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Woodside Energy

Scarborough - Environmental Monitoring Program

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Ben Pace 30/10/2024

Dredging and Spoil Disposal Water Quality Monitoring Report

Scarborough Execute Environmental Monitoring Program

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CLIENT: Woodside Energy Limited

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MARINE

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Acknowledgement Of Country

In the spirit of reconciliation O2 Marine Pty Ltd acknowledge that this project is proposed on the lands of the Ngarluma, Yaburara, Mardudhunera, Yindjibarndi and Wong-Goo-Tt-Oo People. We pay our respects to Elders past, present and emerging and recognise their continuing connection to land, sea, culture and community.

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Acronyms and Abbreviations

Acronym	Full term
AMP	Australian Marine Park
BCH	Benthic Communities and Habitat
BHD	Backhoe Dredge
DLI	Daily Light Integral
DSDMP	Dredging and Spoil Disposal Management Plan
EMP	Environmental Management Plan
FPU	Floating Production Unit
IMO	In-situ Marine Optics
LAT	Lowest Astronomical Tide
MODIS	Moderate Resolution Imaging Spectroradiometer
NRT	Near Real Time
NTU	Nephelometric Turbidity Unit
PAR	Photosynthetically Active Radiation
QC	Quality Control
RGB	Red/Green/Blue
TMMF	Tiered Monitoring and Management Framework
TSHD	Trailing Suction Hopper Dredge
TSS	Total Suspended Solids
VIIRS	Visible Infrared Imaging Radiometer Suite
WBR	Wave Rider Buoy
ZoHI	Zone of High Impact
ZoI	Zone of Influence
ZoMI	Zone of Moderate Impact

Executive Summary

O2 Marine were commissioned by Woodside to complete a water quality monitoring program in line with the Scarborough Project Dredging and Spoil Disposal Management Plan (DSDMP) during trenching, spoil disposal, borrow ground dredging and backfill construction activities. Using a Tiered Monitoring and Management Framework (TMMF), the objective of this program was to provide data to inform the management of these activities and associated water quality to a level where impacts are not predicted to occur to benthic communities and habitats (BCH; i.e., coral communities), to achieve Environmental Protection Outcome (EPO) 6-1(1).

Water quality monitoring systems were deployed at 19 sites throughout the Dampier Archipelago. Each monitoring system included a custom designed stainless steel seabed frame with a pair of loggers mounted to measure multispectral irradiance / Photosynthetically Active Radiation (PAR) which was used to calculate Daily Light Integral (DLI), turbidity, water temperature and water depth. For the majority of sites (17), the frame with loggers attached were installed within the same water depth range as the adjacent coral reef. At the remaining two sites, modified monitoring system designs were used, whereby the frame and loggers were suspended at mid-water depths. Both designs allowed the placement of loggers at a depth that accurately represents the water quality conditions (i.e., light and turbidity) experienced by the neighbouring corals. The monitoring systems were installed at all sites between 5 and 14 May 2023, and retrieved between 27 February and 6 March 2024, equating to approximately 10 months of water quality monitoring data. Throughout this period, five scheduled maintenance visits (excluding installation and retrieval trips) and four reactive trips occurred to fix specific issues and to avoid jeopardising data quality and/or data loss.

All loggers were telemetered in near real time (NRT) during dredging and disposal activities (trenching and spoil disposal in State waters occurring between 21 July 2023 and 31 August 2023, and trenching and spoil disposal (in Commonwealth waters) and borrow ground dredging and backfill construction between 24 November 2023 and 24 January 2024). Logger data underwent daily automatic and manual quality control checks and were then assessed against the tiered management triggers (Tier 1, Tier 2 or Tier 3) for each respective site, as outlined in the DSDMP.

To supplement the NRT monitoring of elevated turbidity and provide a broader spatial resolution, remote sensing data was obtained on a regular basis to capture the spatial extent of any visible surface suspended sediment plumes during dredging and disposal activities at the water quality monitoring sites. Imagery was downloaded from three platforms (Visible Infrared Imaging Radiometer Suite (VIIRS), Sentinel-2 and Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra) with a spatial resolution of 750 m, 60 m and 250 m, respectively.

Throughout the water quality monitoring program, there were no exceedances of management trigger levels recorded at any of the impact and influence sites during trenching and spoil disposal and borrow ground dredging and backfill activities. The results obtained showed no discernible effect on water conditions as a result of these activities, and the variability in water conditions observed across the Dampier Archipelago can be explained by natural dynamics.

The water quality data surveyed during the monitoring period closely matched the natural seasonal dynamics of water conditions experienced in the Dampier Archipelago. The summer season is associated with higher water temperatures, strong west to south-westerly winds, smaller swells and periodic tropical cyclones, whereas winter is characterised by relatively lower temperatures but relatively larger swells than those in summer, prevailing winds from the east, and less likelihood of storm surges. The natural environment in Dampier Archipelago is also characterised by a cross-shelf

gradient of increasing turbidity from the Offshore Zone (north of Rosemary, Legendre and Delambre Islands) to the coastline, which is driven by the influence of wind-driven waves and macrotidal water fluctuations towards shallower areas near the coastline that result in higher shear water velocity increasing sediment resuspension and associated turbidity. Seabed DLI levels were low in the Offshore Zone due to water depth driving the exponential reduction of irradiance with increasing water depth. Reduced seabed light was also recorded for Zone A (between shoreline and Mermaid Sound), which was primarily related to the column turbidity levels. The environmental conditions experienced during the monitoring period included one rainfall event with 70.4 mm in June 2023 and the passing of tropical cyclone Lincoln between 22–23 February 2024 that was approximately 300 km north of the monitoring location. However, neither event had a significant impact on the natural dynamics of water conditions at the monitoring sites.

Satellite-based remote sensing imagery captured the large-scale extent of visible surface sediment plumes during dredging and disposal activities. During the day, the turbid plumes naturally dispersed as a result of wind-driven waves and tides. As demonstrated by both in-situ measurements and satellite imagery, the plumes had a transient nature as water quality conditions returned to background levels within 24 hours following the cessation of activities, which was likely caused by the rapid settlement of suspended sediment and minimal resuspension of sediment settling locally.

Overall, the water quality monitoring program for the Scarborough Project was implemented in accordance with the DSDMP and no Tier 1, Tier 2 or Tier 3 trigger level exceedances were recorded at any impact or influence monitoring site during trenching and spoil disposal and borrow ground dredging and backfill activities. The results showed no discernible effect on water conditions as a result of these activities and as such, there is no impact pathway for change in the most sensitive receptors (e.g., coral communities).

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1. Introduction

1.1. Background

The Scarborough gas resource, located in Commonwealth waters approximately 375 km west of the Burrup Peninsula, forms part of the Greater Scarborough gas fields (Figure 1). The Scarborough gas resource will be developed by Woodside Energy Limited (Woodside) as the Operator. The offshore development (Scarborough Project) targets the Scarborough and North Scarborough gas fields, through constructing multiple subsea gas wells, tied back to a semi-submersible floating production unit (FPU) moored in approximately 900 m of water in the Scarborough field. The offshore facilities are proposed to be connected to onshore gas processing facilities through a trunkline of approximately 430 km in length, coming ashore at the existing Pluto LNG onshore facility.

Construction of the trunkline in State waters and nearshore Commonwealth waters required trenching, spoil disposal, borrow ground dredging and backfill activities (collectively referred to as dredging and associated works) which were managed under the Scarborough Project Dredging Spoil and Disposal Management Plan (DSDMP; Woodside, 2023b) and Scarborough Seabed Intervention and Trunkline Installation Environment Plan (Woodside, 2023a) respectively. The DSDMP outlines how dredging and associated works is managed and complies with the Scarborough Nearshore Component Ministerial Statement No. 1172 Condition 6, including Environmental Protection Outcomes.

The DSDMP identifies Benthic Communities and Habitats (BCH) as a Key Environmental Factor, specifically coral cover, as the most sensitive ecological receptor. A Tiered Monitoring and Management Framework (TMMF), as described in the DSDMP, was implemented to achieve Environmental Protection Outcome (EPO) 6-1(1):

No detectable net reduction of live coral cover at any of the coral impact monitoring locations attributable to the proposal.

The TMMF is a proactive and adaptive framework informed by water quality to manage dredging and associated activities to a level where impacts are not predicted to occur to sensitive BCH receptors such as coral communities and sponges. As part of the TMMF, a water quality monitoring program informs whether EPO 6-1(1) has been met by providing evidence that any changes in coral cover between pre and post dredging as a part of the coral community assessment is not Project attributable.

Woodside commissioned O2 Marine to complete a water quality monitoring program at 19 monitoring locations throughout the Dampier Archipelago to support the application of the TMMF, as described in Section 7.4 of the DSDMP.

1.2. Objectives

The objectives of this report, as described in Section 11.2.1 of the DSDMP, is to summarise the findings of the water quality monitoring program during trenching, spoil disposal, borrow ground dredging and backfill activities undertaken for the Scarborough Project.

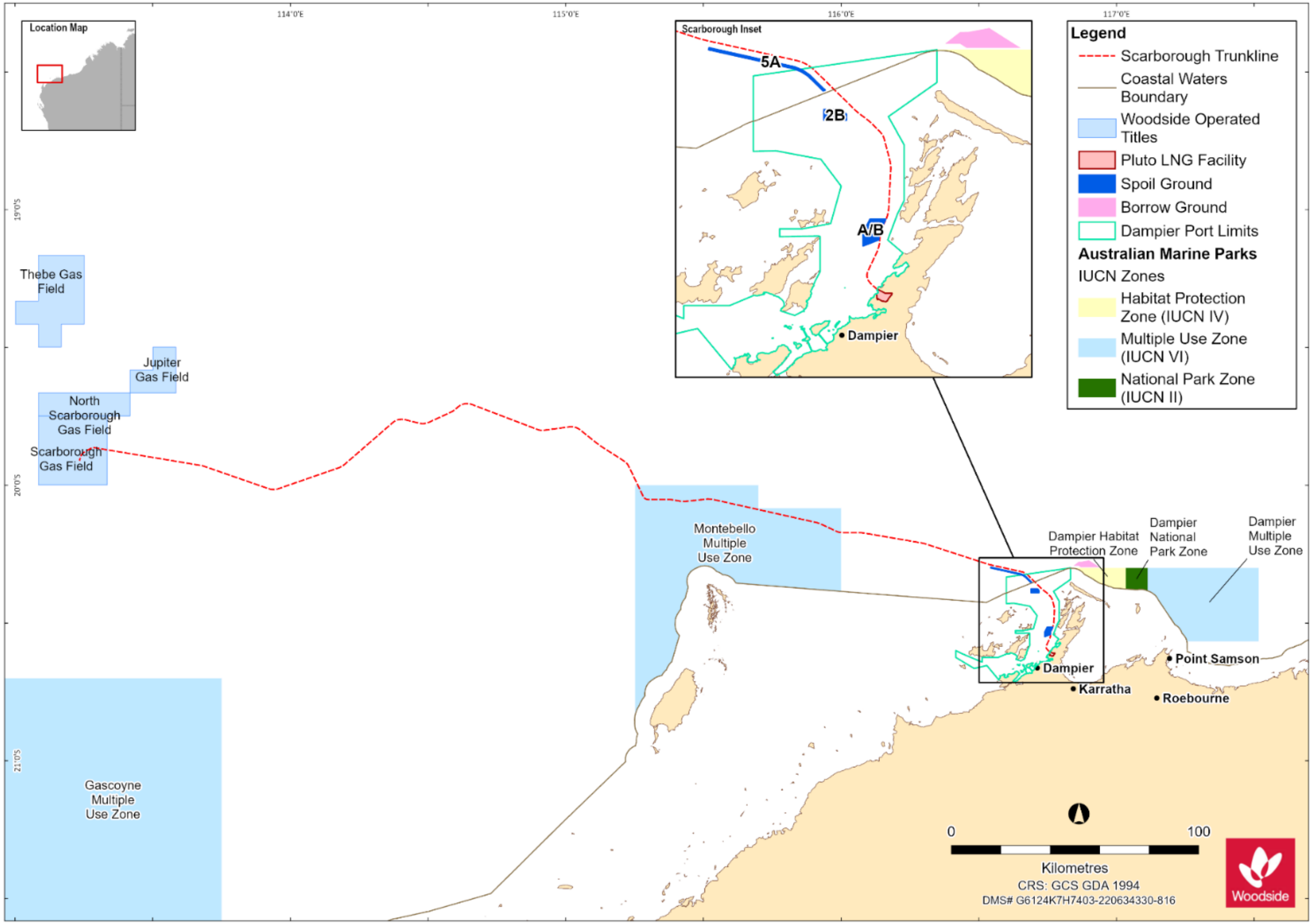

Figure 1: Location of the Scarborough Project

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2. Water Quality Monitoring Program

The water quality monitoring program was implemented in accordance with the methodology described in Section 11.2 of the approved DSDMP. The key elements of this methodology are outlined below.

2.1. Monitoring Sites

The water quality program included the installation of 19 water quality monitoring sites located within waters throughout the Dampier Archipelago, as proposed in Section 11.2.3 of the DSDMP. Site details are presented in Table 1 and site locations shown in Figure 2 and Figure 3. These sites were considered appropriate to provide protection for the adjacent benthic epifaunal communities including corals during the construction phase of the Project. The water quality monitoring sites were selected from a suite of pre-existing Pluto LNG Foundation project monitoring locations, which meant that in most instances long term datasets were available to inform the monitoring programs for both water quality and coral community, Furthermore two new sites (CONI2 and HAUY) were included in this water quality monitoring program which have not been surveyed during previous surveys. Rationale for site selection presented in Section 11.2.3 of the DSDMP.

The sites are distributed across three ecological zones established in the Dampier Archipelago (Figure 2). Ecological zones are defined in Section 5.5.2 of the DSDMP and are based on the sensitivity of benthic receptors as follows:

- Zone A – the trunkline area between the shoreline and KP8, adjacent macroalgae and mangrove habitats within Mermaid Sound, and generally all mangrove, marsh, and seagrass habitats between Nickol Bay and Point Samson. Water quality within Zone A is more turbid and coral communities comprise more sediment-tolerant or resilient species (Blakeway and Radford, 2005)
- Zone B – the trunkline area between KP8 and KP25, adjacent coral and macroalgae habitats within Mermaid Sound, and generally all coral, macroalgae and mixed community habitats between Dolphin Island and Bezout Island, including Madeleine Shoals, and
- Offshore – the trunkline area beyond KP25, and all areas north of a boundary line consisting of Rosemary Island, Legendre Island and Delambre Island. The DSDMP identified that the benthic communities in this Offshore zone are likely to be sparse and comprise largely of sponges and filter feeders and no corals.

The DSDMP (Section 5.5.1) also divides sites into four classifications based on modelling predictions of the plume generated from proposed dredging activities for the purpose of monitoring and management of potential impacts as follows:

- Impact sites – monitoring sites where plume modelling shows the Zone of Moderate Impact (ZoMI) intersects with significant coral habitat. These sites are key for the assessment against EPO 6-1(1) and were used to determine whether there is project-attributable change to live coral cover
- Influence sites – monitoring sites where modelling shows the Zone of Influence (ZoI) intersects with significant benthic biota. A conservative approach of categorising Influence sites as those that occur near the ZoI boundary (within 200 m). These sites may be reclassified as either Impact sites or Reference sites during the post-activity assessment, dependant on whether water

quality monitoring records a Project attributable exceedance of the Tier 2 management trigger or the site is not influenced by the dredge generated plume, respectively

- Reference sites – representative monitoring sites which modelling predicts will occur beyond the ZoI and are not predicted to be impacted or influenced by the sediment plume, and
- Informative sites – monitoring sites that are predicted to be influenced or impacted by the sediment plume from one activity, however well removed from the other activity (i.e., influenced from trenching and spoil disposal or borrow ground dredging and backfill). Data from these locations were used, where appropriate, to assess Project attributability of coral community effects if required. These sites were not reactively managed.

Table 1: Water quality monitoring sites and site classifications

Site Name	Site ID	Site Depth (m LAT)	Ecological Zone	As-installed Coordinates[1]		Distance (m) of As-installed Coordinates from Ecological Receptors during Baseline Monitoring	Distance (m) of As-installed Coordinates from Ecological Receptors during Operational Monitoring	Site Classification	
				Easting	Northing			Trenching and Spoil Disposal	Borrow Ground Dredging and Backfill
Conzinc Island	CONI	4.6	B	476808	7729505	344	344	Impact	Informative
Conzinc Island 2	CONI2	4.0	B	476164	7728558	N/A	222	Impact	Informative
Conzinc Bay North	COBN	5.2	B	479515	7728801	86	86	Impact	Informative
Supply Base	SUP2	6.1	A	473311	7719704	133	42	Influence	Informative
King Bay	KGBY	6.7	A	471999	7717953	553	525	Influence	Informative
South Withnell Bay	SWIT	5.8	A	476598	7723807	164	128	Influence	Informative
Angel Island	ANG2	7.3	B	477533	7731906	384	272	Influence	Informative
Hauy Island	HAUY	9.0	B	494683	7740196	1250	125	Informative	Influence
Mid Intercourse Island	MIDI	2.5	A	463903	7714305	186	136	Reference	Reference
North Withnell Bay	NWIT	6.6	A	477052	7725426	240	151	Reference	Reference
Flying Foam Passage	FFP1	15.9	B	481108	7734062	154	124	Reference	Reference
Gidley island	GIDI	8.2	B	478635	7736374	201	149	Reference	Reference
Hamersley Shoal	HAM3	19.3	B	478089	7746873	330	330	Reference	Reference
High Point	HGPT	7.4	B	467087	7728670	N/A	61	Reference	Reference
Courtney Shoal	CRTS	15.9	B	469000	7736624	1170	198	Reference	Reference
Lady Nora Island	LANI	2.1	B	460627	7738979	N/A	331	Reference	Reference
Legendre Island	LEGD	28.7	B	483562	7749562	234	234	Reference	Reference
Malus Islands	MAL2	7.2	B	464408	7730345	2641	157	Reference	Reference
Marine Park Boundary	MPB	27.7	Offshore	489544	7755357	N/A	N/A	Informative	Influence

1. *The as-installed coordinates for most water quality monitoring sites match the coordinates provided in the approved DSDMP (Section 11.2).*
2. *LAT = Lowest Astronomical Tide.*

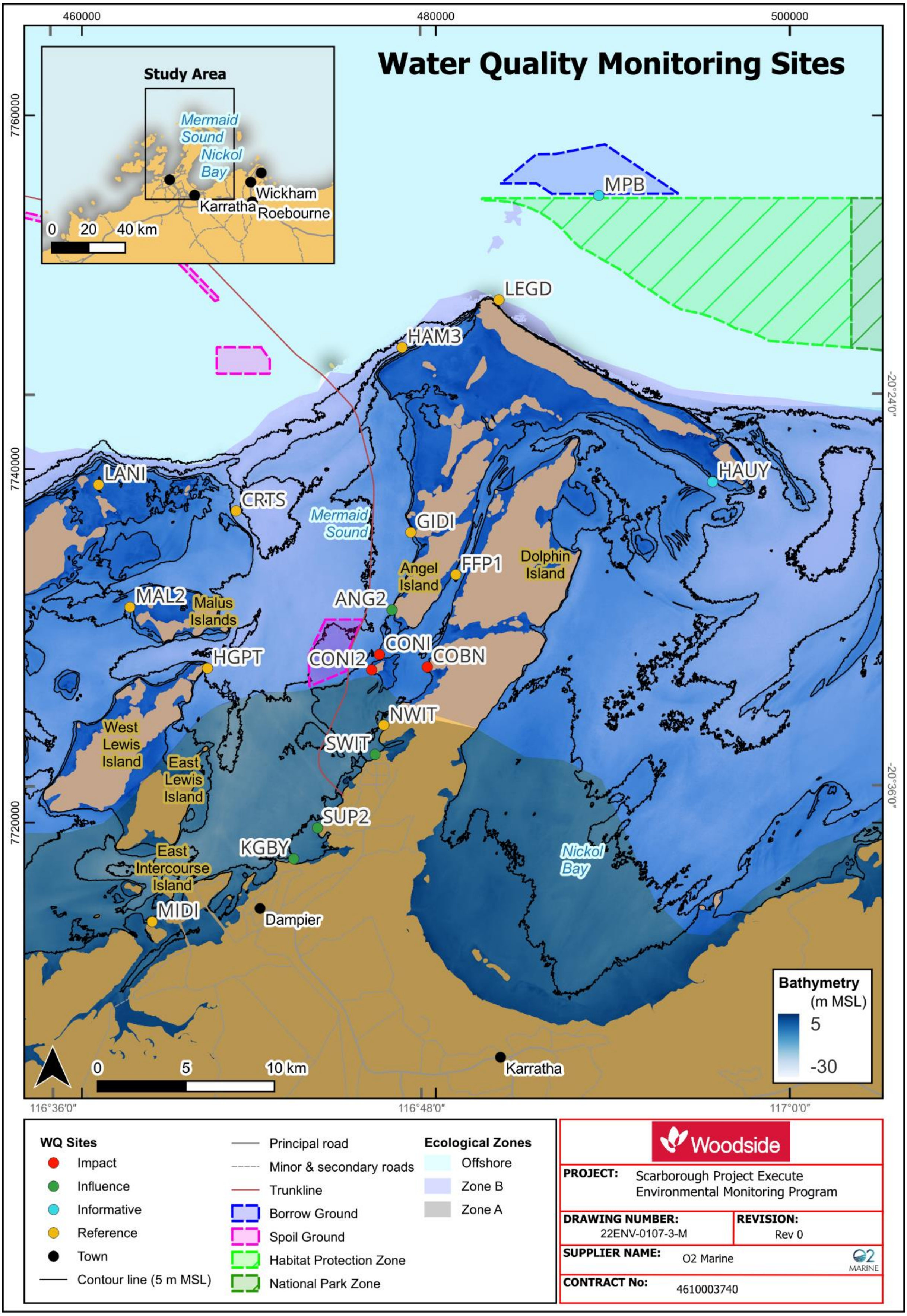


Figure 2: Location of water quality monitoring sites with site classifications for trenching and spoil disposal activities

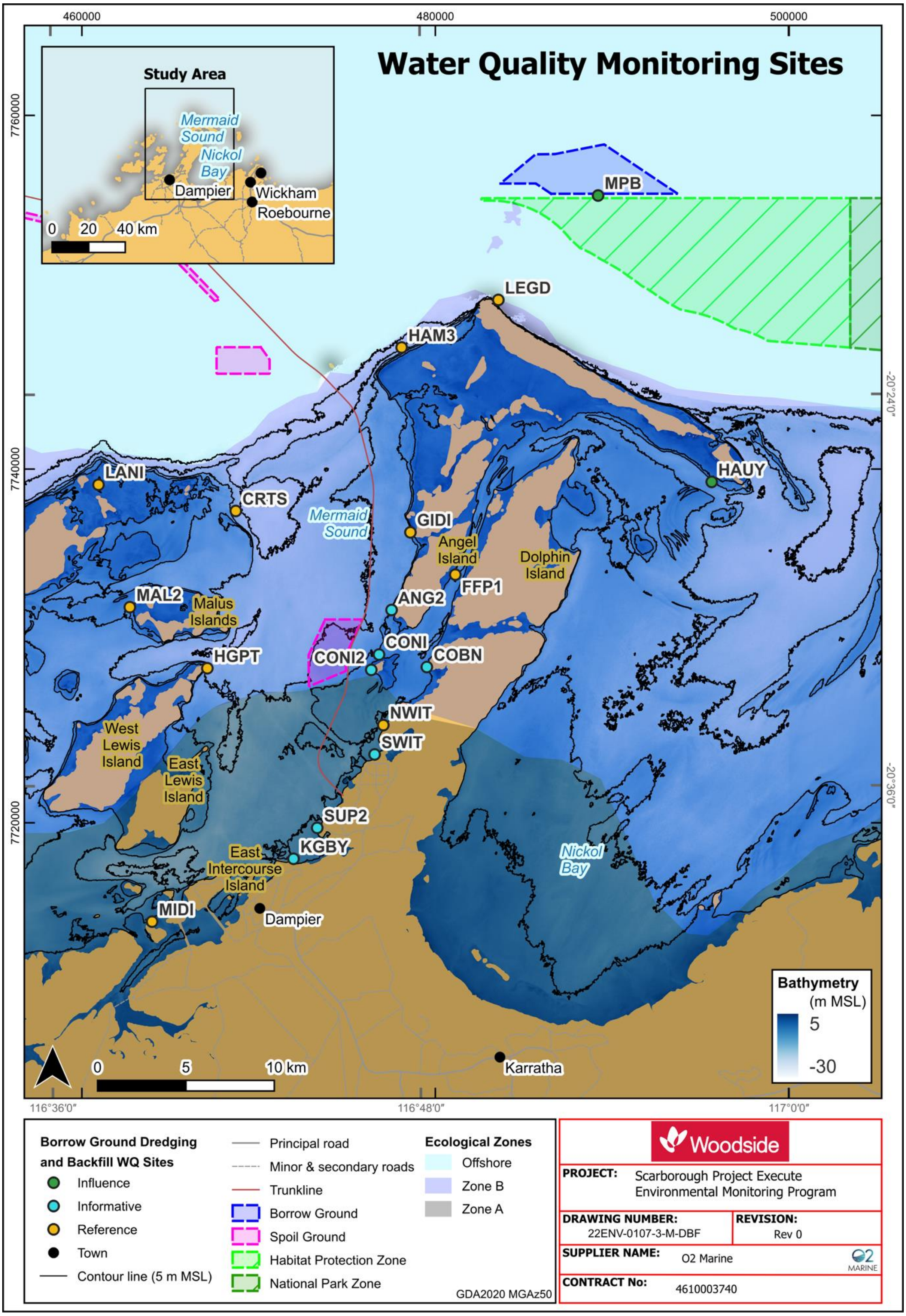


Figure 3: Location of water quality monitoring sites with site classifications for borrow ground dredging and backfill activities

2.1.1. Site Reconnaissance Survey

In accordance with the DSDMP, a site reconnaissance survey was completed in April 2023. The aim of this survey was to assess for the presence of benthic communities within the potential seabed frame location prior to the deployment of the monitoring systems, and to identify areas of highest coral cover relative to location of the monitoring systems (distance from ecological receptors; Table 1) using side scan sonar and video ground truthing. All sites were deemed suitable (i.e., large sand patches free from BCH) and the monitoring systems were located as close as practicable of sensitive ecological receptors (i.e., reef habitat with areas of high coral cover).

2.2. Monitoring System Design

2.2.1. Monitoring Design

The water quality monitoring systems deployed at all monitoring sites, were designed by O2 Marine and included a custom designed stainless steel seabed frame with a pair of data loggers mounted for measurement of the following parameters:

- Multispectral Irradiance (µW cm^{-2} nm^{-1}) / Photosynthetically Active Radiation (PAR; mol m^{-2} s^{-1}) / Daily Light Integral (DLI) (DLI derived from PAR)
- Turbidity (Nephelometric turbidity units; NTU)
- Water temperature (degrees Celsius; °C), and
- Water depth (m; mean sea level).

2.2.2. Mooring Design

Two types of mooring frame designs were used during the Project, with the set up for each site tailored according to its location and water depth.

For the majority of sites (17 sites; CONI, CONI2, COBN, SUP2, KGBY, SWIT, ANG2, HAUY, MIDI, NWIT, FFP1, GIDI, HGPT, CRTS, LANI, MAL2 and MPB), a seabed frame with loggers attached was deployed on the seabed. The loggers were mounted as to collect data at approximately 0.75 m above the seabed to ensure an accurate representation of the water quality (i.e., light and turbidity) conditions that are experienced by the neighbouring corals (Figure 4).

Based on learnings from the 2022 baseline monitoring program (O2Me, 2023), two sites (HAM3 and LEGD) experienced marked differences in water depth between the water quality monitoring loggers and the adjacent coral communities due to significant drop-offs (approximately >10 m) adjacent to the reef. For these two sites, a modified monitoring system design was used whereby the stainless-steel frame and loggers were suspended at a depth (mid-water) that more accurately represented the depth (and associated light conditions) of the nearby (within 100 m) benthic receptors (Figure 5).

Both monitoring system designs incorporated a telemetry system for transmission of near real-time (NRT) data to an online web portal. All monitoring designs were intended to be robust, with due consideration and tolerance for seasonal weather events including tropical cyclones.

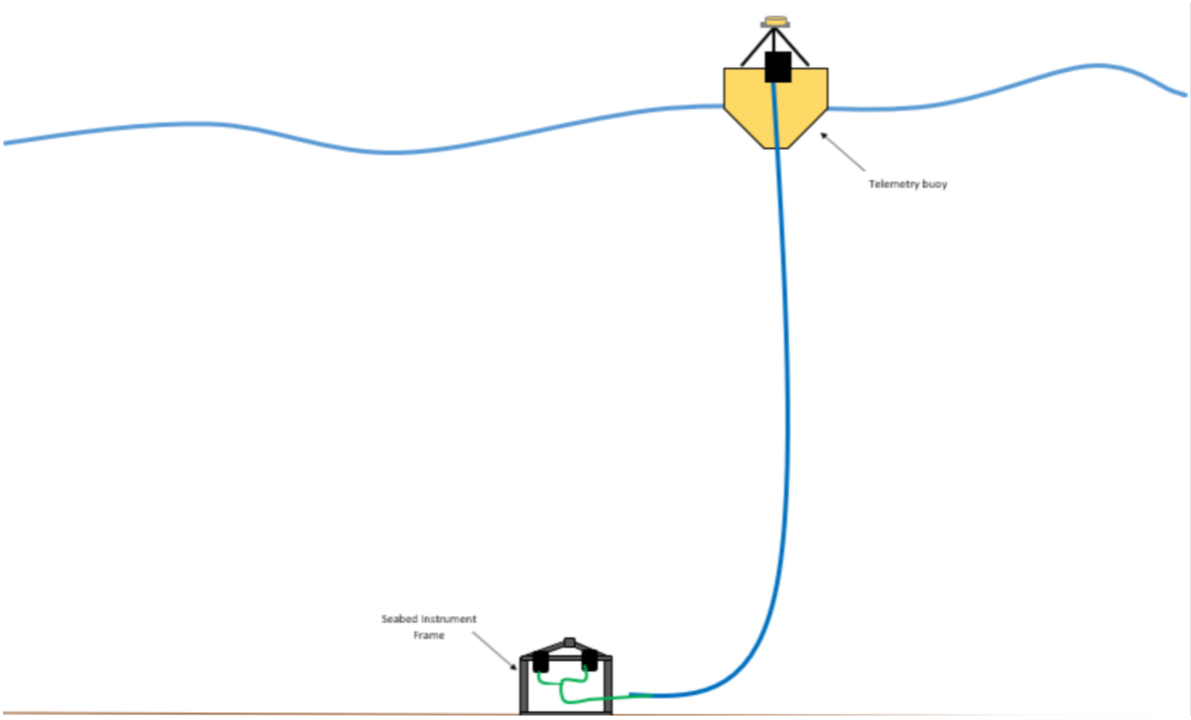


Figure 4: Schematic of L mooring design

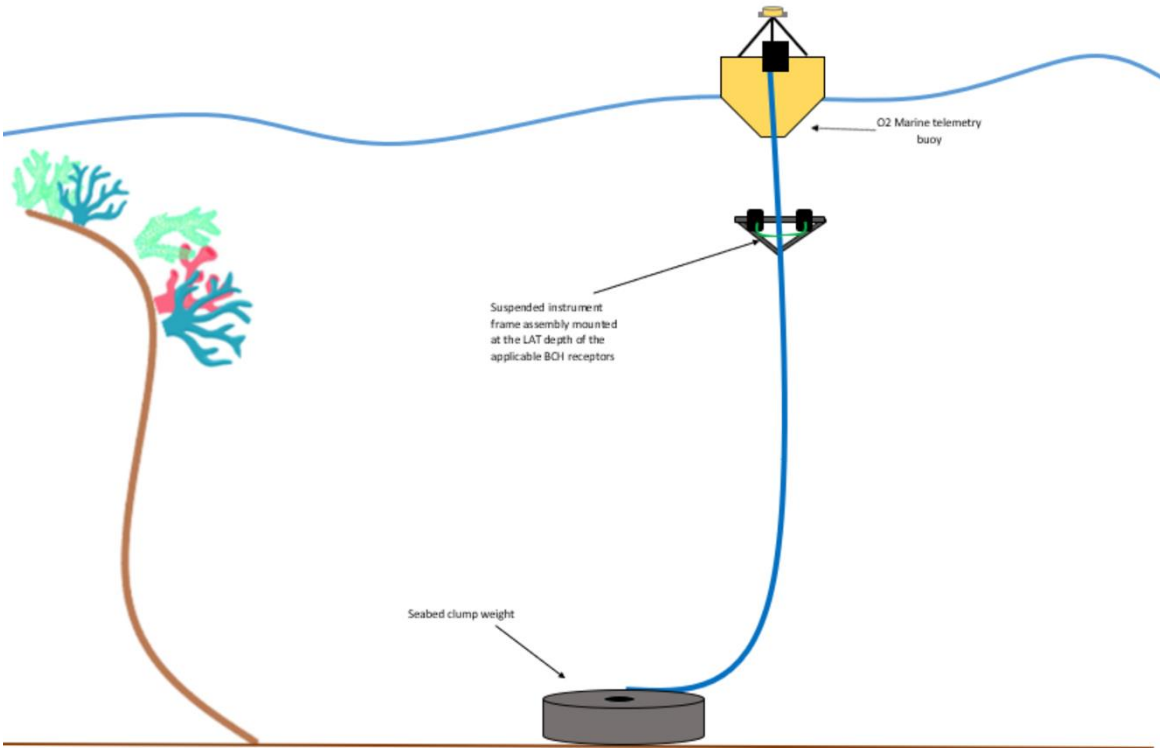


Figure 5: Schematic of a modified L mooring design with adjustable depth for loggers

2.2.3. Water Quality Instruments

2.2.3.1. Instrument Type and Orientation

At each monitoring site, two loggers were deployed: a turbidity logger (NTU-LPT) and multispectral light logger (MS9-LPT), both manufactured by In-situ Marine Optics (IMO). Logger specifications are summarised in Table 2.

All loggers were time-synchronised prior to deployment to ensure all sites were collecting data simultaneously. The loggers were programmed to record data every 15 minutes and were configured to collect 11 samples per burst interval (15 minutes), with the median value recorded to the logger's internal memory card. As copper bio-wipers were present on light and turbidity sensors (to minimise marine fouling), a delay of four seconds prior to sampling and four seconds post sampling was programmed to ensure no interference occurred between the wiper and the optical lens.

The multispectral light loggers (MS9-LPT) were programmed to not record between 20:30 and 03:30 as no light was available between this period and battery and data usage was therefore optimised. DLI was calculated by integrating PAR readings taken from sunrise to sunset without a material effect on the DLI that would have been otherwise obtained from 24-hour measurements.

While the primary data recorded by the loggers was light and turbidity respectively, both types of loggers also recorded temperature and water depth as supplementary informative parameters. These parameters provide important environmental data that may be used in evaluating a trigger exceedance and in identifying and assessing any naturally occurring impacts to the coral communities, such as thermal bleaching.

Table 2: Logger specifications

Parameter	Instrument	Units	Range	Resolution	Recommended Calibration Frequency
Multispectral irradiance	MS9-LPT	Wavelengths (nm): 410, 440, 490, 510, 550, 636, 660, 685, 710 mol m^{-2} d^{-1}	0–400 µW cm^{-2} nm^{-1}	2.5 x 10^{-3} µW cm^{-2} nm^{-1}	Annual
PAR	MS9-LPT	mol m^{-2} d^{-1}	0–8	1.0 x 10^{-5} µW cm^{-2} nm^{-1} sr^{-1}	Annual
Turbidity	NTU-LPT	NTU	0–500	0.05	Annual
Temperature	MS9-LPT NTU-LPT	°C	-55–125	±1%	Annual
Water depth	MS9-LPT NTU-LPT	m	0–300	±1%	Annual

To obtain results representative of the nearby benthic communities, all sensor heads (with the exception of HAM3 and LEGD; refer to Section 2.2.2) were mounted at ~0.75 m from the seabed. To ensure best practice was adhered to and the highest quality of data were captured, each sensor had a specific mounting orientation: the IMO turbidity sensor face was at least 10 cm away from any reflective material other than the sample (i.e., water column) to ensure there were no obstructions causing erroneously high turbidity readings. Ambient light (constant or modulated) is not known to significantly affect the performance of the turbidity sensors; however, it is still best practice to minimise ambient light falling directly onto the sensor face where possible. Therefore, a horizontal mounting orientation was adhered to.

When considering mounting options for the light sensor, a position was selected that allowed an unobstructed vertical view of the sky; free from artificial shadows falling on the lens. It is important the optical window was as flat as possible with the horizon, on both axes. Mounting at angles greater than 20° can cause artificially reflected light to contribute to the signal. In moored applications where the copper bio-wiper was attached, the initial positioning of the frame on the seabed was checked using a remotely operated vehicle or drop camera to ensure tilting angle of the frame was not exceeded.

A single land-based light logger was installed at a remote location near Hearson's Cove to collect ambient above-water measurements of light and air temperature. Although the land-based light logger data was not a requirement as per the DSDMP, the data obtained was informative and was used as a reference point for natural variation of light levels (i.e. sustained periods of cloud cover or low light). This location was secure, was not obstructed by anything that could interfere with the readings (i.e. shading) and easily accessible to download and service.

2.2.3.2. Instrument Maintenance and Calibration

All loggers were calibrated once prior to the deployment of the loggers in accordance with manufacturer's recommendations.

The light and turbidity loggers have a battery capacity capable of exceeding 150 days at 30-minute intervals. However, as a precaution, scheduled maintenance trips were completed every 6–8 weeks (subject to weather and logistical constraints) to ensure quality data was obtained and minimise the risk of data loss throughout the deployment. General onsite maintenance completed (as required) during scheduled maintenance trip included the following tasks:

- Removal of biofouling from seabed frames, loggers, mooring lines and surface buoys
- Cleaning of loggers as per the IMO's specifications
- Replacement of any degraded consumables (e.g., O-rings, etc.)
- Instrument functionality testing, clock calibration and data download
- Recharge internal batteries
- Reapplication of anti-biofouling creams
- Checking of all mooring hardware (e.g., shackles, mousing, anodes, etc.), and
- Instrument functionality and communications check post-reinstallation.

To reduce biofouling, both the light and turbidity sensors were equipped with a copper bio-wiper and faceplate, and a thick layer of zinc oxide cream was applied to all non-copper surfaces. Throughout the Project, ongoing improvements were made to reduce biofouling more effectively, such as the application of copper tape to the top of the loggers and directly adjacent frame struts, and applying lanolin to all non-copper surfaces.

Full redundancy (three full backup equipment and spares) of both light and turbidity loggers were kept on site at the O2 Marine facility in Karratha (Western Australia) in case data drift (not attributed to biofouling) or malfunction was noted on loggers during a scheduled maintenance trip. In such cases, the loggers were returned to Perth for recalibration and replaced it with a spare logger, ensuring minimal gaps of data in the sampling window.

2.3. Timing

2.3.1. Deployment Period and Timing

The water quality monitoring systems were installed between 5 and 14 May 2023, and retrieved between 27 February and 6 March 2024, equating to approximately 10 months of water quality monitoring data (Figure 6). The deployment of the monitoring systems was in accordance with the timing requirements in Section 11.2.2 of the DSDMP. Throughout this period, the water quality monitoring systems had five scheduled maintenance visits (excluding installation and retrieval trips) however, when no data was transmitted or recorded by a logger or specific issues were encountered at certain sites, reactive maintenance trips were required to investigate, troubleshoot and rectify monitoring systems. A total of four reactive trips occurred in June, July and November 2023 and January 2024. Details of the installation scheduled and reactive maintenance trips and retrieval dates for each water quality monitoring site is provided in Appendix A.

Figure 6: Data capture at each water quality monitoring site

2.3.2. Dredging and Disposal Periods

Trenching along the trunkline route in State waters and disposal of dredge spoil at existing Spoil Grounds 2B and/or A/B occurred between 21 July 2023 and 31 August 2023 using a combination of a trailing suction hopper dredge (TSHD) and backhoe dredge (BHD) and associated split hopper barges. Disposal of material to Spoil Ground A/B was only used by the SHB (supporting the BHD) as per the requirements outlined in the DSDMP. Trenching along the trunkline route in Commonwealth waters occurred between 24 November and 20 December 2023 using a TSHD. Offshore borrow ground dredging and backfill activities along the trunkline route were completed between 24 December 2023 and 25 January 2024 using a TSHD[1].

[1] To simplify the naming convention, the second dredging and disposal period (as seen in Figure 6 and various other figures) has been labelled as 'Borrow Ground Dredging' however, it represents seabed disturbances from trenching along the trunkline route in Commonwealth waters as well as offshore borrow ground dredging and backfill activities along the trunkline route.

2.4. Data Management and Analysis

2.4.1. Quality Assurance / Quality Control

Quality assurance of the data collected was ensured through O2 Marine documented processes and field records, including:

- All loggers were manufactured by a reputable Australian company (IMO). Instruments were set to log in Perth before mobilisation to site. Calibration certificates for all loggers were appended to all field reports
- Photographs and video evidence of all assembled moorings, stainless steel seabed frames and equipment was captured before deployment, including loggers installed, logger mounting, serial numbers, bio-wiper functionality and data logging at scheduled times prior to deployment
- All loggers were brand-new when procured prior to Project baseline studies. The loggers were dedicated to the monitoring program and were inspected and serviced prior to deployment during the operational monitoring phase of the Project.
- Loggers deployed during previous trips were replaced on a rotational basis. At each site the loggers were retrieved, serviced, data downloaded, checked, recharged and, if required, redeployed at another site during the trip, or returned to IMO for servicing and calibration in line with IMO's annual calibration requirements
- Recording of times and GPS coordinates of all deployments was completed, including separate time and location for each mooring anchor and seabed frame deployed
- Sites were checked visually, using sonar and/or slide camera (GoPro) prior to system deployment, whenever feasible, to ensure the substrate was appropriate (i.e., no sensitive benthic receptors) for the placement of the monitoring system. Imagery and inspection of monitoring systems was also undertaken post deployment (when possible) to ensure the mooring was deployed correctly in accordance with the mooring schematic (Figure 4 and Figure 5), as well as confirming whether sensitive benthic receptors surrounding the frame were unaffected, and
- To verify functionality of telemetry systems, the online web portal was checked for streaming data prior to and post-deployment of the monitoring system to confirm no damage or issues occurred during re-installation.

Quality Control (QC) was applied in line with O2 Marine's QC and Conventions version 2.2 Procedures (O2Me, 2023), which closely followed or exceeded the requirements of Jones et al. (2015) and Fisher et al. (2015 and 2017). In brief, daily data QC followed a tiered approach and involved derivation of data for QC, removal of irrelevant, inconsistent or erroneous data from datasets, automated assignment of QC flags to each data point, manual determination of QC flags through visual inspection, and comparison of collected data to known background conditions or alternative datasets.

2.4.2. Trigger Level Assessment

Following QC checks (refer to Section 2.4.1), the monitoring data was uploaded daily to the online web portal. An automated near real-time trigger assessment against the tiered management triggers for Tiers 1, 2 and 3 (Table 3) was completed for each respective impact and influence site, as outlined in Section 7.4 of the DSDMP.

If the measured seabed DLI (light) and turbidity data at an impact or influence monitoring site (as applicable to the active activity) exceeded the combined effects of turbidity and seabed light over a defined time period (rolling 24-hr mean and rolling multi-day mean), then the online web portal issued an alert via email and SMS communications to an O2 Marine and Woodside representative. This would trigger a Project attributability assessment to determine if the active activity can reasonably be expected to have contributed to or caused the exceedance. If required this assessment was to be conducted, reported and submitted to Woodside within 12-hours of receiving the SMS/email alert. Both parts of the assessment are required to determine if an exceedance of a management trigger has occurred.

If the measured seabed light and turbidity data does not exceed the combined effects of turbidity and seabed light over a defined time period, then no management trigger was exceeded and water quality monitoring continued.

An O2 Marine scientist manually assessed the data daily to verify the functionality of the loggers, data quality and confirm that no management triggers have been exceeded via the online web portal dashboard.

Table 3: Management trigger levels

Trigger	Ecological Zone	Averaging Period (days)	Turbidity (NTU)	DLI (mol/day)
Tier 1	A	1	>16.07	<1.2
		4	>14	<1.5
		8	>12.57	<1.7
	B	1	>10.5	<1.8
		4	>9.36	<2.2
		8	>8.36	<2.5
	Offshore	22	>11.25	<0.9
Tier 2	A	1	>20.79	<0.7
		5	>16.07	<1.2
		8	>14	<1.5
		12	>12.57	<1.7
	B	1	>13.86	<1.1
		5	>10.5	<1.8
		8	>9.36	<2.2
		12	>8.36	<2.5
	Offshore	26	>11.25	<0.9
Tier 3	A	3	>20.79	<0.7
		7	>16.07	<1.2
		10	>14	<1.5
		14	>12.57	<1.7
	B	3	>13.86	<1.1
		7	>10.5	<1.8
		10	>9.36	<2.2
		14	>8.36	<2.5
	Offshore	28	>11.25	<0.9

2.5. Remote Sensing

2.5.1. Data Collection

To provide a broader spatial resolution and to supplement the NRT monitoring of elevated turbidity, remote sensing data was obtained on a regular basis to capture the spatial extent of any visible surface suspended sediment plumes during dredging and disposal activities at the water quality monitoring sites.

Visible Infrared Imaging Radiometer Suite (VIIRS) sensor was the primary remote sensing platform for daily image capture at 750 m spatial resolution. During periods of high operational activity, VIIRS imagery was supplemented by higher resolution (albeit reduced frequency; 2–3 images weekly) imagery from the Sentinel-2 platform with a spatial resolution of 60 m which is ideal for resolving features in coastal waters. Imagery from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra satellite-based sensors with 250 m spatial resolution were also collected to further complement the remote sensing data.

2.5.2. Near Real Time Analysis

Broad and fine scale satellite NRT imagery from VIIRS transmitted the processed total suspended solids (TSS) and red/green/blue (RGB) data within 1–4 hours of overpass. Imagery and data were automatically uploaded daily (or when satellite sensor data was available) onto the O2 Marine Data Storage and Visualisation Platform and displayed as RGB and TSS scale images. An image snapshot was automatically emailed to an O2 Marine scientist.

There is no NRT data from Sentinel-2 with the latency less than 3 hours.

VIIRS, Sentinel-2 and MODIS images were interrogated to assess the dispersion of any sediment plumes around the area of dredging and disposal, where imagery and environmental conditions allow. Areas in the imagery with cloud cover or in shallow waters (<5 m) were removed from further analysis due to potential for signal contamination.

3. Results

3.1. Tiered Management Trigger Assessment Summary

There were no Tier 1, Tier 2 or Tier 3 trigger level exceedances recorded at any impact or influence monitoring site during trenching, spoil disposal, borrow ground dredging and backfill activities (Table 4). Although DLI was below the respective trigger levels during discrete periods at most monitoring sites, there was no breach of the respective turbidity trigger levels at any monitoring site. Given that DLI and turbidity data did not exceed the combined effects of turbidity and DLI over a defined time period, no management trigger was exceeded. Furthermore, there were no inferred exceedances (requiring attributability assessment) from data gaps there were generated through the QC process.

Results of the assessment of the water quality data against the management trigger level for each impact or influence monitoring site are presented in Appendix B.

Table 4: Summary of management trigger assessment for turbidity and seabed DLI at each impact or influence monitoring site

Site ID	Dredge Plume Modelling Classification		Tiered Monitoring and Management Framework					Report Section
	Trenching and Spoil Disposal	Borrow Ground Dredging and Backfill	Trigger Level	Averaging Period (days)	Turbidity (NTU)	DLI (mol/d)	Combined Trigger Assessment	
Ecological Zone A								
KGBY	Influence	Informative	Tier 1	1	>16.07	<1.2	OK	Section 3.3.1.2
				4	>14	<1.5	OK	
				8	>12.57	<1.7	OK	
			Tier 2	1	>20.79	<0.7	OK	
				5	>16.07	<1.2	OK	
				8	>14	<1.5	OK	
				12	>12.57	<1.7	OK	
			Tier 3	3	>20.79	<0.7	OK	
				7	>16.07	<1.2	OK	
				10	>14	<1.5	OK	
				14	>12.57	<1.7	OK	
SUP2	Influence	Informative	Tier 1	1	>16.07	<1.2	OK	Section 3.3.1.5
				4	>14	<1.5	OK	
				8	>12.57	<1.7	OK	
			Tier 2	1	>20.79	<0.7	OK	
				5	>16.07	<1.2	OK	
				8	>14	<1.5	OK	
				12	>12.57	<1.7	OK	
			Tier 3	3	>20.79	<0.7	OK	
				7	>16.07	<1.2	OK	
				10	>14	<1.5	OK	
				14	>12.57	<1.7	OK	

Site ID	Dredge Plume Modelling Classification: Trenching and Spoil Disposal	Dredge Plume Modelling Classification: Borrow Ground Dredging and Backfill	Tiered Monitoring and Management Framework: Trigger Level	Averaging Period (days)	Turbidity (NTU)	DLI (mol/d)	Combined Trigger Assessment	Report Section
SWIT	Influence	Informative	Tier 1	1	>16.07	<1.2	OK	Section 3.3.1.6
				4	>14	<1.5	OK	
				8	>12.57	<1.7	OK	
			Tier 2	1	>20.79	<0.7	OK	
				5	>16.07	<1.2	OK	
				8	>14	<1.5	OK	
				12	>12.57	<1.7	OK	
			Tier 3	3	>20.79	<0.7	OK	
				7	>16.07	<1.2	OK	
				10	>14	<1.5	OK	
				14	>12.57	<1.7	OK	
Ecological Zone B								
ANG2	Impact	Informative	Tier 1	1	>10.5	<1.8	OK	Section 3.3.2.2
				4	>9.36	<2.2	OK	
				8	>8.36	<2.5	OK	
			Tier 2	1	>13.86	<1.1	OK	
				5	>10.5	<1.8	OK	
				8	>9.36	<2.2	OK	
				12	>8.36	<2.5	OK	
			Tier 3	3	>13.86	<1.1	OK	
				7	>10.5	<1.8	OK	
				10	>9.36	<2.2	OK	
				14	>8.36	<2.5	OK	
COBN	Impact	Informative	Tier 1	1	>10.5	<1.8	OK	Section 3.3.2.3
				4	>9.36	<2.2	OK	
				8	>8.36	<2.5	OK	
			Tier 2	1	>13.86	<1.1	OK	
				5	>10.5	<1.8	OK	
				8	>9.36	<2.2	OK	
				12	>8.36	<2.5	OK	
			Tier 3	3	>13.86	<1.1	OK	
				7	>10.5	<1.8	OK	
				10	>9.36	<2.2	OK	
				14	>8.36	<2.5	OK	
CONI	Impact	Informative	Tier 1	1	>10.5	<1.8	OK	Section 3.3.2.4
				4	>9.36	<2.2	OK	
				8	>8.36	<2.5	OK	
			Tier 2	1	>13.86	<1.1	OK	

Site ID	Dredge Plume Modelling Classification: Trenching and Spoil Disposal	Dredge Plume Modelling Classification: Borrow Ground Dredging and Backfill	Tiered Monitoring and Management Framework: Trigger Level	Averaging Period (days)	Turbidity (NTU)	DLI (mol/d)	Combined Trigger Assessment	Report Section
				5	>10.5	<1.8	OK	
				8	>9.36	<2.2	OK	
				12	>8.36	<2.5	OK	
			Tier 3	3	>13.86	<1.1	OK	
				7	>10.5	<1.8	OK	
				10	>9.36	<2.2	OK	
				14	>8.36	<2.5	OK	
CONI2	Influence	Informative	Tier 1	1	>10.5	<1.8	OK	Section 3.3.2.5
				4	>9.36	<2.2	OK	
				8	>8.36	<2.5	OK	
			Tier 2	1	>13.86	<1.1	OK	
				5	>10.5	<1.8	OK	
				8	>9.36	<2.2	OK	
				12	>8.36	<2.5	OK	
			Tier 3	3	>13.86	<1.1	OK	
				7	>10.5	<1.8	OK	
				10	>9.36	<2.2	OK	
				14	>8.36	<2.5	OK	
HAUY	Informative	Influence	Tier 1	1	>10.5	<1.8	OK	Section 3.3.2.10
				4	>9.36	<2.2	OK	
				8	>8.36	<2.5	OK	
			Tier 2	1	>13.86	<1.1	OK	
				5	>10.5	<1.8	OK	
				8	>9.36	<2.2	OK	
				12	>8.36	<2.5	OK	
			Tier 3	3	>13.86	<1.1	OK	
				7	>10.5	<1.8	OK	
				10	>9.36	<2.2	OK	
				14	>8.36	<2.5	OK	
Offshore Zone								
MPB	Informative	Influence	Tier 1	22	>11.25	<0.9	OK	Section 3.3.3.2
			Tier 2	26	>11.25	<0.9	OK	
			Tier 3	28	>11.25	<0.9	OK	

	Turbidity or Seabed DLI Threshold Not Breached OR Management Trigger not Exceeded
	Turbidity or Seabed DLI Threshold Breached
	Management Trigger Exceeded

3.2. Environmental Conditions

3.2.1. Rainfall

Daily rainfall for the water quality monitoring period (5 May 2023–1 March 2024) was retrieved from the Bureau of Meteorology (BOM, 2024a) for Karratha Aero (station number: 004083) (Figure 7). There was one rainfall event greater than 5 mm that occurred on 20 June 2023 (70.4 mm) which coincided with a low-pressure system off the coast of the North West Shelf. In comparison, very little rain was recorded on 2, 10 and 23 February 2024 (1.2, 0.8 and 0.6 mm, respectively).

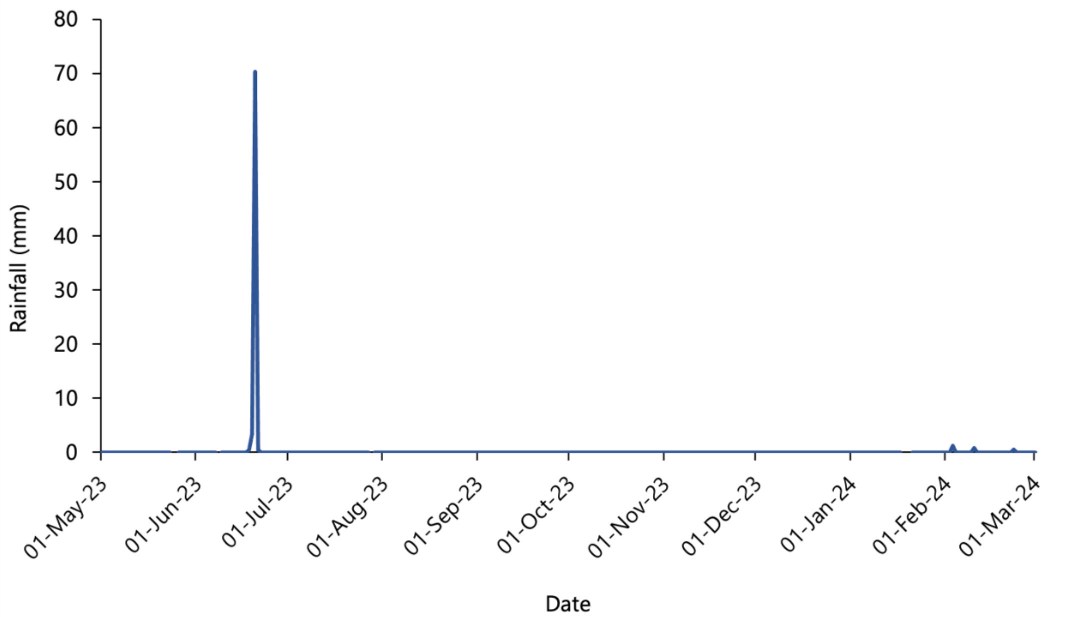


Figure 7: Daily rainfall for Karratha airport (www.bom.gov.au)

3.2.2. Wind, Waves and Tides

Specific wind, wave and tide data were not available for each site. Instead, data were obtained from the Pilbara Ports Authority (PPA) HydroTel web portal. The available data from HydroTel was taken from two locations that best represent each ecological zone:

Zone A:

- Wind, wave and tide: Dampier Port BN09 Meteorological dataset (116.7390328 E, 20.60802194 S)

Zone B and Offshore:

- Wind and tide: Dampier Port BN09 Meteorological dataset (116.7390328 E, 20.60802194 S)
- Wave: Dampier Port WCB Wave Rider Buoy (WRB) dataset (116.7309617 E, 20.435805 S)

Seasonal wind and wave height (sea) roses and tide time-series for Dampier Port in austral winter (May to October 2023, inclusive) and summer (November 2023 to April 2024, inclusive) are provided in Figure 8 to Figure 11. Light winds (ranging from 0–12 m/s) from the north-north east to east-north east were predominant in the winter, whereas the summer period experienced slightly stronger winds (5–>12 m/s) primarily from the west-south west (Figure 8). North-westerly to northly seas ranged from 0–0.5 m in height during winter, while west-south-westerly seas ranging from 0–1 m were predominant in the summer (Figure 9). The tidal range in Dampier Port was approximately 4.8 m (Figure 10). The wave roses recorded at Dampier Port WCB WRB showed that wave heights largely stayed below the 1.5 m mark and generally increase in summer and decrease in winter (Figure 11).

Wind speed and direction, wave direction and significant wave height, and tide data are presented in each of the site summaries for Zone A (Section 3.3.1), Zone B (Section 3.3.2) and offshore Zone (Section 3.3.3).

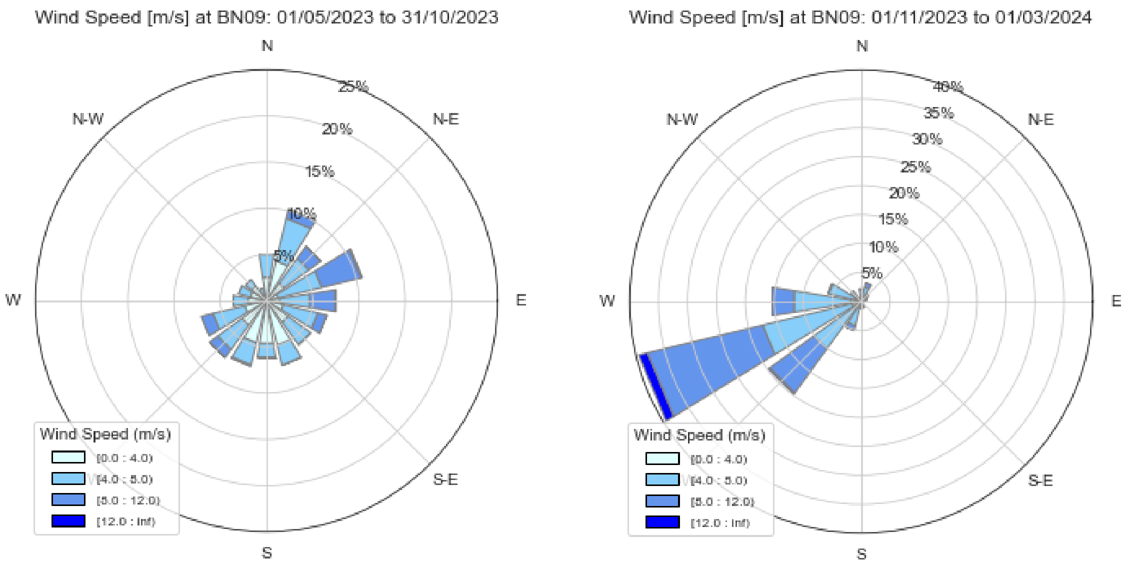


Figure 8: Seasonal wind roses (m/s) for Dampier Port BN09 for austral winter (1 May–31 October 2023; left image) and summer (1 November 2023–1 March 2024; right image)

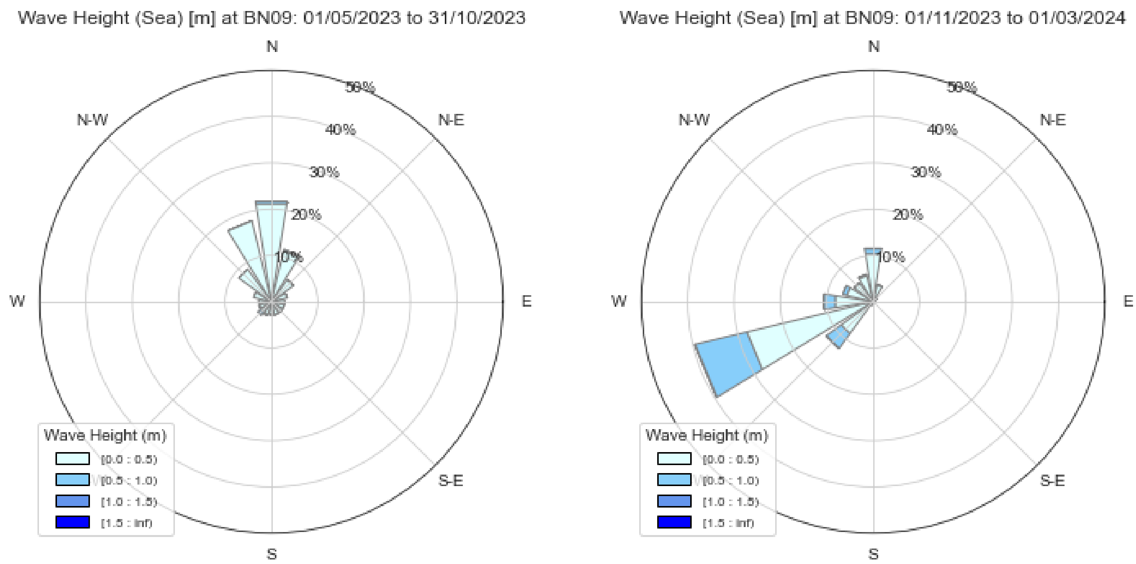


Figure 9: Seasonal wave height (sea) roses (m) for Dampier Port BN09 for austral winter (1 May–31 October 2023; left image) and summer (1 November 2023–1 March 2024; right image)

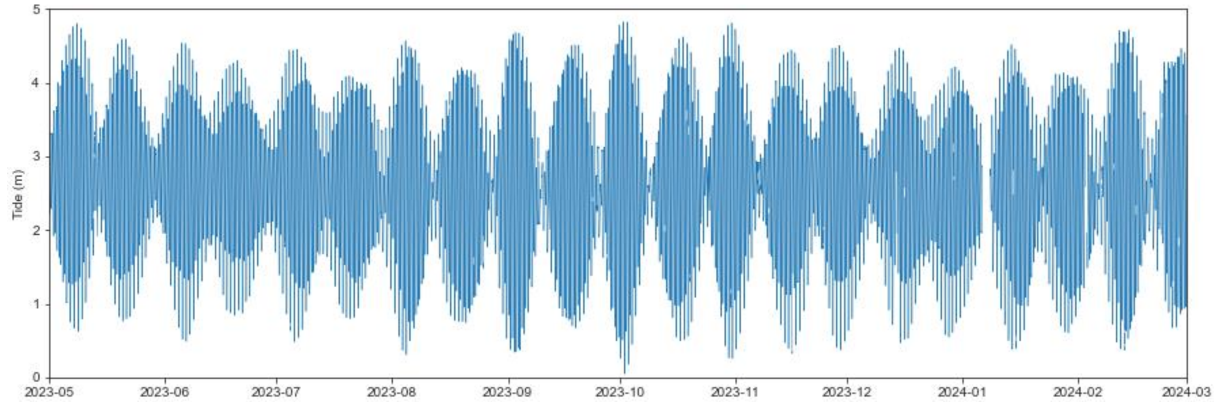


Figure 10: Tides (m) for Dampier Port BN09 for 1 May 2023 to 1 March 2024

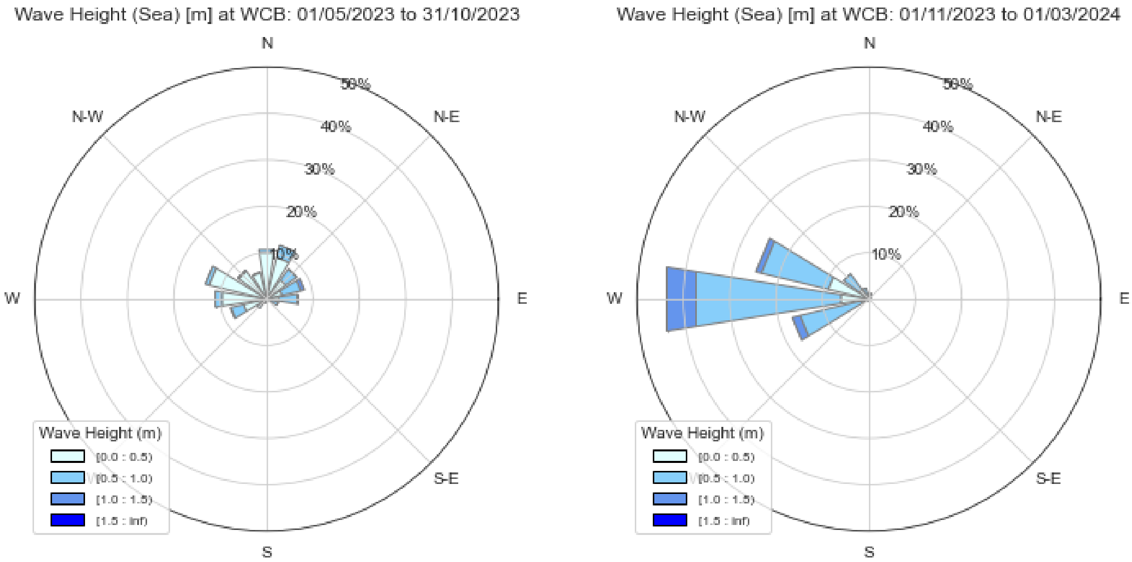


Figure 11: Seasonal wave height (sea) roses (m) for Dampier Port WCB for austral winter (1 May–31 October 2023; left image) and summer (1 November 2023–1 March 2024; right image)

3.2.3. Tropical Cyclones

One long-lasting tropical cyclone was recorded during the monitoring period (Figure 12). Tropical cyclone Lincoln formed in the southern Gulf of Carpentaria coast on 16 February 2024 where it briefly reached tropical cyclone intensity. It then moved west over northern Australia as a tropical low and emerged into waters off the Kimberley coast on 21 February 2024 before turning south to cross the Gascoyne coast and weakening overland on 25 February 2024 (BoM, 2024b). It remained as a tropical low as it crossed approximately 300 km north of the water quality monitoring sites between the 22 and 23 February 2024. As it approached the monitoring sites, light north-easterly to south-easterly winds (<10 knots), low sea waves and swell (<1 m, respectively), and little to no rainfall was recorded (see Section 3.2.1).

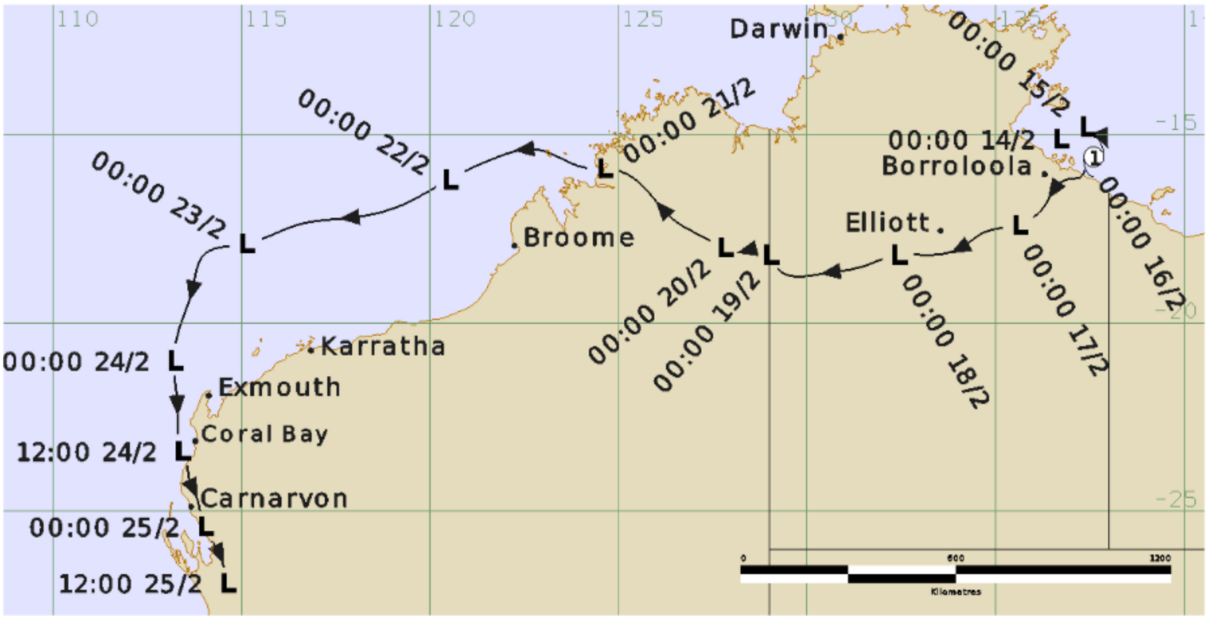


Figure 12: Track and intensity of tropical cyclone Lincoln between 16–25 February 2024 (www.bom.gov.au)

3.2.4. Background Ambient Light

The terrestrial light logger recorded seasonal trends in ambient light and air temperature. Slightly lower DLI (mean: 42 mol/m^2/day) and cooler temperatures (27°C) were recorded during winter compared to summer (52 mol/m^2/day and 33°C, respectively). Drops in ambient light and air temperature were caused by cloud cover and low-pressure systems. The logger malfunctioned during trenching and spoil disposal activities and all data during this period did not pass QC assessment. QC'd data collected for ambient light and air temperature are presented in Appendix C.

3.3. Water Quality

Turbidity, seabed DLI and water temperature data are presented as summary statistics for each monitoring site grouped by ecological zones (A, B and Offshore) and austral seasons (winter and summer). Data summaries for each monitoring site are also grouped by ecological zones and presented below[2].

QC'd data collected for PAR, water depth and turbidity from both the turbidity logger (NTU-LPT) and multispectral light logger (MS9-LPT) at each monitoring site are presented in Appendix C.

3.3.1. Ecological Zone A

3.3.1.1. Summary Statistics

Summary of data collected for each site (KGBY, MIDI, NWIT, SUP2 and SWIT) in Zone A for turbidity (Table 5), seabed light (Table 6) and water temperature (Table 7) are presented below.

Turbidity

Seasonal trends in turbidity were evident in all sites within Zone A, where mean turbidity was lower in winter (mean range; 1.60–2.74 NTU) compared to summer (2.23–3.63 NTU; Table 5). High turbidity in the summer months likely corresponds with periods of greater wind and wave activity and possible sedimentary inputs from increased terrestrial runoff and/or extreme weather events, leading to a resuspension of sediments.

Table 5: Ecological Zone A summary statistics for turbidity (NTU): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
KGBY	Influence	Trunkline trenching	Winter	2.74	2.42	3.53	5.22	1.27	16595
	Informative	Borrow ground dredging	Summer	3.63	3.22	4.85	6.88	1.82	11427
MIDI	Reference	Trunkline trenching	Winter	1.60	1.32	2.15	3.38	1.08	16518
	Reference	Borrow ground dredging	Summer	3.48	2.70	4.54	8.46	2.88	11536
NWIT	Reference	Trunkline trenching	Winter	1.84	1.67	2.39	3.48	0.84	16536
	Reference	Borrow ground dredging	Summer	2.66	2.23	3.50	5.62	1.99	11605
SUP2	Influence	Trunkline trenching	Winter	2.70	2.41	3.52	5.04	1.34	16624
	Informative	Borrow ground dredging	Summer	3.59	3.29	4.69	6.46	1.62	11443
SWIT	Influence	Trunkline trenching	Winter	1.61	1.39	2.11	3.26	1.61	16599
	Informative	Borrow ground dredging	Summer	2.23	2.06	2.90	3.99	2.23	11626

[2] To simplify the naming convention, the second dredging and disposal period (as seen in all site summary figures: Figure 13 to Figure 31, and in Appendix B and Appendix C) has been labelled as 'Borrow Ground Dredging' however, it represents seabed disturbances from trenching along the trunkline route in Commonwealth waters as well as offshore borrow ground dredging and backfill activities along the trunkline route.

Seabed Light

All sites in Zone A, except for MIDI, recorded a higher mean seabed DLI in winter than in summer (Table 6). The highest DLI across both seasons was recorded at site MIDI, with a higher mean seabed DLI in summer (7.20 mol/m^2/day) compared to winter (6.40 mol/m^2/day). Site MIDI is located in shallow waters (2.5 m LAT) compared to the remaining sites in Zone A (ranging from 5.8–6.7 m), which is likely to play an important role in mean light levels received at the seabed. Sites KGBY and SUP2 recorded similar ranges in mean DLI for both seasons (1.51–2.53 mol/m^2/day and 1.53–2.29 mol/m^2/day, respectively).

Table 6: Ecological Zone A summary statistics for seabed DLI (mol/m²/day): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Site Depth (m LAT)	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Days*
KGBY	Influence	Trunkline trenching	6.7	Winter	2.57	2.07	3.63	6.30	1.62	177
	Informative	Borrow ground dredging		Summer	1.53	1.38	2.08	3.34	0.90	117
MIDI	Reference	Trunkline trenching	2.5	Winter	6.47	6.50	8.10	9.08	1.90	176
	Reference	Borrow ground dredging		Summer	7.20	7.36	9.20	12.30	2.96	94
NWIT	Reference	Trunkline trenching	6.6	Winter	3.45	3.33	4.44	5.83	1.38	176
	Reference	Borrow ground dredging		Summer	3.26	2.96	4.34	6.48	1.46	119
SUP2	Influence	Trunkline trenching	6.1	Winter	2.31	2.04	3.10	5.25	1.43	177
	Informative	Borrow ground dredging		Summer	1.55	1.33	2.24	3.53	1.05	117
SWIT	Influence	Trunkline trenching	5.8	Winter	4.77	4.84	5.96	7.96	1.84	177
	Informative	Borrow ground dredging		Summer	4.51	4.26	6.01	7.60	1.68	119

** Number of days is presented instead of number of data points, as DLI only has one daily representative data point.*

Water Temperature

Water temperatures across all sites were relatively lower in winter (mean range: 23.28–23.45°C) compared to summer (28.65–28.86°C), which is primarily driven by season. Seasonal temperatures were relatively consistent between sites in Zone A (Table 7).

Table 7: Ecological Zone A summary statistics for temperature (°C): May 2023 to February 2024 (inclusive)[3]

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
KGBY	Influence	Trunkline trenching	Winter	23.29	22.60	25.93	28.33	2.66	16627
	Informative	Borrow ground dredging	Summer	28.65	28.48	29.91	31.01	1.36	11473
MIDI	Reference	Trunkline trenching	Winter	23.28	22.59	26.02	28.44	2.75	16518
	Reference	Borrow ground dredging	Summer	28.70	28.65	30.16	31.21	1.51	11536
NWIT	Reference	Trunkline trenching	Winter	23.45	23.00	25.96	28.21	2.51	16551
	Reference	Borrow ground dredging	Summer	28.81	28.67	30.00	30.96	1.25	11630
SUP2	Influence	Trunkline trenching	Winter	23.41	22.77	25.95	28.29	2.59	16634
	Informative	Borrow ground dredging	Summer	28.72	28.58	29.93	31.12	1.37	11466
SWIT	Influence	Trunkline trenching	Winter	23.45	22.96	25.99	28.26	2.59	16634
	Informative	Borrow ground dredging	Summer	28.86	28.70	30.11	31.18	1.32	11644

[3] Statistics are provided for the IMO NTU-LPT measured statistics, as the IMO MS9-LPT logger is programmed to turn off between 20:30 and 03:30.

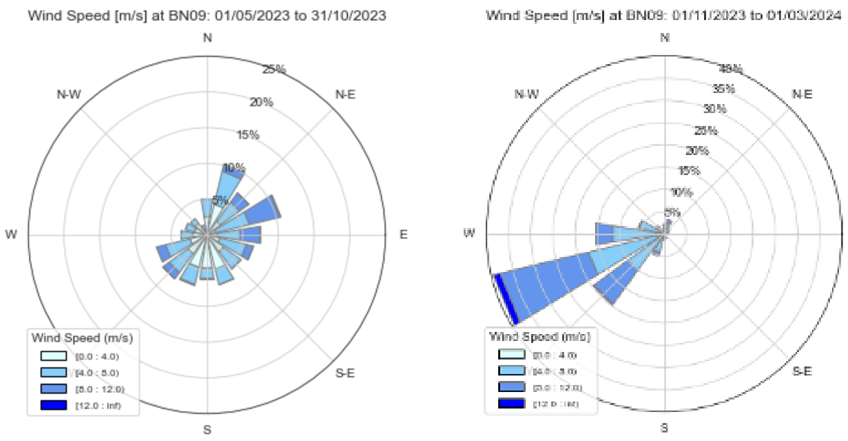
3.3.1.2. KGBY

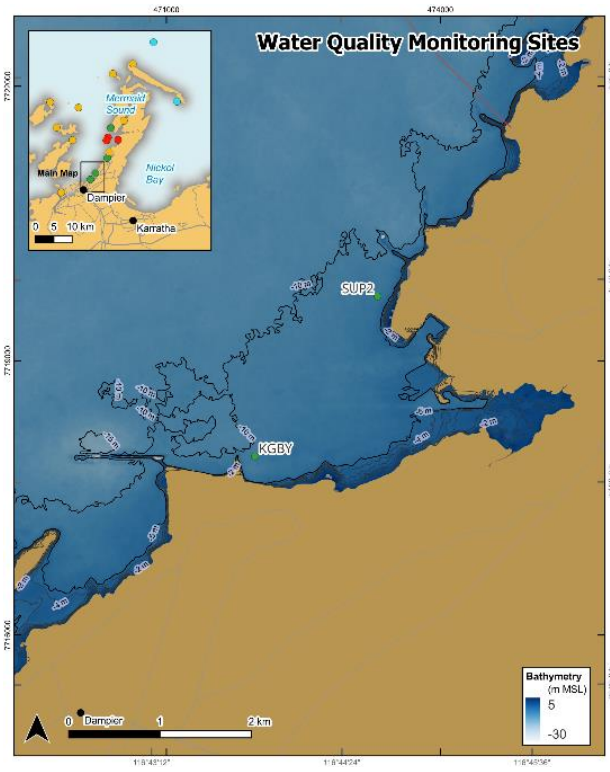
A summary of monitoring data recorded for KGBY is provided in Figure 13 and Section 3.3.1.1.

KGBY is located on the south side of King Bay Supply Base in the Port of Dampier, at a water depth of ~6.7 m LAT. The site is generally protected during easterly conditions in winter, however, is exposed during westerly winds and swell in summer. The sediments are predominantly fine grain sand, silt and clay (WorleyParsons, 2009). Natural turbidity at the site can be exacerbated by tidal flushing through King Bay, daily vessel traffic via berthing activities, propellor wash and movement in shipping channels, and surface run off or airborne dust from the adjacent iron ore facility (Woodside, 2006; WorleyParsons, 2009).

Slightly stronger wind and wave conditions from the west were experienced in the summer months that generally resulted in lower seabed DLI (ranging from 0.2–4.9 mol/m^2/day) and slightly higher daily average turbidity (1.9–8.7 NTU) compared to winter (DLI: 1.2–8.7 mol/m^2/day, turbidity: 1.2–5.6 NTU), which is likely due to its position in Mermaid Sound. Further, a short-term peak in turbidity (8.7 NTU) and drop in seabed DLI (0.4 mol/m^2/day) was apparent during the passing of tropical cyclone Lincoln, which brought easterly winds and waves. At the start of the monitoring program (May 2023), daily average water temperatures were approximately 26°C and gradually decreased with time to approximately 18°C in August 2023 before gradually increasing in the summer months, reaching a maximum of 32°C in late-February 2024.

Site	KGBY
Ecological Zone	A
Site Classification	Influence (Trenching and Spoil Disposal) Informative (Borrow Ground Dredging)
Site Depth	6.7 m LAT
Location Coordinates	471969 E, 7717955 N





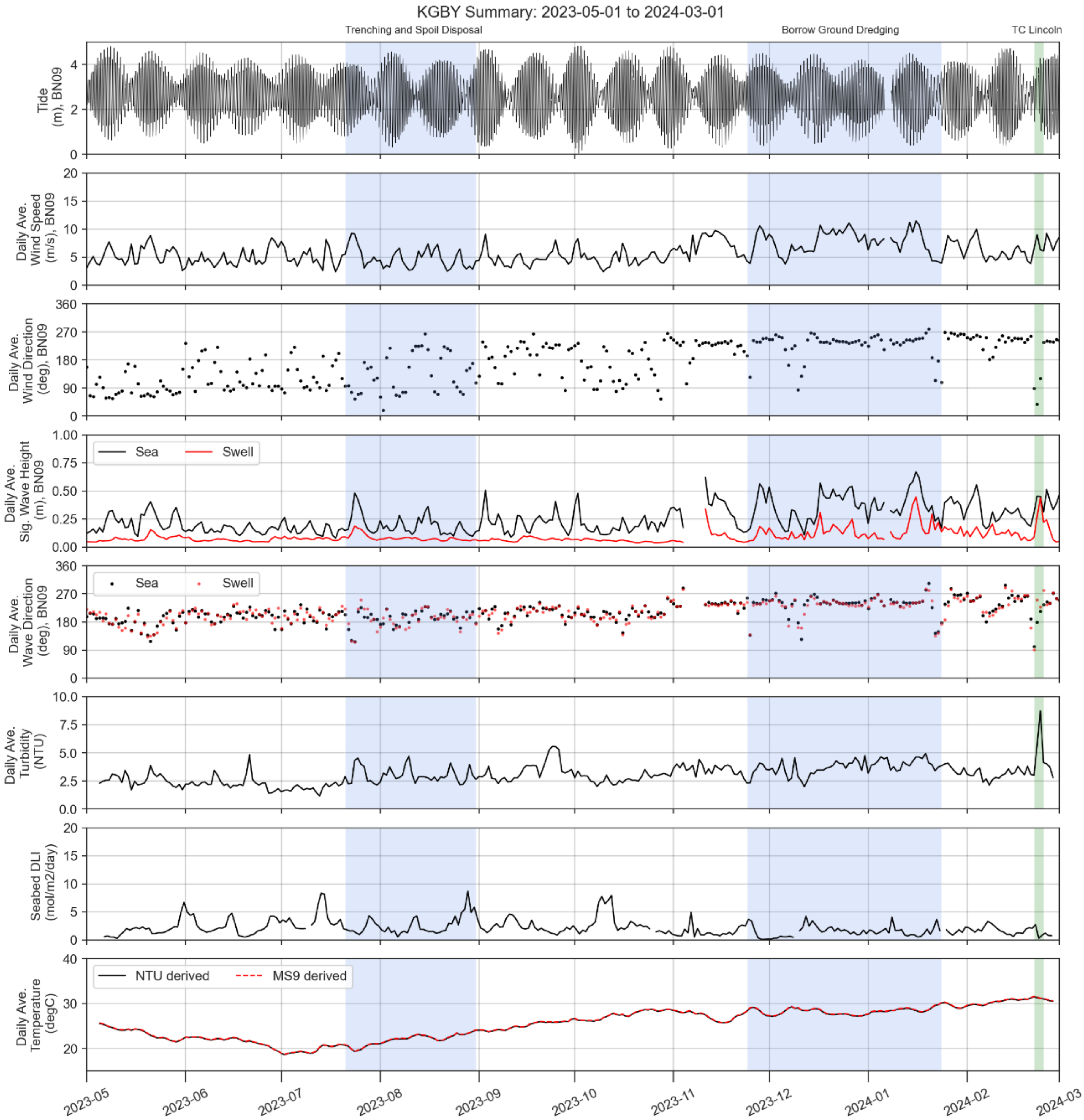


Figure 13: KGBY site summary

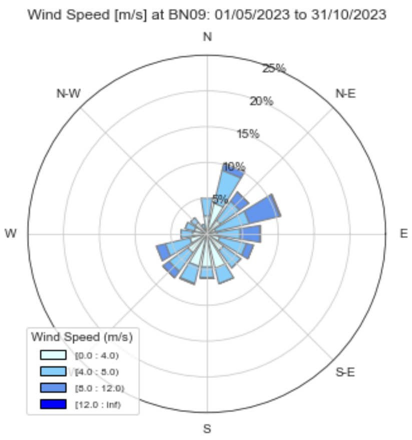
3.3.1.3. MIDI

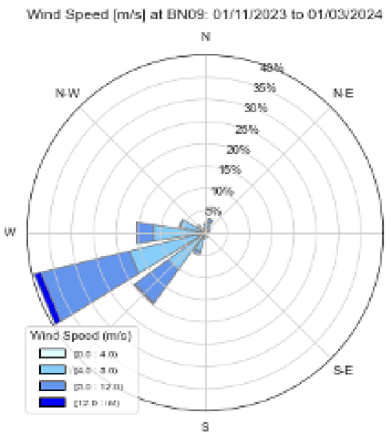
A summary of monitoring data recorded for MIDI is provided in Figure 14 and Section 3.3.1.1.

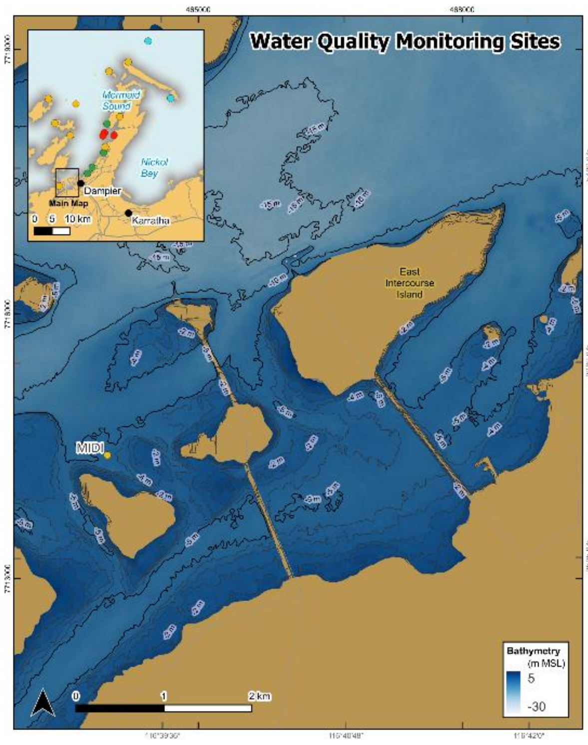
MIDI is the shallowest monitoring site (2.5 m LAT) in Zone A. The site is located on the northern side of West Mid Intercourse Island adjacent to sandy shorelines and is sheltered by surrounding islands and infrastructure. MIDI is generally exposed only during westerly winds and easterly wave conditions. Water movement through the site and surrounding islands is influenced by bridges and causeways connecting East Intercourse Island and East Mid Intercourse Island to mainland and utilised for Rio Tinto iron ore and Dampier Salt export facilities, respectively.

Seabed DLI was relatively consistent throughout the year, ranging from 1.0 to 16.8 mol/m^2/day. The daily average turbidity (ranging from 0.5–5.6 NTU) was relatively lower in the winter months between May and November 2023, whereas peaks in turbidity (up to 9.5 NTU) and associated drops in DLI were observed in summer between November 2023 and February 2024. The relatively higher turbidity in summer compared to winter are likely a result of stronger prevailing west-south-westerly winds and increased significant wave height. Daily average water temperatures at MIDI were identical to site KGBY, with temperatures reaching a minimum of 18°C in August 2023 and gradually increased in the summer months, reaching a maximum of 32°C in late-February 2024.

Site	MIDI
Ecological Zone	A
Site Classification	Reference (Trenching and Spoil Disposal)
	Reference (Borrow Ground Dredging)
Site Depth	2.5 m LAT
Location Coordinates	463966 E, 7714400 N







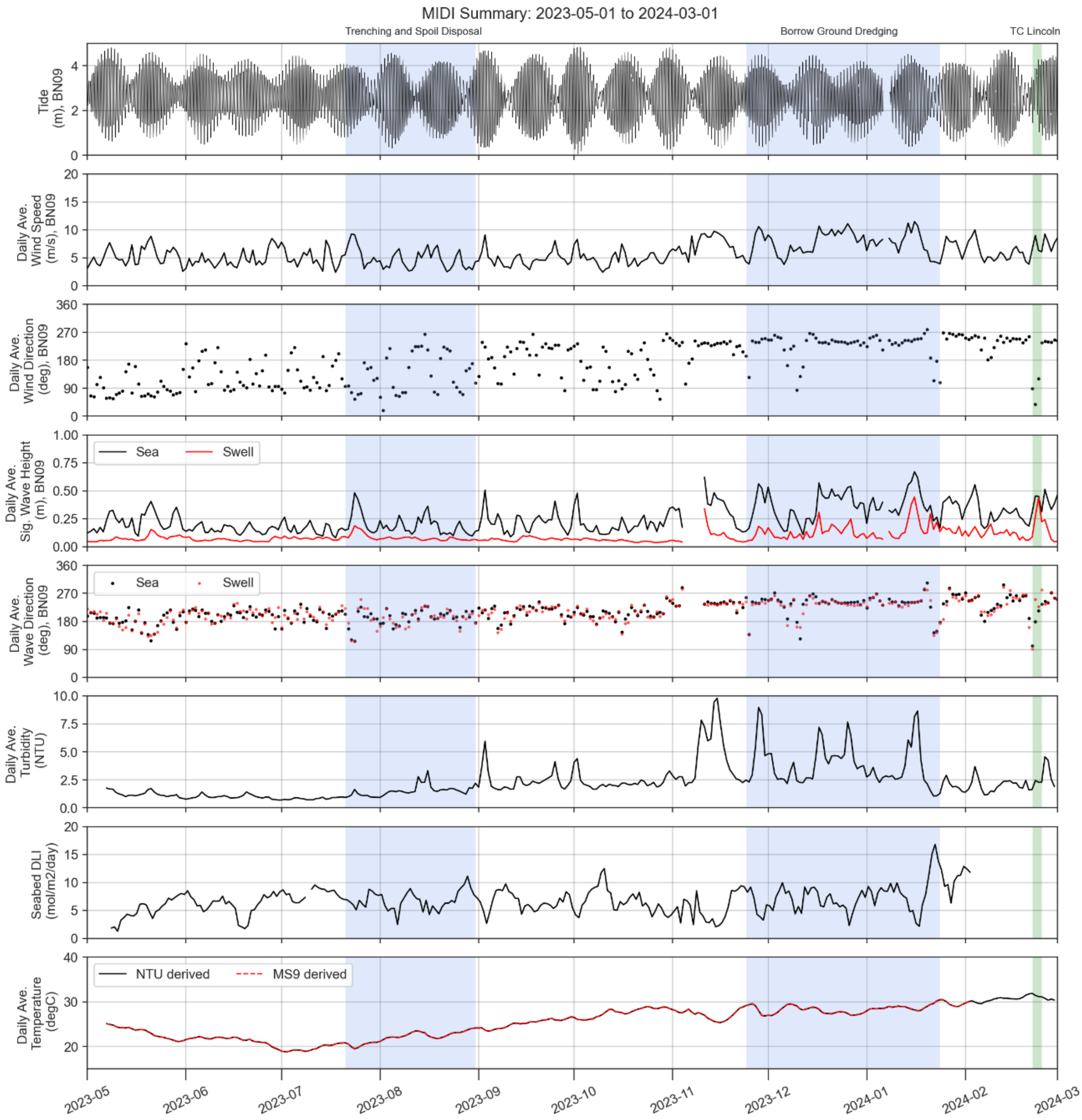


Figure 14: MIDI site summary

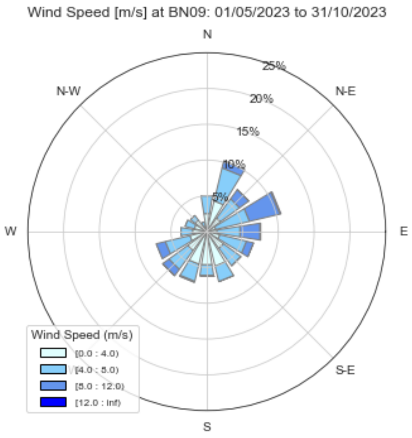
3.3.1.4. NWIT

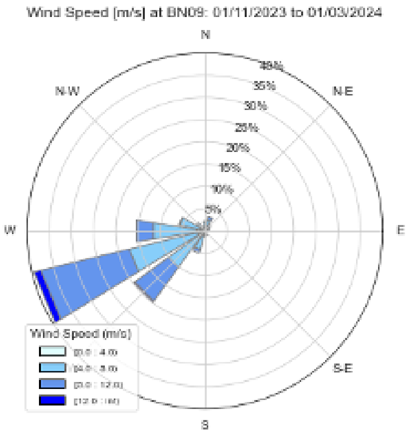
A summary of monitoring data recorded for NWIT is provided in Figure 15 and Section 3.3.1.1.

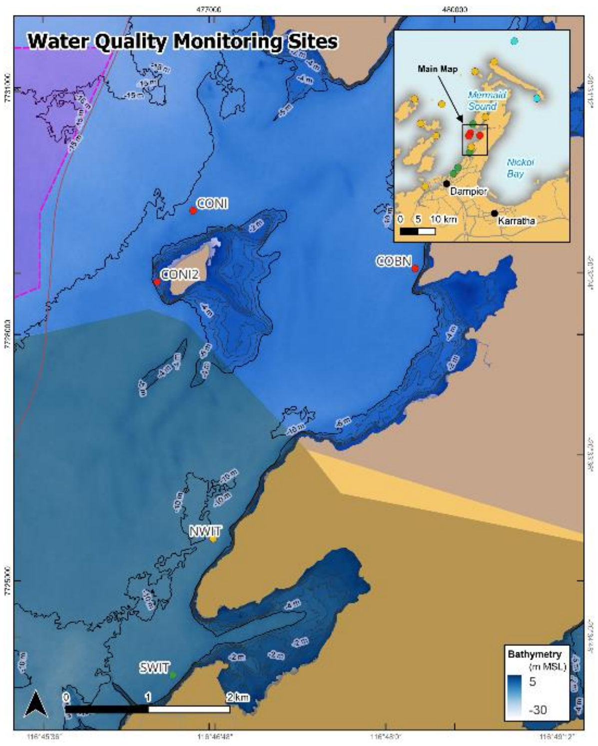
NWIT is located adjacent to rocky shorelines on the northern side of the entrance to Withnell Bay in 6.6 m LAT. Natural turbidity is influenced by tidal flushing of Withnell Bay, and, to a lesser degree, commercial vessel traffic and berthing activities at the nearby Karratha Gas Plant (~2 km south) (Woodside, 2006). The site is exposed in most conditions, with the exception of wind and swell from the east to south east. Tidal flow through Mermaid Sound and Flying Foam Passage (a north-south passage between Angel Island and Dolphin Island) may also contribute to water movement at the site (Pearce et al., 2003).

Daily average turbidity was relatively consistent over the entire monitoring period, with three significant spikes identified in summer (mid-November 2023: 5.2 NTU, late December 2023: 8.0 NTU, and early-January 2024: 8.7 NTU). These spikes in turbidity appear to correlate with the prevailing south-westerly winds and daily average significant wave events. Conversely, seabed DLI was more variable and comparable between seasons, ranging between 0–7.7 mol/m^2/day. At the start of the monitoring program (May 2023), daily average water temperatures were approximately 26°C and gradually decreased with time to approximately 19°C in August 2023 before gradually increasing in the summer months, reaching a maximum of 31°C in late-February 2024.

Site	NWIT
Ecological Zone	A
Site Classification	Reference (Trenching and Spoil Disposal)
	Reference (Borrow Ground Dredging)
Site Depth	6.6 m LAT
Location Coordinates	477052 E, 7725515 N







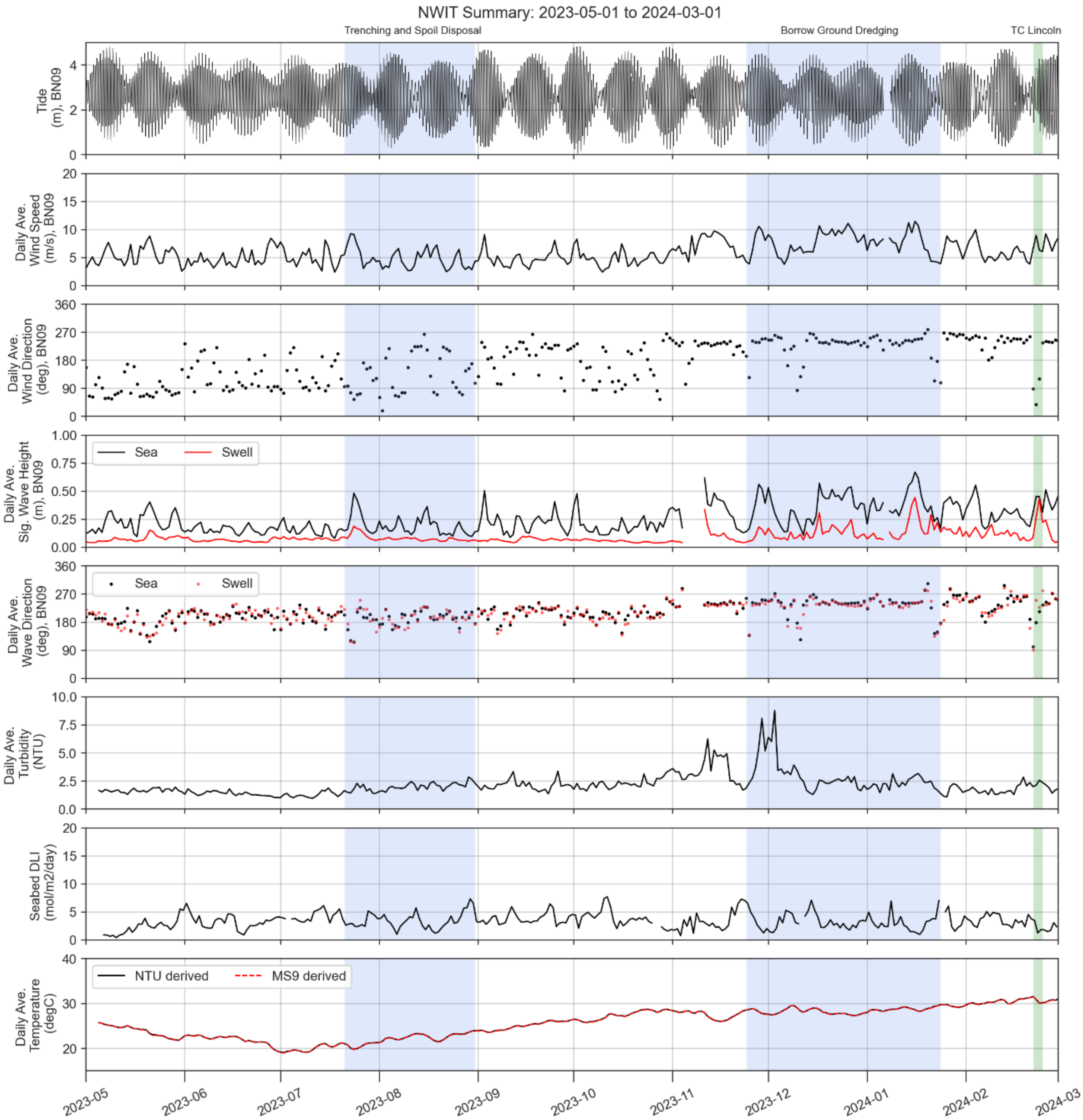


Figure 15: NWIT site summary

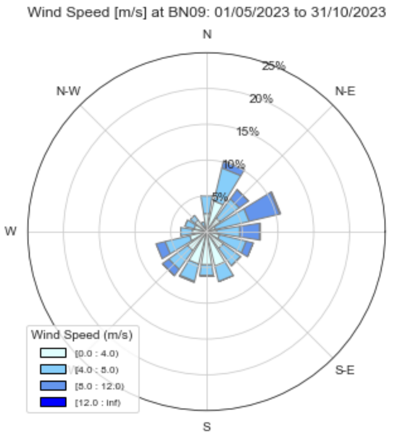
3.3.1.5. SUP2

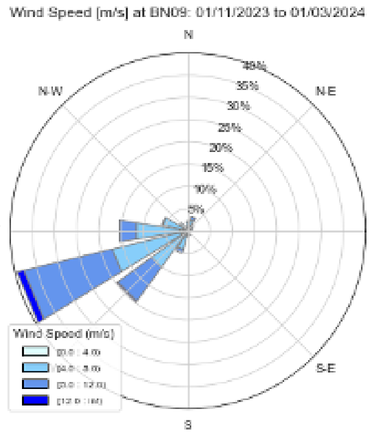
A summary of monitoring data recorded for SUP2 is provided in Figure 16 and Section 3.3.1.1.

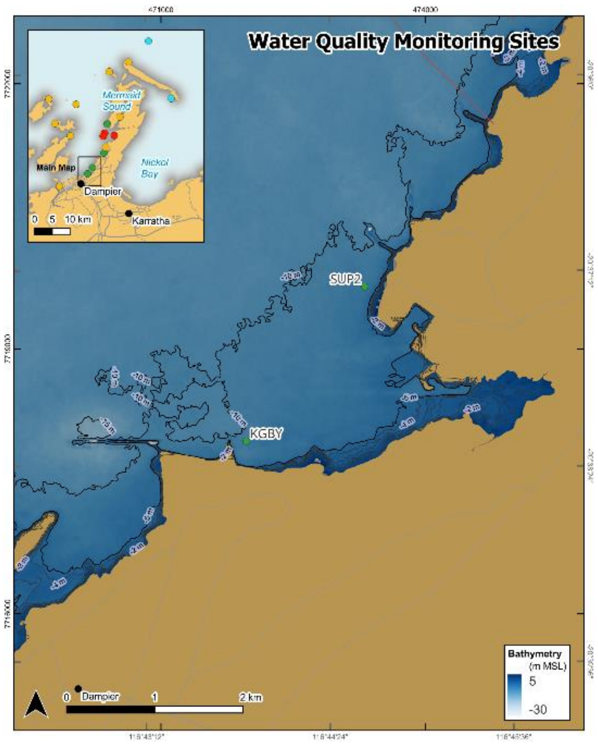
SUP2 is located on the north side of King Bay Supply Base, adjacent to the Dampier Cargo Wharf in 6.1 m LAT. The site is generally protected, particularly in easterly conditions and is exposed during south-westerly winds and swell. The sediments around the Dampier Cargo Wharf are predominantly fine grain sand, silt and clay (WorleyParsons, 2009). Natural turbidity at the site may be exacerbated by daily vessel traffic such as berthing activities, propellor wash and movement in shipping channels from commercial shipping, tugs and other commercial vessels.

Daily average turbidity was slightly lower in the first three months (May–mid-July 2023; ranging from 1.0–3.0 NTU) of the monitoring program compared to the remaining months (August 2023–March 2024; ranging from 1.7–5.6 NTU), which was likely attributed to lower easterly wind waves and swell. Seabed DLI remained relatively consistent throughout the monitoring program (ranging from 0.2–8.0 mol/m^2/day) and were comparable between seasons. Daily average water temperatures were considerably lower in the winter months, reaching a minimum of 19°C in August 2023, compared to the summer months (a maximum of approximately 31°C in late-February 2024).

Site	SUP2
Ecological Zone	A
Site Classification	Influence (Trenching and Spoil Disposal) Informative (Borrow Ground Dredging)
Site Depth	6.1 m LAT
Location Coordinates	473311 E, 7719704 N







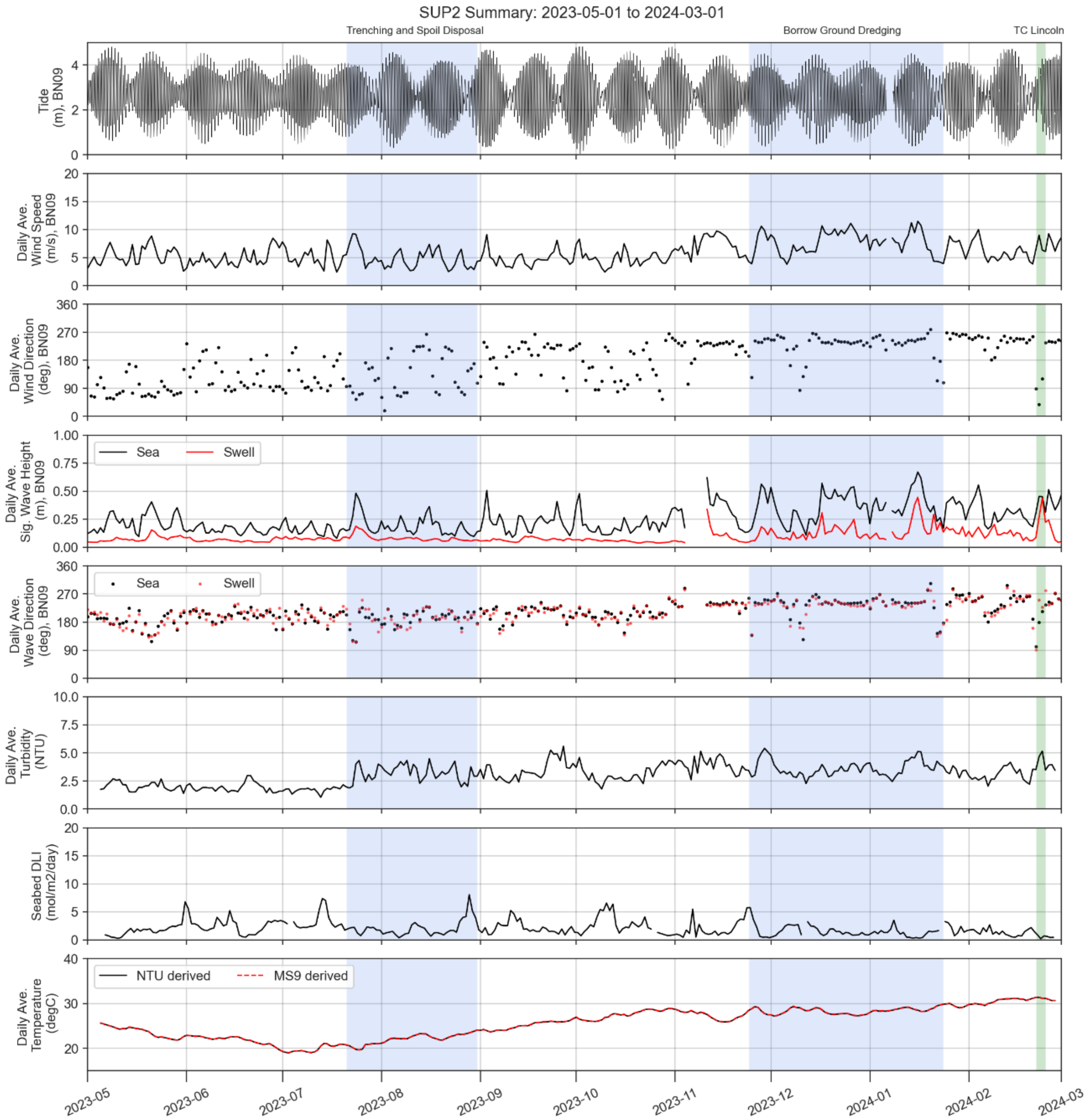


Figure 16: SUP2 site summary

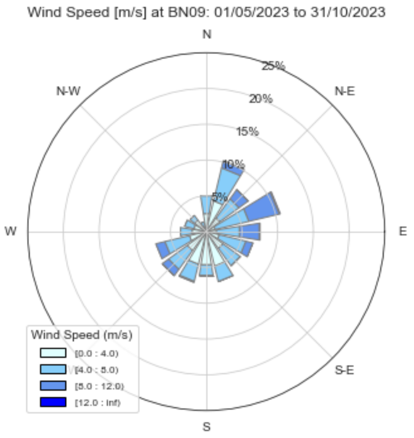
3.3.1.6. SWIT

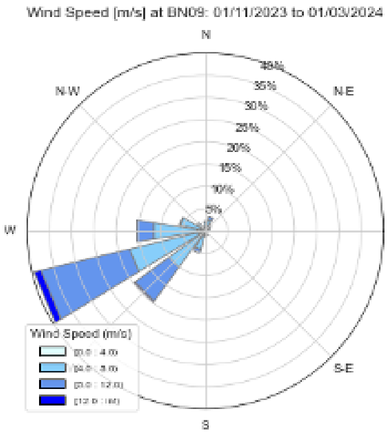
A summary of monitoring data recorded for SWIT is provided in Figure 17 and Section 3.3.1.1.

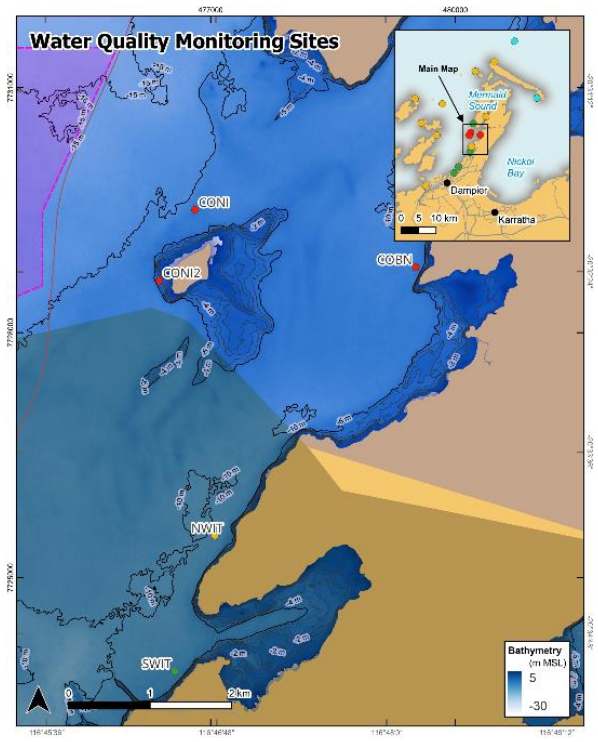
SWIT is located on the southern side of the Withnell Bay entrance, adjacent to the Karratha Gas Plant and situated between two gas export trunklines in ~5.8 m LAT. SWIT is primarily exposed to waves during westerly to north westerly winds and swell during winter. The site experiences tidal flushing from Withnell Bay, in addition to nearby vessel traffic from the adjacent LNG offtake jetty including from berthing activities.

Similarly to site SUP2, the first three months (May–mid-July 2023) of the monitoring program recorded slightly lower daily average turbidity (0.6–1.8 NTU) compared to the remaining months (August 2023–March 2024; 1.3–4.2 NTU). Given the sites' location, the lower turbidity levels during this period were likely attributed to lower easterly wind waves and swell. From August 2023 to March 2024, variable wind and wave conditions generally resulted in slightly higher but variable daily turbidity and lower and variable seabed DLI (0.1–11 mol/m^2/day). Following the same trend found in the other sites within Zone A, daily average water temperatures were approximately 26°C at the start of the monitoring program (May 2023), then gradually decreased during the winter months (approximately 19°C in August 2023) before gradually increasing in the summer months (approximately 31°C in late-February 2024).

Site	SWIT
Ecological Zone	A
Site Classification	Influence (Trenching and Spoil Disposal) Informative (Borrow Ground Dredging)
Site Depth	5.8 m LAT
Location Coordinates	476560 E, 7723855 N







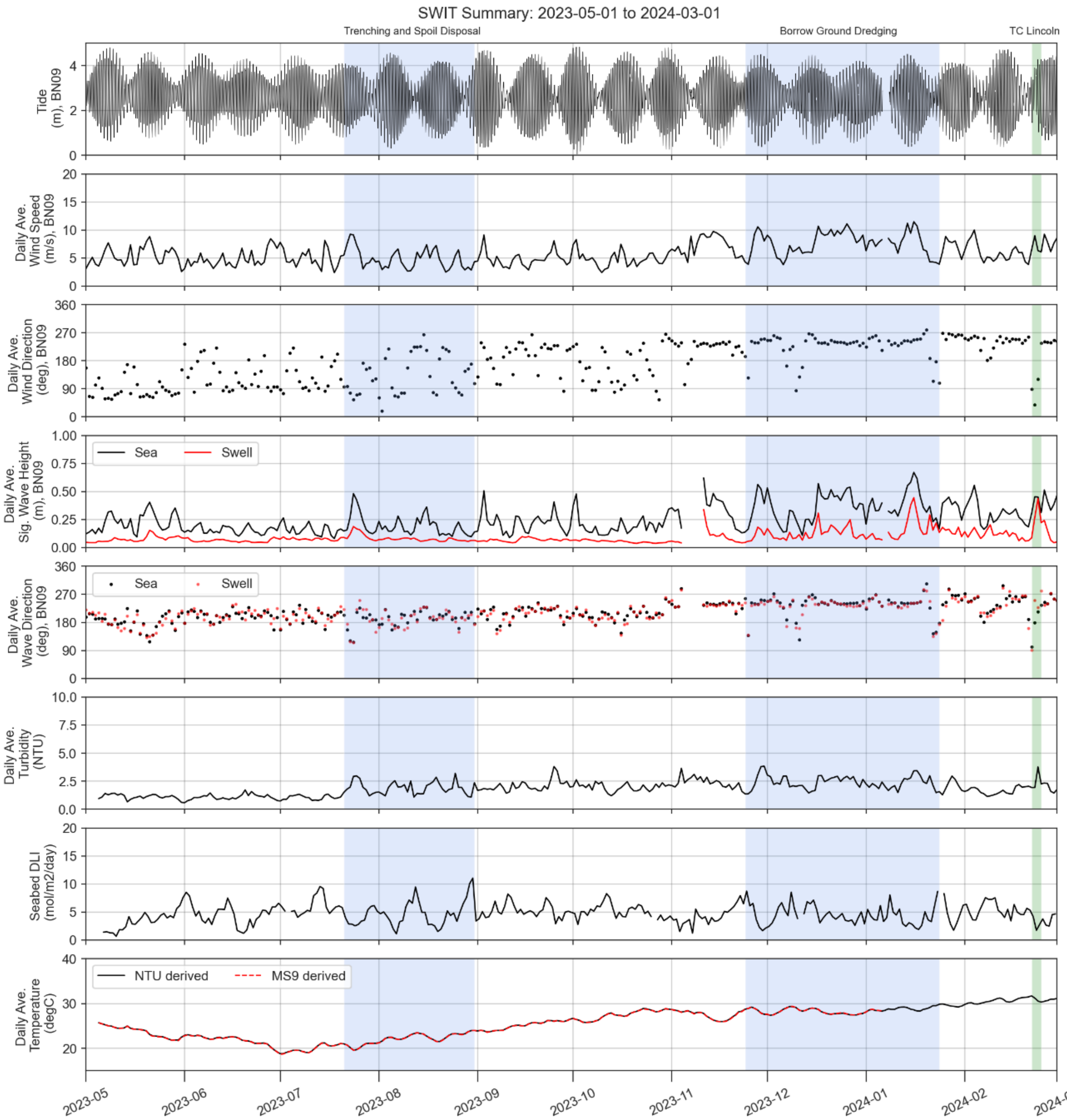


Figure 17: SWIT site summary

3.3.2. Ecological Zone B

3.3.2.1. Summary Statistics

Summary of turbidity (Table 8), seabed light (Table 9) and water temperature (Table 10) data collected for each site in Zone B are presented below.

Turbidity

Slight seasonal differences in turbidity were apparent at most sites in Zone B, where mean turbidity was marginally lower in winter (mean range; 0.38–2.06 NTU) than in summer (0.61–3.21 NTU) with the exception of FFP1, GIDI and HAUY (Table 8). At these three monitoring sites, turbidity remained relatively consistent between seasons, as these sites may experience increased current velocities during spring tides associated with the site-specific topography.

Table 8: Ecological Zone B summary statistics for turbidity (NTU): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
ANG2	Influence	Trunkline trenching	Winter	1.38	1.14	1.79	3.05	1.03	16569
	Informative	Borrow ground dredging	Summer	1.57	1.40	2.04	3.10	0.83	11425
COBN	Impact	Trunkline trenching	Winter	1.94	1.60	2.61	3.80	2.95	16512
	Informative	Borrow ground dredging	Summer	3.21	2.67	4.02	6.66	2.32	11533
CONI	Influence	Trunkline trenching	Winter	1.36	1.20	1.81	2.64	0.74	16582
	Informative	Borrow ground dredging	Summer	2.06	1.82	2.50	3.49	2.02	10793
CONI2	Impact	Trunkline trenching	Winter	1.26	1.12	1.64	2.35	0.66	16518
	Informative	Borrow ground dredging	Summer	1.53	1.43	1.91	2.63	0.68	11824
CRTS	Reference	Trunkline trenching	Winter	0.90	0.82	1.22	1.70	0.48	10732
	Reference	Borrow ground dredging	Summer	0.91	0.81	1.22	1.82	0.51	10396
FFP1	Reference	Trunkline trenching	Winter	1.61	1.26	2.24	3.70	1.47	16477
	Reference	Borrow ground dredging	Summer	1.55	1.36	2.18	3.03	0.80	9634
GIDI	Reference	Trunkline trenching	Winter	1.96	1.09	2.86	6.32	2.80	15520
	Reference	Borrow ground dredging	Summer	1.66	1.22	2.06	4.04	1.17	10904
HAM3	Reference	Trunkline trenching	Winter	0.47	0.30	0.61	1.14	2.13	11926
	Reference	Borrow ground dredging	Summer	0.68	0.58	0.96	1.60	0.50	11877
HAUY	Informative	Trunkline trenching	Winter	2.06	1.68	2.58	4.20	1.89	14324
	Influence	Borrow ground dredging	Summer	1.90	1.71	2.32	3.40	1.40	11494
HGPT	Reference	Trunkline trenching	Winter	1.40	1.25	1.78	2.57	2.14	16371
	Reference	Borrow ground dredging	Summer	1.90	1.73	2.48	3.63	0.90	11327

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
LANI	Reference	Trunkline trenching	Winter	0.73	0.50	0.85	1.90	0.77	16201
	Reference	Borrow ground dredging	Summer	0.89	0.65	1.05	2.12	0.86	11837
LEGD	Reference	Trunkline trenching	Winter	0.38	0.30	0.53	0.92	0.32	15351
	Reference	Borrow ground dredging	Summer	0.61	0.52	0.85	1.37	0.38	12086
MAL2	Reference	Trunkline trenching	Winter	1.03	0.91	1.23	1.71	0.82	16534
	Reference	Borrow ground dredging	Summer	1.26	1.02	1.55	2.87	0.97	11360

Seabed Light

Within Zone B, seabed DLI ranged from 1.78–14.92 mol/m^2/day in winter and 2.63–20.59 mol/m^2/day in summer (Table 9).

Mean DLI at sites HAM3, LANI, LEGD and MAL2 were approximately two to three-fold higher than the remaining sites in Zone B. Water depths ranged significantly between sites in Zone B, from 2.1 m (LANI) to 28.7 m (LEGD) playing an important role in mean light levels received at the seabed for sites within this Zone. Further, some sites were located on unprotected shoals while other sites had some protection from adjacent shorelines and were likely influenced by environmental conditions. For instance, localised wind and wave events at sites LANI (Section 1.1.1.1) and MAL2 (Section 1.1.1.1) resulted in reductions in seabed DLI and corresponded to higher turbidity.

Table 9: Ecological Zone B summary statistics for seabed DLI (mol/m²/day): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Site Depth (m LAT)	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	One daily representative data point
ANG2	Influence	Trunkline trenching	7.3	Winter	3.76	3.83	5.11	6.46	1.59	176
	Informative	Borrow ground dredging		Summer	4.52	4.50	5.94	8.29	1.97	117
COBN	Impact	Trunkline trenching	5.2	Winter	3.73	3.60	4.88	5.95	1.29	176
	Informative	Borrow ground dredging		Summer	4.14	4.07	5.60	7.01	1.69	118
CONI	Influence	Trunkline trenching	4.6	Winter	5.71	5.85	7.47	8.87	2.05	177
	Informative	Borrow ground dredging		Summer	6.31	6.41	7.82	10.11	2.12	112
CONI2	Impact	Trunkline trenching	4.0	Winter	4.36	4.41	5.71	7.05	1.61	176
	Informative	Borrow ground dredging		Summer	4.84	4.76	6.13	7.44	1.64	89
CRTS	Reference	Trunkline trenching	15.9	Winter	2.50	2.14	3.29	4.95	1.27	62
	Reference	Borrow ground dredging		Summer	5.69	5.17	6.94	9.16	1.76	121
FFP1	Reference	Trunkline trenching	15.9	Winter	3.11	2.65	4.86	6.38	1.83	174
	Reference	Borrow ground dredging		Summer	3.87	3.72	5.53	6.93	1.81	98
GIDI	Reference	Trunkline trenching	8.2	Winter	3.81	3.84	5.46	7.11	1.94	169
	Reference	Borrow ground dredging		Summer	4.36	4.35	5.73	7.77	2.01	117
HAM3	Reference	Trunkline trenching	19.3	Winter	9.07	8.89	12.15	14.22	3.11	156
	Reference	Borrow ground dredging		Summer	11.14	10.99	13.67	16.07	2.77	89
HAUY	Informative	Trunkline trenching	9.0	Winter	3.26	3.00	4.78	6.53	1.68	172
	Influence	Borrow ground dredging		Summer	5.21	5.18	6.43	8.42	1.85	119
HGPT	Reference	Trunkline trenching	7.4	Winter	3.00	2.68	3.94	5.78	1.61	175
	Reference	Borrow ground dredging		Summer	2.68	2.35	3.62	5.50	1.87	116
LANI	Reference	Trunkline trenching	2.1	Winter	15.32	15.58	20.01	22.43	4.84	171
	Reference	Borrow ground dredging		Summer	21.84	22.36	24.69	26.38	3.58	121
LEGD	Reference	Trunkline trenching	28.7	Winter	7.93	8.09	9.71	12.12	2.70	107
	Reference	Borrow ground dredging		Summer	3.76	3.83	5.11	6.46	1.59	176
MAL2	Reference	Trunkline trenching	7.2	Winter	4.52	4.50	5.94	8.29	1.97	117

Site	Site Classification	Activity	Site Depth (m LAT)	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	One daily representative data point
	Reference	Borrow ground dredging		Summer	3.73	3.60	4.88	5.95	1.29	176

Water Temperature

Across all sites in Zone B, water temperatures fluctuated with seasons, with lower temperatures recorded in winter (mean range: 22.87–24.10°C) compared to summer (27.00–28.76°C; Table 10).

Table 10: Ecological Zone B summary statistics for temperature (°C): May 2023 to February 2024 (inclusive)[4]

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Points
ANG2	Influence	Trunkline trenching	Winter	23.84	23.38	25.95	28.25	2.23	16582
	Informative	Borrow ground dredging	Summer	28.55	28.44	29.51	30.55	1.10	11449
COBN	Impact	Trunkline trenching	Winter	23.42	22.98	25.94	28.18	2.58	16590
	Informative	Borrow ground dredging	Summer	28.76	28.70	29.80	30.67	1.18	11548
CONI	Influence	Trunkline trenching	Winter	23.59	23.13	25.95	28.24	2.42	16583
	Informative	Borrow ground dredging	Summer	28.61	28.52	29.59	30.53	1.15	11451
CONI2	Impact	Trunkline trenching	Winter	23.54	23.10	25.89	28.22	2.41	16520
	Informative	Borrow ground dredging	Summer	28.66	28.53	29.74	30.64	1.18	11825
CRTS	Reference	Trunkline trenching	Winter	23.11	22.80	23.87	27.67	1.80	10736
	Reference	Borrow ground dredging	Summer	27.63	27.60	28.23	29.13	0.80	10399
FFP1	Reference	Trunkline trenching	Winter	23.32	22.79	25.75	28.16	2.53	16495
	Reference	Borrow ground dredging	Summer	28.40	28.31	29.35	30.27	1.09	9635
GIDI	Reference	Trunkline trenching	Winter	23.71	23.43	25.73	28.23	2.21	15589
	Reference	Borrow ground dredging	Summer	28.53	28.46	29.47	30.41	1.09	10921
HAM3	Reference	Trunkline trenching	Winter	24.79	24.54	26.11	27.30	1.41	11949
	Reference	Borrow ground dredging	Summer	27.40	27.40	28.06	28.74	0.80	11880
HAUY	Informative	Trunkline trenching	Winter	22.87	22.45	24.55	27.85	2.26	14372
	Influence	Borrow ground dredging	Summer	28.04	28.05	28.61	29.15	0.68	11505
HGPT	Reference	Trunkline trenching	Winter	23.55	22.87	25.63	27.71	2.19	16385

[4] Statistics are provided for the IMO NTU-LPT measured statistics, as the IMO MS9-LPT logger is programmed to turn off between 20:30 and 03:30.

	Reference	Borrow ground dredging	Summer	28.23	28.15	29.29	30.03	1.08	11332
LANI	Reference	Trunkline trenching	Winter	24.10	23.76	25.72	28.02	2.02	16201
	Reference	Borrow ground dredging	Summer	27.51	27.45	28.22	29.23	0.92	11838
LEGD	Reference	Trunkline trenching	Winter	24.20	24.03	25.55	27.03	1.53	15391
	Reference	Borrow ground dredging	Summer	27.00	27.09	27.67	28.15	0.79	12086
MAL2	Reference	Trunkline trenching	Winter	23.65	23.06	25.68	28.10	2.21	16534
	Reference	Borrow ground dredging	Summer	28.14	28.02	28.93	29.91	0.97	11360

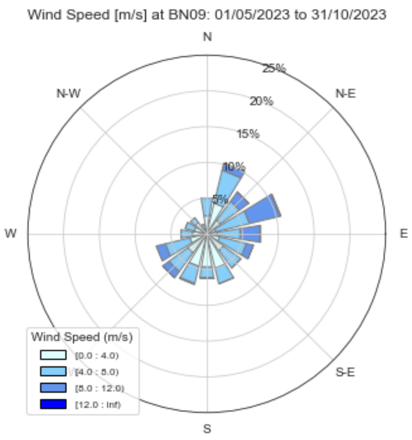
3.3.2.2. ANG2

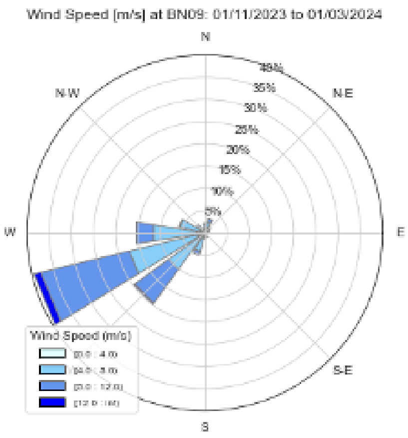
A summary of monitoring data recorded for ANG2 is provided in Figure 18 and Section 3.3.2.1.

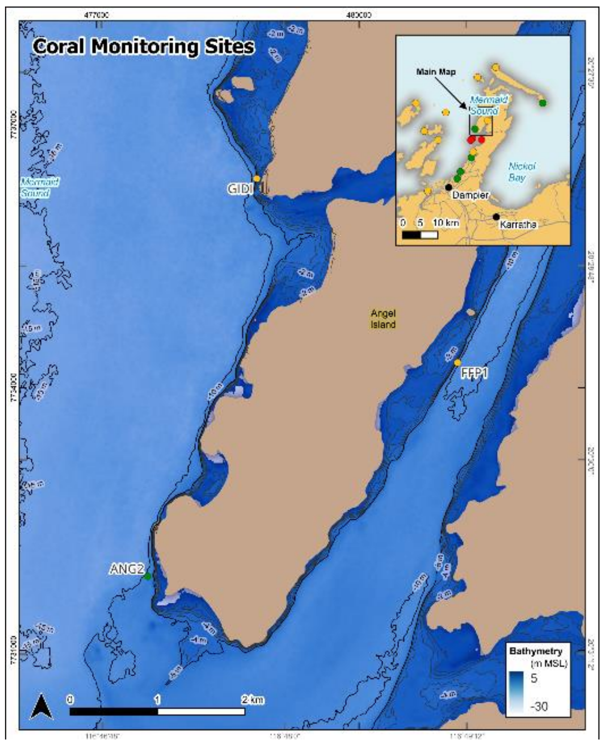
ANG2 is located west of the southern tip of Angel Island, adjacent to rocky shorelines and sandy beaches in ~7.3 m LAT. The site is exposed during south westerly to north westerly wind and waves and experiences tidal movement from the wider Mermaid Sound. The sites' depth and protection from areas of increased tidal movement (e.g., Flying Foam Passage) means variability in water quality is typically driven by increased notable wind and wave events that occur in summer.

Daily average turbidity and seabed DLI were relatively similar across seasons at site ANG2. There was a notable period of increased turbidity (reaching up to 5.3 NTU) and low seabed DLI (0.4 mol/m^2/day) at the beginning of August 2023 that may be related to spring tide cycle. Daily average water temperatures were lower in the winter months (reaching a minimum of 20°C) then gradually increased over the summer months to a maximum of approximately 31°C.

Site	ANG2
Ecological Zone	B
Site Classification	Influence (Trenching and Spoil Disposal)
	Informative (Borrow Ground Dredging)
Site Depth	7.3 m LAT
Location Coordinates	477519 E, 7732026 N







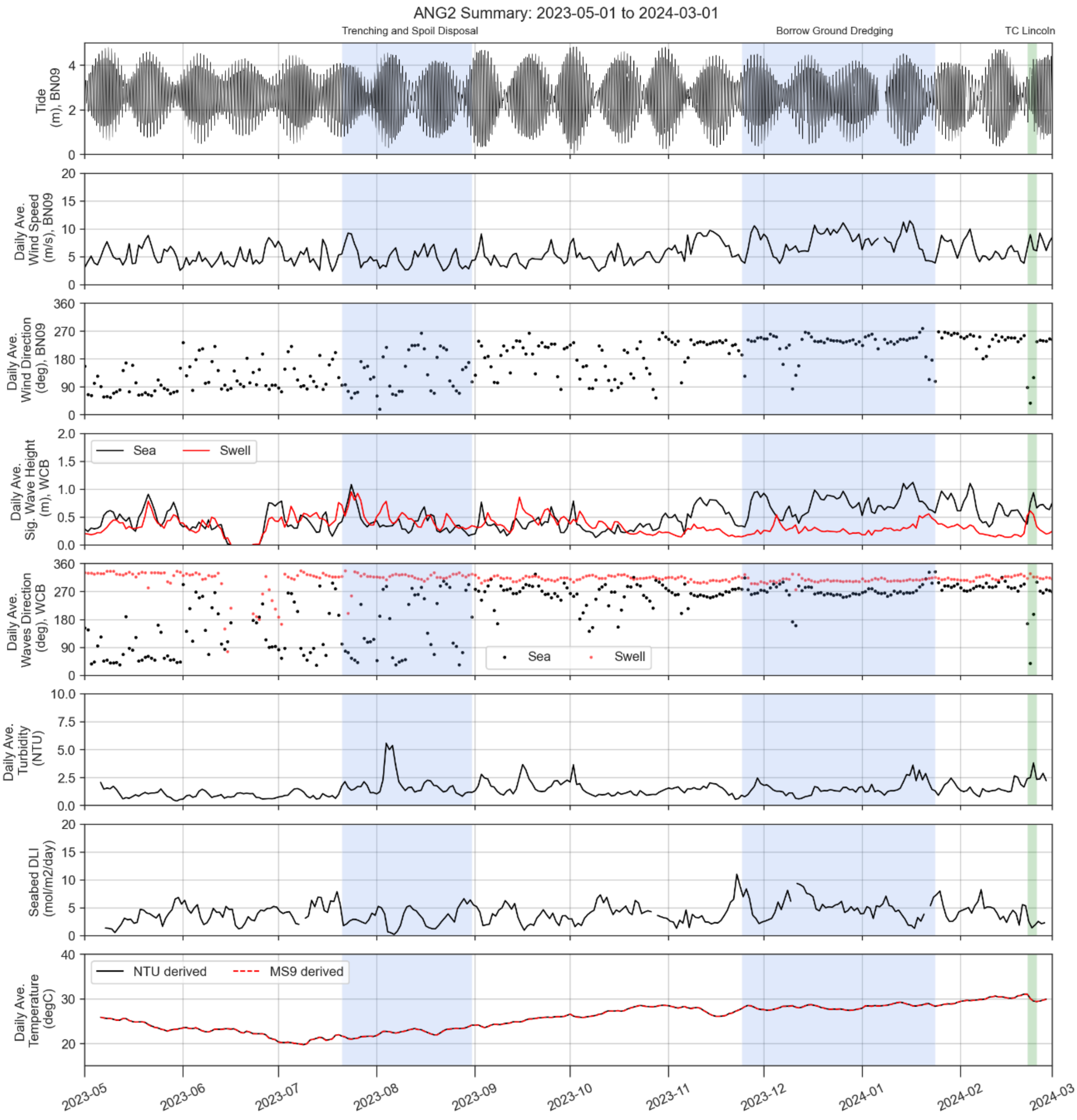


Figure 18: ANG2 site summary

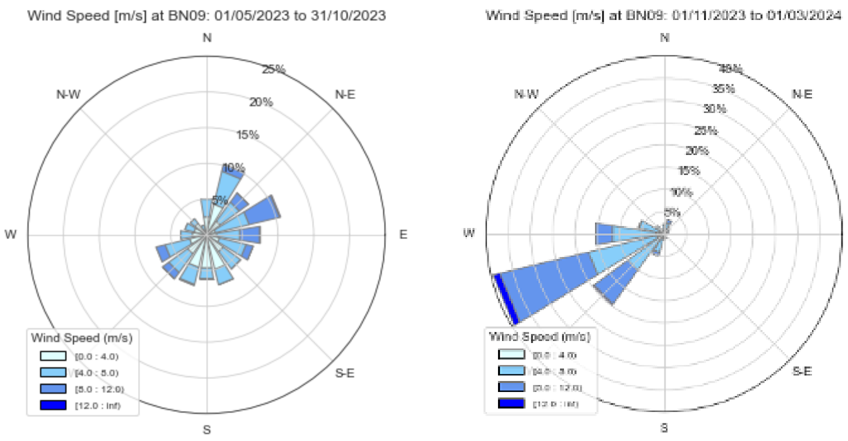
3.3.2.3. COBN

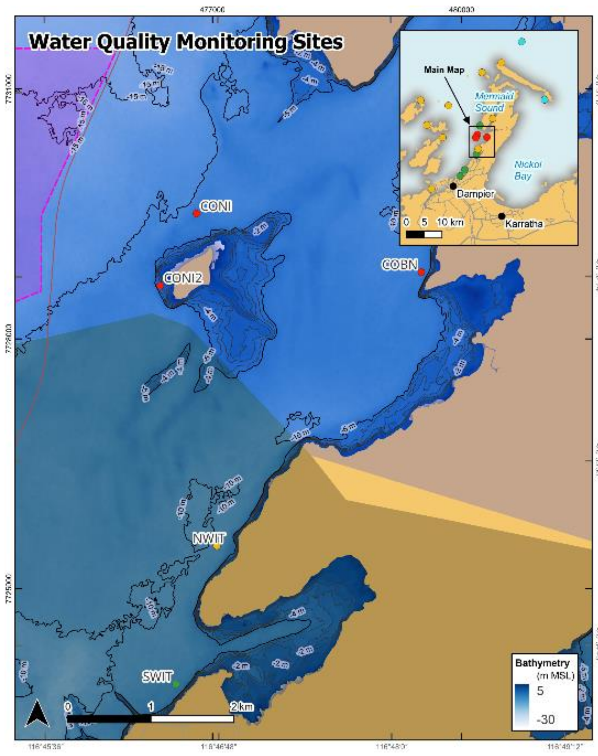
A summary of monitoring data recorded for COBN is provided in Figure 19 and Section 3.3.2.1.

COBN is located to the north of Conzinc Bay, adjacent to rocky shorelines and sandy beaches in ~5.2 m LAT. The site is exposed during northerly, westerly and south westerly conditions, as well as tidal flow through both Flying Foam Passage and Searipple Passage (a west-east passage between Dolphin Island and Burrup Peninsula). As the site is protected from prevailing easterlies, turbidity in the summer months is likely result of currents and semi-diurnal tides. During winter, turbidity and light is influenced by both prevailing weather conditions and currents and tides, resulting in more consistent turbidity.

Daily average turbidity was generally low across both seasons, with a few peaks in turbidity (ranging from 8.2–10.3 NTU) and corresponding drops in seabed DLI (down to 1.2 mol/m^2/day) in summer. There was one notable event at the end of October 2023 (outside of active dredging and disposal activities) in which turbidity was relatively high (17.7 NTU on 26 October 2023), corresponding to strong short-term east-south-easterly winds. The remaining peaks in turbidity during summer coincided with strong westerly wind and wave conditions. Daily average water temperatures were lower in the winter months (reaching a minimum of 19°C) compared to the summer months (reaching a maximum of 31°C).

Site	COBN
Ecological Zone	B
Site Classification	Impact (Trenching and Spoil Disposal) Informative (Borrow Ground Dredging)
Site Depth	5.2 m LAT
Location Coordinates	479515 E, 7728801 N





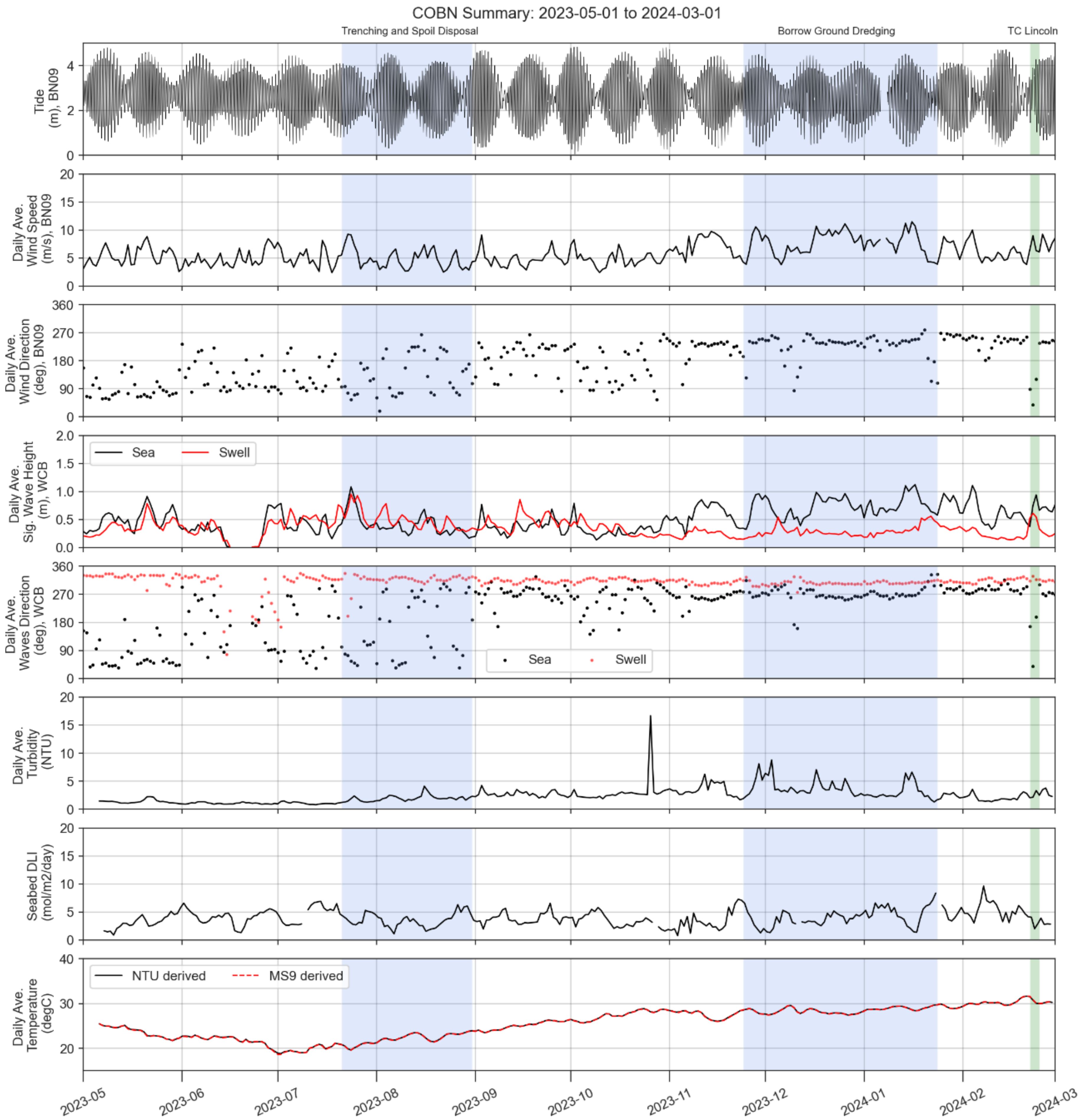


Figure 19: COBN site summary

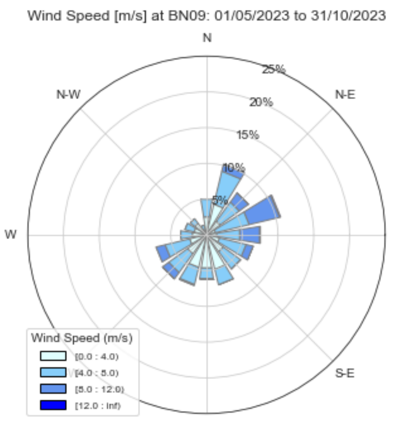
3.3.2.4. CONI

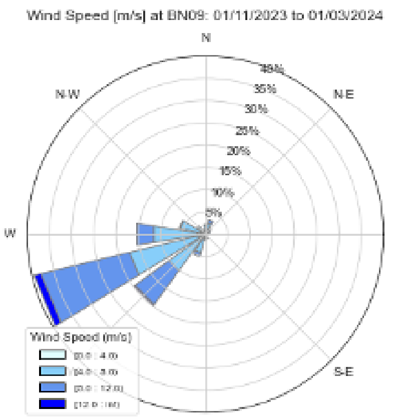
A summary of monitoring data recorded for CONI is provided in Figure 20 and Section 3.3.2.1.

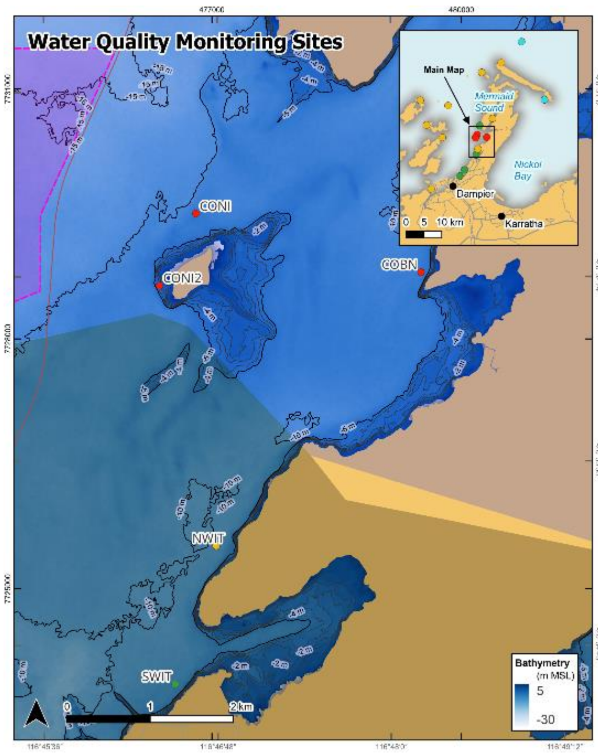
CONI is located north of Conzinc Island in ~5.2 m LAT. Given this sites' location, it is generally not protected from prevailing conditions, and receives tidal flushing through Flying Foam Passage, Searipple Passage and the wider Mermaid Sound. As such, the water quality at site CONI is generally influenced by both prevailing weather conditions and currents and tides, and significant changes in water quality are often associated with significant weather events.

Seabed DLI was variable and similar between seasons, ranging from 0.9–13.1 $mol/m^2/day$. Daily average turbidity was relatively low and consistent over the entire monitoring period (ranging from 0.7 to 3.5 NTU), with two significant spikes identified in the summer months (mid-January and late-February 2024). Of the two, a significant spike in daily average turbidity (reaching a maximum average of 9.5 NTU) occurred during offshore borrow ground dredging and backfill activities. However, the spike in turbidity occurred during offshore borrow ground dredging and site CONI is classified as an informative site, therefore this peak did not breach the respective turbidity trigger levels. Between 21–27 January 2024, seabed DLI and turbidity data did not pass QC assessment and was rejected as the monitoring system was upside down following deployment. Daily average water temperatures were lower during winter (lowest in August reaching a minimum of 20°C) and gradually increased over the summer months to a maximum of approximately 31°C.

Site	CONI
Ecological Zone	B
Site Classification	Impact (Trenching and Spoil Disposal) Informative (Borrow Ground Dredging)
Site Depth	4.6 m LAT
Location Coordinates	476808 E, 7729505 N







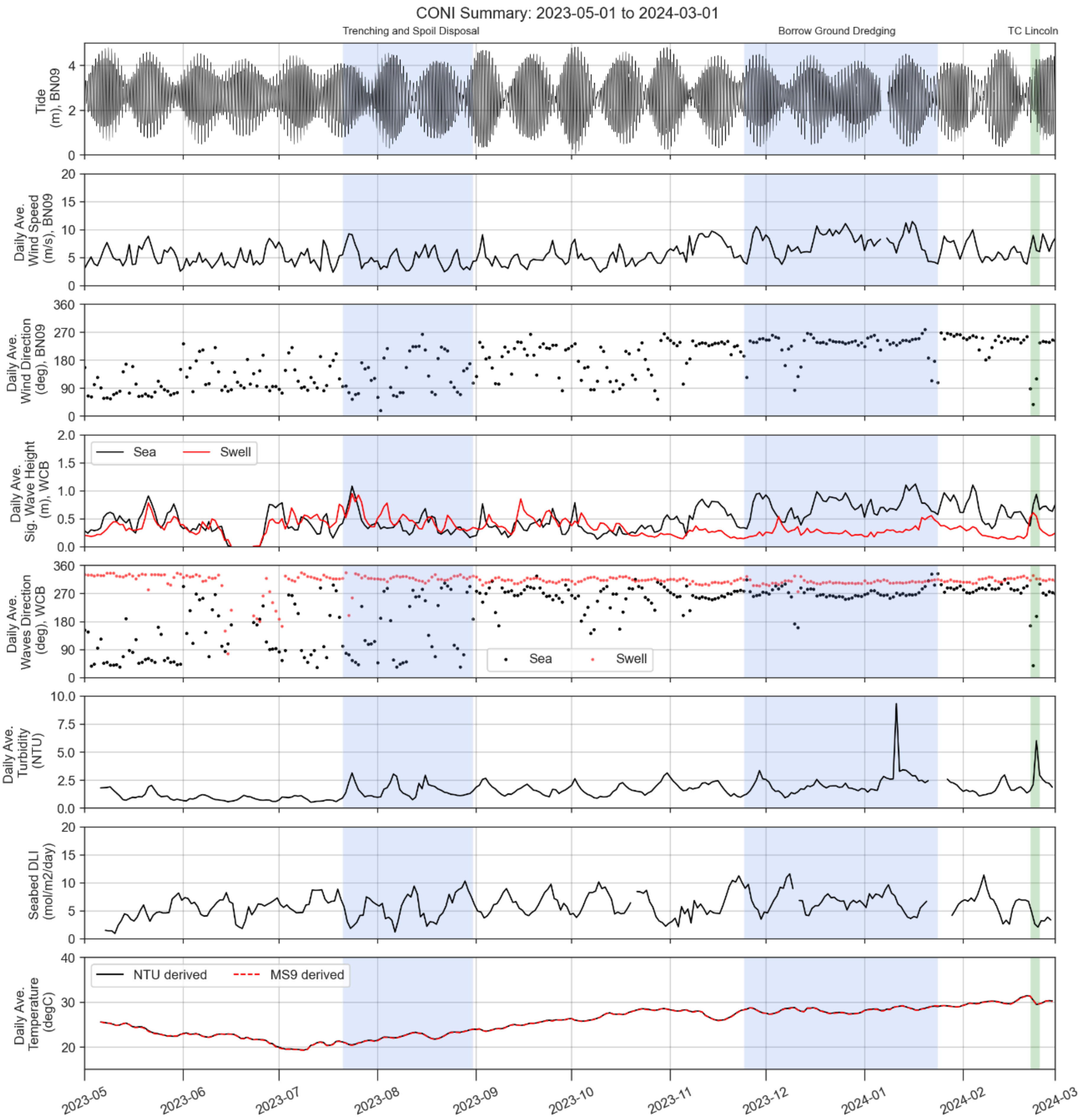


Figure 20: CONI site summary

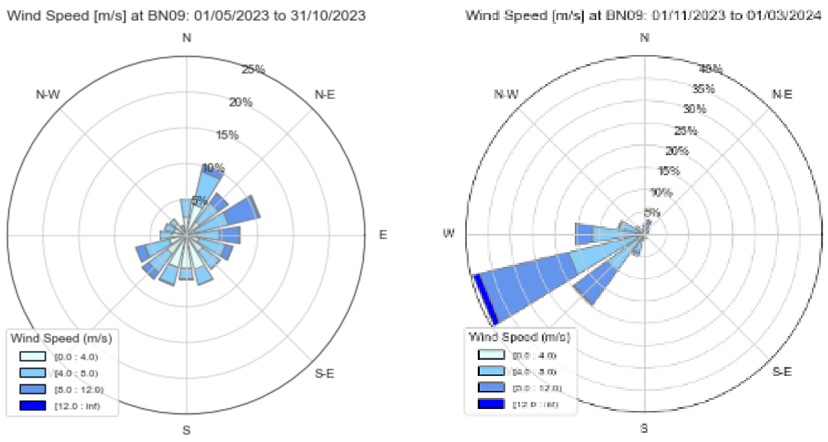
3.3.2.5. CONI2

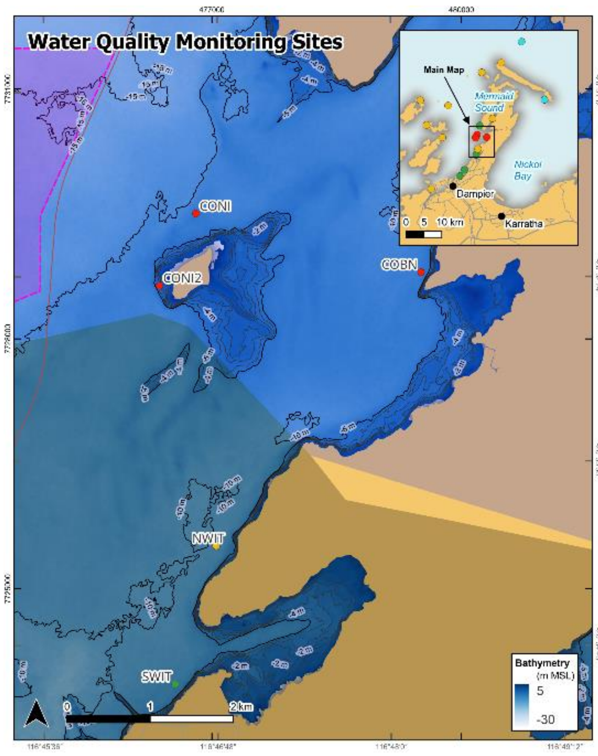
A summary of monitoring data recorded for CONI2 is provided in Figure 21 and Section 3.3.2.1.

CONI2 is located south-east side of Conzinc Island approximately 1 km from site CONI, in ~4.0 m LAT. Given this sites' location, it is generally not protected from prevailing conditions, and receives tidal flushing through Flying Foam Passage, Searipple Passage and the wider Mermaid Sound. As such, the water quality at site CONI is generally influenced by both prevailing weather conditions and currents and tides, and significant changes in water quality are often associated with significant weather events.

Daily average turbidity was relatively low and consistent (ranging from 0.5–3.2 NTU) across the monitoring period. Seabed DLI readings were variable across the months (ranging from 0.7 and 9.2 mol/m^2/day). Both turbidity and seabed DLI readings corresponded to prevailing weather (i.e., high seas resulted in higher turbidity and lower seabed DLI). Between the end of January and the end of the water quality monitoring campaign in early March 2024, seabed DLI data did not pass QC assessment and was rejected due to moderate to heavy biofouling (predominately barnacles). Daily average water temperatures were lower during the winter months (lowest in August reaching a minimum of approximately 20°C) and gradually increased over the summer months to a maximum of approximately 31°C in late-February 2024.

Site	CONI2
Ecological Zone	B
Site Classification	Impact (Trenching and Spoil Disposal)
	Informative (Borrow Ground Dredging)
Site Depth	4.0 m LAT
Location Coordinates	476370 E, 7728639 N





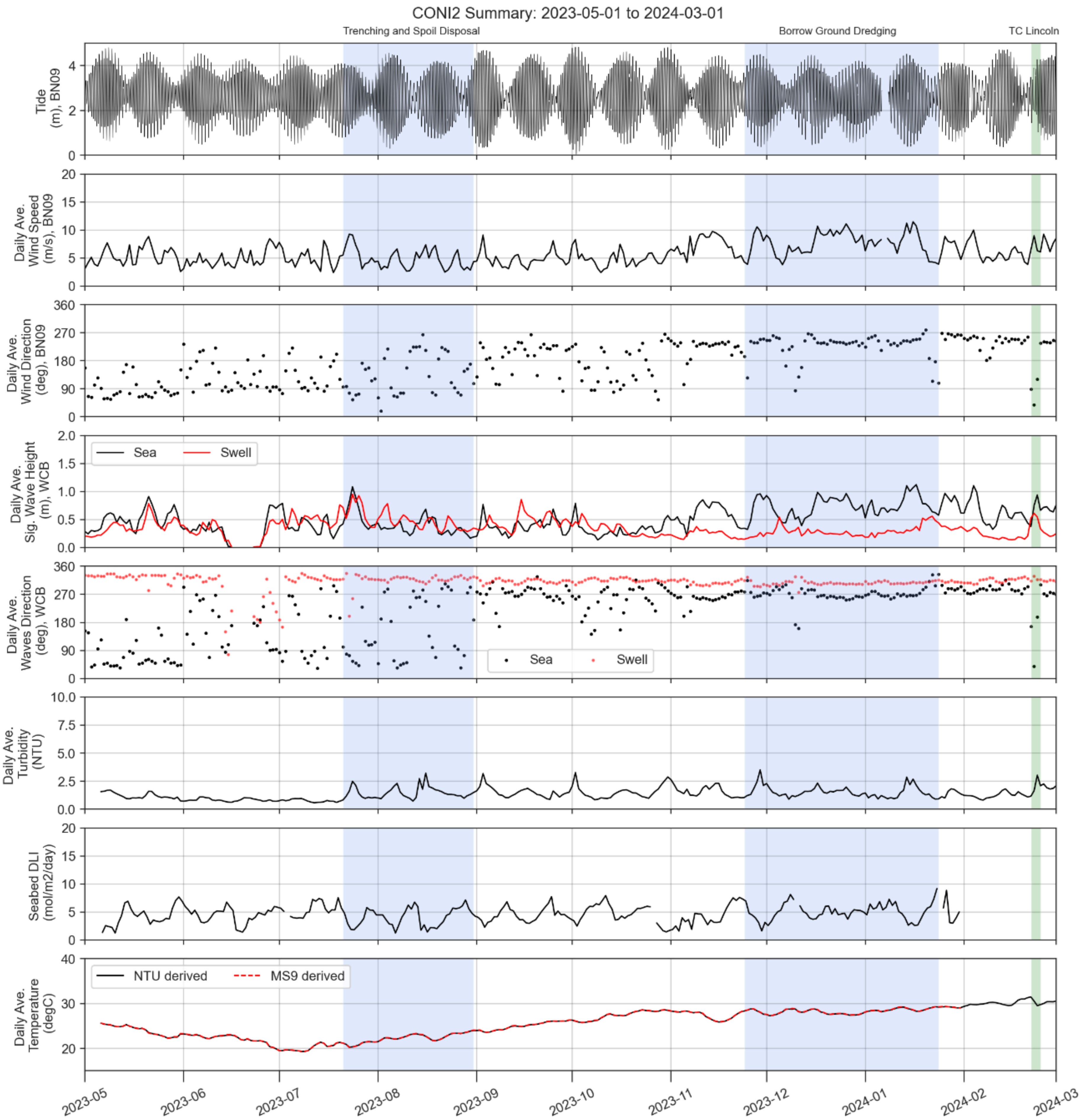


Figure 21: CONI2 site summary

3.3.2.6. CRTS

A summary of monitoring data recorded for CRTS is provided in Figure 22 and Section 3.3.2.1.

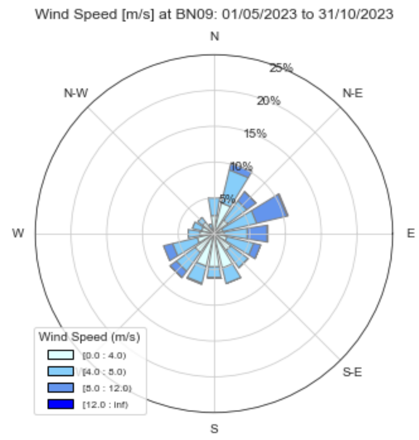
CRTS is located in ~15.9 m LAT on Courtney Shoal in Mermaid Sound, approximately 3 km east of Nelson Rocks. The site is mostly exposed to wind and swell from all directions but is slightly protected from west and south westerly conditions by nearby islands. CTRS however, is more affected by conditions from the north and north west moving into Mermaid Sound with the greatest fetch.

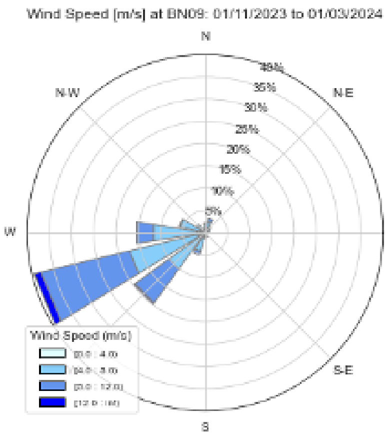
Large sections of turbidity and DLI data between 1 September and 24 October 2023 (outside of active dredging and disposal activities) were removed as the entire monitoring system was moved ~300 m away from its original location which was possibly caused by a third party. Water depth readings revealed the monitoring system was moved into shallower (7 m depth from the original 13 m depth) waters. Furthermore, sensor coverage (i.e., biofouling) was also evident which produced high turbidity readings. As such, all data during this period has been removed. It should be noted that this data was being telemetered during live monitoring and still had the potential to be used as a reference site proxy if required.

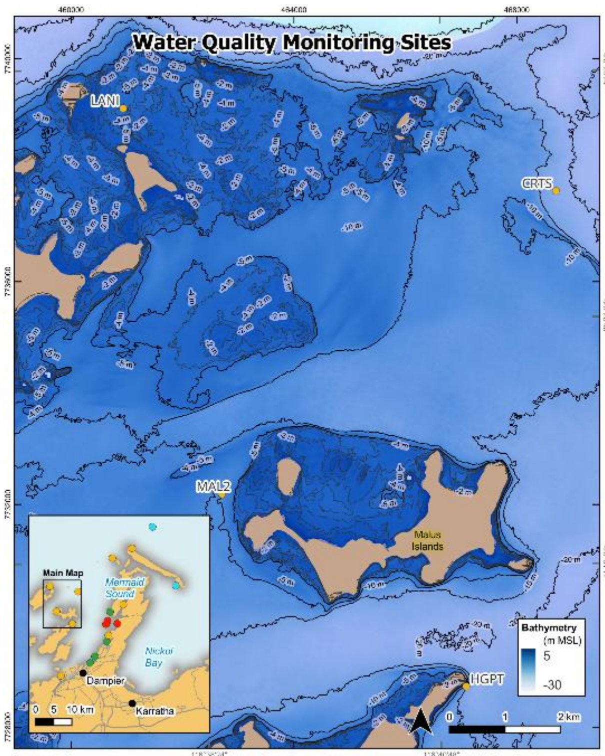
In addition, immediately before and partially during trenching and spoil disposal activities (mid-July to mid-August 2023) in which CTRS is a reference site, the light logger appears to have malfunctioned and data was only recorded in the early morning at intervals that were not consistent with the logger setup. As such, a segment of the DLI data during trenching and spoil disposal did not pass QC assessment and was rejected.

Daily average turbidity was relatively low (ranging from 0.3 and 2.5 NTU) in both summer and winter, and seabed DLI readings were variable across the seasons, ranging from 0.5 and 10.2 mol/m^2/day. These results coincided with changes in prevailing weather (i.e., high seas resulted in higher turbidity and lower seabed DLI). Daily average water temperatures were lower in the winter months (June–August 2023, a minimum of 20°C), then remained relatively stable between late-October 2023 to February 2024, with temperatures ranging between 24.5 and 28.9°C.

Site	CRTS
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	15.9 m LAT
Location Coordinates	468703 E, 7737627 N







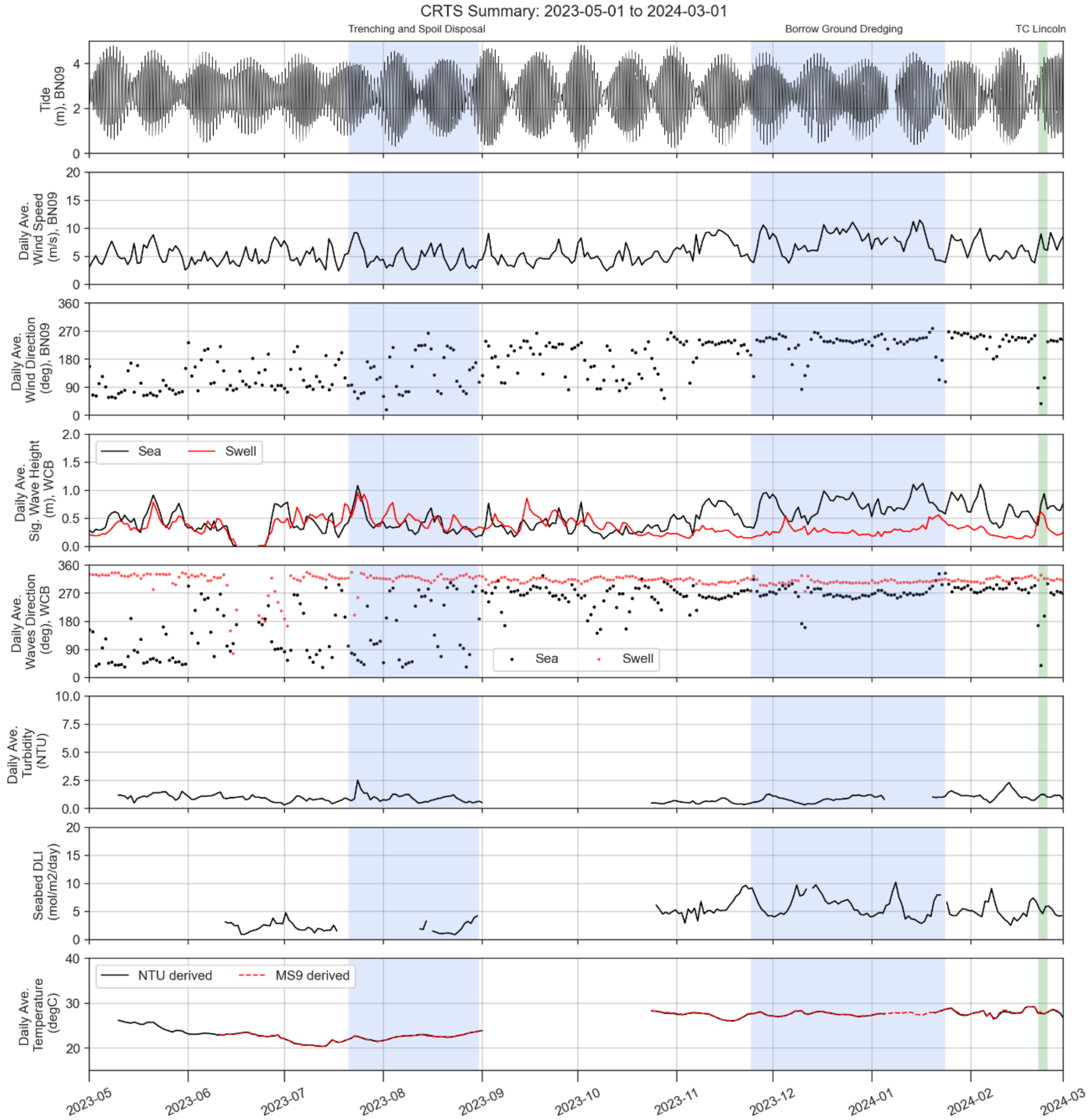


Figure 22: CRTS site summary

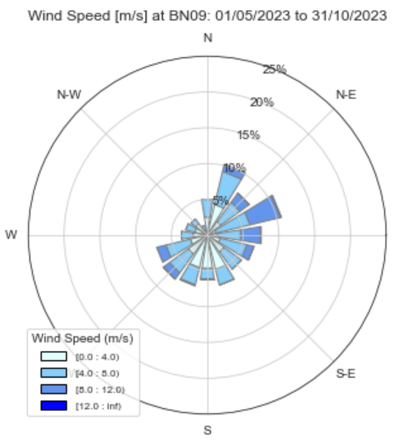
3.3.2.7. FFP1

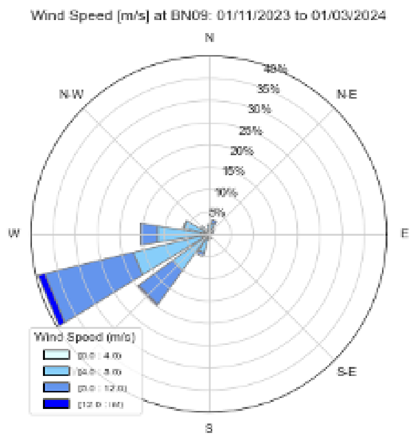
A summary of monitoring data recorded for FFP1 is provided in Figure 23 and Section 3.3.2.1.

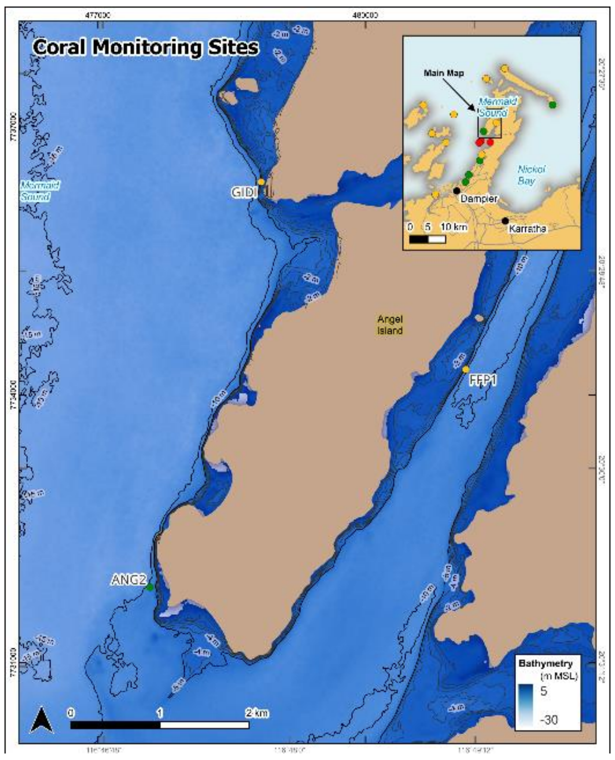
FFP1 is located in Flying Foam Passage between Angel Island and Dolphin Island in waters ~8.6 m LAT. The strongest currents in the Archipelago occur in Flying Foam Passage that can exceed 2 m/s (Forde, 1985: cited in Pearce et al., 2003). The site is generally protected from prevailing wind and swell with the exception of conditions from the south west or north east that travel up the passage. The site is highly influenced by tidal currents, with increased volumes of water moving at speed through the passage during spring tides contributing to higher turbidity and lower light levels, and vice versa during neap tides.

There were no distinct seasonal changes in daily average turbidity (ranging from 0.5–6.5 NTU) and seabed DLI (0.1–8.4 mol/m^2/day) readings. Instead, patterns in both turbidity and seabed DLI were primarily driven by tidal flows (neap and spring tides). Weather conditions such as wind and wave events may influence turbidity and light in Flying Foam Passage however, to a lesser extent than other Zone B sites. From mid-December 2023 to early January 2024 and early to mid-January 2024, seabed DLI and turbidity loggers ceased transmitting due to malfunction in equipment and heavy biofouling (predominately barnacles). Daily average water temperatures were lower during winter (reaching a low of 19°C in August 2023) and gradually increased over the summer months to a maximum of 31°C in February 2024.

Site	FFP1
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	15.9 m LAT
Location Coordinates	481127 E, 7734025 N







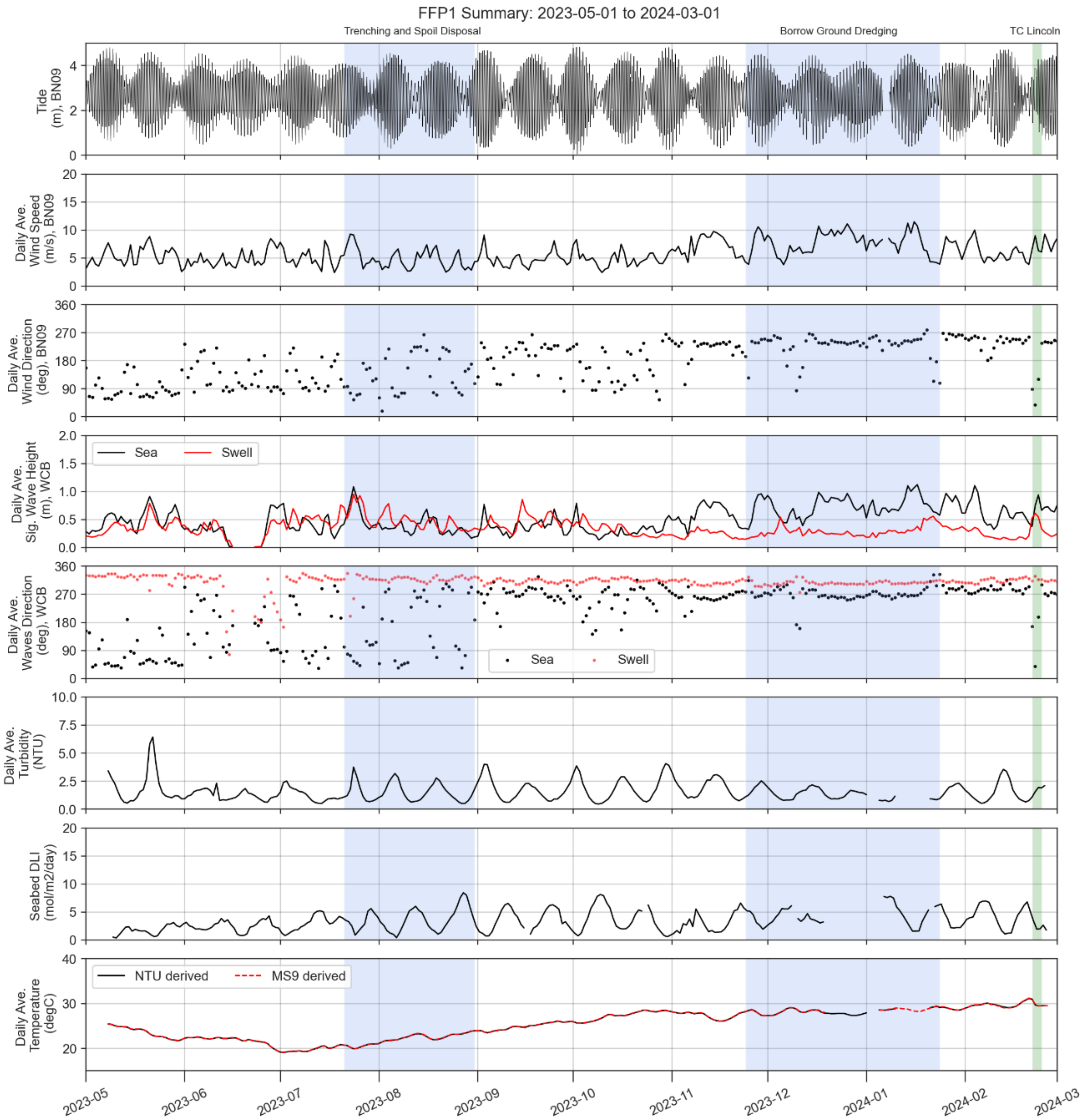


Figure 23: FFP1 site summary

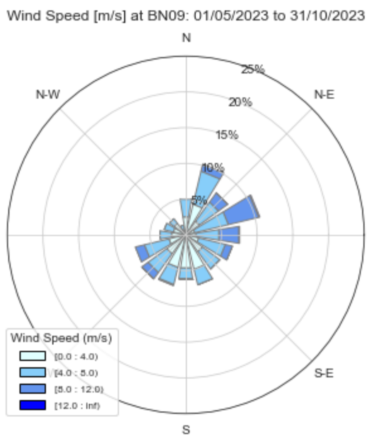
3.3.2.8. GIDI

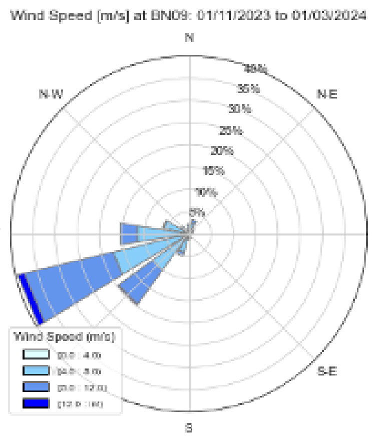
A summary of monitoring data recorded for GIDI is provided in Figure 24 and Section 3.3.2.1.

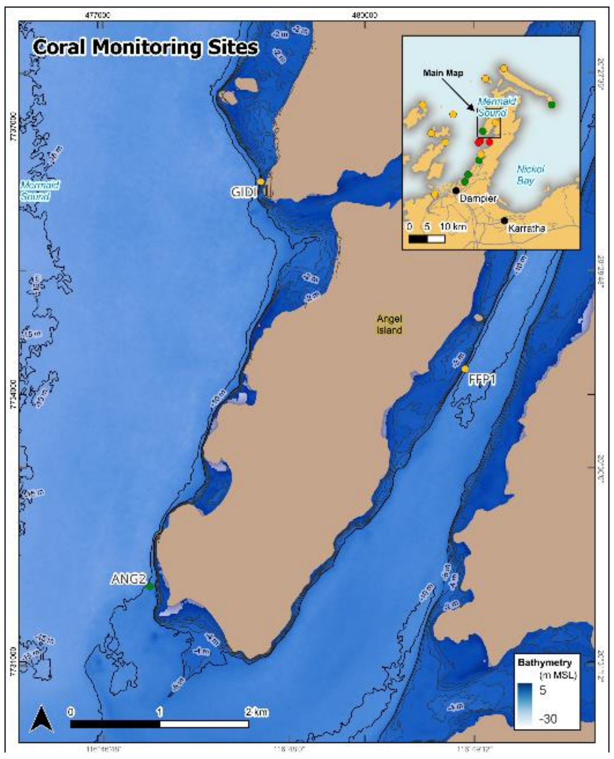
GIDI is located on the west end of Gidley Island in approximately 8.2 m LAT. The site is exposed to wind and swell from the north to south west, particularly westerly conditions with long fetch. Tidal flow is predominantly associated with movement in the wider Mermaid Sound. Due to the site's exposure to weather conditions from the Indian Ocean, water quality is responsive to significant wind and weather events.

Between early-July and mid-October 2023, which encompassed trenching and spoil disposal activities, daily average turbidity showed higher ranges in variability (from 0.3–10.2 NTU) and subsequent drops in seabed DLI (down to 0.3 mol/m^2/day) than the other months. A significant spike in daily average turbidity (10.3 NTU) and correlating drops in DLI (0.6 mol/m^2/day) were recorded on 23 February 2024, which corresponded to an increase in seas and swell that was likely associated with the passing of tropical cyclone Lincoln. Daily average water temperatures followed the same trend as other sites within Zone B, with lower temperatures recorded during winter (approximately 20–26°C) compared to summer (26–31°C).

Site	GIDI
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	8.2 m LAT
Location Coordinates	478589 E, 7736417 N







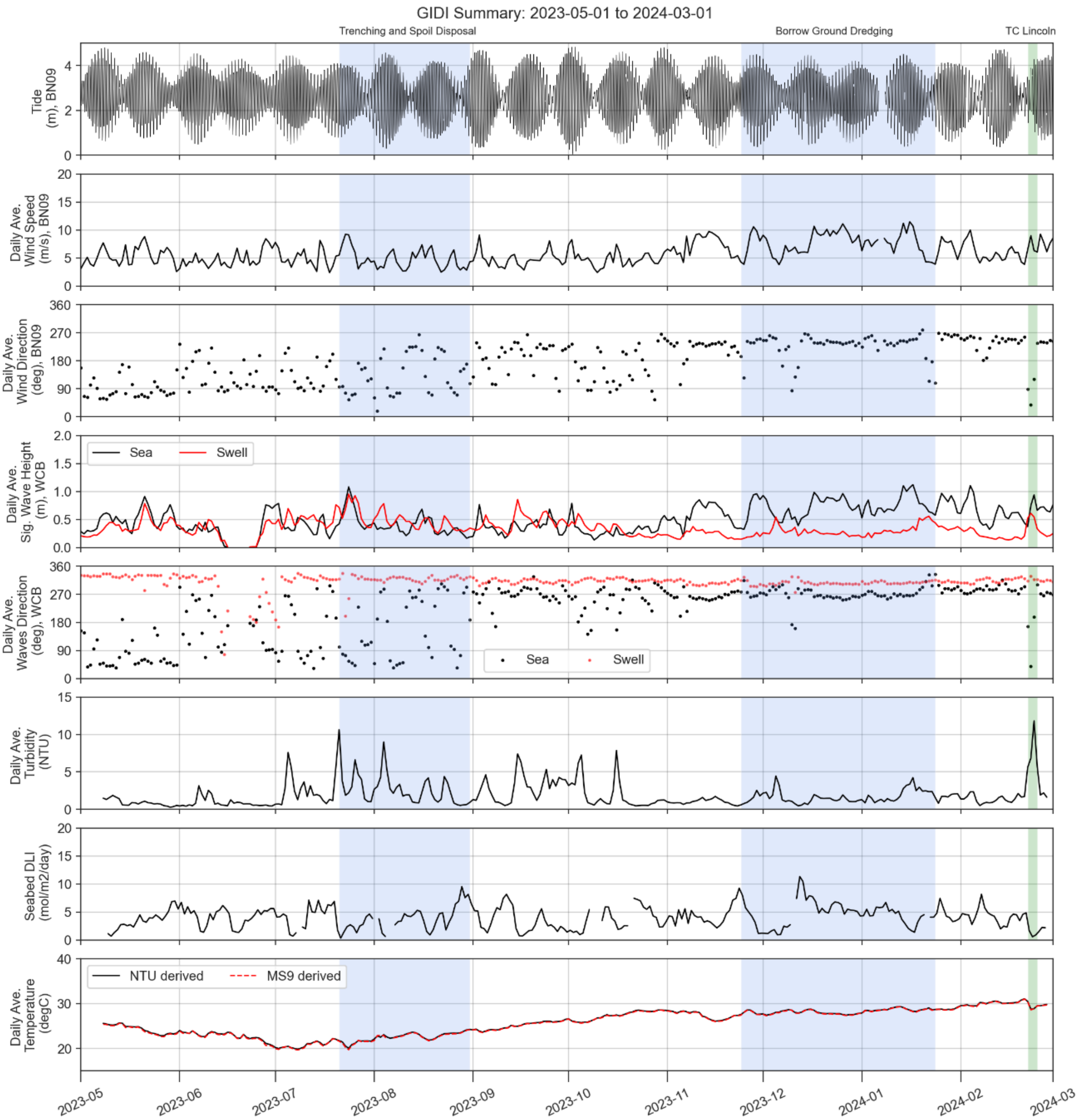


Figure 24: GIDI site summary

3.3.2.9. HAM3

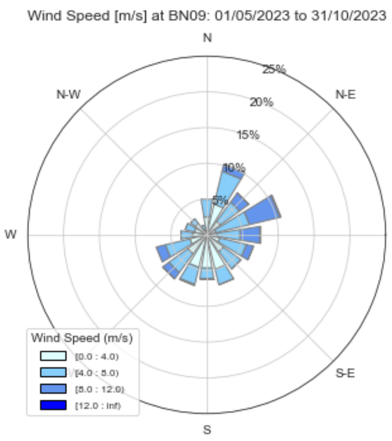
A summary of monitoring data recorded for HAM3 is provided in Figure 25 and Section 3.3.2.1.

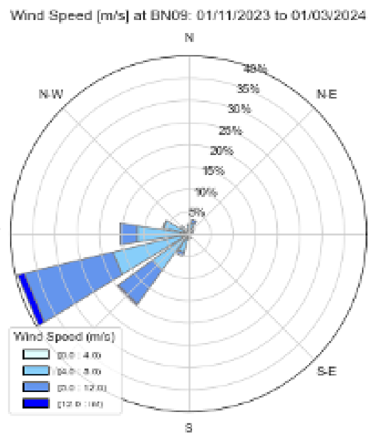
HAM3 is located on Hammersley Shoal in ~19.3 m LAT, approximately 1.5 km north west of Cohen Island in Mermaid Sound. The loggers were suspended mid-water at ~5.4 m that more accurately represented the depth and associated light conditions of the nearby benthic receptors. The site is mostly exposed to wind and swell from all directions however, similarly to CRTS, HAM3 is slightly protected from east to south easterlies by nearby islands, and is more affected by conditions from the north and north west moving into Mermaid Sound with the greatest fetch. Tidal flow through Cape Brugieres Channel into Flying Foam Passage may contribute to natural turbidity by transporting the fine silty sediment characteristic of the area (Pearce et al., 2003; Wiseman, 2021) onto the shoal.

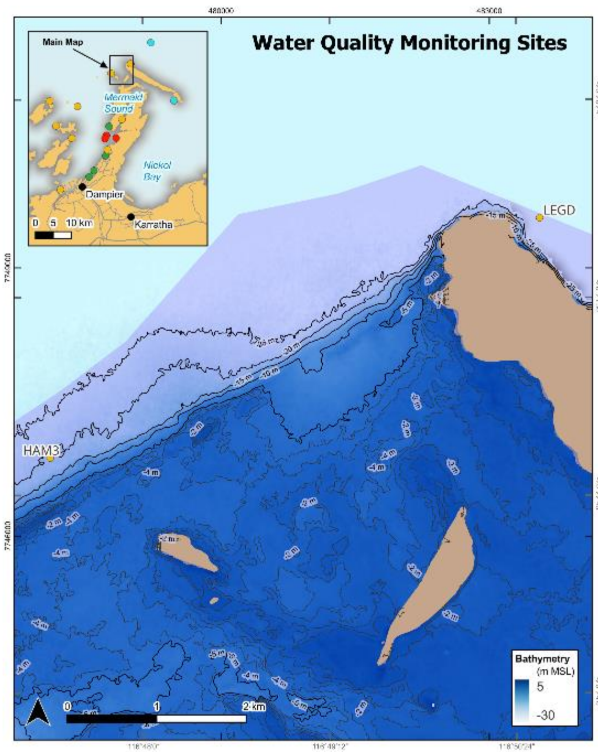
Daily average turbidity was relatively low (ranging from 0.1 and 2.5 NTU) in both summer and winter, and DLI readings were variable across the seasons, ranging from 1.7 and 17.8 mol/m^2/day. A significant spike in turbidity (6.9 NTU) was reported on 16 May 2023, however, it did not appear to be related to any environmental conditions experienced on the day. Sections of turbidity (between early-July to mid-August 2023) and DLI (mid-August and between mid-December 2023 and mid-January 2024) data, which encompassed portions of trenching and spoil disposal, and borrow ground dredging activities respectively, did not pass QC assessment. This was a result of the occasional submergence of the surface buoy that pulled the mid-water column loggers to deeper depths and as such, capturing the parameters at target depth was not achieved. Between mid-December 2023 and mid-January 2024, the loggers were flooded and stopped logging data. Given this site was classified as a reference site which was not predicted to be impacted or influenced by the sediment plume, the loss of this data has not affected the outcomes of this monitoring program.

Daily average water temperatures at the start of the monitoring program (May 2023) were approximately 27°C and gradually decreased to a minimum of 21°C in early June 2023, and then remained relatively constant for the remaining months (23–28°C between late-August 2023 to late-February 2024).

Site	HAM3
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	19.3 m LAT
Location Coordinates	478089 E, 7746873 N







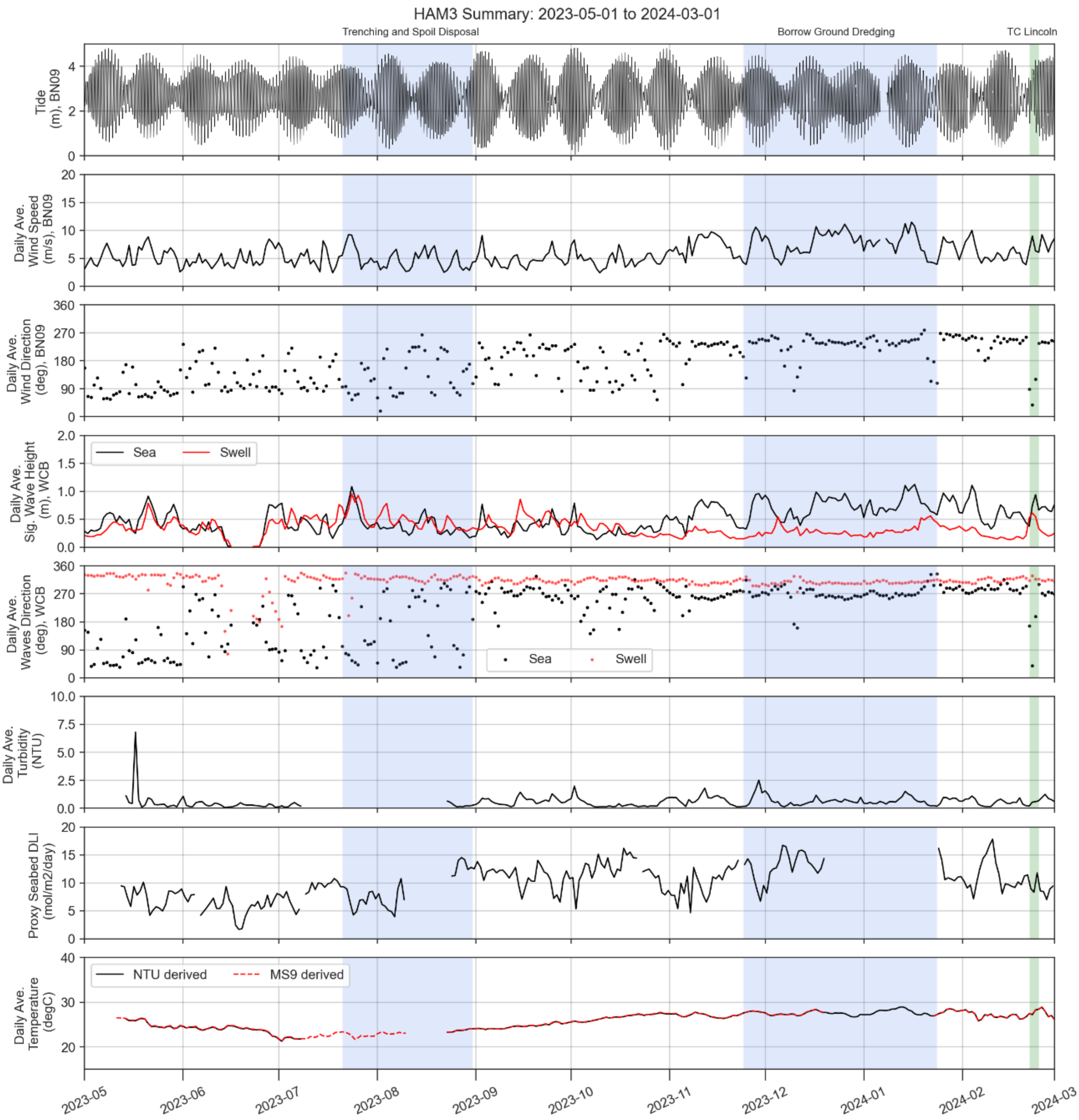


Figure 25: HAM3 site summary

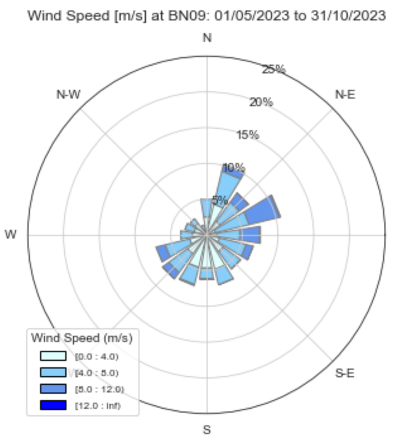
3.3.2.10. HAUY

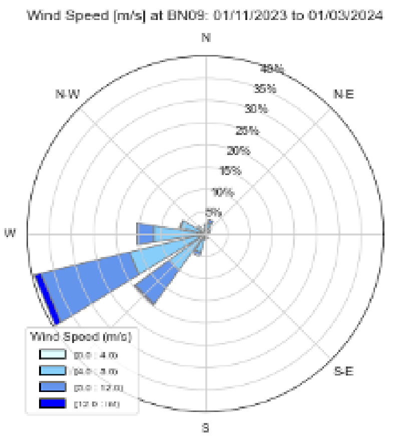
A summary of monitoring data recorded for HAUY is provided in Figure 26 and Section 3.3.2.1.

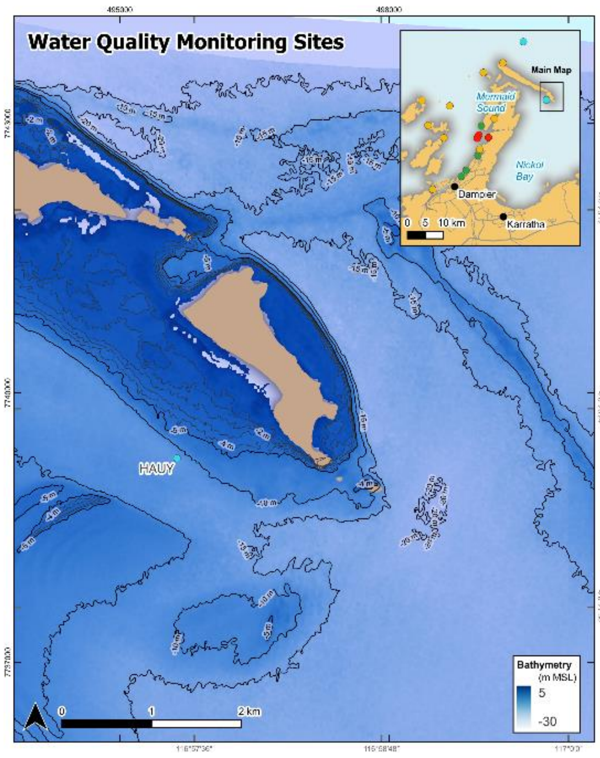
HAUY is located on the south side of Hauy Island to the north of the Archipelago in approximately 9 m LAT. The site is generally exposed to wind and waves from the west to south west and experiences strong currents and tidal flow from a north west–south east direction. HAUY is generally protected from south easterly, easterly and northerly prevailing conditions, especially during summer.

Daily average turbidity and seabed DLI were variable throughout the monitoring period, ranging from 1.6 to 8.8 NTU and 0.1 to 11.4 mol/m^2/day, respectively, but were similar between seasons. Several peaks in turbidity were recorded between mid-May and early-November 2023 that align with spring tides. Lower daily average water temperatures were recorded during the winter months (19–25°C) compared to the summer months where temperatures ranged from 26–29°C.

Site	HAUY
Ecological Zone	B
Site Classification	Informative (Trenching and Spoil Disposal) Influence (Borrow Ground Dredging)
Site Depth	9.0 m LAT
Location Coordinates	494669 E, 7740207 N







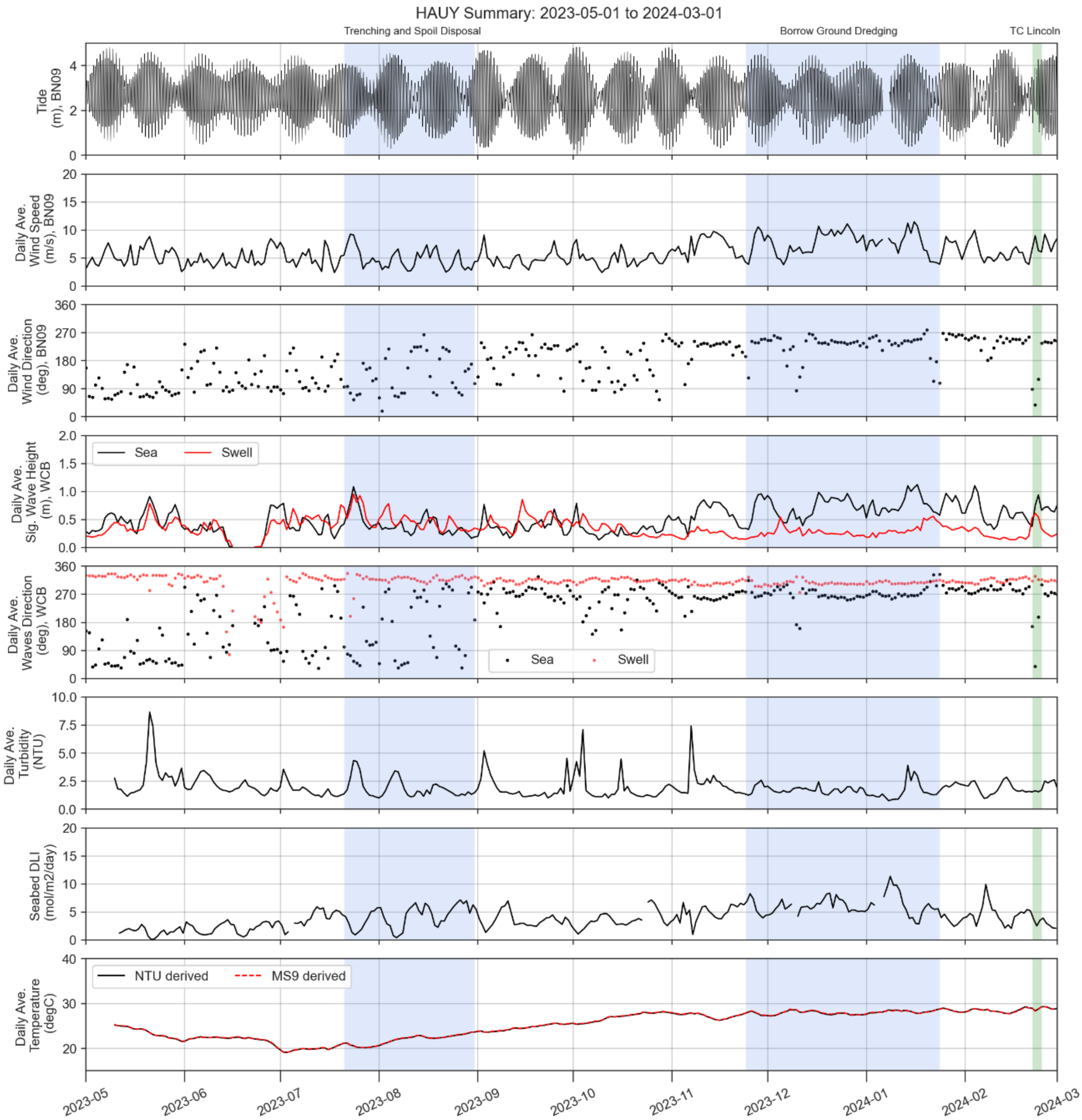


Figure 26: HAUY site summary

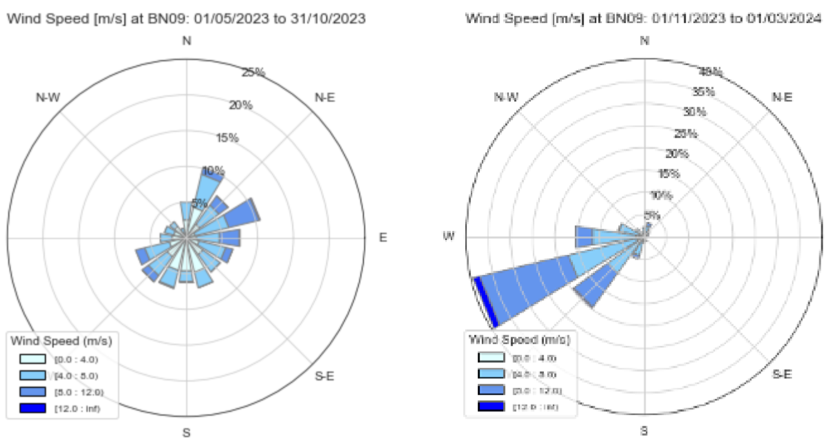
3.3.2.11. HGPT

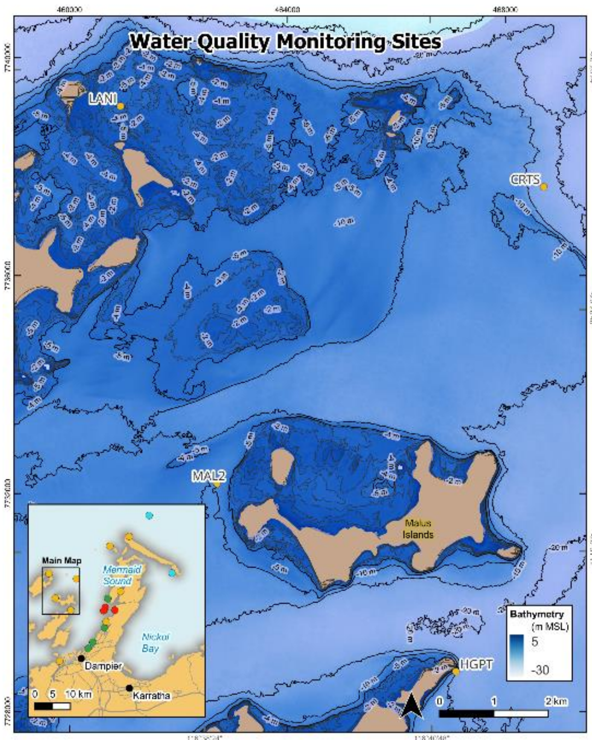
A summary of monitoring data recorded for HGPT is provided in Figure 27 and Section 3.3.2.1.

HGPT is located on the northern tip of High Point of West Lewis Island on the boarder of Dampier Port Limits in ~7.4 m LAT. The site is adjacent to major shipping channels and shipping traffic. The site is partially protected by Malus Island from north-westerly and south-westerly weather conditions during the summer months, however, tidal flow through Mermaid Sound may also contribute to water movement at the site (Pearce et al., 2003).

Relatively low daily average turbidity was experienced throughout summer and winter, which ranged from 0.6–5 NTU. A relatively small increase in turbidity (5 NTU) was recorded at the end of August 2023 towards the end of trenching and spoil disposal activities however, there was no associated decrease in seabed DLI. Seabed DLI was variable and relatively low throughout the monitoring period, ranging between 0 and 10.8 mol/m^2/day. Daily average water temperatures followed the same trend as other sites within Zone B, with lower temperatures recorded during winter (approximately 20–26°C) compared to the summer months (26–31°C).

Site	HGPT
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	7.4 m LAT
Location Coordinates	467093 E, 7728731 N





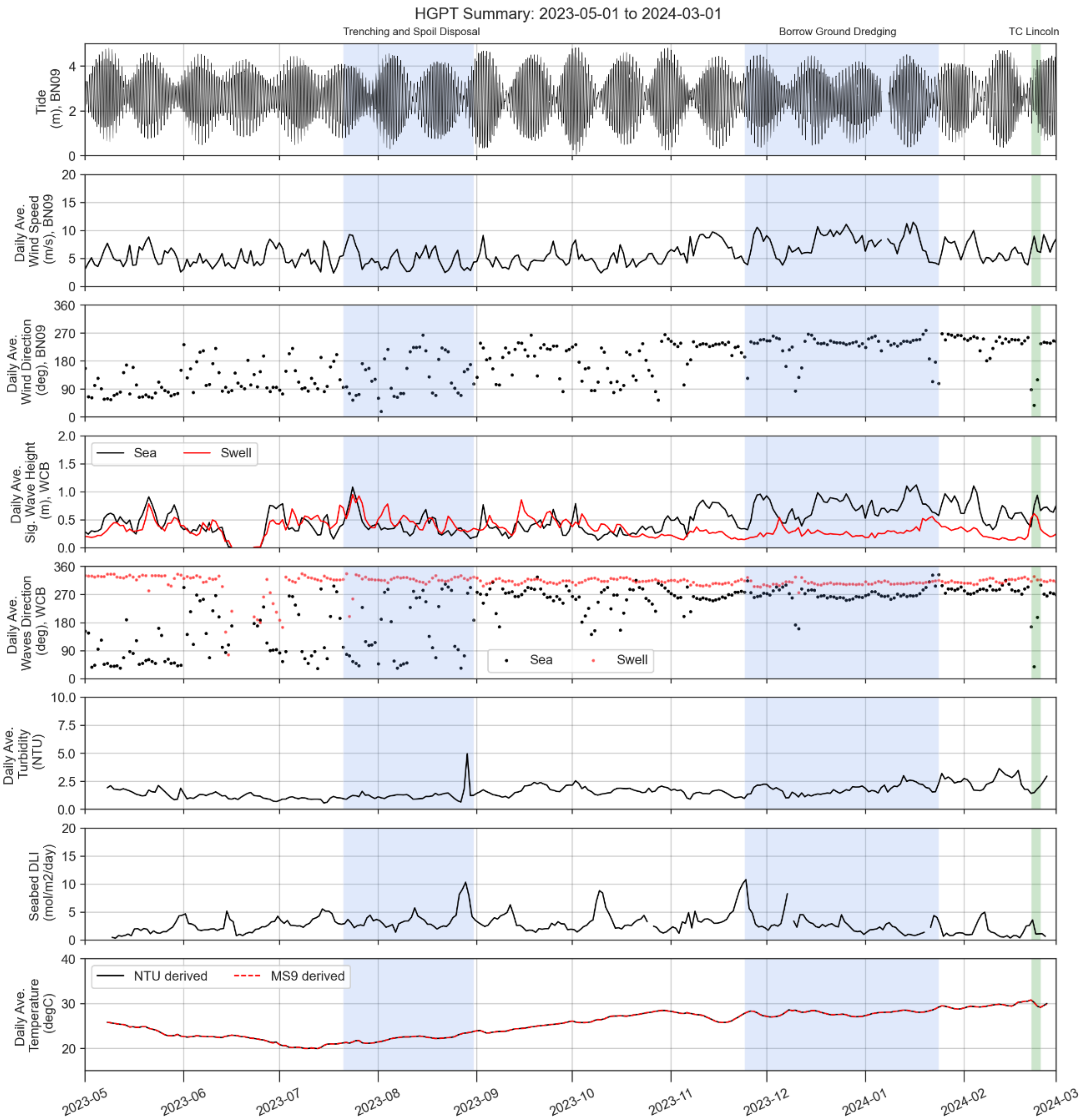


Figure 27: HGPT site summary

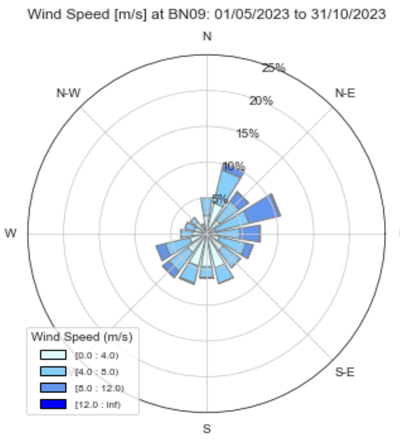
3.3.2.12. LANI

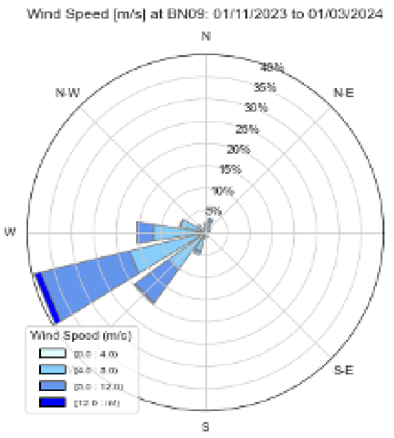
A summary of monitoring data recorded for LANI is provided in Figure 28 and Section 3.3.2.1.

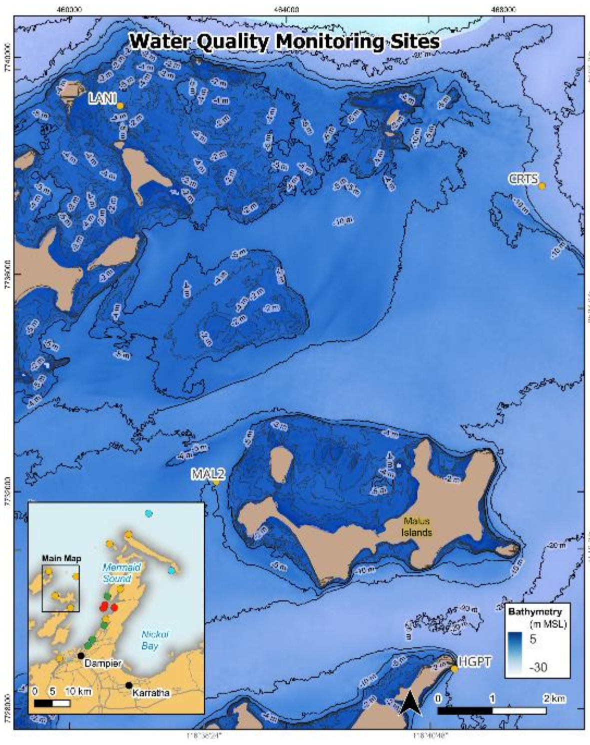
LANI is located in sandy shores between Brigadier Island and Lady Nora Island, approximately 2.5 km north-east of Rosemary Island in 2.1 m LAT. The site is relatively protected from the nearby islands and Miller Rocks and Nelson Rocks during westerly and southerly conditions. It is exposed to conditions from the north to south-east, and receives tidal flow through Boomer Passage.

Throughout the monitoring program, seabed DLI was relatively high (2.8–24.9 mol/m^2/day) and daily average turbidity was relatively low (ranging from 0.2 and 5 NTU), with a few short-lived periods where turbidity levels increased. These peaks in turbidity coincided with a pronounced reduction in seabed DLI likely associated with the shallow water depth of the site, and on some occasions correlating with prevailing wind and wave conditions. Additionally, a short-term peak in turbidity and fall in seabed DLI was apparent during the passing of tropical cyclone Lincoln, which brought easterly winds and waves. Daily average water temperatures remained relatively stable over the monitoring program, with slightly lower temperatures recorded during winter (approximately 20–26°C) compared to summer (27–29°C).

Site	LANI
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	2.1 m LAT
Location Coordinates	462706 E, 7755467 N







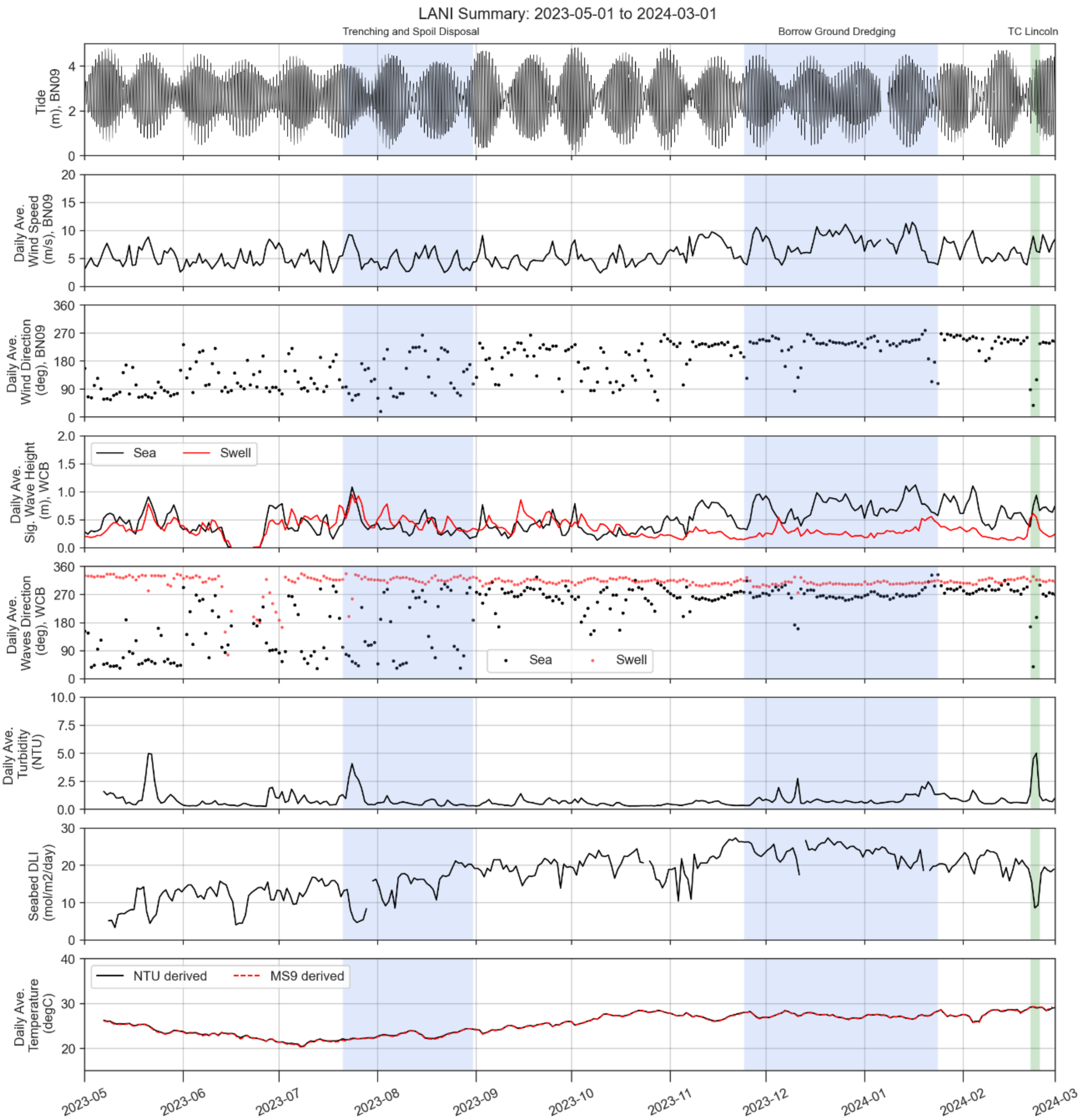


Figure 28: LANI site summary

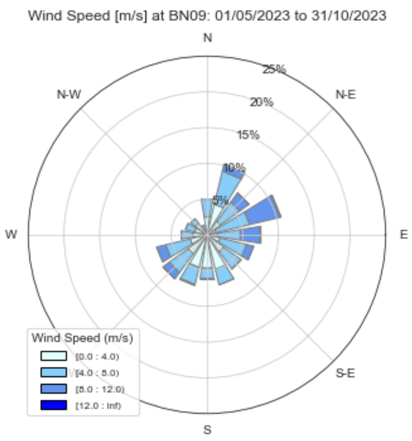
3.3.2.13. LEGD

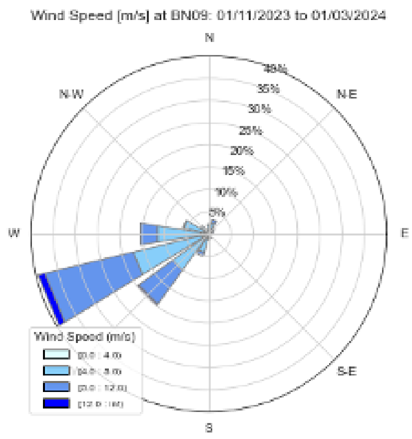
A summary of monitoring data recorded for LEGD is provided in Figure 29 and Section 3.3.2.1.

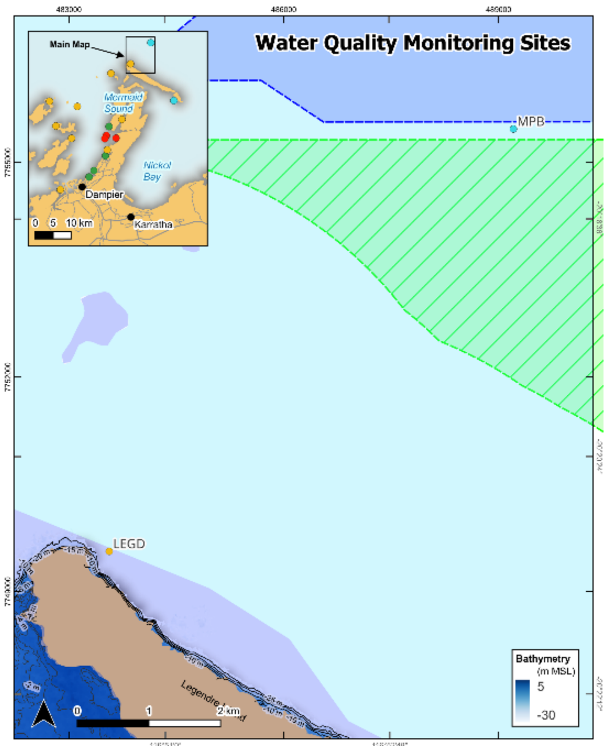
LEGD is located to the north of Legendre Island at the top of the archipelago in ~28.7 m LAT. The loggers were suspended mid-water at ~6.9 m that more accurately represented the depth and associated light conditions of the nearby benthic receptors. The site is located approximately 200 m from Legendre Island rocky cliffs. The site is exposed to weather conditions from the north west to south east with significant fetch.

Similarly to other Zone B sites located near offshore islands in the Dampier Archipelago, daily average turbidity was relatively low (ranging from 0 and 1.7 NTU) across both seasons. DLI readings were temporally variable, ranging from 1 to 16.8 mol/m^2/day, and showed a gradual availability of light to the seabed in summer. Despite the comparatively deeper water of the monitoring site, periods of higher wave heights and stronger wind events lead to slightly elevated turbidity and lower DLI. Comparably to site HAM3, large sections of DLI (between early-July to mid-August, early and mid-October and mid-December 2023) that encompassed portions of trenching and borrow ground dredging activities, did not pass QC assessment. On occasions, the surface buoy would submerge and pull the mid-water column loggers to deeper depths, and record data at deeper water depth than the nearby benthic receptors. Similarly to site LANI, daily average water temperatures remained relatively stable over the monitoring program, with slightly lower temperatures recorded during winter (approximately 21–27°C) compared to summer (27–29°C).

Site	LEGD
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal)
	Reference (Borrow Ground Dredging)
Site Depth	28.7 m LAT
Location Coordinates	483562 E, 7749562 N







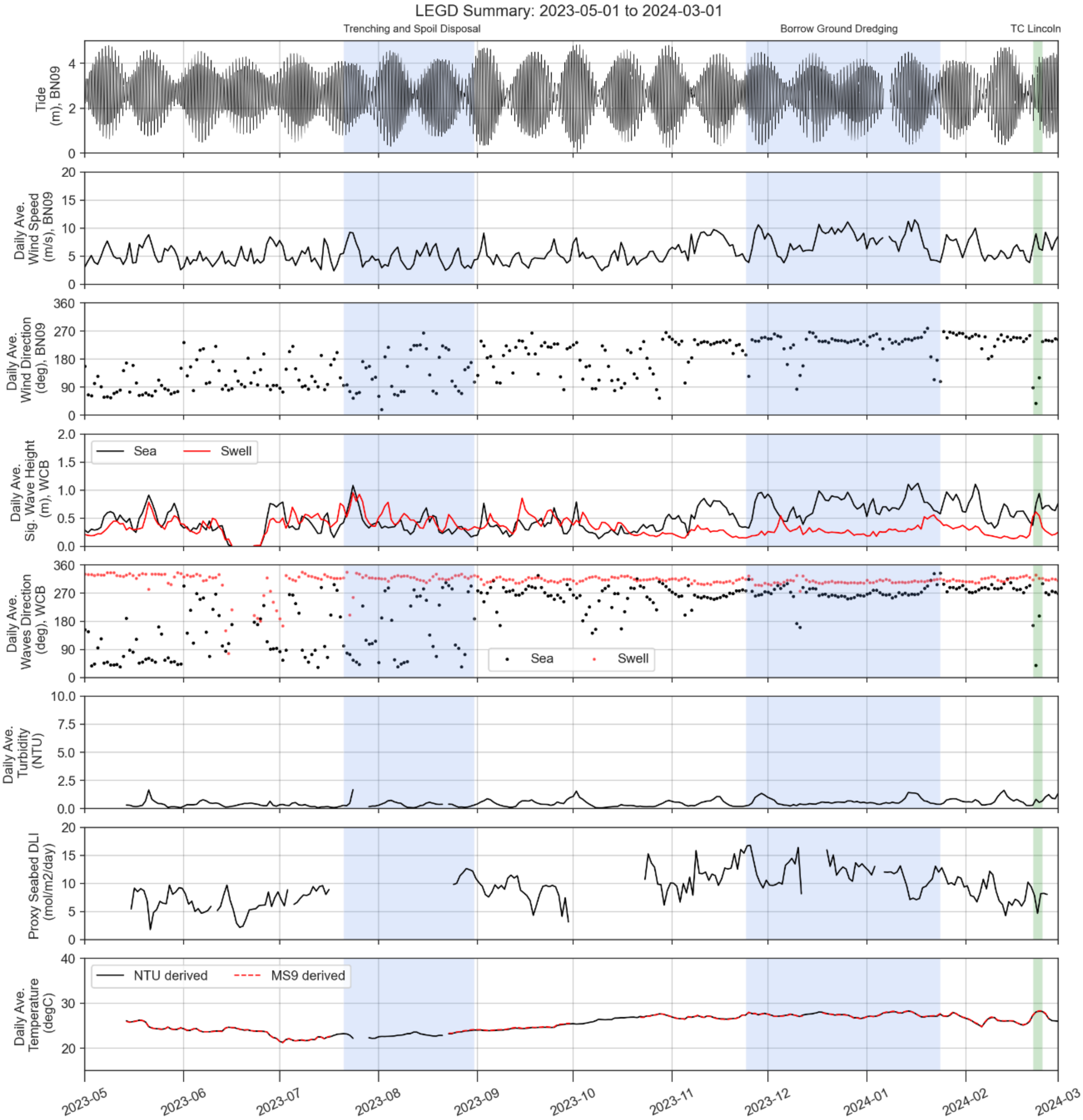


Figure 29: LEGD site summary

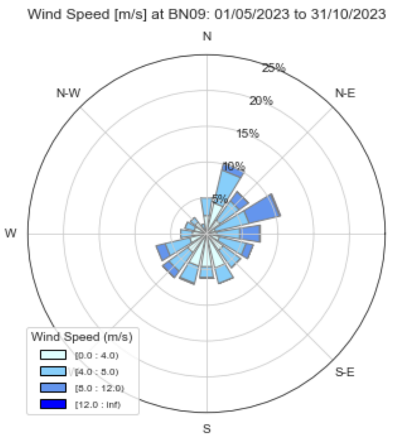
3.3.2.14. MAL2

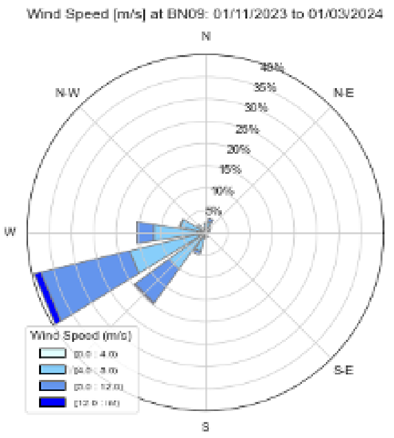
A summary of monitoring data recorded for MAL2 is provided in Figure 30 and Section 3.3.2.1.

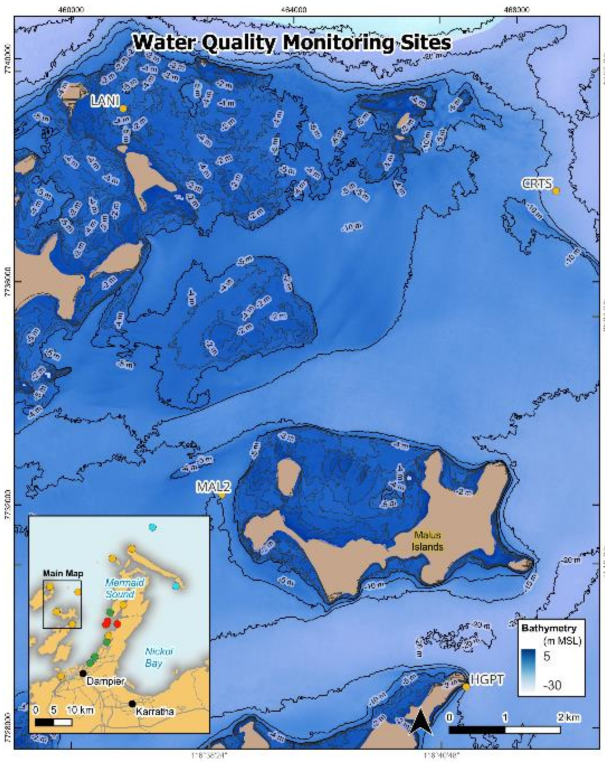
MAL2 is located to the west of Malus Island, adjacent to sandy shores in ~7.2 m LAT. The site is slightly protected from the nearby Rosemary Island during north westerlies, however, is predominately exposed to conditions from the north to south west. Currents and tidal flow around Malus Island are complex due to the bathymetry of the western island group of the Dampier Archipelago. Macroalgae is prevalent throughout the islands, particularly on shallow limestone pavements located on the northern and western portions of West Intercourse, West Lewis and Malus islands (Woodside, 2023) and was often observed on and removed from the seabed frame during maintenance trips throughout the monitoring program. Further, natural turbidity at the site can be exacerbated by shipping traffic (offshore vessels) that may transit between Malus Island and West Lewis Island to the south, and propellor wash generated at the emergency anchorages located in Malus Channel.

Overall, daily average turbidity was relatively low (ranging from 0.4 and 4.9 NTU) and showed relatively consistent turbidity readings in winter compared to summer. Seabed DLI readings were variable across the monitoring period (ranging from 0.6 and 16.6 mol/m^2/day), and showed a slight gradual increase in seabed DLI. The slight variability in turbidity and seabed DLI in summer coincided with changes in prevailing weather (i.e., high seas resulted in higher turbidity and lower seabed DLI). Daily average water temperatures were lower during the winter months (lowest in August reaching a minimum of approximately 20°C) and gradually increased over the summer months to a maximum of approximately 30°C in late-February 2024.

Site	MAL2
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	7.2 m LAT
Location Coordinates	462706 E, 7732185 N







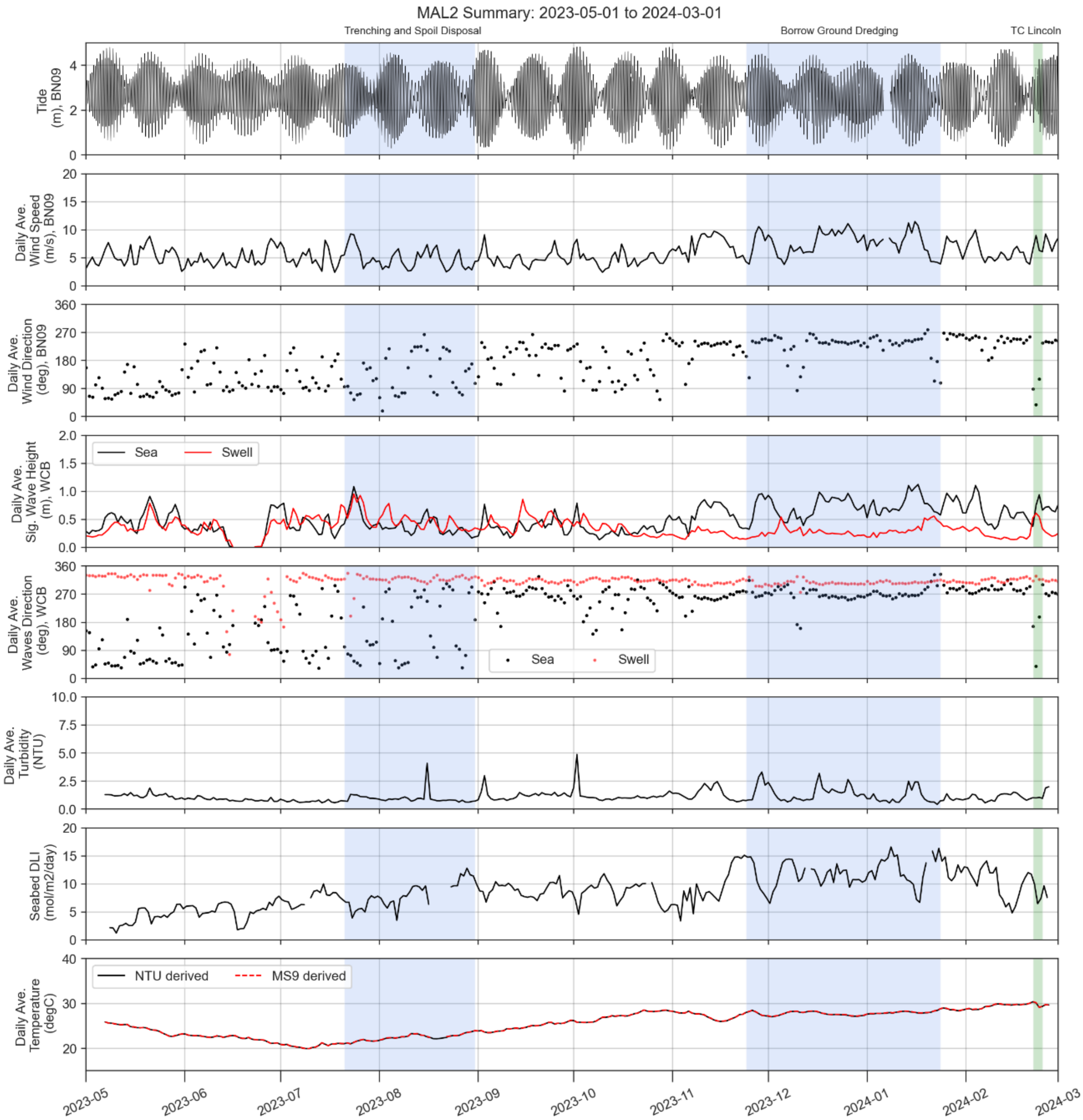


Figure 30: MAL2 site summary

3.3.3. Offshore Zone

3.3.3.1. Summary Statistics

Summary of turbidity (Table 11), seabed light (Table 12) and water temperature (Table 13) data collected for monitoring site MPB in the Offshore Zone is presented below.

Turbidity

In the Offshore Zone, turbidity across both seasons was relatively low, with a mean of 0.40 and 0.72 NTU in winter and summer, respectively (Table 11). Natural turbidity levels are typically lower in the offshore environment compared to the inner Dampier Archipelago.

Table 11: Offshore Zone summary statistics for turbidity (NTU): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
MPB	Informative	Trunkline trenching	Winter	0.40	0.31	0.54	0.92	0.30	13564
	Influence	Borrow ground dredging	Summer	0.72	0.40	0.83	2.29	1.14	12044

Seabed Light

Mean seabed DLI (at 37.7 m depth) in the Offshore MPB site remained relatively low and consistent between winter (0.60 mol/m^2/day) and summer (0.30 mol/m^2/day) months.

Table 12: Offshore Zone summary statistics for seabed DLI (mol/m^2/day): May 2023 to February 2024 (inclusive)

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Days*
MPB	Informative	Trunkline trenching	Winter	0.63	0.55	1.00	1.44	0.43	166
	Influence	Borrow ground dredging	Summer	0.31	0.21	0.52	0.86	0.26	124

** Number of days is presented instead of number of data points, as DLI only has one daily representative data point.*

Water Temperature

Mean water temperatures were relatively lower in winter (23.05°C) compared to summer (26.08°C; Table 13). Throughout the monitoring period, there were no peaks in water temperatures at this site that may have been associated with heat stress.

Table 13: Offshore Zone summary statistics for temperature (°C): May 2023 to February 2024 (inclusive)[5]

Site	Site Classification	Activity	Season	Mean	Median	80th Percentile	95th Percentile	Standard Deviation	No. of Data Points
MPB	Informative	Trunkline trenching	Winter	23.05	23.69	24.52	26.12	1.44	13584
	Influence	Borrow ground dredging	Summer	26.08	26.07	26.90	27.47	0.89	12102

[5] Statistics are provided for the IMO NTU-LPT measured statistics, as the IMO MS9-LPT logger is programmed to turn off between 20:30 and 03:30.

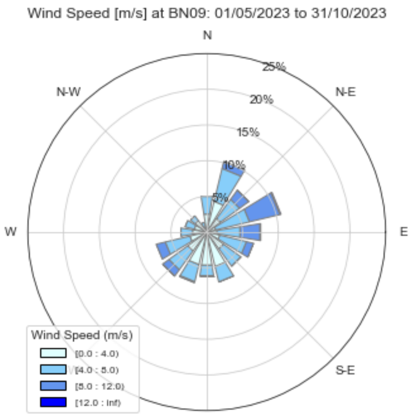
3.3.3.2. MPB

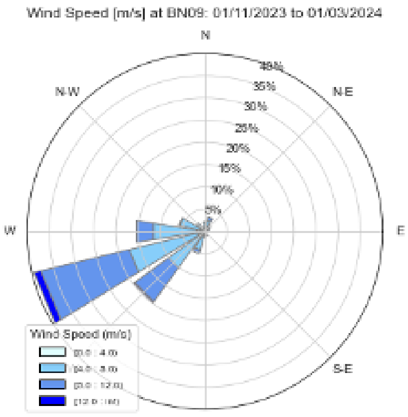
A summary of monitoring data recorded for MPB is provided in Figure 31 and Section 3.3.3.1.

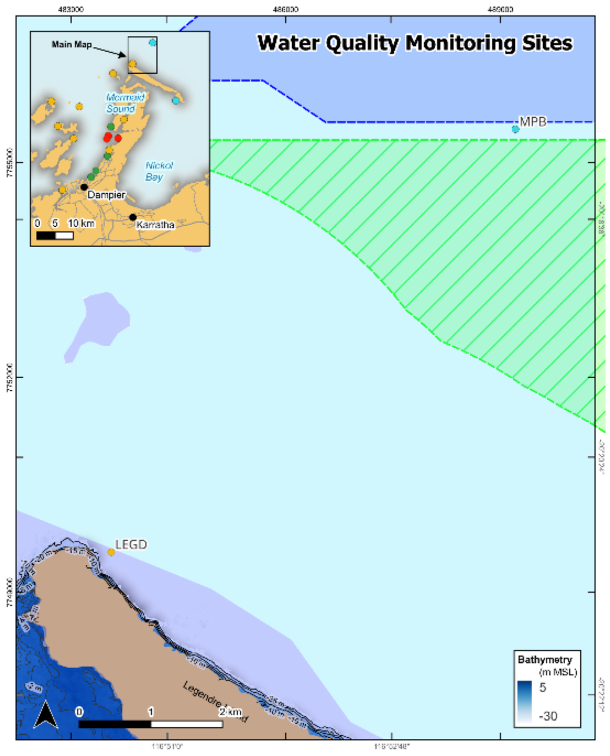
MPB is located ~ 9 km north of Legendre Island bordering the Habitat Protection Zone of the Dampier Australian Marine Park (AMP) and ~6.5 km north-east of Madeleine Shoals in ~37.7 m LAT. The Dampier AMP sediments, which are representative of the MPB site, are characterised by sands. The site is exposed in all local weather conditions, particularly wind waves from the west and east. The Dampier Archipelago provides some protection in south easterly to south westerly conditions.

Turbidity was relatively low (0.4–4.4 NTU) in both summer and winter, with two significant spikes in daily average turbidity reported in mid-January and mid-February 2024. Both spikes did not coincide with prevailing conditions and its distance from the Archipelago limits the influence of resuspended sediments from shorelines. Seabed DLI appears to be limited by depth as it ranged from 0–1.7 mol/m^2/day. At the start of the monitoring program (May 2023), daily average water temperatures were approximately 26°C and gradually decreased to approximately 21°C in July 2023 before gradually increasing in the summer months and ranged from 25–28°C.

Site	MPB
Ecological Zone	B
Site Classification	Reference (Trenching and Spoil Disposal) Reference (Borrow Ground Dredging)
Site Depth	37.7 m LAT
Location Coordinates	489206 E, 7755467 N







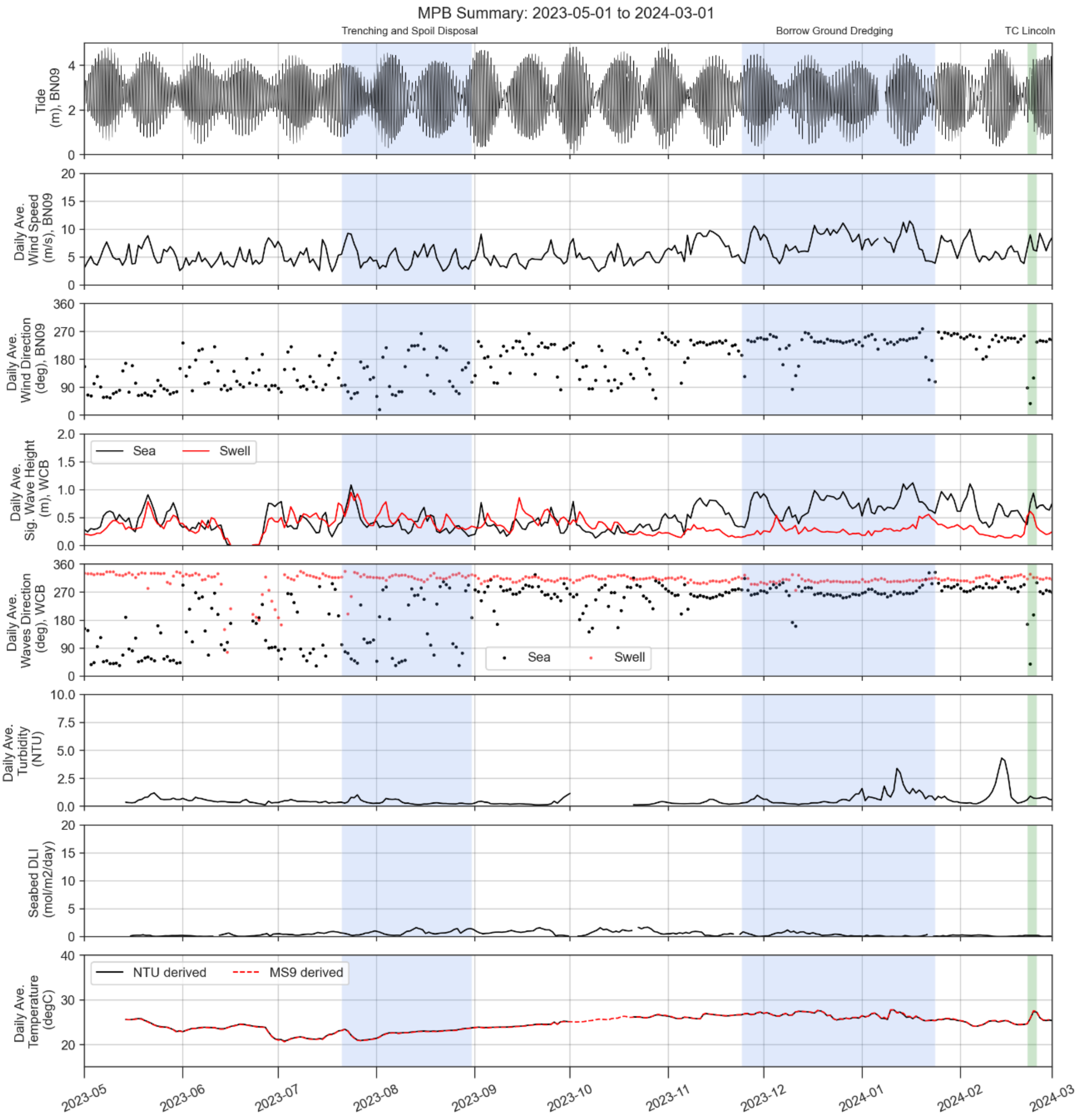


Figure 31: MPB site summary

3.4. Remote Sensing Imagery

Satellite imagery from three platforms (VIIRS, Sentinel and MODIS) were successfully downloaded for most days during trenching, spoil disposal, borrow ground dredging and backfill activities.

During trenching and spoil disposal activities, images were available (from at least one satellite platform) for all of the 41 days. When borrow ground dredging and backfill activities were occurring, images were not available on a single day, 11 December 2023, of the 61 days. During both activities, the satellite imagery downloaded occasionally captured cloud cover or other atmospheric interferences over the monitoring sites, or the orbital swathe did not capture data of the area of interest, and as such, these images could not be used for visual assessment of potential turbid plumes.

During trenching and spoil disposal activities (21 July 2023 and 31 August 2023), surface suspended sediment plumes were visible along the trunkline and/or at spoil grounds A/B and 2B on most days where data was available (e.g., Figure 32). Plumes generated from these activities appeared white in colour compared to the natural turbidity experienced in the region (particularly between Angel and Dolphin Islands and Legendre Island, and Nickol Bay) that appeared as yellow/light brown. Most surface turbid plumes were generally confined to within a few kilometres of the trenching and/or spoil grounds, while during some discrete periods, dispersed low concentration plumes appeared to have extended further in the trenching area (up to approximately 7-8 km long and approximately 2 km wide). At times, the turbid plumes appeared to be adjacent to monitoring sites (sites depended on where the activity was occurring). The plumes, however, were transient and generally dispersed in a south or south-westerly direction or dissipated within 24 hours.

Following the cessation of trenching and spoil disposal activities (between 1 September and 23 November 2023), natural turbid plumes in the nearshore areas were visible around the Dampier Archipelago and Burrup Peninsula (e.g., Figure 34).

During offshore borrow ground dredging and backfill activities (24 December 2023 and 25 January 2024), surface plumes were visible near the borrow ground and stretching east-west as it was dopped out of suspension along the prevailing current (e.g., Figure 33). Plumes generated from these activities appeared white in colour (Figure 33) compared to the natural turbidity experienced in the region (particularly between Angel and Dolphin Islands and Legendre Island, and Nickol Bay) that appeared as yellow/light brown.

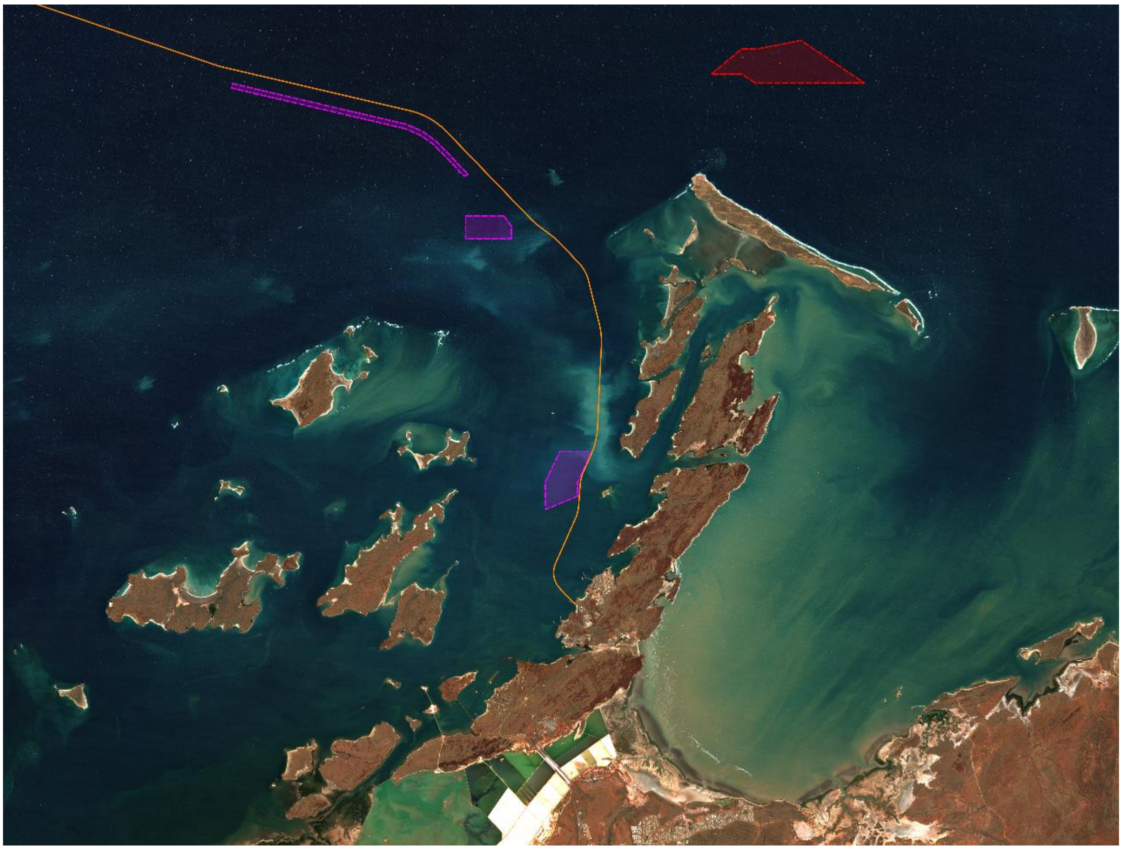


Figure 32: Satellite imagery captured from Sentinel-2 at 10:32 (local time) on 23 July 2023 (top image) and 22 August 2023 (bottom image) during trenching and spoil disposal activities. Trunkline is shown in orange, spoil grounds in purple and borrow ground in red

Figure 33: Satellite imagery captured from Sentinel-2 at 10:32 (local time) on 30 December 2023 (top image) and 9 January 2024 (bottom image), with visible plumes during borrow ground dredging. Trunkline is shown in orange, spoil grounds in purple and borrow ground in red

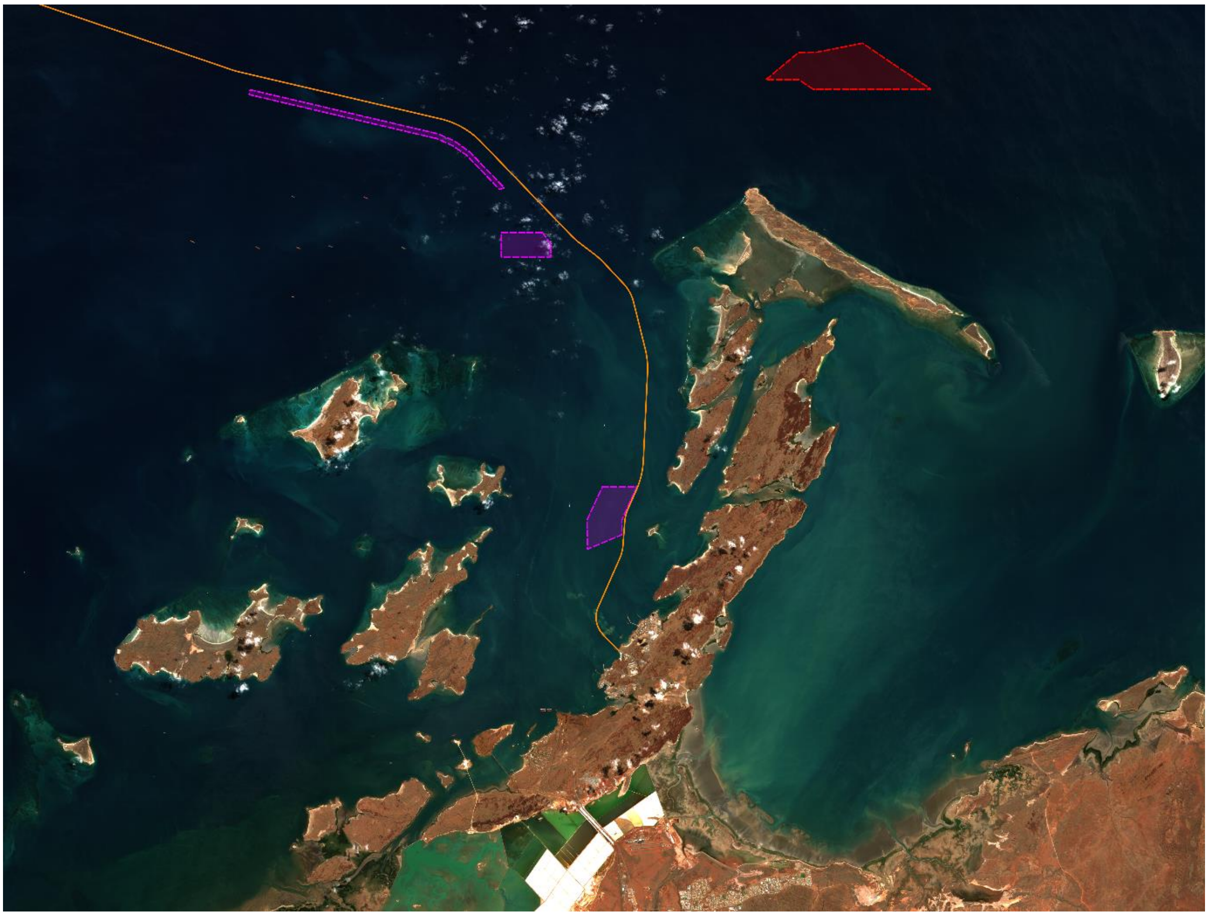


Figure 34: Satellite imagery captured from Sentinel-2 at 10:32 (local time) on 6 September 2023, when no trenching and spoil disposal activities occurred. Trunkline is shown in orange, spoil grounds in purple and borrow ground in red

4. Discussion and Conclusion

4.1. Water Quality Monitoring and Management

During trenching and spoil disposal and borrow ground dredging and backfill activities, there were no Tier 1, Tier 2 or Tier 3 trigger level exceedances recorded at any impact or influence monitoring site. Although DLI was below the respective trigger levels during discrete periods at most monitoring sites (Appendix B), there was no exceedance of a management trigger at any monitoring site since turbidity did not simultaneously reach the trigger level. The results obtained showed no discernible effect on water conditions as a result of trenching and spoil disposal and borrow ground dredging and backfill activities and as such, there is no impact pathway for change in the most sensitive receptors (e.g., coral communities, sponges). The variability in water conditions (i.e., wind, wave, tides, turbidity, water temperature and light) recorded across the Dampier Archipelago is driven by natural dynamics.

4.2. Natural Dynamics of Water Conditions

The Dampier Archipelago experiences distinct summer (typically occurring from November to April) and winter (May to October) seasons. The summer season is associated with high temperatures, strong west to south-westerly winds, smaller swells and periodic tropical cyclones that generate destructive winds, storm surges, high rainfall and extreme short-term turbidity spikes (Pearce et al., 2003). Winter is characterised by relatively lower temperatures and rainfall, but relatively larger swells than those in summer, prevailing winds from the east, and less likelihood of storm surges. Overall, the water quality data collected during the monitoring period reflected the natural seasonal dynamics of water conditions expected, with relatively higher wind speed predominantly from the south-west, and higher water temperature in the summer months between November 2023 and March 2024 (mean; 28.2°C) compared to the winter season (from May to October 2023) when easterly winds predominated and relatively lower water temperatures (23.5°C) were recorded.

The only occurrence of tropical cyclones during the monitoring period was recorded in summer (February 2024). However, during the monitoring period there was very little rainfall recorded on three occasions in summer and only one record in June 2023 during winter. Also of note was that the recorded swell in Zone A was slightly higher during summer than winter, contrary to what was expected.

The prevailing south-west winds during summer, which were higher in intensity and frequency than the easterly winds dominating during winter and entailed larger wind fetch, likely caused a higher degree of sediment resuspension (Dahl et al., 2018). Indeed, the higher seawater temperatures during summer likely resulted in enhanced phytoplankton productivity and thereby, increased turbidity (Liu et al., 2022). Overall, higher turbidity levels were observed during summer (overall mean: 1.9 NTU) than in winter (1.4 NTU). Although relatively higher swell and winds were observed during summer, driven by the occasional storm and tropical cyclone events (Pearce, 2003; Gilmour et al., 2006; Travaglione, 2022), seasonal differences in turbidity levels can also be explained by the existence of different ecological zones within Dampier Archipelago due to zonation such as differences in weather, mixing, and freshwater inputs.

The natural environment in Dampier Archipelago is characterised by a cross-shelf gradient of increasing turbidity from the Offshore Zone (overall mean: 0.5 NTU) to the coastline (Zone A: 2.6 NTU) (Simpson, 1988; Pearce et al., 2003), with intermediate turbidity in Zone B (1.4 NTU). These results are comparable to the turbidity levels reported in the baseline report, in which turbidity was higher in Zone A (daily average in summer and winter; 2.2 and 3.2 NTU) than Zone B (1.5 and 1.9 NTU) and Offshore Zone (0.6 and 0.3 NTU) (Woodside, 2023c). This natural pattern was driven by the increasing influence of wind-driven waves (generally <2 m in height) and macrotidal water fluctuations towards shallower (<10 m) areas near the coastline that result in higher shear water velocity increasing sediment resuspension and turbidity (Forde, 1985).

The semidiurnal tides ranging between 1.9 and 5.1 m across the year within the Dampier Archipelago play a key role in generating turbidity and its dispersal throughout the region (Pearce et al., 2003). The natural patterns observed in seabed DLI across the three Zones, with higher seabed DLI in Zone B (overall mean; 6.3 mol/m^2/day) than in Zone A (3.7 mol/m^2/day) and Offshore Zone (0.45 mol/m^2/day), were primarily related to the turbidity levels and water depth driving the exponential reduction of irradiance with increasing water depth.

Within Zone A, the sites located further south-west (KGBY, MIDI and SUP2) reported higher turbidity and lower seabed DLI levels than the sites located further north-east (NWIT and SWIT). These sites, which are along the mainland Burrup Peninsula, are generally exposed to prevailing wind, waves and tidal movement through Mermaid Sound, vessel activities, dust from adjacent iron ore facilities (WorleyParsons, 2009), and increased local sediment inputs during summer from rainfall events. Natural turbidity and seabed DLI at NWIT and SWIT are likely influenced by tidal flushing from Withnell Bay, and the north-south tidal flow along the Flying Foam Passage may also have contributed to increased turbidity within these monitoring sites.

Similarly, sites COBN, CONI, GIDI and FFP1 in Zone B also had relatively higher turbidity and lower seabed DLI levels compared to the other sites surveyed in Zone B, likely related to the influence of the Flying Foam Passage during falling tides before turning northwards and passing offshore of Gidley Island (Stoddart and Anstee, 2004), together with other tidal flows in the area (i.e., Searipple Passage), enhancing water flow and the resuspension of sediments. The other sites within Zone B (ANG2, CONI2, CRTS, HAM3, LANI, LEGD and MAL2) that are located near the offshore islands or in open ocean adjacent to Burrup Peninsula had relatively lower turbidity and higher seabed DLI levels likely due to the relatively lower effect of hydrodynamic energy or resuspension of sediments prevailing within the 2 to 29 m water depth range found in Zone B. The highest seabed DLI levels were measured at site LANI, which could be explained by its location in a sheltered environment in 2 m water depth.

The only site located in the Offshore Zone (MPB) had one of the lowest turbidity and seabed DLI levels recorded, which could be explained by its location in deep waters (37.7 m). Although the wave height in the Offshore Zone (up to 1 m) was higher than in Zone A (up to 0.5 m), the Offshore Zone is characterised by relatively lower sediment resuspension owing to the higher water depth and the coarser nature of sediments originating from coralline biota that are less likely to be resuspended (Gilmour et al., 2006). The location of the Offshore Zone, which is approximately 8 km from the closest land (Legendre Island), also contributes to maintaining relatively lower turbidity and seabed DLI levels due to the limited influence of turbid waters originated in the coastline.

The occurrence of sporadic extreme events recorded during the monitoring period such as tropical cyclone Lincoln that passed through the region (approximately 300 km north of the monitoring sites) between 22 and 23 February 2024, did not have a profound impact on local water conditions. This was illustrated by the change in wind and wave directions from south-west to east, and the slight increase in seawater temperature in Zones B and Offshore Zone during the tropical low. However, the lack of major peaks in wind speed, wave height, turbidity and seabed DLI across all monitoring sites suggests that the cyclone did not have an impact on the natural dynamics of water conditions. Furthermore, the rainfall event documented in June 2023 may have led to the observed short-term spike in turbidity at sites KGBY, GIDI and LANI located adjacent to shoreline in the mainland as a result of terrestrial/freshwater runoff and seepage.

4.3. Spatial and Temporal Evolution of Plumes

The use of satellite-based remote sensing imagery to supplement the real time monitoring of in-situ turbidity proved valuable as it captured the spatial extent of visible surface suspended sediment plumes during most days of dredging and disposal activities.

The satellite images captured during trenching and spoil disposal activities showed that the dispersal of turbid plumes followed a general south to south-westerly direction along the trunkline route, as expected given the trenching activity. This suggests that plumes were effectively dissipated by water turbulence such as wind-driven waves, currents and tides, which acted as natural dispersal mechanisms of suspended sediments and thereby, likely lessened potential impacts within the trenching and spoil ground areas. This natural dispersion action also likely reduced the turbidity at adjacent sensitive receptors, as represented by the impact and influence monitoring sites.

The visual analysis of consecutive satellite imagery clearly showed the rapid dispersal of plumes. For instance, Figure 32 showed the evolution of a turbid plume that originated along the trunkline south of spoil ground A/B. Around four hours later, the plume had moved approximately 3.5 km south adjacent to site SWIT. The dispersal of the plume on this day (22 August 2023) is partially due to the extended trenching activity taking place along the southern section of the trunkline route. Additionally, wind speeds were 9 km/hr from the north-northeast (BoM 2024c), which is typical of the conditions experienced in the Pilbara region during the winter months. Although no satellite images of the late afternoon were available, images of the following day showed that the water quality returned to natural background conditions following the cessation of activities.

As demonstrated by the in-situ measurements and satellite imagery, the onset and recovery from suspended sediment events across all sites was usually rapid and short-lived. The seabed sediment grain size in the dredging footprint comprised predominantly of sand (60–2000 µm) and small fractions of clay (<2 µm), silt (2–60 µm) and gravel (>2000 µm) (Woodside, 2006; Advisian, 2019). As such, plumes generated by trenching and spoil disposal and borrow ground dredging and backfill activities had a transient nature (i.e., rapid settlement of suspended sediment and minimal resuspension of sediment after settling) which was consistent with the coarse nature of the seabed sediments, resulting in the rapid dispersal of plumes (likely within 24 hours following the cessation of activities). The relatively rapid dispersal and dilution of the plume due to the nature of the dredging activity also reduced the likelihood of significant impacts to BCH inhabiting the nearby monitoring sites, in particular photosynthetic, autotrophic and sessile organisms (Nugues and Roberts, 2002; Powilleit et al., 2006; Jones et al., 2016).

4.4. Conclusion

Overall, the water quality monitoring program for the Scarborough Project was implemented in accordance with the DSDMP and no Tier 1, Tier 2 or Tier 3 trigger level exceedances were recorded at any impact or influence monitoring site during trenching and spoil disposal and borrow ground dredging and backfill activities. The results showed no discernible effect on water conditions as a result of these activities and as such, there is no impact pathway for change in the most sensitive receptors (e.g., coral communities, sponges).

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Appendix A. Dates of Installation, Scheduled/Reactive Maintenance Trips and Retrieval of Water Quality Instruments for each Monitoring Site

Site Name	Site ID	Ecological Zone	Site Depth (m LAT)	Approximate Coordinates		Date Installed, Scheduled/Reactive Maintenance and Retrieved
				Easting (m)	Northing (m)	
Conzinc Island	CONI	B	4.6	476808	7729505	06/05/2023 Installation 22–24/08/2023 Scheduled Maintenance 20/10/2023 Scheduled Maintenance 10–14/12/2023 Scheduled Maintenance 21/01/2024 Scheduled Maintenance 29/02/2024 Retrieval
Conzinc Island 2	CONI2	B	4.0	476370	7728639	06/05/2023 Installation 03/07/2023 Scheduled Maintenance 23/08/2023 Scheduled Maintenance 26/10/2023 Scheduled Maintenance 10/12/2023 Scheduled Maintenance 24/01/2024 Scheduled Maintenance 04/03/2024 Retrieval
Conzinc Bay North	COBN	B	5.2	479515	7728801	06/05/2023 Installation 09/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 27/10/2023 Scheduled Maintenance 11/12/2023 Scheduled Maintenance 24/01/2024 Scheduled Maintenance 29/02/2024 Retrieval
Supply Base	SUP2	A	6.1	473311	7719704	05/05/2023 Installation 03/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 25/10/2023 Scheduled Maintenance 11/12/2023 Scheduled Maintenance 23/01/2024 Scheduled Maintenance 28/02/2024 Retrieval
King Bay	KGBY	A	6.7	471969	7717955	05/05/2023 Installation 09/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 25/10/2023 Scheduled Maintenance 09/12/2023 Scheduled Maintenance 24/01/2024 Scheduled Maintenance 28/02/2024 Retrieval
South Withnell Bay	SWIT	A	5.8	476560	7723855	05/05/2023 Installation 03/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 26/10/2023 Scheduled Maintenance 11/12/2023 Scheduled Maintenance 24/01/2024 Scheduled Maintenance 01/03/2024 Retrieval
Angel Island	ANG2	B	7.3	477519	7732026	06/05/2023 Installation 08/07/2023 Scheduled Maintenance 23/08/2023 Scheduled Maintenance 27/10/2023 Scheduled Maintenance 10/12/2023 Scheduled Maintenance 21/01/2024 Scheduled Maintenance 28/02/2024 Retrieval
Hauy Island	HAUY	B	9.0	495637	7739271	10/05/2023 Installation 04/07/2023 Scheduled Maintenance

Site Name	Site ID	Ecological Zone	Site Depth (m LAT)	Approximate Coordinates		Date Installed, Scheduled/Reactive Maintenance and Retrieved
				Easting (m)	Northing (m)	
						21/08/2023 Scheduled Maintenance 23/10/2023 Scheduled Maintenance 09/12/2023 Scheduled Maintenance 04/01/2024 Reactive Maintenance 02/03/2024 Retrieval
Mid Intercourse Island	MIDI	A	2.5	463966	7714400	07/05/2023 Installation 09/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 25/10/2023 Scheduled Maintenance 11/12/2023 Scheduled Maintenance 19/01/2024 Scheduled Maintenance 29/02/2024 Retrieval
North Withnell Bay	NWIT	A	6.6	477052	7725515	05/05/2023 Installation 03/07/2023 Scheduled Maintenance 24/08/2023 Scheduled Maintenance 26/10/2023 Scheduled Maintenance 11/12/2023 Scheduled Maintenance 24/01/2024 Scheduled Maintenance 01/03/2024 Retrieval
Flying Foam Passage	FFP1	B	15.9	481127	7734025	08/05/2023 Installation 24/08/2023 Scheduled Maintenance 23/10/2023 Scheduled Maintenance 09/12/2023 Scheduled Maintenance 04/01/2023 Reactive Maintenance 21/01/2024 Scheduled Maintenance 02/03/2024 Retrieval
Gidley island	GIDI	B	8.2	478586	7736417	08/05/2023 Installation 08/07/2023 Scheduled Maintenance 23/08/2023 Scheduled Maintenance 20/10/2023 Scheduled Maintenance 23/11/2023 Reactive Maintenance 10/12/2023 Scheduled Maintenance 21/01/2024 Scheduled Maintenance 28/02/2024 Retrieval
Hamersley Shoal	HAM3	B	19.3	478089	7746873	11/05/2023 Installation 08/07/2023 Scheduled Maintenance 21/08/2023 Scheduled Maintenance 22/10/2023 Scheduled Maintenance 21/11/2023 Reactive Maintenance 23/01/2024 Scheduled Maintenance 05/03/2024 Retrieval
High Point	HGPT	B	7.4	467093	7728731	08/05/2023 Installation 22/08/2023 Scheduled Maintenance 25/10/2023 Scheduled Maintenance 08/12/2023 Scheduled Maintenance 20/01/2024 Scheduled Maintenance 27/02/2024 Retrieval
Courtney Shoal	CRTS	B	15.9	468703	7737627	10/05/2023 Installation 11/06/2023 Reactive Maintenance 22/08/2023 Scheduled Maintenance 24/10/2023 Scheduled Maintenance 12/12/2023 Scheduled Maintenance 20–23/01/2024 Scheduled Maintenance 03/03/2024 Retrieval
Lady Nora Island	LANI	B	2.1	460932	7739109	07/05/2023 Installation 29/07/2023 Reactive Maintenance

Site Name	Site ID	Ecological Zone	Site Depth (m LAT)	Approximate Coordinates		Date Installed, Scheduled/Reactive Maintenance and Retrieved
				Easting (m)	Northing (m)	
						22/08/2023 Scheduled Maintenance 24/10/2023 Scheduled Maintenance 12/12/2023 Scheduled Maintenance 20/01/2024 Scheduled Maintenance 03/03/2024 Retrieval
Legendre Island	LEGD	B	28.7	483562	7749562	14/05/2023 Installation 10/06/2023 Reactive Maintenance 04/07/2023 Scheduled Maintenance 29/07/2023 Reactive Maintenance 21–23/08/2023 Scheduled Maintenance 21–22/10/2023 Scheduled Maintenance 12/12/2023 Scheduled Maintenance 04/01/2024 Reactive Maintenance 06/03/2024 Retrieval
Malus Islands	MAL2	B	7.2	462706	7732185	07–08/05/2023 Installation 09/07/2023 Scheduled Maintenance 22/08/2023 Scheduled Maintenance 24/10/2023 Scheduled Maintenance 13/12/2023 Scheduled Maintenance 20/01/2024 Scheduled Maintenance 27/02/2024 Retrieval
Madeline Shoal	MPB	Offshore	27.7	489206	7755467	14/05/2023 Installation 11/06/2023 Reactive Maintenance 21/08/2023 Scheduled Maintenance 21/10/2023 Scheduled Maintenance 22/01/2024 Scheduled Maintenance 06/03/2024 Retrieval

Appendix B. Management Trigger Assessment of Benthic Light and Turbidity Data per Monitoring Site using Running Means Analysis

Appendix B.1. KGBY

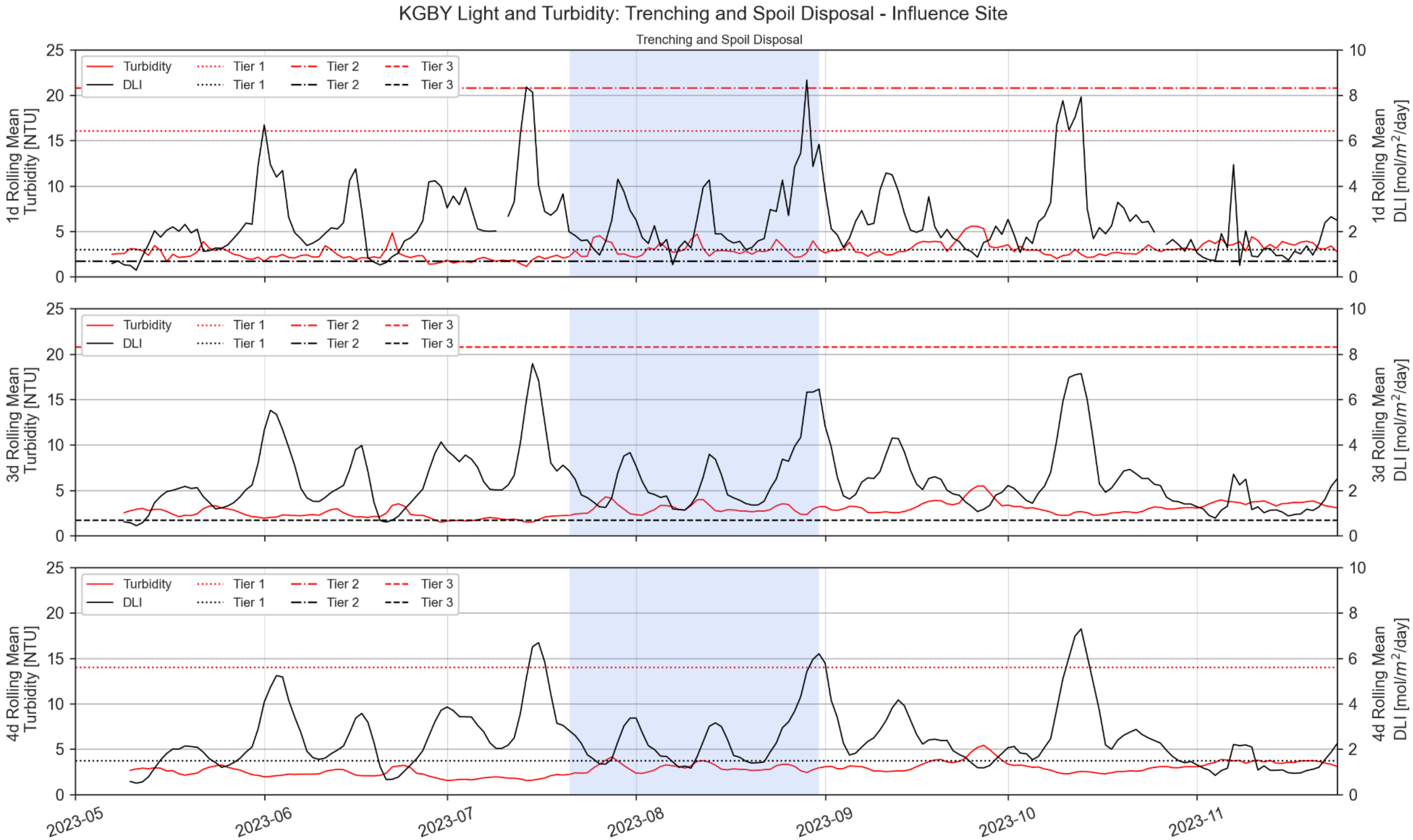

Figure B.1: Assessment of turbidity and light parameters at KGBY against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

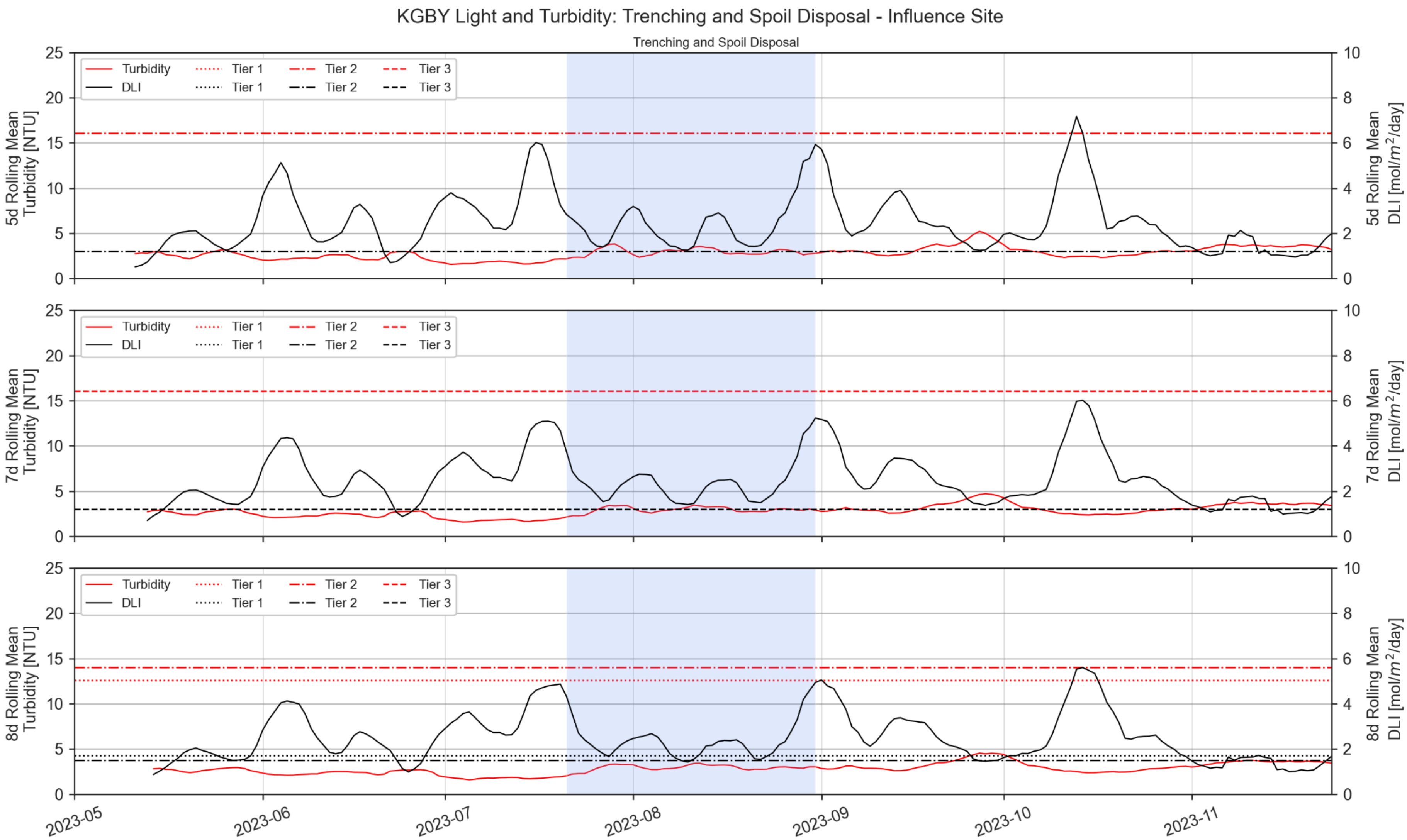

Figure B.2: Assessment of turbidity and light parameters at KGBY against 5-day, 7-day and 8-day Water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

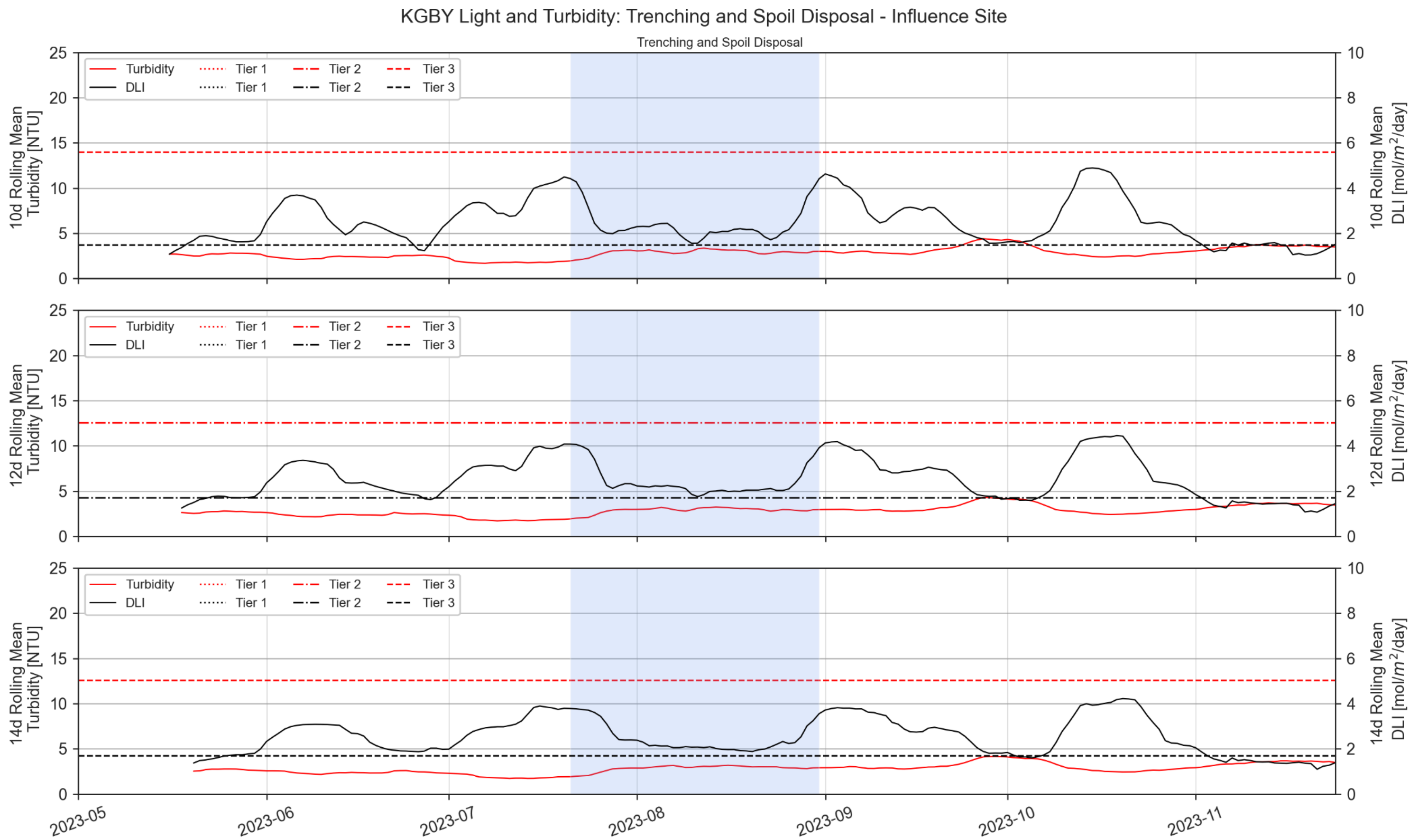

Figure B.3: Assessment of turbidity and light parameters at KGBY against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

Appendix B.2. SUP2

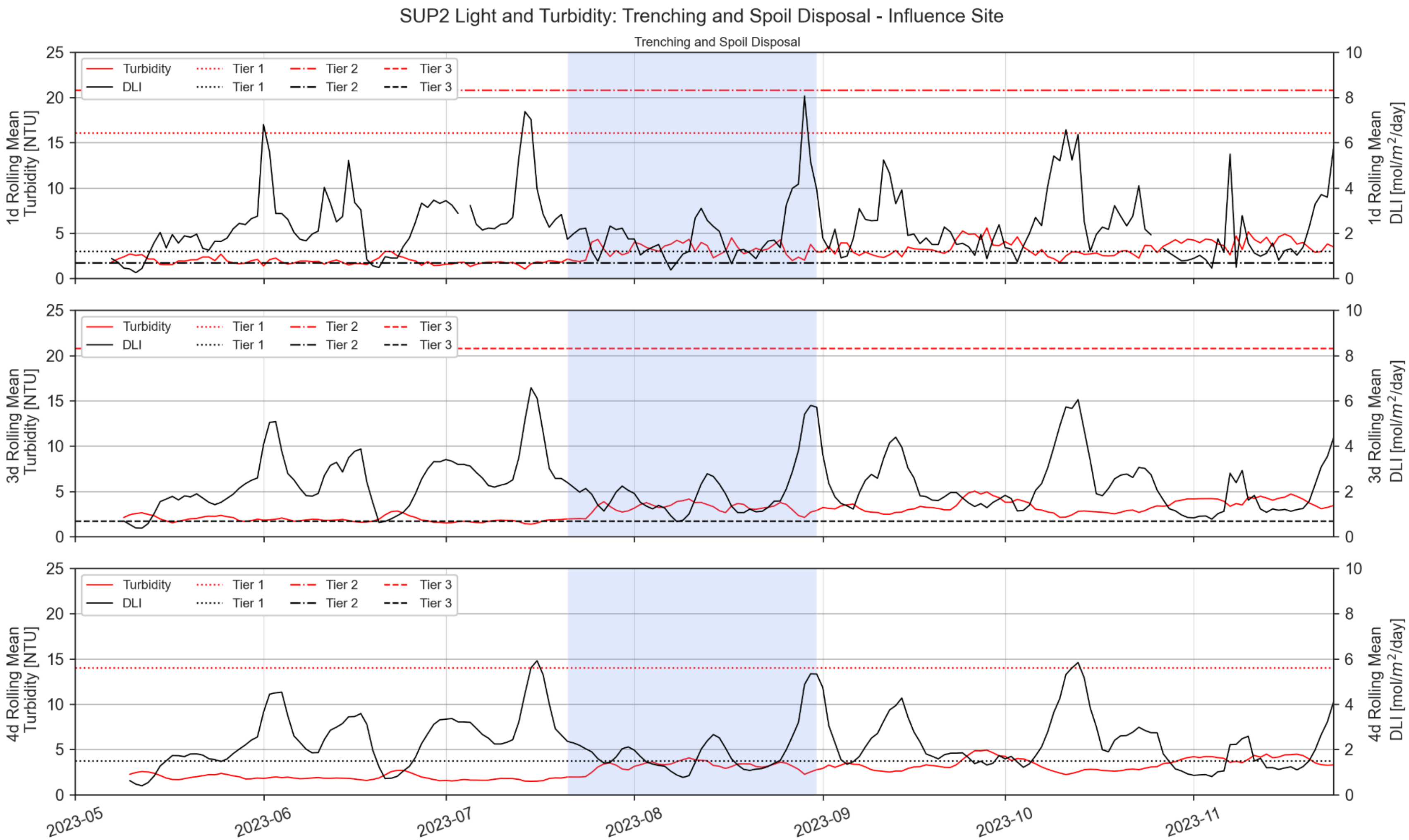

Figure B.4: Assessment of turbidity and light parameters at SUP2 against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

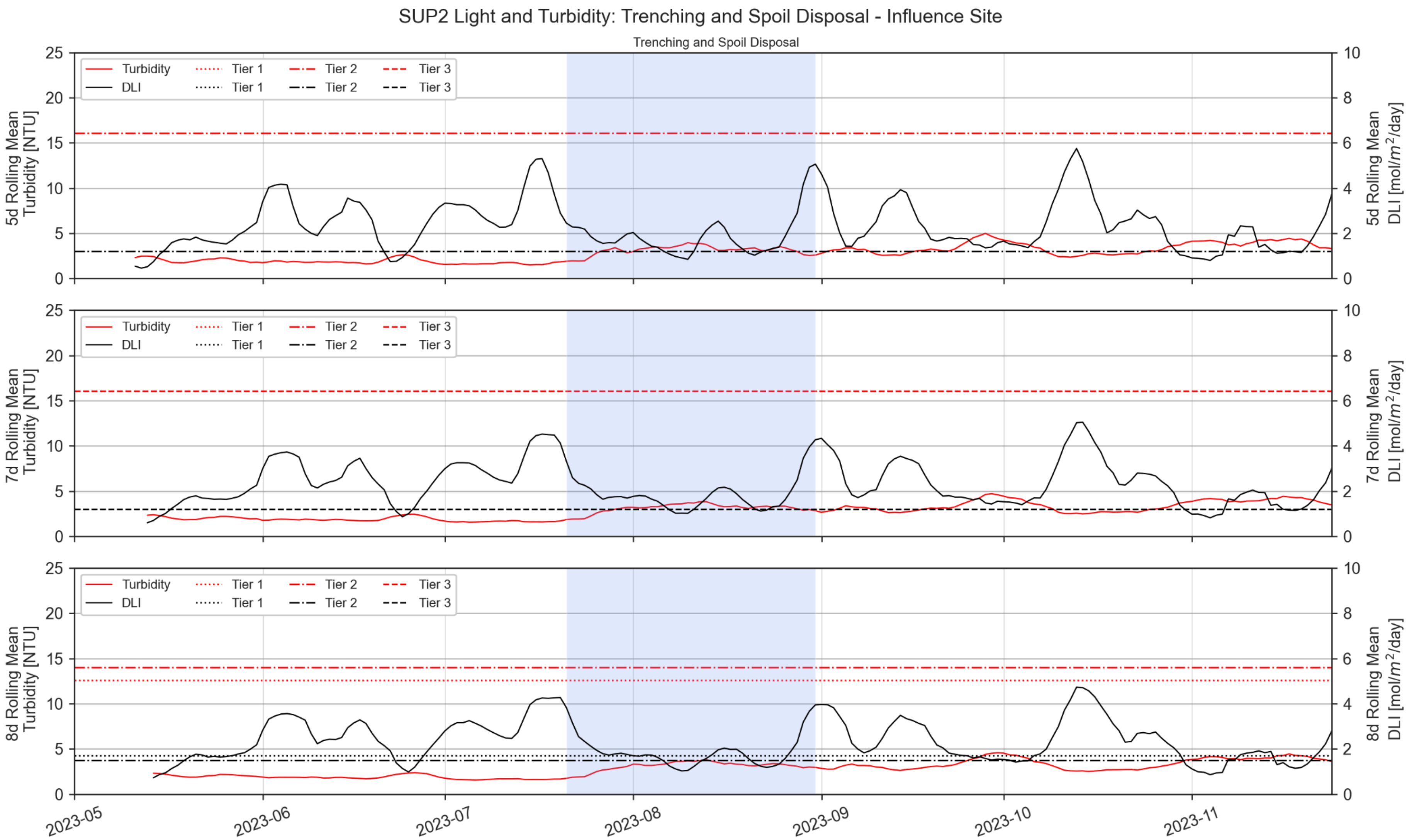

Figure B.5: Assessment of turbidity and light parameters at SUP2 against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

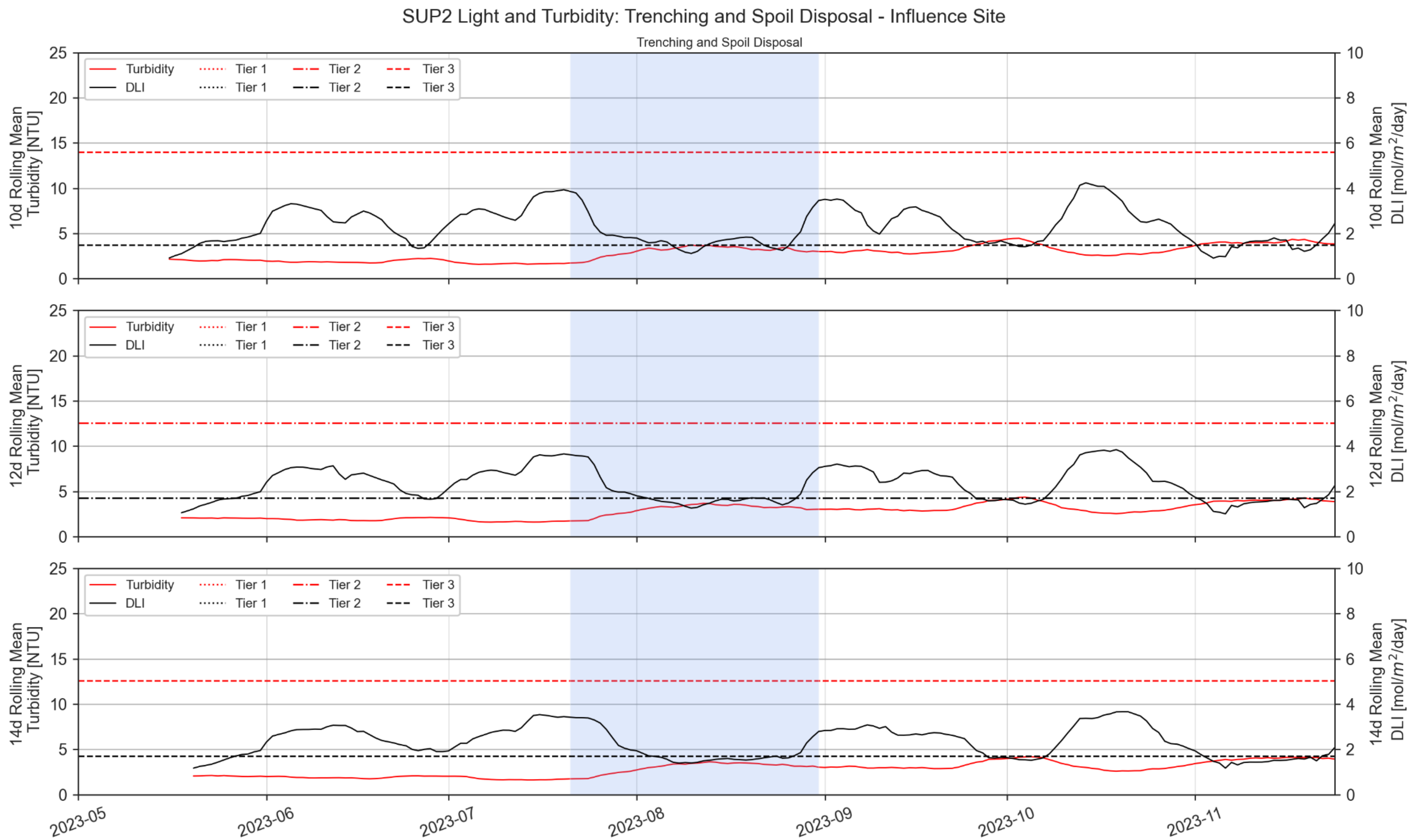

Figure B.6: Assessment of turbidity and light parameters at SUP2 against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

Appendix B.3. SWIT

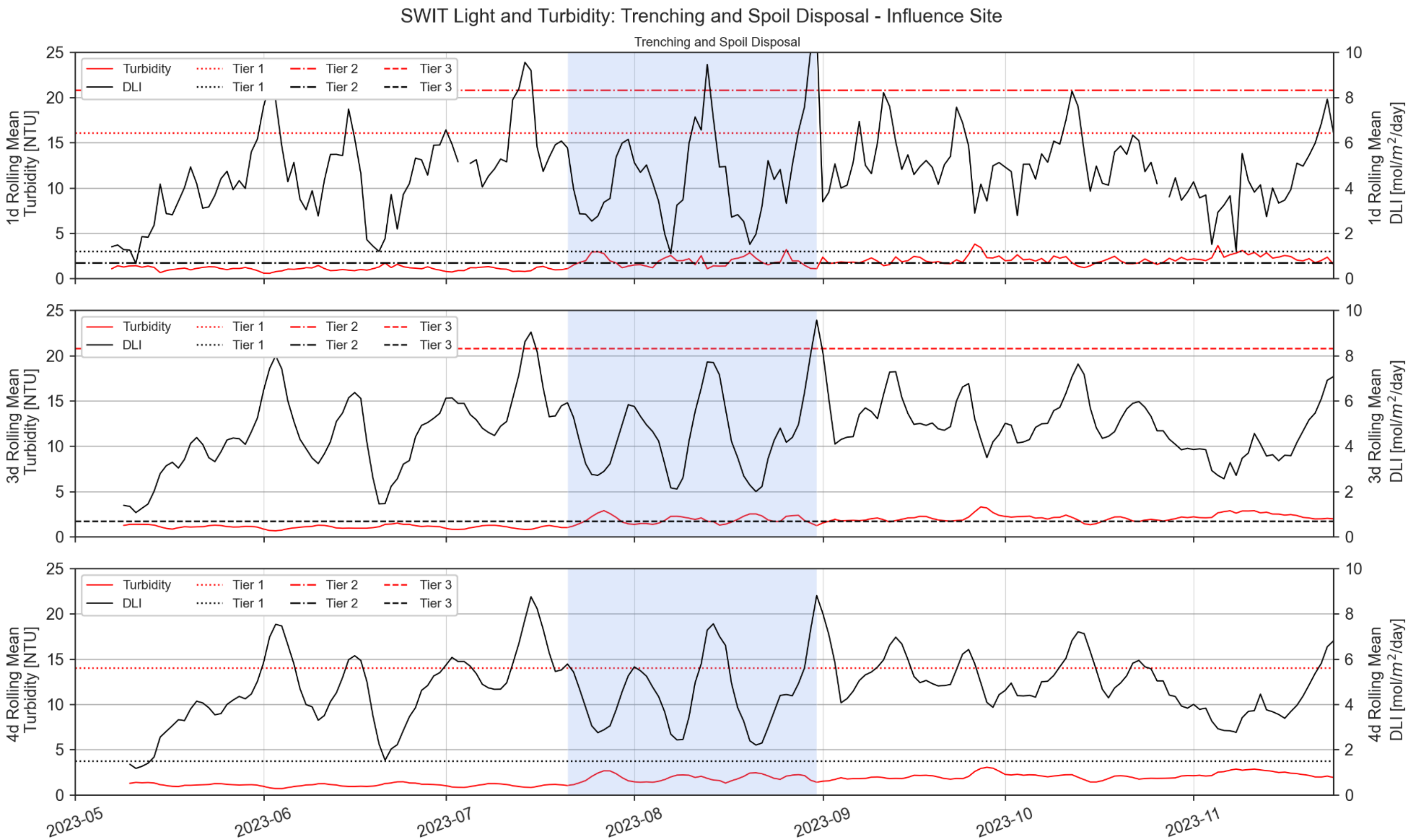

Figure B.7: Assessment of turbidity and light parameters at SWIT against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

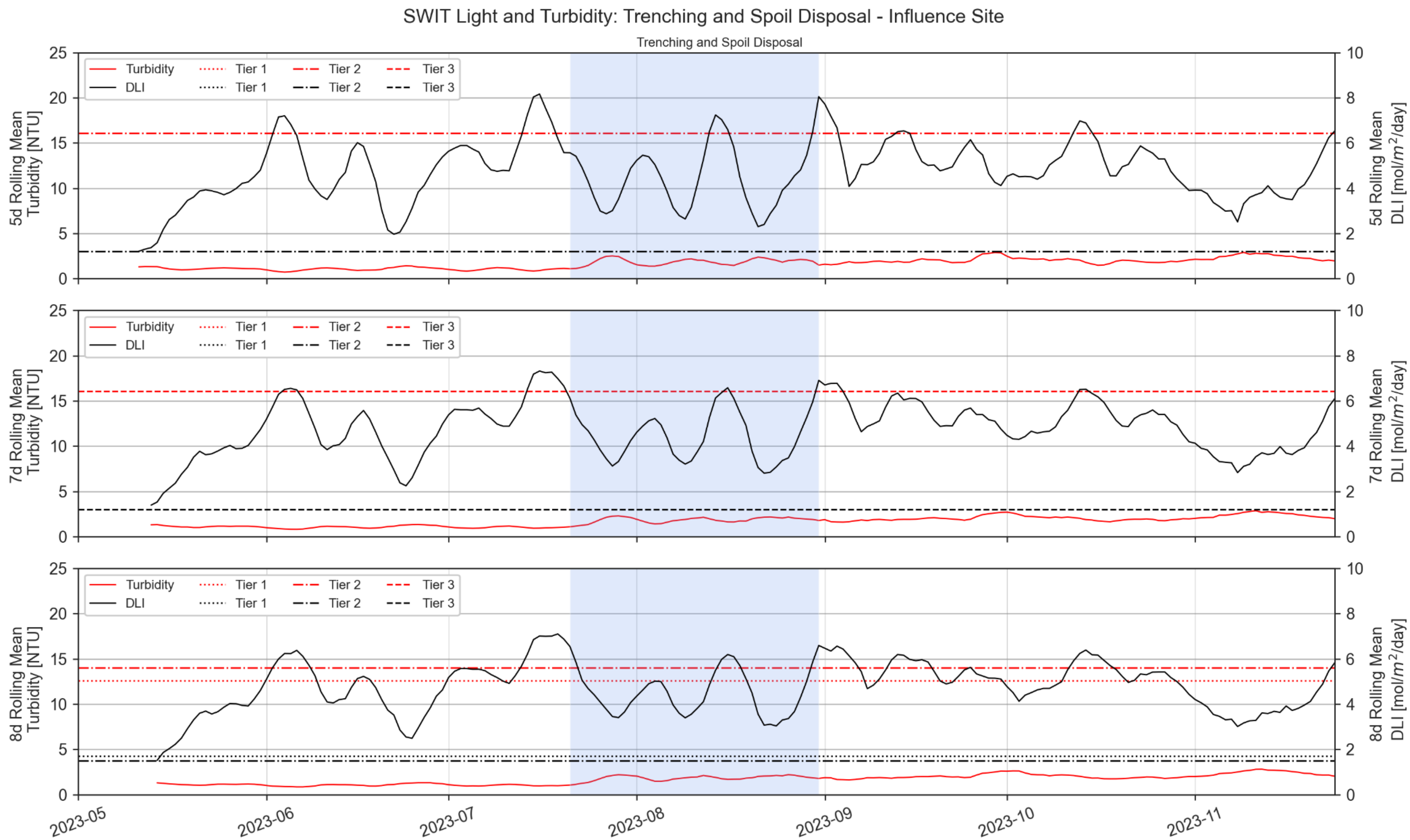

Figure B.8: Assessment of turbidity and light parameters at SWIT against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

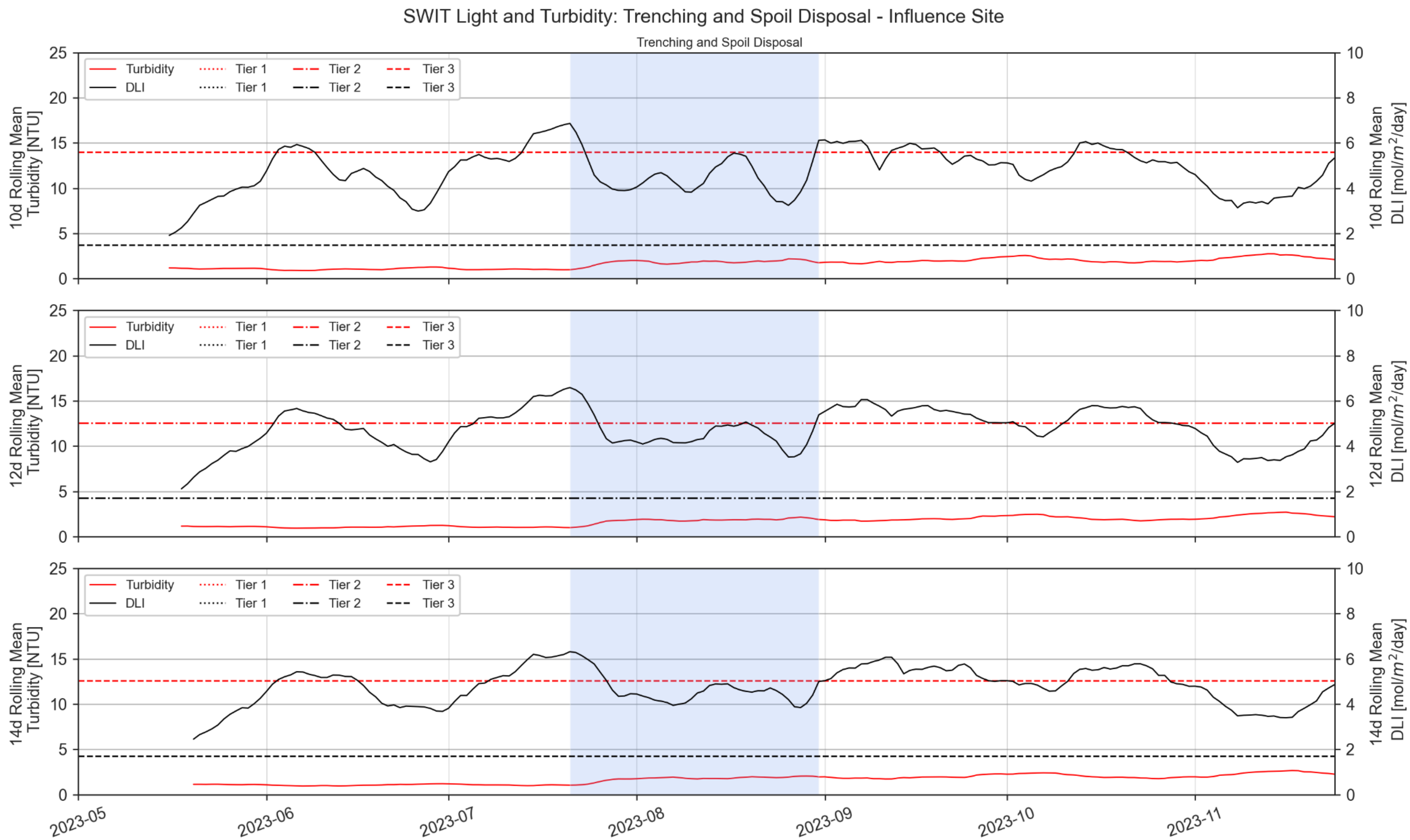

Figure B.9: Assessment of turbidity and light parameters at SWIT against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone A during trenching and spoil disposal activity

Appendix B.4. ANG2

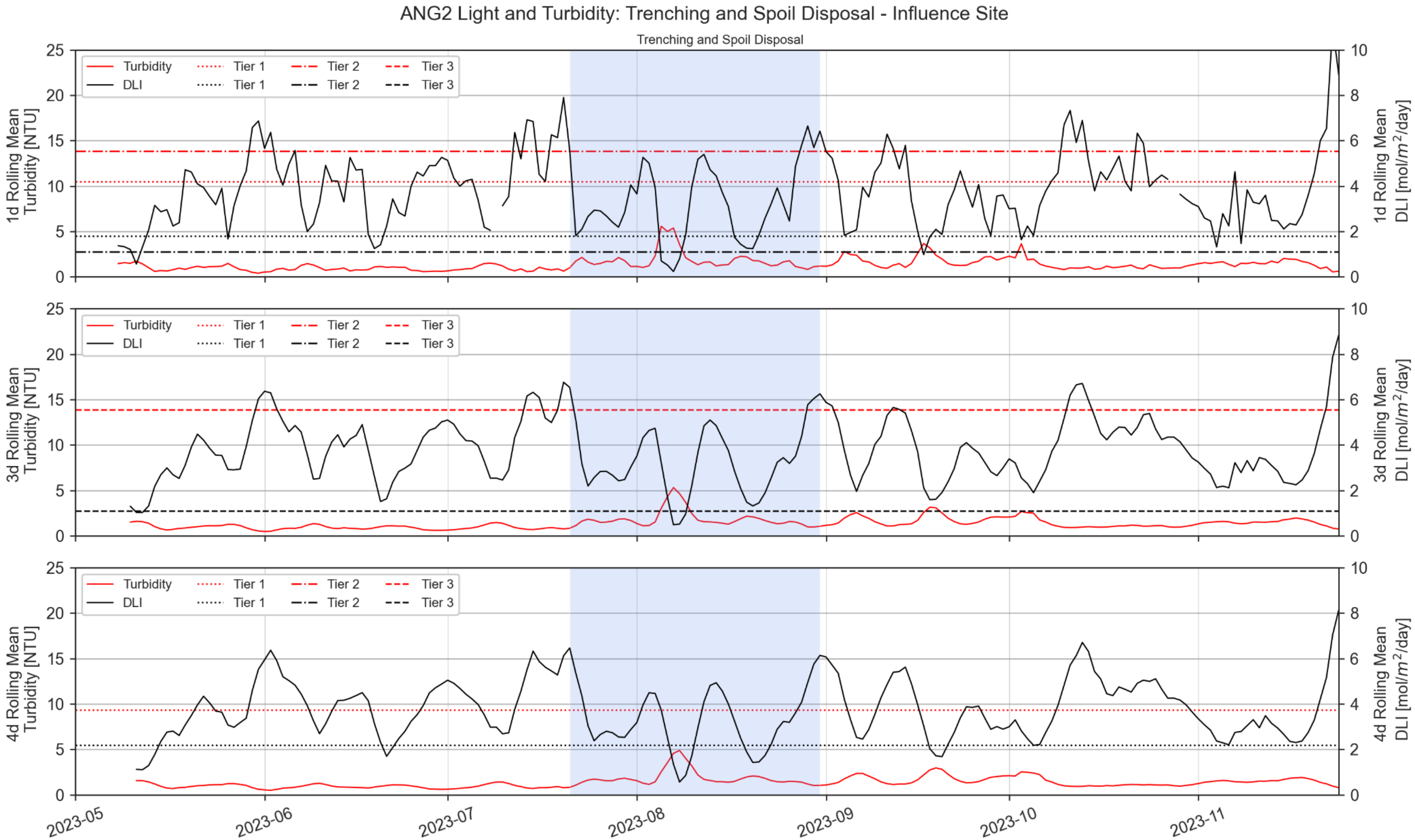

Figure B.10: Assessment of turbidity and light parameters at ANG2 against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

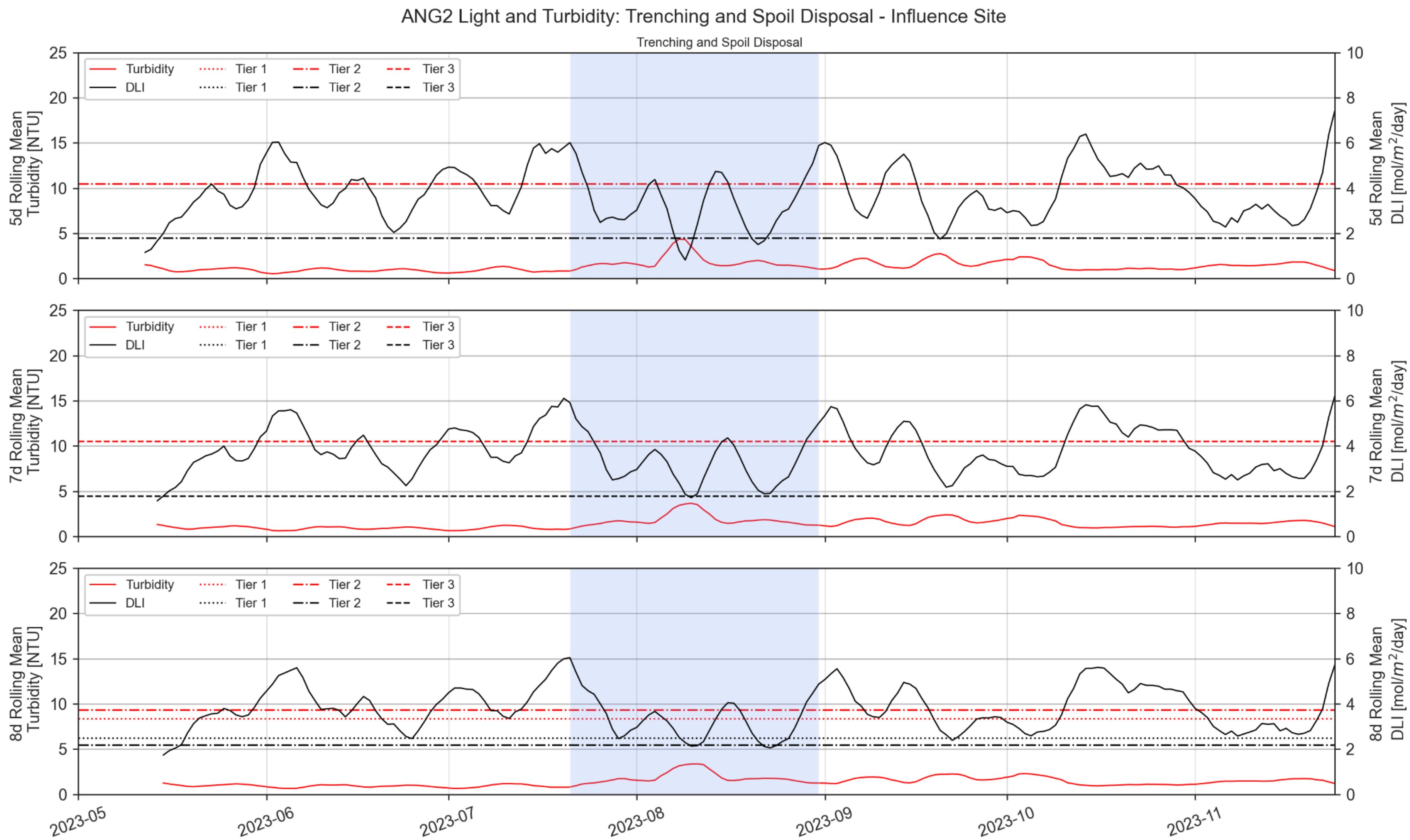

Figure B.11: Assessment of turbidity and light parameters at ANG2 against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

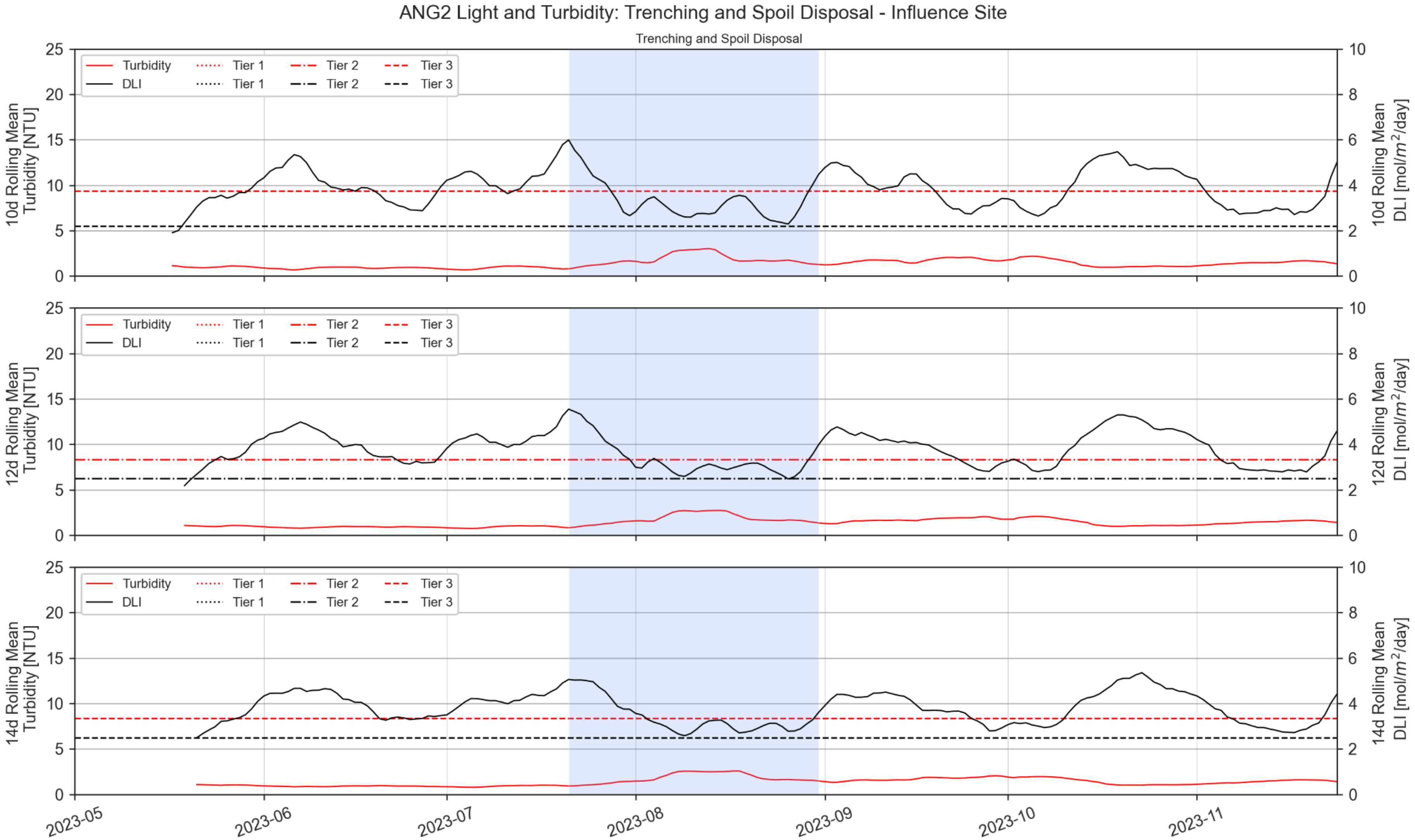

Figure B.12: Assessment of turbidity and light parameters at ANG2 against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

Appendix B.5. COBN

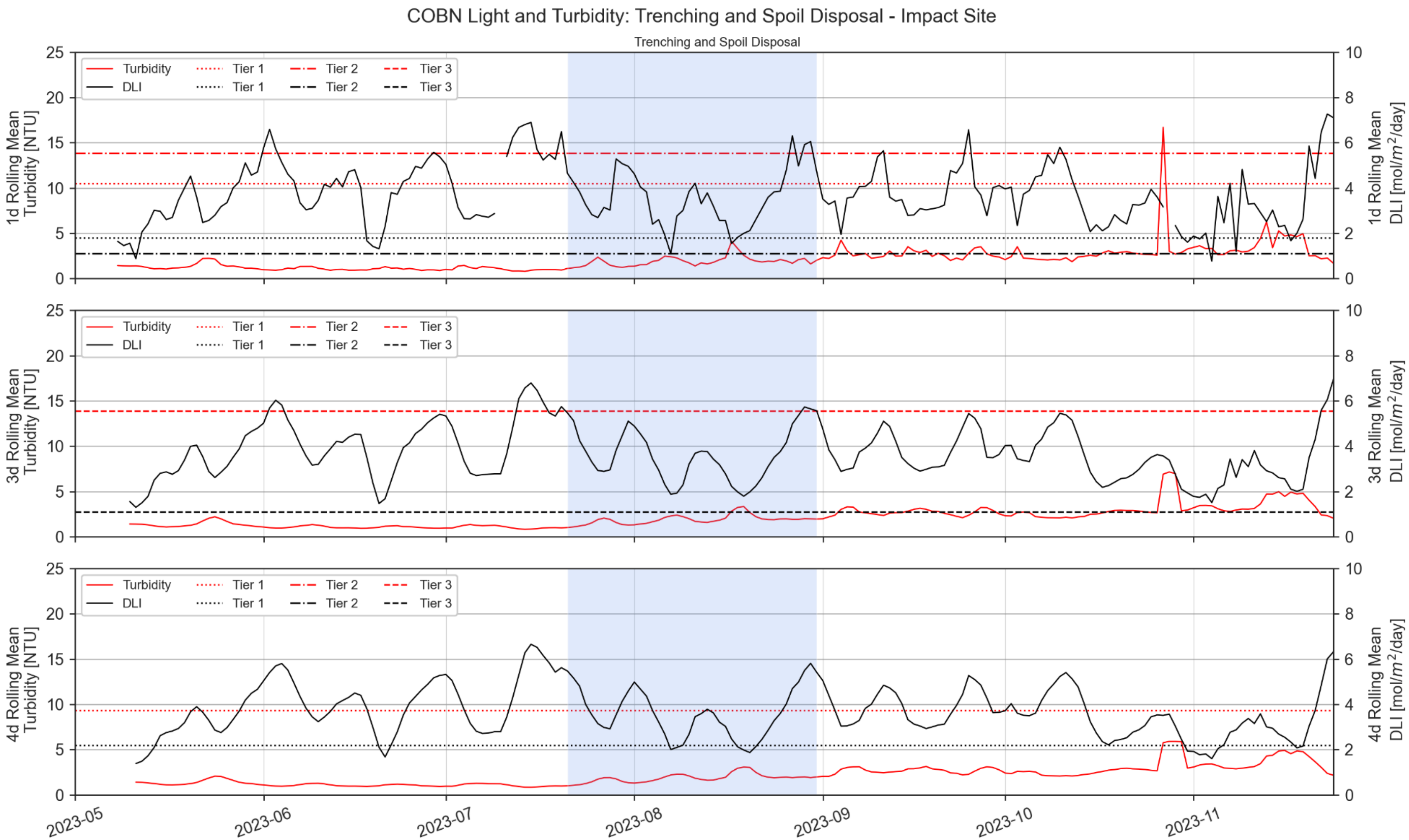

Figure B.13: Assessment of turbidity and light parameters at COBN against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

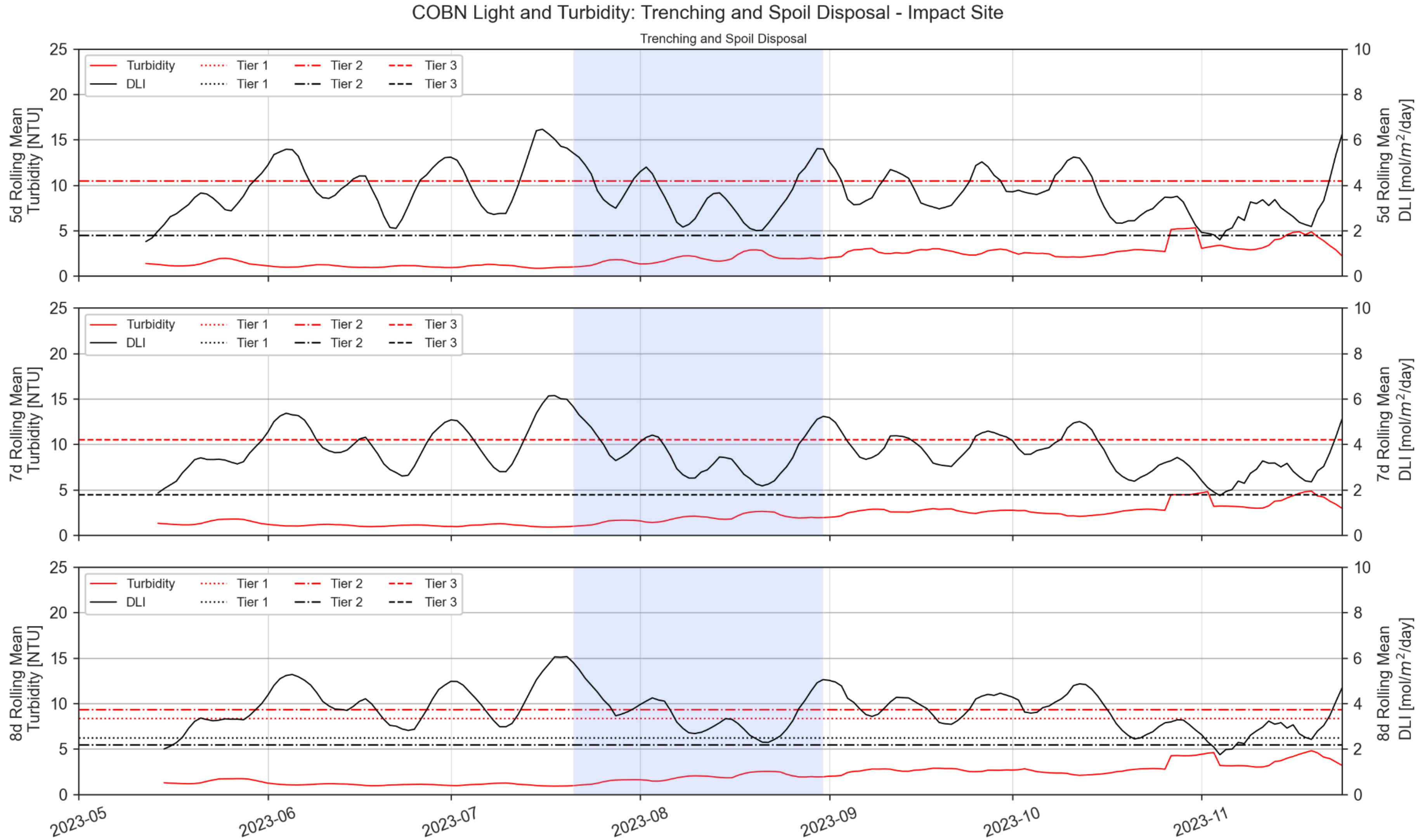

Figure B.14: Assessment of turbidity and light parameters at COBN against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

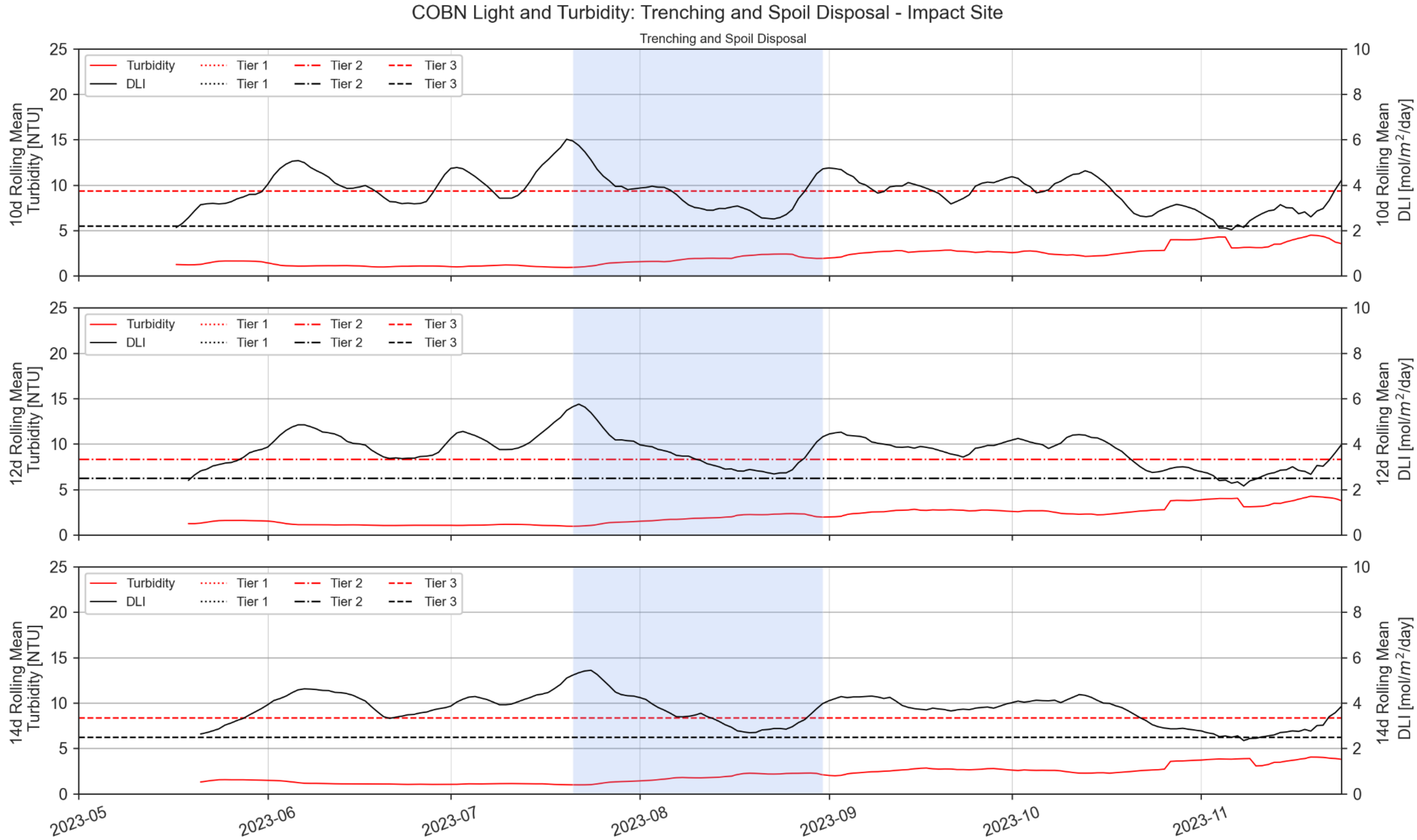

Figure B.15: Assessment of turbidity and light parameters at COBN against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

Appendix B.6. CONI

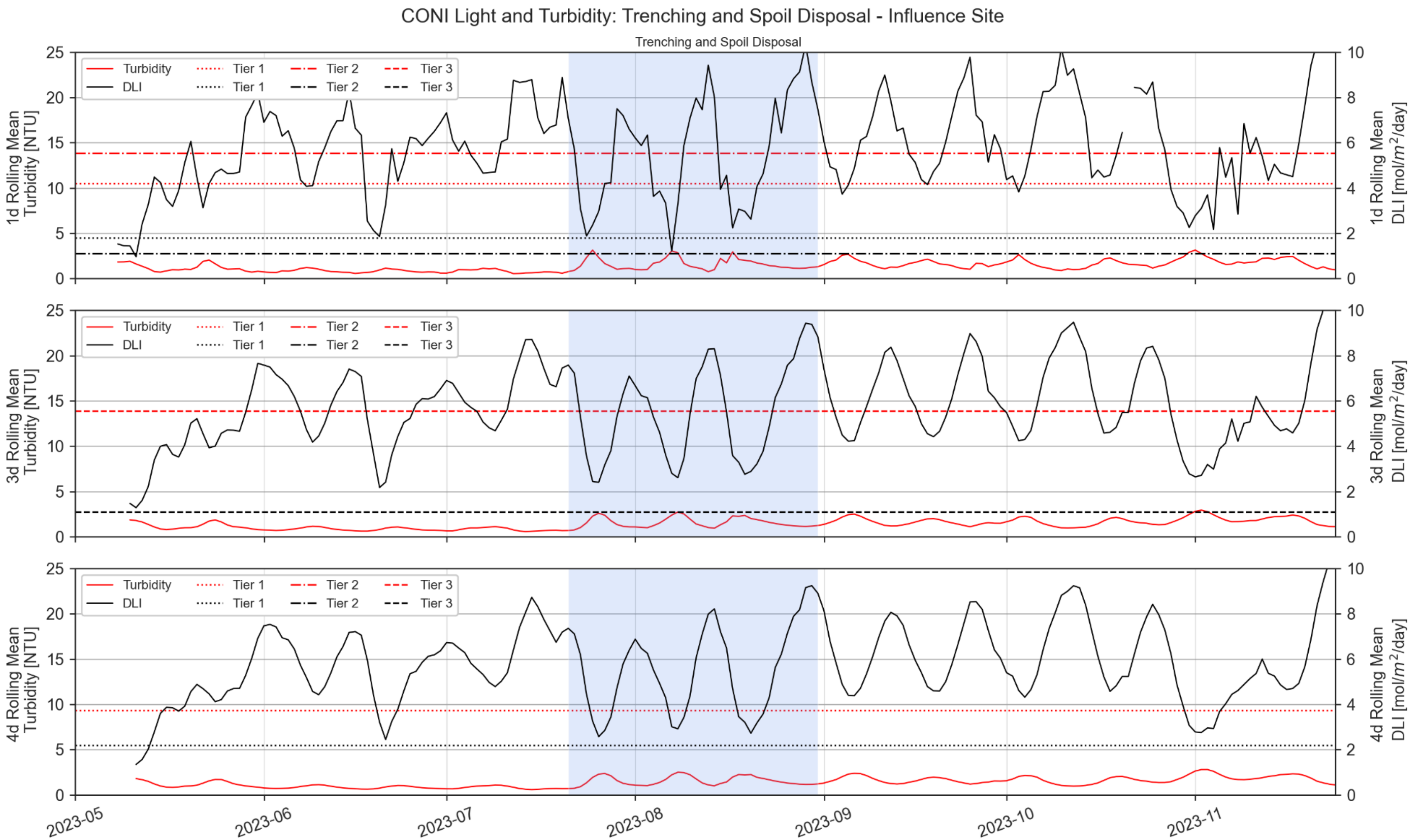

Figure B.16: Assessment of turbidity and light parameters at CONI against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

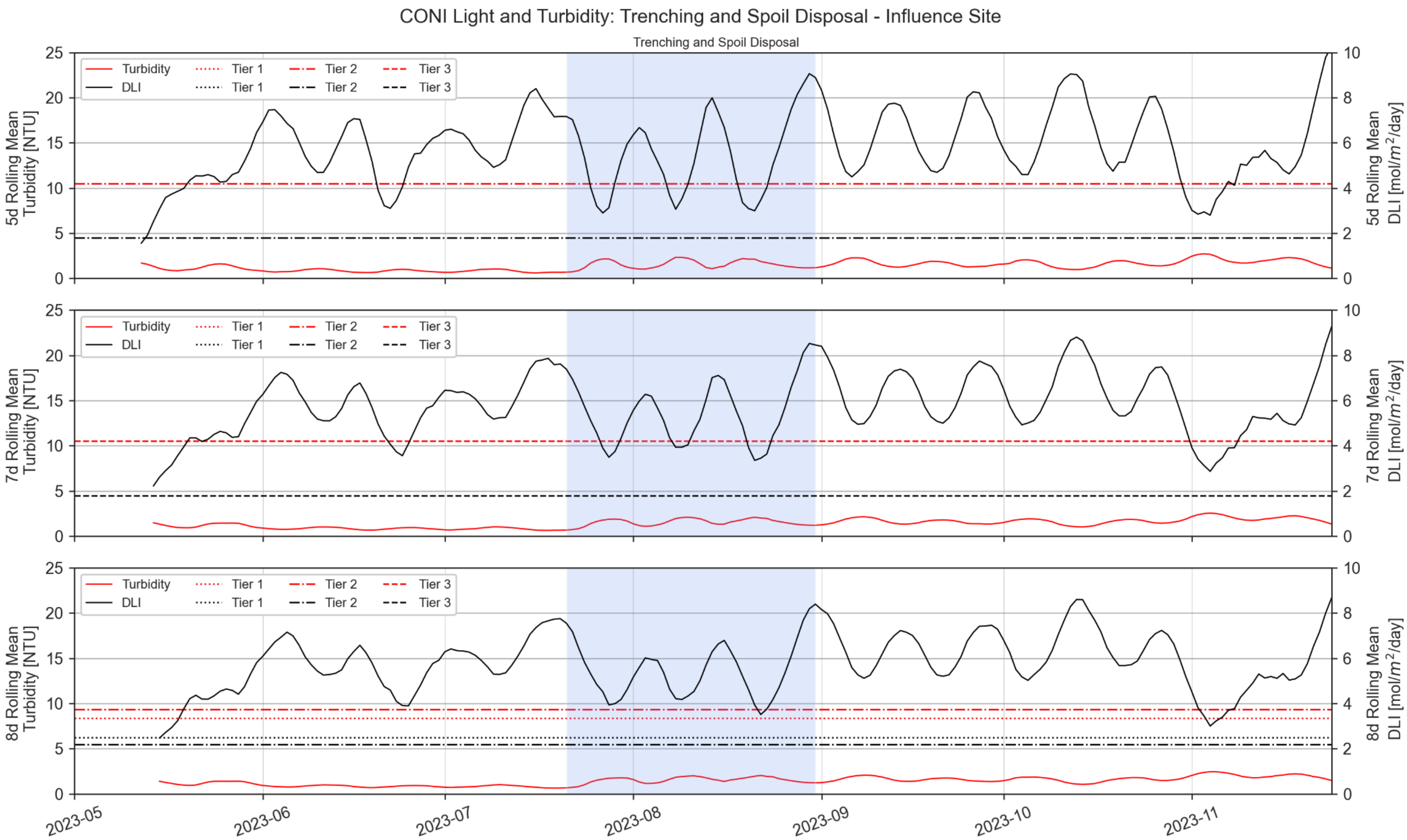

Figure B.17: Assessment of turbidity and light parameters at CONI against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

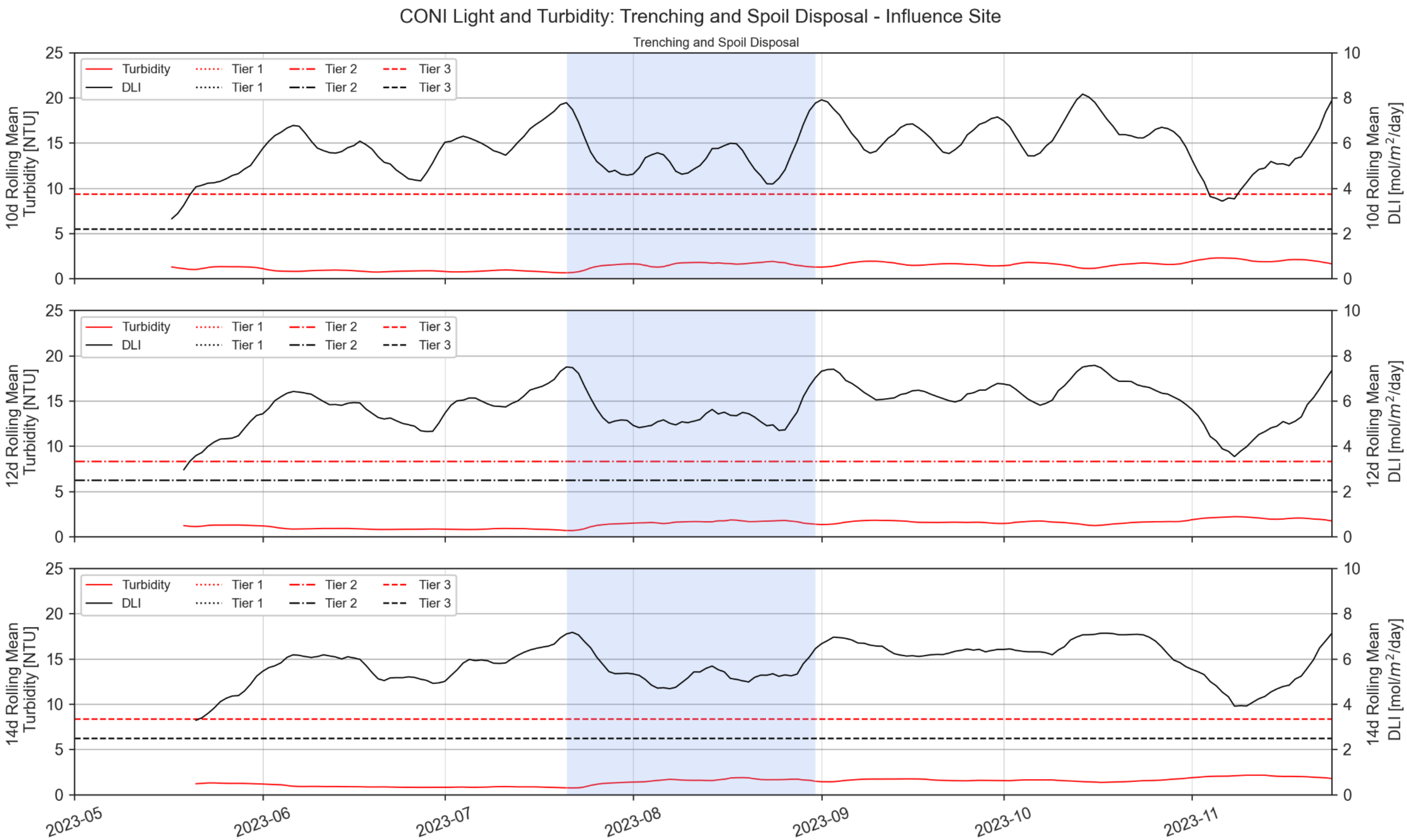

Figure B.18: Assessment of turbidity and light parameters at CONI against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

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Appendix B.7. CONI2

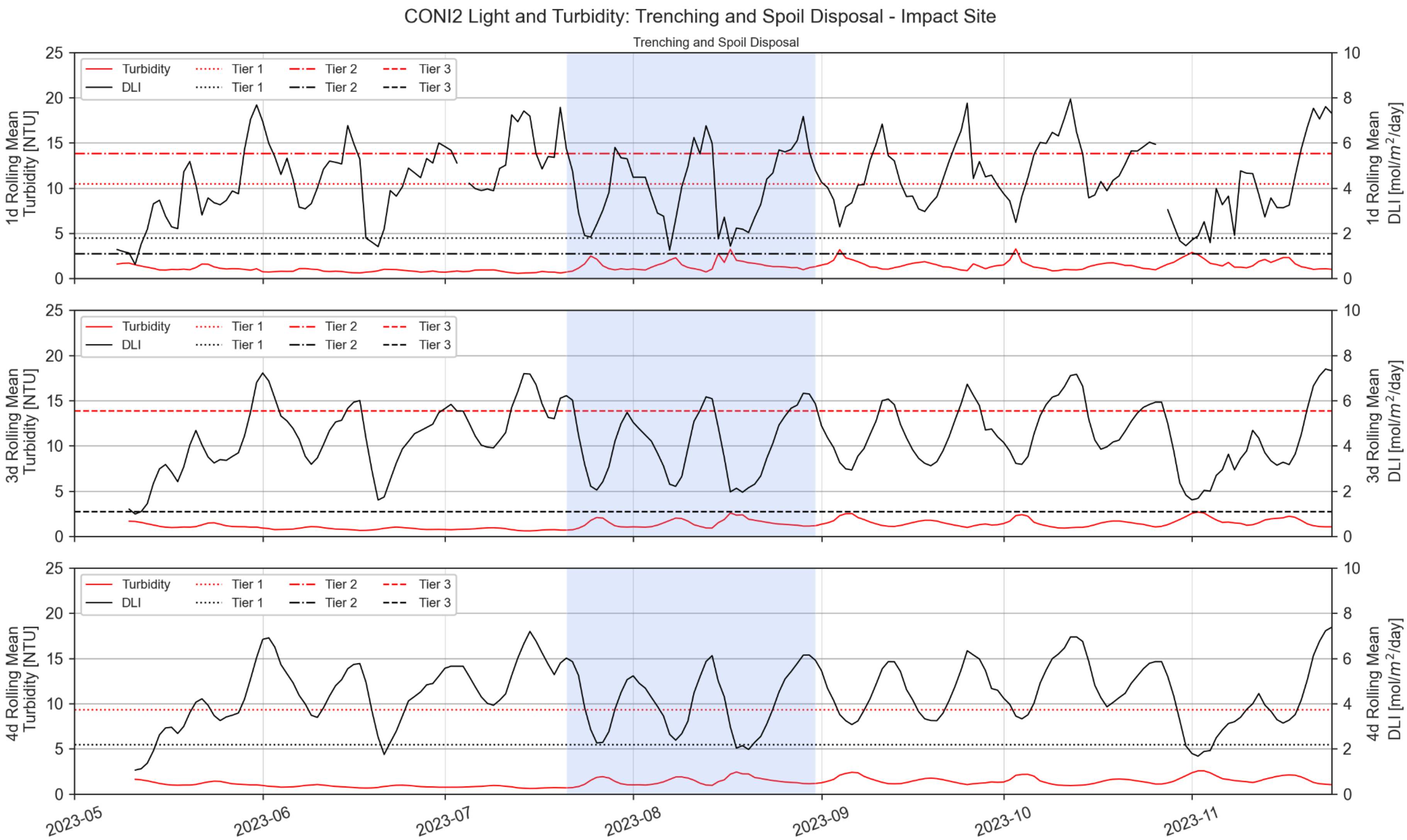

Figure B.19: Assessment of turbidity and light parameters at CONI2 against 1-day, 3-day and 4-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

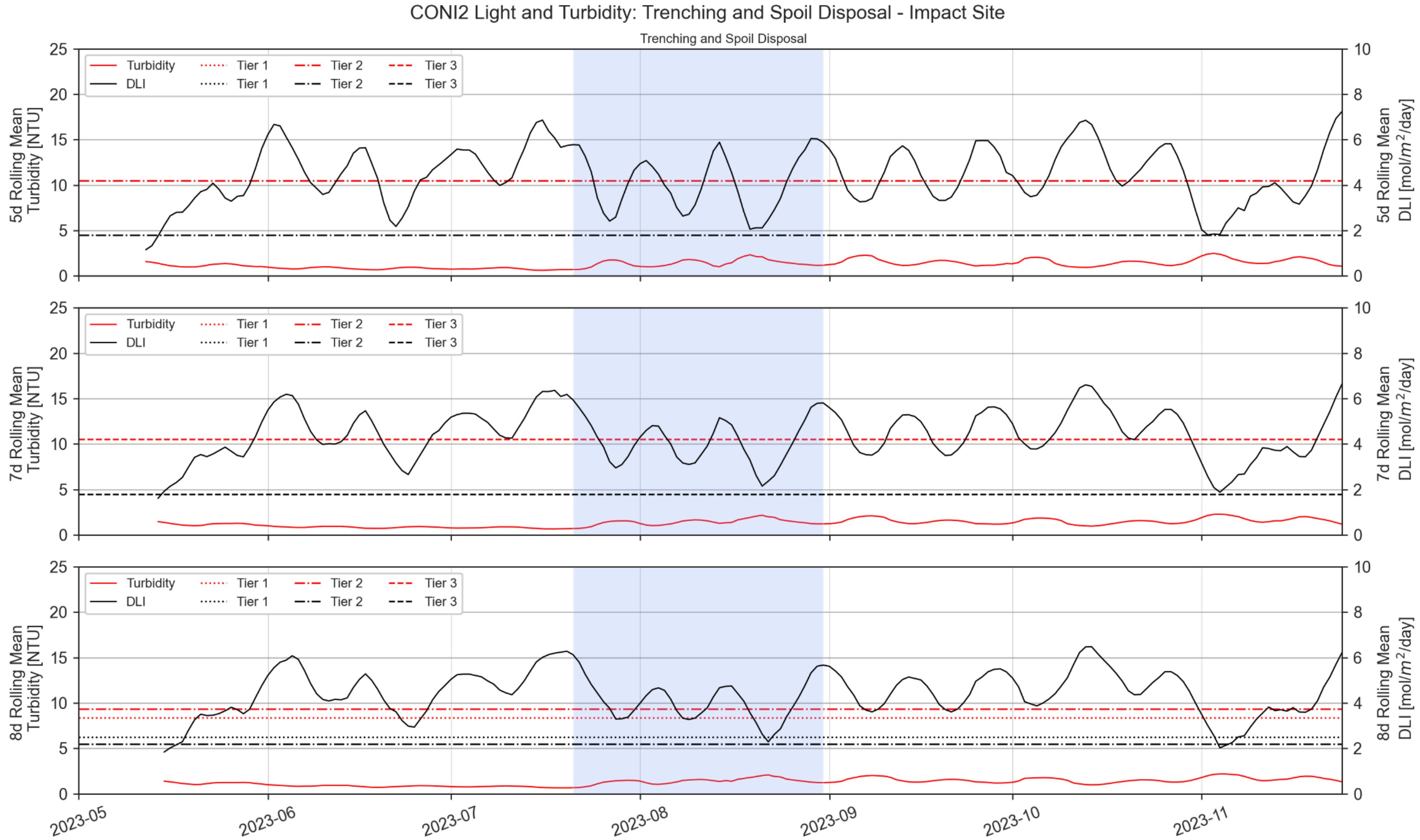

Figure B.20: Assessment of turbidity and light parameters at CONI2 against 5-day, 7-day and 8-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

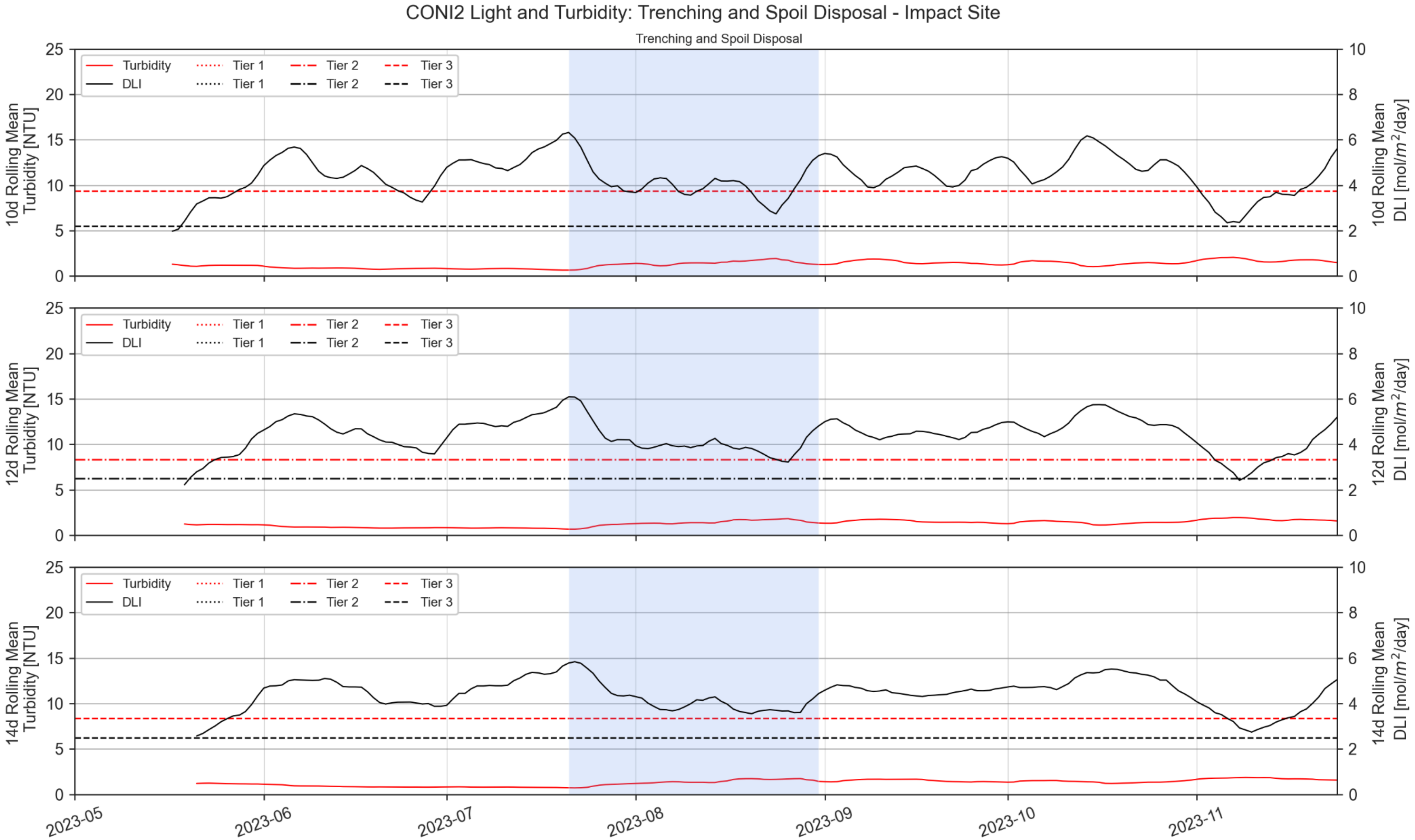

Figure B.21: Assessment of turbidity and light parameters at CONI2 against 10-day, 12-day and 14-day water quality management triggers for Ecological Zone B during trenching and spoil disposal activity

Appendix B.8. HAUY

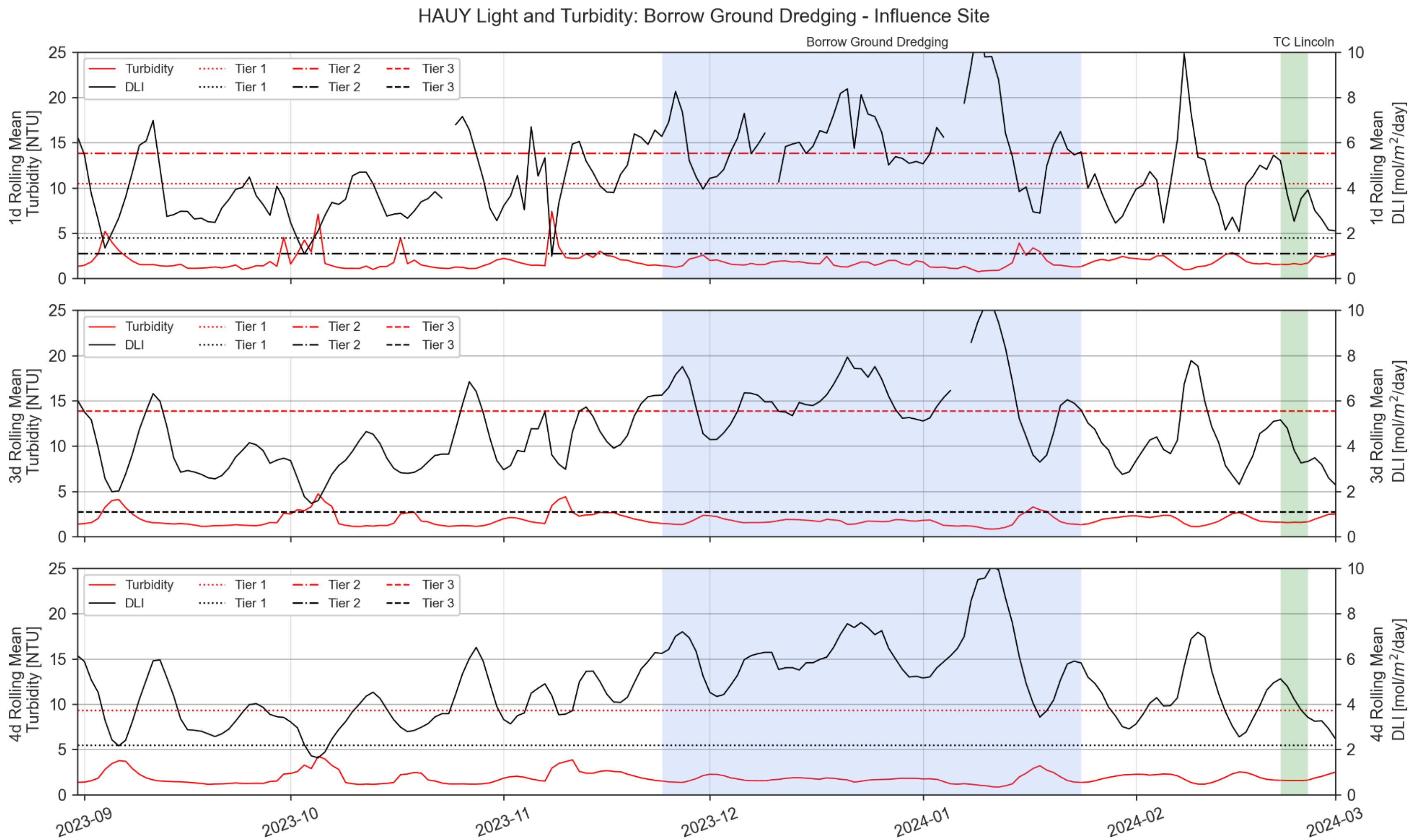

Figure B.22: Assessment of turbidity and light parameters at HAUY against 1-day, 3-day and 4-day water quality management triggers for Offshore Zone during borrow ground dredging activity

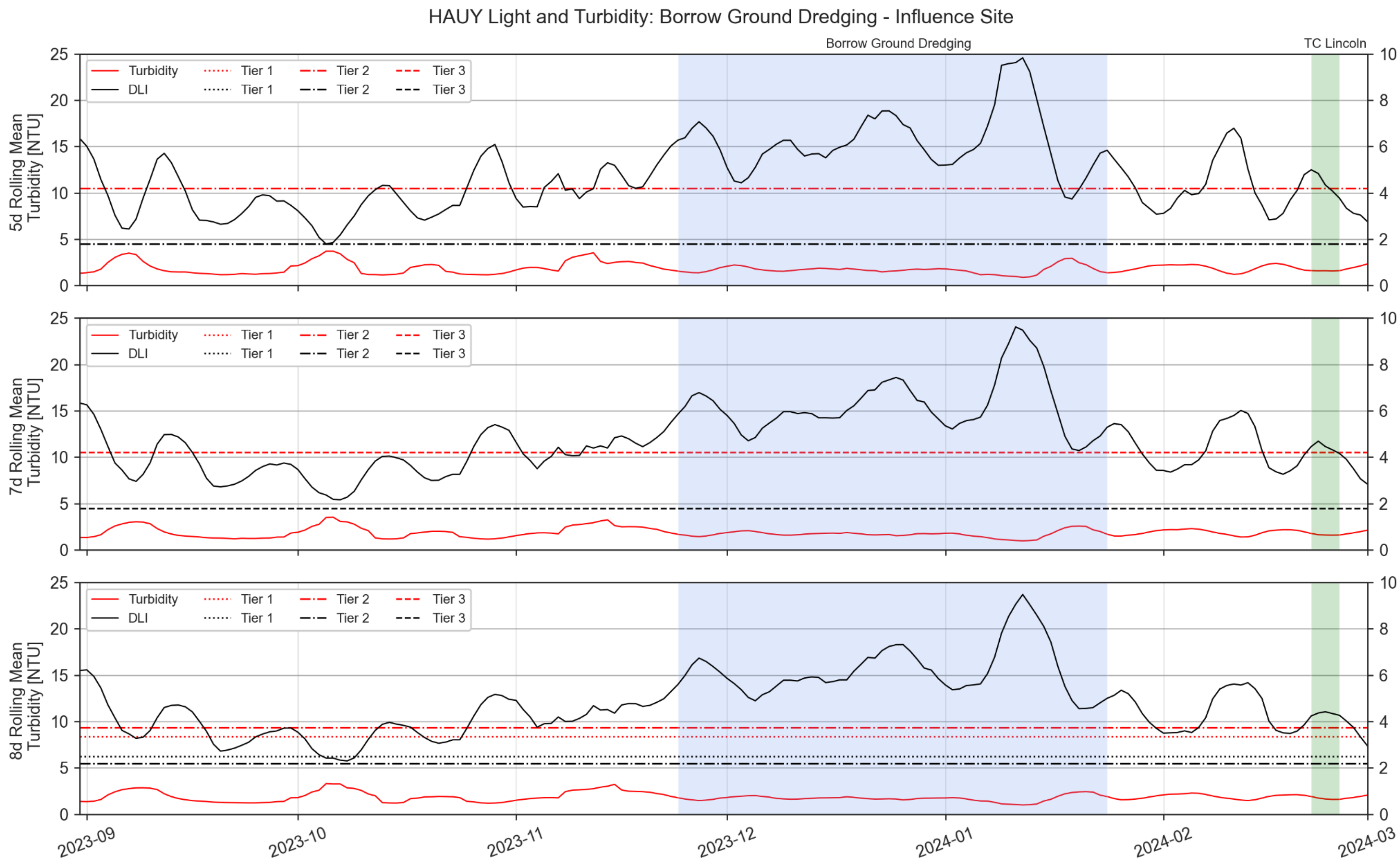

Figure B.23: Assessment of turbidity and light parameters at HAUY against 5-day,7-day and 8-day water quality management triggers for Offshore Zone during borrow ground dredging activity

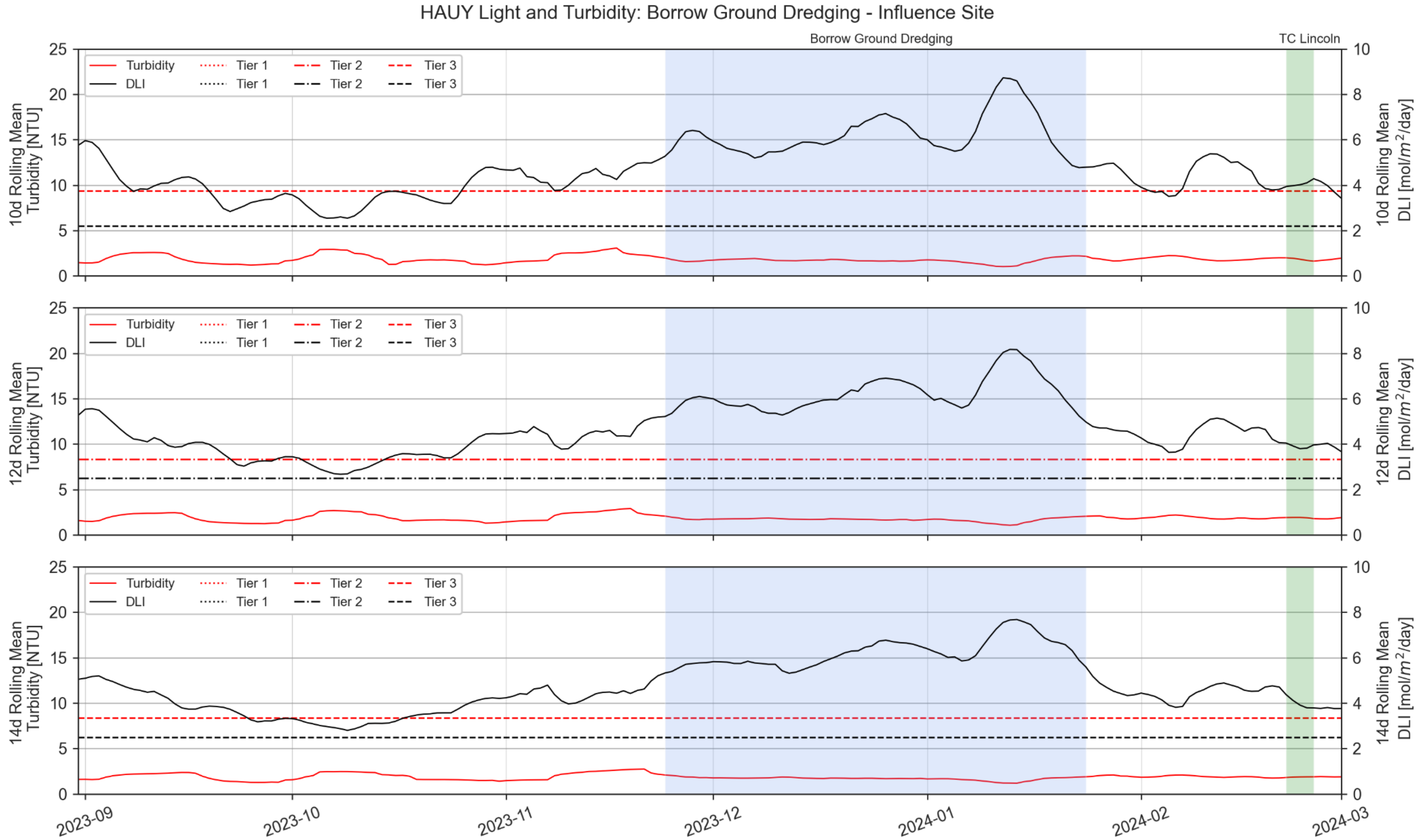

Figure B.24: Assessment of turbidity and light parameters at HAUY against 10-day, 12-day and 14-day water quality management triggers for Offshore Zone during borrow ground dredging activity

Appendix B.9. MPB

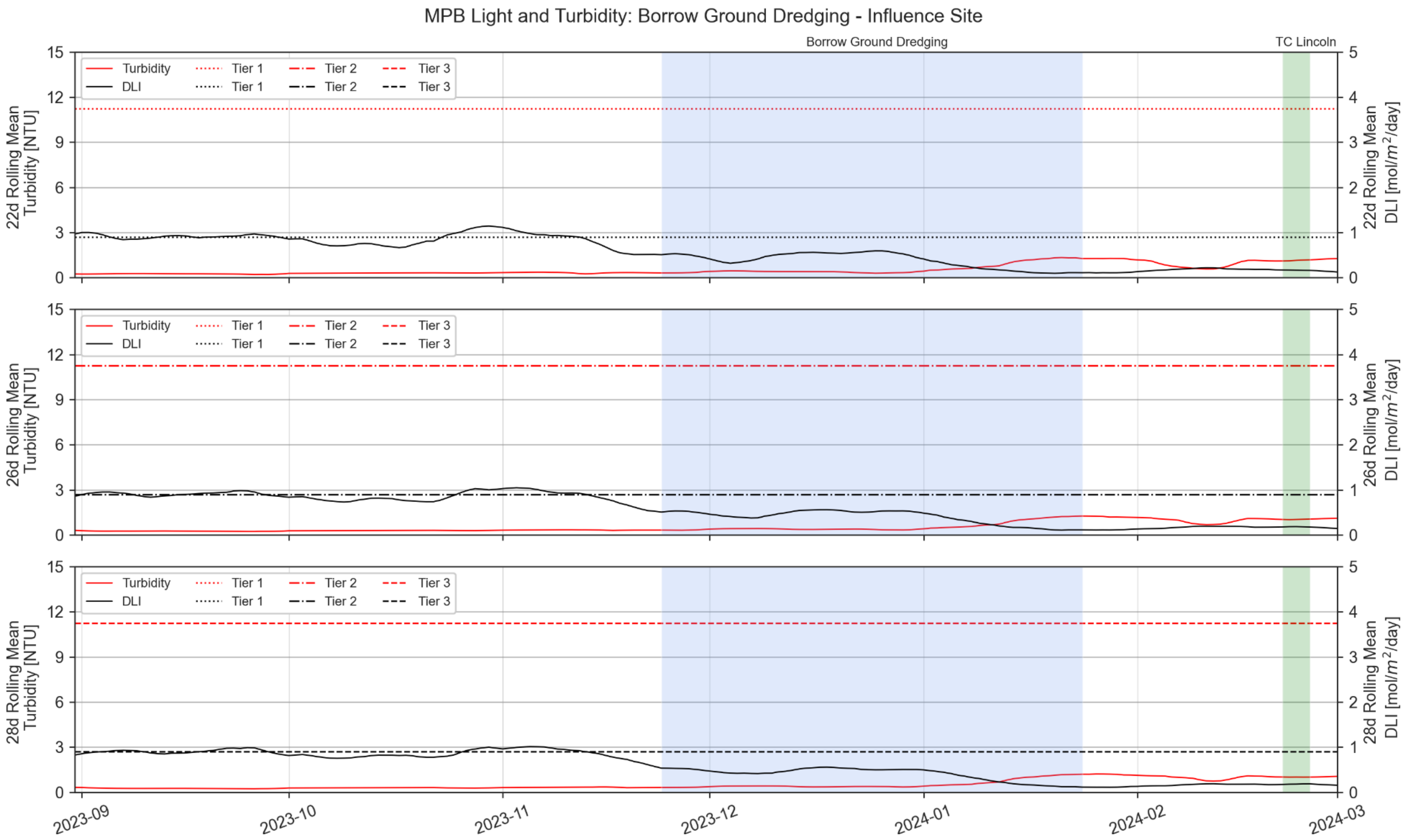

Figure B.25: Assessment of turbidity and light parameters at MPB against 22-day, 26-day and 28-day Water quality management triggers for Offshore Zone during borrow ground dredging activity

Appendix C. Quality Controlled Light and Turbidity Data per Monitoring Site

Appendix C.1. KGBY

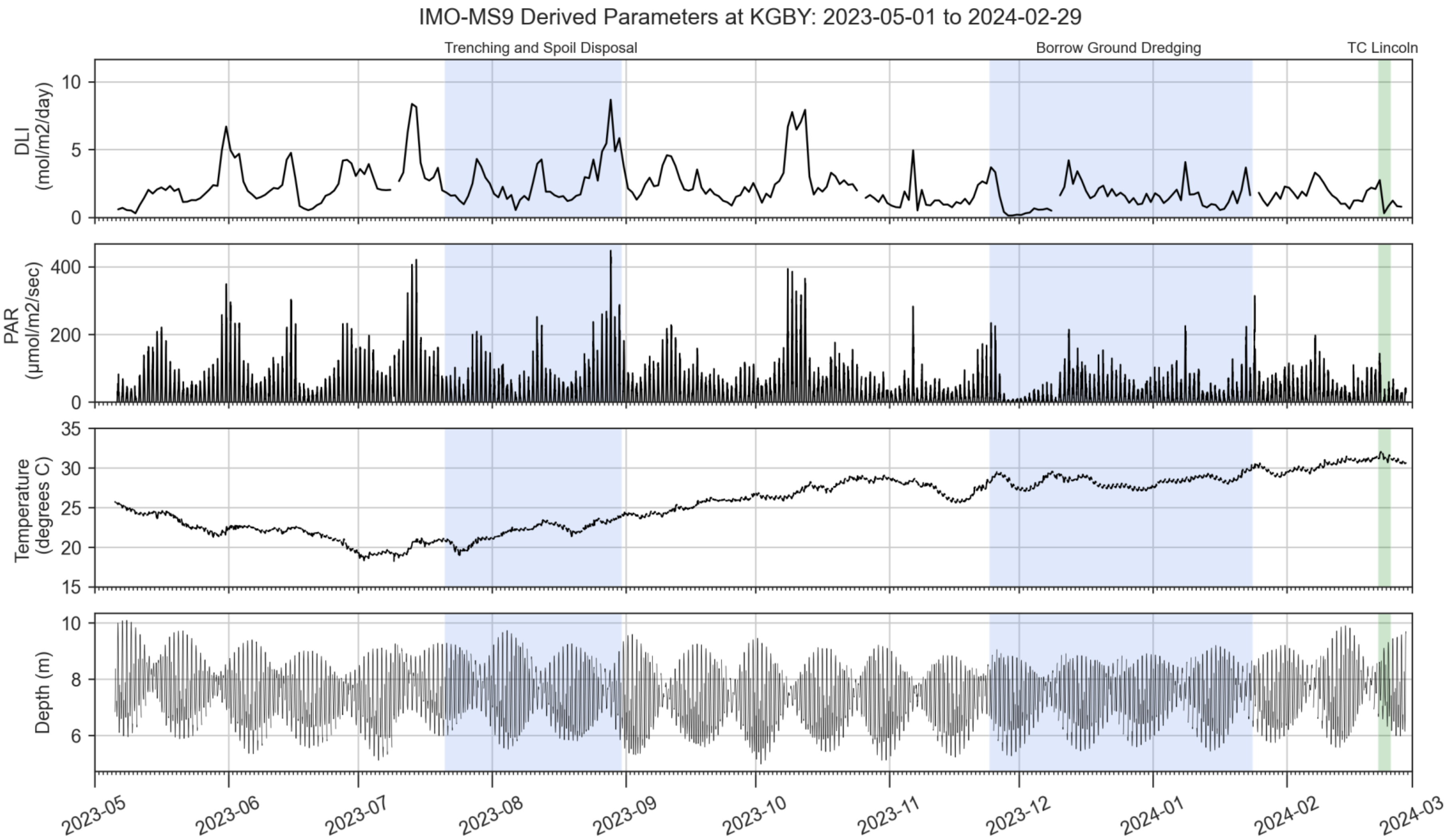

Figure C.1: Quality controlled light parameters at KGBY

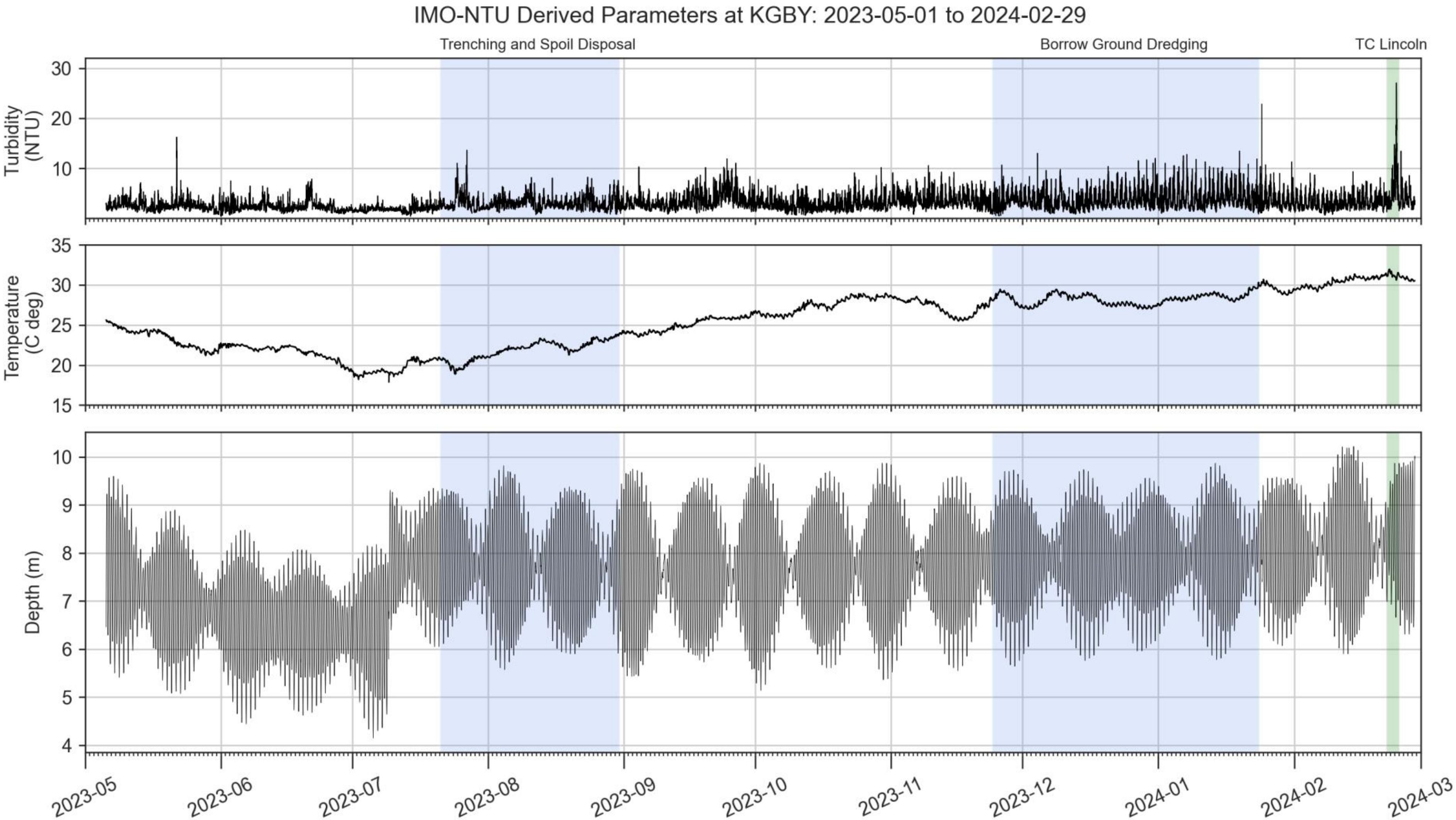

Figure C.2: Quality controlled turbidity parameters at KGBY

Appendix C.2. MIDI

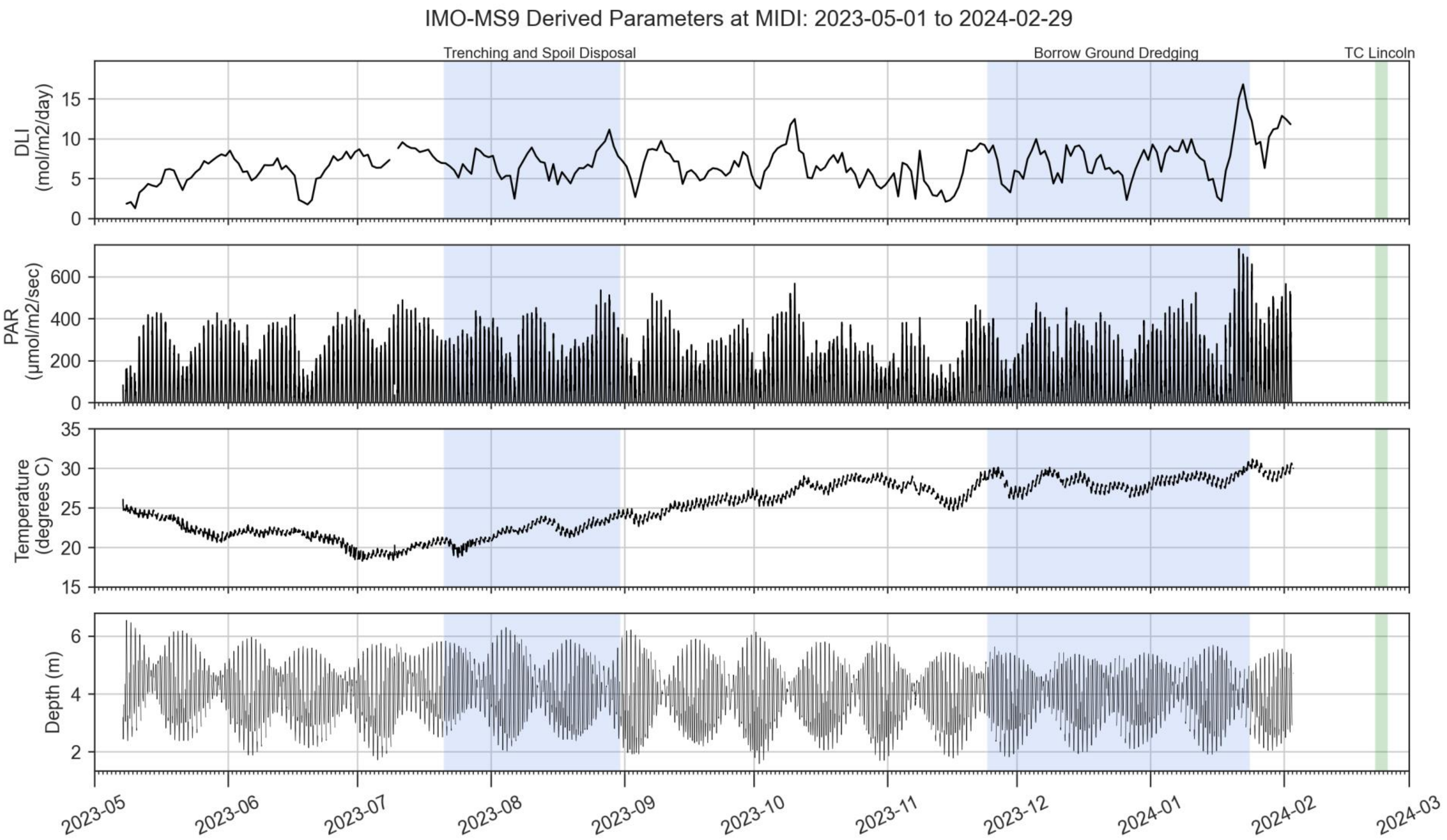

Figure C.3: Quality controlled light parameters at MIDI

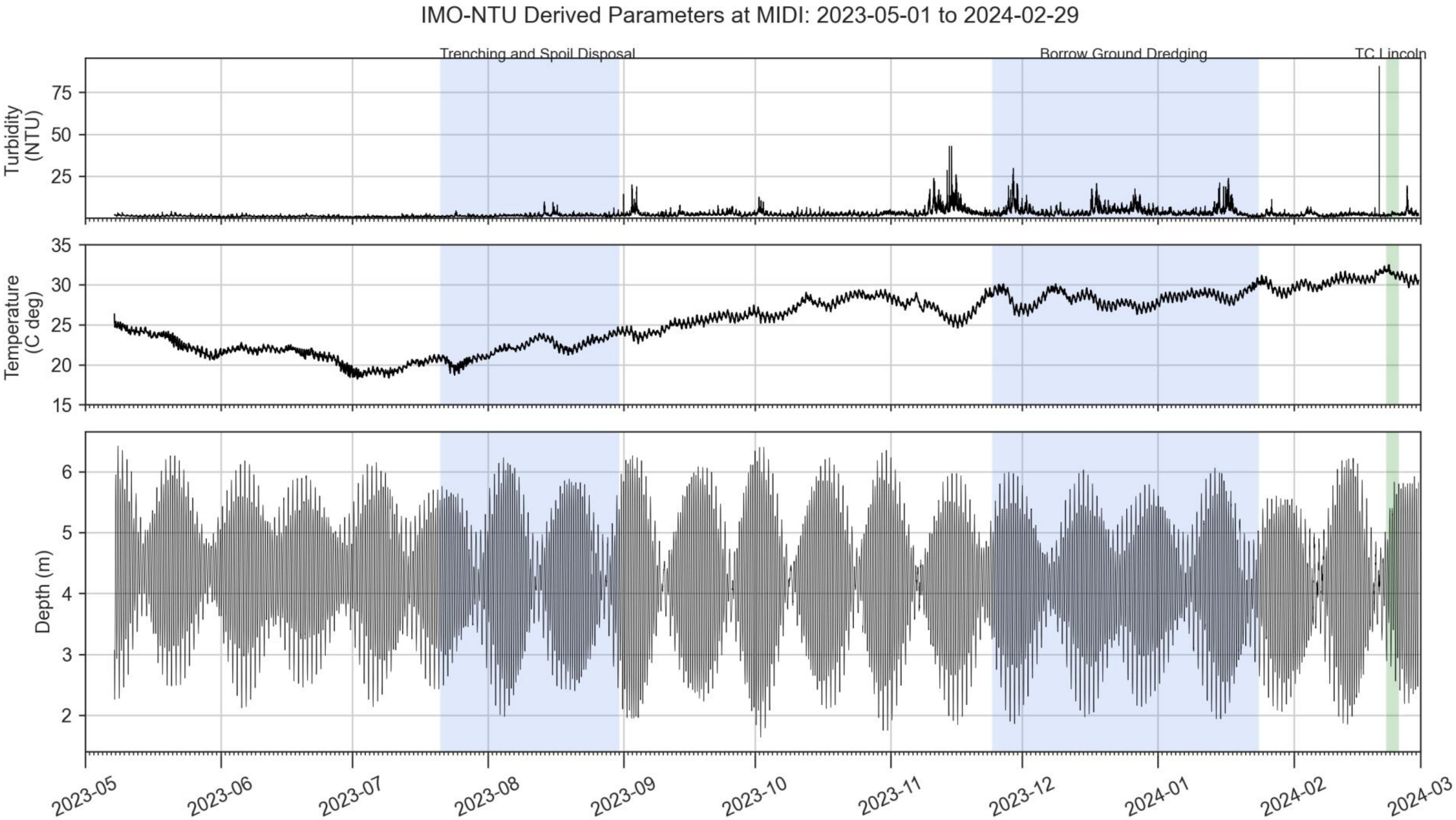

Figure C.4: Quality controlled turbidity parameters at MIDI

Appendix C.3. NWIT

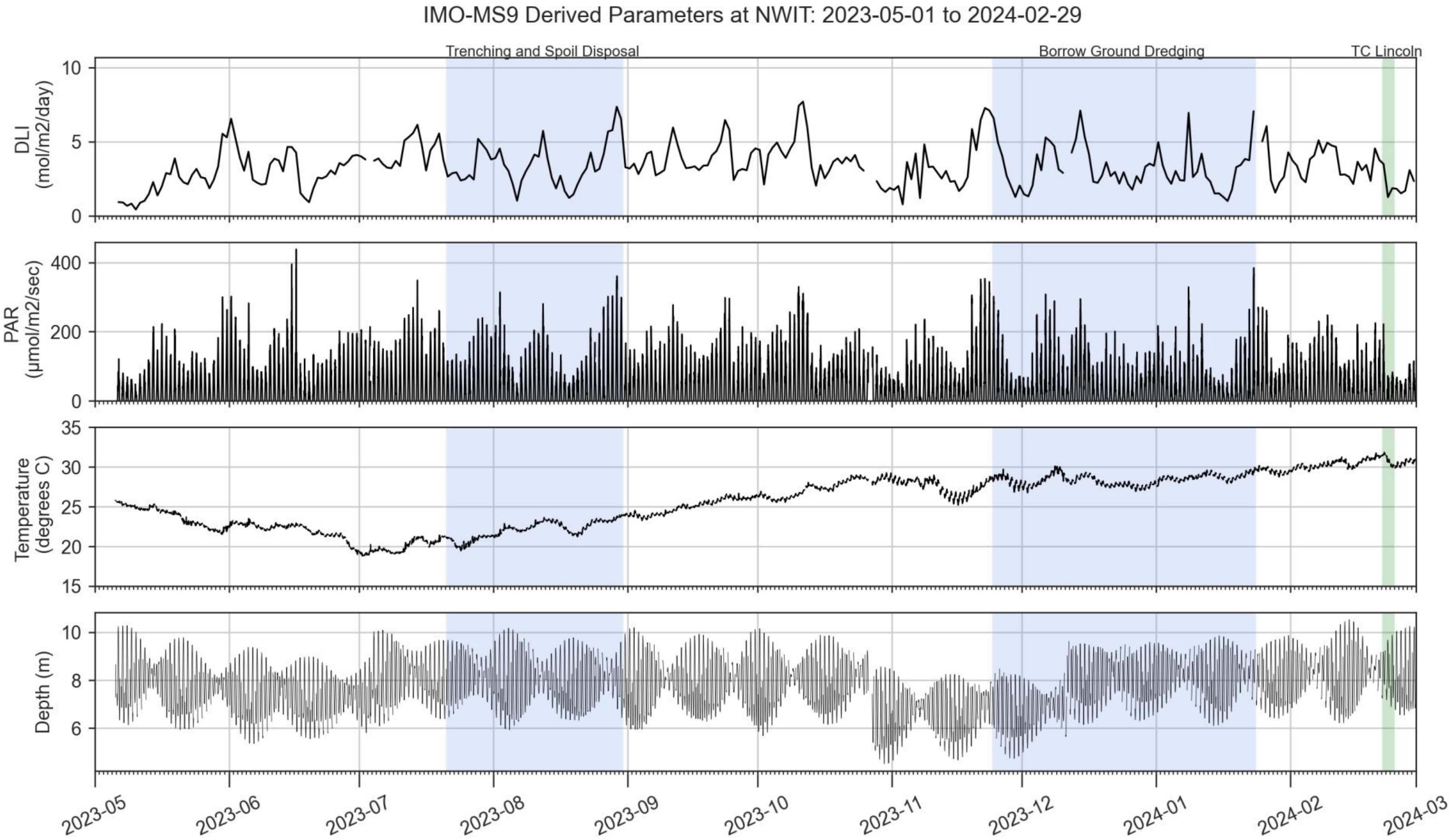

Figure C.4: Quality controlled light parameters at NWIT

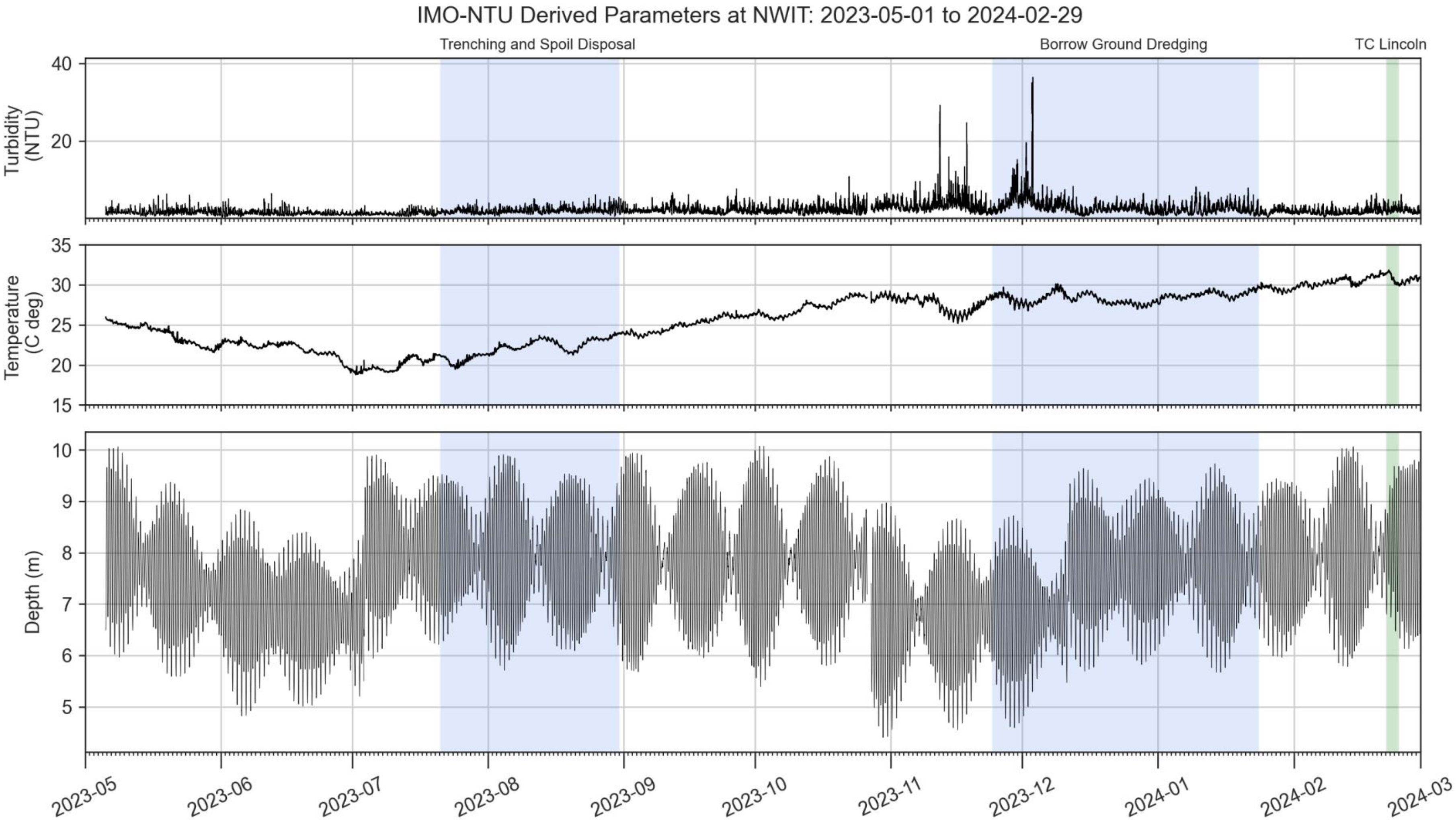

Figure C.5: Quality controlled turbidity parameters at NWIT

Appendix C.4. SUP2

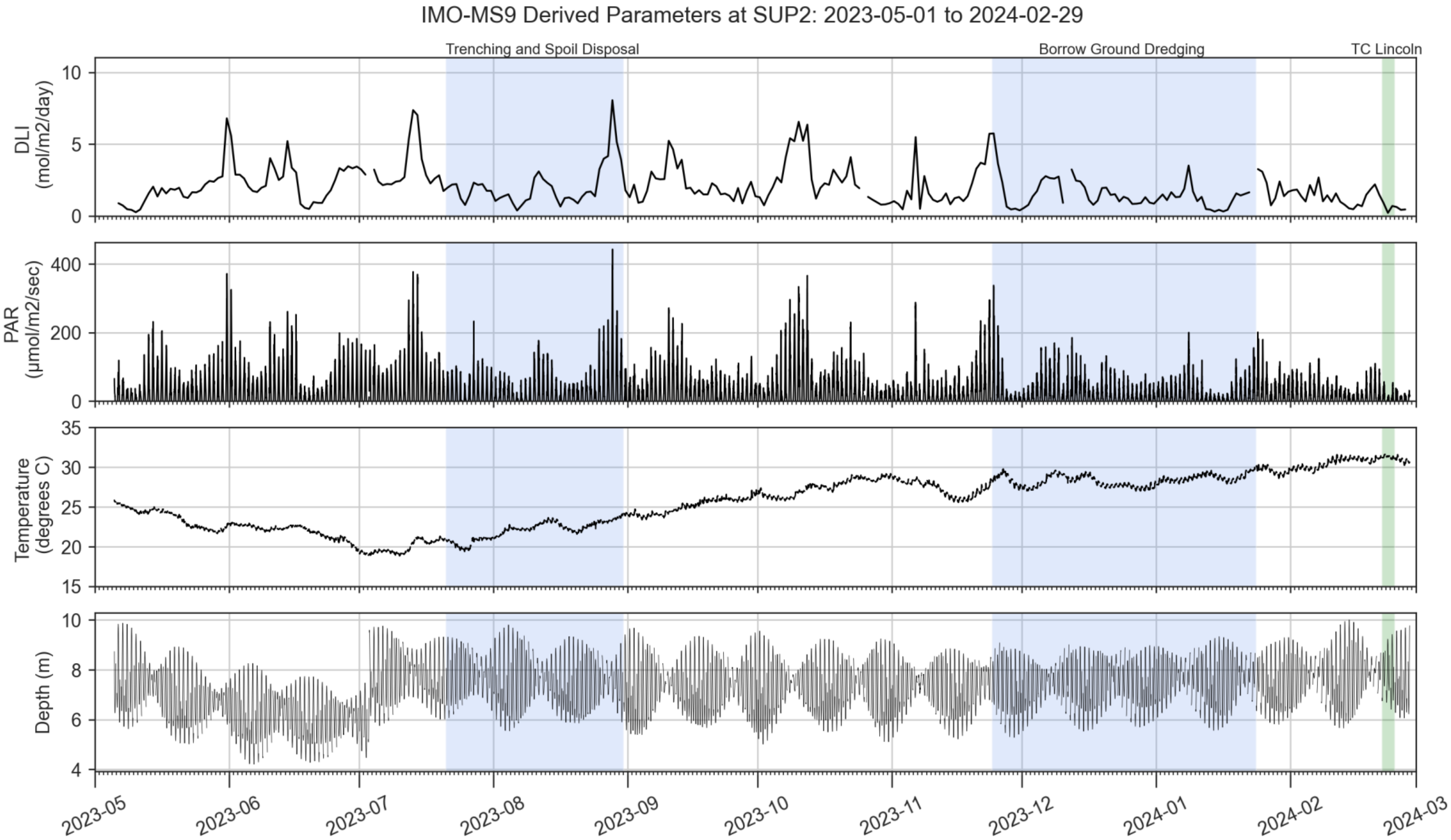

Figure C.6: Quality controlled light parameters at SUP2

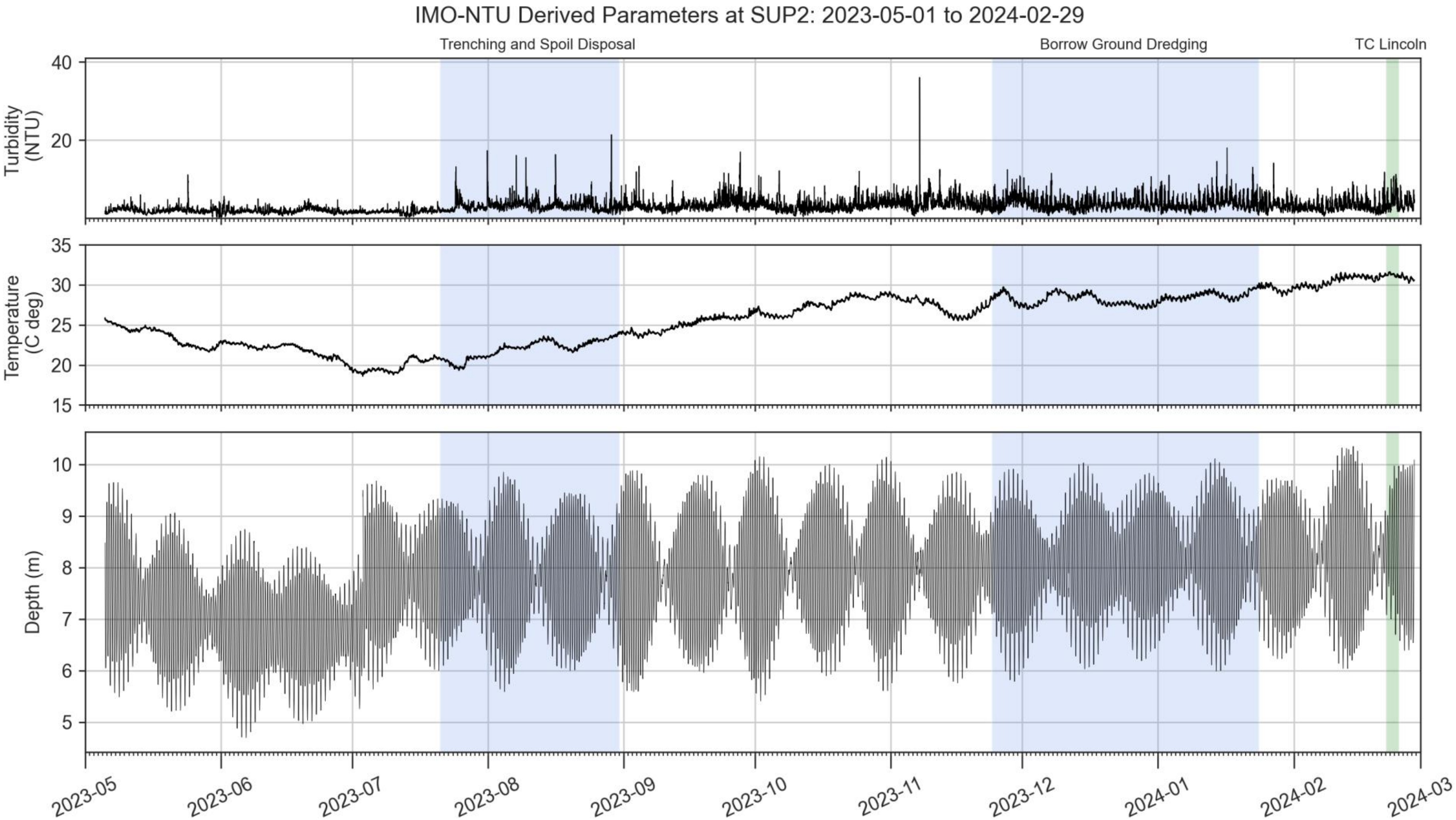

Figure C.7: Quality controlled turbidity parameters at SUP2

Appendix C.5. SWIT

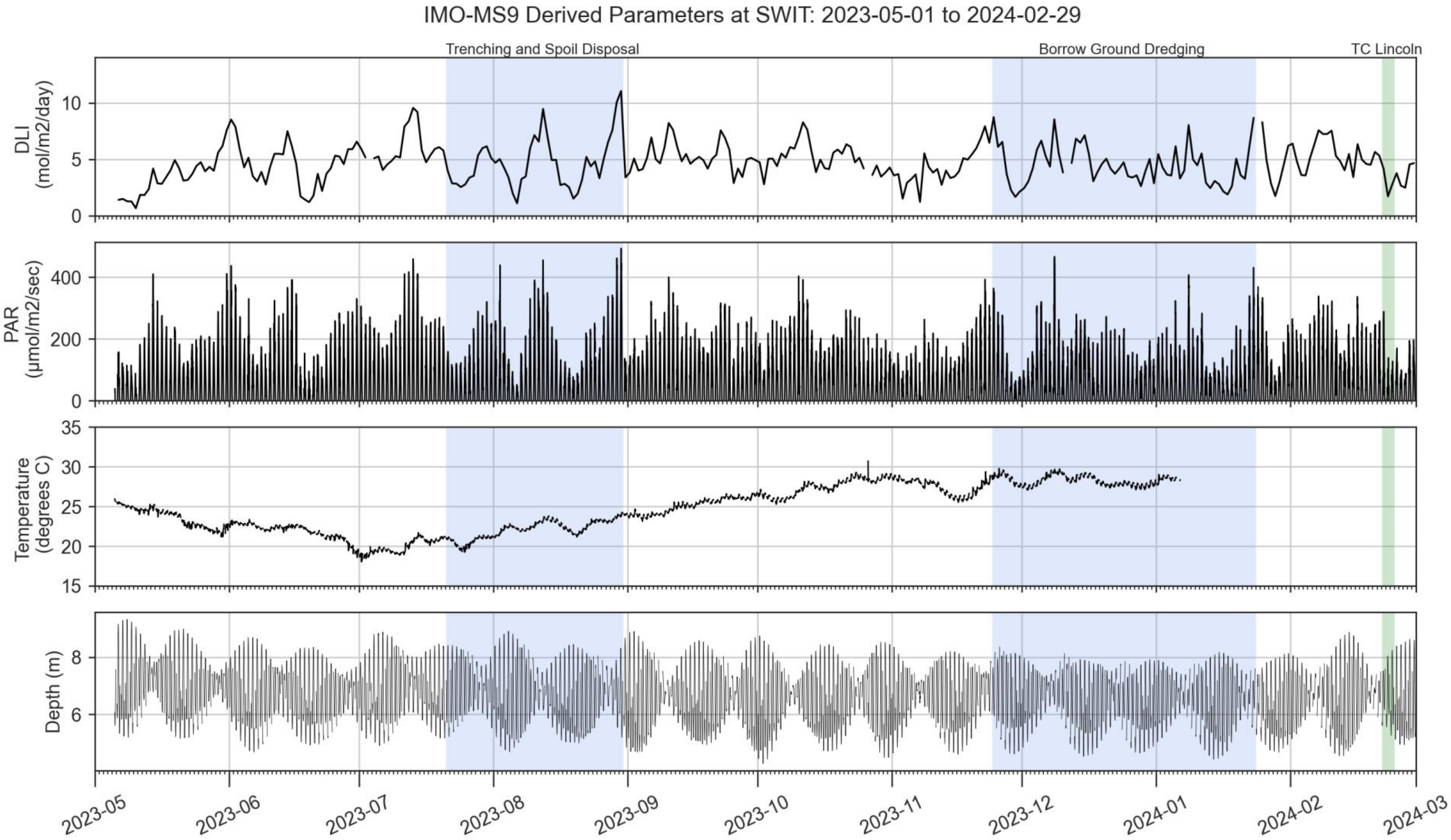

Figure C.8: Quality controlled light parameters at SWIT

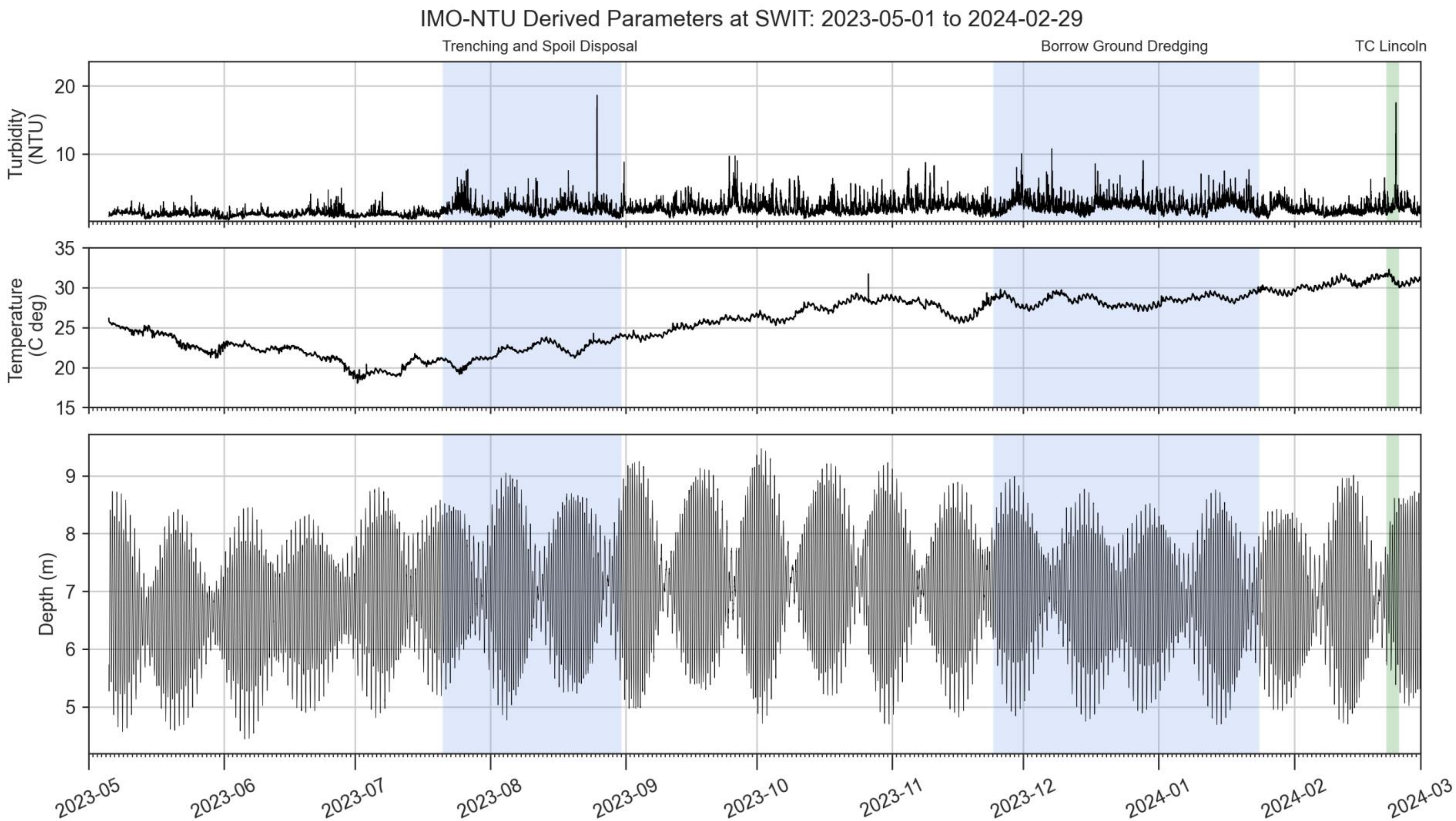

Figure C.9: Quality controlled turbidity parameters at SWIT

Appendix C.6. ANG2

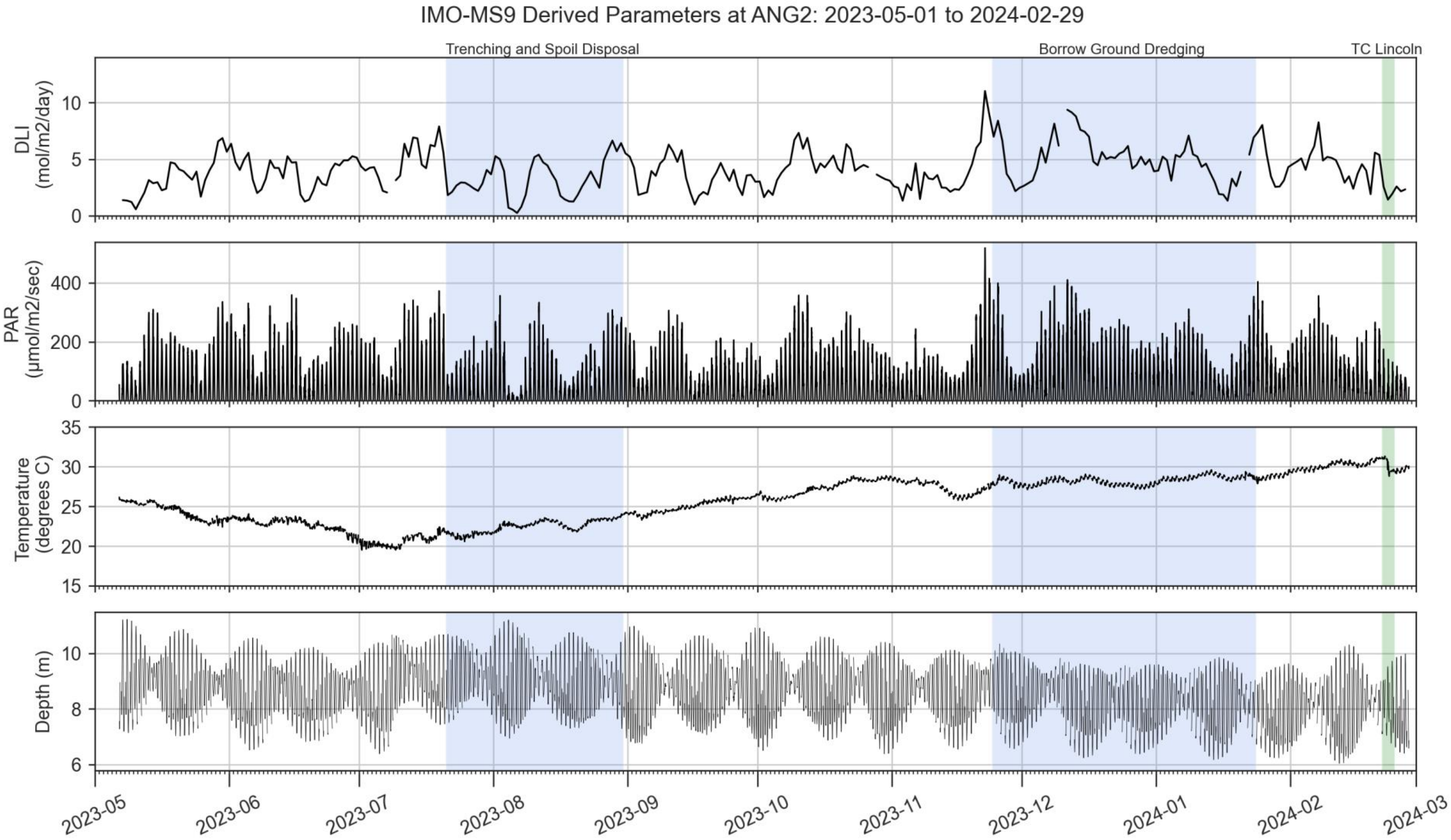

Figure C.10: Quality controlled light parameters at ANG2

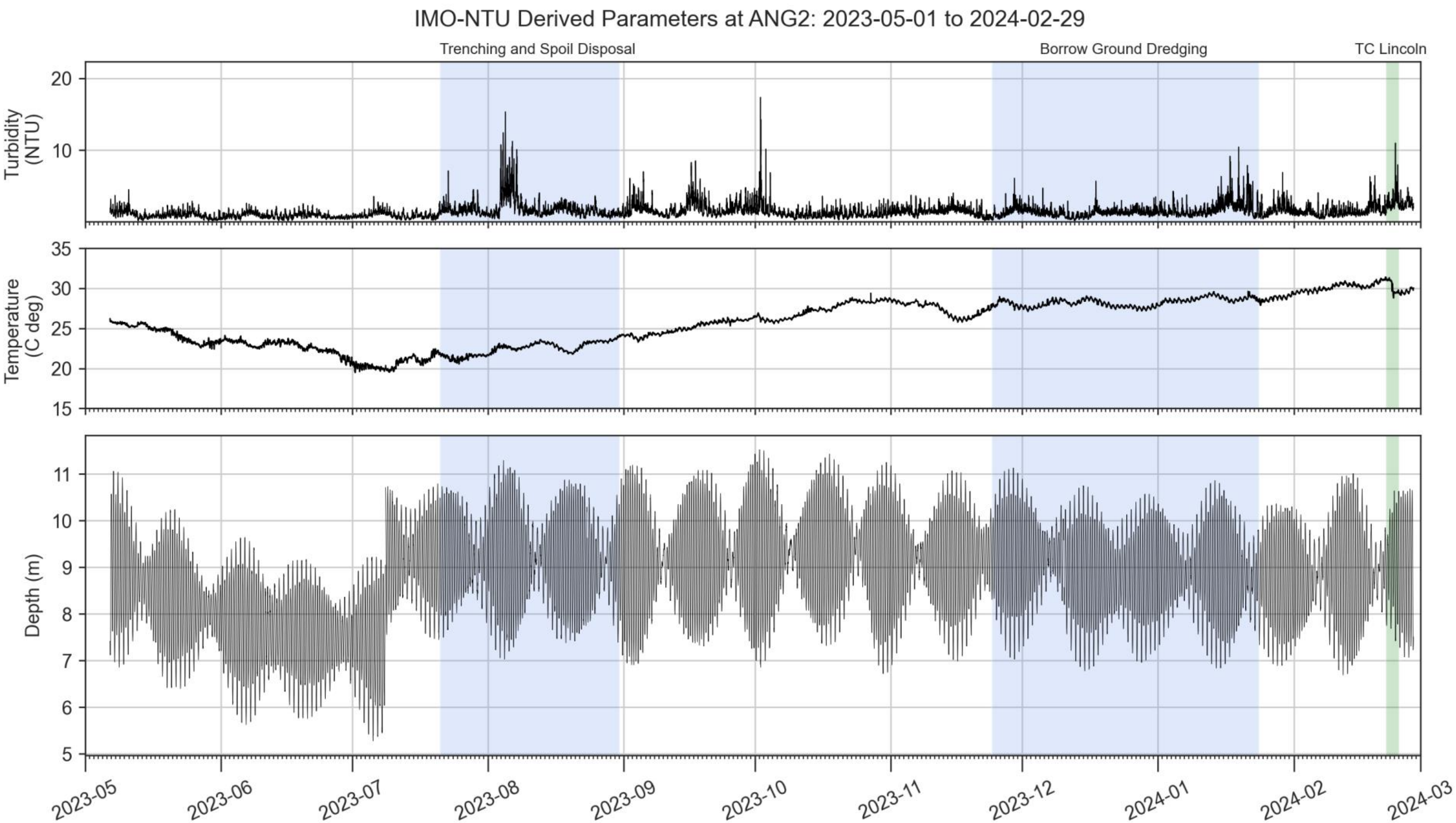

Figure C.11: Quality controlled turbidity parameters at ANG2

Appendix C.7. COBN

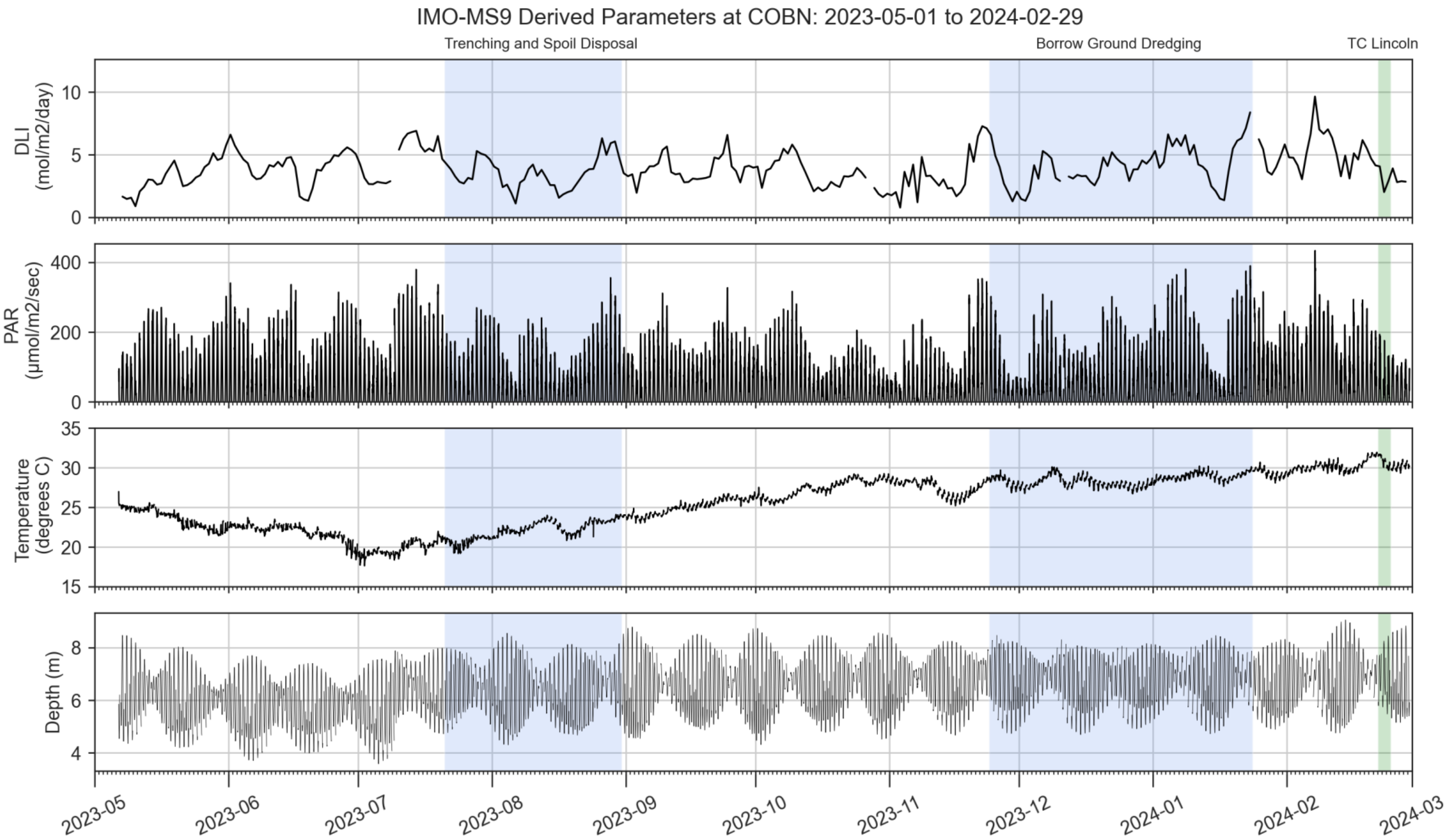

Figure C.12: Quality controlled light parameters at COBN

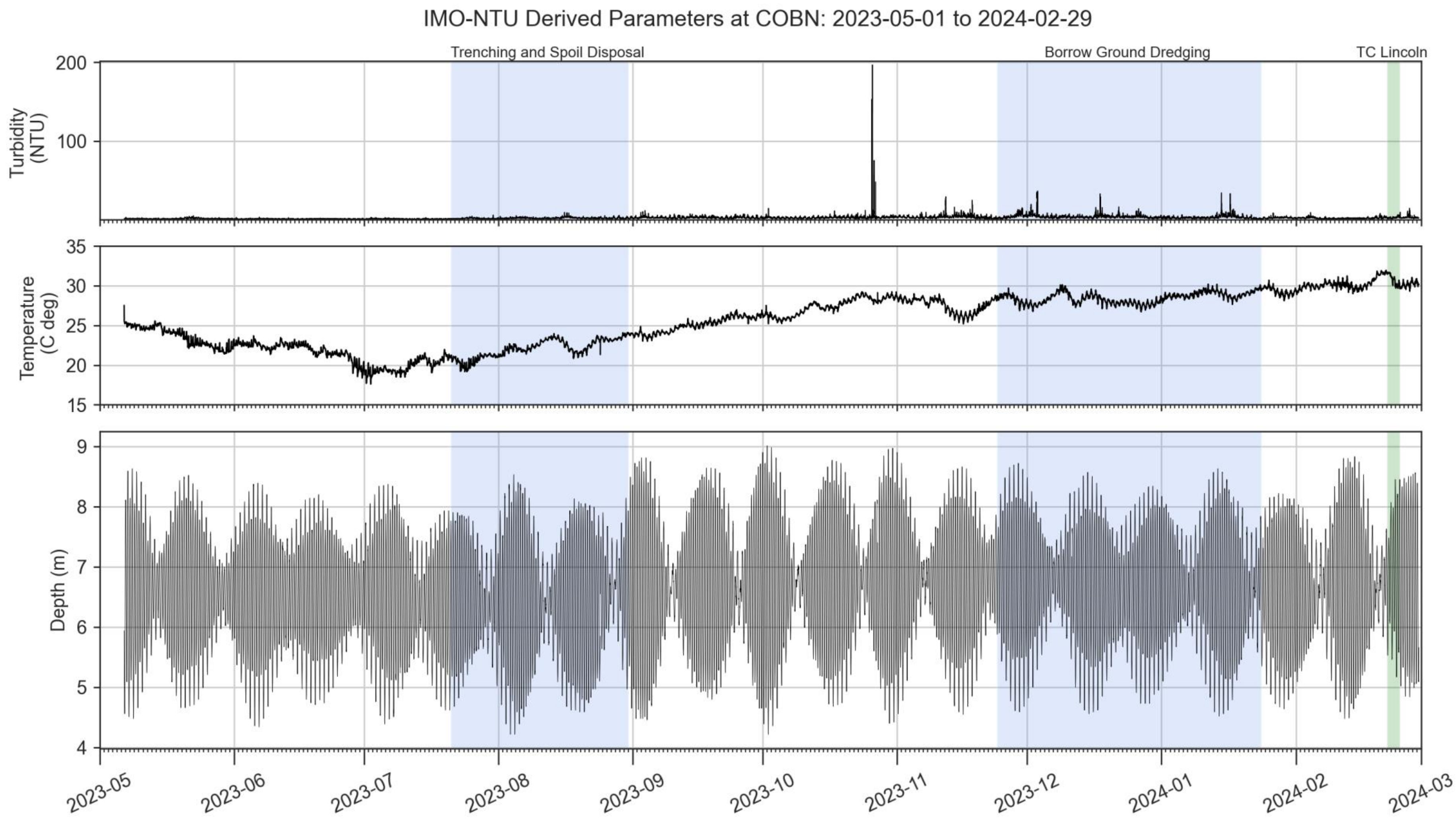

Figure C.13: Quality controlled turbidity parameters at COBN

Appendix C.8. CONI

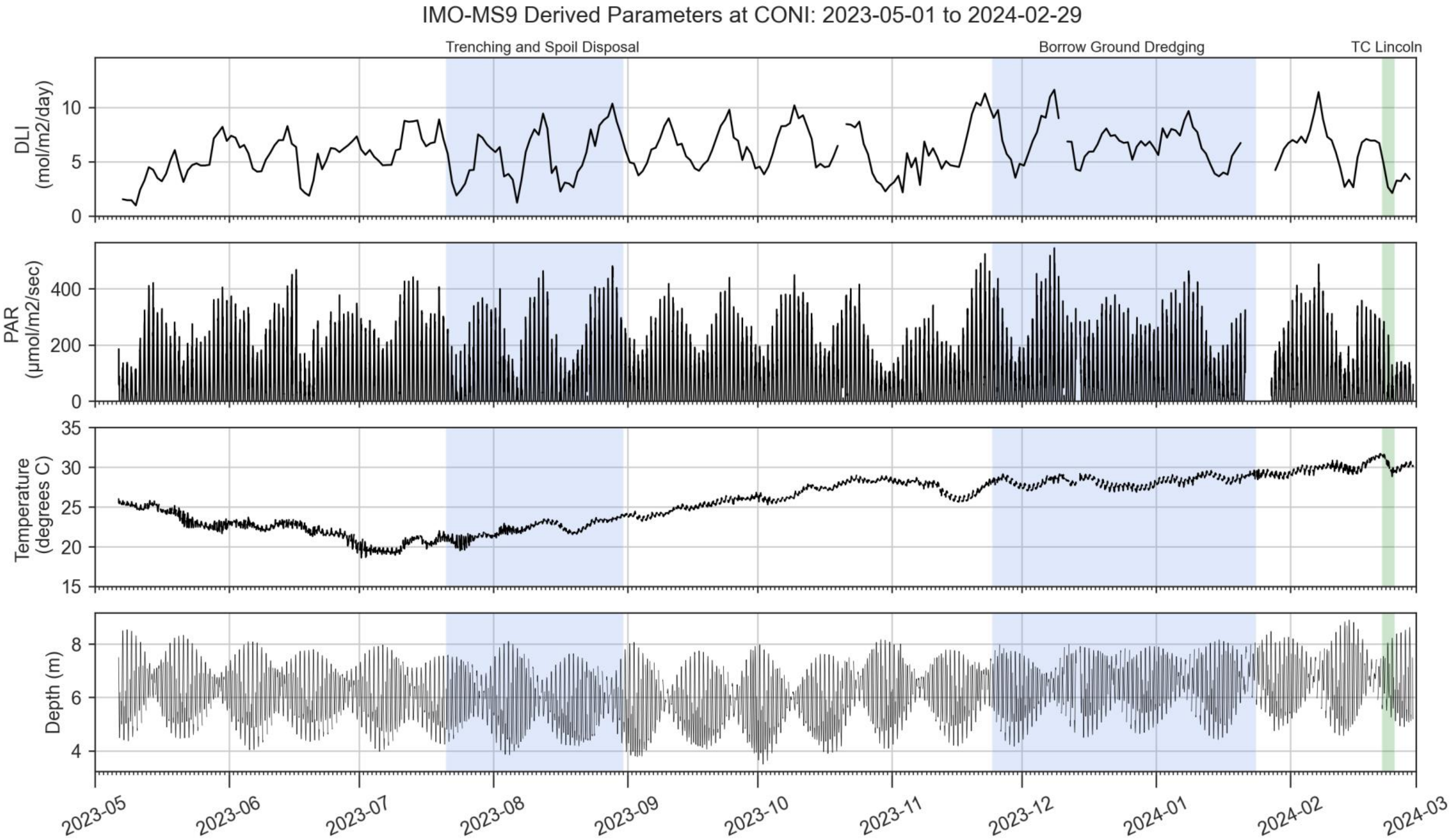

Figure C.14: Quality controlled light parameters at CONI

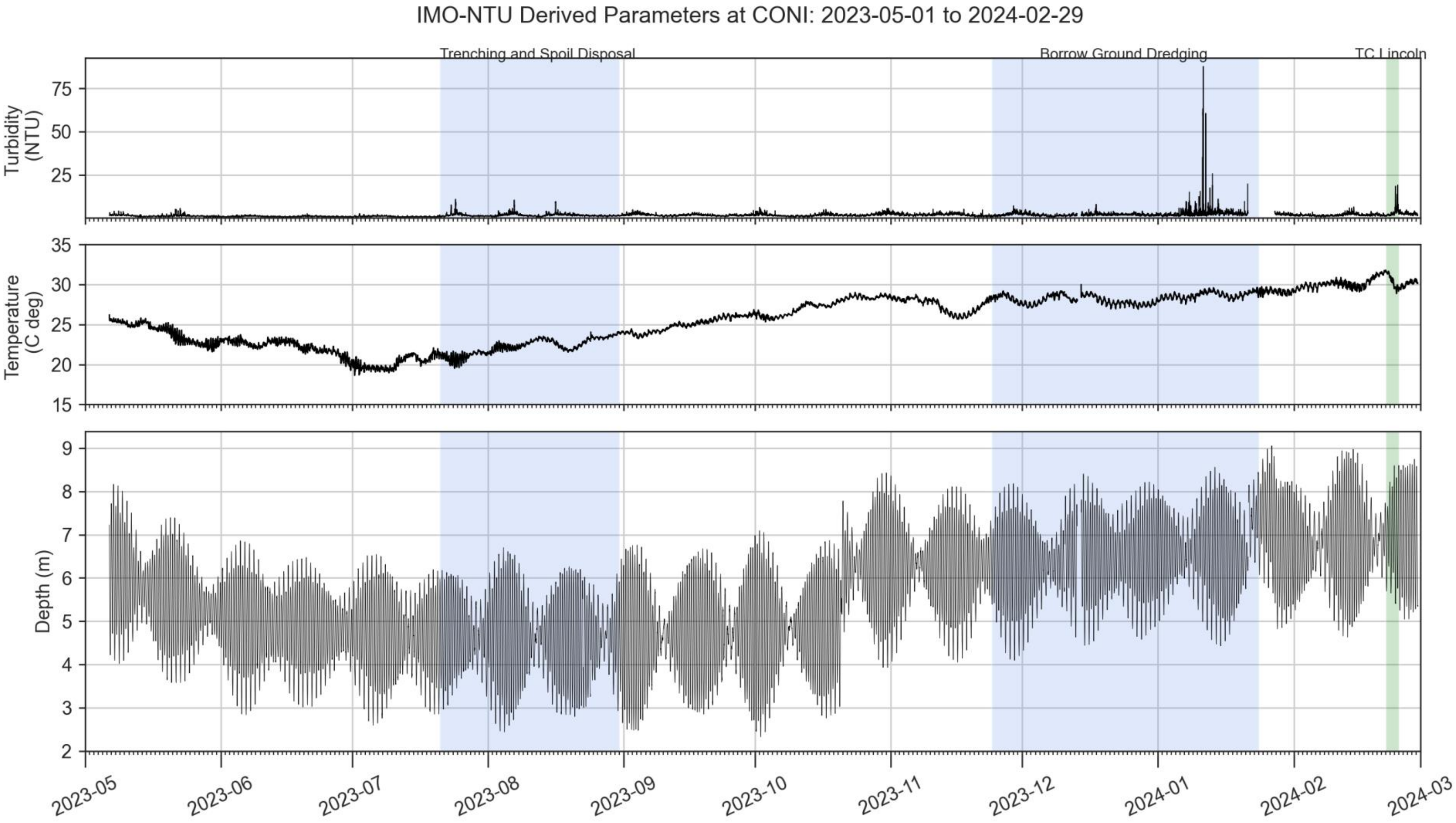

Figure C.15: Quality controlled turbidity parameters at CONI

Appendix C.9. CONI2

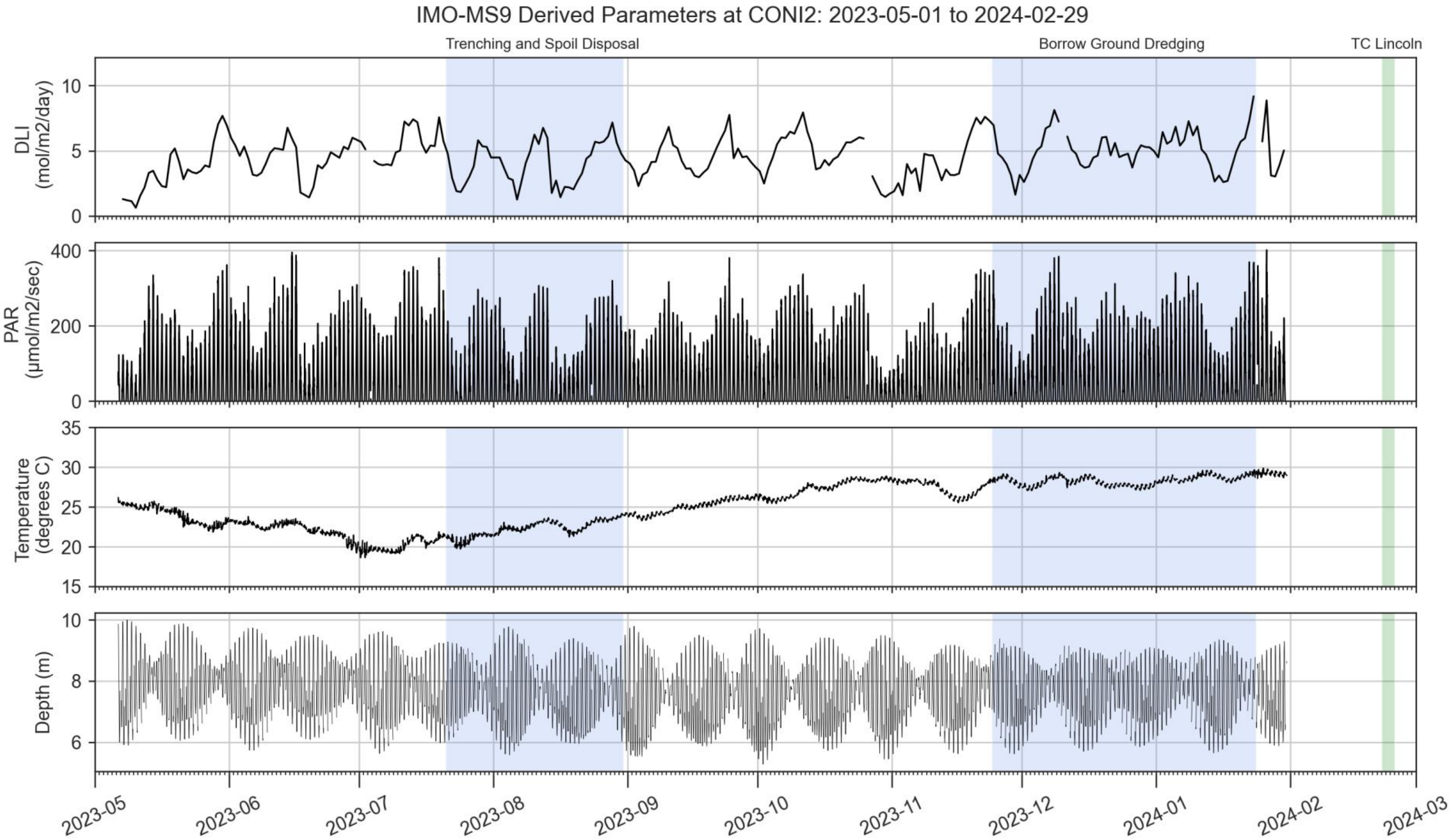

Figure C.16: Quality controlled light parameters at CONI2

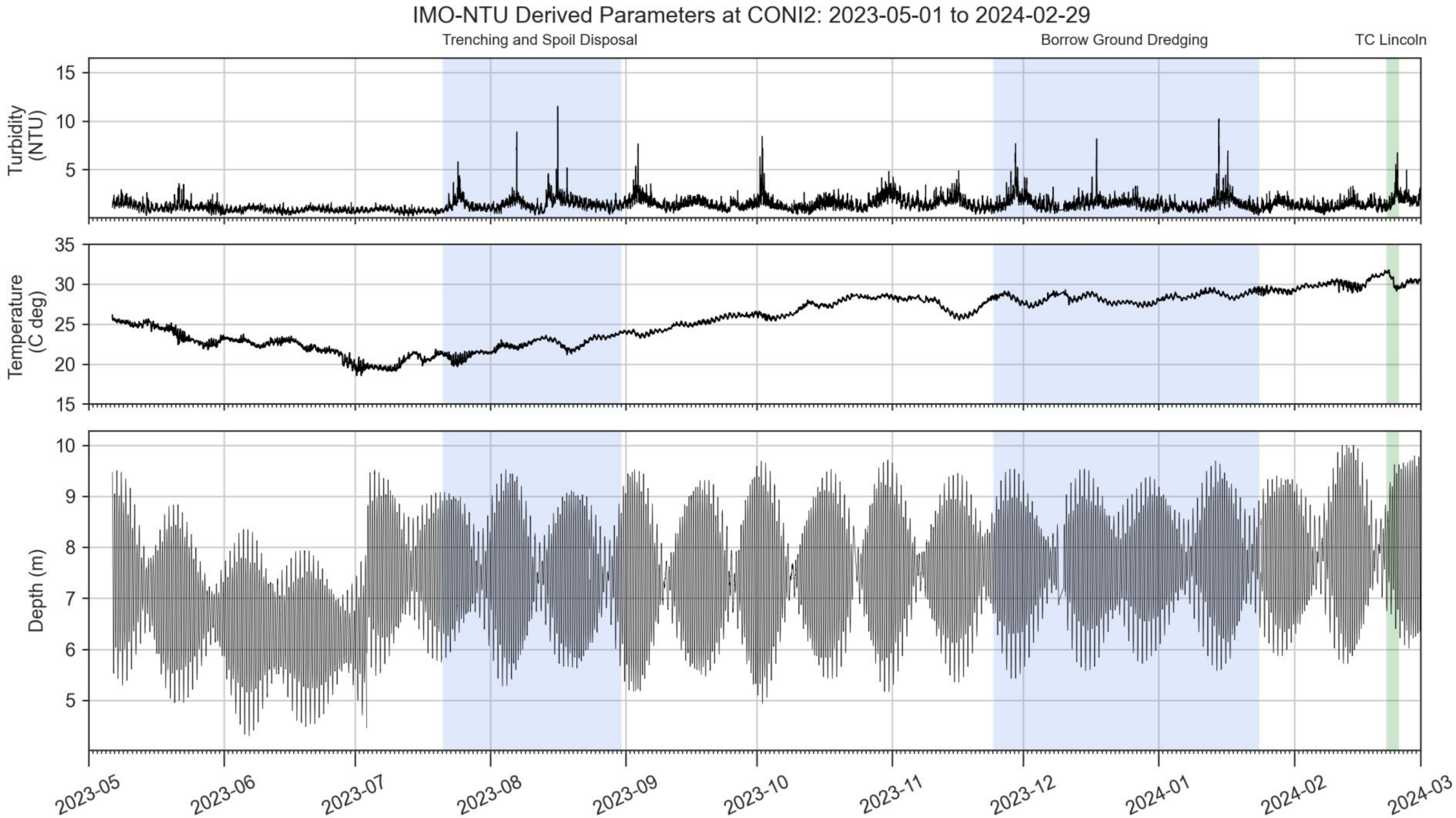

Figure C.17: Quality controlled turbidity parameters at CONI2

Appendix C.10. CRTS

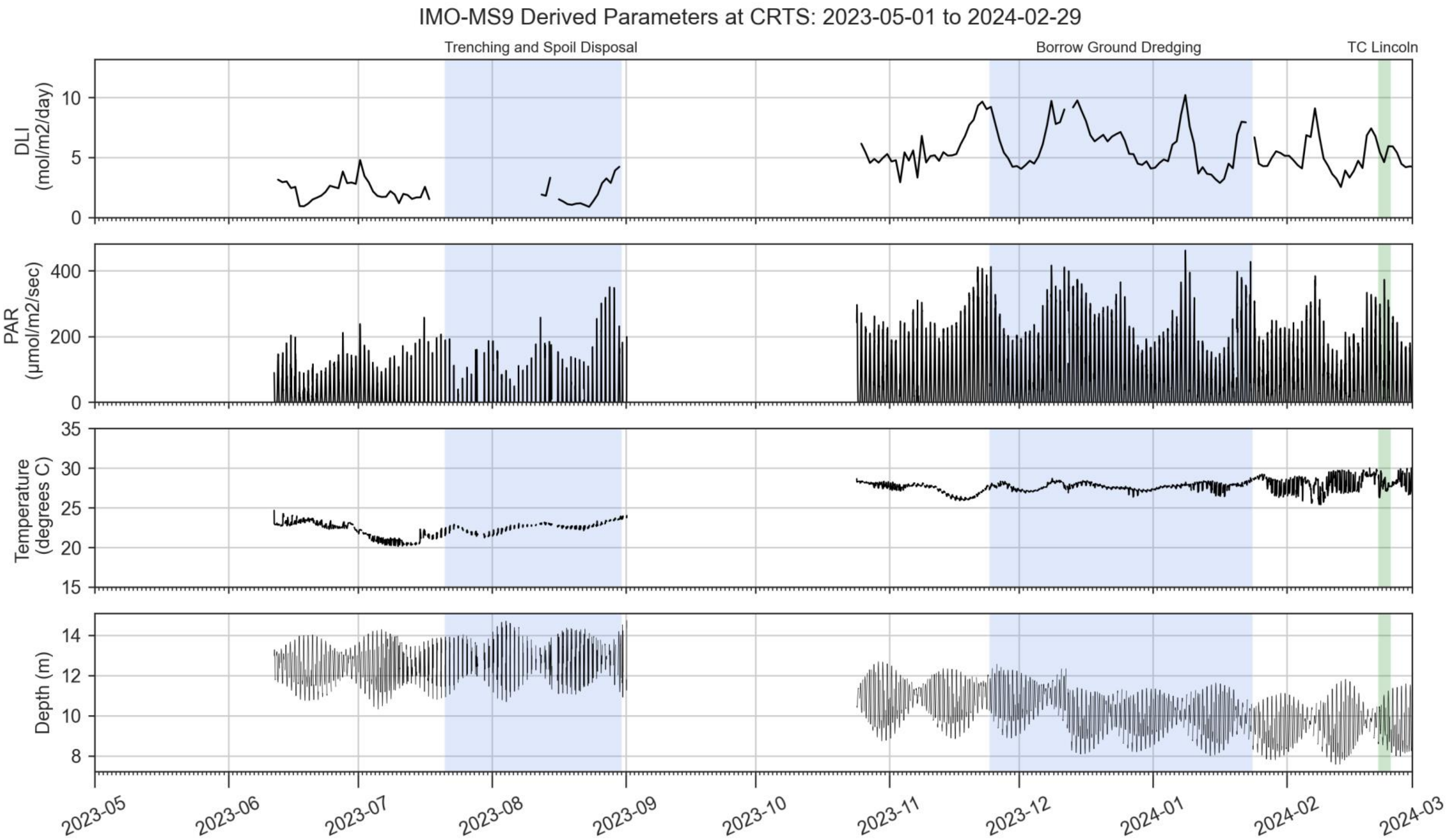

Figure C.18: Quality controlled light parameters at CRTS

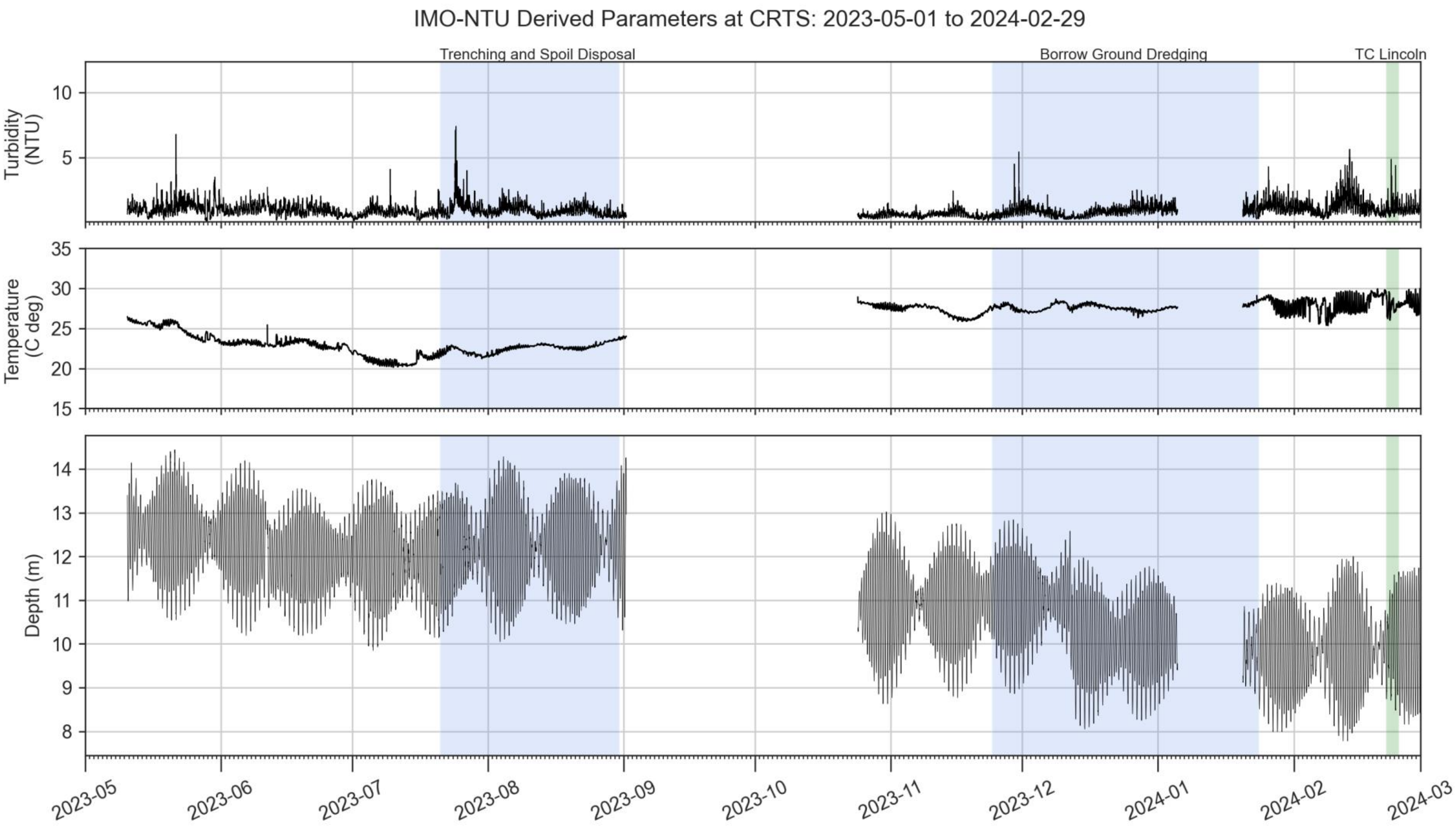

Figure C.19: Quality controlled turbidity parameters at CRTS

Appendix C.11. FFP1

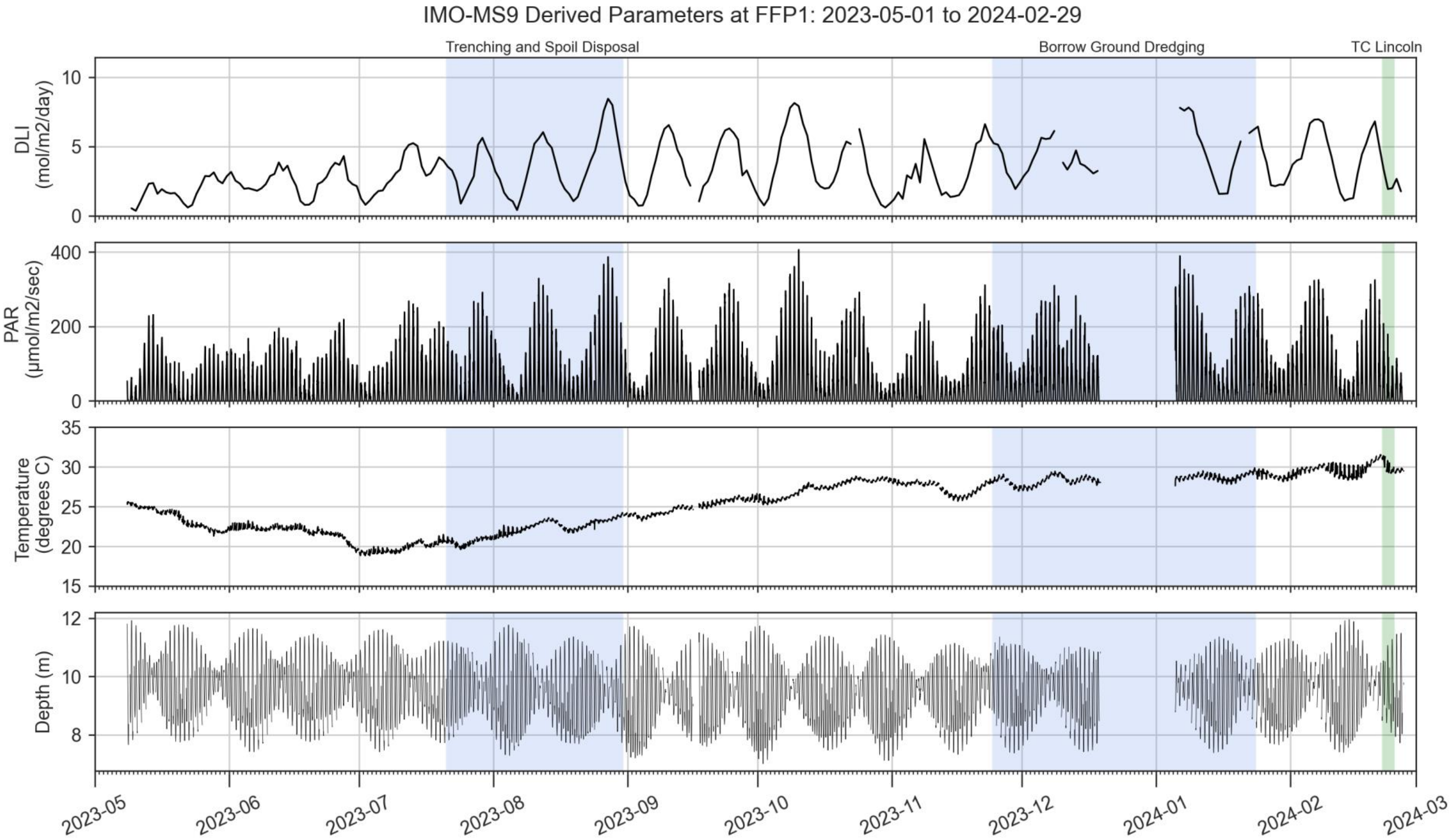

Figure C.20: Quality controlled light parameters at FFP1

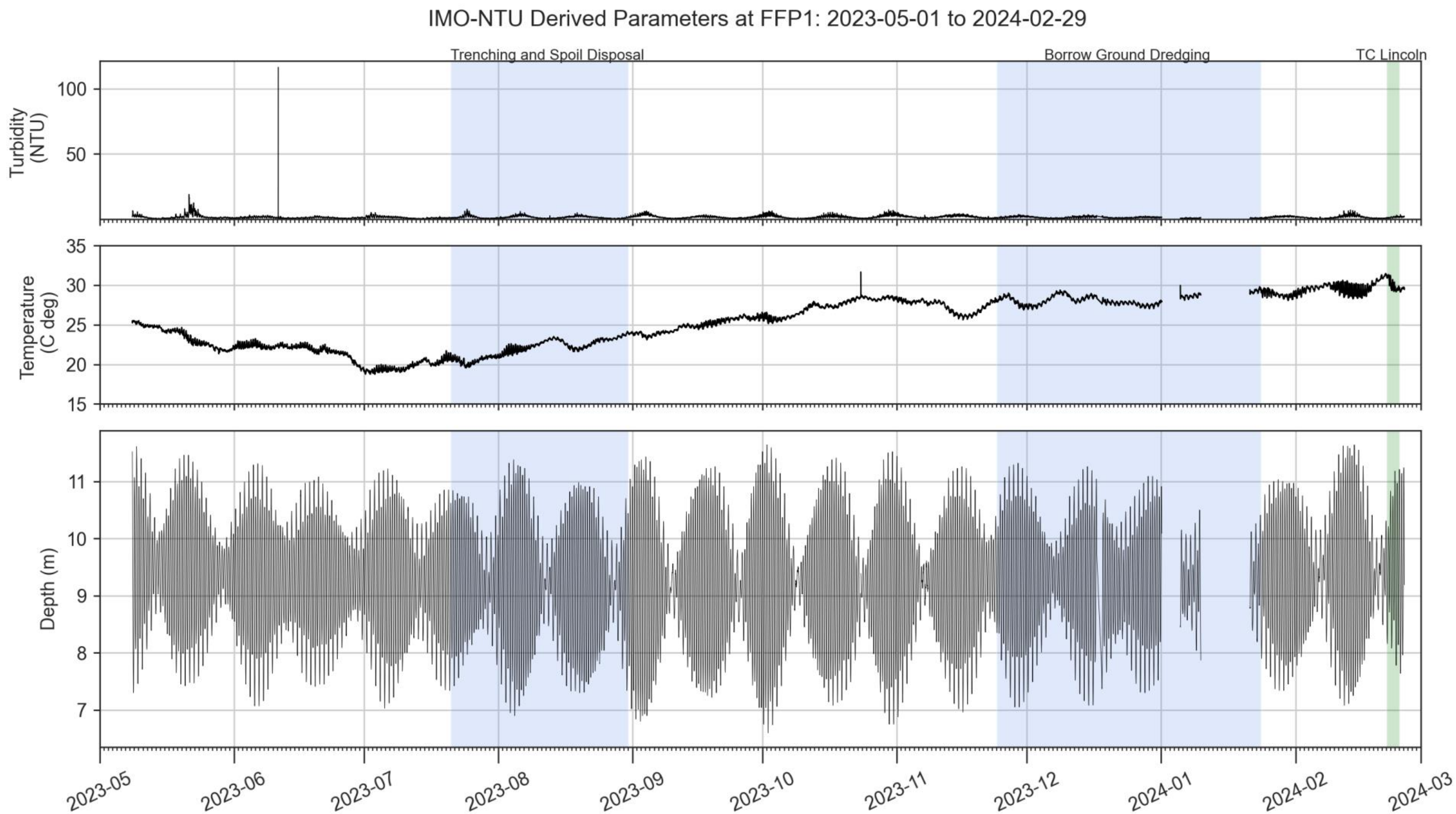

Figure C.21: Quality controlled turbidity parameters at FFP1

Appendix C.12. GIDI

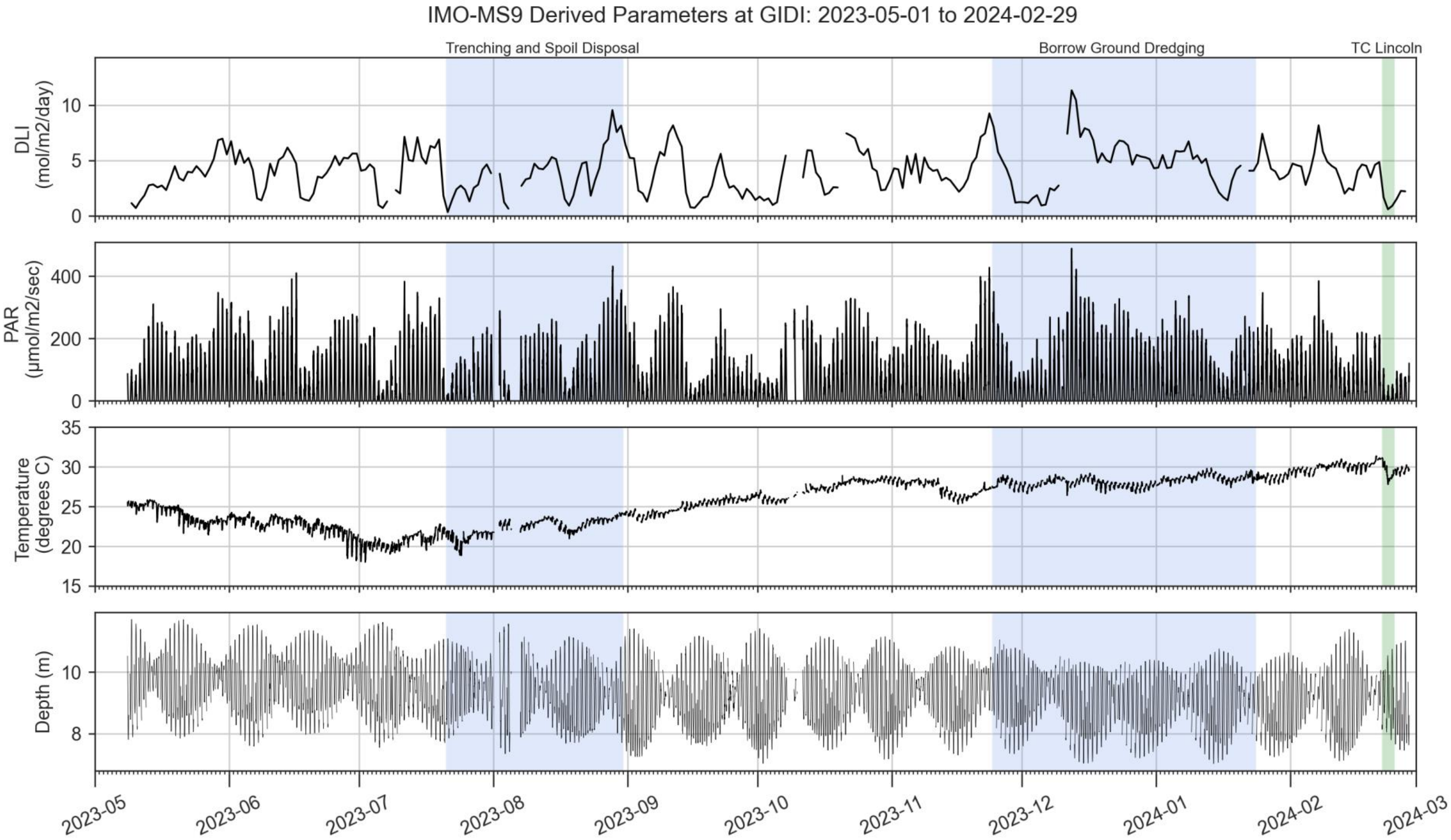

Figure C.22: Quality controlled light parameters at GIDI

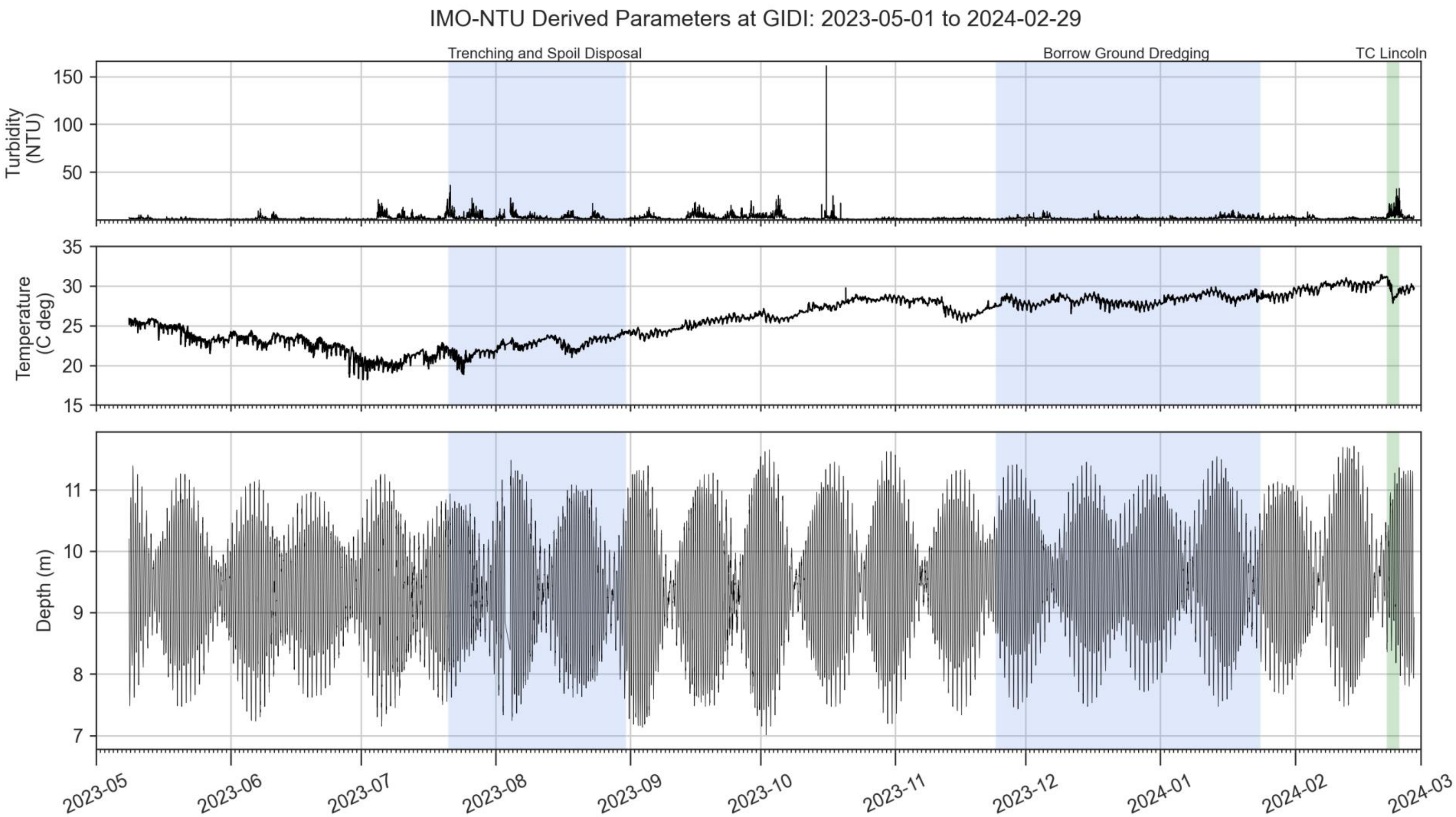

Figure C.23: Quality controlled turbidity parameters at GIDI

Appendix C.13. HAM3

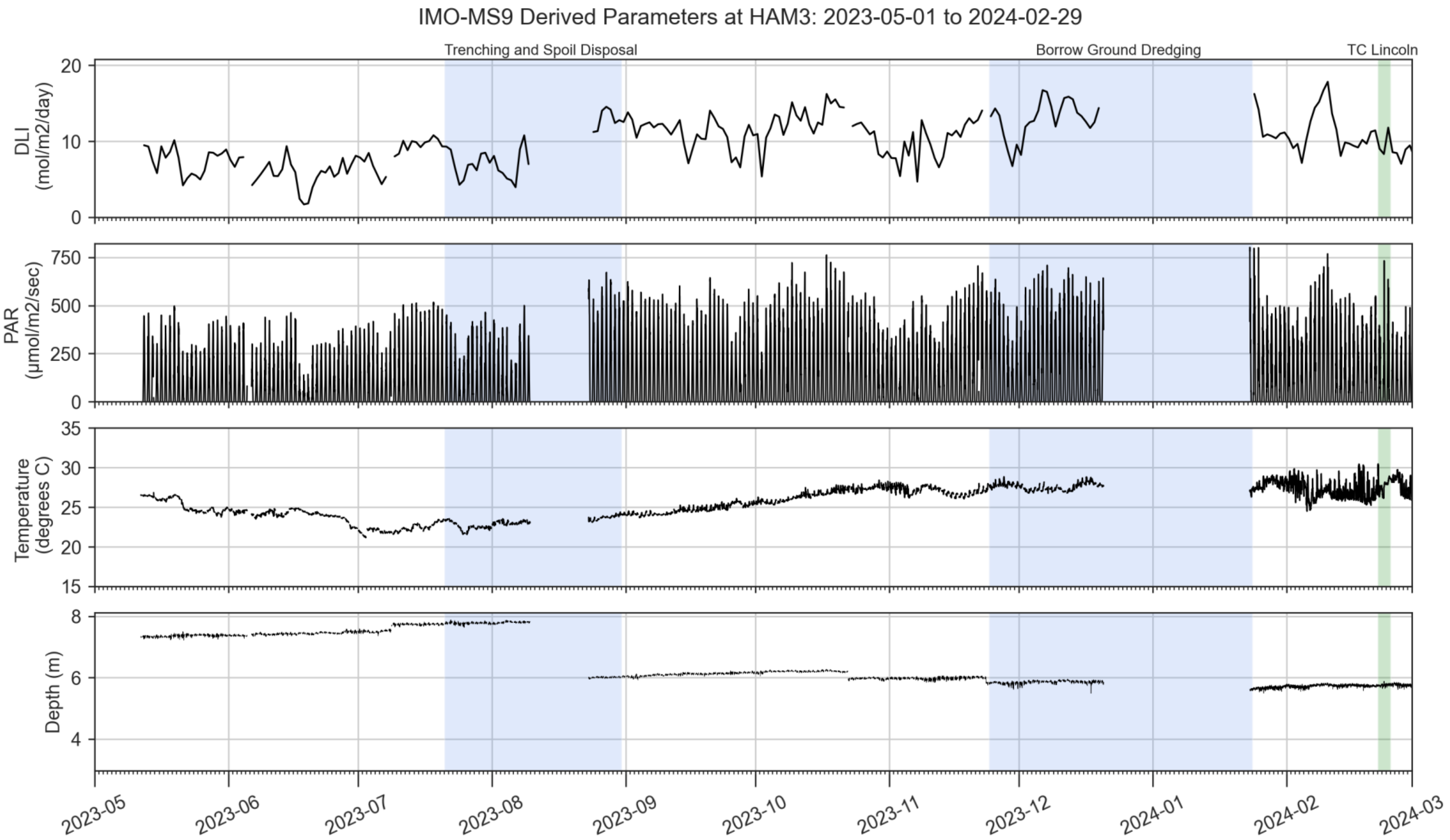

Figure C.24: Quality controlled light parameters at HAM3. Note: the frame and loggers were suspended in mid-water

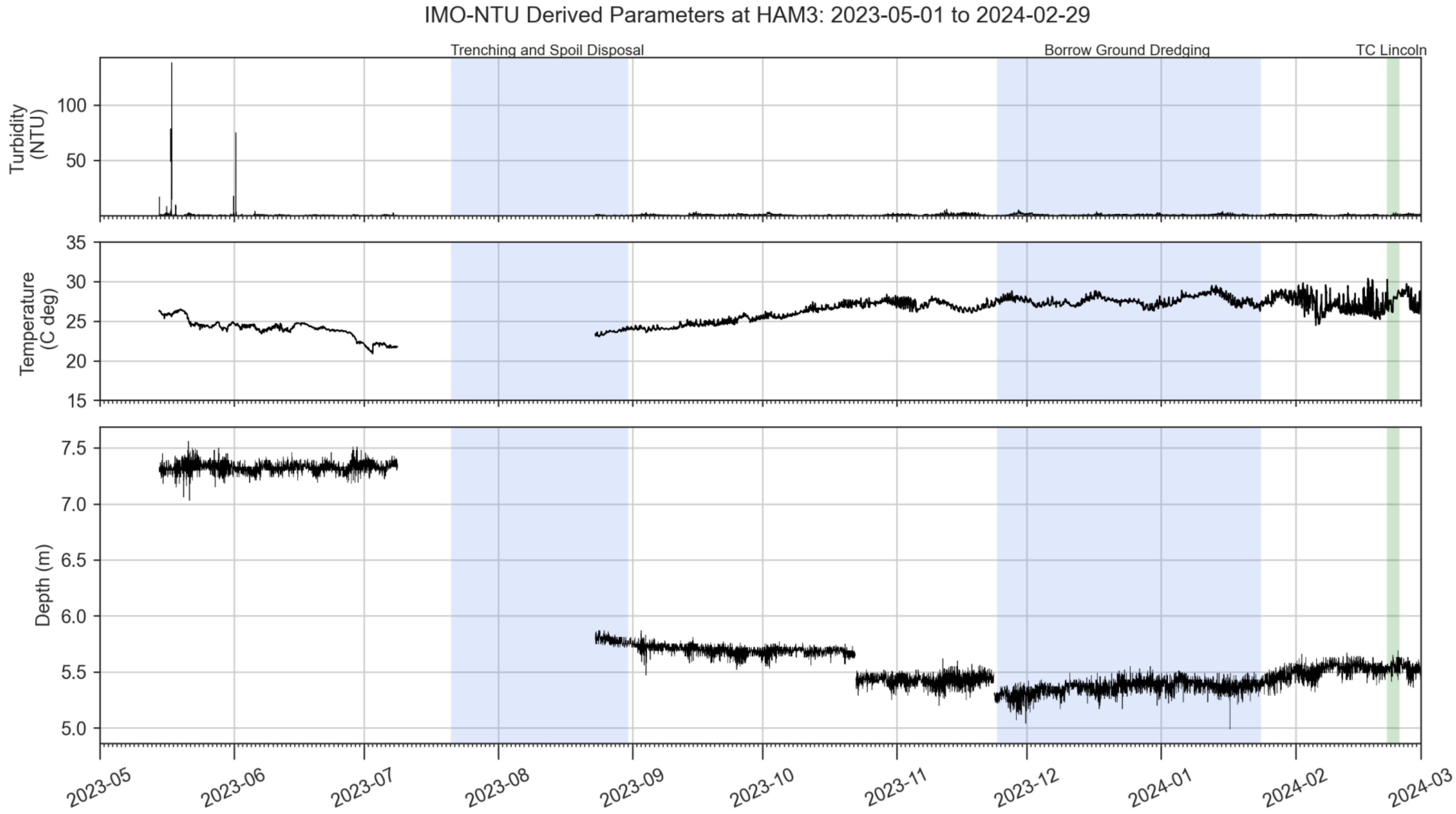

Figure C.25: Quality controlled turbidity parameters at HAM3. Note: the frame and loggers were suspended in mid-water

Appendix C.14. HAUY

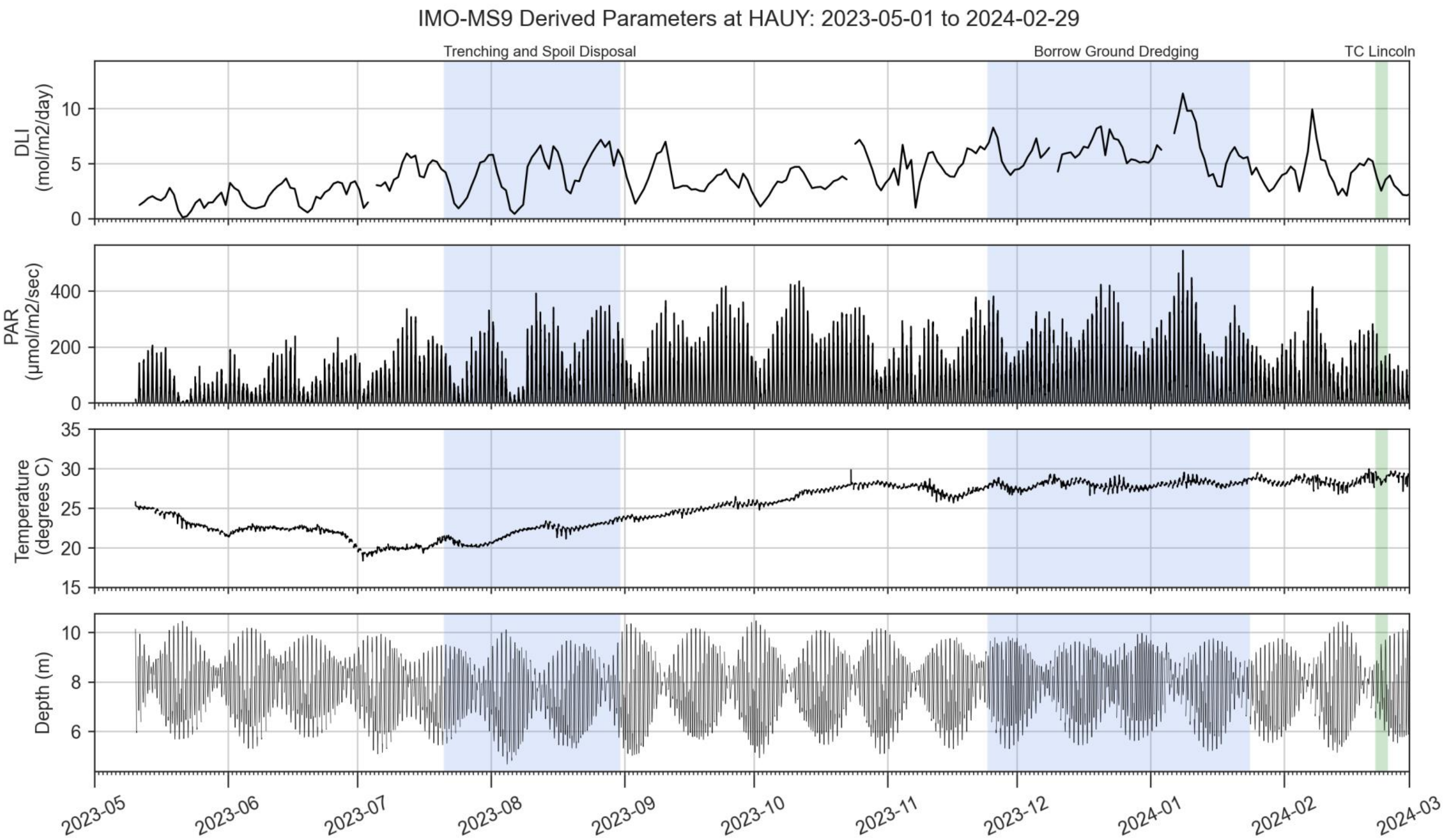

Figure C.26: Quality controlled light parameters at HAUY

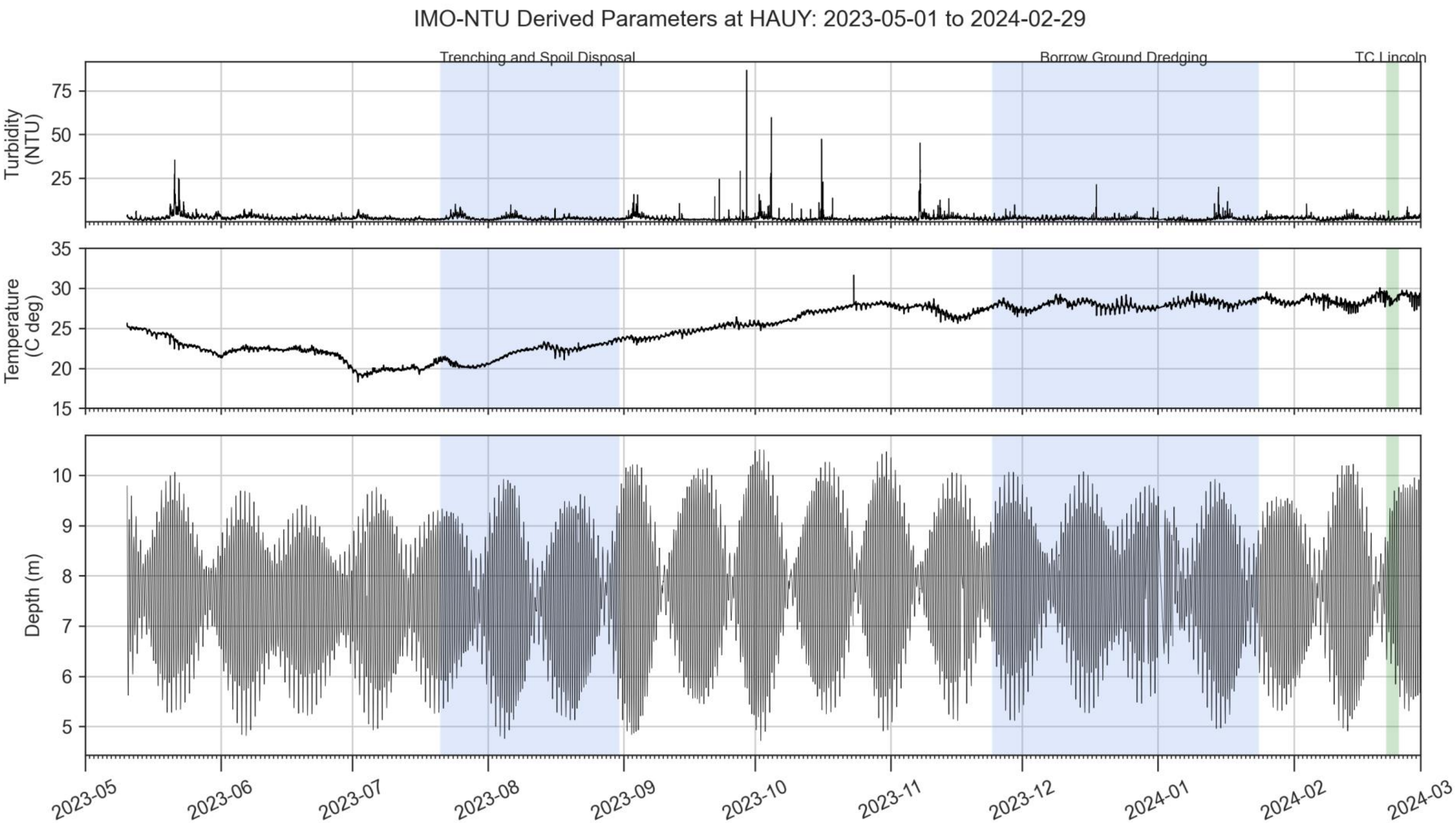

Figure C.27: Quality controlled turbidity parameters at HAUY

Appendix C.15. HGPT

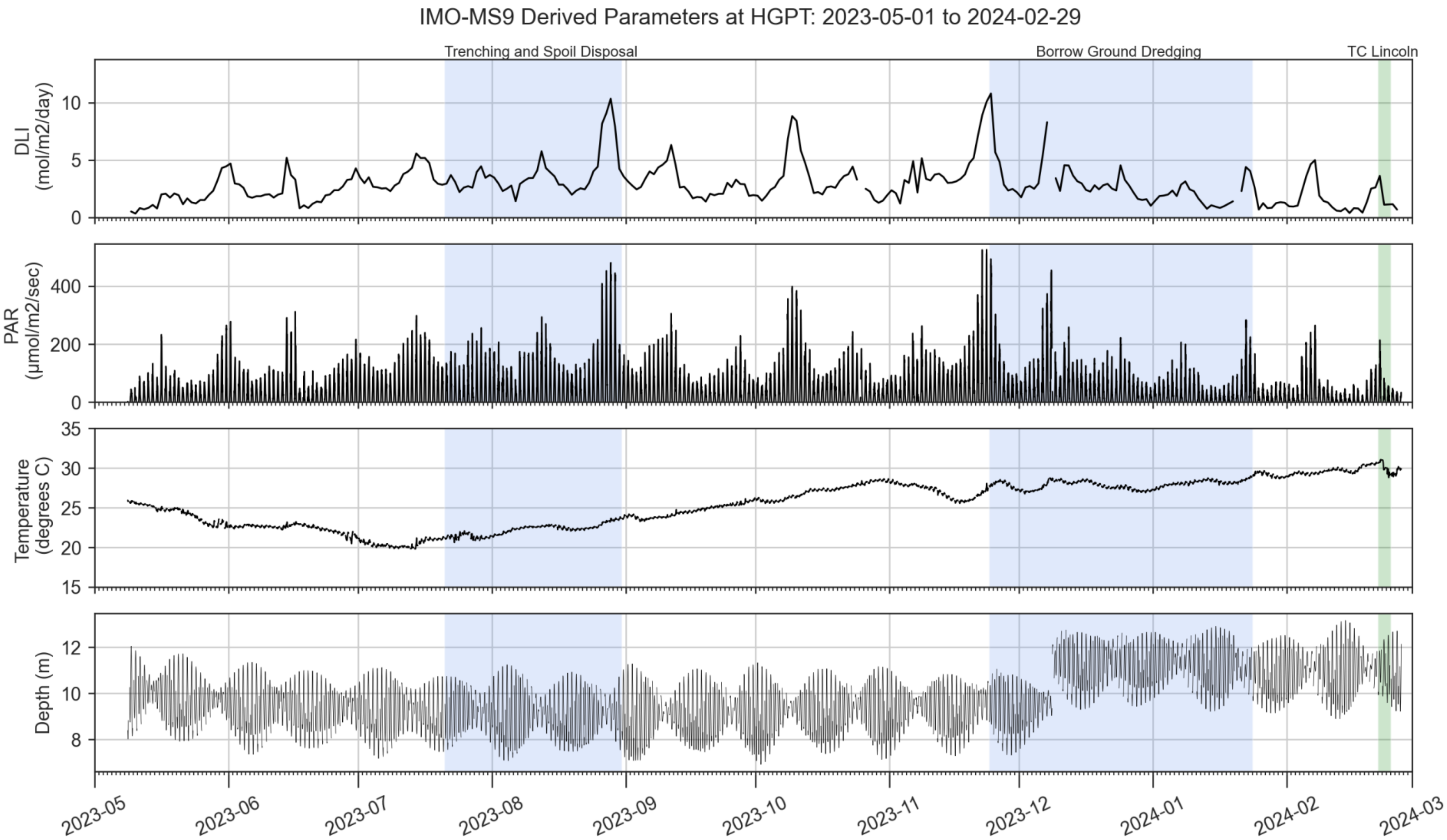

Figure C.28: Quality controlled light parameters at HGPT

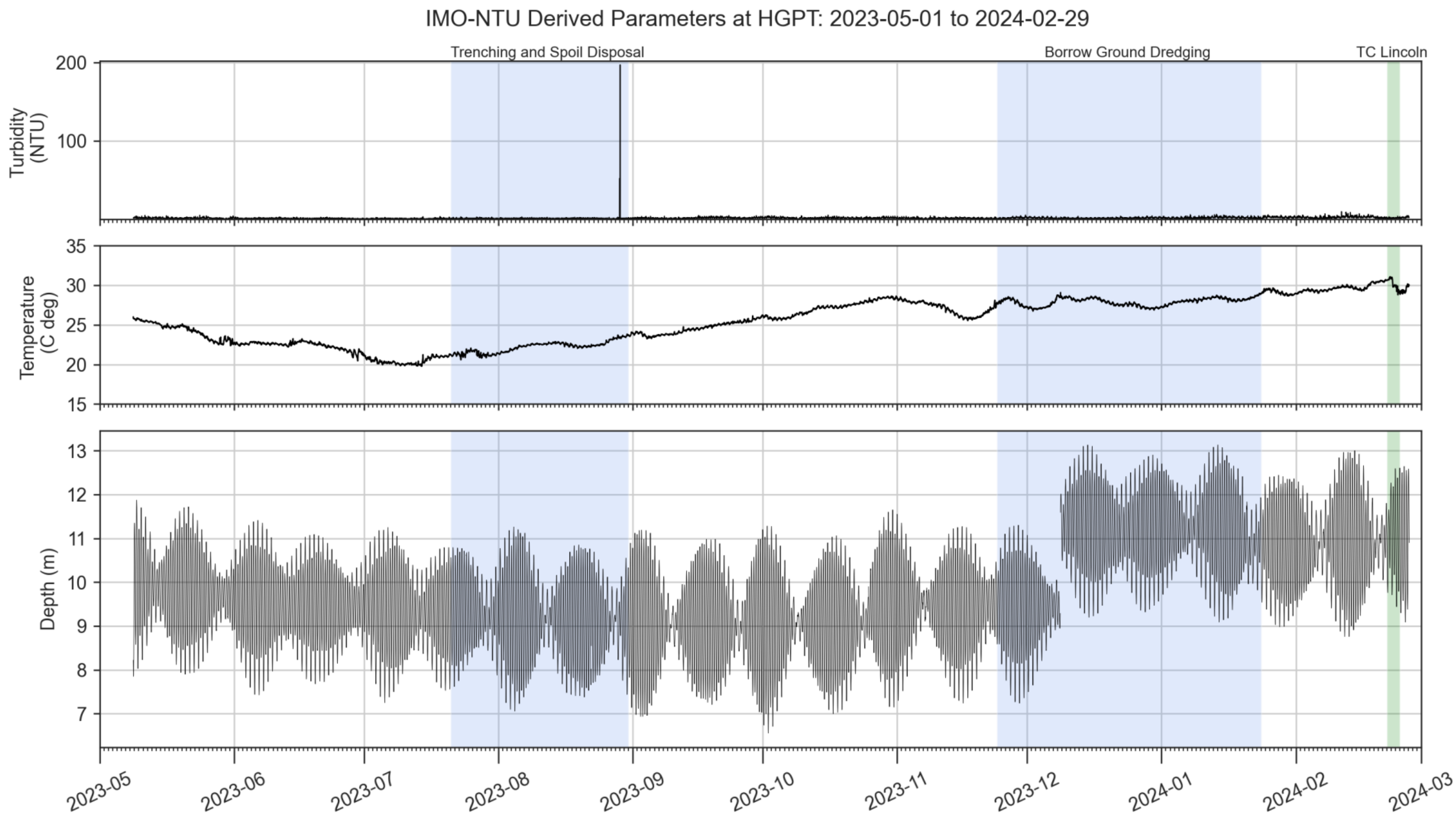

Figure C.29: Quality controlled turbidity parameters at HGPT

Appendix C.16. LANI

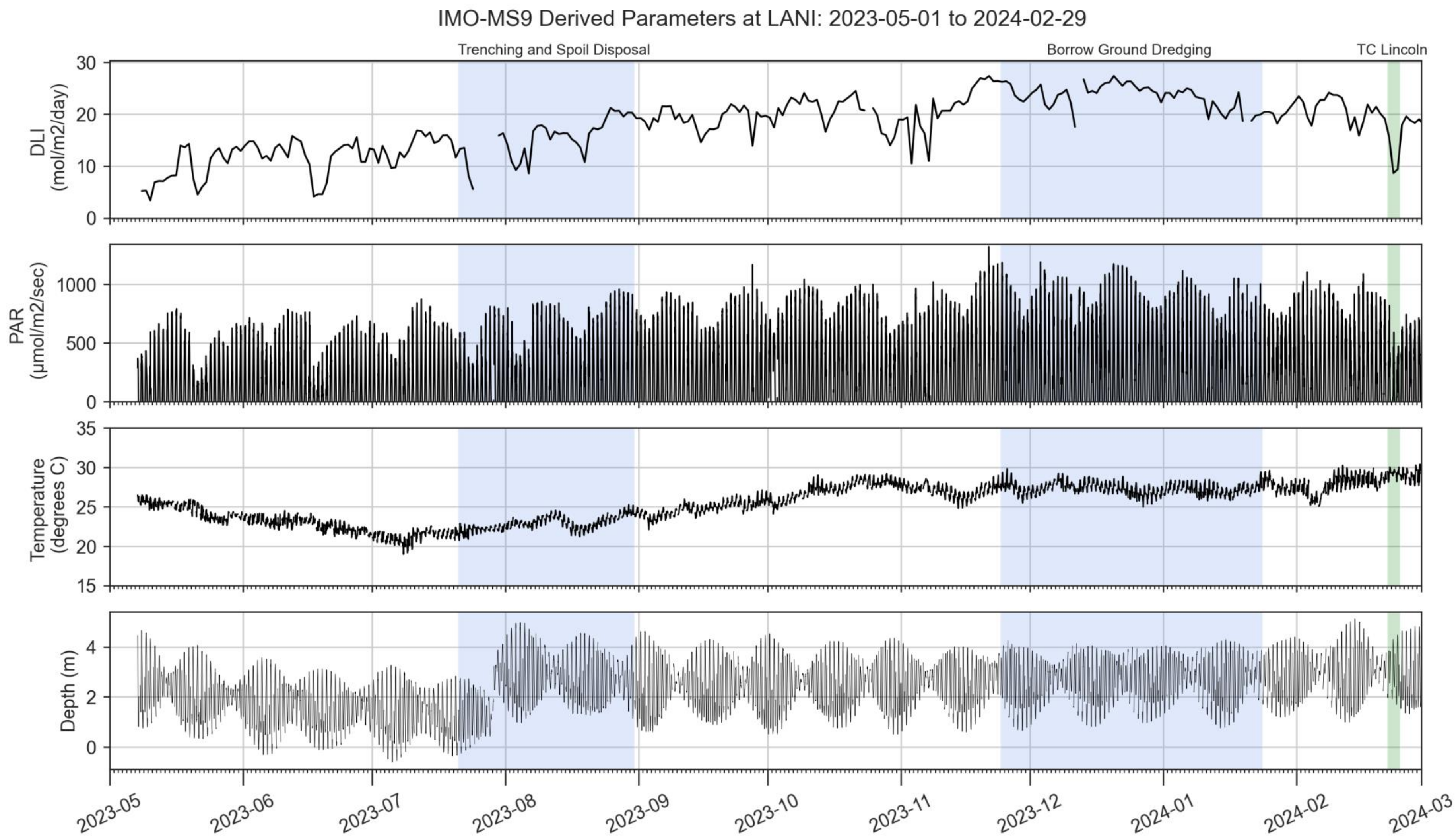

Figure C.30: Quality controlled light parameters at LANI

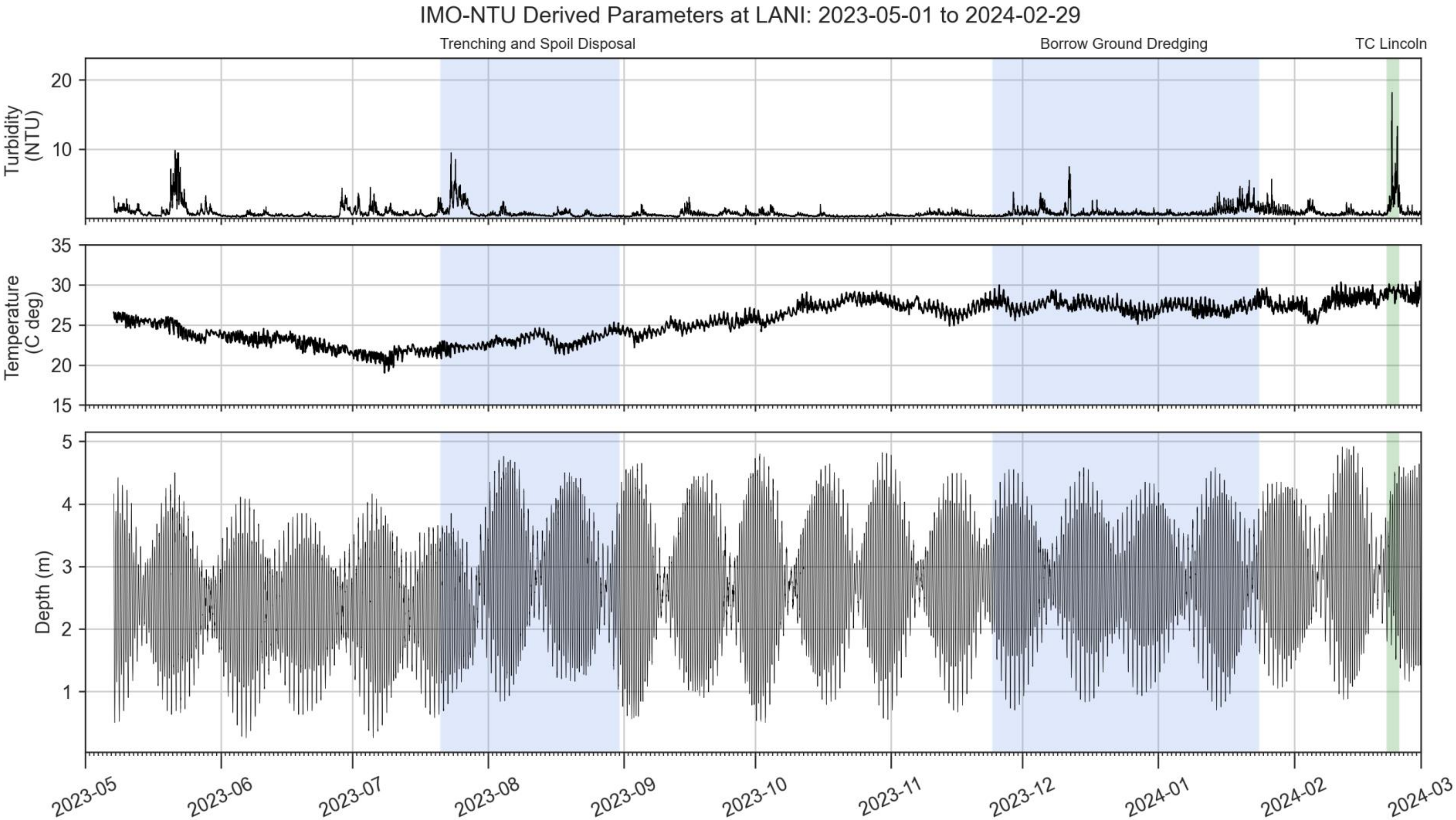

Figure C.31: Quality controlled turbidity parameters at LANI

Appendix C.17. LEGD

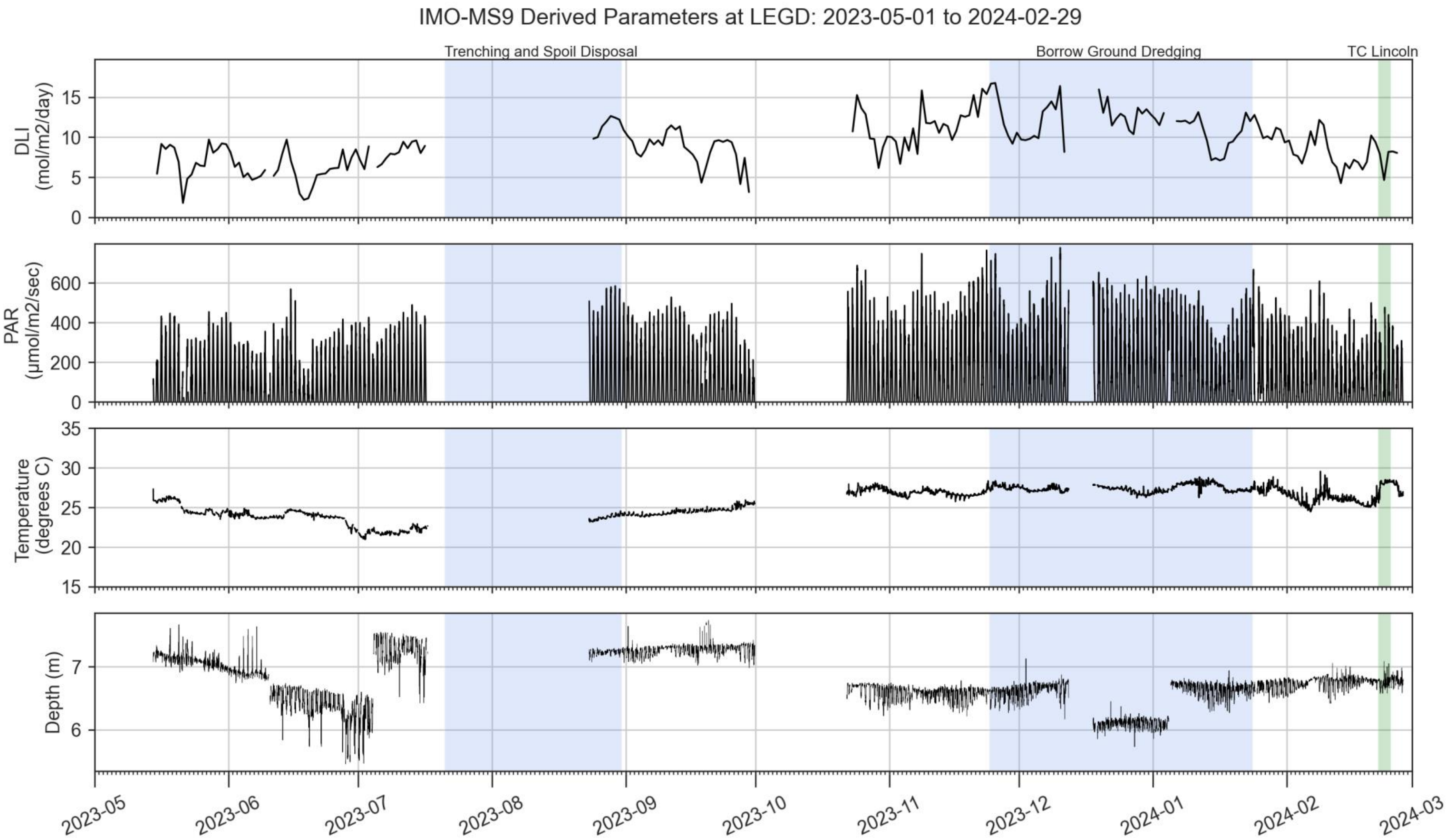

Figure C.32: Quality controlled light parameters at LEGD. Note: the frame and loggers were suspended in mid-water

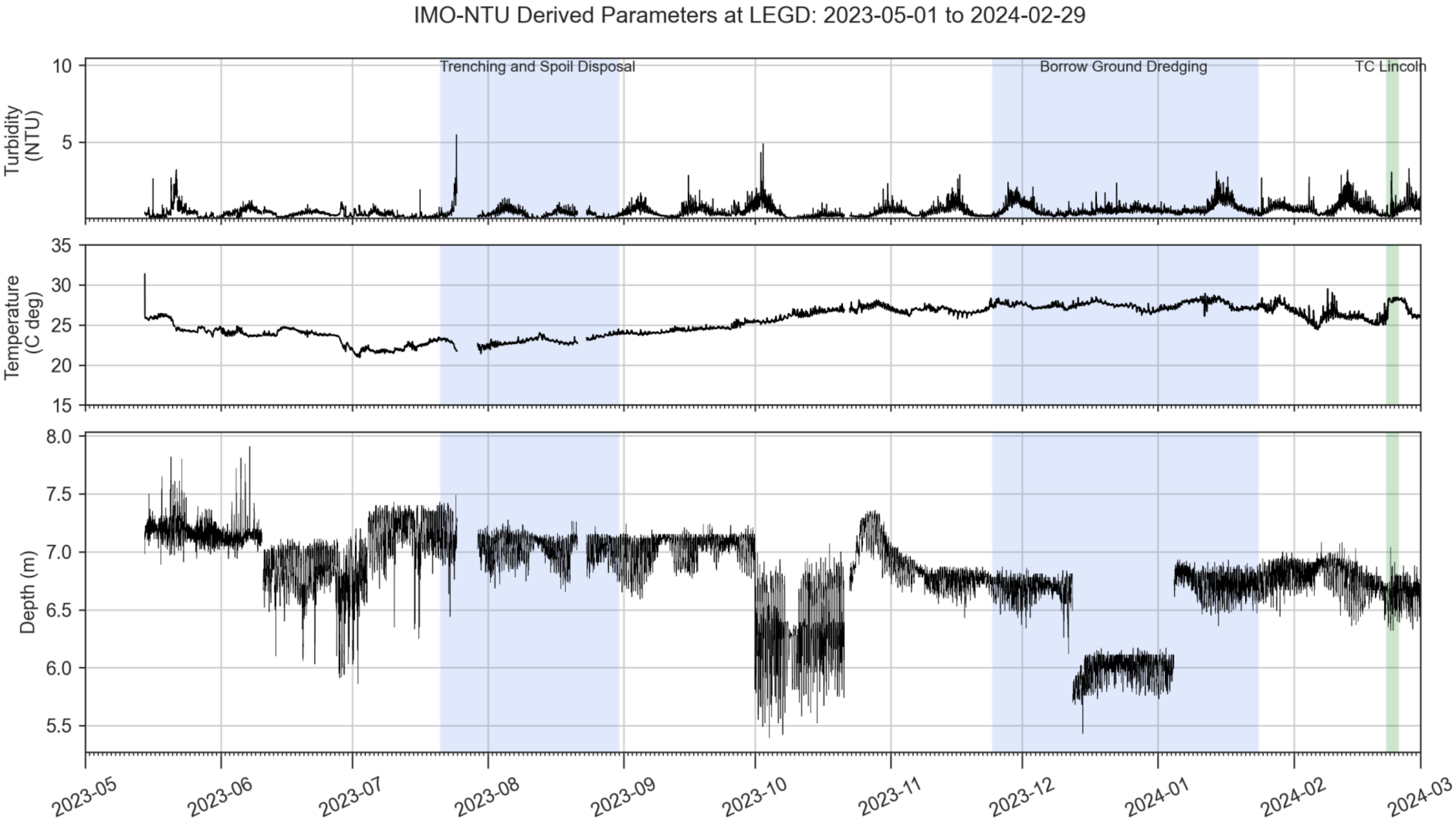

Figure C.33: Quality controlled turbidity parameters at LEGD. Note: the frame and loggers were suspended in mid-water

Appendix C.18. MAL2

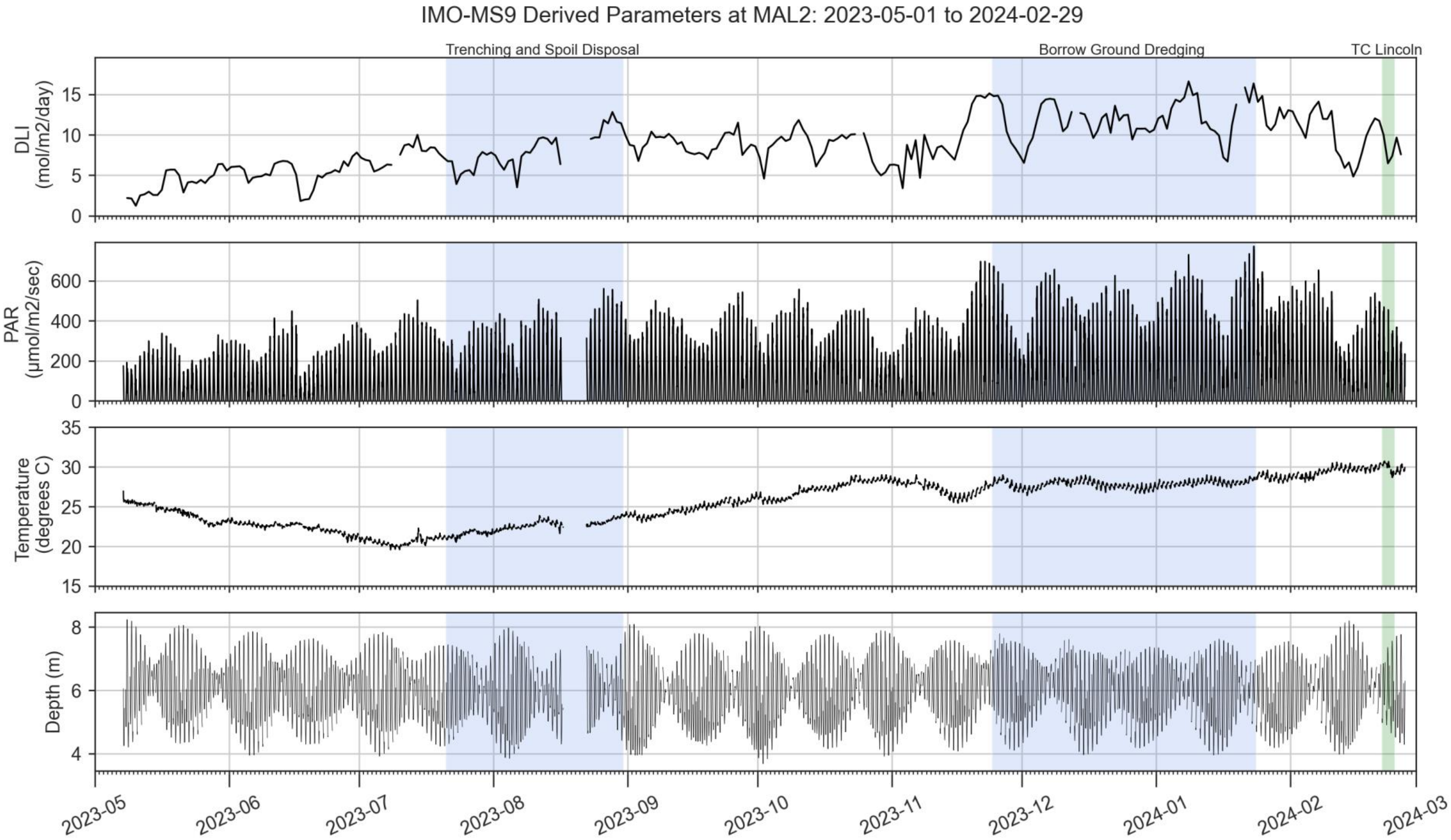

Figure C.34: Quality controlled light parameters at MAL2

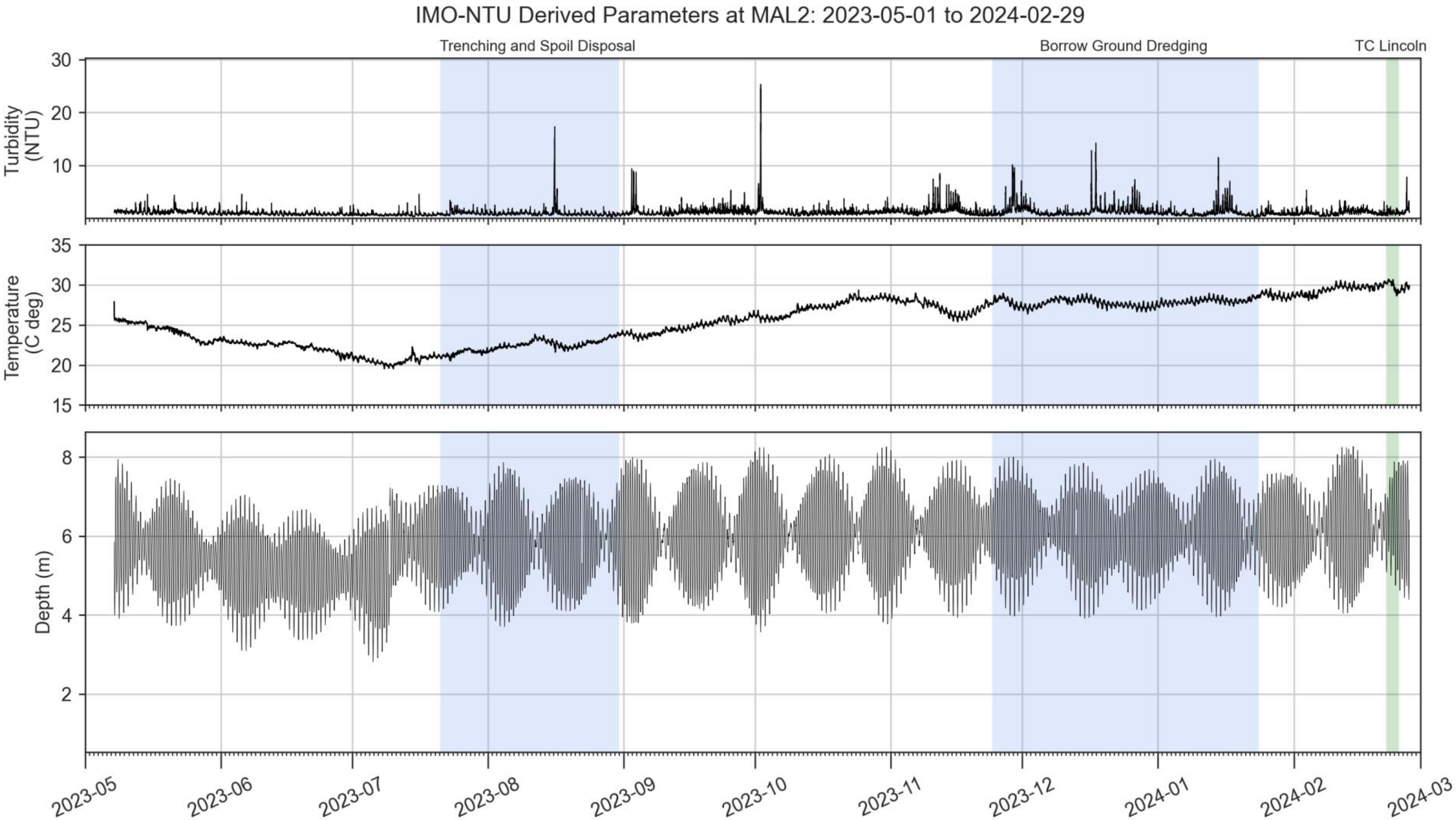

Figure C.35: Quality controlled turbidity parameters at MAL2

Appendix C.19. MPB

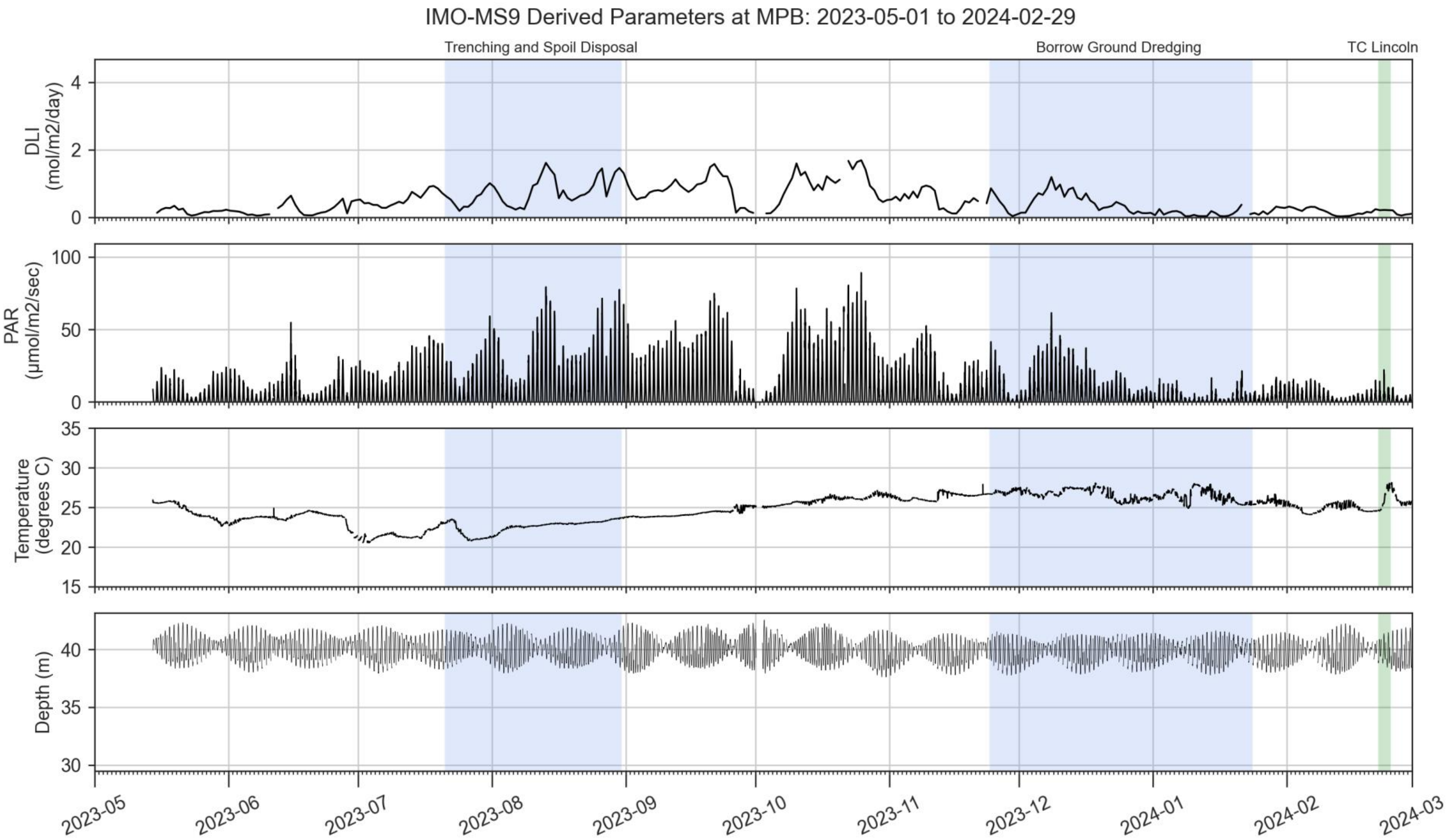

Figure C.36: Quality controlled light parameters at MPB

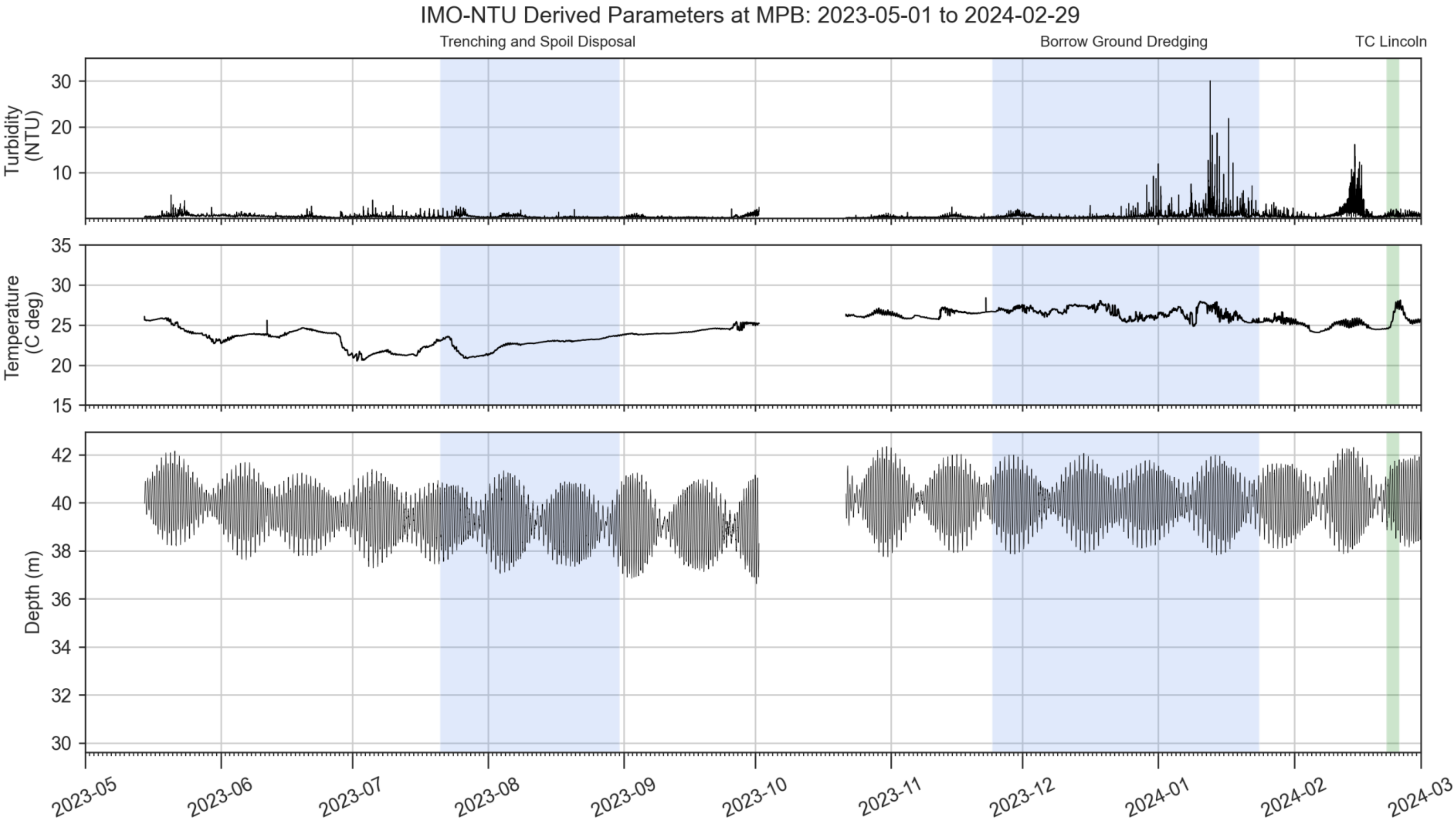

Figure C.36: Quality controlled turbidity parameters at MPB

Appendix C.20. Land-based Logger

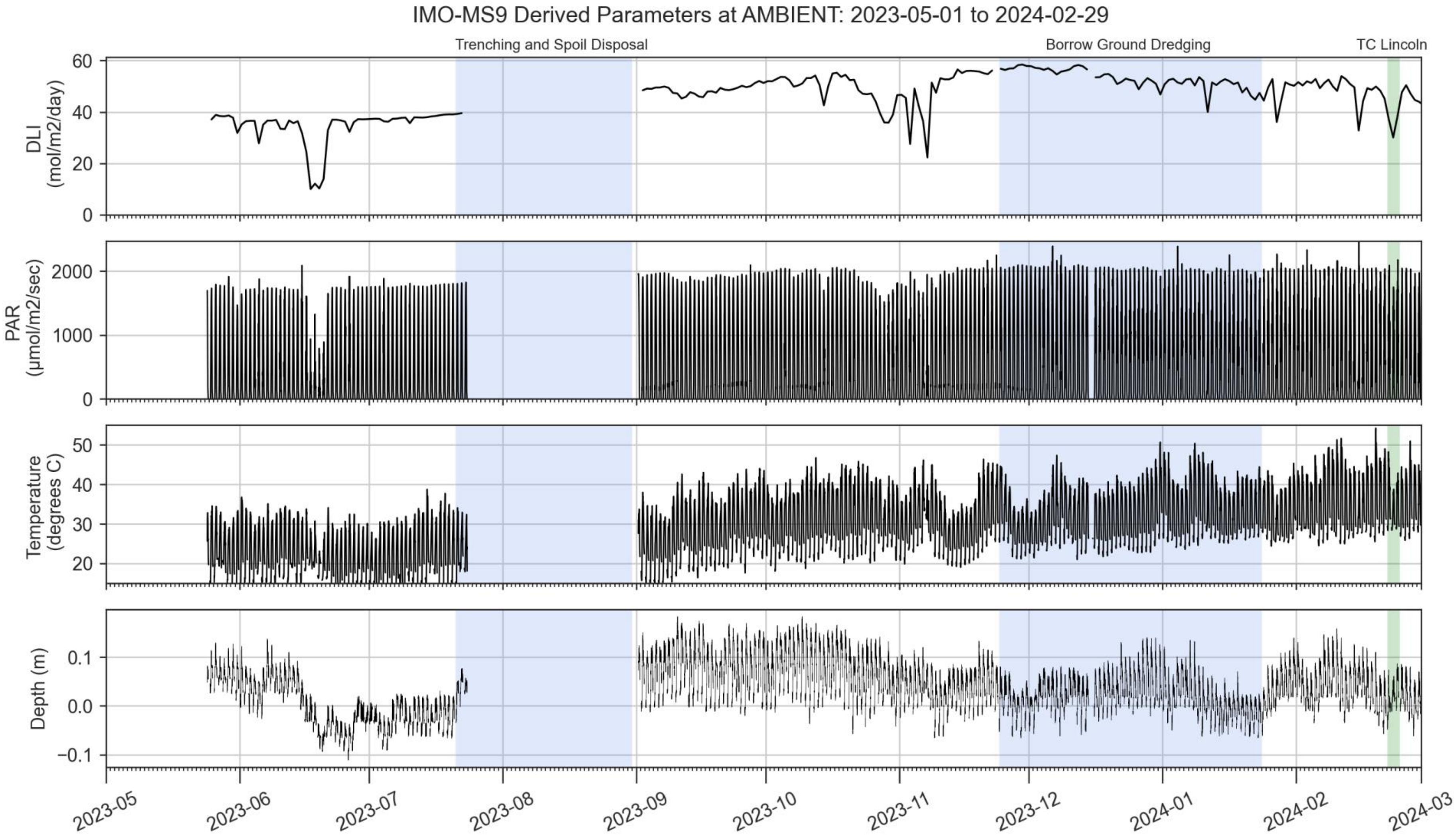

Figure C.37: Quality controlled light parameters at land-based logger

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