Reef Water Quality Science Project RP154P

Enhanced findings of the 2013 Scientific Consensus Statement – Gaps and opportunities

Final report (February 2016)

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IMPORTANT NOTE:

This report was funded through the Department of Environment and Heritage Protection's Reef Water Quality science program. The Office of Great Barrier Reef is considering the process for the synthesis of emerging science as part of any future review of Reef Plan, including the requirement for wider consultation.

The Office of the Great Barrier Reef and Reef Water Quality program commissioned this report to provide an **initial analysis** of emerging reef science since the completion of the 2013 Reef Plan Scientific Consensus Statement (SCS) and **was not intended to provide a comprehensive review**. This report provides a summary of critical research findings and outputs that have become available since the 2013 SCS. Advice on whether each SCS Chapter requires updating in the short term (prior to the proposed 2017/2018 update) is provided, as well as opportunities for additional work to be completed in the short term (next 3 to 6 months). Projects that are currently underway and likely to be relevant to the 2017/2018 update are also identified as well as where further information and expertise may need to be sourced.

The Queensland Government is committed to investment in reef water quality science and as new information becomes available, government policy will be adapted to take account of it. This report is provided in good faith on the understanding that the information is not used out of the context explained above.

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1. Introduction

Scientific Consensus Statements (SCS) regarding the impacts on the Great Barrier Reef (GBR) were produced in 2008 and again in 2013, and are based on many (over 500) peer reviewed scientific papers and reports and a robust peer review process. This work then informed the 2009 and 2013 Reef Water Quality Protection Plans (Reef Plan).

Since the 2013 Scientific Consensus Statement (2013 SCS) was issued, additional published literature and synthesis reports on emerging science and their implications are being used to guide government investments. This information and knowledge may not yet be generally available to regional or wider audiences, especially in an integrated form. Reef Plan partners and stakeholders are discussing how to best address this. Many of these studies have been synthesised as part of the update and development of the regional Water Quality Improvement Plans (WQIPs) in 2014 and 2015. This emerging knowledge, how it augments the 2013 SCS findings and its implications for management are not widely understood.

This makes it difficult to respond to the recent questioning by industry, some scientists and other stakeholders on the merit of the science underpinning Reef Plan's response to reduce the impacts of diffuse agricultural pollutants on the resilience of the GBR (i.e. impacts of key reef contaminants - sediments, nutrients and pesticides - on key reef ecosystems and species such as coral reefs, seagrass meadows, dugongs and turtles).

This project is designed to support the communication of 2013 SCS and emerging Reef Science, and address points of disputes with respect to 2013 SCS. The key objectives are to:

1. Provide an update on emerging reef science and where it may enhance the 2013 SCS (this report);
2. Clarify the scientific basis for 2013 report on specific technical issues (advice for DEHP).

This report provides a summary of critical research findings and outputs that have become available since the 2013 SCS. Advice on whether each SCS Chapter requires updating in the short term (prior to the proposed 2017/2018 update) is provided, as well as opportunities for additional work to be completed in the short term (next 3 to 6 months). Projects that are currently underway and likely to be relevant to the 2017/2018 update are also identified.

Appendix 1 provides a listing of some of the vast volume of new literature now available to update our knowledge and hence management response. Critical examples of key areas where knowledge has expanded or improved since 2013 are summarised below.

This is not a comprehensive overview but provides an indication of the new science. It should also be noted that detailed analysis of the new science and implications for management is not within the scope of this project. The authors also identify areas where additional expertise may be required to complete this assessment.

Chapter 1. Marine and coastal ecosystem impacts

A synthesis of the status of coastal and marine values in each NRM region has been conducted in 2014 -2015 as part of the development and update of the Water Quality Improvement Plans (WQIPs) (Cape York: Coppo and Brodie 2015a; Wet Tropics: Johnson 2014; Burdekin: Coppo and Brodie 2015b; Fitzroy: Johnson et al. 2015; Burnett Mary: Coppo et al. 2014). Whilst this synthesis has not been completed for the Mackay Whitsunday region, additional work (not published) on marine status may have been completed as part of the regional Report Card[1] and Reef Recovery Plan (GBRMPA).

The scope of this work includes all coastal and marine assets including coral reefs, seagrass meadows, mangroves, turtles, dugong, seabirds, whales, fish, coastal wetlands, shorelines and estuaries. Key data sources are hosted within the Reef Rescue Marine Monitoring Program, the AIMS Long Term Monitoring Program, Seagrass Watch, Queensland Wetland Program and relevant research results, many of which have

[1] http://issuu.com/healthyriverstoreef/docs/issu_pilotreportcard_oct14_electron/1

produced annual reports since the 2013 SCS. Reef Plan Report Cards were also released in 2014 (2012-2013 data) and 2015 (2013-2014 data) that report annual Marine Monitoring Program data (State of Queensland, 2013, 2014).

The studies found that the condition of many GBR coastal and marine ecosystems remain in poor condition with clear linkages to land based runoff and poor water quality. There are some signs of recovery of seagrass and some coral reefs in the last 2 years due to relatively low river discharges across the GBR, however, these recovery assessments are based on a relatively limited dataset.

Each report has also identified key knowledge gaps for each region, many of which highlight the lack of knowledge on cumulative pressures on GBR ecosystems, and the need for further monitoring in particular areas including Cape York and Burnett Mary.

These reports draw on many recent papers about the impacts of poor water quality on coastal and marine ecosystems, although there is no updated synthesis of marine impacts from water quality specifically. A number of key examples include:

- Update of the assessment of coral community responses to declining water quality in the Whitsunday Islands (Thompson et al. 2014).
- The effects of increased turbidity on seagrass ecosystems in a case study in Cleveland Bay (Petus et al. 2014).
- Assessment of the acute and additive toxicity of PSII herbicides to seagrass (Wilkinson et al. 2015).
- Persistence of pesticides in marine conditions (Mercurio et al. 2015).
- Establishment of a framework for assessing seagrass resilience (Unsworth et al. 2015).
- Synthesis of the available seagrass monitoring data collected through various ports monitoring programs (Rasheed et al. 2015) and specific analysis of knowledge gaps in the Wet Tropics (McKenzie et al. 2014).
- Analysis of the effects of large river discharge events and category 4/5 cyclones over the last decade on coral reefs (Butler, 2014; Butler et al. 2013, 2015; Jones and Berkelmans 2014; Perry et al. 2014: Beeden et al. 2015). *Note this also links to Chapter 2.*
- Analysis of the effects of sequential multi-year Fitzroy River discharge on coral reef response and recovery inside and outside of Marine Park protected areas in the Keppel Islands (Wenger et al. 2015; van Oppen et al. 2015). *Note this also links to Chapter 2.*
- Changed coral species composition over the last century at several reef locations (Roff et al. 2013; Clarke et al. 2014, 2016) and in comparison to changes over the Holocene (Ryan et al. 2016).
- The importance of the influence of land-derived fine sediment (<16μm) and its clay content on marine ecosystems (Bainbridge et al., 2014, 2015) and the sources of such sediment in the Burdekin Basin.
- Further synthesis work has also been carried out reviewing the effects of port dredging or proposed port dredging and spoil dumping (McCook et al. 2015).
- Burdekin and Fitzroy sediment synthesis includes summary of impacts and extent of influence of sediment on coastal and marine ecosystems (Lewis et al. 2015a,b).
- Knowledge synthesis of the dispersion of sediment and nutrients following major river discharge events based on remote sensing, water analysis, modelling and physico-chemical and biological processes occurring in river plumes (Devlin et al. 2013; Alvarez-Romero et al. 2013; Blondeau-Patissier et al. 2014; Delandmeter et al. 2015).
- The effects of river discharge on lagoonal pH and coral calcification rates (D'Olivo et al. 2013, 2015; Kamya et al. 2014).
- Depositional areas for recent river derived sediment based on benthic sediment sampling (Lewis et al. 2014).

- Processes affecting sediment resuspension and cross - shelf and long-shore transport (Lewis et al. 2014).
- Relationships, correlations and causation between river discharged fine sediment and subsequent GBR lagoonal turbidity and clarity (McDonald et al. 2013; Fabricius et al. 2013, 2014, 2016; Logan et al. 2013, 2014).
- Assessment of the relative contribution of river discharges to nutrient supply in the COTS Initiation Zone (Brinkman et al. 2014).
- Hydrodynamic and water quality relationships associated with COTS outbreaks and larval competence (Hock et al. 2014; Wooldridge and Brodie 2015; Uthicke et al. 2015a,b; Wolfe et al. 2015).
- The effects of river discharge on lagoonal biological communities (DeBose et al. 2015; Alongi et al. 2015; Angly et al. 2016).
- Understanding of the level of endrocrine disruptors in fish (Kroon et al. 2015a, b).

In the period since 2013, GBRMPA also released the GBR Outlook (2014) (GBRMPA 2014a) and the Strategic Assessment of the GBR (GBRMPA, 2014b) and the Queensland Government equivalent for coastal areas (State of Queensland, 2014). These reports both provide a comprehensive update of the status and threats of coastal and marine ecosystems in the GBR (broader than just water quality).

This knowledge has been used to define Ecologically Relevant Targets for the Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions which have been incorporated into the WQIPs (Brodie and Lewis 2014; Brodie et al. 2014; 2015a, 2016; Wooldridge et al. 2015; Brodie et al. in review). These targets are defined on the basis of the water quality concentrations required to meet the GBR Water Quality Guidelines for protection of reef ecosystems, and the associated end of catchment load reductions required to achieve those concentrations. These studies have also assigned the Reef Plan targets at a Basin scale**.**

The economic values of GBR ecosystems was revised as part of the GBR Strategic Assessments (Deloitte Economics, 2013) and further assessment has been completed in the Cape York, Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions as part of the WQIPs (Thomas and Brodie, 2014a,b; Thomas and Brodie, 2015a,b,c). These provide a very early starting point to assessing the costs and benefits of management options for water quality in the GBR.

Opportunities:

Approach for 2017/18 SCS update

Given the availability of published data, papers and commissioned projects, the synthesis of new material will be best addressed within the major SCS update in 2017/18 and should include:

- The annual Report Cards update the MMP data on GBR inner-shelf status, along with wider GBR status from the LTMP and Outlook reporting, and this information is publicly available.
- There are several NESP projects due for completion by March 2016 that will synthesise knowledge of several topics relevant to this SCS Chapter in 2017. These include synthesis of knowledge of emerging contaminants (Project 1.10), establishing a research investment framework for dredging (Project 1.9), assessing cumulative impacts of climatic disturbances on inshore coral reefs (Project 2.1), establishing light thresholds for seagrasses (Project 3.3), developing and refining indicators for seagrass condition assessments (Project 3.4) and synthesising existing seagrass mapping (Project 3.1) (http://nesptropical.edu.au/index.php/research/projects/).
- The Australian Government is also funding a research program specifically relevant to climate impacts on marine ecosystems through the GBR Foundation (see comments under Chapter 2).
- The sediment syntheses produced by Steve Lewis and others for the Burdekin and Fitzroy region provide a solid basis for the update of sediment related information in the GBR. This information has been used for guiding management priorities in the Burdekin and Fitzroy WQIPs. Conceptual models

illustrating the Burdekin sediment story from impacts back to improved management have also been developed (L. Baskerville and S. Imgraden, 2015).

2016 activities

Opportunities to improve application of current scientific knowledge are:

- Consolidation and review of the WQIPs targets as part of the planned Reef Plan mid-term review in 2016 as recommended in Reef Plan 2013 Action 3, including the consolidation of regionally specific end of catchment targets and establishment of ecologically relevant targets for the Mackay Whitsunday region (next 3-6 months).
- Integrated analysis of the condition and trend of inshore coral reefs (mostly from Marine Monitoring Program (MMP)) with midshelf and outer shelf reef data (largely from the AIMS Long Term Monitoring Program) (next 12 months to inform 2017/18 SCS update).
- Continued investigation of the role of land-derived particulate nutrients in the marine environment, and in particular, the likely contribution to the nutrient supply relevant to the COTS Initiation Zone (under Lewis et al. NESP Project, Sediment Working Group Nutrient management sub-group)

Chapter 2. Resilience of Great Barrier Reef marine ecosystems and drivers of change

Since the 2013 SCS was released, the evidence of the role of managing stressors on GBR marine ecosystems such as water quality in the context of ecosystem resilience has been strengthened through numerous scientific publications. In particular, further work on the resilience of seagrass to multiple flood events, port dredging and powerful cyclones has progressed.

A number of key examples include:

- Analysis of the effects of no-take zoning on GBR ecosystems (Emslie et al. 2015) indicating that while no-take status led to increased target species (e.g. coral trout) there was no effect on non-target species such as coral. Wenger et al. (2015) found similar effects in the Keppels where no-take zones provided protection for target species but no protection for corals subjected to major river discharge events.
- An increasing number of publications have pointed out the need for management of all stressors (including local issues such as terrestrial pollutant runoff, dredging and shipping related pollution) and the accurate identification of stressors and their significance in coral reef systems for successful management in the face of climate change, not just management of fishing through no-take zones (Almany 2015; Brown et al. 2013; Graham et al. 2013, 2015; Grech et al. 2015; Anthony et al. 2015; Hughes et al. 2015; Schultz et al. 2015).
- Studies showing evidence for how multiple stressors interaction with each other and produce combined effects on coral reefs (Ban et al. 2014).
- Assessment of the effectiveness of local management of GBR coral reefs showing a consensus view that there was limited efficacy of local management in combating the effects of climate change (Ban et al. 2015).
- Investigation of contrasting rates of coral recovery and reassembly in the GBR after major coral loss, showing the communities that regained coral cover and reassembled had high relative abundance of tabulate *Acropora* spp. Communities that failed to either regain coral cover or reassemble were in near-shore locations and had high relative abundance of *Porites* spp. and soft corals and that under current disturbance regimes, these communities are unlikely to re-establish their pre-disturbance community composition (Johns et al. 2014).
- Understanding the resilience of seagrass communities to a range of stressors (Coles et al. 2015; Petus et al. 2014; McKenna et al. 2015; Rasheed et al. 2014; York et al. 2015).

- Identification of vulnerability and resilience indicators to support coral reef management in a changing climate (McClanahan et al. 2015; Maynard et al. 2015).

Opportunities:

Approach for 2017/18 SCS update

Given the availability of published data, papers and commissioned projects, the synthesis of new material will be best addressed within the major SCS update in 2017/18 and should include:

- NESP Project 2.1 (due for completion by March 2016) will assess cumulative impacts of climatic disturbances on inshore coral reefs, identifying refuges and testing the viability of reef restoration which is directly relevant to this chapter (http://nesptropical.edu.au/index.php/research/projects/project-2-1/).
- The Australian Government, through the GBR Foundation, is also funding a $12.5 million research program to inform management of the GBR in the face of a changing and increasingly variable climate from 2013 to 2017 (http://www.barrierreef.org/our-research/researchers). Topics cover coral reefs and seagrass in terms of climate impacts on ecosystem health and habitat structure, calcification, ocean acidification, and adaptation.

Given the intense work going on at global (coral reefs) and local (GBR) scales regarding the interactive effects of degraded water quality and climate change impacts on coral reefs, and the management regimes needed to successfully manage both local and global issues, this chapter will require some effort to bring up to date.

2016 activities

Aspects of the Chapter update to consider scoping in the shorter term include:

- Consideration of where in the GBR resilience is currently highest (e.g. Cape York possibly) and how best to maintain that resilience in the face of new development pressures and ongoing degradation of GBR ecosystem health.
- Whether management prioritisation of the different pollutants will change dependent on how each pollutant interacts (additive, synergistic, antagonistic) with climate change stressors e.g. ocean pH, higher temperatures and how other factors such as more intense rainfall and more frequent La Ninas affect pollutant discharge.

Chapter 3. Relative risks to the Great Barrier Reef from degraded water quality

As part of the development and update of the Water Quality Improvement Plans (WQIPs), regional assessments of the relative risk of degraded water quality on GBR ecosystems has been completed for each NRM region following the method of Brodie et al. 2013 (reported in the 2013 SCS) (Waterhouse et al. 2014a,b; 2015a,b; 2016). The assessment was completed for the Mackay Whitsunday region by Reef Catchments and incorporated into their WQIP, however, the method has not been reviewed for consistency.

The scope of this work included:

- Incorporation of all Reef Plan loads parameters in the consideration of catchment pollutant loads (TSS, DIN, PN, DIP, PP, PSII herbicides).
- Updating of water quality input data in 2015 for Cape York, Burdekin, Fitzroy WQIPs. This included:
  - New plume loading maps for TSS and DIN, and establishment of PN loading maps.
  - Review of the confidence in remote sensing data for chlorophyll analysis (Petus et al. 2015; Waterhouse et al. 2015c).
  - Revision of the method for incorporating annual concentrations and exceedances of TSS and chlorophyll (Maynard et al. 2015).

- Establishment of 'zones of influence' for each river (where possible) to enable assessment of relative risk at a catchment scale within each region. This was applied in the Cape York, Wet Tropics, Burdekin and Fitzroy regions. Zones of influence have also been established for the Mackay Whitsunday and Burnett Mary region rivers but not incorporated into risk assessments.
- Assessment of the relative contribution of DIN from rivers that contribute to the COTS Initiation Zone (Brinkman et al. 2014).
- Incorporation of coastal wetlands (in a qualitative way).
- Utilisation of the 2014 Source Catchments modelled loads in the Burdekin and Cape York regions including full analysis of the modelled loads, sources and relative contributions.

Emerging information: Coastal and freshwater systems

There is increasing attention on the effects of poor water quality on coastal and freshwater ecosystems, and the relative risk that poor water quality poses to these systems – an issue that was poorly addressed in the 2013 SCS.

The value of wetlands and freshwater systems was recognised in the original Reef Plan 2003, however, the focus since then has largely been on outcomes for the GBR in terms of management and investment priorities.

As part of the WQIP supporting studies, Davis et al. (2015, 2016) have completed a review of current knowledge and derived conceptual models of the generation, transport, transformation, attenuation and ecological effects of agricultural pollutants within GBR catchment freshwater habitats across several spatial and temporal scales. This study highlights that, by virtue of their landscape position (in close proximity to agricultural development), freshwater environments of the GBR catchments face some of the greatest water quality threats of all of the ecosystems within the 'catchment to reef' habitat continuum. It also identifies the risks associated with elevated concentrations of TSS, nutrients and pesticides to freshwater ecosystems and the influence of other factors such as modification of hydrological regimes on these systems.

The impacts of modification of coastal ecosystems on broader ecosystem values and outcomes has also been synthesised by Sheaves et al. (2015), Arthington et al. (2015), Pearson et al. (2013), Brodie et al. (2015c), Waterhouse et al. (2015d) and Davis et al. (2016). In this period, GBRMPA have also progressed the assessment of coastal ecosystems and the relative threats to system function (GBRMPA Blue Maps and Ecological Calculator, unpublished). This work, along with other regionally specific assessments (e.g. Wet Tropics: Sydes 2015, Kroon et al. 2014; Fitzroy: Baker 2015; Marsden, 2015; Jaensch et al. 2015; Burdekin: Tait, 2013) has been used to inform the development of system repair actions in the WQIPs. The Queensland Wetlands Program has also commenced the 'Walking the Landscape' process for each region which facilitates the documentation of the current understanding of fundamental system functions and processes that influence natural resource management options (unpublished work, contact Mike Ronan from DEHP for reports in preparation).

This is an area of increasing concern that warrants considerably more effort in the review of the SCS.

Opportunities:

Approach for 2017/18 SCS update

Given the availability of published data, papers and commissioned projects, the synthesis of new material will be best addressed within the major SCS update in 2017/18 and should include:

- Undertake a specific exercise to synthesise information on impacts of degraded water quality and agricultural development on freshwater and coastal ecosystems and system functions, including knowledge of issues, document impacts, management options, potential management goals and the costs of management (including protection).
- An update on the effectiveness of riparian areas and wetlands in the trapping of catchment pollutants (e.g. Connolly et al. 2015) and on the role of riparian areas and wetlands in ecosystem function and the effectiveness of restoring these systems for GBR health (Pearson et al. 2013, 2015).

2016 Activities

It is recommended that the following activities should occur in the short-term to consolidate understanding and guide investments, as well as be able to inform the 2017/18 SCS update:

- A cross regional synthesis of the management prioritisations in each of the regional WQIPs into a whole of reef context based on a revised GBR-wide relative risk assessment. The assessment should use updated input data and revised methodology, also bearing in mind the importance of protection of ecosystems that are not considered to be at risk from degraded water quality (next 3-6 months).

  Note: The revised cross regional assessment will provide greater confidence in the current funding priorities under the Reef Trust and the Queensland Government Reef funding or provide guidance to revise the current emphasis for future investment to align with the revised outcomes of the assessment.

Chapter 4. Sources of sediment, nutrients, pesticides and other pollutants in the Great Barrier Reef catchment

Substantial progress has been made on understanding the sources and importance of pollutant constituents in recent years. The most significant findings are in relation to sediment sources, transport and fate which has been synthesised by Lewis et al. (2015a) in the Burdekin region, and Fitzroy region (Lewis et al. 2015b).

A number of key examples include:

- Burdekin and Fitzroy sediment synthesis includes summary of impacts and extent of influence of sediment on coastal and marine ecosystems (Lewis et al. 2015a,b).
- The importance of the influence of land-derived fine sediment (<16μm) on marine ecosystems (Bainbridge et al., 2014, 2015).
- Assessment of accelerated erosion rates using sediment tracing, highlighted the contributions from the Bowen and Upper Burdekin catchments (Bartley et al., 2014).
- Further evidence of the dominant role of sub surface erosion of scalds, rills, gullies and streambanks (Bartley et al. 2014) in the delivery of fine sediment to the GBR.
- Studies in the Normanby Basin showing the importance of gully erosion in the overall erosion budget (Brooks et al. 2013; Pietsch et al. 2015; Olley et al. 2013).
- Identification of gully erosion 'hotspots' in the GBR catchments and management options (Wilkinson et al. 2013, 2015).
- Identification of streambank erosion 'hotspots' in the GBR catchments and management options (Bartley et al. 2015).
- Synthesis of sources, transport and significance for marine ecosystems of particulate nutrients discharged from GBR catchments (Brodie et al. 2015).
- Studies to estimate basin-average, long-term denudation rates for the Burdekin catchment (Croke et al. 2015) showing variable denudation rates between sub-catchments of the Burdekin with, for example, the Bowen sub-catchment showing the highest rates.
- Studies examining the rates of streambank and floodplain erosion on the Daintree and Mulgrave Rivers showing floodplain stripping as a major source of erosion in these rivers (Leonard and Nott 2015a, b).
- Regional analysis of the Source Catchments modelling results for the 2012 and 2013 results (Waters et al. 2014; Hateley et al. 2014; Dougall et al. 2014a,b; Fentie et al. 2014; McCloskey et al. 2014) which captures the current and anthropogenic loads, primary sources and loads by land use, as well as full documentation of the program methods.

- Refinement of the Source Catchments modelling platform (2015) to incorporate improved understanding of constituent generation and delivery, such as recent gully mapping, improved hydrology, adjustment of pre-development characteristics and incorporation of sub-surface discharge of sugarcane runoff (Waters et al. in prep).
- Assessment of catchment monitoring results (Turner et al. 2014) and comparison with modelled results (Waters et al. 2014).
- Improved documentation of the sources of pollutants in urban areas relevant to WQIPs (Gunn, 2014), potential water quality influences from port activities (Flint et al. 2015) and investigation of emerging issues in sewage discharges (O'Brien et al. 2014).
- Analysis of Upper Herbert sediment sources and management options (Little, 2014).

Opportunities:

Approach for 2017/18 SCS update

Given the availability of published data, papers and commissioned projects, the synthesis of new material will be best addressed within the major SCS update in 2017/18 and should include:

- NESP Project 1.3 is validating coral geochemical records to reconstruct TSS loads to the GBR lagoon, due for completion in March 2016 (http://nesptropical.edu.au/index.php/research/projects/project-1-3/).
- Studies into the sources of bioavailable particulate nutrients in GBR catchments (Burton et al. 2015) have provided preliminary results showing fine (<10 μm) sediment from surface soil erosion processes is enriched in bioavailable nitrogen and phosphorus relative to fine sediment of sub-surface origin. The enrichment varied depending on the bioavailable nutrient pool and soil type. The contribution of surface and sub-surface sediments to end-of-system bioavailable nutrient loads depends on the proportion of surface and sub-surface sediments reaching the end-of system.
- A substantial gap that has not been progressed since the work of Heather Hunter in 2012 (Hunter 2012) is the potential contribution of groundwater sources to water quality issues in the GBR (especially the Lower Burdekin), and in particular, better understanding of the influence of deep drainage from sugarcane on groundwater systems (but see Rasiah et al. 2013; Connolly et al. 2015; Glanville et al. 2015).

2016 Activities

There has been substantive progress in our knowledge of the topics covered in this SCS Chapter and a majority of this information has been incorporated into the management prioritisations undertaken as part of the WQIPs. It is recommended that:

- A series of communication products that extend these major findings to a range of audiences and making the WQIP outcomes more accessible are developed. Examples include:
    1. Graphical illustration of the key pollutants and sources in each region (by land use and catchment).
    2. Synthesis of the priority sub-catchments for cane, grazing, cropping and horticulture management in the GBR catchments.
    3. Identification of areas that have limited contribution to the pollutant loads and therefore may warrant further attention for protection.
    4. Additional explanation of the sediment pathways, processes and loading identified for Burdekin and Fitzroy catchments to accompany proposed investments.

Chapter 5. The water quality and economic benefits of agricultural management practices (and management and governance generally)

Extensive effort has been made to enhance our understanding of the most cost effective management options in the GBR. In particular, development and update of the WQIPs has involved cost benefit analyses for meeting the water quality targets, and synthesised a great deal of knowledge of management practice options.

Key examples include:

- Application of the INFFER assessment tool to complete cost benefit analyses for meeting the water quality targets in the Wet Tropics (Park and Roberts, 2014), Burdekin (Roberts et al. 2016) and Burnett Mary (Beverly et al. 2015; van Grieken et al. 2014) regions. Star et al. (2015a,b) also completed a prioritisation for the Fitzroy WQIP which utilised a bioeconomic model for estimating the most cost effective areas and actions to meet the targets.
- Synthesis of the costs of management practice change in sugarcane in the Wet Tropics and Burdekin regions (Smith, 2014, 2015; Poggio et al. 2014; van Grieken et al. 2014) and Burnett Mary (van Grieken et al. 2014).
- Synthesis of the costs of management practice change in grazing lands in the Burdekin and Fitzroy regions (Star et al. 2012; Edwards and Star, 2013; Star et al. 2015a,b,c,d).
- Synthesis of management practice options for agriculture in the Wet Tropics region (Sing and Barron, 2014).
- Review of grazing management options (McIvor, 2014).
- A review of nitrogen use efficiency in sugarcane (Schroeder et al. 2014).
- Managing pesticides in agricultural lands (Melland et al. 2015; Davis et al. 2014; Holmes, 2014; Oliver et al. 2014).
- Identification and management of key pollutants in urban and industrial areas (Gunn, 2014; Waltham and Sheaves, 2015).

In addition to the Water Quality Improvement Plans themselves, a number of studies that emphasise the need for governance reform and holistic approaches to management also capture the latest thinking of management approaches required for improving water quality in the GBR. While additional review is required to adequately cover this area of research, a number of topics are highlighted:

- Emphasis of the need for holistic management of catchment to reef processes, recognising the substantial modification of, and value of, the linkages between catchment and reef ecosystems - Waterhouse et al. (2015d) and Creighton et al. (2015) .
- Landscape scale management - Hill et al (2015), Shields et al. (2015), van Oosterzee et al. (2014), Vella and Dale (2014)
- Policy frameworks – Bohnet (2015), Doole (2015), Hamman (2015),
- Delivery options – regulation versus voluntary approaches (Harvey et al. 2014), farmer participation (Taylor et al. 2015)
- Transaction costs of improved management (Coggan et al. 2015).
- Financial contributions and offsets (Dutson et al. 2015)

The WQIPs have also incorporated a number of management scenarios which assess the likelihood of meeting the targets under a number of options (derived from Waters et al. 2014; Hateley et al. 2014). From these assessments, it is clear that changes to management practices alone will not be sufficient to meet the targets, and that a more holistic approach to management – including more innovative approaches will be required. In some cases, this incorporates actions associated with restoring ecosystem function.

The issue of system repair as a management option is a major knowledge gap and is highlighted in a number of recent publications (in addition to the WQIPs where this is identified as a major knowledge gap). Examples include:

- Effectiveness of vegetated systems in managing runoff in cane and bananas (DeBose et al. 2014).
- Effectiveness of riparian vegetation in reducing nitrate loss from cropping lands to the river (Connor et al. 2013; Connolly et al. 2015).
- Repairing estuaries for improved fisheries production (Creighton et al. 2015).

Opportunities -:

Approach for 2017/18 SCS update and 2016 activities

There has been substantive progress in our knowledge of the topics covered in this SCS Chapter and it is recommended that:

- This Chapter is updated in the next 6 months, drawing heavily on the Water Quality Improvement Plans. The update should also refer to findings from the relevant NESP projects due for completion by March 2016 such as: evaluation of the effectiveness of investment in riparian management (Project 1.2), assessing the 2008 Lower Burdekin Water Quality Tender (Project 1.5), testing the effectiveness of managing alluvial gully erosion (Project 1.7), establishing sub-catchment scale monitoring modelling and extension design (Project 1.8), exploring a tradable permit scheme of N reduction in cane (Project 2.2), benchmarking costs of NRM improvements (Project 3.10) and monitoring and reducing system-wide governance risks (Project 3.11) (http://nesptropical.edu.au/index.php/research/projects/).)
- A range of communication products are developed to make this knowledge more accessible to a range of audiences.

Appendix 1: List of key papers relevant for update of the 2013 Scientific Consensus Statement

References

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