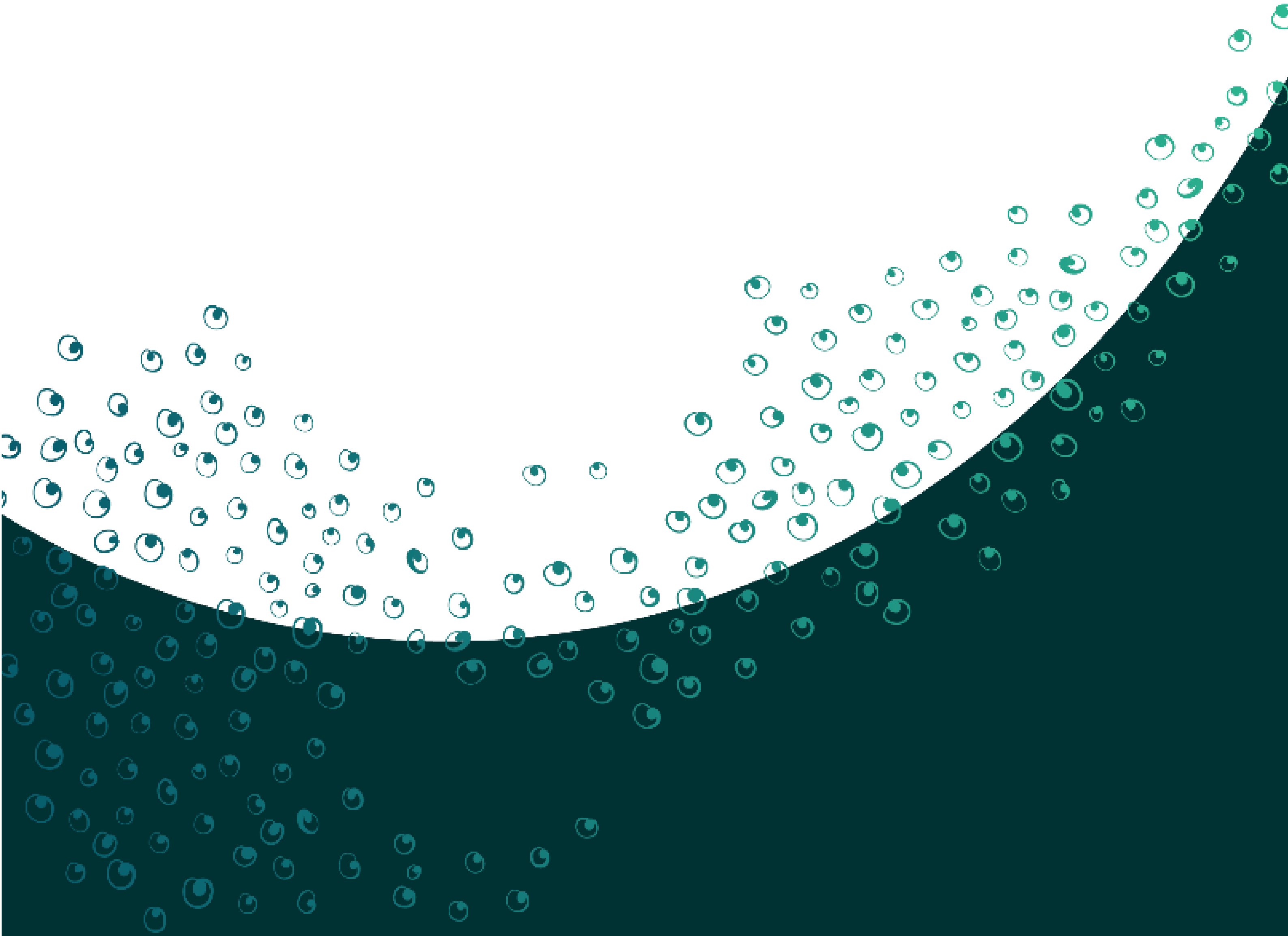

Fine-Scale Water Quality Monitoring in the Lower Burdekin Catchment

Communications Report

Queensland Government

Prepared by: Water Quality & Investigations, Department of Environment and Science

The Department of Environment and Science acknowledges Aboriginal peoples and Torres Strait Islander peoples as the Traditional Owners and custodians of the land. We recognise their connection to land, sea and community, and pay our respects to Elders past, present and emerging.

The department is committed to respecting, protecting and promoting human rights, and our obligations under the Human Rights Act 2019.

Disclaimer

Citation

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Acknowledgements

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September 2023

Executive Summary

This report provides an overview of the findings from the fine-scale water quality monitoring network installed within the Lower Burdekin catchments. The network aims to quantify and communicate the nitrate dynamics within the catchment.

Through a project coordinated by the Queensland Department of Environment and Science, the Water Quality and Investigations team was contracted to expand its real-time monitoring network. The project included the installation of up to 40 fine-scale monitoring sites (micro-sites) across the two priority catchments; the Lower Burdekin and Lower Herbert. This report summarises the data output from the Lower Burdekin catchment to date. A separate report will address the data from the Lower Herbert.

The data collected over the past few years has already provided new insights into nutrient dynamics in the region. Trends displayed along some systems suggest that the extent of wetland ecosystems, and the services that these ecosystems provide, affect the nitrate concentrations. For example, based on the observations so far, there is a reduction in nitrate concentration between sites in the lower network separated by a series of lagoons and wetland environments.

Groundwater-surface water interactions are an emerging concern in some areas. The rising groundwater table has been a known issue in the region for some years. Nutrients, accumulating in the water table may be negatively impacting surface water quality. These areas have demonstrated the highest nutrient concentrations seen throughout the catchment, at times exceeding proposed toxicity guidelines.

River discharge is a significant co-variate to most pollutants monitored in streams. A year with a large reported discharge will often report a large nutrient load. Monitoring in this project has occurred during a prolonged period of La Niña and its associated climate conditions (increased rainfall, earlier onset monsoon, increased number of cyclones). It is recommended that monitoring be conducted over varied climatic conditions to provide further context to end-users.

The data summarised in this report provides value that can’t be found in any other sampling strategy and demonstrates that this program is a crucial tool for the improvement of agricultural practices and the identification of specific drivers affecting nutrient and sediment run-off to the GBR.

This program collects a significant amount of data and major advancements have been made in operationalising anomaly detection algorithms and techniques developed in collaboration with the Queensland University of Technology. Frameworks proposed as part of the ARC Linkage project with QUT have been implemented by the department leveraging the in-house expertise in sensor technology, with plans to integrate the more complex spatial-temporal and machine learning models in the future.

Complex hydrology and irrigation infrastructure have made comparisons within the same stream difficult to assess at times. Comparisons between differing sub-catchments should be made with caution due to differing hydrology, dilution and specific inputs.

Technical failures in the monitoring infrastructure have resulted in site down-time and data gaps in the time series. As the data is displayed publicly in near real time, the data gaps are more noticeable than those in traditional monitoring programs. Data gaps presented publicly without further details can affect confidence in the data and its interpretation.

Many of the technical issues have been addressed and can now be more readily dealt with by collaborators in the region. These include the identification and replacement of wiper units incompatible with the installation setup and modification of installation setups to facilitate a more modular approach, where equipment may be rapidly swapped should failures occur. The knowledge gained from these issues has improved the capacity to identify these and similar issues remotely.

Contents

Project Overview

In 2015, the Australian and Queensland Governments released the Reef 2050 Long-Term Sustainability Plan to focus on actions to address key threats and directly boost the health and resilience of the Great Barrier Reef (GBR) (Australian and Queensland Governments, 2015). A major component of that plan is the Reef 2050 Water Quality Improvement Plan, which identifies the agriculture-based run-off of nutrients, pesticides and sediment, as a primary contributor to water quality decline in GBR catchments (Australian and Queensland Governments, 2018).

Through a project (RP232 - Fine-scale water quality monitoring in high-risk catchments) coordinated by the Queensland Department of Environment and Science, the Water Quality and Investigations (WQI) team was contracted to expand its real-time monitoring network. The project included the installation of up to 40 fine-scale monitoring sites (micro-sites) across the Lower Herbert and Lower Burdekin priority catchments. This report is about the Lower Burdekin network of 22 sites with a separate report to be written for the Lower Herbert.

Water quality data collected at this fine scale were expected to:

- raise community awareness of water quality issues in their local waterways.
- help local industry and resource management groups understand the relationship between land use management practice and water quality.
- contribute to improving Paddock to Reef model outputs for investigation at the sub-catchment scale to identify sources of pollutants.

Monitoring sites were selected via a co-design process with local stakeholders (see acknowledgments) who were best placed to provide knowledge of current and historical water quality projects in the regions, flow and irrigation regimes, and local land use. The co-design process resulted in a long list of potential sites that was distilled down to the final site list (Table 1). Site installation began in October 2020, with most sites online in the Burdekin by February 2021. The most recent installations occurred in May 2022 when the Burdekin River at Dalbeg reference site was brought online along with Kalamia Creek at Lilliesmere Lagoon in the lower catchment. Upon completion of the installation of four additional monitoring sites along Barratta Creek between March and May 2023, our network encompassed a total of 22 monitoring sites. (Figure 1)

Sites have been grouped to identify their land use context. The four site groups are:

- **Reference** – Situated higher in the catchment above contaminant sources, these sites provide a baseline for the water quality within each region. In the case of the Burdekin, a minimally disturbed upper catchment site was selected.
- **Control** – Sites that share the same features as the impact site, except for the key feature of Impact sites (i.e. high nutrient inputs). In the case of Plantation Creek, a control site was selected above the town in effort to quantify additional inputs from urban land use.
- **Impact** – Sites directly downstream of urban areas, highways, sewage treatment plants or intensive agricultural areas, used to determine the influence of these sources of nutrients.
- **End-of-system** – Sites at the lowest practical monitoring point along the river or creek. In the case of this monitoring network, the intent is to capture the maximum extent of upstream land use while avoiding the complexities of monitoring in the estuary.

This nested design aimed to understand changes in water quality between reference sites high up in the catchment, impacted sites within agricultural and urbanised areas, and sites immediately downstream of the previously identified land uses.

Table 1: List of the Micromicro-sites within the Lower Burdekin region (coordinates datum – GDA2020).

Catchment	Site ID	Site name	Site code	Probe optical path length (mm)	Lat.	Lon.	Site type
Haughton River	1190039	Haughton River at Giru Weir Headwater	HRH	5	-19.51	147.11	End-of-system
Barratta Creek	119101A	Barratta Creek at Northcote	BCN	2	-19.69	147.17	Impact
Plantation Creek	1191042	Plantation Creek at Ayr Dalbeg Bridge	PCA	5	-19.64	147.38	Control (*Burdekin main channel inputs*)
Plantation Creek	1191043	Plantation Creek at Wood Street	PCW	2	-19.59	147.40	Control (*Upstream of urban inputs*)
Plantation Creek	1191044	Plantation Creek at Chippendale PS	PCC	2	-19.58	147.43	Impact
Sheepstation Creek	1191045	Sheepstation Creek at Bruce Highway	SBH	5	-19.56	147.34	Impact
Didgeridoo Lagoon	1191046	Didgeridoo Lagoon at Bruce Highway	DLB	5	-19.56	147.25	Impact
Plantation Creek	1191047	Plantation Creek at Old Wharf Road	PCO	2	-19.53	147.49	End-of-system
Sheepstation Creek	1191048	Sheepstation Creek at Toll Road	SCT	2	-19.51	147.33	End-of-system
Kalamia Creek	1191049	Kalamia Creek at Pyotts Road (Retention Gate)	KCP	5	-19.50	147.49	End-of-system
Kalamia Creek	1191031	Kalamia Creek at Lilliesmere Lagoon	KCL	5	-19.54	147.41	Control (*Upstream of sugar mill*)
Burdekin River	1200020	Burdekin River at Down River Pump Station	BRP	2	-19.65	147.48	End-of-system
Burdekin River	120008C	Burdekin River at Dalbeg	BRD	2	-20.30	147.30	Reference
Cassidy Creek	1200126	Cassidy Creek at Kirknie Access Road	CCK	5	-19.79	147.26	Control (*Pivot irrigation practices*)
Burdekin River	1200127	Burdekin River at Tom Fenwick Pump Station	BRT	2	-19.93	147.22	Control (*Burdekin River irrigation network*)
Cassidy Creek	120013A	Cassidy Creek at Leichardt Downs	CCL	2	-19.79	147.25	Impact
Saltwater Creek	1210014	Saltwater Creek at Gardiner Road	SCG	2	-19.78	147.51	End-of-system
Alma Creek	1210015	Alma Creek at Wallace Road	ACW	5	-19.74	147.52	End-of-system

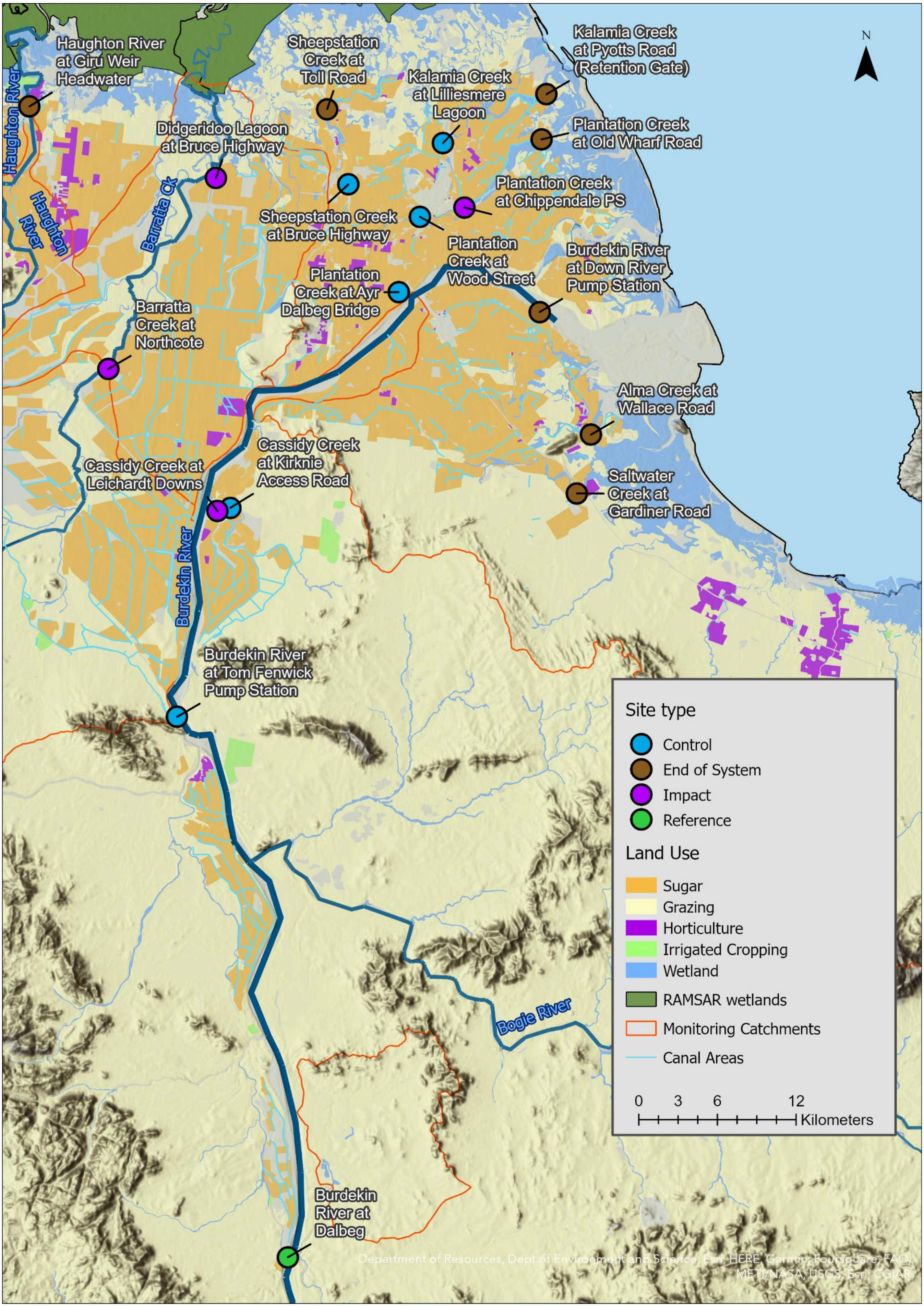

Figure 1: Map of the Lower Burdekin fine scale monitoring sites and broad land use in the area.

Micro-site set-up, data processing and quality

A system for deployment of near real-time nitrate sensors was designed by Water Quality & Investigations. These deployments are referred to as 'micro-sites', This approach stripped back the typical infrastructure requirements normally involved in the installation of long-term water quality monitoring stations and reduced it to the key components. The installation design aimed to balance durability, cost-efficiency and installation times.

Micro-sites are built around TriOS Opus spectral sensors, which measure the nitrogen component of the nitrate molecule ($N\text{-}NO_3^-$) and total suspended solids equivalent units (TSS_{eq}). They also use a pressure transducer to record water level, which provides additional context to the concentration data. Sensors are housed in a PVC pipe extending from the bank into the water.

The on-bank control and logging setup consists of a weatherproof electronics enclosure that houses a Campbell Scientific data logger, telemetry equipment (modem and antennae), solar panel, solar regulator, with cables extending from the box to the probes mounted in the water (Figure 2).

Figure 2: Micro-site infrastructure from Burdekin River at Tom Fenwick Pump Station. The site was installed within the retention dam fed directly from water pumped from the adjacent Burdekin River. From this point, water is pumped into an artificial irrigation network.

Data is recorded every 15 minutes by the logger and transmitted hourly to the WQI's online data platform via the integrated telemetry equipment. The $N\text{-}NO_3^-$ concentrations and stream level readings in Eagle.IO are transmitted to the 1622™WQ web portal developed by CSIRO for public access to visualise near real-time $N\text{-}NO_3$ and water level data.

The high sampling frequency of the system results in a near constant data stream (>35,000 individual data points/day). To verify that the data were of good quality, an automated algorithm has been developed that can process large amounts of data and infer quality codes that are descriptive of probable causes of the flagged anomalies. To infer data quality codes in these data, the algorithms utilise the following features:

- Manufacturer's detection limit values for absorbance at wavelengths associated with nitrate, organic matter, and turbidity.
- Probe specific and lens configuration specific limits on reported parameter outputs ($N\text{-}NO_3^-$ / TSS_{eq}).
- An internally calculated spectral quality index.
- Spike detection algorithms.
- Constant value detection algorithms.

The automated scripts function as follows:

1. Ingestion of data from the online data platform for a given site.
2. Process the data using a defined ruleset for the given probe configuration.
3. Application of relevant quality codes dependent on above listed ruleset.
4. Write the data back into a second reportable parameters data source within the online data platform.
5. Repeat for each site.

This process is hosted on cloud-computing infrastructure and is scheduled to run every hour at 15 minutes past the hour. The modified data stream has resulted in improved efficiencies in error detection compared to that achievable manually. It has been more efficient at identifying wiper failure, lens obstructions, dry readings and saltwater interference; all of which can appear like typical sensor variability. Manual efforts now focus on inspecting flagged values that require specialist technical investigation and site-specific insights, freeing up valuable expert time and resources.

The manual aspect of this process is completed periodically, both to validate the outputs of the automated process and to identify any major deviations from expected values (spikes/sensor drift/biofouling). The codes are applied to the raw data source in WQI's data platform, where the automated script will maintain any manually coded data in its output. This cleaned and processed N-NO_3^- data is linked to CSIRO's 1622 Web portal. At present, the TSS_{eq} data recorded at each micro-site are not being published in the 1622 web portal. The WQI team is investigating options to clean and validate this dataset for public consumption through an alternative platform.

The path length is defined as the distance between the lenses of the probe through which the light passes while traversing the sample medium (i.e. water) before reaching the spectrometer. The accuracy and precision of the probe can be calibrated for optimal results by adjusting the path length. Typically, path length for the Opus probe installations were based on local manual grab samples. In the absence of local sample data, path lengths for the micro-sites were based on estimated concentrations considering site condition and upstream land use. Reference sites capturing natural systems would be expected to have lower turbidity and lower N-NO_3^- values, so longer path lengths (10 mm) were employed. With sites downstream of intensive cropping, sugarcane agriculture or other horticulture, it was anticipated there would be higher N-NO_3^- values, so shorter path lengths (2 mm and 5 mm) were employed. Overall, where possible, shorter paths were installed to capture occasional peaks in the N-NO_3^- concentration values at the expense of capturing a consistent trace for low range values. When interpreting the data and viewing gaps in the time series it is important to consider the specific path length as each has different operational ranges (Table 2).

Table 2: TriOS Opus Probe limits based on the optical path length.

Path length (mm)	2	5	10
Nitrate N-NO_3^- (mg/L) range	0.15 to 50	0.06 to 20	0.03 to 10

How much nitrate is too much?

The Australian and New Zealand Water Quality Guidelines for Fresh and Marine Water (ANZECC & ARMCANZ 2000) recognises that aquatic ecosystems are one of the environmental values in most waterways in Australia and New Zealand.

Three levels of protection are recognised: high ecological value (HEV), slightly to moderately disturbed (SMD) and highly disturbed (HD). The Queensland Environmental Protection (Water and Wetland Biodiversity) Policy 2019 defines four corresponding levels of protection: high ecological value (HEV), slightly disturbed (SD), moderately disturbed (MD) and highly disturbed (HD). Each level of protection is assigned a specific management intent. For HEV waters, the management intent is to maintain natural values/condition. For waters identified as SD, SMD or HD, the intent is to progressively improve them towards the HEV condition.

ANZECC & ARMCANZ (2000) provided a toxicity-based guideline for nitrate for each level of protection for freshwater aquatic ecosystems. However, the guideline for nitrate was erroneous and not currently in use. In the interim, ANZG (2018) recommend using the nitrate guidelines derived by the New Zealand National Institute of Water and Atmospheric Research (NIWA). NIWA has derived a set of nitrate guidelines using the same method that will ultimately be used as a basis for the revision of the Australian and New Zealand guidelines. Therefore, we have adopted the NIWA guideline for nitrate (Hickey 2013) as a reference indicator of risk to aquatic ecosystems in Queensland. Specifically, we have adopted the surveillance guideline (3.5 mg/L) for moderately disturbed aquatic systems as relevant to the majority of the lower Burdekin site network (Table 3).

Table 3: Nitrate toxicity guidelines. Adapted from: NIWA (2014) and Hickey (2013).

Ecosystem Condition	**Toxicity Guideline Value N-NO_3^- (mg/L)**
High Ecological Value	1.5

Slightly Disturbed	1.5
Moderately Disturbed	**3.5**
Highly Disturbed	9.8

Regional water quality objectives (WQO) are also scheduled within the Queensland Environmental Protection (Water and Wetland Biodiversity) Policy 2019. Water Quality Objectives for nitrate are calculated for individual waterways based on the available data from local waterways, with greater emphasis on data from waterways with few anthropogenic impacts. Table 4 provides the WQOs for the Barratta Creek, Haughton River and Burdekin River in the regions where monitoring is occurring.

There is a big difference between the toxicity-based guidelines and WQOs, both in terms of the magnitude of the values and the intent of the values. Toxicity-based guideline values are intended to give guidance on the threshold between low risk and moderate to high risk to the integrity of aquatic ecosystems, whereas WQOs provide an indication of the desired state of an aquatic ecosystem. Also, the data used to assess water quality against each of these guidelines is different. To assess water quality against toxicity-based guidelines, it is necessary to calculate the 95th percentile of the water quality dataset. To assess water quality against the WQOs, it is necessary to calculate the median of the water quality dataset. Graphical elements used in this report use box and whisker plots that show both the median and 95th percentile for the data collected each month.

Table 4: Adapted from: Environmental Protection (Water and Wetland Biodiversity) Policy 2019 – Haughton River Basin Environmental Values and Water Quality Objectives (updated September 2022).

**HD = Highly Disturbed, MD = Moderately Disturbed. No information available for High Ecological Value (HEV) systems, CUMECS = Cubic metres per second*

	Ecosystem condition	**WQO for $N\text{-}NO_3^-$ (mg/L)**
Barratta Creek	HD (lower catchment) MD (upper catchment)	Low Flow (<3.6 m^3/s cumecs)
		0.085
		High Flow (>3.6 m^3/s cumecs)
		0.045
Burdekin Delta catchment fresh waters (excluding Burdekin main channel)	MD	Low Flow (<3.6 m^3/s cumecs)
		0.085
		High Flow (>3.6 m^3/s cumecs)
		0.045
Burdekin Delta sub-catchment fresh waters (Burdekin main channel) – Burdekin River at Dalbeg (Gauge 120008B)	MD	Low Flow <117.1 m^3/s (cumecs)
		0.017
		High Flow ≥117.1 m^3/s (cumecs)
		0.07
Haughton River catchment fresh waters – Haughton River at Powerline (Gauge 119003A)	MD	Low Flow <11.6 m^3/s (cumecs)
		0.01
		High Flow ≥11.6 m^3/s (cumecs)
		0.013

Catchment and Data Overview

It is important to note the differences in cane farming practices between the Burdekin and other cane growing regions in the GBR catchments. For example, Burdekin is one of the last regions within Australia to burn sugarcane before harvesting, citing tropical conditions that render it impossible to cut ‘green’ cane (DAF 2016). Additionally, cane farmers have become increasingly autonomous regarding self-managing practices; in particular, adopting specific N management strategies to increase productivity (Thorburn et al. 2003; DAF 2016). Consequently, cane production and fertiliser application can differ from farm to farm based on the knowledge of the grower. This region also houses an extensive irrigation network which results in permanent flows in streams that may otherwise be ephemeral. This has also contributed to the rising groundwater table in the area and consequent issues for agricultural land use with the increased salinity in the root zone and water logging of soils. This increase in groundwater infiltration rates has also been seen to result in elevated nutrient and pesticide concentrations accumulating in the water table (Shishaye et al. 2021; DNRM 2017).

The major environmental and water quality concerns that have been identified within the lower Burdekin catchment include run-off of fertilisers, pesticides and sediment (DAF 2016). Fertilisers are generally applied with consideration to the wet season and localised rainfall events (Skocaj et al. 2013). Therefore, production and application can differ within the region based on the decisions of the grower and their location within the catchment. There have been efforts to reduce losses of fertiliser and topsoil from the region by introducing a range of best management practices to increase productivity and sustainably (DAF 2016). Best practice also requires that scheduled irrigation should match requirements of the crop for volume, frequency, and timing of water (Skocaj et al. 2013). Furrow-irrigation is practiced in the Burdekin region; however, scheduling can be difficult to manage, potentially resulting in sub-optimal timing of irrigation (DAF 2016) and consequential run-off from the paddock.

Various sites were considered as potential reference sites with little anthropogenic input; however, most of them presented challenges that could not be overcome (e.g. ephemeral streams, and necessity of running cables over large distances). Only one site was considered suitable to act as a reference site in the Lower Burdekin region (Burdekin River at Dalbeg) and this site also presented challenges that will be discussed later. The land use above this site is predominantly grazing, with small conservation areas scattered throughout the catchment. Although the Burdekin at Dalbeg site could not be considered pristine, it does provide a good indication of water quality feeding into the irrigations systems downstream. For the remainder of the catchment, downstream of Dalbeg. sugarcane is the dominant crop, with a few smaller horticulture practices throughout the catchment (Sinclair Knight Merz 2009).

Figure 3 shows the distribution of nitrate-N concentration data collected to date, ordered by median concentration from highest (at the top) to lowest (at the bottom) measured concentrations. Considering the typical distribution of water quality data, the median concentrations would best represent ambient to intra-event conditions, while the upper range of the distribution (rightward) is better representative of concentrations seen during event conditions (high flow). Note that not all sites have been online for the same duration.

Cassidy Creek, Barratta Creek and Didgeridoo Lagoon display the highest peak concentrations, occasionally exceeding the NIWA guideline for the protection of aquatic ecosystems. Notably, the only monitored reference site, Burdekin River at Dalbeg, is in the upper-middle of the plot. Most of the sites below Dalbeg in Figure 3 are in the lower catchment, including several sites on drainage networks and lowland lagoons receiving runoff from agriculture. The exceptions to this are the end-of-system sites for the Burdekin and Haughton Rivers. The Haughton site displays a longer rightward tail where event conditions extend beyond the distribution of the surrounding sites. Burdekin River at Down River Pump Station doesn’t display a drastically different distribution to the upstream Dalbeg site considering the expanded catchment area it is monitoring. This site is often influenced by artificial sand dams downstream, used to help maintain practical water levels for the network of irrigation pump stations.

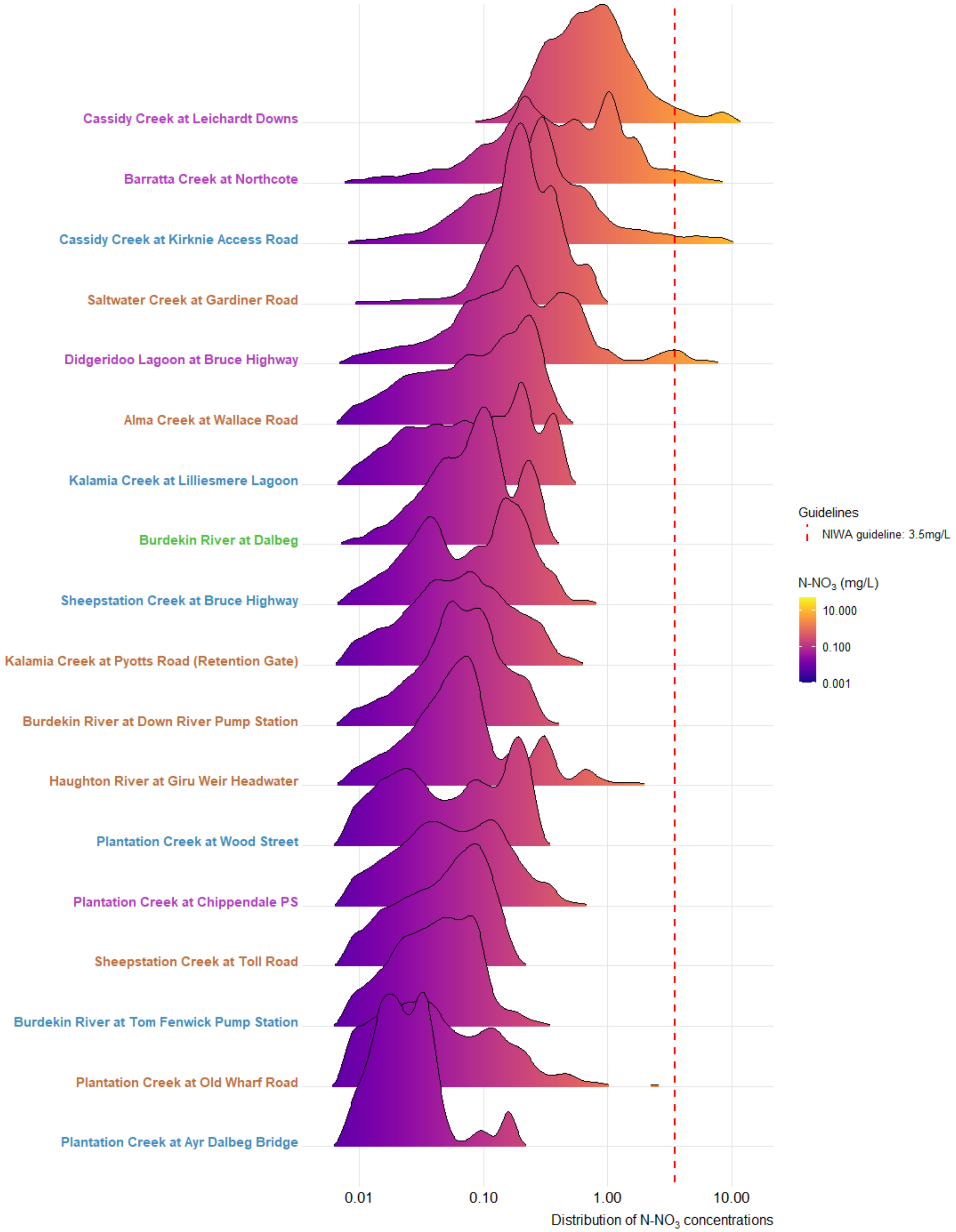

Figure 3: Ridgeline plot showing the distribution of nitrate concentrations observed in the Lower Burdekin catchment. The sites listed in descending order based on the median value. Colours of the site labels on the x axis denote the site type: reference (green), control (blue), impact (purple) and end-of-system (brown).

Rainfall and Hydrology

Based on the observed data, much of the nitrate concentration flux is driven by rainfall. The relationship between the two parameters is complex. Timing and location of rainfall within the catchment can yield different nitrate results depending on the time of year. This can be further confounded by on-ground activity, as reported by local landholders with insight about what was happening in the catchment before the observed rises in N-NO_3^- concentrations. The typical way to visualise and interpret these data is to view concentration against a hydrograph, where the relationship between nitrate concentration and river level (often driven by rainfall) is evident. As mentioned above, this relationship can vary over time. Early in the wet season, the expectation is that large rain events drive up water levels, with a concurrent rise in N-NO_3^- concentrations due to runoff from surrounding fields. By the end of the wet season, the opposite can become apparent, where N-NO_3^- inputs are reduced and rain events will result in a dilution effect (Figure 4).

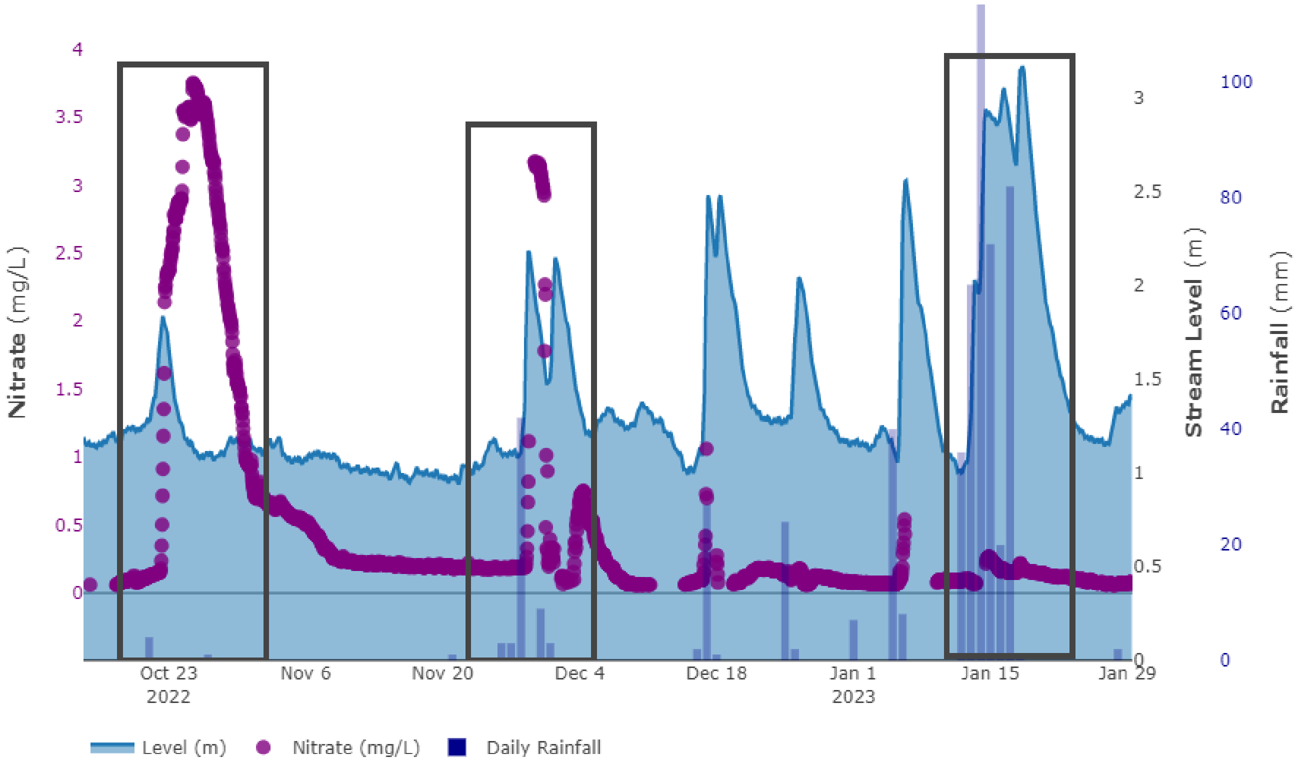

Figure 4: Hydrograph showing data from the Didgeridoo Lagoon at Bruce HWY site. The boxes represent distinct water quality events with differing responses to rainfall. From left to right, the first event shows a minor rainfall event with substantial response in N-NO_3^-, second event shows a somewhat comparable magnitude event to a large rain event, while the third event shows a sizable rain event resulting in only a minor elevation in concentrations at the start, followed by dilution effects.

Rain gauges at Barratta Creek at Northcote (119101A) and Haughton River at Powerline (119003A) are used as a surrogate for upper and lower-catchment rainfall, respectively. From the observed data, wet season conditions occurred between December and April in 2020-21 and November to February in 2021-22. There was unseasonably heavy rainfall in July-August in both 2021 and 2022 (Figure 5), which is seen to be a primary driver of some risk periods observed in the data, as discussed below. The project's observation period fell within La Niña climate patterns that have dominated the weather and produced events outside the typical wet season compared to the long-term average rainfall in the region (Bureau of Meteorology, 2023).

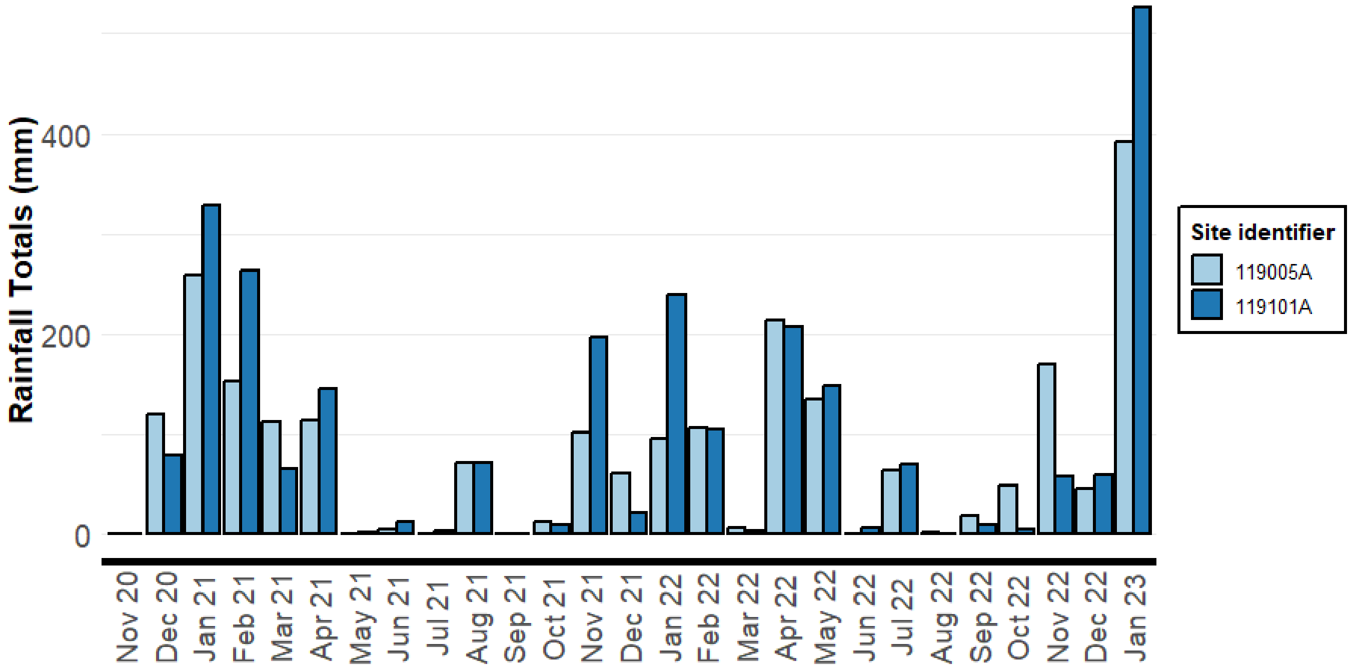

Figure 5: Total monthly rainfall (mm) for the period of observation across two sites in the Lower Burdekin region.

The monitored catchments are highly modified for the purpose of irrigation. As a result, the hydrologic connectivity of the sites can be confounded by a range of factors, including pumped inputs, drainage channels, water retention gates and road infrastructure (Sun et al. 2021). The level of connectivity between sites and sources can vary over time, depending on the operation of the infrastructure, which can make it difficult to quantify the movement of pollutants in these systems. In contrast to natural systems, where increased flow and velocity can ensure comparable concentrations are seen between monitoring locations along the same channel, artificial intervention to these flow regimes can divert or restrict this connectivity entirely.

To compare streams with similar hydrology, methodologies such as the bifurcation ratio can be used by grading lower to higher order streams against basin patterns (Bogale 2021). This also gives an indication of run-off and flood behaviour, as well as the climatic conditions of the region. Applying this methodology to the Burdekin region in the future will help in future comparisons across sites.

The Nitrogen Cycle

Both the under- and over-application of fertiliser can have negative impacts on sugarcane crops. As one of the primary macro nutrients for sugar cane production, nitrogen is essential in facilitating plant growth, photosynthesis and sugar production. While having an adequate supply of nitrogen is important in ensuring an economically viable crop, excess nitrogen will present its own issues with reduced sugar production and profitability (Calcino et al. 2022) Reducing fertiliser run-off has been identified as a win-win for both agriculture profitability and the environment (Skocaj et al. 2013).

Before being taken up by crops, nitrogen-based fertilisers undergo a multi-step transformation through microbial action (WHO 1998). Urea (CH_4N_2O) is the most common form of nitrogenous fertiliser in Australia as of 2016/2017 (Australian Bureau of Statistics 2018), as it is relatively safe to handle and affordable (Mengel 1986). During transformation, soil or plant enzymes first convert the urea N to ammonia, with some volatised in the process depending on the soil conditions. When dissolved in water, ammonia is in an equilibrium state between ammonium and ammonia ($NH_4^+ \rightleftharpoons NH_3$) and ammonium is then transformed into nitrate via soil microorganisms, which can then be utilised by the sugarcane crops (Mengel 1986). Plant biomass can accumulate N, which may be subsequently ‘recycled’ within the environment following decomposition (DES 2022).

Nitrate is highly soluble and mobile. This can lead to loss into the groundwater through subsurface drainage, while overland movement of nitrate is primarily driven by high precipitation, irrigation or floods (Nearing et al. 2005; Wang et al. 2015). This movement contributes to the reported 40% of N-NO_3^- lost from the paddock (Skocaj et al. 2013). Having entered the aquatic environment, nitrate is relativity stable and chemically unreactive (WHO 1998).

Denitrification is the process of removing dissolved nitrogen from the environment and returning it to the atmosphere in a gaseous state. This occurs primarily within anoxic soils and sediments, through microbial action (Martínez-

Espinosa et al. 2021). Wetlands in particular facilitate the denitrification process due to the presence of anoxic soil and rich organic matter (DES 2022). This process is important to slow the impact of eutrophication, particularly in aquatic ecosystems, which can be detrimental to the environment (Martínez-Espinosa et al. 2021).

Further information on the detailed processes within nitrogen cycling in the environment can be found at Wetland*Info,* available at: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/processes-systems/nitrogen-concept-model/processes.html

Monitoring Sites and Results

Comparing the concentration values between sites across the Lower Burdekin catchment can be difficult. Many of the monitored sites are hydrologically atypical. There are a range of factors such as retention/sluice gates, pumping stations and dams that will ultimately limit hydrologic connectivity between sites on the same systems. It is also important to note the differences in dilution between major river systems such as the Burdekin and smaller creeks and tributaries (Weaver et al. 2001).

In the following descriptions, comparisons have been made between sites along the same system in an effort to quantify differences between site types. Where direct comparisons were not clear, efforts have been made to describe what is evident from the data collected at individual sites, drawing context from the knowledge of upstream land use and more broadly relevant data in the rest of the catchment.

Cassidy Creek

The upper Cassidy Creek monitoring site, Cassidy Creek at Kirknie Access Rd (CCK), captures mainly grazing and pivot-irrigated horticulture land use types. The lower catchment site, Cassidy Creek at Leichardt Downs (CCL), has additional inputs from sugarcane growing. While this monitoring area is fed by an irrigation system, the micro-site monitoring locations and flow regimes are relatively representative of natural hydrological stream conditions.

Figure 6: Cassidy Creek at Leichardt Downs river-end infrastructure (downstream location).

Overall, the concentration range across both sites is elevated (Figure 3) compared with sites of similar land use within the region. Pivot-irrigated cropping is the standout difference in this catchment that may play a role in these elevated concentrations. More targeted monitoring would be required to identify specific sources. The 50th (median) and the 95th percentiles of $N\text{-}NO_3^-$ are usually higher in CCL than CCK. As CCL captures a greater area of modified land use and multiple nutrient inputs from the stream network, this aligns with expectation (Figure 3). The maximum reportable values recorded at CCL and CCK were 10.26 and 10.24 mg/L, respectively; however, the upstream CCK site appears to return to ambient state conditions at a marginally faster rate. These concentrations exceed NIWA toxicity guidelines (Table 3) for both Moderately Disturbed ecosystems[1] (MD = 3.5 mg/L) and Highly Disturbed ecosystems[2] (HD = 9.8 mg/L). While peak concentrations have been observed to exceed these guidelines, Figure 7 shows monthly summary data where the 95th percentile only exceeds the MD guideline in July for 2021 and 2022. Concentrations observed across these two sites also frequently exceed the WQO for Burdekin Delta fresh waters in both high and low flow conditions as seen in Figure 7.

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[1] The Australian and New Zealand Guidelines for Fresh and Marine Water Quality define slightly to moderately disturbed systems as "*ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained*" and would include the majority of agricultural landscapes.

[2] The Australian and New Zealand Guidelines for Fresh and Marine Water Quality define highly disturbed systems as, "*Measurably degraded ecosystems of lower ecological value. For example, shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture*."

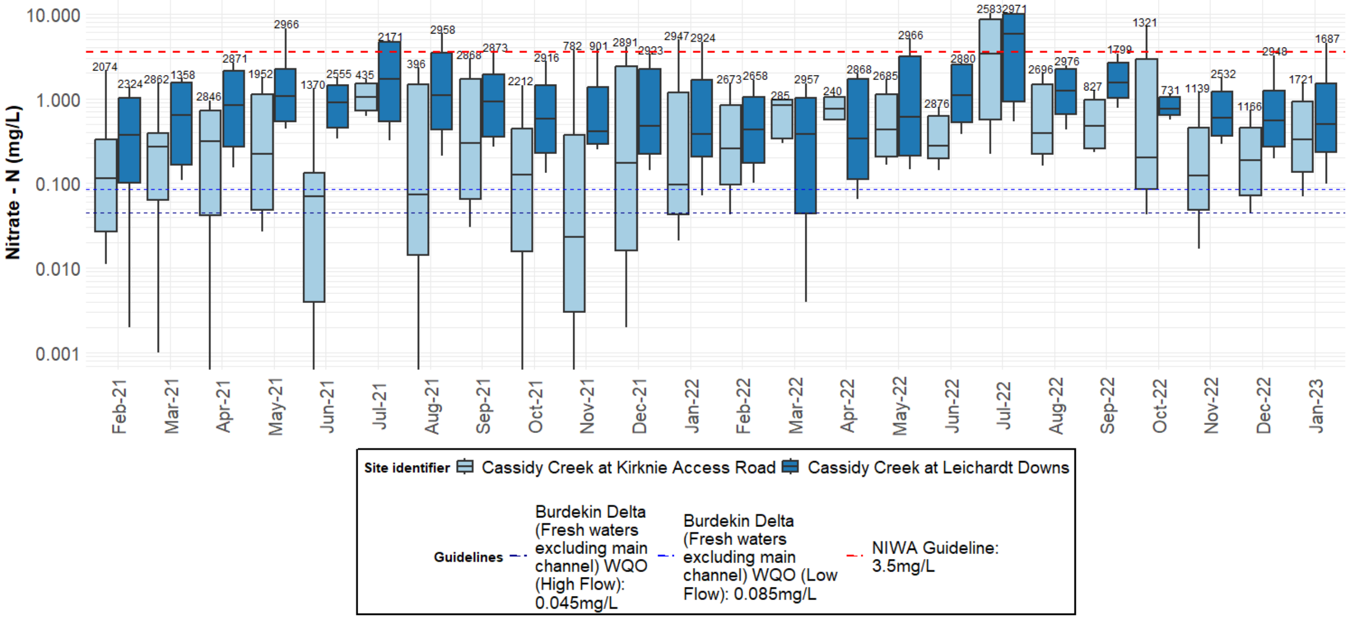

Figure 7: Monthly concentration range across both Cassidy Creek sites for the period of observation. Y-axis is transformed in log10 scale to better display variation and trend in the data collected.
Box and whisker plots have been constructed to facilitate comparison with WQOs and toxicity guidelines. *Numbers above each bar indicate the number of measurements during the month (n).*
Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

The most notable event occurred in July 2022, with an unseasonal peak in both the upstream and downstream locations (Figure 8, right). Rainfall appeared to drive a minor increase in the height of the river, with a large increase in the nitrate-N concentrations. These event concentrations are the highest seen over the period of observation for these sites and the rest of the network, indicating the risk posed by unseasonal rain events over dry periods. It is possible that landholders are more likely to apply large quantities of fertiliser at times when little rainfall is expected. The event flagged on the left-hand box of Figure 8 shows an interesting trend in nitrate-N concentration. Nitrate concentrations in water continued to increase after the event had passed suggesting sub-surface or groundwater inflow was influencing this stream.

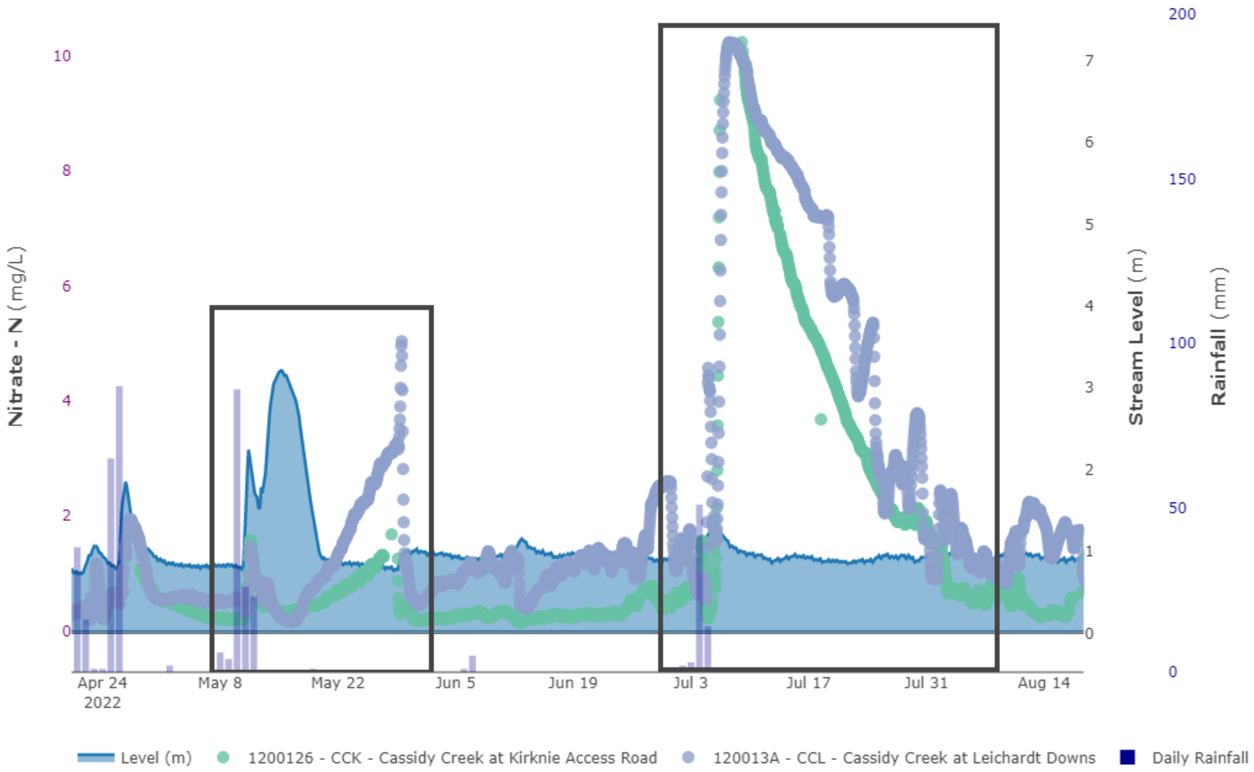

Figure 8: Nitrate concentration trace for both Cassidy Creek sites, plotted against the downstream hydrograph. Periods of interest are encompassed by black boxes. Rainfall has been extracted from Barratta Creek Northcote (119101A).

Sheepstation Creek

Land use surrounding Sheepstation Creek is primarily sugarcane cropping, with some urban and horticultural influences. The Pioneer Sugar Mill sits downstream of the Bruce Highway monitoring site. This waterway is partially fragmented due to the Lower Burdekin Water sluice gates and the network of wetlands and lagoons separating the two sites. Sheepstation at Toll Road (SCT) is ~6 km downstream of Sheepstation at Bruce Highway (SBH).

Figure 9: Sheepstation Creek Bruce Highway micro-site.

In contrast to Cassidy Creek, the downstream site on Sheepstation Creek often reports lower nitrate concentration values than the upstream impact site (Figure 10). Median values are mostly below or close to the regional WQO values for Barratta Creek. The Sheepstation Creek sites exist within a mosaic of palustrine wetlands, which may remove nitrogen through denitrification processes (DAF 2016). High nitrate concentrations within the system can promote the growth of water weeds, which leads to biomass uptake and microbial denitrification, causing shifts in N compartmentalisation within the end-of-system sites (DAF 2016, Azizian et al. 2017). This interpretation of the comparatively low concentrations of nitrate is supported by the observation of large amount of macrophytes within the lower Burdekin region, which strongly suggests that this system is acting as a floating wetland (Department of Environment and Science, Queensland, 2022).

The downstream site within this system is installed on Lower Burdekin Water infrastructure, which acts as a bottleneck between a lagoon upstream and the rest of the creek as it terminates to a diffuse wetland drainage system. This restricts water movement, increasing residence time among the floating vegetation beds, thereby facilitating denitrification processes. Periods when event conditions yield higher concentrations in the downstream site (Figure 10) might indicate the ecosystem’s capacity to assimilate nitrate-N had been exceeded. For nutrients to enter the Great Barrier Reef lagoon, there would need to be a significant flood event capable of breaking the banks.

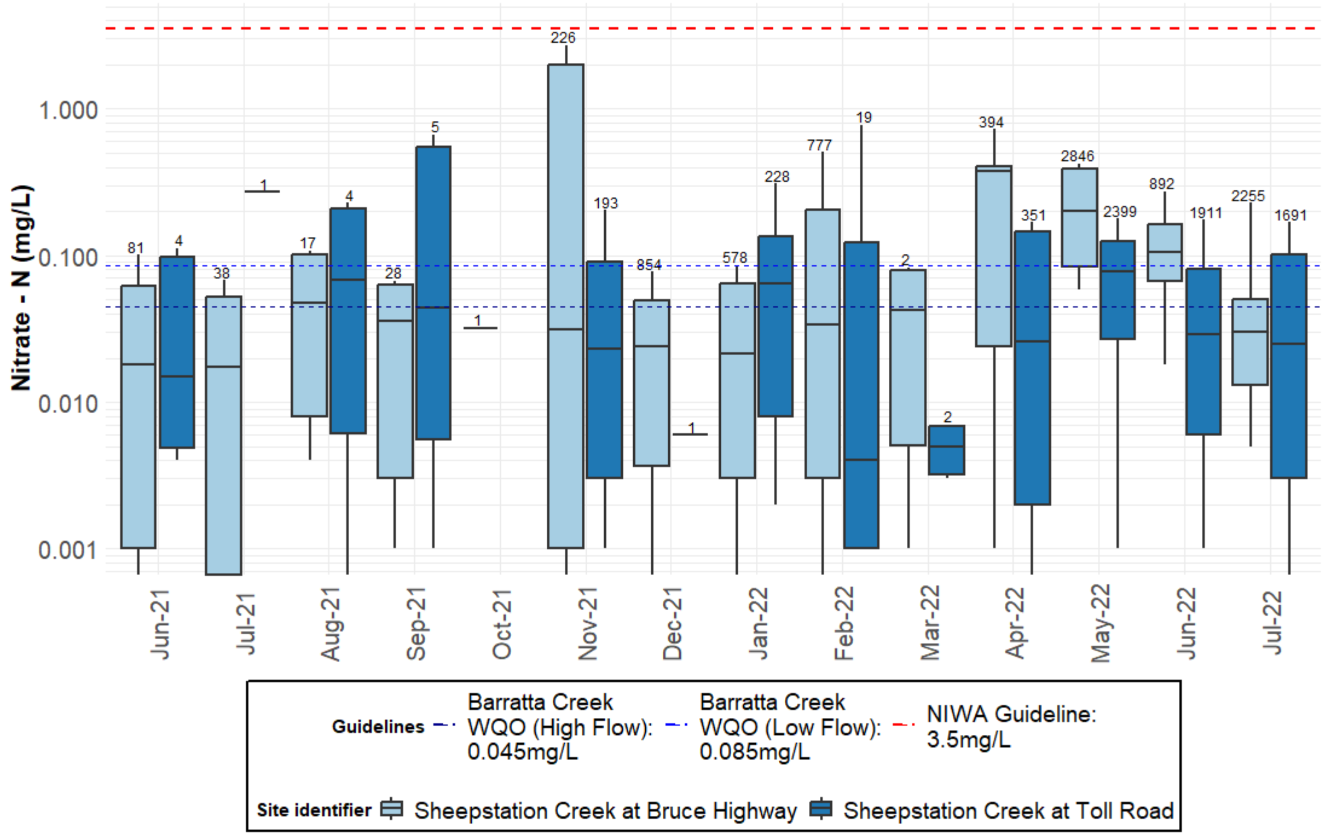

Figure 10: Monthly summary box and whisker plots for nitrate-N concentration in Sheepstation Creek from June 21 to July 22. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

The April 2022 event shows comparable trends across the upstream SBH and downstream SCT site, noting the spike in nitrate-N concentrations at the upstream site (Figure 11). The trend is present in the downstream SCT but has additional ‘noise’ or variability in the trace due to the low concentrations, which fall below the probe’s lower limits (Table 2). These limitations result in difficulties comparing data at times, where the low concentrations can mean no value is reportable at one site while the other holds a reasonable trace. With regards to trends between these two monitoring sites, the nitrate-N concentrations at SCT are noticeably lower than the upstream monitoring location. It is possible that denitrification processes may be occurring within the wetlands between these sites, which would explain some of the typical trends in the dataset so far. The reduced water velocity through the riverine systems of lagoons may facilitate the denitrification processes prior to the end-of-system sites.

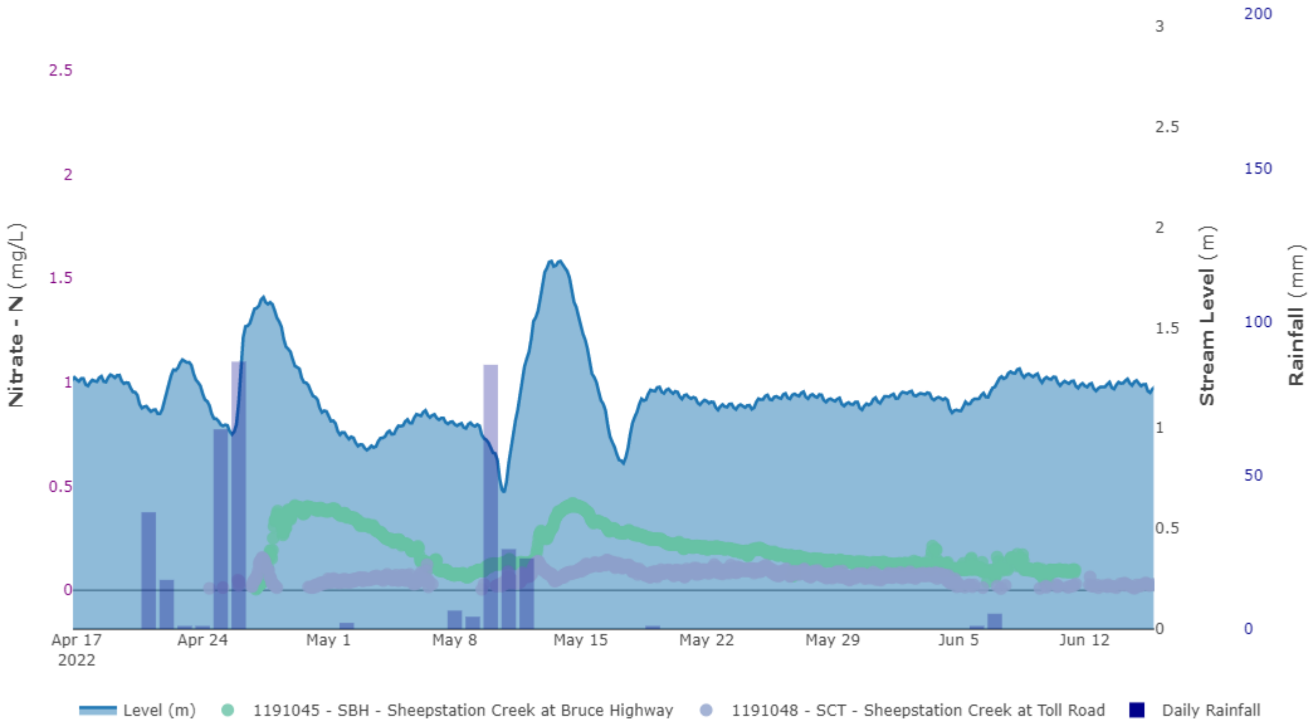

Figure 11: Nitrate concentration in Sheepstation Creek plotted against the upstream (SBH) hydrograph. Rainfall has been extracted from Barratta Creek Northcote (119101A).

Didgeridoo Lagoon

The land use in this catchment is primarily sugarcane cropping. Didgeridoo Lagoon runs adjacent to, and subsequently flows into, the Barratta Creek. This location within a lagoon on the downstream side of the Bruce Highway (Figure 12) and does not have any paired upstream/downstream sites.

Figure 12: Didgeridoo Lagoon micro-site river end infrastructure.

Concentrations at this site exceed the WQOs applicable to Barratta Creek (Figure 13). The period between February and May 2022 showed lower concentrations more compliant with the WQOs for the area. This aligns with the prolonged rainy season evident in Figure 5. Consequently, the inputs to the system were likely exhausted by the end of the wet season. There were notably high concentrations in August and September 2021 when the 95th percentile exceeded the NIWA toxicity guideline (3.5 mg/L).

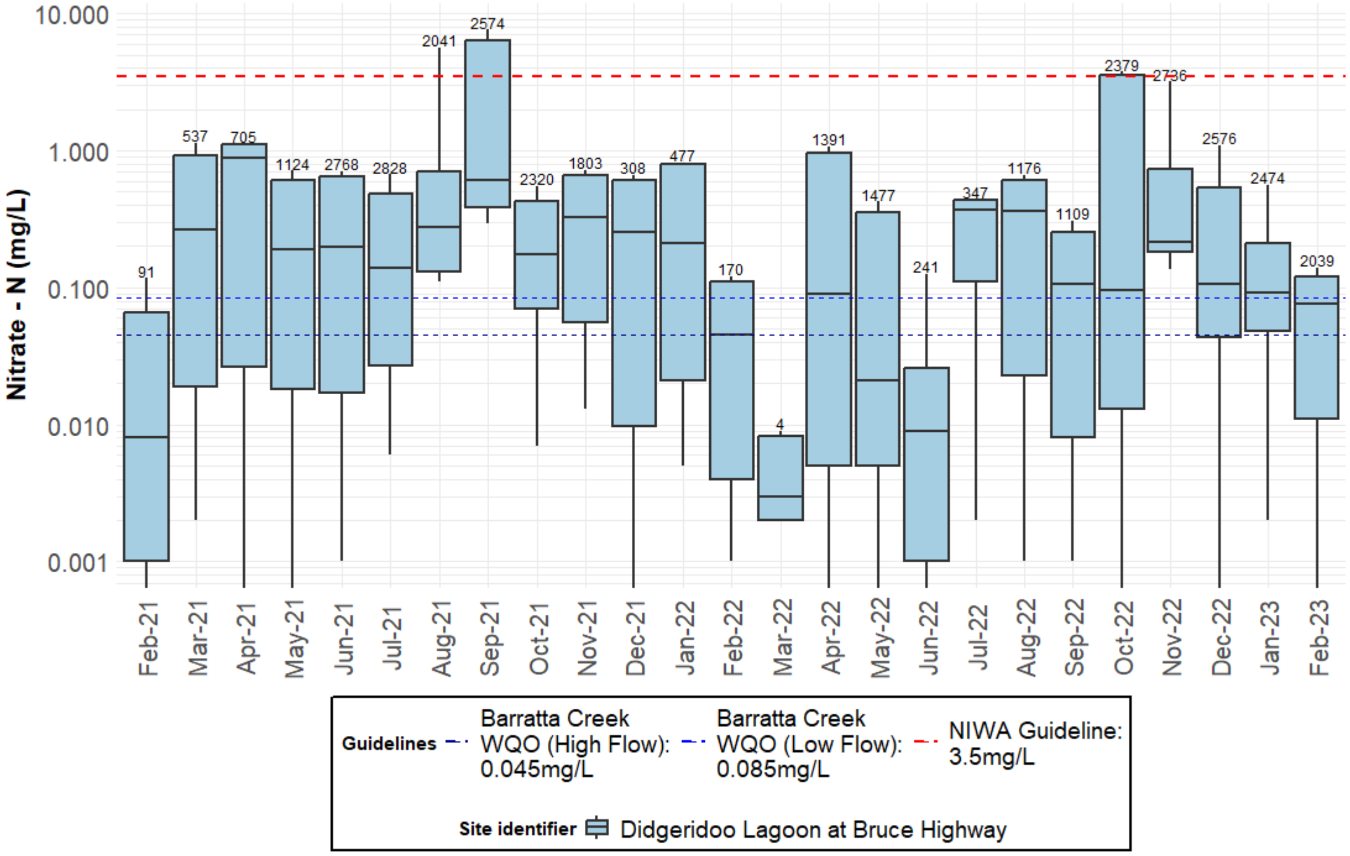

Figure 13: Monthly box and whisker summaries of nitrate concentration at Didgeridoo Lagoon for the period of observation. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*
Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *represents the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Figure 14 shows a time series graph of the event in August flagged in Figure 13. The water level sensor at this site had failed over this period, so there is no record to compare with the likely event conditions. However, it is evident in the probe readings and rainfall noted on 29 August, that there were elevated concentrations (up to 7.6 mg/L). This has been verified by laboratory data and similar events at the nearby Barratta Creek at Northcote site. While there is a data gap, it is worth noting that this style of real-time monitoring retains merit because such intense high magnitude events can be missed or underrepresented in discrete monitoring efforts. In this instance, three discrete (laboratory) data points were collected across the start, peak and fall of the event, thus verifying probe performance.

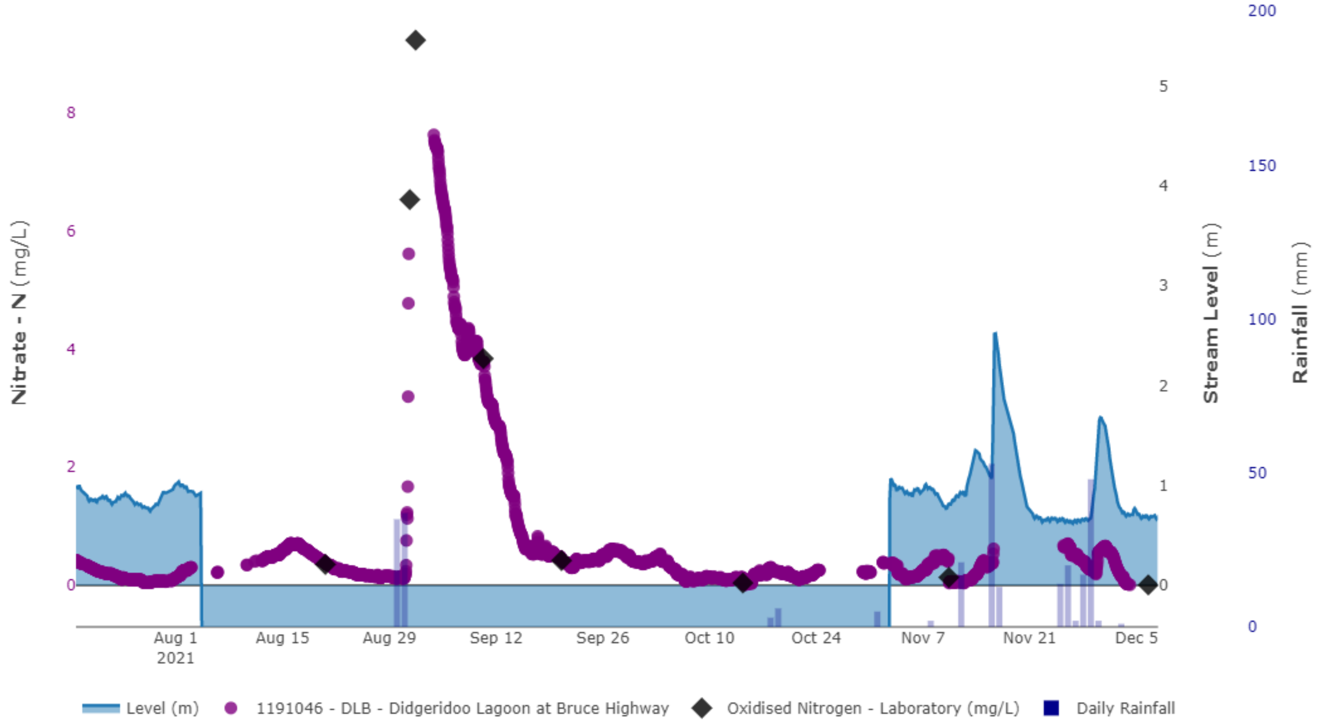

Figure 14: Nitrate concentration from the Opus probe and laboratory results at Didgeridoo Lagoon at Bruce Highway site over the hydrograph. Rainfall has been extracted from Barratta Creek Northcote (119101A).

Plantation Creek

There are four monitoring sites along the cane drain section of Plantation Creek, which runs alongside the natural creek as it passes the Ayr township. Along the length of the creek, the primary land use is sugarcane cropping, mixed among urban developments and horticulture before passing into wetlands along the natural creek path.

Figure 15: Plantation Creek Old Wharf Road monitoring site showing extensive macrophyte growth in the waterway.

The comparability of these sites is at times complex due to the hydrological connectivity of this highly modified drainage network. The upstream control site, Plantation Creek at Ayr Dalbeg Road (PCA), was installed as a means of distinguishing baseline nitrate-N concentrations from the source water pumped from the Burdekin River. Due to installation limitations and its position in the stream, we had limited up-time as it sat dry for most of the year. Of the data that were collected and comparable to the downstream site, Plantation Creek at Wood Street (PCW), the median and 95th percentiles of the monthly observed values were generally lower at PCA (Figure 16).

Plantation Creek at Chippendale Pump Station (PCC), just downstream of Ayr, often displays higher concentrations than the upstream sites, and occasionally the downstream site. This may be indicative of extra N inputs from the Ayr township. Interestingly, the downstream end-of-system site, Plantation Creek at Old Wharf Road (PCO), generally displays lower concentrations compared to other monitoring points along this system. It may be important to note that the site's location is at the end point of the drainage channel running alongside the natural component of Plantation Creek. The terminus is bunded and any inflows into the natural system would either be from groundwater or over-bank flow in flood events.

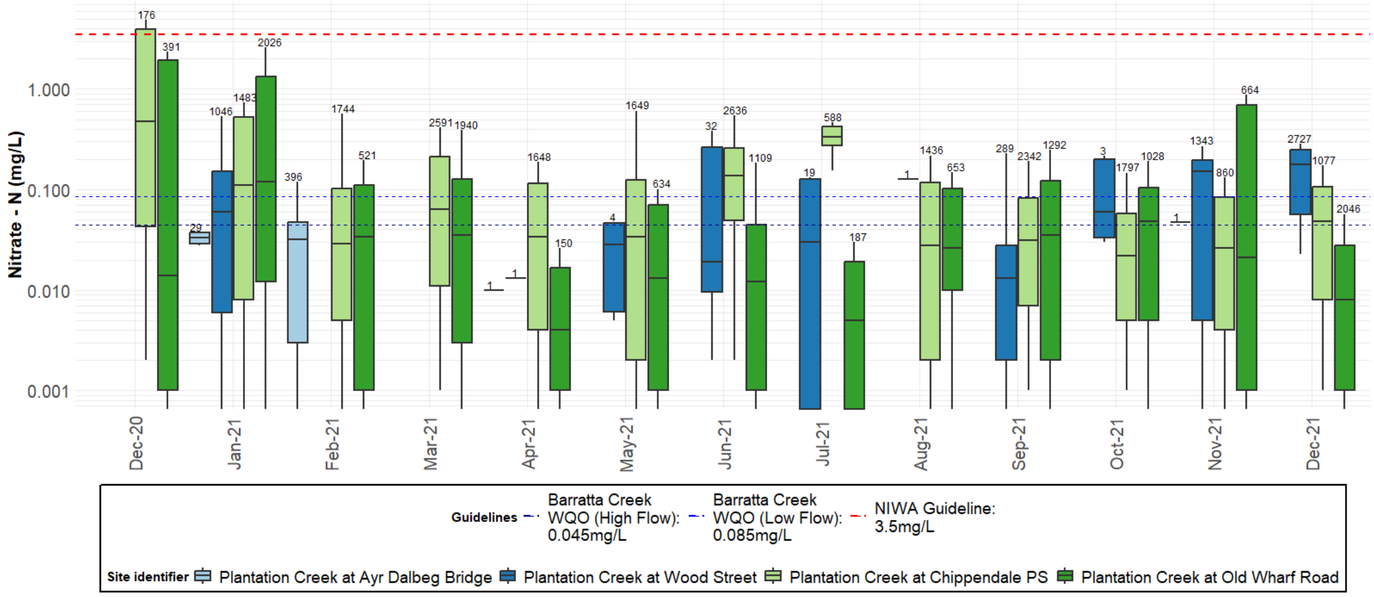

Figure 16: Monthly box and whisker summary plots displaying nitrate-N concentration across the Plantation Creek monitoring sites ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

The reduced nitrate-N concentrations at PCO may be representative of the assimilative capacity of expansive weed mats (*Eichhornia crassipes* – Water Hyacinth) in the channel system (Figure 15). With the restricted flow conditions of this terminus point, increased holding times may allow for denitrification processes to occur. This presents its own challenges in these systems, where the weeds will create issues for pump infrastructure, expansive algae or plant growth will drive down dissolved oxygen resulting in fish kills or in the case of irrigation supply, can impact root development, fertiliser uptake and production. An example of these dynamics and complexities in the system is evident in Figure 17. Comparing concentrations of nitrate-N between the two downstream sites (PCC and PCO) following the event (Figure 17), PCO concentrations drop and stay lower than PCC. PCW, however, seems unaffected by the event showing a more delayed response to an event in early February. There is little overlap with available PCA concentration data to allow for meaningful comparison.

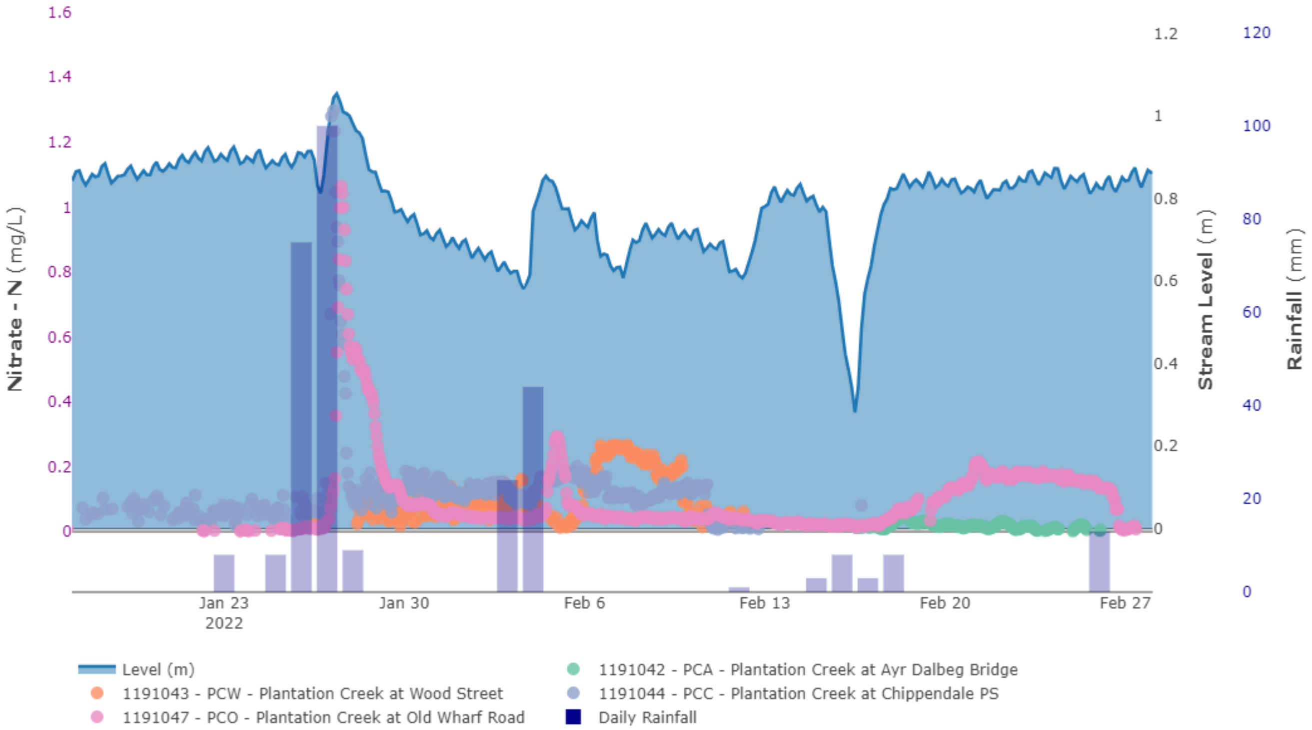

Figure 17: Nitrate concentration shown as a time series for the monitored Plantation Creek sites. The hydrograph plotted is from the PCC site and rainfall has been extracted from the rain gauge at Barratta Creek Northcote (119101A).

Burdekin River at Dalbeg

The primary reference site for the Lower Burdekin is the Burdekin River at Dalbeg (BRD), installed on 28th of April 2022. The site is located on the main channel of the Burdekin River with a large vertical rise needed to keep the electronic components dry. Due to this, the site has been technically difficult to monitor and subject to numerous technical issues (e.g. corrosion) that caused it to go offline from November 2022. Therefore, there were no data for the starting events of the 2022-23 wet season. The late installation meant that there is not a full data set representative of the full seasonal conditions within the region. This limits the comparability of this dataset to other sites in the region. The site was re-installed in March 2023 with a design change in an attempt to remedy the issues encountered in late 2022.

Comparability of sites upstream and downstream (Burdekin River Down River Pump Station – BRP) in low flow conditions is difficult in that the system is separated by ~93 km of braided waterways, weirs and at times artificially created sand dams. The main period of data collection across both sites was between April and November 2022 (Figure 18), which was effectively the dry season. Concentration ranges are not drastically different between the two sites, with the median and 95th percentile values hovering around the WQOs for the system.

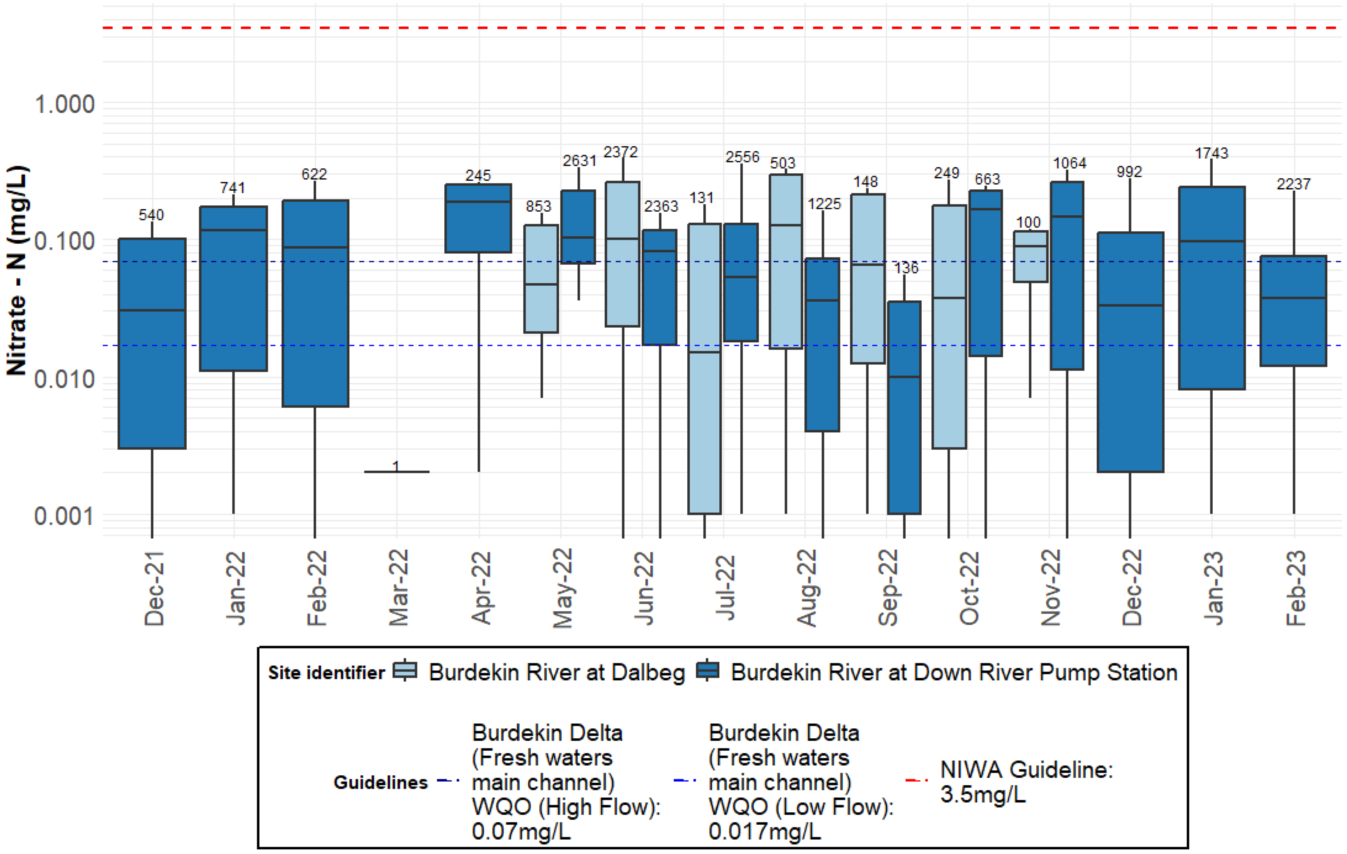

Figure 18: Monthly box and whisker summary plots displaying nitrate-N concentration across the Burdekin River monitoring sites. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

As mentioned above, the factors affecting the data observed at the two sites are not well understood. For example, Figure 19 shows the initial event captured at the Dalbeg monitoring site. For much of the event, the concentrations trace well and are comparable between the sites. On 6-7 June, there was rain at the Barratta Creek Gauging station, which was presumedly seen at the BRD site. Localised rainfall may account for the additional nitrate peaks seen at BRD and not BRP. A longer and more complete dataset is needed to gain a better understanding of nitrate mobilisation though this system.

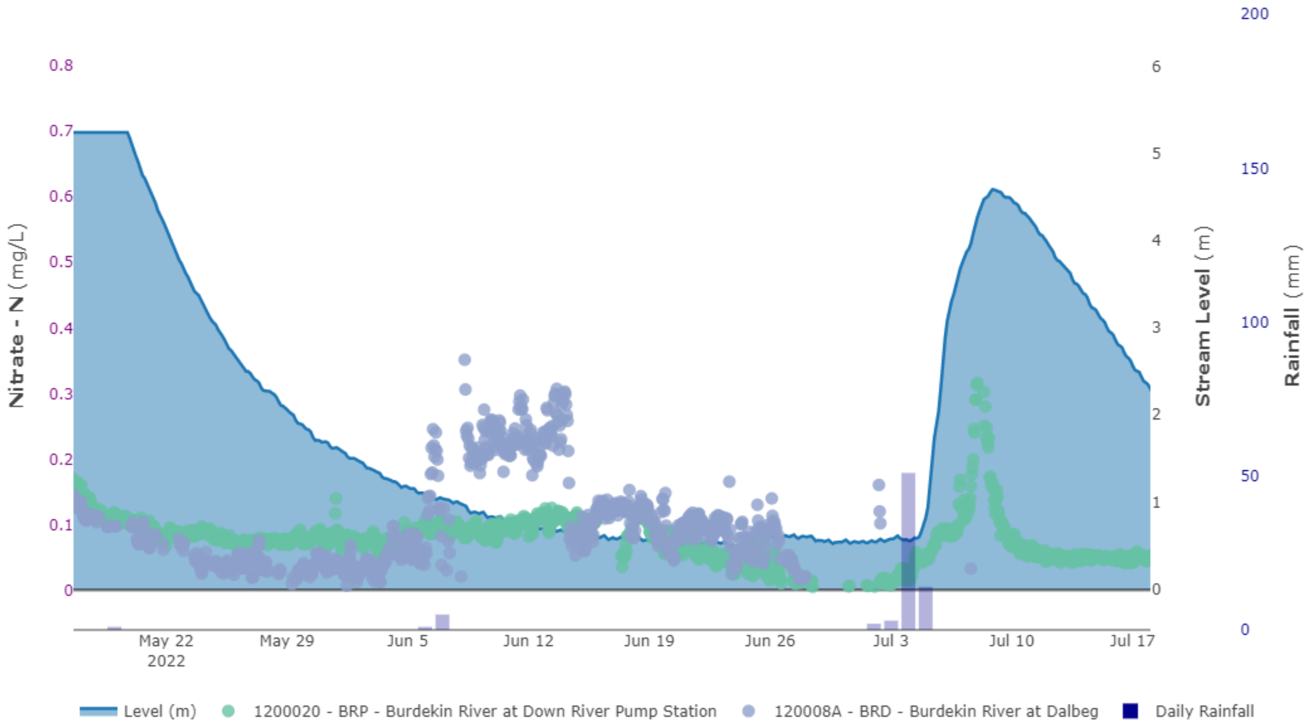

Figure 19: Nitrate concentration shown as a time series for the monitored Burdekin River sites. The hydrograph plotted is from the BRD site and rainfall has been extracted from the rain gauge at Barratta Creek Northcote (119101A).

Burdekin River Down River Pump Station

Burdekin River Down River Pump Station (BRP) is the primary end-of-system site for the Burdekin region and is adjacent to a Lower Burdekin Water pump station near Home Hill. The site is exposed to dynamic tidal influences at times, with moderate to high discharge periods (during the wet season) maintaining a constant freshwater flush. During the dry season, Lower Burdekin Water re-builds a sand-dam (Figure 21) directly downstream of the site to ensure freshwater is available to be pumped for the irrigation network. This change in flow regimes is evident in the data captured by the monitoring site (Figure 20). Prior to August 2021 the tidal influence in the stream level data is evident, but the sustained 1.3 m rise in August marks the installation of the sand dam.

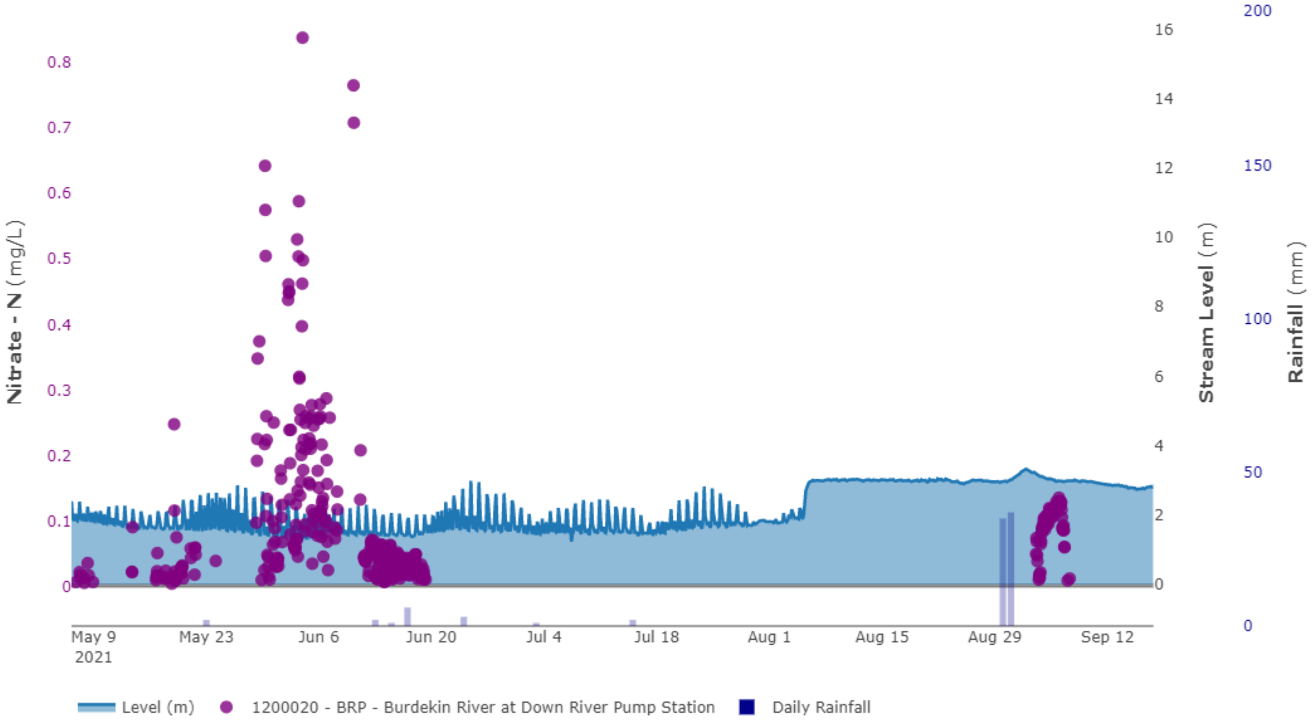

Figure 20: Nitrate concentration shown as a time series for the Burdekin River at Down River Pump Station (PRP) site. The

rainfall data has been extracted from the rain gauge at Barratta Creek Northcote (119101A).

Extra care was taken to ensure the February 2021 installation of the BRP site would survive a major flood along the sandy, easily disturbed banks of the Burdekin River. This was done by co-locating equipment with Lower Burdekin Water infrastructure (Figure 21). The BRP site has experienced some minor issues with debris getting caught between the lenses and tangled cables, temporarily keeping the OPUS probe out of water. More recently, there have been issues with the Opus sensor failing to measure $N\text{-}NO_3^-$ data as well as inconsistent water height readings.

Figure 21: Burdekin River at Down River Pump Station monitoring site is co-located with Lower Burdekin Water pump infrastructure. Photo is looking downstream showing the sand dam has been constructed.

Burdekin River at Tom Fenwick Pump Station

Burdekin River at Tom Fenwick Pump Station (BRT) (Figure 21) is a control site for the Burdekin and Haughton River irrigation network. The BRT site is inside the Tom Fenwick pump station's holding dam, which supplies water to the Haughton River as well as multiple large farming communities. As the dam supplies irrigation water, the pumps are not usually active during large rainfall events, so large discharges flow down the Burdekin River main channel without being captured by the infrastructure at this site. It can also be difficult to discern when pumping is occurring from the sites level sensor alone. As a result, the BRT site simply provides an estimate of analyte concentrations before the water is exported through the irrigation network between the Burdekin and Haughton catchments.

With SunWater permission, the BRT site was installed in February 2021. The site has experienced various issues with the monitoring equipment, mostly stemming from sensor wiper issues. Wipers are installed to prevent biofouling on the lens paths (resulting in erroneous data). The probes themselves have built-in compensation for sediment and organics constituents in the water column, so the nitrate data are robust up to the point where the light beam is restricted. At this point the data is coded as 'bad' and not displayed publicly because there is reduced confidence in the output. These same compensations aren't applied to the TSS_{eq} data, and these measurements are usually the first to start trending upward and provide warning of potential issues. The level sensor also suffered intermittent issues through much of 2022. These factors make interpretation of the time-series data challenging at times.

From this site's data, the medians in most months lie below the WQOs for the Burdekin River main channel. As seen across other sites, there were periods when event conditions pushed these concentrations higher in response to unseasonal rainfall (i.e. August 2021/August 2022). From this it is possible to conclude that input concentrations into the irrigation network are often in line or close to the WQO for the Burdekin main channel. However, due to this complex irrigation network, it is hard to confidently say what the concentration may be after passing through the delivery channel system, where natural processes in the water body have the capacity to break down these constituents further before there are additional inputs from the lowland cropping.

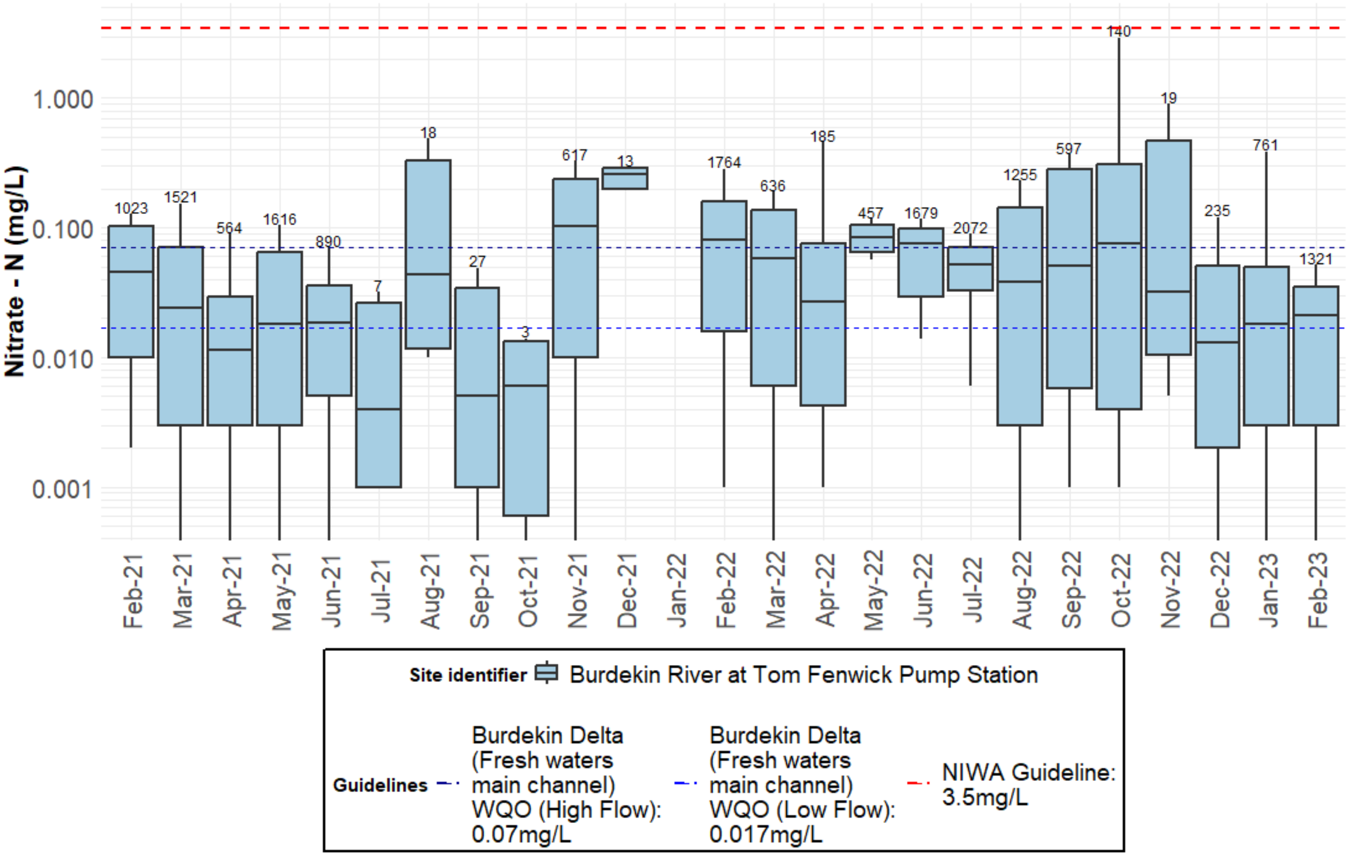

Figure 22: Monthly box and whisker summary plots displaying nitrate-N concentration at the Burdekin River at Tom Fenwick Pump Station (BRT) monitoring site. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Barratta Creek

The Barratta Creek at Northcote (BCN) monitoring site has been active as part of the Great Barrier Reef Catchment Monitoring Program (GBRCLMP) since 2011, and as a stand-alone gauging station since 1974. As the current project came online, this site was upgraded in line with the Opus probe roll-out to provide a near real-time nitrate-N trace to complement the GBRCLMP (i.e. grab samples collected for laboratory analysis) monitoring efforts. Due to limitations in the specific location of the existing infrastructure, the pump location in the stream means that the probe only sees water in event conditions. As a consequence, monthly summary data from this site is skewed toward the event concentrations and has less representation from ambient conditions. Lowering the pump was not practical as there would be a risk of sediment deposition damaging the pump, which would be detrimental to the ongoing GBRCLMP monitoring efforts. To complement this site, four additional sites were installed along the creek in late 2020 using low-cost probes and logging equipment (Bruce Highway, Allen Rd, Vivcox Bridge and Stockham Rd). All these sites suffered teething issues with the logging equipment and compatibility with the wiping equipment on the probes. Efforts were made to remedy and maintain the sites; however, ultimately the probes were removed, and few useful data were obtained. As of March 2023, three of the four sites have been re-installed with infrastructure in-line with the rest of the program. Allen Road could not be brought back online due to a flood event that damaged the pre-existing logging equipment.

Event concentrations observed at BCN (Figure 22) exceed the high flow WQO for Barratta Creek (0.045 mg/L), with exceedances of the NIWA toxicity guideline noted in August-September 2021, July 2022 and November 2022. The additional monitoring sites along this creek will hopefully aid in our understanding of the inputs that may be contributing to these elevated concentrations and the mobilisation of nitrate in Barratta Creek and the receiving waters for the GBR lagoon.

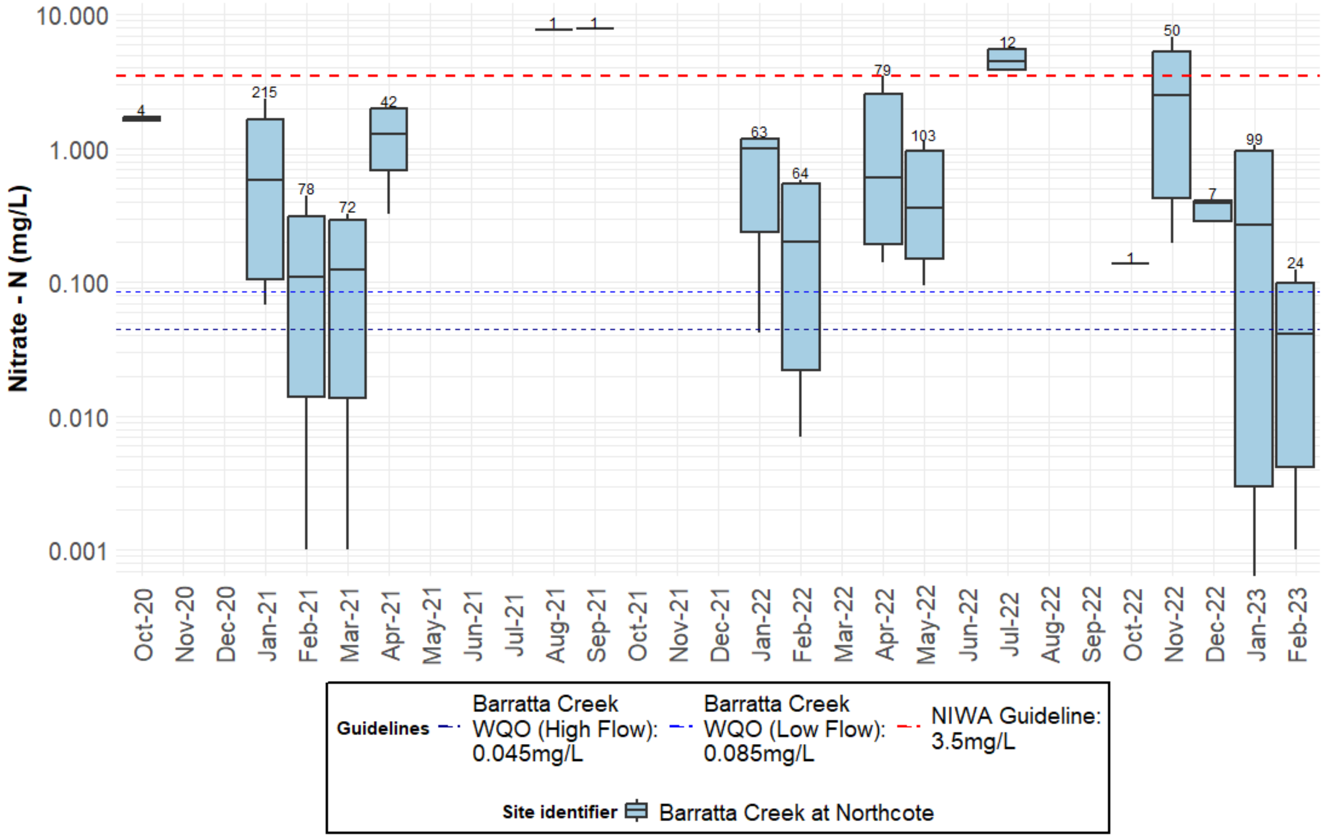

Figure 23: Monthly box and whisker summary plots displaying nitrate-N concentration at the Barratta Creek at Northcote (BCN) monitoring site. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Haughton River at Giru Weir

Haughton River at Giru Weir (HRH) is the end-of-system site for the Haughton River system, 30 km west of Ayr. The site has been monitored as part of the GBRCLMP since 2017; however, unlike BCN, it is monitored with manual grab samples only, with no infrastructure installed by WQI. The catchment is large, with several major land uses, including grazing, horticulture, sugarcane cropping, and some areas of conserved natural forest.

The HRH site was installed in February 2021 within a water storage area monitored by SunWater. It has captured several large rainfall events and detected high concentrations (>1 mg/L) of $N\text{-}NO_3^-$. The HRH site has had multiple height sensor failures. SunWater has its own height feed, which we have used as a surrogate when required. A lengthy data gap occurred between May and November of 2022, when the water level dropped below the sensor path. Lowering the sensor too much can result in issues with sediment deposition and accessibility, which may be considered an unacceptable risk to the existing GBRCLMP monitoring program reliant on the site.

From the available data, concentrations at HRH often exceed the WQOs set for the Haughton River (Figure 23). A planned upstream reference site, Haughton River at Mount Piccaninny (gauging station 119005A), was unsuitable for this style of monitoring. The size of the river and vertical rise required to keep the electrical components high and dry would require a more sizable investment.

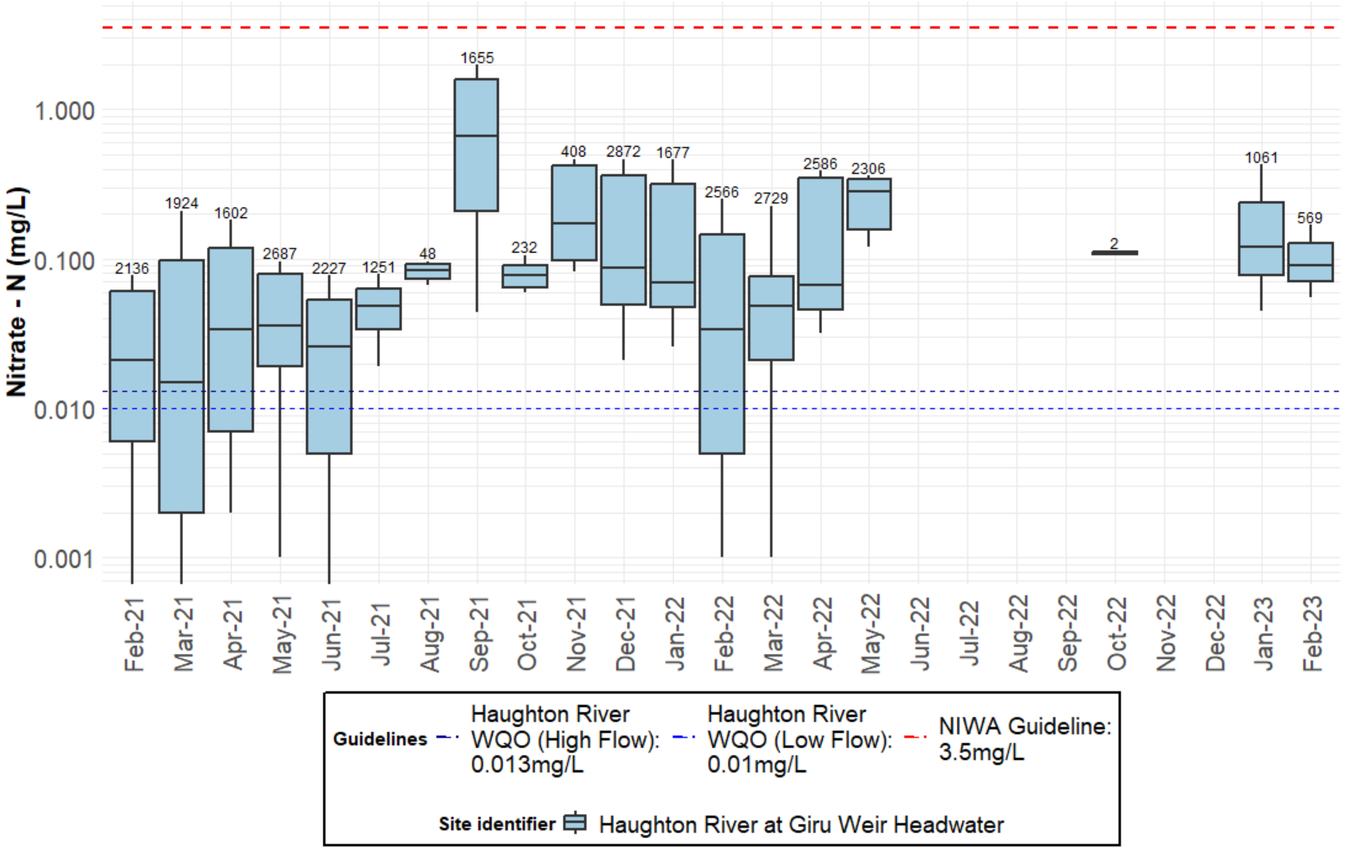

Figure 24: Monthly box and whisker summary plots displaying nitrate-N concentration at the Haughton River at Giru Weir Headwater (HRH) monitoring site. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines*** *Numbers above each bar indicate the number of measurements during the month.*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Kalamia Creek

Kalamia Creek at Pyotts Road (KCP) is the end-of-system site for Kalamia Creek on a Lower Burdekin Water sluice gate that controls the tidal influence for the lagoons upstream. The site captures large portions of sugarcane cropping in addition to smaller portions of horticulture and urban land use. Installed in December 2021, the KCP site has experienced delayed responses to rainfall events, with gradual rises and slower falls in water level (Figure 25). The KCP site has experienced several issues with inflated TSS_{eq} concentrations due to a malfunctioning wiper system and creek debris getting stuck between the instrument lenses.

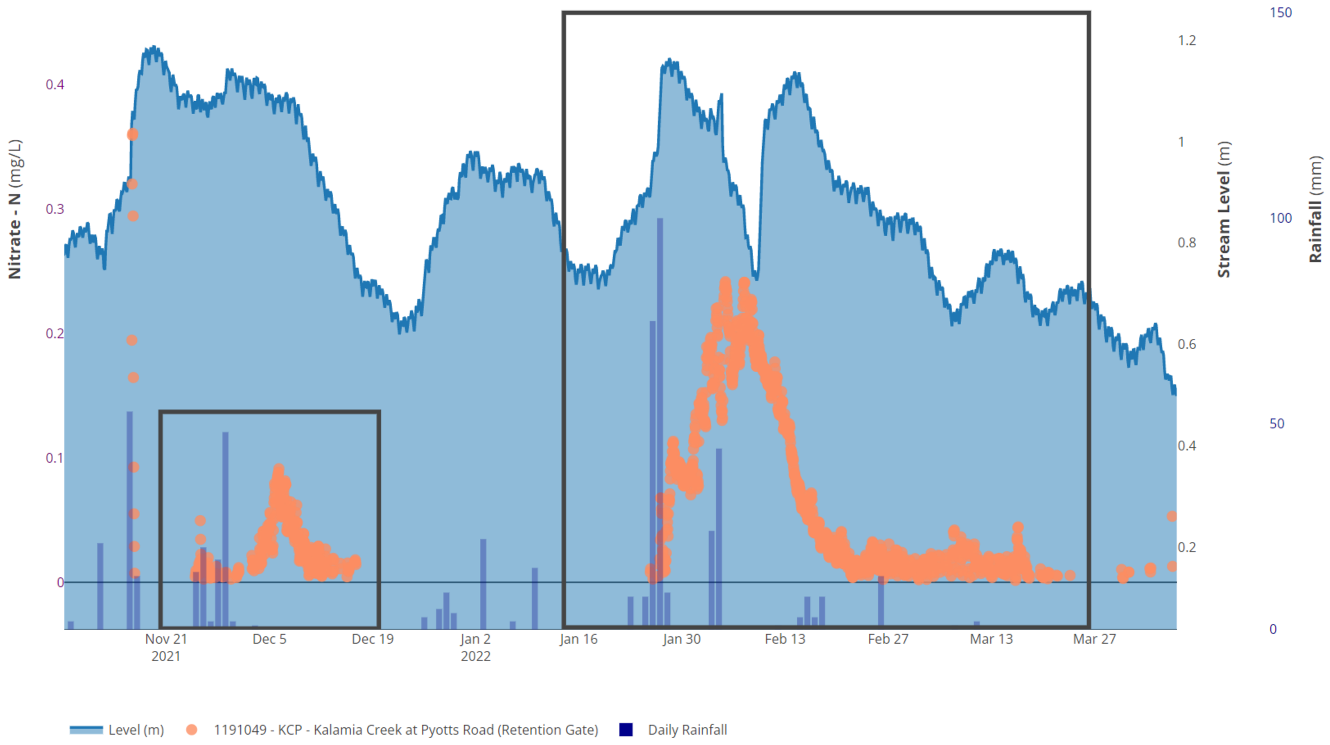

Figure 25 Nitrate concentration shown as a time series for the Kalamia Creek at Pyotts Road (KCP) site highlighting two events of lagged concentration (N- NO_3^-) response to rainfall/water level rise. The rainfall data has been extracted from the rain gauge at Barratta Creek Northcote (119101A).

The upstream site, Kalamia Creek at Lilliesmere Lagoon (KCL), was installed in May 2022 and has provided some good comparison data for nitrate-N concentrations as water flows through this system. Similar in composition to Sheepstation Creek, this system is heavily modified with the irrigation network and is partially fragmented with different lagoons and artificial drain bottlenecks. There is the notable difference that this system captures more of the urban land use from the Ayr township and the Kalamia Sugar Mill. The data from both Kalamia Creek sites indicated a similar pattern to Sheepstation Creek, whereby the upstream site is showing higher concentrations of N-NO_3^- (Figure 26). As was the case in Sheepstation Creek, Kalamia may be monitoring the ecosystem services posed by the system of wetlands that these waters pass through, before discharging into the GBR lagoon.

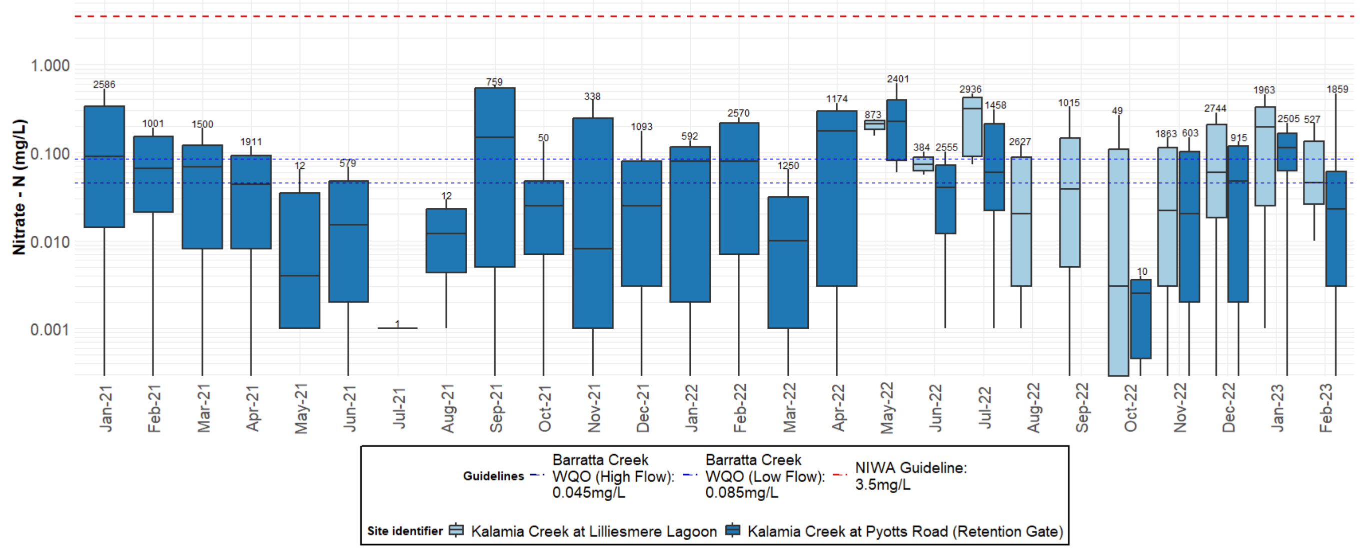

Figure 26: Monthly box and whisker summary plots displaying nitrate-N concentration at the Kalamia Creek monitoring sites. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*
Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Saltwater Creek at Gardiner Road

Saltwater Creek at Gardiner Road (SCG) captures a large catchment, with the site located alongside Lower Burdekin Water infrastructure just upstream of the tidal extent of the creek. The SCG site was positioned upstream of a Lower Burdekin Water sluice gate, meaning that the site's flow regime is anthropogenically influenced and making it difficult at times to see natural response to rainfall in the water level data. The SCG site has encountered issues with the wiper system, which malfunctioned intermittently in 2021 and 2022, resulting in artificially high TSS_{eq} concentrations and gaps in the $N\text{-}NO_3^-$ time-series data.

Data from this site showed that concentrations regularly exceed the WQOs for the system (Figure 27).

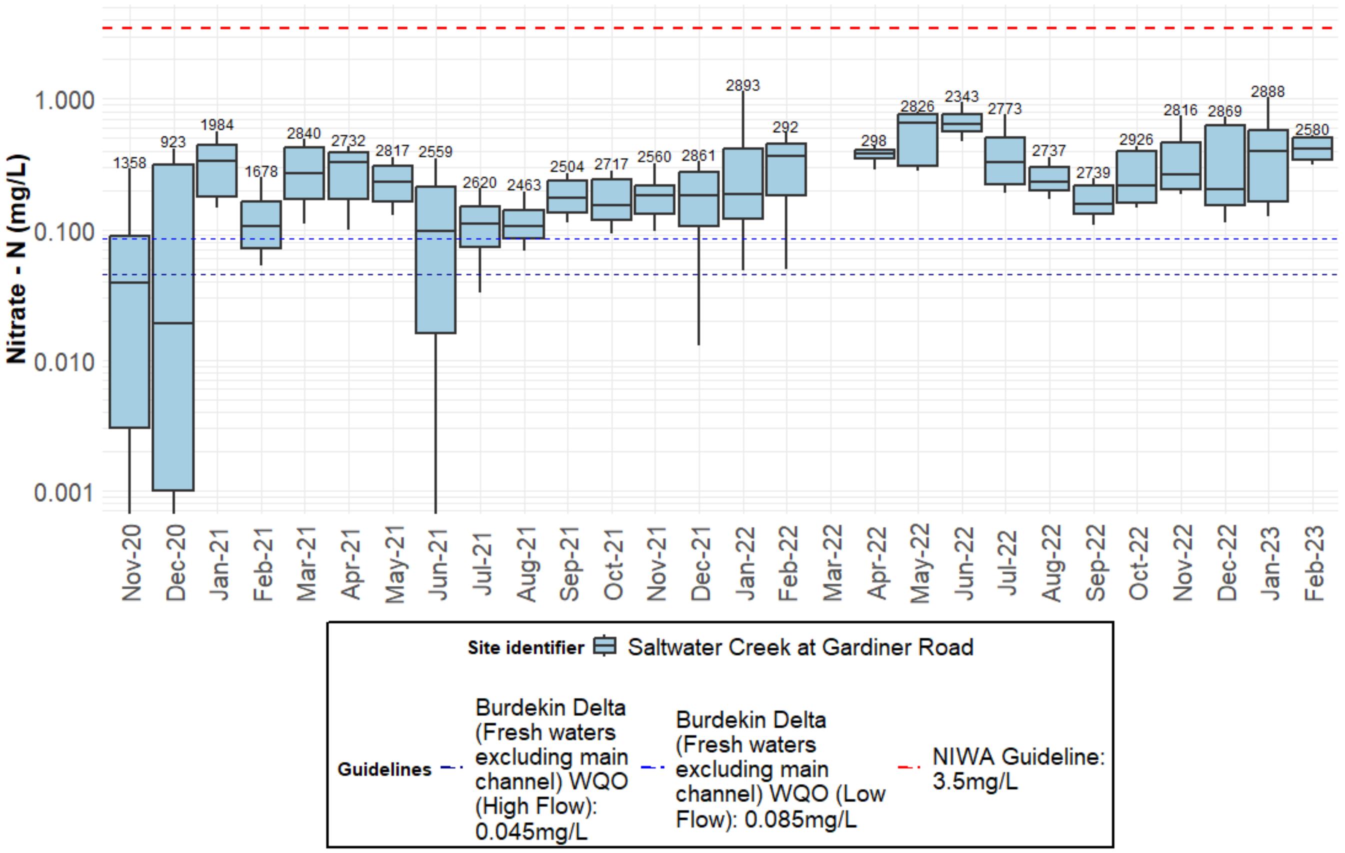

Figure 27: Monthly box and whisker summary plots displaying nitrate-N concentration at the Saltwater Creek at Gardiner Road monitoring site. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Alma Creek at Wallace Road

Alma Creek at Wallace Road (ACW) is the only site in the Alma Creek system and is in the artificial drainage canal running adjacent the natural creek system. The catchment is small, encompassing mostly grazing and sugarcane cropping. The site also likely captures some runoff from the local roads and the Bruce Highway. It is common for channel maintenance work to be carried out at the ACW site throughout the year, as there is a high density of aquatic weeds that regularly require removal.

Installed in November 2020, the ACW site is within a shallow drainage system that overflows to the surrounding wetlands when the water level exceeds ~1.5 m. As the site is on an artificial system adjacent to wetlands, moderate to large rainfall events can result the creek breaking its banks and overflowing into the wetlands. As a result, small increases in water level coupled with significant changes in analyte concentrations are the usual signs of a runoff event.

The ACW site experienced a major technical issue as a consequence of a faulty wiper mechanism, which affected ambient measurements and created a long-term artificial increase in the TSS_{eq} signal. In addition, the ACW site has experienced issues with the Opus sensor itself, which resulted in a gap in TSS_{eq} and $N\text{-}NO_3^-$ data. It has also experienced intermittent telemetry issues due to faulty firmware. Even with these technical issues the program was able to capture many more data points than could be achieved utilising typical grab sampling techniques.

At the ACW site, the median N-NO_3^- concentration (Figure 28) generally lies below the WQO for low flow conditions (0.085 mg/L). Through periods of prolonged rainfall (Figure 5) roughly between November to February for all observed years, median concentrations exceed the WQOs.

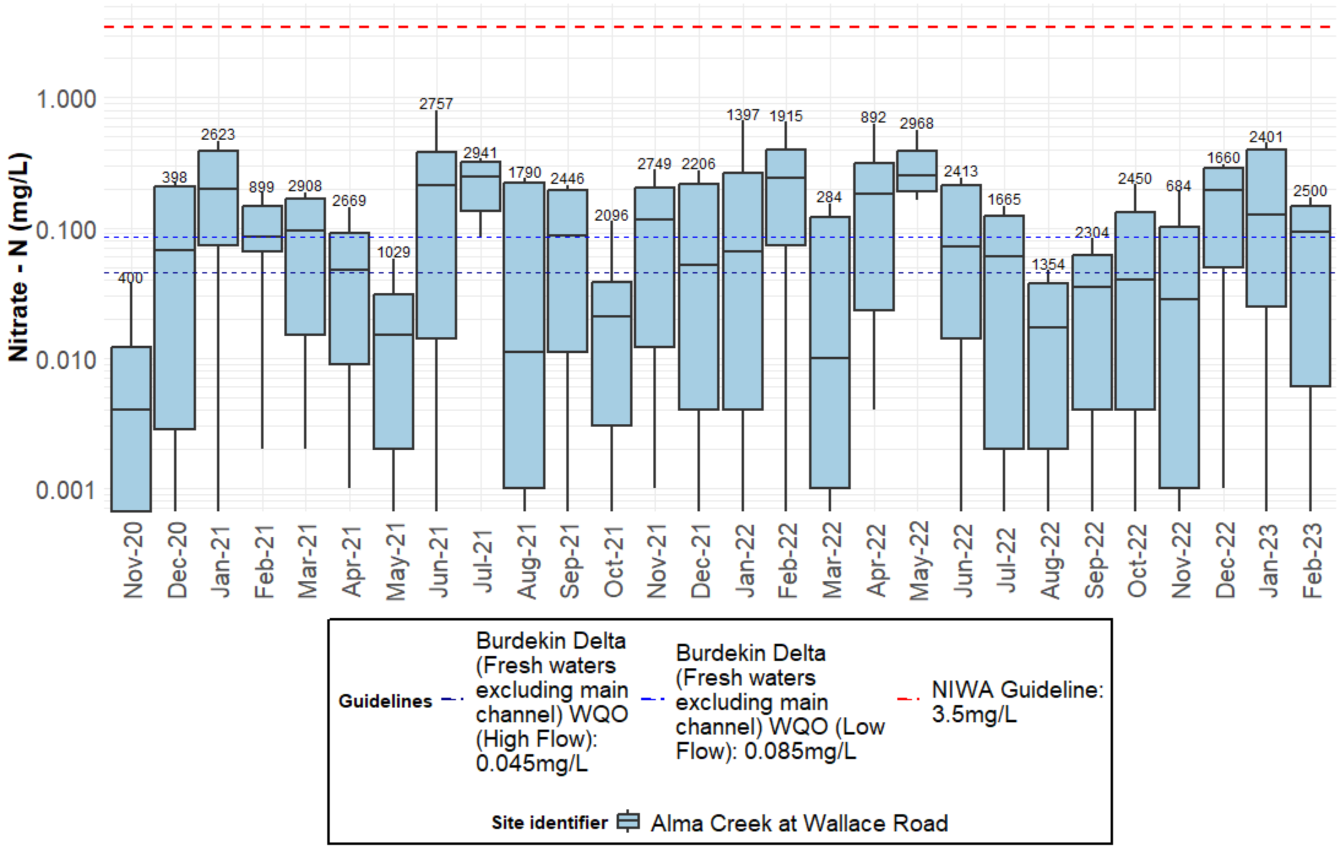

Figure 28: Monthly box and whisker summary plots displaying nitrate-N concentration at the Alma Creek at Wallace Road monitoring site. ***Box and whisker plots have been constructed to facilitate comparison with WQOs and Toxicity guidelines.*** *Numbers above each bar indicate the number of measurements during the month (n).*

Upper whisker: *the maximum value observed.*
Upper box: *the 95th percentile of values observed*
Middle notch: *the median value.*
Lower box: *the 5th percentile of values observed.*
Lower whisker: *the minimum value observed.*

Conclusions and Limitations

An advance in near real-time monitoring of water quality

These data, collected and displayed to the public via 1622wq, demonstrate specific in-stream nitrate-N concentration response to water level rise. These data on their own are valuable and can provide information for natural resource management groups to target remediation or mitigation efforts. They also contribute to the improved understanding of typical nitrate concentrations seen across a range of conditions and sub-catchments in Queensland. The value drawn from the data would be even greater, however, if specific periods of observation could be related to on-ground practice. Much of this knowledge is held by landholders and people in the region, and provision of these data in a digestible and interpretable format will facilitate understanding and appreciation of water quality issues faced in the region for specific stakeholders. There are limitations that need to be considered to contextualise the interim results of the Fine Scale Monitoring program in the Lower Burdekin region. The primary limitation lies in the technical specifications of the sensors and their limited sensitivity for measuring low concentrations.

Technical issues have caused multiple sites to fail periodically; not all were online and functional at the same time, creating gaps in the data series. Additionally, sites may have been partially online, with either the probe or height sensor functioning, causing incomplete data sets, further complicating future interpretation. Real-time monitoring requires the installation of electrical equipment within natural systems, which is fraught with the potential for unforeseen failures and downtime. Replacement equipment lead times from international manufacturers and access constraints have also resulted in data gaps; however, steps are being taken to improve network uptime and minimise this as much as practical. This includes the stocking of replacement equipment so that some technical components may be readily deployed for replacement, modularisation of the electronics setup to facilitate a streamlined replacement procedure, and the identification and remedy of potential weak points of the physical infrastructure installation.

Significant advances have been made in the automated detection of anomalous data points in these data, providing a more robust dataset for the end user. This has also created efficiencies with staff now focussing on manually vetting the more nuanced anomalies and interrogating the datasets for artifacts or trends. The next steps in advancing the utility of these data is to integrate more complex spatial-temporal models that will be able to leverage other sensors in the network to make predictions on water quality parameters, offering potential for in-filling data gaps and improved anomaly detection (Santos-Fernandez et al. 2022). Further to this, the application of methods to automatically delineate event and ambient concentrations will improve the merit of summary statistics for the stream network and facilitate an improved ability to compare events through the year.

What have we learned about the Lower Burdekin Catchment?

Reduced water flow velocity through the riverine system of lagoons would facilitate denitrification in the extensive wetland ecosystems seen in the Lower Burdekin (Eriksson 2001). The monitoring efforts in the Sheepstation Creek, Plantation Creek and Kalamia Creek systems may be better representing the assimilative capacity of these systems with respect to nitrate inputs rather than quantifying net loads (Davis et al. 2014; Xu et al, 2016). Ongoing monitoring in these systems that demonstrate typically low concentrations may benefit from the identification of any significant deviations from the baseline. Should the inputs into these environments exceed the assimilative capacity, the concentrations recorded at the downstream locations will likely show cause for concern. Excessive sediment inputs may also affect wetland processes and reduce the ecosystem services provided. Maintenance and preservation of the wetland ecosystems in the Lower Burdekin catchments will allow the region to benefit from their ecological services to, not just the waterways, but also the receiving environment of the Great Barrier Reef lagoon (Adame et al. 2019; Oza et al. 2021).

The specific climatic conditions over the monitoring period provide a basis for understanding the results, with the program’s commencement coinciding with a three-year La Niña period. Although this may not be an example of the system’s function under normal, ambient conditions, it highlights the risk periods within a wetter year. Additionally, these ENSO events can have a large impact on the overall management, decision-making and productivity of sugarcane growing, but there is little evidence this has extended to nitrogen management strategies (Skocaj et al. 2013). Continuing the monitoring outside of the La Niña oscillation will provide a richer understanding of the system’s function under different ENSO states.

References

Adame, M. F., Arthington, A. H., Waltham, N., Hasan, S., Selles, A., & Ronan, M. (2019). Managing threats and restoring wetlands within catchments of the Great Barrier Reef, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29(5): 829–839 John Wiley and Sons Ltd.

ANZECC & ARMCANZ. (2000). Australian and New Zealand guidelines for fresh and marine water quality / National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines

Australian & Queensland Governments. (2015). Reef 2050 Long-Term Sustainability Plan. The Commonwealth of Australia. Accessed from: https://www.environment.gov.au/system/files/resources/d98b3e53-146b-4b9c-a84a-2a22454b9a83/files/reef-2050-long-term-sustainability-plan.pdf.

Australian Bureau of Statistics. (2018). Land Management and Farming in Australia: 2016-2017 Financial Year. Commonwealth of Australia.

Azizian, M., Boano, F., Cook, P. L. M., Detwiler, R. L., Rippy, M. A., & Grant, S. B. (2017). Ambient groundwater flow diminishes nitrate processing in the hyporheic zone of streams, *Water Resource Research*, 53, 3941–3967.

Bogale, A. (2021). Morphometric analysis of a drainage basin using geographical information system in Gilgel Abay watershed, Lake Tana Basin, upper Blue Nile Basin, Ethiopia. *Applied Water Science* 11, 122.

Bureau of Meteorology. (2023). ENSO Forecast: An alert system for the El Niño–Southern Oscillation. Australian Government, Australia.

Bureau of Meteorology and CSIRO. (2019). A climate guide for agriculture Burdekin, Queensland, *Regional Weather and Climate Guide.*

Calcino, D., Schroeder, B., Panitz, J., Hurney, A., Skocaj, D., Wood, A., & Salter, B. (2022). Australian sugarcane nutrition manual. Sugar Research Australia.

Davis, A. M., Lewis, S. E., O'Brien, D. S., Bainbridge, Z. T., Bentley, C., Mueller, J. F., & Brodie, J. E. (2014). *Water Resource Development and High Value Coastal Wetlands on the Lower Burdekin Floodplain, Australia* (pp. 223–245). https://doi.org/10.1007/978-94-007-7019-5_13.

Department of Agriculture and Fisheries (DAF). (2016). Sugarcane Improved Practices Guide: Burdekin. Queensland Government, Brisbane, Australia.

Department of Environment and Science (DES). (2021). Nitrogen processes – Processes, *WetlandInfo* website. Accessed from: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/processes-systems/nitrogen-concept-model/processes.html.

Department of Environment and Science (DES). (2022). Environmental Protection (Water and Wetland Biodiversity) Policy 2019 – Haughton River Basin Environmental Values and Water Quality Objectives. Queensland Government, Brisbane, Australia.

Department of Environment and Science (DES), (2022), RP232 Fine Scale Water Quality. Queensland Government, Brisbane, Australia.

Department of Environment and Science (DES), Queensland (2022) Floating wetlands, *WetlandInfo* website, accessed 3 March 2023. Available at: https://wetlandinfo.des.qld.gov.au/wetlands/management/treatment-systems/for-agriculture/treatment-sys-nav-page/floating-wetlands/.

Department of Natural Resources and Mines (DNRM), (2017). Lower Burdekin Groundwater Strategy Project: Discussion Paper. Queensland Government, Brisbane, Australia.

Eriksson, P. G. (2001). Interaction effects of flow velocity and oxygen metabolism on nitrification and denitrification in biofilms on submersed macrophytes. *Biogeochemistry*, *55*(1), 29–44.

Grobbelaar J.U. (2009). Encyclopedia of Inland Waters, *Academic Press*.

Hickey C.W. (2013). Updating nitrate toxicity effects on freshwater aquatic species. Report HAM2013-009. *National Institute of Water & Atmospheric Research Ltd*, Hamilton, New Zealand. Available at https://envirolink.govt.nz/assets/Envirolink/1207-ESRC255-Updating-nitrate-toxcity-effects-on-freshwater-aquatic-species-.pdf.

Martínez-Espinosa, C., Sauvage, S., Al Bitar, A., Green, P., Vörösmarty, C., Miguel Sánchez-Pérez, J., (2021). Denitrification in wetlands: A review towards a quantification at global scale, *Science of The Total Environment*, 754.

Mengel, D. (1986). Agronomy Guide: Fertilization – Types and Uses of Nitrogen Fertilizers for Crop Production. *Perdue University Cooperative Extension Service*. West Lafayette, Indiana, United States.

Nearing, M.A., Jetten, V., Baffaut C., Cerdan O., Couturier A., Hernandez M., Le Bissonnais Y., Nichols M.H., NIWA (National Institute of Water & Atmospheric Research Ltd) (2014) Nitrate toxicity guidelines for the National Objectives Framework (https://niwa.co.nz/freshwater/freshwater-update/freshwater-update-60-february-2014/nitrate-toxicity-guidelines-for-the-national-objectives) accessed November 2022.

Nunes J.P., Renschler, C.S., Souchère, V., van Oost, K. (2005). Modelling response of soil erosion and runoff to changes in precipitation and cover. *Catena*. 61(2–3): 131-154.

Oza, T. M., Lane, R., Adame, M. F., & Reef, R. (2021). Coastal wetland management in the Great Barrier Reef: Farmer perceptions. *Geographical Research*, *59*(4), 537–553. https://doi.org/10.1111/1745-5871.12497

Petersen, R. J., Blicher-Mathiesen, G., Rolighed, J., Andersen, H. E., & Kronvang, B. (2021). Three decades of regulation of agricultural nitrogen losses: Experiences from the Danish Agricultural Monitoring Program. *Science of the Total Environment*, *787*. https://doi.org/10.1016/j.scitotenv.2021.147619

Santos-Fernandez, E., Ver Hoef, J. M., Peterson, E. E., McGree, J., Isaak, D. J., & Mengersen, K. (2022). Bayesian spatio-temporal models for stream networks. Computational Statistics and Data Analysis, 170. https://doi.org/10.1016/j.csda.2022.107446

Shishaye, H. A., Tait, D. R., Maher, D. T., Befus, K. M., Erler, D., Jeffrey, L., Reading, M. J., Morgenstern, U., Kaserzon, S., Mueller, J., & De Verelle-Hill, W. (2021). The legacy and drivers of groundwater nutrients and pesticides in an agriculturally impacted Quaternary aquifer system. Science of The Total Environment, 753, 142010. https://doi.org/10.1016/j.scitotenv.2020.142010.

Skocaj D., Everingham Y., & Schroeder B. (2013). Nitrogen Management Guidelines for Sugarcane Production in Australia: Can These Be Modified for Wet Tropical Conditions Using Seasonal Climate Forecasting? *Springer Science Reviews* 1:51–71.

Sinclair Knight Merz, (2009). Groundwater science plan – A science plan for the sustainable management of the Lower Burdekin. *Sinclair Knight Merz Pty Ltd*, Melbourne.

Sun, C., Chen, L., Zhu, H., Xie, H., Qi, S., & Shen, Z. (2021). New framework for natural-artificial transport paths and hydrological connectivity analysis in an agriculture-intensive catchment. *Water Research*, 196 (15): 117015.

Thorburn, P., Biggs, J., Webster, A,. & Biggs, I. (2011). An improved way to determine nitrogen fertiliser requirements of sugarcane crops to meet global environmental challenges. Plant and Soil. 339. 51-67.

Wang, H., Gao, J.E., Li, X.H., Zhang, S.L., & Wang, H.J. (2015). Nitrate Accumulation and Leaching in Surface and Ground Water Based on Simulated Rainfall Experiments*. PLoS One*. 20;10(8):e0136274.

Weaver, D., Reed, A., Grant, J., (2001). Relationships Between Stream Order and Management Priority: a Water Quality Case Study. In *proceedings of the Third Australian Stream Management Conference*, eds Rutherfurd, I., Sheldon, E., Brierley, G. and Kenyon, C. August 27-29, 2001, Brisbane, pp 647-652.

Webster, A. J., Bartley, R., Armour, J. D., Brodie, J. E., & Thorburn, P. J. (2012). Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems. *Marine Pollution Bulletin*, *65*(4–9).

World Health Organisation (WHO). (1998), Guidelines for drinking-water quality, 2nd ed. Addendum to Vol. 2. *Health criteria and other supporting information.*

Xu, Z., Yang, Z., Yin, X., Cai, Y., & Sun, T. (2016). Hydrological management for improving nutrient assimilative capacity in plant-dominated wetlands: A modelling approach. *Journal of Environmental Management*, *177*, 84–92.