Southern Mackay Ambient Marine Water Quality Monitoring Program: Annual Report 2023-2024

Southern Mackay Ambient Marine Water Quality Monitoring Program: Annual Report 2023-2024

A Report for Healthy Rivers to Reef Partnership

Report No. 24/86

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1 Introduction

1.1 Program outline

The Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University (JCU) has been commissioned to assist the Healthy Rivers to Reef Partnership to collect marine water quality data for the southern Mackay region as part of the Mackay-Whitsunday-Isaac regional report card. The report card is released each year, providing an overview of the health and condition of regional catchments, rivers, creeks, and nearshore habitats along this section of the Great Barrier Reef coastline. The information will be used to set strategic and collaborative management action plans to protect the regions marine, freshwater, and estuarine ecosystems. This report has been prepared for the 2023-2024 water quality monitoring period.

Figure 1-1: James Cook University research vessel 'Kasmira' enroute to Aquila Island ready to conduct water quality monitoring in the Southern Mackay region.

1.2 Background

Declining water quality in coastal and marine ecosystems is a major concern for the future of the GBR (Kroon et al., 2016; Brodie et al., 2019; Waterhouse et al., 2022). While major impact events such as cyclones and marine heatwaves cause the most destruction to the reef, water quality is the primary determinant for both resilience to, and recovery of corals in the face of these events (Lam et al., 2018; McNeil et al., 2019). Water quality risks to the GBR include an increased load of fine sediments, nutrients (nitrogen and phosphorous), and pesticides/herbicides that originate from diffuse agricultural sources throughout the catchments and are discharged into the GBR lagoon (Waterhouse et al., 2017). The poor water quality, exacerbated by extreme weather events, continues to be a major pressure on the GBR and will potentially worsen under climate change (Great Barrier Reef Marine Park Authority, 2014). The Reef 2050 plan (Queensland Government, 2018) contains a water quality theme with actions, targets and objectives to address these threats and enable timely and suitable responses to emerging issues and risks.

1.3 Program objectives

As the southern Mackay and Isaac coasts lie within the Great Barrier Reef region, the primary objective of the program is to characterise variability in water quality by monitoring a suite of key parameters to better define potential impacts to water quality. Along with regular monitoring of water quality parameters, an understanding of the meteorological and oceanographic (metocean) conditions that affect the regions coastal ecosystems is important in understanding seasonal and interannual variability in water quality. The extensive marine monitoring program implemented by TropWATER is designed to characterise the ambient water quality so that potential impacts to habitats can be identified. The partnership's objective also moves beyond basic environmental stewardship and incorporates robust scientific research initiatives undertaken by leading researchers and specialists in marine water quality, coastal habitat, seagrass, coral ecology, and natural resource management. The long-term acquisition of data under the partnership presents an invaluable resource for understanding the interannual variability and climatic influences that drive water quality and ecological processes along coastal Queensland.

2 Methods

2.1 Regional Description

The southern Mackay and Isaac region is situated on the central Queensland Coast between Mackay and St Lawrence (Figure 2-1). There is an extensive agricultural presence along the coastal plain, interspersed by several creek systems that link to the marine environment. This section of the Queensland coastline is characterised by large tidal ranges (up to 8 metres) with the adjacent (to the south) Broad Sound and Shoalwater Bay marine areas being the largest shallow macro-tidal bays on Australia's east coast. Strong tidal currents are therefore a feature across this inshore region, often resulting in highly turbid water due to tidal resuspension of bottom sediments (Kleypas 1996). Despite the sediment load, the Northumberland Islands group within this region support a high cover of coral in both incipient (lacking a reef flat) and fringing reef systems (Cheal et al., 2001).

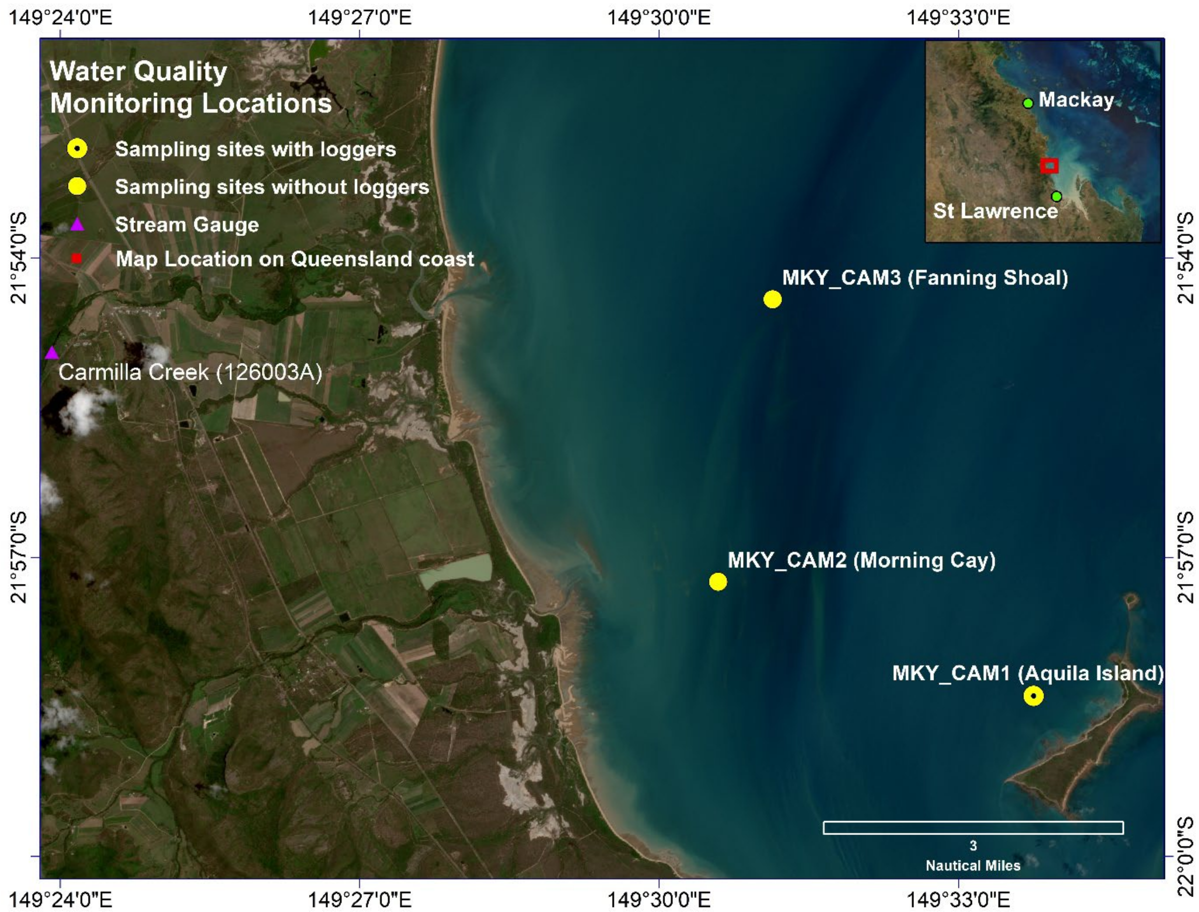

Figure 2-1. Map of the southern Mackay region where water quality monitoring locations (yellow circles), monitoring locations with loggers (yellow/black circle), and the stream gauge (purple triangle) referred to in this report, are located.

2.2 Characterisation of weather, hydrological status, and oceanographic conditions

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 31st March. 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 extracted from Queensland Government open data portal (https://www.data.qld.gov.au/) comprising of the significant wave height (Hs), 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 buoy located at Bailey Reef, 19 nautical miles offshore from Mackay Harbour. Note that this wave buoy is approximately 50 nautical miles north of the southern Mackay monitoring sites and may not be representative of the wave energy experienced at these sites, particularly when the wave direction is from a south-easterly direction, as the southern Mackay region is somewhat protected from this aspect by Cape Townshend and Stanage Point.

2.3 Monitoring and sampling design

The southern Mackay region has three active ambient marine water quality monitoring sites (Figure 2-1, Table 2.1) that were established in September 2017 as part of a broader regional program (see Waltham, Iles and Cartwright, 2022). Ambient water quality monitoring consisting of water samples that are laboratory analysed and spot measurements with a multiparameter instrument were conducted at all three sites approximately every 6-8 weeks (Table 2-2). One site (Aquila Island) also has a pair of data loggers deployed on the seafloor to continuously record environmental data. Regular change-out of loggers to perform sensor maintenance and download data from the instruments occurred in parallel with the water sampling. The sites were chosen to align with key sensitive receptor habitats (e.g., corals or seagrass), and key features in the study region (e.g. river flow points). Coral and seagrass receptor habitat assessments are available in companion reports on the TropWATER website (www.tropwater.com).

Water samples were collected from 0.2 m below water surface by hand. Samples were collected for analytical determination of total nitrogen, total phosphorus, total dissolved nitrogen, total dissolved phosphorus, pH, salinity, electrical conductivity, total suspended solids, chlorophyll-*a* and phaeophytin-*a* (Table 2.3). Dissolved nutrient samples were filtered onsite with a 0.45 µm syringe filter (Sartorius minisart PES 0.45). TSS samples were collected in a 1 L bottle, Chlorophyll-*a* was collected in a dark 1 L bottle, pH and salinity were collected in a 60 mL vial. Water samples were stored on ice immediately and transported to the laboratory for analysis.

Water for chlorophyll determination was filtered through a Whatman 0.45 µm GF/F glass-fibre filter with the addition of approximately 0.2 mL of magnesium carbonate within (less than) 12 hours after collection. Filters were then wrapped in aluminum foil and frozen. Pigment determinations from acetone extracts of the filters were completed using spectrophotometry, following the methodology described in 'Standard Methods for the Examination of Water and Wastewater, 10200 H. Chlorophyll'.

Table 2-1. Location of water quality monitoring sites in the Southern Mackay region.

Site name	Site code	Latitude	Longitude	Av Depth (m)	Loggers deployed
Aquila Island	MKY_CAM1	-21.97	149.55	9	Yes
Morning Cay	MKY_CAM2	-21.95	149.50	10	No
Fanning Shoal	MKY_CAM3	-21.90	149.52	11	No

Table 2-2. Field dates in the 2021-22 reporting period for water sampling, logger maintenance and pesticide sampling at the southern Mackay monitoring locations. Note that pesticide sampling and logger maintenance was only undertaken at Aquila Island.

Date	Water sampling	Logger maintenance	Pesticides
2023-07-18	Yes	Yes	No
2023-09-05	Yes	Yes	No
2023-10-26	Yes	Yes	Yes
2023-12-07	Yes	Yes	Yes
2024-01-16	Yes	Yes	Yes
2024-02-28	Yes	Yes	Yes
2024-04-17	Yes	Yes	No

Physiochemical parameters were measured at three depths in the water column with a multiparameter water quality meter (Hydrolab Quanta, Hydrolab CO, USA). The water quality meter records water temperature, electrical conductivity, pH, % saturation oxygen, and dissolved oxygen (Table 2-4). The three measurement depths were surface (0.25 m below surface), mid-water, and bottom (1 m above seafloor). Photosynthetically active radiation (PAR) was measured at the three depths, and above water with an underwater quantum sensor (LI-192) and light meter (LI-250A) (Licor Biosciences, Nebraska USA). Care was taken to measure PAR without interference of sporadic cloud cover or boat shadow, though occasionally this was unavoidable.

Water clarity as measured with a Secchi disk was recorded at each site at the time of water sampling. A Secchi disk was lowered to a depth where it is no longer visible then raised back to depth where it becomes visible again. The mean depth between those two points was then recorded as Secchi disk depth.

Table 2-3. Water quality parameters that were analysed using water samples collected at three locations, Aquila Island, Morning Cay and Fanning Shoal, 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-NO3- 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	-
Nitrogen oxides (NOx)	4500-NO3 - F	1 µg N L-1
Chlorophyll		
Chlorophyll-a	10200-H	0.2 µg L-1
Phaeophytin-a		

Table 2-4. Physiochemical measurements that were collected at three locations, Aquila Island, Morning Cay, and Fanning Shoal.

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

2.4 Pesticide monitoring

Passive samplers were deployed at Aquila Island (MKY_CAM1) for pesticide monitoring over the wet season (Figure 2.2, Table 2.5). Each set of passive samplers contained an Empore™ SPE disk (ED), and a passive flow monitor (PFM). Passive samplers were supplied and analysed by Queensland Alliance for Environmental Health Sciences (QAEHS) at The University of Queensland. Samplers were extracted and the extract then analysed by liquid chromatography mass spectrometry (LCMS) for polar pesticides. An additional 10% samplers were deployed, extracted, and analysed for QA/QC purposes, which also included lab and field blanks, duplicates, and matrix recovery spikes. Water concentration estimates (either time weighted average or point in time) were calculated where possible, otherwise mass loads per sampler are given. Water concentration estimates are derived by applying sampling rates from calibration studies to the amount of analyte accumulated by the sampler. The twenty-two herbicides and insecticides used to calculate pesticide risk metrics (ms-PAF) are listed in Table 2.6.

Figure 2-2. Pesticide monitoring passive samplers such as these were retrieved from Aquila Island (MKY_CAM1) over the reporting period (Table 2-5). Note: biological growth on the samplers.

Table 2-5. Pesticide passive samplers deployed at Aquila Island (MKY_CAM1) during the 2021-2022 wet season.

Site name	Site code	Start date	End date	Duration (days)
Aquila Island	MKY_CAM1	2023-10-26	2022-12-07	42
Aquila Island	MKY_CAM1	2023-12-07	2023-02-01	40
Aquila Island	MKY_CAM1	2024-01-16	2024-02-28	43
Aquila Island	MKY_CAM1	2024-02-28	2023-04-17	49

Table 2-6. Pesticide analytes used for ms-PAF calculations to determine the pesticide risk baseline. Column two shows 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
Haloxyfop	OH	ED	1 ng sampler-1
Hexazinone	PSII	ED	1 ng sampler-1
Imidacloprid	I	ED	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
Pendimethalin	OH	ED	5 ng sampler-1
Prometryn	PSII	ED	1 ng sampler-1
Simazine	PSII	ED	1 ng sampler-1
Tebuthiuron	PSII	ED	1 ng sampler-1
Terbuthylazine	PSII	ED	1 ng sampler-1

2.5 Seafloor mounted continuous dataloggers

A pair of water quality loggers were deployed at Aquila Island (MKY_CAM1) to measure water temperature, water depth, turbidity, and light. The loggers were attached to stainless steel frame to be placed on the seafloor (Figure 2.3). The loggers used are NTU-LPT and MS9-LPT loggers manufactured by In-situ Marine Optics, Perth WA (https://insitumarineoptics.com). The loggers record a burst of 50 measurements of water temperature (°C), water depth (m), turbidity (NTU), and light (PAR, µmol m^{-2} s^{-1}) at a frequency of 5 Hz every 10-minutes.

Figure 2-3. Water quality loggers attached to instrument frames ready for deployment to the seabed. The horizontally orientated logger is an NTU-LPT turbidity logger, and the vertically orientated logger is a MS9-LPT multispectral light logger manufactured by Insitu Marine Optics.

Table 2-7. 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 NTU	0.05 NTU
Irradiance	µW cm^{-2} nm^{-1}	0 – 400 µW cm^{-2} nm^{-1}	2.5 x 10^{-3} W cm^{-2} nm^{-1}

Logger data processing
After each deployment, dataloggers are returned to the laboratory and their logfiles downloaded. The mean values for water temperature, water depth, turbidity and irradiance were calculated for each 10-minute burst interval.

RMS Depth
A pressure sensor is located on the MS9-LPT water quality logging instrument. The pressure sensor is used to determine changes in water depth due to tide and to produce a proxy for wave action. The average water depth and Root Mean Square (RMS) water depth can be used to analyse the influence that tide and water depth may have on turbidity, deposition, and light levels at an instrument location. The RMS water height is a measure of short-term variation in pressure at the sensor. Changes in pressure over a 10 second time-period at the sensor are caused by wave energy. RMS water height can be used to analyse the link between wave re-suspension and SSC. It is important to clearly establish that RMS water height is not a measurement of wave height at the sea surface. What it does provide is a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. For example, where two sites both have the same surface wave height, if site one is 10 m deep and has a measurement of 0.01 RMS water height and site two is 1m deep and has a measurement of 0.08 RMS water height. Even though the surface wave height is the same at both sites, the RMS water height is greater at the shallower site, and we would expect more re-suspension due to wave shear stress at this site.

Each time a pressure measurement is made the pressure sensor takes 50 measurements over a period of 10 seconds. From these 50 measurements, average water depth (m) and Root Mean Square (RMS) water height are calculated.

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

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

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

bPAR
Photosynthetically active radiation (PAR) was calculated from the response of the nine individual irradiance channels on the MS9 logger. Light data between 400 and 700 nm was interpolated and integrated internally. The mean value for PAR was calculated for each 10-minute burst interval.

Daily light integral (DLI) describes the number of photosynthetically active photons that are delivered to a specific area over a 24-hour period.

Daily light integral (DLI) was calculated as follows:

$$DLI = \sum_i PAR_i * \frac{600}{1000000}$$ [Equation 2]

Where:

DLI is the daily light integral in mol photons m^{-2} d^{-1}

i is each PAR reading during the day

PAR is the photosynthetically active radiation in µmol photons m^{-2} s^{-1}

600 is the time interval between readings

1,000,000 is the unit conversion

Suspended Sediment Concentration

Suspended sediment concentration was calculated from turbidity data after establishing a relationship with each site. Full methods are provided in (Cartwright, Iles, Mattone, O'Callaghan, & Waltham, 2022).

The following equation may be used to calculate suspended sediment concentration from logger data acquired from IMO-NTU turbidity loggers at each site:

$$SSC = Turb * Cf \pm e$$ [Equation 3]

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.

Quality control

During logger processing the data is passed through automatic and manual quality control steps to flag data. The automated QC steps are rule-based tests. Manual QC follows the automated steps to catch anything missed or which is difficult for machine to detect. A concise description of rules for flagging data is in Appendix 1. More detail of the data processing workflow and quality control procedures is contained in a separate document (Iles, Cartwright, Johns, & Waltham, 2023).

Statistical summaries for each water quality parameter measured are provided in the results section. Annual values (mean, median, minimum, maximum) are calculated over the twelve-month period corresponding to both the water year and reporting period (July 2023 to June 2024). Data collected over the monitoring period has been compared to the Pioneer River and Plane Creek Basins Environmental Values and Water quality objectives (EPP, 2019). The three Southern Mackay sites are in water area/type SD2383 open coastal waters (including macrotidal) landward of the plume line, shown in WQ1222 (s3, s4).

3 Results and Discussion

3.1 Rainfall and river flows

Daily rainfall for the Mackay region is shown in Figure 3.1. The northern wet season is defined as between 1st November and 30th April, whereas the annual rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September, and hence is a better indication of the start of the wet season. Comparatively, this year's onset was later than average for Mackay, occurring on 7th November 2023, with total wet season rainfall of 1361 mm.

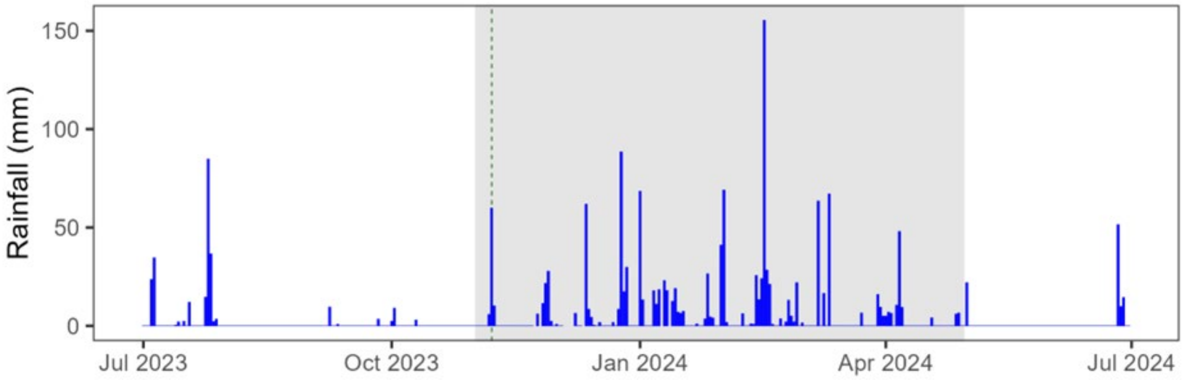

Figure 3-1. Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the 2023-2024 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

The first rainfall greater than 5 mm for the full water year occurred on 4th July 2023, while total rainfall for the water year was 1703 mm (Figure 3.2). There was a notable dry season rainfall event totalling 141 mm over five consecutive days in late July 2023. Most of the rainfall fell throughout the wet season, with the largest rainfall event of the year occurring from the 13th to 18th February 2024, with rainfall totalling 270 mm over five days.

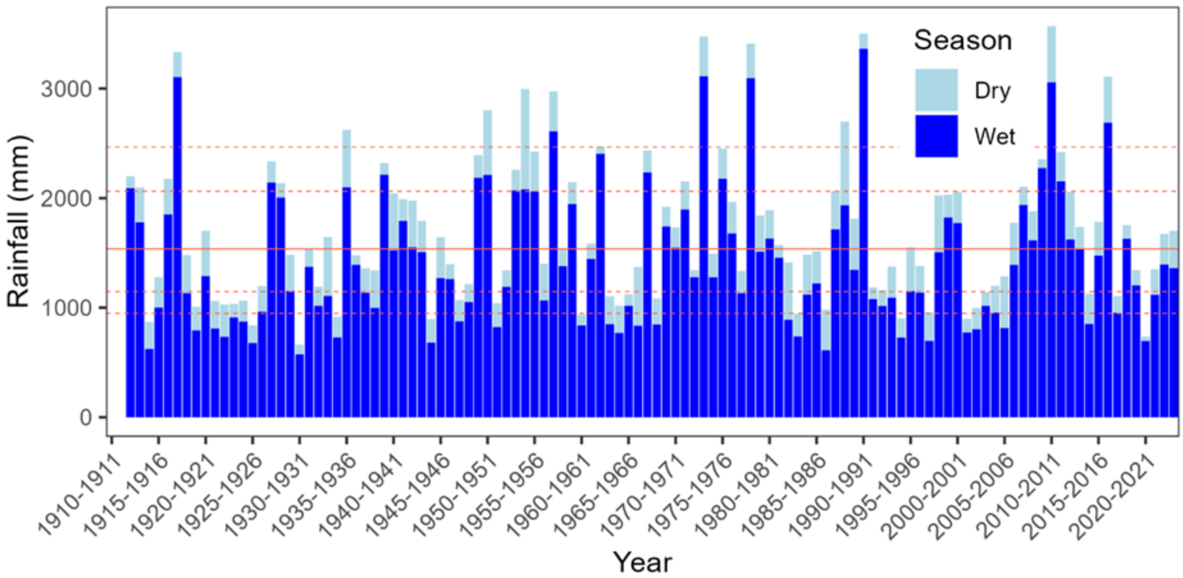

Figure 3-2: Annual rainfall by water year for the Mackay region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall 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/

The Hydrograph for Carmila Creek shows a small discharge event across January 2024 (Figure 3.3). Carmila Creek is a small catchment compared to the Pioneer River and Sandy Creek further north up the coast. Hydrographs for streams in the Pioneer Basin (Pioneer River) and Plane Basin (Sandy Creek) are presented in Figure 3.3. Total discharge for the 2023-2024 reporting period was 525 GL (Pioneer River) and 59 GL (Sandy Creek). There was a notable fresh flow in July 2023 coinciding with local rainfall, with discharge peaking at 8.2 GL day^{-1} at Pioneer River and 1.3 GL day^{-1} at Sandy Creek. The largest river discharge event was in mid-February 2024 with stream discharge peaking at 33 GL day^{-1} at Pioneer River. While the Pioneer River peak flow event was smaller than the previous year, 2022-2023 (146.5 GL day^{-1}), more regular smaller flows occurred during 2023-2024. Each of these stream discharge events correlate to local rainfall events.

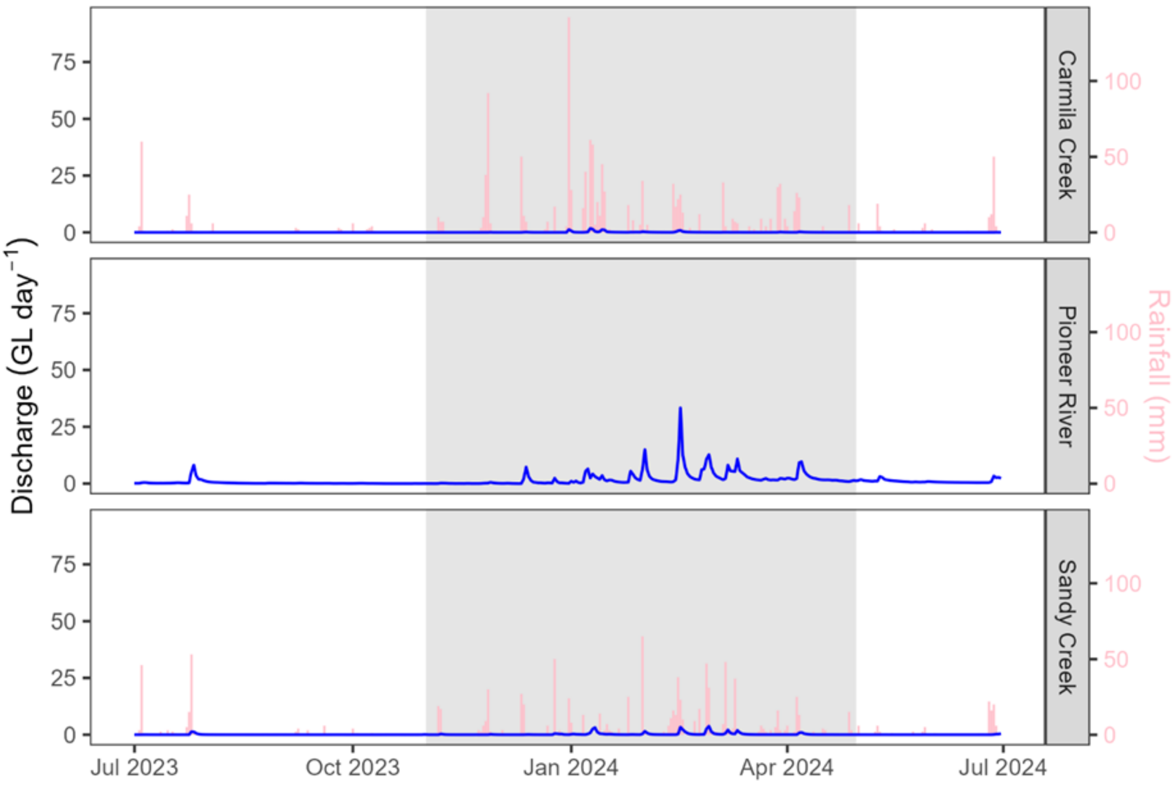

Figure 3-3: Stream discharge (GL d^{-1}) recorded for the Pioneer River (station 125007A) and Sandy Creek (station 126001A) during the 2023-2024 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/

3.2 Oceanographic conditions

Waves detected offshore from Mackay were predominantly 0.5 to 1.2 m in height and from a south-easterly direction (Figure 3-4). October 2021 showed the lowest wave activity of the year while February and April 2022 displayed the largest significant wave heights for the July 2021 – June 30, 2022, period (Figure 3-5).

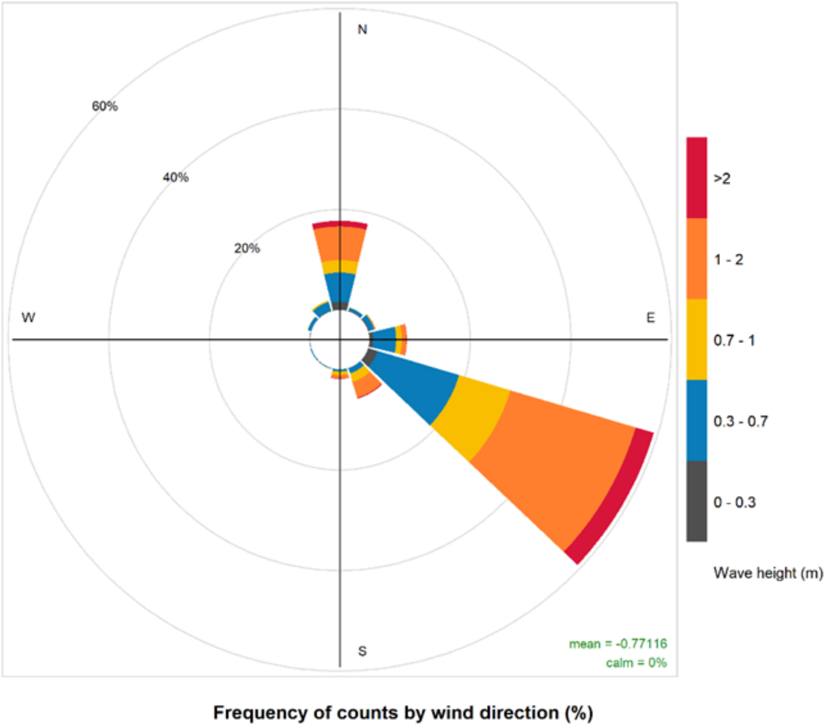

Figure 3-4. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2023, and June 30, 2024. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

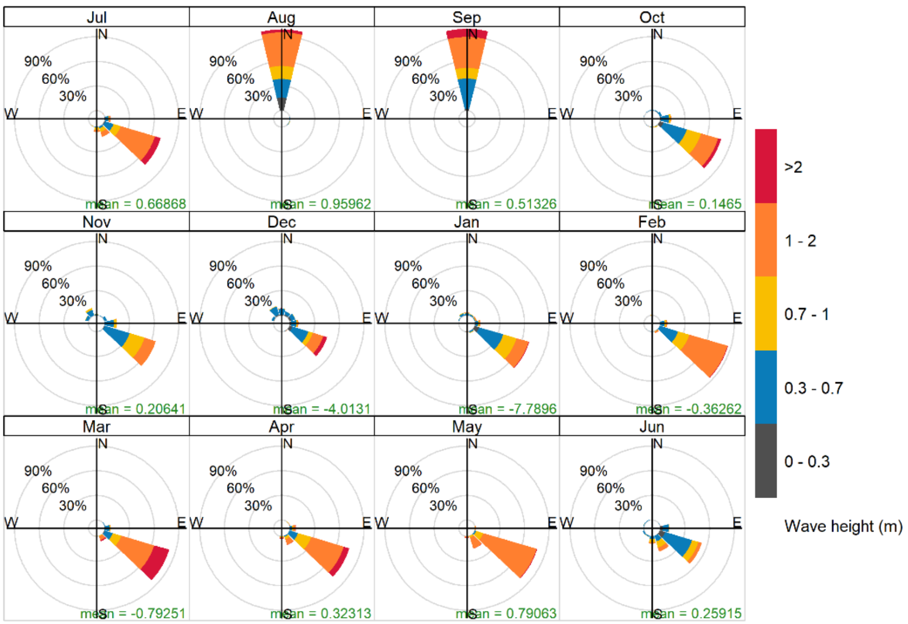

Figure 3-5. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2023, and June 30, 2024. Note that wave direction data was missing for the entire period of August/ September 2023. Values shown in this plot for those months are good for wave height information only. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring.

3.3 Water quality

3.3.1 Physiochemical

Dissolved oxygen (DO) concentrations at the water quality monitoring sites ranged from 5.53 to 8.11 mg L^{-1} with a mean value of 6.38 mg L^{-1} over the reporting period. DO concentrations were similar between sites and across the three profile depths on each sampling occasion, with a slight trend of higher DO in the winter months and lower DO in the summer evident (Figure 3.6). There were some higher DO concentrations in surface waters compared to mid- and bottom- waters between September and October 2023. DO was generally within acceptable WQO range (95 - 105 %sat) throughout the year, except event measurements in mid-January 2024 and early-June 2024 where DO (%sat) was below the WQO lower limit. The annual mean DO across all sites was 95.9 %sat which is within the WQO range.

Electrical conductivity (EC) at the three locations ranged from 52.6 to 55.8 mS cm^{-1} with an annual mean of 54.7 mS cm^{-1} and was in the range typical of seawater (Figure 3.7). There was little difference in EC values throughout the water column, indicating the waters were well mixed. Slightly lower EC values were apparent in July 2023 during an unseasonably large rain event.

Water temperature ranged between 20.3 and 29.2 °C with an annual mean of 25.6 °C (Figure 3.8). There is a strong seasonal effect on water temperatures in the region, with the highest water temperatures observed during surveys in the summer months, and cooler water temperatures observed during the winter months. Water temperature was generally similar throughout the vertical water column profiles at all sites, indicating that the water column is well mixed throughout the region.

pH values ranged between 8.06 and 8.48 with an annual mean of 8.19 across all sites throughout the year (Figure 3.9). Unfortunately, pH values measured in the field between September-December 2023 over the reporting year were deemed unreliable due to sensor malfunction and suspected poor calibration, and quality control procedures removed these values from the dataset. Note that a new instrument has been acquired to solve this issue.

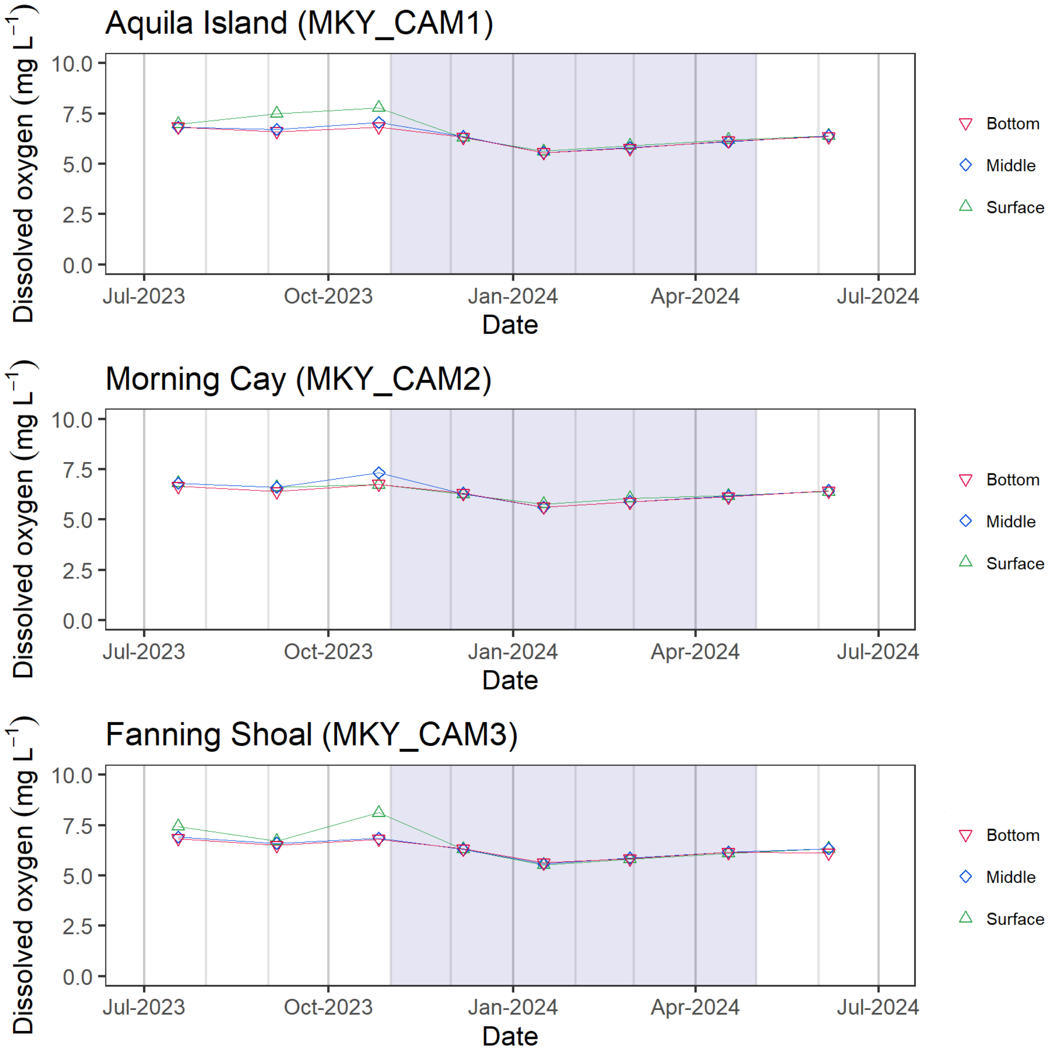

Figure 3-6. Dissolved oxygen concentration (mg/L) at three water quality monitoring sites in the southern Mackay region showing results for the top, middle, and bottom water.

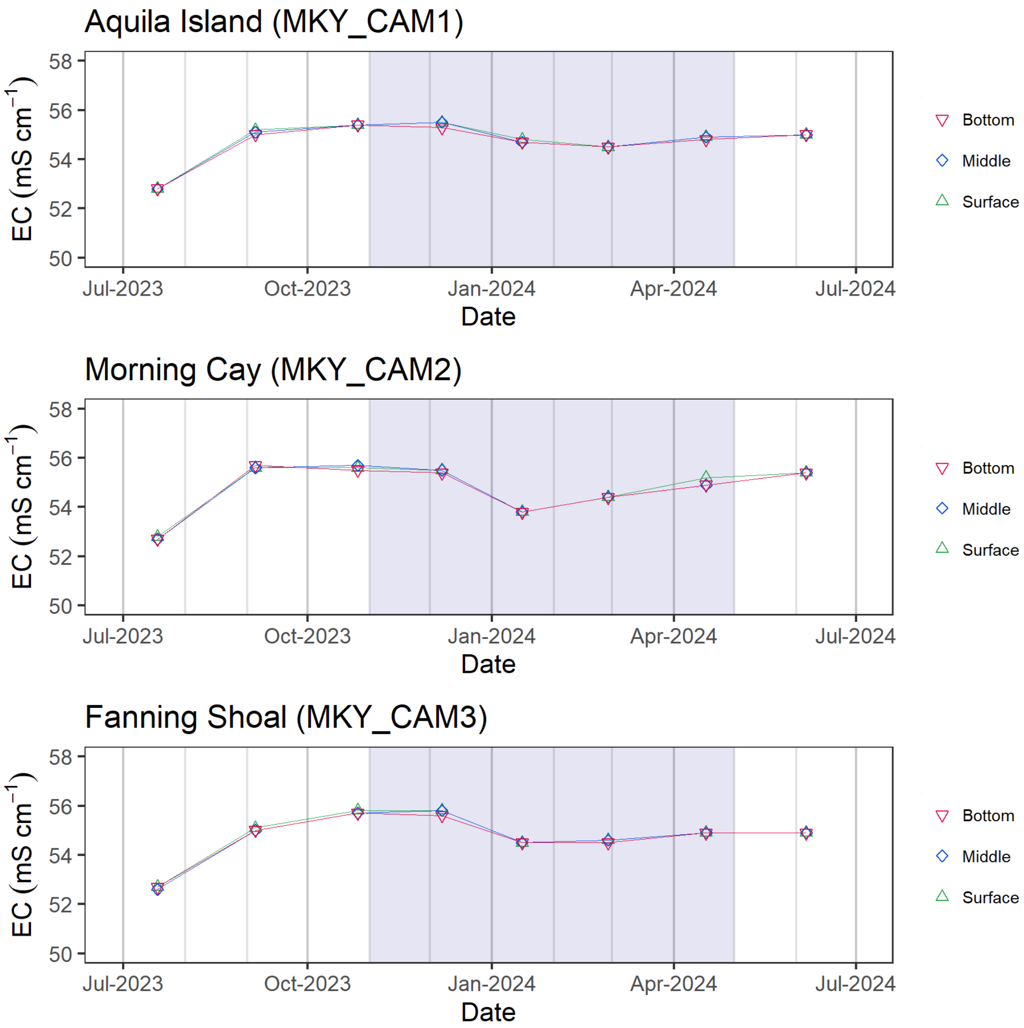

Figure 3-7. Electrical conductivity recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water. Note that the December surface water conductivity at Fanning Shoal may have been instrument error.

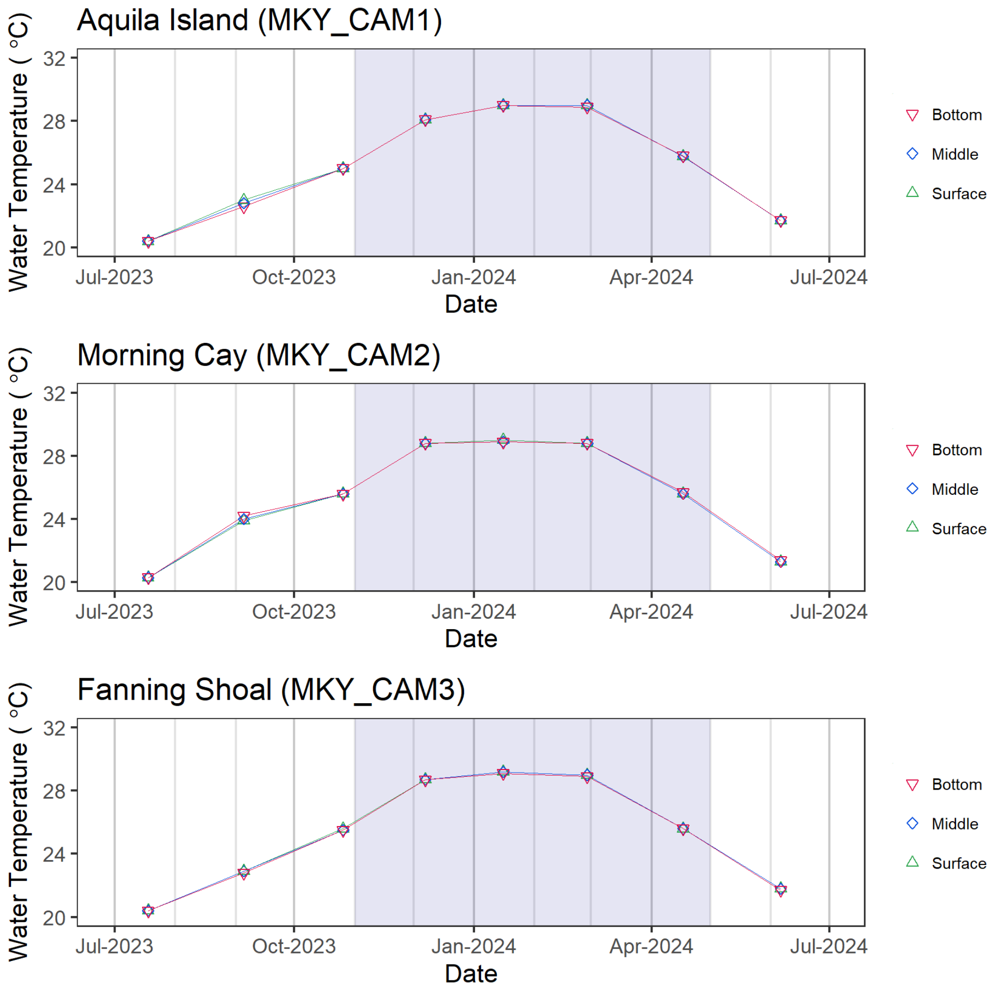

Figure 3-8. Water temperature recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water.

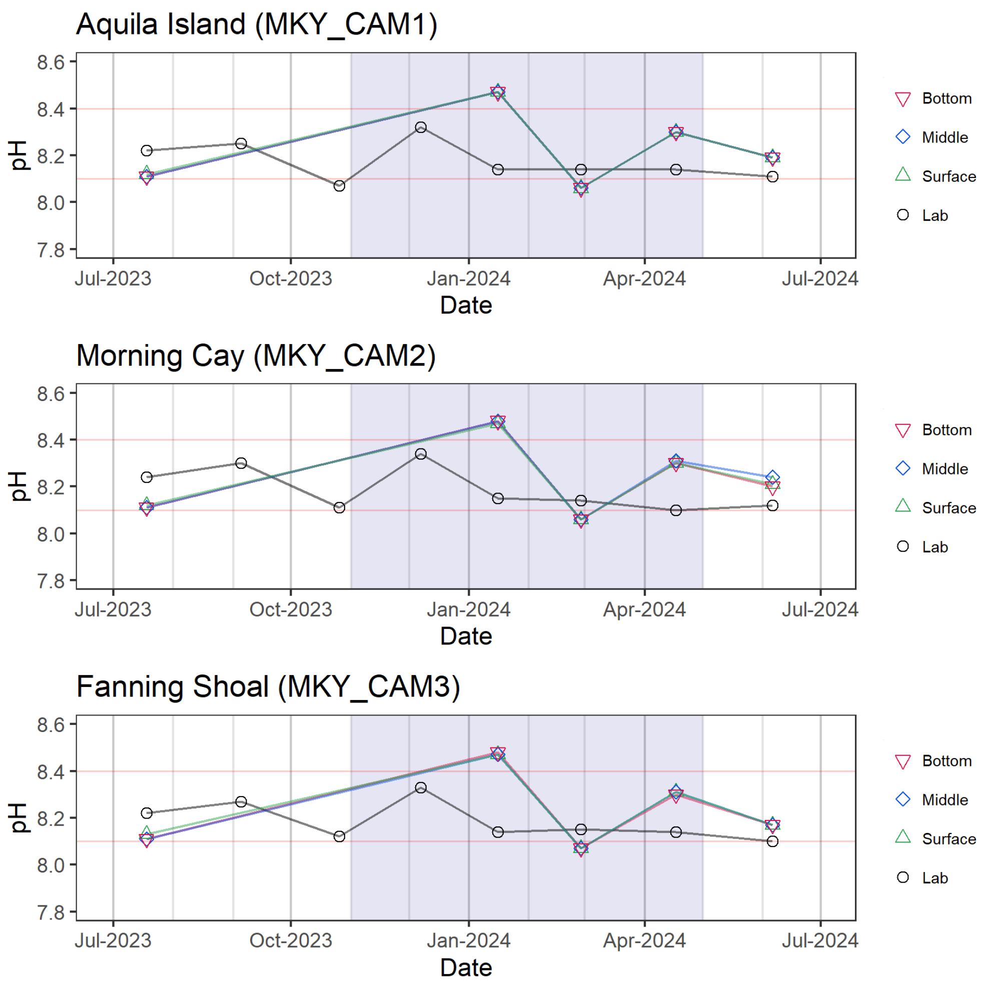

Figure 3-9. pH recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water. Note the potential failure of the field instrument hence Laboratory data is preferred.

3.3.2 Nutrients

Nitrogen concentrations measured in water samples collected from the three Southern Mackay water quality sites are shown in Figure 3.10. Total nitrogen (TN) concentrations ranged from 102 to 211 µg L^{-1}. Median TN was 112 µg L^{-1} and below the WQO 80th percentile of 115 µg L^{-1}. Total dissolved nitrogen (TDN) concentrations ranged from 87 to 126 µg L^{-1}. Median TDN was 99 µg L^{-1} and exceeded the WQO 80th percentile of 95 µg L^{-1}. Particulate nitrogen (PN) concentrations ranged from 0 to 108 µg L^{-1}. Mean PN across the three sites was 19.6 µg L^{-1}. The mean PN was just below the aquatic ecosystem water quality objective of ≤ 20 µg L^{-1} (ann. mean). PN exceeded the WQO's in the dry season but not in the wet season. The mean dry season PN = 20.2 µg L^{-1} and WQO dry season mean = 16 µg L^{-1}. The mean wet season PN = 19.1 µg L^{-1} and WQO wet season mean = 24 µg L^{-1}. Oxidised nitrogen (NO_x) concentrations ranged from <1 to 7 µg L^{-1}. Several NOx values were below the limit of reporting (<1), and so alternative analysis options will be explored for future sampling so that more precise values can be given.

Phosphorus concentrations measured in water samples collected from the three Southern Mackay water quality sites are shown in Figure 3.11. Total phosphorus (TP) concentrations ranged from 6 to 15 µg L^{-1}. Median TP was 7.5 µg L^{-1} and exceeded the WQO 20th percentile of 6 µg L^{-1} but was below the 50th and 80th WQO percentiles. Total dissolved phosphorus (TDP) concentrations ranged from 4 to 9 µg L^{-1}. Median TDP was 6 µg L^{-1} and exceeded the WQO 20th percentile of 4 µg L^{-1} but was below the 50th and 80th WQO percentiles. Particulate phosphorus (PP) concentrations ranged from 0 to 9 µg L^{-1}. Mean PP across the three sites was 2.7 µg L^{-1}, which is below the aquatic ecosystem water quality objective of 2.8 µg L^{-1} (ann. mean). PP just exceeded the WQO's in the dry season, but was below in the wet season. The mean dry season PP = 2.4 µg L^{-1} and WQO dry season mean = 2.3 µg L^{-1}. The mean wet season PP = 3 µg L^{-1} and WQO wet season mean = 3.3 µg L^{-1}.

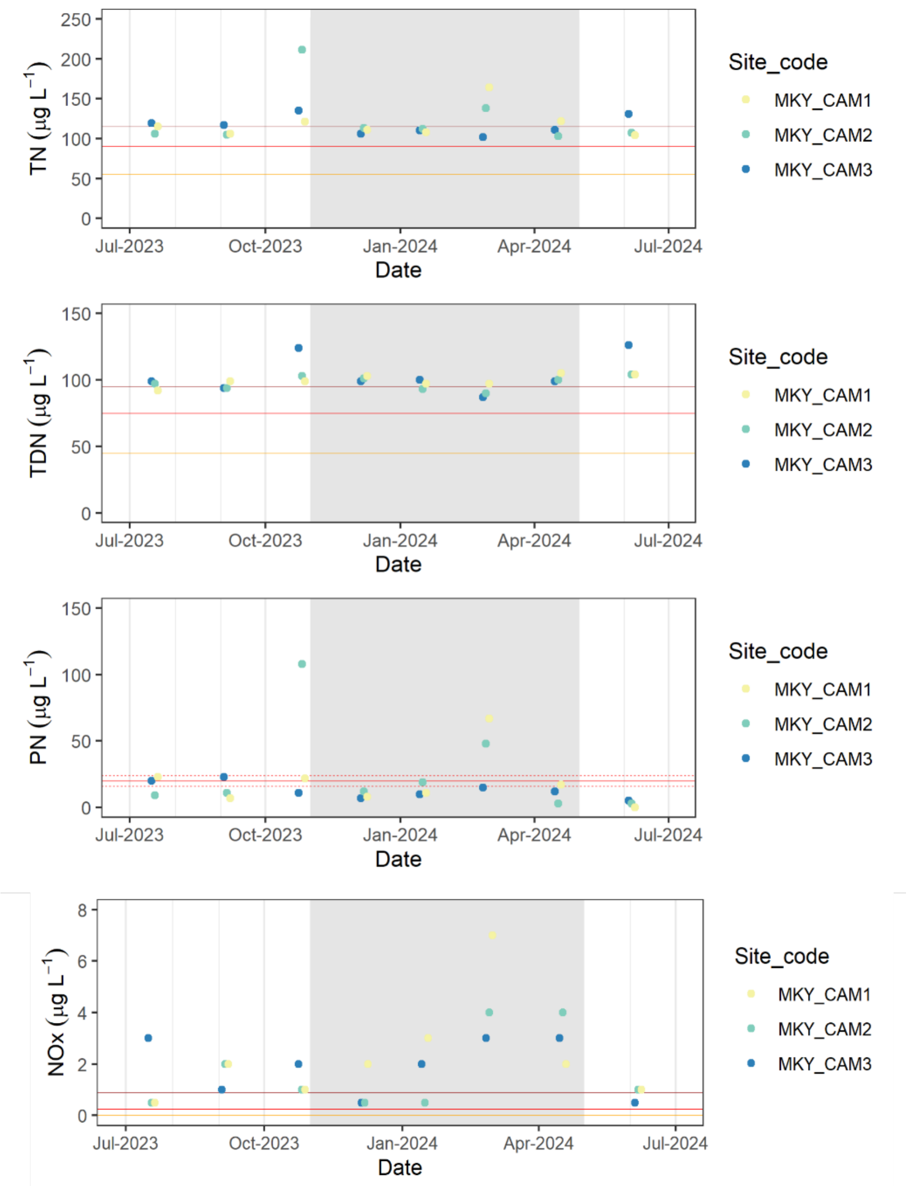

Figure 3-10. Particulate Nitrogen (PN), Total Dissolved Nitrogen (TDN), Total Nitrogen (TN), and oxidised nitrogen (NOx) concentrations measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Note unequal y-axis.

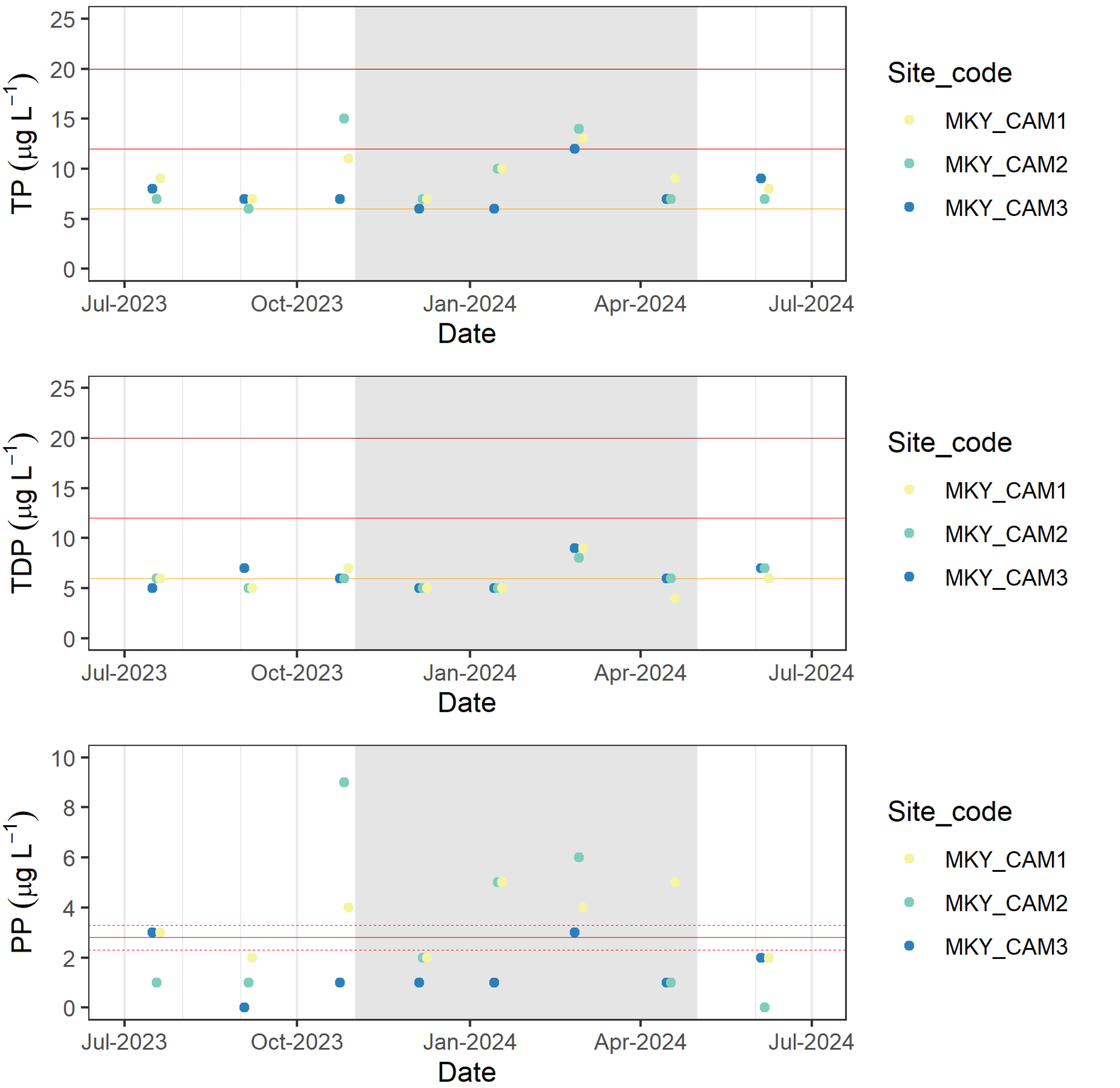

Figure 3-11. Total Phosphorus (TP), Total Dissolved Phosphorus (TDP), and Particulate Phosphorus (PP) concentrations measured in water samples collected from the three Southern Mackay water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Horizontal lines represent EPP 2019 WQO 20th (orange), 50th (red) and 80th (dark red) percentiles. Horizontal red line on PP panel represents EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means. Note unequal y-axis.

3.3.3 Water clarity

Secchi depth ranged from 1 m to 6 m with a mean of 2.7 m over the reporting period (Figure 3-12). Water clarity as measured by Secchi disk depth was poorer in the wet season compared to the dry season, with a peak Secchi depth in December 2023. The mean Secchi depth season was 2.9 m in the wet season and 2.5 m in the dry season. Water clarity was generally poor throughout the reporting period and the Southern Mackay sites are characterised by sand-mud substrate, with strong tidal currents leading to sediment resuspension. As such, water clarity is typically best during neap tides when tidal currents are not as strong.

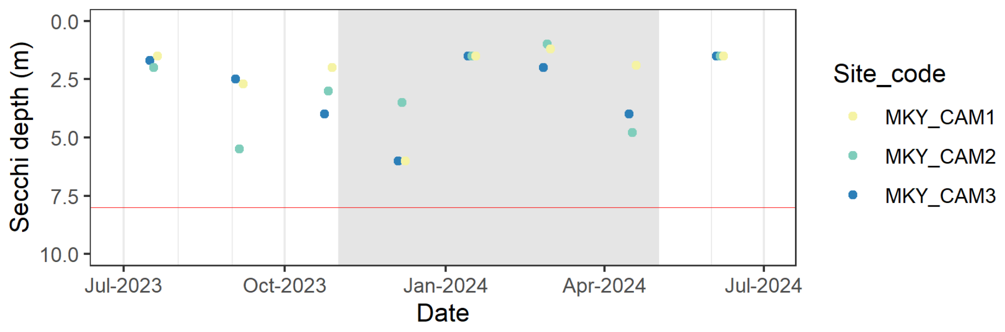

Figure 3-12. Secchi disk depth recorded at the three water quality sites throughout the reporting period. Horizontal red line represents EPP 2019 WQO annual mean.

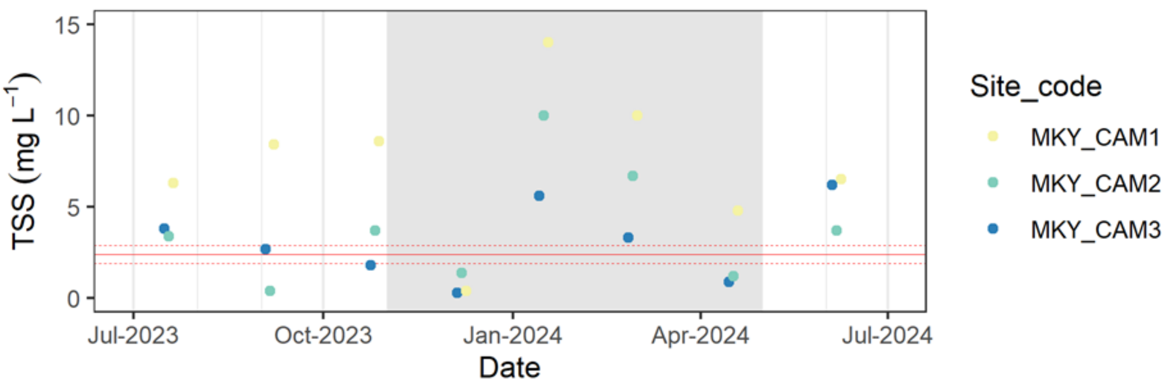

Figure 3-13. Total suspended solids (TSS) measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Horizontal red lines represent EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means.

3.3.4 Chlorophyll a

Chlorophyll-a showed high variability between both location and time of year across the three sampling sites, ranging from <0.2 to 20.92 µg L^{-1} (Figure 3-14). Chlorophyll-*a* concentrations measured over the reporting period exceeded the WQO value (annual mean 0.45 µg L^{-1})

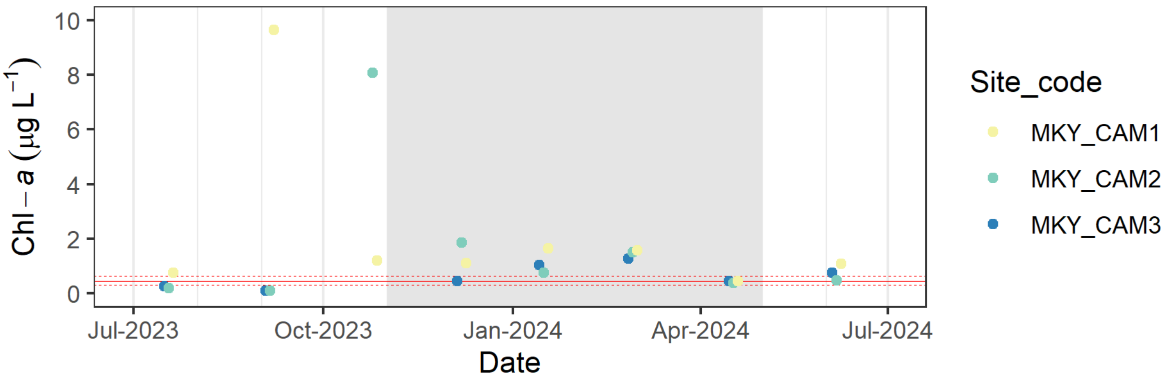

Figure 3-14. Chlorophyll-a concentrations measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), throughout the reporting period. Horizontal red lines represent EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means.

3.3.5 Pesticides

Pesticides detected at Aquila Island (MKY_CAM1) are presented in Table 3-1. Photosystem-II inhibiting herbicides (PSII) were present in three of the four sampling windows, Atrazine detected in the third window, Diuron detected in the second and third, Hexazinone detected in the second, and Tebuthiuron detected in the third and fourth windows. Atrazine concentrations were below GBRMPA 2010 default guideline values (GBRMPA, 2010), as were concentrations of Diuron, Hexazinone, and Tebuthiuron. The rainfall event during the first sampling window, at the end of November 2023, was not recorded in the stream discharge data and no pesticides were detected during that sampling window. However, rainfall events in January 2024 were recorded in stream discharge data during the second and third sampling windows, when pesticides were detected.

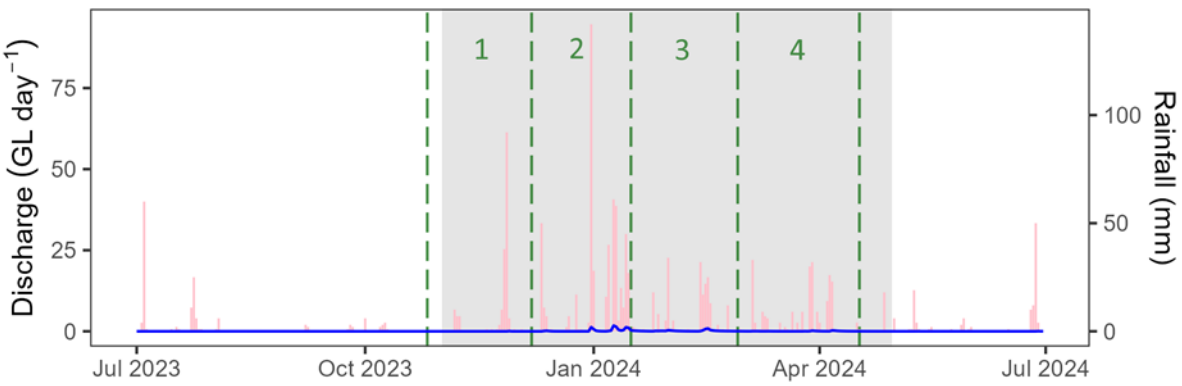

Figure 3-15. Passive sampler deployment periods (green numbers and dashed lines) overlayed on the stream discharge plot (GL d-1) recorded for Carmila Creek (station 126 003A) during the 2023-2024 reporting period. The nominal wet season period is shaded grey. Rainfall data from the Carmila gauging station is also shown in pink. Data source: https://water-monitoring.information.qld.gov.au/

Table 3-1. Pesticide mass per sampler recovered from passive samplers deployed at Aquila Island (MKY_CAM1).

Deployment #		**1**	**2**	**3**		**4**
Deployment Date		26/10/2023	7/12/2023	16/01/2024		28/02/2024
Retrieval Date		07/12/2024	16/01/2024	28/02/2024		17/04/2024
Days Deployed		42	40	43		49
Flow Rate (cm/s)		23.3	24.4	23		19.7
		Primary	Primary	Primary	Duplicate	Primary
Pesticide Name	LOQ					
2,4-D	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Ametryn	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Atrazine	1.00	*<1.00*	*<1.00*	**2.10**	**1.40**	*<1.00*
Atrazine desethyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Atrazine desisopropyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Bromacil	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Diuron	0.500	*<0.500*	**2.19**	**0.855**	**0.824**	*<0.500*
Fluazifop	0.100	*<0.100*	*<0.100*	*<0.100*	*<0.100*	*<0.100*
Fluometuron	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Fluroxypyr	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Haloxyfop	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Hexazinone	1.00	*<1.00*	**1.30**	*<1.00*	*<1.00*	*<1.00*
Imazapic	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Imidacloprid	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
MCPA	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Metolachlor (S+R)	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Metribuzin	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Metsulfuron methyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Prometryn	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Propazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Simazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Tebuconazole	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Tebuthiuron	1.00	*<1.00*	*<1.00*	**1.11**	*<1.00*	**1.15**
Terbuthylazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Terbutryn	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*	*<5.00*

Table 3-2. Pesticide water concentration recovered from passive samplers deployed at Aquila Island (MKY_CAM1).

Deployment #	**1**	**2**	**3**		**4**
Deployment Date	26/10/2023	7/12/2023	16/01/2024		28/02/2024
Retrieval Date	07/12/2024	16/01/2024	28/02/2024		17/04/2024
Days Deployed	42	40	43		49
Flow Rate (cm/s)	23.3	24.4	23		19.7
	Primary	Primary	Primary	Duplicate	Primary
Pesticide Name					
2,4-D	*<0.726*	*<0.748*	*<0.713*	*<0.713*	*<0.670*
Ametryn	*<1.31*	*<1.35*	*<1.28*	*<1.28*	*<1.21*
Atrazine	*<0.173*	*<0.178*	**0.356**	**0.237**	*<0.159*
Atrazine desethyl	*<0.207*	*<0.213*	*<0.203*	*<0.203*	*<0.191*
Atrazine desisopropyl	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Bromacil	*<0.117*	*<0.121*	*<0.115*	*<0.115*	*<0.108*
Diuron	*<0.104*	**0.469**	**0.175**	**0.168**	*<0.096*
Fluazifop	*<0.017*	*<0.018*	*<0.017*	*<0.017*	*<0.016*
Fluometuron	*<0.125*	*<0.129*	*<0.123*	*<0.123*	*<0.116*
Fluroxypyr	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Haloxyfop	*<0.090*	*<0.092*	*<0.088*	*<0.088*	*<0.083*
Hexazinone	*<0.169*	**0.227**	*<0.166*	*<0.166*	*<0.156*
Imazapic	*N/R*	*N/R*	*N/R*	*N/R*	*N/R*
Imidacloprid	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
MCPA	*<0.526*	*<0.542*	*<0.516*	*<0.516*	*<0.485*
Metolachlor (S+R)	*<0.169*	*<0.175*	*<0.166*	*<0.166*	*<0.156*
Metribuzin	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Metsulfuron methyl	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Prometryn	*<0.286*	*<0.295*	*<0.281*	*<0.281*	*<0.264*
Propazine	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Simazine	*<0.117*	*<0.121*	*<0.115*	*<0.115*	*<0.108*
Tebuconazole	*<0.173*	*<0.178*	*<0.170*	*<0.170*	*<0.159*
Tebuthiuron	*<0.133*	*<0.137*	**0.145**	*<0.130*	**0.141**
Terbuthylazine	*<0.159*	*<0.164*	*<0.156*	*<0.156*	*<0.147*
Terbutryn	*<1.12*	*<1.15*	*<1.10*	*<1.10*	*<1.03*

3.4 In-situ loggers

3.4.1 Water temperature

Water temperature recorded by the in-situ loggers is presented in *Figure 3-16.* Water temperature is primarily driven by season, with a low of 19.62 °C in June 2024 and a peak of 30.97 °C February 2024. Intra-seasonal variation (wiggliness of the graph) appears to be correlated with local rainfall, which in North Queensland is typically heavily influenced on a sub-seasonal scale by the Madden-Julian Oscillation (Klingaman, 2012). The water temperature may be directly influenced by both the increased inflow of freshwater from the creeks and rivers due to the rain, as well as a decrease of incoming energy from the sun due to shading from the clouds.

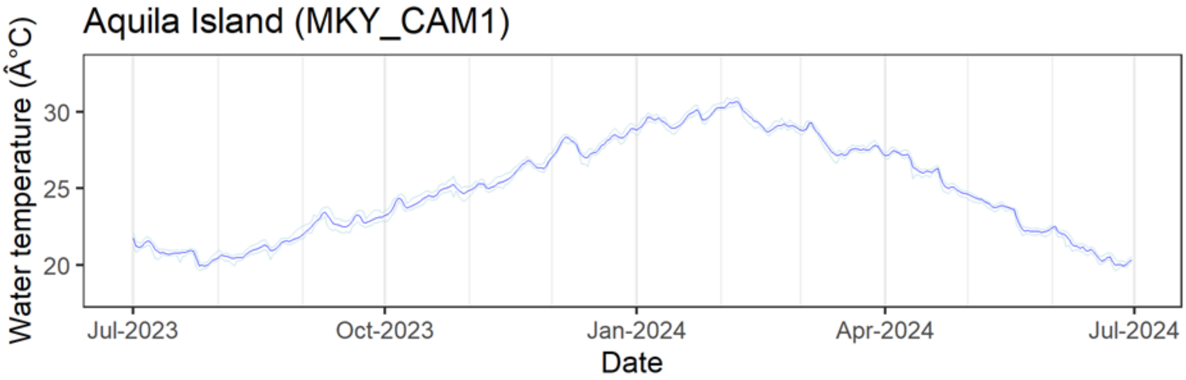

Figure 3-16. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the southern Mackay region.

Table 3-3. Monthly summary statistics for water temperature (°C) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2023	20.81	20.83	0.49	19.66	22.10	20.56	21.12	4463
Aug-2023	21.05	21.01	0.48	19.95	22.48	20.61	21.46	4464
Sep-2023	22.86	22.86	0.38	21.73	23.81	22.60	23.13	4318
Oct-2023	24.39	24.43	0.56	22.84	25.80	23.98	24.84	4462
Nov-2023	25.85	25.77	0.67	24.49	27.26	25.25	26.45	4320
Dec-2023	27.94	28.03	0.59	26.45	29.28	27.39	28.36	4461
Jan-2024	29.53	29.52	0.44	28.45	30.55	29.21	29.85	4460
Feb-2024	29.56	29.29	0.67	28.46	30.97	29.04	30.27	4173
Mar-2024	27.88	27.64	0.66	26.64	29.42	27.43	28.42	4464
Apr-2024	26.16	26.18	0.94	24.41	27.70	25.22	27.14	4317
May-2024	23.31	23.69	0.91	21.88	24.82	22.29	24.05	4464
Jun-2024	20.95	20.87	0.78	19.62	22.61	20.27	21.39	4318
Dry season	22.23	22.12	1.51	19.62	25.80	20.89	23.58	26489
Wet season	27.82	27.77	1.59	24.41	30.97	26.62	29.13	26195
Overall	25.01	24.92	3.20	19.62	30.97	22.10	27.76	52684

3.4.2 Water depth

The daily mean tidal range for each site is presented in Figure 3-17. The southern Mackay region is mixed semidiurnal macrotidal, with daily tidal range measured to be from 2.44 to 8.24 mm over the reporting period.

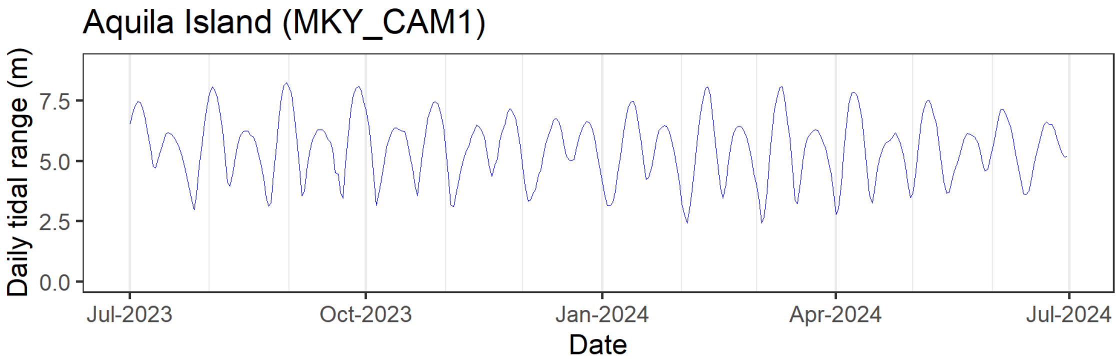

Figure 3-17. Daily tidal range measured by insitu loggers at Aquila Island (MKY_CAM1).

Table 3-4. Monthly summary statistics for water depth (m) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2023	8.55	8.54	1.77	4.99	12.49	7.03	10.03	4463
Aug-2023	8.53	8.51	1.86	4.61	12.86	7.02	10.03	4464
Sep-2023	8.68	8.66	1.89	4.71	12.94	7.17	10.25	4318
Oct-2023	8.68	8.65	1.80	4.69	12.43	7.24	10.19	4462
Nov-2023	8.57	8.54	1.76	5.10	12.28	7.09	10.05	4320
Dec-2023	8.74	8.69	1.72	5.59	12.38	7.23	10.19	4461
Jan-2024	8.84	8.83	1.75	5.59	13.06	7.36	10.26	4460
Feb-2024	8.75	8.71	1.81	4.98	13.06	7.30	10.15	4173
Mar-2024	8.99	8.95	1.80	5.17	13.35	7.57	10.40	4464
Apr-2024	8.91	8.90	1.79	4.93	12.83	7.50	10.36	4317
May-2024	8.83	8.83	1.76	5.05	12.67	7.31	10.31	4464
Jun-2024	8.64	8.62	1.77	5.39	12.66	7.09	10.12	4318
Dry season	8.65	8.64	1.81	4.61	12.94	7.15	10.14	26489
Wet season	8.80	8.77	1.78	4.93	13.35	7.33	10.25	26195
Overall	8.73	8.70	1.80	4.61	13.35	7.24	10.19	52684

3.4.3 Wave activity

The Aquila Island logger site is located along the inshore coast and is exposed to varying levels of waves. The site is generally protected from the prevailing south-easterly swells by Cape Townshend and Stanage Point. Notable high energy periods with high wave peaks occurred in November, in December 2023 when Cyclone Jasper generated large swells along the coast of Queensland, and again in late January 2024 when Severe Tropical Cyclone Kirrily made landfall northwest of Mackay (Figure 3-18).

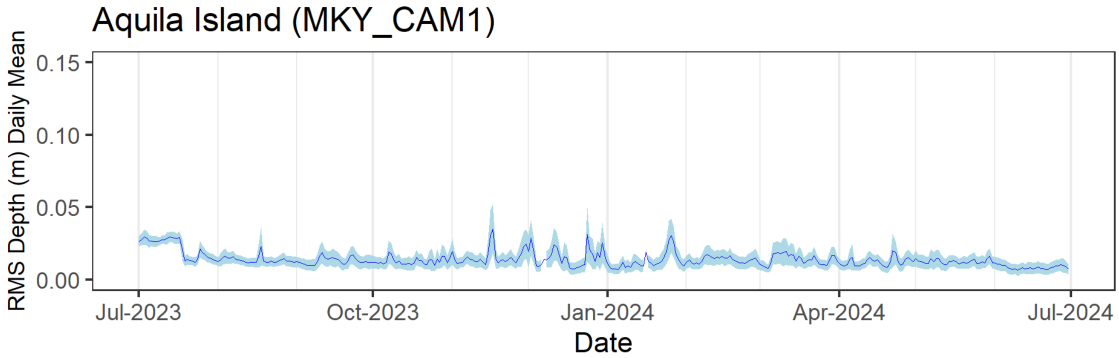

Figure 3-18. RMS depth measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue).

Table 3-5. Monthly summary statistics for wave activity (Depth RMS) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2023	0.022	0.024	0.008	0.006	0.047	0.015	0.028	4463
Aug-2023	0.014	0.013	0.005	0.004	0.074	0.011	0.016	4464
Sep-2023	0.013	0.012	0.006	0.000	0.052	0.010	0.016	4318
Oct-2023	0.013	0.012	0.006	0.000	0.053	0.009	0.015	4462
Nov-2023	0.016	0.014	0.009	0.001	0.092	0.010	0.018	4320
Dec-2023	0.015	0.013	0.010	0.000	0.110	0.009	0.019	4461
Jan-2024	0.013	0.011	0.008	0.000	0.084	0.008	0.015	4460
Feb-2024	0.014	0.013	0.005	0.000	0.042	0.010	0.017	4173
Mar-2024	0.014	0.013	0.007	0.002	0.064	0.010	0.017	4464
Apr-2024	0.012	0.012	0.006	0.000	0.078	0.009	0.015	4317
May-2024	0.013	0.012	0.005	0.000	0.042	0.009	0.015	4464
Jun-2024	0.009	0.009	0.004	0.000	0.029	0.006	0.011	4318
Dry season	0.014	0.013	0.007	0.000	0.074	0.009	0.017	26489
Wet season	0.014	0.013	0.008	0.000	0.110	0.009	0.017	26195
Overall	0.014	0.013	0.007	0.000	0.110	0.009	0.017	52684

3.4.4 Turbidity

Turbidity measured at Aquila Island (MKY_CAM1) in the southern Mackay region is presented in Figure 3-19. The annual mean turbidity at Aquila Island was 10.64 NTU for the reporting period. Turbidity values follow a cycle that is consistent with daily tidal ranges, with periods of high turbidity corresponding with spring tides and lower turbidity with neap tides. Periods where daily mean turbidity values were at their lowest, in late August, early January, and early February, correspond with neap tides in those months.

Monthly mean and median turbidity were calculated for each of the monitoring sites (Table 3-6).

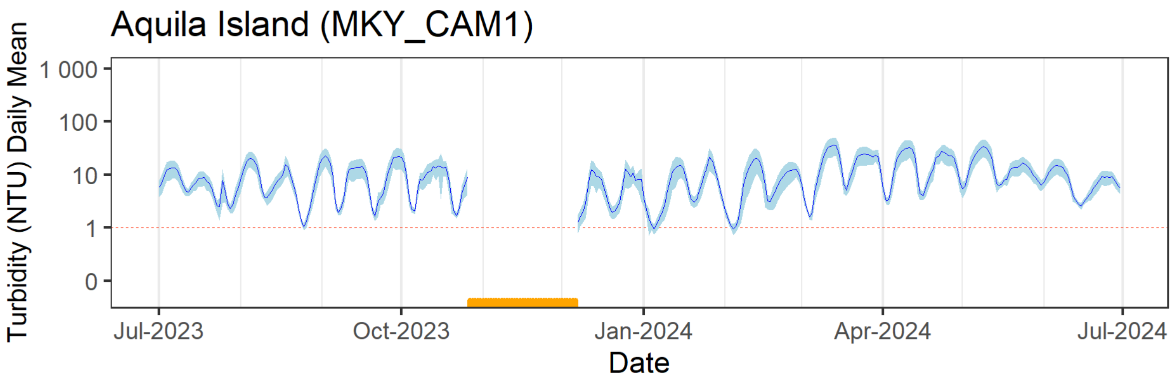

Figure 3-19. Turbidity measured at measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters. Periods of missing data are indicated by the orange bar.

While turbidity is a primary indicator of water quality (Erftemeijer et al., 2012), the relationship between turbidity and benthic light is not always strong (Sofonia and Unsworth, 2010; Kirk, 1985). As benthic photosynthetically active radiation (bPAR) is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae, and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include bPAR in the suite of water quality variables when capturing local baseline conditions of ambient water quality. This may be especially relevant in the southern Mackay region due to the naturally variable turbidity to which habitats are adapted.

Table 3-6. Monthly mean, median (Med), and standard deviation (SD) for turbidity (NTU) measured by in-situ loggers at Aquila Island in the southern Mackay region.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2023	7.00	5.83	4.31	1.39	26.96	3.73	9.20	4463
Aug-2023	8.75	6.73	6.92	0.72	43.71	3.43	12.07	4463
Sep-2023	11.14	8.12	8.81	1.28	47.50	3.64	17.49	3636
Oct-2023	8.85	6.94	6.98	1.37	116.18	3.03	13.44	2957
Nov-2023	NA	NA	NA	NA	NA	NA	NA	NA
Dec-2023	6.56	5.08	5.11	0.50	38.17	2.45	9.47	3556
Jan-2024	7.31	4.64	6.84	0.58	68.80	2.39	10.76	4460
Feb-2024	8.52	5.53	7.97	0.57	58.74	2.35	12.96	4172
Mar-2024	17.36	14.66	13.13	1.32	83.47	6.07	26.14	4464
Apr-2024	17.09	13.40	12.34	2.15	70.51	6.26	26.35	4316
May-2024	15.04	11.39	10.68	3.46	75.16	7.16	18.86	4464
Jun-2024	8.03	6.87	4.68	2.10	25.84	4.18	10.68	4317
Dry season	9.83	7.48	7.89	0.72	116.18	4.20	13.18	24300
Wet season	11.57	7.86	10.88	0.50	83.47	3.33	16.34	20968
Overall	10.64	7.60	9.43	0.50	116.18	3.81	14.52	45268

3.4.5 Photosynthetically active radiation (PAR)

PAR was highly variable at Aquila Island throughout the reporting period, with daily light integral (DLI), which is the sum of all PAR per day, values shown in Figure 3-20. Patterns of PAR are closely correlated to tidal cycles with fortnightly increases in DLI values corresponding with neap tides or weaker tidal flows. Peaks of DLI values in January and February of 2024 correspond with periods of lower turbidity values around neap tides in those months. Low light conditions were recorded between March-June 2024 when mean NTU values were at their highest.

Note: some PAR data was removed during the Quality Control (QC) process due to instability of the logger frames on the benthic surface. Due the very strong currents in this location the logger frames required a specialised mooring technique. Prior to this being implemented, the loggers were recorded as being ‘tilted’ beyond a level where the data is considered ‘good’. For example, if a light logger is pointing away from the light source (surface of water) the recorded PAR will be less than the actual PAR.

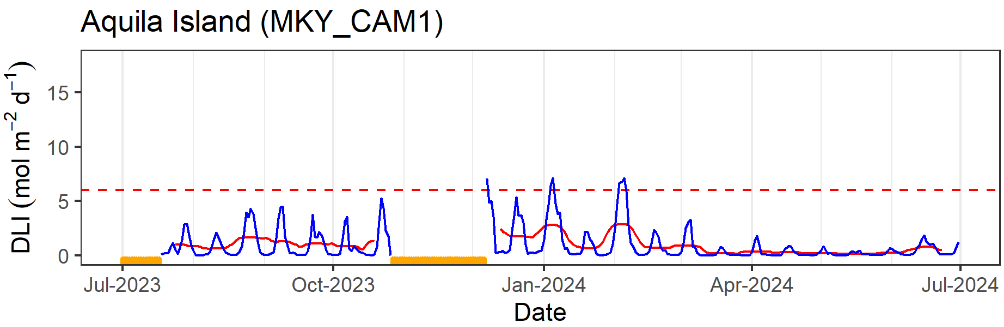

Figure 3-20. Daily light integral (mol photons m^{-2} d^{-1}) of benthic photosynthetically active radiation measured at Aquila Island. Rolling 14-day average (red line) and light requirements from the water quality objective for shallow inshore areas (red dash) shown. Periods of missing or QC-removed data are indicated by the orange bar.

Table 3-7. Monthly summary statistics for Daily Light Integral (DLI: mol photons m^{-2} d^{-1}) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n (days)
Jul-2023	0.99	0.72	0.96	0.08	2.92	0.19	1.36	14
Aug-2023	1.05	0.35	1.32	0.01	4.32	0.09	1.58	31
Sep-2023	1.10	0.36	1.36	0.03	4.51	0.09	1.70	30
Oct-2023	1.14	0.41	1.52	0.00	5.24	0.06	1.70	26
Nov-2023	-	-	-	-	-	-	-	0
Dec-2023	1.89	0.45	2.11	0.16	7.06	0.29	3.64	25
Jan-2024	1.59	0.71	1.99	0.01	7.10	0.14	2.17	31
Feb-2024	1.68	0.48	2.29	0.02	7.12	0.10	2.36	29
Mar-2024	0.48	0.05	0.88	0.01	3.32	0.01	0.54	31
Apr-2024	0.30	0.09	0.45	0.01	1.82	0.02	0.38	30
May-2024	0.19	0.11	0.22	0.01	0.84	0.03	0.31	31
Jun-2024	0.52	0.30	0.51	0.05	1.84	0.10	0.85	30
Dry season	0.81	0.30	1.13	0.00	5.24	0.08	1.07	162
Wet season	1.16	0.29	1.79	0.01	7.12	0.06	1.32	146
Overall	0.98	0.30	1.49	0.00	7.12	0.07	1.13	308

3.4.6 Water quality logger data

Logger data collected at 10-minute intervals which has passed through the quality control process is presented in Figure 3.21.

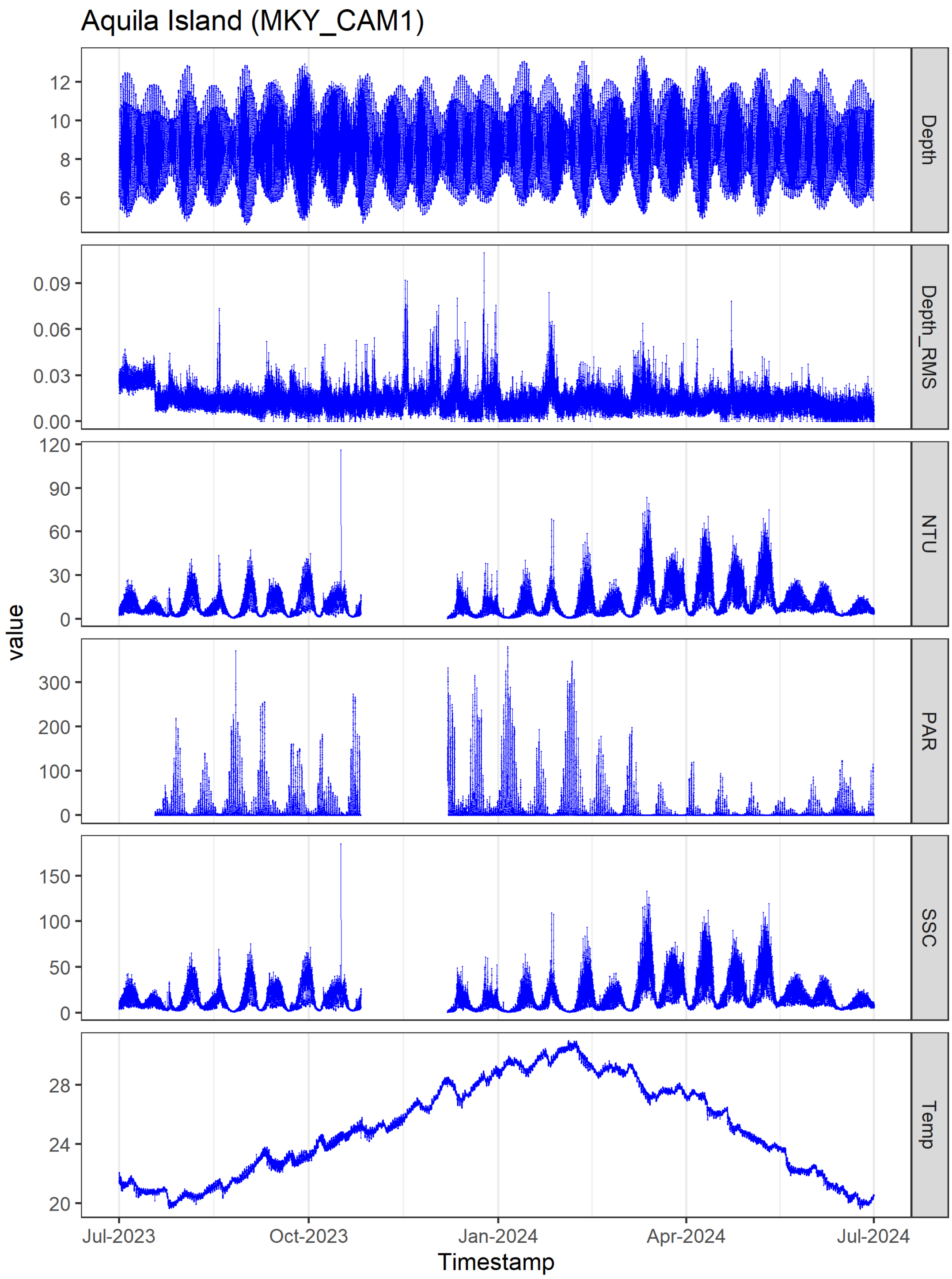

Figure 3-21. Data collected at Aquila Island with In-situ Marine Optics (IMO) dataloggers. Data presented excludes data flagged as flag 4 (Bad data). For more information on Quality Control Procedures see Appendix 1.

3.4.7 Data Recovery

Data recovery and quality control flagging for in situ loggers varied across the sites (Figure 3.22). Overall, data recovery for the reporting period was near 100 % with the exception of some flagged and missing data for the PAR sensor. Data flagged as bad data (QC flag 4 – red) was removed prior to preparing figures and tables for this report. A brief description of the quality control process and QC flags is provided in Appendix 1 while more substantive outline of the quality control process undertaken on the logger data is outlined in Iles et al. (2023).

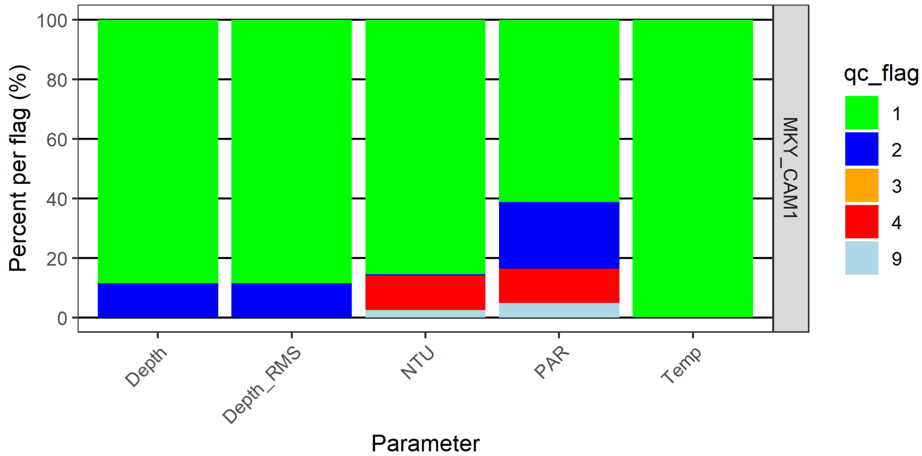

Figure 3-22. Data recovery and qc flags at the Aquila Island (MKY_CAM1) logger site over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2 (blue) indicates a 'probably good value'; flag 3 (yellow) indicates 'probably bad value', flag 4 (red) indicates a 'bad value' and flag 9 (grey) indicates data that is missing.

4 Conclusions and Recommendations

4.1 Conclusions

4.1.1 Climatic conditions

1. The 2023-2024 wet season received slightly more rainfall when compared to the previous year's monitoring (2022-20223). The wet season rainfall total was 1361 mm, while total rainfall for the year was 1703 mm, which was just above the median annual rainfall since 1910. Comparison of these data with future (and past) years is needed to characterise ambient water quality conditions and to determine metocean drivers of water quality variability. It is important to capture monitoring data over a range of climatic conditions, which continues to be a key conclusion reported as part of this monitoring program.

4.1.2 Ambient water quality

1. Water temperature continues to be largely driven by seasonal conditions, with minor intra-season variations in the reporting year correlating with periods of rainfall locally.
2. The water column was generally well mixed, as would be expected from high energy coastal sites, with little variation in temperature throughout the water column although some slight stratification was observed for dissolved oxygen. Values for pH were consistent throughout the water column. Mixing is particularly important when considering dissolved oxygen concentrations, which is known to reach critical levels for fish in coastal waters in Queensland.
3. Particulate nitrogen (PN), particulate phosphorus (PP), and total nitrogen (TN) were below water quality objective (WQO) 80th percentile values, whereas mean annual Chlorophyll-*a* concentrations exceeded WQO values. Oxidised nitrogen (NOx)regularly exceeded WQO 80th percentile values throughout the reporting year, however several values were also below the limit of reporting, so alternative analysis options for NOx will be explored for future sampling to determine more accurate levels.

4.1.3 Turbidity

1. Continuous turbidity logging data reflects the pattern found more broadly in North Queensland coastal marine environments, that turbidity is strongly correlated to tidal cycles and wave energy, particularly during periods of minimal rainfall. This is especially relevant for the Southern Mackay, where the substrate is predominantly sand-mud and tidal ranges are very large, leading to strong currents and resuspension of sediments.
2. Guideline values for turbidity in the southern Mackay region should take into consideration the natural variability of suspended sediment that is due to the strong tidal currents that are a feature of the region. This natural variability in turbidity supports many turbid reefs, both insipid and fringing, that are adapted to these conditions.
3. As the data set here continues to increase, assessment of the rainfall patterns (frequency and duration), and metocean conditions can be examined, providing more detailed insight into the long-term water quality relationships across this region.
4. Water clarity as measured by Secchi disk depth was generally low, with the annual mean value below the WQO.

4.1.4 Photosynthetically active radiation (PAR)

1. Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly highs in PAR coinciding with neap tides and weaker tidal flows. Daily light integral (DLI) values rarely met WQO values during the year. Larger episodic events, such as low-pressure systems and storms, can lead to extended periods of low light conditions due to a combination of strong winds, increases in wave height and resuspension of particles, as well as rainfall leading to increased catchment flows and an input of suspended solids (Fabricius et al., 2013).
2. For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality. This may be especially relevant in the southern Mackay region due to the naturally variable turbidity to which habitats are adapted.

4.2 Recommendations

This monitoring program has been underway since 2017 and should remain in place to continue to characterise and build a detailed understanding of the water quality dynamics in and around the southern Mackay and Isaac region. This understanding will continue to assist managers with future strategic planning. With an emerging long-term dataset, there is potential for answering important research questions around coastal processes and water quality guidelines in this important region of the Great Barrier Reef coastline.

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Appendix 1. Quality control procedures

To complement the new loggers that were introduced into the program in the 2021-22 reporting year, a new quality control (QC) process for water quality data has been implemented. The QC process is science-based, sourced from public documentation, and based on the quality assurance of Real Time Oceanographic (QARTOD) program (NOAA, 2020), which is adopted by CSIRO, IMOS, and AIMS. Data goes through both automated and manual quality control steps. The 12 automated control tests are outlined in Table A5.

Table A 1. Quality Control rules applied to the logger data in the automated process.

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

Dependent on the outcome of these QA tests, data may be flagged 'good data' (green), 'probably good data' (blue), 'probably bad data' (orange) and 'bad data' (red). There are four sensors on each logger: Temperature, Depth, Tilt, and either turbidity (NTU) or photosynthetically active radiation (PAR). For each sensor on the logger the 'worst' flag from QC rules 1 to 12 is reported for each 10-minute time interval (Figure A-1). End user decides what level of data 'quality' they wish to use for their application. For example, for most applications 'good data' and 'probably good data' is considered acceptable, 'probably bad data' could be used with caveats, and 'bad data' should be discarded. Unwanted data can easily be masked in excel or other data management programs by filtering by 'QC flag'. A full technical report with detailed descriptions of the quality control procedures and tests as applied to the data in this project is available on the TropWATER website (Iles et al., 2023).

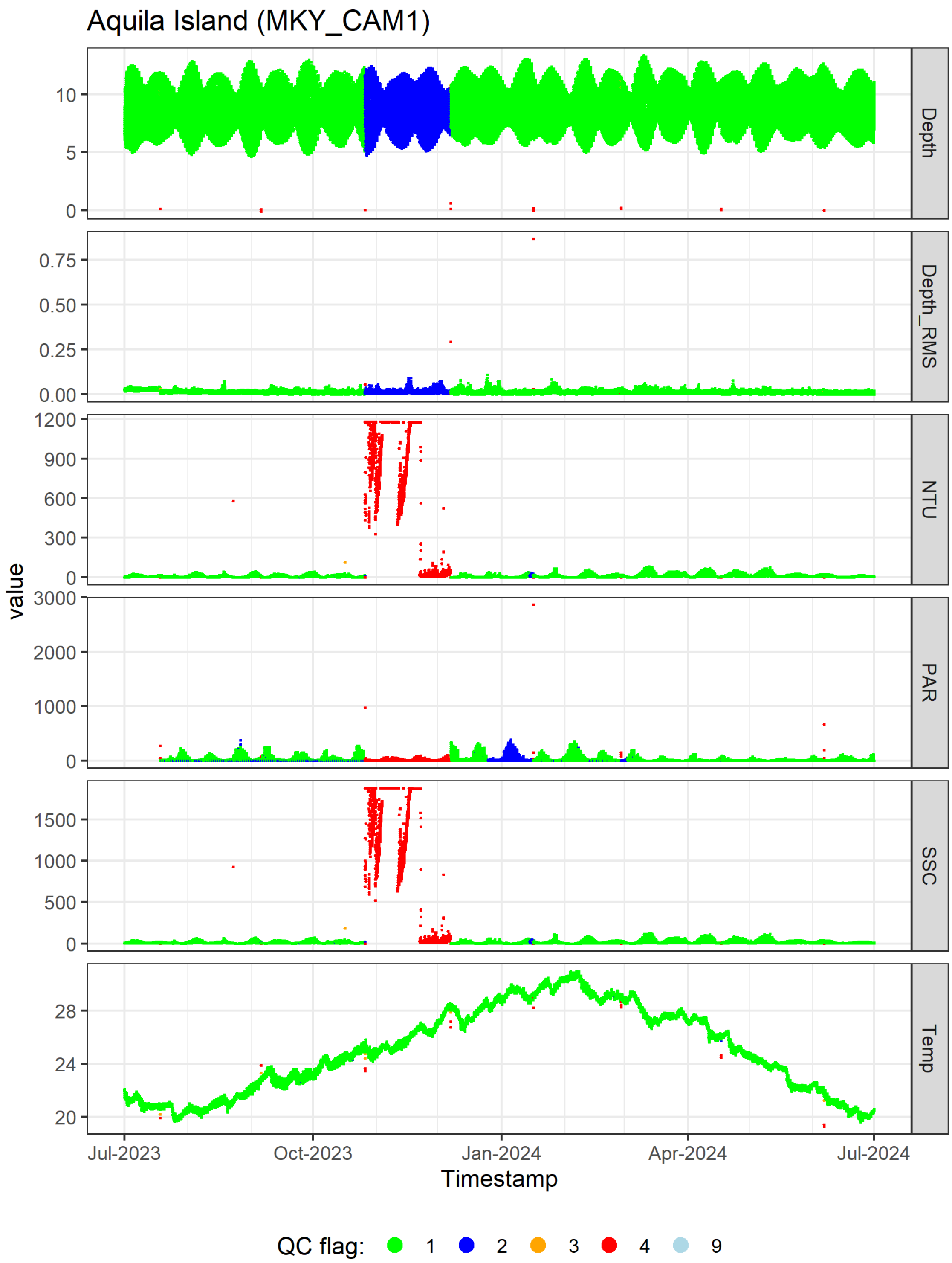

Figure A 1. Raw data collected at Aquila Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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