2	<3.2	136	123	10
Dissolved Arsenic (ug/l)	<1	<1	<4	<4	ND
Total Arsenic (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Cadmium (ug/l)	<0.05	<0.05	<0.2	<0.2	ND
Total Cadmium (ug/l)	<0.053	<0.053	<0.21	<0.21	ND
Dissolved Chromium (ug/l)	<0.5	<0.5	1.2	1.1	9
Total Chromium (ug/l)*	0.58	0.55	2.3	3.1	30
Dissolved Cobalt (ug/l)	<0.2	<0.2	<0.6	<0.6	ND
Total Cobalt (ug/l)	<0.21	<0.21	<0.63	<0.63	ND
Dissolved Copper (ug/l)	<0.5	<0.5	<1	<1	ND
Total Copper (ug/l)	<0.53	<0.53	1.2	<1.1	ND
Dissolved Iron (ug/l)	<20	<20	4	<4	ND
Total Iron (ug/l)	<21	<21	230	230	0
Dissolved Lead (ug/l)	<0.1	<0.1	<1	<1	ND
Total Lead (ug/l)	<0.11	<0.11	<1.1	<1.1	ND
Dissolved Manganese (ug/l)	<0.5	<0.5	4	4	0
Total Manganese (ug/l)	<0.53	<0.53	8.2	8.2	0
Dissolved Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Total Mercury (ug/l)	<0.08	<0.08	<0.08	<0.08	ND
Dissolved Molybdenum (ug/l)	<0.2	<0.2	11.3	10.5	7
Total Molybdenum (ug/l)	<0.21	<0.21	10.9	10.6	3
Dissolved Nickel (ug/l)	<0.5	<0.5	<7	<7	ND
Total Nickel (ug/l)	<0.53	<0.53	<7	<7	ND
Dissolved Selenium (ug/l)	<1	<1	<4	<4	ND
Total Selenium (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Dissolved Silver (ug/l)	<0.1	<0.1	<0.4	<0.4	ND
Total Silver (ug/l)	<0.11	<0.11	<0.43	<0.43	ND
Dissolved Tin (ug/l)	<0.5	<0.5	<5	<5	ND
Total Tin (ug/l)	<0.53	<0.53	<5.3	<5.3	ND
Dissolved Vanadium (ug/l)	<1	<1	1.8	1.3	32
Total Vanadium (ug/l)	<1.1	<1.1	1.9	2	5
Dissolved Zinc (ug/l)	<1	<1	<4	<4	ND
Total Zinc (ug/l)	<1.1	<1.1	<4.2	<4.2	ND
Total Phosphorus (ug/l)	<4	<4	20	28	33
Dissolved Reactive Phosphorus (ug/l)	<4	<4	15.5	15.4	1
Total Nitrogen (ug/l)	<110	<110	<300	<300	ND
Total Kjeldahl Nitrogen (TKN) (ug/l)	<100	<100	<200	<200	ND
Total Ammonia (ug/l)	<10	<10	24	24	0
Nitrate-N + Nitrite-N (ug/l)	<2	<2	65	65	0
Chlorophyll a (ug/L)	<0.2	<0.2	0.7	0.8	13