# Drought Resilient Pasture Landscapes
# Water quality 2023-2024
# Final Report

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## Executive Summary

A core element of the Drought Resilient Pasture Landscapes project (2022-2024) was a coaching program to develop producers' skills and knowledge in: pasture assessment, setting herbage mass targets to maximise pasture productivity and the health of agricultural ecosystems, feed budgeting, and using climate forecasts in the feed budgeting process. These practices have impact at the regional scale of pasture landscapes and complement other considerations such as soil type, waterway buffer width, vegetation, and design that operate at the local scale.

This study was conducted to assess water quality in a number of upland river systems, with catchments dependent on regionally practiced pasture and grazing management. The aim was to improve the knowledge of land managers of waterway health and to understand the connections between pasture management and waterway health. This study was a part of the Drought Resilient Pasture Landscapes (DRPL) project, that received funding from the Australian Government's Future Drought Fund.

Overall, sites were enriched in total nitrogen and total phosphorus, low in sediment load, and experienced periods of high water temperature and low oxygen saturation. While the amount of bioavailable nutrients was generally low at most sites, the pool of potential nutrient availability was high, suggesting a legacy of lingering nutrient addition. Careful management of phosphatic and nitrogenous fertiliser applications also remains an important component for the health of waterways so as to not further add to the existing nutrient load. With the exception of a few outlier points (and the upstream Apsley River site (APSR2) with a known source of upstream nutrient input), sites were similar to each other. Current land use practices will have an impact on water quality and nutrient loads, but historic land use has a long-lasting legacy effect. For example, the periods of high water temperature and low oxygen saturation are likely a legacy from the large-scale removal of vegetation that has removed overstory plant communities from providing shade to water surfaces. The low level of sediment load observed at all sites is suggestive of good ground cover and adequate level of herbage mass, which combine to reduce rainfall runoff and soil erosion and loss.

Restoring and protecting riparian vegetation and good management of pasture landscapes improves river health, and increases river resilience. Riparian vegetation and pastures with good ground cover and adequate herbage mass reduce erosion, and minimise and trap sediment and nutrients from land run-off, limiting the amount of new pollutants entering the river. Riparian vegetation also significantly reduces summer water temperatures compared to streams that have no shading. The most important step in restoring riparian vegetation is preventing further vegetation loss or damage to restoration efforts by controlling stock access as appropriate.

# 1. Introduction

Agriculture relies heavily on ecosystem services, such as soil formation and pollination, to produce food, fibre and fuel crops. Additionally, agricultural landscapes provide broader societal benefits like carbon sequestration, biodiversity conservation and flood mitigation. Pasturelands are fundamental to agricultural production, yet their management practices can significantly influence water quality and sedimentation (McDowall 2008). Grazing animals can impact water chemistry through biomass removal, altering nutrient storage and modifying soil structure. Reduced plant cover due to grazing can increase nutrient concentrations in plant tissues, delaying nutrient transfer to roots. Agricultural management is frequently linked to nutrient loading in surface waters through runoff and groundwater discharge (Jansen et al. 2019).

Understanding the interactions between pasture management and water quality is crucial for developing sustainable land management plans that protect water resources and maintain ecosystem health. Previous studies indicate that, under some conditions, grazing can accelerate erosion and nutrient loss compared to ungrazed conditions (Donovan & Monaghan, 2021). Livestock can also cause soil compaction, reducing infiltration and increasing runoff, but this depends on their management. The relative importance of pastures as a nutrient source to rivers compared to other agricultural sources remains unclear. Additionally, factors like soil fertility, fertilizer application, ground cover and soil type influence nutrient loss from pastureland.

A core element of the Drought Resilient Pasture Landscapes project (2022-2024) was a coaching program to develop producers' skills and knowledge in: pasture assessment, setting herbage mass targets to maximise pasture productivity and the health of agricultural ecosystems, feed budgeting, and using climate forecasts in the feed budgeting process. These practices have impact at the regional scale of pasture landscapes and complement other considerations such as soil type, waterway buffer width, vegetation, and design that operate at the local scale.

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# 2. Methods

## 2.1. Study area and sampling sites

Sites for water quality monitoring were located on the properties of eight participants in the DRPL program. All sites were in the Northern Tablelands of NSW between the towns of Walcha and Deepwater (a linear distance of 170 km). The eight sites were located across six rivers and four catchments (Figure 1, Table 1). The western, or inland, draining rivers were Deepwater River and Macintyre River in the Border Rivers catchment, and Macdonald River in the Namoi River catchment. The eastern, or coastal, draining rivers were Mann River in the Clarence River catchment, and Gara River and Apsley River in the Macleay River catchment. There were two sites in the Gara River, approximately 40 km apart, with GARA2 being the upstream site and GARA1 being the downstream site. Malpas Dam (municipal water supply for Armidale) is located between these two sites, with GARA2 situated around 11 km upstream of the dam. Similarly, APSR1 and APSR2 in the Apsley River are approximately 8.5 km apart, with APSR2 being upstream and APSR1 downstream. Several small tributaries, including Ohio and Mainey's Creek, join the Apsley River between these two sites.

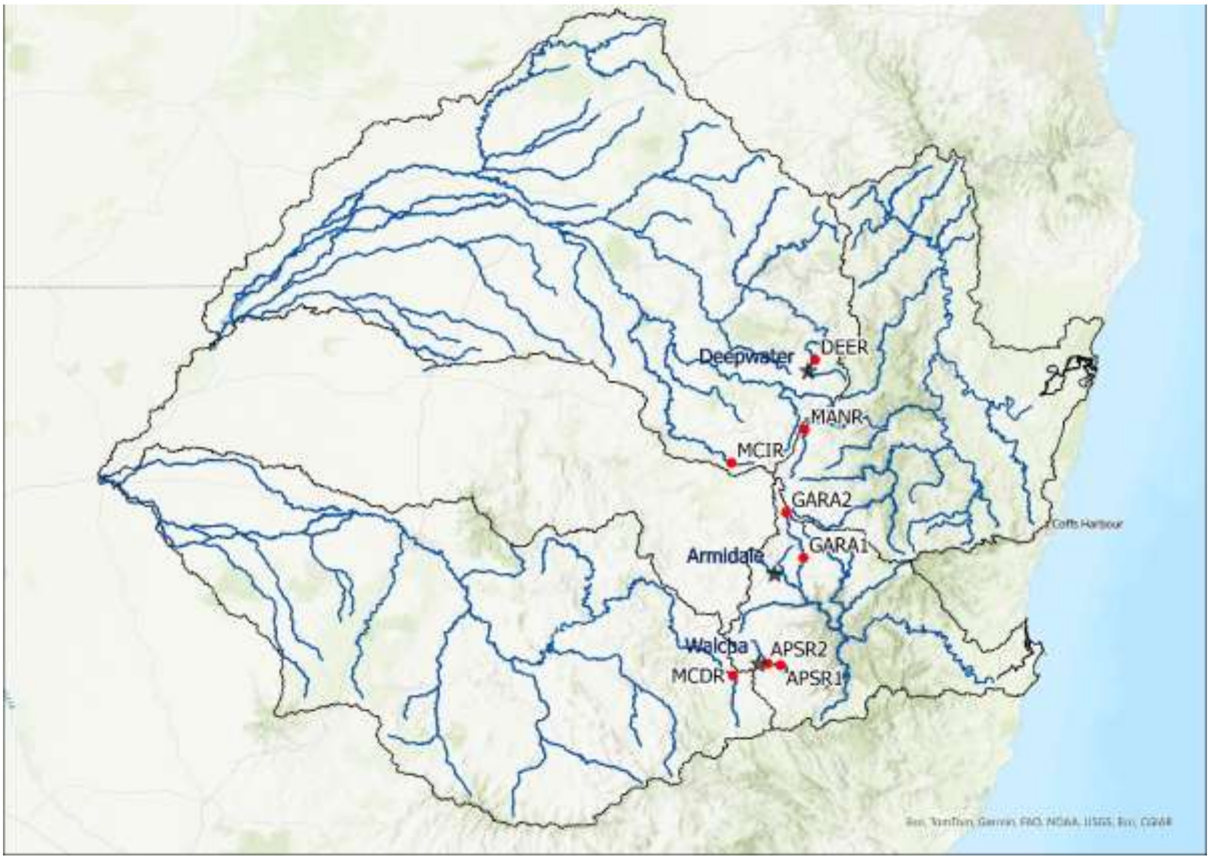

*Figure 1 Location of water sampling sites at Clarence River, Macleay River, Border River and Namoi River Catchments, New South Wales, Australia.*

## 2.2. Water sample collection and analysis

Water quality samples were collected from June 2023 to June 2024. Members of the UNE Aquatic Ecology Lab conducted quarterly sample collections, while landholders collected the samples monthly in the intervening periods (Table 1). Water samples were collected in triplicate from the same location each month. Landholder samples were collected from a depth of approximately 0.2 m, frozen at -4°C, and delivered to the lab for analysis. Water parameters analysed varied between UNE and landholder collected samples (Table 2), but lab analysis of each parameter followed the same protocols. These results are presented in sections 3.1 and 3.2.

Physico-chemical parameters (temperature, pH, dissolved oxygen (DO) concentration mg/L and saturation (% sat), specific conductance (µS/cm), salinity (PSS) and turbidity (NTU)) were measured in-situ using a YSI ProDSS at each site during each lab-conducted sampling occasion. Triplicate sets of water samples were collected for: (i) total nitrogen (TN, µg/L) and total phosphorous (TP, µg/L) (ii) dissolved nitrites + nitrates (NOx, µg N/L), and filterable reactive phosphorous (FRP, µg P/L), and (iii) dissolved organic carbon (DOC, mg/L) concentration. All samples were collected at approximately 0.2 m depth in triplicate 50 mL, thrice-rinsed, pre-labelled PET vials and frozen until analysis.

*Table 1 Water sample sites and collection dates in 2023-2024.*

| Site | River | Catchment | Flow Direction | Collector | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEER | Deepwater River | Border Rivers | West | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  | x | x |  | x |  |  | x | x |  | x | x |  |
| MCIR | Macintyre River | Border Rivers | West | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  | x | x |  | x | x |  |  | x |  | x |  |  |
| MCDR | Macdonald River | Namoi River | West | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  | x | x |  | x | x |  | x | x |  | x | x |  |
| MANR | Mann River | Clarence River | East | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  | x | x |  | x |  |  |  |  |  |  | x |  |
| GARA2 | Gara River | Macleay River | East | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  |  |  |  |  |  |  |  |  |  |  |  |  |
| GARA1 | Gara River | Macleay River | East | UNE | x |  |  | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  | x | x |  | x | x |  | x | x |  | x | x |  |
| APSR2 | Apsley River | Macleay River | East | UNE |  |  | x | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  |  |  |  | x | x |  | x |  |  | x | x |  |
| APSR1 | Apsley River | Macleay River | East | UNE |  |  | x | x |  |  | x |  |  | x |  |  | x |
|  |  |  |  | Landholder |  |  |  |  | x | x |  | x | x |  | x | x |  |

*Table 2 Variables analysed and default trigger values or target values for physical and chemical stressors. ANZECC trigger values are for south-east Australia for slightly disturbed ecosystems based on Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000). Sites in the Border Rivers and Namoi Catchments have catchment specific target values outlined in their surface water resource plans. *No Chl-a value is given for upland streams. Not all variables have established trigger values.*

|  |  | Temp (°C) | DO (%) | DO (mg/L) | Cond (µS/cm) | pH | Turbidity (NTU) | DOC (mg/L) | Chl-a (µg/L) | TSS (mg/L) | TN (µg N/L) | TKN (µg/L) | TP (µg P/L) | NOx (µg N/L) | FRP (µg P/L) | Sediment (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collector | UNE | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
|  | Landholder |  |  |  |  |  |  |  | x |  | x | x | x | x | x |  |
| WQ Guideline Values | ANZECC Trigger Value | >80%ile<br><20%ile | 90-110 | NA | 30-350 | 6.5-8 | 2-25 | NA | * | NA | 250 | NA | 20 | 15 | 15 | NA |
|  | Border Rivers SWRP | >80%ile<br><20%ile | 90-110 | NA | 250-330 | 6.5-7.5 | 25 | NA |  | NA | 250 | NA | 20 | NA | NA | NA |
|  | Namoi SWRP | >80%ile<br><20%ile | 90-110 | NA | 475-715 | 6.5-7.5 | 25 | NA |  | NA | 250 | NA | 20 | NA | NA | NA |

DO = dissolved oxygen; Cond = electrical conductivity; DOC = dissolved organic carbon; Chl-a = chlorophyll-a; TSS = total suspended solids; TN = total nitrogen; TKN = total Kjeldahl nitrogen; TP = total phosphorus; NOx = dissolved nitrate and nitrite; FRP = filterable reactive phosphorus

TP content in the samples was determined after Kjeldahl digestion of unfiltered water samples, using a SEAL Analytical AQ400 Discrete Analyzer following AQ400 method no. EPA-135-C. Total Kjeldahl nitrogen (TKN) was determined in the unfiltered water sample using AQ400 method no. EPA-151-C. TN was reported as the sum of TKN and NOx. NOx and FRP samples were filtered through rinsed Whatman GF/C filters (0.7 µm) analysed colourimetrically using a SEAL Analytical AQ400 Discrete Analyser with the AQ400 methods no. EPA-118-C and EPA-127-A, respectively. DOC samples were pre-filtered through Sartorius Minisart glass fibre (0.45 µm and 0.2 µm) filters, then frozen (-80°C) until analysis. DOC samples were analysed using the supercritical water oxidation technique using an InnovOx Total Organic Carbon Analyser (GE Analytical Instruments). For chlorophyll-a (Chl-a, µg/L) and total suspended solid (TSS, mg/L) concentration, water was filtered through Whatman GF/C filter paper (0.7 µm) using an electric vacuum pump (EYELA Tokyo Rakahikai Corporation Aspirator A- 35 at approximately 7 PSI). Filter papers for chlorophyll-a analysis were placed into pre-labelled 10 mL vials, maintained in the dark and refrigerated below 4°C until analysis. Chlorophyll-a content was determined spectrophotometrically after extraction with 90% acetone as described in the Standard Method (Part 1000) (Rice et al. 2012).

*Figure 2 Eco-Detection Ion-Q auto-analyser installed at site GARA2.*

## 2.3. Eco-Detection Auto-analyser

The Eco Detection Ion-Q+ is a fully autonomous multiparameter laboratory grade water analysis system designed for remote water monitoring and testing of analytes in real-time. The system features remotely adjustable sensitivity for higher range requirements. Analytes collected were chloride, fluoride, nitrate, and sulphate. Auxiliary sensors integrated with the device are turbidity, electrical conductivity, pH, temperature and dissolved oxygen. Readings were collected every six hours. Data are accessed via the cloud and are real-time data sourced directly from the in-field water sensors. These results are presented in section 3.3.

The Eco-Detection unit was installed in May 2023 at the upstream Gara River site (GARA2). Reagents for water analysis were replaced approximately every two months. Additionally, while the Ion-Q+ system has an anti-fouling function incorporated into its operation, this does not include the auxiliary sensors which required cleaning approximately once a month during the warmer seasons.

## 2.4. Sediment Collection and Data Loggers

Time-integrated suspended sediment samplers were deployed at each site for the duration of the project. Sampler design followed Phillips & Russell (2000) and was made of PVC tube that was 1 m long with a 100 mm diameter and caps at both ends with a 4 mm diameter opening. Tubes were attached to star pickets that were driven into the river bed (Figure 3). Sediments were collected from tubes quarterly, dried at 40°C, weighed, then placed in a combustion oven at 500°C to determine sediment load and organic matter content. These results are included in section 3.1.

Continuous data loggers (PME MiniDOT) were deployed at each site for the entirety of the project (Figure 4). Water temperature and dissolved oxygen (DO) were logged every ten minutes. These loggers were downloaded and cleaned quarterly. Loggers were attached to star pickets holding the time integrated sediment samplers and were placed about 20 cm above the substrate. The sediment sampler and data logger installation were washed away and lost at APSR1 during the last quarter. All logger data were checked for abnormal readings or indications that the logger was exposed to air. Periods with abnormal readings were excluded from the data. These results are presented in section 3.4.

*Figure 3 Time integrated suspended sediment sampler installed at site.*

*Figure 4 Continuous dissolved oxygen and temperature logger (PME miniDOT).*

## 2.5. Data analysis

ANZECC default trigger values (Table 2) for upland freshwater systems are shown on the figures provided in this report: a single line represents a maximum value beyond which is likely to cause harm to aquatic ecosystems; two lines show the maximum (top line) and minimum (bottom line) values, above and below which, respectively, are likely to cause harm to aquatic ecosystems. The default trigger values were developed for protection of slightly to moderately disturbed ecosystems generally and do not account for site-specific environmental variability (ANZECC 2000). For sites within the Murray-Darling Basin, zone specific water quality management targets have been established using reference condition streams, and End-of-Valley conductivity targets for long term salinity planning (Table 2). These zone-specific targets do not account for location specific environmental variation (NSW DPIE 2020a & 2020b).

# 3. Results and Discussion

## 3.1. Physico-chemical Parameters

Spot measurements of water temperature followed an expected seasonal pattern (Figure 5). The area experienced warmer than average summer air temperatures (BOM, 2024) and the Gara River sites had temperatures above 30°C in December (GARA1 32.3 ± 0.4°C, Table 8; & GARA2 30.4 ± 0.3°C, Table 7). Water temperature is naturally dynamic and varies from daily to seasonally. Water temperature influences many ecosystem processes like nutrient cycling, and biological processes such as metabolic rates (Bonacina et al 2023). Human activities can influence the natural temperature regime in a variety of ways. Thermal stratification, for example, can occur in dams creating colder than normal temperatures in bottom layers. Temperatures can increase when riparian vegetation is removed, reducing shading. In these upland streams, increased exposure to high water temperatures is likely to harm aquatic biota through reduction in dissolved oxygen, and to alter biogeochemical processes including increased release of sediment-bound nutrients (Xiaolong et al 2020).

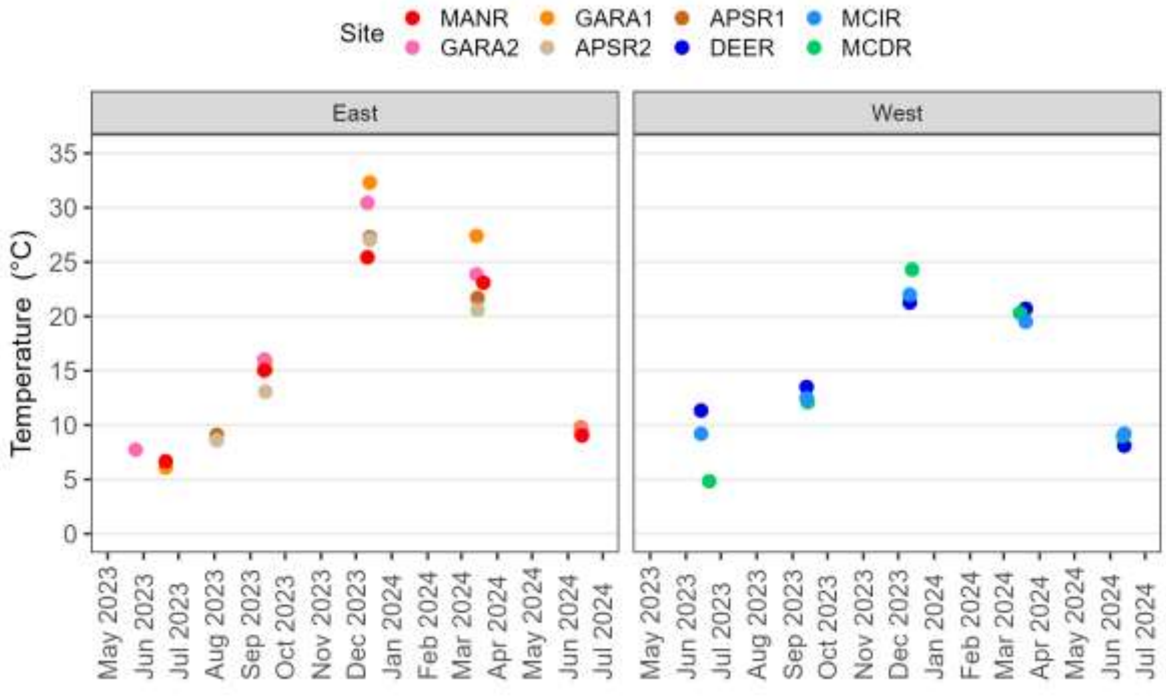

*Figure 5 Temperature readings collected by UNE. Sites are separated based on direction of catchment flow.*

Spot measurements of electrical conductivity also reflected seasonal changes, increasing in warmer months and decreasing in cooler months (Figure 6). Most sites remained within, or only slightly above, the ANZECC trigger values except the Macintyre River (MCIR) which remained above trigger values all year (442 to 758 µS/cm, Table 4). Salinity in the upper Macintyre River is known to be high, likely due to contributions of saline groundwater, and is diluted downstream (NSW DPIE 2020b). Electrical conductivity is strongly associated with underlying geology but can be raised artificially by the increased mobilisation of salts due to land use changes. Conductivity varies with temperature but is generally stable, so rapid or extreme changes can indicate potential pollution.

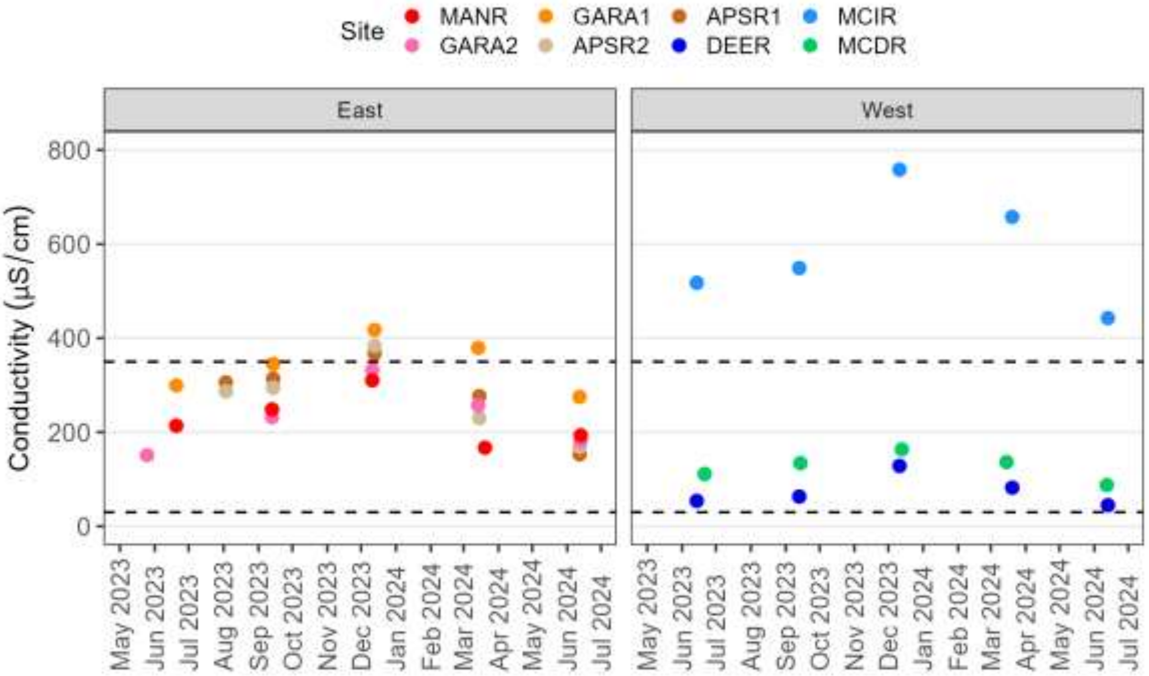

*Figure 6 Conductivity readings collected by UNE. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

Dissolved oxygen saturation was variable among sites during warmer months (Figure 7). Inland catchments (West) had dissolved oxygen saturation below ANZECC guidelines in December 2023 and March 2024. In the Macintyre River, this approached hypoxia (low saturation) in December, likely due to a small fresh, and associated influx of organic material, that occurred after a period of low flows (Figure 25 middle). In the coastal catchments (East), the Gara River was supersaturated with oxygen (greater than 100%) in December (GARA2 161.1 ± 11.4 °C, Table 7; GARA1 139 ± 2.9 °C, Table 8) and March (GARA2 124.4 ± 1.6 °C; GARA1 142.1 ± 0.2 °C), and the Apsley River exceeded guidelines in September (APSR2 144.5 ± 2.4°C, Table 9). The remaining rivers having saturation levels within or slightly below the minimum trigger values. Dissolved oxygen spot measurements were not controlled for time of day.

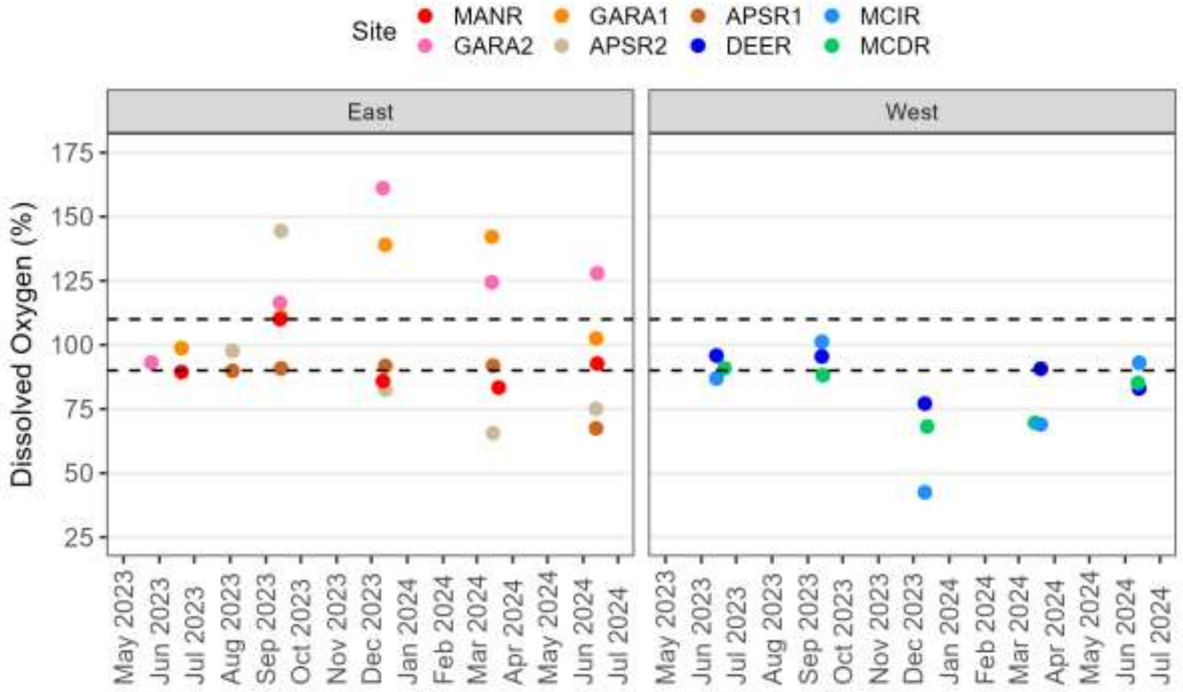

*Figure 7 Dissolved oxygen saturation readings collected by UNE. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

Algal biomass (measured as chlorophyll-a) remained low and similar amongst sites for most of the year (Figure 8). The Apsley and Macintyre Rivers were the only sites with elevated chl-a concentrations in late summer into autumn. Upland streams are often shallow, fast-flowing and shaded; conditions that limit the potential for phytoplankton growth, and therefore there is no ANZECC trigger value for chlorophyll-a in upland streams (ANZECC 2000). The trigger value for lowland streams, freshwater lakes and reservoirs is 5 µg/L. Concentrations above 5 µg/L are known to cause excessive and potentially harmful algal blooms. The frequent exceedances of both dissolved (Figure 18 & Figure 20) and total nutrients (Figure 16 & Figure 19) as well as lack of riparian shading, create conditions that promote algal growth. While this was not reflected in the concentrations of chlorophyll-a measured from within the water column, high amounts of benthic algae (attached to substrate) and aquatic plant growth were observed (Figure 9).

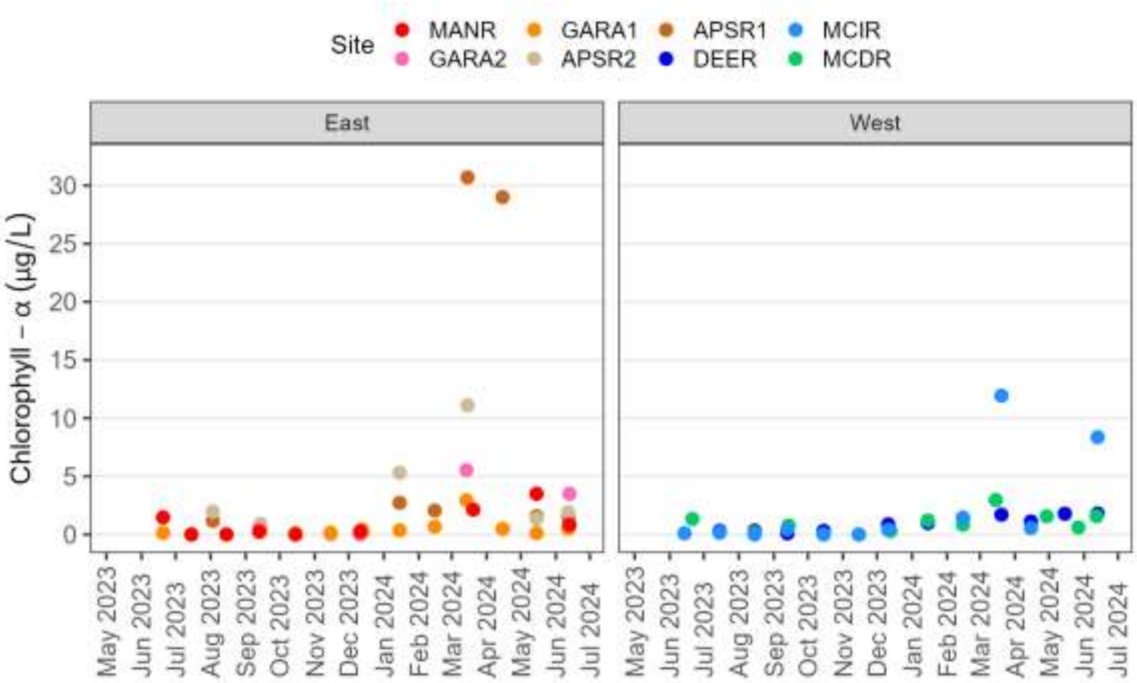

*Figure 8 Chlorophyll-a concentration readings collected by UNE. Sites are separated based on direction of catchment flow.*

*Figure 9 Site photos of algae and aquatic plant growth. From top to bottom and left to right: MANR Sep 2023; GARA2 Mar 2024; DEER Mar 2024; APSR1 Oct 2023, MCIR Mar 2024; APSR2 Mar 2024.*

In the eastern draining catchments, pH was more alkaline than the ANZECC maximum guideline at most sites during the sample period while in the western draining catchments, pH was generally lower (Figure 10). The parent material of the surrounding soil strongly affects background water pH levels, with basalt-derived soils naturally being more alkaline than granite or trap-derived soils in this region (Reid et al 2006). pH levels vary naturally throughout the day with temperature and rates of photosynthesis but can also be influenced by changes in land use and resulting run-off or erosion. Most aquatic organisms have adapted to survive in a range of pH levels (generally 6-9), but rapid fluctuations or chronic exposure to values higher or lower than is typical can be harmful.

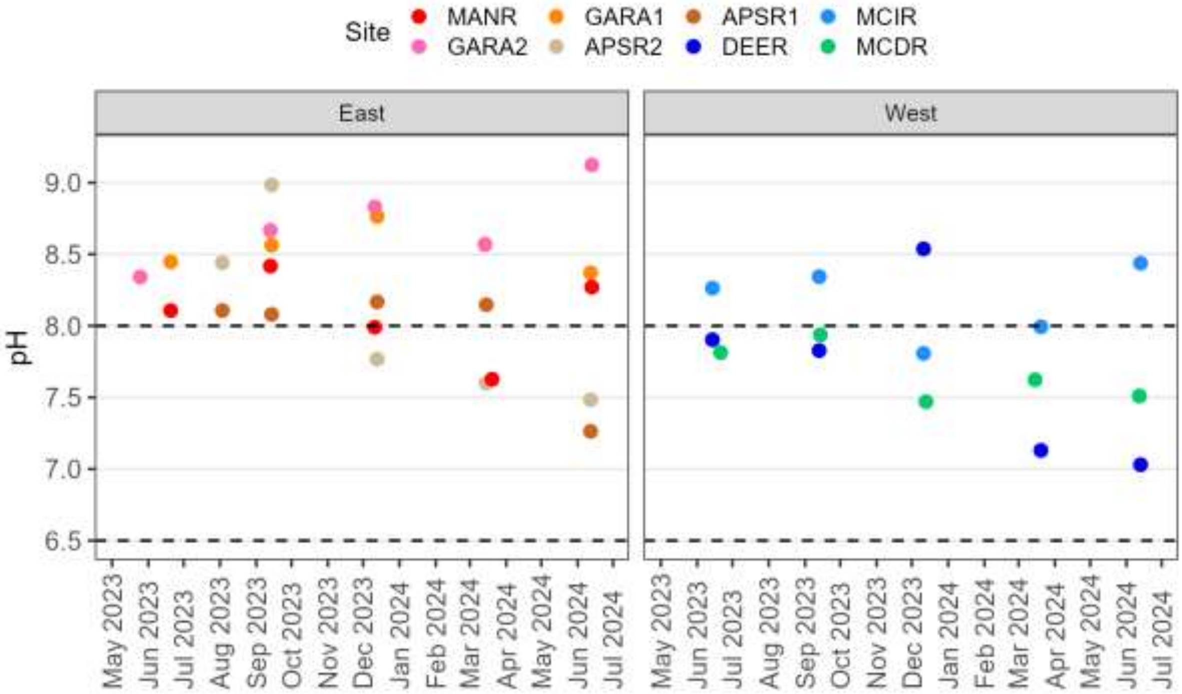

*Figure 10 pH readings collected by UNE. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

Turbidity was low at all sites and was within or below ANZECC guidelines in all months except June 2024 (Figure 11). The increased turbidity in June at MCDR (28.9 ± 0.1 NTU, Table 5), APSR2 (32.8 ± 0.2 NTU, Table 9), and APSR1 (41.1 ± 0.2 NTU, Table 10), followed heavy rainfall and increased river discharge (Figure 26, Figure30, & Figure 31), which likely increased sediment run-off or bank erosion within the catchment. Total suspended solids were correspondingly low (Figure 13). These low turbidity and total suspended solids values are also reflected in the sediment accumulated in the time-integrated suspended sediment samplers (Figure 14). The amount of sediment collected was negligible at most sites, with the highest amount collected between April, May, and June 2024 at APSR2 (7.1 g dry weight; Table 11) and MCDR (10.2 g dry weight; Table 11). High turbidity reduces light penetration, affecting rates of primary productivity and oxygen production. Suspended sediments in the water can also have negative impacts on aquatic plants and macroinvertebrate habitat by smothering when those sediments settle. Additionally, sediment run-off can carry pollutants such as bacteria and soil-bound nutrients, adding to the total nutrient load in the river.

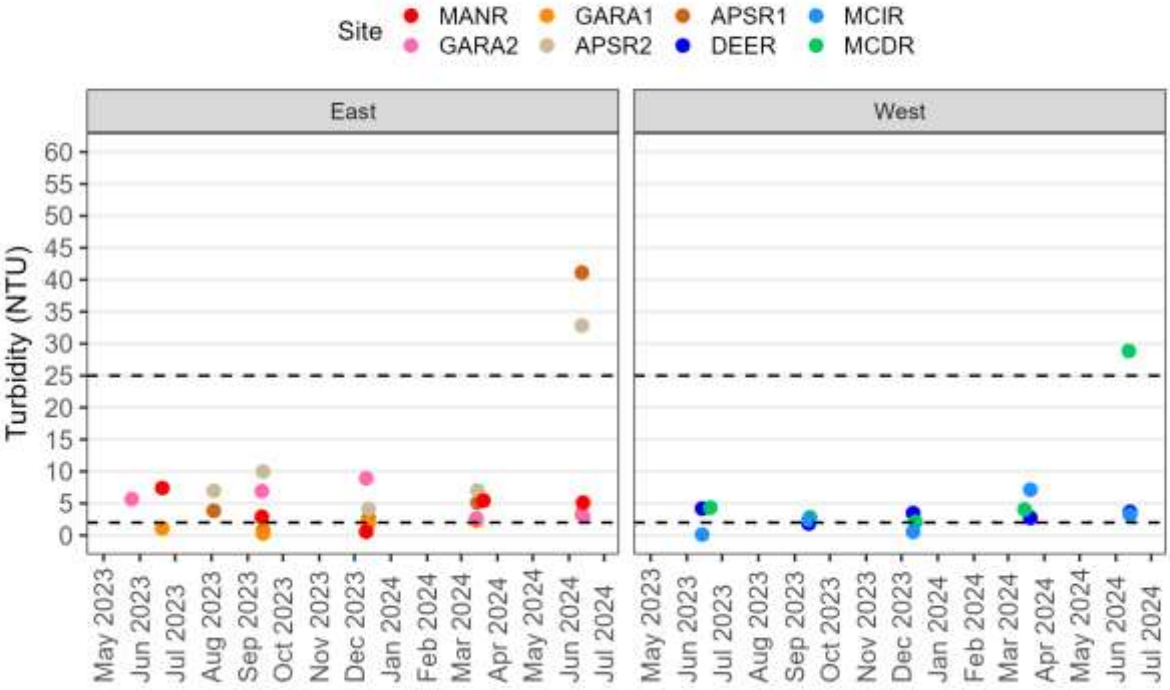

*Figure 11 Turbidity readings collected by UNE. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

*Figure 12 Observations of increased turbidity. Left: APSR1 May 2024; right: MCDR May 2024.*

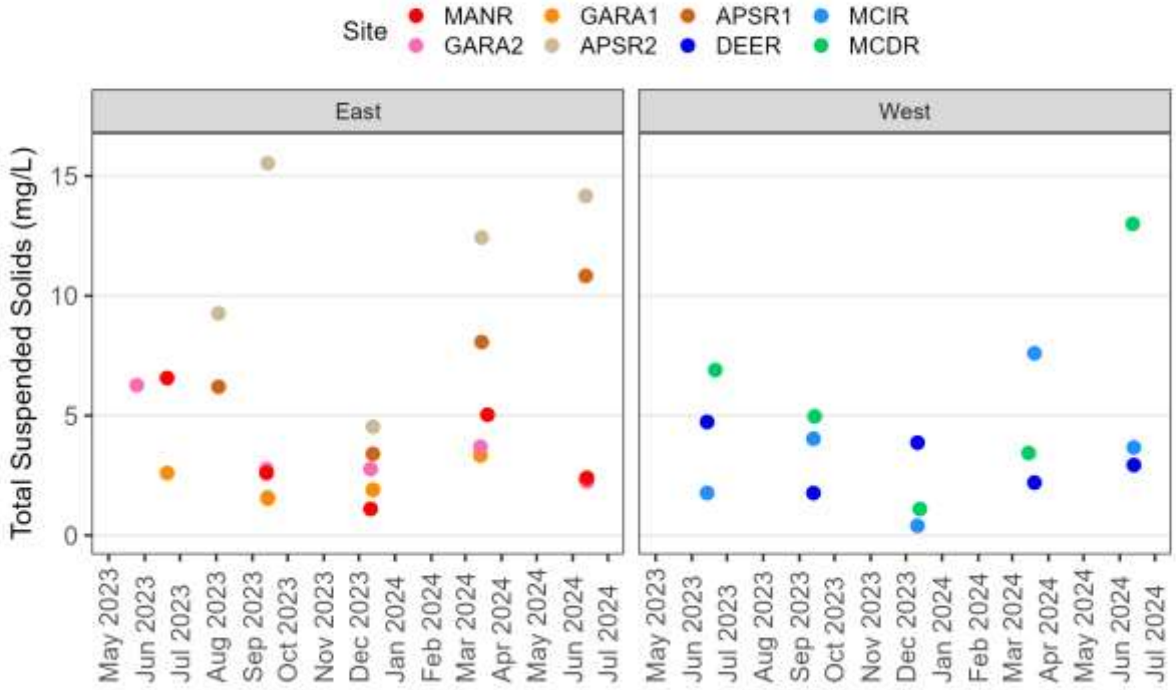

*Figure 13 Total suspended solids readings collected by UNE. Sites are separated based on direction of catchment flow.*

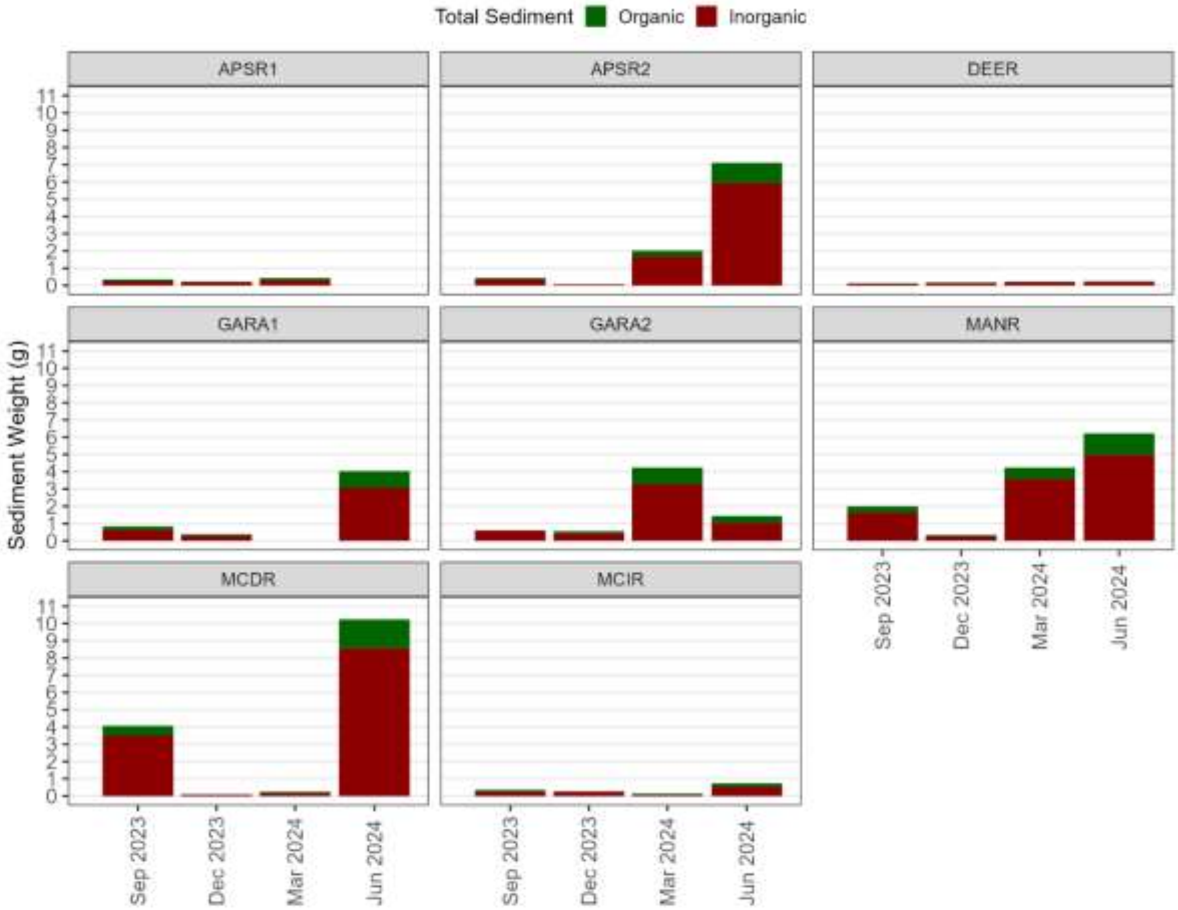

*Figure 14 Results of quarterly collections of suspended sediment samples from the time-integrated sediment samplers. The sampler was washed away at APSR1 and there was no sample for the last quarter.*

## 3.2. Nutrient Parameters

Dissolved organic carbon (DOC) is a fraction of the total organic carbon, which is a measure of the amount of organic matter in an ecosystem. Carbon is an essential element for life and in aquatic ecosystems organic matter from sources such as leaf litter fuels primary and secondary production. In Australian waters, concentration of DOC generally ranges from 1-10 µg/mL (Boulton et al 2014). All sites had DOC concentrations within the expected range (Figure 15). Low concentrations of DOC can limit primary productivity and reduce the amount of energy available for transfer up the food web, whereas high concentrations can increase bacterial activity thereby increasing oxygen demand.

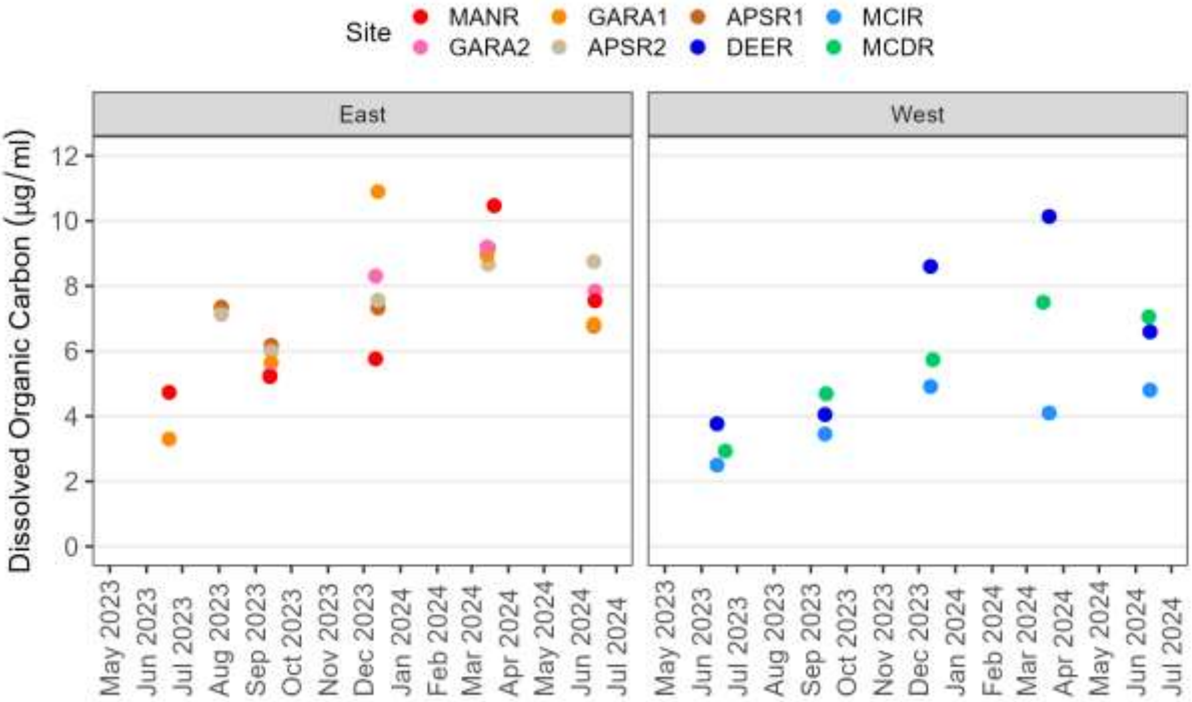

*Figure 15 Dissolved organic carbon values. Samples collected by UNE. Sites are separated based on direction of catchment flow.*

Total nitrogen was above ANZECC guidelines at all sites for most of the year (Figure 16). The highest recorded concentration was in November 2023 at APSR1 (4632.7 ± 1362.7 µg N/L, Table 10); other high values were at or below 2,500 µg N/L (Table 3 to Table 10), which is 10 times the ANZECC trigger value. Values of total nitrogen decreased at most sites in April, May, and June 2024, falling below the trigger value at GARA1, MCIR, and DEER. Total Kjeldahl nitrogen, which is composed of total organic nitrogen and ammonia, was the largest component of total nitrogen (Figure 17).

Inorganic nitrogen, measured as oxides of nitrogen (dissolved nitrate + nitrite; $NO_x$), was a small component of the total nitrogen. All sites were at or slightly above ANZECC trigger values for $NO_x$ for most of the year (Figure 18). The highest values were recorded at APSR2 in April (638.3 ± 15.4 µg N/L, Table 9), May (727.3 ± 50.1 µg N/L), and June 2024 (637 ± 4.4 µg N/L). The Apsley River downstream site, APSR1, only had elevated values of nitrates and nitrites in June (509.3 ± 17.9 µg N/L, Table 10). In the western draining catchments, each site had a different month with elevated concentrations of nitrates and nitrites. In February, DEER had $NO_x$ values of 352.7 ± 30.8 µg N/L (Table 3Table 3). MCIR had a value of 163.7 ± 144.8 µg N/L in April (Table 4), and MCDR had a value of 511 ± 7.8 µg N/L in June (Table 5). Nutrient concentrations were similar across sites for most of the study period.

Nitrogen enters aquatic systems as nitrogen gas from the atmosphere, as well as from vegetation, run-off, and groundwater. Inorganic nitrogen is the form that is readily available for use by plants and algae. Excess inorganic nitrogen in a system can fuel nuisance algal and plant growth. Organic nitrogen is transformed into bioavailable inorganic forms (ammonium, nitrate, nitrite) by microorganisms. The inorganic nitrogen can then be incorporated into living tissue as organic nitrogen and cycled through the food web or released back into the atmosphere as a gas. Nitrogen is naturally transformed and recycled within a balanced ecosystem. Anthropogenic input of nitrogen can alter this natural balance. Sources of excess nitrogen can include point sources such as sewage outfalls (a known contributor upstream of APSR2), as well as diffuse sources like fertilisers and animal waste.

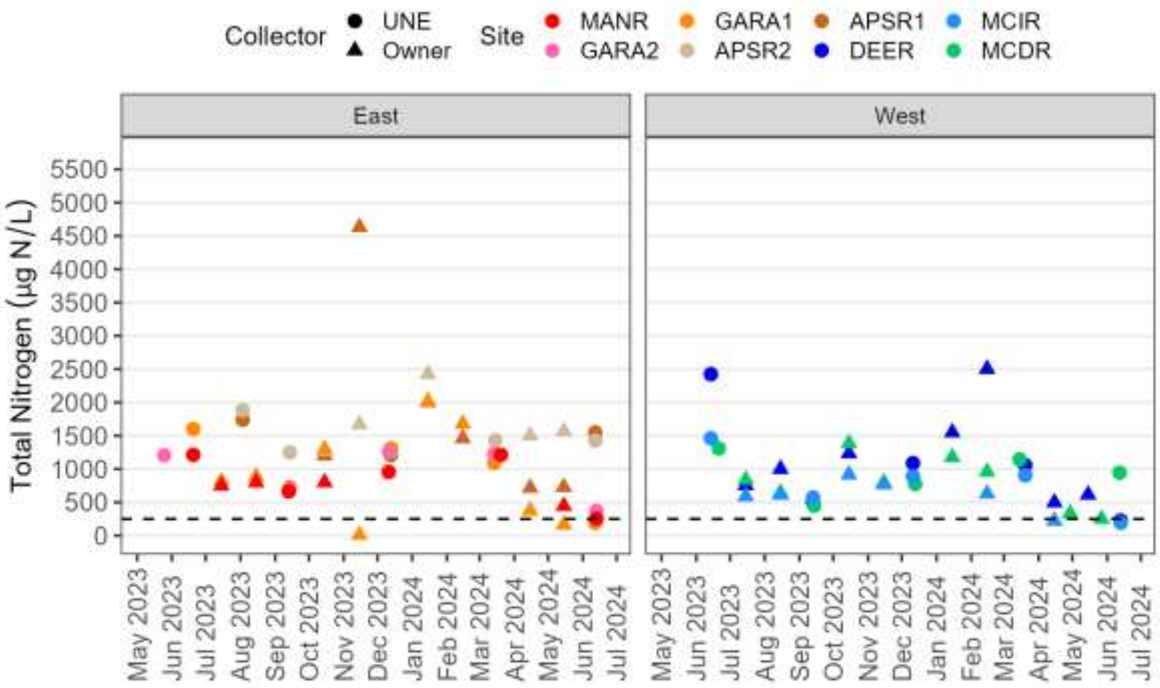

*Figure 16 Total nitrogen values. Samples collected by UNE and landholders. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

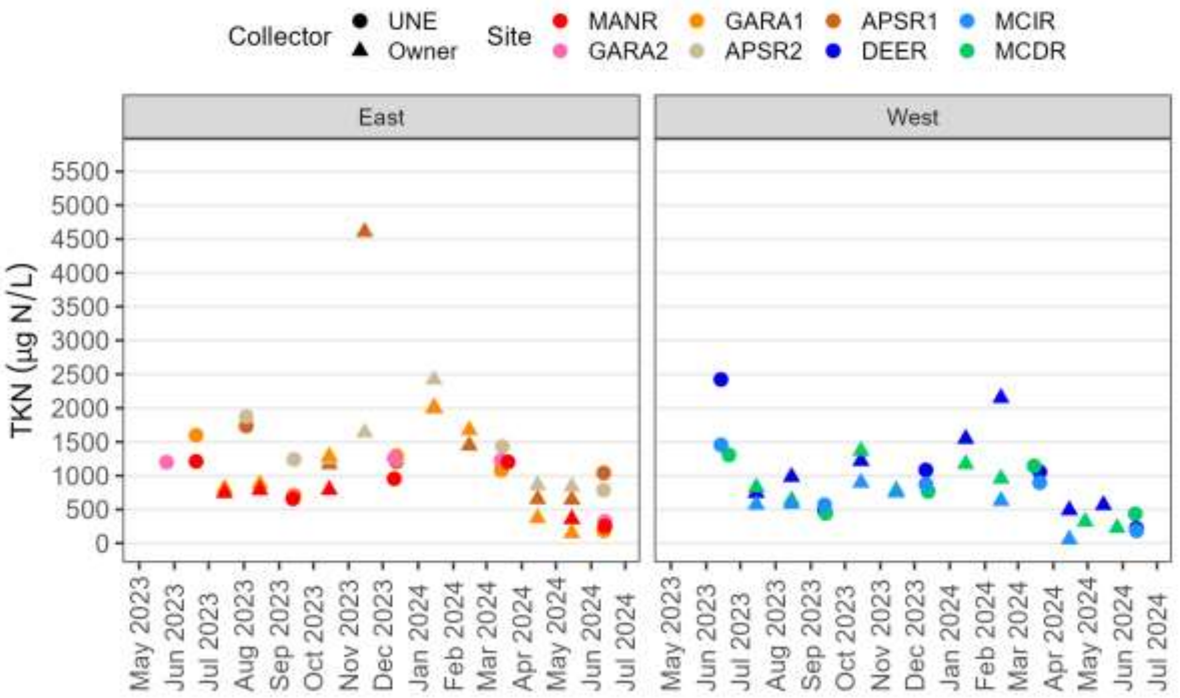

*Figure 17 Total Kjeldahl nitrogen values. Samples collected by UNE and landholders. Sites are separated based on direction of catchment flow.*

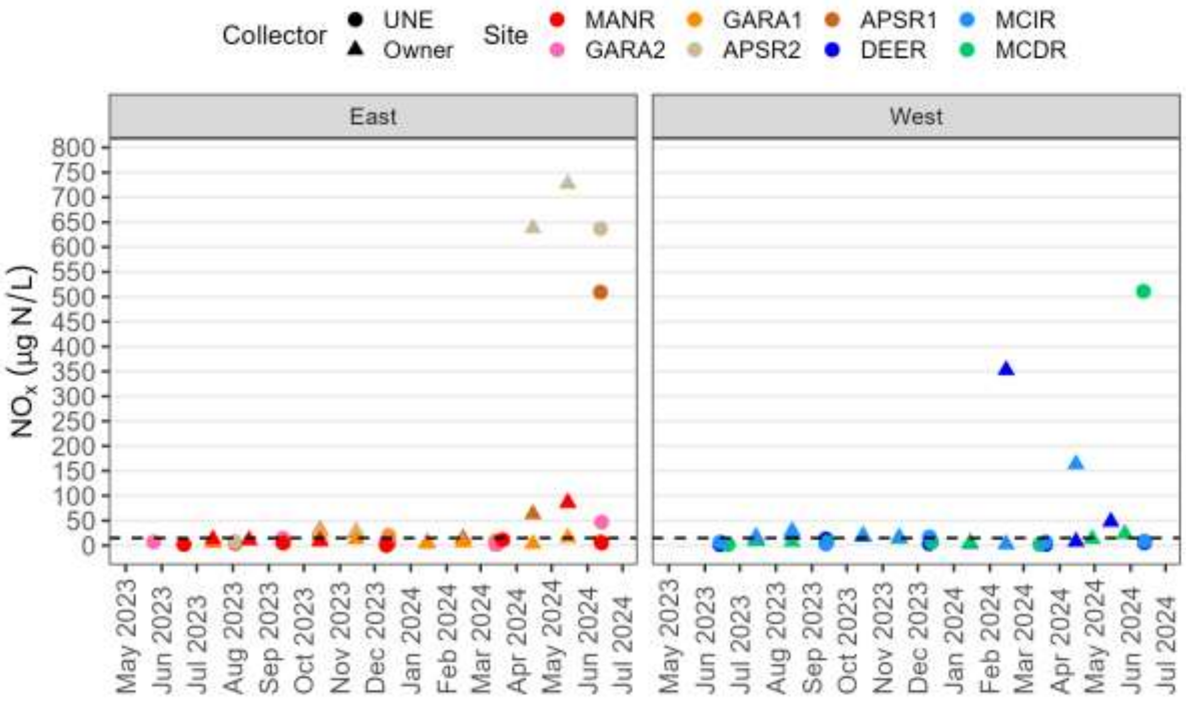

*Figure 18 Dissolved nitrate and nitrite values. Samples collected by UNE and landholders. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

Similar to total nitrogen, values of total phosphorus (TP) were mostly above the ANZECC trigger value (Figure 19). The upstream Apsley River site (with upstream sewage outfall) consistently had the highest TP values, ranging between 148.3 ± 56.6 to 320.7 ± 16 µg P/L in all months but August 2023 which had a lower value of 85.7 ± 71.1 µg P/L (Table 9). Within the eastern draining catchments, variation in TP values amongst sites and concentrations of TP generally increased after February 2024. Within the western draining catchments, values were similar amongst sites with the exception of December, February, and March in the Macintyre River which had levels of TP ranging from 286.7 ± 16.8 to 325.7 ± 77.4 µg P/L (Table 4)

Filterable reactive phosphorus (FRP) is a measure of orthophosphate, the bioavailable form of phosphorus. The upstream Apsley River site and the Macintyre River site were consistently above the ANZECC trigger value and similar in their range from 35 ± 3 to 144 ± 2.6 µg P/L (Table 9 & Table 4). The remaining sites were below the trigger value during the cooler and drier months at the start of sample collection.

Most phosphorus is bound to sediment particles or within living organisms and is biologically unavailable. Inorganic phosphate is the form of phosphorus that is readily available for use by plants and algae. Inorganic phosphate is transformed into organic phosphate when it is incorporated into plant tissue, and then transformed back into inorganic phosphorus when it decomposes. Phosphorus is transformed and recycled continuously throughout the aquatic food web. Inputs of phosphorus to aquatic ecosystems come largely from sediment run-off and erosion of subsoils and streambanks (Davis & Koop 2006), which can be accelerated due to changes in land use. More direct sources of phosphorus, such as sewage outfalls, also contribute to high phosphorus levels as is seen at APSR2 (Figure 19 & Figure 20).

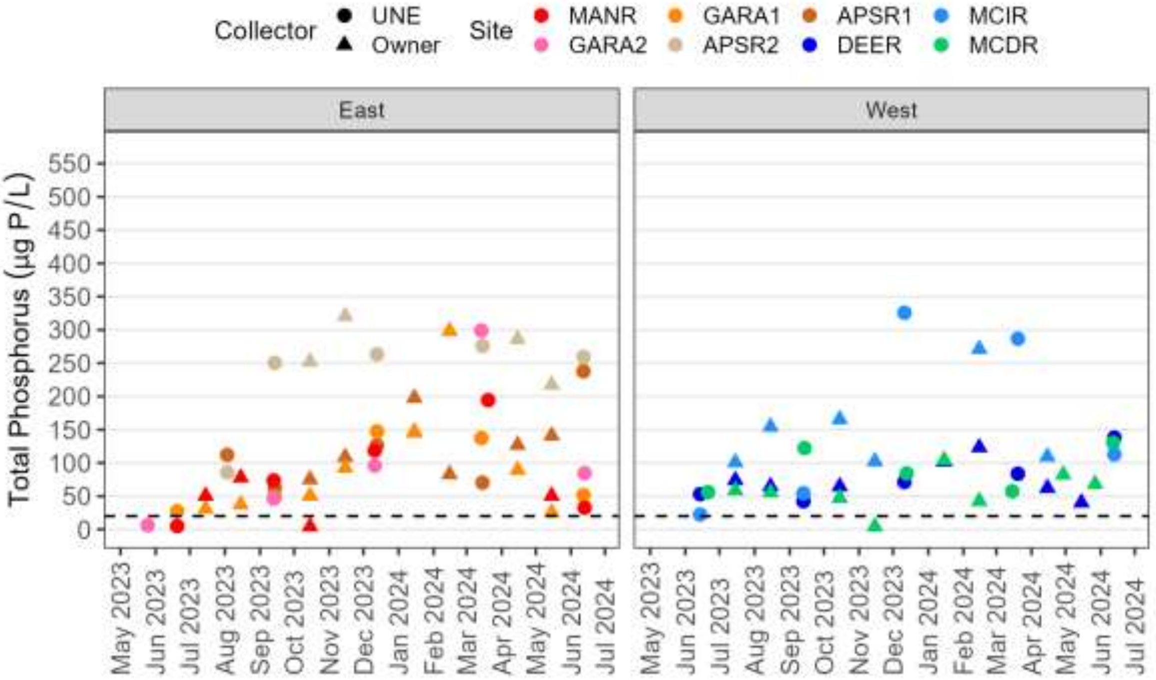

*Figure 19 Total phosphorus values. Samples collected by UNE and landholders. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

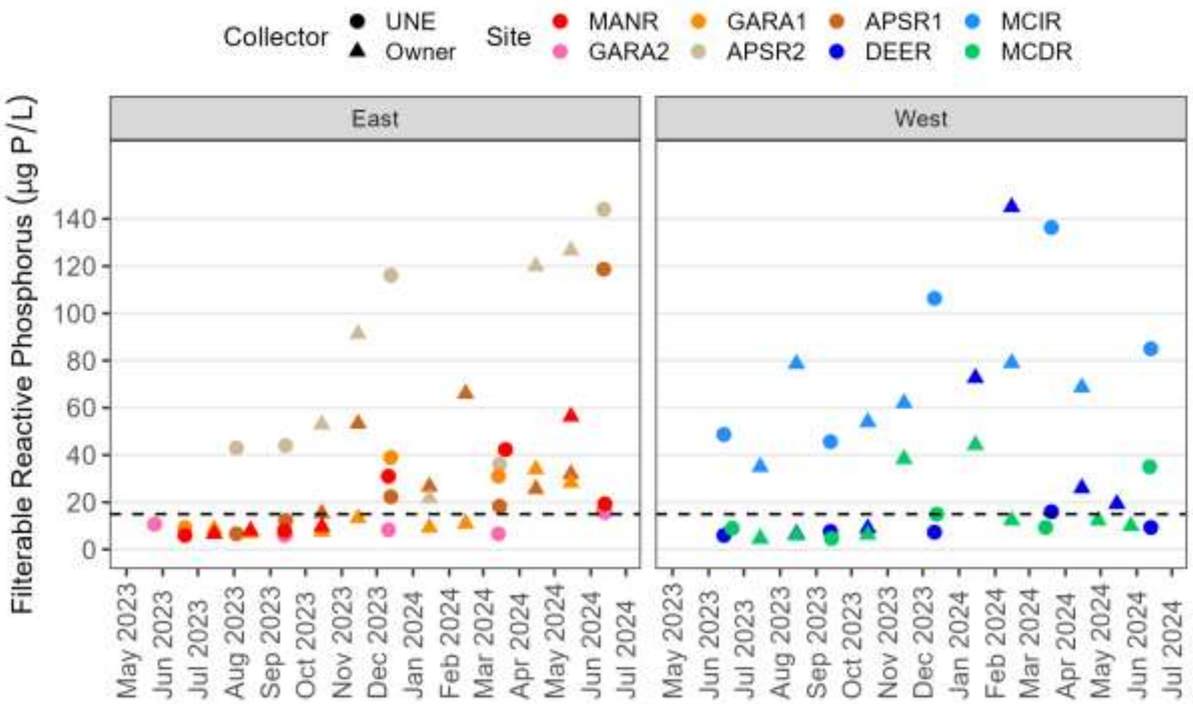

*Figure 20 Filterable reactive phosphorus values. Samples collected by UNE and landholders. Sites are separated based on direction of catchment flow. Dashed lines indicate ANZECC (2000) default trigger values for upland rivers.*

Nitrogen and phosphorus are essential elements for plant growth, but increased inputs into rivers due to human activities results in eutrophication. The supply of one or both of these nutrients is often the factor limiting plant and algal growth. Thus, increasing the supply of these nutrients results in excessive plant or algal growth, assuming there are no other constraints on growth (Boulton et al 2014). These nutrients also have a long residence time within the system and can fuel future plant growth. In upland headwater streams, these nutrients are also transported downstream contributing to eutrophication in lowland and coastal areas.

## 3.3. Auto-Analyser Results (GARA2)

The Eco-detection auto-analyser unit that was located at GARA2, the upstream Gara River site, collected water quality readings four times a day over the duration of the sampling period. Both conductivity (Figure 21) and pH (Figure 22) reflected daily temperature-related changes. Conductivity values stayed mostly within trigger values throughout the year (Figure 21). Values of pH were mostly above the trigger value (Figure 22), but were consistent with spot measurements (Figure 10). Daily turbidity readings at GARA2 were mostly within trigger values; however, the eco-detection unit experienced high levels of bio-fouling between maintenance periods (Figure 23).

The results from additional parameters analysed are shown in Table 12 and Table 13. Chloride, fluoride, and sulphate were not analysed in water samples from other sites. Nitrate concentrations were below detection limits for most of the year but showed a large increase in May (0 – 389 ppb) and June 2024 (0- 496 ppb; Table 13), which follows the trend seen in spot measurements (Figure 18).

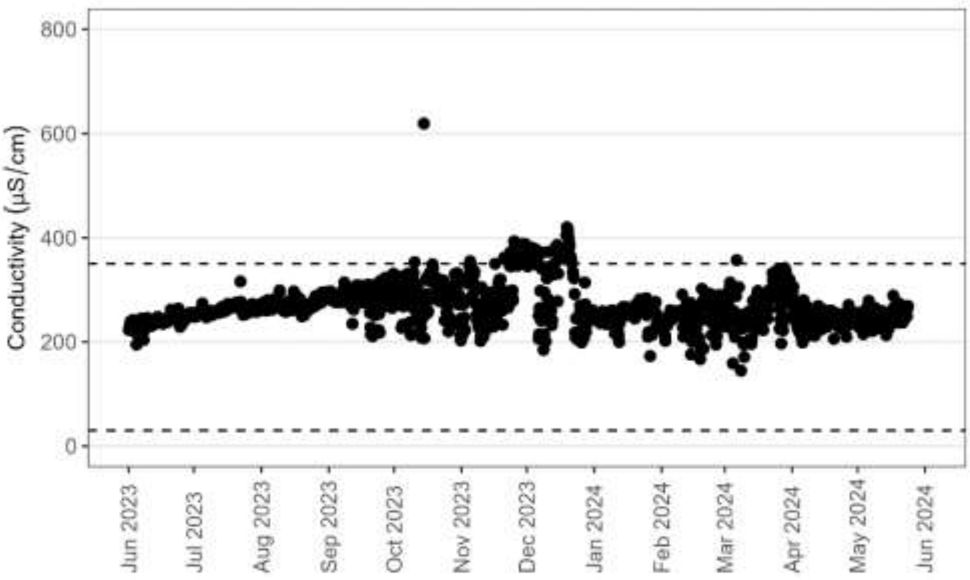

*Figure 21 GARA2 Eco-Detection unit continuous readings of Electrical Conductivity. Readings were taken four times a day.*

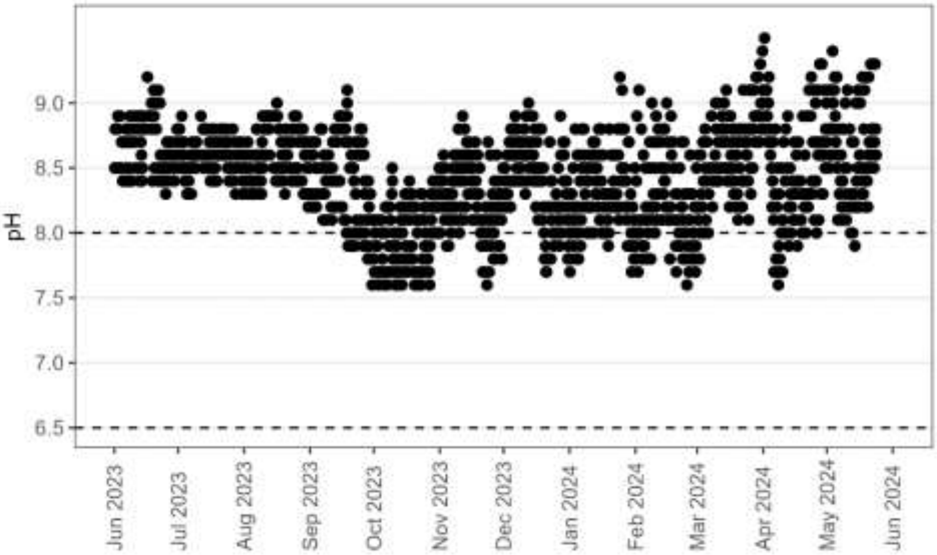

*Figure 22 GARA2 Eco-Detection unit continuous readings of pH. Readings were taken four times a day.*

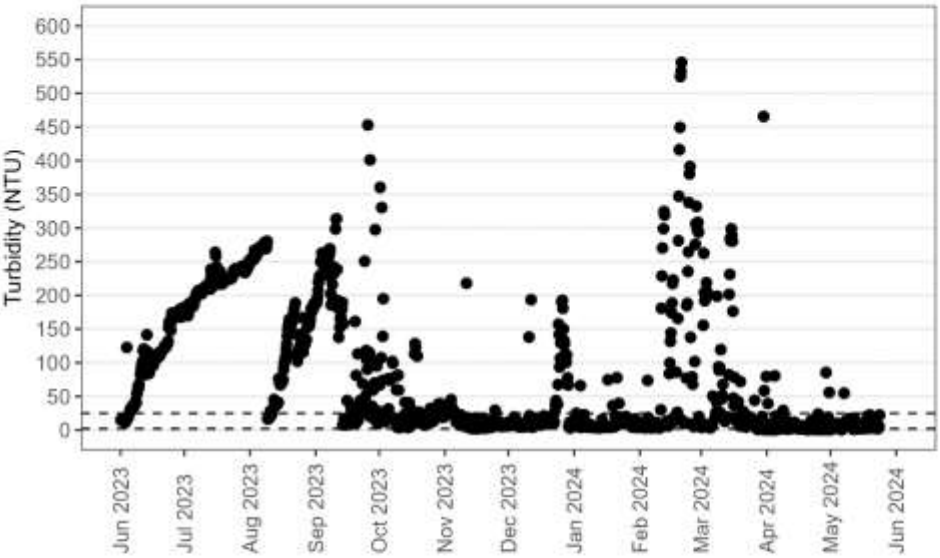

*Figure 23  GARA2 Eco-Detection unit continuous readings of Turbidity. Readings were taken four times a day.*

## 3.4. Dissolved Oxygen and Temperature Loggers

Temperature and levels of dissolved oxygen in aquatic ecosystems are important drivers of ecosystem function. Aeration of aquatic environments occurs through atmospheric gas exchange at the water surface and through photosynthesis by aquatic plants and algae. Oxygen concentrations are expected to be at their maximum in the afternoon when photosynthesis rates are highest. Oxygen concentrations then drop overnight when photosynthesis ceases and living organisms continue to consume oxygen (respire). Levels of oxygen can drop to lethal levels by early morning if biological oxygen production during the day was not enough to meet the demand at night. The production of oxygen is controlled by numerous factors including the amount of light penetration through the water column. The balance between oxygen production and consumption can be disrupted by factors such as excess plant or algal growth in the presence of high nutrient availability. The biological oxygen demand of microbial decomposers as plants and algae die, combined with oxygen consumption by living organisms, can exceed the amount of oxygen that was produced during the day.

Dissolved oxygen concentration is strongly influence by temperature. The solubility of gases in liquids decreases with increasing temperature, meaning warm water can hold less dissolved oxygen than cool water. The potential for hypoxic (low dissolved oxygen) conditions is greatest in the summer when temperatures are warmer and the biological demand for oxygen is greatest. The natural cycle of daily oxygen fluctuations is a process to which aquatic biota are well adapted, but when oxygen levels drop too low for too long it can exceed the tolerance limits of an organism.

Continuous logging of temperature and dissolved oxygen data provides a full picture of daily fluctuations and more accurately reflects environmental conditions than spot measurements. Large daily fluctuations with high maximum temperatures and large swings in dissolved oxygen can indicate the potential for hypoxic or anoxic conditions to develop. Large daily fluctuations are also a sign that the equilibrium between re-aeration, oxygen production and oxygen consumption needs to be restored.

All sites had days when dissolved oxygen fell below 2 mg/L overnight, a level which is harmful to most aquatic fauna with prolonged exposure. These low overnight levels began occurring as water temperatures were increasing in October 2023 (Figure 24-Figure 31). Hypoxic conditions (0.03 mg/L) appeared first at MANR in October (Figure 27), followed by APSR1 (0.06 mg/L) in November (Figure 31), and APSR2 (0.04 mg/L) in December (Figure 30). The largest daily fluctuations in both oxygen and temperature occurred in GARA1, which also had the highest recorded daily temperature of 36.5°C in December (Figure 29). The variation in dissolved oxygen is not associated with chlorophyll-a spot measurements (Figure 8), indicating that benthic algae and aquatic plants (Figure 9) are more important for oxygen production than phytoplankton. MCIR had the lowest maximum temperature (25.6°C) and the smallest daily fluctuations in both temperature and dissolved oxygen (Figure 25). This was also the location with the most riparian overstory vegetation present.

## Deepwater River

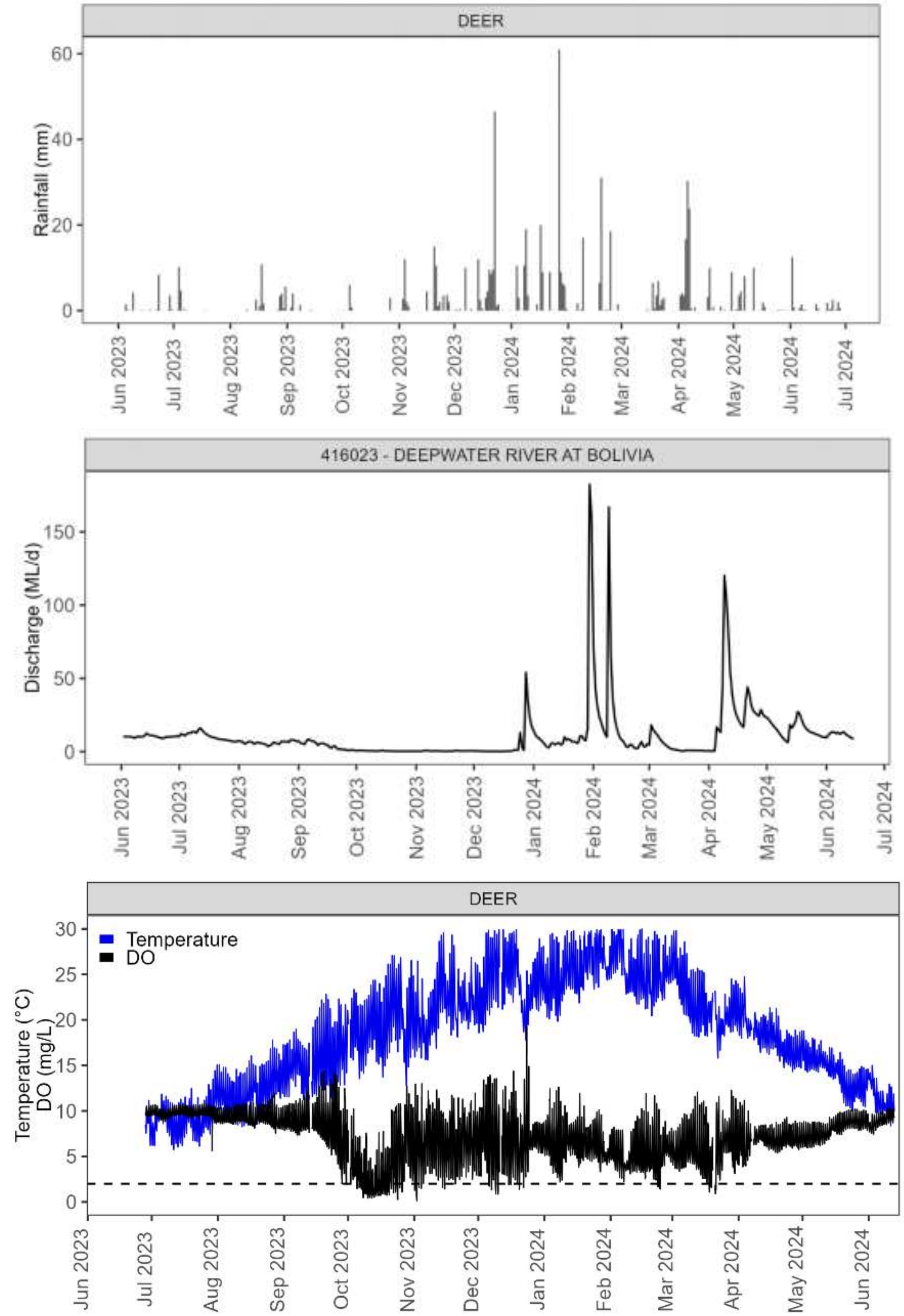

*Figure 24 top) Actual and interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) DEER continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life.*

## Macintyre River

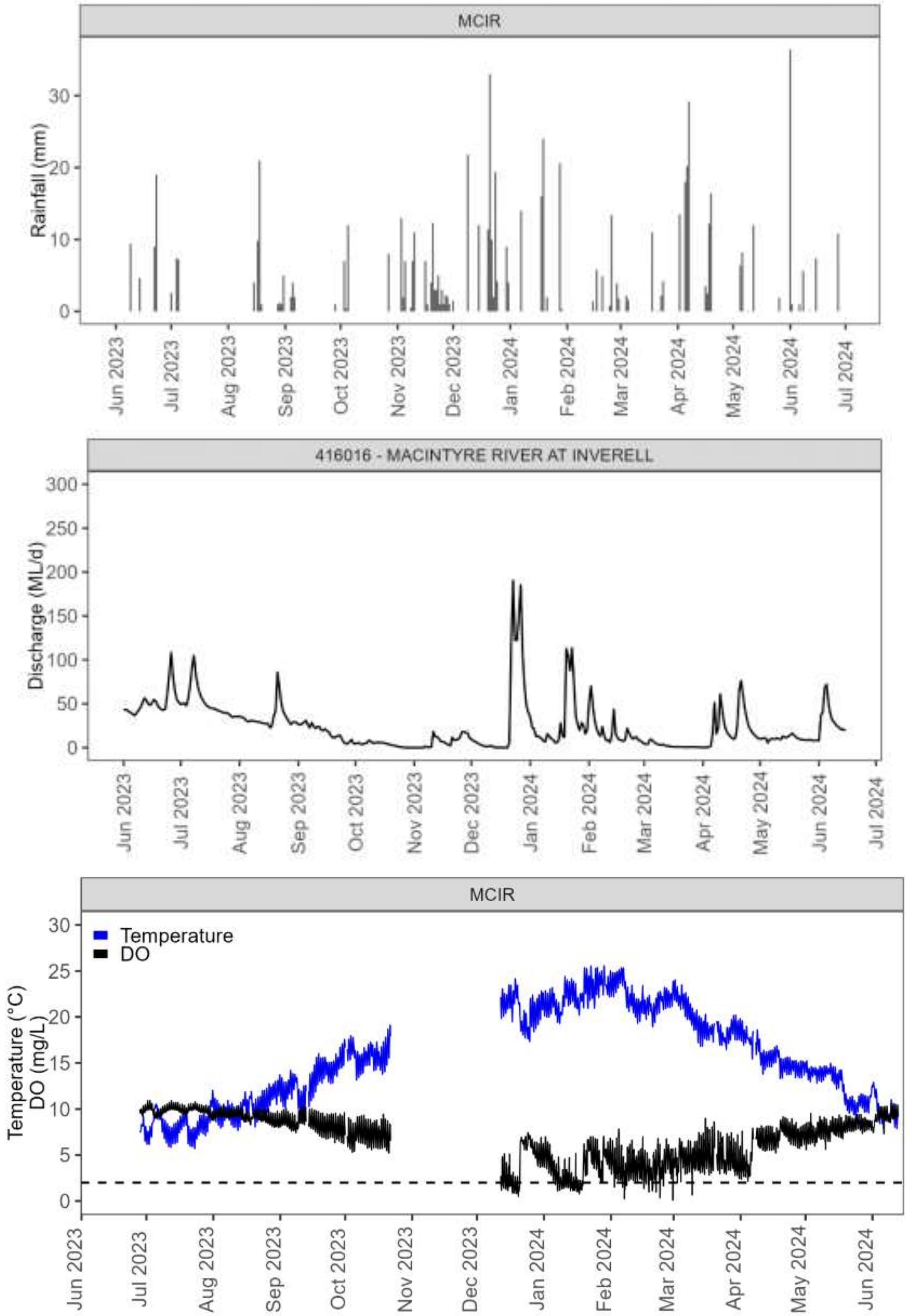

*Figure 25 top) Actual and interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) DEER continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life. The quality of readings decreased between mid-October and mid-December and were not included in the figure.*

## Macdonald River

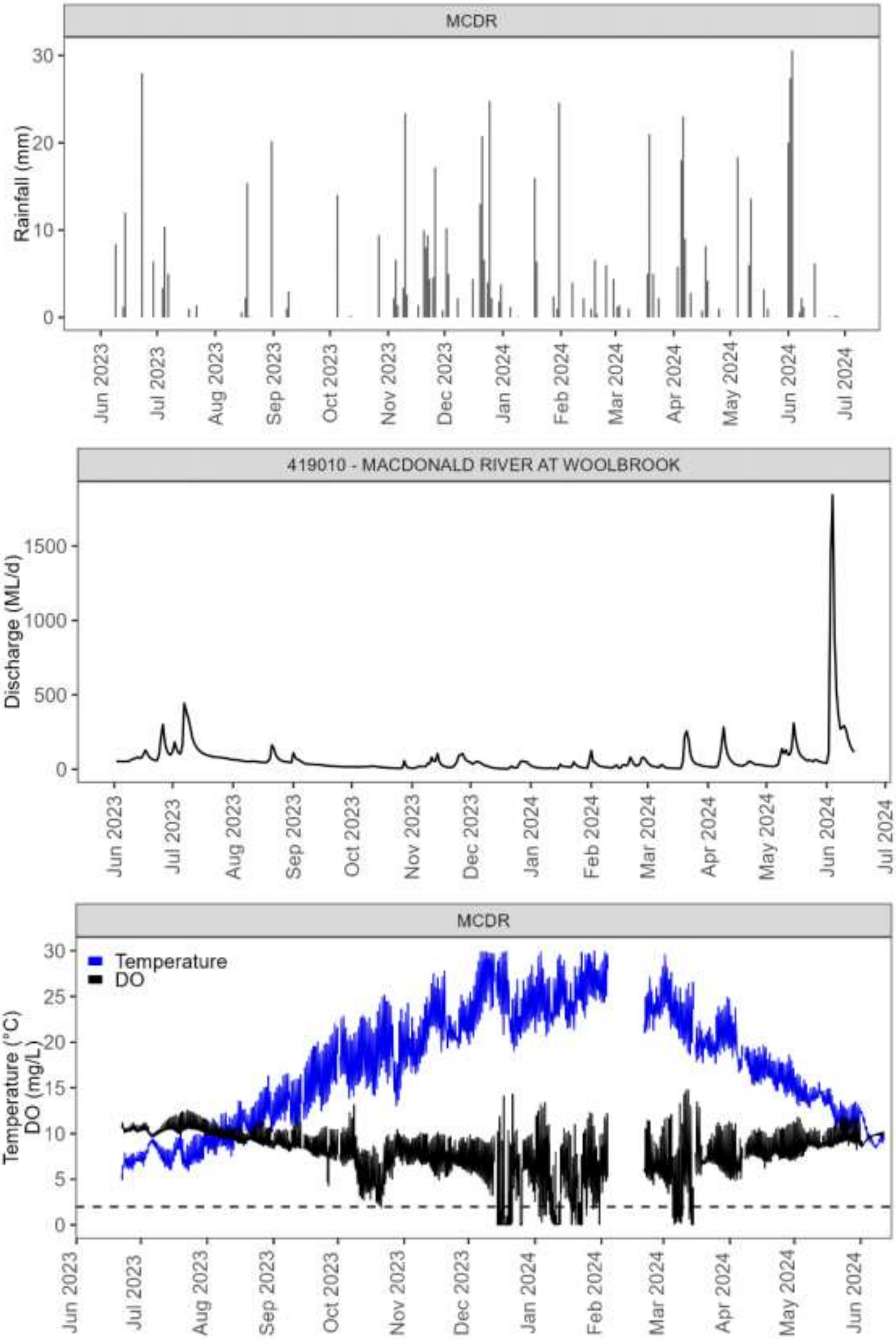

*Figure 26 top) Actual rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) MCDR continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life.*

## Mann River

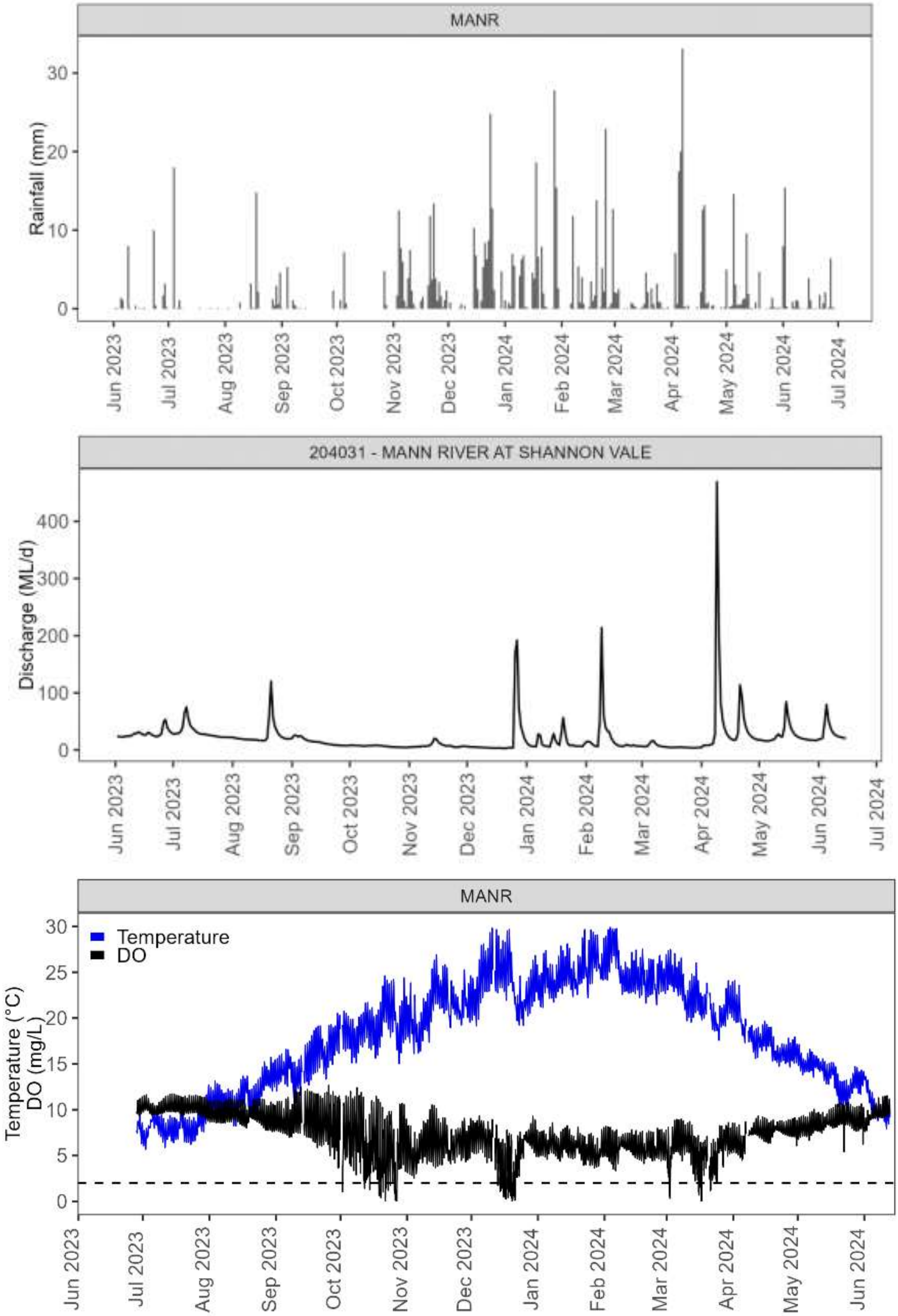

*Figure 27 top) Interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) MANR continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life.*

## Gara River

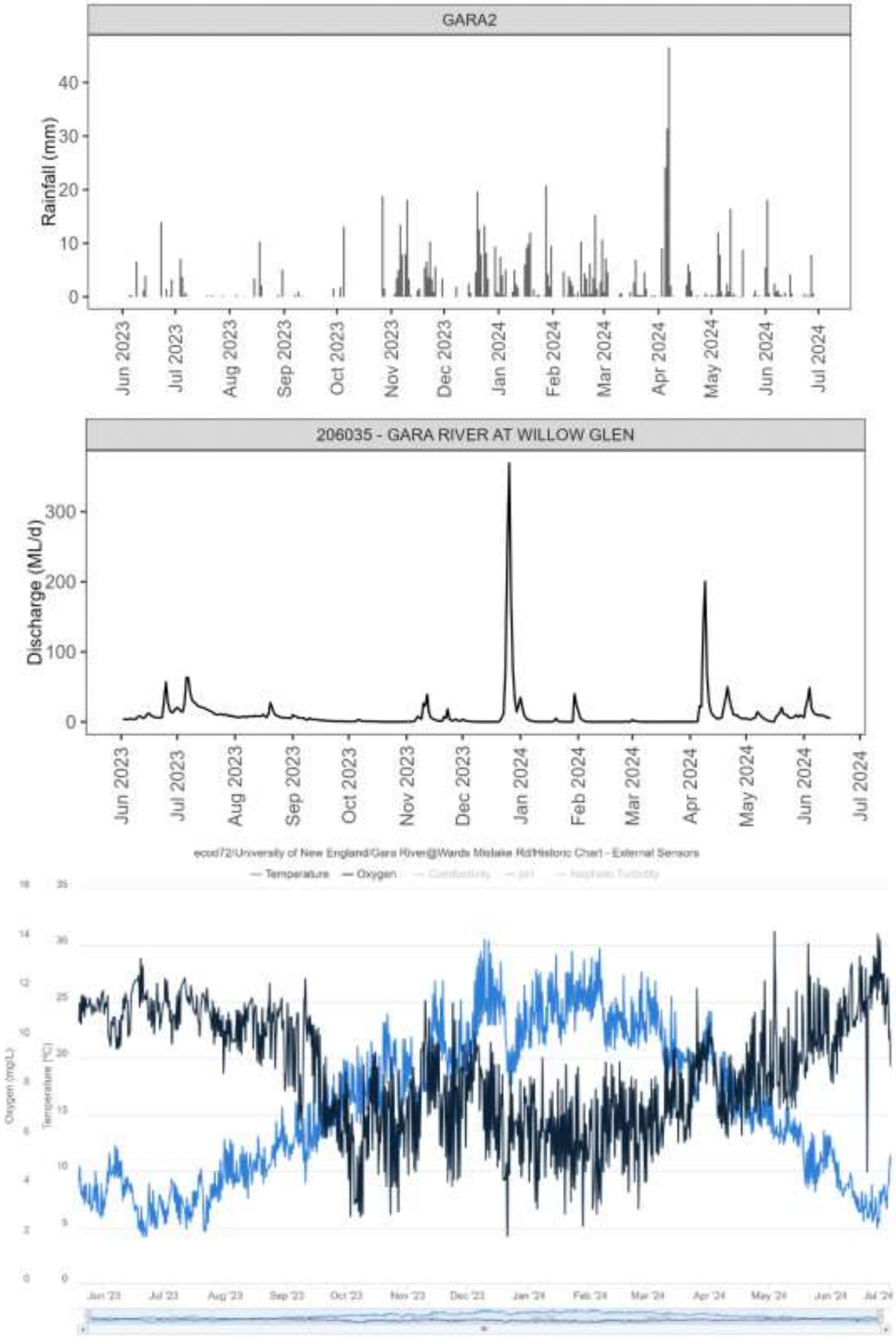

*Figure 28 top) Interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) GARA2 continuous dissolved oxygen and temperature readings from auto-sampler.*

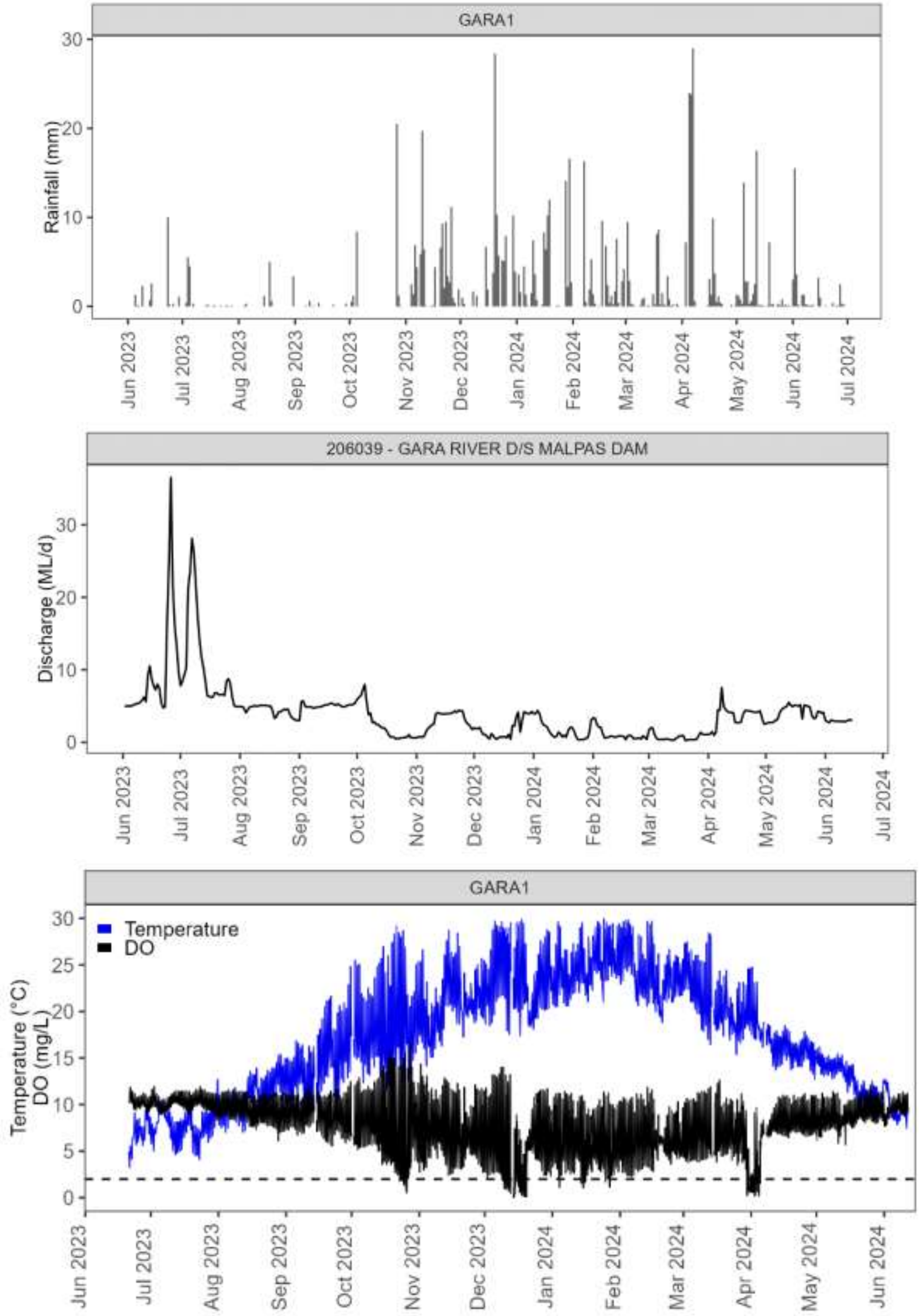

*Figure 29 top) Interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest upstream gauge; bottom) GARA1 continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life.*

## Apsley River

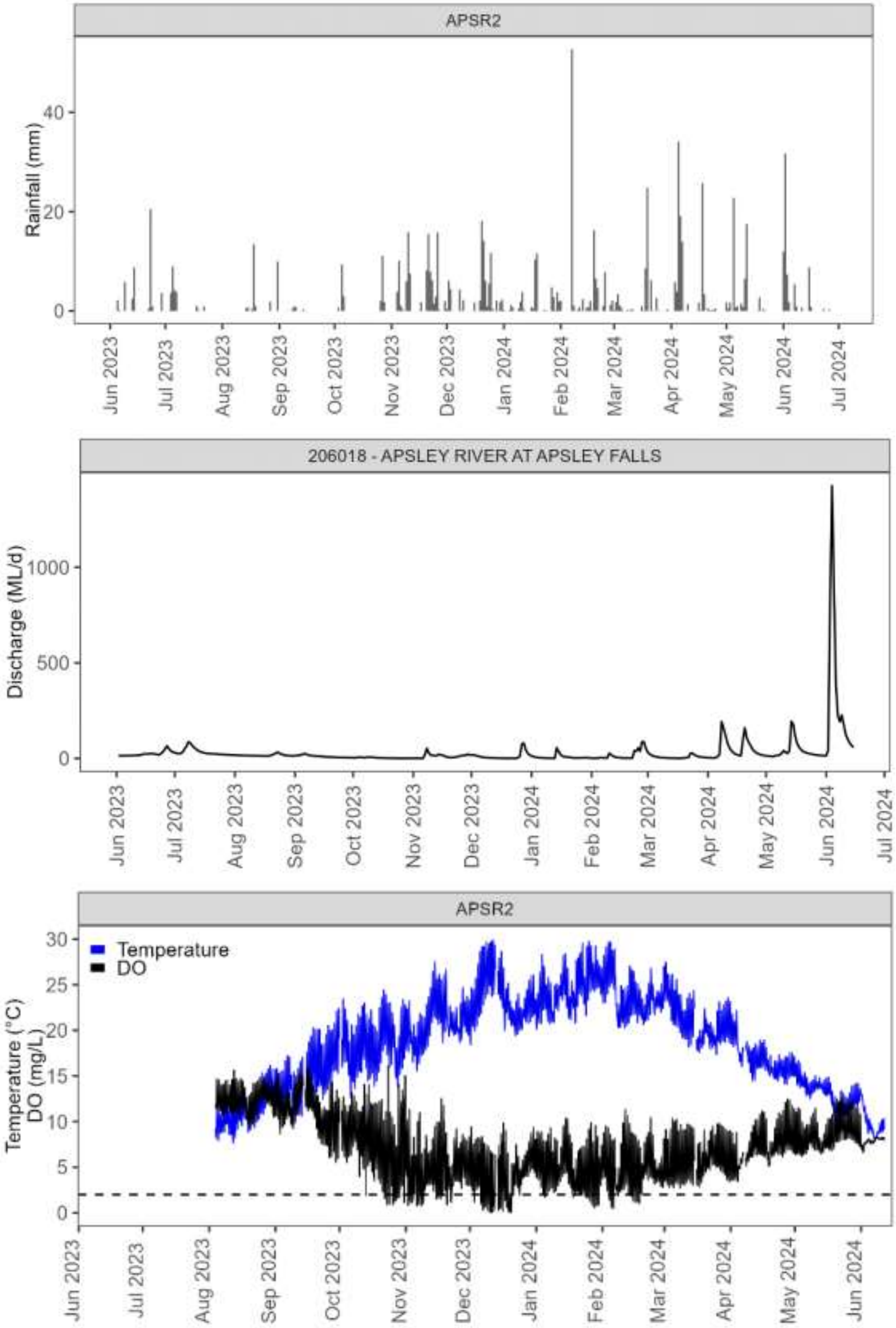

*Figure 30 top) Interpolated rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) APSR2 continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful.*

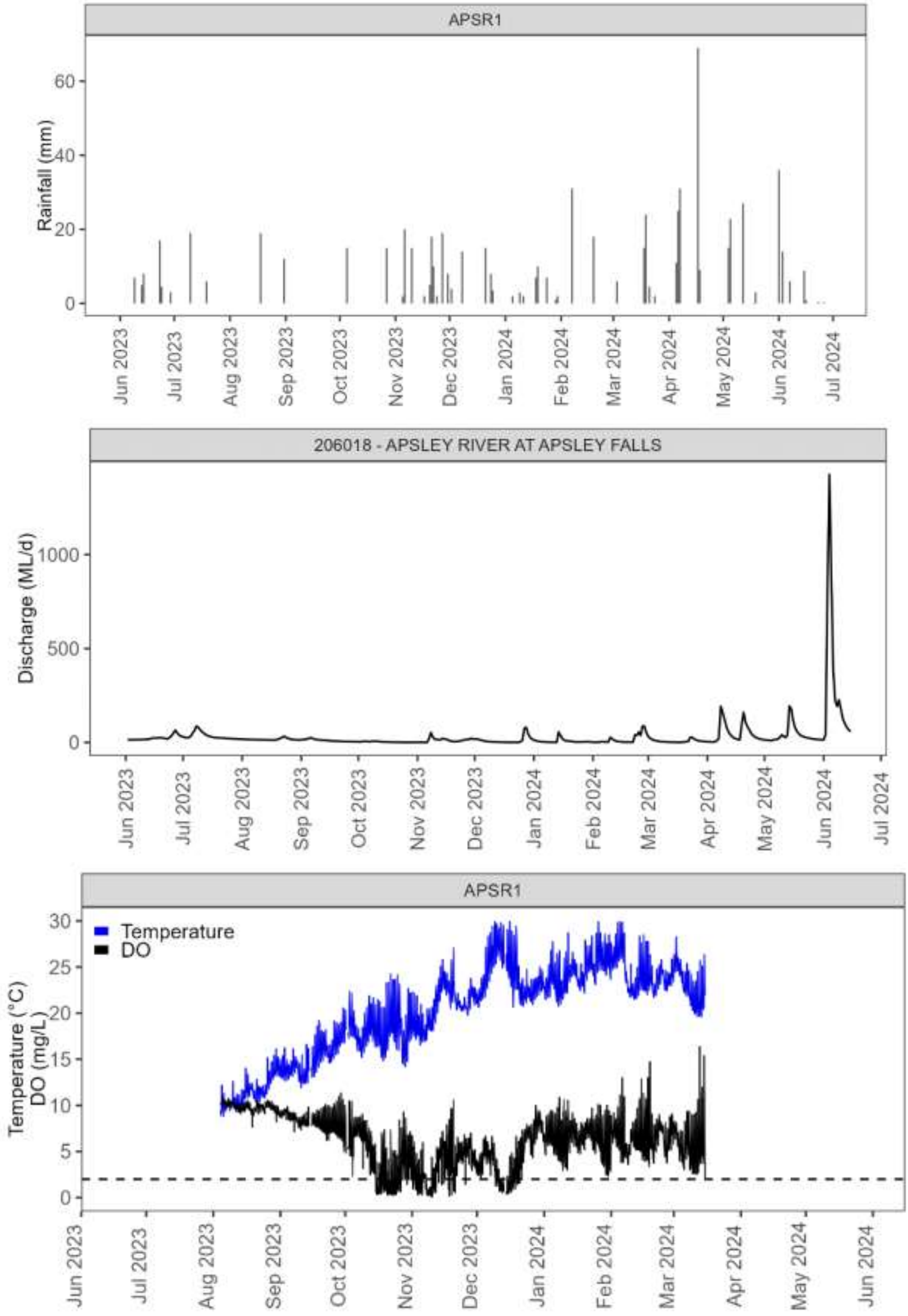

*Figure 31 top) Actual rainfall data from Ag360; middle) Discharge measured at WaterNSW nearest downstream gauge; bottom) APSR1 continuous dissolved oxygen and temperature readings from PME miniDOT logger. Oxygen levels below 2 mg/L (dashed line) are considered harmful to most aquatic life.*

# 4. Conclusion

Overall, sites were enriched in total nitrogen and total phosphorus, low in sediment load, and experienced periods of high water temperature and low oxygen saturation. While the amount of bioavailable nutrients was generally low at most sites, the pool of potential nutrient availability was high, suggesting a legacy of lingering nutrient addition. Careful management of phosphatic and nitrogenous fertiliser applications also remains an important component for the health of waterways so as to not further add to the existing nutrient load. With the exception of a few outlier points (and the upstream Apsley River site (APSR2) with a known source of upstream nutrient input), sites were similar to each other. Current land use practices will have an impact on water quality and nutrient loads, but historic land use has a long-lasting legacy effect. For example, the periods of high water temperature and low oxygen saturation are likely a legacy from the large-scale removal of vegetation that has removed overstory plant communities from providing shade to water surfaces. The low level of sediment load observed at all sites is suggestive of good ground cover and adequate level of herbage mass, which combine to reduce rainfall runoff and soil erosion and loss.

The similarity amongst sites across the region suggests that historic land-use practices have a stronger influence on baseline nutrient concentrations than current practices. Additionally, care should be exercised in interpreting these water quality results as the water quality trigger values and targets that nutrient concentrations are measured against may be inappropriate for this region and more specific region-derived target values would more accurately reflect water quality (NSW DPIE 2020a & 2020b). The input of additional nutrients into these waterways should be avoided regardless of the underlying cause of the high total nutrient levels. Downstream areas are also high in nutrients (NSW DPIE 2020a & 2020b; Ryder et al 2014; Ryder et al 2016) and the potential for harmful algal blooms is increased in lowland rivers.

Water temperatures have increased globally due to climate change; and alterations to river landscapes, like the removal of riparian vegetation, have made rivers less resilient to the impacts of rising temperatures (Johnson et al 2024). In shallow waters, temperatures are generally moderated by shading from riparian vegetation. The influence of shading on water temperatures was evident in the continuous temperature data, with smaller daily fluctuations and lower maximum temperatures seen at MCIR where the riparian vegetation remained intact. Moderating temperature swings is important not only for the health of aquatic life, but also for the influence it has on nutrient cycling. Nutrient cycling at the sediment-water interface is a microbially mediated process, regulated both by temperature (Liu et al 2018) and dissolved oxygen availability (Xia et al 2018). High temperatures and anoxic conditions increase the potential for release of sediment bound nutrients into the water column (Davis & Koop 2006).

Restoring and protecting riparian vegetation and good management of pasture landscapes improves river health, and increases river resilience. Riparian vegetation and pastures with good ground cover and adequate herbage mass reduce erosion, and minimise and trap sediment and nutrients from land run-off (McKergow et al 2003), limiting the amount of new pollutants entering the river. Riparian vegetation also significantly reduces summer water temperatures compared to streams that have no shading (Marsh et al 2005). The most important step in restoring riparian vegetation is preventing further vegetation loss or damage to restoration efforts by controlling stock access as appropriate.

# 5. References

Anzecc, A., (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, 1, pp.1-314.

Bonacina, L., Fasano, F., Mezzanotte, V. and Fornaroli, R. (2023), Effects of water temperature on freshwater macroinvertebrates: a systematic review. Biol Rev, 98: 191-221. https://doi.org/10.1111/brv.12903

Boulton, A., Brock, M., Robson, B., Ryder, D., Chambers, J. and Davis, J. (2014). Australian freshwater ecology: processes and management. John Wiley & Sons.

Bureau of Meteorology (2024). Available at: http://www.bom.gov.au/climate/current/season/nsw/archive/202402.summary.shtml (Accessed: 12 Aug 2024).

Davis, J. Richard, and Klaus Koop (2016). "Eutrophication in Australian rivers, reservoirs and estuaries–a southern hemisphere perspective on the science and its implications." *Hydrobiologia,* 559: 23-76.

Donovan, M. and Monaghan, R., (2021). Impacts of grazing on ground cover, soil physical properties and soil loss via surface erosion: A novel geospatial modelling approach. Journal of Environmental Management, 287, p.112206.

Haworth, R. J., Gale, S. J., Short, S. A., & Heijnis, H. (1999). Land Use and Lake Sedimentation on the New England Tablelands of New South Wales, Australia. Australian Geographer, 30(1), 51–73. https://doi.org/10.1080/00049189993765

Jansen, Lara S, Steffan Pierre and Elizabeth H Boughton, 'Interactions of Fire, Grazing and Pasture Management: Short-Term and Long-Term Responses of Water Quality to Management Regimes in Subtropical Isolated Wetlands' (2019) 280 Agriculture, ecosystems & environment 102

Johnson, M. F., Albertson, L. K., Algar, A. C., Dugdale, S. J., Edwards, P., England, J., Gibbins, C., Kazama, S., Komori, D., MacColl, A. D. C., Scholl, E. A., Wilby, R. L., de Oliveira Roque, F., & Wood, P. J. (2024). Rising water temperature in rivers: Ecological impacts and future resilience. WIREs Water, 11(4), e1724. https://doi.org/10.1002/wat2.1724

Liu, Q., Ding, S., Chen, X., Sun, Q., Chen, M. and Zhang, C. (2018). Effects of temperature on phosphorus mobilization in sediments in microcosm experiment and in the field. Applied Geochemistry, 88, pp.158-166.

Marsh, N., Rutherford, J.C. and Bunn, S.E., (2005). The role of riparian vegetation in controlling stream temperature in a southeast Queensland stream. CRC for Catchment Hydrology, Monash University.

McDowell, Richard W, (2008). Grazed Pastures and Surface Water Quality, Nova Science Publishers.

McKergow, L.A., Weaver, D.M., Prosser, I.P., Grayson, R.B. and Reed, A.E. (2003). Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. Journal of Hydrology, 270(3-4), pp.253-272.

NSW DPIE (2020a). Water quality technical report for the Namoi surface water resource plan area (SW14). INT18/109352 https://water.dpie.nsw.gov.au/__data/assets/pdf_file/0003/456933/Water-quality-technical-report-for-the-Namoi-surface-water-resource-plan-area-SW14.pdf

NSW DPIE (2020b). Water quality technical report for the Border Rivers surface water resource plan area (SW16). INT18/12429 https://water.dpie.nsw.gov.au/__data/assets/pdf_file/0005/456926/Water-quality-technical-report-for-the-Border-Rivers-surface-water-resource-plan-area-SW16.pdf

Phillips, J. M., M. A. Russell, et al. (2000). “Time-integrated sampling of fluvial suspended sediment: a simple methodology for small catchments.” Hydrological Processes 14: 2589 – 2602.

Reid, N., Green, S., Fittler, J. (2006). Water Quality on New England Wool Properties. Land & Water Australia, Canberra, Australia. https://hdl.handle.net/1959.11/8665
https://www.snelandcare.org.au/landwaterwool/FS5_Water.pdf

Rice, Eugene W., Laura Bridgewater, and American Public Health Association, eds. (2012). Standard methods for the examination of water and wastewater. Vol. 10. Washington, DC: American public health association.

Ryder, D., Mika, S., Richardson, M., Burns, A., Veal, R., Lisle, P., Schmidt, J. and Osborne, M., 2014. Clarence Catchment Ecohealth Project: Assessment of River and Estuarine Condition 2014. University of New England.

Ryder, D., Mika, S., Vincent, B., Burns, A. and Schmidt, J., 2016. Macleay Ecohealth Project 2015-2016: Assessment of River and Estuarine Condition. University of New England.

Xia, X., Zhang, S., Li, S., Zhang, L., Wang, G., Zhang, L., Wang, J. and Li, Z. (2018). The cycle of nitrogen in river systems: sources, transformation, and flux. Environmental science: Processes & impacts, 20(6), pp.863-891.

Xiaolong Cheng, Yanan Huang, Ran Li, Xunchi Pu, Wendian Huang, Xianfan Yuan, (2020). Impacts of water temperature on phosphorus release of sediments under flowing overlying water, Journal of Contaminant Hydrology, Volume 235, 103717, ISSN 0169-7722, https://doi.org/10.1016/j.jconhyd.2020.103717.

# 6. Appendix

## 6.1. Site Specific Water Quality Results Tables

## DEER

*Table 3 DEER site specific water quality data. Presented as mean ± sd.*

| Site | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER | DEER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | 11.3 ± 0.1 | 95.8 ± 0 | 10.5 ± 0 | 7.9 ± 0.1 | 54.1 ± 0.1 | 168.2 ± 3.2 | 4.2 ± 0.2 | *No Volume | 3.8 ± 0.2 | 2424 ± 299.2 | 2422.3 ± 299.3 | 1.7 ± 0.6 | 53 ± 13.1 | 6 ± 1 | 4.7 ± 0.2 |
| Jul 2023 | | | | | | | | 0.3 ± 0 | | 756.8 ± 82.7 | 745.3 ± 84 | 11.5 ± 4.1 | 74 ± 28.3 | 4.7 ± 0.6 | |
| Aug 2023 | | | | | | | | 0.3 ± 0 | | 1000.5 ± 61.5 | 983 ± 52.3 | 21.3 ± 9.3 | 64.7 ± 47.1 | 6.7 ± 1.2 | |
| Sep 2023 | 13.5 ± 0.2 | 95.5 ± 1.5 | 9.9 ± 0.1 | 7.8 ± 0 | 63.3 ± 0.8 | 149.4 ± 3.3 | 1.8 ± 0.3 | 0.1 ± 0 | 4.1 ± 0.3 | 497.7 ± 52.3 | 484.7 ± 52.6 | 13 ± 1 | 42.3 ± 3.1 | 7.7 ± 0.6 | 1.8 ± 0.2 |
| Oct 2023 | | | | | | | | 0.3 ± 0 | | 1235.7 ± 104.8 | 1218 ± 105.7 | 17.7 ± 1.5 | 64.7 ± 17.4 | 9 ± 1 | |
| Nov 2023 | | | | | | | | | | | | | | | |
| Dec 2023 | 21.3 ± 0.2 | 77.1 ± 3.2 | 6.8 ± 0.3 | 8.5 ± 0.2 | 128.4 ± 0.4 | 166.7 ± 4.6 | 3.5 ± 2.9 | 0.9 ± 0.5 | 8.6 ± 0.6 | 1087.7 ± 34.2 | 1084 ± 33.8 | 3.7 ± 2.5 | 71.3 ± 11.7 | 7.3 ± 1.5 | 3.9 ± 1.1 |
| Jan 2024 | | | | | | | | 1 ± 0 | | 1550.3 ± 250.3 | 1546.3 ± 248.3 | 4 ± 2 | 102 ± 34 | 72.7 ± 3.5 | |
| Feb 2024 | | | | | | | | 1.4 ± 0 | | 2502.7 ± 1318.9 | 2150 ± 1348.6 | 352.7 ± 30.8 | 123.3 ± 35 | 145 ± 14.9 | |
| Mar 2024 | 20.7 ± 0.1 | 90.7 ± 3.3 | 8.1 ± 0.3 | 7.1 ± 0 | 82.3 ± 0.4 | 114.1 ± 8.2 | 2.7 ± 0.2 | 1.7 ± 0.3 | 10.1 ± 0.1 | 1057.7 ± 37.4 | 1055.7 ± 38.2 | 2 ± 1 | 83.7 ± 93.9 | 16 ± 1 | 2.2 ± 0.1 |
| Apr 2024 | | | | | | | | 1.1 ± 0 | | 498 ± 16.1 | 490.3 ± 9.7 | 7.7 ± 6.5 | 62.3 ± 32.7 | 26 ± 9.2 | |
| May 2024 | | | | | | | | 1.8 ± 0 | | 614.7 ± 305.4 | 566.7 ± 336.6 | 48 ± 65 | 40.3 ± 27.8 | 19.3 ± 7.6 | |
| Jun 2024 | 8.1 ± 0 | 83 ± 0.1 | 9.8 ± 0 | 7 ± 0 | 45 ± 0 | 148.2 ± 0.2 | 3.6 ± 0 | 1.8 ± 0 | 6.6 ± 0.2 | 227 ± 51.5 | 221.7 ± 52.5 | 5.3 ± 1.5 | 138 ± 20 | 9.3 ± 0.6 | 2.9 ± 0.2 |

## MCIR

*Table 4 MCIR site specific water quality data. Presented as mean ± sd.*

| Site | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR | MCIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | 9.2 ± 0 | 86.9 ± 0.3 | 10 ± 0 | 8.3 ± 0 | 517.7 ± 2.1 | 169.4 ± 0.8 | 0.1 ± 0.1 | 0.1 ± 0 | 2.5 ± 0.2 | 1462.3 ± 71.9 | 1455.3 ± 69 | 7 ± 3 | 22.3 ± 30 | 48.7 ± 14.5 | 1.8 ± 0.2 |
| Jul 2023 | | | | | | | | 0.2 ± 0 | | 590.3 ± 116.3 | 572.8 ± 120.3 | 17.5 ± 5.3 | 100.7 ± 28 | 35 ± 3 | |
| Aug 2023 | | | | | | | | 0 ± 0 | | 614.7 ± 71.8 | 585.7 ± 87.2 | 29 ± 16.5 | 154.3 ± 14 | 78.7 ± 7 | |
| Sep 2023 | 12.5 ± 0.4 | 101.2 ± 4.4 | 10.8 ± 0.4 | 8.3 ± 0 | 549 ± 0 | 173.6 ± 1.5 | 2.5 ± 0.6 | 0.4 ± 0.1 | 3.5 ± 0.2 | 572.7 ± 11.6 | 569.7 ± 13.3 | 3 ± 1.7 | 54.3 ± 0.6 | 45.7 ± 2.3 | 4 ± 0.5 |
| Oct 2023 | | | | | | | | 0 ± 0 | | 916.3 ± 157.5 | 897 ± 158.2 | 19.3 ± 2.1 | 165.7 ± 11.4 | 54 ± 7.6 | |
| Nov 2023 | | | | | | | | 0 ± 0 | | 768.8 ± 59.9 | 752.3 ± 56.4 | 16.5 ± 4.5 | 102.3 ± 12.7 | 62 ± 42.9 | |
| Dec 2023 | 22 ± 1.4 | 42.5 ± 5.8 | 3.6 ± 0.5 | 7.8 ± 0 | 758.3 ± 2.5 | 138.7 ± 26.3 | 0.5 ± 0.3 | 0.4 ± 0.2 | 4.9 ± 0.4 | 890.3 ± 84.1 | 873.3 ± 88.9 | 17 ± 5.2 | 325.7 ± 77.4 | 106.3 ± 6.7 | 0.4 ± 0 |
| Jan 2024 | | | | | | | | | | | | | | | |
| Feb 2024 | | | | | | | | 1.5 ± 0 | | 631.3 ± 403.1 | 629 ± 403.7 | 2.3 ± 1.4 | 271.3 ± 26.5 | 79 ± 7.6 | |
| Mar 2024 | 19.5 ± 0.3 | 69 ± 10.2 | 6.3 ± 0.9 | 8 ± 0 | 657.7 ± 5 | 115.7 ± 31.1 | 7.1 ± 0.7 | 11.9 ± 0.3 | 4.1 ± 0.3 | 905.3 ± 61.2 | 898.3 ± 63 | 7 ± 1.7 | 286.7 ± 16.8 | 136.3 ± 9.8 | 7.6 ± 1 |
| Apr 2024 | | | | | | | | 0.6 ± 0 | | 222.3 ± 131.5 | 58.7 ± 13.6 | 163.7 ± 144.8 | 109.5 ± 59.5 | 68.7 ± 5.5 | |
| May 2024 | | | | | | | | | | | | | | | |
| Jun 2024 | 9.2 ± 0 | 93 ± 0.1 | 10.7 ± 0 | 8.4 ± 0 | 442.8 ± 11.4 | 159.5 ± 0.9 | 3.2 ± 0.2 | 8.4 ± 5 | 4.8 ± 0.4 | 193.7 ± 146.8 | 185 ± 146 | 8.7 ± 5.1 | 112.7 ± 62.9 | 85 ± 7.8 | 3.7 ± 0.2 |

## MCDR

*Table 5 MCDR site specific water quality data. Presented as mean ± sd.*

| Site | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR | MCDR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | 4.8 ± 0.1 | 90.9 ± 0.1 | 11.7 ± 0 | 7.8 ± 0 | 111.3 ± 0.1 | 198 ± 1.2 | 4.3 ± 0 | 1.3 ± 0.1 | 2.9 ± 0.3 | 1309.7 ± 196 | 1307.7 ± 196 | 2 ± 0 | 56 ± 45.6 | 9 ± 0 | 6.9 ± 0.5 |
| Jul 2023 | | | | | | | | 0.2 ± 0 | | 839 ± 151.8 | 830.5 ± 158.5 | 8.5 ± 6.9 | 58.7 ± 33.8 | 4.7 ± 0.6 | |
| Aug 2023 | | | | | | | | 0.2 ± 0 | | 645.3 ± 64.2 | 638 ± 68.4 | 7.3 ± 10.1 | 55.7 ± 41.3 | 6 ± 0 | |
| Sep 2023 | 12.1 ± 0.2 | 88.1 ± 0.5 | 9.5 ± 0.1 | 7.9 ± 0 | 134.3 ± 1.1 | 157.5 ± 2.8 | 2.8 ± 0.4 | 0.8 ± 0.3 | 4.7 ± 0.1 | 450.3 ± 43.8 | 443.7 ± 42 | 6.7 ± 2.1 | 122.3 ± 16 | 4.7 ± 0.6 | 5 ± 0.6 |
| Oct 2023 | | | | | | | | 0 ± 0 | | 1387.3 ± 426.2 | 1367.3 ± 423.9 | 20 ± 2.6 | 47.3 ± 5.5 | 6.3 ± 0.6 | |
| Nov 2023 | | | | | | | | 0 ± 0 | | 796.7 ± 84.9 | 783 ± 87.5 | 13.7 ± 9.1 | 4.5 ± 0 | 38.3 ± 56 | |
| Dec 2023 | 24.3 ± 0 | 68.2 ± 0.8 | 5.7 ± 0.1 | 7.5 ± 0 | 163.6 ± 0 | 163 ± 0.4 | 2.1 ± 0 | 0.3 ± 0 | 5.7 ± 0.9 | 773.7 ± 189.2 | 767 ± 191.9 | 6.7 ± 8.1 | 84.3 ± 29.7 | 15 ± 3.5 | 1.1 ± 0 |
| Jan 2024 | | | | | | | | 1.2 ± 0 | | 1178.3 ± 203.3 | 1172.3 ± 201 | 6 ± 4 | 104.3 ± 50.8 | 44.3 ± 0.6 | |
| Feb 2024 | | | | | | | | 0.8 ± 0 | | 958.7 ± 198.2 | 956.3 ± 198.9 | 2.3 ± 1.4 | 42.5 ± 5.5 | 12.3 ± 0.6 | |
| Mar 2024 | 20.3 ± 0 | 69.6 ± 0.2 | 6.3 ± 0 | 7.6 ± 0 | 136.6 ± 0 | 103.5 ± 1.4 | 4.1 ± 0.2 | 3 ± 0.2 | 7.5 ± 0.2 | 1145 ± 72.3 | 1143 ± 73.2 | 2 ± 1 | 57.3 ± 83.9 | 9.3 ± 0.6 | 3.4 ± 0.3 |
| Apr 2024 | | | | | | | | 1.6 ± 0 | | 333.8 ± 75.9 | 320.3 ± 78.4 | 13.5 ± 3.5 | 82.3 ± 34.8 | 12.3 ± 2.1 | |
| May 2024 | | | | | | | | 0.6 ± 0 | | 252.5 ± 52.1 | 229 ± 32.6 | 23.5 ± 19.5 | 68.5 ± 41.5 | 10 ± 2 | |
| Jun 2024 | 9 ± 0 | 85.1 ± 0.1 | 9.8 ± 0 | 7.5 ± 0 | 87.7 ± 0 | 128.4 ± 0.2 | 28.9 ± 0.1 | 1.6 ± 0.1 | 7.1 ± 0.3 | 945.3 ± 77.5 | 434.3 ± 69.7 | 511 ± 7.8 | 130.3 ± 32.9 | 35 ± 1.7 | 13 ± 0.5 |

## MANR

*Table 6 MANR site specific water quality data. Presented as mean ± sd.*

| Site | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR | MANR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | 6.7 ± 0.1 | 89.4 ± 0.1 | 10.9 ± 0 | 8.1 ± 0 | 214 ± 0.1 | 158.6 ± 2.7 | 7.4 ± 4.3 | 1.5 ± 0.5 | 4.7 ± 0.1 | 1213.7 ± 191 | 1211.7 ± 191 | 2 ± 0 | 5 ± 0 | 6 ± 1 | 6.6 ± 0.5 |
| Jul 2023 | | | | | | | | 0 ± 0 | | 749.2 ± 101.3 | 744.2 ± 108.9 | 12.7 ± 2.1 | 50.3 ± 43.8 | 6.7 ± 1.2 | |
| Aug 2023 | | | | | | | | 0 ± 0 | | 799.8 ± 41.8 | 788.8 ± 42.6 | 11 ± 1 | 78 ± 29.5 | 8 ± 1 | |
| Sep 2023 | 15 ± 0.3 | 110 ± 2.1 | 11.1 ± 0.1 | 8.4 ± 0.1 | 248.6 ± 0.3 | 162.3 ± 4 | 2.9 ± 2.1 | 0.2 ± 0.1 | 5.2 ± 0.1 | 663.7 ± 18.8 | 658.3 ± 17.8 | 5.3 ± 1.5 | 73.7 ± 4.7 | 8 ± 2.6 | 2.6 ± 0.1 |
| Oct 2023 | | | | | | | | 0 ± 0 | | 800 ± 30.2 | 791.7 ± 34.5 | 8.3 ± 4.6 | 4.5 ± 0 | 9.7 ± 3.2 | |
| Nov 2023 | | | | | | | | | | | | | | | |
| Dec 2023 | 25.4 ± 0.1 | 85.9 ± 0.2 | 7 ± 0 | 8 ± 0 | 310.4 ± 0 | 155.1 ± 2.9 | 0.6 ± 0 | 0.3 ± 0.1 | 5.8 ± 0.8 | 955.3 ± 130 | 955.3 ± 130 | 0 ± 0 | 118.7 ± 14.8 | 31 ± 3.6 | 1.1 ± 1 |
| Jan 2024 | | | | | | | | | | | | | | | |
| Feb 2024 | | | | | | | | | | | | | | | |
| Mar 2024 | 23.1 ± 0 | 83.3 ± 0.1 | 7.1 ± 0 | 7.6 ± 0 | 167.2 ± 0.1 | 129.9 ± 1.2 | 5.4 ± 0 | 2.1 ± 0.4 | 10.5 ± 0.3 | 1214.3 ± 83 | 1203 ± 83.3 | 11.3 ± 2.3 | 194.3 ± 25.7 | 42.3 ± 4.2 | 5 ± 0.1 |
| Apr 2024 | | | | | | | | | | | | | | | |
| May 2024 | | | | | | | | 3.5 ± 0 | | 444.3 ± 13.3 | 357.7 ± 10.4 | 86.7 ± 22.9 | 50.5 ± 26.5 | 56.3 ± 6.4 | |
| Jun 2024 | 9 ± 0.1 | 92.7 ± 0.1 | 10.7 ± 0 | 8.3 ± 0 | 193.5 ± 0.1 | 147.7 ± 0.5 | 5.1 ± 1.5 | 0.8 ± 0.1 | 7.5 ± 0.2 | 257.7 ± 27 | 252.7 ± 24.2 | 5 ± 3 | 32.7 ± 18 | 19.3 ± 1.2 | 2.4 ± 0 |

## GARA2

*Table 7 GARA2 site specific water quality data. Presented as mean ± sd.*

| Site | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 | GARA2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | 7.7 ± 0.1 | 93.1 ± 0.6 | 11.3 ± 0.4 | 8.3 ± 0 | 151.3 ± 0.2 | 125.2 ± 8.5 | 5.7 ± 2.3 | | | 1206.7 ± 209.9 | 1199.7 ± 209.4 | 7 ± 1 | 6.3 ± 2.3 | 10.7 ± 1.2 | 6.3 ± 1.9 |
| Jun 2023 | | | | | | | | | | | | | | | |
| Jul 2023 | | | | | | | | | | | | | | | |
| Aug 2023 | | | | | | | | | | | | | | | |
| Sep 2023 | 16 ± 0.1 | 116.4 ± 3 | 11.5 ± 0.2 | 8.7 ± 0 | 231.9 ± 0.5 | 158.4 ± 2.5 | 6.9 ± 5.3 | 0.4 ± 0.2 | 5.3 ± 0.1 | 691.7 ± 79.5 | 677 ± 78.5 | 14.7 ± 1.5 | 46.3 ± 17.8 | 6 ± 0 | 2.8 ± 0.4 |
| Oct 2023 | | | | | | | | | | | | | | | |
| Nov 2023 | | | | | | | | | | | | | | | |
| Dec 2023 | 30.4 ± 0.3 | 161.1 ± 11.4 | 12.3 ± 1 | 8.8 ± 0.1 | 332.4 ± 3.2 | 135.7 ± 1.2 | 8.9 ± 4 | 0 ± 0 | 8.3 ± 1.7 | 1261.3 ± 187.8 | 1253.7 ± 194.7 | 7.7 ± 7.4 | 95.7 ± 35.6 | 8.3 ± 0.6 | 2.8 ± 0.5 |
| Jan 2024 | | | | | | | | | | | | | | | |
| Feb 2024 | | | | | | | | | | | | | | | |
| Mar 2024 | 23.9 ± 0.2 | 124.4 ± 1.6 | 10.5 ± 0.2 | 8.6 ± 0.1 | 256.9 ± 0.5 | 154.9 ± 4 | 2.7 ± 0.2 | 5.5 ± 0.4 | 9.2 ± 0.8 | 1229.3 ± 134.8 | 1227.3 ± 136.6 | 2 ± 1.7 | 299 ± 237.6 | 6.7 ± 0.6 | 3.7 ± 0.3 |
| Apr 2024 | | | | | | | | | | | | | | | |
| May 2024 | | | | | | | | | | | | | | | |
| Jun 2024 | 9.5 ± 0.4 | 127.9 ± 9.8 | 14.6 ± 1 | 9.1 ± 0.1 | 181.8 ± 2.1 | 147.1 ± 4.1 | 2.9 ± 0.3 | 3.5 ± 1.1 | 7.8 ± 0.3 | 373 ± 14.4 | 326 ± 10.1 | 47 ± 8.7 | 84.5 ± 25.5 | 15.7 ± 10.7 | 2.2 ± 0.2 |

## GARA1

*Table 8 GARA1 site specific water quality data. Presented as mean ± sd.*

| Site | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 | GARA1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | 6.1 ± 0 | 98.7 ± 0.9 | 12.2 ± 0.1 | 8.4 ± 0 | 299.6 ± 0.1 | 171.1 ± 2 | 1.1 ± 0.3 | 0.1 ± 0.1 | 3.3 ± 2.3 | 1600.7 ± 200.3 | 1599 ± 200.8 | 1.7 ± 0.6 | 27.7 ± 23.5 | 9.3 ± 1.2 | 2.6 ± 0.3 |
| Jul 2023 | | | | | | | | 0 ± 0 | | 816.5 ± 87 | 811.5 ± 89.8 | 5 ± 2 | 31 ± 8.5 | 8.7 ± 2.1 | |
| Aug 2023 | | | | | | | | 0 ± 0 | | 885.8 ± 47 | 875.5 ± 47.4 | 10.5 ± 0.5 | 37.5 ± 0.7 | 7 ± 1 | |
| Sep 2023 | 15.8 ± 0.1 | 111 ± 0.4 | 11 ± 0 | 8.6 ± 0.1 | 345.2 ± 0.2 | 157.8 ± 3.6 | 0.3 ± 0 | 0.3 ± 0 | 5.6 ± 0.2 | 710.3 ± 85.3 | 705.7 ± 86.4 | 4.7 ± 1.2 | 48 ± 18.7 | 6.3 ± 0.6 | 1.5 ± 0.2 |
| Oct 2023 | | | | | | | | 0.1 ± 0 | | 1302 ± 162 | 1286.7 ± 160.8 | 15.3 ± 3.5 | 50.5 ± 64.3 | 7.7 ± 2.1 | |
| Nov 2023 | | | | | | | | 0.1 ± 0 | | 13.3 ± 1.5 | *Below limit | 13.3 ± 1.5 | 92.7 ± 8.5 | 13.3 ± 4 | |
| Dec 2023 | 32.3 ± 0.4 | 139 ± 2.9 | 10.1 ± 0.2 | 8.8 ± 0 | 417.5 ± 0.9 | 130.3 ± 0.6 | 1.9 ± 0.3 | 0.4 ± 0.3 | 10.9 ± 0.4 | 1311.7 ± 98.3 | 1295.7 ± 102.9 | 16 ± 6.6 | 147.3 ± 33.2 | 39 ± 8.9 | 1.9 ± 0.5 |
| Jan 2024 | | | | | | | | 0.4 ± 0 | | 2018.3 ± 402 | 2014.3 ± 402.9 | 4 ± 4.3 | 145.3 ± 56 | 9.3 ± 1.2 | |
| Feb 2024 | | | | | | | | 0.7 ± 0 | | 1680.2 ± 268.1 | 1673.7 ± 267.8 | 6.5 ± 0.5 | 298.3 ± 15 | 11 ± 0 | |
| Mar 2024 | 27.4 ± 0.2 | 142.1 ± 0.2 | 11.2 ± 0 | 8.6 ± 0 | 379.3 ± 13.8 | 135.2 ± 6.8 | 2.3 ± 0 | 2.9 ± 0.2 | 9 ± 0.5 | 1092 ± 70.2 | 1082.7 ± 71.2 | 9.3 ± 2.5 | 137.3 ± 32.6 | 31 ± 2.6 | 3.3 ± 0.1 |
| Apr 2024 | | | | | | | | 0.5 ± 0 | | 376.7 ± 34.2 | 373 ± 33.4 | 3.7 ± 5.5 | 89.5 ± 29.5 | 34 ± 3.5 | |
| May 2024 | | | | | | | | 0.1 ± 0 | | 165.7 ± 20.1 | 149.7 ± 5.9 | 16 ± 17.3 | 25.7 ± 28 | 28.3 ± 2.5 | |
| Jun 2024 | 9.8 ± 0 | 102.5 ± 0 | 11.6 ± 0 | 8.4 ± 0 | 275.1 ± 0 | 134.1 ± 0.5 | 3.4 ± 0 | 0.5 ± 0.1 | 6.8 ± 0.3 | 191.7 ± 6.7 | 183.7 ± 4 | 8 ± 2.6 | 51.7 ± 24.1 | 16.7 ± 1.5 | 2.3 ± 0.8 |

## APSR2

*Table 9 APSR2 site specific water quality data. Presented as mean ± sd.*

| Site | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 | APSR2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | | | | | | | | | | | | | | | |
| Jul 2023 | | | | | | | | | | | | | | | |
| Aug 2023 | 8.6 ± 0 | 97.7 ± 0.3 | 11.4 ± 0 | 8.4 ± 0 | 286.9 ± 0.1 | 138.3 ± 2.1 | 7 ± 0.5 | 2 ± 0.3 | 7.1 ± 0.2 | 1882.7 ± 476.7 | 1874.7 ± 479.1 | 8 ± 3.6 | 85.7 ± 71.1 | 43 ± 1 | 9.3 ± 4.8 |
| Sep 2023 | 13.1 ± 0.1 | 144.5 ± 2.4 | 15.3 ± 0.3 | 9 ± 0 | 294.8 ± 0.2 | 153.3 ± 2.5 | 10 ± 0.2 | 0.9 ± 0 | 6 ± 0.2 | 1249.7 ± 52.3 | 1240.7 ± 53.6 | 9 ± 1.7 | 250.3 ± 2.1 | 44 ± 2.6 | 15.5 ± 0.8 |
| Oct 2023 | | | | | | | | 0 ± 0 | | 1271.7 ± 94.1 | 1245.3 ± 92.8 | 26.3 ± 1.5 | 252.3 ± 84.9 | 53 ± 4.4 | |
| Nov 2023 | | | | | | | | 0 ± 0 | | 1670.5 ± 258 | 1641 ± 254.2 | 29.5 ± 4.5 | 320.7 ± 16 | 91.3 ± 65.5 | |
| Dec 2023 | 27 ± 0.1 | 82.5 ± 1 | 6.6 ± 0.1 | 7.8 ± 0 | 383.6 ± 0.2 | 157.9 ± 0.5 | 4.1 ± 0 | 0.4 ± 0.6 | 7.6 ± 1.3 | 1271.3 ± 108.2 | 1250 ± 112.5 | 21.3 ± 5 | 263.3 ± 79.4 | 116 ± 5.3 | 4.5 ± 1.5 |
| Jan 2024 | | | | | | | | 5.3 ± 0 | | 2425.7 ± 604.4 | 2421.7 ± 604 | 4 ± 2 | 148.3 ± 56.6 | 21.7 ± 1.5 | |
| Feb 2024 | | | | | | | | | | | | | | | |
| Mar 2024 | 20.6 ± 0 | 65.5 ± 0.2 | 5.9 ± 0 | 7.6 ± 0 | 230.1 ± 0.1 | 142.1 ± 1 | 7 ± 0.1 | 11.1 ± 1 | 8.7 ± 0.8 | 1434 ± 67.5 | 1432.3 ± 68.9 | 1.7 ± 1.5 | 276 ± 42.7 | 36 ± 3 | 12.4 ± 1.2 |
| Apr 2024 | | | | | | | | 0.5 ± 0 | | 1500.7 ± 131.9 | 862.3 ± 120.6 | 638.3 ± 15.4 | 286 ± 79.2 | 120 ± 5.3 | |
| May 2024 | | | | | | | | 1.4 ± 0 | | 1565.7 ± 109.7 | 838.3 ± 71.3 | 727.3 ± 50.1 | 217.7 ± 32.6 | 126.7 ± 3.1 | |
| Jun 2024 | 9.2 ± 0 | 75 ± 0 | 8.6 ± 0 | 7.5 ± 0 | 168.6 ± 0 | 134.6 ± 0.6 | 32.8 ± 0.2 | 1.9 ± 0.2 | 8.7 ± 1.3 | 1425.7 ± 39.5 | 788.7 ± 35.2 | 637 ± 4.4 | 259.3 ± 104.2 | 144 ± 2.6 | 14.2 ± 0.4 |

## APSR1

*Table 10 APSR1 site specific water quality data. Presented as mean ± sd.*

| Site | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 | APSR1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Temp (°C) | DO (%) | DO (mg/L) | pH | Cond (µS/cm) | ORP | Turbidity (NTU) | Chla (µg/L) | DOC (mg/L) | TN (µg N/L) | TKN (µg N/L) | NOx (µg N/L) | TP (µg P/L) | FRP (µg P/L) | TSS (mg/L) |
| May 2023 | | | | | | | | | | | | | | | |
| Jun 2023 | | | | | | | | | | | | | | | |
| Jul 2023 | | | | | | | | | | | | | | | |
| Aug 2023 | 9.1 ± 0 | 89.9 ± 0.1 | 10.4 ± 0 | 8.1 ± 0 | 306.1 ± 0.1 | 162.7 ± 0.8 | 3.8 ± 0 | 1.2 ± 0.5 | 7.4 ± 0.2 | 1737.3 ± 241.8 | 1733.3 ± 241 | 4 ± 3 | 112 ± 87.8 | 6.7 ± 0.6 | 6.2 ± 0.3 |
| Sep 2023 | 15.1 ± 0.1 | 90.8 ± 0.3 | 9.1 ± 0 | 8.1 ± 0 | 313.9 ± 0.1 | 163.1 ± 2 | 0.7 ± 0.1 | 0.4 ± 0.2 | 6.2 ± 0.3 | 721.7 ± 40.1 | 711.7 ± 40.1 | 10 ± 2.6 | 62 ± 5 | 12.3 ± 0.6 | 1.6 ± 0.1 |
| Oct 2023 | | | | | | | | 0 ± 0 | | 1201.3 ± 163.7 | 1170.7 ± 166.3 | 30.7 ± 3.1 | 75.3 ± 27.5 | 15.3 ± 2.3 | |
| Nov 2023 | | | | | | | | 0.1 ± 0 | | 4632.7 ± 1362.7 | 4607 ± 1363.4 | 25.7 ± 7 | 109 ± 26.5 | 53.3 ± 62.1 | |
| Dec 2023 | 27.3 ± 0.1 | 91.8 ± 0.9 | 7.3 ± 0.1 | 8.2 ± 0 | 367.9 ± 0.2 | 146.3 ± 0.6 | 2.7 ± 0.1 | 0.2 ± 0.2 | 7.3 ± 1.3 | 1209.3 ± 24.9 | 1205 ± 24.3 | 4.3 ± 2.5 | 126.7 ± 12.7 | 22.3 ± 3.1 | 3.4 ± 0.8 |
| Jan 2024 | | | | | | | | 2.7 ± 0 | | 2005 ± 1222.7 | 1999 ± 1224.3 | 6 ± 4 | 197.7 ± 98.1 | 26.7 ± 2.1 | |
| Feb 2024 | | | | | | | | 2.1 ± 0 | | 1460.7 ± 76.8 | 1446.7 ± 69.3 | 14 ± 9 | 83 ± 79 | 66 ± 7.8 | |
| Mar 2024 | 21.7 ± 0 | 91.9 ± 0.3 | 8.1 ± 0 | 8.1 ± 0 | 276.9 ± 0.1 | 133.5 ± 0.1 | 5.1 ± 0.4 | 30.7 ± 0.3 | 9.2 ± 0.4 | 1183 ± 48.4 | 1181 ± 48.4 | 2 ± 0 | 70.3 ± 81.7 | 18.3 ± 5.8 | 8.1 ± 1.2 |
| Apr 2024 | | | | | | | | 29 ± 0 | | 717.7 ± 141 | 654.3 ± 141.5 | 63.3 ± 6.1 | 127 ± 36 | 25.7 ± 0.6 | |
| May 2024 | | | | | | | | 1.6 ± 0 | | 730 ± 123.5 | 645 ± 42.3 | 85 ± 90.1 | 141 ± 51.1 | 32 ± 9.5 | |
| Jun 2024 | 9.3 ± 0 | 67.5 ± 0.1 | 7.7 ± 0 | 7.3 ± 0 | 153.1 ± 0.1 | 138.2 ± 0.4 | 41.1 ± 0.2 | 1.5 ± 0.1 | 6.8 ± 2.2 | 1549.3 ± 60.5 | 1040 ± 43.6 | 509.3 ± 17.9 | 237.7 ± 43.5 | 118.7 ± 2.1 | 10.8 ± 8 |

## 6.2. Sediment Samples

*Table 11 Quarterly samples collected from time-integrated sediment samplers. APSR September samples represent only one month of sediment accumulation. *no sample retrieved. **sediment sampler was lost with high flows. AFDW means Ash-Free Dry Weight, which is the mass of inorganic suspended sediments after the organic proportion has been combusted at 500 °C.*

| Site | Sediment Component | Sep 2023 | Dec 2023 | Mar 2024 | Jun 2024 |
|---|---|---|---|---|---|
| DEER | Dry Weight (g) | 0.1259 | 0.1831 | 0.228 | 0.2513 |
| | AFDW (g) | 0.0912 | 0.1445 | 0.1881 | 0.1946 |
| | Organic (g) | 0.0347 | 0.0386 | 0.0399 | 0.0567 |
| MCIR | Dry Weight (g) | 0.3564 | 0.2726 | 0.1447 | 0.7323 |
| | AFDW (g) | 0.2288 | 0.2419 | 0.0669 | 0.5337 |
| | Organic (g) | 0.1276 | 0.0307 | 0.0778 | 0.1986 |
| MCDR | Dry Weight (g) | 4.0628 | 0.101 | 0.2374 | 10.2338 |
| | AFDW (g) | 3.4981 | 0.081 | 0.1711 | 8.5618 |
| | Organic (g) | 0.5647 | 0.02 | 0.0663 | 1.672 |
| MANR | Dry Weight (g) | 1.9933 | 0.3309 | 4.2434 | 6.2211 |
| | AFDW (g) | 1.6273 | 0.2665 | 3.5799 | 4.9676 |
| | Organic (g) | 0.366 | 0.0644 | 0.6635 | 1.2535 |
| GARA2 | Dry Weight (g) | 0.39321 | 0.5576 | 4.2418 | 1.4351 |
| | AFDW (g) | 0.5954 | 0.4362 | 3.2808 | 1.0155 |
| | Organic (g) | 0 | 0.1214 | 0.961 | 0.4196 |
| GARA1 | Dry Weight (g) | 0.8305 | 0.3826 | * | 4.043 |
| | AFDW (g) | 0.6345 | 0.2932 | * | 3.0809 |
| | Organic (g) | 0.196 | 0.0894 | * | 0.9621 |
| APSR2 | Dry Weight (g) | 0.4302 | 0.0764 | 2.0176 | 7.1134 |
| | AFDW (g) | 0.3653 | 0.0599 | 1.7057 | 5.9405 |
| | Organic (g) | 0.0649 | 0.0165 | 0.3119 | 1.1729 |
| APSR1 | Dry Weight (g) | 0.3477 | 0.2396 | 0.4295 | ** |
| | AFDW (g) | 0.2152 | 0.1789 | 0.29 | ** |
| | Organic (g) | 0.1325 | 0.0607 | 0.1395 | ** |
| | AFDW | 0.2288 | 0.2419 | 0.0669 | 0.5337 |

## 6.3. Auto-Analyser Data (GARA2)

*Table 12 Physical water parameters recorded at GARA2 Eco-Detection unit.*

| | Temp (°C) | | | Conductivity (µS/cm) | | | Turbidity (NTU) | | | DO (mg/L) | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| May 2023 | 7.7 | 17.3 | -5.1 | 168.6 | 238 | 0 | 8 | 21.8 | 0.8 | 11.1 | 11.9 | 10.4 | 8.6 | 8.9 | 8.1 |
| Jun 2023 | 6.1 | 17.6 | -6.8 | 240.3 | 264 | 195 | 100.7 | 182 | 11.1 | 11.1 | 13.4 | 9.4 | 8.6 | 9.2 | 8.3 |
| Jul 2023 | 6.4 | 17.5 | -7 | 262.4 | 316 | 247 | 218.3 | 264 | 169.7 | 11 | 12.4 | 8.5 | 8.6 | 8.9 | 8.3 |
| Aug 2023 | 7.2 | 19 | -5.6 | 273.7 | 299 | 249 | 155.1 | 280.3 | 16.5 | 10.1 | 12.2 | 7.8 | 8.6 | 9 | 8.2 |
| Sep 2023 | 11.9 | 29.4 | -3.1 | 287.6 | 331 | 211 | 125.7 | 704.8 | 7.7 | 8.4 | 12.4 | 3.5 | 8.4 | 9.1 | 7.6 |
| Oct 2023 | 13.3 | 29.1 | -3.6 | 289.2 | 619 | 203 | 34.8 | 360.3 | 3.5 | 6.1 | 9.5 | 2.4 | 8 | 8.5 | 7.6 |
| Nov 2023 | 16.6 | 29 | 5.1 | 301.3 | 393 | 202 | 13.1 | 218 | 2.1 | 7.6 | 11.5 | 3.9 | 8.3 | 8.9 | 7.6 |
| Dec 2023 | 19.1 | 33.2 | 8.7 | 309.8 | 420 | 185 | 31 | 193.6 | 2.9 | 7.2 | 10.2 | 1.9 | 8.4 | 9 | 7.7 |
| Jan 2024 | 20.6 | 34.6 | 10.7 | 252.6 | 284 | 173 | 10.8 | 77.8 | 3.3 | 6 | 9.2 | 2.3 | 8.3 | 9.2 | 7.7 |
| Feb 2024 | 21.1 | 32.9 | 11.9 | 248.1 | 302 | 167 | 102.3 | 545.9 | 3 | 6.1 | 9.1 | 2.8 | 8.2 | 9.1 | 7.6 |
| Mar 2024 | 16.9 | 25.8 | 7.6 | 266.1 | 357 | 145 | 55.6 | 465.7 | 0.5 | 7.8 | 12 | 3 | 8.6 | 9.4 | 7.8 |
| Apr 2024 | 13.1 | 24.8 | 2 | 246.1 | 306 | 199 | 6.9 | 85.5 | 0.4 | 8.1 | 12.3 | 5.7 | 8.5 | 9.5 | 7.6 |
| May 2024 | 10 | 18.5 | -3.2 | 253.8 | 304 | 213 | 6.8 | 54.8 | 0.6 | 9.6 | 14.3 | 7 | 8.6 | 9.4 | 7.9 |
| Jun 2024 | 7.3 | 12.3 | -0.6 | 257 | 283 | 236 | 28.9 | 116 | 5.8 | 11.1 | 14.2 | 4.5 | 8.5 | 9.1 | 7.9 |

*Table 13 Chemical water parameters recorded at GARA2 Eco-Detection unit. A value of zero indicates reading was below detection limits.*

| | Chloride (ppb) | | | Fluoride (ppb) | | | Nitrate (ppb) | | | Sulphate (ppb) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| May 2023 | 4362.7 | 6314 | 3819 | 0 | 0 | 0 | 0 | 0 | 0 | 2215.9 | 4262 | 1624 |
| Jun 2023 | 5417.5 | 8741 | 4298 | 0 | 0 | 0 | 0 | 0 | 0 | 2426 | 4528 | 1795 |
| Jul 2023 | 7041.7 | 9066 | 2088 | 0 | 0 | 0 | 0 | 0 | 0 | 2528.6 | 3174 | 1459 |
| Aug 2023 | 8029.9 | 9059 | 6502 | 0 | 0 | 0 | 0 | 0 | 0 | 2480.3 | 3206 | 1950 |
| Sep 2023 | 8053.8 | 10041 | 7280 | 27.7 | 107 | 0 | 0.6 | 58 | 0 | 1873.6 | 2900 | 937 |
| Oct 2023 | 10183 | 12026 | 7966 | 0 | 0 | 0 | 0 | 0 | 0 | 932.2 | 1649 | 126 |
| Nov 2023 | 12417 | 16682 | 10078 | 0 | 0 | 0 | 0 | 0 | 0 | 3359.9 | 9878 | 68 |
| Dec 2023 | 10681 | 14669 | 7558 | 0 | 0 | 0 | 0 | 0 | 0 | 3780.2 | 12706 | 1222 |
| Jan 2024 | 9411.9 | 11034 | 8175 | 0 | 0 | 0 | 0 | 0 | 0 | 2086.9 | 4104 | 287 |
| Feb 2024 | 10491 | 12163 | 7530 | 0 | 0 | 0 | 0 | 0 | 0 | 2020.2 | 3626 | 646 |
| Mar 2024 | 11936 | 14076 | 9663 | 0 | 0 | 0 | 0 | 0 | 0 | 1492.1 | 3546 | 626 |
| Apr 2024 | 9797.2 | 14292 | 8033 | 0 | 0 | 0 | 0 | 0 | 0 | 1895.4 | 4904 | 0 |
| May 2024 | 8890.5 | 9879 | 7567 | 0 | 0 | 0 | 20.5 | 389 | 0 | 2579 | 3689 | 1383 |
| Jun 2024 | 8787.7 | 15249 | 6710 | 0 | 0 | 0 | 181.6 | 496 | 0 | 3510.8 | 5366 | 2333 |

## 6.4. Site Specific Supplemental Figures

### Deepwater River (DEER)

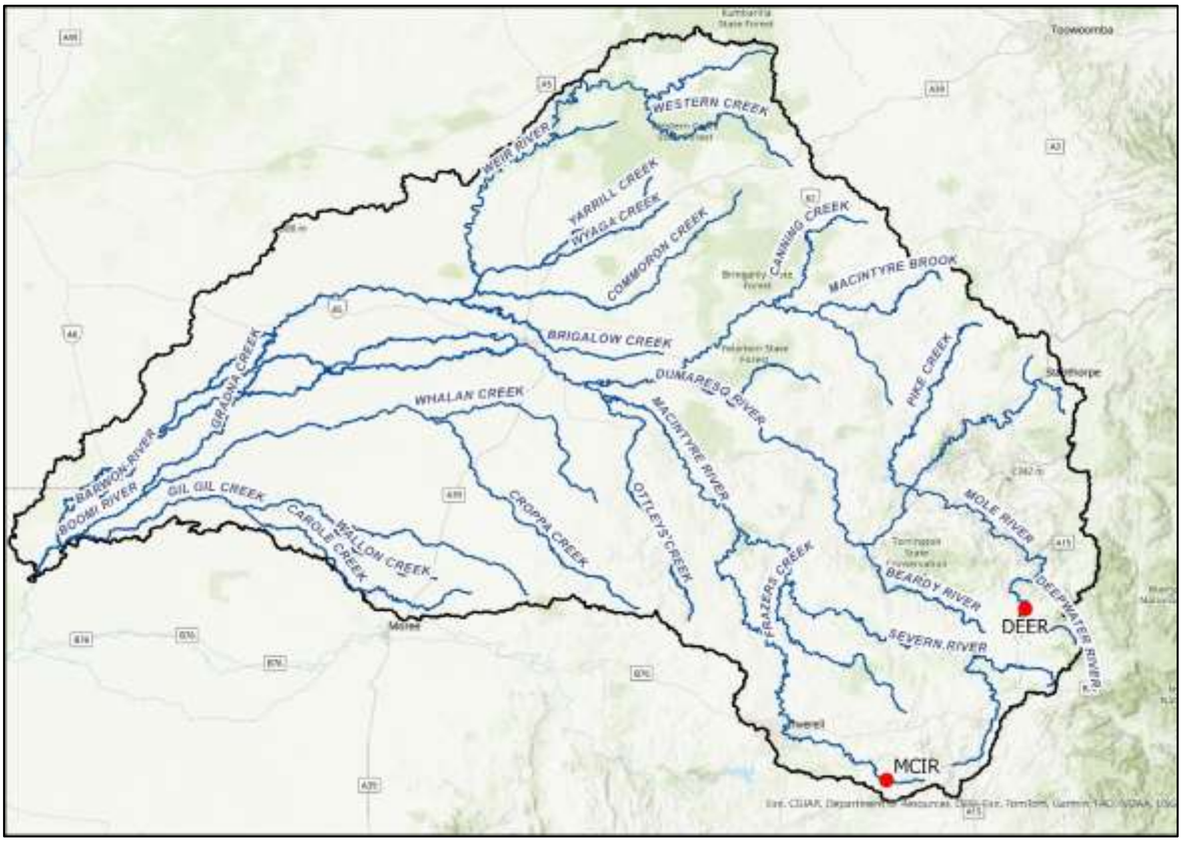

Figure 6-1 Site Location.

Figure 6-2 Photos of site location.

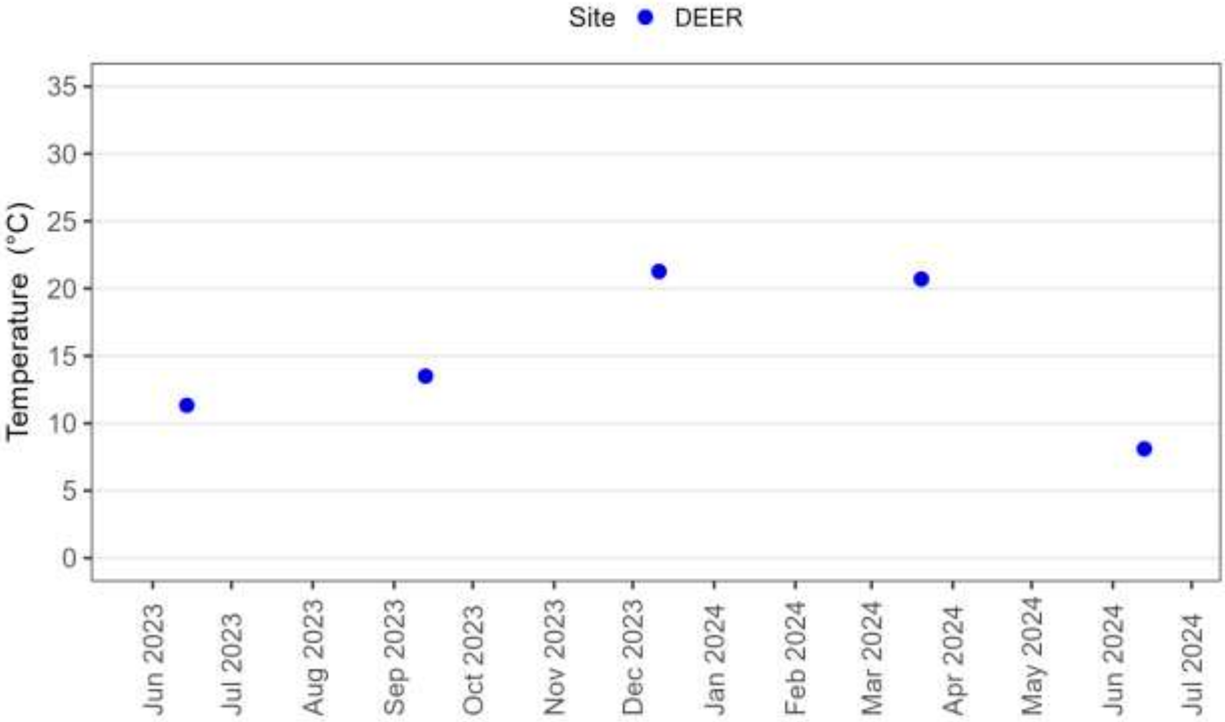

*Figure 6-3 Temperature readings collected by UNE.*

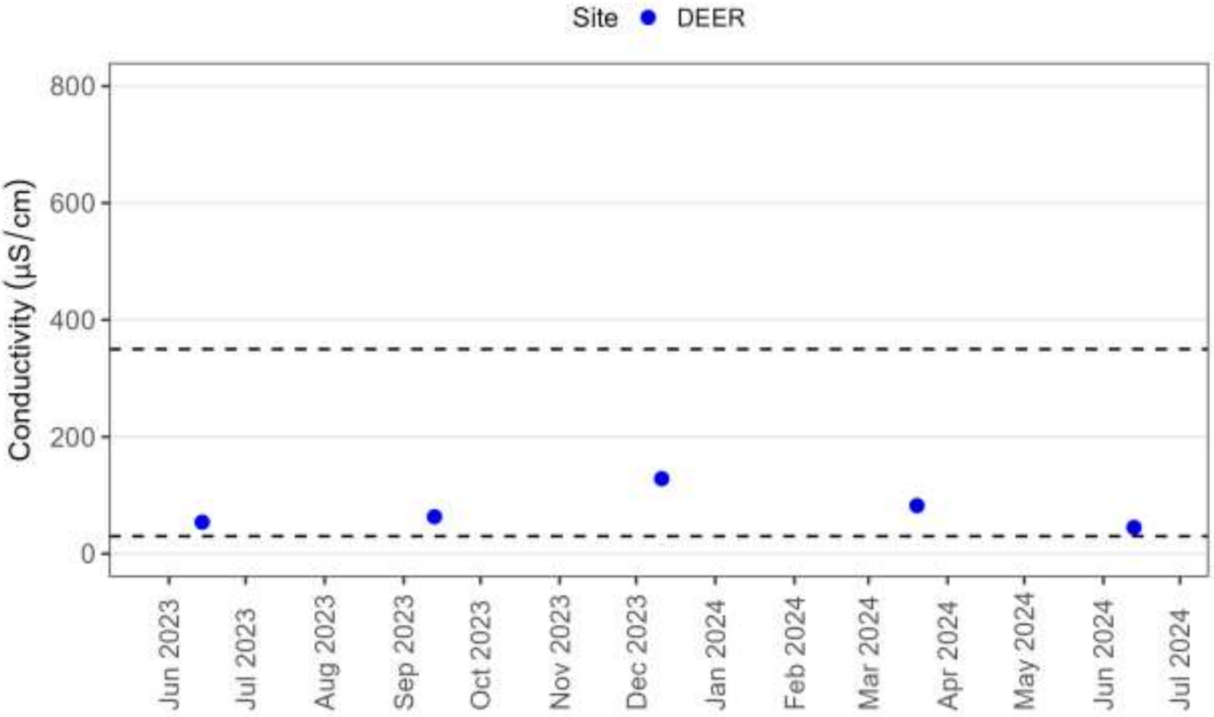

*Figure 6-4 Electrical conductivity readings collected by UNE.*

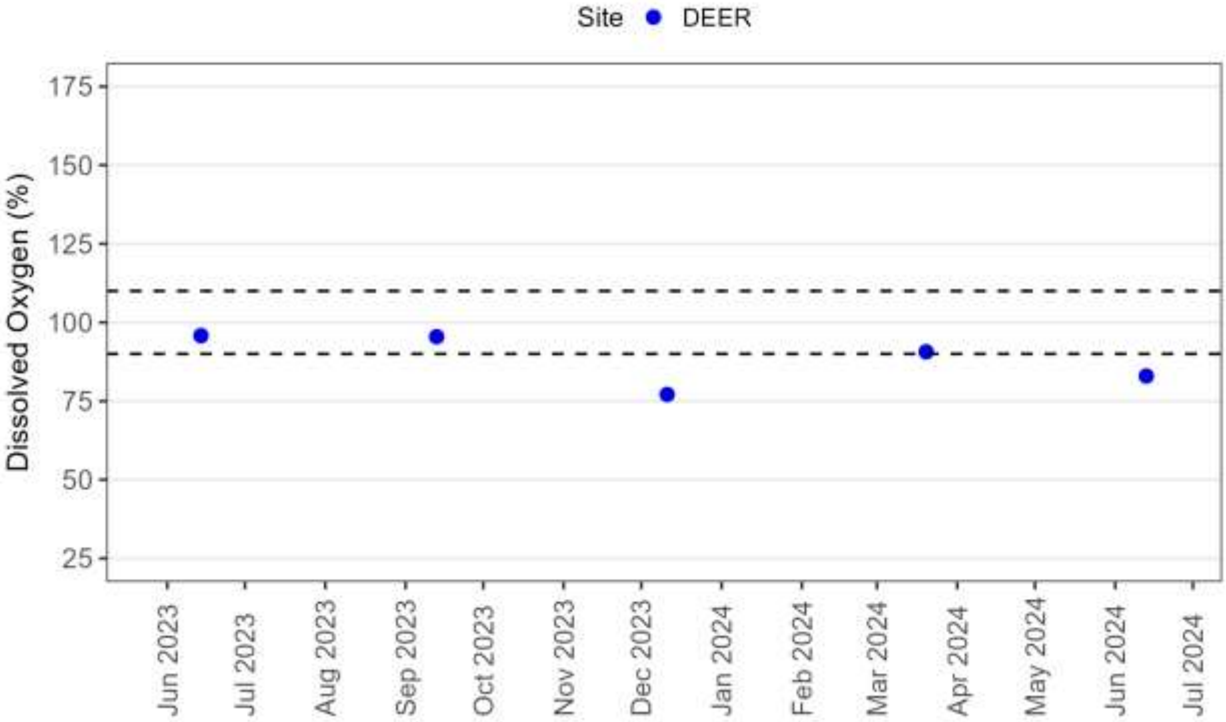

*Figure 6-5 Dissolved Oxygen readings collected by UNE.*

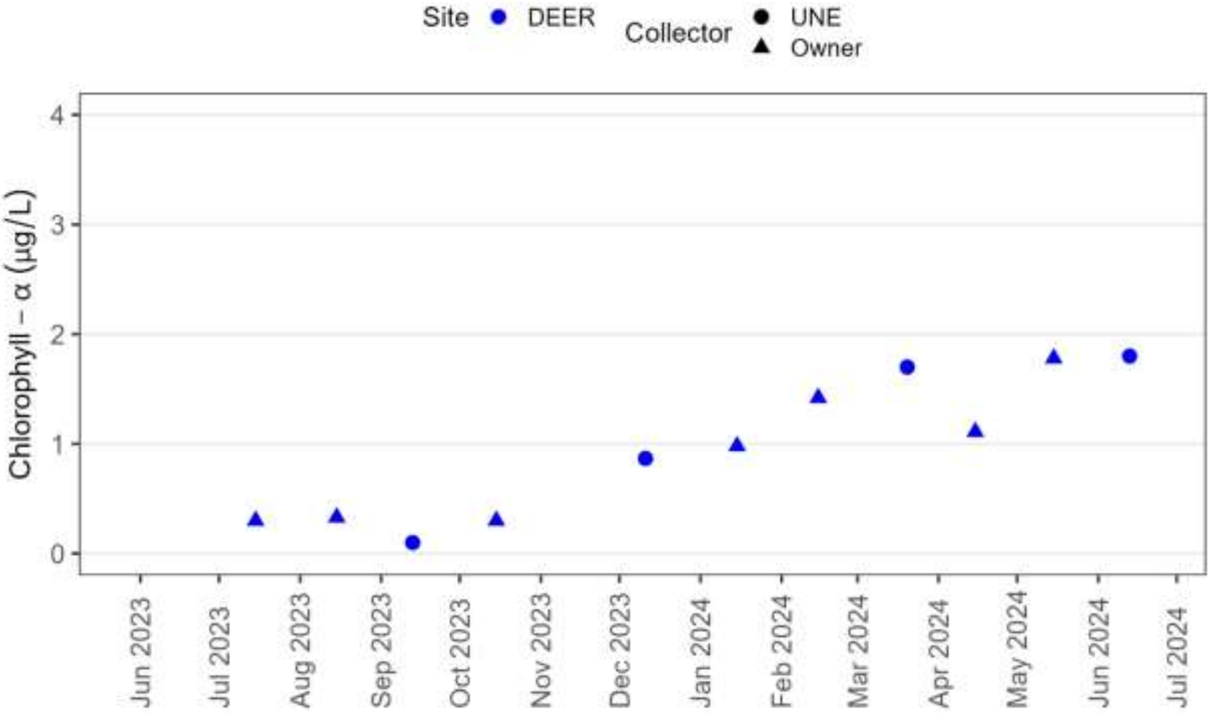

*Figure 6-6 Chlorophyll-a data from water samples collected by UNE (circles) and landholder (triangle).*

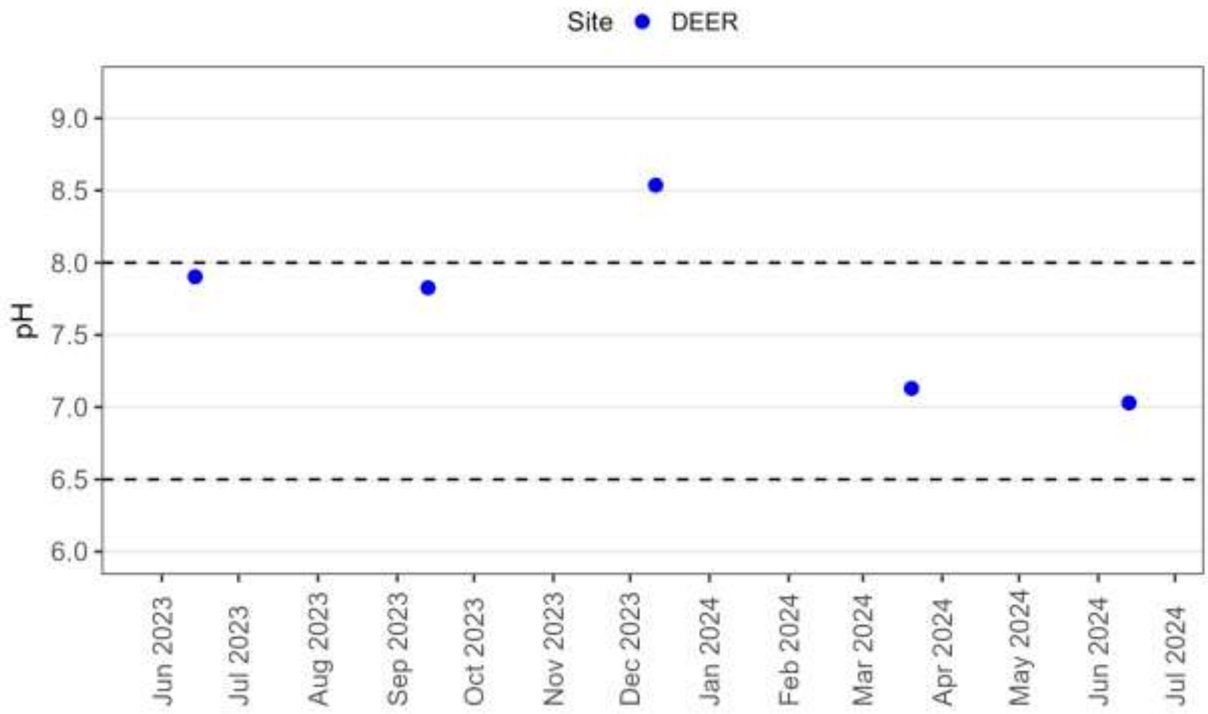

*Figure 6-7 pH readings collected by UNE.*

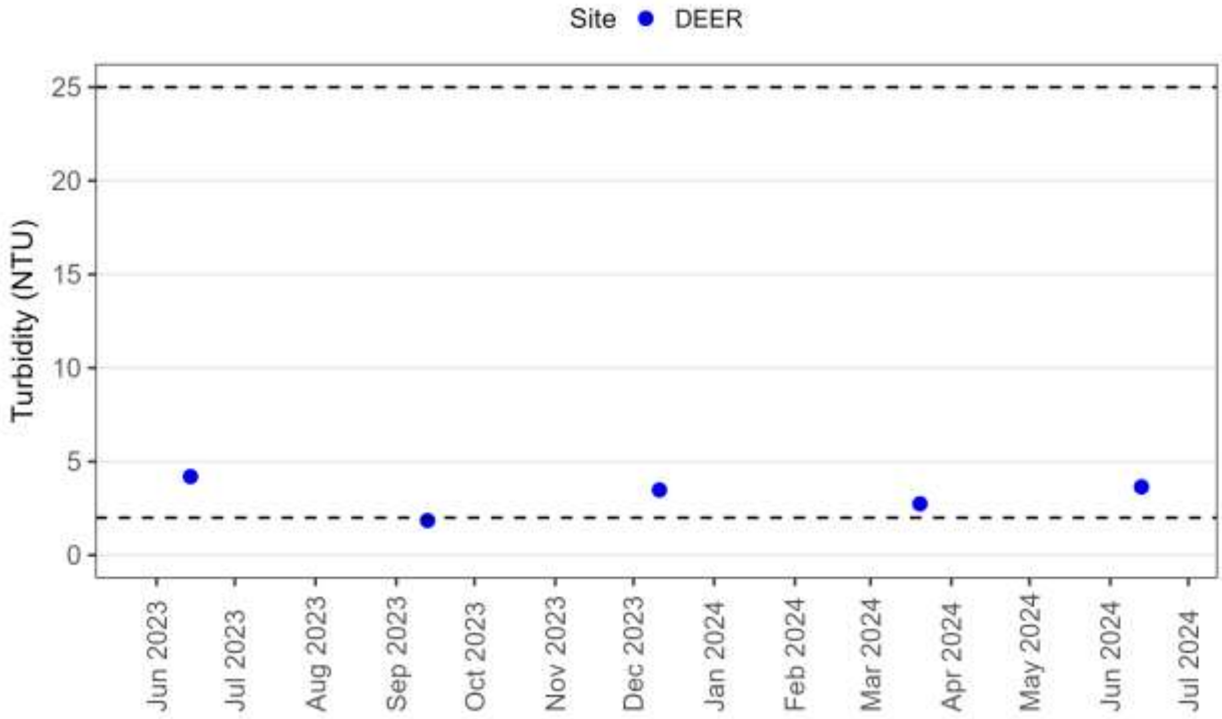

*Figure 6-8 Turbidity readings collected by UNE.*

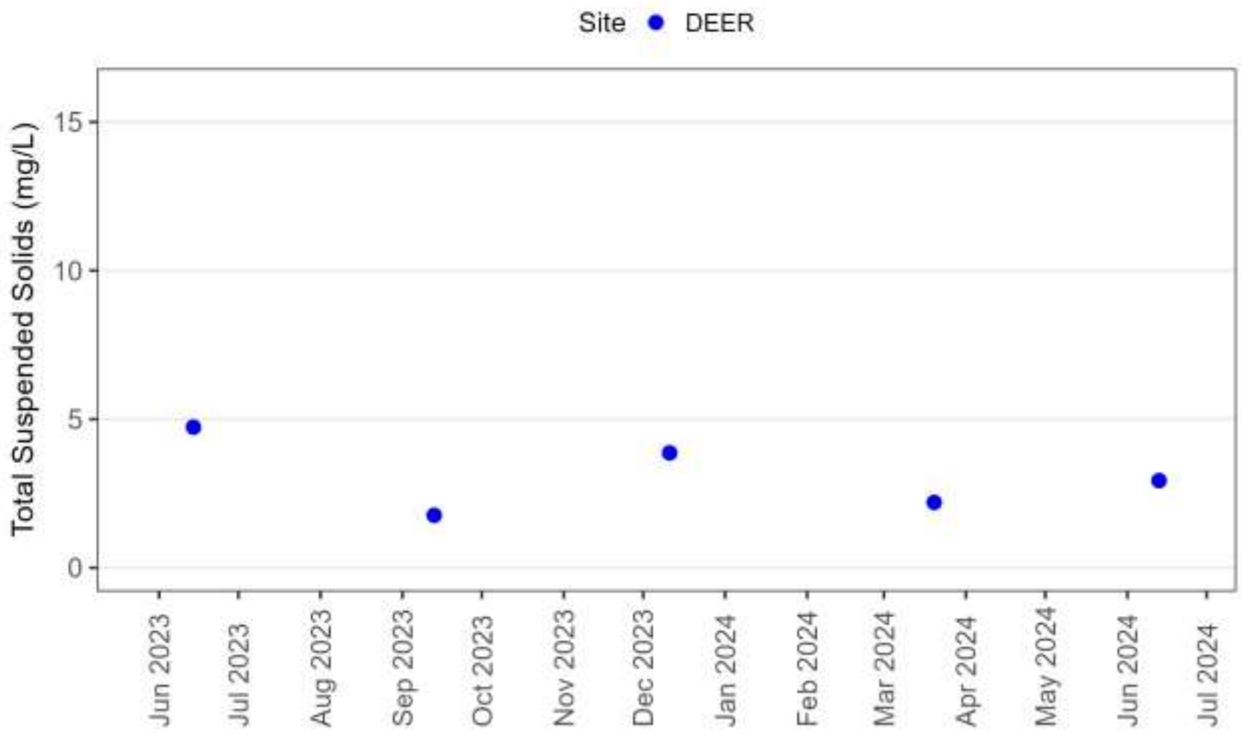

*Figure 6-9 Total suspended solids data from water samples collected by UNE.*

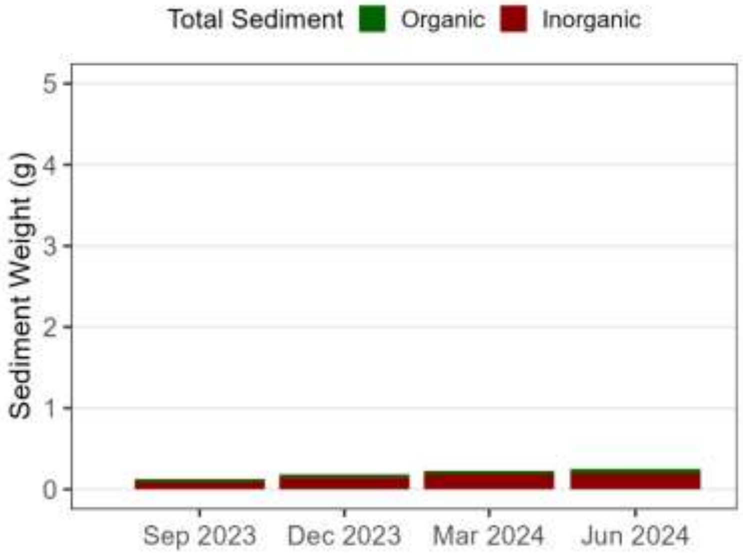

*Figure 6-10 Quarterly sediment accumulation in time-integrated sediment sampler.*

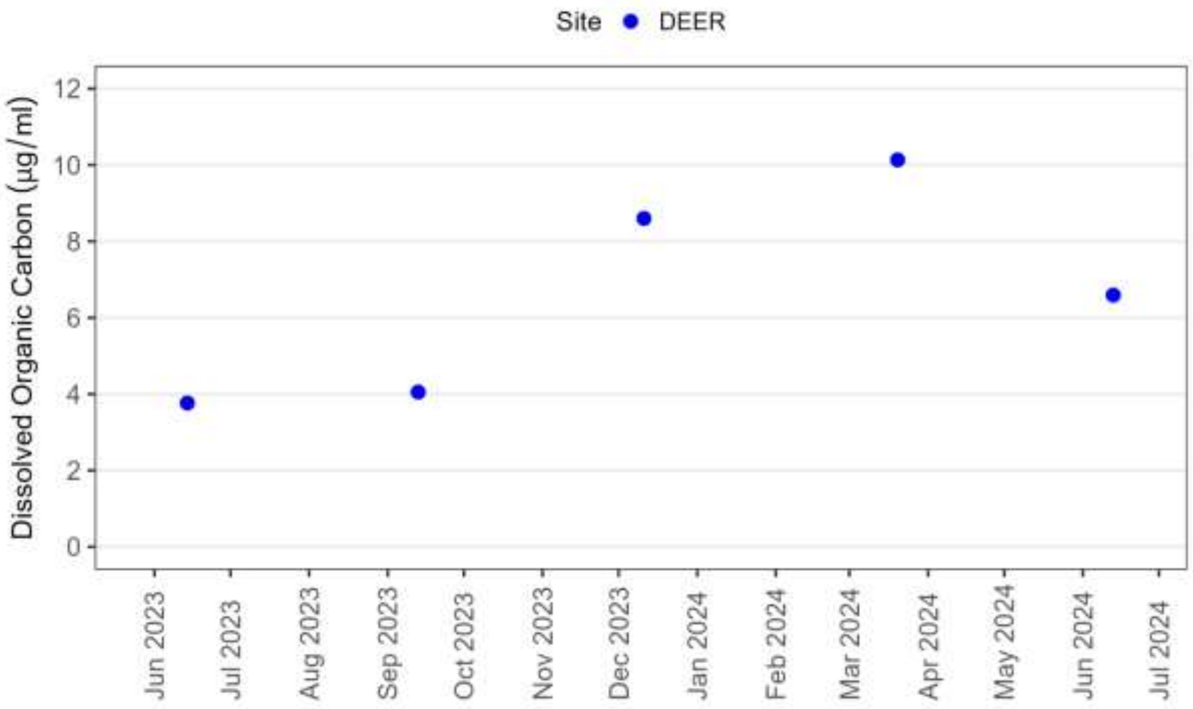

*Figure 6-11 Dissolved organic carbon values from water samples collected by UNE.*

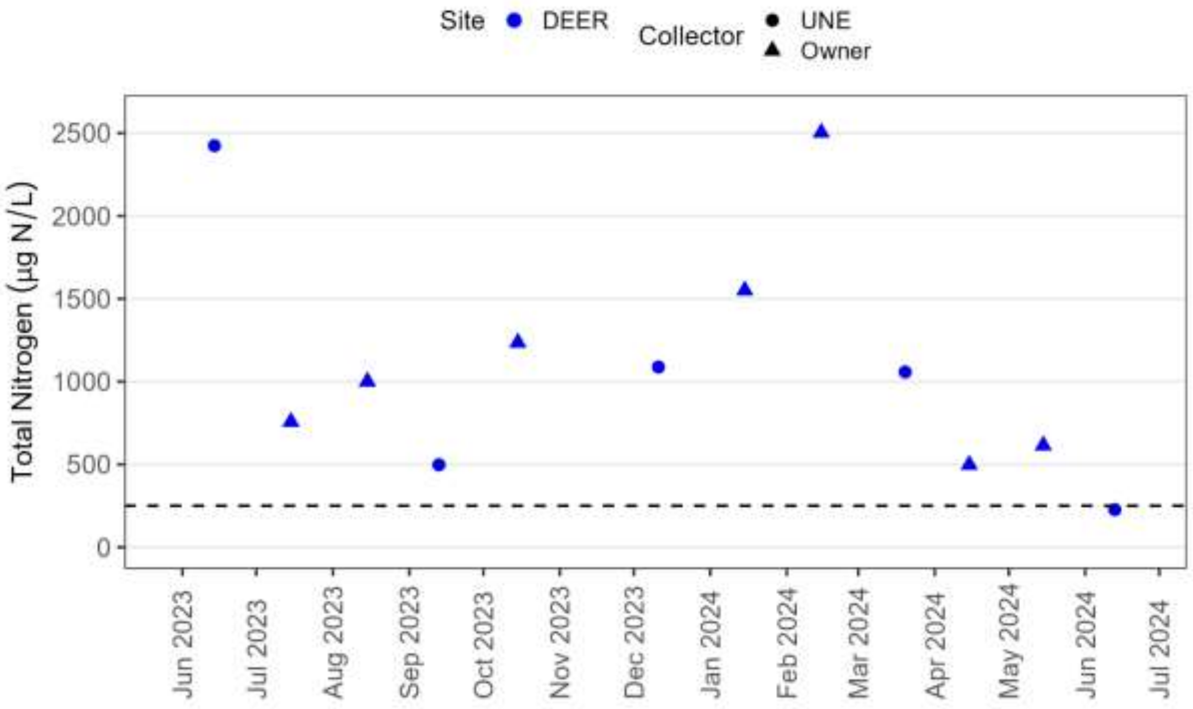

*Figure 6-12 Total nitrogen values from water samples collected by UNE (circle) and landholder (triangles).*

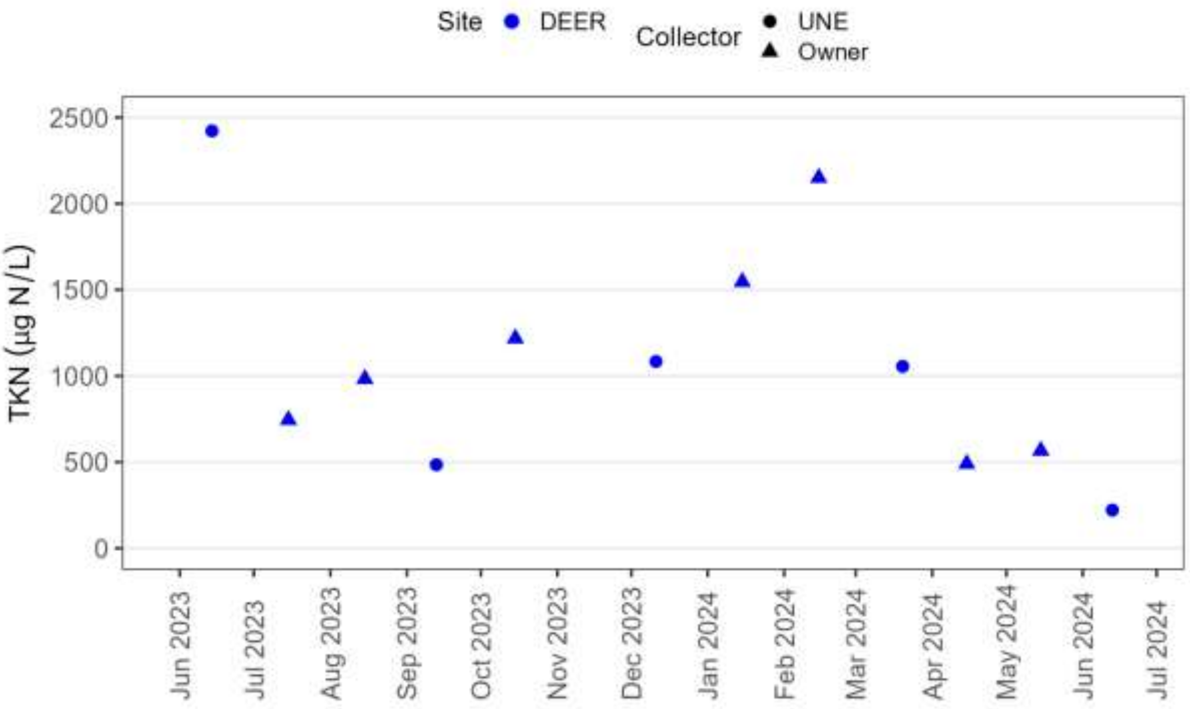

*Figure 6-13 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

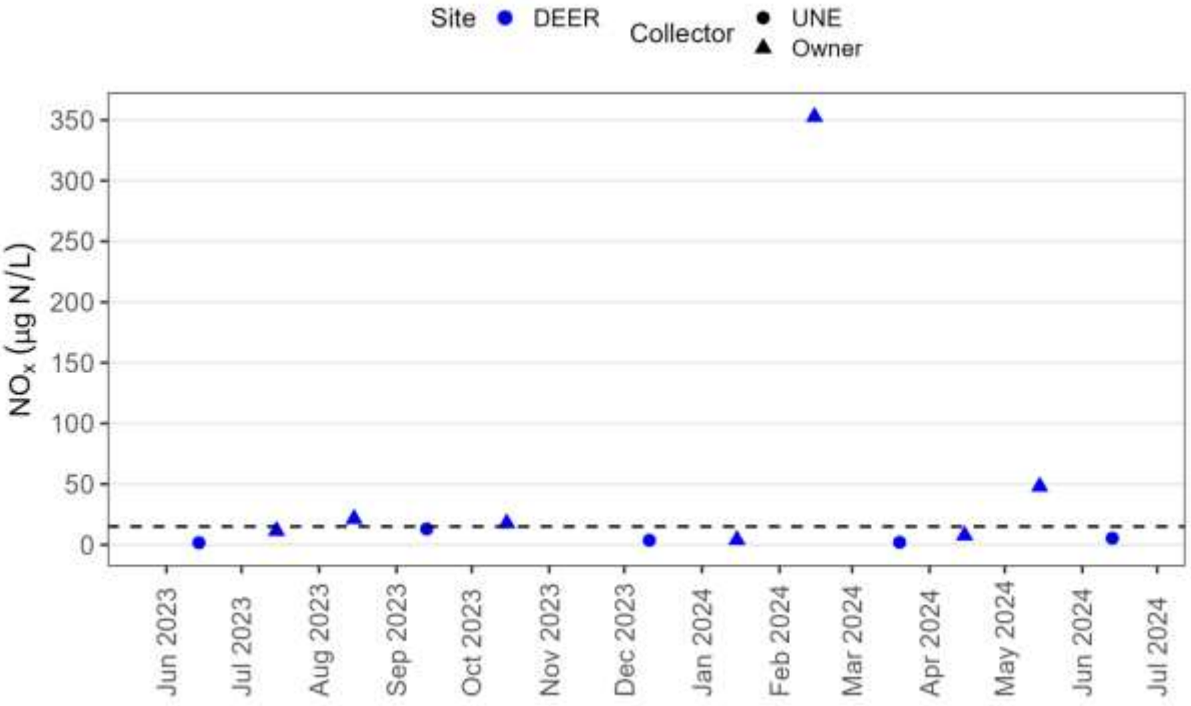

*Figure 6-14 Oxides of nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

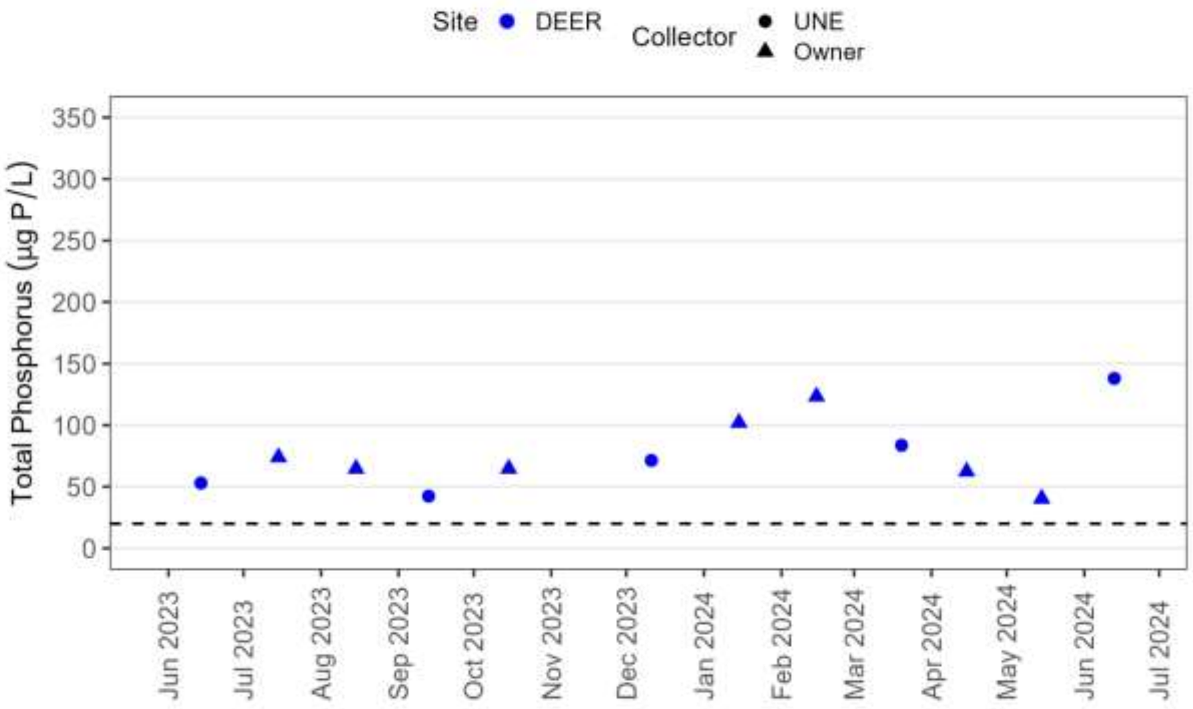

*Figure 6-15 Total phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

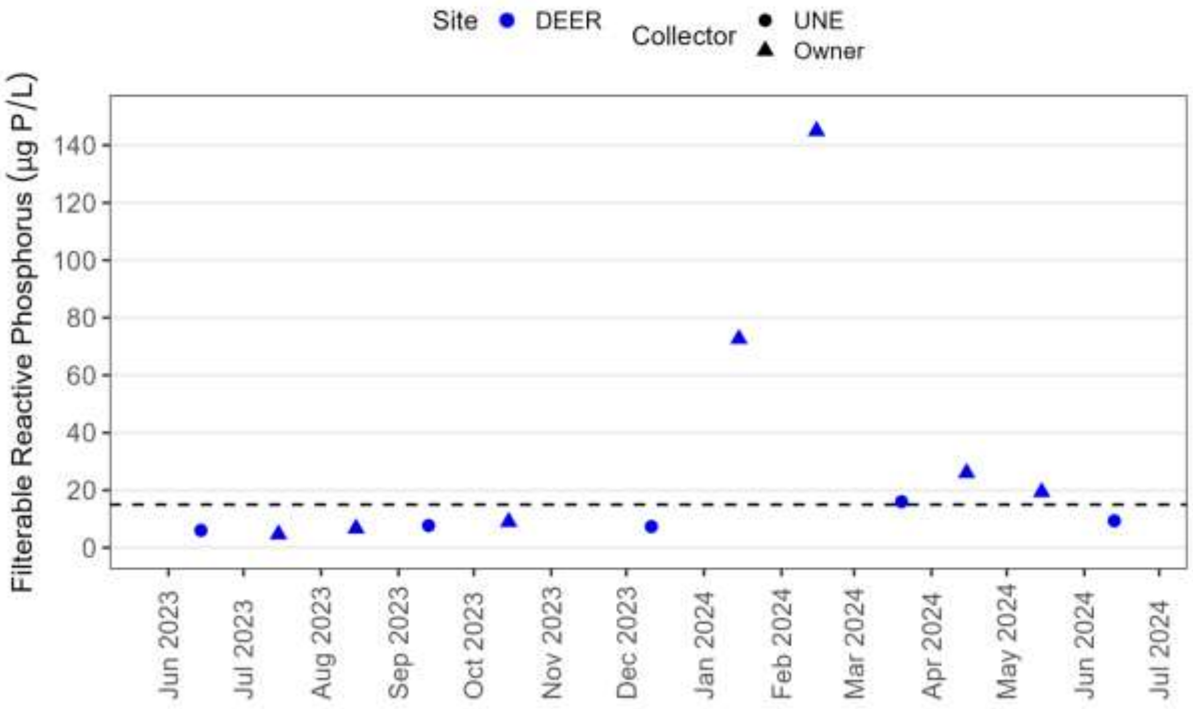

*Figure 6-16 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

# Macintyre River (MCIR)

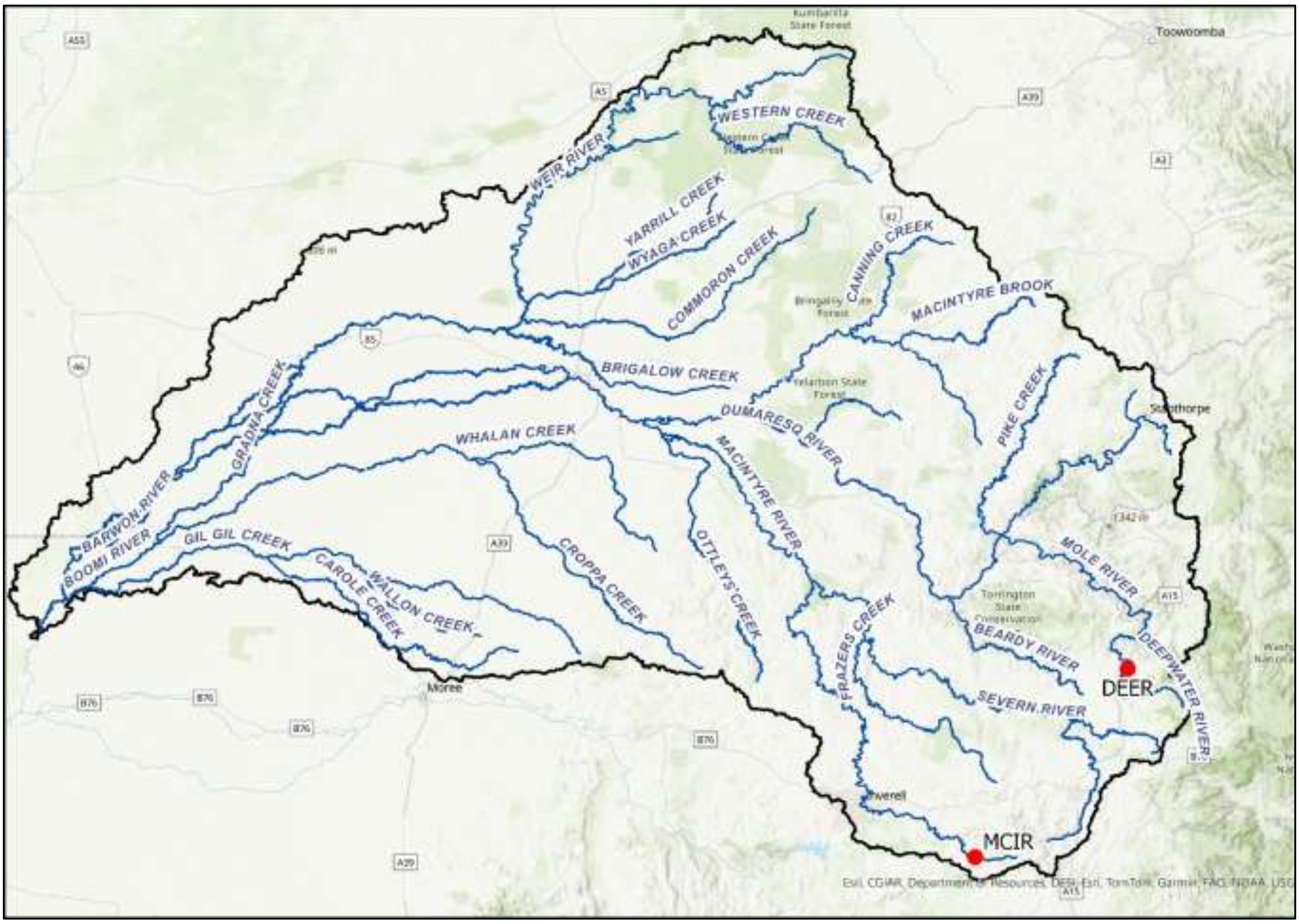

*Figure 6-17 Site Location.*

*Figure 6-18 Photos of site location.*

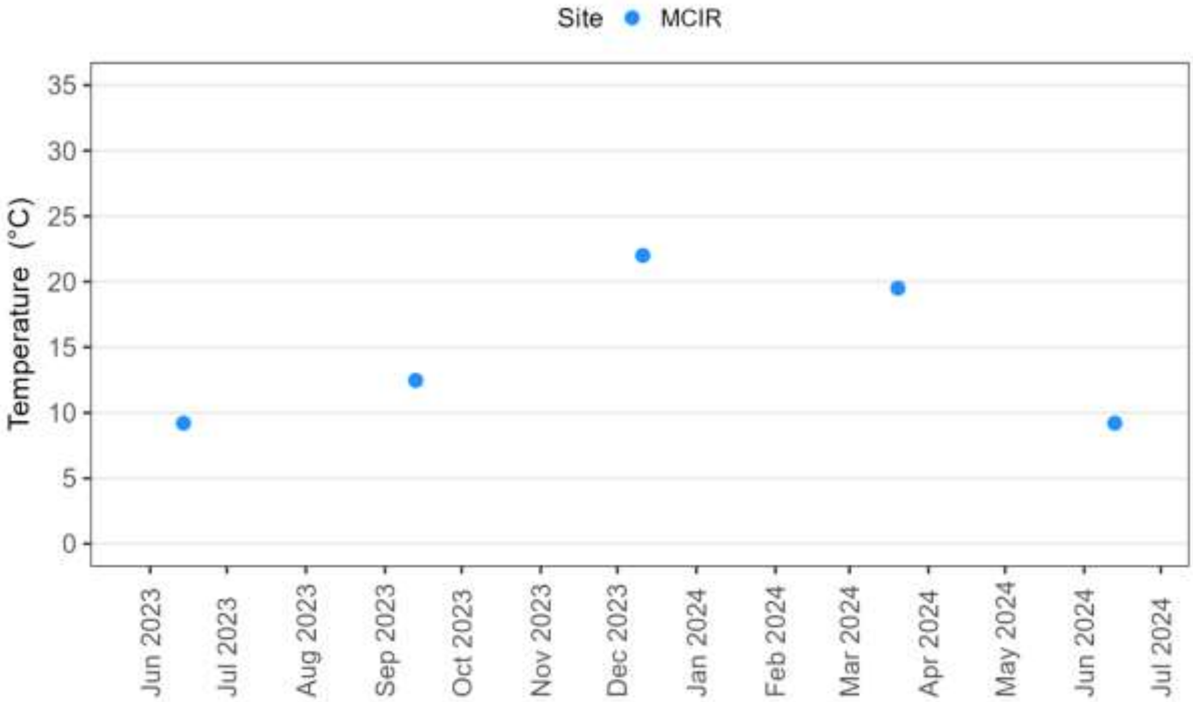

*Figure 6-19 Temperature readings collected by UNE.*

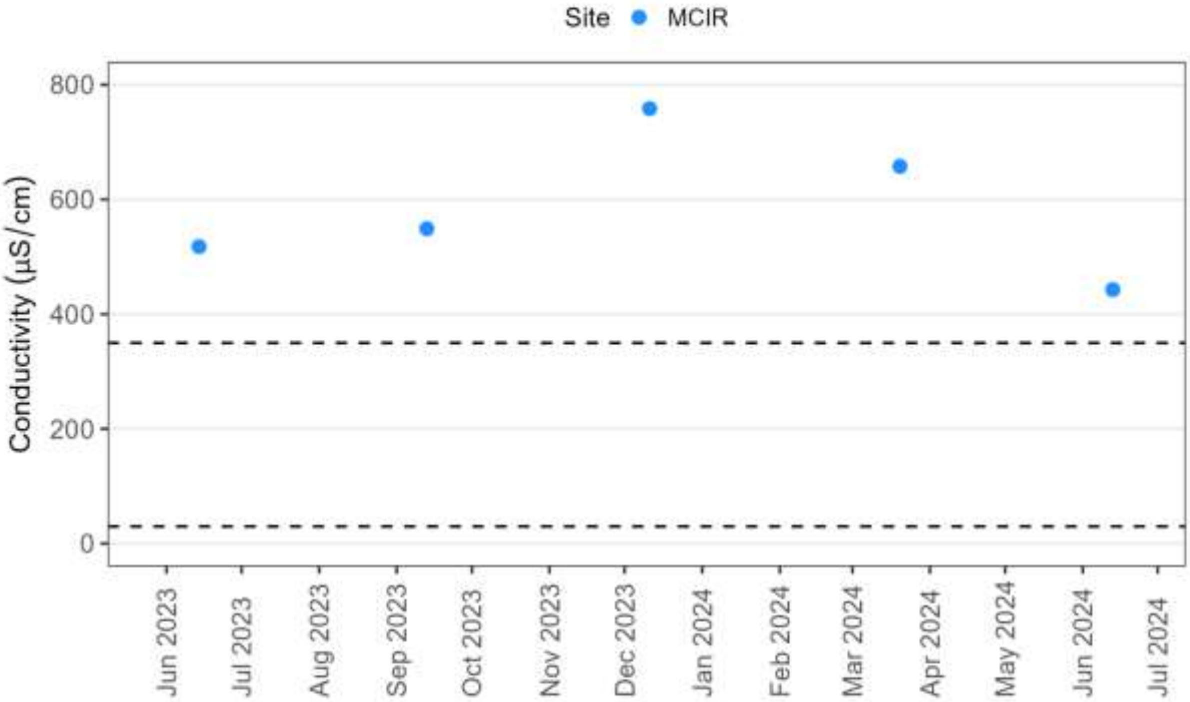

*Figure 6-20 Electrical conductivity readings collected by UNE.*

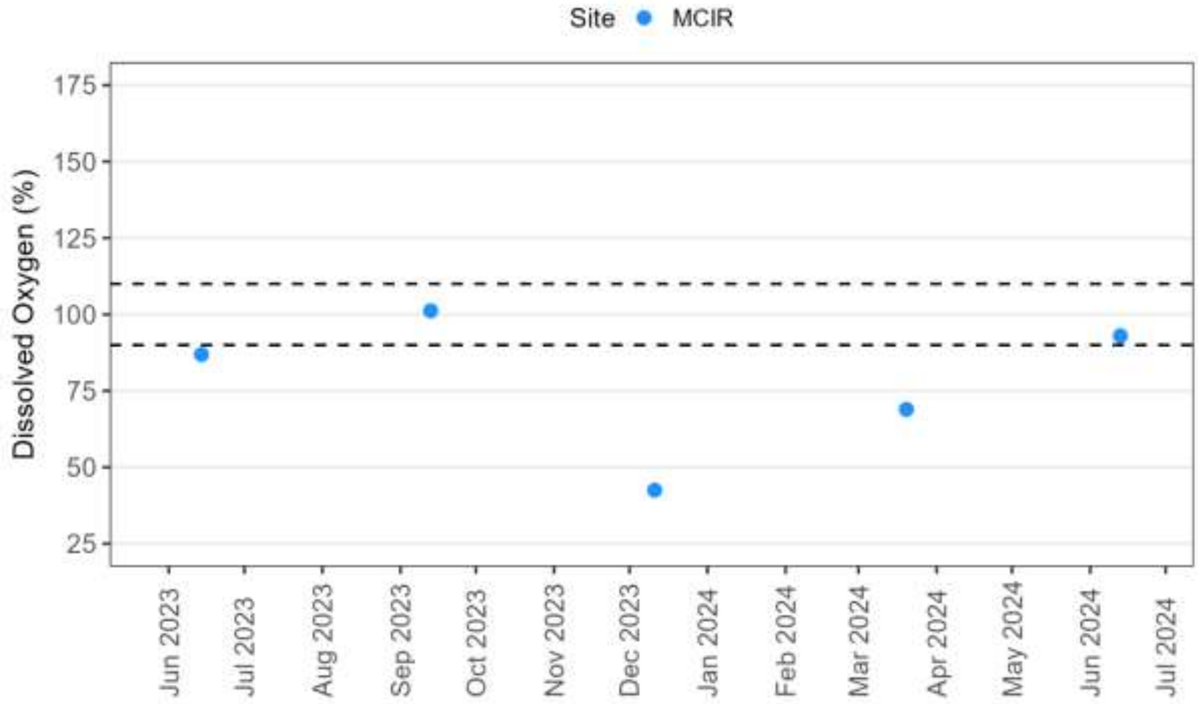

*Figure 6-21 Dissolved Oxygen readings collected by UNE.*

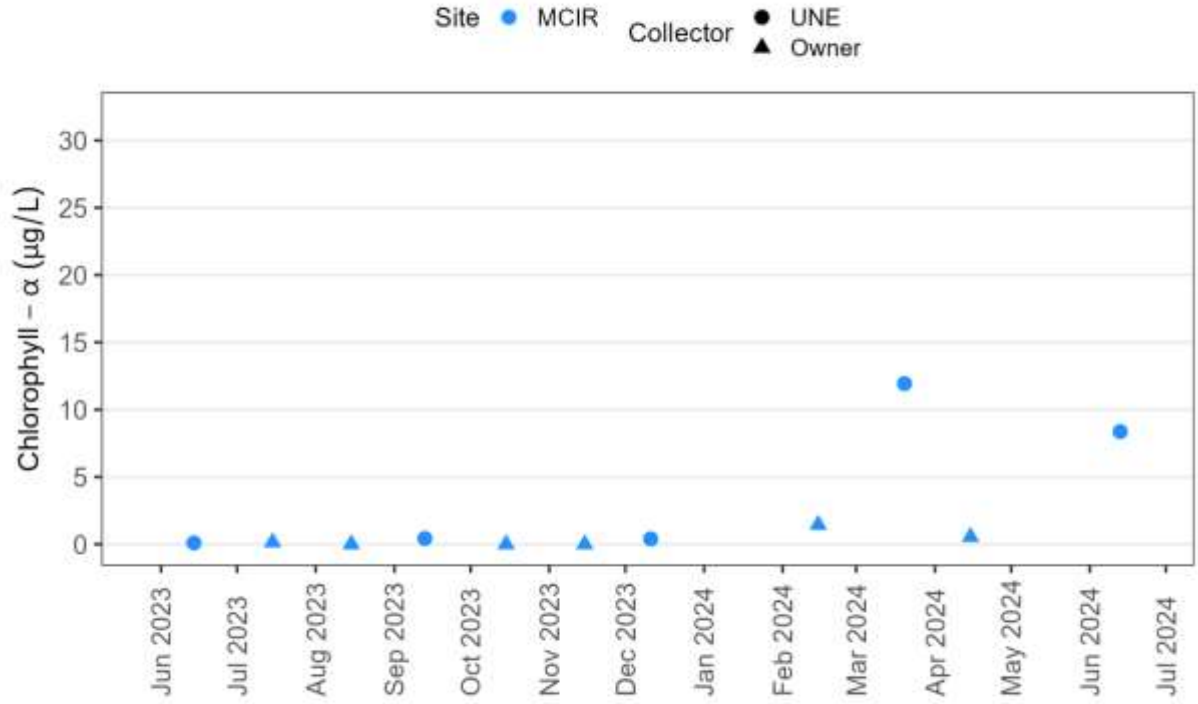

*Figure 6-22 Chlorophyll-a data from water samples collected by UNE (circles) and landholder (triangle).*

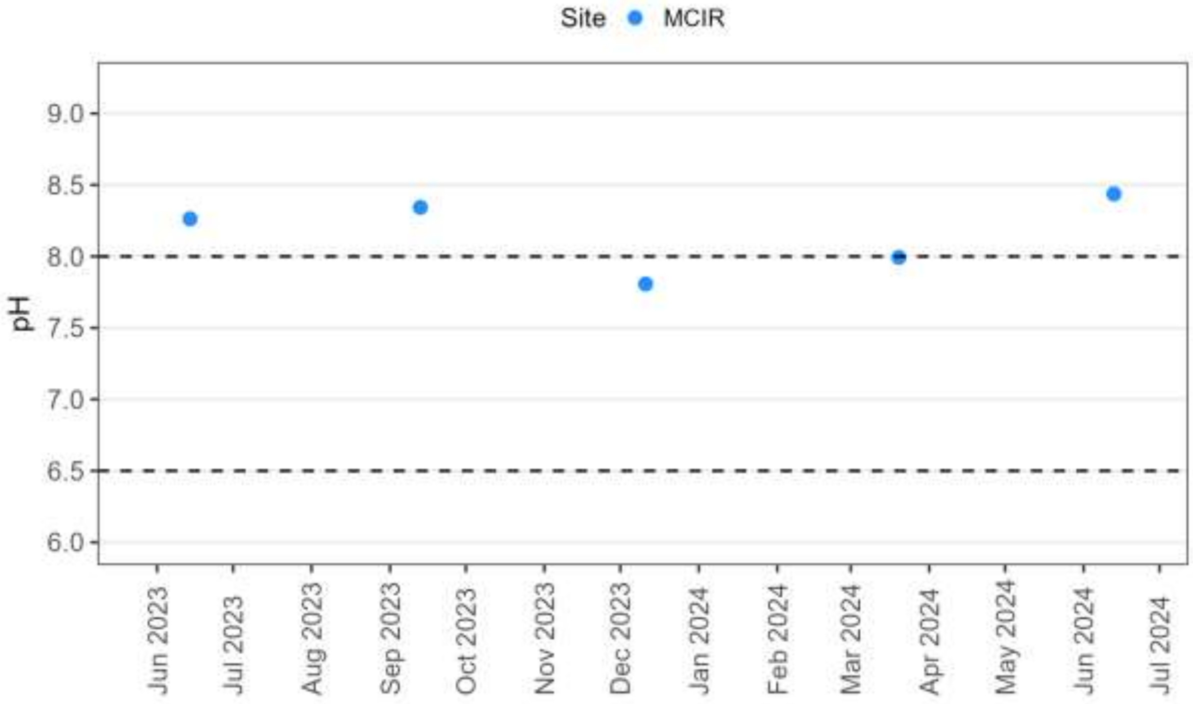

*Figure 6-23 pH readings collected by UNE.*

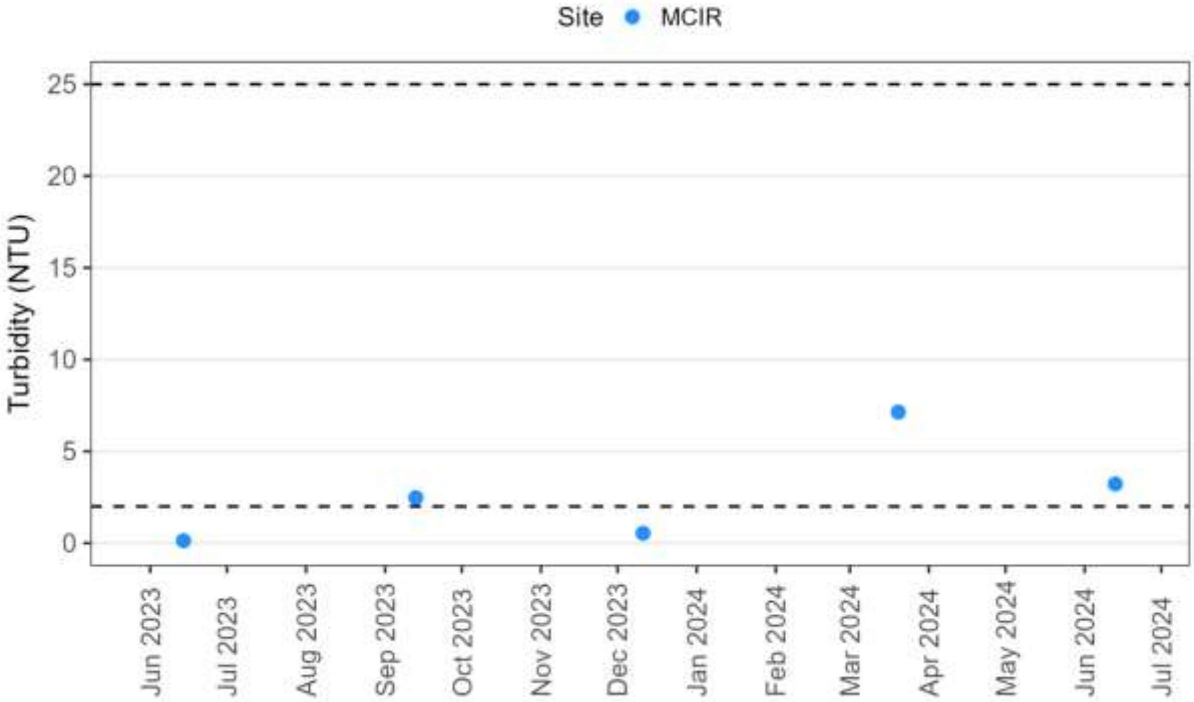

*Figure 6-24 Turbidity readings collected by UNE*

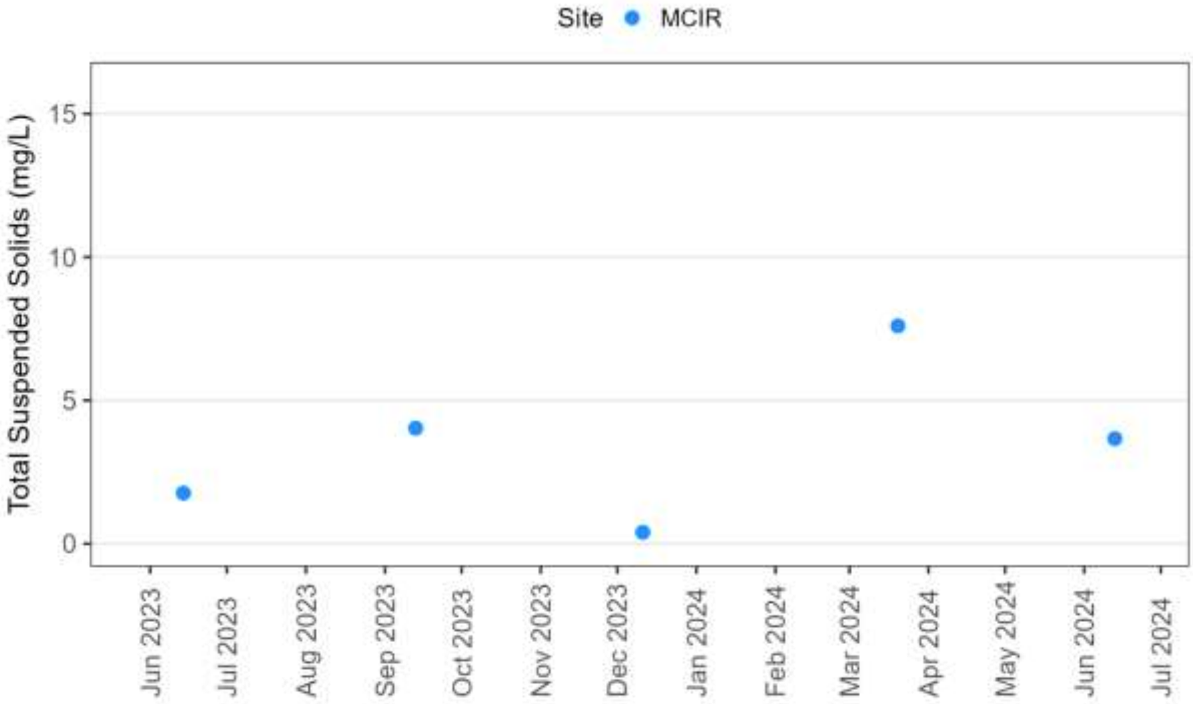

*Figure 6-25 Total suspended solids data from water samples collected by UNE.*

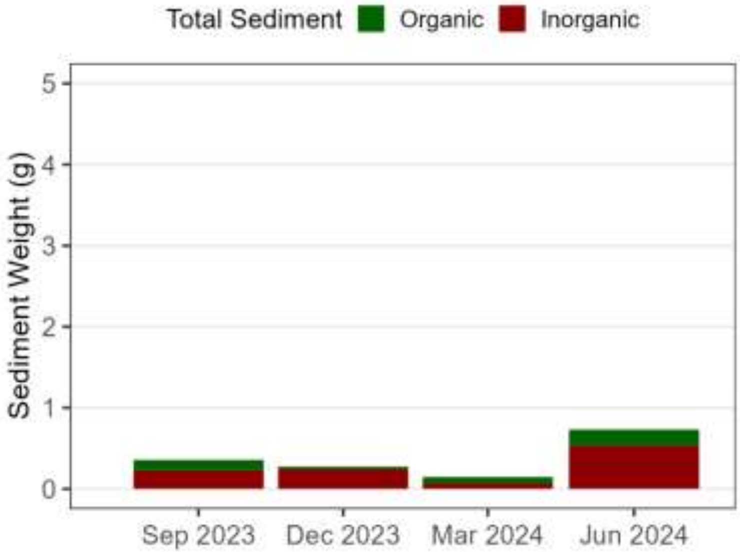

*Figure 6-26 Quarterly sediment accumulation in time-integrated sediment sampler.*

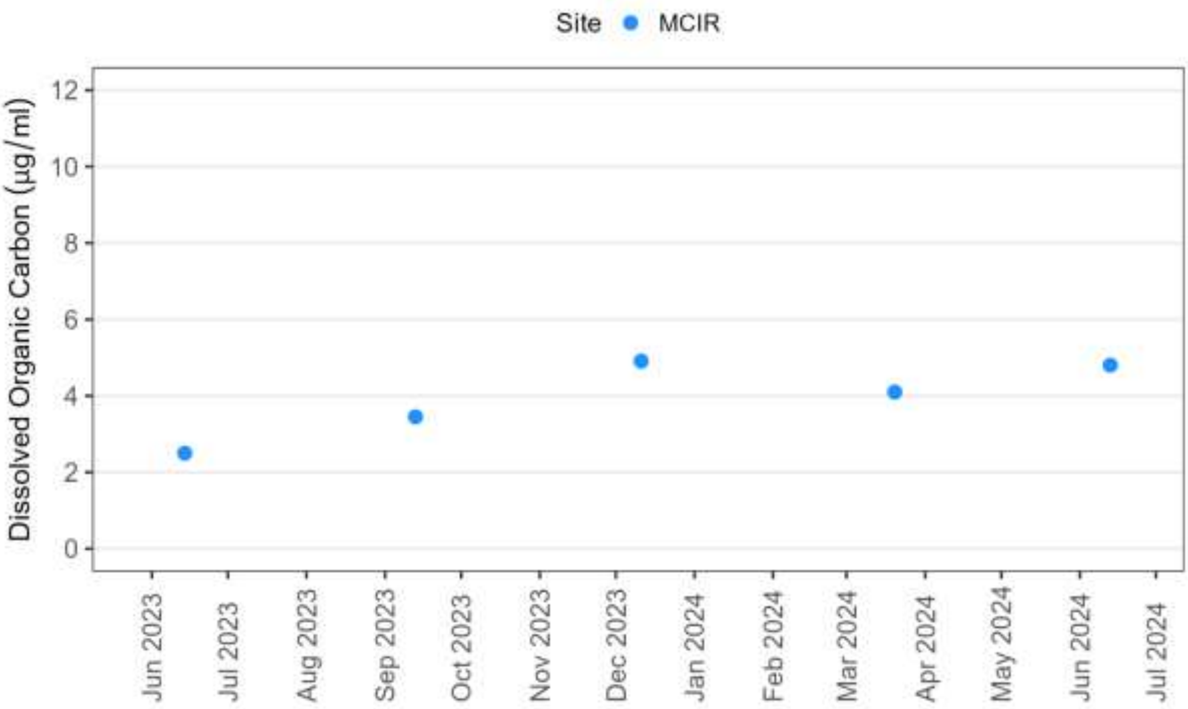

*Figure 6-27 Dissolved organic carbon values from water samples collected by UNE.*

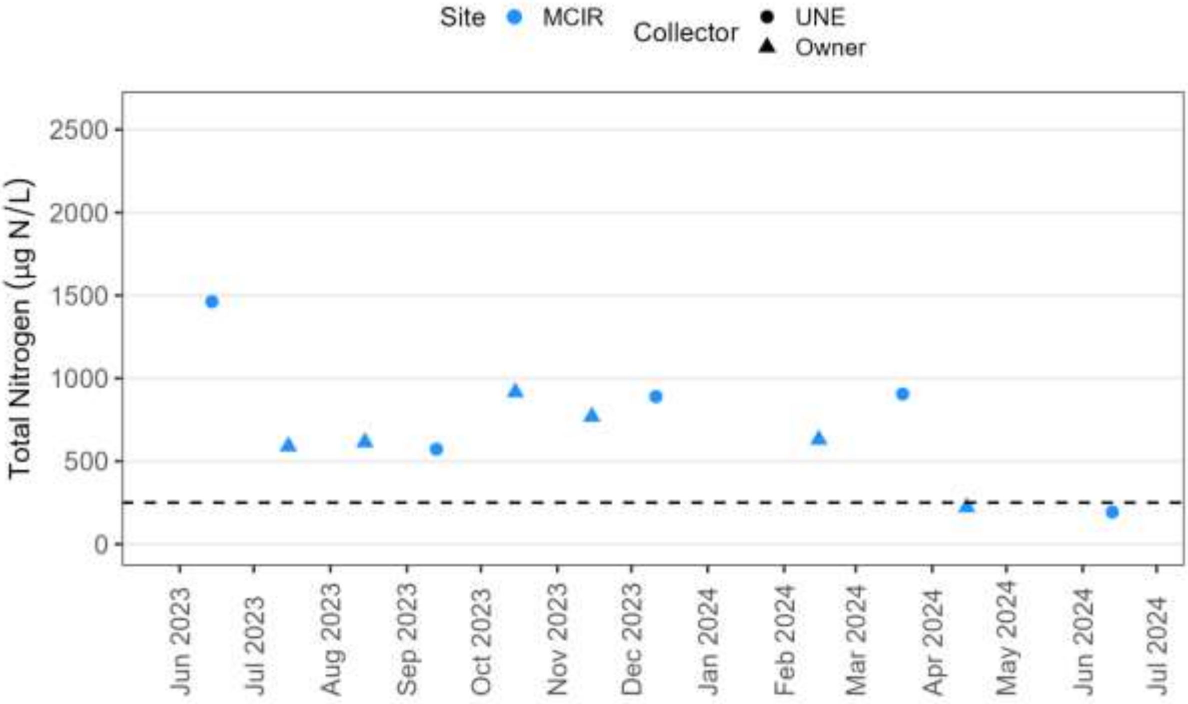

*Figure 6-28 Total nitrogen values from water samples collected by UNE (circle) and landholder (triangles).*

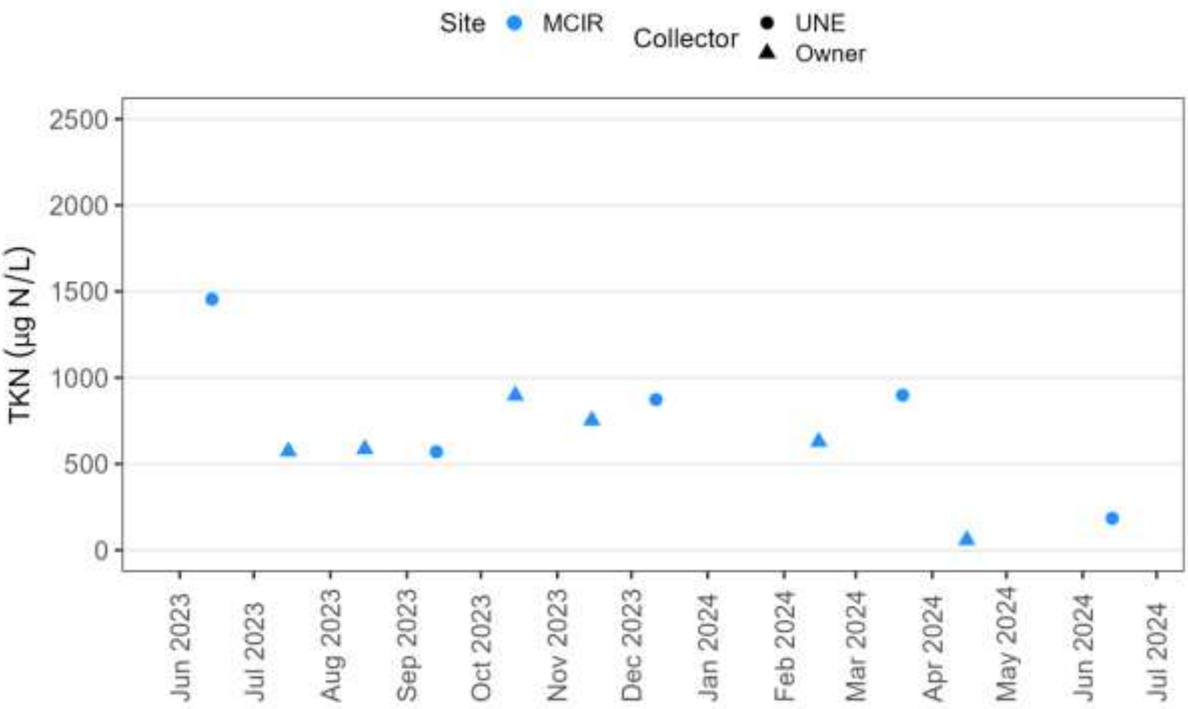

*Figure 6-29 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

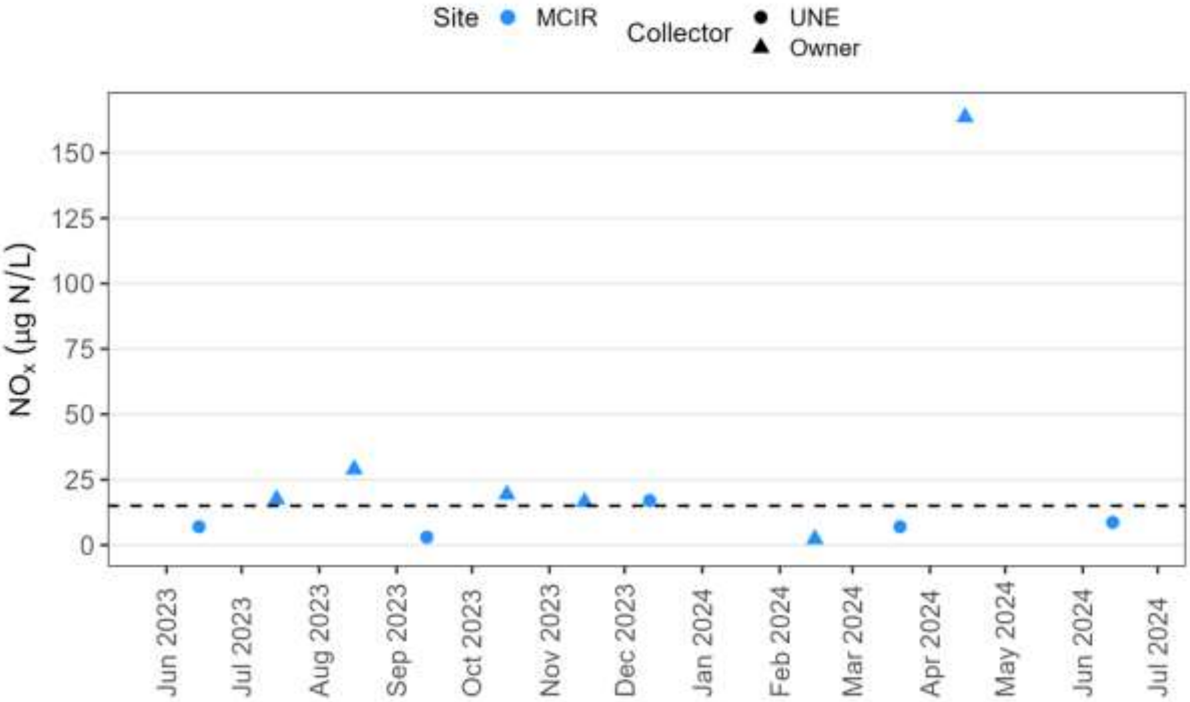

*Figure 6-30 Oxides of nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

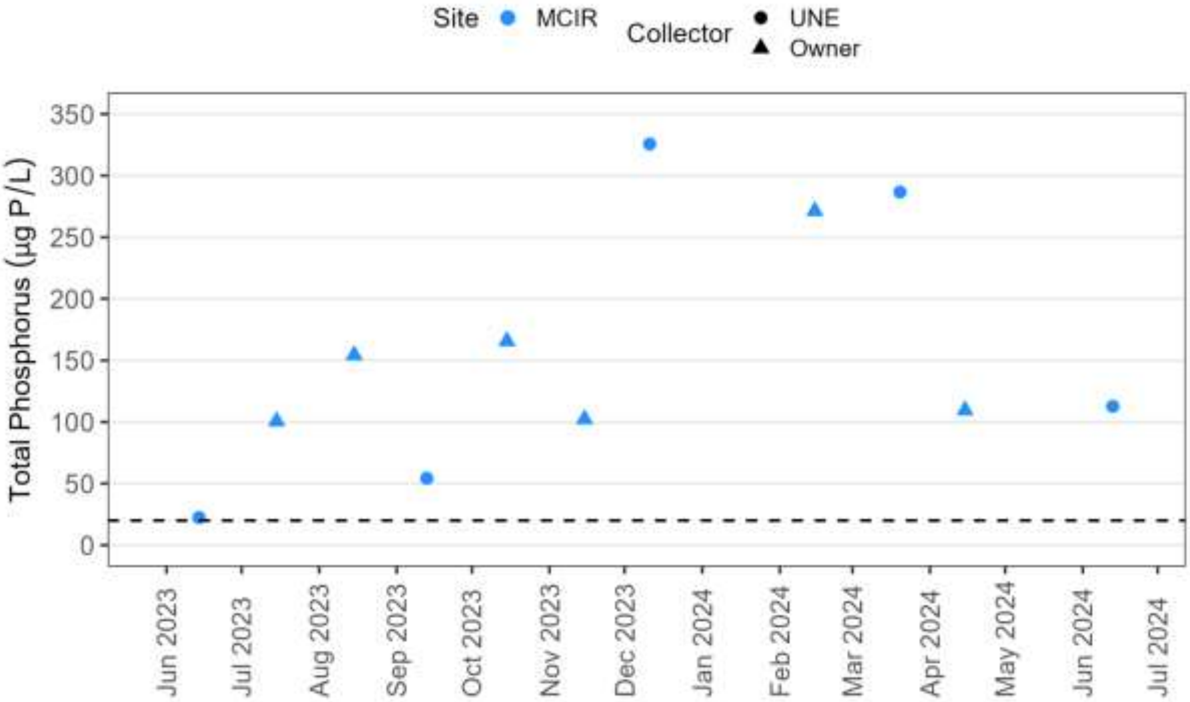

*Figure 6-31 Total phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

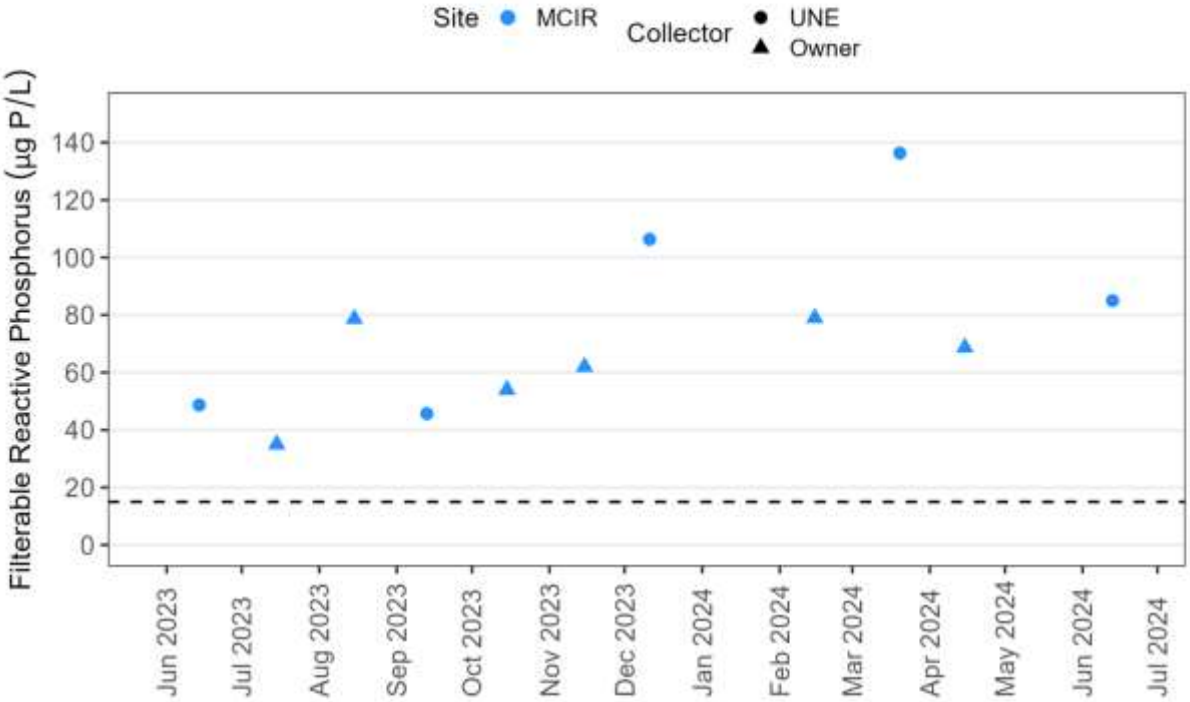

*Figure 6-32 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

## Macdonald River (MCDR)

*Figure 6-33 Site Location.*

*Figure 6-34 Photos of site location.*

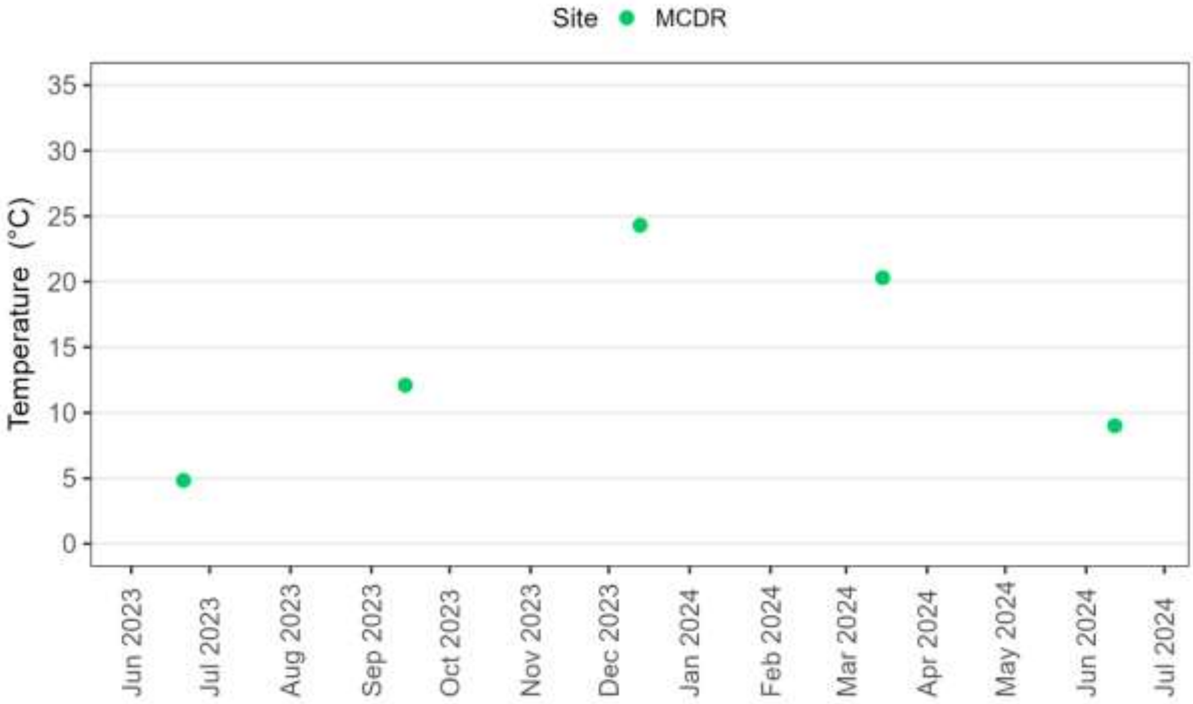

*Figure 6-35 Temperature readings collected by UNE.*

*Figure 6-36 Electrical conductivity readings collected by UNE.*

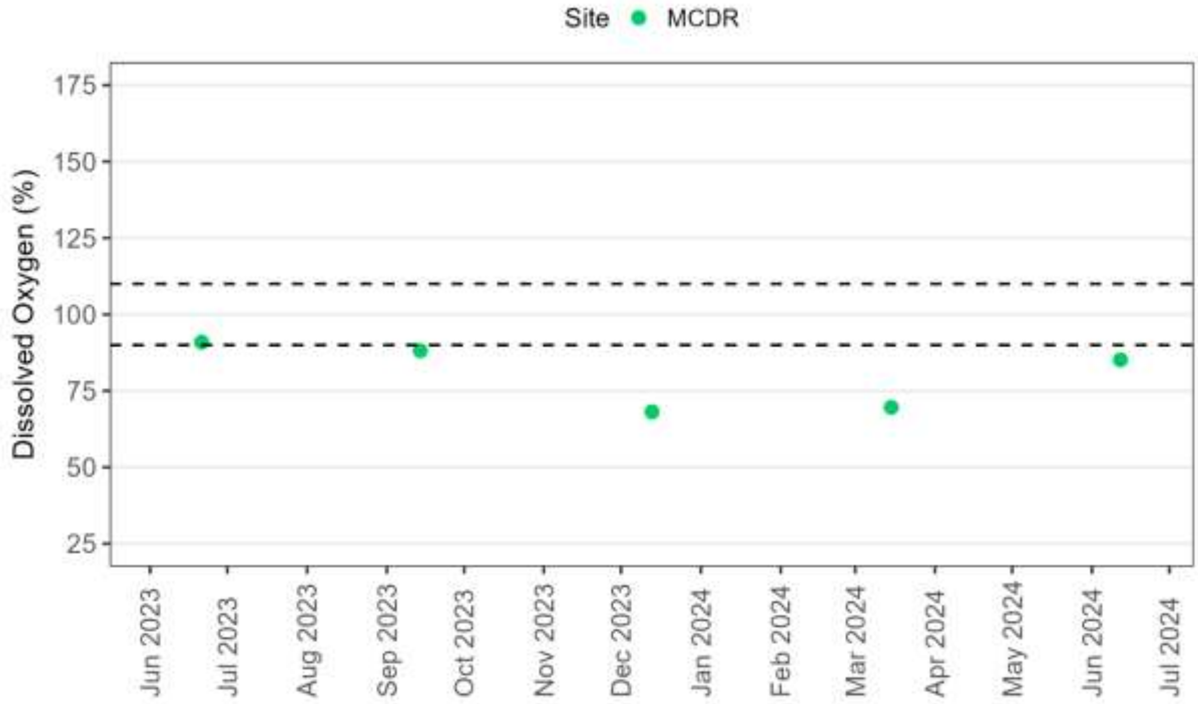

*Figure 6-37 Dissolved Oxygen readings collected by UNE.*

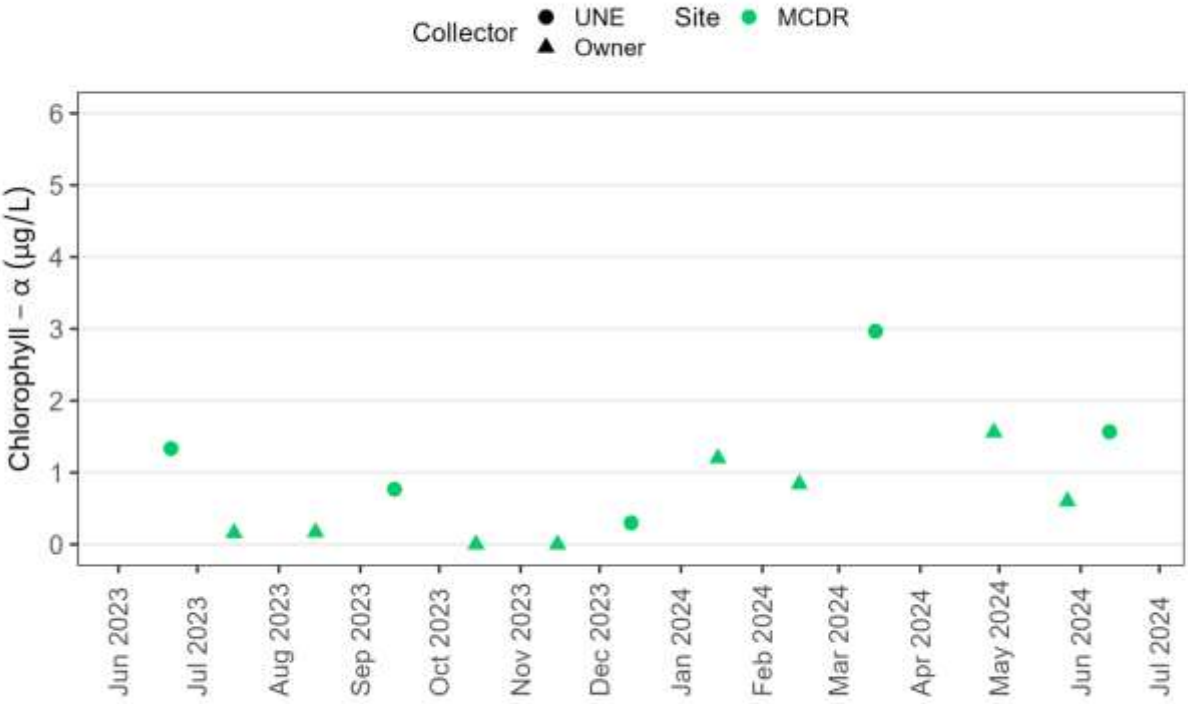

*Figure 6-38 Chlorophyll-a data from water samples collected by UNE (circles) and landholder (triangle).*

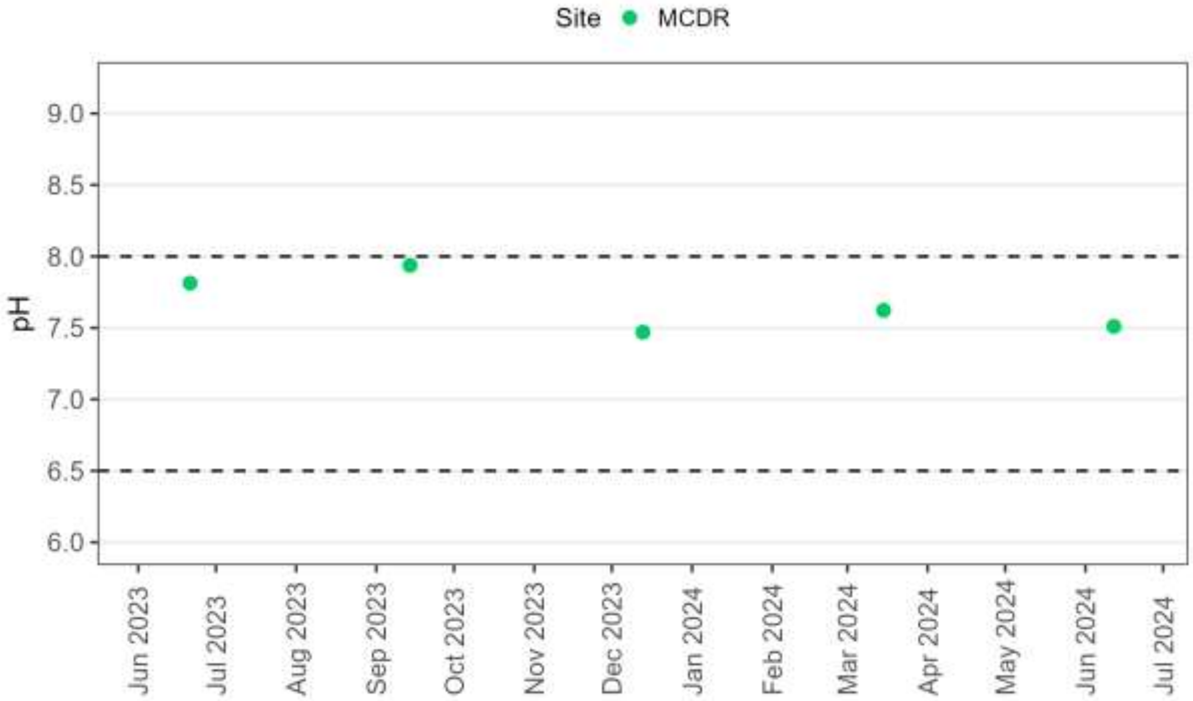

*Figure 6-39 pH readings collected by UNE.*

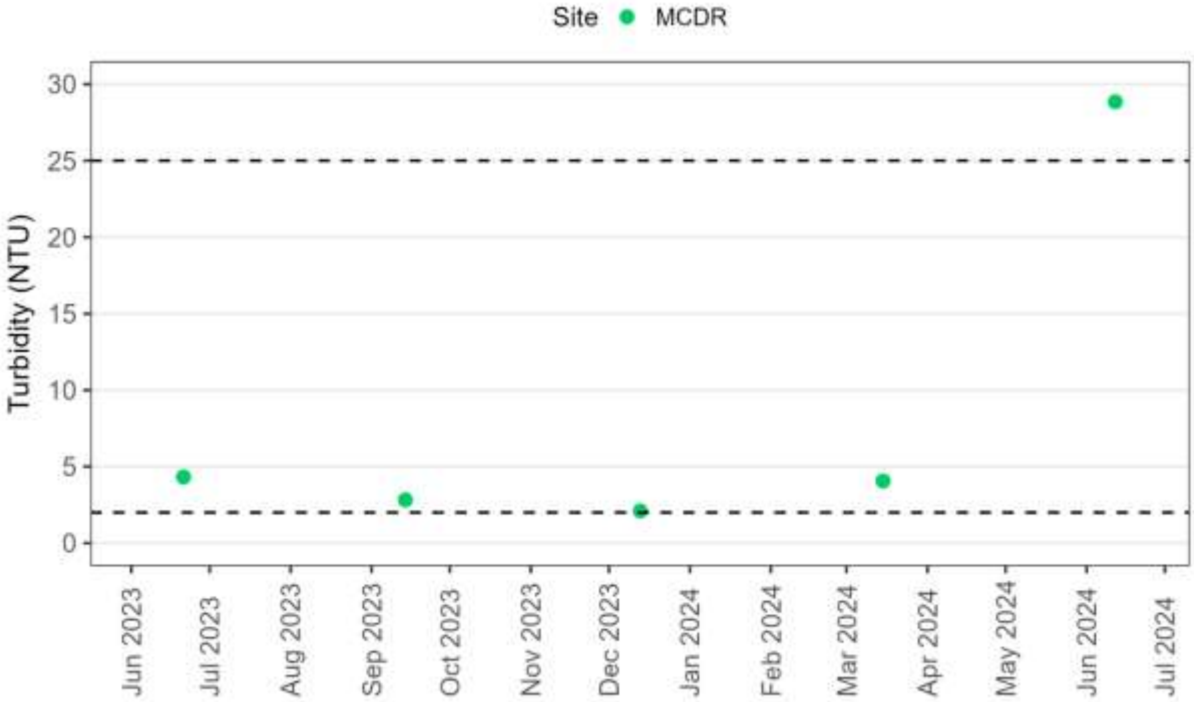

*Figure 6-40 Turbidity readings collected by UNE.*

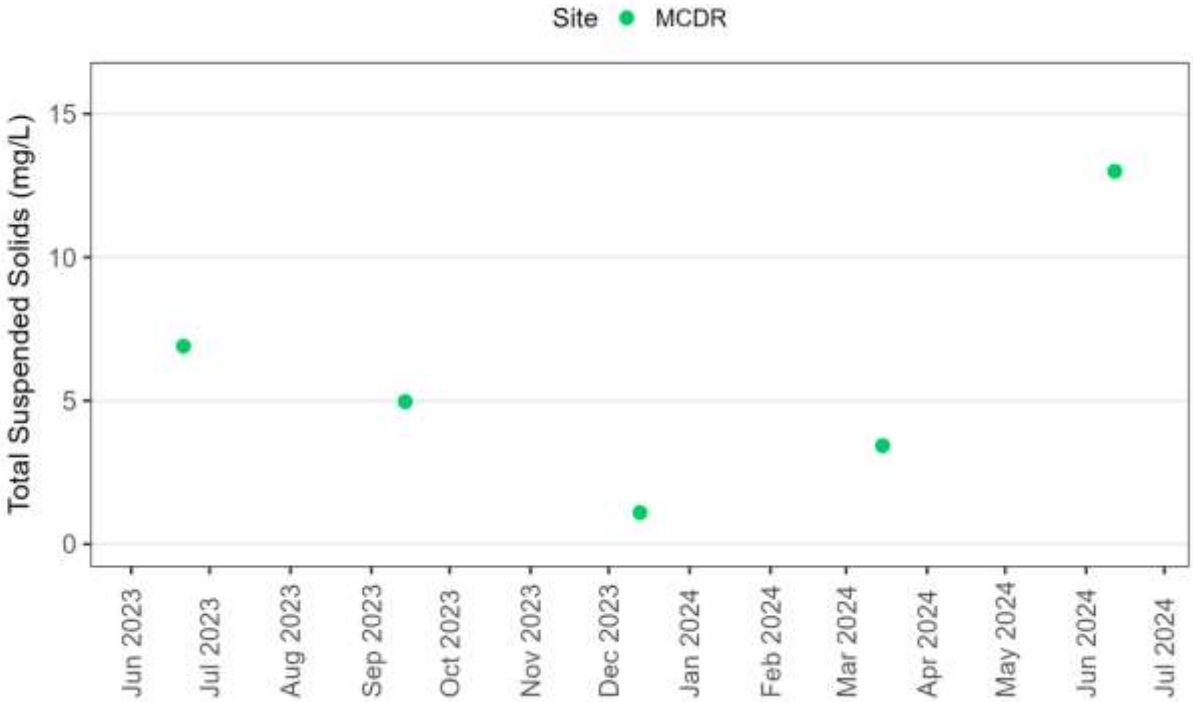

*Figure 6-41 Total suspended solids data from water samples collected by UNE.*

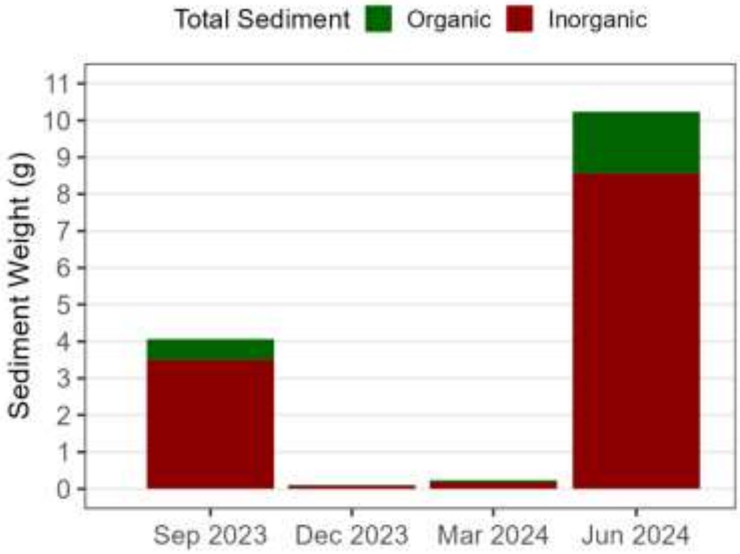

*Figure 6-42 Quarterly sediment accumulation in time-integrated sediment sampler.*

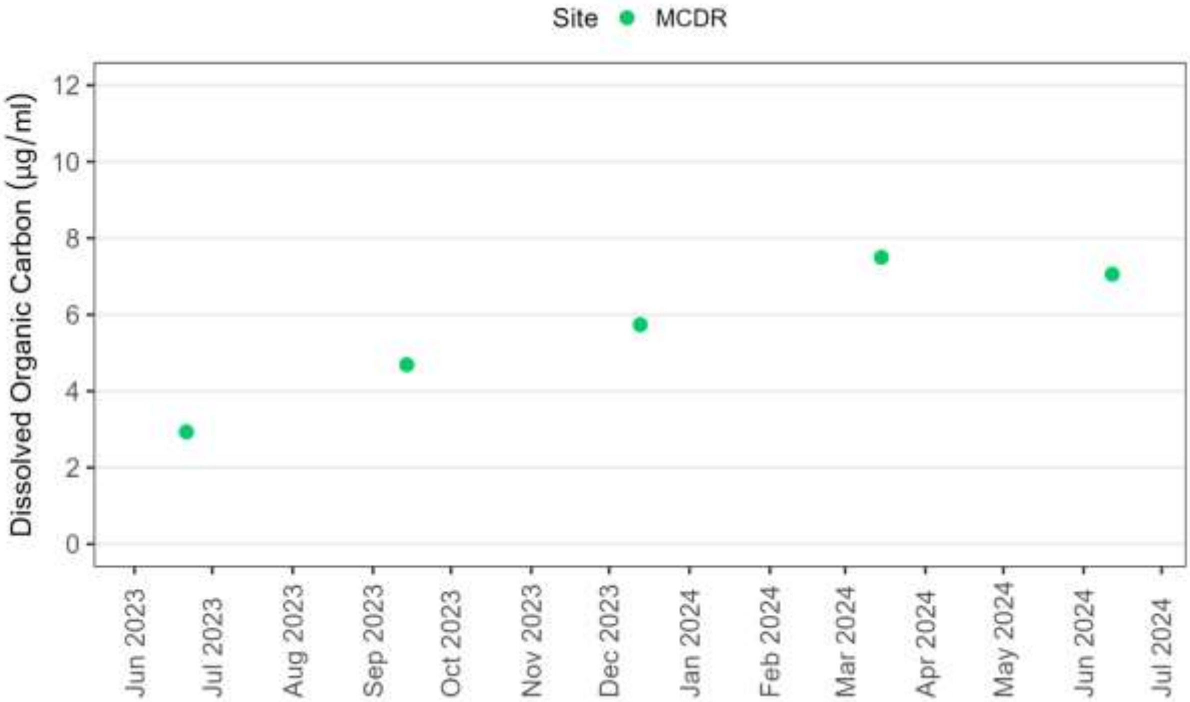

*Figure 6-43 Dissolved organic carbon values from water samples collected by UNE.*

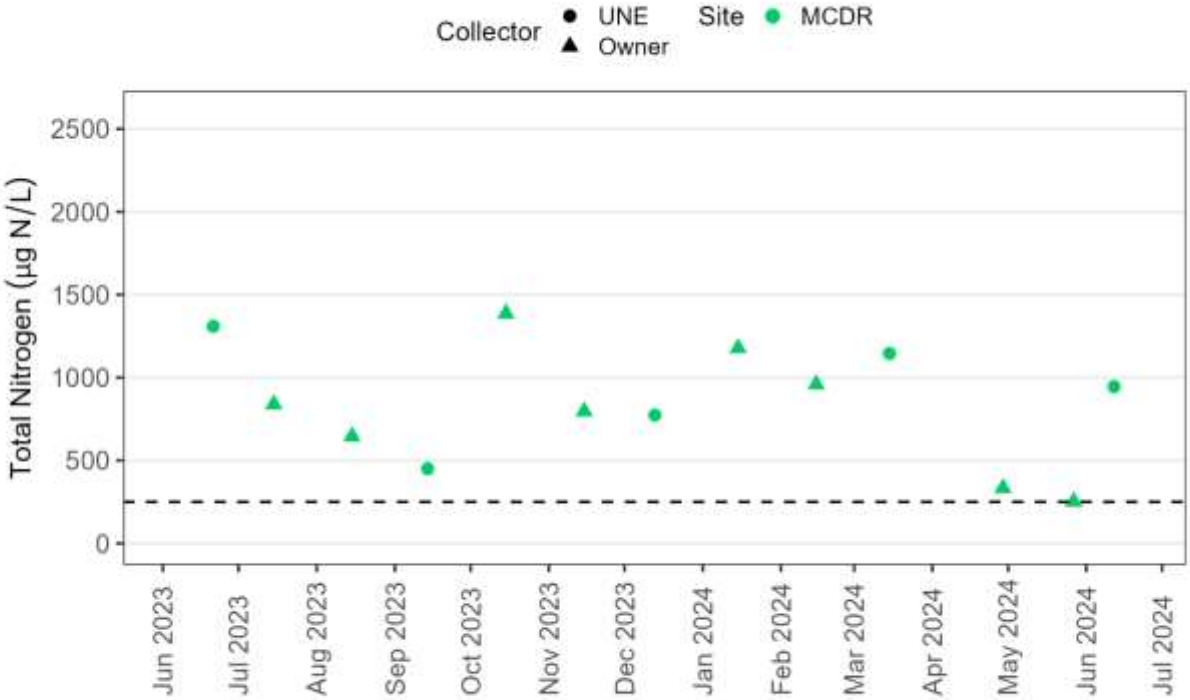

*Figure 6-44 Total nitrogen values from water samples collected by UNE (circle) and landholder (triangles).*

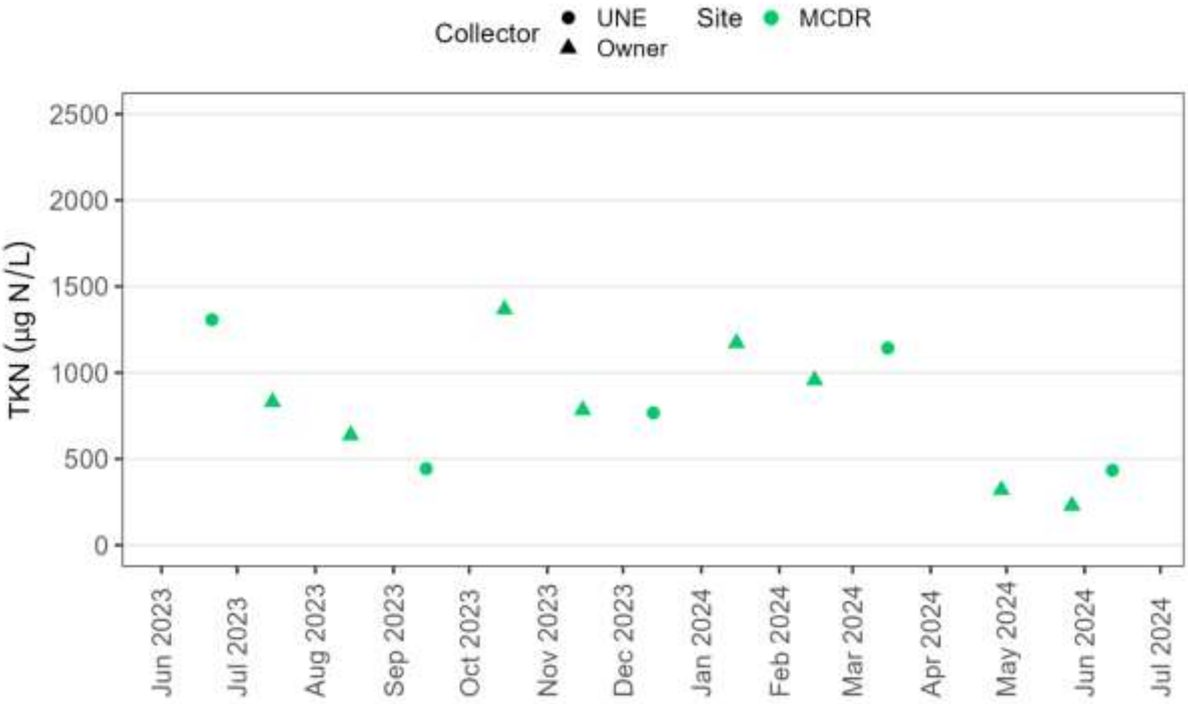

*Figure 6-45 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

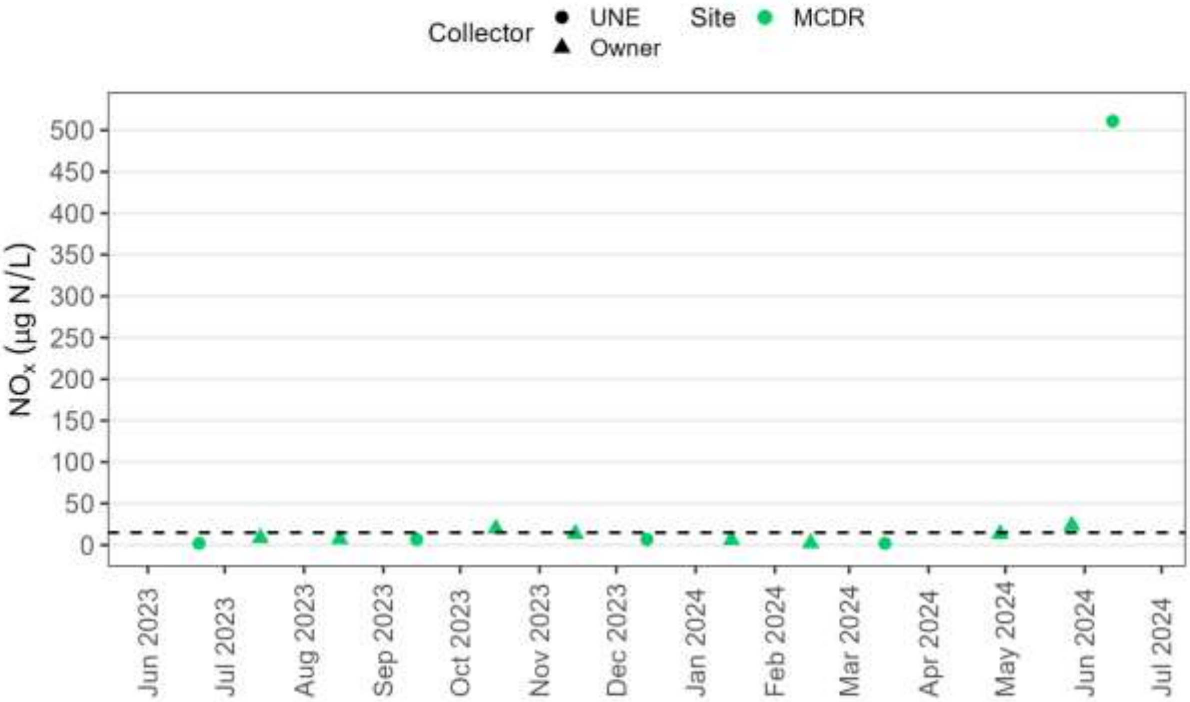

*Figure 6-46 Oxides of nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

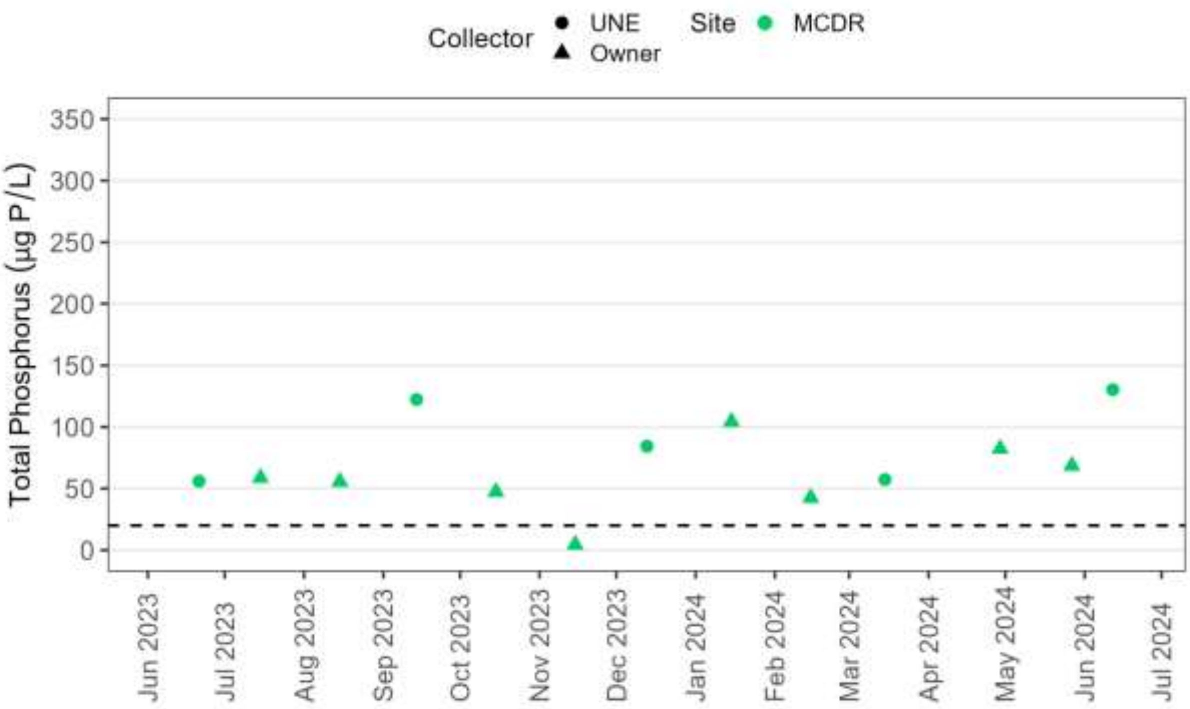

*Figure 6-47 Total phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

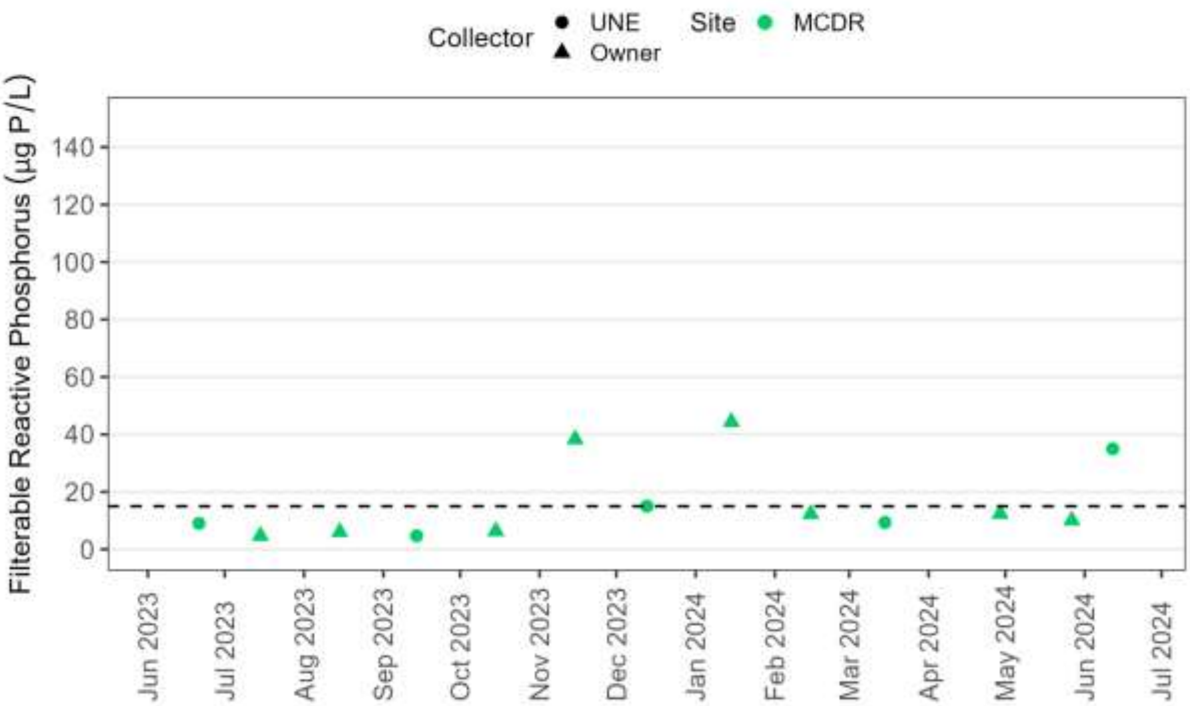

*Figure 6-48 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

## Mann River (MANR)

*Figure 6-49 Site Location.*

*Figure 6-50 Photos of site location.*

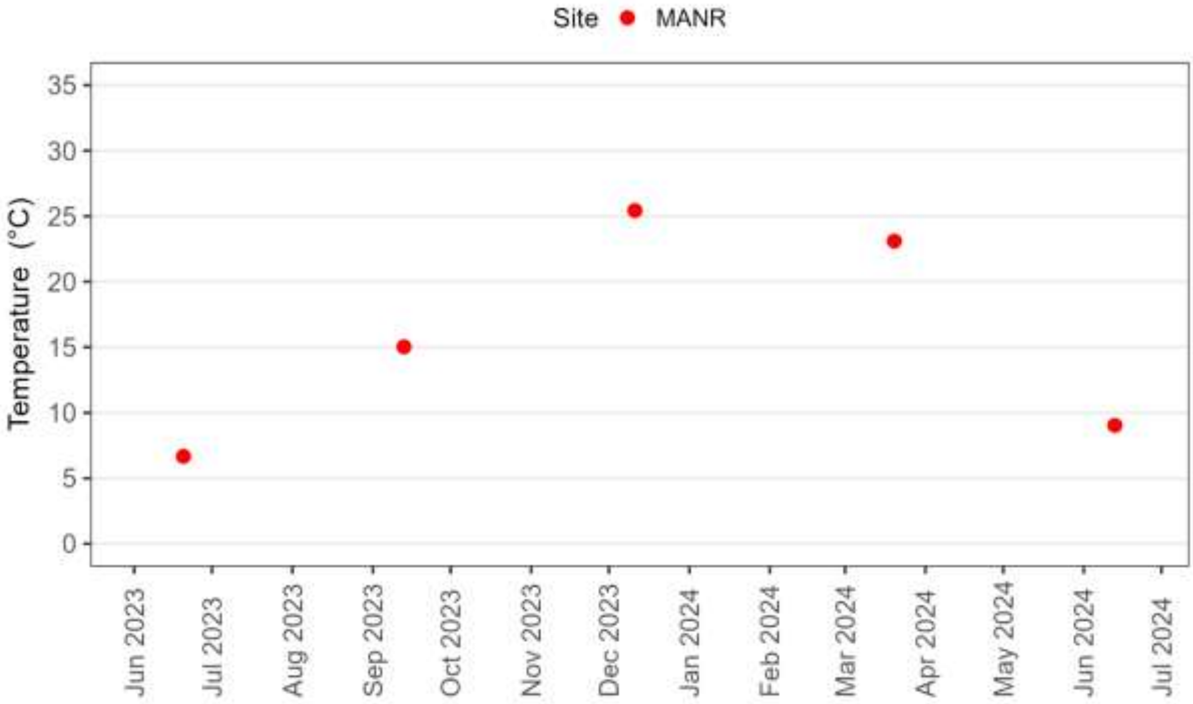

*Figure 6-51 Temperature readings collected by UNE.*

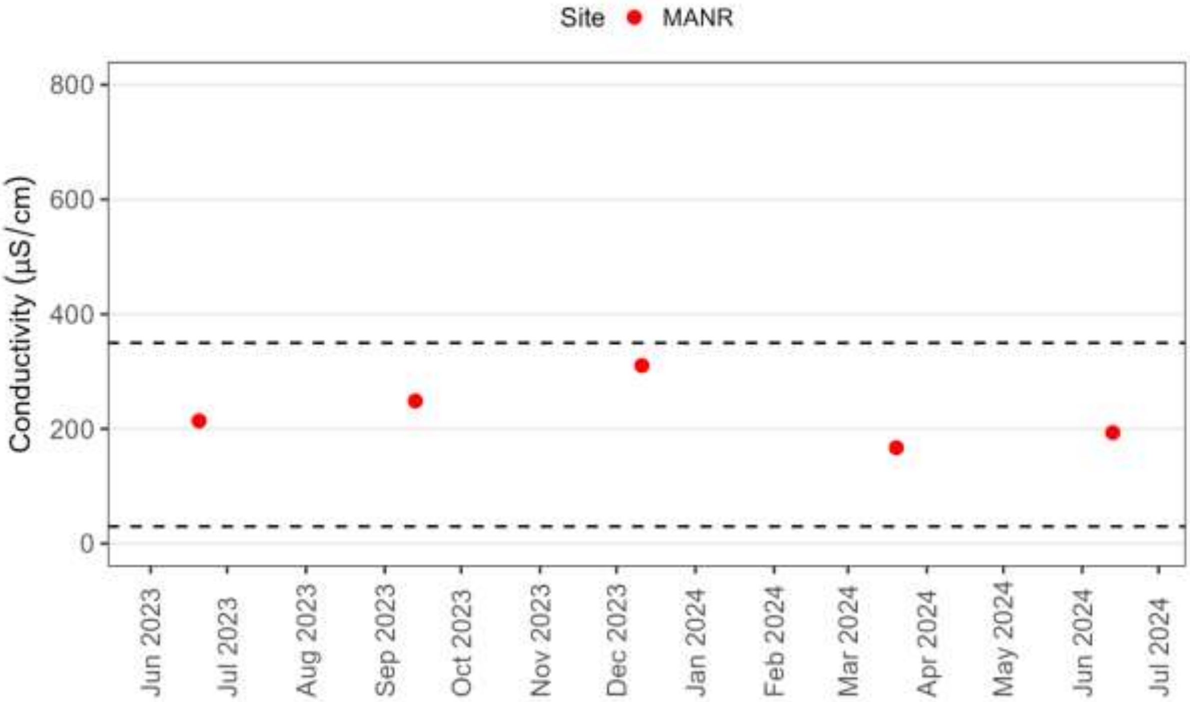

*Figure 6-52 Electrical conductivity readings collected by UNE.*

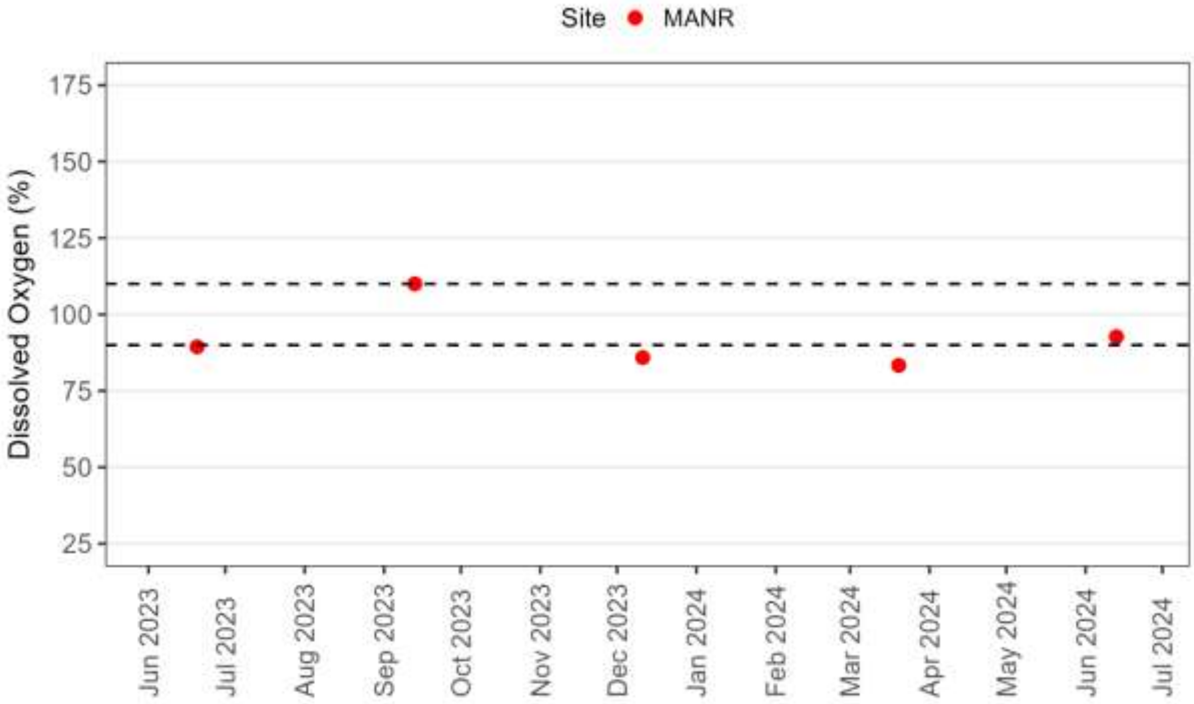

*Figure 6-53 Dissolved Oxygen readings collected by UNE.*

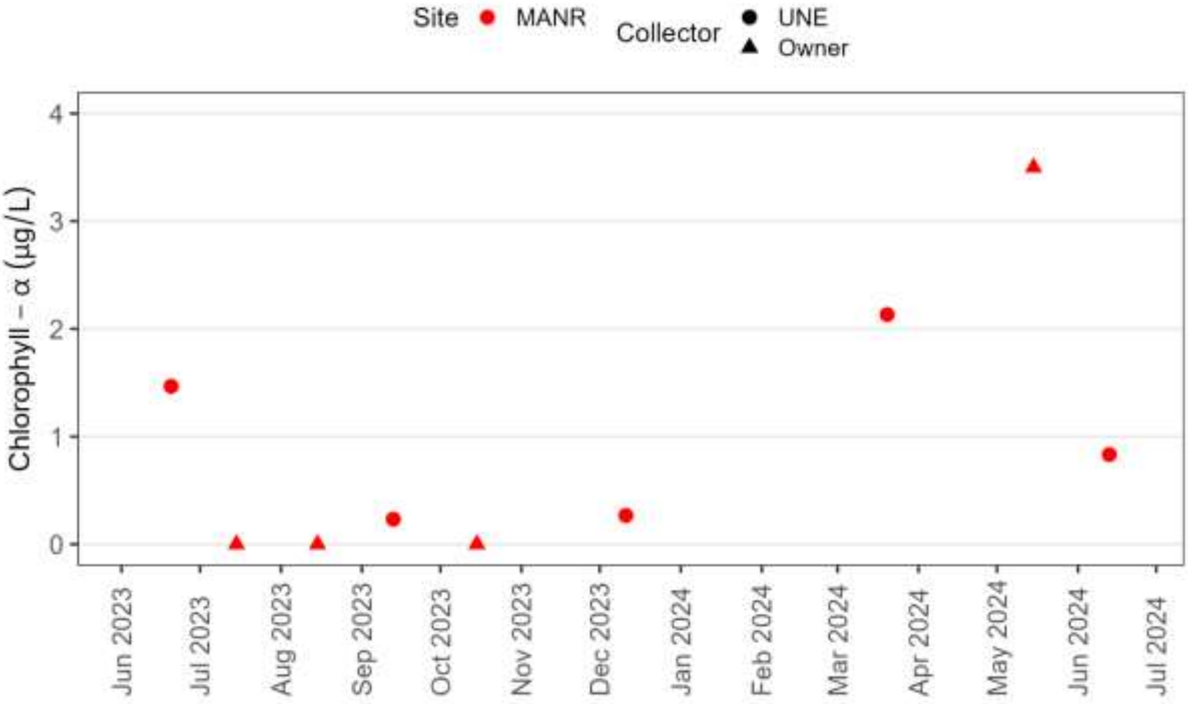

*Figure 6-54 Chlorophyll-a data from water samples collected by UNE (circles) and landholder (triangle).*

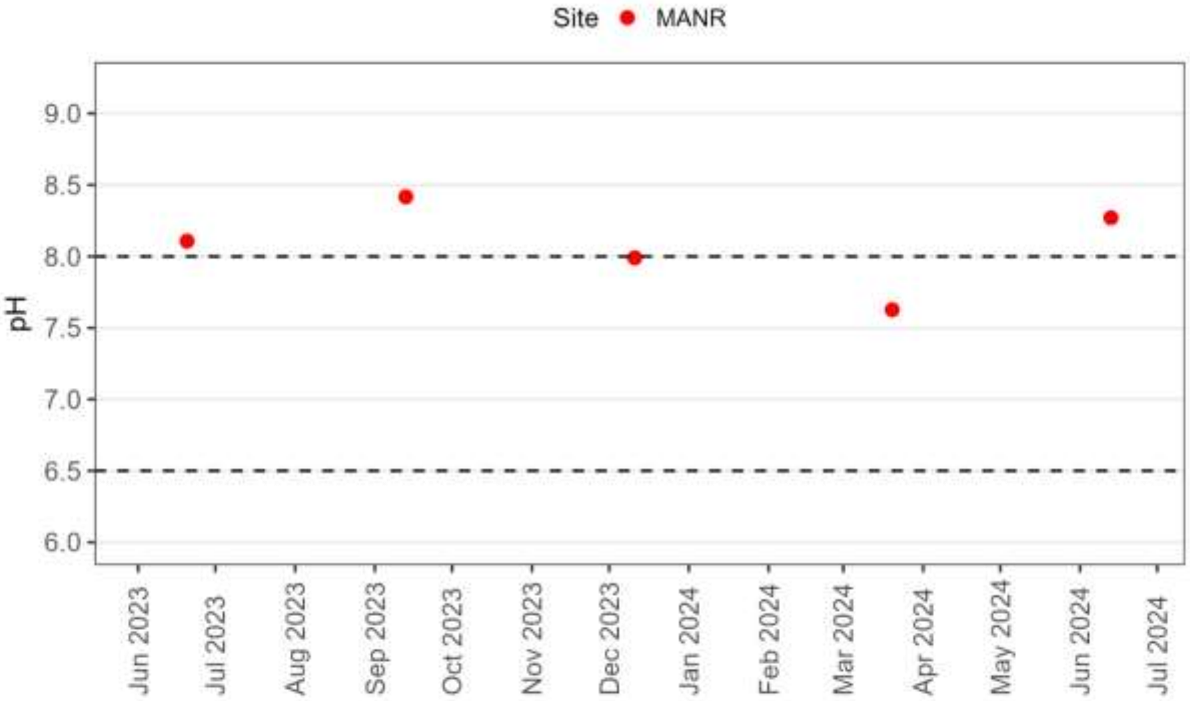

*Figure 6-55 pH readings collected by UNE.*

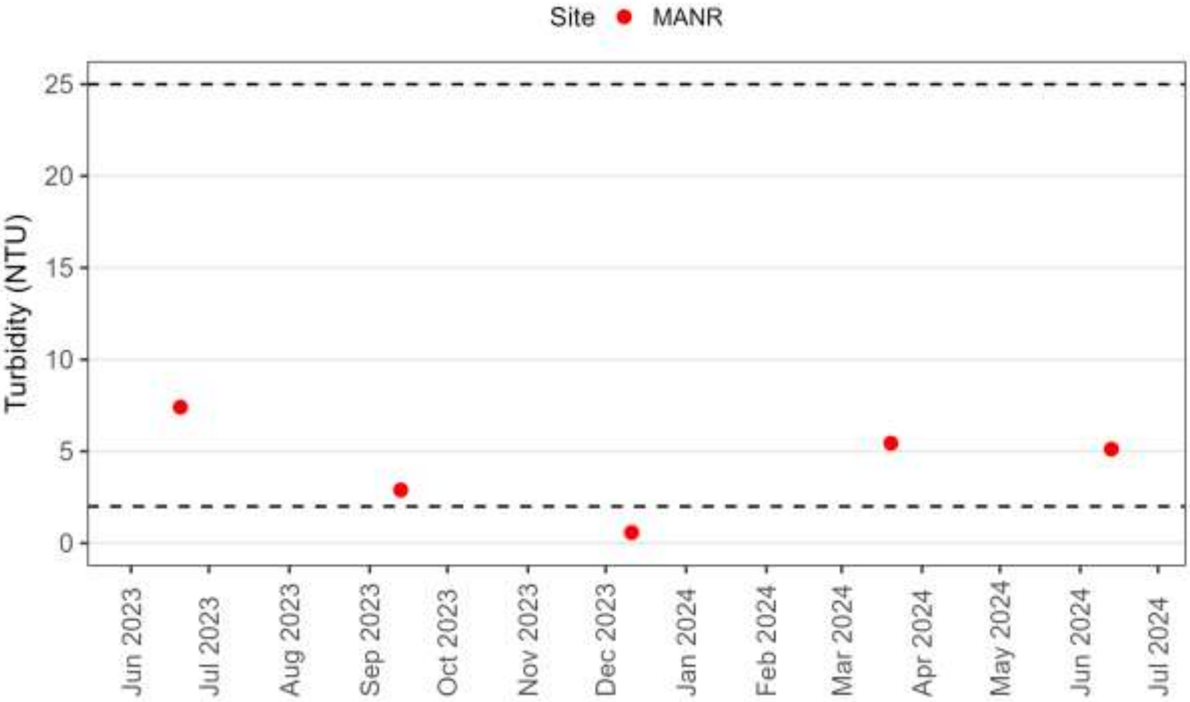

*Figure 6-56 Turbidity readings collected by UNE.*

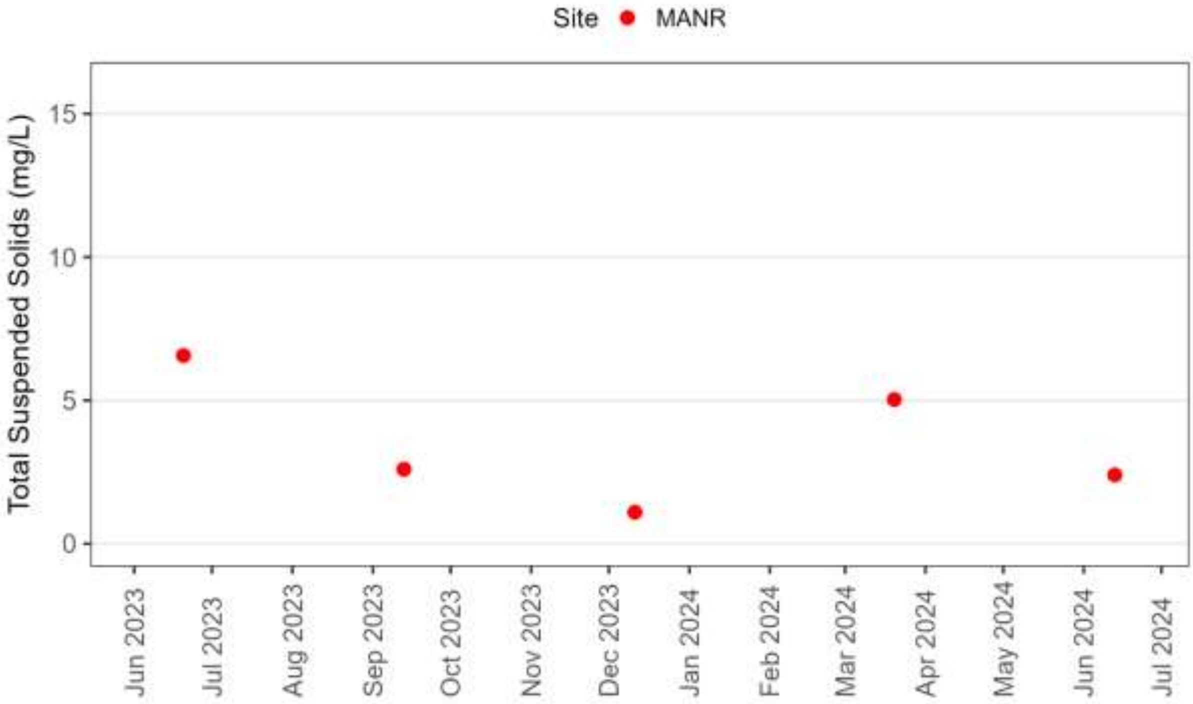

*Figure 6-57 Total suspended solids data from water samples collected by UNE.*

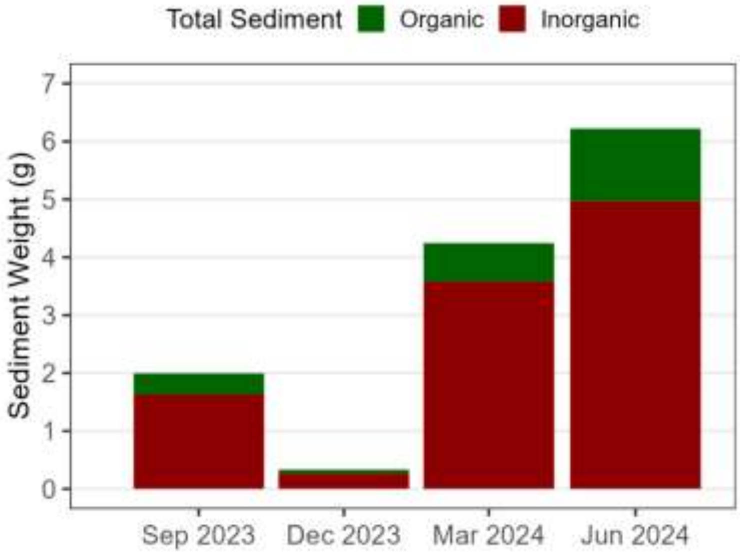

*Figure 6-58 Quarterly sediment accumulation in time-integrated sediment sampler.*

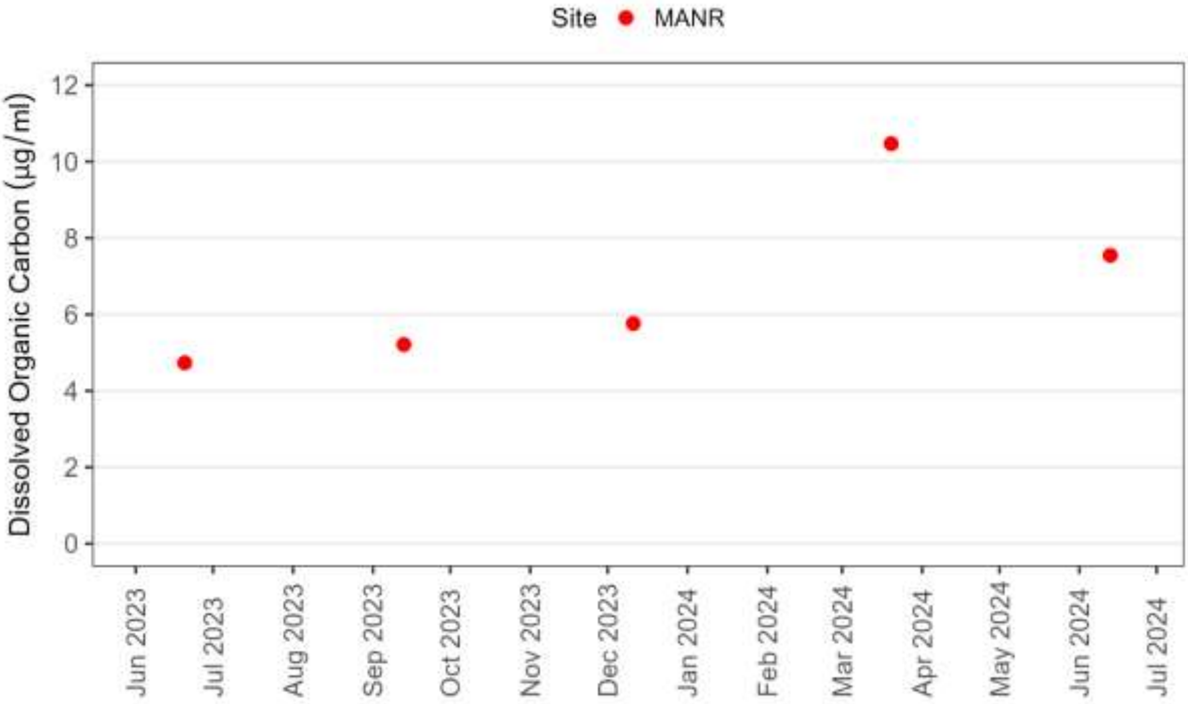

*Figure 6-59 Dissolved organic carbon values from water samples collected by UNE.*

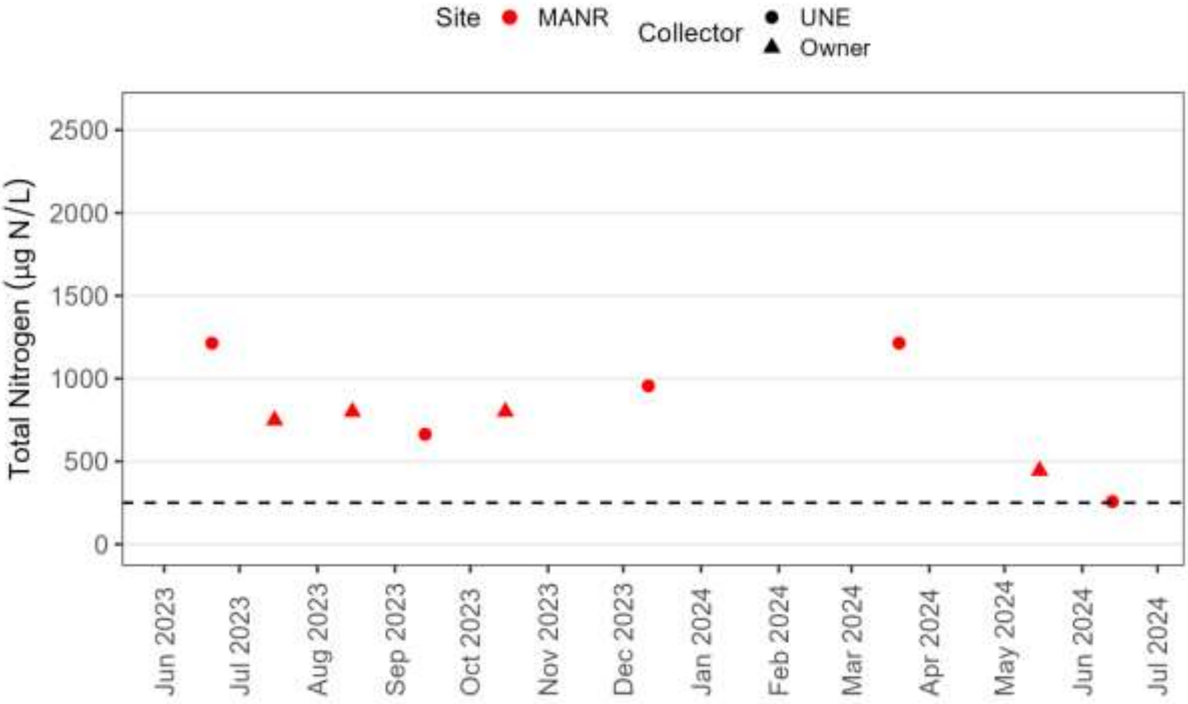

*Figure 6-60 Total nitrogen values from water samples collected by UNE (circle) and landholder (triangles).*

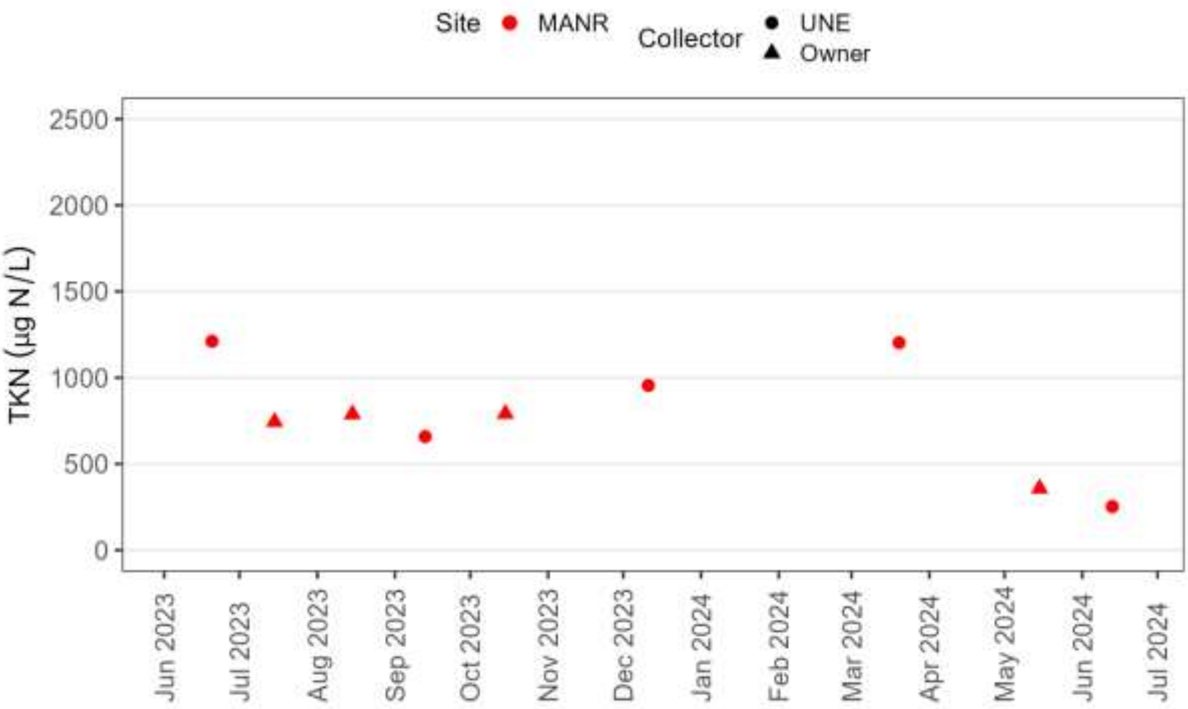

*Figure 6-61 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

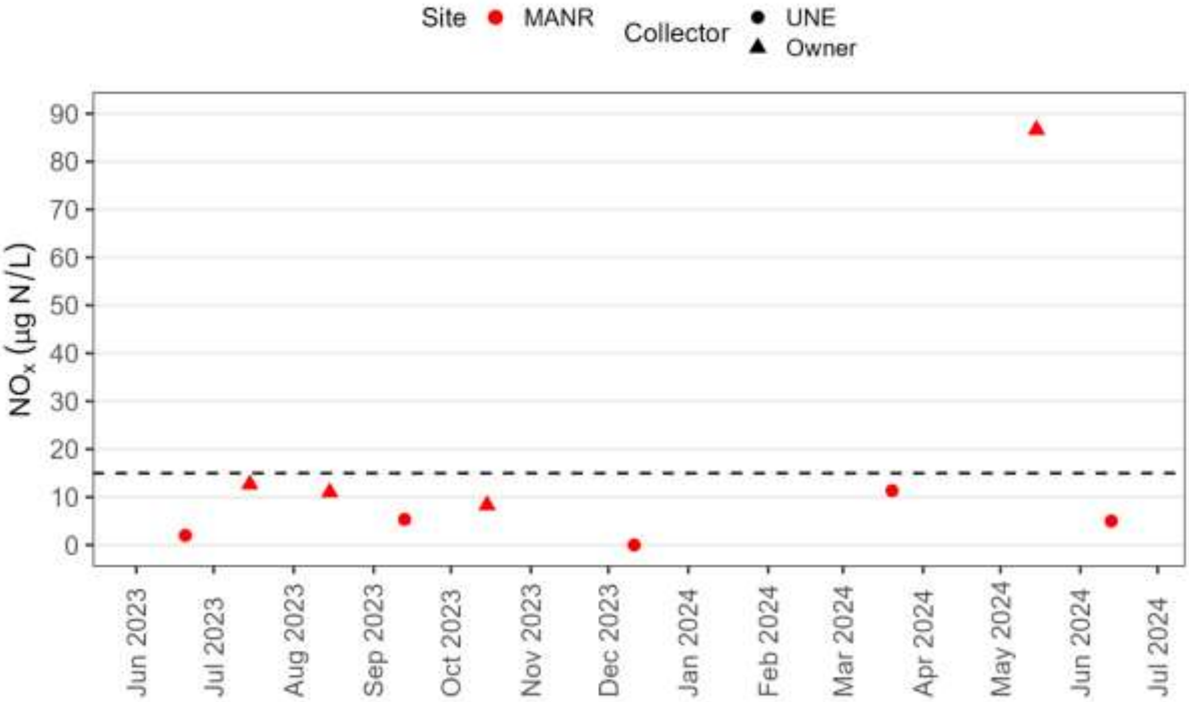

*Figure 6-62 Oxides of nitrogen data from water samples collected by UNE (circle) and landholder (triangle).*

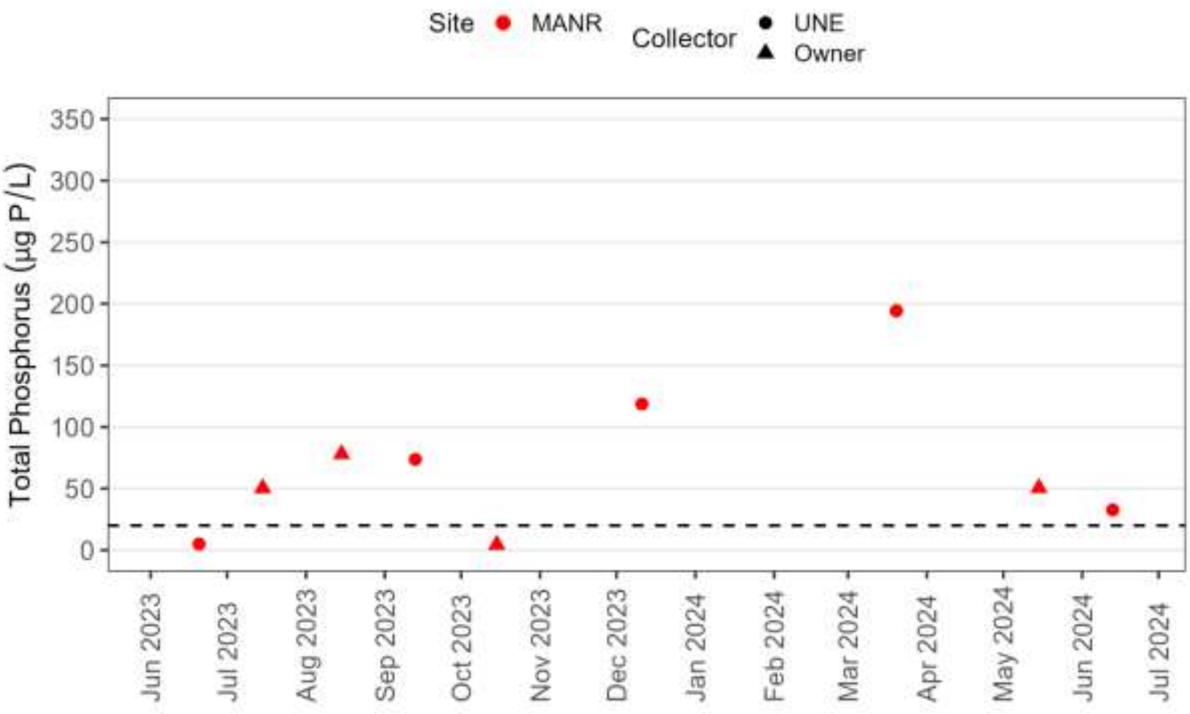

*Figure 6-63 Total phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

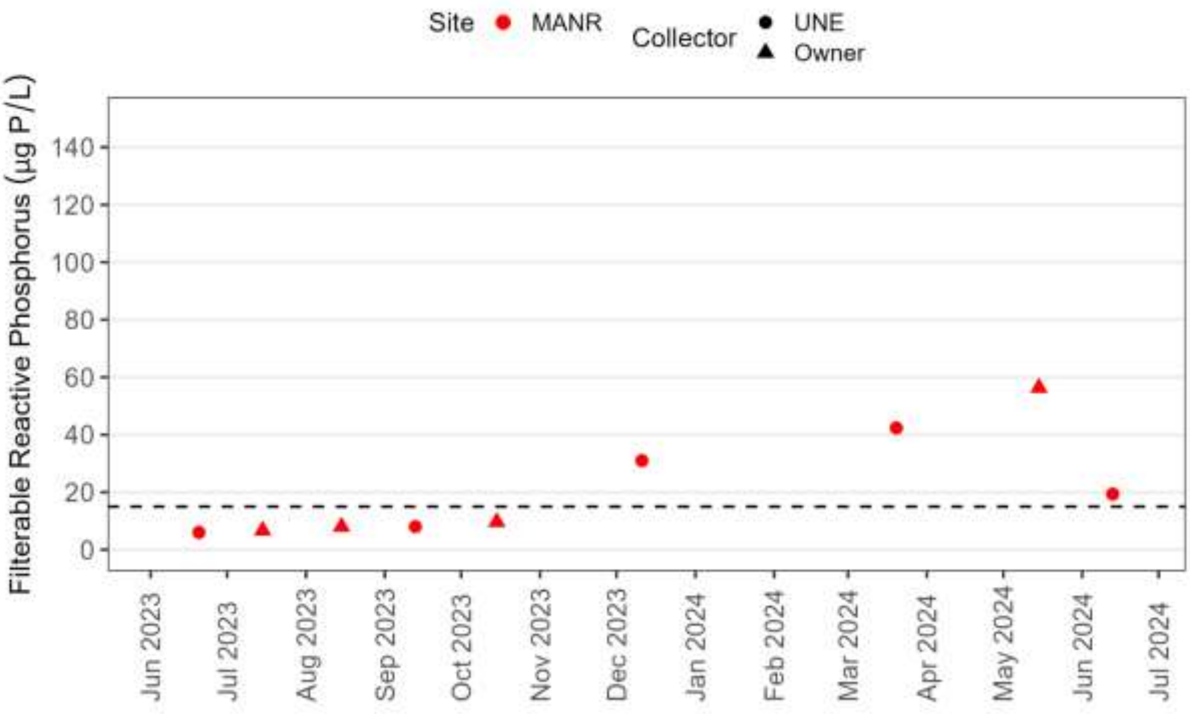

*Figure 6-64 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholder (triangle).*

## Gara River (GARA2 & GARA1)

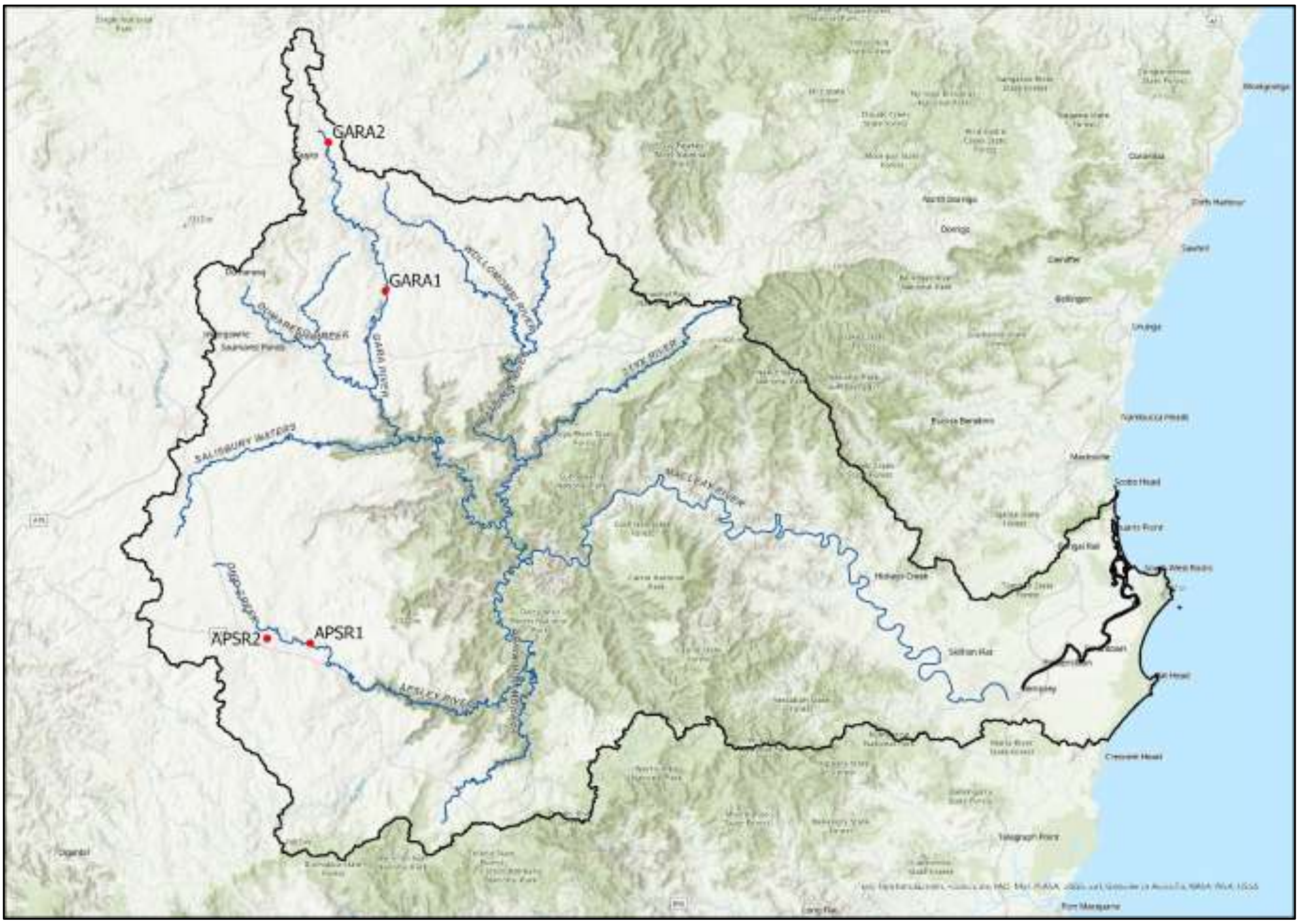

*Figure 6-65 Site Location.*

### GARA2

*Figure 6-66 Photos of site location.*

GARA1

*Figure 6-67 Photos of site location.*

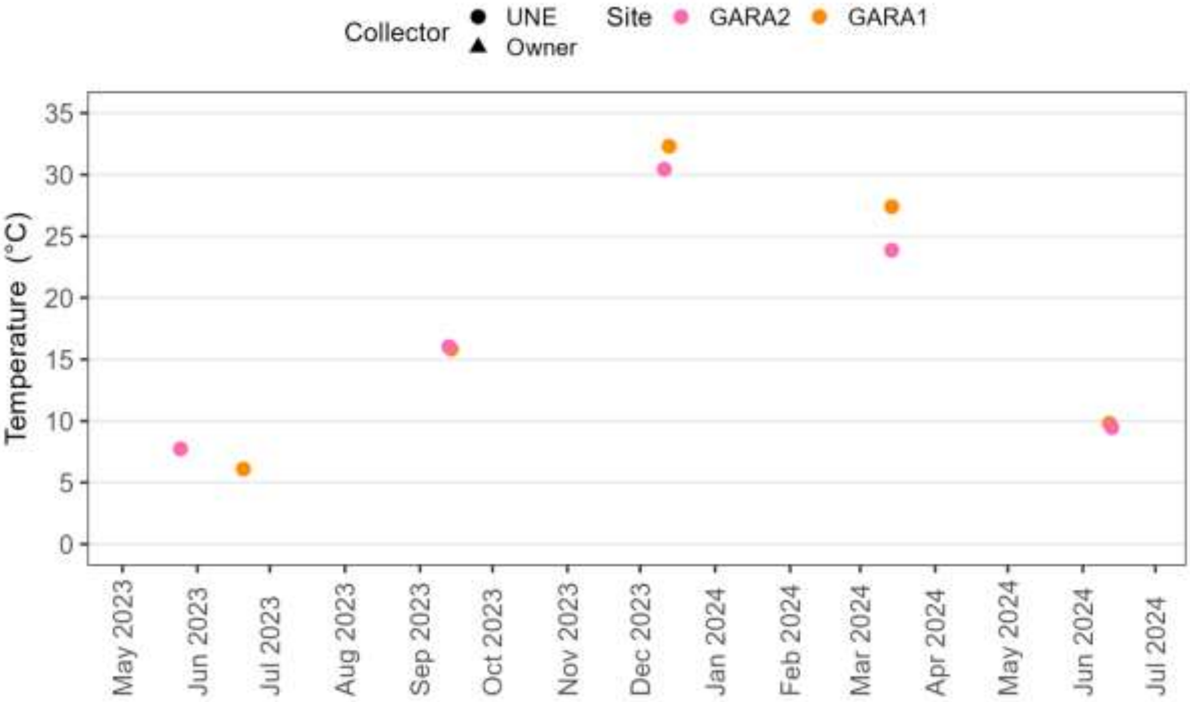

*Figure 6-68 Temperature readings collected by UNE.*

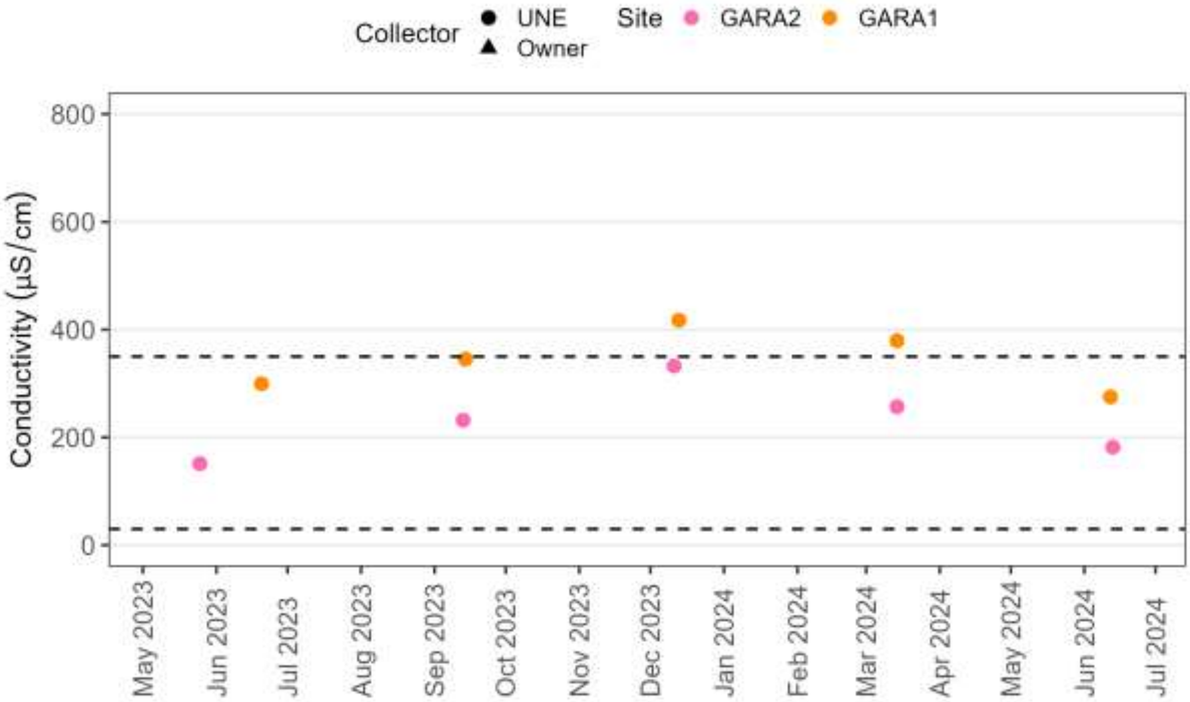

*Figure 6-69 Electrical conductivity readings collected by UNE.*

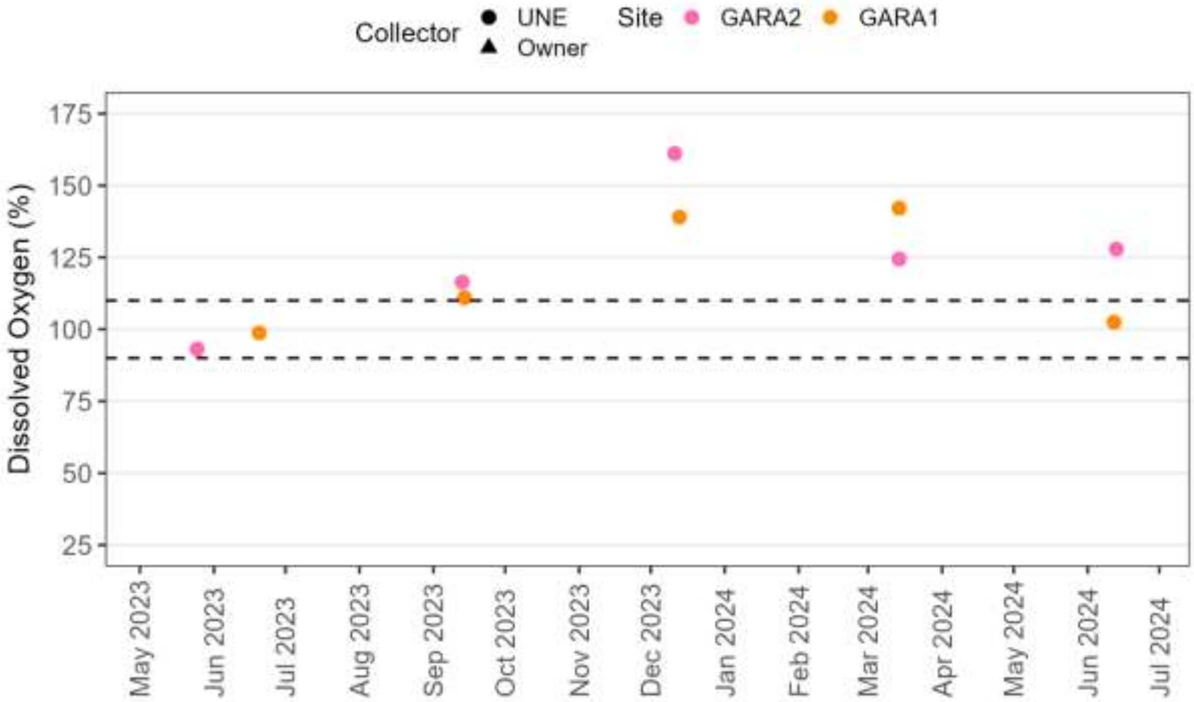

*Figure 6-70 Dissolved Oxygen readings collected by UNE.*

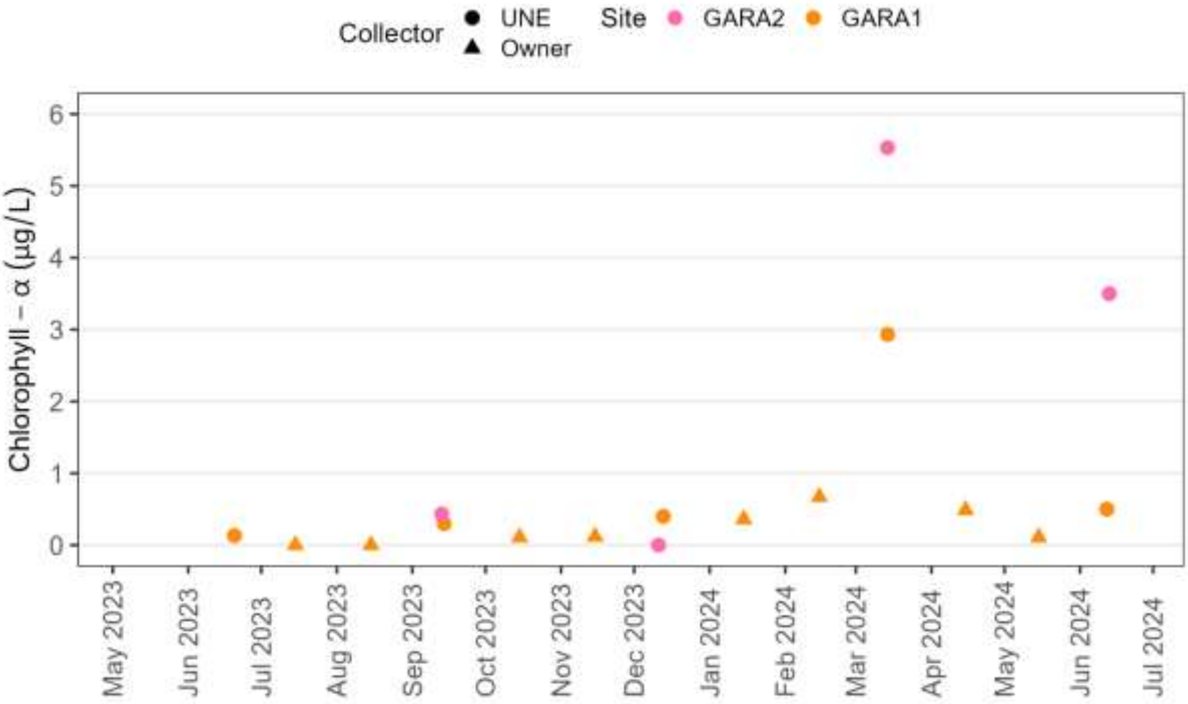

*Figure 6-71 Chlorophyll-a data from water samples collected by UNE (circles) and landholders (triangle).*

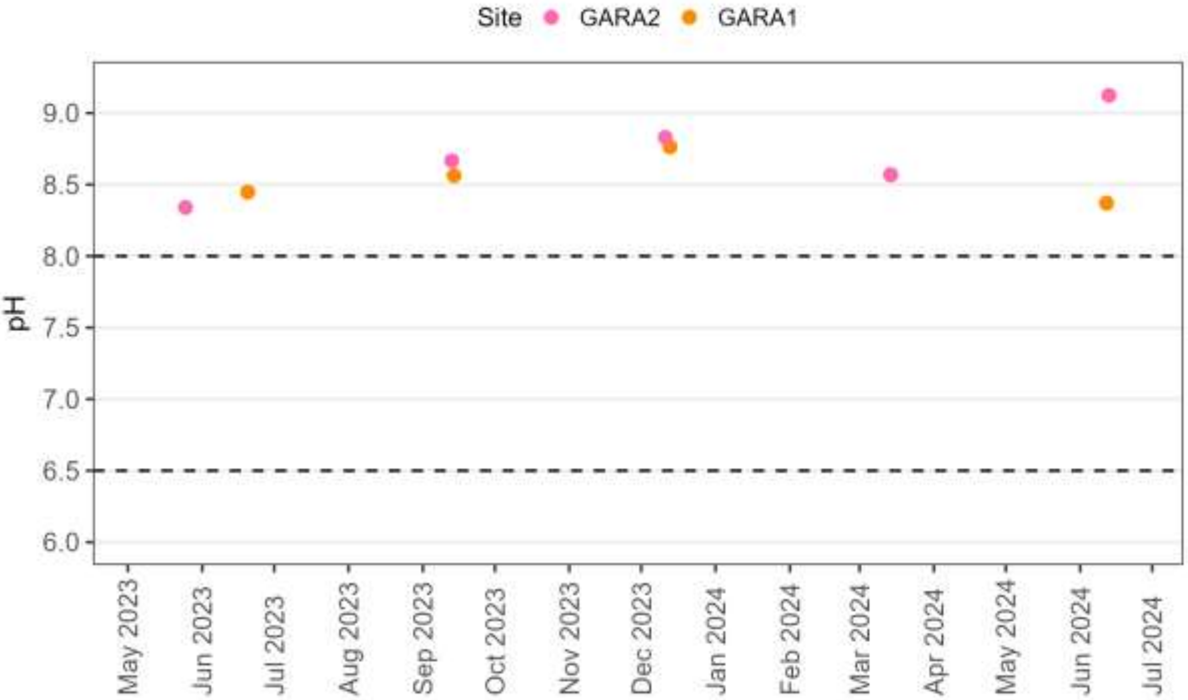

*Figure 6-72 pH readings collected by UNE.*

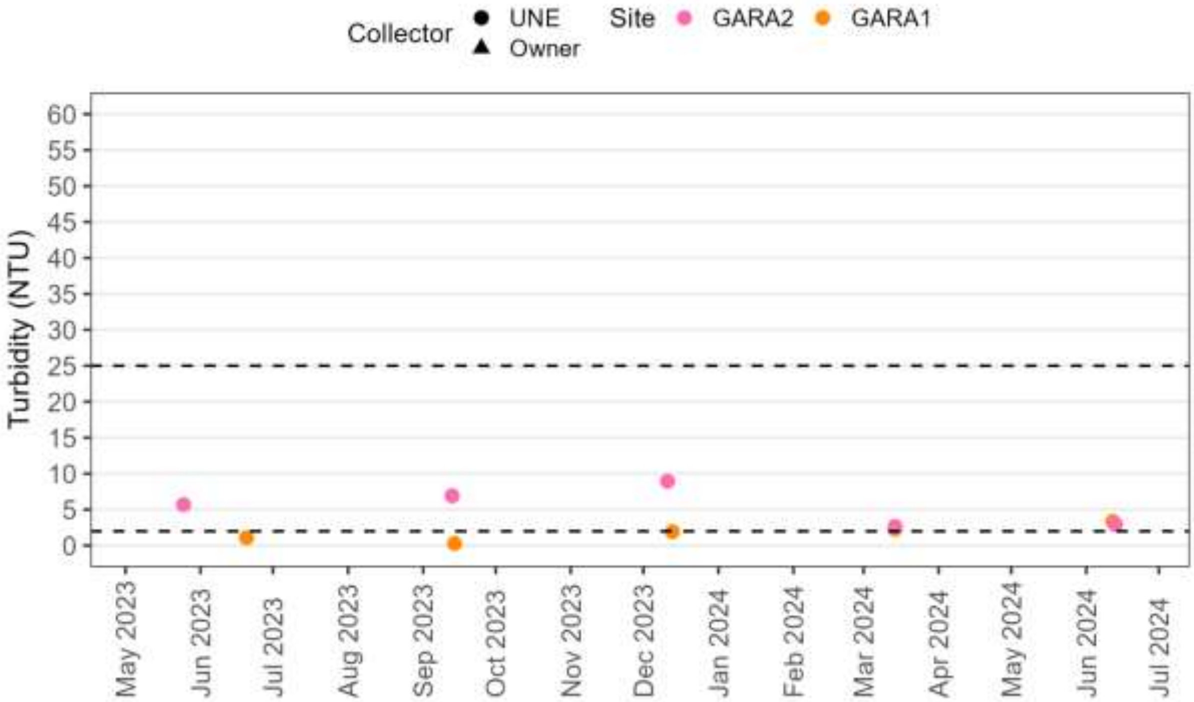

*Figure 6-73 Turbidity readings collected by UNE.*

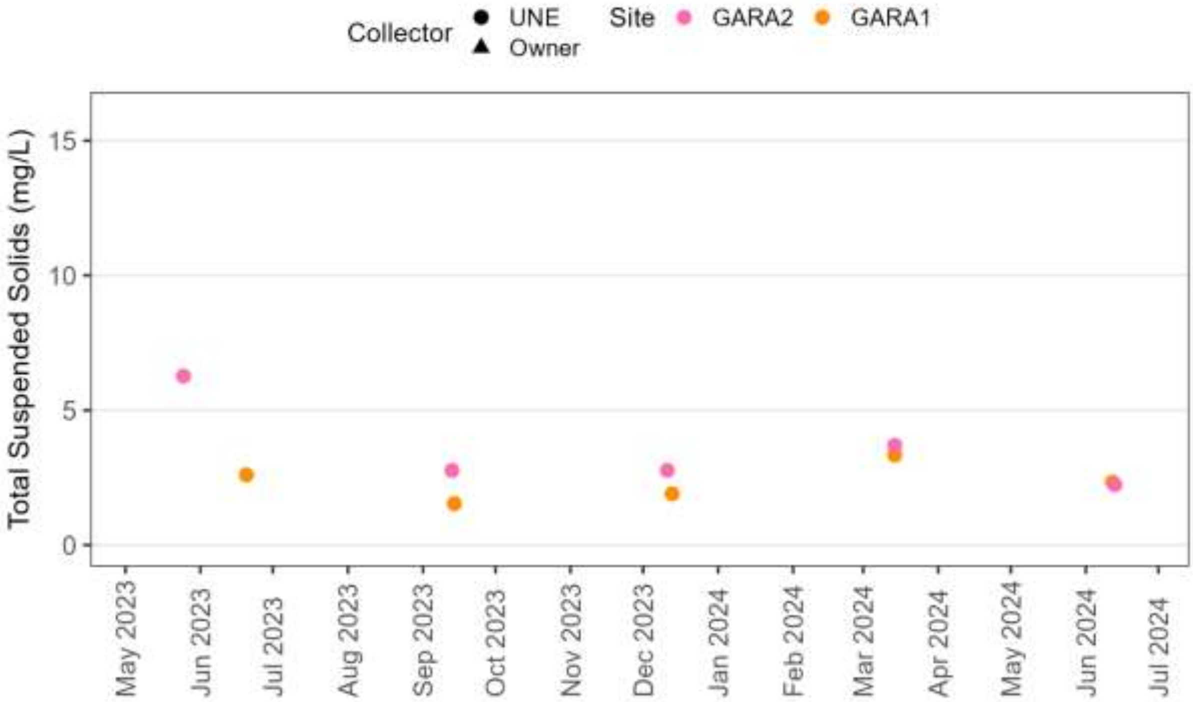

*Figure 6-74 Total suspended solids data from water samples collected by UNE.*

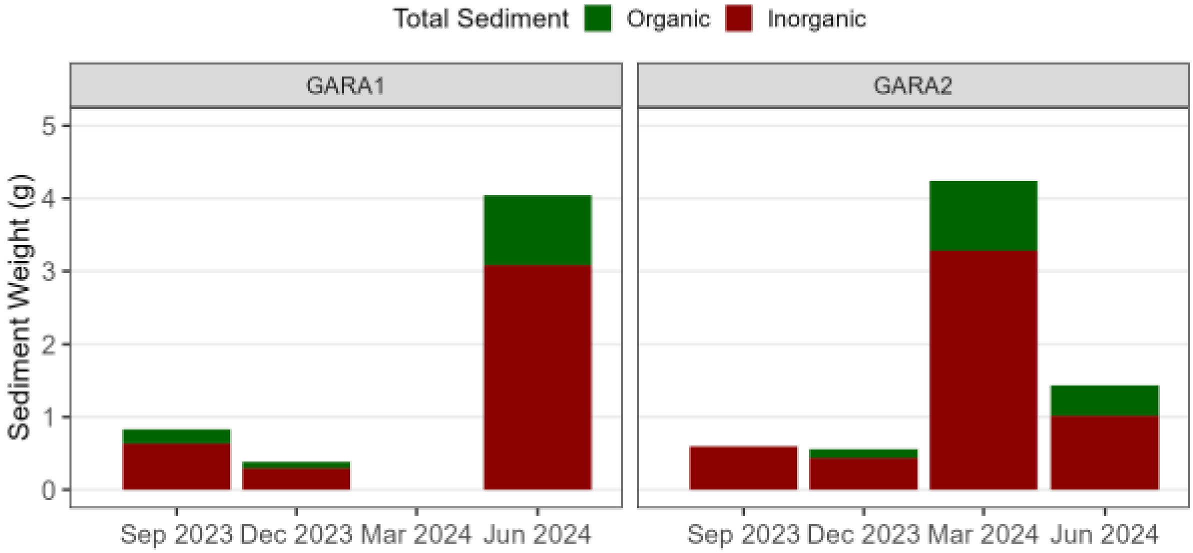

*Figure 6-75 Quarterly sediment accumulation in time-integrated sediment sampler.*

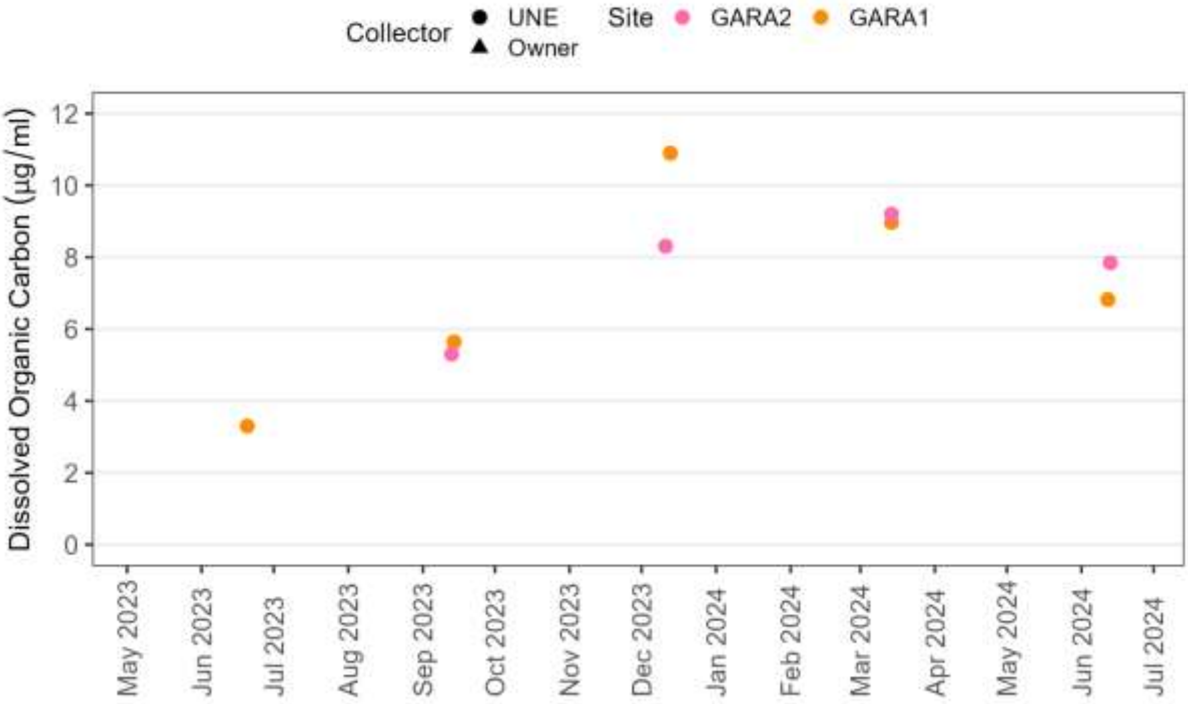

*Figure 6-76 Dissolved organic carbon values from water samples collected by UNE.*

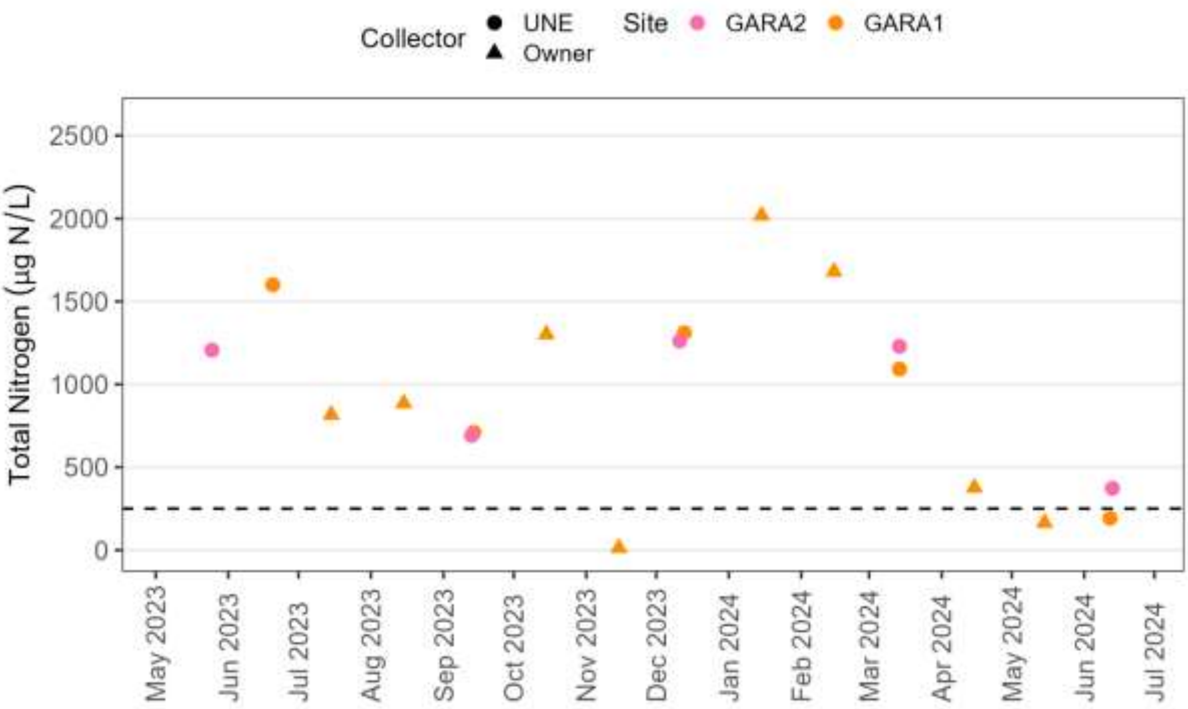

*Figure 6-77 Total nitrogen values from water samples collected by UNE (circle) and landholders (triangles).*

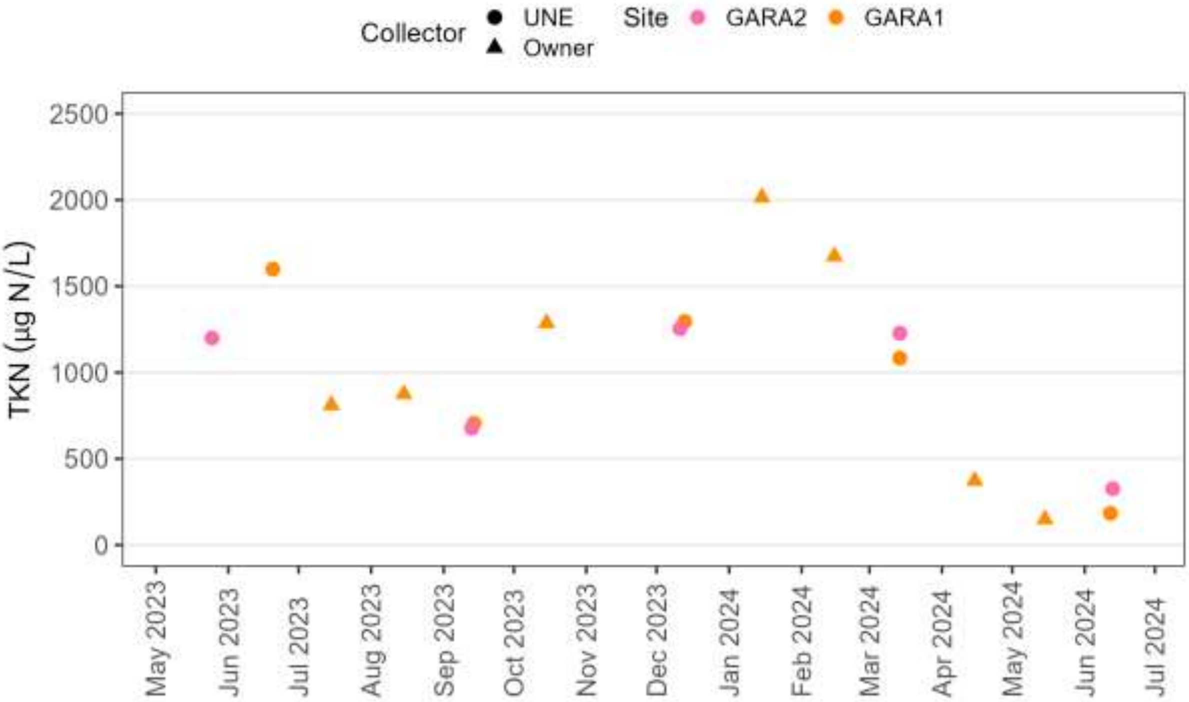

*Figure 6-78 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholders (triangle).*

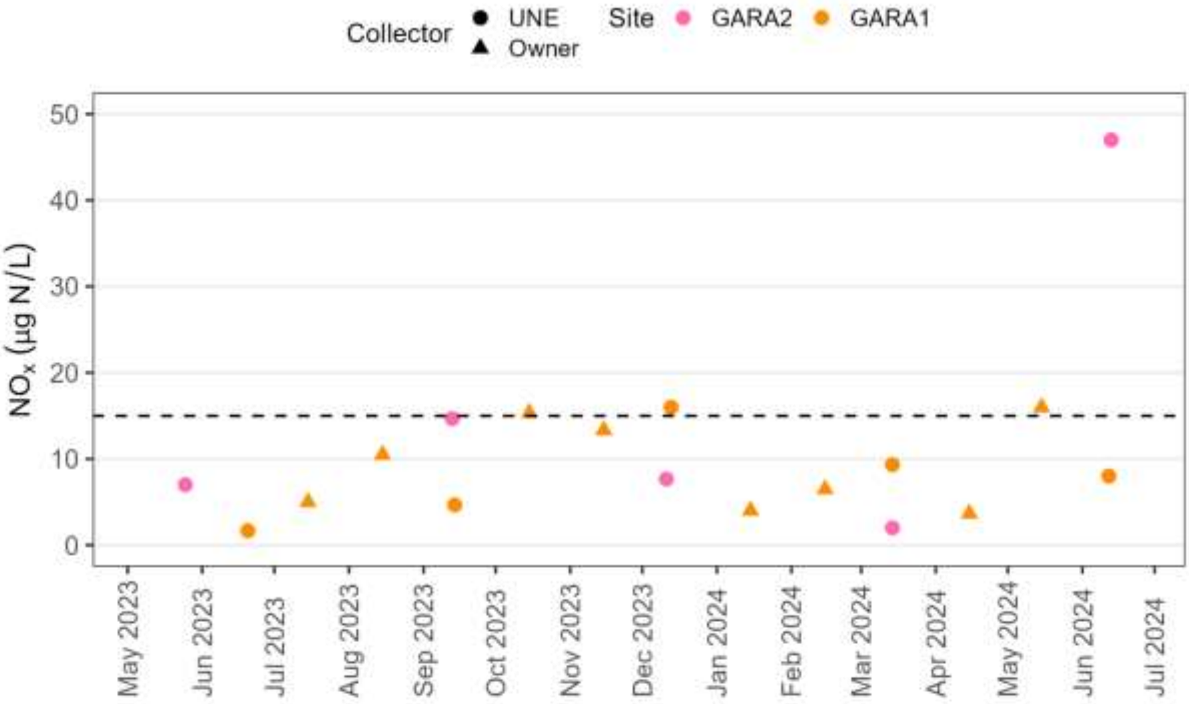

*Figure 6-79 Oxides of nitrogen data from water samples collected by UNE (circle) and landholders (triangle).*

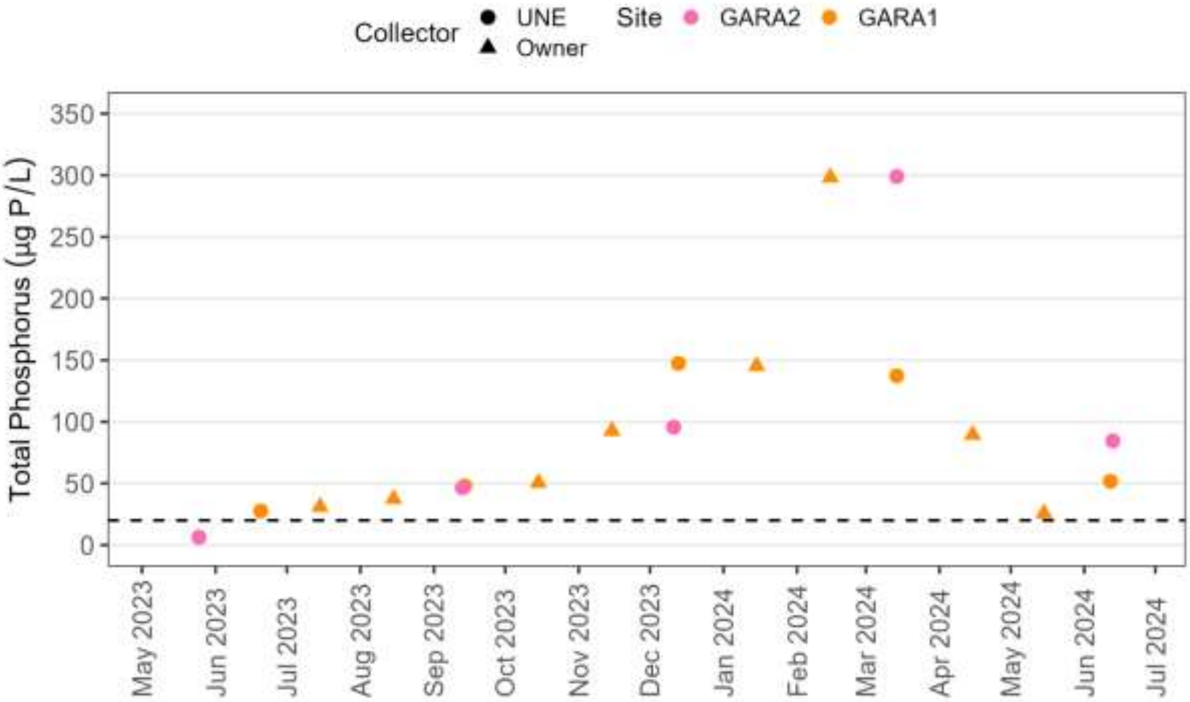

*Figure 6-80 Total phosphorus data from water samples collected by UNE (circle) and landholders (triangle).*

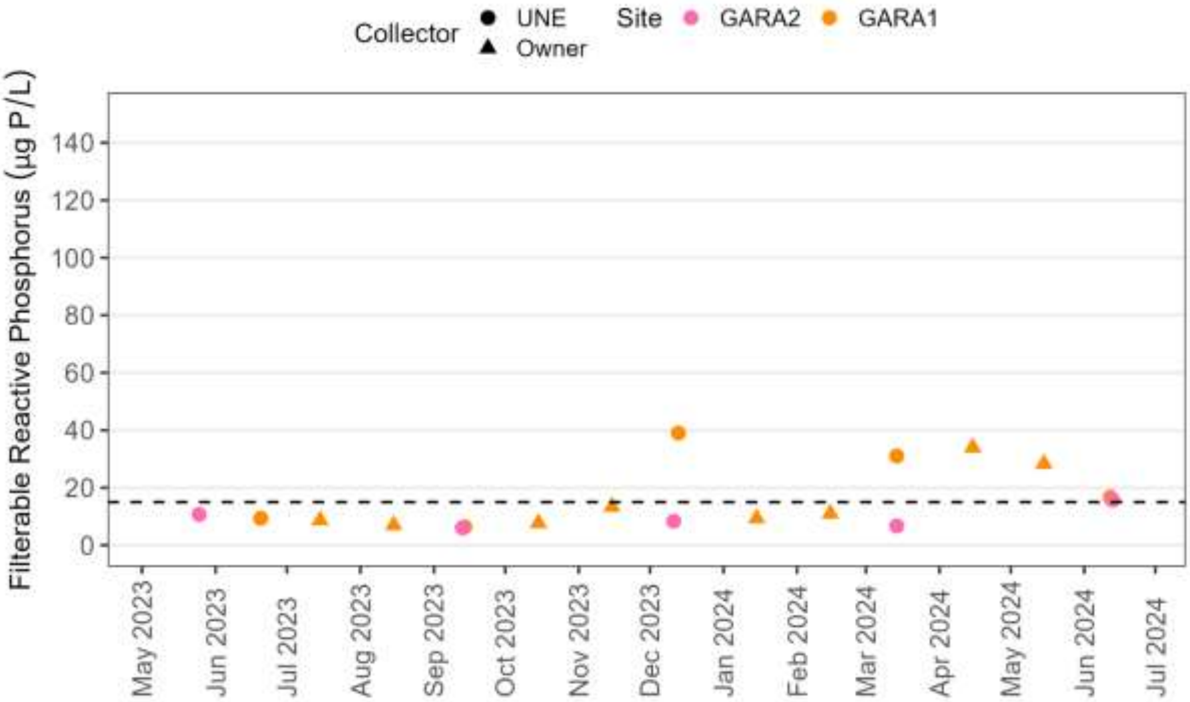

*Figure 6-81 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholders (triangle).*

## Apsley River (APSR2 & APSR1)

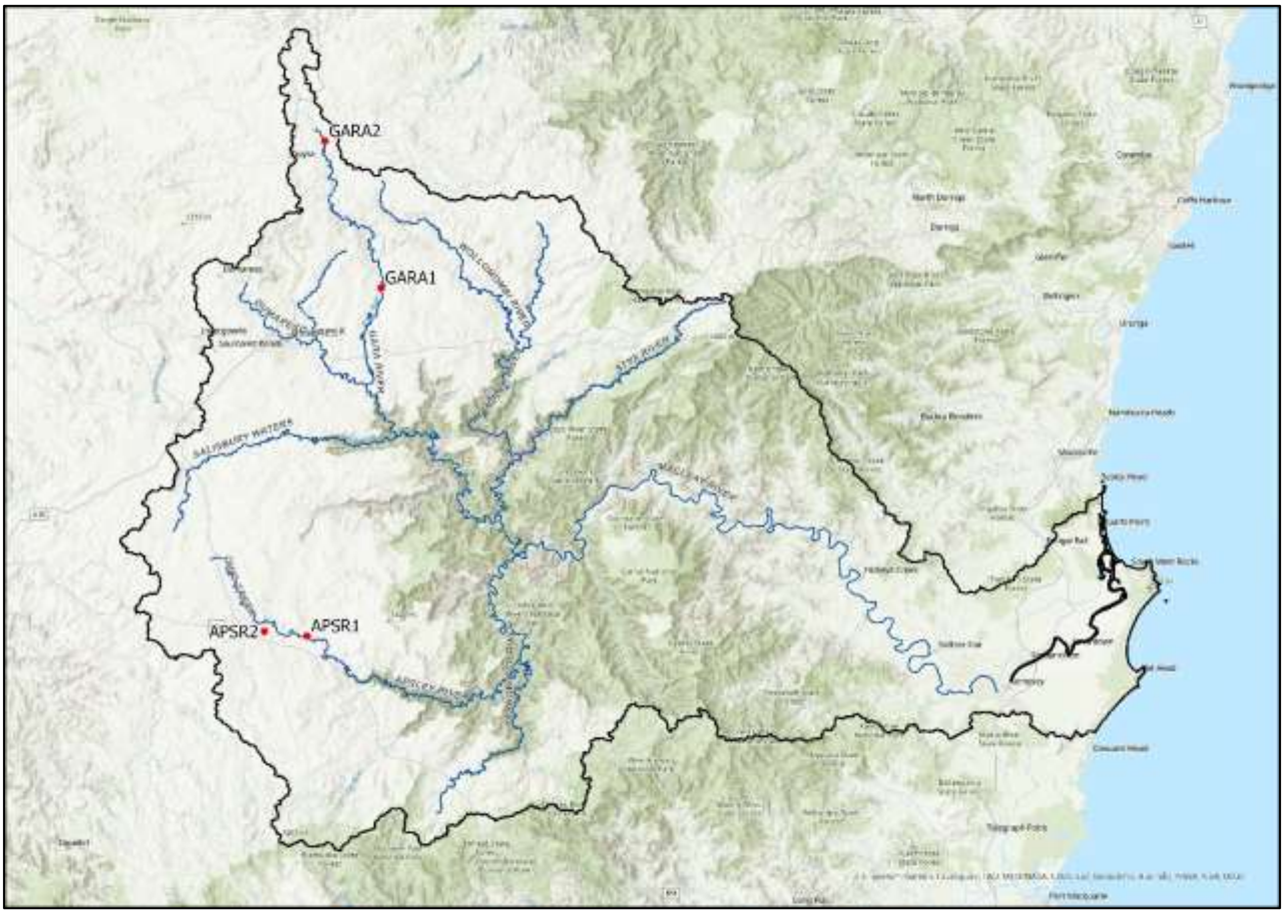

*Figure 6-82 Site Location.*

### APSR2

*Figure 6-83 Photos of site location.*

APSR1

*Figure 6-84 Photos of site location.*

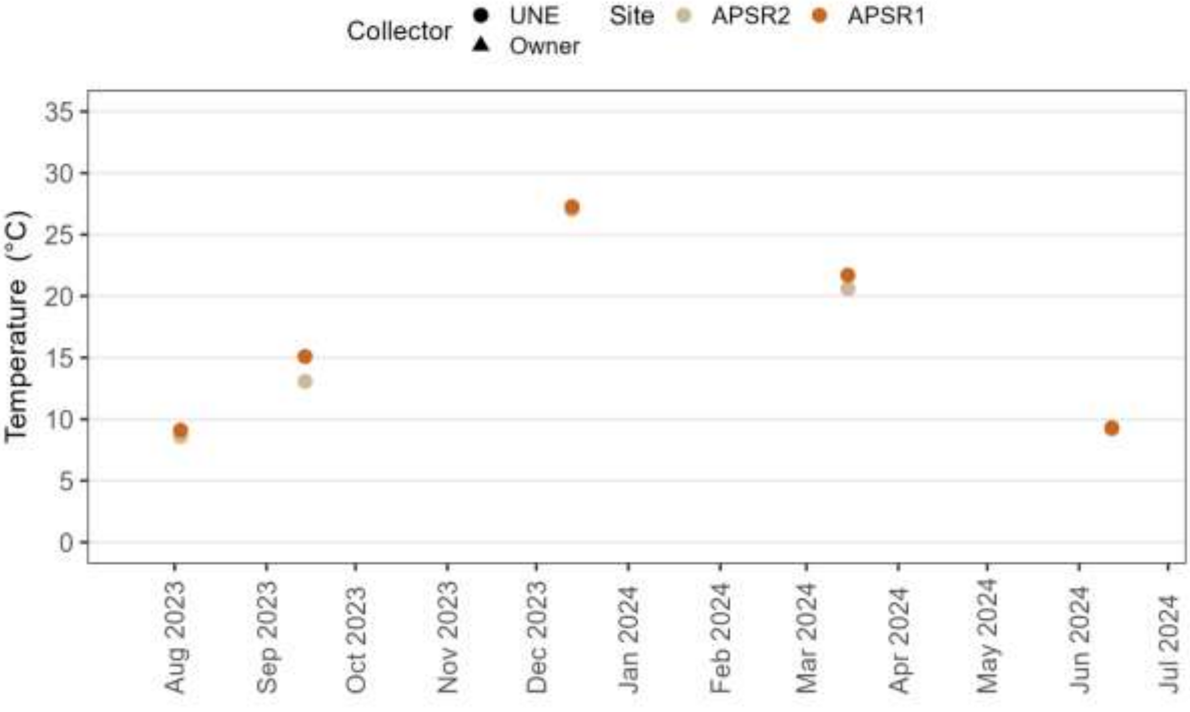

*Figure 6-85 Temperature readings collected by UNE.*

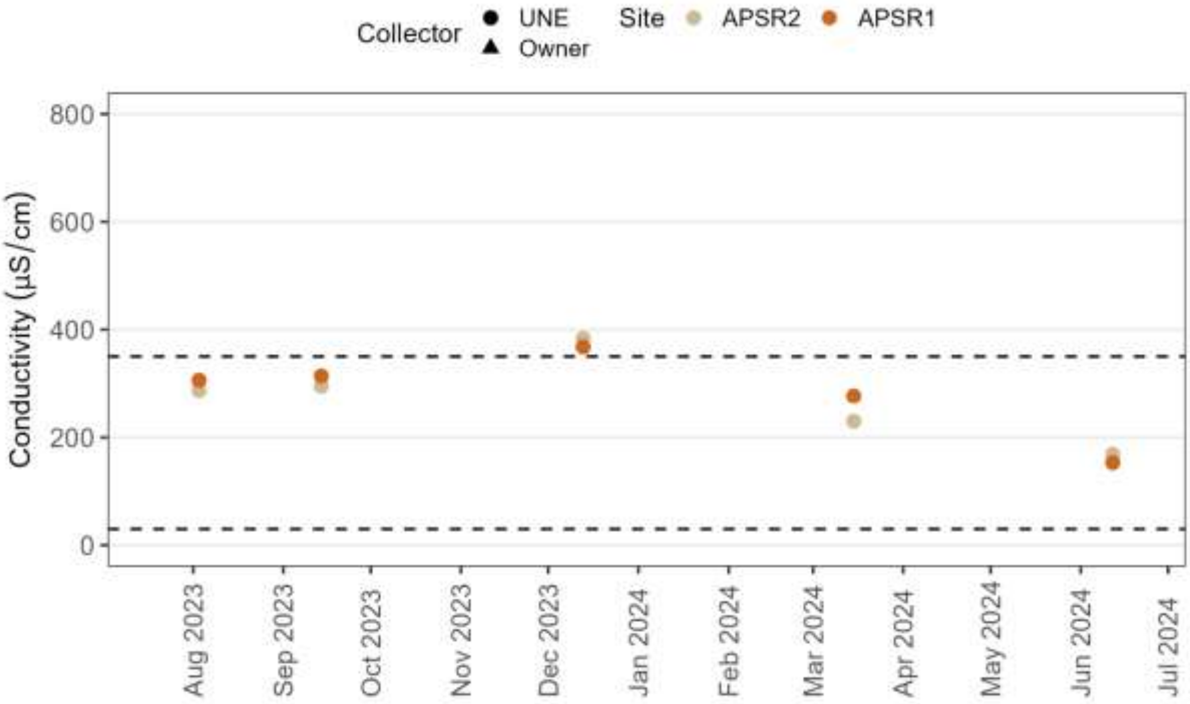

*Figure 6-86 Electrical conductivity readings collected by UNE.*

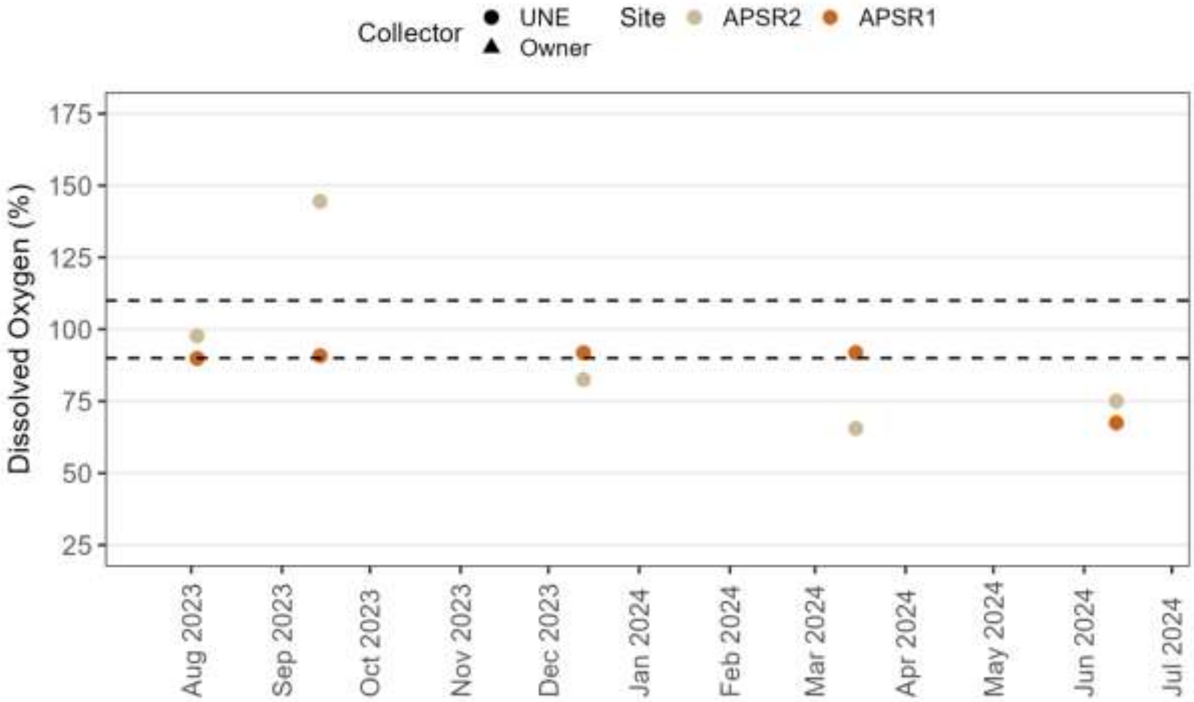

*Figure 6-87 Dissolved Oxygen readings collected by UNE.*

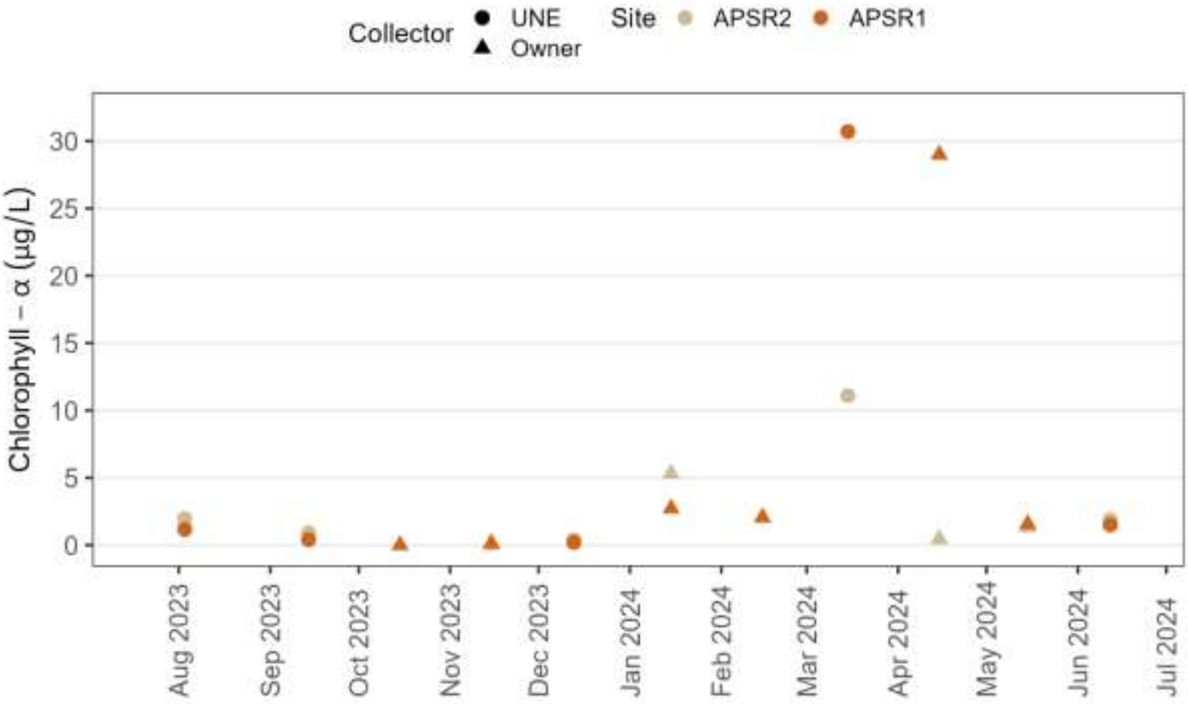

*Figure 6-88 Chlorophyll-a data from water samples collected by UNE (circles) and landholders (triangle).*

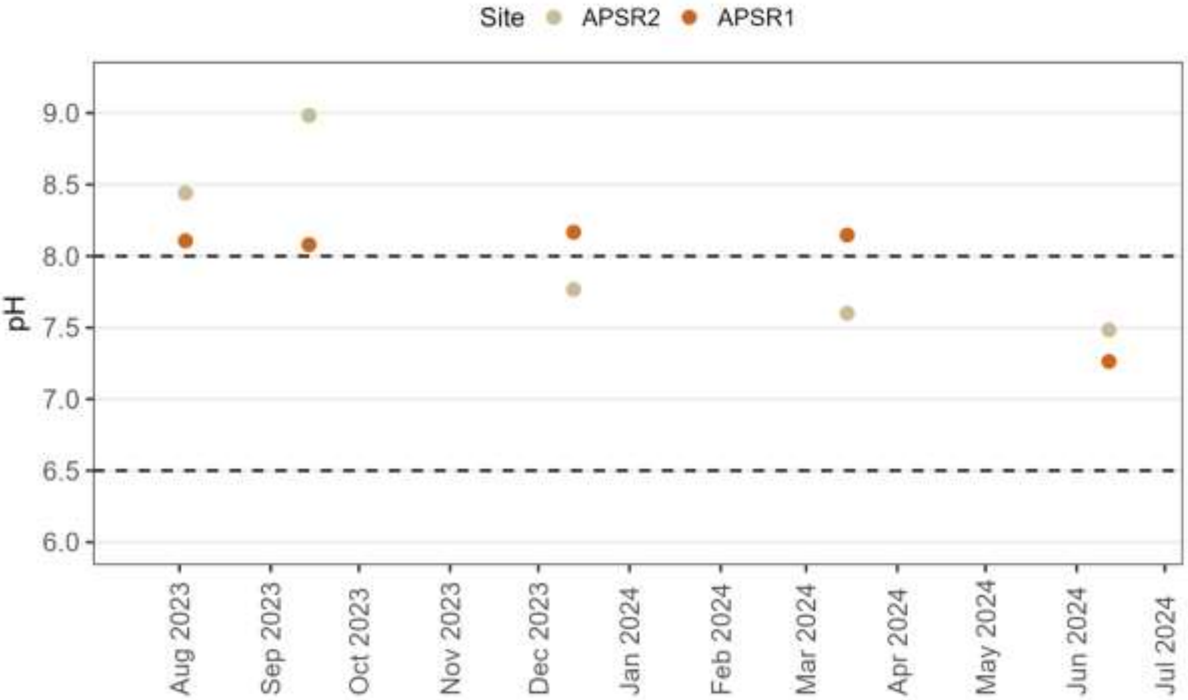

*Figure 6-89 pH readings collected by UNE.*

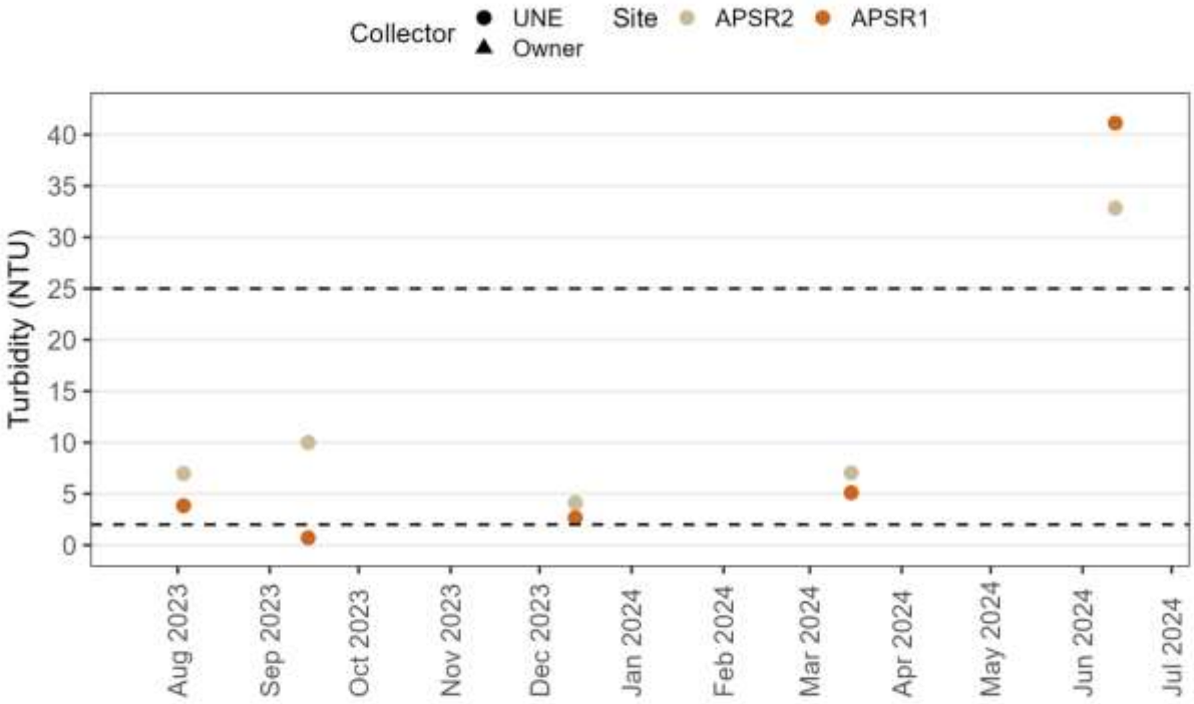

*Figure 6-90 Turbidity readings collected by UNE.*

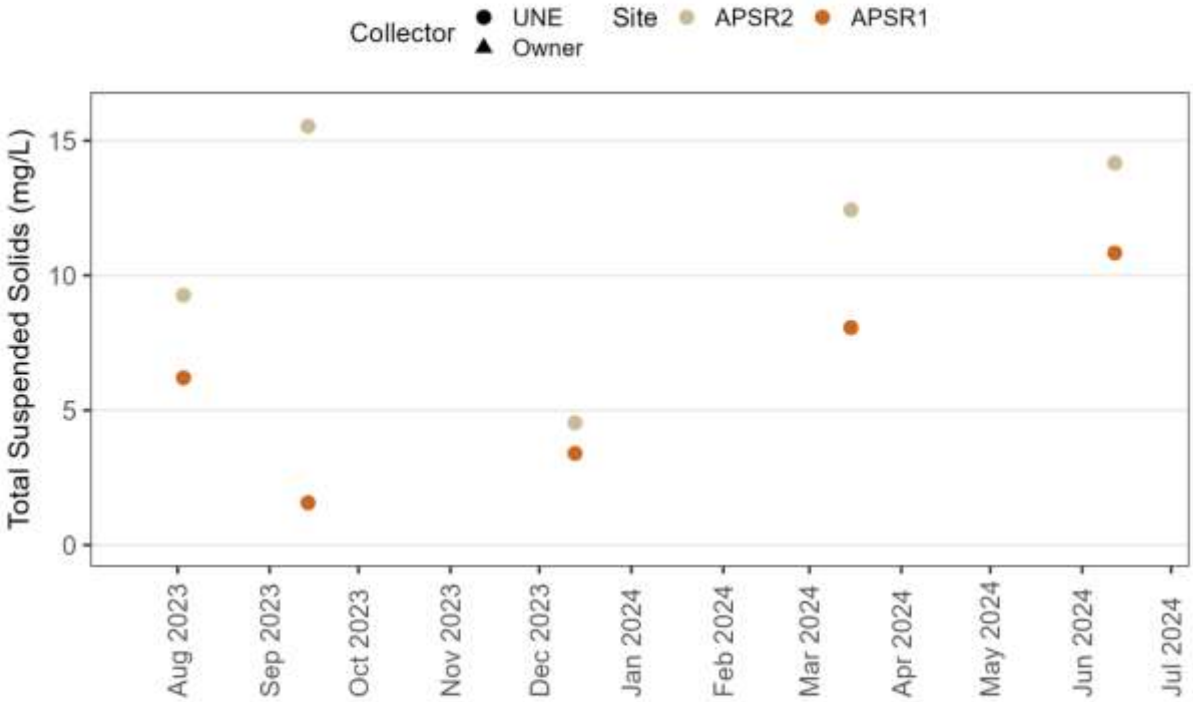

*Figure 6-91 Total suspended solids data from water samples collected by UNE.*

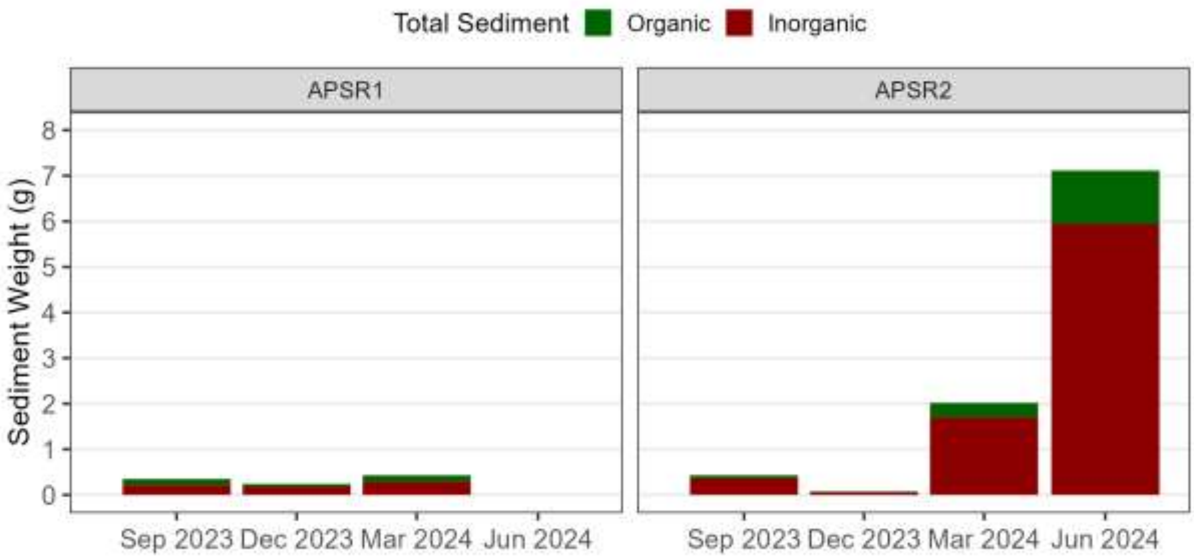

*Figure 6-92 Quarterly sediment accumulation in time-integrated sediment sampler.*

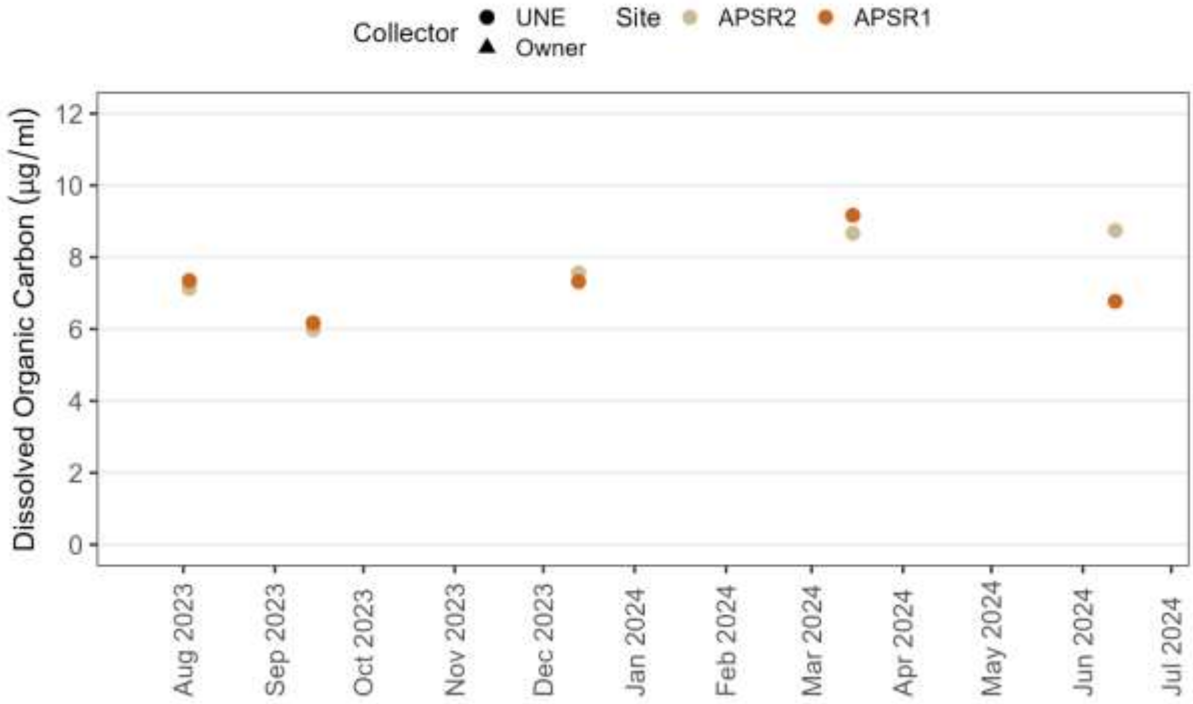

*Figure 6-93 Dissolved organic carbon values from water samples collected by UNE.*

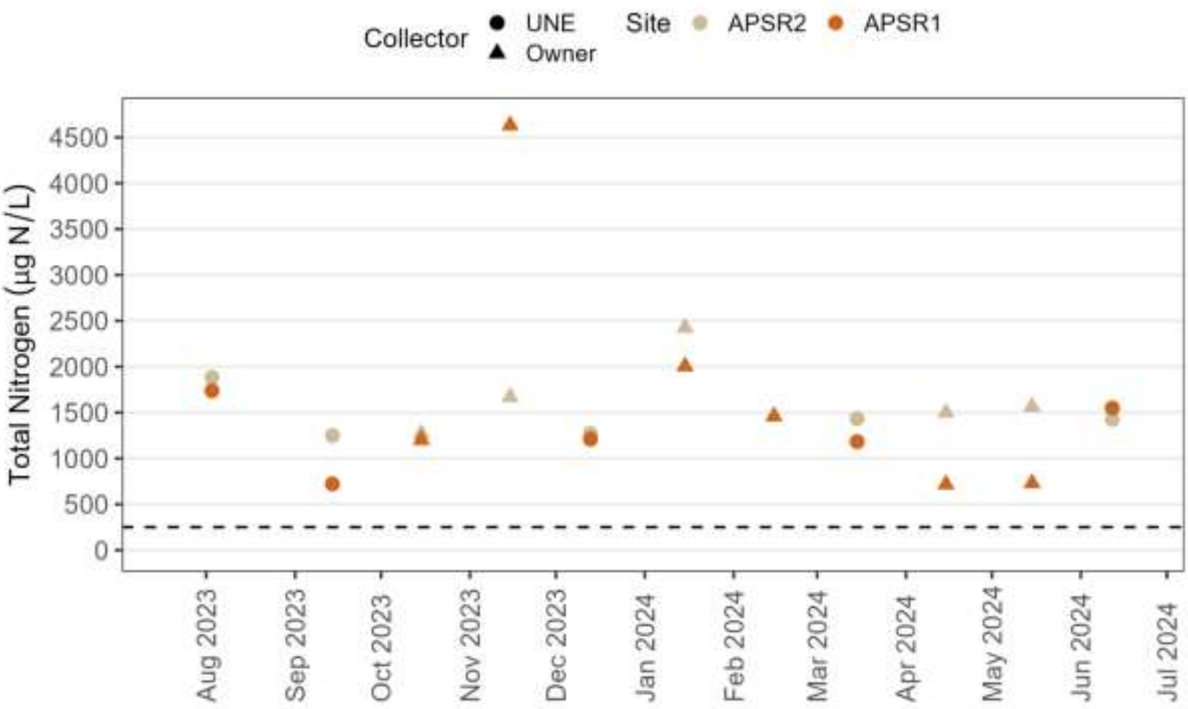

*Figure 6-94 Total nitrogen values from water samples collected by UNE (circle) and landholders (triangles).*

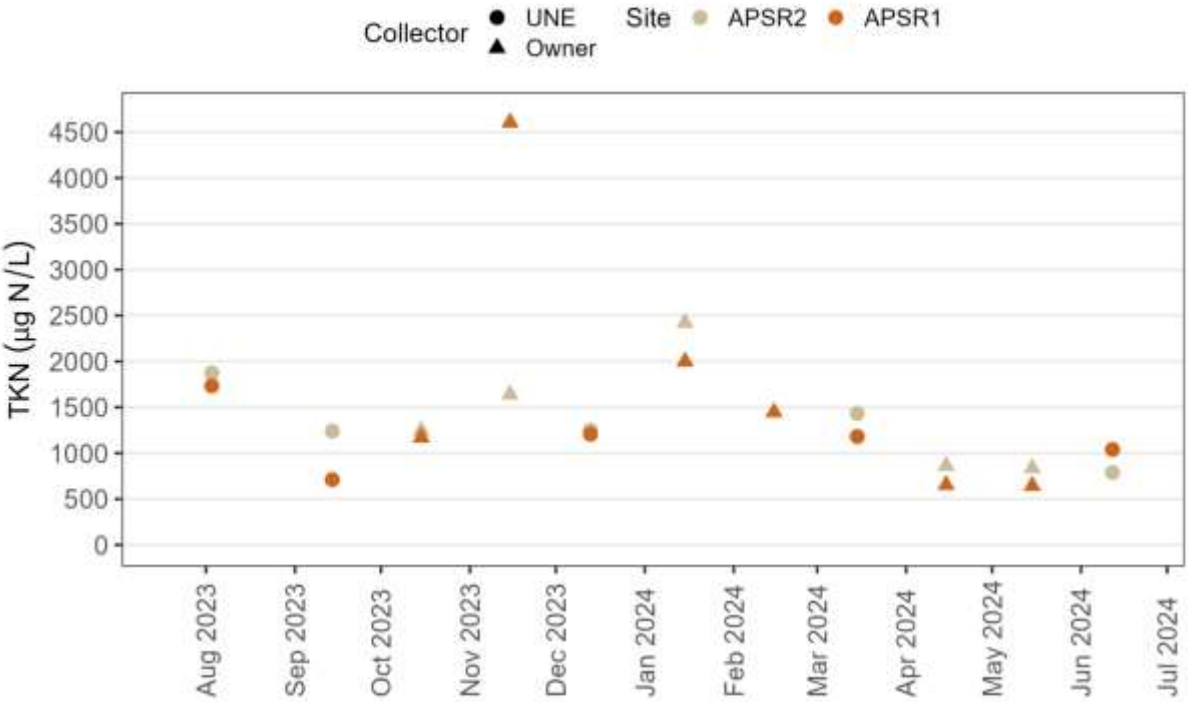

*Figure 6-95 Total Kjeldahl nitrogen data from water samples collected by UNE (circle) and landholders (triangle).*

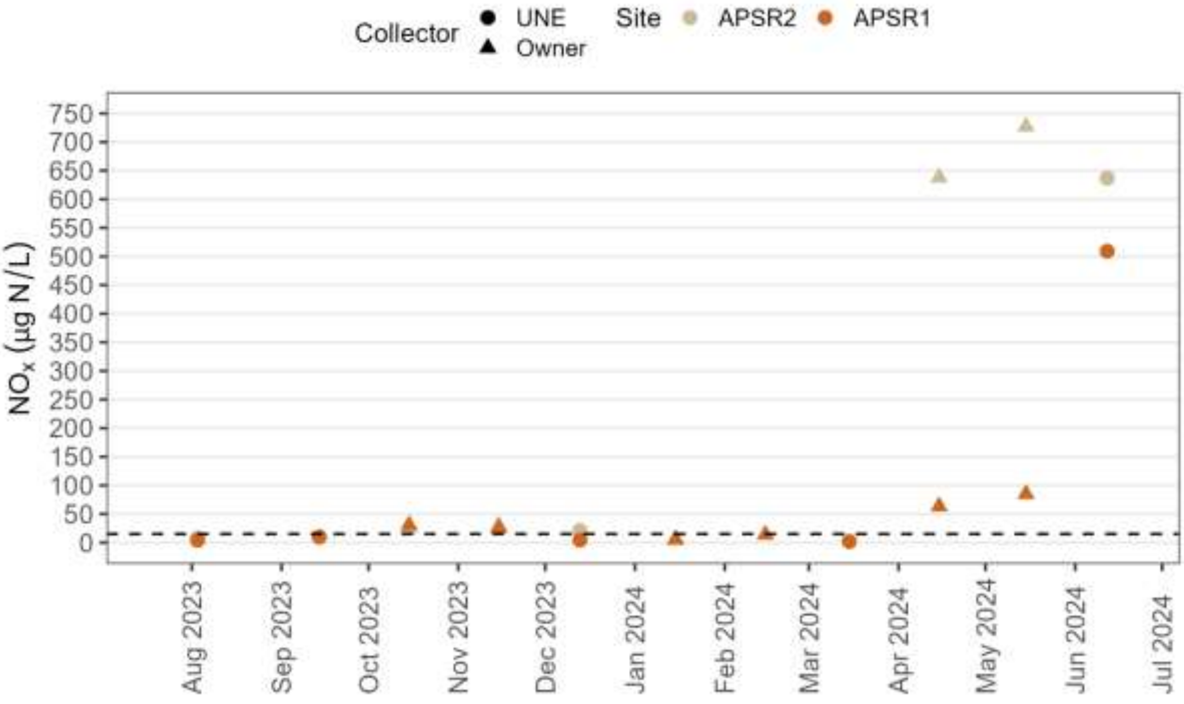

*Figure 6-96 Oxides of nitrogen data from water samples collected by UNE (circle) and landholders (triangle).*

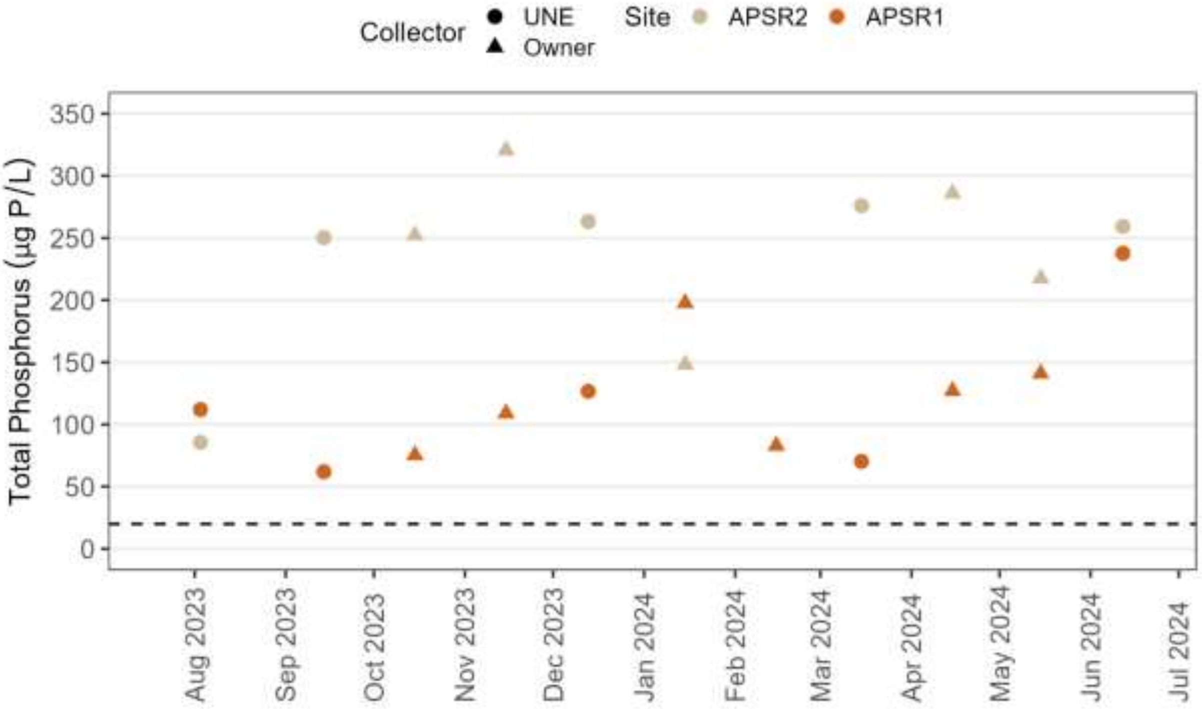

*Figure 6-97 Total phosphorus data from water samples collected by UNE (circle) and landholders (triangle).*

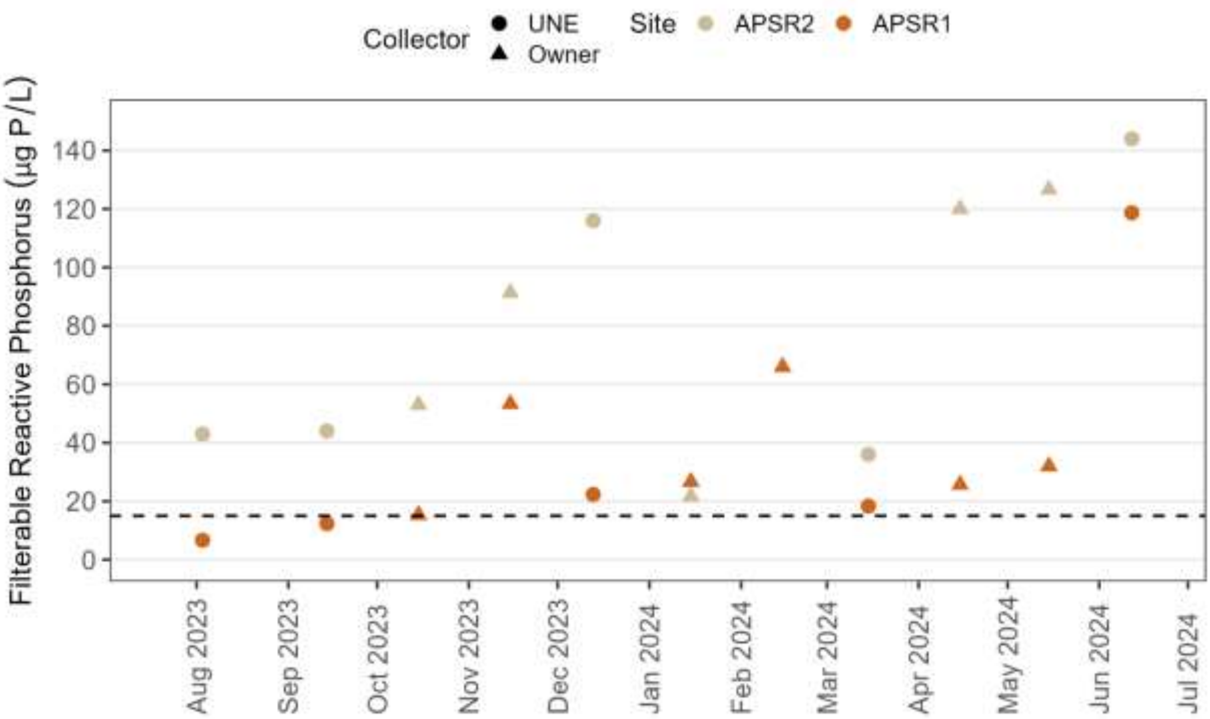

*Figure 6-98 Filterable reactive phosphorus data from water samples collected by UNE (circle) and landholders (triangle).*