Tropical Water Quality Hub

National Environmental Science Programme

Bioavailable Nutrients: Sources, delivery and impacts in the Great Barrier Reef:

Workshop held 15 March 2018

Briefing / key messages paper

Jane Waterhouse, Dr Joanne Burton, Dr Alexandra Garzon-Garcia, Dr Stephen Lewis, Dr Jon Brodie, Dr Zoe Bainbridge, Dr Barbara Robson, Professor Michele Burford, Dr Renee Gruber and Cameron Dougall

Queensland Government

The Tropical Water Quality hub is funded by the Australian Government's National Environmental Science Program

Outside Front Cover Photo: *Cattle grazing in the Bowen catchment, by Alex Garzon-Garcia*

This briefing / key messages paper should be cited as:

Waterhouse, J., Burton, J., Garzon-Garcia, A., Lewis, S., Brodie, J., Bainbridge, Z., Robson, B., Burford, M., Gruber, R., Dougall, C. (2018). *Bioavailable Nutrients: Sources, delivery and impacts in the Great Barrier Reef: Workshop, 15 March 2018. Briefing / key messages paper.* Supported by the Office of the Great Barrier Reef's Queensland Reef Water Quality Program, and the Australian Government National Environmental Science Program Tropical Water Quality Hub.

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub and the State of Queensland.

The Tropical Water Quality Hub is part of the Australian Government's National Environmental Science Program and is administered by the Reef and Rainforest Research Centre Limited (RRRC). The NESP TWQ Hub addresses water quality and coastal management in the World Heritage listed Great Barrier Reef, its catchments and other tropical waters, through the generation and transfer of world-class research and shared knowledge.

This publication is available for download from the NESP Tropical Water Quality Hub and the Queensland Government website:

http://www.nesptropical.edu.au

https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-projects

Bioavailable Nutrients:
Sources, delivery and impacts in the Great Barrier Reef:

Workshop held 15 March 2018

Briefing / key messages paper[1]*

This paper was coordinated by Jane Waterhouse[1] with contributions from Dr Joanne Burton[2], Dr Alexandra Garzon-Garcia[2], Dr Stephen Lewis[3], Dr Jon Brodie[1], Dr Zoe Bainbridge[3], Dr Barbara Robson[4], Professor Michele Burford[5], Dr Renee Gruber[4] and Cameron Dougall[6].

[1]C_2O Consulting, coasts climate oceans, [2]Queensland Department of Environment and Science, [3]TropWATER, James Cook University, [4]Australian Institute of Marine Science, [5]Griffith University, [6]Queensland Department of Natural Resources, Mines and Energy

Funding for the workshop and the supporting documents including this paper was provided by the Office of the Great Barrier Reef (OGBR) within the Department of Environment and Science (DES), and the Australian Government National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub. The organisations of the contributing authors also provided considerable in-kind contributions.

Queensland Government

Tropical Water Quality

* This paper should be cited as: Waterhouse, J., Burton, J., Garzon-Garcia, A., Lewis, S., Brodie, J., Bainbridge, Z., Robson, B., Burford, M., Gruber, R., Dougall, C. (2018). Bioavailable Nutrients: Sources, delivery and impacts in the Great Barrier Reef: Workshop, 15 March 2018. Briefing / key messages paper. Supported by the Office of the Great Barrier Reef's Queensland Reef Water Quality Program, and the Australian Government National Environmental Science Program Tropical Water Quality Hub.

Sampling for BAN at Vertosol Gully, by Alex Garzon-Garcia

BACKGROUND

On behalf of the Office of the Great Barrier Reef (OGBR), C²O Consulting coasts climate oceans coordinated a workshop on 15 March 2018 aiming to provide clearer direction for future efforts to support improved understanding and management of bioavailable nutrient sources, pathways and impacts in the Great Barrier Reef (GBR). The outcomes will guide investment in management responses associated with bioavailable nutrients for achieving outcomes for the health of the Reef.

The workshop was intended to provide:

1. An agreed conceptual model of the delivery, transformation and fate of bioavailable nutrients from their source to the Reef. This will help communicate this complex issue for management, policy and modelling and support understanding of where future research investments need to focus.
2. A clear picture of current knowledge and additional research required to determine: what happens to particulate nutrients in the marine environment; what are the risks of particulate nutrients on varying timescales in the GBR lagoon; what is the contribution of particulate nutrients to bioavailable nutrients in the GBR lagoon relative to the bioavailable nutrients (primarily dissolved inorganic nitrogen) discharged directly from agriculture; and what are the management options for managing bioavailable nutrients. Ultimately, identify the key research required, how much funding that research requires, and who can undertake the research.
3. An indication of the effort required and the benefits of including new information into Source Catchment and eReefs modelling.
4. Consensus of the potential management implications of new evidence related to bioavailable nutrient delivery, transport and fate.

This paper presents a summary of the key messages that have been extracted from the workshop and associated discussions. It is supported by a Concept Paper which expands on the material presented here. It is underpinned by the current conceptual understanding presented in **Attachment 1**.

MARINE INTERACTIONS

The risk of particulate nutrients to the marine environment

- Nutrient inputs are most important during river discharge events and for a period of time afterwards. For the Wet Tropics rivers – that is every year. For the Burdekin and Fitzroy – that is every 3 to 5 years (or less). This is when the availability of bioavailable nutrients can influence adverse ecosystem effects e.g. crown of thorns larval survivorship (November to February), bleaching susceptibility (coupled with temperature – January to March), coral disease (coupled with temperature – January to March). Effects of nutrients on seagrass in areas of resuspension (leading to reduced light) may be important throughout the year. During discharge periods, nutrient inputs may be important in deeper areas (>15m) – associated with phytoplankton growth and reduced light (knowledge is less certain).
- Outside of those times, terrestrial influences are small and nutrient requirements for productivity are dominated by recycling in the GBR lagoon or from water column PON/DON. Resuspension of material outside of discharge periods is thought to be less important for nutrient bioavailability, but this is yet to be quantified. Upwelling mostly restricted to some outer shelf areas (e.g. Swains, Palm Passage, far northern GBR). PON may be more available than DON.
- Marine risk is assessed as DIN only at this stage – so does not fully capture the bioavailable component of particulate nutrients or dissolved organic nutrients (except perhaps indirectly in the Chlorophyll and light attenuation input data). Currently only linked back to end of catchment DIN loads for basin scale prioritisation.
- Strong evidence of these nutrient inputs exists for N, with less knowledge about P inputs and the interactions between N, P and C.
- The eReefs biogeochemical model captures the delivery and transformation of particulate nutrients through labile and refractory detritus to dissolved forms. This representation works at the regional scale but additional evidence from process-based studies provide a new opportunity to improve parameterisation of the model at local scales and get better performance at the river mouth. Examples include the Department of Environment and Science (DES) / National Environmental Science Program (NESP) experimental data.

Sediment pump, by Stephen Lewis

Partitioning and fate of particulate nutrients in the GBR - land-derived contributions

- The current conceptual understanding of the delivery, transport and fate of bioavailable nutrients in the GBR is represented in **Attachment 1**.
- PON is mineralised in the water column to bioavailable form (e.g. DIN) and we have some idea of the rates. PON can be mineralised to ammonium in the sediment matrix and transformed to either nitrate (nitrification) or N2 (nitrification coupled with denitrification), or N2O. The relative proportion of the rates of these two processes will vary depending on the redox conditions within the sediment matrix. Studies using 15N in the Brunswick River NSW with microphytobenthos (MPB) present showed that thirty-three days after the 15N was assimilated by MPB, 27% remained in the sediment, 16.5% had been effluxed as NO3-, 20.8% had been effluxed as NH4+, 20.7% had been effluxed as N2 and 15.1% was not accounted for. It is predicted that most (12.6%) of the 15N label that was not accounted for was probably lost as dissolved organic N (DON) fluxes. However, this is for the specific conditions of the Brunswick River estuary. The eReefs model handles mineralisation as a simple function of organic N concentrations and temperature, and denitrification as a function of nitrate concentrations, temperature and dissolved oxygen. It is still believed that between 10 and 30% of the DON from the river is bioavailable after discharge into the lagoon.
- Studies in Moreton Bay have shown that P fluxes into bottom sediments, not out of sediment, even when fine transported sediment deposits on the surface of the sediment. However, the role of resuspension due to wind mixing in releasing P into the water column is poorly understood.
- Some forms of terrestrial organic matter from riparian vegetation have been shown to inhibit algal growth, especially cyanobacteria. The effect of these forms of DOM on marine species is unknown.
- Organic and inorganic phosphorus is likely also important. The eReefs biogeochemical model indicates that: (1) though nitrogen is more often limiting, phosphorus does sometimes limit phytoplankton and coral symbiont growth in the GBR, and (2) nitrogen fixation by Trichodesmium makes an important contribution to the nitrogen supply. Nitrogen fixation is in turn limited by the phosphorus supply. Recent process studies in marine waters also show that nitrogen and phosphorus often co-limit production, contrary to previous assumptions.
- We have improved understanding of how much of the particulate nitrogen becomes bioavailable once it enters the lagoon. In the case study of the Burdekin River in Cyclone Debbie, experimental results indicate that 25% of the end of system DIN load was generated in the plume (from the Burdekin River itself not including discharge from Barratta Creek and the Haughton River). Had the event been large enough to trigger a plume that travelled to Palm Island (i.e. an additional 9 days of travel time) it is estimated that the same order of magnitude as the end of system DIN load would have been generated.
- Algae consumes DIN that has been derived from sediment in marine conditions. Both DIN and DRP derived from sediments is consumed by algae in freshwater conditions. Carbon has an important influence in mediating this process in both fresh and marine waters.
- A new rapid bioassay technique has been developed that allows testing of catchment derived sediment nutrient bioavailability. Key sediment indicators have been identified including organic carbon, organic nitrogen, adsorbed ammonium and C:N ratios.
- Temporal and spatial variables need to be considered when examining the amount of DIN being generated from particulate sources. PIN is an important source of DIN from plume sediment, this tends to occur in short timeframes (hours) at low salinity (<6 PSU). DIN can also be generated by the mineralisation of PON. This process occurs in longer timeframes (days) as the sediment is being transported.

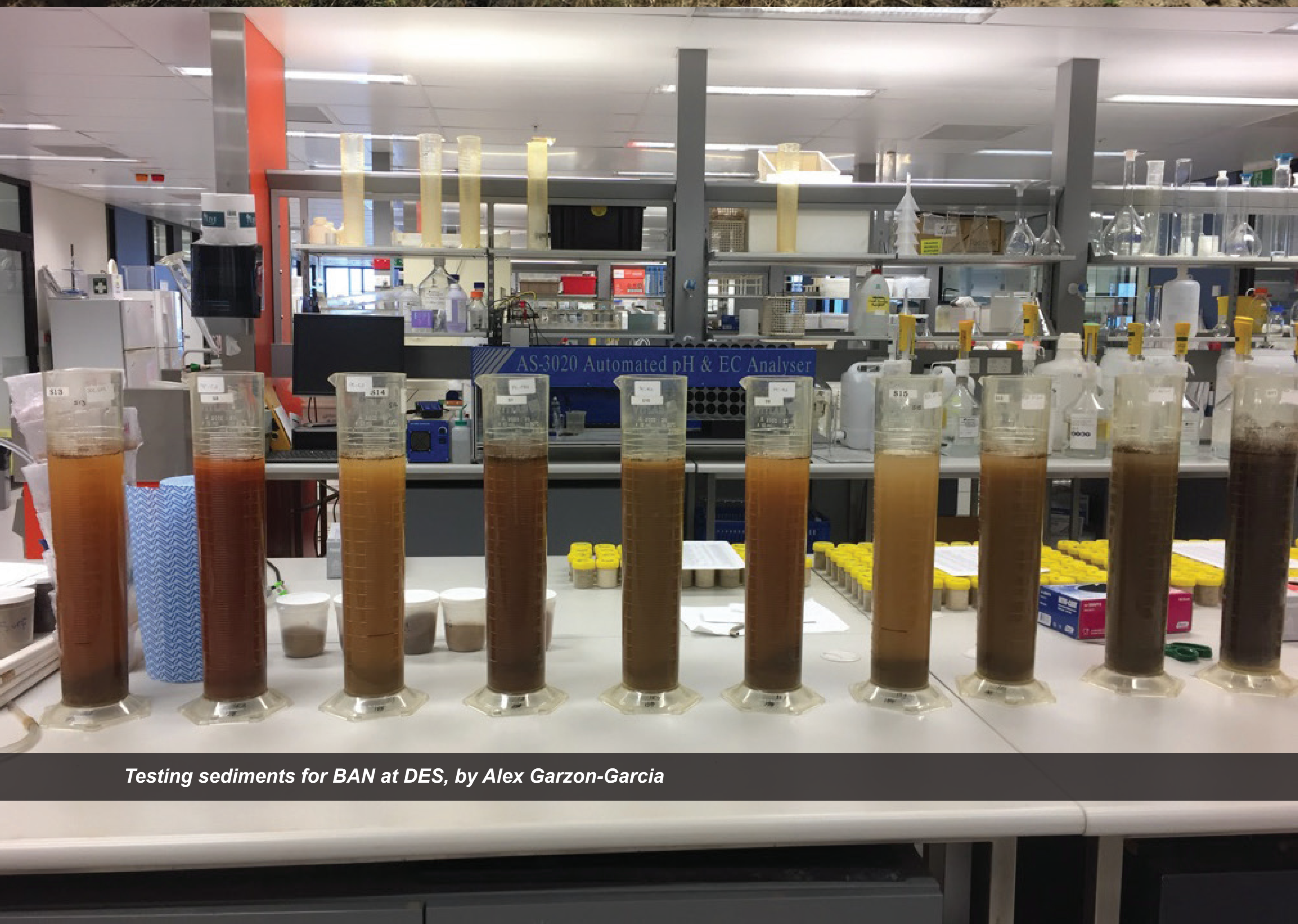
IMPLICATIONS FOR MANAGEMENT AND SUPPORTING INFORMATION NEEDS

The new knowledge of the bioavailability of particulate nutrients has implications for management in several areas including the selection of management options, prioritisation and target setting. There are also implications for monitoring, modelling and future information needs. These have been captured from the supporting documentation, the workshop and further discussion with workshop participants and are summarised below.

Management area	Implications
Management options	• The relative importance of specific management of particulate nutrients in the catchment is boosted due to knowledge of more rapid timeframes for the bioavailability of particulate nutrients than previous assumed. The extent of influence is inshore and midshelf areas. • The carbon – nutrient interaction in the marine environment is important, which requires specific monitoring and management of carbon inputs from both soil and vegetation in the catchment. The effect of vegetation type will be important to consider when doing landscape restoration. • In grazing and dryland cropping catchments, we can now view eroded sediments as a significant source of bioavailable particulate nutrients (DIN in the marine environment). • Different management practices will target different erosion processes and should be considered in the context of generation of fine sediment and particulate bioavailable nutrient yields per unit area. There is a need to develop and promote land management practices that reduce loss of nutrient-rich fine sediments. • Nutrient markets/offsets and trading for nitrogen forms should take into account the bioavailability of the different pools of particulate nutrients. • It is important to communicate that our understanding of nutrient budgets has changed and that this improved knowledge may influence (within) catchment prioritisation.
Prioritisation	• Adding the bioavailability of particulate nutrients to the prioritisation of erosion management will accelerate the benefit to water quality of these investments. However, assessment of the time lags of managing DIN from fertiliser versus soil erosion is important, especially if the relative importance of DIN and PN is assessed. • Further targeting of effort to manage DIN from erosion requires additional information for refinement (see 'Information needs'). • Explicit addition of particulate nutrient loads and assessment of their bioavailability (e.g., by catchment, sediment type in plume) is required for future marine nutrient risk assessments – both in the marine modelling and in linking to end of catchment loads.
Target setting	• The 2017 GBR end of catchment load targets for PN and PP mirror the fine sediment reductions for each basin. There is a need to specifically address bioavailable particulate nutrients when the targets are revised for the WQIP update in 2022 (need to be prepared to do that in 4 years time). This would require further quantification of DIN from erosion and quantification of the bioavailability of particulate nutrients in more catchments (both during transport to end-of-catchment and in the estuarine/marine receiving water columns). • Setting ecologically relevant P targets is important and should be progressed for definition by 2022.

<table>
<tr><th>Management area</th><th>Implications</th></tr>
<tr><td>Modelling needs</td><td>Improved representation of particulate nutrients (PN, PP and POC) and bioavailable particulate nutrients (DIN from mineralisation, DIN from desorption, solubilised DIN, DRP, bioavailable DON and DOC) in the catchment models. This must be coupled with improved sediment modelling. Intrinsic soil property data will be required for catchments other than the Bowen and Johnstone. Improve the catchment modelling to:
Account for pre-development and current bioavailable nutrients in catchments will support the targeting and management of DIN from erosion. This will allow reporting on DIN reductions associated with erosion mitigation.
Provide greater resolution of the model outputs and fine scale validation of the model outputs.
Improve the distinction of PP and PN pathways between hillslopes and gullies.
Develop pedo-transfer functions from intrinsic soil properties for finer scale analysis of bioavailable nutrient sources and delivery (longer term needs).
Improve marine modelling (eReefs) capability to:
Simulate dissolved and particulate organic matter decay rates that vary as a function of stoichiometry and/or origin, incorporating knowledge of decay rates and POM composition gained from catchment and marine studies of particulate organic matter.
Adjust parameterisation of inorganic nutrient adsorption/desorption from suspended mineral sediments as information regarding these processes becomes available. Incorporate improved understanding of benthic sediment contributions in the eReefs model.
Provide better representation of the transport of flocs and N fixation and test the sensitivity of ecosystem response to P inputs.</td></tr>
<tr><td>Monitoring needs</td><td>Monitor bioavailable properties (at least PIN, POC, SOC/DOC, adsorbed ammonium, particle size distribution) at Paddock to Reef program monitoring locations (paddock, sub catchment and end of system sites) and specific project areas (e.g. rehabilitation treatments) to be able to assess the bioavailability of particulate nutrients to phytoplankton using indicators of bioavailability. This will also improve modelled equations for bioavailable nutrient delivery
High resolution soil mapping to support improved modelling (Extend soil database). This will include the addition of additional soil parameters that will be required to use pedotransfer functions to estimate sediment properties. The list of parameters will be provided in the final report from RP178a.
Undertake high resolution mapping (e.g. repeat LiDAR) of channel processes and deposition–in strategic locations to inform bioavailable nutrient contributions from different erosion processes.
Extend routine measurement of nutrients (including PIN, DOC and POC) in the Marine Monitoring Program and include monitoring of midshelf areas in strategic locations where bioavailable nutrient sources may be important or where existing knowledge can be extended, e.g. link to crown-of-thorns starfish initiation in the Wet Tropics transects.</td></tr>
</table>

Sampling for BAN at Vertosol Gully, by Alex Garzon-Garcia



Testing sediments for BAN at DES, by Alex Garzon-Garcia

The following **information needs and dependencies** have been identified through this process (these are in addition to the supporting monitoring and modelling needs identified above):

1. Greater understanding of **bioavailable particulate nutrient source and delivery in the catchment** to optimise the benefits of management interventions (i.e. reduce fine sediment and bioavailable particulate nutrients collectively). This will require:
   - Specific studies to understand the generation of bioavailable particulate nutrients under different land management conditions are required, specifically for hillslope erosion. Focus catchments could include continuation of the current efforts in the Johnstone and Bowen/Burdekin catchments, plus addition of the Olive Pascoe basin for end of system and native paddock scale sites.
   - Monitor and calibrate DIN reduction from erosion management. This needs to be carried out to cover different erosion management techniques for comparison, different soil types and at least until a stable state has been achieved (could be >10 years for gully rehabilitation works) including paddock scale, monitoring of rehabilitation projects and end of system sites.
   - Greater confidence in the knowledge of pre-development sources (reference conditions) linked to soil types, land use and erosion processes through establishment of a catchment to marine monitoring program in a relatively pristine area such as the Olive Pascoe Basins, based on the design of the NESP Project 2.1.5 design. Tracing and dating in sediment cores could also be examined to look at the end of different catchments to examine shifts in sources and nutrient regimes.
   - Assessment of existing knowledge of the sources of bioavailable nutrients in the context of particle size (‘clean and dirty’ sediment) to select areas where there is likely to be fine sediment and potentially bioavailable nutrient benefits (overlay maps) from erosion management. Use this to assess potential sources of ‘ecologically relevant’ fine sediment (organic matter and flocs) (depending on whether they stay in that form in transport).
   - Identification of priority areas for soil mapping and ground truthing. This needs to be supported by improved methods for capturing and measuring particle size distributions (and ensure comparable datasets).
   - Acquisition of higher resolution soils data (initially water dispersible silt and clay, POC, PN, PP, adsorbed ammonium, SOC, SON, DRP). To be verified with development of pedo-transfer functions as part of RP178a and classification of soils (disaggregate into finer scale) to provide better estimate of bioavailable nutrient delivery in the models.
   - Development of nutrient budget from all sources (e.g. Johnstone bioavailable particulate nutrient from grazing versus sugar cane; for grazing lands bioavailable particulate nutrients, cattle, rainfall. Could be progressed with existing information in 2 case studies. For example, test the model data with multiple lines of evidence and trialling in the 2 Major Integrated Project (MIP) locations. Use to evaluate end of system loads, accounting for bioavailable particulate nutrient inputs.
   - Finer scale validation of the study of bioavailable nutrient catchment modelling study (RP178a Burton, Garzon-Garcia, Ellis) – this will assist to assess evaluation outcomes from management practice improvement, plume sourcing information and better marine risk assessment, and could be undertaken by analysis of multiple lines of evidence (existing monitoring data, tracing and experimental results).
   - Investigation of the effect of vegetation type (i.e. Carbon) on the bioavailability of particulate nutrients in-situ and as they are transported through catchments. This may influence on ground management practices such as trash blanketing and choosing species and tree density to be used in rehabilitation.

- Assessment of the effect of mill mud/mud ash application on bioavailable P forms at block (runoff/deep drainage) and catchment scale.
- Investigation of how bioavailable particulate nutrients interact in wetlands and the role of riparian areas in trapping or processing bioavailable nutrients. Quantification of the potential wetland treatment efficacy needs to take these particulate nutrient processing factors into account. Both N and P will be important to investigate in wetlands as freshwater algae respond to both. Residence times are vital to the efficacy of wetland treatment and in some catchments, it will not be possible to achieve appropriate residence times.

2. Further investigation of the rates and processes that influence nutrient **bioavailability in the marine environment**, including assessment of:
    - Remineralisation rates of particulate organic material derived from terrestrial versus marine sources.
    - The role of resuspension in injecting DIN and PON from sediment pools into the water column and implications for remineralisation. These factors should be considered in the assessment of the risk of particulate bioavailable nutrients to the GBR.
    - The interaction of fine sediment, bioavailable nutrients and Chlorophyll in the central midshelf areas of the GBR. This will require frequent measurement of these parameters and analysis of the data correlations.
    - The role of phosphorus in supporting phytoplankton growth, relative to nitrogen. This can be explored in more detail using the eReefs biogeochemical models, supported with marine process studies to confirm model results and improve parameterisation and representation of phosphorus and nitrogen fixation processes in the model.
    - The effect of carbon on nutrient bioavailability (combined laboratory and field analysis).
    - The differential and combined effects of bioavailable nutrients (N, P, C) on algal groups and linking to COTS initiation and survival.
    - Phytoplankton dynamics in times of river discharge on the midshelf areas of the GBR, and measurement of nutrient enrichment across the GBR, especially in the midshelf and outer shelf between Townsville and Cairns where river discharge extends beyond inshore areas.
    - Cumulative impacts of multiple nutrient stressors on GBR ecosystems.
3. **Integrated assessment** of the catchment to reef interactions of fine sediment and bioavailable nutrients, drawing on the above information. This could include:
    - Extension of the research effort to other systems (getting a good picture for the Burdekin, and some in the Tully / Johnstone) to differentiate between land use and the distinction of anthropogenic influences. In particular it is important to get a better understanding of pre-development loads of bioavailable nitrogen and phosphorus by studying pristine / conservation catchments or long term rehabilitation sites (e.g. Weany Creek). This information can also be obtained by examining nutrient regime shifts in sediment cores from receiving waters.
    - Extended application of the approach adopted in NESP Project 2.1.5 to other catchments (e.g. Herbert, Johnstone, Olive-Pascoe). This would need to be supported by laboratory based analysis of bioavailable nutrient processing from soils in different locations, experimental manipulation of carbon (build on DES/Griffith Uni indicator work) and extension of the monitoring in existing locations (Burdekin, Tully) to incorporate midshelf areas.

MAIN DIFFERENCES TO OUR PREVIOUS THINKING

Brodie et al. (2015) concluded: *Overall, we suggest management of anthropogenic sources of PN (mainly erosion) is likely to be very important to the health of the GBR (particularly the inshore GBR) but not as important as the management of anthropogenic sources of DIN (mostly fertiliser use). This finding is* ***based on our current assumptions that almost all the PN discharged from rivers to the GBR is likely to be bioavailable within its residence time in the GBR lagoon, but PN is likely to be dispersed over a much smaller area than DIN***.

We now have case study evidence of how much of the PN becomes bioavailable once it enters the lagoon, and in what timeframes. In the Burdekin River in Cyclone Debbie, experimental results indicate that the bioavailable nutrients from PN is in the same order of magnitude as the end of system DIN load (from the Burdekin River itself not including discharge from Barratta Creek and the Haughton River). This is a greater proportion of bioavailable nutrients than previously assumed, and with a more rapid mineralisation rate than previously assumed. A case study using catchment model improvements also highlights the importance of the variability in particulate nutrient generation and the need for much finer scale prioritisation using available digital soil constraints mapping.

The new evidence strengthens the case for specifically targeting the management of particulate nutrients in the GBR catchments for minimising risks to the GBR from anthropogenic land-based nutrient inputs as the timeframes of bioavailability in the marine environment can be within a few days.

CONCLUSIONS

The outcomes of the workshop and associated discussions are compelling for re-assessing the relative importance of the role of land-derived particulate nutrients to GBR health, highlighting that targeted management of particulate nutrients in the GBR catchments is warranted. However, this requires improved knowledge of the sources and delivery of particulate nutrients in specific locations, supported by improvements in catchment and marine modelling capability. These needs have been identified through the workshop and supporting work.

The project has demonstrated the value of greater collaboration between the catchment and marine research teams, and between these teams and the modellers. A majority of the outcomes of this project are hinged on this extremely positive collaboration. It is recommended that a forum is established for regular communication between experts in this field and across the paddock to reef landscape. The participants at the workshop indicated a willingness to support this kind of initiative. It would be beneficial to facilitate additional discussion among participants to refine the timelines required for delivering the key information needs.

GLOSSARY

DIN .... dissolved inorganic nitrogen = nitrate, nitrite and ammonium. Nitrogen in these forms is highly bioavailable and can be taken up directly by plants including phytoplankton and other algae

DON .... dissolved organic nitrogen. DON includes any dissolved nitrogen in a chemical form that is compounded with carbon. This includes a wide range of substances, from very bioreactive urea (applied as fertiliser on crops), RNA and DNA, through to very refractory (i.e. unreactive) dissolved substances. As measured in practice, DON also includes colloidal nitrogen. DON is typically assumed to be less bioavailable than DIN

PN .... particulate nitrogen. PN includes nitrogen in any form that does not pass through a filter, from nitrogen associated with suspended soils and leaf litter, to living and dead phytoplankton and organic aggregates of carbohydrates and detrital animal material

PON .... particulate organic nitrogen. PON is PN in organic forms, i.e. carbon compounds. The majority of particulate nitrogen in the water column is usually PON

PIN .... particulate inorganic nitrogen. This includes the soluble nitrate and ammonium in the interstitial pore water, and adsorbed ammonium

DRP .... dissolved reactive phosphorus (i.e. dissolved inorganic phosphorus plus highly reactive dissolved organic phosphorus)

DOP .... dissolved organic phosphorus. Analogous to DON and usually part of the same chemical compounds, DOP is dissolved phosphorus in organic forms, from DNA and RNA to anisotol phosphorus. The ratio between nitrogen, phosphorus and carbon in dissolved and particulate organic material is often an important indicator of its bioavailability and nutritional quality

PP .... particulate phosphorus. PP is the sum of PIP and POP

POP .... particulate organic phosphorus. Analogous to PON and usually part of the same chemical compounds and biological materials

PIP .... particulate inorganic phosphorus. Particulate inorganic phosphorus can be an important constituent of PP. PIP includes both inorganic phosphorus adsorbed to sediment particle surfaces, which exists in equilibrium with DRP in the surrounding water and is readily bioavailable, and chemically immobilised phosphorus, which is very unreactive and not likely to contribute to biological processes on relevant time-scales

BAN .... Bioavailable nutrients. Nutrients (especially nitrogen and phosphorus) that are in forms that support biological processes such as growth of phytoplankton

Bioavailable PN ..... Bioavailable Particulate Nitrogen. BAN that is specifically derived from the mineralisation, desorption and dissolution of PN associated with eroded soils.

Bioavailable PP ..... Bioavailable Particulate Phosphorus. BAN that is specifically derived from the mineralisation, desorption and dissolution of PP associated with eroded soils

ATTACHMENT 1: CURRENT CONCEPTUAL UNDERSTANDING

The current conceptual understanding is outlined below

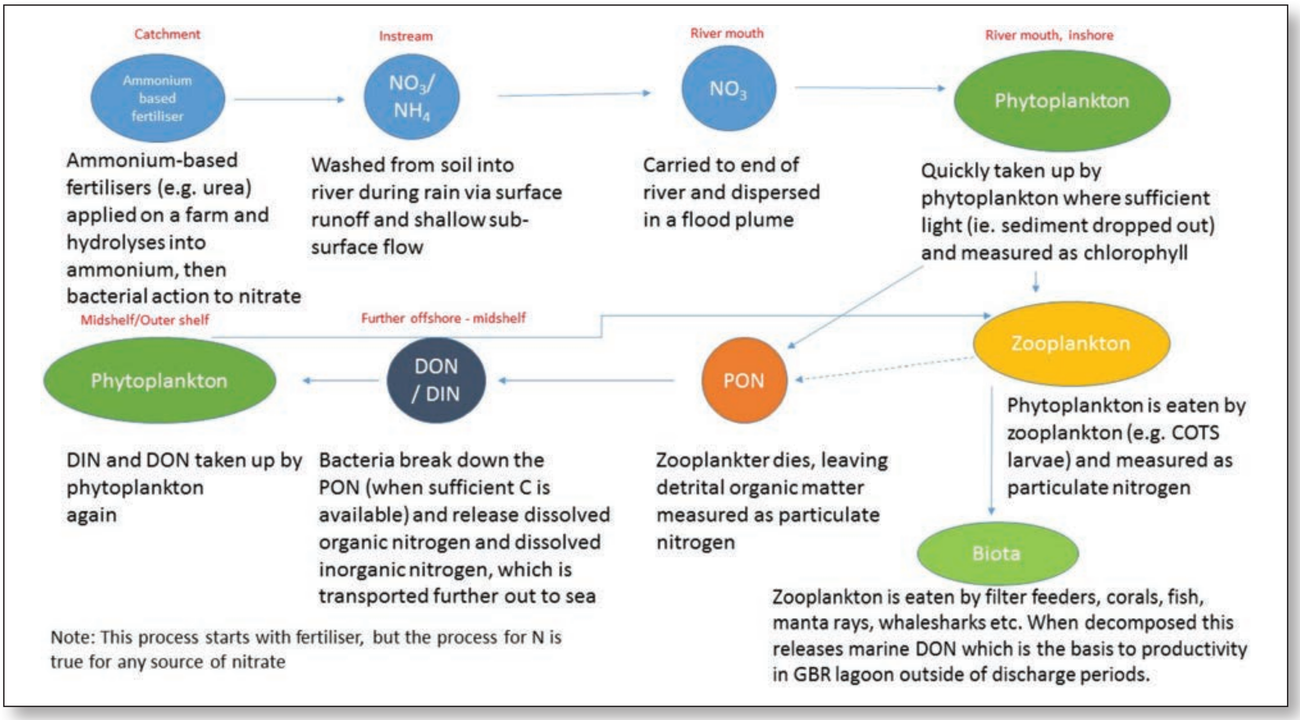


Figure 1: Cycling of nitrogen from ammonium-based fertilisers

Explanatory text and notes:

1. This model ignores lateral movement of nitrate-N in perched water-tables/groundwater which is often the major source of base-flow DIN.
2. This model also ignores exchangeable ammonium-N which is the major form of mineral N in runoff/sediments from enhanced efficiency fertilisers incorporating nitrification inhibitors.
3. The form of nutrients that is measured in the marine environment is not necessarily the same as the form of nutrients that was generated in the catchment and delivered to the end of system. Constant nutrient cycling occurs, so it is complex to determine whether different forms are directly important for catchment management.
4. There are three periods that are considered to be the most important in terms of potential ecological impact on GBR ecosystems:
   - river discharge periods (greatest influence);
   - wet season (periodic river discharge, higher temperature); and
   - non-wet (dry) season with no river discharge (usually cooler temps – but resuspension events and potential mineralisation).

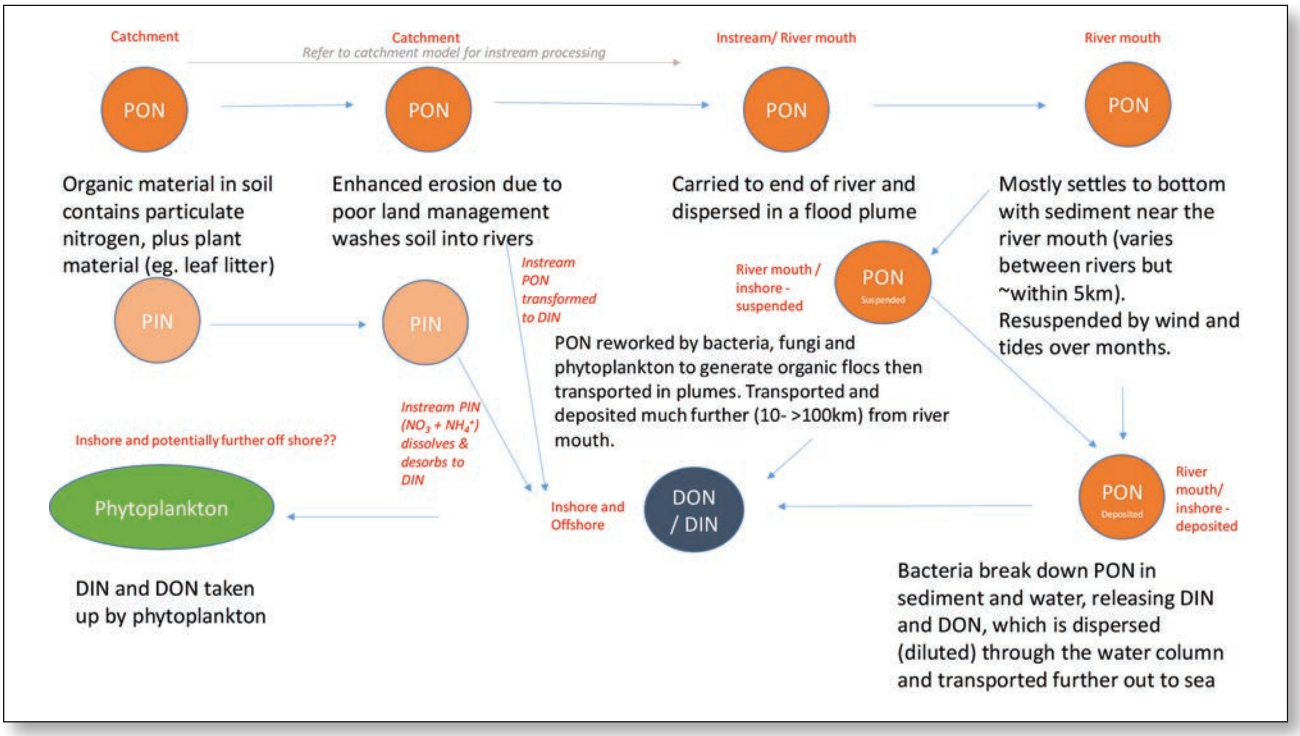


Figure 2: Cycling of nitrogen from soil organic matter. Note: Nitrate associated with the soil will immediately dissolve becoming DIN in stream. This is not currently represented

Explanatory text and notes:

1. A significant proportion of the PON in runoff falls to the bottom (sediments) in close proximity to the river mouth along with inorganic terrestrial sediment.
2. Some of the remaining PN is incorporated into organic aggregates within runoff plumes and can be dispersed more widely in the GBR lagoon.
3. DON in river discharge may also be converted to PON in estuarine processing and may thus enter the PON pool.
4. A portion of this terrestrial PN is ultimately mineralised to DIN by water column and benthic bacteria, provided sufficient carbon is available, and then may enter the GBR inorganic N cycle. Much of the PN may be quickly converted to N2 via mineralization, nitrification and denitrification processes and hence removed from the N cycle in the lagoon.
5. Current understanding of the influence of PON on nutrient availability, and whether it persists for a longer period after delivery (months) indicates that:
   - Input may continue in the longer term from mineralisation but unlikely to have important impact - not at concentrations that are of concern to ecosystems
   - However, if direct uptake of DON occurs, it can reduce light penetration for longer periods of time leading to secondary processes in mid-shelf areas which can have implications. Importantly though, bleaching response is eliminated in this time, and COTS recruitment – so assume limited impact from this source.

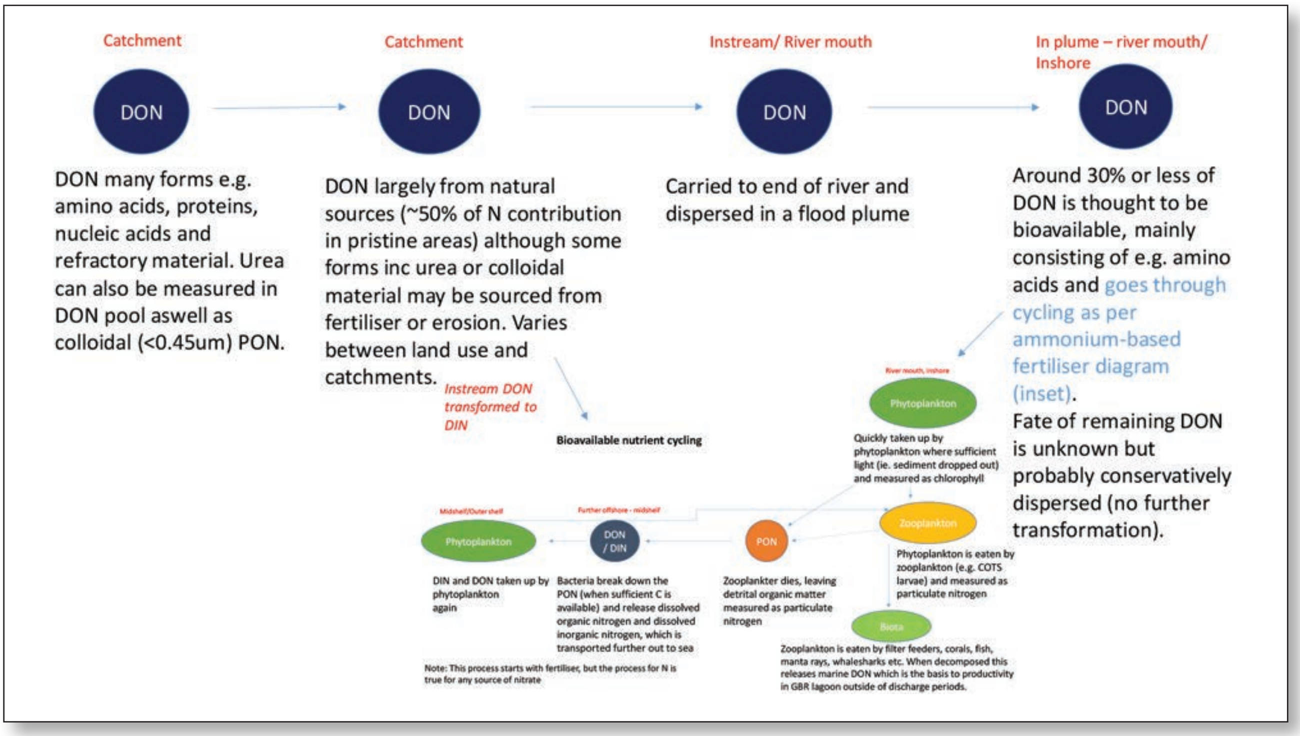


Figure 3: Cycling of nitrogen from dissolved organic sources

Explanatory text and notes:

1. The DON in terrestrial runoff is derived from degraded plant material and soil and differs in character from marine DON. A significant, but still uncharacterised fraction of the terrestrial DON in runoff is mineralised to DIN in the GBR lagoon and then enters GBR food webs.
2. Sources of increased DON (excluding urea fertiliser) in catchments are associated with improved drainage and other hydrological modifications, fertilised soils and potentially changed rainfall intensities.

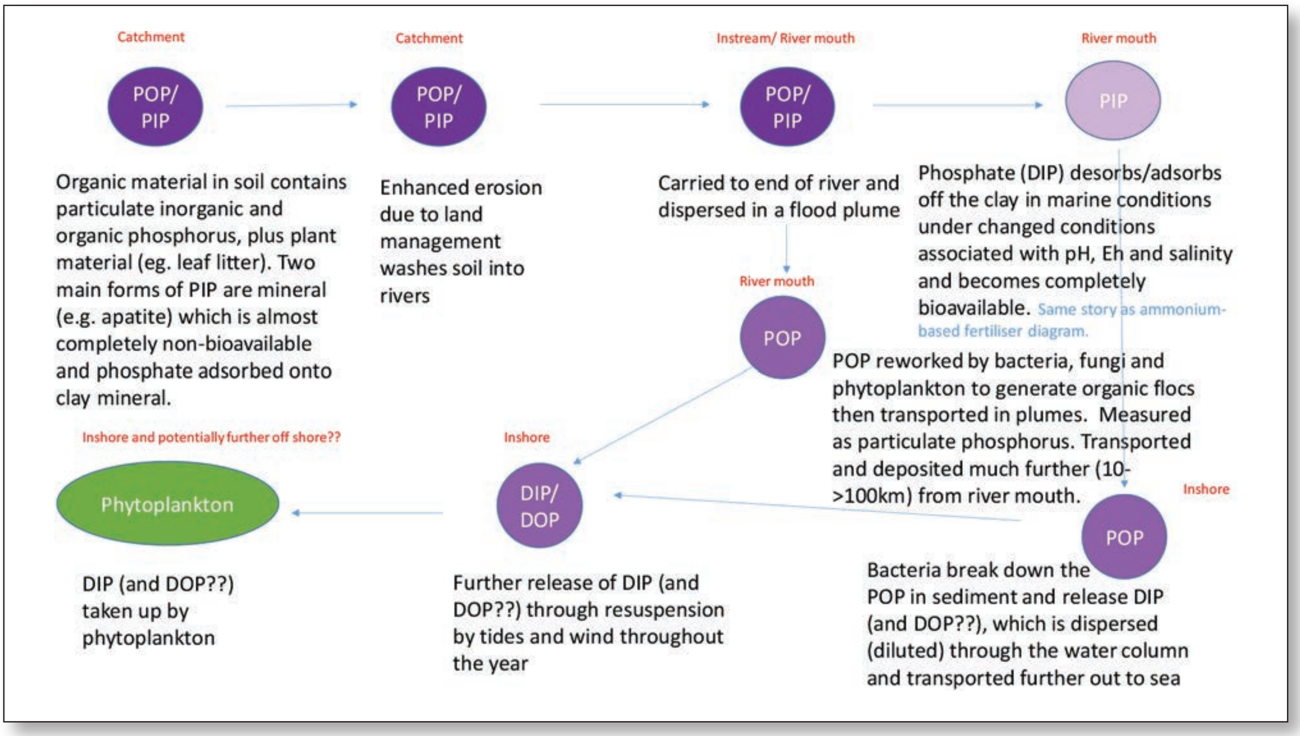


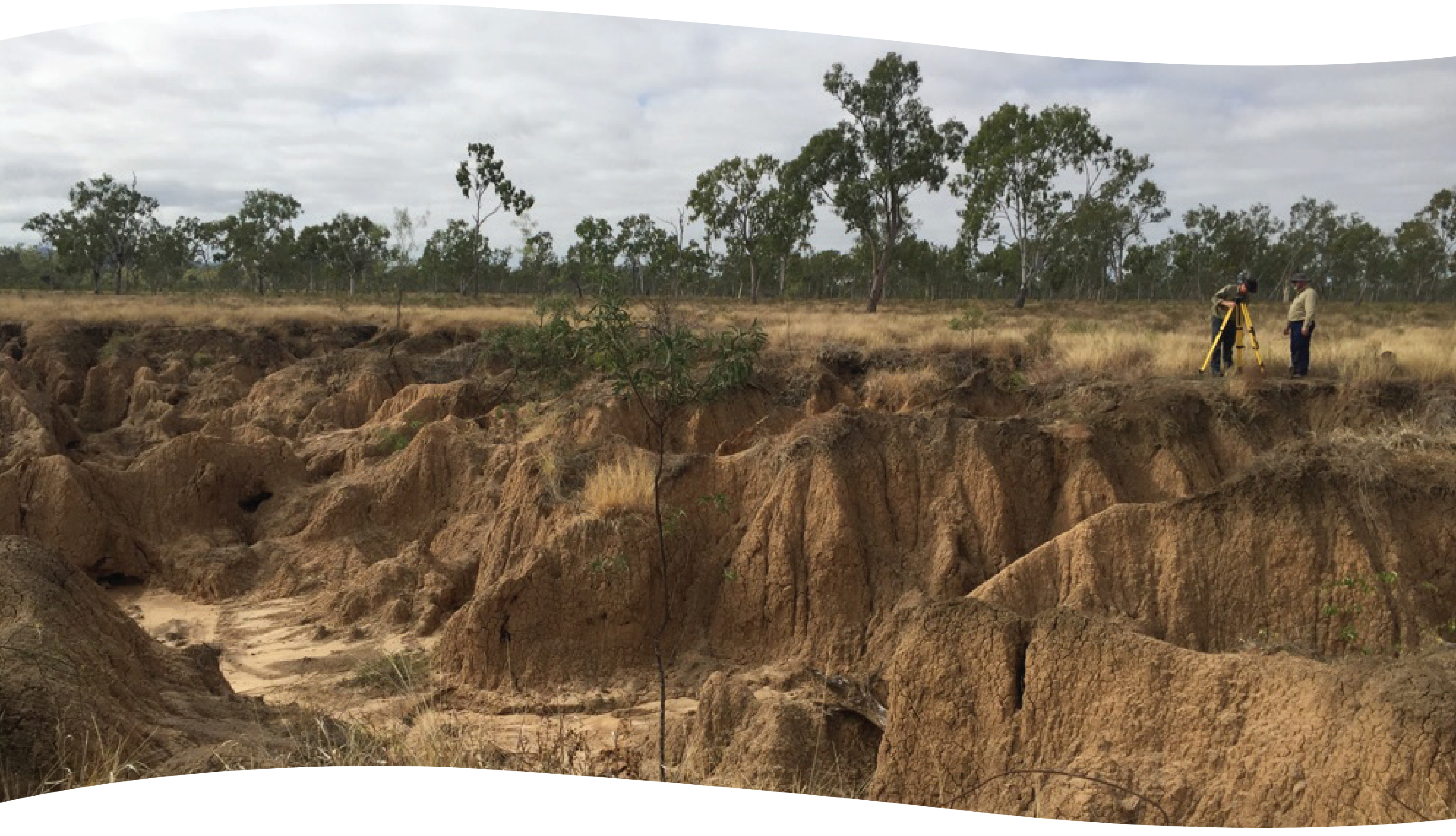
Figure 4: Cycling of particulate organic and inorganic phosphorus

Explanatory text and notes:

1. The POP in terrestrial runoff is derived from degraded plant material and soil and differs in character from marine POP.
2. PIP is P attached to soil particles. In the case of PIP, it can be released when particulates reach marine waters to produce phosphate (DIP).
3. POP may be processed by bacteria, provided sufficient carbon is available, with DOP and DIP being products.
4. Bacteria can also utilise these sources and produce smaller DOP molecules, e.g. phosph-esters, phosphonates, which can be used by phytoplankton. Phytoplankton also use DIP for growth.

Outside Back Cover: *Strathalbyn Gullies, by Alex Garzon-Garcia*

Sampling gully banks for BPN in the Bowen catchment, by Alex Garzon-Garcia



Reef & Rainforest
RESEARCH CENTRE

www.nesptropical.edu.au