

Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2024-2025

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EXECUTIVE SUMMARY

The 2024–2025 reporting year provides a comprehensive dataset describing ambient water quality across the Port of Mackay and Port of Hay Point. Through the integration of discrete sampling, in situ profiling, passive samplers and continuous seafloor-mounted loggers, the program continues to strengthen a robust long-term evidence base for understanding water-quality variability in a dynamic, tidally energetic coastal environment.

Rainfall and river-discharge patterns followed a typical dry–tropical seasonal cycle, with an early October rainfall onset followed by several short-lived runoff events during February and March 2025. These events produced brief increases in turbidity and freshwater influence but did not result in sustained shifts in coastal physicochemical conditions.

Nutrient and chlorophyll-*a* concentrations across sites were generally low to moderate but showed persistent elevation in some nitrogen fractions and chlorophyll-*a* relative to background expectations for open coastal waters. Concentrations varied seasonally and episodically, with short-lived particulate-dominated events—most notably at Freshwater Point in October 2024—contributing to higher values at individual sites. Despite this, there was no evidence of progressive temporal increase in nutrients or chlorophyll-*a* across the long-term monitoring record.

Physicochemical measurements captured clear seasonal patterns in temperature, salinity, dissolved oxygen and turbidity. Turbidity was generally low for much of the year, punctuated by short-term increases associated with wet-season rainfall or wind- and tide-driven resuspension. Continuous logger data resolved these short-term dynamics and highlighted predictable seasonal patterns in mixing and light availability. Multispectral irradiance measurements demonstrated strong blue–green light penetration during dry-season conditions and increased attenuation during periods of elevated turbidity, emphasising the role of suspended sediments in controlling benthic light quality.

Long-term analyses indicate that variations in water quality across the Mackay and Hay Point region are primarily driven by natural seasonal and year-to-year changes in rainfall, river discharge, and related hydrological processes. While statistical analyses identified longer-term patterns in several parameters, these did not indicate a sustained increase or decrease in water quality. Instead, they reflect natural variability typical of the region. Overall, the 2024–2025 data describe a system in which nutrient levels and productivity fluctuate but remain within a stable long-term range, underscoring the importance of ongoing, detailed monitoring to detect emerging changes and support effective environmental management of port activities.

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1 INTRODUCTION

1.1 Background

Since July 2014, The Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University (JCU) has partnered with North Queensland Bulk Ports (NQBPs) to undertake long-term environmental monitoring and research surrounding the Port of Mackay and Hay Point (Figure 1-1). As part of this partnership, an ambient marine water quality monitoring program has been established incorporating discrete field measurements, continuous dataloggers, and laboratory analysis of nutrients, pesticides, Per- and polyfluoroalkyl substances (PFAS), and trace metals. The program characterises spatial and temporal variability in water quality and provides a detailed understanding of factors that may influence sensitive marine habitats within the surrounding port coastal waters.

Declining water quality remains a major pressure on the GBR, with elevated fine sediments, nutrients, and pesticides from catchments reducing the resilience of ecosystems to extreme events such as cyclones and marine heatwaves (Brodie et al., 2019; Waterhouse et al., 2017, 2022; Lam et al., 2018). Despite sustained investment in land-based pollution reduction, recent assessments show that progress towards Reef 2050 water quality targets remains limited, with reductions in nutrients, fine sediments and pesticides still falling short of required trajectories (Moran et al., 2025; Waterhouse et al., 2022; Reef Water Quality Report Card, 2024). Maintaining high water quality is crucial for protecting the ecological health of the GBR and sustaining its substantial economic, cultural, and social value; recent assessments estimate the Reef contributes \$6.4 billion annually and supports ~64,000 jobs (GBRF, 2025).

The Mackay–Hay Point region is a dynamic coastal environment influenced by strong tidal processes, episodic freshwater flows, and seasonal meteorology. Long-term environmental monitoring provides the high-quality evidence needed to understand natural variability, detect emerging trends, and support adaptive management responses under a changing climate.

1.2 Program objectives

Because the Ports of Mackay and Hay Point lie within the Great Barrier Reef region, the monitoring program's primary objective is to support effective management of environmental risks associated with port operations. The program is designed to characterise ambient water-quality variability, enabling the early identification of risks to nearby sensitive habitats and informing the timely implementation of mitigation measures that support adaptive management of port activities.

In addition to its role in meeting mandatory monitoring and reporting requirements, data collected through this program underpin the development of site-specific water-quality objectives for critical port activities. These objectives are informed by predictive modelling approaches to ensure management thresholds are both environmentally relevant and achievable within the context of local hydrodynamic and ecological conditions.

The partnership also extends beyond routine compliance monitoring, incorporating targeted research led by specialists in marine water quality, coastal habitats, seagrass, coral ecology, and natural resource management. Long-term acquisition of robust, scientifically defensible data

provides an invaluable foundation for understanding interannual variability, climatic influences, and ecological drivers along coastal Queensland, enabling proactive and evidence-based stewardship of this important region.

2 METHODS

2.1 Regional description

The Mackay region sits to the south of the Cumberland Islands and to the north of Broad Sound. The ocean floor slopes from the shore to a depth of 50 metres at the mid-shelf, until it drops at the continental shelf approximately 200 kilometres from the coast. With the largest tidal range on the east coast of Australia (6.7m maximum range), tidal currents are strong in the region. Wind and waves predominantly come from a south easterly direction, with the winds being highly influenced by the South Pacific trade winds. Both Pioneer River and Sandy Creek discharge into the ocean in the Mackay region.

2.2 Port description

The Port of Mackay and the Port of Hay Point are situated on the central Queensland Coast (Figure 2 1). The Port of Mackay is located approximately four kilometres north of the Pioneer River and is enclosed by large break walls that protect the port and marina property, while also allowing exchange of oceanic waters. The port has a series of operational and associated commercial loading/unloading facilities, and an extensive marina operation and commercial fishing fleet. The commercial port is multi-commodity mainly exporting sugar and grain. North Queensland Bulk Ports Corporation (NQBPC) is the Port Authority for this location and also holds operational control for marine-side activities and common-user infrastructure; outside of this, a variety of operators manage cargo-specific activities. .

The Port of Hay Point is situated approximately 40kms to the south of Pioneer River and Mackay City. Two coal terminals operate in the port: 1) Dalrymple Bay Coal Terminal; and 2) BMA Hay Point Coal Terminal. Like the Port of Mackay, NQBPC is the Port Authority for the port, however for Hay Point, NQBPC does not directly operate these facilities, outside of maintaining marine-side infrastructure and related activities (shipping channels and associated infrastructure and activities).

In both ports, routine maintenance dredging is necessary to maintain declared navigational depths within the swing basin and berth areas, departure paths, aprons, and harbours. Any dredging activity necessary in the operating ports are undertaken in accordance with Commonwealth and State approvals with management objectives guided by the Port of Mackay Long Term Dredge Management Plan and the Port of Hay Point Long Term Dredge Management Plan.

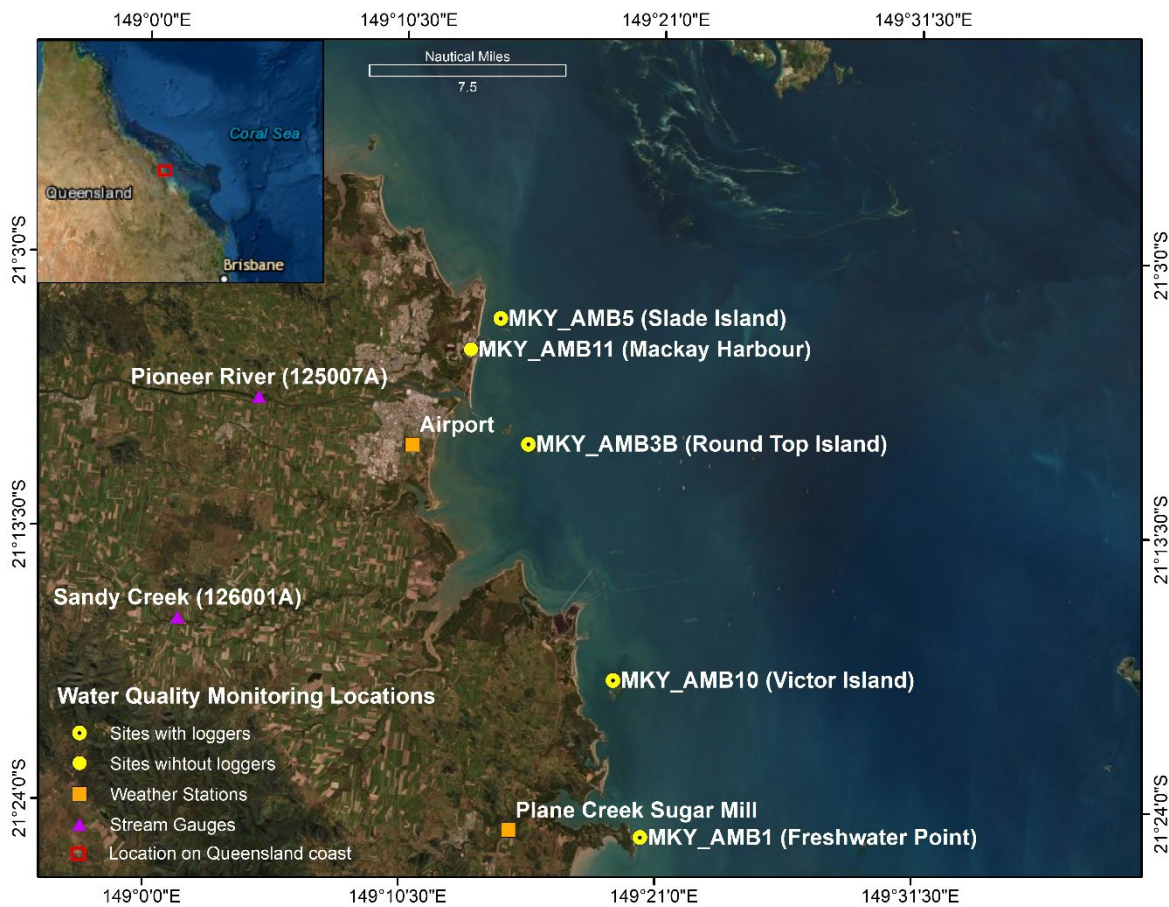


Figure 2—1 Map of Mackay and Hay Point showing the water quality monitoring locations (yellow circles), meteorological stations (orange squares), and stream gauges referred to in this report.

2.3 Characterisation of weather, hydrological status, and oceanographic conditions

2.3.1 Rainfall and hydrology

Climate data for the region was extracted from the Australian Bureau of Meteorology climate data online tool (<http://www.bom.gov.au/climate/data/>). Total rainfall, rainfall onset date, along with wet season rainfall totals were calculated. The nominal wet season is defined as 1st November to 30th April. The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. Stream discharge data for streams discharging into the coastal waters of the region was extracted from the Queensland Government water monitoring information portal (<https://water-monitoring.information.qld.gov.au/>). Total discharge and date of first significant discharge event were calculated. The water year reported throughout is defined as 1st July to 30th June. Wave data for the region was obtained from Queensland Government (<https://www.data.qld.gov.au/>) comprising of the significant wave height (H_s), calculated as the average of the highest third of the waves in a recorded period (26.6 minutes), and the Peak Direction (which the waves are coming from), as recorded by the wave buoys located at Bailey Reef, 19 nautical miles offshore from Mackay Harbour, and the Hay Point Triaxys Directional Wave Buoy (0.5 nm off Hay Point jetty).

2.3.2 Wave climate

Wave characteristics were derived from the Triaxys directional wave buoy deployed offshore from Hay Point. Significant wave height (H_s) was used as the primary measure of wave energy and represents the average height of the highest one-third of waves recorded during each sampling interval. Peak wave direction describes the direction from which the most energetic waves are propagating, based on the dominant component of the wave energy spectrum. These parameters together provide a fundamental description of the height and directional structure of the local wave field and are routinely used to assess coastal hydrodynamics, sediment transport potential, and the influence of regional weather systems.

Wave-period metrics were also examined to further characterise sea-state dynamics. Peak period (T_p) represents the period associated with the strongest spectral energy, while zero-crossing period (T_z) describes the mean interval between successive up-crossings of the average water level. T_p and T_z provide complementary information on the temporal structure of waves, enabling distinction between short-period, locally generated wind-sea and longer-period waves. Collectively, H_s , peak direction, T_p and T_z form a comprehensive description of wave climate conditions relevant to coastal processes and water quality variability within the monitoring region.

2.4 Monitoring and sampling design

2.4.1 Site overview

The Mackay region has five active ambient marine water quality monitoring sites (Figure 2.1, Table 2.1). The Freshwater Point site (MKY_AMB1) is located approximately 200 m offshore of Freshwater Point and 18 km south–southeast of Hay Point. The site sits in ~9 m of water and is characterised by a sandy–muddy substrate with extensive seagrass meadows dominated by *Halophila*, *Halodule*, and *Zostera* species (McKenzie et al., 2025).

The Round Top Island site (MKY_AMB3B) is located approximately 5 km offshore of the Pioneer River, 11 km north–northwest of Hay Point, and 8 km south–southeast of Mackay Harbour. The island is surrounded by shallow waters and fringing coral reefs dominated by hard corals, as documented through the NQBP coral monitoring program (Chartrand et al., 2024). Areas of low-density seagrass, primarily *Halophila* species, are also present within the surrounding waters (Rasheed et al., 2024). The monitoring site is positioned on the north-western side of the island in approximately 11 m water depth.

The Slade Island site (MKY_AMB5) is located near the small islet 2 km north-east of Mackay Harbour and 7 km north-north-east of the Pioneer River mouth, within the open coastal waters of Mackay Port. Slade Island is surrounded by shoals, and the seabed is characterised by a sandy substrate interspersed with scattered coral, with both hard and soft corals (NQBP coral monitoring site).

Victor Islet is a small island with fringing coral reefs, dominated by soft corals (NQBP coral monitoring site), and situated approximately 5 km south of the Port of Hay Point and 8 km north of Plane Creek.

The Mackay Harbour site sits within the boat harbour at the Port of Mackay, adjacent to the public boat ramp.

More detailed information on the condition of the seagrass meadows and coral reefs adjacent to these water quality sites is available in companion reports accessible via the TropWATER Technical Report page (<https://www.tropwater.com/reports-and-publications>) or the NQBP Research and Reports page (<https://nqbp.com.au/sustainability/research-and-reports>).

Table 2-1 Names, locations, and features of the Mackay and Hay Point water quality monitoring sites included in this report.

Site name	Site code	Latitude	Longitude	Depth (m)	Site features
Freshwater Point	MKY_AMB1	-21.42	149.34	9	Coral/seagrass/other invertebrates
Round Top Island	MKY_AMB3B	-21.17	149.26	11	Coral/seagrass/other invertebrates
Slade Island	MKY_AMB5	-21.09	149.24	10	Coral
Victor Island	MKY_AMB10	-21.32	149.32	8	Coral/seagrass/other invertebrates
Mackay Harbour	MKY_AMB11	-21.11	149.22	6	Sediment

2.4.2 Field sampling schedule

Field sampling is undertaken at all sites approximately every eight weeks. Each visit includes retrieval and re-deployment of dataloggers, collection of discrete water samples for laboratory analysis, and collection of in situ water quality measurements. Table 2-2 lists sampling dates from July 2024 to June 2025.

Table 2-2 Field dates for water sampling, logger maintenance, and metal detection sampling at the Mackay and Hay Point sites during the 2024-2025 reporting year.

Date	Water sampling	Logger maintenance	Metals sampling	Physico-chemical
2024-07-30	Yes	Yes	No	Hydrolab
2024-10-01	Yes	Yes	No	Hydrolab
2024-11-27	Yes	Yes	Yes	ProDSS
2025-03-05	Yes	Yes	No	ProDSS
2025-04-08	Yes	Yes	Yes	ProDSS

2025-06-04	Yes	Yes	No	ProDSS
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2.5 Water quality Sampling

2.5.1 Water sample collection

Surface water was collected manually from approximately 0.2 m below the water surface. Samples were obtained for laboratory analysis of nutrients (total nitrogen, total phosphorus, total dissolved nitrogen, total dissolved phosphorus), suspended solids, salinity, electrical conductivity, pH, chlorophyll-a and phaeophytin-a (Table 2-3). Nutrient samples were filtered onsite using 0.45 µm PES syringe filters and stored on ice prior to transport to the laboratory. Total suspended solids (TSS) samples were collected in 1 L bottles, while chlorophyll samples were collected in dark 1 L bottles. Salinity and pH samples were collected in 60 mL vials. All samples were transported on ice and analysed promptly following standard laboratory procedures.

2.5.2 Chlorophyll and pigment processing

Chlorophyll-a samples were filtered within 12 hours of collection using Whatman GF/F 0.45 µm glass fibre filters amended with approximately 0.2 mL of magnesium carbonate. The filters were wrapped in aluminium foil, frozen, and delivered to the TropWATER water quality laboratory for analysis. Chlorophyll-a and phaeophytin-a concentrations were determined spectrophotometrically following APHA Method 10200 H.

2.5.3 Metals sampling

Water samples for ultra-trace filterable metals were collected on two occasions within the reporting period. Samples were filtered onsite using 0.45 µm PES syringe filters and stored on ice prior to laboratory analysis. Analytes included arsenic, cadmium, copper, zinc, lead, nickel, silver and mercury, with methods and reporting limits provided in Table 2-4.

2.5.4 Laboratory analysis

Laboratory analysis of routine water quality parameters, nutrients, pigments and metals followed standard APHA methods. Reporting limits and analytical procedures are detailed in Tables 2-3 and 2-4.

Table 2-3 Water quality parameters that were analysed using water samples collected, and the methods and reporting limits of the laboratory analysis.

Parameter	APHA method number	Reporting limit
Routine water quality analysis		
pH	4500-H+ B	-
Salinity	2520 B	0.1 PSU
Electrical conductivity (EC)	2510 B	5 µS cm ⁻¹

Total Suspended Solids (TSS)	2540 D @ 103 - 105°C	0.2 mg L ⁻¹
Nutrients		
Total nitrogen (TN)	Simultaneous 4500-NO ₃ -F and 4500-P F analyses after alkaline persulphate digestion	10 µg N L ⁻¹
Total dissolved nitrogen (TDN)		
Total phosphorus (TP)		1 µg P L ⁻¹
Total Dissolved phosphorus (TDP)		
Particulate nitrogen (PN)	Calculated as PN = TN - TDN	-
Particulate phosphorus (PP)	Calculated as PP = TP - TDP	-
Chlorophyll		
Chlorophyll- <i>a</i>	10200-H	0.2 µg L ⁻¹
Phaeophytin- <i>a</i>		

Table 2-4 Ultra-trace filterable metals analysed from water samples collected on two occasions during the reporting year.

Parameter	APHA method number	Reporting limit
Filterable metals		
Arsenic (As)	3125B ORC/ICP/MS	-
Cadmium (Ca)		0.2 µg L ⁻¹
Copper (Cu)		1 µg L ⁻¹
Zinc (Zn)		5 µg L ⁻¹
Lead (Pb)		0.2 µg L ⁻¹
Nickel (Ni)		0.5 µg L ⁻¹
Silver (Ag)		0.1 µg L ⁻¹
Mercury (Hg)		0.1 / 0.04 µg L ⁻¹

2.5.5 Water quality guidelines

Results from discrete water samples and continuous logger measurements were assessed against the water quality objectives (WQOs) specified in the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP, 2019), and against guideline values from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018), where applicable. Environmental values (EVs), management intents, and associated WQOs for surface waters in the Mackay–Whitsunday basins were revised in 2022 and are listed in Schedule 1 of the EPP (Water and Wetland Biodiversity).

For nutrients, chlorophyll-a, turbidity, and other physico-chemical parameters, results were compared directly to the site- and zone-specific WQOs defined for open coastal waters within the Mackay–Whitsunday region. These objectives are based on long-term regional monitoring datasets and can incorporate seasonal considerations (dry and wet season), or an annual mean/ median, reflecting expected background conditions for each management zone. The applicable WQOs differ among sites according to their designated environmental values and management intent and were applied accordingly when interpreting results.

The Freshwater Point site (MKY_AMB1) is located within waters designated as open coastal waters landward of the plume line (WQ1222) and is managed as high ecological value (HEV). The Victor Island site (MKY_AMB10) is also located within open coastal waters landward of the plume line (WQ1222) but is classified as slightly to moderately disturbed (SMD). The Round Top Island (MKY_AMB3B) and Slade Island (MKY_AMB5) sites fall within the Ports: MD2341 Mackay Port open coastal waters, where the management intent is defined as moderately disturbed (MD). Mackay Harbour is zoned under Ports: MD2341 Mackay Marine and harbour (within walls), enclosed coastal waters (MD). As a result of these separate zonings, the applicable nutrient and physico-chemical WQOs vary between sites.

For filterable metals, results were assessed using the default guideline values (DGVs) from the ANZG (2018), following the assessment framework outlined in the EPP (Water and Wetland Biodiversity) Policy 2019. In accordance with this framework, metal concentrations at sites classified as slightly to moderately disturbed (Victor Island, Round Top Island, and Slade Island) were compared against guideline values corresponding to 95% species protection, while results from the high ecological value site at Freshwater Point were assessed against the more conservative criteria corresponding to 99% species protection.

This combined assessment approach ensures that nutrient and productivity-related parameters are evaluated against locally relevant, ecosystem-based objectives, while metals are assessed using nationally consistent, toxicity-based guideline values appropriate to each site’s environmental value and management intent.

2.6 Pesticide monitoring

Passive samplers were deployed at Slade Island (MKY_AMB5) to monitor pesticide concentrations across two deployments targeting the wet season and first flush events (Table 2-5). Each deployment included an Empore™ SPE disk (ED), a microporous polyethylene tube (MPT), and a passive flow monitor (PFM). Concentrations of pesticides and insecticides used in the calculation of pesticide risk metrics (Warne et al., 2020) are reported in Table 2-6, with the full list of analytes and detections provided in Appendix A. The second wet-season deployment (27/11/2024–20/02/2025)

remained in the field longer than scheduled due to severe flooding, which prevented access to the site during two attempted retrievals and reduced the direct comparability of results between deployments.

Table 2-5 Pesticide and PFAS passive samplers deployed at Slade Island (MKY_AMB5)) during the 2024-2025 wet season.

Site name	Site code	Start date	End date	Duration (days)
Slade Island	MKY_AMB5	01/10/2024	27/11/2024	57
Slade Island	MKY_AMB5	27/11/2024	20/02/2025	84

Table 2-6 Pesticide analytes used for ms-PAF calculations to determine the pesticide risk baseline. The type of pesticide photosystem two inhibiting herbicide (PSII), other herbicide (OH), and insecticide (I). Note: A full list of pesticides monitored via passive samplers is included in Appendix 1.

Analyte	Type	Detection method	Limit of reporting (LOR)
2,4-D	OH	ED	5 ng sampler ⁻¹
Ametryn	PSII	ED	5 ng sampler ⁻¹
Atrazine	PSII	ED	1 ng sampler ⁻¹
Diuron	PSII	ED	1 ng sampler ⁻¹
Fipronil	I	ED	5 ng sampler ⁻¹
Fluroxypyr	OH	ED	1 ng sampler ⁻¹
Haloxypop	OH	ED	1 ng sampler ⁻¹
Hexazinone	PSII	ED	1 ng sampler ⁻¹
Imazapic	OH	ED	
Imidacloprid	I	ED	1 ng sampler ⁻¹
Isoxaflutole (as diketonitrile)	OH	ED	0.1 ng sampler ⁻¹
MCPA	OH	ED	5 ng sampler ⁻¹
Metolachlor	OH	ED	1 ng sampler ⁻¹
Metribuzin	PSII	ED	1 ng sampler ⁻¹
Metsulfuron-methyl	OH	ED	1 ng sampler ⁻¹
Prometryn	PSII	ED	1 ng sampler ⁻¹
Simazine	PSII	ED	1 ng sampler ⁻¹
Tebuthiuron	PSII	ED	1 ng sampler ⁻¹

Terbutylazine	PSII	ED	1 ng sampler ⁻¹
Triclopyr	OH	ED	5 ng sampler ⁻¹

2.7 In situ physicochemical measurements

In situ measurements of temperature, electrical conductivity, pH, dissolved oxygen (% saturation and concentration), and turbidity were collected using either a calibrated Hydrolab Quanta multiparameter water quality meter or a calibrated YSI ProDSS multiparameter sonde (Table 2-7). Measurements were made at three depths: 0.25 m below the surface, mid-water, and 1 m above the seafloor —to provide an understanding of variability throughout the water column. Photosynthetically active radiation (PAR) was measured concurrently at each depth, and above water, using a LI-192 underwater quantum sensor connected to a LI-250A light meter. Where possible, PAR measurements were collected without interference from clouds or vessel shading, although occasional variability was unavoidable. Water clarity was assessed at each visit using a Secchi disk.

Table 2-7 *Physiochemical measurements that were collected at five locations, Freshwater Point, Slade Island, Round Top Island, Victor Island, and Mackay Harbour.*

Parameter	Units
Multiparameter water quality meter	
Water temperature	Degrees Celsius (°C)
Electrical conductivity (SpC)	mS cm ⁻¹
Salinity	PSU
pH	
Dissolved Oxygen	%sat
Dissolved Oxygen	mg L ⁻¹
Turbidity	FNU
Light meter	
Photosynthetically active radiation (PAR)	μmol m ⁻² s ⁻¹
Water clarity	
Secchi disk depth	Meters (m)

2.8 Seafloor mounted continuous dataloggers

Continuous water quality measurements were obtained using a pair of seafloor-mounted dataloggers attached to a stainless-steel instrument frame (Figure 2—2). The instrumentation included an NTU-LPT turbidity logger and an MS9-LPT multispectral light logger, both manufactured by In-situ Marine Optics (Perth, WA; <https://insitumarineoptics.com>). Each logger collected bursts of 50 measurements at 5 Hz every 10 minutes, providing high-frequency data on water temperature (°C), water depth (m), turbidity (NTU) and underwater light (photosynthetically active radiation; PAR, $\mu\text{mol m}^{-2} \text{s}^{-1}$).



Figure 2—2 Water quality loggers attached to instrument frames ready for seafloor deployment. The horizontally oriented logger is an NTU-LPT turbidity logger; the vertically oriented logger is an MS9-LPT multispectral light logger (In-situ Marine Optics).

The logger pair remained in situ on the seafloor between field visits and were retrieved and redeployed approximately every eight weeks during routine sampling. This deployment approach ensures continuous, comparable data while enabling regular calibration checks, servicing and data download. Specifications for the loggers, including sensor ranges and accuracy, are provided in Table 2- 8.

Table 2-8 Specifications of NTU-LPT turbidity logger and MS9-LPT multispectral light loggers.

Parameter	Units	Sensor range	Accuracy / Resolution
Water temperature	Degrees Celsius (°C)	-55 to 125 °C	+/- 1.0 °C
Water depth	Meters (m)	0 – 90 m	+/- 1.0 %
Turbidity	Nephelometric turbidity units (NTU)	0 – 400/1000 NTU	0.05 NTU

Irradiance	$\mu\text{W cm}^{-2} \text{ nm}^{-1}$	0 – 400 $\mu\text{W cm}^{-2} \text{ nm}^{-1}$	$2.5 \times 10^{-3} \text{ W cm}^{-2} \text{ nm}^{-1}$
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2.8.1 Logger data processing and quality control

Following each deployment, dataloggers were returned to the laboratory for pre-processing and quality control. Raw logfiles were initially processed to calculate median values for water temperature, water depth, turbidity and irradiance for each 10-minute burst interval (50 measurements at 5 Hz). These median values form the basis of the high-frequency time-series used in subsequent analysis.

Automated rule-based quality control (QC) was then applied using procedures described in Iles et al. (2023). This automated step detects and flags spurious readings resulting from instrument fouling, low battery voltage, sensor drift, surface interference, shading, or anomalous values outside expected environmental ranges. Following automated QC, each dataset was visually inspected and subjected to manual QC to ensure removal of artefacts not captured by rule-based processes. Final datasets were then ingested into the water quality database for analysis and reporting. A description of QC rules is provided in the Appendix and further details in Iles et al. (2023).

2.8.2 Suspended sediment concentration

Suspended sediment concentration (SSC) was derived from turbidity measurements by applying site-specific conversion factors established in 2022 for the Mackay region (Cartwright et al., 2022). The relationship between turbidity (NTU) and SSC (mg L^{-1}) is typically site-dependent, reflecting differences in particle size distribution, composition and optical properties of suspended sediments. Although there is no formalised protocol for re-establishing turbidity–SSC relationships, recalibration is recommended periodically, particularly following major hydrodynamic or sediment disturbance events that could alter sediment characteristics at the seabed.

SSC was calculated from logger-derived turbidity values using the following equation:

$$SSC = Turb * Cf \pm e \quad \text{[Equation 1]}$$

Where:

SSC is the calculated suspended sediment concentration in mg L^{-1}

Turb is the measured turbidity value in NTU

C_f is the conversion factor (unique for each site)

e is the root mean square error value

Note that error values are not presented in the converted data values.

2.8.3 RMS water depth

The MS9-LPT logger includes an integrated pressure sensor used to determine water depth and to derive a proxy measure of wave activity at the seafloor. Both the mean water depth and the root mean square (RMS) water depth are useful for examining the influence of tide and wave-driven pressure fluctuations on turbidity, sediment resuspension and benthic light availability.

RMS water depth represents short-term variability in pressure over the 10-second burst interval and is therefore related to wave energy at the seabed. It is important to note that RMS water depth does not measure wave height at the sea surface. Instead, it provides an index of near-bed orbital motion or wave shear stress, which varies with depth. For instance, identical surface wave conditions may produce markedly different RMS values at shallow versus deep sites. Consequently, RMS water depth is a useful relative indicator of potential resuspension between sites of different depths.

For each burst, the pressure sensor records 50 readings over a 10-second period. Average depth (m) and RMS water height are then calculated from these 50 readings.

RMS water height, D_{rms} , is calculated as follows:

$$RMS_{depth} = \sqrt{\frac{\sum_{n=1}^N (D_n - \bar{D})^2}{N}} \quad [\text{Equation 2}]$$

Where D_n is the n_{th} of the 50 readings and $\bar{D}$ is the mean water depth of the n readings.

2.8.4 RMS Depth and Turbidity Analysis

Turbidity behaviour was assessed in relation to short-period variation in water depth (RMS depth), which provides an index of high-frequency water-column motion around the sensor. RMS depth was calculated from the 1-minute depth record using a rolling window (7-point centred mean), and the first derivative of the smoothed depth series was used to classify each observation into one of three tidal stages: rising, falling, or stable. Rising tide was defined as periods where the rate of depth increase exceeded 0.005 m per time-step, falling tide where the rate of decrease exceeded 0.005 m per time-step, and all remaining periods were classified as stable.

For each tidal stage, turbidity (NTU) was paired with the corresponding RMS depth value and analysed using Pearson correlation to quantify the strength of association. Scatterplots of RMS depth vs NTU were produced for each site, coloured by tidal stage, with fitted linear regression lines to illustrate differences in slope and data structure among tidal conditions. This approach allowed assessment of whether turbidity variability at each site was linked to short-period water motion and whether this relationship differed between rising, falling and stable tidal states.

2.8.5 Benthic photosynthetically active radiation (bPAR)

Turbidity is often assumed to be the primary driver of light limitation at the seabed (Erftemeijer et al., 2012), but the relationship between turbidity and benthic photosynthetically active radiation (bPAR) is not always consistent (Sofonia & Unsworth, 2010). Because bPAR represents the amount of light actually reaching benthic photosynthetic habitats (e.g. seagrass, algae, corals), it is considered a more biologically relevant indicator of habitat condition and has been incorporated increasingly into management frameworks and threshold-based guidelines (e.g. Chartrand et al., 2012).

Light attenuation in water follows an exponential decay with depth due to absorption and scattering by dissolved and particulate matter (Kirk, 1994). As a result, absolute bPAR values are not directly comparable among sites with differing depths. To address this, bPAR was calculated from

the nine irradiance channels of the MS9 logger, with wavelengths between 400–700 nm interpolated and integrated internally. Median bPAR for each burst was derived from the 50 measurements collected over the 10-second interval.

The daily light integral (DLI), representing the total number of photosynthetically active photons delivered to the seabed over a 24-hour period, was calculated from the bPAR time series using Equation 2.

Daily light integral (DLI) was calculated as follows:

$$DLI = \sum_i PAR_i * \frac{600}{1000000} \quad \text{[Equation 3]}$$

Where:

DLI is the daily light integral in mol photons m⁻² d⁻¹

i is each bPAR reading during the day

bPAR is the benthic photosynthetically active radiation in μmol photons m⁻² s⁻¹

600 is the time interval between readings

1,000,000 is the unit conversion

2.9 Benthic multispectral irradiance

Spectral light is a key determinant of benthic primary production because different phototrophic organisms—such as corals, seagrasses and macroalgae—use specific wavelengths of the visible spectrum with differing efficiency (Jones et al., 2021). Bulk PAR alone does not fully characterise the underwater light environment because spectral composition can vary independently of total irradiance due to turbidity, sediment resuspension, phytoplankton biomass and coloured dissolved organic matter.

Benthic multispectral irradiance was measured at each ambient monitoring site using IMO-LPT MS9 loggers mounted on seafloor frames. Each logger contains nine discrete irradiance channels spanning 410–700 nm (Table 2.9), enabling wavelength-specific assessment of attenuation across the blue, green, yellow and red regions of the spectrum.

2.9.1 Data extraction and normalisation (spectral-shape analysis)

Raw spectral irradiance values were extracted from each MS9 logger and filtered to include daylight measurements only. To examine relative spectral shape, irradiance from all nine wavelength channels was normalised to the maximum channel value within each observation. This normalisation removes the influence of absolute light intensity and short-term variability associated with cloud cover, sun angle, and surface conditions, enabling direct comparison of wavelength-specific contributions across time, sites, and seasons. Normalised spectra were used to assess changes in relative spectral composition rather than absolute light availability.

Table 2-9 Wavelength specifications of the In-situ Marine Optics MS9 nine wavelength multispectral light sensor. Each channel has a 10 nm full-width-half-maximum spectral response.

Irradiance channel	1	2	3	4	5	6	7	8	9
Wavelength (nm)	410	440	490	520	550	570	610	660	700
Colour	Violet	Blue	Cyan	Green	Green	Yellow	Orange	Red	Red

2.9.2 Turbidity classification for spectral response analysis

To support interpretation of spectral-shape variability, each daylight spectral observation was paired with a two-hour mean turbidity value derived from co-located nephelometric sensors. Observations were categorised into three turbidity classes: low (<1 NTU), moderate (1–5 NTU), and high (>5 NTU).

These turbidity classes were applied specifically to interpret normalised multispectral irradiance profiles and to examine how wavelength-specific attenuation patterns varied under contrasting optical conditions associated with sediment resuspension and seasonal hydrodynamics.

2.9.3 Spectral Indices

To quantify changes in benthic light quality, spectral indices were calculated from raw, non-normalised irradiance values. These indices summarise the relative shape of the light field, providing sensitive indicators of turbidity, scattering, absorption, and overall benthic light quality. Because different wavelengths attenuate at different rates—blue light being most sensitive to suspended sediments, and red light strongly absorbed by water—spectral indices allow optical changes to be detected even when total PAR remains relatively unchanged.

These metrics are particularly relevant for assessing habitat condition because seagrass and many coral symbionts rely disproportionately on the blue–green portion of the spectrum for efficient photosynthesis. Changes in spectral quality can therefore influence ecological performance even when light quantity is sufficient.

The following subsections describe each spectral index used in this study and the specific optical processes they represent.

BLUE:GREEN RATIO (BG RATIO)

The BG ratio measures the relative contribution of short-wavelength (blue) light to mid-wavelength (green) light:

$$BG\ ratio = \frac{mean(410-490\ nm)}{mean(520-570\ nm)} \quad [Equation\ 4]$$

Higher values indicate clearer water and lower scattering, as blue wavelengths are preferentially attenuated by suspended sediments.

NORMALISED 490 NM IRRADIANCE (N490)

N490 is the normalised irradiance at 490 nm and serves as an indicator of blue-light penetration. It is particularly sensitive to suspended particulate matter and is widely used in both in situ and remote-sensing optical assessments.

PAR QUALITY INDEX (PQI)

PQI quantifies the proportion of irradiance within the wavelength range most efficiently used by seagrass, macroalgae, and some coral symbionts:

$$PQI = \frac{chan440 + chan490 + chan520 + chan550}{\text{sum of all 9 channels}} \quad [\text{Equation 5}]$$

Higher PQI values correspond to a greater proportion of photosynthetically efficient blue–green light within the total PAR spectrum, and therefore higher-quality benthic light conditions.

RED ATTENUATION RATIO (RAR)

RAR expresses the relative dominance of red wavelengths compared to shorter wavelengths:

$$RAR = \frac{\text{mean}(610-700 \text{ nm})}{\text{mean}(410-570 \text{ nm})} \quad [\text{Equation 6}]$$

Elevated RAR values generally indicate increased turbidity, higher scattering of short wavelengths, or the influence of coloured dissolved organic matter.

BLUE→GREEN SPECTRAL SLOPE (SLOPE_{BG})

The spectral slope between 438.8 nm and 568.3 nm quantifies the rate at which short wavelengths are attenuated relative to green light:

$$\text{Slope}_{BG} = \frac{I_{570} - I_{440}}{570 - 440} \quad [\text{Equation 7}]$$

Positive values indicate strong blue attenuation, while values approaching zero reflect optically clear conditions.

2.10 Long term trend analysis

The Mackay region ambient marine water quality program has operated continuously since July 2014, providing more than 11 years of data suitable for examining seasonal patterns and long-term temporal variability in key water quality parameters. To analyse these irregularly spaced time series, Generalized Additive Models (GAMs) were applied using the *mgcv* package in R (Wood, 2017). Data were pooled across sites to improve power for detecting seasonal and interannual patterns and to provide a regional summary of ambient conditions.

Multi-year data from discrete water sample collections were modelled using the general form:

$$\text{response} \sim \text{month} + \text{time}$$

where the response is the parameter of interest, *month* represents seasonal cyclicity, and *time* represents long-term change

Seasonality was modelled using a cyclic cubic regression spline applied to the month term, while long-term trends were modelled using a thin-plate regression spline applied to time. To limit overfitting, spline flexibility was constrained to $k = 5$ for the seasonal component and $k = 20$ for the

long-term trend. Outliers were removed only where values failed standard QA/QC procedures or were identified as non-physical (e.g. sensor fouling, calibration artefacts). Environmentally plausible extreme values were retained to preserve the full range of natural variability.

A gamma error distribution with a log link was used, reflecting the non-negative, right-skewed nature of most water quality parameters and its robust performance for environmental time-series data.

Model outputs include two smooth components: a seasonal smooth describing the average wet–dry cycle, and a long-term smooth describing gradual temporal change. The fitted values shown in the plots represent the combined effect of these components, with seasonal oscillations superimposed on the broader multi-year trend. Examining both smooths together allows assessment of whether observed variability is dominated by seasonal processes, longer-term change, or short-term event-driven fluctuations.

3 RESULTS AND DISCUSSION

3.1 Rainfall and river flows

Rainfall across the Mackay region during the 2024–2025 reporting period followed a broadly typical seasonal pattern, with very dry conditions through winter and early spring, a marked increase in rainfall from late October onward, and a pronounced peak in mid-wet-season associated with coastal troughs and monsoonal influences (Figure 3-1).). Daily rainfall remained low across July–September, with only scattered light falls recorded prior to the onset of more sustained rainfall in early October. While the climatological northern wet season is typically defined as occurring between November and April, rainfall onset is defined as the date when cumulative rainfall since 1 September first exceeds 50 mm, providing a more functional indicator of the commencement of wet-season hydrological influence. Under this definition, the 2024–2025 rainfall onset occurred on 10 October, marking the transition from dry-season conditions to increased catchment runoff and freshwater input during the reporting period.

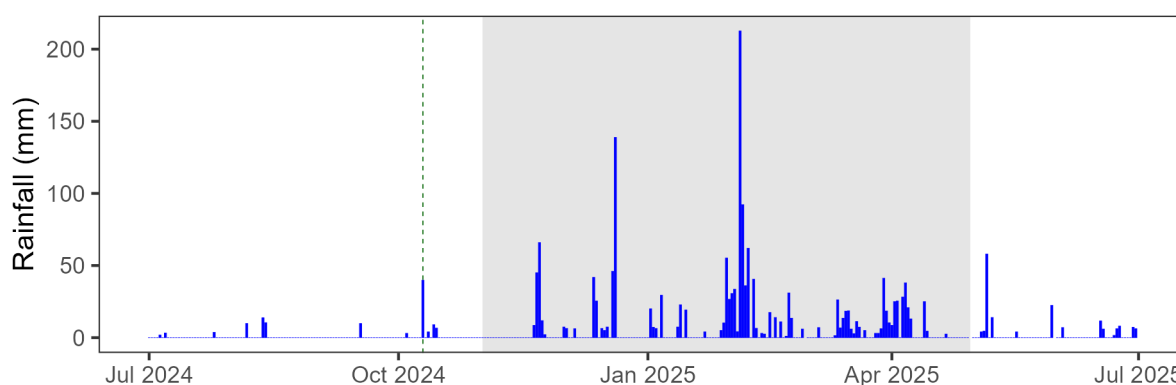


Figure 3—1 Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the 2024-2025 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: <http://www.bom.gov.au/climate/data/>

The highest rainfall intensity occurred during February 2025, when several strong convective and trough-driven events produced multiple days exceeding 50–100 mm, including one extreme event

above 200 mm. Rainfall declined through March and April and returned to low, sporadic totals by May, marking a clear transition back into the dry season.

In a long-term context, the 2024–2025 rainfall year fits within the typical interannual variability for Mackay (Figure 3-2). Total annual rainfall was moderate compared with the long-term mean—well below the extreme monsoonal or cyclone-driven years (e.g., 2010–2011, 2016–2017), yet still characterised by a distinct wet-season rainfall peak. The earlier-than-average onset and pronounced mid-season rainfall pulse align with years in which early trough activity initiates the wet season, followed by episodic monsoonal bursts later in summer. Overall, the 2024–2025 rainfall pattern was broadly consistent with long-term average conditions for the region, without the anomalies associated with major wet or drought years.

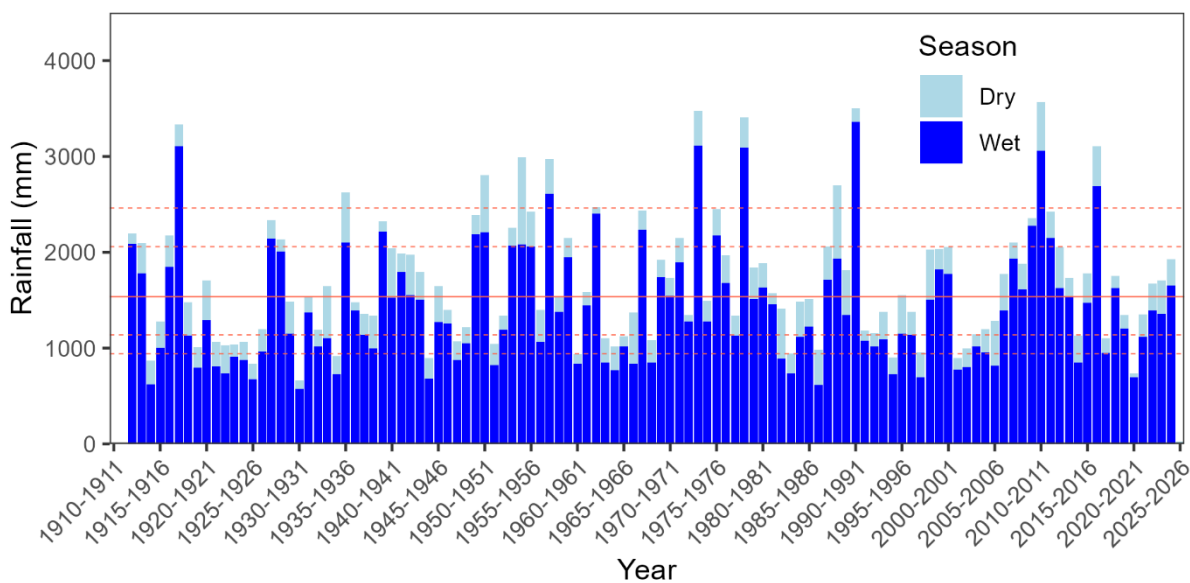


Figure 3—2 Annual rainfall by water year for the Mackay region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Daily rainfall data was obtained from the Plane Creek Sugar Mill (station 033059). Data source: <http://www.bom.gov.au/climate/data/>

Stream discharge patterns for the Pioneer Basin (Pioneer River at Dumbleton Weir, 125016A) and the Plane Basin (Sandy Creek, 126001A) reflected the timing and intensity of rainfall across the 2024–2025 reporting year (Figure 3-3). Both systems exhibited very low baseflow through winter and early spring, with near-zero discharge from July to late October, consistent with the extended dry season and minimal catchment runoff.

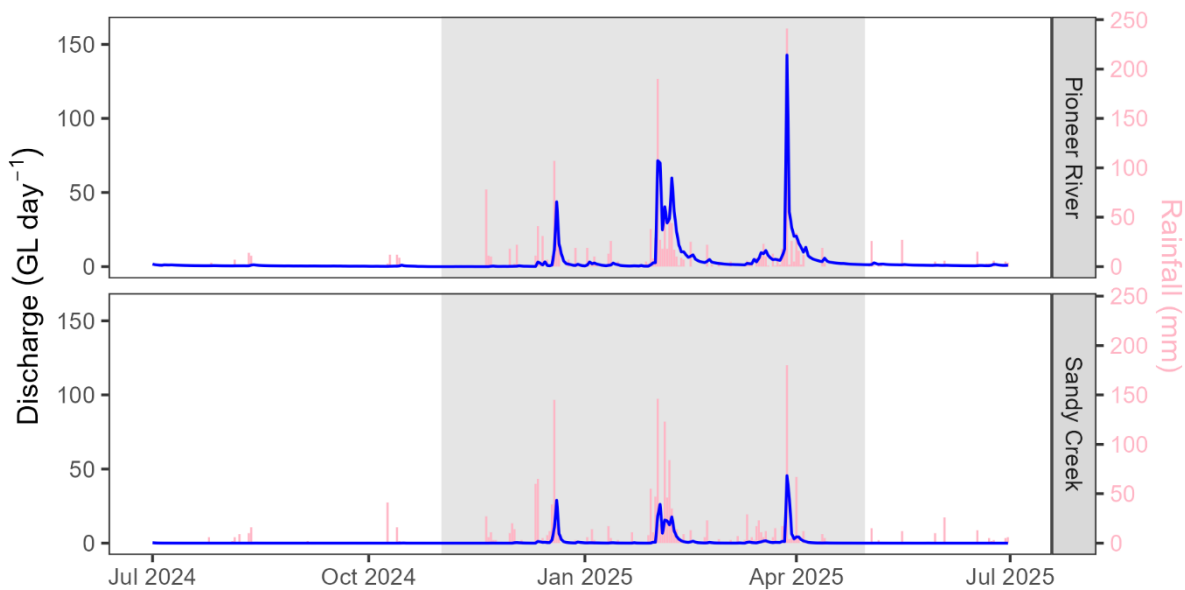


Figure 3—3 Stream discharge (GL d^{-1}) recorded for the Pioneer River (station 125016A) and Sandy Creek (station 126001A) during the 2023-2024 reporting period. The nominal wet season period is shaded grey. Rainfall data (pink line) is from Pioneer River at Mirani Weir Tailwater (station 125007A) and Sandy Creek at Homebush (station 126001A). Note that rainfall is measured on right y-axis and may not be accurate to the exact mm but included to show trends. Data source: <https://water-monitoring.information.qld.gov.au/>

A clear transition into the wet season occurred following the early-October rainfall onset, after which several moderate flow events were recorded. A notable early wet-season pulse occurred in mid-late December, with daily mean discharge reaching $\sim 43.7 \text{ GL day}^{-1}$ in the Pioneer River (20 Dec 2024) and $\sim 28.9 \text{ GL day}^{-1}$ in Sandy Creek (20 Dec 2024), before receding as rainfall eased. A further sequence of rainfall events in early February 2025 generated sharp freshwater pulses in both systems, with the Pioneer River peaking at $\sim 71.5 \text{ GL day}^{-1}$ (1 Feb 2025) and Sandy Creek at $\sim 26.2 \text{ GL day}^{-1}$ (2 Feb 2025).

The largest hydrological event of the reporting year occurred in late March 2025, when discharge peaked at $\sim 142.8 \text{ GL day}^{-1}$ in the Pioneer River and $\sim 45.6 \text{ GL day}^{-1}$ in Sandy Creek (28 Mar 2025). Satellite imagery from April 14 (two weeks following the event) shows pronounced sediment plumes from both systems extending well offshore, illustrating the scale of the hydrological impact (Figure 3-4). Following this, both systems displayed declining discharge through April with smaller secondary pulses, and by May–June flows returned to low/baseflow conditions.

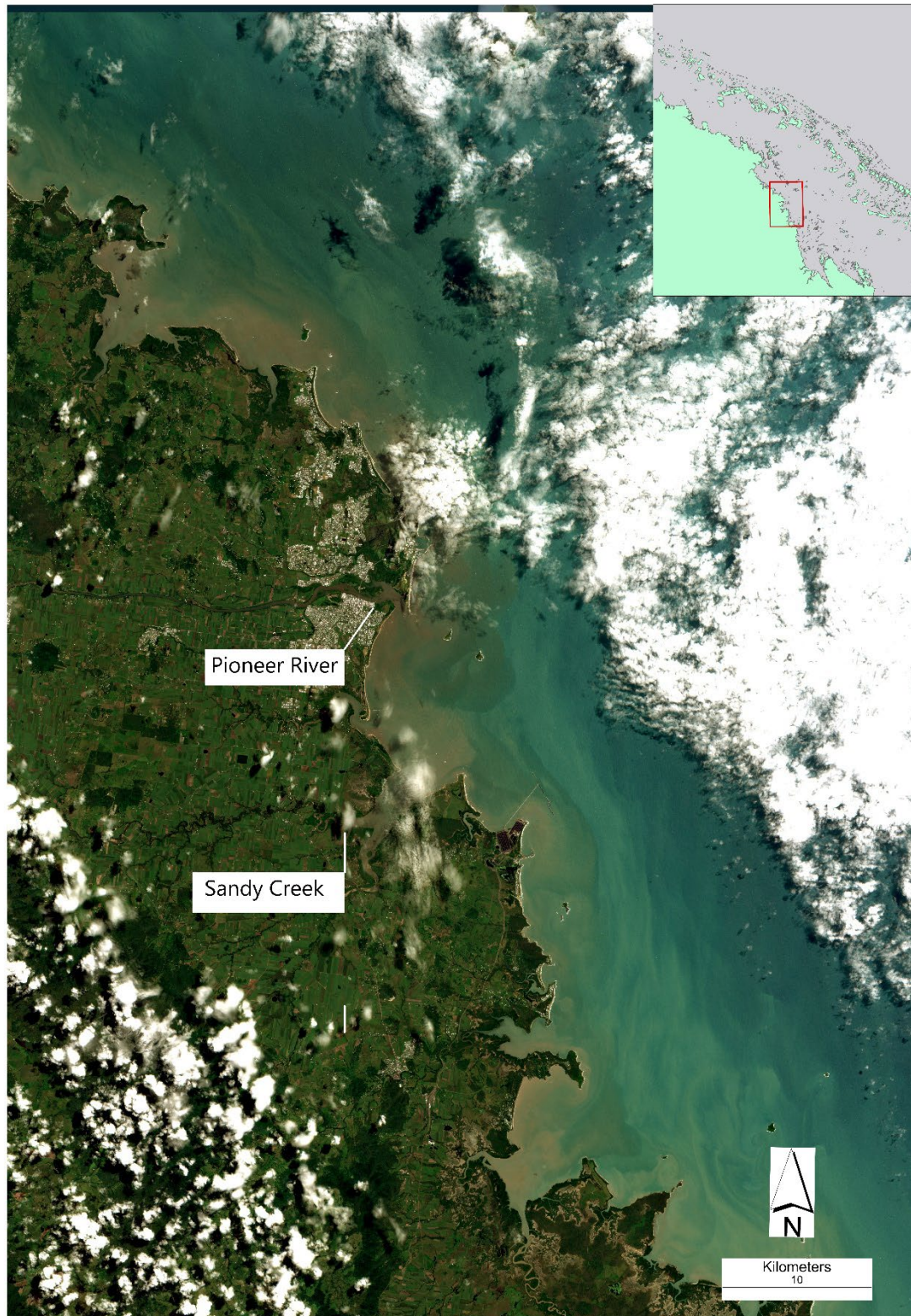


Figure 3—4 Sentinel-2 imagery captured on 14 March 2025, shortly after the peak flows from the Pioneer River ($>142.8 \text{ GL day}^{-1}$) and Sandy Creek ($>45.6 \text{ GL day}^{-1}$). The image shows extensive flood plumes and elevated turbidity dispersing along the Mackay coastline, highlighting the strong connection between major catchment flow events and coastal water quality. The inset map (top right) shows the location of the Mackay region within the central Queensland coast.

3.2 Wave climate

Wave conditions recorded by the Hay Point Triaxys buoy during the 2024–2025 reporting year were characteristic of an inshore, trade-wind–dominated coastal environment. Significant wave height (H_s) generally remained low to moderate, ranging from about 0.1 to 2.3 m, with most observations below 1 m (Figure 3-4, Figure 3-6). Calm to moderately energetic wind-sea conditions were dominant, reflecting the short fetch and sheltered position of the coast. Higher wave heights above 2 m were infrequent and associated with short-lived periods of stronger southeasterly winds or offshore weather systems.

Waves predominantly approached from the southeast to east–southeast sector throughout the year, consistent with the prevailing trade-wind regime that influences the central Queensland coastline. A small amount of variability was observed seasonally (Figure 3-5). During winter months (June to August), wave direction was strongly constrained to the southeast and wave heights were generally lowest, often below 0.5 m. During the summer and early wet-season months (December to March), wave direction broadened slightly, with more easterly components during periods of monsoonal influence. This period also showed a modest increase in typical wave heights, as well as the majority of the higher-energy events recorded in the dataset.

Overall, the FY 2024–2025 wave climate at Hay Point reflects a stable and predictable pattern dominated by southeast trade-wind forcing, with moderate seasonal shifts in both wave height and directional spread. These observations provide important context for understanding processes such as sediment resuspension, turbidity fluctuations and coastal hydrodynamics within the local marine environment.

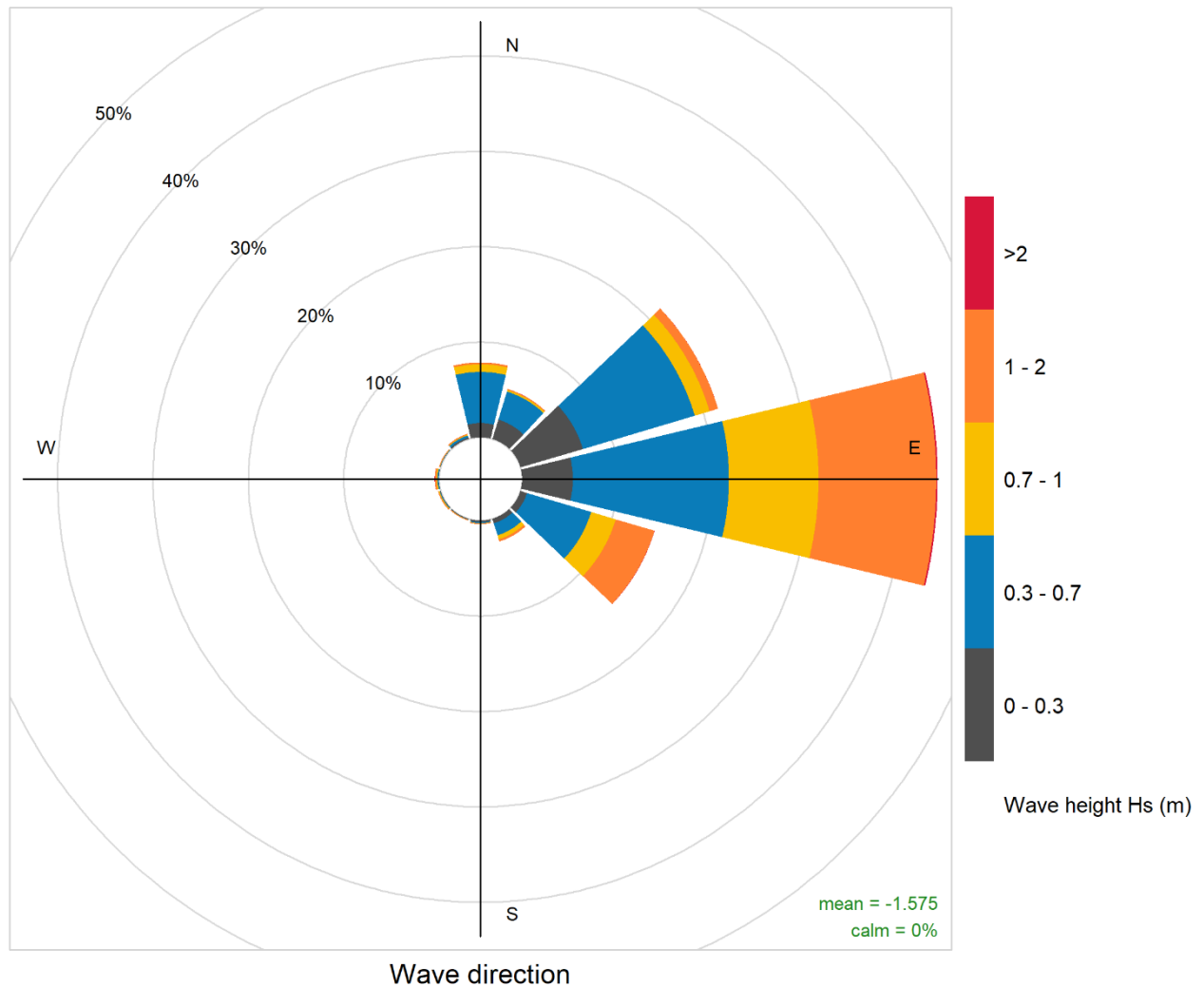


Figure 3—5 Frequency of counts by wave direction (%), and significant wave height (m) at the Hay Point wave buoy station between July 1, 2024, and June 30, 2025.

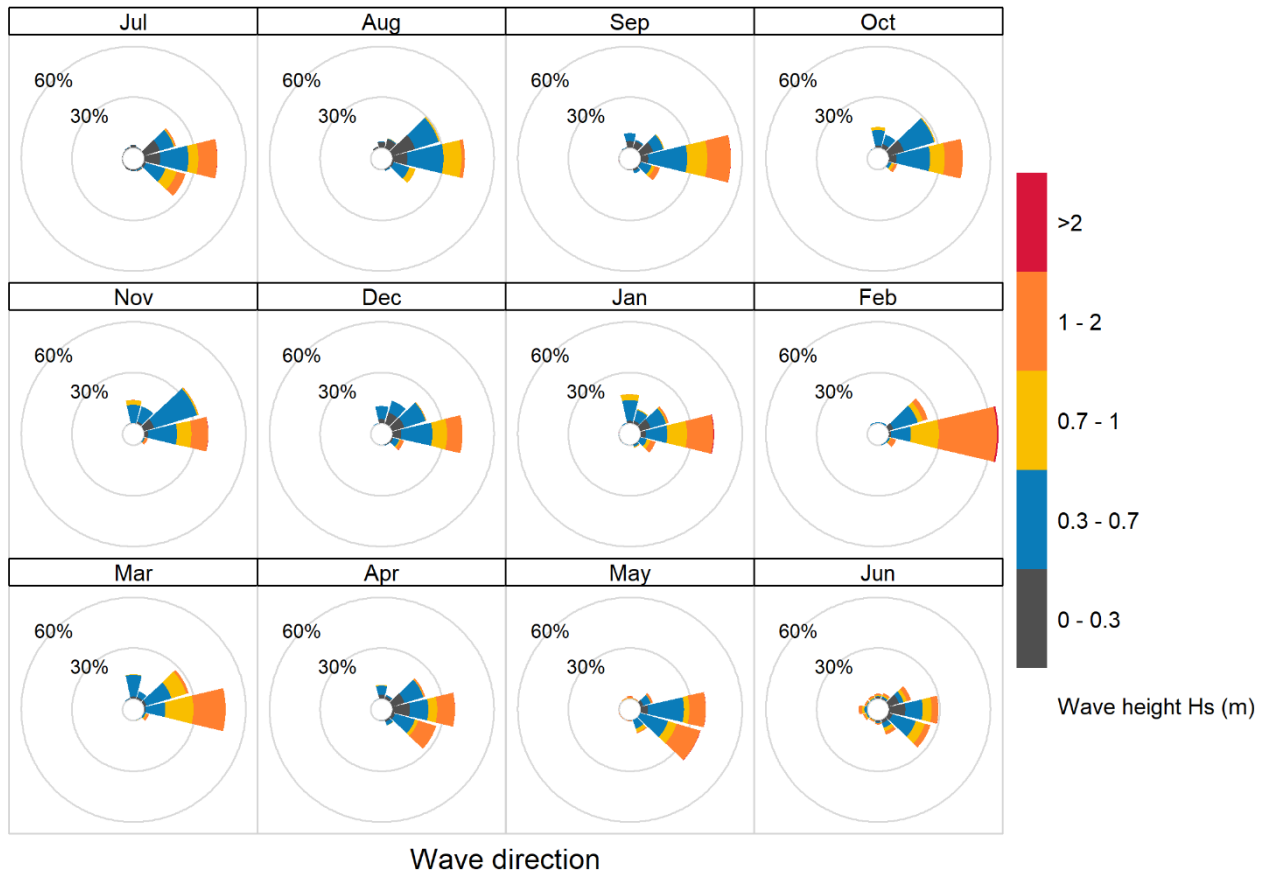


Figure 3—6 Frequency of counts by wave direction (%), and significant wave height (m) for each month at the Hay Point wave buoy station between July 1, 2024, and June 30, 2025.

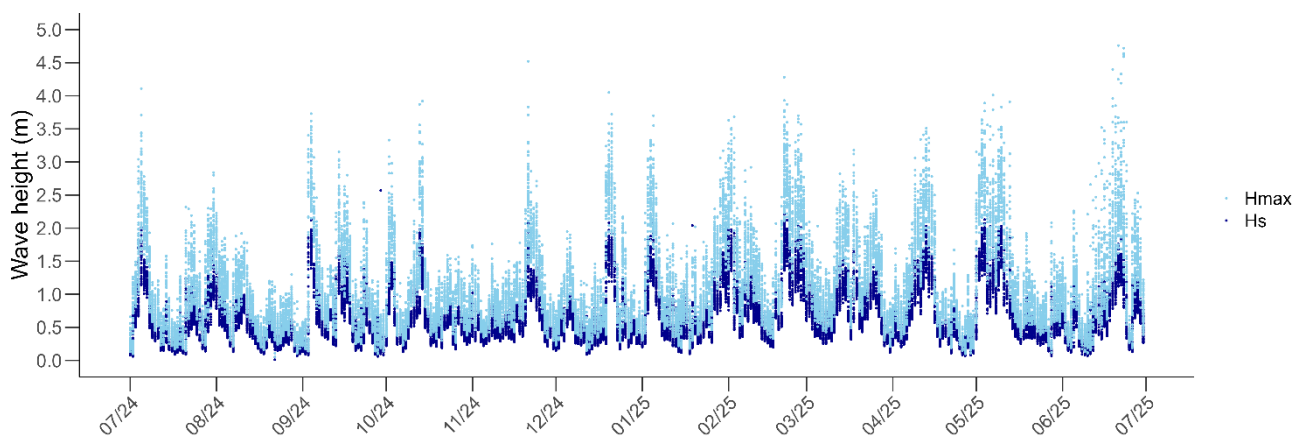


Figure 3—7 Time series of significant wave height (H_s) and maximum wave height (H_{max}) at the Hay Point wave buoy station between July 1, 2024, and June 30, 2025.

Wave period data (Tp and Tz) showed patterns consistent with the low to moderate wave heights observed throughout the year (Figure 3-7). Zero-crossing period (Tz) generally ranged between 3 and 7 seconds, while peak period (Tp) was slightly higher, typically 4–10 seconds during most conditions. These values indicate that the local wave climate is dominated by short-period wind-sea generated by regional trade winds, rather than longer-period swell. Seasonal variation was modest, with slightly longer peak periods occurring during summer and early autumn when larger weather systems occasionally increased offshore fetch. During calm winter periods, both Tp and Tz contracted toward the lower end of the range, reflecting the prevalence of locally generated, lower-energy waves. Overall, the period data align closely with the observed height and directional patterns, further supporting the interpretation of Hay Point as an inshore environment shaped primarily by short-period trade-wind seas.

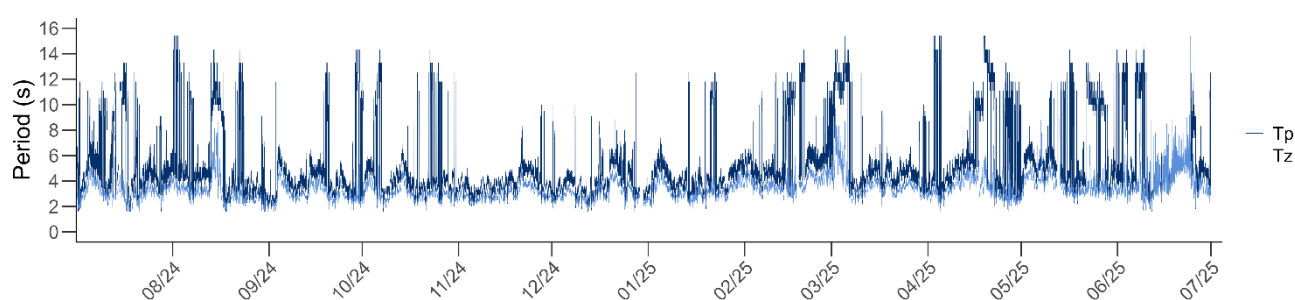


Figure 3—8 Time series of wave period at the Hay Point wave buoy station between July 1, 2023, and June 30, 2024. Peak energy wave (Tp: light blue) and zero upcrossing wave (Tz: dark blue).

3.3 Water quality

3.3.1 Nutrients

Nutrient concentrations across the Mackay ambient monitoring sites were broadly characteristic of well-flushed inshore coastal waters, with low to moderate nitrogen concentrations and generally low phosphorus levels over the 2024–2025 monitoring period (July 2024 – April 2025). When assessed against the relevant EPP (2019) water-quality objectives (WQOs), several nitrogen metrics exceeded guideline values at multiple sites, while phosphorus concentrations largely remained below applicable thresholds.

Total nitrogen (TN) concentrations were typically in the range $\sim 100\text{--}200\ \mu\text{g L}^{-1}$, with a regional median of approximately $130\ \mu\text{g L}^{-1}$. Median TN values exceeded the open-coastal WQO ($90\ \mu\text{g L}^{-1}$) at all sites except Mackay Harbour, where values were generally near the objective. A single markedly elevated TN concentration ($2699\ \mu\text{g L}^{-1}$) was recorded at Freshwater Point in October 2024, with approximately two-thirds of this nitrogen present as particulate nitrogen. Field observations indicated the presence of a *Trichodesmium* bloom at the time of sampling, suggesting this result reflects a biologically driven episodic event rather than seasonal nutrient enrichment. Excluding this event, TN concentrations showed limited seasonal variability and remained within the range typically observed for inshore coastal waters influenced by episodic wet-season processes.

Total dissolved nitrogen (TDN) ranged from 98 to 154 $\mu\text{g L}^{-1}$ (median $\sim 115 \mu\text{g L}^{-1}$) and comprised the majority of TN at all sites. Median TDN concentrations exceeded the relevant WQO (75 $\mu\text{g L}^{-1}$) across the Mackay region, reflecting elevated background dissolved nitrogen typical of this inshore coastal setting rather than discrete point-source inputs.

Particulate nitrogen (PN) concentrations were typically low to moderate, with a regional median of approximately 18 $\mu\text{g L}^{-1}$. Mean or median PN concentrations were below or near the applicable WQO at most sites. A single markedly elevated PN concentration (2581 $\mu\text{g L}^{-1}$) was recorded at Freshwater Point in November 2024, coincident with a *Trichodesmium* bloom, indicating a biologically driven episodic event. Excluding this event, PN concentrations showed limited variability and were consistent with dry-season and early wet-season conditions.

Total phosphorus (TP) concentrations were typically low, with a regional median of approximately 8 $\mu\text{g L}^{-1}$ and median values remaining below the applicable WQOs at all sites, including Mackay Harbour. A single elevated TP concentration (116 $\mu\text{g L}^{-1}$) was recorded at Freshwater Point in November 2024, coincident with a *Trichodesmium* bloom, indicating a biologically driven episodic event. Excluding this event, TP concentrations showed limited variability and remained within the range typically observed for inshore coastal waters.

Total dissolved phosphorus (TDP) concentrations ranged from ~ 2 to $\sim 13 \mu\text{g L}^{-1}$ (median $\sim 6 \mu\text{g L}^{-1}$) and remained below guideline values throughout the monitoring period, including during the October 2024 event. Particulate phosphorus (PP) concentrations were generally low, with short-lived increases primarily associated with the November 2024 Freshwater Point bloom, rather than sustained wet-season particulate inputs.

Overall, while nitrogen concentrations—particularly TN and TDN—frequently exceeded regional water-quality objectives, these exceedances were spatially consistent across sites and dominated by dissolved forms, suggesting strong regional and catchment-scale influences rather than localised port-related enrichment. Phosphorus concentrations remained largely within WQO's, with short-lived increases in particulate fractions occurring during isolated sampling events rather than reflecting persistently elevated conditions.

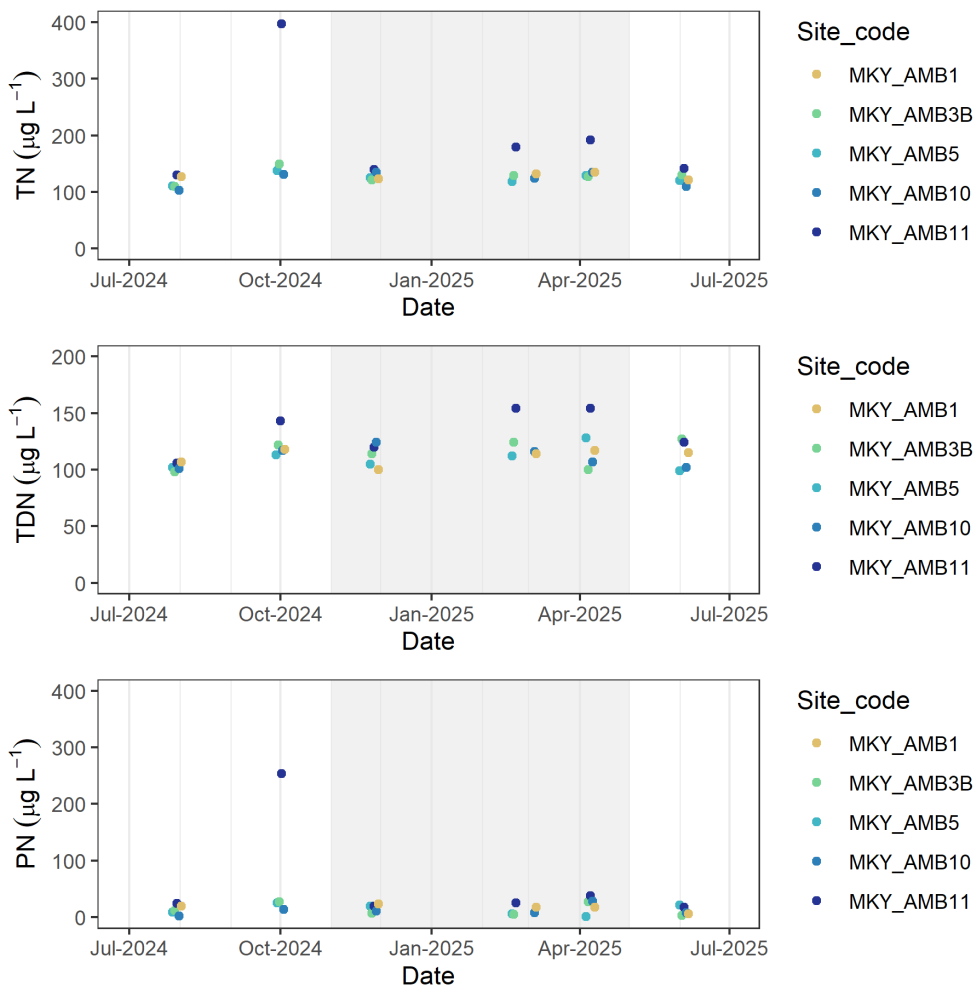


Figure 3—9 Total nitrogen (TN; $\mu\text{g L}^{-1}$), total dissolved nitrogen (TDN; $\mu\text{g L}^{-1}$), and particulate nitrogen (PN; $\mu\text{g L}^{-1}$) concentrations measured in water samples collected from the five water quality sites in the Mackay region, Freshwater Point (MKY_AMB1), Round Top Island (MKY_AMB3B), Slade Island (MKY_AMB5), Victor Island (MKY_AMB10) and Mackay Harbour (MKY_AMB11), for the 2024-2025 reporting period, with the shaded area representative of the wet season. Note: A single outlier has been removed, see in-text for details.

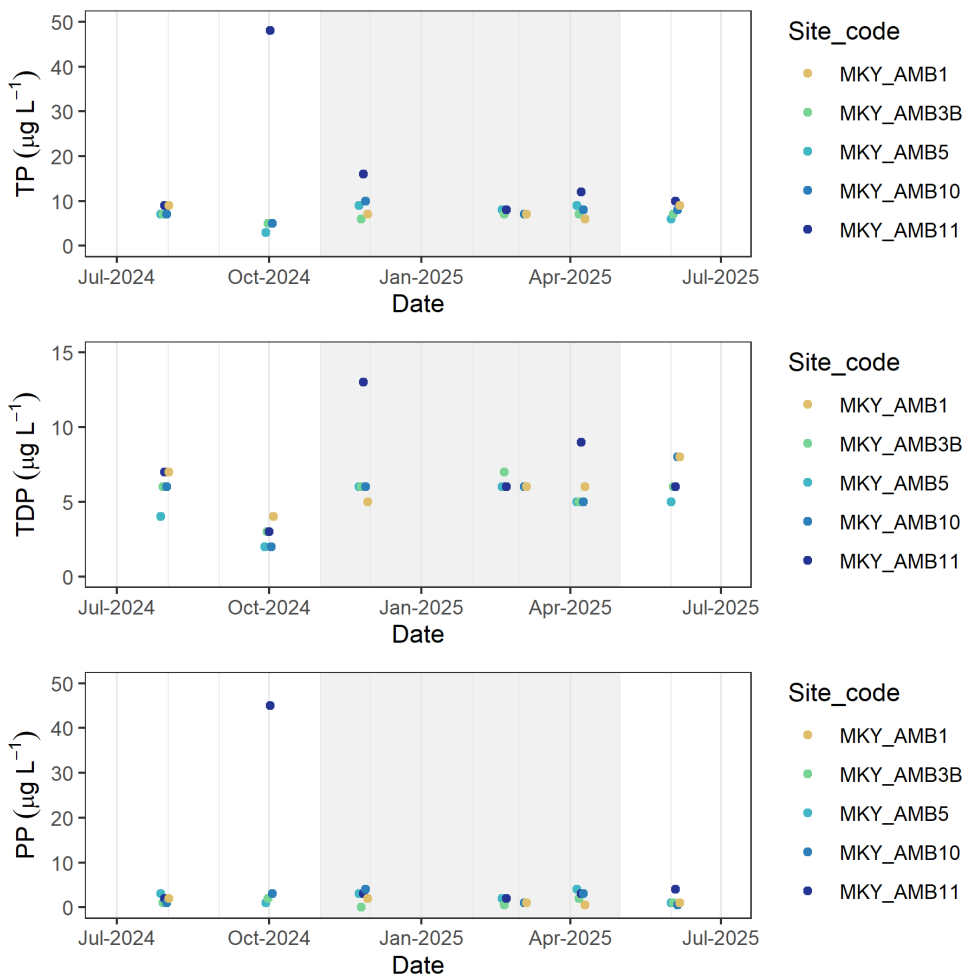


Figure 3—10 Total phosphorus (TP), total dissolved phosphorus (TDN), and particulate phosphorus (PN) concentrations measured in water samples collected from the five water quality sites in the Mackay region, Freshwater Point (MKY_AMB1), Round Top Island (MKY_AMB3B), Slade Island (MKY_AMB5), Victor Island (MKY_AMB10) and Mackay Harbour (MKY_AMB11), for the 2023-2024 reporting period, with the shaded area representative of the wet season.

3.3.2 Chlorophyll

Chlorophyll-a concentrations across the Mackay ambient monitoring sites were consistently low in absolute terms throughout the monitoring period, with values ranging from 0.57 to 2.15 µg L⁻¹ and a median concentration of approximately 1 µg L⁻¹. These concentrations are typical of well-flushed inshore coastal waters and are substantially below levels commonly associated with phytoplankton bloom conditions.

The highest chlorophyll-a concentration (2.15 µg L⁻¹) was recorded at Freshwater Point in October 2024. This observation coincided with slightly elevated suspended solids and particulate nutrient concentrations and represents a short-lived increase rather than a sustained elevation. Outside this event, chlorophyll-a concentrations showed little temporal variability across sites.

When assessed against the EPP (2019) water-quality objectives, mean chlorophyll-a concentrations exceeded the applicable guideline values at most sites. These exceedances reflect the low numerical thresholds specified for open coastal waters rather than the presence of bloom conditions or elevated phytoplankton biomass. This interpretation is supported by consistently low phaeophytin-a concentrations ($<0.2 \mu\text{g L}^{-1}$ in most samples), indicating limited pigment degradation and low overall phytoplankton turnover.

Overall, chlorophyll-a concentrations indicate low phytoplankton biomass and an absence of eutrophic conditions across the region during the reporting period, despite exceedance of conservative guideline thresholds.

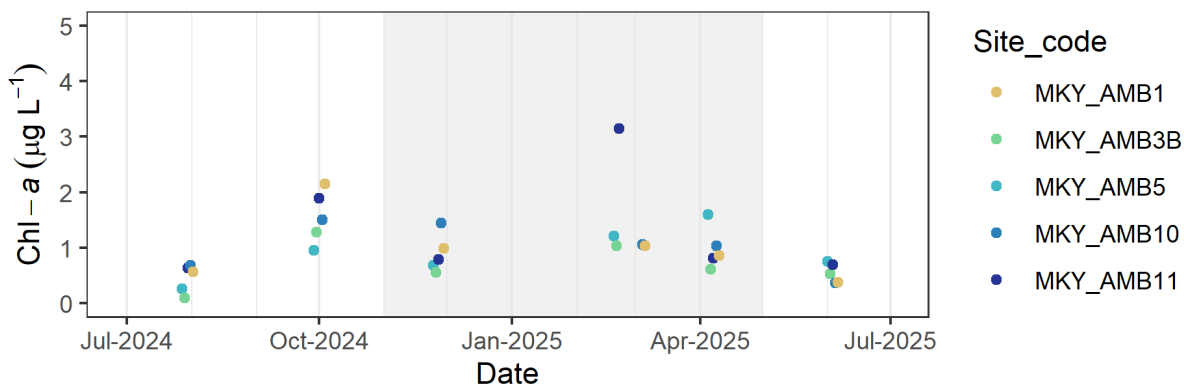


Figure 3—11 Chlorophyll-a concentrations ($\mu\text{g L}^{-1}$) measured in water samples collected from the Mackay and Hay Point region throughout the reporting period. Grey area indicates wet season.

3.3.3 Filterable metals

Filterable metal concentrations measured across the Mackay ambient monitoring sites during the 2024–2025 reporting period were uniformly low and generally at or near analytical detection limits, consistent with well-flushed inshore coastal waters and limited contamination pressure.

Arsenic concentrations showed very little spatial or temporal variability, ranging from 1.4 to $1.6 \mu\text{g L}^{-1}$ across all sites and sampling events. These values are consistent with background concentrations commonly observed in marine waters of the central Queensland coast.

Zinc concentrations were low across all sites during both early and late wet-season sampling. Zinc was below the laboratory limit of detection ($<5 \mu\text{g L}^{-1}$) at all sites except Freshwater Point, where a concentration of $6 \mu\text{g L}^{-1}$ was measured in November 2024. This value remained below the ANZG 99% and 95% species protection guideline values for marine waters.

Copper concentrations were low in absolute terms at most sites, typically $\leq 1 \mu\text{g L}^{-1}$. Slightly higher concentrations were recorded at Mackay Harbour (MKY_AMB11) during the early wet-season sampling event in November 2024 ($2 \mu\text{g L}^{-1}$), with marginally elevated values also observed at Victor Island (MKY_AMB10) and Round Top Island (MKY_AMB3B) (approximately $1 \mu\text{g L}^{-1}$).

These concentrations exceeded the ANZG 99% species protection level at several sites and, at Mackay Harbour, also exceeded the 95% species protection level. However, elevated copper concentrations were not persistent, were not observed consistently across seasons, and did not continue in subsequent sampling events, indicating short-lived exposures rather than sustained

enrichment. The recurring observation of modest copper elevation within Mackay Harbour across multiple monitoring years, despite concentrations being lower than those reported previously, suggests a localised and episodic source, potentially related to antifouling inputs and reduced flushing within the harbour environment, and highlights copper as a parameter warranting continued routine monitoring rather than evidence of progressive deterioration.

Lead concentrations were generally below detection limits ($<0.2 \mu\text{g L}^{-1}$) at all sites. Two isolated detections were recorded: $0.8 \mu\text{g L}^{-1}$ at Mackay Harbour (MKY_AMB11) and $0.3 \mu\text{g L}^{-1}$ at Slade Island (MKY_AMB5), in November 2024. These values were not repeated in April 2025 samples and remained below guideline values.

Nickel, cadmium, silver, and mercury concentrations were consistently below detection limits across all sites and sampling periods, indicating no evidence of enrichment from anthropogenic sources.

When assessed against ANZG (2018) default guideline values, applying 95% or 99% species protection criteria according to site-specific environmental value and management intent as defined in the EPP (2019), only copper showed guideline exceedances during either dry- or wet-season sampling.

Overall, the consistently low and stable metal concentrations observed across the Mackay monitoring sites are indicative of a low-risk metal environment and align with expectations for open coastal waters subject to strong tidal mixing and flushing.

Table 3-1 Filterable metals from the Mackay and Hay point sampling sites in 2024-2025 wet and dry seasons. Bold values indicate values above limit of detection, orange values exceed the 99% level of species protection, red values exceed the 95% level of species protection.

Site name	Site code	Ag	As	Cd	Cu	Hg	Ni	Pb	Zn
Early wet season (27/11/2024)		µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹
Freshwater Point	MKY_AMB1	<0.1	1.4	<0.2	<1	<0.00004	<0.5	<0.2	6
Victor Island	MKY_AMB10	<0.1	1.6	<0.2	1	<0.00004	<0.5	<0.2	<5
Round Top Island	MKY_AMB3B	<0.1	1.4	<0.2	1	<0.00004	<0.5	<0.2	<5
Slade Island	MKY_AMB5	<0.1	1.5	<0.2	<1	<0.00004	<0.5	0.3	<5
Mackay Harbour	MKY_AMB11	<0.1	1.6	<0.2	2	<0.00004	<0.5	0.8	<5
Late wet season (07/04/2025)									
Freshwater Point	MKY_AMB1	<0.1	1.5	<0.2	<1	<0.0001	<0.5	<0.2	<5
Victor Island	MKY_AMB10	<0.1	1.6	<0.2	<1	<0.0001	<0.5	<0.2	<5
Round Top Island	MKY_AMB3B	<0.1	1.5	<0.2	<1	<0.0001	<0.5	<0.2	<5
Slade Island	MKY_AMB5	<0.1	1.5	<0.2	<1	<0.0001	<0.5	<0.2	<5
Mackay Harbour	MKY_AMB11	<0.1	1.5	<0.2	<1	<0.0001	<0.5	<0.2	<5
Limit of detection (LOD)[#]		0.1	0.5	0.2	1	0.0001	0.5	0.2	5
ANZG 99% level of species protection		0.8	-	0.7	0.3	0.1	7	2.2	7
ANZG 95% level of species protection		1.4	-	5.5	1.3	0.4	70	4.4	15

3.3.4 Ambient Nutrient Variability in Relation to Regional Water Quality Objectives

Nutrient and chlorophyll-a concentrations measured at the Mackay ambient water-quality monitoring sites were compared with the relevant regional water-quality objectives (WQOs) defined under the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP 2019) to provide context for interpreting ambient spatial and seasonal variability. These comparisons are intended to support understanding of background conditions in inshore coastal waters and do not represent compliance thresholds for port-related activities, which are assessed separately using site-specific criteria and predictive modelling frameworks defined under relevant Long-Term Dredge Management Plans (LTDMs).

EPP (2019) WQOs vary by parameter and location and are defined using different statistical forms, including annual medians, seasonal means and percentile-based targets. Accordingly, the comparisons presented here apply the form of statistic specified by each WQO—annual, seasonal or percentile-based—with seasonal statistics emphasised where appropriate to reflect the strong seasonal signal and episodic, event-driven behaviour characteristic of the Mackay region, rather than as pass/fail compliance assessments.

Table 3-2 Seasonal nutrient and chlorophyll-a statistics for Freshwater Point (MKY_AMB1), presented as dry- and wet-season mean, median, or percentile-based values (20th, 50th and 80th percentiles), consistent with the form of the applicable EPP (2019) open-coastal water-quality objectives. Results are provided to contextualise ambient variability, with interpretive notes highlighting dominant seasonal and episodic influences.

Parameter	Seasonal Mean / Median ($\mu\text{g L}^{-1}$)	WQO	WQO Basis	Status - wet/dry	Interpretive context (ambient conditions)
Chlorophyll-a	1.03/ 0.96	0.32/ 0.63	Dry season mean/ Wet season mean	Above/ above	Concentrations are consistent with historical observations for the Mackay region. Phaeophytin-a concentrations were consistently low ($<0.2 \mu\text{g L}^{-1}$ in most samples), indicating limited pigment degradation and low phytoplankton turnover; values reflect conservative guideline settings rather than elevated productivity.
Particulate Nitrogen (PN)	20/ 18	16/ 24	Dry season/ Wet season mean	Above/ below	Seasonal and annual PN statistics are influenced by a single October 2024 event associated with a <i>Trichodesmium</i> bloom. Outside this event, PN concentrations were generally low and consistent with background conditions.
Particulate Phosphorus (PP)	2.0/ 1.0	2.3/ 3.3	Dry season/ Wet season mean	Below/ below	PP concentrations were generally low, with short-lived increases linked to elevated suspended material during wet-season sampling rather than sustained particulate enrichment.
Total Dissolved Nitrogen (TDN)	107-114.5-117	45-75-95	20 th 50 th 80 th percentile	Above WQO	Elevated percentile values reflect wet-season dominance and runoff-related inputs. Concentrations outside peak wet-season conditions were typically lower and within the historical regional range.

Total Dissolved Phosphorus (TDP)	5-6-7	4-9-17	20 th 50 th 80 th percentile	Below WQO	TDP remained consistently low across seasons, indicating limited dissolved phosphorus availability and minimal risk of phosphorus-driven productivity.
Total Nitrogen (TN)	123-129.5-135	55-90-115	20 th 50 th 80 th percentile	Above WQO	Seasonal TN values reflect both dissolved and particulate contributions, with upper percentiles influenced by wet-season inputs and the October 2024 bloom event. Median concentrations were consistently elevated relative to WQOs but showed no sustained increase through time.
Total Phosphorus (TP)	7-8-9	6-12-20	20 th 50 th 80 th percentile	Below WQO	TP concentrations were generally low, with upper percentile values reflecting short-lived particulate inputs during wet-season conditions, including influence from the October 2024 bloom event.
Values shown represent seasonal summary statistics used to contextualise ambient variability relative to regional WQOs. These comparisons are not intended to represent compliance criteria for dredging or port operations.					

*Table 3-3 Comparison of annual nutrient and chlorophyll-a concentrations with the relevant EPP (2019) water-quality objectives for **Round Top Island** (MKY_AMB3B). Annual medians or means (as required by each WQO) are colour-coded to indicate values below, near, or above the applicable WQO threshold (green, yellow, and red respectively).*

Parameter	Seasonal Mean / Median ($\mu\text{g L}^{-1}$)	WQO	WQO Basis	Status - wet/dry	Interpretive context (ambient conditions)
Chlorophyll-a	0.64 / 0.73	0.32/ 0.63	Dry season mean/ Wet season mean	Above/ above	Seasonal mean concentrations exceeded the dry- and wet-season WQOs, indicating consistently measurable phytoplankton biomass at this site. However, low phaeophytin-a suggests limited degradation and turnover, consistent with stable background production rather than bloom conditions.

Particulate Nitrogen (PN)	14/ 13	16/ 24	Dry season/ Wet season mean	Below/ below	PN concentrations were low in both seasons and below the applicable seasonal WQOs. This indicates limited particulate nutrient input and minimal influence from resuspension or external sources.
Particulate Phosphorus (PP)	1.33/ 0.83	2.3/ 3.3	Dry season/ Wet season mean	Below/ below	PP concentrations remained low across seasons and below seasonal WQOs. Observed values are consistent with background marine particulate dynamics at an exposed island site.
Total Dissolved Nitrogen (TDN)	118	75	Annual median	Above WQO	Median TDN concentrations exceeded the annual WQO, indicating elevated dissolved nitrogen relative to guideline expectations. This elevation was persistent but stable and likely reflects regional marine nutrient background rather than episodic or localised inputs.
Total Dissolved Phosphorus (TDP)	6.0	9.0	Annual median	Below WQO	Median TDP concentrations were low and below the annual WQO. This indicates limited dissolved phosphorus availability at this site.
Total Nitrogen (TN)	128	90	Annual median	Above WQO	Median TN concentrations exceeded the annual WQO, driven primarily by the dissolved nitrogen fraction. Concentrations were stable across seasons, suggesting a consistent ambient nitrogen signal rather than event-driven enrichment.
Total Phosphorus (TP)	7.0	12	Annual median	Below WQO	TP concentrations remained below the annual median WQO. Variability was limited and consistent with low particulate and dissolved phosphorus inputs.

Values shown represent seasonal summary statistics used to contextualise ambient variability relative to regional WQOs. These comparisons are not intended to represent compliance criteria for dredging or port operations.

Table 3-4 Seasonal nutrient and chlorophyll-a statistics for Slade Island (MKY_AMB5), summarised as dry- and wet-season mean, median, or percentile-based values (20th, 50th and 80th percentiles) consistent with EPP (2019) open-coastal water-quality objectives, with interpretation focused on natural seasonal and event-driven variability.

Parameter	Seasonal Mean / Median ($\mu\text{g L}^{-1}$)	WQO	WQO Basis	Status - wet/dry	Interpretive context (ambient conditions)
Chlorophyll-a	0.60 / 1.16	0.32/ 0.63	Dry season mean/ Wet season mean	Above/ above	Seasonal mean chlorophyll-a concentrations exceeded both dry- and wet-season WQOs, indicating consistently elevated phytoplankton biomass relative to guideline expectations. Concentrations were higher in the wet season, consistent with increased nutrient availability and reduced flushing during wetter conditions.
Particulate Nitrogen (PN)	9 / 6	16/ 24	Dry season/ Wet season mean	Below/ below	PN concentrations were low in both seasons and well below the applicable seasonal WQOs. This indicates limited particulate nitrogen input and minimal influence from resuspension or terrestrial sources at this site.
Particulate Phosphorus (PP)	1.67 / 3.0	2.3/ 3.3	Dry season/ Wet season mean	Below/ below	PP concentrations remained below seasonal WQOs, with higher values observed during the wet season. This pattern suggests short-lived increases associated with suspended material rather than sustained particulate enrichment.
Total Dissolved Nitrogen (TDN)	108.5	75	Annual median	Above WQO	Median TDN concentrations exceeded the annual WQO, indicating elevated dissolved nitrogen relative to guideline thresholds. Concentrations were stable across the monitoring period, suggesting a persistent ambient signal rather than episodic enrichment.

Total Dissolved Phosphorus (TDP)	5.0	9.0	Annual median	Below WQO	Median TDP concentrations were low and remained below the annual WQO. This indicates limited dissolved phosphorus availability at Slade Island.
Total Nitrogen (TN)	122.5	90	Annual median	Above WQO	Median TN concentrations exceeded the annual WQO, driven primarily by the dissolved nitrogen fraction. Values showed limited variability, indicating a consistent ambient nitrogen signal rather than event-driven inputs.
Total Phosphorus (TP)	7.5	12	Annual median	Below WQO	TP concentrations were low and remained below the annual median WQO. Variability was modest and consistent with background marine phosphorus conditions.
Values shown represent seasonal summary statistics used to contextualise ambient variability relative to regional WQOs. These comparisons are not intended to represent compliance criteria for dredging or port operations.					

Table 3-5 Seasonal nutrient and chlorophyll-a statistics for Victor Island (MKY_AMB10), presented as dry- and wet-season mean, median, or percentile-based values (20th, 50th and 80th percentiles) as specified under the EPP (2019) open-coastal water-quality objectives, reflecting ambient conditions in a reef-influenced island setting.

Parameter	Seasonal Mean / Median ($\mu\text{g L}^{-1}$)	WQO	WQO Basis	Status - wet/dry	Interpretive context (ambient conditions)
Chlorophyll-a	0.85 / 1.18	0.32 / 0.63	Dry season / Wet season mean	Above / above	Seasonal mean chlorophyll-a concentrations exceeded both dry- and wet-season WQOs, indicating persistent phytoplankton biomass relative to guideline expectations. Higher wet-season values are consistent with increased nutrient availability and reduced flushing during wetter conditions.

Particulate Nitrogen (PN)	8.0 / 15.7	16/ 24	Dry season/ Wet season mean	Below/ below	PN concentrations remained below seasonal WQOs in both seasons, with higher values during the wet season. This pattern indicates modest seasonal particulate inputs rather than sustained enrichment.
Particulate Phosphorus (PP)	1.5 / 2.7	2.3/ 3.3	Dry season/ Wet season mean	Below/ below	PP concentrations were below seasonal WQOs, with wet-season values approaching but not exceeding guideline thresholds. Variability is consistent with short-lived increases in suspended material during wetter periods.
Total Dissolved Nitrogen (TDN)	111.5	75	Annual median	Above WQO	Median TDN concentrations exceeded the annual WQO, indicating elevated dissolved nitrogen relative to guideline expectations. Concentrations were stable, suggesting a persistent ambient nitrogen signal rather than episodic inputs.
Total Dissolved Phosphorus (TDP)	6.0	9.0	Annual median	Below WQO	Median TDP concentrations were low and remained below the annual WQO. This indicates limited dissolved phosphorus availability at this site.
Total Nitrogen (TN)	127.5	90	Annual median	Above WQO	Median TN concentrations exceeded the annual WQO and were dominated by the dissolved nitrogen fraction. This indicates elevated ambient nitrogen availability rather than particulate- or event-driven enrichment at this site.
Total Phosphorus (TP)	7.5	12	Annual median	Below WQO	TP concentrations were low and remained below the annual median WQO. Observed variability was limited and consistent with marine-dominated phosphorus conditions.

Values shown represent seasonal summary statistics used to contextualise ambient variability relative to regional WQOs. These comparisons are not intended to represent compliance criteria for dredging or port operations.

Table 3-6 Comparison of annual nutrient and chlorophyll-a concentrations with the relevant EPP (2019) water-quality objectives for **Mackay Harbour** (MKY_AMB11). Annual medians or means (as required by each WQO) are colour-coded to indicate values below, near, or above the applicable WQO threshold (green, yellow, and red respectively).

Parameter	Seasonal Mean / Median ($\mu\text{g L}^{-1}$)	WQO	WQO Basis	Status - wet/dry	Interpretive context (ambient conditions)
Chlorophyll-a	1.33	<2	Annual mean	Below WQO	Annual mean chlorophyll-a concentrations were below the applicable WQO, indicating low to moderate phytoplankton biomass within the harbour. Values are consistent with historical observations for semi-enclosed coastal harbour environments.
Particulate Nitrogen (PN)	8.0 / 15.7	Not Defined	NA		PN concentrations showed seasonal variability, with higher values during the wet season reflecting increased particulate inputs and reduced flushing. No guideline values are defined for PN at this site; results are interpreted as ambient harbour conditions.
Particulate Phosphorus (PP)	1.5 / 2.7	Not Defined	NA		PP concentrations were higher during the wet season, consistent with increased suspended material and particulate inputs under higher runoff and lower flushing conditions. No WQOs are defined for PP at this location.
Total Dissolved Nitrogen (TDN)	111.5	Not Defined	NA		TDN concentrations indicate elevated dissolved nitrogen within the harbour relative to open coastal sites. No WQO is defined for TDN at Mackay Harbour, and values are interpreted as representative of ambient harbour conditions.
Total Dissolved Phosphorus (TDP)	6.0	Not Defined	NA		TDP concentrations were low and showed limited variability across the monitoring period. No WQO is defined for TDP at this site.

Total Nitrogen (TN)	160.5	<160	Annual median	Near WQO	Median TN concentrations were close to the applicable WQO, indicating elevated but not exceeding guideline expectations. Values reflect combined dissolved and particulate nitrogen within a semi-enclosed harbour setting.
Total Phosphorus (TP)	11	<20	Annual median	Below WQO	Median TP concentrations were below the applicable WQO, indicating low overall phosphorus availability. Variability was consistent with background harbour conditions rather than sustained enrichment.
Values shown represent seasonal summary statistics used to contextualise ambient variability relative to regional WQOs. These comparisons are not intended to represent compliance criteria for dredging or port operations.					

3.4 Physicochemical

3.4.1 Dissolved oxygen

Dissolved oxygen (DO) concentrations were consistently high across all Mackay ambient monitoring sites, generally ranging from 6.1–8.6 mg L⁻¹ (Figure 3-7). Corresponding oxygen saturation levels ranged from 87–126% (Figure 3-8), reflecting well-oxygenated conditions throughout the water column.

Vertical differences were minor. Dissolved oxygen concentrations were consistently high throughout the water column, with only minor decreases observed with depth and no evidence of hypoxic conditions during the monitoring period.

DO is reported both as mg L⁻¹ (absolute concentration) and % saturation (relative to solubility at the measured temperature and salinity), allowing clearer interpretation under varying seasonal and physical conditions.

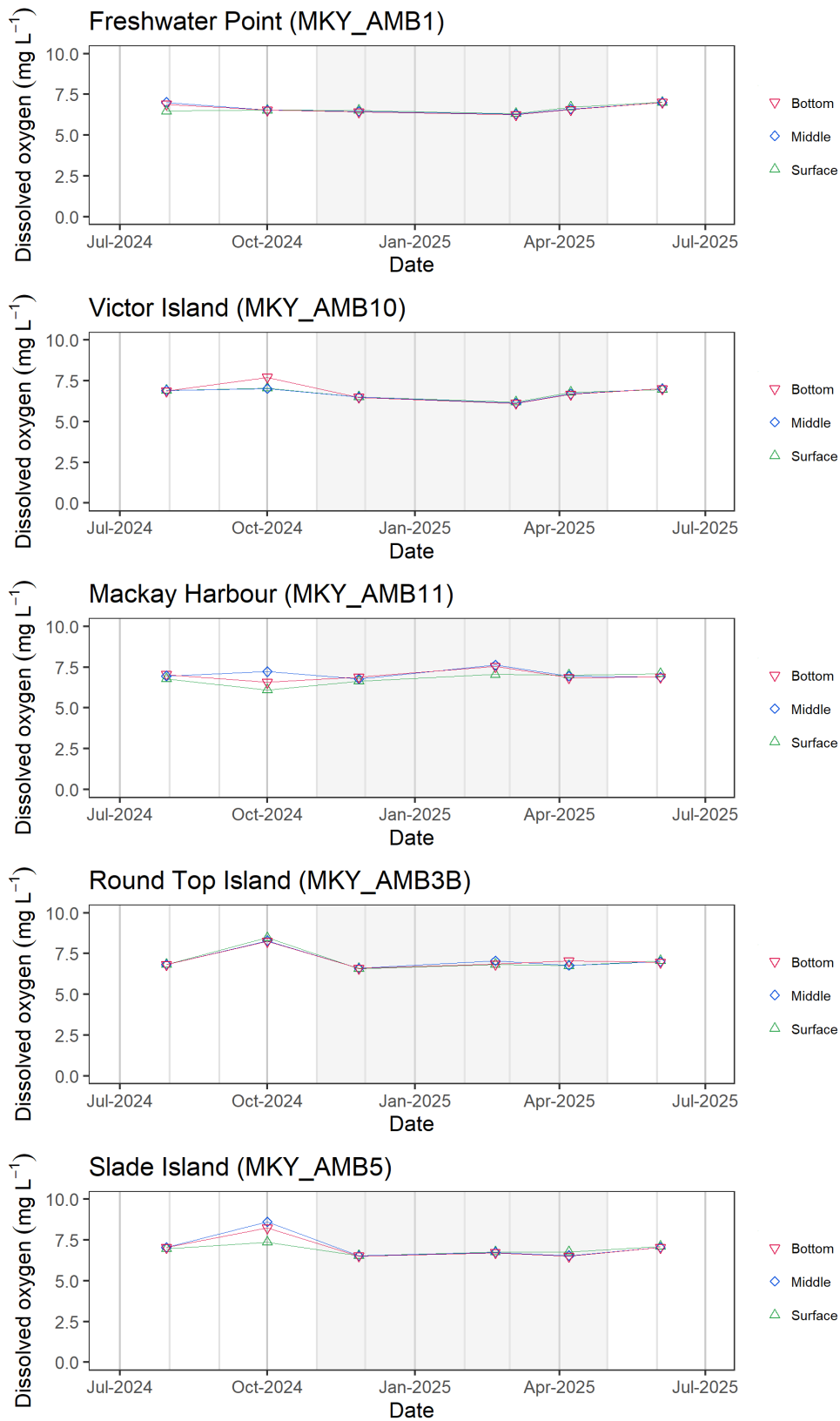


Figure 3—12 Dissolved oxygen concentration (mg L⁻¹) at the Mackay and Hay Point monitoring sites, shown for surface, mid-water, and bottom depths. Grey area indicates wet season.

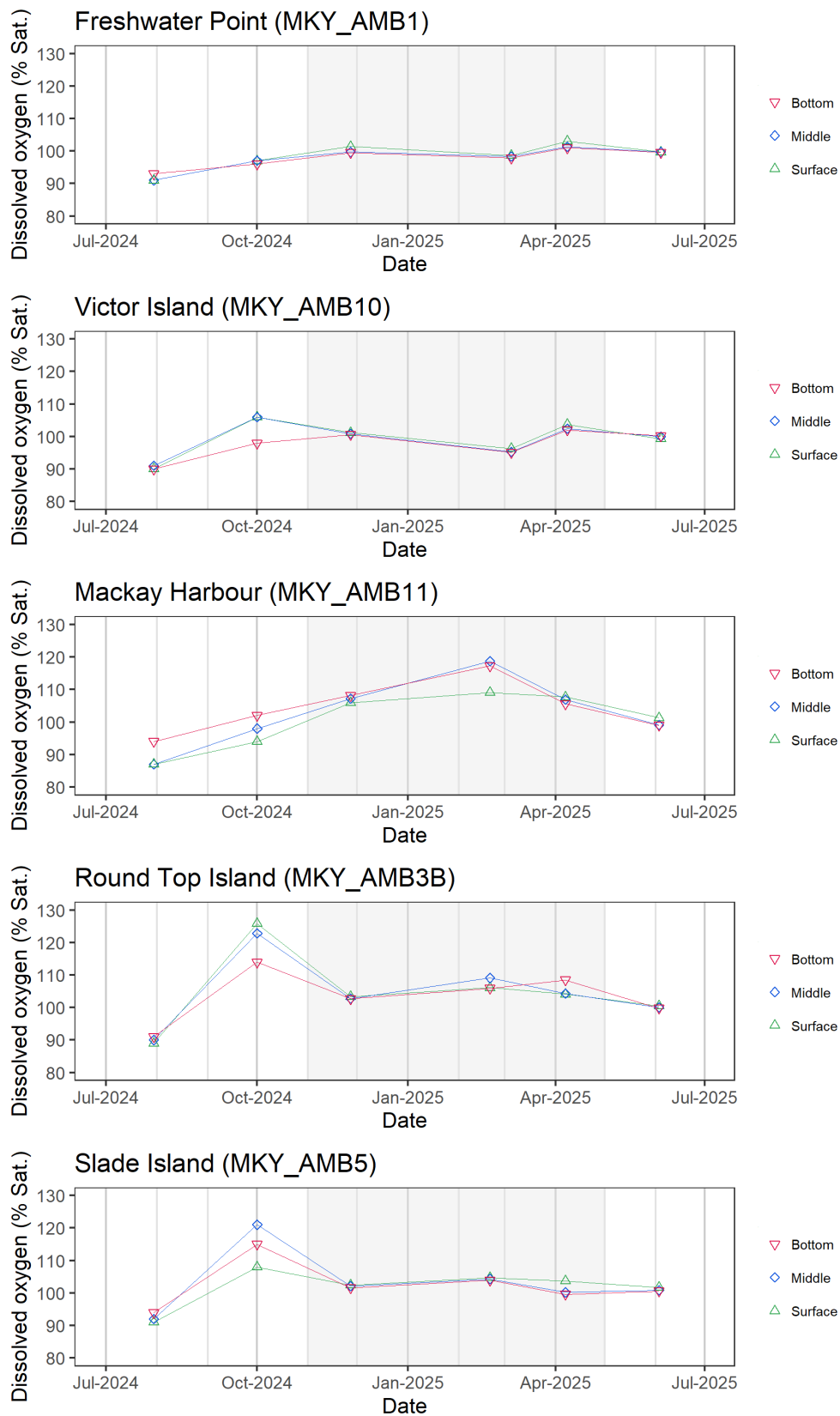


Figure 3—13 Dissolved oxygen (% saturation) at the Mackay and Hay Point monitoring sites. Grey area indicates wet season.

3.4.2 Conductivity

Electrical conductivity (EC) showed the expected seasonal pattern for tropical inshore waters (Figure 3-9). Across the monitoring period, EC values ranged from approximately 46 to 56 mS cm⁻¹, with lower values recorded during the late wet season (February–April 2025), coinciding with periods of increased rainfall and modest freshwater influence. The highest EC values occurred during the dry season (September–November 2024), reflecting reduced rainfall, higher salinity and evaporative concentration.

In addition to this seasonal signal, site locality appears to influence the magnitude of wet-season EC responses. The Mackay coastal cluster—Mackay Harbour (MKY_AMB11), Slade Island (MKY_AMB5) and Round Top Island (MKY_AMB3B)—is located closest to the Pioneer River and Sandy Creek discharge zone and tended to show slightly greater wet-season reductions in EC. In contrast, the more southerly sites, Victor Island (MKY_AMB10) and Freshwater Point (MKY_AMB1), are situated further from this discharge convergence and may be influenced by different freshwater plume pathways during runoff events.

Despite these spatial differences, EC remained within marine ranges throughout the year across all sites, indicating that conditions were predominantly marine-dominated, with wet-season freshwater inputs resulting in minor and short-lived dilution rather than sustained estuarine influence.

3.4.3 Salinity

Salinity varied modestly in line with expected seasonal patterns (Figure 3-10). Values ranged from 32.4–37.2 PSU, with the lowest values observed in March–April 2025 during late wet-season freshwater inflow. By contrast, the highest salinities were recorded during the dry season (October–November 2024), exceeding 37 PSU at several sites.

Vertical salinity gradients were minimal, indicating a generally well-mixed water column during sampling. Only minor stratification was evident where surface salinity dipped below 34 PSU during wet-season events.

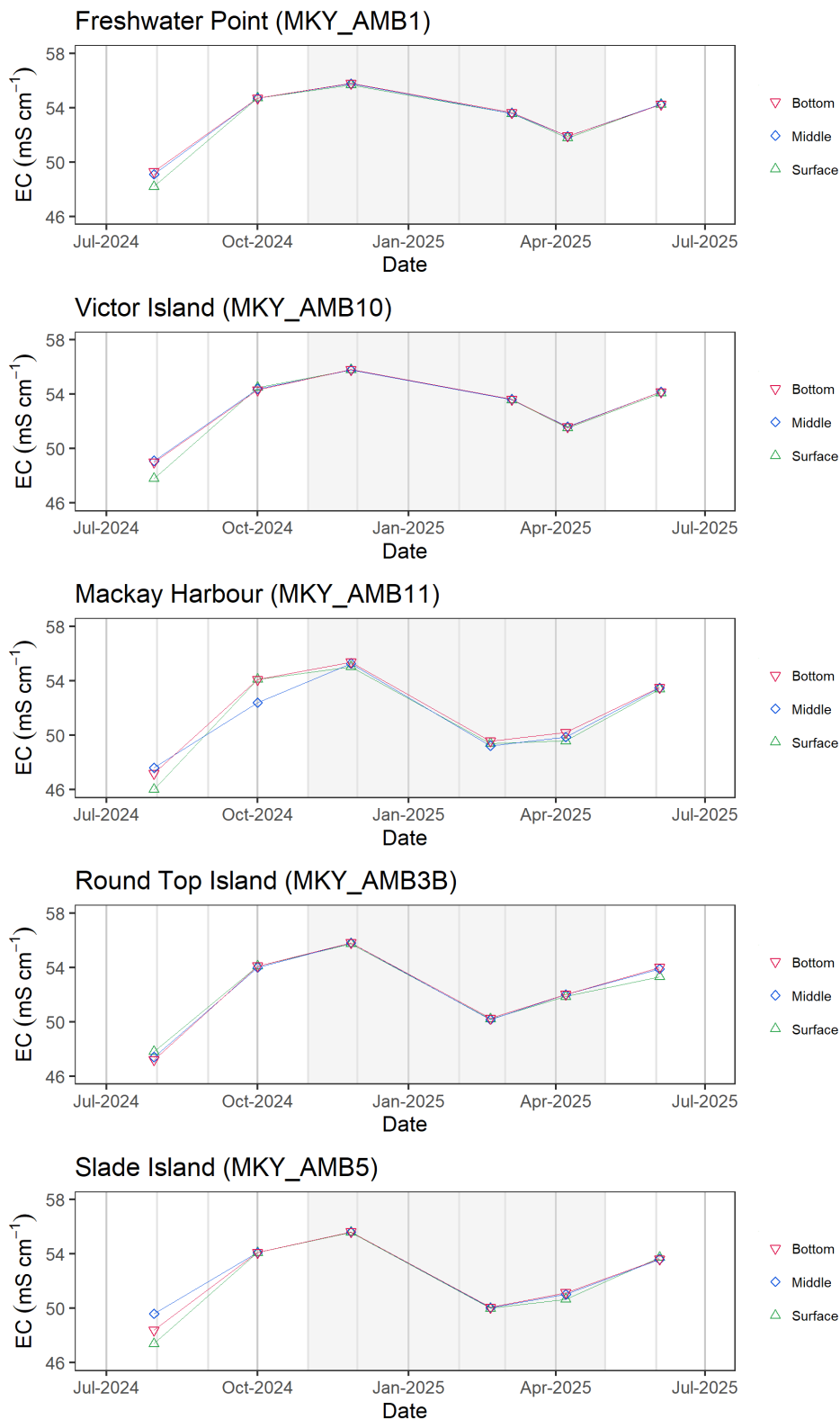


Figure 3—14 Electrical conductivity (mS cm^{-1}) at the Mackay and Hay Point monitoring sites for surface, mid-water, and bottom depths. Grey area indicates wet season.

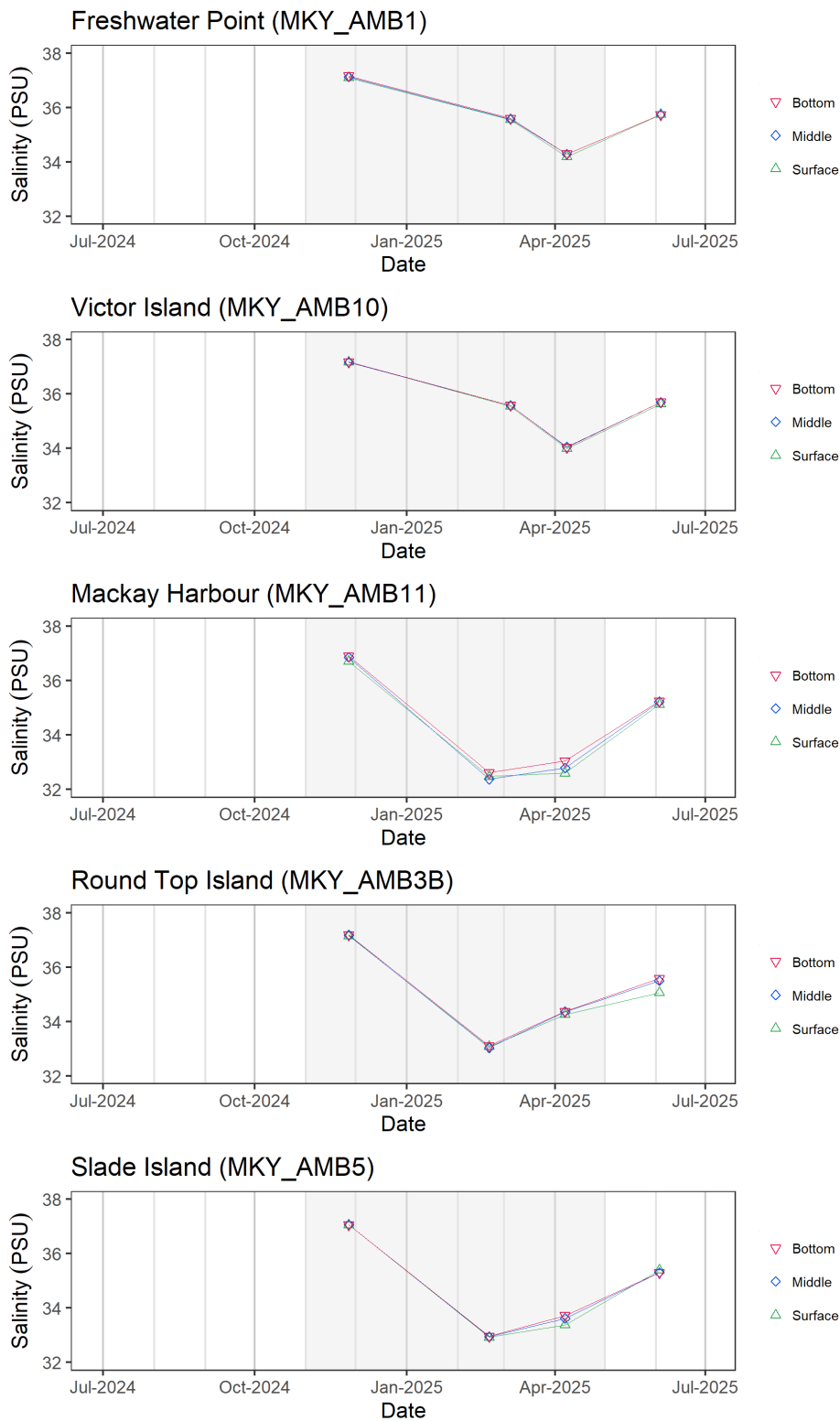


Figure 3—15 Salinity (PSU) recorded at the Mackay and Hay Point monitoring sites for surface, mid-water, and bottom depths. Grey area indicates wet season. Note that salinity was only added to the in-situ measured parameters with the introduction of the YSI probe in November 2024.

3.4.4 Water temperature

Water temperature displayed clear seasonal variation characteristic of tropical coastal waters (Figure 3-11). The coolest temperatures were observed in July 2024 (18.7–19 °C), with temperatures steadily increasing into summer and peaking between 28–29.1 °C during March–April 2025. Temperature differences among depths were negligible, indicating a vertically mixed water column during all sampling events. No thermal stratification was observed.

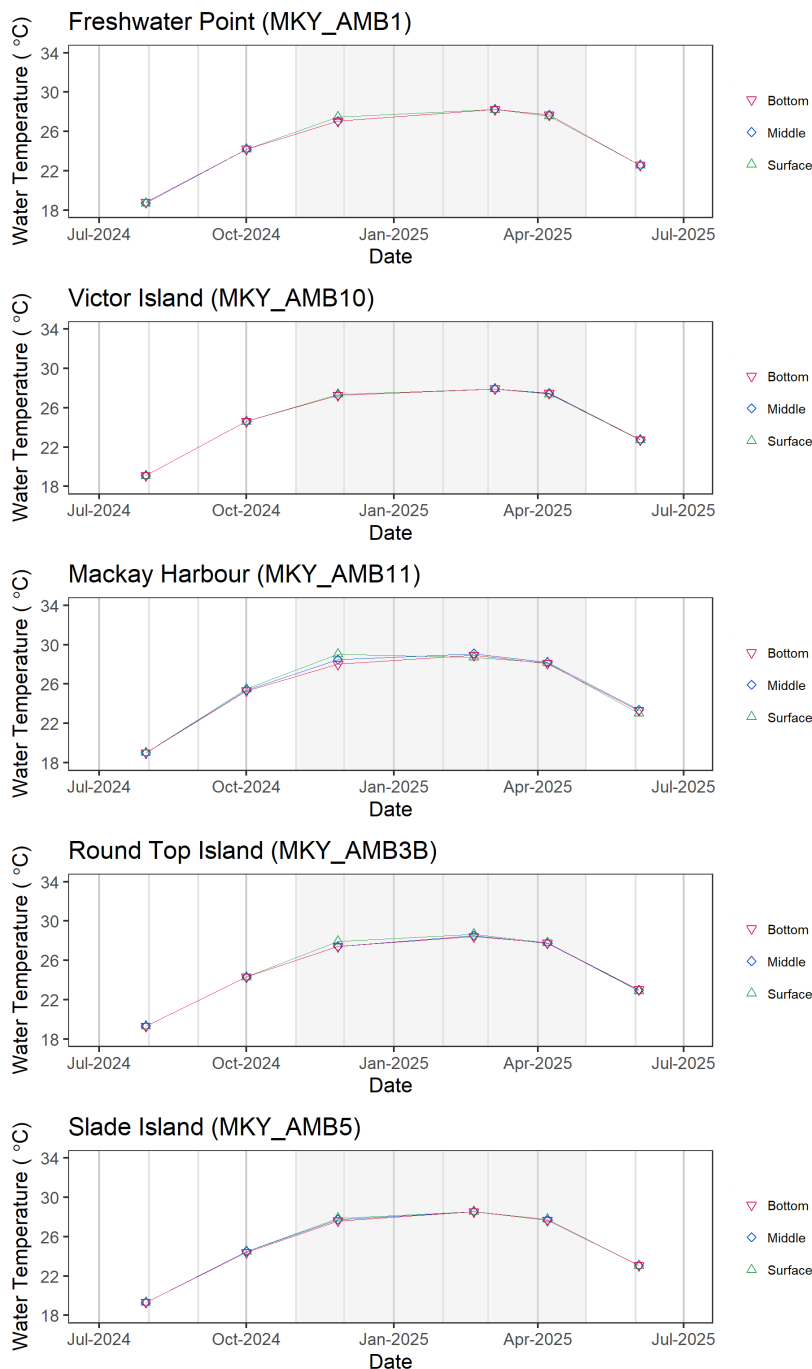


Figure 3—16 Water temperature recorded at the Mackay and Hay Point monitoring sites for surface, mid-water, and bottom depths over the reporting period. Grey area indicates wet season.

3.4.5 pH

pH remained stable across all sites and depths, typically ranging from 7.9–8.7 (Figure 3-12). This narrow range is characteristic of well-buffered inshore marine waters. Slightly elevated pH values (>8.3) during several dry-season sampling events may indicate increased photosynthetic activity under high-light, low-turbidity conditions. No acidification events or departures from typical marine pH ranges were observed.

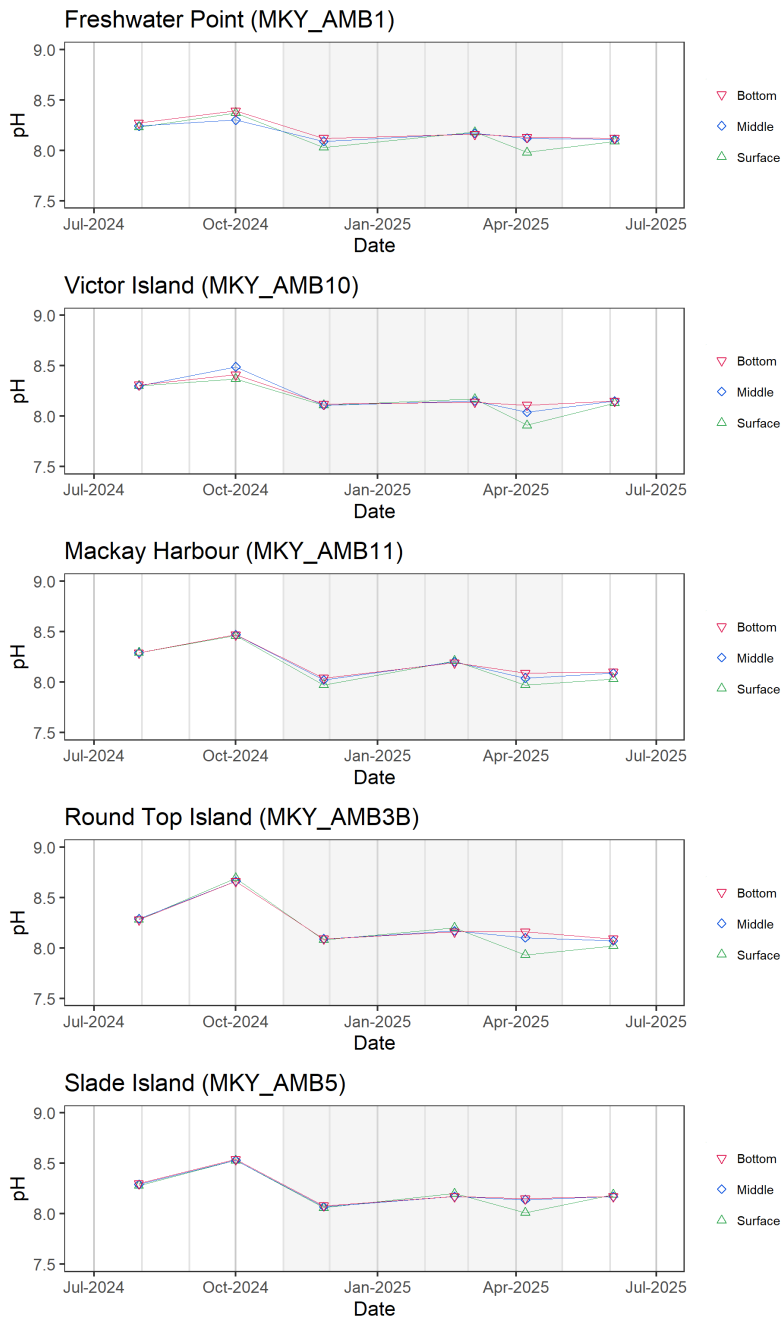


Figure 3—17 The pH recorded at the Mackay and Hay Point monitoring sites for surface, mid-water, and bottom depths over the reporting period. Grey area indicates wet season.

3.4.6 Water clarity

Secchi depth measurements ranged from 1–8 m across the monitoring period (Figure 3-13). The clearest conditions occurred during the dry season (August–October 2024), when Secchi depths commonly exceeded 5–6 m. Reduced clarity (1–3 m) was observed during March–April 2025, consistent with increased turbidity from wet-season freshwater inputs and resuspension under higher wind conditions.

3.4.7 Turbidity

In-situ turbidity measurements (FNU) collected across all Mackay ambient sites showed low to moderate values for most of the year, ranging from 0.26–14.3 FNU (Figure 3-17). Turbidity was generally lowest during dry-season sampling (July–October 2024), consistent with clear water and limited sediment mobilisation under calm seasonal conditions.

Across multiple sites—including Freshwater Point (MKY_AMB1), Victor Island (MKY_AMB10), and Slade Island (MKY_AMB5)—the highest turbidity values occurred during the late wet season (February–April 2025). These peaks likely reflect increased suspended sediments associated with runoff, wind-driven resuspension, and enhanced tidal mixing following rainfall.

Depth profiles revealed mild but consistent vertical stratification during higher-turbidity events. Bottom-water turbidity was typically greater than mid- and surface waters at Freshwater Point, Victor Island, and Slade Island, indicating sediment resuspension near the seabed under energetic tidal conditions. In several cases (e.g., April 2025 at the three sites), surface turbidity remained low while bottom turbidity increased, further supporting a resuspension-dominated process rather than catchment-derived plume influence.

Round Top Island (MKY_AMB3B) and Mackay Harbour (MKY_AMB11) showed only small fluctuations across seasons, with no pronounced wet-season peaks, consistent with the sheltered nature of these sites and limited local sediment sources.

Overall, turbidity remained low across the region for most sampling occasions, with short-lived wet-season increases and minor depth-related differences indicating episodic bottom resuspension rather than persistent water-column turbidity.

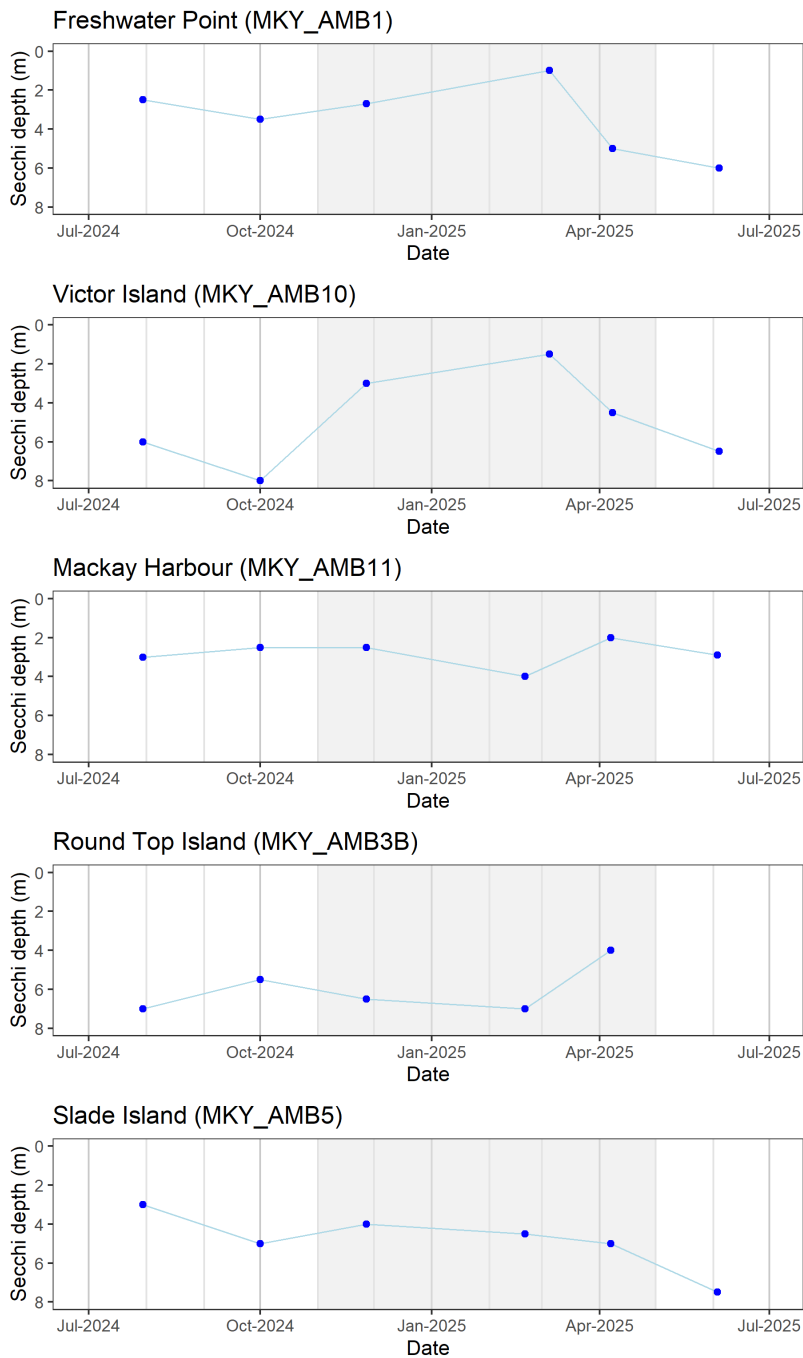


Figure 3—18 Secchi depth (m) recorded at the Mackay and Hay Point monitoring sites over the reporting period. Grey area indicates wet season.

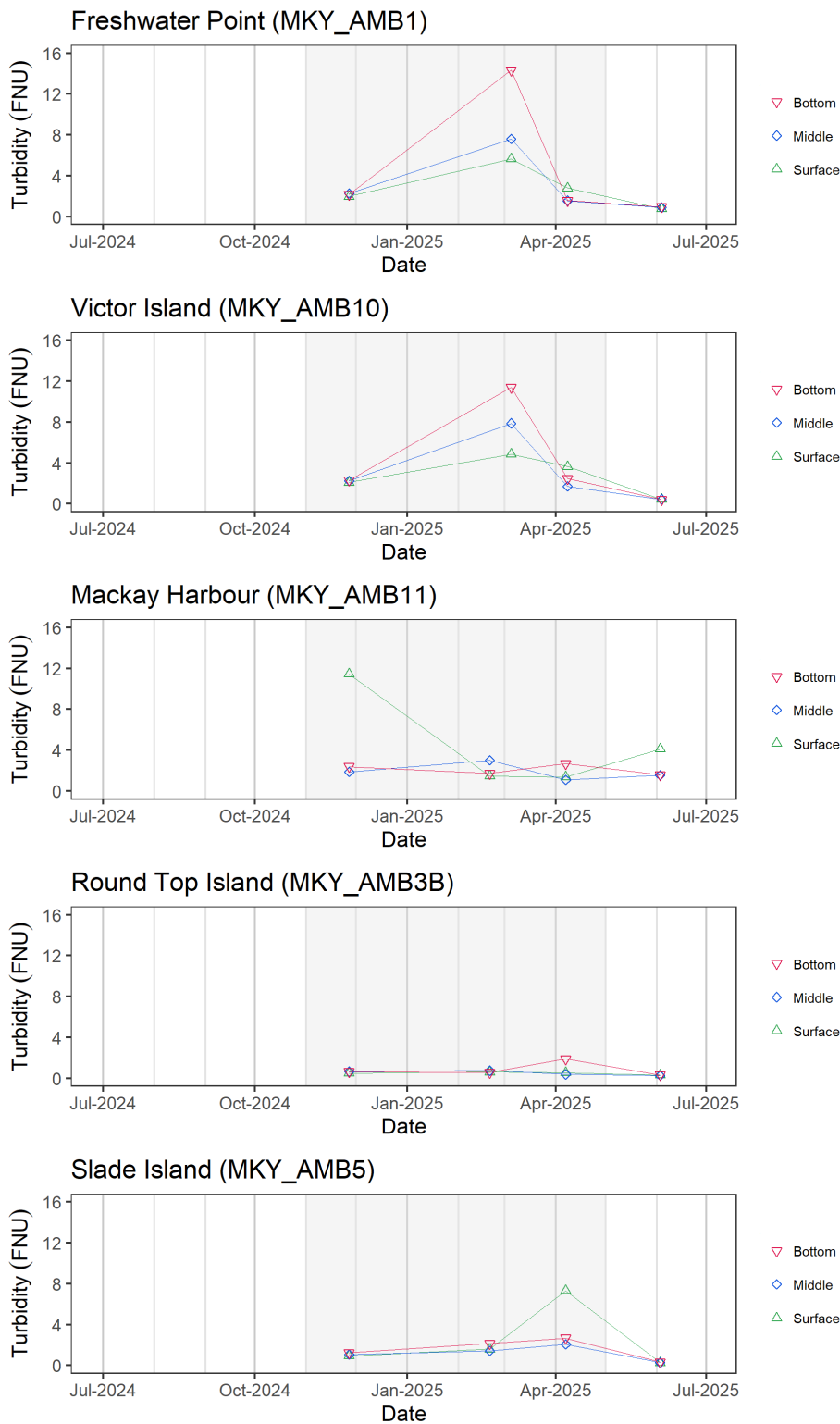


Figure 3—19 Turbidity (FNU) recorded at the Mackay and Hay Point monitoring sites over the reporting period. Grey area indicates wet season.

3.5 Seafloor mounted continuous dataloggers

3.5.1 Water temperature

Seafloor temperatures across the Mackay region showed a clear and consistent seasonal cycle, ranging broadly from the winter minimum in July–August to the late wet-season maximum in February–April, closely mirroring regional water-column profiles. All sites exhibited warm-season peaks near or above 29–30 °C and cool-season minima around 18.7–19 °C, indicating strong seasonal control and well-mixed local hydrodynamics. At Freshwater Point, temperatures ranged 18.7–29.8 °C (median ~26 °C), while Victor Island recorded a similar range of 18.9–29.6 °C. Slade Island showed the highest summer maxima (18.7–30.1 °C), consistent with its shallower and more exposed position, whereas Round Top Island ranged 19.1–29.7 °C, aligning closely with regional patterns. Collectively, the logger record confirms thermally stable, well-flushed conditions across all Mackay ambient sites.

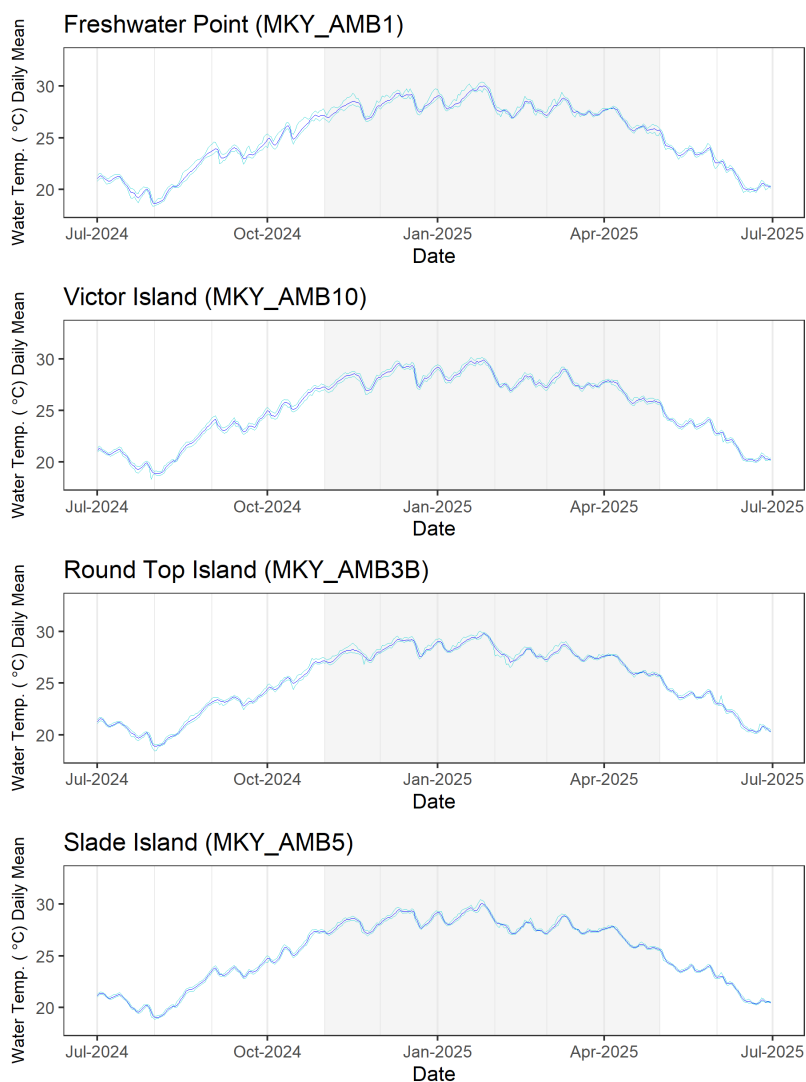


Figure 3—20 Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at the Mackay and Hay Point monitoring sites over the reporting period.

3.5.2 Water depth and tidal signal

Logger-derived water depth records demonstrated strong tidal influence across the region, consistent with the mixed semidiurnal mesotidal regime characteristic of the central Queensland coast. Daily tidal ranges were substantial at all sites and aligned closely with predicted tide heights, reinforcing the dominance of tidal forcing. At Freshwater Point, depths varied ~5.9–8.5 m (range ~2.6 m), while Victor Island exhibited a similar range of ~6.1–8.7 m (~2.5–2.6 m). Slade Island showed the largest tidal range (~5.8–8.6 m, ~2.7–2.8 m), reflecting greater exposure to open coastal exchange, and Round Top Island recorded ~6.0–8.6 m (~2.5–2.6 m). These data confirm consistent, tide-driven water-level fluctuations across all sites, with implications for sediment resuspension and light variability.

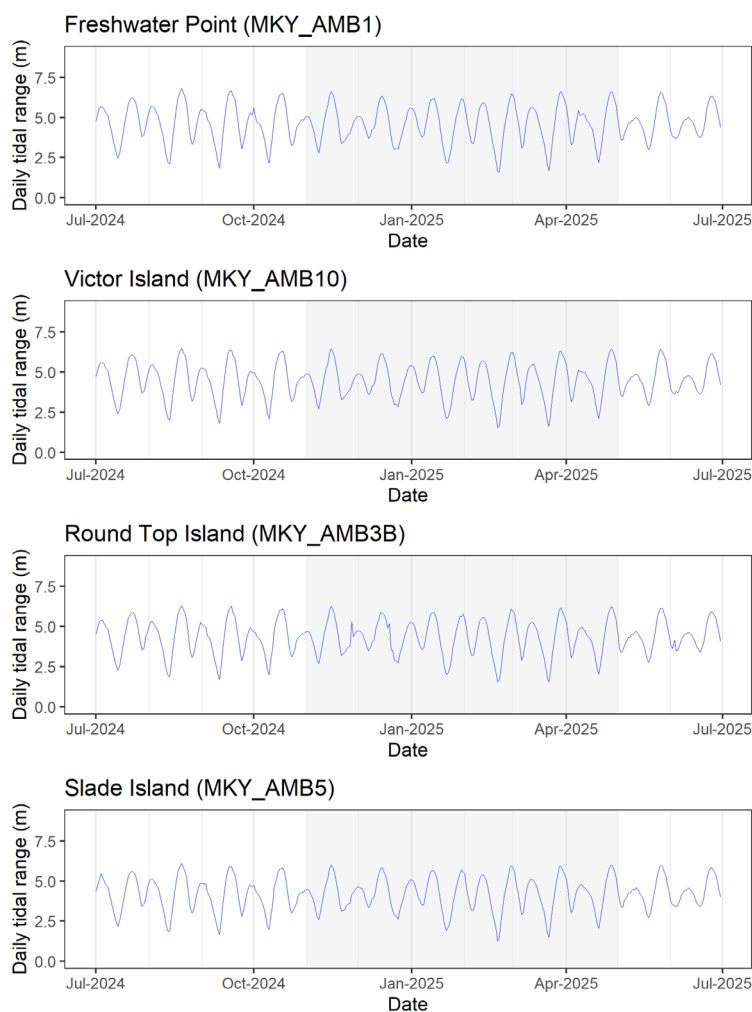


Figure 3—21 Daily tidal range measured at the Mackay and Hay Point monitoring sites over the reporting period.

3.5.3 Wave activity

Near-bed wave activity, assessed using the RMS depth metric, was generally low throughout the Mackay region, reflecting the predominance of tidal currents over wave-driven orbital motion in this part of the GBR lagoon. RMS values remained at the low-energy end of the spectrum across all sites, indicating limited wave disturbance at the seabed except during brief periods of elevated

wind or swell. Freshwater Point consistently recorded very low RMS depths (0.01–0.05 m), while Victor Island showed similar low-energy conditions (0.01–0.04 m). Slade Island experienced slightly greater wave exposure (0.02–0.12 m), consistent with its more open-coastal positioning, and Round Top Island remained within the low range (0.01–0.06 m) with only occasional minor increases. Overall, wave-forced seabed mobilisation is low relative to tidal processes in this region.

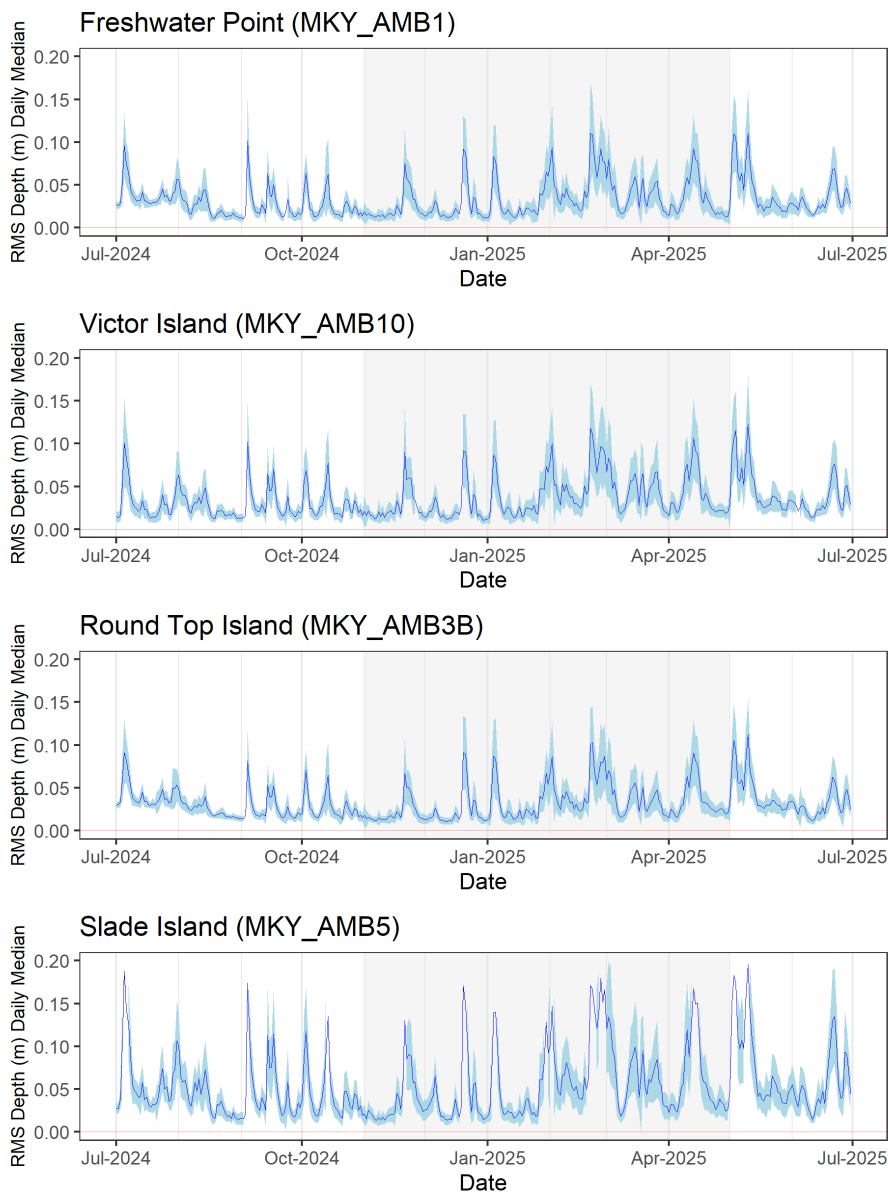


Figure 3—22 RMS depth (m) measured at the Mackay and Hay Point monitoring sites over the reporting period. Values presented are daily mean (blue line) +/- standard deviation (light blue ribbon).

3.5.4 Turbidity

Turbidity exhibited a mix of generally low background levels punctuated by short-lived increases linked to tidal resuspension or wind-induced mixing—patterns consistent with the well-flushed but dynamic inshore environment of the central GBR. Regionally, most turbidity values fell below 10

NTU, indicating frequent clear-water conditions, while occasional higher peaks occurred during spring tides or wind events. At Freshwater Point, turbidity ranged 0.2–22 NTU, typically remaining below 5 NTU. Victor Island showed similarly low to moderate values (0.1–16 NTU). Slade Island, being more exposed and shallower, displayed the widest variability (0.3–180 NTU) with sporadic pulses associated with strong tidal or wind conditions. Round Top Island ranged 0.2–14 NTU, with most values in the low range. These patterns highlight site-specific differences in exposure and sediment mobility while confirming overall good ambient clarity across the region.

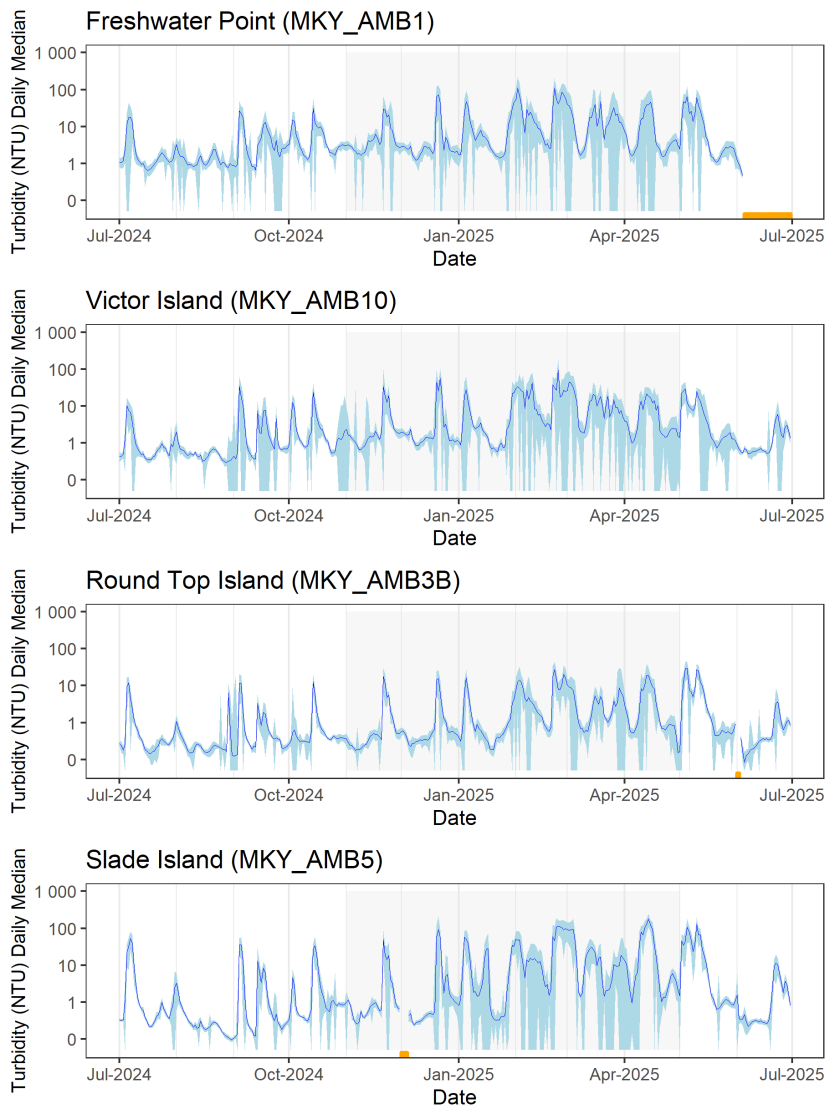


Figure 3—23 Turbidity measured at the Mackay and Hay Point monitoring sites over the reporting period. Results presented are daily mean (blue line) and standard deviation (light blue). Y-axis is in log scale. Orange bar indicates missing data.

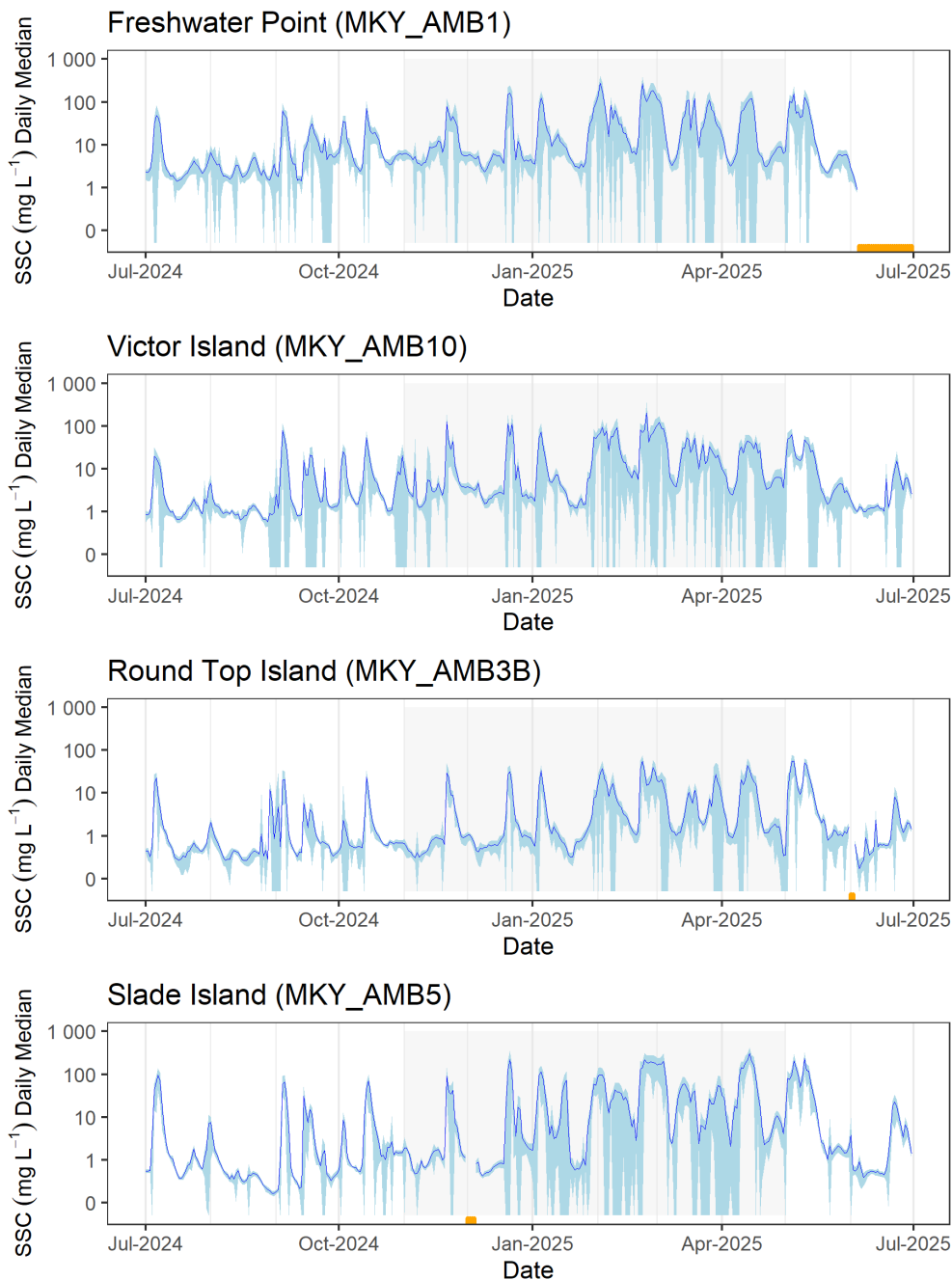


Figure 3—24 Suspended sediment concentration calculated from turbidity measurements at the Mackay and Hay Point monitoring sites over the reporting period.

3.5.5 Relationship between turbidity and RMS depth

Analysis of turbidity behaviour relative to RMS Depth—a metric reflecting short-period variability in water motion around the sensor—revealed distinct site-specific patterns across the four Mackay locations. Consistent with previous analyses, these relationships showed no systematic distinction between wet- and dry-season conditions, reinforcing that turbidity dynamics at these sites are primarily governed by short-term hydrodynamic processes rather than seasonal state alone, with

seasonal effects expressed mainly through changes in the frequency of forcing events rather than in turbidity response mechanisms.

At Freshwater Point, NTU and RMS Depth were moderately correlated overall, with the strongest relationship observed during stable tidal periods ($r = 0.52$). This indicates that turbidity variability is most clearly linked to short-period water-column motion—such as wave-driven shear stress—when background tidal acceleration is minimal and the hydrodynamic environment is relatively steady (Figure 3—25).

A similar pattern was evident at Round Top Island, where stable tides again produced a strong positive correlation ($r = 0.52$), while falling tides showed little to no relationship ($r = 0.08$). This suggests that during ebb conditions, increased current shear, changing flow direction, or enhanced horizontal advection disrupt the coupling between near-bed motion and local turbidity response at this more exposed site (Figure 3—26).

In contrast, Slade Island exhibited consistent correlations across all tidal stages ($r = 0.46$ – 0.49), indicative of a relatively uniform energy environment in which turbidity and short-period water motion covary more predictably regardless of tidal phase (Figure 3—27).

The weakest relationships were observed at Victor Island ($r = 0.18$ – 0.28), despite its proximity to the other island sites. This likely reflects the influence of localised environmental controls, such as sheltering by surrounding reefs, reduced wave energy, or limited availability of easily resuspended sediments, which decouple RMS Depth from turbidity fluctuations (Figure 3—28).

Collectively, these results indicate that turbidity is most strongly aligned with wave-related shear stress during periods of stable tidal conditions, when resuspension processes dominate local variability. During rising and falling tides, turbidity appears to be increasingly influenced by advection, changing flow regimes, sediment supply limitations, and local circulation patterns, rather than short-period vertical water motion alone. This explains both the reduced correlations observed during transitional tidal phases and the limited expression of seasonal differences in turbidity behaviour across sites.

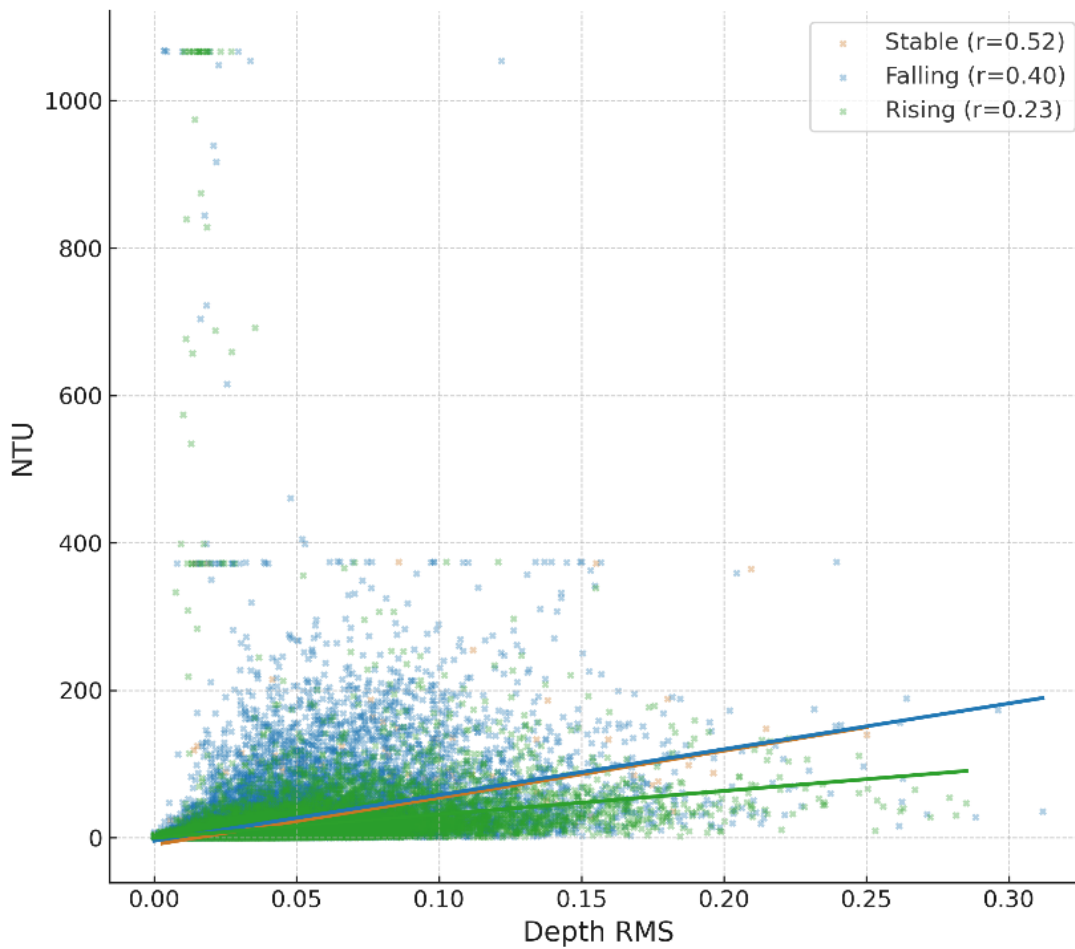


Figure 3—25 Relationship between turbidity (NTU) and short-period depth variability (RMS Depth) at Freshwater Point (MKY_AMB1) coloured by tidal stage. Regression lines and Pearson correlation coefficients (r) are shown for rising, falling, and stable tide conditions. Stable tidal periods show the strongest positive association between NTU and RMS Depth, indicating clearer expression of turbidity dynamics when short-period water movement is minimal.

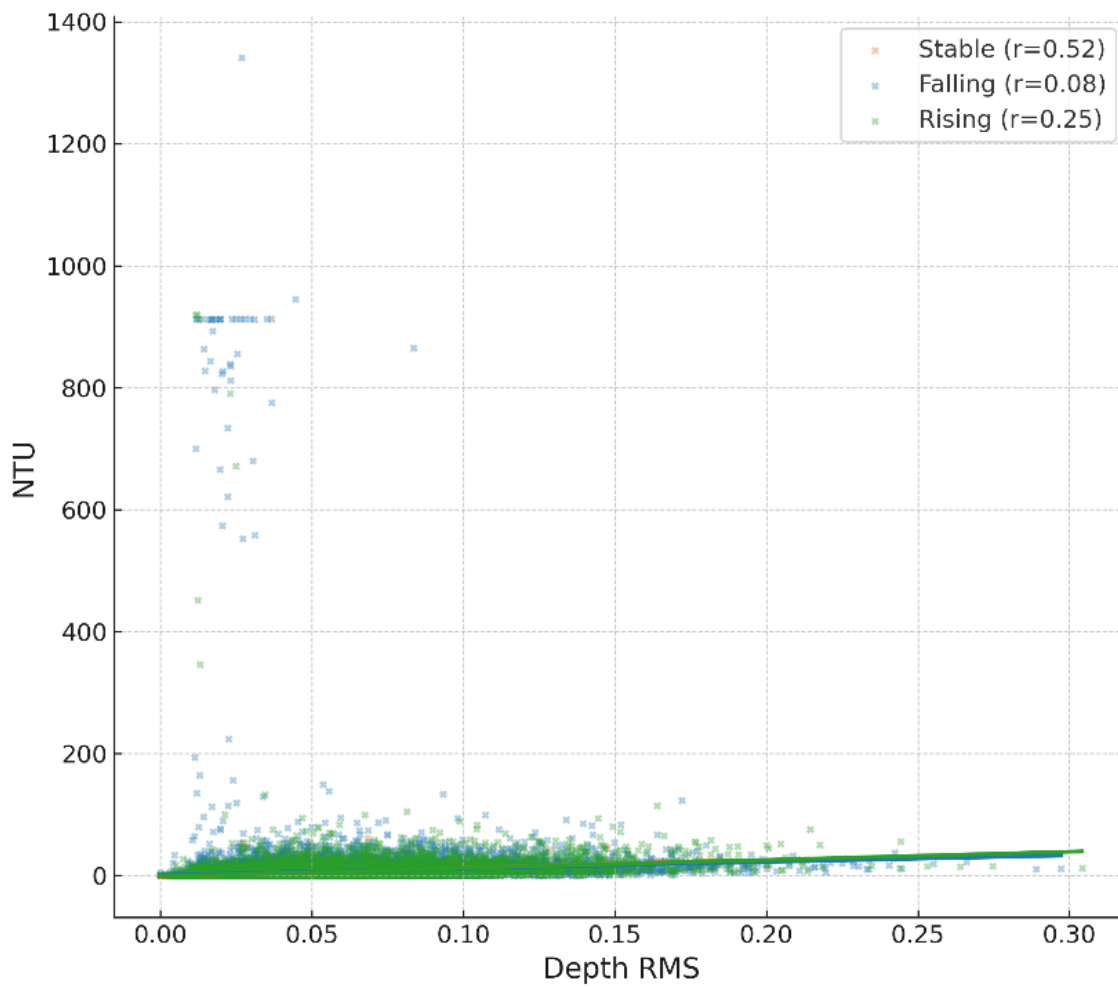


Figure 3—26 Relationship between turbidity (NTU) and RMS Depth at Round Top Island (MKY_AMB3B) across different tidal stages. Stable tide conditions show a strong positive correlation, while falling tide shows minimal association, suggesting a shift in local hydrodynamic influence during ebb flow at this exposed island site.

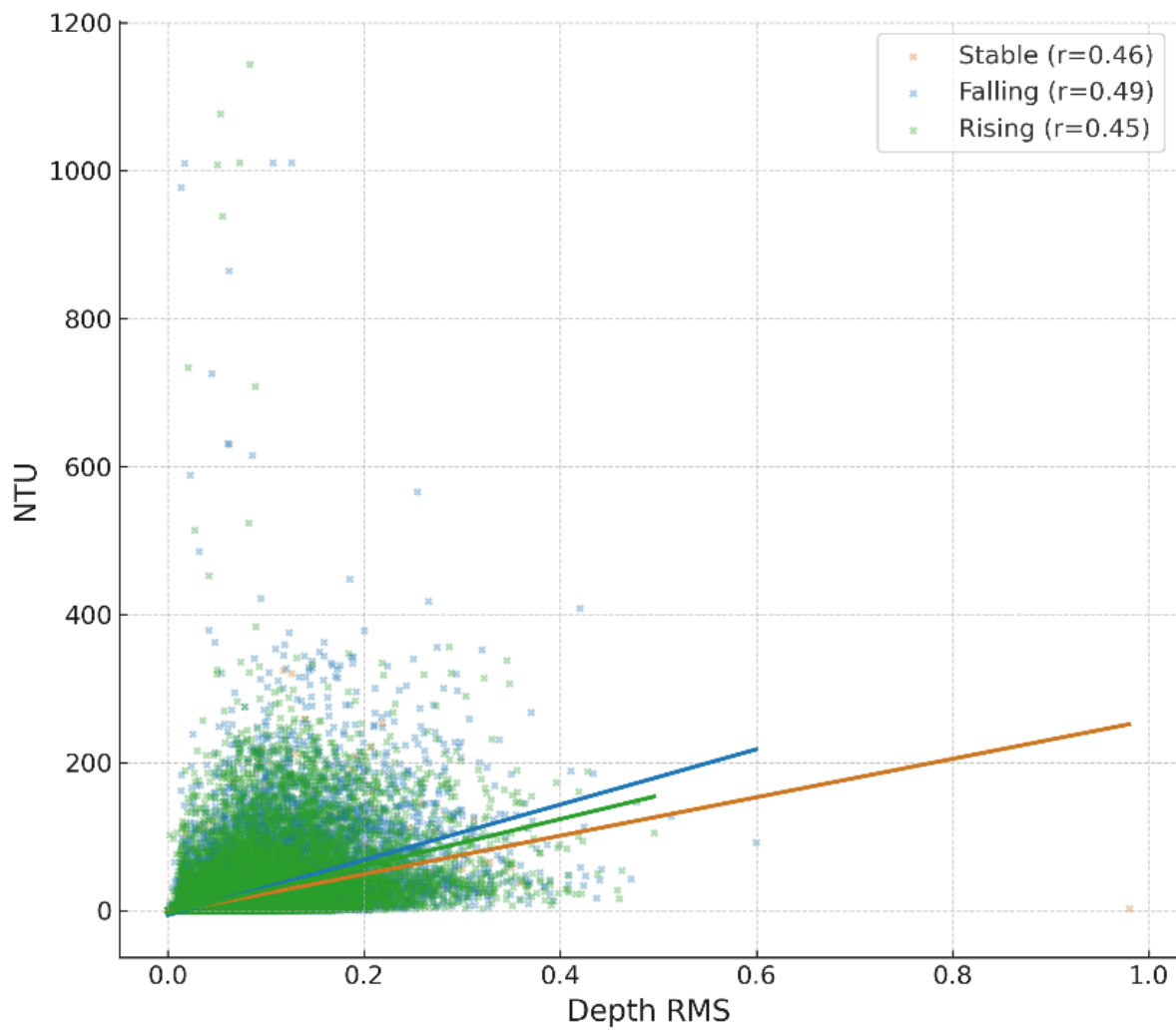


Figure 3—27 Relationship between turbidity (NTU) and RMS Depth at Slade Island (MKY_AMB5), showing consistent moderate correlations across rising, falling, and stable tide conditions. This suggests that turbidity and short-period water motion vary coherently throughout the tidal cycle at this moderately exposed site.

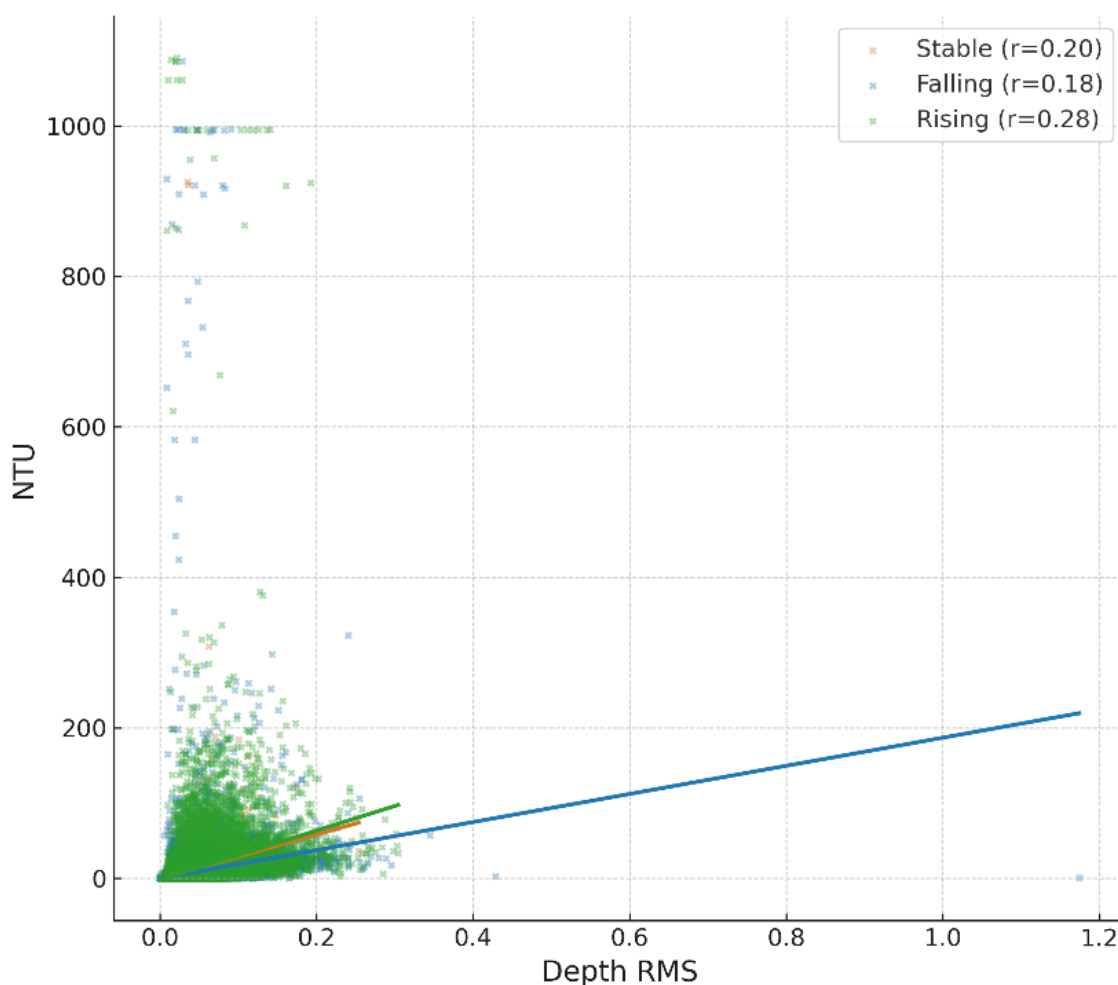


Figure 3—28 Relationship between turbidity (NTU) and RMS Depth at Victor Island (MKY_AMB10) coloured by tidal stage. Correlations are weak across all tidal phases, reflecting localised environmental conditions—such as reef sheltering and reduced wave exposure—that decouple short-period water movement from turbidity variability at this inner-island site.

3.5.6 Benthic photosynthetically active radiation (bPAR)

Benthic light levels reflected the interplay between water clarity, depth, and seasonal variability in solar irradiance, with generally low to moderate daily light integrals (DLIs) typical of inshore coastal waters influenced by periodic turbidity and variable cloud cover. Across the Mackay region, DLI values commonly ranged from near zero on turbid or cloudy days to $>7\text{--}10 \text{ mol photons m}^{-2} \text{ d}^{-1}$ during clear dry-season conditions (Figure 3—29). At Freshwater Point, bPAR ranged $0\text{--}7.5 \text{ mol m}^{-2} \text{ d}^{-1}$, while Victor Island recorded $0\text{--}9.0 \text{ mol m}^{-2} \text{ d}^{-1}$, reflecting slightly clearer conditions at times. Slade Island showed the highest values ($0\text{--}12.8 \text{ mol m}^{-2} \text{ d}^{-1}$), consistent with its shallower depth and generally clearer water conditions, and Round Top Island ranged $0\text{--}10.3 \text{ mol m}^{-2} \text{ d}^{-1}$. Occasional periods of missing data at several sites were attributed to logger tilt affecting sensor alignment, and on two occasions, loggers and the mooring buoy went missing from the Slade Island

site. Overall, bPAR records demonstrate variable but generally suitable light conditions for benthic habitats across the Mackay region.

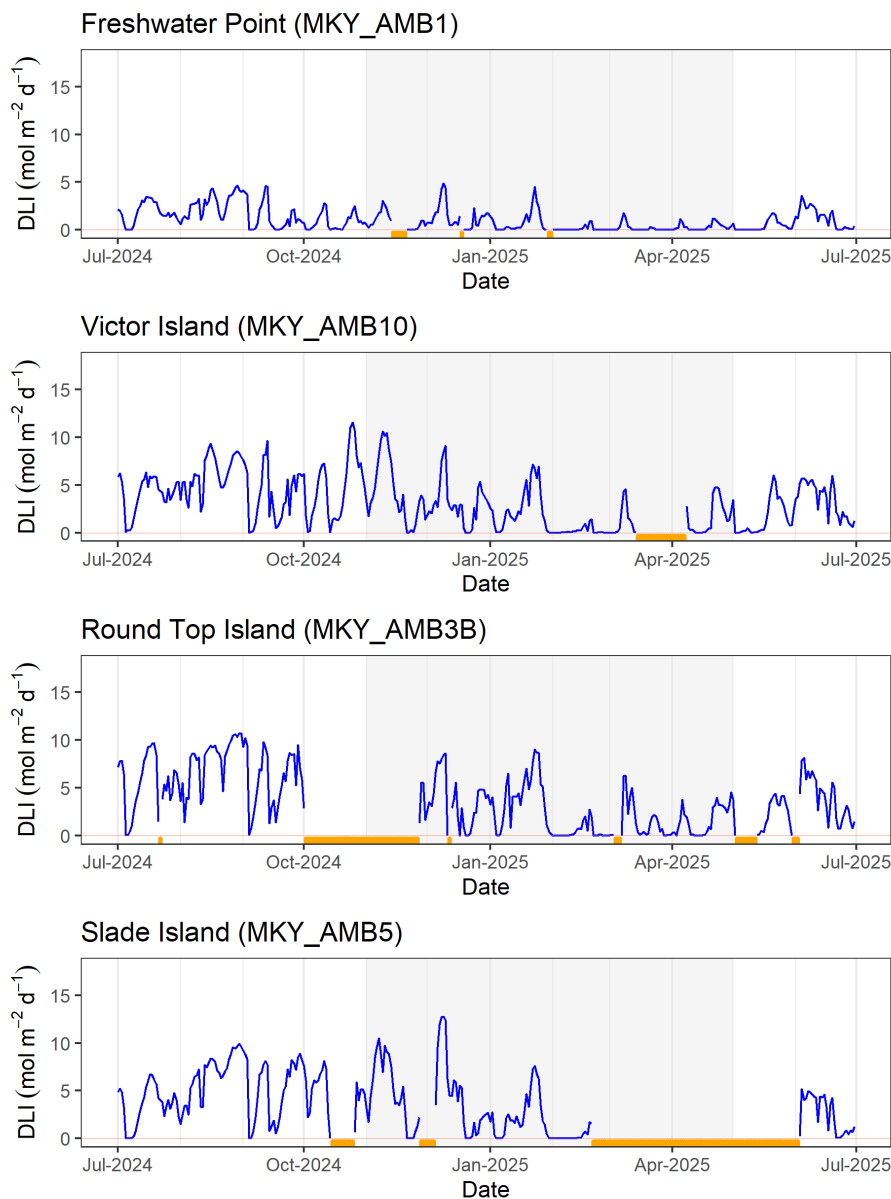


Figure 3—29 Daily light integral ($\text{mol photons m}^{-2} \text{d}^{-1}$) of benthic photosynthetically active radiation (PAR) measured at the Mackay and Hay Point monitoring sites over the reporting period. Periods of missing data are indicated by the orange bar.

3.6 Benthic multispectral irradiance and light-quality indices

Benthic multispectral irradiance measurements collected from MS9 loggers showed clear and consistent relationships between spectral light composition, turbidity, and seasonal hydrodynamics across the four Mackay and Hay Point monitoring sites. The fundamental driver of spectral shape was water clarity, with strong contrasts observed between dry-season low-turbidity conditions and wet-season sediment-affected periods. These patterns are illustrated in the normalised wavelength spectra for each site (Figure 3—30 to Figure 3—33).

Across all sites, low-turbidity conditions (<1 NTU) were characterised by spectra dominated by high relative irradiance in the blue–green region (440–520 nm). Under these clear-water conditions, the spectral curve showed a broad peak centred around 490–550 nm, reflecting efficient transmission of short wavelengths. These periods coincided predominantly with the dry season (May–October), when calmer hydrodynamic conditions, reduced wind-driven resuspension and minimal freshwater inputs promoted higher optical clarity.

In contrast, wet-season (November–April) conditions and moderate to high turbidity events (>5 NTU) were associated with pronounced attenuation of shorter wavelengths (410–490 nm). This resulted in a shift of the spectral maximum toward 550–570 nm, coupled with increased dominance of yellow–green and red wavelengths. Wet-season spectra were substantially more variable, reflecting episodic sediment resuspension, riverine inputs, and changes in coloured dissolved organic matter. These shifts in spectral shape under different turbidity classes are shown in the multispectral profiles (Figure 3-30 to Figure 3-33) and demonstrate the strong sensitivity of the blue portion of the spectrum to sediment-related light limitation.

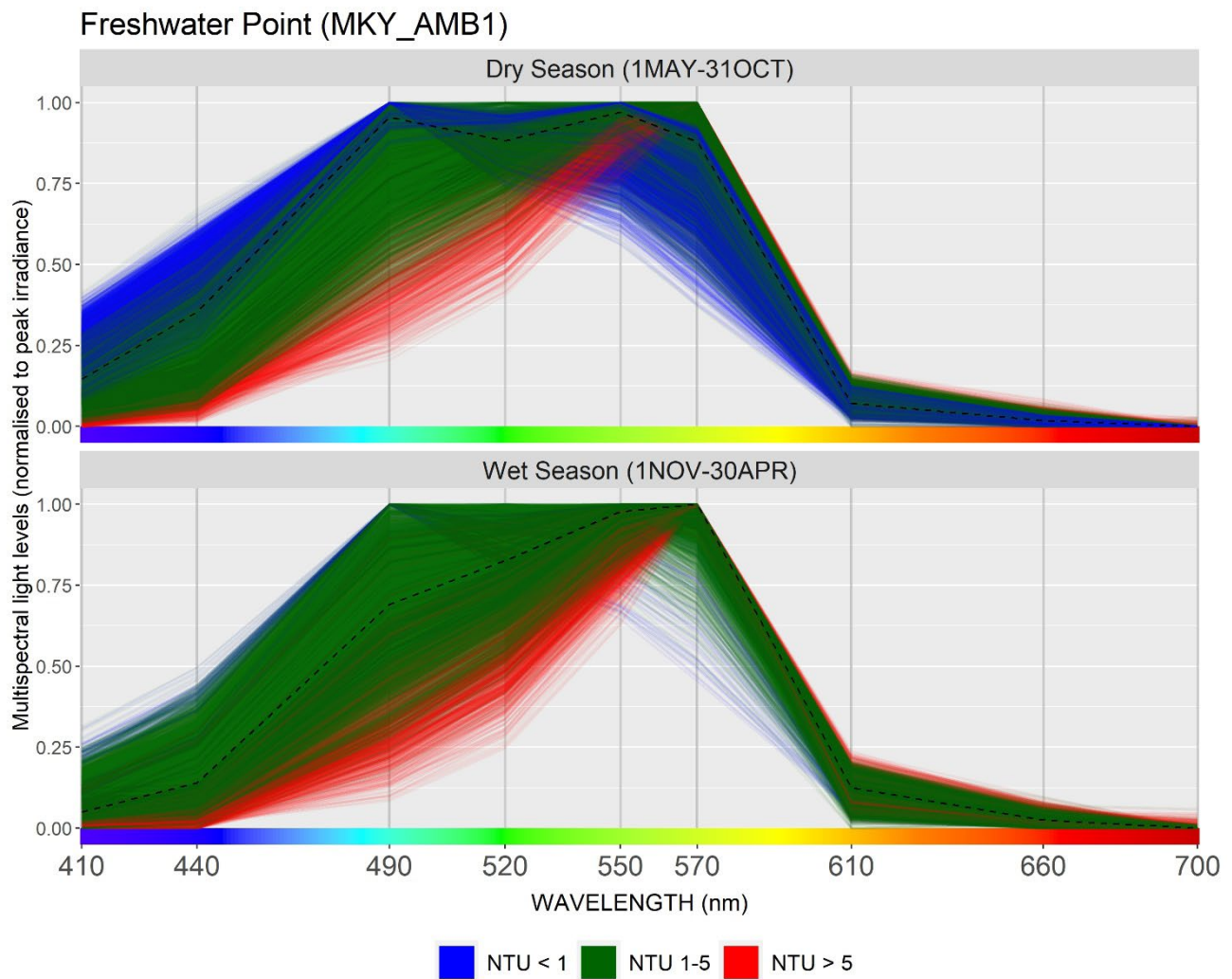


Figure 3—30 Multispectral irradiance profiles at Freshwater Point (MKY_AMB1) in the dry (top) and wet (bottom) seasons. Spectral responses are highly variable, reflecting the site's dynamic hydrodynamic environment. Clear-water periods show strong blue-green irradiance, while increased turbidity—particularly during wind-driven or spring-tide resuspension events—produces stronger blue attenuation and increased dominance of longer wavelengths.

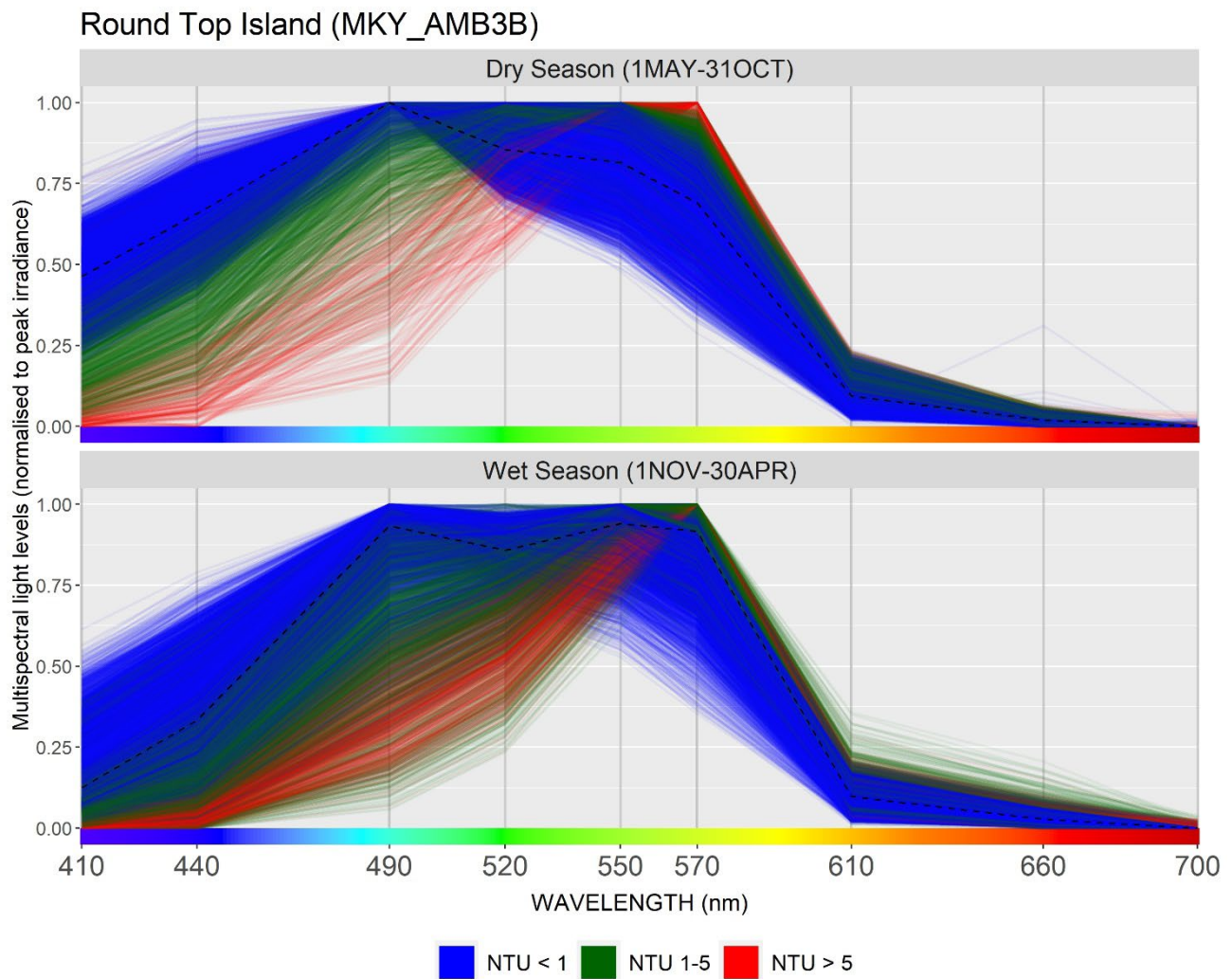


Figure 3—31 Multispectral irradiance profiles at Round Top Island (MKY_AMB3) in the dry (top) and wet (bottom) seasons. Spectral responses are highly variable, reflecting the site's dynamic hydrodynamic environment. Clear-water periods show strong blue-green irradiance, while increased turbidity—particularly during wind-driven or spring-tide resuspension events—produces stronger blue attenuation and increased dominance of longer wavelengths.

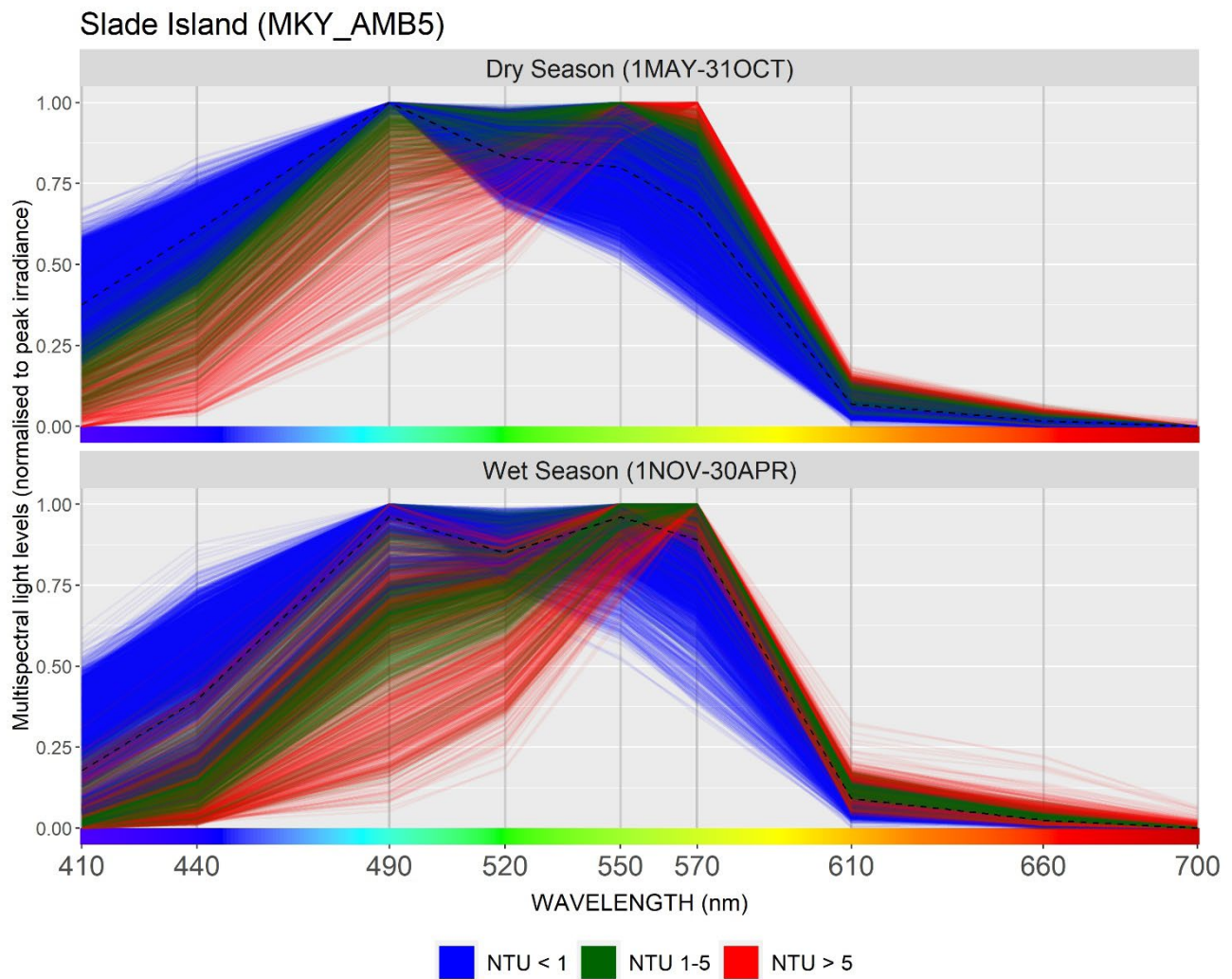


Figure 3—32 Multispectral irradiance profiles at Slade Island (MKY_AMB5) in the dry (top) and wet (bottom) seasons. Spectral responses are highly variable, reflecting the site's dynamic hydrodynamic environment. Clear-water periods show strong blue-green irradiance, while increased turbidity—particularly during wind-driven or spring-tide resuspension events—produces stronger blue attenuation and increased dominance of longer wavelengths.

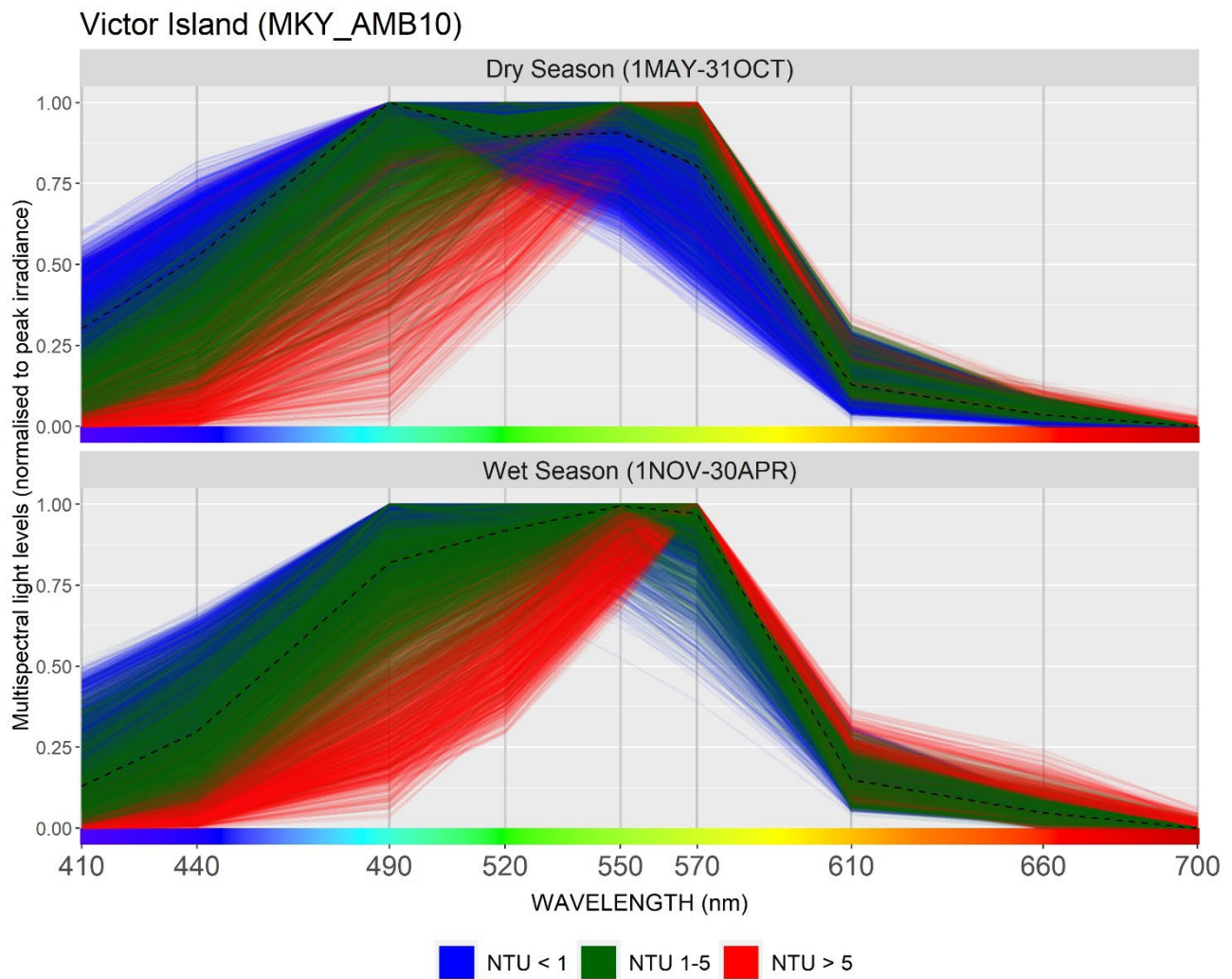


Figure 3—33 Multispectral irradiance profiles at Victor Island (MKY_AMB10) in the dry (top) and wet (bottom) seasons. Spectral responses are highly variable, reflecting the site’s dynamic hydrodynamic environment. Clear-water periods show strong blue-green irradiance, while increased turbidity—particularly during wind-driven or spring-tide resuspension events—produces stronger blue attenuation and increased dominance of longer wavelengths.

To summarise these wavelength-specific behaviours, five spectral indices were calculated (BG, N490, PQI, RAR and SlopeBG). Spatial and seasonal patterns in these indices are presented in Figure 3-34 to Figure 3-38. Consistent with the spectra, N490, BG ratio, and PQI were highest under clear-water conditions, indicating strong blue-green wavelength transmission and high-quality benthic light. Conversely, RAR and SlopeBG increased during turbid periods, reflecting greater absorption of blue light and increased contribution of red wavelengths under sediment-rich conditions.

While the overarching turbidity–spectral patterns were consistent regionally, clear site-level differences emerged:

- Round Top Island (MKY_AMB3B) displayed the highest overall light quality, with persistently strong N490 and PQI values, indicative of well-flushed, clear-water conditions with minimal wet-season degradation.
- Victor Island (MKY_AMB10) also exhibited high blue-light penetration and low RAR, reflecting its position adjacent to deeper channels with strong tidal mixing.
- Slade Island (MKY_AMB5) showed more variable spectral signatures, with rapid spectral shifts during resuspension or spring-tide events, consistent with its shallow, hydrodynamically exposed setting.
- Freshwater Point (MKY_AMB1) had the lowest light quality across indices, with persistently reduced blue-light transmission, elevated RAR, and green-dominant spectra during turbidity events, consistent with its nearshore, sediment-influenced environment.

Together, these results demonstrate that benthic spectral irradiance in the Mackay region is governed by short-lived turbidity events superimposed on predictable seasonal hydrological cycles, and that local depth, exposure and hydrodynamic regime strongly influence light quality.

Within the context of the current NQBP-TropWATER monitoring program, this indicates that benthic light availability is primarily driven by episodic disturbances rather than sustained deterioration, and that changes in photosynthetically usable radiation (PUR) are highly site-specific. The spectral indices applied here provide a sensitive and process-based means of detecting shifts in light quality and availability relevant to benthic phototrophic communities—including seagrass, macroalgae, and coral symbionts—beyond what can be inferred from turbidity or chlorophyll-a alone.

Importantly, these findings highlight opportunities for future integration of multispectral and in situ monitoring to improve port-related environmental management. Spectral metrics such as those presented here could support event-based assessments of light reduction during high-turbidity episodes, improve attribution of observed changes to natural versus operational drivers, and contribute to the development of site- and depth-specific light thresholds. Over time, the accumulation of comparable spectral datasets across locations and years has the potential to make a meaningful contribution to the evidence base required for refining or developing future guideline values for PUR, supporting more ecologically relevant and defensible light-based objectives in coastal and port environments.

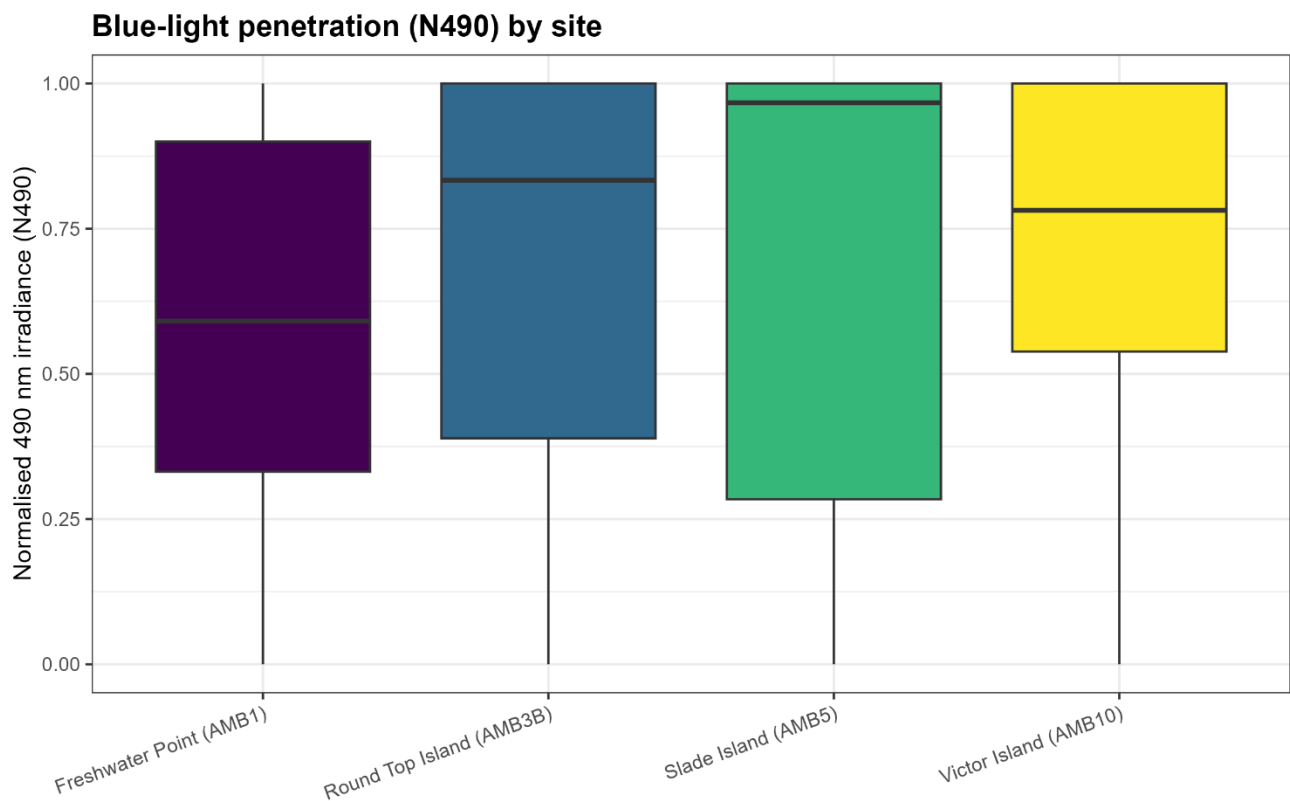


Figure 3—34 Distribution of normalised 490 nm irradiance (N490) recorded at the Mackay and Hay Point monitoring sites. Higher N490 values indicate stronger transmission of short (blue) wavelengths and generally clearer water conditions. Freshwater Point showed the lowest N490 values, while Round Top Island and Victor Island exhibited consistently high blue-light penetration.



Figure 3—35 Boxplots showing the distribution of Par Quality Index (PQI) across the Mackay and Hay Point monitoring sites. PQI represents the proportion of benthic irradiance contributed by blue–green wavelengths (440–570 nm). Higher PQI values correspond to clearer optical conditions and greater availability of photosynthetically usable radiation (PUR). PQI was lowest at Freshwater Point and highest at Round Top Island and Victor Island.

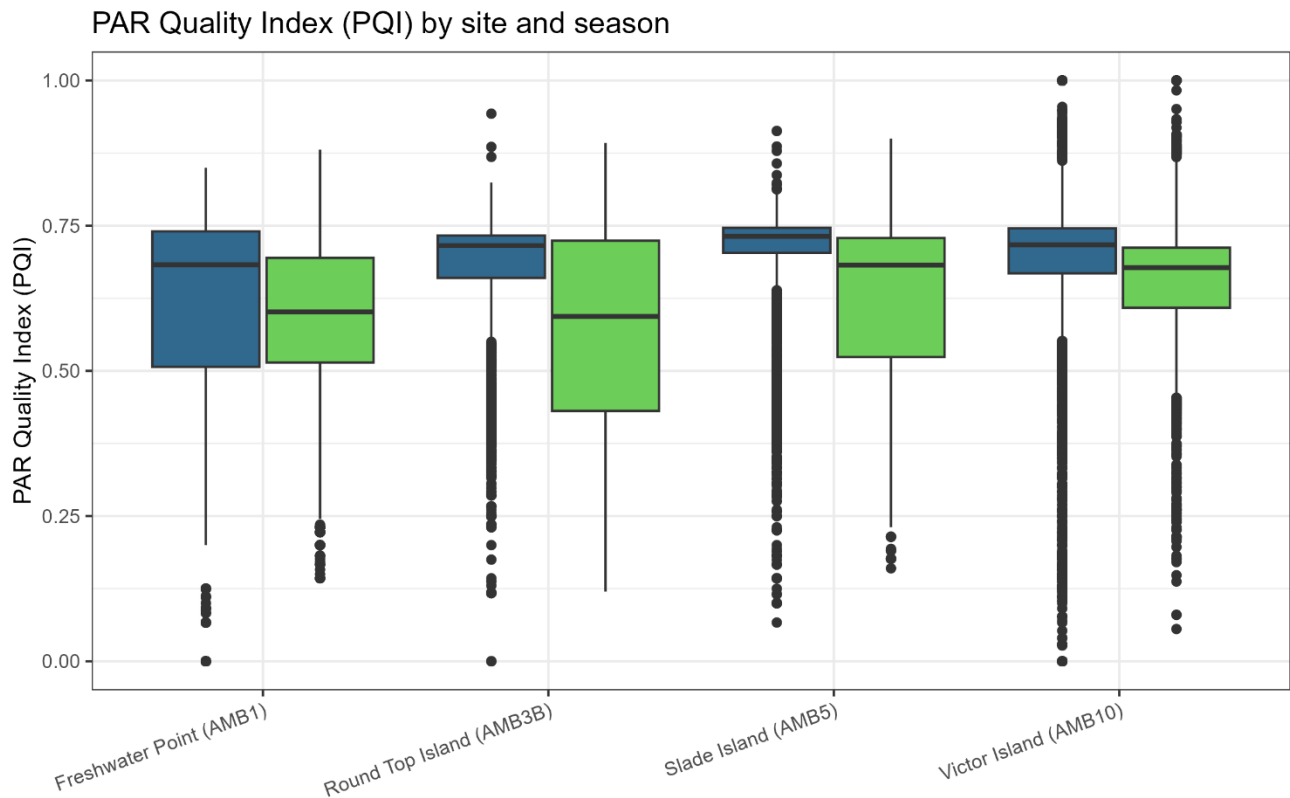


Figure 3—36 PQI values separated into wet-season (Green) and dry-season (Blue) conditions. Dry-season PQI values were consistently higher at all sites, reflecting enhanced blue–green light transmission during periods of reduced runoff and calmer hydrodynamic conditions. Wet-season distributions showed greater variability and more frequent low-quality light conditions, particularly at Freshwater Point and Slade Island.

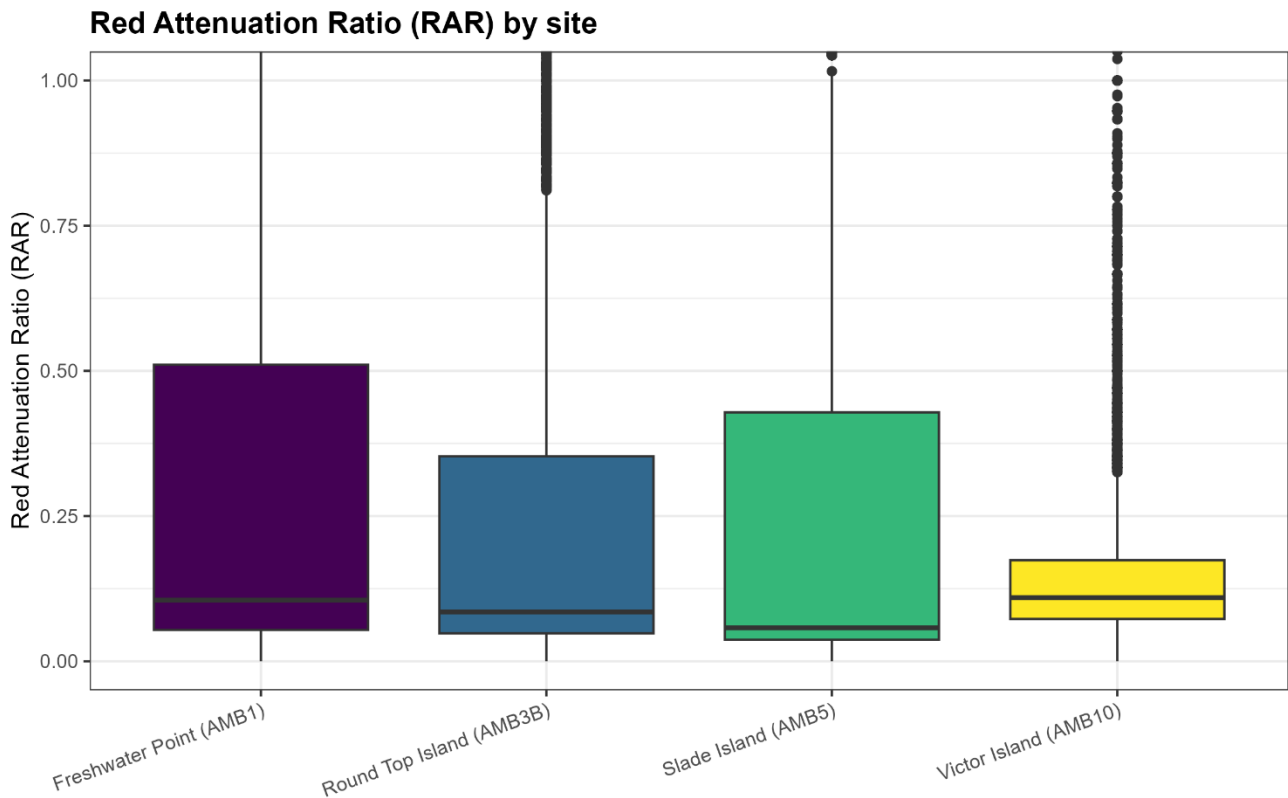


Figure 3—37 RAR quantifies the relative dominance of red wavelengths (610–700 nm) compared with short and mid-visible wavelengths. Elevated RAR values indicate stronger attenuation of blue–green light under turbid conditions. After trimming extreme outliers, RAR showed highest variability at Freshwater Point and Slade Island, consistent with episodic sediment resuspension.

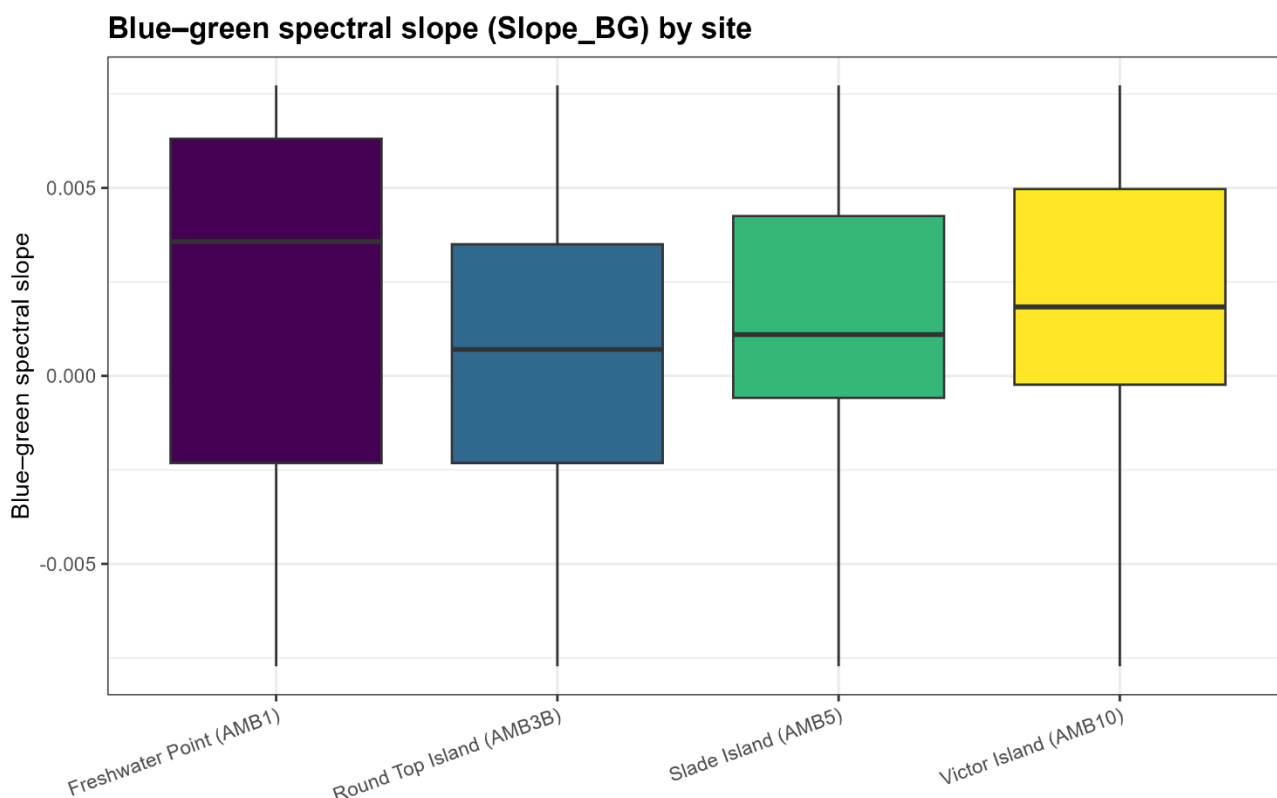


Figure 3—38 SlopeBG describes the rate of attenuation between blue (≈ 440 nm) and green (≈ 570 nm) wavelengths. Steeper (more positive) slopes indicate stronger suppression of blue light relative to green, typically associated with turbidity or coloured dissolved organic matter. Freshwater Point showed the steepest slopes, while Round Top Island and Victor Island showed flatter, clear-water spectral gradients.

3.7 Long-term trend analysis

3.7.1 Rainfall and river discharge

Long-term rainfall and river-discharge records show a strongly episodic pattern characteristic of the dry-tropical climate of central Queensland (Figure 3-33; Figure 3-34). Across the 2014–2025 period, both rainfall and hydrological responses were dominated by short-lived but intense wet-season events separated by extended dry periods with little or no flow. High-magnitude rainfall pulses occurred irregularly, with particularly strong clusters in the 2016–2017 and 2023–2024 wet seasons, during which daily totals exceeded 200–300 mm on several occasions. These high-rainfall periods corresponded closely with peaks in river discharge, including a major flood in early 2017 and several moderate-to-large events in 2019, 2023, and 2024.

Despite this interannual variability, there is no clear evidence of a consistent upward or downward trend in the magnitude or frequency of rainfall or runoff over the past decade. Instead, variability appears to reflect the influence of regional climatic drivers such as the El Niño–Southern Oscillation and the monsoon trough, which modulate the timing and intensity of wet-season rainfall. The hydrograph indicates that the catchment responds rapidly to large rainfall events, producing sharp,

high-flow spikes followed by rapid recession to baseflow or zero flow, typical of small to medium tropical catchments with limited water storage.

The timing and scale of these events are important for coastal water quality, as large discharge pulses are the primary mechanism for delivering sediments, nutrients and other land-sourced materials to the nearshore marine environment. Years with multiple high-flow events (e.g. 2017 and 2024) therefore exert a disproportionately large influence on coastal turbidity and plume extent, while years with subdued rainfall produce minimal freshwater input to the marine system. Overall, the long-term record highlights the highly variable nature of freshwater delivery to the region and underscores the importance of considering interannual climate variability when interpreting water-quality conditions within the ambient monitoring program.

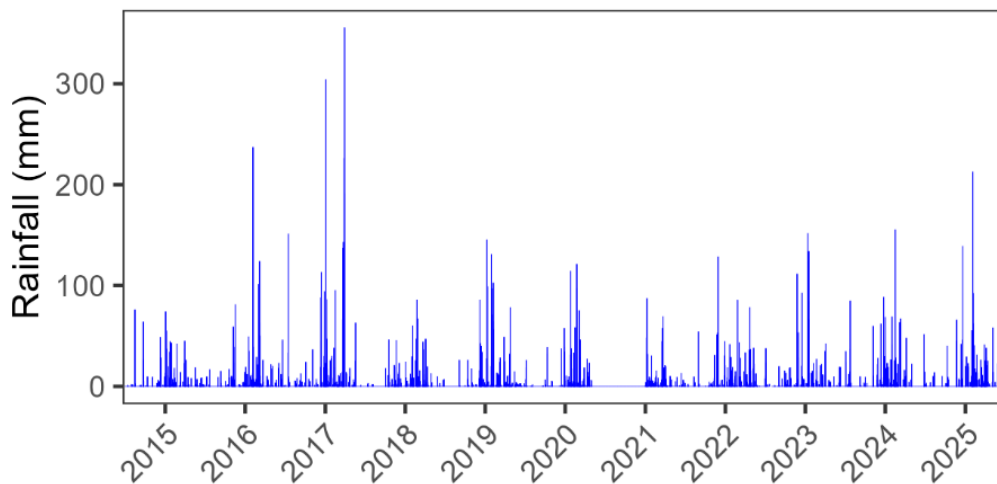


Figure 3—39 Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the duration of the ambient water quality monitoring program (July 2014– June 2025. Data source: <https://water-monitoring.information.qld.gov.au/>

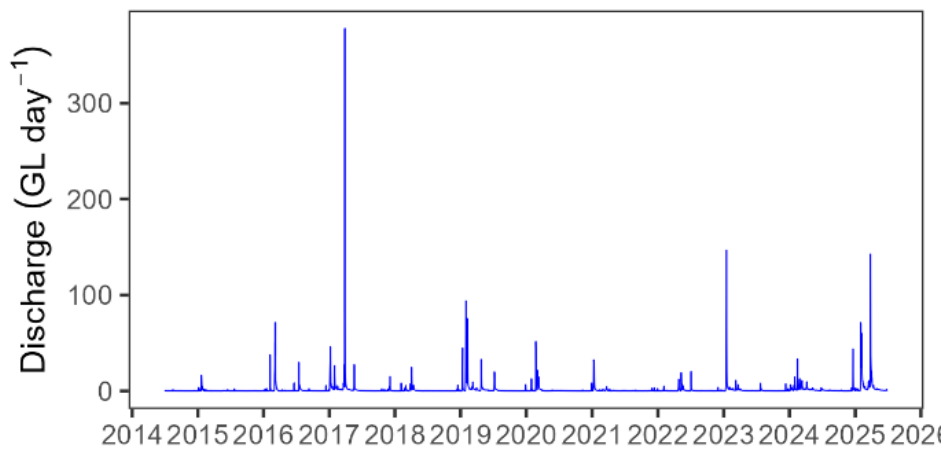


Figure 3—40. Stream discharge (ML d^{-1}) from the Pioneer River (station 125016A) for the duration of the ambient water quality monitoring program (July 2014 – June 2025). Data source: <https://water-monitoring.information.qld.gov.au/>

Table 3-7. Northern rainfall onset date as recorded at Plane Creek Sugar Mill (station 033059).

Reporting year	Rainfall onset
2014-2015	23/09/2014
2015-2016	21/10/2015
2016-2017	4/10/2016
2017-2018	18/10/2017
2018-2019	14/10/2018
2019-2020	12/10/2020
2020-2021	06/01/2020
2021-2022	13/11/2021
2022-2023	04/10/2022
2023-2024	07/11/2023
2024-2025	10/10/2024

Rainfall onset dates for the region show that the wet season typically begins in early–mid October, with several years displaying an onset within a narrow two-week window (Table 3-7). Early onsets

occurred in September 2014, while later onsets occurred in November 2021, November 2023, and most notably in January 2021, indicating substantial interannual variability. The 2024–2025 wet season commenced on 10 October 2024, aligning closely with the long-term pattern of an early-October onset.

3.7.2 Generalized additive mixed effects models (GAMM)

GAMM outputs for nutrients, chlorophyll-a, particulate fractions and electrical conductivity are presented in Figure 3—41 - Figure 3—43, with model summaries provided in the Appendix. Across all parameters, the models identified strong and highly significant seasonal patterns reflecting wet-season runoff and dry-season clarity. Many parameters also showed statistically significant long-term smooths; however, these represented non-directional interannual variability rather than monotonic increases or decreases. As expected for dynamic coastal waters, long-term temporal structure explained only a modest proportion of overall variance.

Total Nitrogen (TN)

The GAMM identified significant seasonal ($p = 7.9 \times 10^{-4}$) and long-term ($p = 5.15 \times 10^{-6}$) components in TN. The long-term smooth captured interannual fluctuations rather than a sustained directional trend, with concentrations declining from 2015 to ~2019 before stabilising with typical variability thereafter. The modest adjusted R^2 (0.084) is consistent with nitrogen dynamics being driven by both catchment inputs and hydrodynamic mixing.

Total Dissolved Nitrogen (TDN)

TDN exhibited a strong seasonal cycle ($p < 2 \times 10^{-16}$) and a significant long-term smooth ($p < 2 \times 10^{-16}$). The temporal component reflected broad decadal-scale variability, including a decline from 2015 to ~2020 followed by relatively stable concentrations. The smooth was moderately complex (edf = 6.86), indicating gradual fluctuations rather than a consistent long-term increase or decrease.

Particulate Nitrogen (PN)

PN displayed a significant seasonal effect ($p = 3.8 \times 10^{-4}$) but no significant long-term temporal structure ($p = 0.74$). Concentrations were highly event-driven, with peaks associated with wet-season runoff and sediment resuspension. This pattern reflects PN's sensitivity to short-term hydrodynamic processes rather than sustained long-term shifts.

Total Phosphorus (TP)

TP showed significant seasonal variation ($p = 0.0020$) and a significant long-term smooth ($p < 2 \times 10^{-16}$). The temporal smooth captured modest decadal variability superimposed on episodic wet-season pulses, but did not indicate a persistent upward or downward trend. Most variation occurred during short-duration particulate-driven events.

Total Dissolved Phosphorus (TDP)

TDP exhibited strong seasonality ($p = 3.3 \times 10^{-4}$) and a significant long-term component ($p = 0.0074$). The long-term smooth indicated a gentle decline from 2015 to ~2019, followed by stable concentrations during 2020–2024. The adjusted R^2 (0.079) reflects limited but meaningful structure in an otherwise variable dissolved-nutrient dataset.

Particulate Phosphorus (PP)

PP displayed a strong seasonal cycle ($p < 2 \times 10^{-16}$), while the long-term smooth was not significant ($p = 0.11$). Similar to PN, PP concentrations were largely driven by episodic resuspension events rather than systematic long-term change.

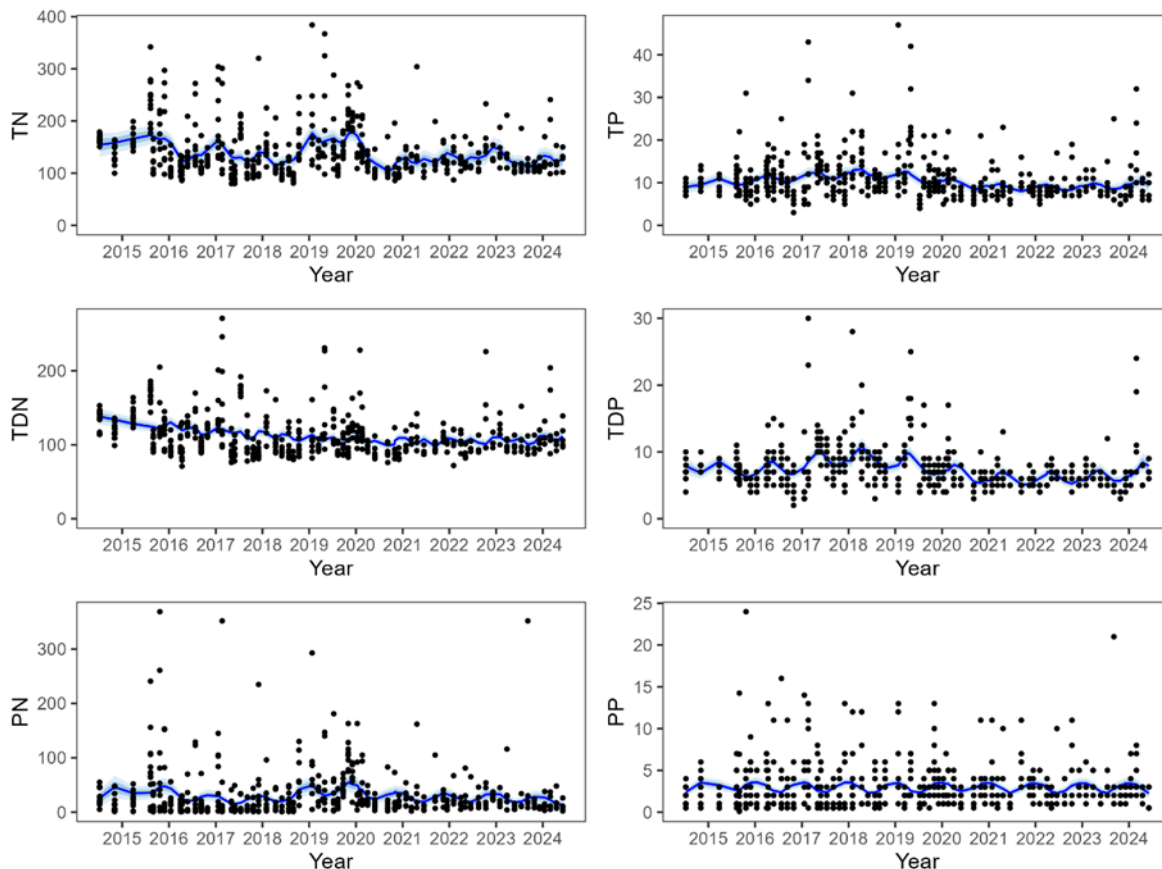


Figure 3—41 Nutrient data from water samples collected in the Mackay region between 2014 and 2025. TN = total nitrogen, TP = total phosphorus, TDN = total dissolved nitrogen, TDP = total dissolved phosphorus, PN = particulate nitrogen, PP = particulate phosphorus. Units = $\mu\text{g L}^{-1}$. General additive mixed effects model (GAMM) showing standard error (blue ribbon) and 95% confidence intervals (light blue).

Chlorophyll-a

Chlorophyll-a exhibited a strong seasonal signal ($p < 2 \times 10^{-16}$), with elevated wet-season concentrations linked to nutrient supply, vertical mixing and resuspension during rainfall and discharge events. These hydrodynamic processes redistributed nutrients and phytoplankton within the photic zone, generating short-lived increases in biomass.

The long-term smooth was weak ($p = 0.0125$) and did not represent a coherent directional trend, instead reflecting minor interannual variability. Overall chlorophyll-a concentrations remained low, indicating no evidence of eutrophication pressure at the ambient sites.

Electrical Conductivity

EC displayed both strong seasonal structure ($p < 2 \times 10^{-16}$) and a significant long-term component ($p < 2 \times 10^{-16}$), with one of the highest model fits (adjusted $R^2 = 0.345$). Seasonal minima corresponded

with wet-season rainfall and freshwater inflow, with pronounced depressions during high-rainfall years such as 2017. These patterns align with typical GBR coastal salinity cycles, where freshwater inputs reduce conductivity during the wet season.

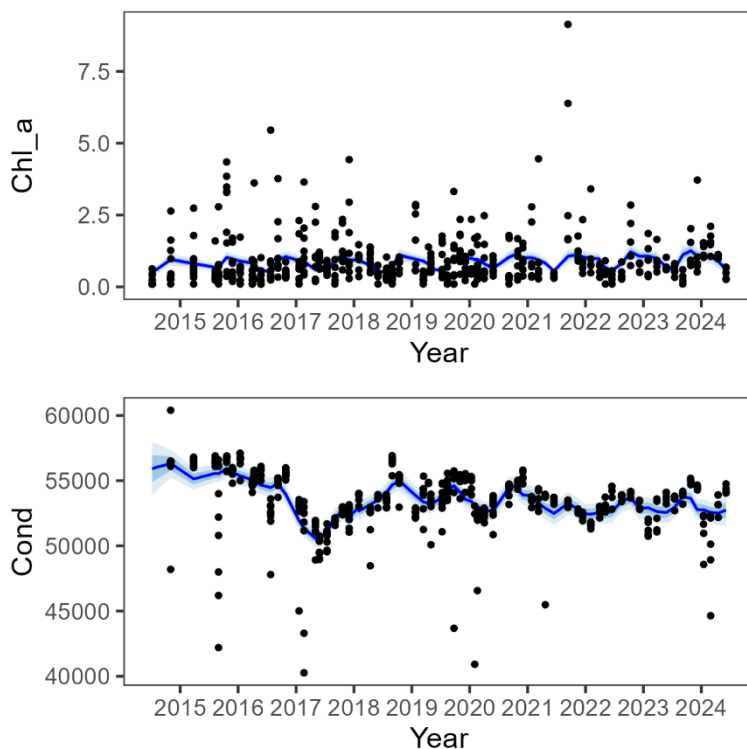


Figure 3—42 Long-term chlorophyll-a (top) and electrical conductivity (bottom) at the Mackay ambient monitoring sites from 2014–2025.

Total Suspended Solids (TSS)

TSS exhibited a significant seasonal pattern ($p = 0.0095$) and a significant long-term smooth ($p < 2 \times 10^{-16}$). The model explained a moderate proportion of the variance (adjusted $R^2 = 0.161$), consistent with suspended sediment concentrations being driven by episodic resuspension and storm-related inputs.

The long-term smooth indicates greater variability and more frequent elevated TSS values in the earlier part of the record (2015–2019), followed by lower and more stable conditions from approximately 2020 onwards. Interpretation of the early period is, however, constrained by more limited data coverage, meaning this pattern is best described as a decline and subsequent stabilisation in TSS variability, rather than clear evidence of a sustained elevated baseline during the early years.

Seasonally, TSS increased during wet-season months in response to runoff, river discharge and increased particulate inputs, consistent with short-lived hydrological forcing rather than persistent background enrichment.

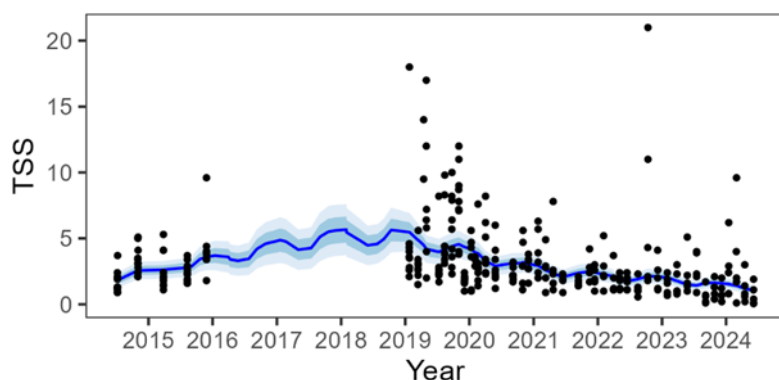


Figure 3—43 Long-term total suspended solids (TSS) showing a significant seasonal pattern and a declining trend after 2019. No data were collected between 2016 and 2018.

3.7.3 Interpretation of Long-Term Trends

The long-term temporal patterns identified by the GAMMs are consistent with a well-mixed, hydrodynamically energetic coastal system in which seasonal processes dominate water-quality variability. The significant long-term smooths observed for several parameters primarily reflect interannual climatic variability, rather than sustained directional change. Pronounced wet–dry seasonality in nitrogen, phosphorus, chlorophyll-a and TSS continues to be driven by rainfall, river discharge and short-lived turbidity events, with these influences typically dissipating rapidly due to strong tidal mixing characteristic of the Mackay shelf.

For several dissolved nutrient species, the GAMM smooths captured a decline from approximately 2015 to 2019 followed by stable concentrations in more recent years. These multi-year fluctuations likely reflect climatic and hydrological variability, such as shifts in wet-season intensity, rather than consistent improvement in catchment condition. The absence of increasing chlorophyll-a concentrations supports the interpretation that phytoplankton biomass remains low, with no evidence of escalating eutrophication risk at the monitored sites.

Particulate nutrient fractions and TSS were strongly event-driven, showing episodic increases linked to storms, high-energy resuspension and wet-season pulses. TSS variability was greater in the earlier part of the record, followed by lower and more stable conditions from approximately 2020 onwards. Given the episodic nature of high-TSS events and the sparser data coverage in earlier years, this pattern is most appropriately interpreted as a decline and subsequent stabilisation in variability, rather than evidence of a sustained elevated baseline or progressive degradation of sediment conditions.

Optical and conductivity patterns also aligned more closely with hydrological variability than with any sustained anthropogenic influence. Conductivity minima corresponded with periods of high rainfall and freshwater inflow, while multispectral irradiance results demonstrated that changes in underwater light quality were largely governed by turbidity-driven attenuation of blue–green wavelengths, rather than nutrient-driven shifts in phytoplankton. This reinforces that light limitation in the region is primarily sediment-driven, not productivity-driven.

Overall, the GAMM results indicate that climatic variability and seasonal hydrological processes remain the dominant drivers of long-term water-quality variability in the Mackay region. The models show no evidence of sustained directional change through time, such as progressively

increasing nutrient concentrations or declining water quality, despite short-term exceedances of water-quality objectives observed in some parameters.

While median and mean concentrations of some nutrients and chlorophyll-a exceed current WQOs at several sites, the GAMM analysis demonstrates that these values are not associated with a persistent upward trend or chronic enrichment over the monitoring record. Instead, variability is characterised by episodic responses to rainfall, runoff, and resuspension events superimposed on a stable long-term baseline.

Continued long-term monitoring remains essential for detecting emerging pressures under increasing climatic variability; however, the GAMM results indicate that ambient water quality across the region has remained broadly stable over time within the context of a tidally energetic, naturally variable coastal environment.

4 CONCLUSION

The 2024–2025 ambient water-quality monitoring results for Mackay and Hay Point describe a tidally energetic, well-mixed coastal system characterised by strong seasonal and event-driven variability. Physicochemical conditions, including salinity, temperature, dissolved oxygen and water clarity, followed predictable seasonal cycles and reflected the dominant influence of tidal mixing and episodic wet-season rainfall rather than sustained shifts in baseline conditions.

Nutrient and chlorophyll-a concentrations were generally low to moderate across sites, although median concentrations of several parameters exceeded current water-quality objectives at multiple locations. These exceedances reflect background conditions that commonly sit above existing guideline thresholds, rather than a dominance of isolated extreme events. Temporal analyses indicate that nutrient concentrations are not increasing through time. Instead, observed variability was driven by seasonal hydrological processes, episodic runoff, and short-lived biologically or particulate-dominated events, rather than progressive enrichment or long-term deterioration in water quality.

High-frequency logger data continued to provide valuable insight into short-term hydrodynamic drivers of water quality. Semidiurnal tides dominated vertical mixing, near-bed wave energy remained generally low aside from occasional wind-driven events, and turbidity was characterised by predominantly clear background conditions punctuated by brief resuspension or runoff-related pulses. Multispectral irradiance measurements captured clear seasonal shifts in both the quantity and spectral quality of benthic light, with stronger blue–green light penetration during dry-season conditions and increased attenuation during periods of elevated turbidity.

Long-term rainfall and river-discharge records confirmed that freshwater delivery to the coastal zone is governed by episodic wet-season events and strong interannual variability, with no clear directional trend over the past decade. Consistent with this, GAMM analyses indicated that temporal patterns in nutrients, chlorophyll-a, TSS and conductivity are dominated by seasonal and interannual hydrological variability rather than progressive change through time. Periods of lower dissolved nutrient concentrations observed between 2015 and 2019 form part of this broader variability and do not represent a sustained directional shift.

Spatial differences in water-quality and optical conditions were evident across the monitoring sites, reflecting contrasts in local setting, exposure, and proximity to key sources and receptors. Round

Top Island and Victor Island generally exhibited relatively stable conditions across the monitoring period, consistent with their more exposed island settings and reef-influenced environments and provide important reference locations for assessing background coastal conditions. In contrast, Freshwater Point and Slade Island showed greater short-term variability, particularly during periods of elevated turbidity, reflecting their shallower depths, proximity to riverine inputs and port activities, and higher sensitivity to episodic resuspension and runoff events.

These spatial patterns were most apparent during wet-season sampling and episodic resuspension events, highlighting the influence of local-scale processes superimposed on regional hydrodynamic forcing. Collectively, the current network of monitoring sites captures a representative gradient of exposure, habitat type, and hydrodynamic setting across the Mackay region, encompassing seagrass-dominated nearshore environments, reef-influenced island sites, and harbour conditions. This diversity underpins the continued relevance of the existing site locations for detecting both background variability and site-specific responses and supports their ongoing use as a robust framework for long-term ambient water-quality and optical monitoring.

Overall, the 2024–2025 monitoring results indicate that while median and mean concentrations of some nutrients and chlorophyll-a exceed current water-quality objectives, there is no evidence of a sustained increasing trend or progressive degradation over the long-term record. Instead, observed variability is characterised by episodic, climate-driven fluctuations operating within a highly dynamic coastal system. Continued long-term, high-resolution monitoring remains essential for distinguishing natural variability from emerging pressures and for supporting evidence-based environmental management in the Mackay and Hay Point region.

5 REFERENCES

Australian Institute of Marine Science (AIMS). 2023. *Marine Monitoring Program: Annual report for inshore water quality and seagrass, Mackay–Whitsunday region*. Great Barrier Reef Marine Park Authority, Townsville.

ANZECC/ARMCANZ. (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Australian and New Zealand Governments (ANZG). (2018). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Canberra: Australian and New Zealand Governments and Australian State and Territory Governments.

Cartwright, P., Iles, J.A., Mattone, C., O'Callaghan, M., Johns, J., & Waltham, N.J. (2022). *Establishing turbidity–suspended sediment concentration relationships for North Queensland port waters*. TropWATER Technical Report, James Cook University, Townsville.

Chartrand, K.M., Rasheed, M.A., & Unsworth, R.K.F. (2012). Predicting the impact of reduced light availability on seagrass meadows in coastal waters. *Marine Pollution Bulletin*, 65(5), 293–305.

Chartrand KM, Murphy T and Hoffmann LR. 2024. Port of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2022-2023. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 24/23, James Cook University, Cairns.

Erftemeijer, P.L.A., Riegl, B., Hoeksema, B.W., & Todd, P.A. (2012). Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin*, 64(9), 1737–1765.

Iles, J.A., Cartwright, P., & Waltham, N.J. (2023). *Automated Quality Control of High-Frequency Marine Water Quality Data*. TropWATER Technical Report, James Cook University, Townsville.

Jones, A.R., Skidmore, J.A., & McKinna, L.I.W. (2021). Advances in optical remote sensing for monitoring water quality and benthic habitats. *Frontiers in Marine Science*, 8, 625938.

Kirk, J.T.O. (1994). *Light and Photosynthesis in Aquatic Ecosystems* (2nd ed.). Cambridge University Press, Cambridge.

McKenna, S.A., Forte Valiente, L., & Rasheed, M.A. (2025). *Bowen – McCanes Bay / Port Denison Seagrass Assessments November 2024*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns. Report 25/04.

McKenna, S., Langlois, L., Edwards, C., Peed, J., Rasheed, M., Hoffmann, L., Chartrand, K., & Cleguer, C. (2025). *Bowen – McCanes Bay / Port Denison Marine Megafauna and Habitat Assessments August 2025*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns.

McKenzie, L.J., Collier, C.J., Langlois, L.A., Brien, H. and Yoshida, R.L. 2025, Marine Monitoring Program: Annual Report for Inshore Seagrass Monitoring 2023–24. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville. 185pp.

Moran, D., Waterhouse, J., Petus, C., Howley, C., Lewis, S., Gruber, R., James, C., Logan, M., Bove, U., Brady, B., Choukroun, S., Connellan, K., Davidson, J., Mellors, J., O’Callaghan, M., O’Dea, C., Shellberg, J., Dick, E., Polglase, L., Tracey, D., Molinari, B., Zagorskis, I., 2025. *Great Barrier Reef Marine Monitoring Program Inshore Water Quality Monitoring: Annual Report 2023–24*. Great Barrier Reef Marine Park Authority, Townsville. 322 pp

NOAA IOOS QARTOD (2020). *Manual for Real-Time Quality Control of In-Situ Oceanographic Data*. Version 2.1. U.S. Integrated Ocean Observing System, National Oceanic and Atmospheric Administration

Queensland Government. (2019). *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*. Department of Environment and Science, Brisbane.

Queensland Government. (2024). *Reef Water Quality Report Card 2023*. Queensland Government, Brisbane.

Rasheed M.A., Van De Wetering, C., York, P. and McKenna, S. A., (2024) *Annual Seagrass Monitoring in the Mackay and Hay Point Region – 2023*, JCU Centre for Tropical Water & Aquatic Ecosystem Research, Cairns

Ryan, E. J., Smithers, S. G., Lewis, S. E., Clark, T. R., Zhao, J. X., & Hua, Q. (2018). Fringing reef growth over a shallow last interglacial reef foundation at a mid-shelf high island: Holbourne Island, central Great Barrier Reef. *Marine Geology*, 398, 137-150.

Sofonia, J.J., & Unsworth, R.K.F. (2010). Development and assessment of a spatially explicit light attenuation model for seagrass. *Marine Ecology Progress Series*, 406, 135–144.

Warne MStJ, Neelamraju C, Strauss J, Smith RA, Turner RDR, Mann RM. 2020. *Development of a method for estimating the toxicity of pesticide mixtures and a Pesticide Risk Baseline for the Reef 2050 Water Quality Improvement Plan*. Brisbane: Department of Environment and Science, Queensland Government.

Waterhouse, J., Collier, C., Logan, M., Lewis, S., Brodie, J., Bainbridge, Z., & Kroon, F. (2022). Pollutant impacts on the Great Barrier Reef: A review of progress towards the Reef 2050 water quality improvement targets. *Marine Pollution Bulletin*, 176, 113–129.

Wood, S. N. (2017). *Generalized Additive Models: An introduction with R* (2nd ed.): Chapman and Hall/CRC.

Worley Consulting. (2024). *North Queensland Bulk Ports Bowen Wharf Environmental Values Assessment*. Prepared for North Queensland Bulk Ports Corporation, Mackay.

APPENDIX A PESTICIDES ANALYSES

ED-PPCP WATER CONCENTRATION NG/L

Site Name	Slade Island	Slade Island	Slade Island
Deployed Date	01/10/2024	01/10/2024	27/11/2024
Retrieved Date	27/11/2024	27/11/2024	20/02/2025
Days Deployed	57	57	85
Flow Rate (cm/s)	28.2	28.2	28.2
Site Code	MKY-AMB5	MKY-AMB5	MKY-AMB5
Sample Name	TRP124_ED_SLA	TRP124_ED_SLA DUP	TRP225_ED_SLA
Analyte			
2,4,5-T	*<0.119	*<0.119	*<0.080
2,4-D	<0.499	<0.499	<0.334
3,4 Dichloroaniline	*<0.119	*<0.119	*<0.080
Ametryn	<0.898	<0.898	<0.602
Ametryn hydroxy	*<0.119	*<0.119	*<0.080
Atrazine	<0.119	<0.119	1.77
Atrazine desethyl	<0.142	<0.142	<0.095
Atrazine desisopropyl	*<0.119	*<0.119	*<0.080
Bendiocarb	*<0.059	*<0.059	*<0.040
Bromacil	<0.081	<0.081	0.467
Bromoxynil	*<0.119	*<0.119	*<0.080
Carbaryl	*<0.059	*<0.059	*<0.040
Carbendazim	0.165	0.158	<0.095
Carbofuran	*<0.119	*<0.119	*<0.080
DCPMU	*<0.012	*<0.012	*0.424
DCPU	*<0.059	*<0.059	*<0.040
Diazinon	<0.024	<0.024	<0.016
Difenoconazole	*<0.593	*<0.593	*<0.398
Diketonitrile	*<0.012	*<0.012	*0.556
Diuron	0.270	0.196	13.7
Fipronil	<0.052	<0.052	<0.035
Fluazifop	*<0.012	*<0.012	*<0.008

Fluometuron	<0.086	<0.086	<0.058
Fluroxypyr	*<0.119	*<0.119	*<0.080
Haloxypop	<0.062	<0.062	<0.041
Hexazinone	0.228	0.154	7.13
Imazapyr	*<0.178	*<0.178	*<0.119
Imazethapyr	*<0.119	*<0.119	*<0.080
Imidacloprid	*<0.119	*<0.119	*2.13
MCPA	<0.361	<0.361	<0.242
Malathion	*<0.119	*<0.119	*<0.080
Mecoprop	<0.065	<0.065	<0.044
Metalaxyl	*<0.012	*<0.012	*<0.008
Methidathion	*<0.593	*<0.593	*<0.398
Methiocarb	*<0.119	*<0.119	*<0.080
Methomyl	*<0.119	*<0.119	*<0.080
Metolachlor (S+R)	0.148	<0.116	1.93
Metribuzin	*<0.119	*<0.119	*0.184
Metsulfuron methyl	*<0.119	*<0.119	*0.103
Oryalin	*<0.083	*<0.083	*<0.056
Picloram	*<0.593	*<0.593	*<0.398
Prometryn	<0.196	<0.196	<0.132
Propachlor	*<0.095	*<0.095	*<0.064
Propazine	*<0.119	*<0.119	*<0.080
Propiconazole	*<0.119	*<0.119	*<0.080
Propoxur	<0.097	<0.097	<0.065
Simazine	<0.081	<0.081	<0.054
Simazine hydroxy	*<0.119	*<0.119	*<0.080
Tebuconazole	*<0.119	*<0.119	*<0.080
Tebuthiuron	<0.091	<0.091	0.475
Terbutylazine	<0.109	<0.109	0.160
Terbutylazine desethyl	*<0.119	*<0.119	*<0.080
Thiamethoxam	*<0.083	*<0.083	*<0.056
Triclopyr	<0.299	<0.299	<0.201

^ - Limit of Reporting (LOR) raised by blank level: Where an analyte is detected in field or lab blanks above the Limit of Quantification (LOQ), the effective LOR is raised to the average blank value plus three times the standard deviation

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Data reported as <LOR where applicable, and expressed as a water concentration estimate

N/R - Not Reportable: Where a data point is not able to be reliably reported due to unavoidable analytical issues such as matrix interference or unacceptable analyte performance/recovery

Water concentration estimates provided here are derived by applying sampling rates from calibration studies to the amount of analyte accumulated by the sampler

ED MASS PER SAMPLER

Site Name		Slade Island	Slade Island	Slade Island
Deployed Date		01/10/2024	01/10/2024	27/11/2024
Retrieved Date		27/11/2024	27/11/2024	20/02/2025
Days Deployed		57	57	85
Flow Rate (cm/s)		28.2	28.2	28.2
Site Code		MKY-AMB5	MKY-AMB5	MKY-AMB5
Sample Name		TRP124_ED_SLA	TRP124_ED_SLA DUP	TRP225_ED_SLA
Analyte	LOQ			
2,4,5-T	1.00	<1.00	<1.00	<1.00
2,4-D	5.00	<5.00	<5.00	<5.00
3,4 Dichloroaniline	1.00	<1.00	<1.00	<1.00
Ametryn	5.00	<5.00	<5.00	<5.00
Ametryn hydroxy	1.00	<1.00	<1.00	<1.00
Atrazine	1.00	<1.00	<1.00	22.3
Atrazine desethyl	1.00	<1.00	<1.00	<1.00
Atrazine desisopropyl	1.00	<1.00	<1.00	<1.00
Bendiocarb	0.500	<0.500	<0.500	<0.500
Bromacil	1.00	<1.00	<1.00	8.64
Bromoxynil	1.00	<1.00	<1.00	<1.00
Carbaryl	0.500	<0.500	<0.500	<0.500
Carbendazim	1.00	1.16	1.11	<1.00
Carbofuran	1.00	<1.00	<1.00	<1.00
DCPMU	0.100	<0.100	<0.100	5.33
DCPU	0.500	<0.500	<0.500	<0.500
Diazinon	0.100	<0.100	<0.100	<0.100
Difenoconazole	5.00	<5.00	<5.00	<5.00
Diketonitrile	0.100	<0.100	<0.100	6.99
Diuron	0.500	1.89	1.37	143

Fipronil	0.500	<i><0.500</i>	<i><0.500</i>	<i><0.500</i>
Fluazifop	0.100	<i><0.100</i>	<i><0.100</i>	<i><0.100</i>
Fluometuron	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Fluroxypyr	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Haloxypop	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Hexazinone	1.00	1.96	1.32	91.4
Imazapyr	1.50	<i><1.50</i>	<i><1.50</i>	<i><1.50</i>
Imazethapyr	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Imidacloprid	1.00	<i><1.00</i>	<i><1.00</i>	26.8
MCPA	5.00	<i><5.00</i>	<i><5.00</i>	<i><5.00</i>
Malathion	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Mecoprop	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Metalaxyl	0.100	<i><0.100</i>	<i><0.100</i>	<i><0.100</i>
Methidathion	5.00	<i><5.00</i>	<i><5.00</i>	<i><5.00</i>
Methiocarb	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Methomyl	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Metolachlor (S+R)	1.00	1.27	<i><1.00</i>	24.7
Metribuzin	1.00	<i><1.00</i>	<i><1.00</i>	2.32
Metsulfuron methyl	1.00	<i><1.00</i>	<i><1.00</i>	1.29
Oryzalin	0.700	<i><0.700</i>	<i><0.700</i>	<i><0.700</i>
Picloram	5.00	<i><5.00</i>	<i><5.00</i>	<i><5.00</i>
Prometryn	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Propachlor	0.800	<i><0.800</i>	<i><0.800</i>	<i><0.800</i>
Propazine	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Propiconazole	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Propoxur	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Simazine	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Simazine hydroxy	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Tebuconazole	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Tebuthiuron	1.00	<i><1.00</i>	<i><1.00</i>	7.78
Terbuthylazine	1.00	<i><1.00</i>	<i><1.00</i>	2.18
Terbuthylazine desethyl	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>
Thiamethoxam	0.700	<i><0.700</i>	<i><0.700</i>	<i><0.700</i>

*Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring
Program: Annual Report 2024-2025*

Triclopyr	5.00	<5.00	<5.00	<5.00
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[^] - Limit of Reporting (LOR) raised by blank level: Where an analyte is detected in field or lab blanks above the Limit of Quantification (LOQ), the effective LOR is raised to the average blank value plus three times the standard deviation

Data reported as <LOR where applicable, and expressed as a water concentration estimate

N/R - Not Reportable: Where a data point is not able to be reliably reported due to unavoidable analytical issues such as matrix interference or unacceptable analyte performance/recovery

Water concentration estimates provided here are derived by applying sampling rates from calibration studies to the amount of analyte accumulated by the sampler

PE REPORT NG/ SAMPLER

Site Name		Slade Island	Slade Island	Slade Island	Slade Island	Lab Blank
Deployed Date		01/10/2024	01/10/2024	27/11/2024	27/11/2024	
Retrieved Date		27/11/2024	27/11/2024	20/02/2025	20/02/2025	
Days Deployed		57	57	85	85	
Site Code		MKY-AMB5	MKY-AMB5	MKY-AMB5	MKY-AMB5	
QAEHS Acronym	LOQ					
PFBA	1.10	<1.10	N/R (IS rec 5.0%)	<1.10	<1.10	0.061
PFPeA	1.10	<1.10	<1.10	<1.10	<1.10	not detected
PFHxA	0.900	<0.900	<0.900	<0.900	<0.900	not detected
PFHpA	0.900	<0.900	N/R (IS rec 7.0%)	<0.900	<0.900	not detected
PFOA	1.00	<1.00	N/R (IS rec 5.0%)	<1.00	<1.00	not detected
PFOA Total	1.00	<1.00	N/R (IS rec 5.0%)	<1.00	<1.00	not detected
PFNA	0.900	<0.900	N/R (IS rec 3.0%)	<0.900	<0.900	not detected
PFDA	0.800	<0.800	N/R (IS rec 3.0%)	<0.800	<0.800	not detected
PFUnDA	0.700	<0.700	N/R (IS rec 3.0%)	<0.700	<0.700	not detected
PFDODA	1.70	<1.70	N/R (IS rec 2.0%)	<1.70	<1.70	not detected

PFPPrS	1.10	<1.10	<1.10	<1.10	<1.10	not detected
PFBS	1.10	<1.10	<1.10	<1.10	<1.10	not detected
PFPeS	0.900	<0.900	<i>N/R (IS rec 7.0%)</i>	<0.900	<0.900	not detected
PFHxS	1.00	<1.00	<i>N/R (IS rec 7.0%)</i>	<1.00	<1.00	not detected
PFHxS Total	1.00	<1.00	<i>N/R (IS rec 7.0%)</i>	<1.00	<1.00	not detected
PFHpS	1.00	<1.00	<i>N/R (IS rec 7.0%)</i>	<1.00	<1.00	not detected
PFOS	1.00	<1.00	<i>N/R (IS rec 2.0%)</i>	1.66	1.65	not detected
PFOS Total	1.00	<1.00	<i>N/R (IS rec 2.0%)</i>	1.90	1.87	not detected
8Cl-PFOS	1.00	<1.00	<i>N/R (IS rec 2.0%)</i>	<1.00	<1.00	not detected
9Cl-F53B	1.00	<1.00	<i>N/R (IS rec 2.0%)</i>	<1.00	<1.00	not detected
PFECHS	1.60	<1.60	<i>N/R (IS rec 2.0%)</i>	<1.60	<1.60	not detected
FBSA	0.900	<0.900	<0.900	<0.900	<0.900	not detected
FHxSA	0.700	<0.700	<i>N/R (IS rec 7.0%)</i>	<0.700	<0.700	not detected
FOSA	1.00	<1.00	<i>N/R (IS rec 1.0%)</i>	<i>N/R (IS rec 6.0%)</i>	<i>N/R (IS rec 5.0%)</i>	not detected
N-EtFOSAA	1.00	<1.00	<i>N/R (IS rec 3.0%)</i>	<1.00	<1.00	not detected
N-MeFOSAA	1.00	<1.00	<i>N/R (IS rec 2.0%)</i>	<1.00	<1.00	not detected
4:2 FTS	1.00	<1.00	<1.00	<1.00	<1.00	not detected
6:2 FTS	1.25	<2.08[^]	<2.08[^]	<2.08[^]	<2.08[^]	1.05
8:2 FTS	1.00	<1.00	<i>N/R (IS rec 3.0%)</i>	<1.00	<1.00	not detected
6:2 FTCA	0.900	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	not detected

8:2 FTCA	0.800	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	<i>N/R (IS rec 0.0%)</i>	not detected
5:3 FTCA	1.00	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>	<i><1.00</i>	not detected
6:2 FTAB_pos	1.00	<i><1.00</i>	<i>N/R (IS rec 2.0%)</i>	<i><1.00</i>	<i><1.00</i>	not detected
ADONA	1.00	<i><1.00</i>	<i>N/R (IS rec 7.0%)</i>	<i><1.00</i>	<i><1.00</i>	0.081
GenX	1.20	<i><1.20</i>	<i><1.20</i>	<i><1.20</i>	<i><1.20</i>	not detected

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Data reported as <LOR where applicable, and expressed as a water concentration estimate

N/R - Not Reportable: Where a data point is not able to be reliably reported due to unavoidable analytical issues such as matrix interference or unacceptable analyte performance/recovery

Water concentration estimates provided here are derived by applying sampling rates from calibration studies to the amount of analyte accumulated by the sampler

* - Sampling rate for analyte not available: Water concentration estimate provided using the atrazine as the surrogate sampling rate for comparison purposes only

PE WATER CONCENTRATION NG/L

Analyte	Site Name	Slade Island	Slade Island	Slade Island	Slade Island
	Deployed Date	01/10/2024	01/10/2024	27/11/2024	27/11/2024
	Retrieved Date	27/11/2024	27/11/2024	20/02/2025	20/02/2025
	Days Deployed	57	57	85	85
	Site Code	MKY-AMB5	MKY-AMB5	MKY-AMB5	MKY-AMB5
	QAEHS Acronym				
Perfluorobutanoic acid	PFBA	<1.73	N/R	<1.16	<1.16
Perfluoropentanoic acid	PFPeA	<1.97	<1.97	<1.32	<1.32
Perfluorohexanoic acid	PFHxA	<1.43	<1.43	<0.962	<0.962
Perfluoroheptanoic acid	PFHpA	<1.12	N/R	<0.750	<0.750
Perfluorooctanoic acid	PFOA	<1.61	N/R	<1.08	<1.08
Total (linear + branched) Perfluorooctanoic acid	PFOA Total	<1.61	N/R	<1.08	<1.08
Perfluorononanoic acid	PFNA	<0.555	N/R	<0.372	<0.372
Perfluorodecanoic acid	PFDA	<0.815	N/R	<0.547	<0.547
Perfluoroundecanoic acid	PFUnDA	NA	NA	NA	NA
Perfluorododecanoic acid	PFDoDA	NA	NA	NA	NA
Perfluoropropane sulfonate	PFPrS	<1.33	<1.33	<0.890	<0.890
Perfluorobutane sulfonate	PFBS	<1.40	<1.40	<0.936	<0.936

Perfluoropentane sulfonate	PFPeS	<1.47	N/R	<0.988	<0.988
Perfluorohexane sulfonate	PFHxS	<1.47	N/R	<0.983	<0.983
Total (linear + branched) Perfluorohexane sulfonate	PFHxS Total	<1.47	N/R	<0.983	<0.983
Perfluoroheptane sulfonate	PFHpS	NA	NA	NA	NA
Perfluorooctane sulfonate	PFOS	<1.43	N/R	1.59	1.58
Total (linear + branched) Perfluorooctane sulfonate	PFOS Total	<1.43	N/R	1.82	1.79
8-Chloroperfluoro-1-octanesulfonate	8Cl-PFOS	NA	NA	NA	NA
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonate	9Cl-F53B	NA	NA	NA	NA
Perfluoroethylcyclohexane sulfonate	PFECHS	NA	NA	NA	NA
Perfluorobutane sulfonamide	FBSA	<0.858	<0.858	<0.575	<0.575
Perfluorohexane sulfonamide	FHxSA	NA	NA	NA	NA
Perfluorooctane sulfonamide	FOSA	NA	NA	NA	NA
N-ethyl-fluorooctane sulfonamidoacetic acid	N-EtFOSAA	NA	NA	NA	NA
N-methyl-fluorooctane sulfonamidoacetic acid	N-MeFOSAA	NA	NA	NA	NA
4:2-Fluorotelomer sulfonate	4:2 FTS	NA	NA	NA	NA
6:2-Fluorotelomer sulfonate	6:2 FTS	NA	NA	NA	NA
8:2-Fluorotelomer sulfonate	8:2 FTS	NA	NA	NA	NA
6:2 Fluorotelomer carboxylic acid	6:2 FTCA	NA	NA	NA	NA
8:2 Fluorotelomer carboxylic acid	8:2 FTCA	NA	NA	NA	NA
5:3 Fluorotelomer carboxylic acid	5:3 FTCA	NA	NA	NA	NA
6:2 Fluorotelomer sulfonamido propyl betaine	6:2 FTAB_pos	NA	NA	NA	NA

Trifluoromethoxy propoxy propanoate	ADONA	NA	NA	NA	NA
Hexafluoropropylene oxide dimer acid	GenX	NA	NA	NA	NA

APPENDIX B LOGGER DATA SUMMARIES

Summary	Site_code	param	MY	mean	median	sd	min	max	Q1	Q3	n	Month	Year	Season
Monthly	MKY_AMB1	Depth	01/07/2024	9.98	9.95	1.46	7.09	13.33	8.73	11.11	4460	Jul	2024	NA
Monthly	MKY_AMB1	Depth	01/08/2024	10.21	10.17	1.50	6.92	13.73	9.01	11.36	4464	Aug	2024	NA
Monthly	MKY_AMB1	Depth	01/09/2024	10.31	10.28	1.51	7.05	13.91	9.13	11.51	4320	Sep	2024	NA
Monthly	MKY_AMB1	Depth	01/10/2024	10.54	10.51	1.50	7.11	13.66	9.33	11.76	4462	Oct	2024	NA
Monthly	MKY_AMB1	Depth	01/11/2024	10.45	10.40	1.45	7.26	13.94	9.30	11.62	4319	Nov	2024	NA
Monthly	MKY_AMB1	Depth	01/12/2024	10.18	10.16	1.44	7.22	13.64	8.97	11.32	4464	Dec	2024	NA
Monthly	MKY_AMB1	Depth	01/01/2025	10.33	10.31	1.48	7.37	13.78	9.11	11.45	4464	Jan	2025	NA
Monthly	MKY_AMB1	Depth	01/02/2025	10.43	10.42	1.46	7.56	14.05	9.26	11.52	4032	Feb	2025	NA
Monthly	MKY_AMB1	Depth	01/03/2025	10.48	10.45	1.56	7.11	13.95	9.25	11.71	4461	Mar	2025	NA
Monthly	MKY_AMB1	Depth	01/04/2025	10.23	10.20	1.51	6.70	13.43	9.07	11.46	4317	Apr	2025	NA
Monthly	MKY_AMB1	Depth	01/05/2025	10.18	10.14	1.46	6.90	13.46	8.95	11.39	4464	May	2025	NA
Monthly	MKY_AMB1	Depth	01/06/2025	10.26	10.22	1.45	7.32	13.67	8.95	11.45	4315	Jun	2025	NA
Seasonal	MKY_AMB1	Depth	NA	10.25	10.21	1.49	6.90	13.91	9.02	11.42	26485	NA	NA	Dry
Seasonal	MKY_AMB1	Depth	NA	10.35	10.33	1.49	6.70	14.05	9.15	11.50	26057	NA	NA	Wet
Fiscal	MKY_AMB1	Depth	NA	10.30	10.28	1.49	6.70	14.05	9.09	11.47	52542	NA	NA	NA
Monthly	MKY_AMB10	Depth	1/07/2024	7.85	7.83	1.42	5.10	11.19	6.65	8.92	4462	Jul	2024	NA
Monthly	MKY_AMB10	Depth	1/08/2024	7.66	7.63	1.43	4.59	11.08	6.50	8.73	4464	Aug	2024	NA

Monthly	MKY_AMB10	Depth	1/09/2024	7.75	7.74	1.44	4.66	11.30	6.61	8.86	4320	Sep	2024	NA
Monthly	MKY_AMB10	Depth	1/10/2024	7.78	7.73	1.43	4.55	10.97	6.62	8.91	4461	Oct	2024	NA
Monthly	MKY_AMB10	Depth	1/11/2024	7.82	7.81	1.39	4.59	11.13	6.69	8.94	4318	Nov	2024	NA
Monthly	MKY_AMB10	Depth	1/12/2024	7.86	7.84	1.39	4.97	11.24	6.68	8.94	4464	Dec	2024	NA
Monthly	MKY_AMB10	Depth	1/01/2025	8.07	8.04	1.43	5.18	11.50	6.88	9.18	4464	Jan	2025	NA
Monthly	MKY_AMB10	Depth	1/02/2025	8.26	8.25	1.41	5.46	11.70	7.14	9.33	4032	Feb	2025	NA
Monthly	MKY_AMB10	Depth	1/03/2025	8.18	8.16	1.50	5.11	11.65	6.99	9.35	4461	Mar	2025	NA
Monthly	MKY_AMB10	Depth	1/04/2025	8.05	8.03	1.46	4.65	11.18	6.93	9.22	4316	Apr	2025	NA
Monthly	MKY_AMB10	Depth	1/05/2025	7.95	7.92	1.42	4.75	11.15	6.77	9.10	4464	May	2025	NA
Monthly	MKY_AMB10	Depth	1/06/2025	7.81	7.80	1.39	4.97	11.12	6.59	8.93	4316	Jun	2025	NA
Seasonal	MKY_AMB10	Depth	NA	7.80	7.78	1.42	4.55	11.30	6.62	8.91	26487	NA	NA	Dry
Seasonal	MKY_AMB10	Depth	NA	8.04	8.02	1.44	4.59	11.70	6.87	9.17	26055	NA	NA	Wet
Fiscal	MKY_AMB10	Depth	NA	7.92	7.90	1.44	4.55	11.70	6.74	9.04	52542	NA	NA	NA
Monthly	MKY_AMB3B	Depth	1/07/2024	8.96	8.92	1.36	6.28	12.36	7.82	9.97	4461	Jul	2024	NA
Monthly	MKY_AMB3B	Depth	1/08/2024	9.03	9.00	1.38	6.05	12.36	7.94	10.04	4464	Aug	2024	NA
Monthly	MKY_AMB3B	Depth	1/09/2024	9.15	9.13	1.38	6.16	12.52	8.08	10.20	4320	Sep	2024	NA
Monthly	MKY_AMB3B	Depth	1/10/2024	8.87	8.82	1.39	5.67	11.83	7.79	9.96	4461	Oct	2024	NA
Monthly	MKY_AMB3B	Depth	1/11/2024	9.48	9.43	1.42	6.20	13.18	8.35	10.60	4318	Nov	2024	NA
Monthly	MKY_AMB3B	Depth	1/12/2024	10.02	9.83	1.63	6.45	14.02	8.87	11.24	4464	Dec	2024	NA
Monthly	MKY_AMB3B	Depth	1/01/2025	8.97	8.95	1.38	6.10	12.23	7.82	10.01	4464	Jan	2025	NA
Monthly	MKY_AMB3B	Depth	1/02/2025	9.42	9.46	1.43	6.54	13.07	8.27	10.48	4026	Feb	2025	NA
Monthly	MKY_AMB3B	Depth	1/03/2025	9.34	9.29	1.43	6.25	12.49	8.23	10.45	4464	Mar	2025	NA

Monthly	MKY_AMB3B	Depth	1/04/2025	9.55	9.50	1.40	6.26	12.58	8.43	10.66	4316	Apr	2025	NA
Monthly	MKY_AMB3B	Depth	1/05/2025	9.59	9.56	1.38	6.44	12.58	8.46	10.70	4464	May	2025	NA
Monthly	MKY_AMB3B	Depth	1/06/2025	9.13	9.10	1.35	6.39	12.32	7.96	10.19	4317	Jun	2025	NA
Seasonal	MKY_AMB3B	Depth	NA	9.12	9.08	1.39	5.67	12.58	8.00	10.19	26487	NA	NA	Dry
Seasonal	MKY_AMB3B	Depth	NA	9.46	9.42	1.49	6.10	14.02	8.31	10.53	26052	NA	NA	Wet
Fiscal	MKY_AMB3B	Depth	NA	9.29	9.26	1.45	5.67	14.02	8.15	10.35	52539	NA	NA	NA
Monthly	MKY_AMB5	Depth	1/07/2024	9.60	9.55	1.30	7.05	12.75	8.51	10.56	4462	Jul	2024	NA
Monthly	MKY_AMB5	Depth	1/08/2024	9.47	9.45	1.33	6.60	12.69	8.43	10.45	4464	Aug	2024	NA
Monthly	MKY_AMB5	Depth	1/09/2024	9.50	9.47	1.33	6.58	12.77	8.46	10.50	4320	Sep	2024	NA
Monthly	MKY_AMB5	Depth	1/10/2024	9.71	9.61	1.33	7.00	12.94	8.66	10.77	4462	Oct	2024	NA
Monthly	MKY_AMB5	Depth	1/11/2024	9.44	9.42	1.31	6.48	12.59	8.43	10.44	4317	Nov	2024	NA
Monthly	MKY_AMB5	Depth	1/12/2024	9.10	9.11	1.32	6.22	12.15	8.02	10.14	4464	Dec	2024	NA
Monthly	MKY_AMB5	Depth	1/01/2025	9.31	9.27	1.33	6.58	12.41	8.23	10.29	4464	Jan	2025	NA
Monthly	MKY_AMB5	Depth	1/02/2025	9.59	9.57	1.33	6.94	13.18	8.52	10.57	4029	Feb	2025	NA
Monthly	MKY_AMB5	Depth	1/03/2025	9.84	9.78	1.39	6.87	13.07	8.75	10.93	4464	Mar	2025	NA
Monthly	MKY_AMB5	Depth	1/04/2025	9.95	9.90	1.35	6.84	12.90	8.84	11.08	4320	Apr	2025	NA
Monthly	MKY_AMB5	Depth	1/05/2025	10.00	9.96	1.32	6.98	12.96	8.90	11.07	4464	May	2025	NA
Monthly	MKY_AMB5	Depth	1/06/2025	9.93	9.90	1.31	7.29	13.13	8.78	10.93	4310	Jun	2025	NA
Seasonal	MKY_AMB5	Depth	NA	9.70	9.65	1.33	6.58	13.13	8.63	10.74	26482	NA	NA	Dry
Seasonal	MKY_AMB5	Depth	NA	9.53	9.52	1.37	6.22	13.18	8.46	10.55	26058	NA	NA	Wet
Fiscal	MKY_AMB5	Depth	NA	9.62	9.58	1.36	6.22	13.18	8.55	10.64	52540	NA	NA	NA
Monthly	MKY_AMB1	Depth_RMS	1/07/2024	0.04	0.03	0.02	0.01	0.25	0.03	0.05	4460	Jul	2024	NA

Monthly	MKY_AMB1	Depth_RMS	1/08/2024	0.02	0.02	0.02	0.00	0.14	0.01	0.03	4464	Aug	2024	NA
Monthly	MKY_AMB1	Depth_RMS	1/09/2024	0.03	0.02	0.03	0.00	0.29	0.01	0.04	4320	Sep	2024	NA
Monthly	MKY_AMB1	Depth_RMS	1/10/2024	0.03	0.02	0.02	0.00	0.26	0.01	0.03	4462	Oct	2024	NA
Monthly	MKY_AMB1	Depth_RMS	1/11/2024	0.03	0.02	0.02	0.00	0.25	0.01	0.03	4319	Nov	2024	NA
Monthly	MKY_AMB1	Depth_RMS	1/12/2024	0.03	0.02	0.03	0.00	0.24	0.01	0.03	4464	Dec	2024	NA
Monthly	MKY_AMB1	Depth_RMS	1/01/2025	0.03	0.02	0.03	0.00	0.28	0.01	0.04	4464	Jan	2025	NA
Monthly	MKY_AMB1	Depth_RMS	1/02/2025	0.06	0.04	0.04	0.00	0.31	0.03	0.07	4032	Feb	2025	NA
Monthly	MKY_AMB1	Depth_RMS	1/03/2025	0.04	0.03	0.03	0.00	0.23	0.02	0.05	4461	Mar	2025	NA
Monthly	MKY_AMB1	Depth_RMS	1/04/2025	0.04	0.03	0.03	0.00	0.23	0.02	0.05	4317	Apr	2025	NA
Monthly	MKY_AMB1	Depth_RMS	1/05/2025	0.05	0.03	0.04	0.00	0.27	0.02	0.06	4464	May	2025	NA
Monthly	MKY_AMB1	Depth_RMS	1/06/2025	0.03	0.03	0.02	0.00	0.16	0.02	0.04	4315	Jun	2025	NA
Seasonal	MKY_AMB1	Depth_RMS	NA	0.03	0.03	0.03	0.00	0.29	0.02	0.04	26485	NA	NA	Dry
Seasonal	MKY_AMB1	Depth_RMS	NA	0.04	0.03	0.03	0.00	0.31	0.02	0.05	26057	NA	NA	Wet
Fiscal	MKY_AMB1	Depth_RMS	NA	0.04	0.03	0.03	0.00	0.31	0.02	0.04	52542	NA	NA	NA
Monthly	MKY_AMB10	Depth_RMS	1/07/2024	0.03	0.02	0.03	0.00	0.29	0.02	0.04	4462	Jul	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/08/2024	0.03	0.02	0.02	0.00	0.16	0.02	0.04	4464	Aug	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/09/2024	0.03	0.02	0.03	0.00	0.27	0.02	0.04	4320	Sep	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/10/2024	0.03	0.03	0.02	0.00	0.22	0.02	0.04	4461	Oct	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/11/2024	0.03	0.02	0.02	0.00	0.35	0.01	0.03	4318	Nov	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/12/2024	0.03	0.02	0.03	0.00	0.26	0.01	0.03	4464	Dec	2024	NA
Monthly	MKY_AMB10	Depth_RMS	1/01/2025	0.04	0.03	0.03	0.00	0.28	0.02	0.04	4464	Jan	2025	NA
Monthly	MKY_AMB10	Depth_RMS	1/02/2025	0.06	0.05	0.04	0.01	0.30	0.03	0.08	4032	Feb	2025	NA

Monthly	MKY_AMB10	Depth_RMS	1/03/2025	0.05	0.04	0.03	0.00	0.25	0.03	0.06	4461	Mar	2025	NA
Monthly	MKY_AMB10	Depth_RMS	1/04/2025	0.04	0.03	0.03	0.00	0.30	0.02	0.06	4316	Apr	2025	NA
Monthly	MKY_AMB10	Depth_RMS	1/05/2025	0.05	0.04	0.04	0.01	0.30	0.03	0.07	4464	May	2025	NA
Monthly	MKY_AMB10	Depth_RMS	1/06/2025	0.03	0.03	0.02	0.00	0.22	0.02	0.04	4316	Jun	2025	NA
Seasonal	MKY_AMB10	Depth_RMS	NA	0.04	0.03	0.03	0.00	0.30	0.02	0.04	26487	NA	NA	Dry
Seasonal	MKY_AMB10	Depth_RMS	NA	0.04	0.03	0.03	0.00	0.35	0.02	0.05	26055	NA	NA	Wet
Fiscal	MKY_AMB10	Depth_RMS	NA	0.04	0.03	0.03	0.00	0.35	0.02	0.05	52542	NA	NA	NA
Monthly	MKY_AMB3B	Depth_RMS	1/07/2024	0.04	0.04	0.02	0.02	0.27	0.03	0.05	4461	Jul	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/08/2024	0.03	0.02	0.01	0.01	0.11	0.02	0.03	4464	Aug	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/09/2024	0.03	0.02	0.02	0.01	0.23	0.02	0.03	4320	Sep	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/10/2024	0.03	0.02	0.02	0.00	0.19	0.02	0.03	4461	Oct	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/11/2024	0.02	0.02	0.02	0.00	0.21	0.01	0.03	4318	Nov	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/12/2024	0.02	0.02	0.03	0.00	0.26	0.01	0.02	4464	Dec	2024	NA
Monthly	MKY_AMB3B	Depth_RMS	1/01/2025	0.03	0.02	0.03	0.00	0.26	0.01	0.04	4464	Jan	2025	NA
Monthly	MKY_AMB3B	Depth_RMS	1/02/2025	0.05	0.04	0.04	0.01	0.30	0.03	0.07	4026	Feb	2025	NA
Monthly	MKY_AMB3B	Depth_RMS	1/03/2025	0.04	0.03	0.03	0.00	0.24	0.02	0.05	4464	Mar	2025	NA
Monthly	MKY_AMB3B	Depth_RMS	1/04/2025	0.04	0.03	0.03	0.00	0.24	0.02	0.05	4316	Apr	2025	NA
Monthly	MKY_AMB3B	Depth_RMS	1/05/2025	0.05	0.04	0.03	0.01	0.30	0.03	0.06	4464	May	2025	NA
Monthly	MKY_AMB3B	Depth_RMS	1/06/2025	0.03	0.03	0.02	0.00	0.15	0.02	0.04	4317	Jun	2025	NA
Seasonal	MKY_AMB3B	Depth_RMS	NA	0.03	0.03	0.02	0.00	0.30	0.02	0.04	26487	NA	NA	Dry
Seasonal	MKY_AMB3B	Depth_RMS	NA	0.03	0.02	0.03	0.00	0.30	0.02	0.04	26052	NA	NA	Wet
Fiscal	MKY_AMB3B	Depth_RMS	NA	0.03	0.03	0.03	0.00	0.30	0.02	0.04	52539	NA	NA	NA

Monthly	MKY_AMB5	Depth_RMS	1/07/2024	0.06	0.05	0.05	0.02	0.46	0.03	0.08	4462	Jul	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/08/2024	0.04	0.03	0.03	0.00	0.22	0.02	0.06	4464	Aug	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/09/2024	0.05	0.04	0.05	0.00	0.41	0.02	0.07	4320	Sep	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/10/2024	0.05	0.04	0.04	0.00	0.44	0.02	0.06	4462	Oct	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/11/2024	0.04	0.03	0.04	0.00	0.47	0.02	0.05	4317	Nov	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/12/2024	0.04	0.03	0.05	0.00	0.42	0.02	0.05	4464	Dec	2024	NA
Monthly	MKY_AMB5	Depth_RMS	1/01/2025	0.05	0.03	0.05	0.00	0.48	0.02	0.06	4464	Jan	2025	NA
Monthly	MKY_AMB5	Depth_RMS	1/02/2025	0.10	0.07	0.07	0.01	0.60	0.05	0.13	4029	Feb	2025	NA
Monthly	MKY_AMB5	Depth_RMS	1/03/2025	0.07	0.06	0.05	0.00	0.37	0.04	0.09	4464	Mar	2025	NA
Monthly	MKY_AMB5	Depth_RMS	1/04/2025	0.07	0.05	0.06	0.00	0.42	0.03	0.08	4320	Apr	2025	NA
Monthly	MKY_AMB5	Depth_RMS	1/05/2025	0.08	0.06	0.07	0.00	0.50	0.04	0.11	4464	May	2025	NA
Monthly	MKY_AMB5	Depth_RMS	1/06/2025	0.06	0.05	0.04	0.00	0.33	0.03	0.08	4310	Jun	2025	NA
Seasonal	MKY_AMB5	Depth_RMS	NA	0.06	0.04	0.05	0.00	0.50	0.03	0.07	26482	NA	NA	Dry
Seasonal	MKY_AMB5	Depth_RMS	NA	0.06	0.04	0.06	0.00	0.60	0.02	0.08	26058	NA	NA	Wet
Fiscal	MKY_AMB5	Depth_RMS	NA	0.06	0.04	0.05	0.00	0.60	0.02	0.07	52540	NA	NA	NA
Monthly	MKY_AMB1	NTU	1/07/2024	3.95	1.30	9.11	0.49	199.90	0.99	2.19	4459	Jul	2024	NA
Monthly	MKY_AMB1	NTU	1/08/2024	1.50	1.13	1.58	0.45	47.69	0.87	1.65	4416	Aug	2024	NA
Monthly	MKY_AMB1	NTU	1/09/2024	6.74	2.98	10.32	0.44	128.86	1.51	7.39	4320	Sep	2024	NA
Monthly	MKY_AMB1	NTU	1/10/2024	6.61	3.23	9.50	0.67	141.36	2.08	7.44	4460	Oct	2024	NA
Monthly	MKY_AMB1	NTU	1/11/2024	7.72	3.42	14.56	0.79	282.21	2.33	6.21	4313	Nov	2024	NA
Monthly	MKY_AMB1	NTU	1/12/2024	10.44	2.49	28.17	0.66	365.10	1.81	3.76	4429	Dec	2024	NA
Monthly	MKY_AMB1	NTU	1/01/2025	12.66	4.75	21.56	0.81	206.11	2.17	12.57	4461	Jan	2025	NA

Monthly	MKY_AMB1	NTU	1/02/2025	44.68	22.35	60.39	1.21	374.68	7.00	55.20	4031	Feb	2025	NA
Monthly	MKY_AMB1	NTU	1/03/2025	24.49	12.96	36.44	1.04	460.83	5.68	24.96	4459	Mar	2025	NA
Monthly	MKY_AMB1	NTU	1/04/2025	13.91	3.64	27.19	0.85	255.43	2.27	10.11	4316	Apr	2025	NA
Monthly	MKY_AMB1	NTU	1/05/2025	18.01	4.14	29.71	0.85	269.37	1.92	22.49	4464	May	2025	NA
Monthly	MKY_AMB1	NTU	1/06/2025	1.01	0.94	0.45	0.34	2.92	0.67	1.16	483	Jun	2025	NA
Seasonal	MKY_AMB1	NTU	NA	7.24	2.06	16.18	0.34	269.37	1.16	5.17	22602	NA	NA	Dry
Seasonal	MKY_AMB1	NTU	NA	18.66	4.84	36.30	0.66	460.83	2.44	17.34	26009	NA	NA	Wet
Fiscal	MKY_AMB1	NTU	NA	13.35	3.21	29.31	0.34	460.83	1.70	11.00	48611	NA	NA	NA
Monthly	MKY_AMB10	NTU	1/07/2024	1.76	0.64	3.38	0.22	35.25	0.45	1.07	4459	Jul	2024	NA
Monthly	MKY_AMB10	NTU	1/08/2024	0.59	0.49	0.59	0.18	15.18	0.38	0.62	4456	Aug	2024	NA
Monthly	MKY_AMB10	NTU	1/09/2024	5.10	0.97	11.55	0.20	150.95	0.60	4.13	4317	Sep	2024	NA
Monthly	MKY_AMB10	NTU	1/10/2024	4.44	1.47	8.19	0.36	125.86	0.90	3.45	4460	Oct	2024	NA
Monthly	MKY_AMB10	NTU	1/11/2024	6.10	1.63	18.31	0.42	251.92	1.14	2.82	4311	Nov	2024	NA
Monthly	MKY_AMB10	NTU	1/12/2024	7.45	1.49	20.17	0.38	322.89	1.11	2.23	4444	Dec	2024	NA
Monthly	MKY_AMB10	NTU	1/01/2025	6.58	2.12	13.67	0.34	173.14	0.91	5.09	4464	Jan	2025	NA
Monthly	MKY_AMB10	NTU	1/02/2025	28.09	16.67	37.35	1.25	376.25	5.52	34.11	4031	Feb	2025	NA
Monthly	MKY_AMB10	NTU	1/03/2025	17.94	10.47	23.68	1.16	251.83	4.83	20.85	4407	Mar	2025	NA
Monthly	MKY_AMB10	NTU	1/04/2025	8.17	3.47	10.97	0.54	121.25	1.64	10.66	4315	Apr	2025	NA
Monthly	MKY_AMB10	NTU	1/05/2025	8.95	3.36	12.02	0.47	115.03	1.23	11.65	4464	May	2025	NA
Monthly	MKY_AMB10	NTU	1/06/2025	1.69	0.75	2.68	0.33	46.94	0.58	1.74	4308	Jun	2025	NA
Seasonal	MKY_AMB10	NTU	NA	3.76	0.89	8.28	0.18	150.95	0.55	2.51	26464	NA	NA	Dry
Seasonal	MKY_AMB10	NTU	NA	12.18	3.14	23.49	0.34	376.25	1.44	13.40	25972	NA	NA	Wet

Fiscal	MKY_AMB10	NTU	NA	7.93	1.68	18.05	0.18	376.25	0.77	6.76	52436	NA	NA	NA
Monthly	MKY_AMB3B	NTU	1/07/2024	1.36	0.31	3.48	0.09	36.20	0.22	0.56	4314	Jul	2024	NA
Monthly	MKY_AMB3B	NTU	1/08/2024	0.64	0.22	2.05	0.09	64.72	0.17	0.30	4464	Aug	2024	NA
Monthly	MKY_AMB3B	NTU	1/09/2024	1.66	0.37	5.06	0.09	193.56	0.23	0.98	4279	Sep	2024	NA
Monthly	MKY_AMB3B	NTU	1/10/2024	1.21	0.40	3.34	0.19	99.06	0.33	0.61	4461	Oct	2024	NA
Monthly	MKY_AMB3B	NTU	1/11/2024	1.84	0.42	4.81	0.13	78.23	0.24	0.74	4318	Nov	2024	NA
Monthly	MKY_AMB3B	NTU	1/12/2024	2.00	0.48	5.32	0.13	66.95	0.33	0.76	4464	Dec	2024	NA
Monthly	MKY_AMB3B	NTU	1/01/2025	2.18	0.59	4.72	0.12	64.78	0.37	1.36	4329	Jan	2025	NA
Monthly	MKY_AMB3B	NTU	1/02/2025	9.52	4.95	12.10	0.28	149.36	1.72	12.58	4026	Feb	2025	NA
Monthly	MKY_AMB3B	NTU	1/03/2025	4.74	2.43	8.73	0.28	223.73	1.15	5.70	4437	Mar	2025	NA
Monthly	MKY_AMB3B	NTU	1/04/2025	4.85	1.22	8.74	0.08	133.77	0.66	5.79	4316	Apr	2025	NA
Monthly	MKY_AMB3B	NTU	1/05/2025	7.60	1.95	12.03	0.08	129.42	0.56	9.36	4411	May	2025	NA
Monthly	MKY_AMB3B	NTU	1/06/2025	0.90	0.37	1.61	0.03	48.32	0.24	0.95	3937	Jun	2025	NA
Seasonal	MKY_AMB3B	NTU	NA	2.26	0.39	6.32	0.03	193.56	0.24	0.97	25866	NA	NA	Dry
Seasonal	MKY_AMB3B	NTU	NA	4.12	0.94	8.25	0.08	223.73	0.45	4.12	25890	NA	NA	Wet
Fiscal	MKY_AMB3B	NTU	NA	3.19	0.57	7.40	0.03	223.73	0.31	2.18	51756	NA	NA	NA
Monthly	MKY_AMB5	NTU	1/07/2024	6.31	0.57	16.50	0.17	141.32	0.35	1.40	4462	Jul	2024	NA
Monthly	MKY_AMB5	NTU	1/08/2024	0.47	0.24	0.96	0.07	15.22	0.18	0.33	4464	Aug	2024	NA
Monthly	MKY_AMB5	NTU	1/09/2024	4.97	0.34	11.75	0.08	115.12	0.20	3.27	4320	Sep	2024	NA
Monthly	MKY_AMB5	NTU	1/10/2024	4.28	0.83	10.58	0.21	117.16	0.48	1.81	4446	Oct	2024	NA
Monthly	MKY_AMB5	NTU	1/11/2024	4.93	0.76	14.20	0.17	144.24	0.50	1.32	4277	Nov	2024	NA
Monthly	MKY_AMB5	NTU	1/12/2024	11.97	0.60	39.57	0.19	418.19	0.37	2.10	3814	Dec	2024	NA

Monthly	MKY_AMB5	NTU	1/01/2025	13.76	2.30	24.17	0.20	251.57	0.59	16.02	4463	Jan	2025	NA
Monthly	MKY_AMB5	NTU	1/02/2025	45.56	20.16	56.79	0.60	355.70	7.13	62.56	4017	Feb	2025	NA
Monthly	MKY_AMB5	NTU	1/03/2025	28.21	12.41	42.57	0.69	447.70	3.61	32.13	4464	Mar	2025	NA
Monthly	MKY_AMB5	NTU	1/04/2025	34.37	6.03	55.93	0.40	344.38	2.36	38.79	4319	Apr	2025	NA
Monthly	MKY_AMB5	NTU	1/05/2025	28.42	3.80	44.24	0.30	375.99	1.01	40.67	4429	May	2025	NA
Monthly	MKY_AMB5	NTU	1/06/2025	2.22	0.39	4.10	0.11	49.65	0.29	2.23	4303	Jun	2025	NA
Seasonal	MKY_AMB5	NTU	NA	7.80	0.64	22.53	0.07	375.99	0.29	2.46	26424	NA	NA	Dry
Seasonal	MKY_AMB5	NTU	NA	23.10	3.97	43.94	0.17	447.70	0.90	23.02	25354	NA	NA	Wet
Fiscal	MKY_AMB5	NTU	NA	15.29	1.27	35.54	0.07	447.70	0.40	10.77	51778	NA	NA	NA
Monthly	MKY_AMB1	PAR	1/07/2024	20.81	0.07	37.31	-0.03	235.30	0.05	27.90	4460	Jul	2024	NA
Monthly	MKY_AMB1	PAR	1/08/2024	31.02	0.02	52.11	-0.06	253.71	-0.01	43.01	4464	Aug	2024	NA
Monthly	MKY_AMB1	PAR	1/09/2024	16.29	0.00	37.97	-0.05	237.88	-0.02	9.60	4320	Sep	2024	NA
Monthly	MKY_AMB1	PAR	1/10/2024	10.11	0.29	21.64	-0.03	179.89	0.26	8.63	4357	Oct	2024	NA
Monthly	MKY_AMB1	PAR	1/11/2024	10.87	0.27	23.26	-0.06	201.99	0.09	9.49	3259	Nov	2024	NA
Monthly	MKY_AMB1	PAR	1/12/2024	16.34	0.30	34.00	-0.04	289.65	-0.01	16.83	4189	Dec	2024	NA
Monthly	MKY_AMB1	PAR	1/01/2025	10.11	0.01	26.74	-0.06	264.72	-0.01	5.32	4175	Jan	2025	NA
Monthly	MKY_AMB1	PAR	1/02/2025	1.04	-0.21	6.01	-0.38	73.73	-0.24	-0.14	3984	Feb	2025	NA
Monthly	MKY_AMB1	PAR	1/03/2025	2.27	0.19	9.31	-0.38	117.59	0.18	0.26	4437	Mar	2025	NA
Monthly	MKY_AMB1	PAR	1/04/2025	3.99	0.06	10.77	-0.08	92.23	-0.05	1.92	4282	Apr	2025	NA
Monthly	MKY_AMB1	PAR	1/05/2025	4.83	-0.06	14.57	-0.09	127.63	-0.07	0.41	4464	May	2025	NA
Monthly	MKY_AMB1	PAR	1/06/2025	15.28	0.23	31.27	-0.07	237.03	0.21	11.07	4315	Jun	2025	NA
Seasonal	MKY_AMB1	PAR	NA	16.42	0.24	35.68	-0.09	253.71	-0.01	12.47	26380	NA	NA	Dry

Seasonal	MKY_AMB1	PAR	NA	7.29	0.16	21.60	-0.38	289.65	-0.04	2.45	24326	NA	NA	Wet
Fiscal	MKY_AMB1	PAR	NA	12.04	0.20	30.11	-0.38	289.65	-0.02	5.81	50706	NA	NA	NA
Monthly	MKY_AMB10	PAR	1/07/2024	47.32	0.02	80.02	-0.02	432.91	0.01	70.38	4460	Jul	2024	NA
Monthly	MKY_AMB10	PAR	1/08/2024	71.72	0.03	110.23	-0.04	466.53	0.00	118.02	4464	Aug	2024	NA
Monthly	MKY_AMB10	PAR	1/09/2024	45.86	0.10	86.44	-0.03	505.27	0.00	51.52	4320	Sep	2024	NA
Monthly	MKY_AMB10	PAR	1/10/2024	54.60	0.51	102.91	-0.03	592.70	0.00	60.74	4461	Oct	2024	NA
Monthly	MKY_AMB10	PAR	1/11/2024	48.69	0.51	93.76	-0.04	571.80	0.00	56.00	4316	Nov	2024	NA
Monthly	MKY_AMB10	PAR	1/12/2024	36.18	0.88	67.36	0.01	465.14	0.06	46.84	4464	Dec	2024	NA
Monthly	MKY_AMB10	PAR	1/01/2025	29.38	0.30	61.14	0.03	371.87	0.07	30.64	4464	Jan	2025	NA
Monthly	MKY_AMB10	PAR	1/02/2025	2.58	0.04	7.87	-0.08	93.05	-0.01	0.64	4031	Feb	2025	NA
Monthly	MKY_AMB10	PAR	1/03/2025	13.60	0.02	40.64	-0.08	266.88	-0.04	2.72	1978	Mar	2025	NA
Monthly	MKY_AMB10	PAR	1/04/2025	18.78	0.02	49.59	-0.03	310.98	0.00	6.86	3262	Apr	2025	NA
Monthly	MKY_AMB10	PAR	1/05/2025	18.40	0.01	49.79	-0.04	403.22	-0.01	6.34	4464	May	2025	NA
Monthly	MKY_AMB10	PAR	1/06/2025	40.50	0.03	73.68	-0.04	424.56	0.02	46.06	4316	Jun	2025	NA
Seasonal	MKY_AMB10	PAR	NA	46.43	0.03	87.68	-0.04	592.70	0.00	51.58	26485	NA	NA	Dry
Seasonal	MKY_AMB10	PAR	NA	26.71	0.08	63.86	-0.08	571.80	0.01	17.46	22515	NA	NA	Wet
Fiscal	MKY_AMB10	PAR	NA	37.37	0.07	78.26	-0.08	592.70	0.01	32.63	49000	NA	NA	NA
Monthly	MKY_AMB3B	PAR	1/07/2024	65.98	0.00	114.35	-0.06	531.77	-0.02	89.75	4165	Jul	2024	NA
Monthly	MKY_AMB3B	PAR	1/08/2024	94.41	0.04	140.14	-0.05	537.70	-0.02	164.86	4252	Aug	2024	NA
Monthly	MKY_AMB3B	PAR	1/09/2024	70.42	0.92	115.23	-0.05	543.37	-0.02	99.02	4180	Sep	2024	NA
Monthly	MKY_AMB3B	PAR	1/10/2024	69.78	0.65	93.45	0.08	310.22	0.09	153.68	68	Oct	2024	NA
Monthly	MKY_AMB3B	PAR	1/11/2024	47.53	4.47	75.31	0.03	293.84	0.06	62.17	492	Nov	2024	NA

Monthly	MKY_AMB3B	PAR	1/12/2024	46.99	1.07	80.75	0.03	406.97	0.07	62.75	3978	Dec	2024	NA
Monthly	MKY_AMB3B	PAR	1/01/2025	48.15	1.21	84.94	0.05	512.42	0.08	61.36	4267	Jan	2025	NA
Monthly	MKY_AMB3B	PAR	1/02/2025	4.95	0.08	15.94	-0.09	148.26	0.06	0.45	4026	Feb	2025	NA
Monthly	MKY_AMB3B	PAR	1/03/2025	18.58	0.00	49.94	-0.11	423.01	-0.07	8.14	3603	Mar	2025	NA
Monthly	MKY_AMB3B	PAR	1/04/2025	18.98	0.25	43.19	-0.10	262.97	0.11	9.62	4169	Apr	2025	NA
Monthly	MKY_AMB3B	PAR	1/05/2025	29.63	0.12	55.96	-0.08	330.75	0.08	32.19	2566	May	2025	NA
Monthly	MKY_AMB3B	PAR	1/06/2025	46.33	0.09	84.08	0.03	463.93	0.07	52.27	3937	Jun	2025	NA
Seasonal	MKY_AMB3B	PAR	NA	64.37	0.11	111.49	-0.08	543.37	-0.01	83.89	19168	NA	NA	Dry
Seasonal	MKY_AMB3B	PAR	NA	28.33	0.12	63.74	-0.11	512.42	0.07	18.30	20535	NA	NA	Wet
Fiscal	MKY_AMB3B	PAR	NA	45.73	0.12	91.79	-0.11	543.37	0.05	42.64	39703	NA	NA	NA
Monthly	MKY_AMB5	PAR	1/07/2024	40.78	-0.01	72.93	-0.05	367.41	-0.02	53.36	4445	Jul	2024	NA
Monthly	MKY_AMB5	PAR	1/08/2024	76.81	0.01	117.31	-0.06	463.33	-0.02	129.64	4464	Aug	2024	NA
Monthly	MKY_AMB5	PAR	1/09/2024	60.20	0.06	105.08	-0.06	529.88	-0.04	76.06	4308	Sep	2024	NA
Monthly	MKY_AMB5	PAR	1/10/2024	62.04	1.85	92.34	-0.08	398.62	-0.05	103.29	2668	Oct	2024	NA
Monthly	MKY_AMB5	PAR	1/11/2024	55.77	0.40	98.12	-0.08	484.36	-0.05	71.96	3829	Nov	2024	NA
Monthly	MKY_AMB5	PAR	1/12/2024	54.07	0.40	107.67	-0.04	567.70	0.00	57.64	3725	Dec	2024	NA
Monthly	MKY_AMB5	PAR	1/01/2025	27.66	0.11	59.66	-0.04	368.52	0.00	27.39	4455	Jan	2025	NA
Monthly	MKY_AMB5	PAR	1/02/2025	3.14	0.03	11.70	-0.02	114.12	0.02	0.28	2805	Feb	2025	NA
Monthly	MKY_AMB5	PAR	1/03/2025	NA	NA	NA	NA	NA	NA	NA	NA	Mar	2025	NA
Monthly	MKY_AMB5	PAR	1/04/2025	NA	NA	NA	NA	NA	NA	NA	NA	Apr	2025	NA
Monthly	MKY_AMB5	PAR	1/05/2025	NA	NA	NA	NA	NA	NA	NA	NA	May	2025	NA
Monthly	MKY_AMB5	PAR	1/06/2025	30.08	0.09	58.74	0.05	307.68	0.07	26.43	3940	Jun	2025	NA

Seasonal	MKY_AMB5	PAR	NA	53.85	0.09	93.86	-0.08	529.88	-0.02	73.09	19825	NA	NA	Dry
Seasonal	MKY_AMB5	PAR	NA	36.92	0.04	83.11	-0.08	567.70	0.00	29.23	14814	NA	NA	Wet
Fiscal	MKY_AMB5	PAR	NA	46.61	0.08	89.81	-0.08	567.70	-0.02	48.61	34639	NA	NA	NA
Monthly	MKY_AMB1	Temp	1/07/2024	20.34	20.55	0.80	18.35	21.53	19.66	21.06	4460	Jul	2024	NA
Monthly	MKY_AMB1	Temp	1/08/2024	21.00	20.85	1.56	18.41	24.27	19.88	22.30	4464	Aug	2024	NA
Monthly	MKY_AMB1	Temp	1/09/2024	23.62	23.61	0.46	22.45	25.26	23.26	23.93	4320	Sep	2024	NA
Monthly	MKY_AMB1	Temp	1/10/2024	25.80	25.77	0.95	23.92	27.83	24.98	26.67	4462	Oct	2024	NA
Monthly	MKY_AMB1	Temp	1/11/2024	27.68	27.75	0.61	26.46	29.34	27.10	28.26	4319	Nov	2024	NA
Monthly	MKY_AMB1	Temp	1/12/2024	28.61	28.68	0.56	27.23	29.77	28.18	29.05	4464	Dec	2024	NA
Monthly	MKY_AMB1	Temp	1/01/2025	28.98	28.99	0.73	27.62	30.41	28.29	29.62	4464	Jan	2025	NA
Monthly	MKY_AMB1	Temp	1/02/2025	27.69	27.63	0.45	26.87	29.04	27.39	27.88	4032	Feb	2025	NA
Monthly	MKY_AMB1	Temp	1/03/2025	27.74	27.52	0.54	26.96	29.40	27.30	28.15	4461	Mar	2025	NA
Monthly	MKY_AMB1	Temp	1/04/2025	26.54	26.08	0.85	25.19	28.06	25.84	27.65	4317	Apr	2025	NA
Monthly	MKY_AMB1	Temp	1/05/2025	23.81	23.75	0.64	22.02	25.89	23.41	24.04	4464	May	2025	NA
Monthly	MKY_AMB1	Temp	1/06/2025	20.98	20.49	0.99	19.70	22.86	20.11	21.93	4315	Jun	2025	NA
Seasonal	MKY_AMB1	Temp	NA	22.59	23.01	2.19	18.35	27.83	20.59	24.00	26485	NA	NA	Dry
Seasonal	MKY_AMB1	Temp	NA	27.88	27.86	1.01	25.19	30.41	27.30	28.54	26057	NA	NA	Wet
Fiscal	MKY_AMB1	Temp	NA	25.22	25.95	3.15	18.35	30.41	22.98	27.85	52542	NA	NA	NA
Monthly	MKY_AMB10	Temp	1/07/2024	20.35	20.64	0.75	18.34	21.56	19.64	21.00	4462	Jul	2024	NA
Monthly	MKY_AMB10	Temp	1/08/2024	21.05	21.15	1.53	18.71	24.03	19.72	22.29	4464	Aug	2024	NA
Monthly	MKY_AMB10	Temp	1/09/2024	23.62	23.55	0.48	22.66	25.17	23.27	23.91	4320	Sep	2024	NA
Monthly	MKY_AMB10	Temp	1/10/2024	25.84	25.71	0.93	24.14	27.57	25.08	26.80	4461	Oct	2024	NA

Monthly	MKY_AMB10	Temp	1/11/2024	27.76	27.81	0.57	26.55	28.79	27.21	28.27	4318	Nov	2024	NA
Monthly	MKY_AMB10	Temp	1/12/2024	28.70	28.82	0.63	27.02	29.82	28.27	29.22	4464	Dec	2024	NA
Monthly	MKY_AMB10	Temp	1/01/2025	29.04	29.16	0.66	27.65	30.16	28.45	29.61	4464	Jan	2025	NA
Monthly	MKY_AMB10	Temp	1/02/2025	27.64	27.57	0.42	26.77	28.70	27.33	27.95	4032	Feb	2025	NA
Monthly	MKY_AMB10	Temp	1/03/2025	27.80	27.57	0.57	26.85	29.22	27.37	28.21	4461	Mar	2025	NA
Monthly	MKY_AMB10	Temp	1/04/2025	26.56	26.13	0.82	25.48	28.04	25.87	27.56	4316	Apr	2025	NA
Monthly	MKY_AMB10	Temp	1/05/2025	23.90	23.80	0.62	22.61	25.92	23.51	24.10	4464	May	2025	NA
Monthly	MKY_AMB10	Temp	1/06/2025	21.11	20.57	0.99	19.95	23.12	20.25	22.08	4316	Jun	2025	NA
Seasonal	MKY_AMB10	Temp	NA	22.65	23.03	2.18	18.34	27.57	20.69	24.05	26487	NA	NA	Dry
Seasonal	MKY_AMB10	Temp	NA	27.93	27.88	1.02	25.48	30.16	27.34	28.61	26055	NA	NA	Wet
Fiscal	MKY_AMB10	Temp	NA	25.27	25.97	3.14	18.34	30.16	22.98	27.88	52542	NA	NA	NA
Monthly	MKY_AMB3B	Temp	1/07/2024	20.55	20.80	0.67	18.64	21.69	20.00	21.10	4461	Jul	2024	NA
Monthly	MKY_AMB3B	Temp	1/08/2024	20.74	20.65	1.31	18.44	23.31	19.69	21.80	4464	Aug	2024	NA
Monthly	MKY_AMB3B	Temp	1/09/2024	23.39	23.33	0.34	22.41	24.52	23.18	23.59	4320	Sep	2024	NA
Monthly	MKY_AMB3B	Temp	1/10/2024	25.61	25.42	0.92	24.13	27.51	24.84	26.41	4461	Oct	2024	NA
Monthly	MKY_AMB3B	Temp	1/11/2024	27.68	27.73	0.44	26.77	28.86	27.26	28.05	4318	Nov	2024	NA
Monthly	MKY_AMB3B	Temp	1/12/2024	28.62	28.67	0.52	27.34	29.56	28.25	29.10	4464	Dec	2024	NA
Monthly	MKY_AMB3B	Temp	1/01/2025	28.97	29.06	0.53	27.98	30.02	28.49	29.39	4464	Jan	2025	NA
Monthly	MKY_AMB3B	Temp	1/02/2025	27.73	27.71	0.40	26.53	28.70	27.46	28.01	4026	Feb	2025	NA
Monthly	MKY_AMB3B	Temp	1/03/2025	27.79	27.63	0.47	27.07	29.05	27.43	28.11	4464	Mar	2025	NA
Monthly	MKY_AMB3B	Temp	1/04/2025	26.57	26.11	0.77	25.56	27.86	25.90	27.57	4316	Apr	2025	NA
Monthly	MKY_AMB3B	Temp	1/05/2025	24.05	23.94	0.58	22.96	25.84	23.65	24.25	4464	May	2025	NA

Monthly	MKY_AMB3B	Temp	1/06/2025	21.34	20.85	0.98	20.12	23.82	20.45	22.27	4317	Jun	2025	NA
Seasonal	MKY_AMB3B	Temp	NA	22.62	22.99	2.07	18.44	27.51	20.80	24.01	26487	NA	NA	Dry
Seasonal	MKY_AMB3B	Temp	NA	27.90	27.89	0.94	25.56	30.02	27.41	28.52	26052	NA	NA	Wet
Fiscal	MKY_AMB3B	Temp	NA	25.24	25.91	3.10	18.44	30.02	22.98	27.88	52539	NA	NA	NA
Monthly	MKY_AMB5	Temp	1/07/2024	20.53	20.81	0.67	19.01	21.50	19.93	21.12	4462	Jul	2024	NA
Monthly	MKY_AMB5	Temp	1/08/2024	20.96	21.01	1.35	18.84	23.56	19.82	22.06	4464	Aug	2024	NA
Monthly	MKY_AMB5	Temp	1/09/2024	23.56	23.52	0.41	22.78	24.88	23.25	23.80	4320	Sep	2024	NA
Monthly	MKY_AMB5	Temp	1/10/2024	25.82	25.66	1.02	24.20	27.55	24.97	26.94	4462	Oct	2024	NA
Monthly	MKY_AMB5	Temp	1/11/2024	27.86	27.86	0.54	26.93	28.84	27.34	28.39	4317	Nov	2024	NA
Monthly	MKY_AMB5	Temp	1/12/2024	28.75	28.82	0.55	27.55	29.67	28.34	29.26	4464	Dec	2024	NA
Monthly	MKY_AMB5	Temp	1/01/2025	29.07	29.20	0.61	27.91	30.43	28.57	29.53	4464	Jan	2025	NA
Monthly	MKY_AMB5	Temp	1/02/2025	27.73	27.77	0.40	27.02	28.67	27.40	28.07	4029	Feb	2025	NA
Monthly	MKY_AMB5	Temp	1/03/2025	27.75	27.54	0.55	27.03	29.07	27.34	28.10	4464	Mar	2025	NA
Monthly	MKY_AMB5	Temp	1/04/2025	26.52	26.11	0.80	25.53	27.93	25.83	27.52	4320	Apr	2025	NA
Monthly	MKY_AMB5	Temp	1/05/2025	23.94	23.79	0.57	22.79	25.71	23.57	24.14	4464	May	2025	NA
Monthly	MKY_AMB5	Temp	1/06/2025	21.35	20.77	0.96	20.25	23.40	20.52	22.30	4310	Jun	2025	NA
Seasonal	MKY_AMB5	Temp	NA	22.70	23.04	2.10	18.84	27.55	20.82	24.00	26482	NA	NA	Dry
Seasonal	MKY_AMB5	Temp	NA	27.96	27.98	1.01	25.53	30.43	27.36	28.64	26058	NA	NA	Wet
Fiscal	MKY_AMB5	Temp	NA	25.31	25.89	3.11	18.84	30.43	23.03	27.97	52540	NA	NA	NA

APPENDIX C QUALITY CONTROL

To support the ongoing use of high-resolution in-situ loggers within the NQBP ambient monitoring program, a standardised and science-based quality control (QC) framework has been applied consistently across recent reporting years. This QC process is derived from internationally recognised Real-Time Oceanographic Data Quality Control (QARTOD) procedures (NOAA, 2020), which are widely adopted by CSIRO, IMOS and AIMS. The same framework has now been embedded in the program for several years, providing a robust and repeatable approach to ensuring confidence in long-term logger datasets.

Logger data undergo both automated and manual QC steps. The automated workflow applies 12 objective tests (Table A6), which evaluate sensor performance, environmental plausibility, stability, and instrument integrity. Each result is assigned a QC flag: ‘good data’ (green), ‘probably good data’ (blue), ‘probably bad data’ (yellow), or ‘bad data’ (red). These flags allow users to make transparent, reproducible decisions about data suitability for different applications.

Table A- 1 QC tests applied to logger data

QC rule 1: Syntax test	QC rule 7: Spike test
QC rule 2: Impossible date test	QC rule 8: Rate of change test
QC rule 3: In/out-water test	QC rule 9: Stationary test
QC rule 4: Global range test	QC rule 10: Standard deviation test
QC rule 5: Regional range tests	QC rule 11: Burst count test
QC rule 6: Impossible depth test	QC rule 12: Orientation test

Each logger includes four core sensors—temperature, depth, tilt, and either turbidity (NTU) or photosynthetically active radiation (PAR). For every 10-minute interval, the ‘worst’ QC flag from tests 1–12 is retained for that sensor, providing a conservative assessment of data reliability. Figures A 1 – A4 presents the QC-flagged datasets for the current reporting period, while Figure A-5 summarises the proportion of records in each QC category for every parameter.

For most analyses, ‘good’ and ‘probably good’ data are considered fit-for-purpose, while ‘probably bad’ data may be usable with caution depending on context. ‘Bad’ data should be excluded. Data with specific QC categories can be easily filtered or masked in Excel, R, Python, or other data management platforms. Figure A-3 shows the

A full technical description of the QC methodology, test definitions and implementation is provided in the TropWATER technical report (Iles et al., 2023), available on the TropWATER website.

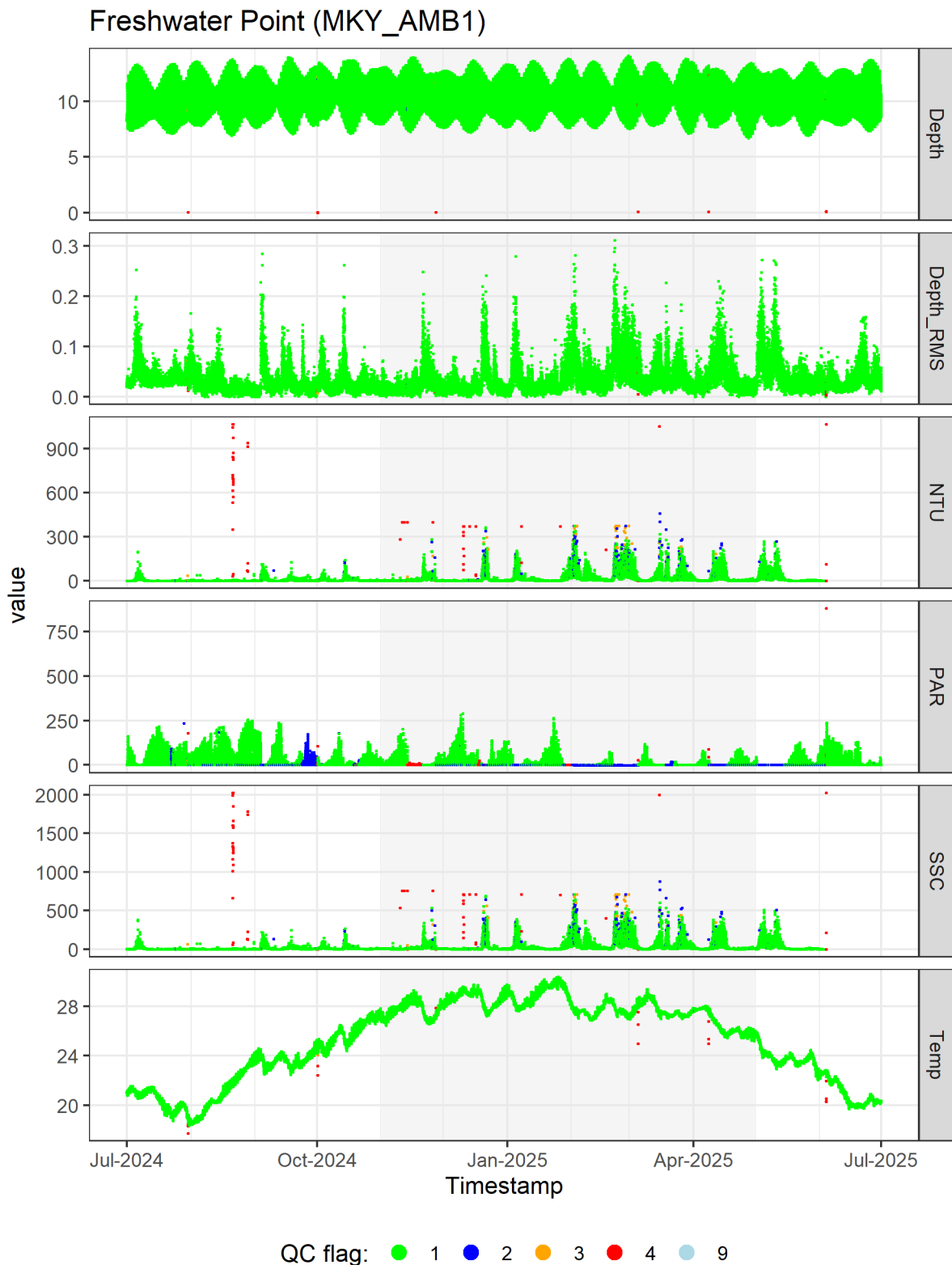


Figure A 1 Raw data collected at Freshwater Point with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

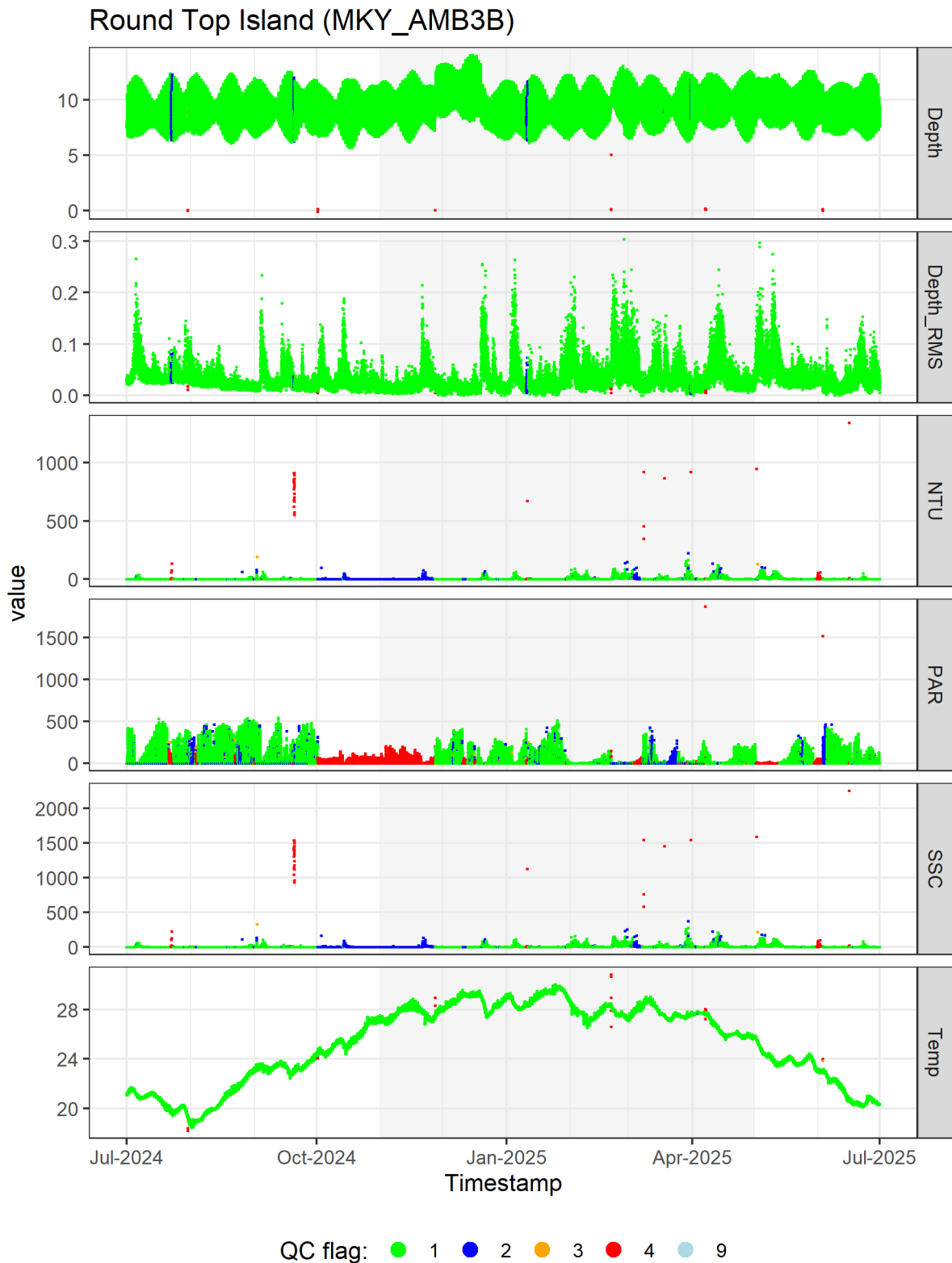


Figure A 2 Raw data collected at Round Top Island with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

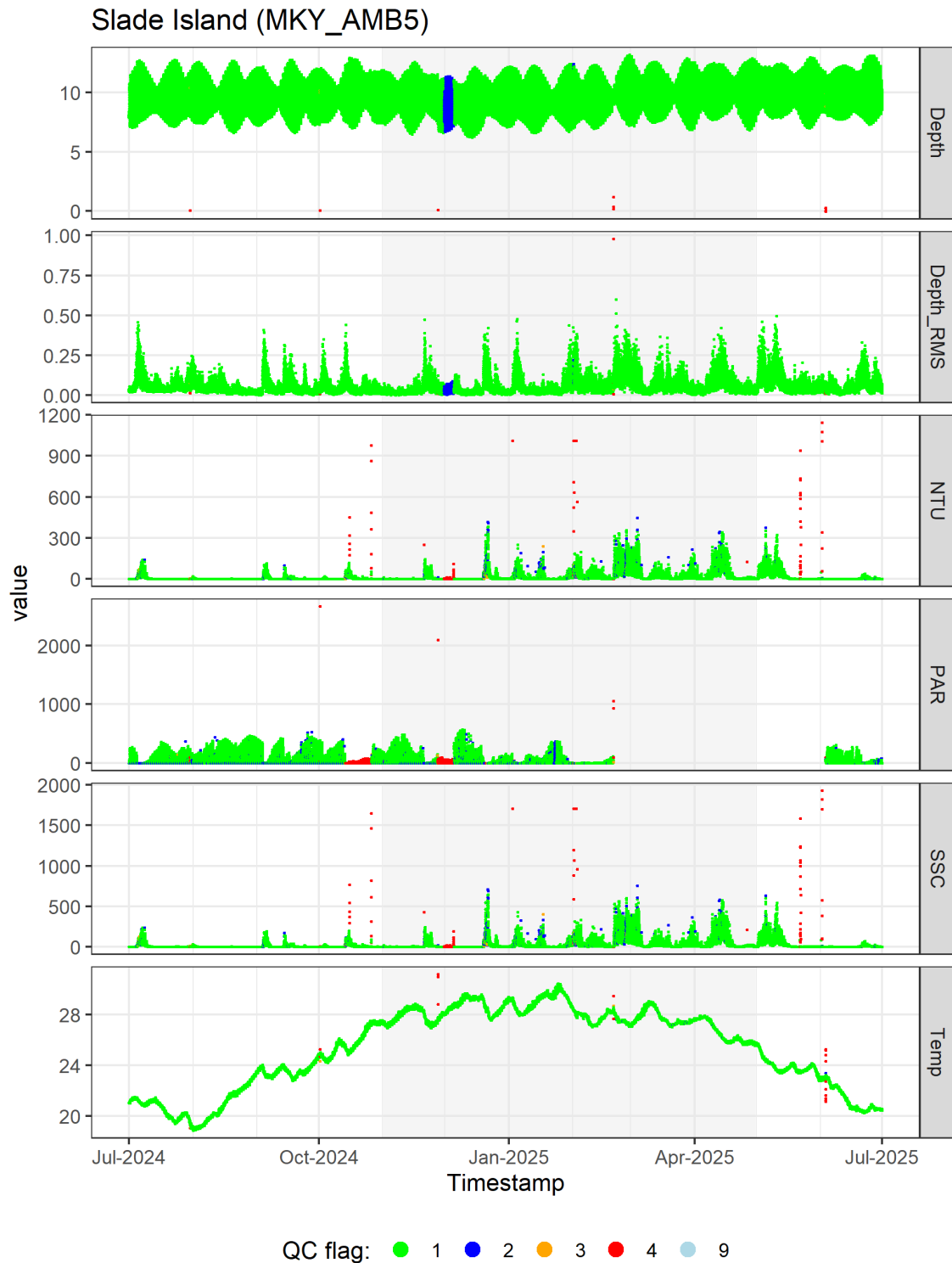


Figure A 3 Raw data collected at Slade Island with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

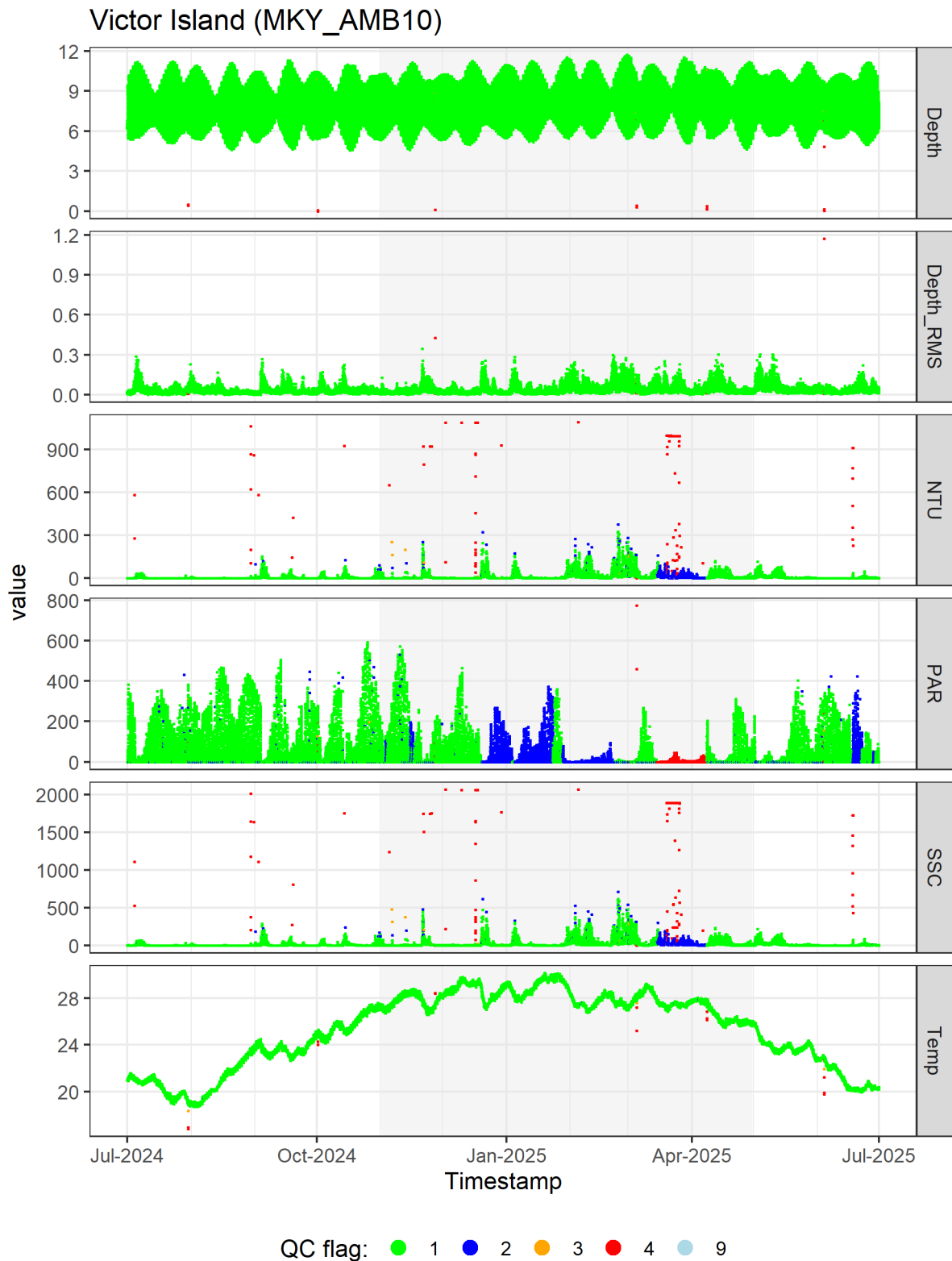


Figure A 4 Raw data collected at Victor Island with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

Data Recovery

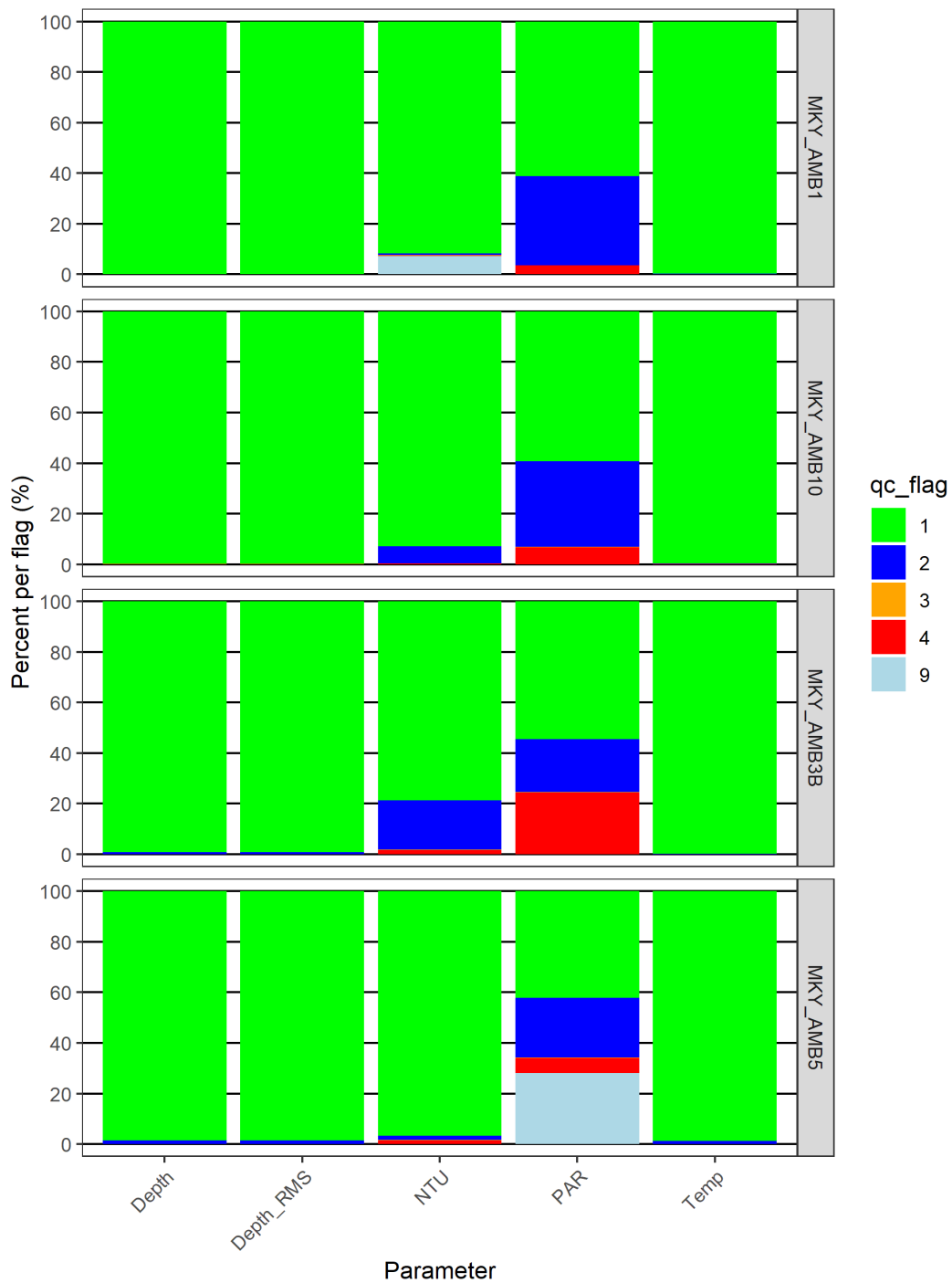


Figure A 5 Logger data recovery statistics for the Mackay and Hay Point monitoring sites over the reporting period.

APPENDIX D GAMM MODEL OUTPUTS

Table A- 2 Summary of Generalised Additive Mixed Model (GAMM) results for chlorophyll-*a*, showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.19257    0.06973  -2.762  0.00596 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df    F p-value
s(Month) 2.697    3 12.91 <2e-16 ***
s(Time)  1.000    1  2.57   0.11
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0623
Scale est. = 0.80869    n = 508
      k'      edf    k-index p-value
s(Month)  3 2.696818 0.9102315   0.085
s(Time)   19 1.000000 0.7460750   0.000
```

Table A- 3 Summary of Generalised Additive Mixed Model (GAMM) results for Phaeophytin-*a*, showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.6189    0.4741  -1.305   0.192

Approximate significance of smooth terms:
      edf Ref.df    F p-value
s(Month) 1.395    3  1.156  0.076 .
s(Time)  1.000    1  0.780  0.377
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = -0.000541
Scale est. = 114.86    n = 512
      k'      edf    k-index p-value
s(Month)  3 1.394874 0.5606653  0.0100
s(Time)   19 1.000001 0.5250946  0.0025
```

Table A- 4 Summary of Generalised Additive Mixed Model (GAMM) results for conductivity, showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.88905    0.00381   2858  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Ref.df      F p-value
s(Month)    2.553   3.00 10.46  <2e-16 ***
s(Time)    13.809  13.81 16.12  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.345
Scale est. = 0.0011115 n = 506
              k'      edf k-index p-value
s(Month)    3  2.553388 0.9567618 0.1675
s(Time)    19 13.808873 0.8348152 0.0050
```

Table A- 5 Summary of Generalised Additive Mixed Model (GAMM) results for particulate nitrogen (PN), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.37054    0.06246   53.97  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Ref.df      F p-value
s(Month)    1.998   3.000  4.749 0.000334 ***
s(Time)     6.109   6.109  2.932 0.007364 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0792
Scale est. = 2.0051 n = 515
              k'      edf k-index p-value
s(Month)    3  1.998492 0.8946861 0.67
s(Time)    19  6.109065 0.7184913 0.00
```

Table A- 6 Summary of Generalised Additive Mixed Model (GAMM) results for total dissolved nitrogen (TDN), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.72640    0.02059   229.6  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df    F p-value
s(Month) 2.732  3.000 4.621 0.00196 **
s(Time)   2.777  2.777 19.889 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.113
Scale est. = 0.049169 n = 517
      k'    edf k-index p-value
s(Month)  3  2.732304 0.9601777 0.2275
s(Time)   19 2.777358 0.6628685 0.0000
```

Table A- 7 Summary of Generalised Additive Mixed Model (GAMM) results for total nitrogen (TN), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.93811    0.02395   206.2  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df    F p-value
s(Month) 2.706  3.00 7.680 1.05e-05 ***
s(Time)  14.272 14.27 6.895 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.199
Scale est. = 0.079891 n = 510
      k'    edf k-index p-value
s(Month)  3  2.705829 0.8862358 0.0075
s(Time)   19 14.272428 0.7738054 0.0000
```

Table A- 8 Summary of Generalised Additive Mixed Model (GAMM) results for particulate phosphorous (PP), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.08067    0.04974   21.73  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df    F  p-value
s(Month) 2.046     3 4.79 0.000378 ***
s(Time)   1.000     1 0.11 0.740778
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0223
Scale est. = 0.91941 n = 514
      k'    edf k-index p-value
s(Month)  3 2.046334 0.8982217 0.1775
s(Time)   19 1.000000 0.8354334 0.0125
```

Table A- 9 Summary of Generalised Additive Mixed Model (GAMM) results for total dissolved phosphorous (TDP), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.99653    0.03618   55.18  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df    F  p-value
s(Month) 2.498  3.000 17.66  <2e-16 ***
s(Time)   6.864  6.864 11.32  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.187
Scale est. = 0.11941 n = 517
      k'    edf k-index p-value
s(Month)  3 2.498220 0.9278870 0.095
s(Time)   19 6.864399 0.7084751 0.000
```

Table A- 10 Summary of Generalised Additive Mixed Model (GAMM) results for total phosphorous (TP), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.33840    0.03678   63.58  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df      F p-value
s(Month) 1.976   3.00 4.221 0.000788 ***
s(Time)   4.630   4.63 7.503 5.15e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.084
Scale est. = 0.18042 n = 516
      k'      edf k-index p-value
s(Month)  3 1.975731 0.9591242 0.2125
s(Time)   19 4.630470 0.7646477 0.0000
```

Table A- 11 Summary of Generalised Additive Mixed Model (GAMM) results for total suspended solids (TSS), showing the fitted smooth terms for month (seasonality) and time (long-term trend).

```
Family: Gamma
Link function: log

Formula:
value ~ s(Month, fx = FALSE, bs = "cc", k = 5) + s(Time, fx = FALSE,
  bs = "tp", k = 20)

Parametric coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.99083    0.09223   10.74  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
      edf Ref.df      F p-value
s(Month) 1.802   3.000  2.591 0.0095 **
s(Time)   4.398   4.398 22.486 <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.161
Scale est. = 0.4122 n = 312
      k'      edf k-index p-value
s(Month)  3 1.802146 0.8987739 0.0475
s(Time)   19 4.397548 0.7307422 0.0000
```