Towards the standardisation of bioavailable particulate nitrogen in sediment methods

Final report

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Disclaimer

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Executive Summary

Recent research has indicated that eroded sediment from grazing catchments may contribute a significant proportion of end-of-catchment dissolved inorganic nitrogen (DIN) loads to the Great Barrier Reef (GBR), and is also a source of significant quantities of DIN generated in marine event plumes (Garzon-Garcia *et al.*, 2018a; Lewis *et al.*, 2018). Further, it has been demonstrated that algae in both freshwater and marine environments will grow when exposed to the nutrients associated with eroded sediments (Franklin *et al.*, 2018; Garzon-Garcia *et al.*, 2018b) which suggests that eroded sediment may be an important contributor of bioavailable nutrients to the GBR. Together this new evidence shifts the conceptual understanding of nutrient cycling in grazed GBR catchments and how it is represented in modelling and monitoring programs and highlights the need to track the effectiveness of on-ground remediation at reducing bioavailable particulate nitrogen (BPN) (Garzon-Garcia *et al.*, 2018a; Waterhouse *et al.*, 2018).

Methods utilised in recent BPN research are lab-intensive, time critical, and are not logistically feasible to implement more broadly across routine monitoring programs. It was therefore proposed to undertake a methods standardisation phase in order to develop equations that could be used to estimate BPN from standard water quality monitoring parameters across monitoring programs at a range of spatial scales (e.g. gully monitoring or end of catchment river monitoring).

There has been a significant investment of resources to manage fine sediment eroding from grazing lands through the Landholders Driving Change Burdekin Major Integrated Project (MIP; funded by the Queensland Government through the Queensland Reef Water Quality Program), in particular towards rehabilitating gullies (e.g. Strathalbyn, Mt Wickham, and Strathbogie in the Burdekin Catchment). Further investments made through the National Environmental Science Programme (NESP Tropical WQ Hub Projects 3.1.7 led by Andrew Brooks and 2.1.4/ 5.9 led by Rebecca Bartley) and at other sites through the MIP and Queensland Government Paddock to Reef Program have been undertaken to monitor the effectiveness of management interventions at reducing fine sediments. The inclusion of monitoring and evaluation of BPN reductions from erosion management at these sites is a step towards reporting on DIN reductions and Reef Plan water quality targets for DIN in grazing lands.

The objectives of this project were:

1. To develop standardised method recommendations for BPN monitoring based on 2018/19 wet season event monitoring across a range of scales.

2. A preliminary analysis of 2018/19 wet season BPN monitoring data from gully rehabilitation sites. This component contributes to assessing the effectiveness of gully rehabilitation techniques and advancing modelling related to this activity.

Standardised method recommendations for BPN monitoring

BPN is composed of the following nitrogen (N) pools: 1. Solubilised DIN; 2. Mineralisable particulate organic nitrogen (PON) and dissolved organic nitrogen (DON) and 3. Desorbed ammonium-N (Figure 1).

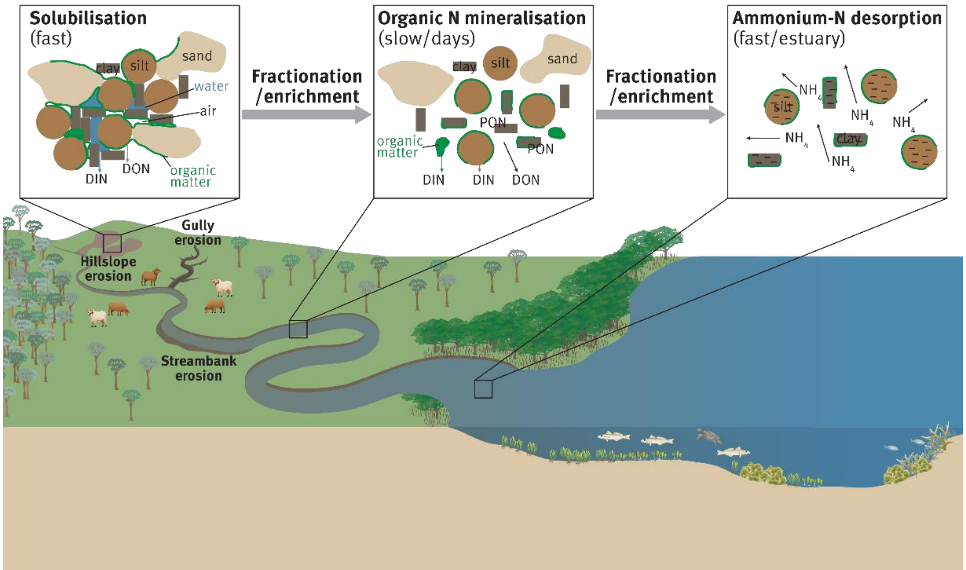


Figure 1. Processes that generate bioavailable particulate nitrogen from erosion in catchments and associated bioavailable particulate nitrogen pools.

Solubilised DIN pool*:* This pool is already measured as part of the monitored DIN (nitrate-N + ammonium-N), however not all of the monitored DIN in-stream or end-of-catchment may necessarily have been generated from eroded soil. Additional sources may include groundwater, rainfall inputs through direct runoff and cattle fodder supplementation (e.g., urea licks). Understanding what proportion of the monitored DIN is contributed by sources other than BPN is necessary to fully understand DIN export in grazing (and agricultural) catchments.

Mineralisable PON and DON pools (PMN): We found that variations in these processes due to climate and catchment conditions combined with the logistical challenges of transporting samples to the lab in an appropriate timeframe mean that it is challenging and expensive to develop equations to confidently predict these pools from standard monitoring parameters. A more cost effective way forward is to benchmark lab-determined PMN against routinely measured water quality parameters in research projects associated with gully rehabilitation projects and catchment nutrient tracing. This would allow development/validation of equations that allow PMN to be predicted for a wide range of conditions.

Organic carbon: We recommend that monitoring of particulate and dissolved organic carbon be included in monitoring programs as it is an important indicator of nutrient bioavailability and gully rehabilitation effects. Adding these parameters would increase current monitoring costs by 8-15%.

Desorbed ammonium-N: We recommend that adsorbed ammonium-N is monitored and quantified in the lab using the method developed and validated in field programs in this project (see Appendix 1) as part of the GBR Catchment Loads Monitoring Program (initially in predominantly grazing catchments) and as part of gully rehabilitation projects. Direct measurement of this parameter is simple, has high confidence and is likely to be more cost effective than validating the equations developed in this project and extending the work to other catchments and or multiple wet seasons to improve the confidence in the equation. Adding this parameter would increase current monitoring costs by 5-10%.

Gully rehabilitation monitoring recommendations

For this project gullies at Strathalbyn, Mt Wickham and Strathbogie (Burdekin Catchment) and at Croc Station (Normanby Catchment) were monitored. At the time of reporting, flow data for these sites were unavailable and only monitored concentration data are reported. These data only cover one wet season for most sites as part of this interim BPN study (except for Croc Station) and therefore only reflect the short-term effects of rehabilitation on water quality. These results are to be considered preliminary and should not be used as conclusive findings with respect to the effectiveness of gully rehabilitation techniques. For this reason, we have not included any interpretation of the results in this report but provide some preliminary observations below with further observations and concentration plots in Appendix 2.

General observations include:

- The majority of carbon, nitrogen and phosphorus in gully outlets is particulate
- The majority of dissolved nitrogen is dissolved organic nitrogen (DON)
- Adsorbed NH_4-N can be a significant BPN fraction (can be larger than water soluble ammonium)
- In all sites studied (Mt Wickham, Strathalbyn and Croc station) there were effective reductions in the concentrations of total and particulate carbon, particulate nitrogen and particulate phosphorus with gully treatments. In contrast, the effect of treatment on sediment quality (i.e. the content of carbon, nitrogen or phosphorus in a particular mass of sediment) varied. This suggests that in order to understand the effectiveness of gully rehabilitation it is important to be able to calculate yields rather than concentrations alone. It also indicates that sediment quality maybe an important indicator of the effect of gully rehabilitation.
- The reduction of the dissolved fractions was not as effective. Although the total concentrations of nutrients were reduced, at some sites the most bioavailable nutrient fraction concentrations were increased for some treatments. This indicates soil amendments may have an effect on the bioavailable nutrients exported from gully treatments.
- Erosion treatment options that include soil amendments will require additional/stricter monitoring of both short-term (immediate, plus early wet seasons) and longer-term (four to five wet seasons down the track) nutrient runoff monitoring. Ideally, the effect of treatments on soil health within gully systems would also be incorporated as part of future gully rehabilitation project monitoring. This would generate enhanced understanding of the effects of gully rehabilitation treatments on downstream water quality and particulate nutrient bioavailability.

Based on the experience of processing and analysing BPN and water quality samples from gully rehabilitation projects over the 2018-19 wet season, we have made a number of recommendations relating to experimental design and sampling strategy in this report. It is important to note that a minimum of four years of monitoring of BPN and other water quality parameters is required to determine the effectiveness of gully management strategies. A longer time may be needed for nutrients as soil amendments made during rehabilitation can be expected to change sediment quality over time.

Contents

Background

Recent research has indicated that eroded sediment from grazing catchments may contribute a significant proportion of end-of-catchment dissolved inorganic nitrogen (DIN) loads to the Great Barrier Reef (GBR), and is also a source of significant quantities of DIN generated in marine event plumes (Garzon-Garcia *et al.*, 2018a; Lewis *et al.*, 2018). The understanding of DIN generation from the erosion of sediment, referred to from here on as ***bioavailable particulate nitrogen*** (BPN), was determined through laboratory and field experiments undertaken during focused research projects (RP128G, RP178a, NESP 2.1.5) (Burton *et al.*, 2015; Garzon-Garcia *et al.*, 2017; Garzon-Garcia *et al.*, 2018a; Garzon-Garcia *et al.*, 2018b). These studies also highlighted the need to track the effectiveness of management at reducing BPN (Garzon-Garcia *et al.*, 2018a; Waterhouse *et al.*, 2018). However, the methods used in the research projects are not logistically possible to implement across monitoring programs. It was therefore proposed to undertake a methods standardisation phase in order to develop a methodology for estimating BPN that can be adopted consistently across monitoring programs at a range of spatial scales.

There has been a significant investment of resources to manage fine sediment eroding from grazing lands through the Landholders Driving Change Burdekin Major Integrated Project (MIP; funded by the Queensland Government through the Queensland Reef Water Quality Program), in particular towards rehabilitating gullies (e.g. Strathalbyn, Mt Wickham, and Strathbogie in the Burdekin Catchment). Further investments at these sites (including National Environmental Science Programme - NESP - Tropical WQ Hub Projects 3.1.7 led by Andrew Brooks and 2.1.4/ 5.9 led by Rebecca Bartley) and at other sites through the MIP and Queensland Government Paddock to Reef Program (e.g. GBR Catchment Loads Monitoring Program) have been undertaken to monitor the effectiveness of management interventions at reducing fine sediments. The inclusion of monitoring and evaluation of BPN reductions from erosion management at these sites would be a step towards reporting on DIN reductions and Reef Plan water quality targets for DIN in grazing lands (Queensland Government, 2013).

Objectives

In this report, we present:

1. Standardised method recommendations for BPN monitoring based on 2018/19 wet season event monitoring across a range of scales by teams running the current projects indicated in Table 1.

2. A preliminary analysis of BPN monitoring data from gully rehabilitation sites obtained during the 2018/19 wet season, which contributes to assessing the effectiveness of gully rehabilitation techniques and advancing modelling related to this activity.

Methods

Working hypotheses

It was envisaged that the standard water quality parameters plus organic carbon and particle size measurements could be used to estimate BPN. This would be a practical and cost effective alternative to the adoption of the methods that have been applied in research projects (for a full description of methods see (Garzon-Garcia *et al.*, 2018a)).

BPN is composed of the following nitrogen (N) pools:

1. Solubilised DIN - fast occurring process at source in which the DIN (all the NO_3^- N and the fraction of the NH_4^+-N not adsorbed onto sediment) in the eroded soil pore water and leached from the soil and litter enters the aquatic environment via runoff. This fraction will be transported to the stream system irrespective of the bulk soil being delivered.

2. Mineralisable particulate organic nitrogen (PON) and *dissolved organic nitrogen (DON) (Potential mineralisable nitrogen - PMN)* - This is a slow occurring process with a timeframe of days to weeks (depending on the length of time sediment is in suspension and or water travel time) in which the organic fraction of particulate N associated with the eroded sediment and the organic fraction of dissolved N that has been mobilised from eroded soil, vegetation litter or microbial processes are mineralised to DIN during stream transport by the action of micro-organisms (bacteria and fungi). A fraction of the DON may be directly bioavailable to phytoplankton without the need to be mineralised.

3. Desorbed ammonium-N - This is a physico-chemical process in which the ammonium ion (NH_4^+) adsorbed to negatively charged silt and clay particles in eroded sediment is desorbed (becomes soluble) through exchange processes with other ions in water. This process is particularly likely to occur when terrestrial sediment enters saline water containing high concentration sodium and magnesium in the estuaries.

The DIN at source (i.e. pool 1 above) is already measured as part of the monitored DIN (nitrate-N + ammonium-N), and hence this fraction is not included in the method standardisation. It is important to note that not all of the monitored DIN in-stream or end-of-catchment may necessarily be from this source. Additional sources may include groundwater, rainfall inputs through direct runoff and cattle fodder supplementation (e.g., urea licks). Understanding what proportion of the monitored DIN is contributed by sources other than BPN is necessary to fully understand DIN export in grazing (and agricultural) catchments.

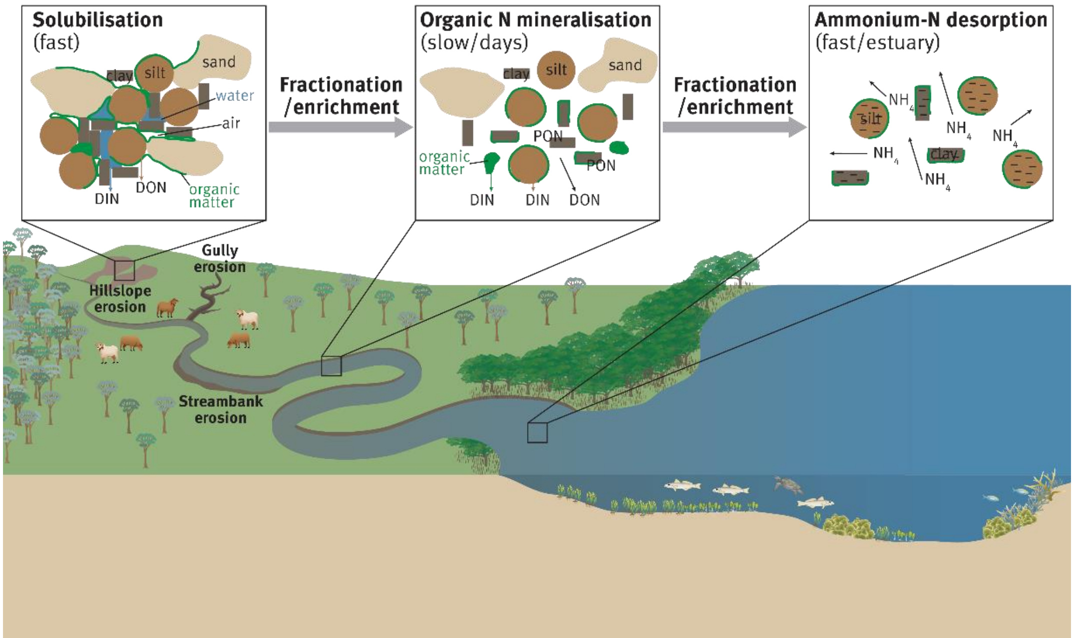


Figure 1. Processes that generate bioavailable particulate nitrogen from erosion in catchments and associated bioavailable particulate nitrogen pools

Sampling

Water quality samples during the 2018/19 wet season (December - April) were taken for several sites in two different catchments with the support of field teams indicated in Table 1. The lab where water quality parameters and particle size were analysed is also presented in Table 1.

Table 1. Details for water quality and bioavailable particulate nitrogen samples taken during the 2018/19 wet season

Sampling site	Catchment	Sub-catchment	Sampling support	Linked projects	WQ parameters	Particle size	Sampling method
Mt Wickham	Burdekin	Bowen River (Sandalwood creek)	NQ Dry Tropics, TropWater lab JCU	NESP 2.1.4 (Bartley et al.)	Chem Centre DES - TropWater	TropWater (ALS)	Automated
Strathbogie	Burdekin	Bogie River (Capsize creek)	NQ Dry Tropics, TropWater lab JCU	NESP 2.1.4 (Bartley et al.)	Chem Centre DES	Chem Centre DES	Automated
Strathalbyn	Burdekin	Bonnie Doon creek	Greening Australia	NESP 3.1.7 (Brooks et al.)	Chem Centre DES	Chem Centre DES	Automated
Croc Station	Normanby	Laura River	NESP 3.1.7	NESP 3.1.7 (Brooks et al.)	Chem Centre DES	Chem Centre DES	Automated
Inkerman	Burdekin EoC	n/a	NESP 5.8, WQI/DES, BBIFMAC	NESP 5.8 (Lewis et al.)	Chem Centre DES	Chem Centre DES	Manual grab
Normanby marine plumes	Normanby	n/a	Howley Environmental Consulting, CYWMP		TropWater	TropWater (ALS)	Manual grab

The aim was to obtain samples for three events for each site during the wet season, with the best possible cover across the hydrograph (three samples: rising, peak and falling stages) to analyse BPN in addition to the more traditional water quality parameters, total and dissolved carbon and particle size.

Samples were collected using the selected methods for sampling water quality parameters at each site, which included: manual/grab sampling and automated (ISCO system) sampling (Table 1).

Sample processing and laboratory analysis

BPN samples were treated as follows:

- Mineralisable PON and Mineralisable DON – A 1L representative sample was refrigerated as soon as possible after collection and submitted to the Chemistry Centre lab at Department of Environment and Science (DES), ideally within 48 hours. This sample was then divided in four and incubated in the laboratory at 25°C in a shaker incubator to quantify DIN at day 0, 1, 3 and 7. The mineralisation of organic nitrogen at 1, 3 and 7 days was quantified by subtracting DIN measured at the start of the incubation (0 day) from DIN measured at each of the corresponding days, and is designated as potentially mineralised N at 1 (PMN 1), 3 (PMN 3) and 7 (PNM 7) days (see detailed method in Appendix 1). This experiment could not attribute how much of the DIN mineralised is sourced from PON or DON, but integrated the outcome of both processes together, which is what occurs during in-stream transport.
- Adsorbed ammonium-N – An extraction of the adsorbed ammonium was to be carried out within 48 hours of initial sample collection, ideally in the field or as soon as the sample was delivered to an intermediary lab. The process comprised adding a water subsample into a 50 mL tube containing K_2SO_4 salt to obtain a final 0.5 M solution, extracting for 10 minutes, filtering to <0.45 μm and freezing the sample for submission to the DES Chemistry Centre lab to analyse for ammonium-N. The adsorbed ammonium was calculated by subtracting the water-soluble ammonium-N (i.e., the NH_4-N component of DIN) from the extracted ammonium-N for the corresponding sample (see detailed method in Appendix 1). Although this process was the ideal one, it was suggested to the sampling teams that if it was too difficult to filter the sample in the field or lab in the desired timeframe, they could submit the extracted sample frozen to the DES Chemistry Centre lab for filtering there. The last option was for extraction and filtration to be carried out on frozen samples (as collected) at the DES Chemistry Centre lab.

Most of the water quality parameters were analysed at the DES Chemistry Centre lab with some exceptions (Table 1). The parameters were: total suspended solids (TSS), total organic carbon (TOC), dissolved organic carbon (DOC), total Kjeldahl nitrogen (TKN), dissolved Kjeldahl nitrogen (DKN), ammonium-N (NH_4^+-N), nitrogen oxides-N (NO_x-N), total Kjeldahl phosphorus (TKP), dissolved Kjeldahl phosphorus (DKP), dissolved reactive phosphate-P (DRP) and various particle size distribution metrics using a laser sizer [D50 (μm), D90 (μm), % <16 μm, %<63 μm and surface area ($m^2 kg^{-1}$)]. Most of these parameters are routinely measured as part of water quality programs like the GBR Catchment Loads Monitoring Program and detailed methods for their analysis can be found in their reports (viz. (Wallace *et al.*, 2015)). Some additional water quality parameters were calculated from the former (see Appendix 1 for methods) including particulate nitrogen (PN), particulate organic carbon (POC), particulate phosphorus (PP), dissolved organic nitrogen (DON), dissolved organic phosphorus (DOP); and some ratios including POC:PON, DOC:DON, DIN:DRP and DOC:DIN. The carbon parameters are not routinely measured, and methods are presented in Appendix 1. The particle size methods varied slightly depending on the lab/project carrying out the analysis (Table 1 and Appendix 1).

Data analysis

Method standardisation

A multivariate analysis was carried out using the dataset collected during the 2018/19 wet season to determine if it is possible to predict the more complex to sample and measure BPN parameters [mineralisable PON + mineralisable DON (PMN) and adsorbed ammonium-N], from water quality parameters that are routinely measured or that could be included as part of current monitoring programs. The multivariate analysis was carried out for parameters reported in concentration (mg/L) and also for these parameters normalised by TSS and reported as mg/kg.

The multivariate analysis method was an all-subsets step-up regression using the Leaps package in R (Lumley, 2017) to determine which combination of water quality parameters measured on a water sample best estimated each of the BPN parameters. This type of regression tests all the possible combinations of parameters and reports on the best subsets for each size (number of explanatory variables used in the regression). The multiple linear model with a significant regression for all parameters ($p<0.05$) and the best adjusted R^2 was selected, considering the latter measure is an unbiased estimator of the model fit and allows comparison of R^2 between regressions with different numbers of variables. The selection also considered that the number of water quality parameters in the equation was reasonable (preferably less than 3) and that the combination of parameters and the type of relationship with the BPN parameter (positive or negative) made sense in terms of the biogeochemical processes that may be driving it. The predictive R^2, a measure that estimates how well the model predicts responses for new observations, was calculated for the selected models. This measure is calculated by systematically removing each observation from the data set, estimating the regression equation, and determining how well the model predicts the removed observation.

The water quality parameters used in the multivariate analysis were: TSS, POC, PN, PP, DOC, DON, DOP, NH_4^+-N, NO_x-N, PO_4^{-2}-P, POC:PON, DOC:DON, DIN:PO_4^{-2}-P, DOC:DIN, D50, D90, % <16 μm, %<63 μm and sediment surface area.

Gully rehabilitation monitoring

Data were grouped by sampling site to present a comparison of the main water quality parameters (carbon, nitrogen and phosphorus) in terms of their fractions (particulate, dissolved and bioavailable) between sampled control and treatment gully sites for the 2018/19 wet season. We also included BPN data sampled during the 2017/18 wet season for Croc Station (collaboration with NESP 3.1.7 Brooks *et al.*). Data are presented using box-plots. Flow data were not available and there were very limited sampling points per event, hence loads and yields could not be calculated. Additionally, these data only cover one or two wet seasons and time since treatment varies between gully sites, but is generally less than 3 years and may still represent short-term effects of rehabilitation techniques on water quality. ***These results are to be considered as preliminary only and should not be used to obtain conclusive findings with respect to gully rehabilitation techniques***. Longer-term monitoring and load and yield calculations are required for this evaluation.

Results and Discussion

Method standardisation

Sampling and lab processing

Samples from 7 projects/sites were received for BPN and water quality analysis at the DES Chemistry Centre lab (Table 2). For the four gully rehabilitation sites, the number of sampled treatments and gully types present are indicated in Table 2. Between 1 and 3 events were sampled at each site (Table 2). In total, 82 adsorbed ammonium-N samples were analysed and 57 PMN incubations experiments were carried out to obtain PMN at 1, 3 and 7 days (Table 2). Unfortunately, water quality parameter results for the Normanby marine plumes were not available when this report was prepared (note that these analyses were not conducted by the DES Chemistry Centre lab), and BPN samples from this project could not be included as part of the step-up regression analysis.

For the majority of samples, adsorbed ammonium-N was extracted and filtered in the field (66% of samples). In fewer cases, the sampling teams carried out the extraction in the field and froze the sample to be filtered at the DES Chemistry Centre lab (18% of samples). For the remaining samples (16%), the full extraction process was carried out in the DES Chemistry Centre lab. The 34% of samples that were not fully extracted and filtered in the field corresponded mostly to samples coming from the Normanby catchment where the remoteness of sampling sites made it difficult to get samples to an intermediary lab within the stipulated timeframe. Filtering of the Burdekin extracted samples was carried out in the TropWater lab within 48 hours, before submission of the filtrate to the DES Chemistry Centre for analysis.

It was very difficult to get the samples for PMN incubation to the lab in the desired 48-hour timeframe. Only 5 of the 57 samples arrived at the lab and were incubated in less than 48 hours. On average the time between incubation and sampling time was 5 days and 31 samples were incubated as late as 7 days after sampling. This has important implications for the validity of the data. Even though the samples were refrigerated within 48 hours of sampling, it is possible that there were some chemical and/or biological reactions during transport due to the fact that samples sent with ice or ice bricks are unlikely to be maintained at <4°C during the whole transport time.

Table 2. Bioavailable particulate nitrogen sampling summary details for the 2018/19 wet season

Type of site	Sampling site	Treatments	Gully type	Time since treatment	No. Events	Adsorbed NH4-N samples	PMN samples
Gully remediation site	Mt Wickham	Control and 1 treatment	Hillslope + alluvial	1 year	Control: 2, Treat: 2	21	11
Gully remediation site	Strathbogie	Control	Hillslope	1 year	Control: 1 event	4	6
Gully remediation site	Strathalbyn	Control and 3 treatments	Alluvial	Treat 1: 2 years Treat 4: 1 year	Control: 2, Treat1: 2, Treat4: 2, Treat6: 1	13	20
Gully remediation site	Croc Station	Control and 2 treatments	Alluvial	Treat 1: 3 years Treat 2: 2 years	Control:2, Treat: 2	10	0
End of catchment	Burdekin EoC Inkerman	n/a	n/a	n/a	2	16	12
Marine flood plume	Normanby marine plumes	n/a, Annan-Endeavour River, Kennedy River, Normanby River, Pascoe River	n/a	n/a	3	17	0
					Total	81	49

Estimation of adsorbed ammonium-N

It was possible to obtain a relatively good multiple linear regression to predict adsorbed ammonium-N for Burdekin River catchment water samples (omitting samples from the Normanby catchment). We selected the equation described in Table 3 from the step-up regression analysis outputs.

Table 3. Multiple linear equation parameters and fit to predict adsorbed ammonium-N for Burdekin River catchment water samples

Predicted variable	Parameter 1	Parameter 2	b	RSE	adjusted r^2	predictive r^2
Adsorbed NH_4-N	+5.543e-7 TSS**	+1.322e-3 DOC/DON***	-1.046e-2*	0.02	0.56	0.51

(***) p<0.001, (**) p<0.01, (*) p<0.05

The units of all equation paremeters are in mg L^{-1}

The equation described in Table 3 allows the estimation of the concentration of adsorbed ammonium-N in a water sample, and shows that this concentration is dependent on the concentration of TSS in the sample and on the ratio of DOC to DON. The latter ratio has been found to be correlated to the lability (ease to biological degradation) of the DON fraction (Garzon-Garcia *et al.*, 2018a), which may have a role in the equilibrium between the soluble and adsorbed ammonium-N phases.

Although the equation fit is relatively good, when comparing the measured values against the predicted values (Figure 2), it can be observed that the equation tends to under-predict the adsorbed ammonium-N by 28% on average.

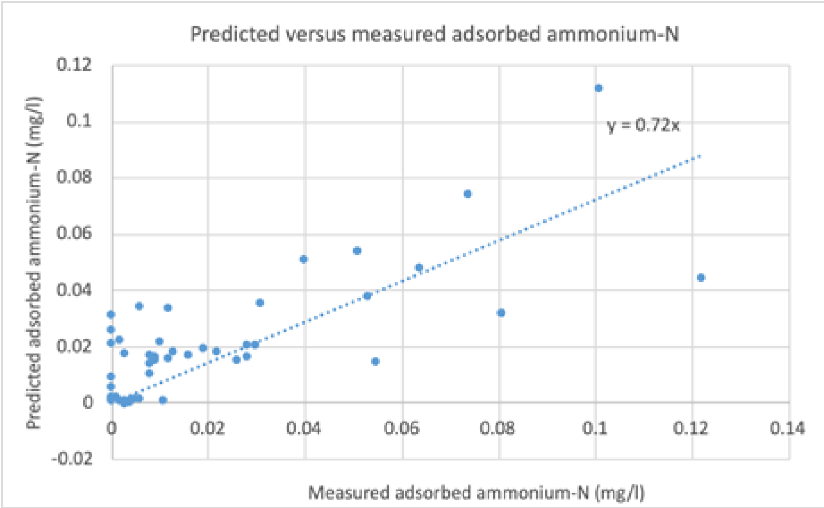


Figure 2. Origin-forced linear regression between modelled adsorbed NH_4-N using parameters in Table 3 [TSS (mg/l) and DOC : DON] and measured adsorbed NH_4-N for all samples obtained in the Burdekin River catchment (from gully rehabilitation sites to end-of-catchment) (see Table 1 and Table 2)

Additionally, it is possible that this equation would only work for the Burdekin catchment and so it would need to be tested for other catchments and for marine sediment plumes.

Estimation of potential mineralisation of organic nitrogen (PMN)

As noted earlier, the remoteness of the Cape York catchment made it difficult to obtain samples for estimating the potential mineralisation of organic N (PMN) due to the necessity of transporting them refrigerated to the laboratory within 48 hours. As a result, all samples used for estimation of PMN were from the Burdekin catchment.

Measured PMN on Burdekin samples indicated that during this wet season there was a tendency for net immobilisation of DIN in freshwater samples. This contrasts with PMN results for a data set of 41 lab-generated sediments (<10 µm) sourced from different soil types, land uses and surface and subsurface soils from the Bowen catchment (Garzon-Garcia *et al.*, 2018a) that predominantly indicated net mineralisation.

We obtained good predictive power for the PMN measured on this wet season data, noting that it was mostly negative (immobilisation). The three equations selected as the best fit from the step-up regression analysis outputs are described in Table 4.

Table 4. Multiple linear equation parameters and fit to predict the potential mineralisation of organic N in 1 (PMN1), 3 (PMN3) and 7 days (PMN7) for Burdekin River catchment water samples

Predicted variable	Parameter 1	Parameter 2	Parameter 3	b	RSE	adjusted r^2	predictive r^2
PMN1	-0.005 DOC***	-0.039 NOx**		5.357	139.3	0.69	0.55
PMN3	-0.0286 DOC***	-0.075 NOx***	+ 0.25 DON***	-48.953	198.7	0.82	0.71
PMN7	-0.146 DOC***		+0.43 DON***	-42.167	184.4	0.87	0.84

(***) p<0.001, (**) p<0.01, (*) p<0.05

The units of all equation paremeters are in mg kg^{-1} of sediment

PMN1 inversely depends on the content of DOC and NOx-N per kg of sediment in the water sample. DOC (the soluble fraction of POC) has been found to correlate with the ease of degradability (lability) of the POC and PON (Garzon-Garcia *et al.*, 2014), with higher content indicating more lability and lower contents less lability. NOx-N availability to microorganisms would reduce the need to mineralise PON and DON to obtain mineral N sources.

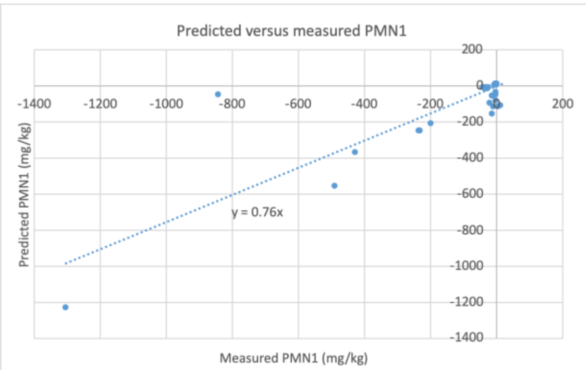
PMN3 can be estimated using the same parameters and similar relationships to estimate PMN1 with the addition of DON and PMN7 can also be estimated using DOC, but instead of NOx-N using DON. This result suggests that at longer timeframes the mineralisation or immobilisation of N is not driven by the direct availability of mineral sources (DIN), but rather by the lability of the organic N sources.

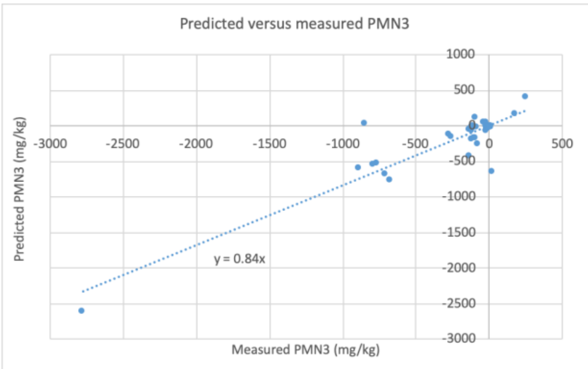
It can be observed from the previous equations, that the longer the timeframe the better the predictive power of the equations.

Limitations:

Although the fit of the equations is relatively good with up to 87% of the variance explained, when comparing the measured values against the predicted values by applying the equations (Figure 3), it can be observed that the equations tend to under-predict both the negative PMN values and the positive PMN values by between 13-24% on average. Additionally, and most importantly, very low PMN values (immobilisation) for a few samples drive the regressions, mostly at short timeframes (1 and 3 days). This does not allow for the models to accurately predict the higher and positive PMN values. Considering that this dataset was biased towards immobilisation, the latter is a very important limitation of these regressions. Additionally, we do not know what effect the long timeframe (>48 hours) between sampling and incubation had on N mineralisation processes. The fact that immobilisation occurred in the majority of samples from this wet season irrespective of where the samples were collected (i.e. gullies, end of system or marine) indicates that the 18/19 wet season events in the Burdekin had special characteristics that caused immobilisation instead of mineralisation. The latter is more likely to be the driver of immobilisation in the majority of samples rather than the delay in receiving samples (i.e., >48 hours) considering previous research findings (Lewis *et al.*, 2018; Garzon-Garcia *et al.*, 2018a). Net N immobilisation occurs when the metabolic N requirements of bacteria mineralising available organic carbon sources for energy exceed the N released from these sources. Consequently, any mineral N at the microsites of bacterial activity is absorbed by the microbes, resulting in a net removal (immobilisation) of mineral N.

Additionally, it should be noted that as these equations were developed using samples from the Burdekin Catchment only, we do not know if they would be applicable to other catchments or for marine sediment plumes from the Burdekin River or elsewhere.





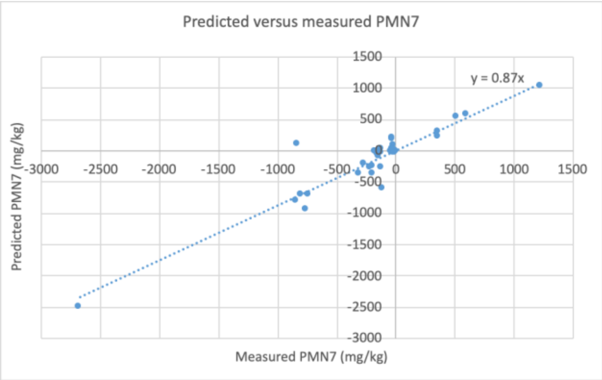


Figure 3. Linear regressions between modelled and measured PMN using parameters in Table 4 DOC (mg/kg) and NOx-N to estimate PMN in 1 day (a), DOC (mg/kg),NOx-N (mg/kg) and DON (mg/kg) to estimate PMN in 3 days (b), and DOC (mg/kg) and DON (mg/kg) to estimate PMN in 7 days (c). Lines represent a linear regression (y=ax+b) with b=0.

Recommendations

Adsorbed ammonium-N

Considerations:

- The regression equations developed to estimate adsorbed ammonium-N from other water quality parameters have a moderate predictive power (r^2=0.51-0.57), which indicates there is still 40 to 50% of unexplained variance in the prediction.
- The equations are only applicable for water quality samples obtained in the Burdekin catchment (from gully outlets to end-of-catchment) and are based on data from one wet season, so we will need further validation in this catchment (as well as in other catchments).
- Monitoring adsorbed ammonium-N was successful using the proposed methods for all field programs.

With all these considerations in mind and given there is no appreciable increase in sampling and field processing time (as the method to sample this parameter can be carried out in parallel to that of nitrate-N and ammonium-N), ***we recommend that adsorbed ammonium-N is monitored and quantified in the lab using the method developed and validated in field programs in this project (see Appendix 1) as part of the GBR Catchment Loads Monitoring Program (initially in predominantly grazing catchments) and as part of gully rehabilitation projects, instead of being predicted by the developed equations***. ***The cost of including this parameter ($19 per sample without technical personnel costs) would only be between 5-10% of the total cost of analysing a sample for the full nutrient suite.*** The additional resources required for sampling to validate and extend these equations to other catchments would likely exceed the resources needed to directly measure the parameter in monitoring programs. Additionally, we are not confident the predictive power using equations can be further improved.

Driver:

The driver for monitoring this bioavailable nutrient fraction is that it would provide information on how much adsorbed ammonium is exported with sediment from gully rehabilitation sites and catchments. This fraction will go into solution and become bioavailable to algae as the sediment enters the river estuaries (i.e., increased salinity zones). Currently this fraction is monitored as PN at freshwater end of catchment sites but contributes to DIN in the river estuaries. Discriminating this fraction is of importance to better understand the impact of particulate nutrients to the Reef. Additionally, it would enable the validation of the modelling of the adsorbed ammonium pool in the ‘DIN generation from sediment’ model. Following the successful development and application of this model in a pilot study in 2017/18 (Project RP178a, Garzon-Garcia *et al.*, 2018a), there is the opportunity to transfer BPN ‘pedotransfer functions’ (prediction of BPN from parent soil properties) to Dynamic SedNet models so that DIN generation from sediment can be modelled. A proposal to do this has been submitted to the Queensland Water Monitoring Network for consideration.

Potential mineralisation of organic nitrogen (PMN)

Considerations:

- The regression equations developed in this study to estimate potential mineralisation of organic nitrogen (PMN) from other water quality parameters are biased towards net immobilisation and may not predict high net mineralisation values well.
- The equations are currently only applicable in the Burdekin catchment and need further development because the accurate prediction of net immobilisation or net mineralisation in a water sample requires more extensive testing.
- Measuring PMN directly in the laboratory is logistically difficult because of the requirement to dispatch refrigerated samples from the field to the lab within 48 hours.
- Organic carbon is an important pool explaining the potential mineralisation of organic nitrogen.

With these considerations in mind and the additional high cost of PMN analyses ($510 per sample without technical personnel costs), ***we do not recommend including PMN as part of the monitoring parameters of field programs, but we recommend including the monitoring of particulate and dissolved organic carbon fractions ($30 per sample without technical personnel costs)***. The most cost-effective way forward, would be to benchmark lab-determined PMN against routinely measured water quality parameters in research projects associated with gully rehabilitation projects and catchment nutrient tracing. This would allow development/validation of pedo-transfer functions that allow PMN to be predicted for a wide range of conditions. Previous research has indicated that particulate and dissolved organic carbon are important explanatory variables of PMN, hence the importance of including these parameters in monitoring programs. Additionally, data from gully rehabilitation nutrient monitoring (see next section) has indicated that the effectiveness of gully rehabilitation may cause changes in the organic carbon concentrations exported from gully systems, in particular to the particulate organic carbon of sediment. Understanding these links is of importance to be able to measure, quantify and model the effects of gully rehabilitation on downstream water quality.

PMN is a key determinant of BPN, and its monitoring for Dynamic SedNet model validation of 'DIN generation from sediment' will require further development.

Gully rehabilitation monitoring recommendations

At the time of reporting, flow data for these sites were unavailable and only monitored concentration data are reported. The main fractions (particulate, dissolved and bioavailable) that comprise carbon, nitrogen and phosphorus in gully outlet water samples (grouped by treatment at each gully site) are presented in Appendix 2. These data only cover one wet season for most sites (except for Croc Station) and therefore only reflect the short-term effects of rehabilitation on water quality. ***These results are to be considered preliminary and should not be used to obtain conclusive findings with respect to gully rehabilitation techniques***, hence we have not included any interpretation of the results in this report but have presented some preliminary observations to note below and all the concentration results in Appendix 2. Longer term monitoring and load and yield calculations will give more insight into this. The Catchment and Riverine Processes team, Landscape Sciences, DES will work with Andrew Brooks (NESP 3.1.7) and Rebecca Bartley (NESP 5.9) to finalise the load and yield calculations for BPN results from the 2018/19 wet season, if the available data is sufficient for this task, to include in the final NESP reports.

The experience of processing and analysing BPN and water quality samples from gully rehabilitation projects can be summarised in the following recommendations:

- To determine effectiveness of rehabilitation strategies, monitoring of BPN and other water quality parameters needs to be conducted for a minimum of 4 -10 years (longer time may be needed for nutrients).
- Efforts should be made to obtain a representative sample cover across the hydrograph for each event including at least one sample on the rise, one sample on the peak and one sample on the fall for each sampling site. Depending on the magnitude of the event, more samples would be ideal.
- Samples that are representative of hydrograph stages should be obtained for each gully treatment for comparison. BPN sampling for this wet season had very different levels of hydrograph cover between different treatments; with some treatments having only one sample across an event.
- It is important to monitor different events across the wet season because the export of some

parameters is highly dependent on wet/dry history and antecedent event conditions. Because of this temporal effect, it would be ideal to compare treatments on an event basis and not to bulk the data.

- It is important to obtain some measure of flow (e.g. water depth) at each sampling time to be able to obtain flow by modelling or other methods. This would allow load calculations to be obtained.
- Ideally, yield (load divided by catchment area) would be the metric to use for comparison between different treatments.
- An effective experimental design with similar catchment areas between treatments would facilitate the analysis, though this is not always possible in practice. Monitoring water quality above the gully as well as in the gully outlet would facilitate the analysis and understanding of sources.

Preliminary observations to note include:

- The majority of carbon, nitrogen and phosphorus in gully outlets is particulate
- The majority of dissolved nitrogen is dissolved organic nitrogen (DON)
- Adsorbed NH_4-N can be a significant BPN fraction (can be larger than water soluble ammonium)
- In all sites studied (Mt Wickham, Strathalbyn and Croc station) there were effective reductions in the concentrations of total and particulate carbon, particulate nitrogen and particulate phosphorus with gully treatments. In contrast, the effect of treatment on sediment quality (i.e. the content of carbon, nitrogen or phosphorus in a particular mass of sediment) varied. This suggests that in order to understand the effectiveness of gully rehabilitation it is important to be able to calculate yields rather than concentrations alone. It also indicates that sediment quality maybe an important indicator of the effect of gully rehabilitation.
- The reduction of the dissolved fractions was not as effective. Although the total concentrations of nutrients were reduced, at some sites the most bioavailable nutrient fraction concentrations were increased for some treatments. This indicates soil amendments may be having an effect on exported bioavailable nutrients from gully treatments.
- Erosion treatment options that include soil amendments will require additional/stricter monitoring of both short-term (immediate, plus initial wet seasons) and longer-term (four to five wet seasons down the track) nutrient runoff monitoring. Ideally, the effect of treatments on soil health within gully systems would also be incorporated as part of future gully rehabilitation project monitoring. This would allow better understanding of the effects of gully rehabilitation treatments on downstream water quality and particulate nutrient bioavailability.

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Appendices

Appendix 1 Analytical methods for BPN

Potential mineralisable organic N in a water sample

Sampling

The process was as follows:

-Fill 2 A bottles (1 L each) completely with the water sample leaving a few cm of headspace and refrigerate this bottle in the dark at 4 degrees.

-Send to the Chemistry Centre at the Department of Environment and Science (DES) within 48 hours.

Laboratory analysis

This process was carried out as soon as the samples got to the lab. For **each sampling point**:

1. Label a set of 4 D bottles (300 ml) with field_id, sampling point name, and add to each the incubation times 0d, 1d, 3d or 7d
2. Subsample the 1L A bottles to fill each D bottle with the same volume of sample. Mix well before pouring so all sediment is in suspension and fill bottles randomly.
3. Place bottles marked 1d, 3d, and 7d in the shaker incubator at 25°C in the dark with the shaker at a speed in which the sediment in the bottles is kept in suspension (75 RPM).
4. For the sample labelled 0d, subsample 60 ml to filter to <0.45um into an E bottle labelled in the same way to the D bottle being filtered.
5. Freeze the D bottle and E bottles to submit the D bottles for TOC (W_TOC_NDI) and total Kjeldahl N and P (W_KJ_AA), and the E bottle for total dissolved Kjeldahl N and P (W_KJD_AA), filtered inorganic nutrients (W_FIL_AA) and DOC (W_DOC_NDI).
6. Repeat steps 4 to 5 at 1d, 3d and 7d for the corresponding bottles.

Potential mineralisable-N is calculated by subtracting the mineral-N (NO_x^--N + NH_4^+-N) after the incubation for each timeframe (PMN1- 1 day, PMN3- 3 days, PMN7- 7 days) from the mineral N at day 0. If the value is positive, it means there was net organic N mineralisation, if the value is negative it means there was organic N immobilisation.

Adsorbed ammonium-N

Sampling/Processing

The process had to be carried out within 48 hours of initial sample collection and was as follows:

- The DES Chemistry Centre prepared a 50 mL tube pre-filled with 3.49 gm of K_2SO_4 salt, labelled with "Ads NH4" and a mark at 40 mL, and supplied an additional 50 mL tube labelled 'Filtered Ads NH4' to filter into.
- Mark the tubes with sample ID
- Shake each sample well and take a representative subsample by filling the 'tube with salt' to the 40 mL mark
- Shake for 10 seconds
- Leave to sit chilled in the dark for 10 minutes
- Rinse the filter with a few subsample drops before collecting the filtrate
- Filter at least **>30 mL** into the empty tube (at around the same time filtered nutrients are carried out noting filtering time). No need to shake the sample before filtering. *If needed, the sample can be centrifuged to facilitate filtering.
- Freeze immediately and submit for analysis to the DES Chemistry Centre by overnight transport with enough ice bricks to keep frozen. The 'tube with salt' can be discarded.

If there was not enough time to filter or extract the adsorbed ammonium-N in the field the following alternatives were possible:

Alternative 1:

- Mark the tubes with sample ID
- Shake each sample well and take a representative subsample by filling the 'tube with salt' to the 40 mL mark
- Shake for 10 seconds
- Freeze immediately and submit for analysis to the DES Chemistry Centre by overnight transport with enough ice bricks to keep frozen. The filtering of the adsorbed ammonium-N was carried out in the lab at the same time than filtered nutrients.

Alternative 2:

- No extraction of adsorbed ammonium-N in the field. The extraction was carried out fully in the laboratory from the frozen D bottle submitted for total nutrients. The filtering of the adsorbed ammonium-N was carried out in the lab at the same time than filtered nutrients.

The adsorbed ammonium-N is calculated by subtracting the ammonium-N in the water sample (traditional filtered nutrients method) from the salt extracted adsorbed ammonium-N. It can be reported in mg L^{-1} or mg kg^{-1} by dividing by the total suspended solids concentration and converting units.

Particle size distribution

Particle Size Distribution (PSD) analysis was undertaken by the Chem Centre (DES) by laser diffraction using a Malvern Mastersizer 3000. Laser diffraction is a technique that estimates the particle size distribution of sediment in suspension based on the intensity and directional pattern by which particles scatter light. The Malvern Mastersizer provides PSD for size ranges from 0.24 to 2000 µm. The particle size distributions results obtained are based on a spherical model, while in reality most particles are non-spherical or irregular. The laser light obscuration (the degree of laser obstructed by the particles) used is between 5 and 15% to obtain optimal results and the refractive index used is 1.52. Particle size distribution results are reported on a % distribution by volume basis. The results used in this report correspond to the Mechanical dispersion (MECD) reading - PSD measured on the 5^{th} reading after mechanical dispersion with the laser sizer commences.

Particle Size Distribution (PSD) analysis was also undertaken by the TropWater (ALS lab) using a Malvern Mastersizer 3000 using a similar method to the DES Chem Centre, except that data was reported for the pre dispersion reading (PRED) – with no mechanical dispersion and measured as the initial reading.

Total and dissolved organic carbon

Total and dissolved organic carbon are determined on the total sample or the filtrate (<0.45 μm) respectively, by automated C determination after high temperature combustion at 680°C over a platinum catalyst or wet oxidation with persulfate (APHA/AWWA/WEF (2012) method 5310).

Nutrient calculations

The following calculations were performed to obtain additional nutrient pools:

Total nitrogen (TN) = TKN + NO_x^- -N

Particulate organic carbon (POC) = TOC – DOC

Particulate nitrogen (PN) = TKN – DKN

Dissolved organic nitrogen (DON) = DKN - NH_4^+-N

Dissolved organic phosphorus (DOP) = DKP – DRP

Dissolved inorganic nitrogen (DIN) = NO_x^- -N + NH_4^+-

Appendix 2 Gully rehabilitation nutrient monitoring

Here we present carbon, nitrogen and phosphorus fraction concentration data for controls and treatments at three gully rehabilitation sites: Mt Wickham, Strathalbyn and Croc Station. Treatment details can be observed in Table 5.

Mt Wickham data were obtained for a control and one gully treatment and are presented in boxplots by combining data obtained for before and after the treatment was stablished for various events that occurred during the 2018/19 wet season [before: control (n =3), treatment (n=5); after: control (n=7), treatment (n=8)]. Note that there is a seasonal effect on the before and after data as the before treatment samples were taken during the late dry season and the after samples during the wet season. For details on control and treatment design and further analysis on the effectiveness of gully remediation on total suspended solids and total nitrogen for this site see (Bartley *et al.*, 2019).

Strathalbyn data were obtained for a control and two gully treatments and are presented in boxplots by combining data for each of two rainfall events (E1 and E3) sampled during the wet season 2018/19 [Event 1: control (n=1); Event 3: control (n=3)]. Treatment 4 (n = 13) was only sampled for E1 and treatment 1 (n=3) was only sampled for E3. There was a third event sampled (E2) but, there were no samples submitted for the control, so data obtained for that event for treatment 4 (13 samples) are not presented or analysed here. For more details on control and treatment design see (Wearne *et al.*, 2018).

Croc Station data were obtained for a control and two gully treatments (Treatment 1: Gully 2.2, 2.3 and 2.4; Treatment 2: Gully 1.1) (Brooks *et al.*, 2018) and are presented in boxplots by combining all data for wet season 2017/18 [one event sampled: control (n=22), treatment 1 (n=9), treatment 2 (n=6)] and for a control and one treatment (treatment 1) by combining all data for wet season 2018/19 [two events sampled: control (n=4), treatment 1 (n=5)] . For more details on control and treatment design see Brooks *et al.* 2018.

Table 5. Characteristics of monitored gully sites and treatments.

Sampling site	Treatments	Gully type/slope	Time since treatment	Soil type/Geology	Treatment description
Mt Wickham	Control and 1 treatment	Hillslope + alluvial / 10%	1 year	Hypernatric brown Sodosol/granite, granodiorite	Hillslope recontouring, significant earthworks, soil treatment and chute structures, retention structures in gully bed and active revegetation
Strathbogie	Control	Hillslope / 6-7%	1 year	Black vertosol/granite, basalt	TBA
Strathalbyn	Control and 3 treatments	Alluvial	Treat 1: 2 years Treat 4: 1 year	Vertosols, Sodosols, duplex soils	Treat 1: Regrade/batter, gypsum, rock soil capping, graded rock bed, mulching (Rhodes grass hay), seeding. Treat 4: Regrade/batter, gypsum, rock soil capping, graded rock bed, mulching (bunds), seeding, stock exclusion
Croc Station	Control and 2 treatments	Alluvial	3 years		Treat 1: Regrade, gypsum, geofabric gully head, coarse sandstone head, shale capping everywhere, rock check dams, gully catchment contour dams. Treat 2: Regrade, gypsum, geofabric gully head, shale capping head, coarse basalt shoot head

Statistical analyses have not been carried out for comparisons between control and treatments because there are very few samples in some cases to comply with statistical requirements. These data only cover one wet season for most sites (except for Croc Station) and may reflect the short-term effects of rehabilitation on water quality (see time since treatment in Table 5). Additionally, some sites had very few samples taken. ***These results are to be considered preliminary and should not be used to obtain conclusive findings with respect to gully rehabilitation techniques***, hence we have not included any interpretation of the results in this report. Nonetheless, some initial observations can be drawn from the data and are to be noted.

General observations:

- The majority of carbon, nitrogen and phosphorus in gully outlets is particulate.
- The majority of dissolved nitrogen is dissolved organic nitrogen (DON).
- The majority of the DIN is oxidised N (NOx-N).
- Adsorbed NH_4-N can be a significant BPN fraction (can be larger than water soluble ammonium).
- In all sites studied (Mt Wickham, Strathalbyn and Croc station) there were effective reductions in the concentrations of total and particulate carbon, particulate nitrogen and particulate phosphorus with gully treatments.
- The reduction of the dissolved fractions was not as effective, and although the total concentrations of nutrients were reduced, at some sites the most bioavailable nutrient fraction concentrations were increased for some treatments indicating soil amendments may be having an effect on exported bioavailable nutrients from gully treatments:
    - DOC for treatment 4 at Strathalbyn
    - DON for treatments 1 and 4 at Strathalbyn
    - DIN for Mt Wickham's treatment, treatment 1 and 4 at Strathalbyn and treatment 1 for wet season 2018/19 at Croc Station. This was due mainly to an increase in oxidised-N, except for Croc Station in which there was also an increase in ammonium-N.
    - Adsorbed ammonium-N for Mt. Wickham's treatment
    - DRP for treatment 4 at Strathalbyn.
- There were effective reductions of dissolved phosphorus fractions for Mt Wickham treatment and all Croc station treatments, due to DOP reduction in the former and both DOP and dissolved reactive P reduction in the latter.
- The carbon content of the sediment was reduced for the treatment at Mt Wickham and increased for treatments at Strathalbyn and Croc Station.
- The nitrogen content of the sediment increased for all treatments at all sites.

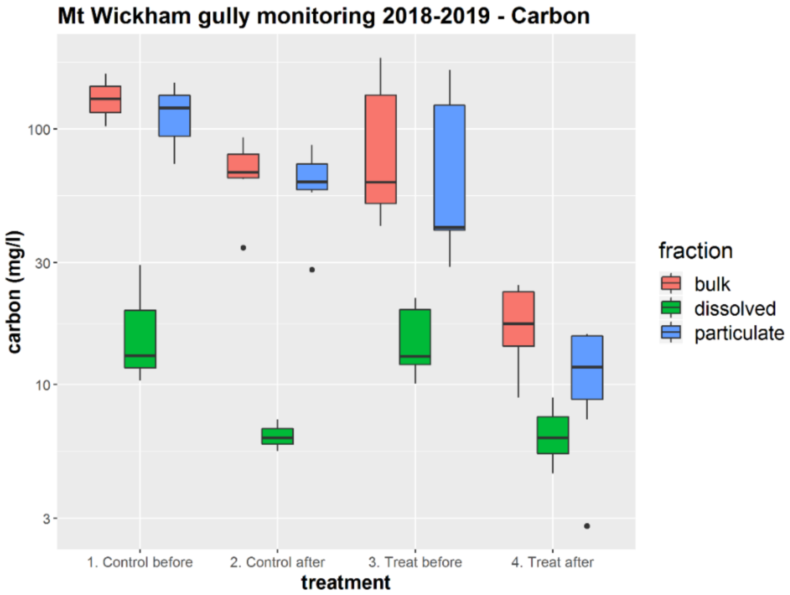
*Although sampling and lab analysis was carried out for Strathbogie, data are not presented or analysed here because samples for bioavailable nutrients were only received for a control site (treatment-now control, 8 samples).

Mt Wickham gully monitoring

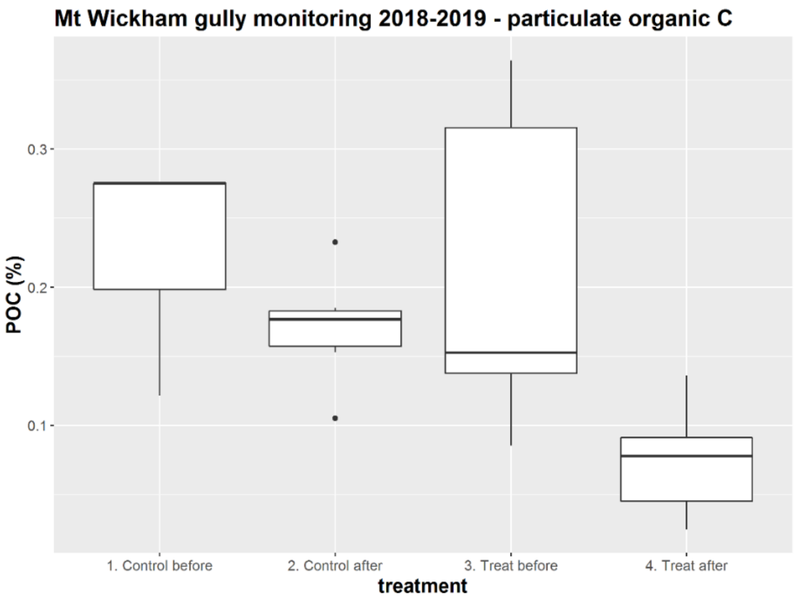
*Note that there is a seasonal effect on the before and after data as the before treatment samples were taken during the late dry season and the after samples during the wet season.

Summary observations:

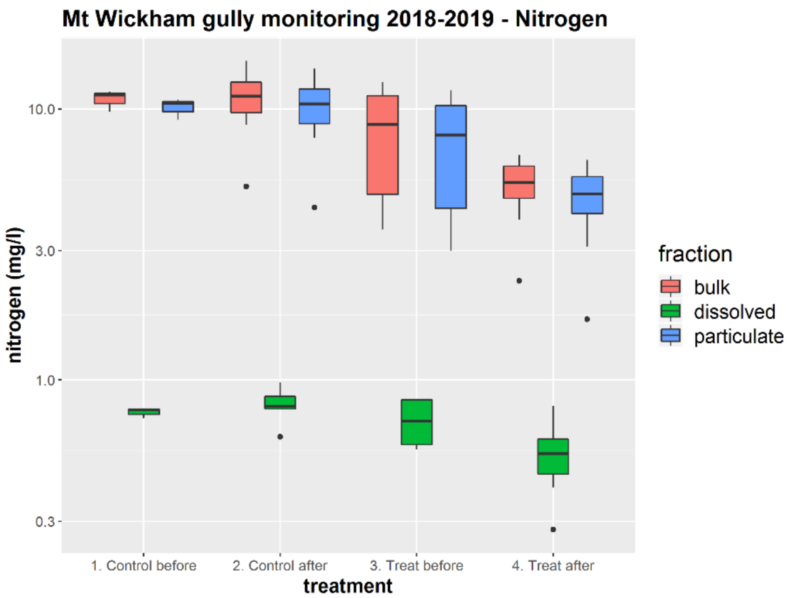
- Reduction in exported particulate organic carbon fraction after treatment.
- Reduction in organic carbon content of sediment particles after treatment.
- Reduction in exported particulate and dissolved nitrogen fractions after treatment (compared to control after treatment).
- Increase in nitrogen content of sediment particles after treatment.
- Increase in most bioavailable nitrogen fractions (DIN, adsorbed ammonium-N) after treatment, due to oxidised N increase for DIN.
- More immobilisation of N in sediment after treatment (longer timeframes).
- Reduction in exported particulate and dissolved P fractions after treatment, the latter due to reduction in DOP.



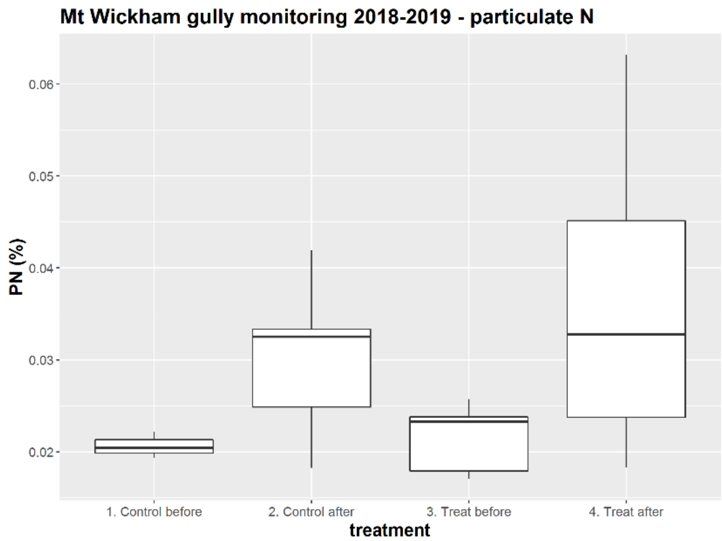
Mt Wickham gully monitoring 2018-2019 - Carbon
carbon (mg/l)
100
30
10
3
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment
fraction
bulk
dissolved
particulate



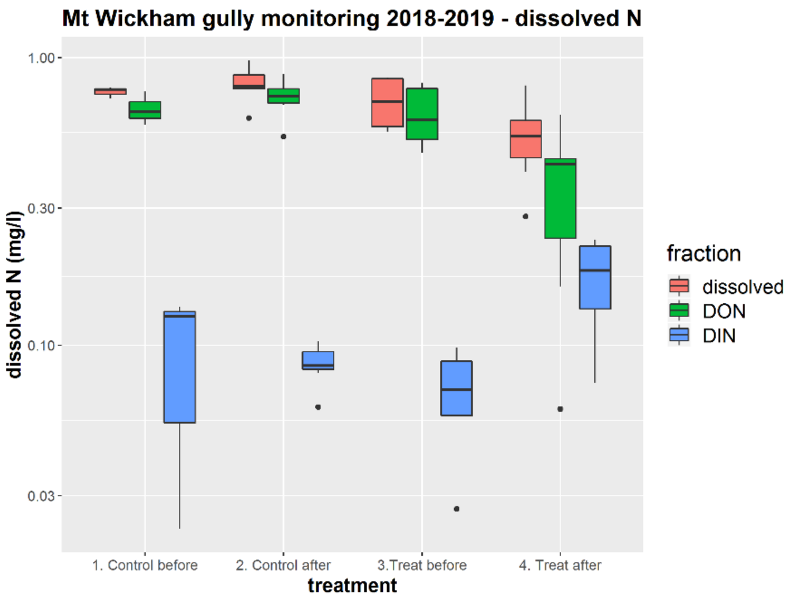
Mt Wickham gully monitoring 2018-2019 - particulate organic C
POC (%)
0.3
0.2
0.1
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment



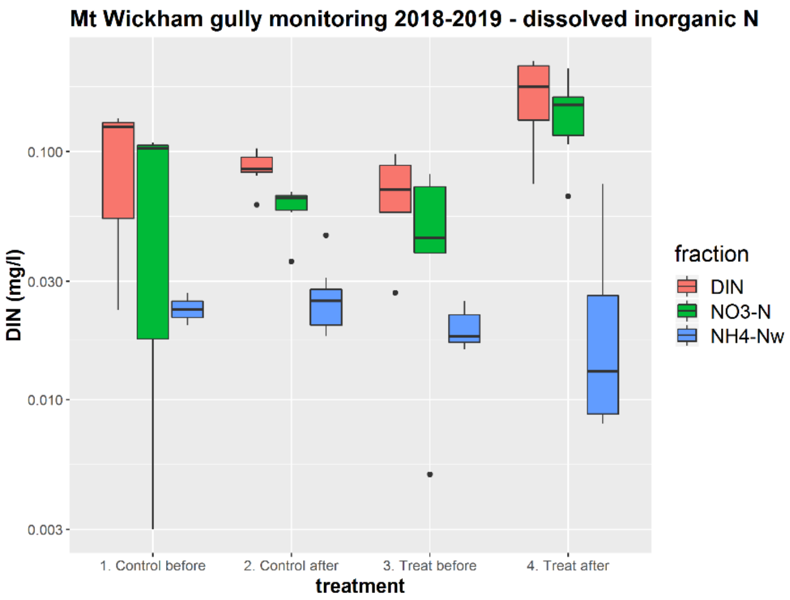
Mt Wickham gully monitoring 2018-2019 - Nitrogen
nitrogen (mg/l)
10.0
3.0
1.0
0.3
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment
fraction
bulk
dissolved
particulate

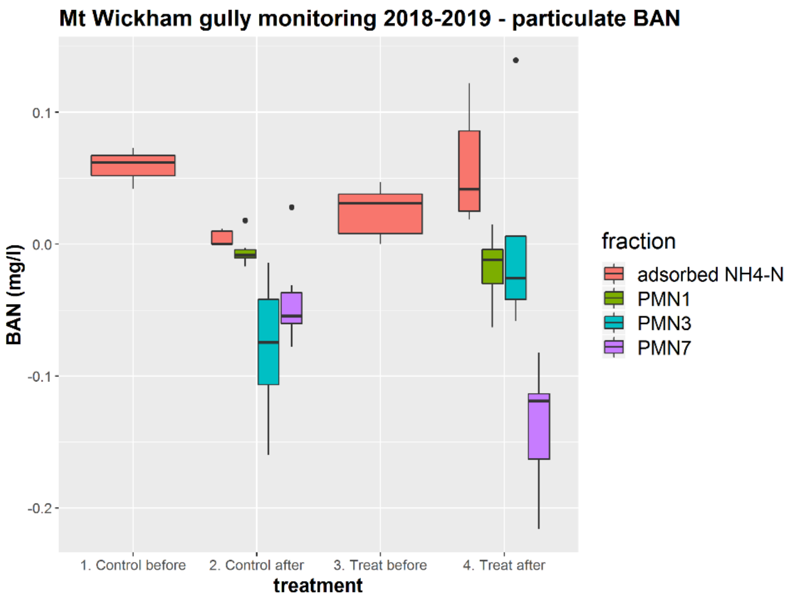


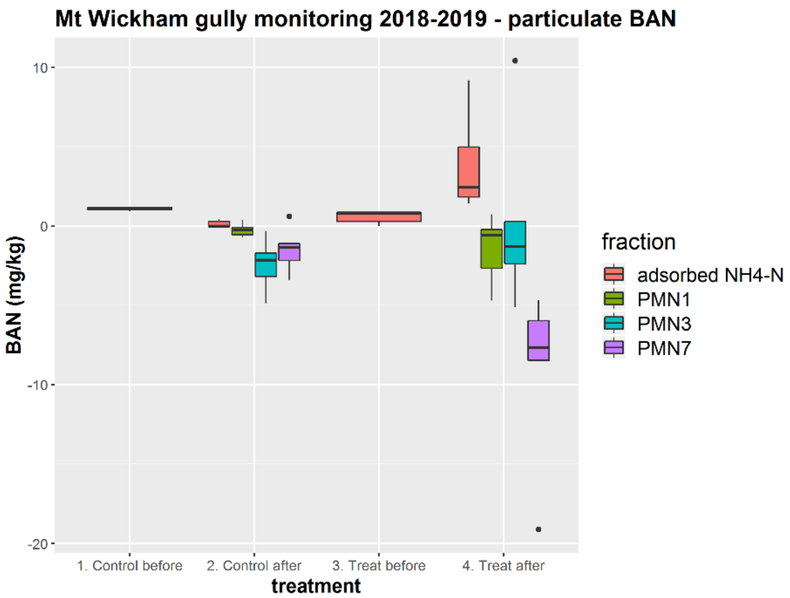
Mt Wickham gully monitoring 2018-2019 - particulate N
PN (%)
0.06
0.05
0.04
0.03
0.02
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment

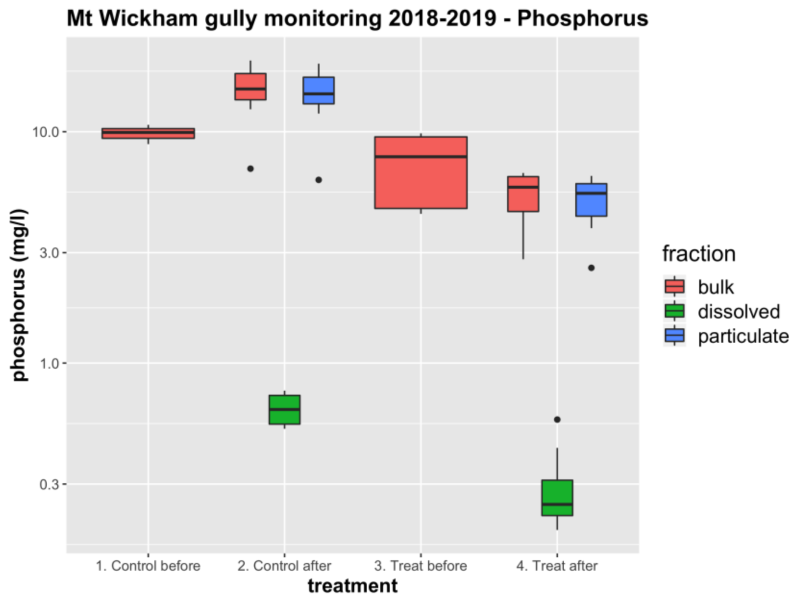


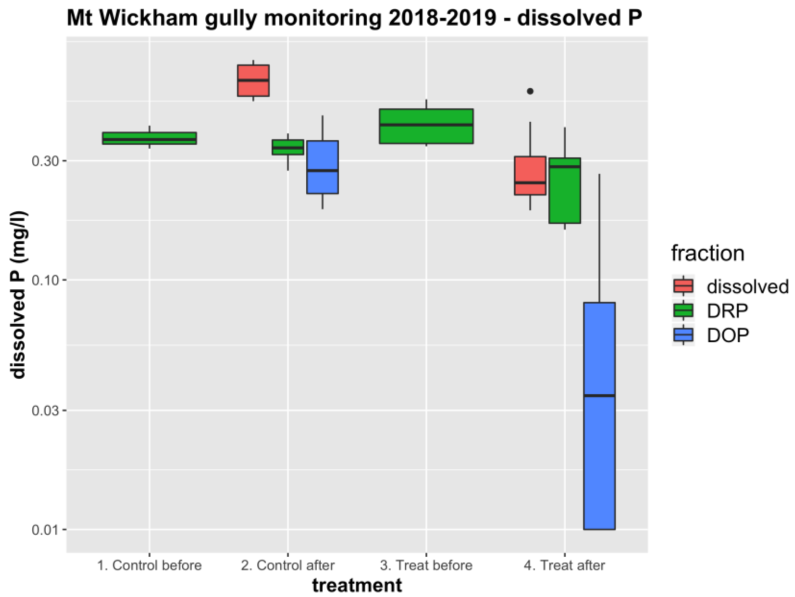
Mt Wickham gully monitoring 2018-2019 - dissolved N
dissolved N (mg/l)
1.00
0.30
0.10
0.03
1. Control before
2. Control after
3.Treat before
4. Treat after
treatment
fraction
dissolved
DON
DIN


Mt Wickham gully monitoring 2018-2019 - dissolved inorganic N
DIN (mg/l)
0.100
0.030
0.010
0.003
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment
fraction
DIN
NO3-N
NH4-Nw


Mt Wickham gully monitoring 2018-2019 - particulate BAN
BAN (mg/l)
0.1
0.0
-0.1
-0.2
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment
fraction
adsorbed NH4-N
PMN1
PMN3
PMN7


Mt Wickham gully monitoring 2018-2019 - particulate BAN
BAN (mg/kg)
10
0
-10
-20
1. Control before
2. Control after
3. Treat before
4. Treat after
treatment
fraction
adsorbed NH4-N
PMN1
PMN3
PMN7

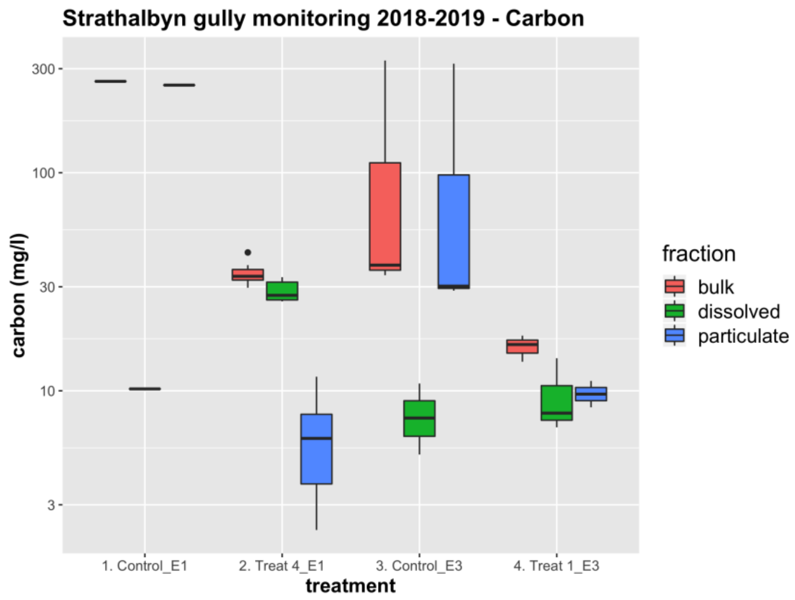


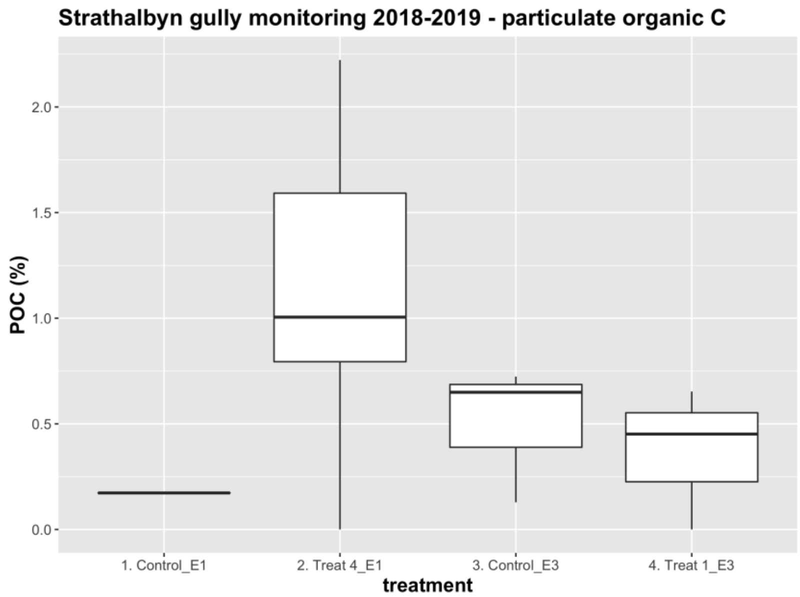


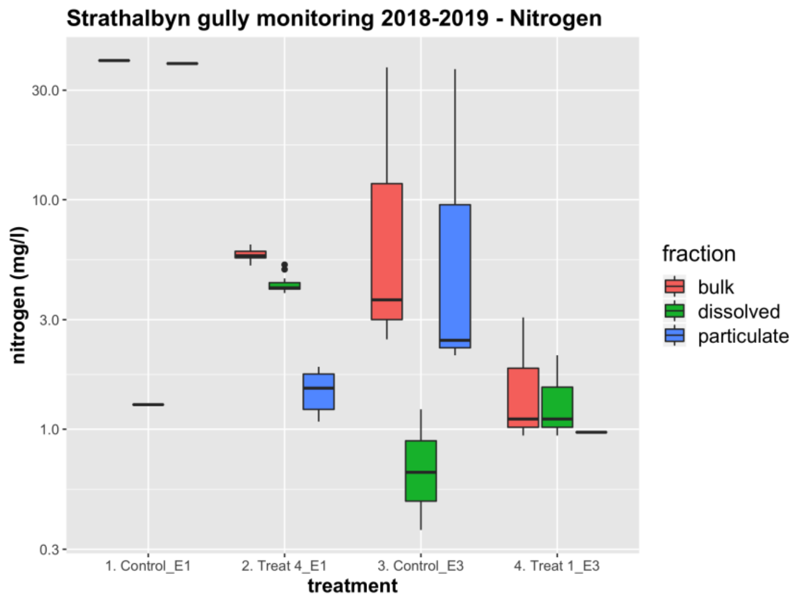
Strathalbyn gully monitoring

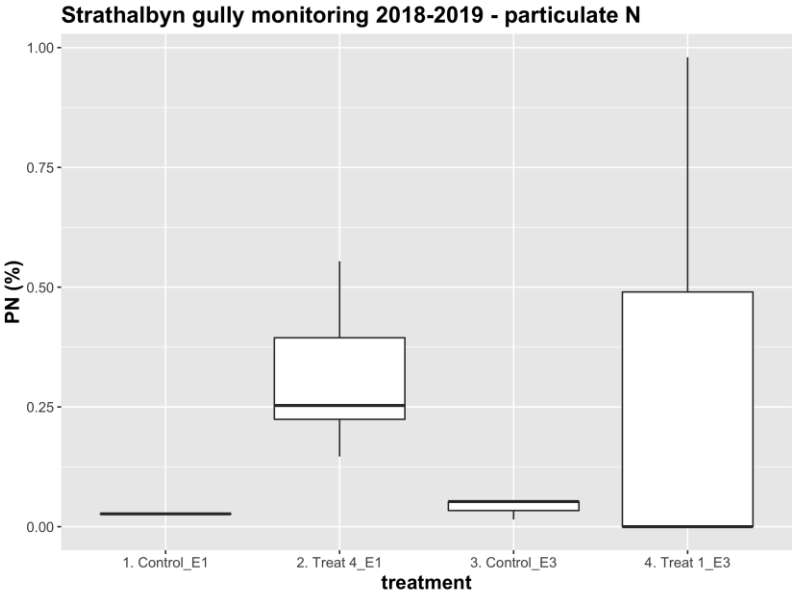
Summary observations:

- Reduction in the exported particulate organic carbon fraction for all treatments (compared to control for each event).
- Increase in the exported dissolved organic carbon fraction for treatment 4.
- Reduction in exported particulate N fraction for all treatments.
- Increase in nitrogen content of sediment particles for treatments 1 and 4. Content points at surface sediment sources from treatment 4 and both surface and subsurface sources from treatment 1.
- Increase in exported dissolved N fraction for treatments 1 and 4.
- Increase in most bioavailable nitrogen fractions (DON, DIN) for treatments 1 and 4, due to oxidised N increase for DIN.
- More immobilisation of N in sediment for treatment 1.
- Reduction in exported particulate P fractions in all treatments.
- Increase in DRP for treatment 4.

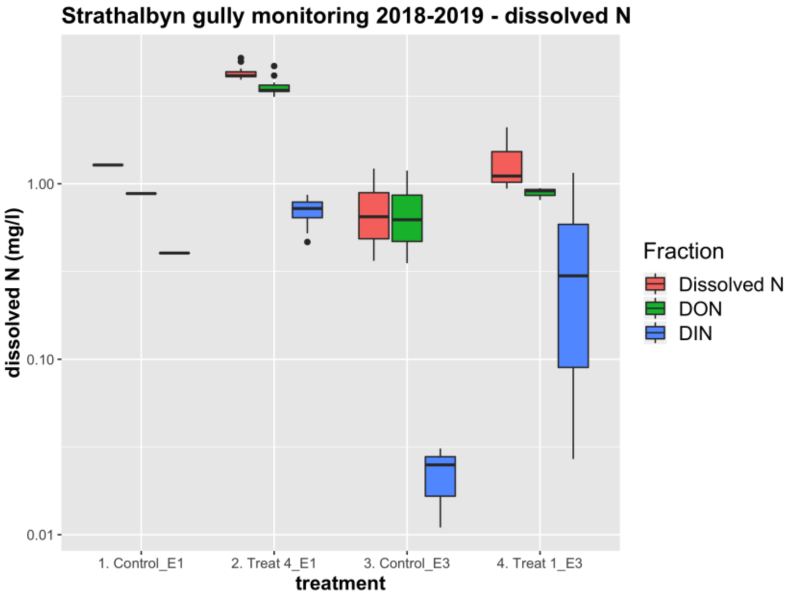

Strathalbyn gully monitoring 2018-2019 - Carbon
carbon (mg/l)
300
100
30
10
3
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
fraction
bulk
dissolved
particulate


Strathalbyn gully monitoring 2018-2019 - particulate organic C
POC (%)
2.0
1.5
1.0
0.5
0.0
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment

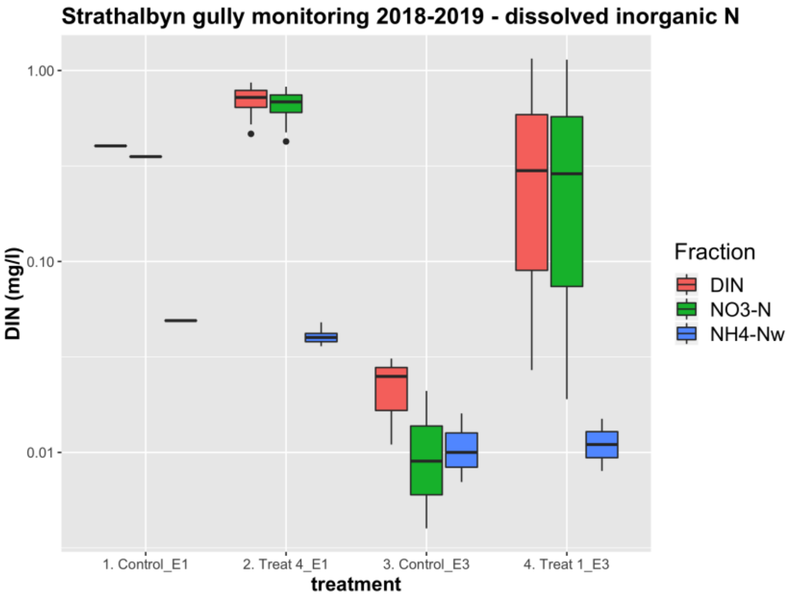

Strathalbyn gully monitoring 2018-2019 - Nitrogen
nitrogen (mg/l)
30.0
10.0
3.0
1.0
0.3
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
fraction
bulk
dissolved
particulate



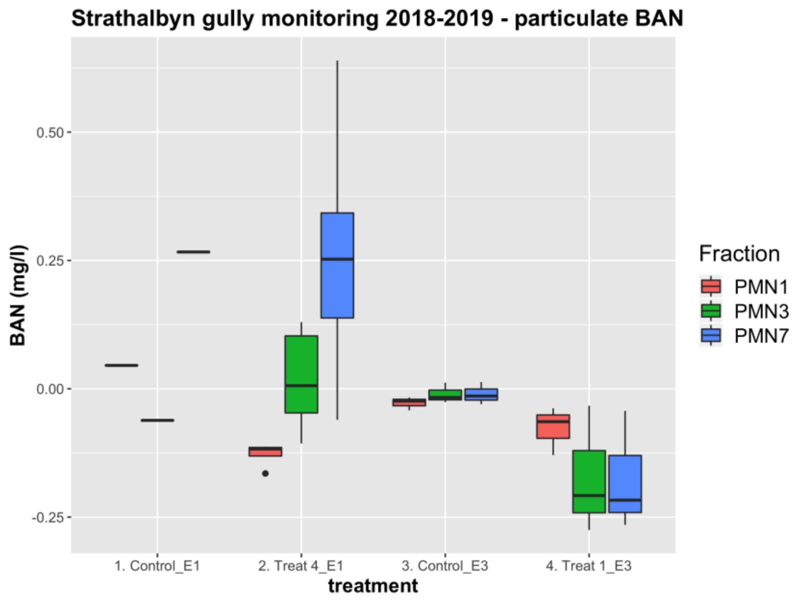
Strathalbyn gully monitoring 2018-2019 - particulate N
PN (%)
1.00
0.75
0.50
0.25
0.00
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment

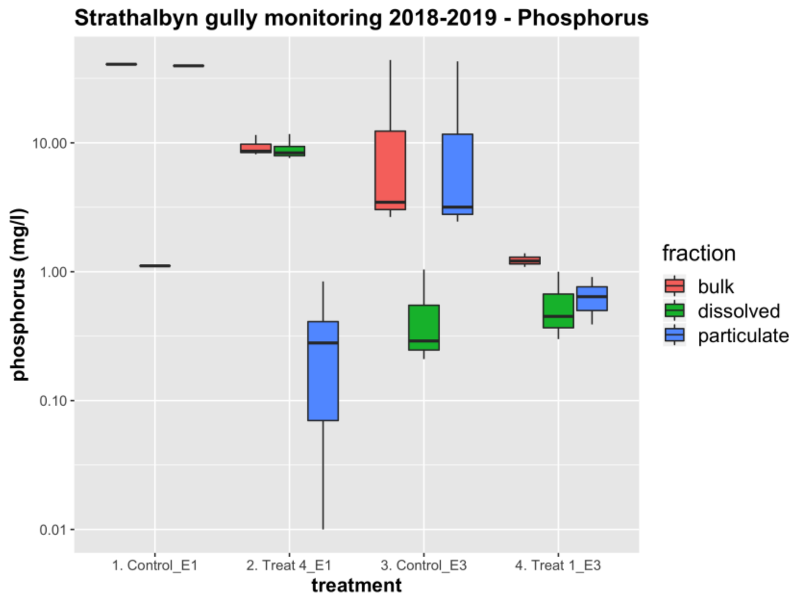


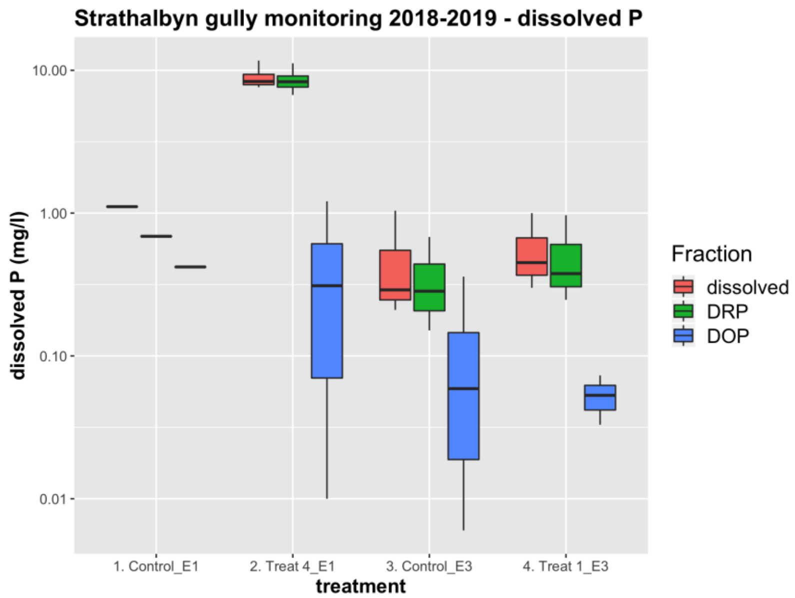
Strathalbyn gully monitoring 2018-2019 - dissolved N
dissolved N (mg/l)
1.00
0.10
0.01
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
Fraction
Dissolved N
DON
DIN



Strathalbyn gully monitoring 2018-2019 - dissolved inorganic N
DIN (mg/l)
1.00
0.10
0.01
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
Fraction
DIN
NO3-N
NH4-Nw


Strathalbyn gully monitoring 2018-2019 - particulate BAN
BAN (mg/l)
0.50
0.25
0.00
-0.25
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
Fraction
PMN1
PMN3
PMN7

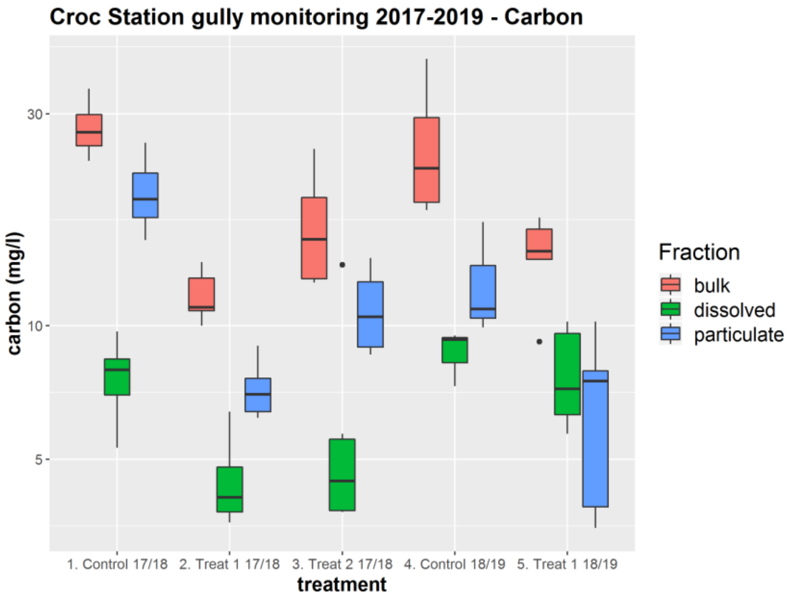

Strathalbyn gully monitoring 2018-2019 - Phosphorus
phosphorus (mg/l)
10.00
1.00
0.10
0.01
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
fraction
bulk
dissolved
particulate

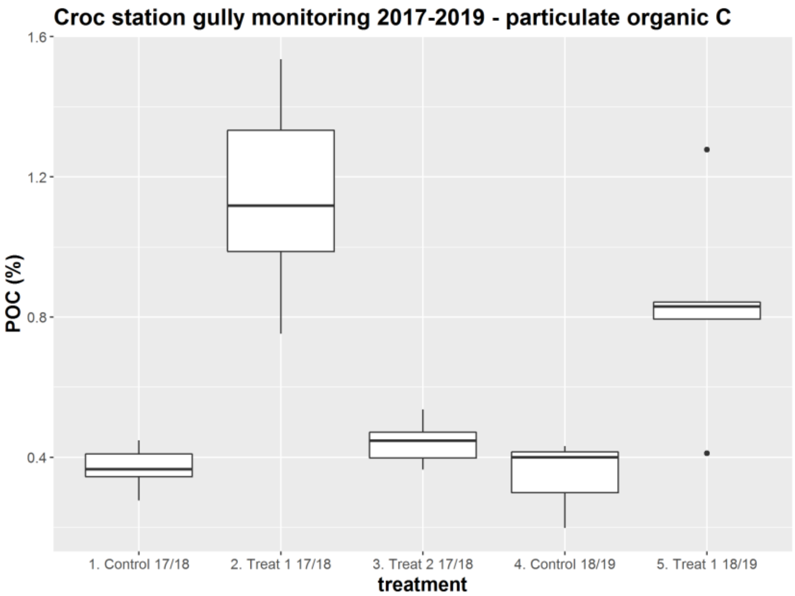

Strathalbyn gully monitoring 2018-2019 - dissolved P
dissolved P (mg/l)
10.00
1.00
0.10
0.01
1. Control_E1
2. Treat 4_E1
3. Control_E3
4. Treat 1_E3
treatment
Fraction
dissolved
DRP
DOP

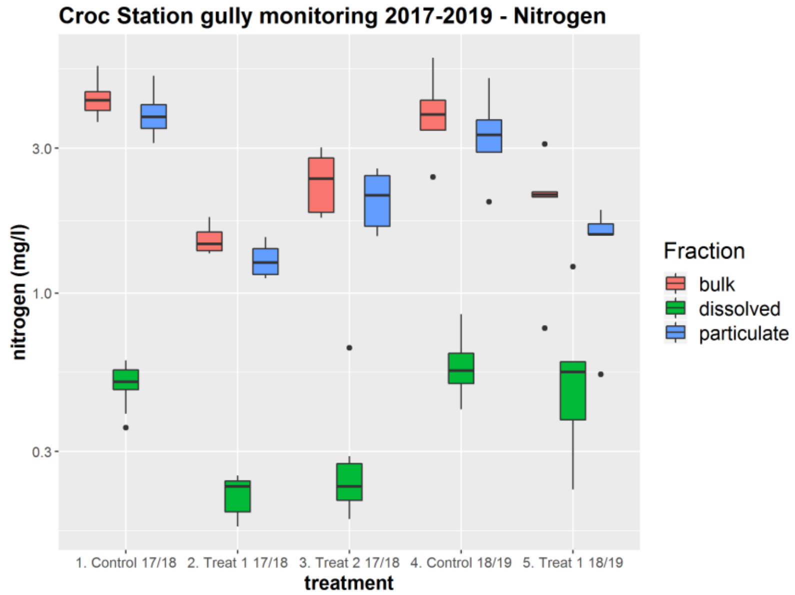
Croc Station gully monitoring

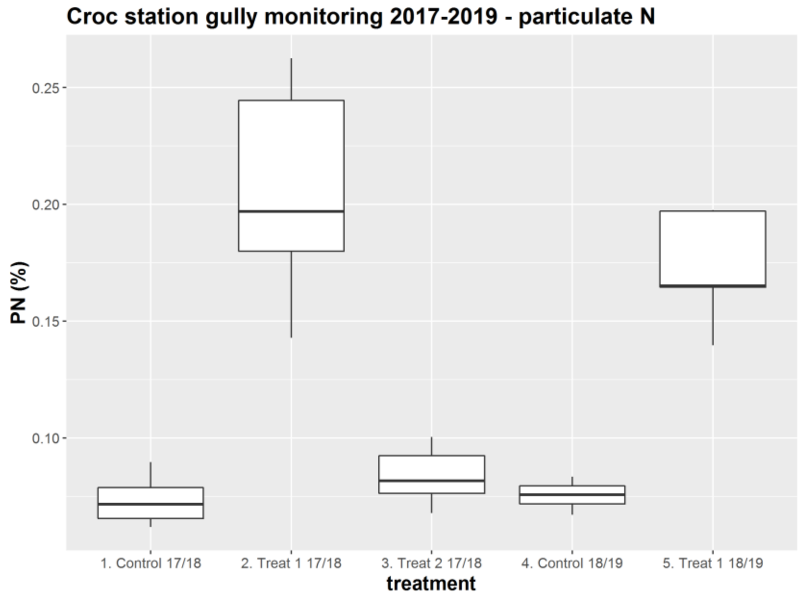
Summary observations:

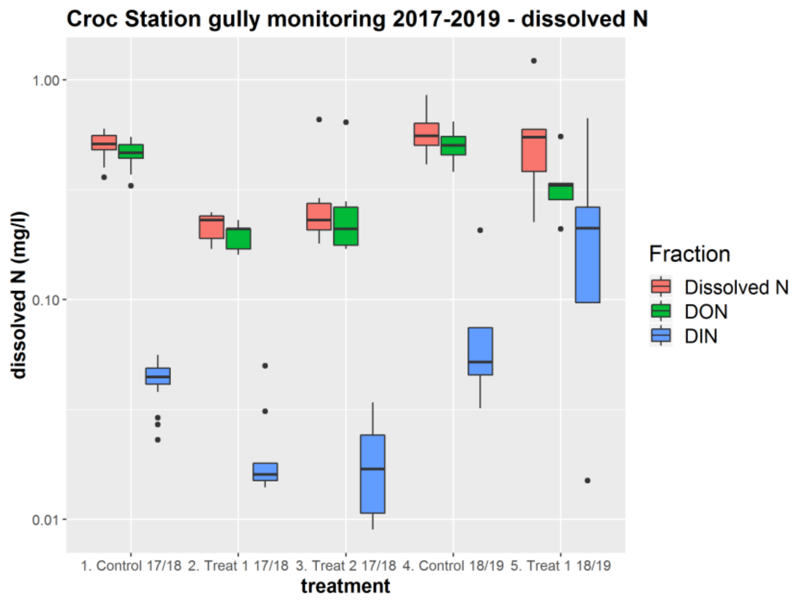
- Reduction in the exported particulate organic carbon fraction for all treatments (compared to control for each season) and for the dissolved organic carbon for all treatments in season 2017/18 only.
- Reduction in exported particulate and dissolved N fractions for all treatments (compared to control for each season), more markedly in season 2017/18 for the latter.
- Increase in carbon and nitrogen content of sediment particles for all treatments, but more markedly in treatment 1. Carbon and nitrogen content in this treatment indicate surface sediment sources, contrary to treatment 2 in which it indicates subsurface sediment sources.
- Decrease in some bioavailable nitrogen fractions (DON, DIN) for all treatments except for season 2018/19 in which DIN increased in treatment 1, due to an increase in both oxidised-N and ammonium-N.
- No significant changes in adsorbed ammonium-N.
- Reduction in exported particulate and dissolved P fractions in all treatments.
- Reduction in DRP and DOP for all treatments.

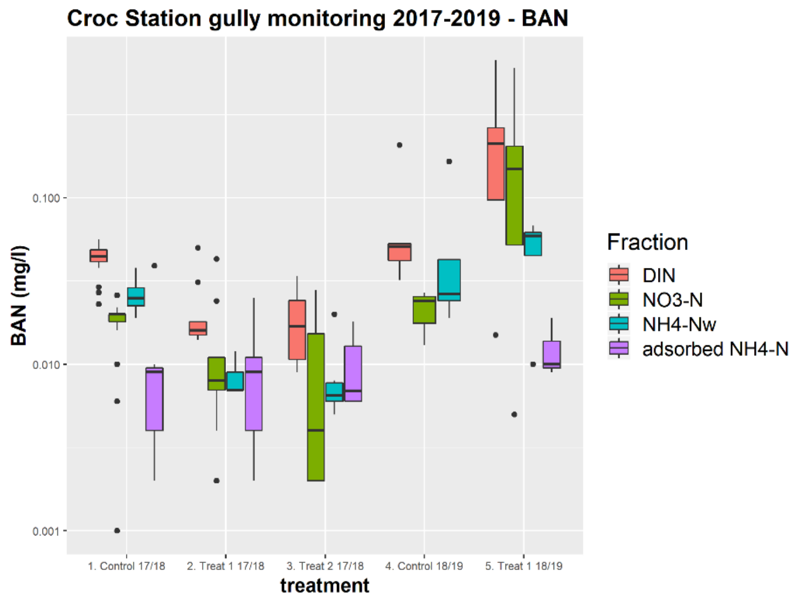


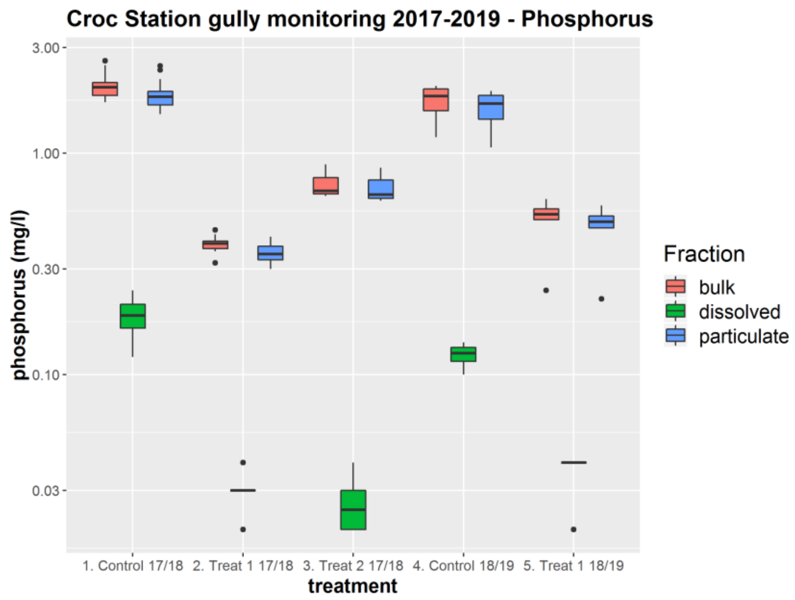


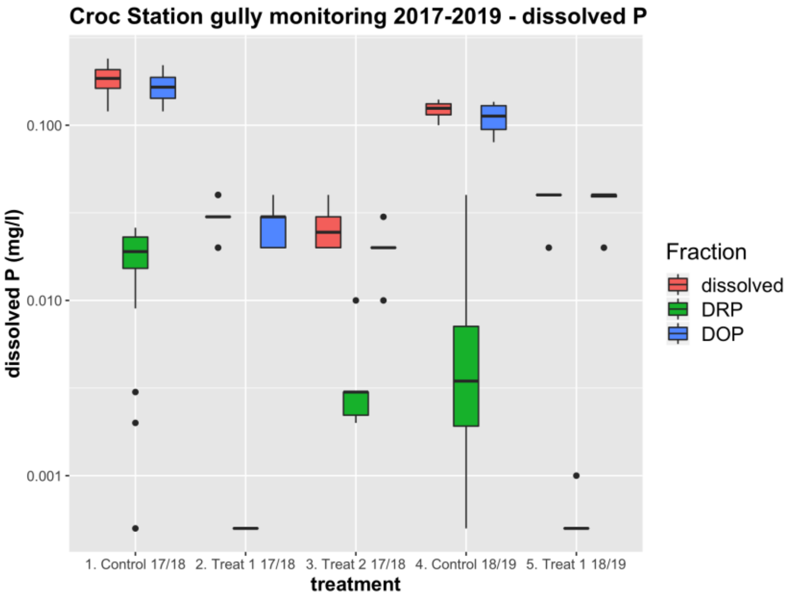

Croc Station gully monitoring 2017-2019 - Nitrogen
nitrogen (mg/l)
3.0
1.0
0.3
Fraction
bulk
dissolved
particulate
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment


Croc station gully monitoring 2017-2019 - particulate N
PN (%)
0.25
0.20
0.15
0.10
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment


Croc Station gully monitoring 2017-2019 - dissolved N
dissolved N (mg/l)
1.00
0.10
0.01
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment
Fraction
Dissolved N
DON
DIN


Croc Station gully monitoring 2017-2019 - BAN
BAN (mg/l)
0.100
0.010
0.001
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment
Fraction
DIN
NO3-N
NH4-Nw
adsorbed NH4-N


Croc Station gully monitoring 2017-2019 - Phosphorus
phosphorus (mg/l)
3.00
1.00
0.30
0.10
0.03
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment
Fraction
bulk
dissolved
particulate


Croc Station gully monitoring 2017-2019 - dissolved P
dissolved P (mg/l)
0.100
0.010
0.001
1. Control 17/18
2. Treat 1 17/18
3. Treat 2 17/18
4. Control 18/19
5. Treat 1 18/19
treatment
Fraction
dissolved
DRP
DOP