

Burdekin Region

Water Quality Improvement Plan 2016



*Better Water
for the
Burdekin*



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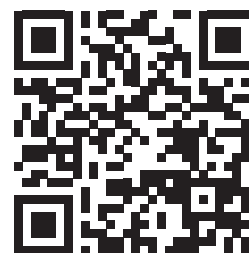
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The WQIP has been developed by NQ Dry Tropics with a broad range of stakeholders and research providers over the last 18 months; every contribution has been greatly appreciated by the project team. The contributions of Australian Government and Queensland Government staff, stakeholders and other technical experts involved in the development of the WQIP are highly valued and their input and review of the WQIP has enhanced the relevance of the plan for implementation. Jane Waterhouse from C2O (coasts climate oceans) Consulting undertook overall coordination and preparation of the plan.

The draft Burdekin WQIP was circulated to over 50 stakeholders for review. The feedback we received has improved the final draft and we are grateful for the effort from individuals in their review. The final draft WQIP was also peer reviewed by three highly regarded experts: Dr Roger Shaw, Di Tarte and Hugh Yorkston. The project team would like to extend their personal gratitude to this team for their extremely helpful feedback.

Collaboration with other WQIP coordinators has also been beneficial and has assisted in continuing to progress a consistent approach to water quality improvement in the Great Barrier Reef at a regional scale.



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Acronyms & units of measurement

Acronyms

ACTFR	Australian Centre for Tropical Freshwater Research
AGO	Australian Greenhouse Office
AHD	Australian Height Datum
AIMS	Australian Institute of Marine Science
ANZECC	Australian and New Zealand Environment and Conservation Council
APSIM	Agricultural Production Systems Simulator
AWQG	Australian Water Quality Guidelines
BBIFMAC	Burdekin Bowen Integrated Floodplain Management Advisory Committee
BCR	Benefit : Cost Ratio
BHWSS	Burdekin Houghton Water Supply Scheme
BMP	Best Management Practice
BPS	Burdekin Productivity Services
BRIA	Burdekin river Irrigation area
BWQIP	Burdekin Water Quality Improvement Plan
Chl-a	Chlorophyll-a
Cl	Chloride
COTS	Crown of Thorns Starfish
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Queensland Department of Agriculture and Fisheries
DEHP	Queensland Department of Environment & Heritage Protection
DIN	Dissolved inorganic nitrogen (nitrate, nitrite & ammonia)
DNRM	Queensland Department of Natural Resources, Mines
DPA	Dugong Protection Area
DSITI	Queensland Department of Science Information Technology and Innovation
EV	Environmental value
EPP	Environmental Protection Policy
ERT	Ecologically Relevant Target
FHA	Fish Habitat Area
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GIS	Geographic Information System
GPS	Global Positioning System
HEV	High Ecological Value
HD	Highly Disturbed
HWMP	Health Waterways Management Plan
INFFER	Investment Framework for Environmental Resources
IPCC	International Panel on Climate Change

ITRARC	Image-based Tropical rapid assessment of riparian condition
JCU	James Cook University
LG	Local Government
LT	Load Target
MAT	Management Action Target
N	Nitrogen
NRM	Natural Resource Management
NWQMS	National Water Quality Management Strategy
P	Phosphorus
P2R	Paddock to Reef
PN	Particulate Nitrogen
PP	Particulate Phosphorus
PRN	Potentially Reactive Nitrogen
PSII herbicides	Photosystem II inhibiting herbicides
QWQG	Queensland Water Quality Guidelines
QLUMP	Queensland Land use Mapping Program
RCT	Resource Condition Target
Reef 2050 Plan	Reef 2050 Long Term Sustainability Plan
RPT	Reef Plan Target
SedNet	Sediment River Network model
SOI	Southern Oscillation Index
SMD	Slightly to Moderately Disturbed
STP	Sewage Treatment Plant
TropWATER	Centre for Tropical Water and Aquatic Ecosystem Research
TSS	Total Suspended Sediment
WHA	World Heritage Area
WQ	Water Quality
WQIP	Water Quality Improvement Plan
WQO	Water Quality Objective
WSUD	Water Sensitive Urban Design

Units of measurement

ha	hectare
ha/yr	hectares per year
kg	kilogram
kt/yr	kilotonnes (thousands of tonnes) per year
kg/ha/yr	kilograms per hectare per year
mg/L	Milligrams per litre
ML	Megalitres (millions of litres)
ML/day	Megalitres per day
sq/km	Square kilometres
t	Tonne
t/yr	Tonnes per year
µg/L	Micrograms per litre
µg N/L	Micrograms of nitrogen per litre
µg P/L	Micrograms of phosphorus per litre
µS/cm	Micro-Siemens per centimetre (conductivity)

Note to the reader

Water quality is a one of the key factors in determining the future diversity and productivity of the Great Barrier Reef (GBR). The primary objective of this Water Quality Improvement Plan (WQIP) for the Burdekin Dry Tropics Natural Resource Management (NRM) region is to support and guide decision making and investment around protection of the GBR and the local ecosystems as they relate to water quality and to which its resilience is intimately linked. The plan is an attempt to address all human activities in the region which have the potential to have a major influence on regional water quality.

This plan consolidates information into a guide useful to anybody working to improve the quality of water in the Burdekin Dry Tropics region of the GBR. It updates and builds on the 2009 Burdekin WQIP and the Black Ross WQIP (2010) and the learnings of those involved in their delivery, extending both the geographic area and range of issues covered. It has been written for use by all levels of government, industry representative bodies, non- government service and advocacy organisations, land holders and members of the Burdekin regional community.

The plan steps through the logic to establishing priorities and strategies for managing water quality in the Burdekin NRM region; starting with an overview of the region's water resource, aquatic and wetland assets followed by analysis of the pressures which influence the quality of natural waters. This lays the foundation for development of pragmatic water quality targets based on objective ecologically relevant criteria. Modelling benefit cost analysis then provides economic assessment and informs priority setting with respect to water quality improvement strategies and actions. The plan concludes with analysis and statement of what assurances can be given that investment in the actions will ultimately lead to the targeted water quality outcomes over approximately the next 30 years.

The Burdekin WQIP is structured as follows:

1. Why do we need a Water Quality Improvement Plan?
2. What are the values of the Burdekin Region and what is their status?
3. What are the water quality issues in the Burdekin region?
4. What management goals and targets do we need to achieve water quality outcomes?
5. What are the priority management options for meeting the targets?
6. How are we going to achieve the targets?
7. What challenges do we face in the future?
8. How will we measure success?
9. What is the Burdekin WQIP Catchment Atlas?

A Community summary, a series of supporting technical reports and the Burdekin WQIP Catchment Atlas have been published separately. Copies of these are available from the NQ Dry Tropics web site at: www.nqdrytropics.com.au/.



Our message

The **Burdekin Water Quality Improvement Plan** (Burdekin WQIP) represents a strategy that has been developed by a range of partner organisations and individuals, including landholders, industry bodies, the scientific community, Government and the NQ Dry Tropics. We aim to reduce the loss of sediment, nutrients and pesticides from the catchments within the Burdekin Region, and consider other pollutants that may be relevant at a local scale. In the case of agricultural lands, runoff of sediments, nutrients and pesticides not only represent a loss of productivity and a cost to landholders, but also result in environmental degradation. Ultimately, they impact on important wetlands, aquatic habitats and ecosystems downstream and enter the Great Barrier Reef World Heritage Area.

Good water quality is fundamental to human health and wellbeing; in healthy well managed environments, natural functions help to maintain water quality by providing 'ecosystem services'. Poor water quality is not only a risk to the region's outstanding and valuable assets like the Great Barrier Reef (GBR), but ultimately if left untreated, degraded water quality is or will become a human health risk, which leads to greater community costs and losses. The cost of treating poor water quality is far greater than preventing it or allowing further degradation.

The Burdekin region has a core group of very experienced sugarcane and grazing extension officers, the best water quality research data in the whole GBR and 10 years of Australian Government Reef Rescue and Reef Programme delivery capacity to build from. Significant resource commitments must be continued, and increased, to deliver the substantial water quality outcomes required for the GBR. In current circumstances, we estimate that the level of investment required to meet the Reef 2050 Plan pollutant load reduction targets for the Burdekin region is at least four times as much as previous commitments, including the following estimates for the first five years:

- Cane extension and incentives in priority areas - \$60 million scaling up from current Reef Programme investments;
- Grazing extension and incentives in priority areas- \$140 million scaling up from current Reef Programme investments;
- Horticulture extension and incentives in priority areas- \$4 million scaling up from current Reef Programme investments;
- Grain crops extension and incentives in priority areas- \$350,000 scaling up from current Reef Programme investments;
- Active gully and streambank remediation in priority areas – this has not been costed at this time as further work is required to assess existing funding support (Reef Trust and Queensland Government) and smaller scale priorities for gully remediation. An initial investment of \$180,000 is recommended to support the establishment of a Bowen Broken Bogie Catchment Action Plan (2016 to 2025) to guide site specific investment over the next 10 years;
- Strategic planning to support acceleration of water quality improvement in urban areas - \$175,000 building on existing local government initiatives; and
- Establishment of a Lower Burdekin Catchment Action Plan (2016-2015) and implementation of priority system repair actions - \$2.98 million building on existing (disparate) plans and strategies.

We will integrate these focused implementation programs with nested monitoring programs specifically designed to detect and quantify the improvement in water quality and to calculate the costs and benefits of investment. These monitoring programs are essential to ensure that the spatial prioritisation of implementation strategies continues to improve as implementation progresses and are likely to cost in the order of \$9 million over the first five years. Resources to fill priority knowledge gaps and support the development of innovative practices are also required (\$3 to \$4 million), in addition to funds for increased communication, compliance and auditing.

If these priority implementation and monitoring strategies are funded appropriately (in the order of \$226 million over the next five years) we estimate that the following pollutant load target reductions will be achieved:

- Total suspended sediment: A further 10 to 15 per cent reduction in end of catchment TSS loads;
- Dissolved Inorganic Nitrogen: A further 20 to 25 per cent reduction in end of catchment DIN loads;
- Particulate Nitrogen: A further 5 to 10 per cent reduction in end of catchment PN loads; and
- Photosystem-II inhibiting herbicides: A further 85-90 per cent reduction in end of catchment PSII herbicides loads.

These achievements, coupled with the achievements to date, would deliver steady progress towards the 2025 targets. A focused investment that measurably improves water quality in the Burdekin Region has the potential to improve the health of the GBR from Cairns to the Whitsundays.

Executive Summary

Regional context, status and values

Declining water quality in the Burdekin region has contributed to the loss of seagrass meadows and coral cover in the region.

Steady but gradual improvements in water quality have been predicted in the Burdekin Region since 2008.

- The Burdekin Region contains a significant range of high value environmental assets including freshwater waterways, groundwater ecosystems, the Bowling Green Bay Ramsar wetland site, and the Great Barrier Reef (GBR) and associated ecosystems. These areas are also highly valued for commercial and recreational uses including tourism, recreational boating and fishing and also provide ecosystem goods and services which are yet to be adequately quantified.
- Declining water quality in the Burdekin region has contributed to the loss of seagrass meadows and coral cover in the region. Coastal ecosystems including freshwater wetlands, saltmarsh and floodplains have been heavily modified from agricultural and urban land uses. The hydrological regime has been greatly modified from catchment development, with the Burdekin Falls Dam in the upper catchment and rising water tables and saltwater intrusion in the Lower Burdekin floodplain.
- Steady but gradual improvements in water quality have been predicted in the Burdekin Region since 2008, reported as modelled reductions in end of catchment pollutant loads. There is significant momentum available for the ongoing investment in addressing water quality issues in the region.
- The Burdekin WQIP has adopted a whole of system approach to managing water quality in the region, recognising the important role of catchment ecosystems to the health of the GBR. The values of both catchment and the GBR are core to achieving multiple management outcomes.
- The Burdekin Region is the second largest NRM region in the GBR catchment (134,000 square kilometres), and includes five river basins - the Black, Ross, Burdekin, Haughton and the Don - divided into nine major catchments (Black, Ross, Upper Burdekin, Cape Campaspe, Belyando, Suttor, Bowen Bogie Broken, Lower Burdekin and Don) and 52 sub-catchments for water quality analysis, reporting and management planning. River discharge varies considerably between years, with a peak flow of 34 million ML in the 2010-2011 wet season, compared to 1.2 million ML in 2013-2014.
- Extensive grazing of native pastures is the dominant land use (90 per cent), with relatively small but significant areas of sugarcane, horticulture and urban centres in the coastal areas, and dryland cropping and mining in the upper catchments.



Priority water quality issues

The priority pollutants for management in the Burdekin Region are total suspended sediment (TSS), particulate nutrients, dissolved inorganic nitrogen (DIN) and photosystem-II inhibiting herbicides (PSII herbicides).

Grazing lands contribute by far the largest proportion of the TSS and particulate nutrient loads to the end of catchment loads in the Burdekin Region.

Sugarcane contributes the majority of the DIN and PSII herbicide loads. The greatest nutrient source from urban areas is sewage treatment plant discharges.

- The priority pollutants for management in the Burdekin Region are total suspended sediment (TSS), particulate nutrients, dissolved inorganic nitrogen (DIN) and photosystem-II inhibiting herbicides (PSII herbicides). The losses of sediments and nutrients to the GBR have increased several-fold since European settlement as a result of catchment development, and PSII herbicides are entirely associated with human use.
- Grazing lands contribute by far the largest proportion of the TSS and particulate nutrient loads to the end of catchment loads in the Burdekin Region; however, it is recognised that generation from other land uses including new urban areas can also contribute high rates per unit area. Sugarcane contributes the majority of the DIN and PSII herbicide loads, with relatively minor loads from other crops. The greatest nutrient source from urban areas is sewage treatment plant discharges with small loads from operations outside of Townsville. The timing of losses of pollutants in terms of delivery, extent of influence and which ecosystems are at risk is a critical factor in determining the relative importance of pollutants to the receiving environments. For example, pesticide runoff presents very high to moderate risk to freshwater reaches of rivers and freshwater / coastal wetlands from irrigation tail-water runoff in the dry season, whereas for coastal and marine ecosystems, any risk from pesticide runoff delivered from the Lower Burdekin areas is only going to occur in wet season rainfall events. For nutrients, the highest risk periods for coastal and marine ecosystems are during wet season events. The potential risk of nutrients and pesticides to groundwater systems, and whether this flows to the marine environment as an additional pollutant source that is not currently accounted for is not fully understood.
- Current understanding of cumulative and synergistic effects of water quality pollutants in the region is less well known, although there is evidence that degraded areas are less resilient to other pressures such as climate change, and exposure to pesticides can also result in greater susceptibility to impacts from other stressors such as increased nutrients or elevated temperatures.



Management objectives and targets

Targets are established for catchment condition, land management and end of catchment pollutant load reductions.

Targets include:

- groundwater levels and salinity in the Lower Burdekin region;
- adoption of improved management practices with water quality and industry sustainability benefits in sugarcane, horticulture, grazing and cropping;
- groundcover;
- riparian extent;
- natural wetland extent and function; and
- catchment specific pollutant load reductions for TSS, PN, DIN, PP, DIP and PSII herbicides.

- Environmental Values (EVs) and water quality objectives (WQOs) have been scheduled under the *Environmental Protection Policy (Water) 2009* for the Townsville region and its marine waters, and draft localised guidelines are presented for the Don, Houghton and their marine waters.
- Targets are established for catchment condition, land management and end of catchment pollutant load reductions. These include: groundwater levels and salinity in the Lower Burdekin region; adoption of improved management practices with water quality and industry sustainability benefits in sugarcane, horticulture, grazing and cropping; groundcover; riparian extent; natural wetland extent and function; and catchment specific pollutant load reductions for TSS, PN, DIN, PP, DIP and PSII herbicides. The targets build on the Reef Water Quality Protection Plan targets and Reef 2050 Plan targets for 2025 and extend those to develop catchment-specific pollutant load reduction targets that are predicted to meet ecological thresholds.
- Catchment-specific targets for the WQIP include:
 - a 50 per cent reduction in fine sediment from the Burdekin Basin by 2025;
 - a 60 per cent reduction in potentially bioavailable nitrogen in the region which is comprised of an 80 per cent reduction of DIN from the Lower Burdekin sugarcane areas, and a 52 per cent reduction of PN from the Burdekin Basin by 2025; and
 - a 90 per cent reduction of PSII herbicides from the Lower Burdekin sugarcane areas by 2015.
- Importantly, the Wet Tropics River nitrogen loads also have to be reduced by the most recently proposed ERTs which range between basins (20 to 80 per cent) as well as the proposed Burdekin reductions to deliver the outcomes needed for GBR health.
- The Reef Water Quality Protection Plan targets will be updated in 2016 as part of the revision of the plan. Current efforts to refine the ecologically relevant targets using new evidence including the eReefs modelling will provide greater confidence in the current targets and establish ecologically relevant targets for the Basins where they are yet to be defined. Therefore, it is possible that there will be some adjustments to the targets recommended in this plan, and these should be revised in 2017.



Priority management options

Best management practice options for most land uses in the region are well developed and there is good evidence of the water quality benefits associated with those practices.

A large proportion of graziers and sugarcane farmers in the Burdekin Region are operating below industry standard.

- Best management practice options for most land uses in the region are well developed and there is good evidence of the water quality benefits associated with those practices in the grazing and sugarcane industries. Frameworks have been defined for the region through the Paddock to Reef (P2R) Water Quality Risk Framework which identifies the priority practices for improving water quality. The priority actions and sub-catchments are summarised in Table 1.
- A large proportion of graziers and sugarcane farmers in the Burdekin Region are operating below industry standard ('C' practice, or High Risk in the P2R Water Quality Risk Framework; as reported in the 2014 Report Card Queensland Government, 2015). A majority of horticulture is at B practice for nutrient management, C or B for soil and water.
- The costs for sediment reduction (at end of catchment) from hillslope erosion (management of stocking rates and groundcover) are higher for shifting from B to A practice than C to B practice, and range from less than \$10 per tonne to \$160 per tonne. The most cost effective reductions would be achieved in the Bowen Broken Bogie catchment (typically less than \$30 per tonne); however, hillslope erosion is only part of the soil management issue and gully erosion dominates in these landscapes. This is likely to require substantially higher costs for remediation to reduce soil loss. The costs of gully erosion management vary considerably depending on the specific characteristics of the gully, the combination of management options and the timeframe for intervention (passive management versus active remediation). Costs in the range of \$80 per tonne to an average of \$160 per tonne have been estimated for B practice gully management. Management of streambank erosion can also be costly, depending on the site. The costs of gully and streambank remediation are unlikely to be able to be met by the landholder.
- In sugarcane, smaller farms incur relatively larger upfront capital costs per hectare with economies of scale operating for practice shifts. For nutrients, moving farmers from D class nutrient management practices to C and B class management is deemed to be profitable across the region, with higher per hectare costs estimated in the Delta region than the BRIA for D to B shifts due to smaller farm sizes. All other changes (C to B, C to A and B to A) are expected to incur upfront costs to growers, with limited ongoing maintenance costs and, in most cases, financial benefits in the longer term. For herbicides, all practice class shifts are expected to cost growers across the region, except for shifting from C to B management practice in the BRIA. As for other practices the costs for herbicide management changes are typically higher in the Delta than the BRIA.
- The costs of system repair actions such as revegetation, restoration of bunds and fish passage are very site specific and can be expensive.
- While the costs of pollution abatement in urban and industrial land uses is typically more expensive than agricultural land uses, the timing and certainty of improvement is compelling when rapid reductions are required.



Achieving the targets, costs and challenges

Good progress has been made towards achievement of the Reef Plan TSS and PN load reduction targets for 2018. Progress towards the DIN and PSII herbicide targets has been slower.

A mix of management options including planning and regulation, financial incentives, extension and research and technology development will be required.

- Modelling predicts that good progress has been made towards achievement of the Reef Plan TSS and PN load reduction targets for 2018 (85 per cent towards the 20 per cent anthropogenic TSS load reduction target and 75 per cent towards the 20 per cent PN anthropogenic load reduction target), and it is predicted that sustained progress supported by equivalent levels of investment to the last 8 years could achieve the Reef Plan target. Progress towards the DIN and PSII herbicide targets has been slower and the 2018 targets are highly unlikely to be met in the next two years (32 per cent towards the 50 per cent anthropogenic load reduction target and 33 per cent towards the 60 per cent PSII herbicide load reduction target).
- Modelling scenarios of management options indicate that achieving almost full adoption of best management practices (B class) in sugarcane, grazing and horticulture will not achieve the 2025 end of catchment pollutant load targets for TSS, DIN and PN. However, the PSII herbicide reduction targets can be achieved if there was widespread adoption of best management practices in herbicide management in the Lower Burdekin sugarcane industry. Advanced management options such as large scale gully remediation, adoption of higher efficiency irrigation techniques, restoration of hydrological function and strategic land conversion in targeted locations will be required.
- Reductions in pollutant loads from other land uses in addition to sugarcane and grazing such as horticulture, grains and urban areas could also contribute to these target reductions and should be considered. The Don, Ross and Black Basins were not considered in the target assessments due to limited knowledge of specific marine impacts from these catchments, and therefore it is recommended that further analysis is conducted to derive ERTs for these basins.
- A benefit cost analysis for management options returns a relatively low benefit cost ratio due to the scale of the effort required (currently relatively low adoption of best management practices), the current high capital investment required in large scale remediation works and advanced management practices that deliver the highest pollutant load reductions, and the fact that the mix of management options will not achieve the pollutant reduction targets. However, targeting practices will result in greater benefits, reinforcing that widespread improvements in fertiliser and weed management and targeted adoption of advanced irrigation practices in sugarcane, and large scale gully remediation in the Bowen Broken Bogie catchment are likely to be some of the most cost effective options for nutrient, pesticide and sediment management in the region.
- A mix of management options including planning and regulation, financial incentives, extension and research and technology development will be required. The benefit cost analysis of different policy options showed that the application of Regulation (supported by extension) to shift to C class practices for grazing, sugarcane and horticulture industries (with a lead in time of 10 years) is potentially three times more cost effective than using incentives and extension for all practice shifts. A mixed scenario aiming to meet the pollutant reduction targets including adoption of best management practice in sugarcane, grazing and horticulture, plus large scale adoption of advanced irrigation techniques in sugarcane, large scale gully remediation in the Bowen Broken Bogie catchment and Regulatory measures to shift to C practices is potentially the most cost effective scenario that meets the targets appears to be a cost effective solution.
- Incremental (adaptive) change to the current suite of agricultural management practices under the current pattern of land use mean we will not meet the Reef Water Quality Protection Plan (Reef Plan) targets for 2018 and delivering longer term ecologically relevant targets will be very challenging. Research and development to investigate innovative (transformative) land use and practices change and the associated extension and education programs are critical for implementation of the WQIP over the next 5 to 10 years. Resource condition targets (for 2025) and management action targets (for 2020 and 2025) have been defined for each pollutant and major land uses in the Burdekin Region.

Achieving the targets, costs and challenges *cont.*

It is estimated that significant investment of around \$226 million over the next five years, or approximately \$45 million per year, is required to implement the actions identified within the Burdekin WQIP.

It is estimated that at least 50 per cent of landholders will need to improve management practices to best management standards in the next 5 years.

Significant increases in the current level of investment will be required if the end of catchment load reduction targets to maintain GBR health are to be met.

- It is estimated that significant investment of around \$226 million over the next five years, or approximately \$45 million per year, is required to implement the actions identified within the Burdekin WQIP. A large proportion of this upfront cost will cover capital investments, and ongoing maintenance costs beyond the first five years is likely to be reduced however, large scale investment will need to be maintained in the long term. In addition:
 - It is estimated that at least 50 per cent of landholders will need to improve management practices to best management standards in the next 5 years to achieve sufficient progress towards the proposed catchment targets.
 - It is difficult to estimate the pollutant load reductions likely to be achieved with this scenario with confidence as the assumptions regarding sediment reductions from streambank and gully erosion would be highly dependent on specific locations. However, simple calculations indicate that the proposed suite of actions would achieve at least the following reductions by 2020 a further 10-15 per cent reduction in end of catchment TSS loads (at least 20 per cent towards target), 5-10 per cent reduction in PN (at least 9 per cent towards target) and 20-25 per cent reduction in DIN (at least 26 per cent towards target).
 - A more detailed implementation plan should be developed to support this WQIP and identify specific locations for remediation. Greater specification of actions and consideration of barriers to management practice uptake will also enable selection of the most effective options in terms of environmental, economic and social outcomes.
 - Additional gains would be made from targeting investment in the highest pollutant generation areas identified in the sub-catchment prioritisations. Investment in large scale gully remediation techniques is the most cost effective management option for sediment management in the Bowen Broken Bogie catchment and therefore, this should be the focus of future efforts supported by R&D over the next 3 to 5 years.
 - Increased attention to system function, landscape processes and the systems that link the catchment and marine landscapes are required to improve water quality and ecosystem health outcomes in the GBR.
- It is certain that significant investment, delivered in a focused and coordinated way, will be required to make substantial progress towards pollutant reductions for water quality outcomes in the Burdekin Region. This level of funding is currently not within the scope of the current Australian and Queensland Government commitments and program. Significant increases in the current level of investment will be required if the end of catchment load reduction targets to maintain GBR health are to be met. Given the scale of effort required, there are likely to be logistical issues around program delivery that need to be anticipated and addressed.
- Water quality will continue to decline if there is ongoing development and expansion of the development footprint in the region, such as changing grazing land to intensive agriculture or industrial or urban development. Therefore, protection of remaining natural assets and the ecosystem services they provide is critical for the future of the GBR. New agricultural expansion needs to begin at B class practice to minimise the risk of adding to the problem. Failure to meet regulated standards will also have implications for the health of the GBR. Climate change impacts associated with sea surface temperatures, and increased storm intensity are likely to drive significant reef ecosystem decline over the next 30 years.

Implementation

An adaptive approach is required for water quality improvement in the Burdekin Region, linking to other GBR-wide initiatives.

Significant research efforts are still needed to integrate and improve the basis for decision making.

Effective water quality management needs greater community involvement and education delivered by local organisations.

- An adaptive approach is required for water quality improvement in the Burdekin Region, linking to other GBR-wide initiatives. This must be supported by a clear monitoring and modelling program to evaluate progress and provide feedback on management decisions as part of the Paddock to Reef Program. A combination of direct monitoring of the effect of actions at the paddock, sub-catchment and end of catchment scale supported by system modelling techniques is required to estimate and predict the regional outcomes.
- Research is required to resolve current uncertainties around many issues such as: the fate of pollutants lost via deep drainage in coastal areas; the role of irrigation in pollutant losses in sugarcane; the assessment of the sources and bioavailability of PN; the role of phosphorus in driving the status of ecosystem health; and refining the understanding of which gully and streambank erosion management options provide the most effective outcomes.
- Significant research efforts are still needed to integrate and improve the basis for decision making around mining related erosion, urban stormwater, dams and bunds, water treatment, water extraction policy and ecosystem restoration (systems repair).
- Effective water quality management needs greater community involvement and education delivered by local organisations.

A number of considerations for implementation are highlighted:

1. Ecologically relevant targets for pollutant load reductions should be viewed as a trajectory from baseline estimates in 2013, Reef Plan targets by 2018 and catchment-specific ecologically relevant targets by 2025.
2. Broadscale adoption of agricultural best management practices will not be sufficient to meet the targets. More intensive actions such as large scale gully remediation in grazing lands, and adoption of more innovative practices for fertiliser, pesticide and irrigation management in sugarcane will be required. Improvements in pollutant management from urban areas and other agricultural areas including horticulture and cropping will also be necessary.
3. There are obvious practical challenges with respect to realising these scenarios in terms of costs, technical feasibility, other barriers to adoption such as costs and social issues including demography, time lags between management action and response, and the timeframes required to meet the targets.
4. There are serious concerns about the potential shortfalls in meeting the targets if the resources for implementation of the WQIP are not adequate, and the implications to freshwater, coastal and marine ecosystems. There needs to be further consideration of the trade-offs that maybe required between the level of management change considered politically and locally socially acceptable, and the desire to maintain the values of the receiving environments including the GBR.
5. The role of restored floodplain and coastal ecosystem functions in ecosystem health recovery is likely to become more important as more extreme land use management options, such as shifting to A class practices or land conversion, may be considered unacceptable by the community.
6. Local government should be supported to holistically manage urban waterways in collaboration with other water quality initiatives in the region.
7. The local and regional significance of specific sites and structures as pollutant sources and drivers of water quality issues needs to be recognised and fully understood in the regional context.
8. The influence of climate change is likely to become more significant over time and should be incorporated into any implementation strategies.
9. There is a significant risk to the investment achieving the proposed targets and thus support GBR recovery if broad scale land management changes occur in the region. The compromise than is that such development, if it proceeds, must only be progressed using absolute top of the range BMPs.

Table 1. Summary of issues, priority actions and priority sub-catchments for major land uses in the Burdekin Region.

Land use	Issue	Priority Action	Priority Sub-Catchment
Grazing	Sediment and particulate nutrients from soil erosion; gully erosion is the dominant source of sediment, vegetation management or broad scale clearing.	Stock management for: - Increased groundcover on hill slopes. - Reduced gully development. - Streambank stability. - Direct intervention or detention storage for 'point source' sediment, including gullies and scalds - Development of an agreed Bowen Broken Bogie Catchment Action Plan (2016-2025) for guiding action.	- Bowen R. - Bogie R. - Pelican Ck. - Little Bowen R. - Burdekin Delta - Burdekin R. (below dam) - Glenmore Ck. - Rosella Ck. - Don R.
Irrigated sugarcane	Nutrient and PSII herbicides loss off farm, fallow management, rising shallow groundwater.	- Optimising fertiliser and pesticide application rates, placement and timing. - Optimising irrigation systems and scheduling to reduce runoff and deep drainage. - Conjunctive use irrigation. - Improving water recycling capability. - Reducing tillage and erosion.	- Haughton R. - Burdekin Delta - Barratta Ck. - Burdekin R. (below dam) These sub-catchments are typically divided into the BRIA and Delta areas. While management practice improvements are important in both areas, current evidence indicates that the BRIA is higher priority due to greater proportion of surface runoff and potentially more cost effective changes with typically larger farm sizes than the Delta.
Horticulture	Nutrient, PSII herbicides and soil loss off farm.	- Optimising fertiliser and pesticide application rates, placement and timing. - Optimising irrigation systems and scheduling. - Improving water recycling capability. - Managing fallow crops.	- Don R. - Abbot Bay - Upstart Bay
Dryland Cropping	Sediment nutrient and chemical loss off farm.	- Optimising fertiliser and pesticide use. - Reducing tillage and erosion.	Suttor R.
Urban & peri-urban	Sediment, nutrients, mixed chemical and gross pollutants.	- Strict site management for any earthworks. - Continued high standard STP management. - WQ Planning, Water Sensitive Urban Design and strict earthworks control for all new developments.	- Black (Townsville and Palm Island) - Ross (Townsville and Magnetic Island) - Carmichael River (New Mine Village) - Lower Burdekin (Ayr/Home Hill) - Don River (Bowen)
Intensive development sites, eg. Industry, Ports, Mining, Urban and Service infrastructure	Vegetation management or broad scale clearing, sediment sources and resuspension, nutrients, mixed chemical and gross pollutants, noise and marine animal strikes.	Diligent legal control and compliance of: - Industrial and mineral processing sites. - New or existing coal and mineral mines. - Port development and operations dredging, material handling and shipping. - Linear infrastructure erosion. - Intensive agriculture nutrient & energy capture.	- Ross (Port, industry, Intensive ag.) - Black (Mineral processing) - Carmichael River (Coal) - Abbot Bay (Port) - Pelican Creek (Coal) - Native Companion Creek (Coal) - Belyando floodplain (Rail) - Fox Creek (Rail) - Mistake Creek (Rail)
Conservation	Vegetation management or broad scale clearing, water infrastructure changing hydrology, climate change adaptation.	- Land zoning. - Restoration of connectivity at landscape scale. - Integrated surface and groundwater irrigation management. - Dams, weir and bund wall design and operational management of flows for weed and salt control. - Legal control and compensation/offsetting mechanisms for mines. - Development of an agreed Lower Burdekin Floodplain Action Plan for guiding action.	- Black (Cape Pallarenda) - Ross (wetlands) - Haughton (wetlands) - Barratta (wetlands) - Burdekin Delta (wetlands) - Upstart Bay (Wongaloo wetlands) - Abbot Bay (Beaches & Caley wetlands) - Don River (Beaches & coastal erosion) - Carmichael River (Coal Mining)

1. Why we need a Water Quality Improvement Plan?

1.1 Background

There is a range of threats impacting the health and function of the Great Barrier Reef (GBR) and its catchments. To understand how these impacts affect the ecosystem as a whole, it is necessary to recognise the ecological processes at work and how the system works across the landscape. A broad range of threats is outlined in the Reef 2050 Long Term Sustainability Plan (Reef 2050 Plan; Commonwealth of Australia, 2015) and only those specifically relating to water quality are addressed in this plan. The Reef 2050 Long Term Sustainability Plan (Reef 2050 Plan; Commonwealth of Australia, 2015a) is a joint initiative between the Australian and Queensland Governments to provide an overarching strategy for management of the GBR, and contains objectives, targets and actions across several themes including: biodiversity, ecosystem health, heritage, water quality, community benefits and governance. The Reef 2050 Plan includes a specific action to 'Finalise and implement plans (Water Quality Improvement Plans - Healthy Waters Management Plans) for Reef catchments and key coastal areas, identifying implementation priorities for protection of the Reef' (WQA7).

The natural assets of the Burdekin Region also provide high economic returns every year, including commercial fishing (estimated at \$66 million in 2011-2012), tourism (\$29 million) and recreation (\$81 million) (2011-12 figures reported in Thomas and Brodie, 2015). Ecosystem goods and services also provide significant economic values for the region, but these non-market values are difficult to quantify for GBR ecosystems (see Section 2.1.5).

Water quality determines the suitability of water for different uses and is essential to social and economic well-being, and ecological health; in healthy well managed environments, natural functions help to maintain water quality by providing 'ecosystem services'. Water supports people, agriculture, animals and plants, and is one of the key factors central to the health of the whole ecosystem as it connects places, processes and species. In the Burdekin Dry Tropics region (herein referred to as the 'Burdekin Region') there are many highly valuable ecological systems, including the internationally recognised Great Barrier Reef World Heritage Area (GBRWWHA), Ramsar Wetlands of Bowling Green Bay and in the northern part of the region, the Wet Tropics World Heritage Area. The region contains large areas of National Parks and Conservation areas for wildlife. If left untreated, degraded water quality is or will become a human health risk, which leads to greater community costs and losses and threatens the values and integrity of these conservation areas. The cost of treating poor water quality is far greater than preventing it or allowing further degradation.

Prior to European settlement, the Burdekin Region was covered with woodlands, grasslands and forests, coastal floodplains and wetlands. These ecosystems provided a wide range of ecological services which assisted in the development and maintenance of the GBR. They acted as natural filtering systems, reducing excess sediment and nutrients entering waterways when it rained, slowed water allowing it to recharge aquifers, provided nursery and breeding grounds for many species of fish. During the past 150 years, agricultural production, urban expansion, transport infrastructure, tourism and mining have dramatically changed how this land is used. Agricultural development has expanded in the region since the late 1800s and has led to a significant rise in the volume of sediment, nutrient and pesticide run-off entering our waterways and, eventually, the GBR (Brodie et al. 2013a; Waters et al. 2014). These changes can be detected using historic data such as coral coring and geochemical records (e.g. Carilli et al. 2009; Lewis et al. 2012a).

The greatest water quality risks to the Burdekin Region and the GBR are from existing and ongoing development activities which historically discharge excess loads of nutrients, fine sediments and pesticides into the GBR lagoon and, changing climatic conditions (Brodie et al. 2013a). Rising shallow groundwater and associated salinity in the Lower Burdekin sugarcane areas also have potential implications for freshwater, coastal and marine ecosystems. Excess nitrogen discharge leads to increased larval survival of crown-of-thorns starfish (COTS) larvae and is associated with outbreaks of COTS populations, which have a destructive effect on coral reefs (Fabricius et al. 2010). Nutrients can also lead to excessive algal growth and can increase susceptibility to bleaching and disease in corals. Fine sediment contributes to making water turbid and reducing sunlight, which seagrass and corals need to grow. Pesticides are used for weed control, however, they do not discriminate between pest and non-pest species, and when released into waterways, pose a risk to freshwater and some inshore and coastal habitats. In an assessment of the relative risk of degraded water quality to the GBR, the Burdekin Region was identified as high risk to coral reef and seagrass ecosystems (Brodie et al. 2013b).

In recent years, governments and the community have made a great deal of effort to enhance water quality in the GBR, primarily through catchment management. The Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan [<http://www.reefplan.qld.gov.au/>]) initially established in 2003 and revised in 2009 and 2013, provides the foundation for managing water quality in the GBR. Reef Plan 2013 states that its long term goal is *"to ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental effect on the health and resilience of the Great Barrier Reef."* The Plan identifies actions, mechanisms and partnerships to build on existing Government policies, and industry and community initiatives to assist in halting and reversing the decline in the quality of water entering the GBR lagoon from GBR catchments. The Plan includes the deliverable of *'a Water Quality Improvement Planning process*

(aligned with Healthy Waters Management Plan guideline under the Environment Protection Policy Water) to consider Reef Plan's long term goal and use of consistent modelling information to set regional and subregional water quality and management action targets that align with Reef Plan'. In 2014, the Australian Government's Reef Programme committed to funding the update of the Water Quality Improvement Plan (WQIP) for the Burdekin Region.

A WQIP was developed for the Burdekin Basin in 2009 (Dight, 2009) and focused largely on how beef and sugarcane production affected water quality in the region. It has successfully guided investment into reducing the water quality impacts associated with these two industries. For example, between 2008 and 2013, Reef Rescue Water Quality Improvement Grants gave land managers the opportunity to amend their farming practices for the benefit of their business and water quality. Some of these changes included:

- methods to apply nutrients and chemicals in a more precise, targeted way, which meant less money spent on fertilisers and pesticides, and less contaminants contained in run-off from the farm;
- capturing and reusing irrigation tailwater through recycle pits, which saved money on power and water while once again significantly reducing contaminated run-off; and
- fencing riparian areas to keep out cattle, and providing watering points away from the creek. This protected stream banks from erosion and encouraged cattle to graze more sustainably on other parts of the farm.

Since 2009, there is new knowledge about how the system works in terms of the sources and impacts of pollutants on important aquatic ecosystems, and what options are available for managing water quality in the most cost-effective way. There is also greater recognition of the need to address issues associated with modification of ecosystem function, landscape processes and the systems that link the catchment and marine landscapes to improve water quality and ecosystem health outcomes in the GBR.

The Black Ross WQIP (2010) (Gunn and Manning, 2010) was also developed around this time for the greater Townsville area and consequently, has a strong focus on urban water quality issues.

1.2 Burdekin WQIP implementation and achievements to date

Implementation of priorities and actions identified in the 2009 Burdekin WQIP have contributed to achievements in water quality in the Burdekin Region as a whole over the last 6 years.

Since 2009, there have been a number of major funding programs to support water quality improvement in the Burdekin Region (listed in Section 6.4.1).

The Australian Government's Reef Rescue initiative (2008-2013) invested over \$32 million into grazing/farming communities within the Burdekin Region to assist with practice changes aimed at reducing sediment, nutrients and pesticides leaving farms and entering the GBR. This investment was continued through the Australian Government's Reef Programme, with an additional \$15 million (2013-2016) for a targeted extension and financial incentives program, and the 'GameChanger' project has also supported fast-tracking adoption of game-changing sugarcane nutrient and pesticide management practices over the same period. A major project to restore coastal ecosystems for the GBR and Bowling Green Bay Ramsar site is also being conducted (\$2 million, 2013-2018). More recently, the Australian Government's Reef Trust provides targeted investment focused on improving water quality, restoring coastal ecosystem health and enhancing species protection in the GBR region. Reef Trust is currently investing in a competitive tender approach that targets nitrogen discharge from sugarcane in the Burdekin (up to \$3.3 million, 2016-2019) and Saving Our Soils which involves promotion of A-class grazing management (\$3 million between the Burdekin and Fitzroy, 2015-2018).

The Queensland Government has supported the Reef Plan Paddock to Reef Monitoring, Modelling and Reporting Program (Paddock to Reef program) which is reported annually (Queensland Government, 2015), the Reef Water Quality Protection Program including regulations and more recently, development of BMP. The Queensland Government NRM Investment Strategy projects are targeting the improvement of landscape resilience in sugarcane in the Lower Burdekin Delta (\$240,000; 2013-2016) and grazing lands (\$580,000; 2013-2016), and a Regional Delivery Project is focusing on promoting sustainable soils management across the region (\$1.5 million; 2013-2018).

Project Catalyst, a project that involves a group of innovative farmers that are developing and testing management practices that improve the quality of the water leaving sugarcane crops, has been supported by the Coca-Cola Foundation (\$2.5 million across the Burdekin, Mackay and Wet Tropics regions, 2010-2015).

The achievements against the targets defined in the 2009 Burdekin WQIP, supported by this investment, are reported in *Appendix 1: Assessment of progress against Burdekin WQIP 2009 targets*, and several key outcomes are identified below (see also NQDT, 2014). (Note that adoption in this period was measured by the number of landholders engaged in the program; since 2013, reporting emphasises the area of land where management practice improvements have occurred).

Water quality improvement in the Burdekin Region is based on sound science. Scientific support for the \$32 million Reef Rescue program in the Burdekin lies in findings from initiatives such as the 2009 WQIP, which integrated a wealth of research undertaken in the terrestrial, marine, and aquatic environments of the region. The outputs of the Reef Rescue Water Quality Research and Development Program (www.reefrescueresearch.com.au) and the Paddock to Reef program (www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/) have also helped provide a robust evidence base for investment decisions. Integration of research outputs with monitoring and practice change data has maintained relevance and validity of program activities, and ensured that adaptive management is a reality rather than a theoretical ideal.

Strong partnerships with industry have been established. Through strong partnerships with industry groups, a robust program of activities has been developed to invest funds in grants and associated activities in the region over the last five years. Partnerships with industry were instrumental in ensuring a high level of involvement from farmers and graziers in water quality improvement programs.

Adoption of improved management practices exceeded targets and its farmers have provided a high rate of co-contribution. Engagement of agricultural industries has resulted in 540 graziers and farmers, around 35 per cent of total number in the Burdekin Region, adopting practices to improve the quality of water leaving their properties (2008-2013). Farmers and graziers who have received grants have contributed more than \$1.30 for every dollar received from Reef Rescue and Reef Programme funding.

Reef Rescue and Reef Programme have initiated sustained change in the Burdekin Region. Four key areas indicate high potential for continued change and confirmation that water quality improvement actions have affected attitudes to environmentally sound production:

- involvement of farmers and graziers in planning activities to improve water quality on their properties has built their confidence to undertake further works;
- training and dissemination of information related to improving water quality has given farmers and graziers tools and knowledge to make decisions about modifications ranging from small incremental shifts to whole-of-system changes which will improve water quality on their properties;
- as farmers and graziers implement changes through grant projects, they experience economic benefits of improved practices, which finances and supports a business case for further changes;
- farmers bring forward management practice changes as a result of financial support (through grants) reducing significant capital costs associated with making the change; and
- farmers and graziers are “looking over the fence” at projects completed by neighbours and registering interest in taking advantage of an opportunity to change their practices.

Water quality improvement activities in the Burdekin Region are predicted to have reduced pollutant loads. Paddock to Reef program modelling predicts moderate to very good progress toward load reduction targets for the region’s main pollutants of nitrogen, phosphorus, sediment and PSII herbicides (Queensland Government, 2015). Between 2009 and 2014 the following reductions in anthropogenic loads (the ‘human influence’ estimated using the Source Catchments modelling by subtracting the modelled pre-development loads from the modelled current total loads; Queensland Government, 2015) were estimated for the Burdekin Region: Total suspended sediment (TSS) 17 per cent, Dissolved Inorganic Nitrogen (DIN) 16 per cent, Particulate Nitrogen (PN) 15 per cent, Particulate Phosphorus (PP) 15.5 per cent and photosystem II inhibiting herbicides (PSII herbicides) 20 per cent. These reductions represent significant progress towards the Reef Plan 2013 reduction targets (by 2018) for TSS (85 per cent achievement), PN (75 per cent) and PP (78 per cent). While the progress

Water quality improvement in the Burdekin Region is based on sound science.

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Water quality improvement activities in the Burdekin Region are predicted to have reduced pollutant loads.

Between 2009 and 2014 the following reductions were estimated for the Burdekin Region:



Total suspended sediment (TSS) reduced by 17 per cent



Dissolved Inorganic Nitrogen (DIN) reduced by 16 per cent



Particulate Nitrogen (PN) reduced by 15 per cent



Particulate Phosphorus (PP) reduced by 15.5 per cent



Photosystem II inhibiting herbicides (PSII herbicides) reduced by 20 per cent

There is still much to do.

towards the DIN and PSII herbicide targets is slower, at approximately 30 per cent of the targets, it is still significant in the timeframes and taking into account historical practices.

Indicators of GBR health in inshore areas influenced by the Burdekin Region have shown a steady decline in condition both before and after the implementation of the 2009 WQIP (GBRMPA, 2014a; Reef Check, 2014; Coppo and Brodie, 2015). This may in part be indicative of lags in the ecological system between achievement of a change in land management, the influence this has on marine water quality and the response of the GBR system as a whole.

There is still much to do. Notwithstanding these substantial achievements, more than half of the region's farmers and graziers have not been involved in voluntary water quality programs; these landholders manage nearly two-thirds of the area. Many farmers and graziers have submitted applications for grants for which funds were unavailable. This demonstrates the significant momentum available for the ongoing investment in addressing water quality issues in the region. Feedback from extension events confirms a growing need for extension services and resources to support these services.

Continued decline and continued projected decline in GBR health indicates that the scale of effort needs to be significantly expanded, and suggests the need for consideration of alternative options for reducing pollutant discharges to the GBR, and protection of areas that remain intact and provide important ecosystem services.

1.3 About the Burdekin WQIP

Scope

This WQIP has been developed to address requirements for Healthy Waters Management Plans (HWMP) specified in section 24 of the Environmental Protection Policy (Water) 2009. Where WQIPs adequately address matters specified under the EPP Water for HWMPs, they may be accredited as HWMPs. The HWMP guidelines are available from the Department of Environment and Heritage Protection website at http://www.ehp.qld.gov.au/water/policy/water_quality_improvement_plans.html. A WQIP is designed to identify the main issues impacting waterways and the coastal and marine environment from land-based activities, and to prioritise management actions that will halt or reverse the trend of declining water quality within a region.

The 2016 Burdekin WQIP updates, extends and consolidates the 2009 plan, and expands the scope to include:

- the Haughton and Don River and Abbot Bay sub-catchments;
- links to the existing Black-Ross (Townsville) 2010 WQIP;
- the EPP Water scheduled Environmental Values (EVs) and Water Quality Objectives (WQOs) for the Black and Ross Basins and draft EVs/WQOs for the Haughton and Don Basins;
- recognition of community expectations for maintaining and protecting health ecosystems based on the environment's assimilative capacity and the impacts on their resilience from approved water and land use activities;
- the impact of established and developing urban and industrial areas, including the coastal urban areas of Ayr, Home Hill and Bowen;
- the impacts of the horticultural and grains industries;
- the real and predictable impacts of future development actions;
- advances in our knowledge of water quality issues and threats through monitoring and modelling including surface and groundwater interactions;
- the results of recent research and development projects that have enhanced our understanding of water quality impacts associated with different agricultural practices and sources;
- major point sources of water quality pollution or risk including past present and proposed industry, aquaculture, mining, dams, bunds and major linear infrastructure;
- marine development impacts on water quality including port development and dredging recognises recent potential impacts on water quality, such as port expansions; and
- the pervasive implications of a changing climate for water quality and water quality management.

The region's economy is highly dependent on a healthy environment with high quality functioning ecosystems. Many industries generate substantial income for the region either directly or indirectly related to the environment, including a significant contribution from environmental tourism to the region's economy. While the focus of the WQIP is predominantly on agriculture, which is identified as the greatest source of diffuse pollutants, it is recognised that other industries and activities are also a source of pollutants and have the potential for adverse impacts on water quality. For urban and industrial development issues this plan draws heavily on Townsville City Council's Black-Ross WQIP (2010) and the subsequent learnings of local government and their partners in the implementation of that plan. The plan does not update or replace the existing Black Ross WQIP, rather, it provides a regional perspective to water quality management and cross references to that WQIP for specific management actions and priorities. Other pollutant sources considered include point source pollution from a range of land uses including urban, heavy industry, aquaculture and mining. While these additional issues are raised and their significance is subjectively assessed using risk analysis, detailed assessment of these industries is outside the scope of this WQIP. These industries are generally managed either by their own industry codes of practice or legislated regulations.

The WQIP boundaries

The region of immediate relevance to the 2016 Burdekin WQIP includes the rivers, creeks, wetlands and their watersheds that discharge into the coastal areas from Bowen in the south to Crystal Creek north of Townsville. This area covers the extensive rangelands of the region, the coastal floodplain of the Lower Burdekin with its numerous small creeks, intensive agriculture and complex system of irrigation channels, the Haughton and Don River basins, the urban centre of Townsville in the Black and Ross River basins, and smaller coastal centres of Ayr, Home Hill and Bowen (Figure 1.1). Discharge from the Burdekin River during wet season events can extend northwards for over 300 kilometres to areas around Cairns and the detectable freshwater plume may cover several thousand square kilometres of the GBR. However, the marine boundary for reporting in the WQIP is the marine NRM boundary defined by the Great Barrier Reef Marine Park Authority (GBRMPA).

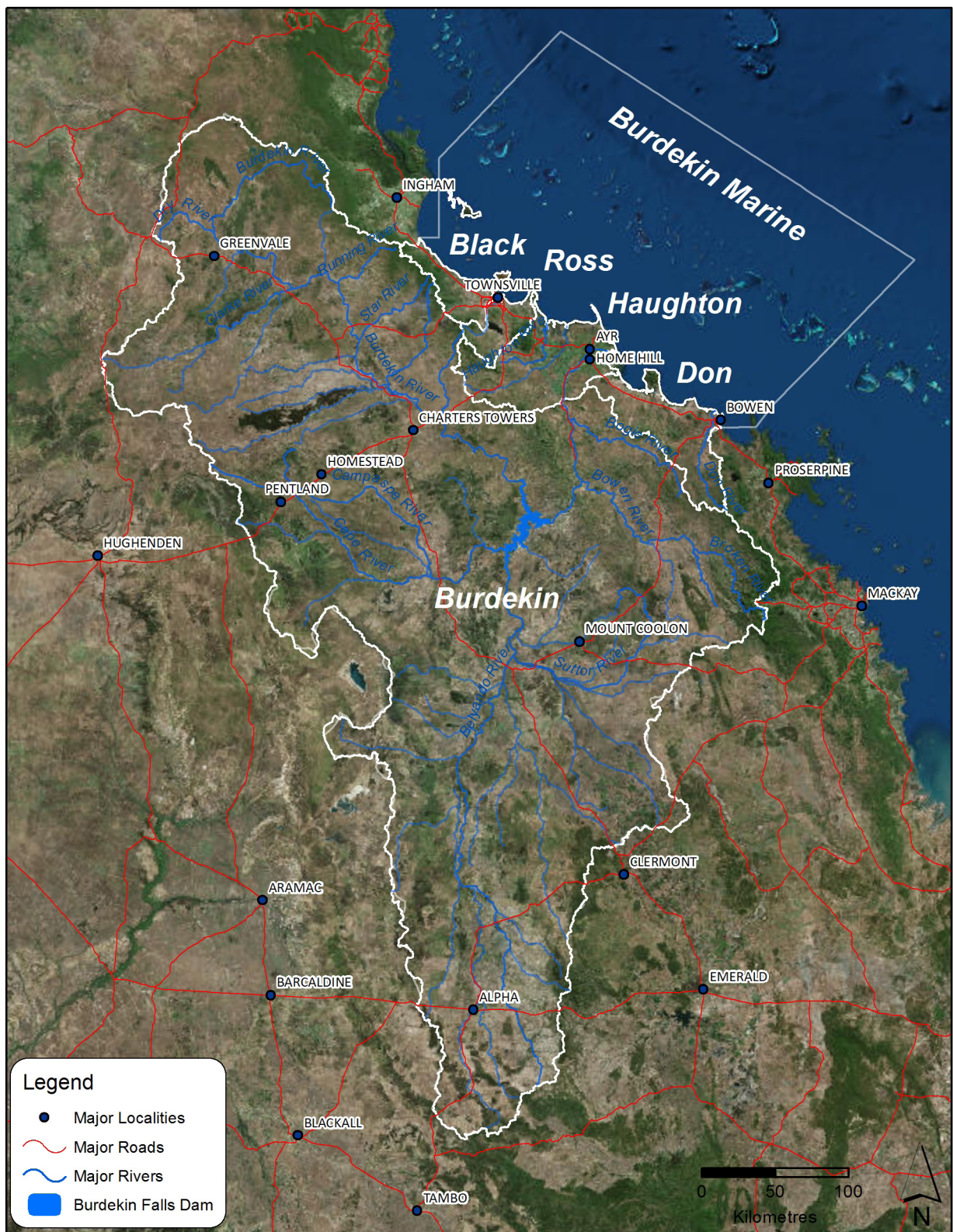


Figure 1.1 Map showing the Burdekin WQIP region.

Objectives of the WQIP

The vision and intended long term outcomes of the 2009 WQIP are still relevant to the region, and have been combined with the relevant Reef 2050 Plan Outcomes and Objectives for this WQIP (shown in brackets) as follows:

Outcomes:

- i. the status and ecological functions of ecosystems within the Great Barrier Reef World Heritage Area are in at least good condition with a stable to improving trend;
- ii. reef water quality sustains the Outstanding Universal Value of the Great Barrier Reef World Heritage Area, builds resilience and improves ecosystem health over each successive decade;
- iii. freshwater, estuarine and marine ecosystems are ecologically healthy, productive, resilient, enjoyed and valued;
- iv. terrestrial ecosystems are sustainably managed for good water quality; and
- v. surface and ground water resources are sustainably managed for good water quality.

Long term resource condition objectives:

- i. the Great Barrier Reef World Heritage Area retains its integrity and system functions by maintaining and restoring the connectivity, resilience and condition of marine and coastal ecosystems (Reef 2050 Plan, EHO2);
- ii. trends in the condition of key ecosystems including coral reefs, seagrass meadows, estuaries, islands, shoals and inter-reefal areas are improved over each successive decade (Reef 2050 Plan, EHO3);
- iii. over successive decades the quality of water entering the Reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef (Reef 2050 Plan, WQO1); and
- iv. over successive decades the quality of water in or entering the Reef from all sources including industrial, aquaculture, port (including dredging), urban waste and stormwater sources has no detrimental impact on the health and resilience of the Great Barrier Reef (Reef 2050 Plan, WQO2).

This WQIP provides a framework to develop strategies to achieve this vision and outcomes at a regional level, and aims to:

1. describe the values of the region, and the current state and drivers of water quality issues in the region;
2. identify the priority water quality and ecosystem health issues for the region, in terms of:
 - key pollutant drivers of water quality issues, spatially and by sector;
 - desired water quality environmental and use values that the community aspires to protect/enhance;
3. develop regional end of catchment pollutant reduction targets to maintain the desired in-stream, coastal and marine values of the region;
4. estimate and clearly document the effectiveness of current regionally specific management interventions;
5. estimate the implications and costs of intervention options based on least cost risk abatement to protect desired values:
 - identify key pollutants to be reduced and key sources (sectoral and practices);
 - estimate annualised pollutant delivery at end of catchment (and where available, sub-catchment scale), progressing to estimates of loss to catchment waterways and groundwater as information becomes available;
 - as information becomes available, map the risk of off-site pollution at the smallest practical scale, and estimate and map as applicable production efficiency (yield/inputs) and pollution intensity (unit production/pollution eg. nutrient, TSS, pesticide);
6. develop an implementation strategy in consultation with government, industry and community groups for managing water quality in the region and achieving the proposed targets, through identification of improved management practices and projects that can be adopted to meet targets and objectives in the most cost effective manner. This will guide strategic investment in water quality issues in the region for the next 5 to 10 years and includes strategies for long term planning consistent with the Reef 2050 Plan; and
7. develop and agree with stakeholders on a robust, adaptive, relevant and transparent monitoring, evaluation and reporting and review framework for progress at all scales to ensure public accountability and community support for long term re-investment in water quality protection, by the least cost interventions.

In recognition of the significant connections between catchment and coastal and marine ecosystems, and natural and social systems, this plan adopts a whole-of-system approach that provides an integrated framework for catchment management and the protection, maintenance and restoration of freshwater, coastal and marine ecosystems.

1.4 Approach to updating the Burdekin WQIP

Using existing knowledge and information

This Burdekin WQIP builds on the existing Burdekin Basin and Black-Ross WQIPs. The WQIPs are consistent with the *Framework for Marine and Estuarine Water Quality Protection* (2002), and apply the framework described in the National Water Quality Management Strategy (NWQMS, 1992). In Queensland, this is linked through the *Environmental Protection Act 1994* which is the main legislation for water quality in freshwater, estuarine and marine areas, and includes the *Environmental Protection (Water) Policy 2009* (EPP Water, 2009) and the *Environmental Protection Regulation 2008* (EPR, 2008). The *EPP (Water) 2009* provides targets for water quality management through the development of environmental values, and water quality guidelines and objectives under the framework provided by the National Water Quality Management Strategy (NWQMS, 1992) at a catchment scale. The *Environmental Protection Regulation 2008* provides a regulatory regime for Environmentally Relevant Activities that have the potential to impact on water quality, including, but not limited to industry, agriculture, aquaculture, mining, and waste disposal. The Environmental Protection Act also sets monitoring requirements related to release of wastewater at a regional and local scale. WQIPs and HWMPs are prepared to meet relevant requirements, including HWMP requirements specified in section 24 of the *EPP (Water) 2009*.

Environmental Values (EVs) and water quality objectives (WQOs) have been scheduled under the *EPP (Water) 2009* for the Townsville region waters (Black and Ross River Basins, Magnetic Island and adjacent coastal waters) (<http://www.ehp.qld.gov.au/water/policy/townsville.html>). Work to identify EVs throughout the Burdekin Region has been undertaken by or on behalf of NQ Dry Tropics and is reported in this WQIP (Kerr, 2013). These include values for primary industries, recreational and aesthetics, drinking water, industrial, cultural and spiritual and aquatic ecosystems. Further work to localise EVs and aquatic ecosystem water quality guidelines in Don, Haughton and marine waters has been undertaken based on work conducted subsequent to the previous WQIP and is included in this draft WQIP for comment. In the Burdekin Basin, comprehensive consultation processes have been undertaken to establish EVs and WQOs (Kerr, 2013) but these are not scheduled yet.

These guidelines are applied through various planning controls and policies by local and Queensland Government agencies. It is the role of the WQIP to identify where these are most relevant for protecting or improving the water quality of the region.

In 2010, GBR protection requirements (*Great Barrier Reef Protection Amendment Act 2009*) were brought in under the *Environmental Protection Act 1994* and the *Chemical Usage (Agricultural and Veterinary) Control Act 1988* and associated regulations. The legislation is intended to reduce the impact of agricultural activities (sugarcane growing and cattle grazing) on the quality of water entering the GBR, and contribute to achieving the targets outlined in Reef Plan.

The legislation required sugarcane growers in the Wet Tropics (with sugarcane production areas greater than 70 hectares) and cattle graziers (on properties greater than 2,000 hectares) in the Burdekin catchment to complete an Environmental Risk Management Plan (ERMP). In 2016, the Queensland Government is considering alternatives to ERMP's such as Environmental Protection Orders for land degradation issues. All sugarcane growers and graziers within the Wet Tropics, Burdekin and Mackay Whitsunday catchments are also required to calculate and use no more than the optimum amount of nitrogen and phosphorus fertiliser, follow chemical use conditions, and keep residual herbicide and fertiliser use records.

In December 2012 the Queensland Government announced agreements with the sugarcane and grazing industries to support the development and implementation of Best Management Practice (BMP) programs to boost agricultural productivity and help protect the GBR. The grazing and sugarcane BMP systems are currently being rolled out and will contribute to achieving water quality targets under Reef Plan, and include accountable reporting of industry performance, underpinned by accreditation systems.

The existing legislation remains in place as producers transition to industry BMP systems and is currently being reviewed (March 2016).

Additional legislative and policy context that is relevant to the development and implementation of the WQIP is included in *Appendix 2: Key legislation and policy considerations for regional water quality planning in Queensland*. The plan also builds on a range of related local plans and strategies, many of which should be considered in conjunction with the strategies identified in this plan. Key examples include:

- 'A community-based Natural Resource Management Strategy for the Burdekin-Bowen Floodplain Sub-Region of the Burdekin Dry Tropics Region' (Burdekin Bowen Integrated Floodplain Management Advisory Committee, 2000) and associated Business and Communication Plan (Musso and Rickert, 2001);
- 'Freshwater Wetlands of the Barratta Creek Catchment Management Investment Strategy' (EcoConcern and ACTFR, 2007);

- ‘Draft Sheep Station Creek Catchment Management Plan’ (Tait, 2004); and
- ‘Coastal ecosystems management – Lower Burdekin Floodplain Review of coastal ecosystem management to improve the health and resilience of the Great Barrier Reef World Heritage Area’ (GBRMPA, 2013).

Additional legislative and policy context that is relevant to the development and implementation of the WQIP and local plans, strategies, discussion papers are included in *Appendix 2: Key legislation and policy considerations for regional water quality planning in Queensland*.

Building the evidence base

NQ Dry Tropics has adopted the principle of using the best available knowledge for the development of this WQIP, and commissioned a number of supporting science studies to assist in building this current information base. The studies are grouped into four main areas, and are listed in Table 1.1.

1. Regional context, system understanding, status and values
2. Goals and targets
3. Management options
4. Spatial prioritisation

Each of the studies informs one or several steps in the development of the WQIP. Figure 1.2 illustrates how the studies fit into the overall WQIP framework, derived from the National Water Quality Management Strategy.

The supporting studies have generated standalone reports which have been independently peer reviewed to inform the WQIP, and are available on the NQ Dry Tropics website (www.nqdrytropics.com.au). The spatial prioritisation report provides a comprehensive synthesis of a majority of the supporting studies, and should be consulted for further detail and justification for the management priorities identified in this WQIP.

Table 1.1. Summary of the supporting studies completed to support the update of the Burdekin WQIP.

Sub component	Description	Project Lead and team
Regional context, system understanding, status and values		
1. Regional context	Collation of existing information on regional characteristics including natural and anthropogenic systems (agriculture, infrastructure, population etc).	Jane Waterhouse, C ₂ O Consulting Alastair Buchan, NQ Dry Tropics
2. Understanding system functions and interactions – ‘Walking the Landscape’.	The ‘Walking the Landscape’ process, developed and facilitated by the Queensland Wetlands Program, was used to capture a whole-of-landscape understanding of catchment/sub catchment function in the Lower Burdekin catchment. Using available data sets and key experts, catchments were assessed in detail and an understanding of how they function was documented e.g. in terms of hydrology, geology etc. The findings from the process were compiled into data tables, maps and schematics. The GBRMPA Blue Maps and Eco-calculator were used to inform this assessment.	Mike Ronan, Amelia Selles, DEHP Jim Tait, Econcern Donna Audas, Paul Groves, GBRMPA
3. State of freshwater ecosystems and conceptual understanding of agricultural impacts.	Synthesis of existing knowledge of freshwater ecosystems in the region, and articulation of the conceptual understanding of the influence of agricultural pollutants on these assets. The Queensland Wetlands Program wetland mapping was used to identify wetland extent.	Aaron Davis, Jon Brodie, TropWATER JCU Richard Pearson Davis et al. (2015) Queensland Wetlands Program
4. Riparian condition assessment.	The 2009 WQIP included information from a report undertaken by the Australian Centre for Freshwater Research (ACTFR) in 2007, which assessed the condition of riparian vegetation in the Burdekin catchment using satellite imagery and field surveys (Lymburner and Dowe, 2007). The Paddock to Reef Program now includes a component which reports riparian condition in the GBR catchments, which is being used to inform the update (included in the Catchment Atlas).	Paddock to Reef Program
5. Status and values of the coastal and marine environments in the Burdekin Region.	Review and synthesis of the current status of coastal and marine assets in the Burdekin Region. Includes all coastal and marine assets including coral reefs, seagrass meadows, mangroves, turtles, dugong, seabirds, whales, fish, coastal wetlands, shorelines and estuaries.	Caroline Coppo, Jon Brodie, TropWATER JCU Coppo and Brodie. (2015)

Sub component	Description	Project Lead and team
6. Ecosystem services and economic values of the Burdekin marine region.	Collation of comparative regional industry statistics and summarised data on economic values of ecosystem services and industries in the Burdekin NRM region.	Colette Thomas, Jon Brodie, TropWATER JCU Thomas and Brodie (2015)
7. Climate Change.	Climate Change implications for water quality management in the Burdekin Dry Tropics.	Alastair Buchan, NQ Dry Tropics Buchan (2015)
Goals and Targets		
8. Setting ecologically relevant pollutant load reduction targets for the Burdekin Region	Definition of individual end of river pollutant load reduction targets for all of the coastal basins in the Burdekin Region based on the Reef Plan 2013 targets. The study also set ecologically relevant targets for end-of-catchment pollutant loads in the Burdekin Region.	Jon Brodie, Steve Lewis, Zoe Bainbridge, Jane Waterhouse, TropWATER, JCU Scott Wooldridge, AIMS Carol Honchin, GBRMPA Brodie et al. (2016)
Management options		
9. Update management practice synthesis for grazing, sugarcane, horticulture and urban land uses.	Update of the 2009 WQIP guidelines for management practice in grazing and sugarcane (Coughlin et al. 2007, 2008; Davis 2006). A regional analysis of urban and special site pollutant sources and recent guidance for incorporation of urban issues into WQIPs (Gunn, 2014) is also incorporated. Paddock to Reef Water Quality Risk Framework.	NQ Dry Tropics with input from external experts. Alastair Buchan, NQ Dry Tropics Buchan (2016)
10. System repair options	Identification of issues and priorities for system repair actions in the region. Primary inputs: 1. GBRMPA Blue Maps and Eco-calculator; 2. Qld Wetlands Program mapping and 'Walking the Landscape' process; and 3. Existing priorities identified for system repair in the Lower Burdekin.	NQ Dry Tropics with input from external experts. Jim Tait, Econcern Paul Groves, Donna Audas, GBRMPA Queensland Wetlands Program
Spatial prioritisation		
11. Burdekin sediment story.	Synthesis of current knowledge of the sources, delivery and fate of sediments in the coastal and marine environment in the Burdekin Region.	Steve Lewis, Zoe Bainbridge, Jon Brodie, TropWATER JCU Rebecca Bartley, Scott Wilkinson, Elizabeth Lui, CSIRO Jo Burton, DSITI Lewis et al. (2015)
12. Water quality relative risk assessment in the Burdekin Region – pollutant sources, dynamics, impacts.	Assessment of the relative risk of degraded water quality on Burdekin coastal and marine ecosystems and makes recommendations for regional management priorities considering the types and range of pollutant sources in the region.	Jane Waterhouse, Steve Lewis, Jon Brodie, Michelle Devlin, Caroline Petus, Eduardo da Silva, Dieter Tracy, TropWATER JCU Cameron Dougall, DNRM Jeff Maynard, Maynard Marine Waterhouse et al. (2015) Maynard et al. (2015) Petus et al. (2015)
13. Economics of sugarcane management practices.	Analysis and evaluation of financial-economic data for sugarcane production systems. Identifies the weighted benefit-cost of shifting between various management practice classes at different farm sizes and land types for nutrients and pesticides, presented in a spreadsheet tool including individual management practice scenarios. <i>Note that inputs on economics of other land uses was collated through direct interaction with experts through the INFFER process.</i>	Marcus Smith, JCU Smith (2015) A number of industry specific experts were also engaged to assist in deriving estimates of the cost effectiveness of management practice shifts in other industries.
14. INFFER analysis of management options and costs for meeting targets.	Integrated assessment of the benefits and costs of achieving water quality targets using the INFFER (Investment Framework for Environmental Resources) analysis. The framework aims to help people determine whether the environmental/natural resource projects they are investing in will deliver tangible results within budget; whether the tools and technical capacity needed to attain those results will be available to the project; and whether the people who need to come on board to make it happen will be there when the time comes for action. www.inffer.com.au .	Anna Roberts, Geoff Park, Michelle Dickson, Natural Decisions Roberts et al. (2016)

Sub component	Description	Project Lead and team
15. Overall regional spatial prioritisation.	The outcomes of the above studies were used to identify priority pollutants, locations and land uses for targeting investment and management in the WQIP	Jane Waterhouse, C2O Consulting Paul Duncanson, NQ Dry Tropics Additional input from project leaders and additional experts. Waterhouse et al. (2016)

Modelled end-of-catchment pollutant load estimates are referenced throughout the WQIP, and are generated from the Source Catchments model framework in the Paddock to Reef program for key pollutants: TSS, DIN, PN, DIP, PP and PSII herbicides (Waters et al. 2014). To generate annual average load estimates, the Source Catchments modelling framework is used as a synthesis tool that incorporates new information on paddock modelling of TSS, speciated N and P, and PSII herbicides, plus spatially and temporally remote sensed inputs including groundcover. This provides a consistent set of end-of-catchment pollutant loads for each of the basins and catchments in the Burdekin region, which is part of a larger project that models all of the 35 GBR catchments (see Waters et al. 2014). A fixed climate period is used (1986 to 2013) for all model runs to normalise for climate variability and provide a consistent representation of pre-development and anthropogenic generated catchment loads. This therefore represents an ‘average’ year rather than the extremes such as those recorded in the period 2008 to 2013. In addition, functionality from the previous iteration of catchment modelling, SedNet/ANNEX (for example see Cogle et al. 2006), has been incorporated into Source Catchments to represent hillslope, gully and streambank erosion and floodplain deposition processes. This has also improved in the most recent update of the Source Catchments modelling platform (2015) with improved gully mapping. Other improvements include extension of the model run period (was 1986 to 2009 in previous reporting), improved hydrological calibration and additional load validation (Cameron Dougall, pers. comm.). The confidence in the modelling is increasing each year due to considerable and ongoing improvements. The available monitoring data in the Burdekin region shows good correlation with the end-of-catchment monitoring data.

The model produces pre-European and current annual average pollutant load estimates. Anthropogenic load is then calculated as the difference between the long term average annual load and the estimated pre-European annual loads. Load reductions associated with improved management practice are calculated by comparing annual changes to a ‘baseline’ year. The ‘baseline’ for the current iteration is set as 2013, using the 2013/2014 management practice adoption data. The WQIP uses the 2013 baseline data for reporting pollutant loads in the Burdekin Region.

Technical advice and stakeholder engagement

The major focus for management, with regard to water quality impact on the GBR lagoon, relates to activities associated with sugarcane, grazing and to a lesser extent, horticulture and urban areas. NQ Dry Tropics staff, stakeholder representatives and technical experts have been engaged in the update of the WQIP through a Technical Group (listed in Appendix 3. WQIP Technical Group Members). This group was involved in the INFFER process through specific industry workshops and then the overall project assessment, in addition to being invited to review the draft Burdekin WQIP.

In recognition of the extensive work and engagement processes that have already occurred across the region with regard to planning, consultation and water management, it was decided to approach consultation and engagement in two main phases. The first phase, early in the process and at a less intense level, aimed to raise awareness of the overall WQIP process. Information published on the NQ Dry Tropics website included a WQIP ‘Frequently Asked Questions’ sheet and a one-pager of basic WQIP information. This was provided to NQ Dry Tropics staff to distribute to their stakeholders at local meetings. Presentations were given on opportunistic occasions, based around already scheduled industry and catchment group meetings.

The second phase of consultation and engagement for the WQIP was more detailed and focused on communicating the content of the draft WQIP with key stakeholders. NQ Dry Tropics continues to engage with local government, the Reef Urban Stormwater Management Improvement Group (RUSMIG), and the Local Marine Advisory Committees which also include representatives from other industries such as tourism, commercial fishing and aquaculture.

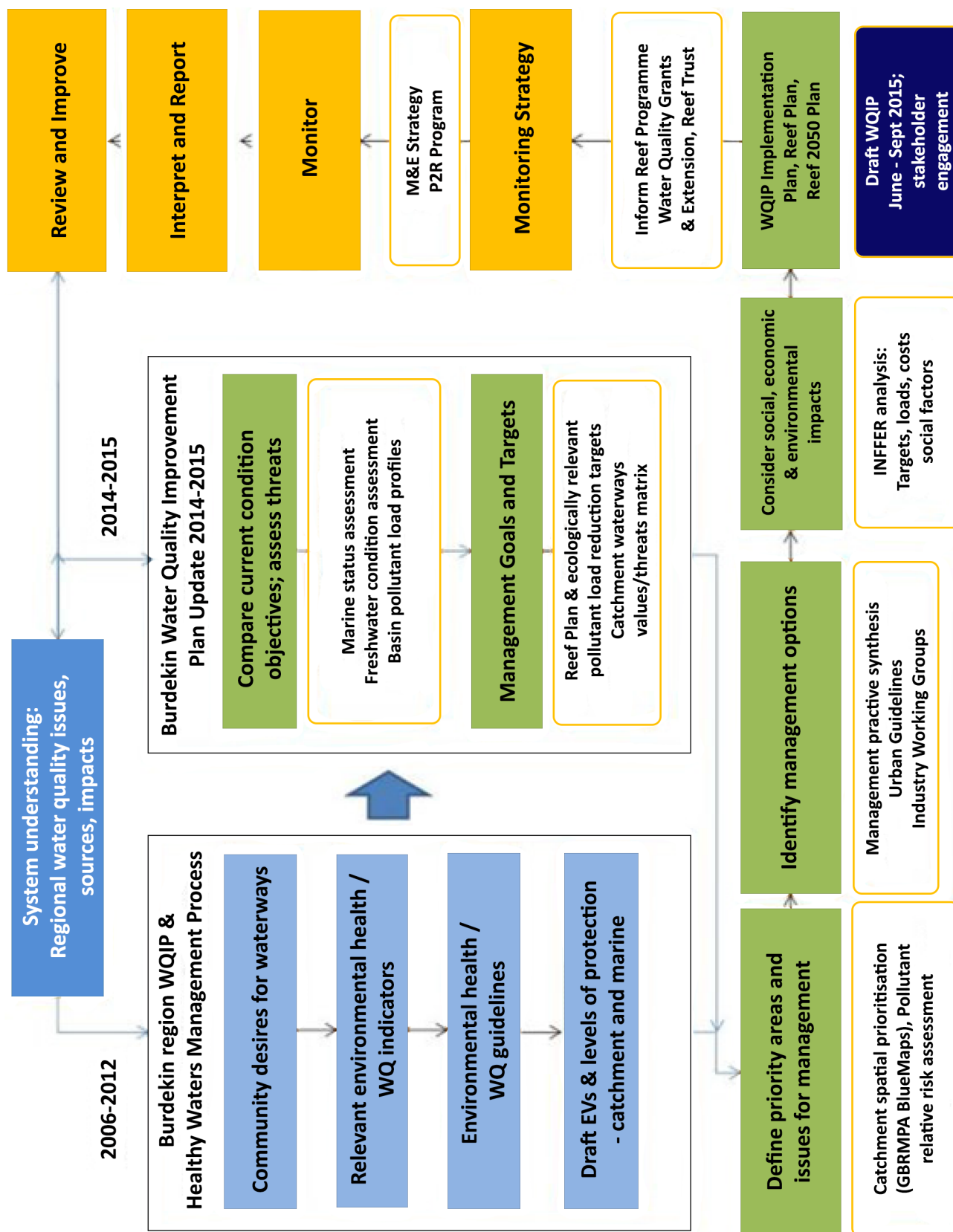


Figure 1.2. The overarching framework for the Burdekin WQIP informed by a number of supporting studies. The light blue boxes indicate steps completed as part of the previous WQIP and HWMP planning processes, green and white boxes indicate current work, and orange boxes represent future steps (over 5 years).

2. What are the values of the Burdekin Region & what is their status ?

2.1 Understanding the system – parts and processes

2.1.1 Geology, landscape and soils

The Burdekin Region covers a land area of around 134,000 square kilometres (QLUMP, 2009). The physical environment across the Burdekin Region is highly diverse. It includes coastal floodplains, low lying hills and mountain ranges that extend westwards into undulating plains, escarpments, dissected plateaus and inland mesas that back onto the Great Dividing Range (NQ Dry Tropics, 2016). Depending upon the underlying geology, combined with the local topography, the soils and their response to rainfall vary widely across the region (Roth et al. 2002).

The coastal ranges enclose the eastern margins of the Upper Burdekin and the Bowen Broken Bogie catchments where rainfall is greatest, and terrain is rugged with steep thickly forested slopes. In contrast the Belyando, Cape and Suttor catchments drain low relief floodplain country and most streams are characterised by wide braided channels on alluvial plains (see Figure 2.1). Roth et al. (2002) report that large areas of the Upper Burdekin catchment contain soils of igneous origin (both granites and basalt) that erode quite easily. While also inherently productive, soil nutrient levels have been severely affected by intense weathering. The Belyando and Suttor catchments consist mainly of remnant sedimentary formations, although granitic intrusions in the form of isolated ranges are also common. Easily eroded cracking clays, with highly dispersive properties due to high sodium content, are common in this part of the Burdekin Basin. Soils in the Lower Burdekin catchment coastal floodplain are derived from river deposits that include cracking clays and duplex soils, some of which are easily dispersed. Maps showing inherent soil erodibility are now available (Zund and Payne, 2014; maps produced by Department of Natural Resources and Mines [DNRM], 2015).



Figure 2.1. Land elevation in the Burdekin Region.

A more detailed description of the geology, landscape and soils of the Burdekin WQIP region can be found in the Burdekin Dry Tropics Natural Resource Management Plan 2016-2026 (2016).

2.1.2 Climate

Intense wet season rainfall, mostly falling between November and April, is followed by very low rainfall over the remainder of the year. While the average rainfall ranges from around 500 to 1500 millimetres annually, it is highly variable across the region (see Figure 2.2), as well as from year to year. This strong seasonal and inter-annual variability in rainfall is strongly linked to the El Niño Southern Oscillation and the formation of tropical low pressure systems, monsoonal activity and cyclones (Lough, 2001).

The higher altitude coastal ranges, particularly in the north and south, have a wet tropical climate with cooler temperatures and more broadly distributed rainfall. In contrast, rainfall gets progressively lower towards the west and more variable than in the coastal areas, and is lowest in the western and southern areas adjacent to the Great Dividing Range. The dry seasons are longer and cooler, and the wet seasons hotter and more unpredictable in the rangelands. Nevertheless, temperatures vary relatively little across the region despite its large size (Roth et al. 2002).

2.1.3 Rivers and catchments

The Burdekin Region includes all the rivers, creeks and their watersheds that discharge into the GBR from Crystal Creek in the north, to Bowen in the south. The catchment is a very large area, which comprises approximately eight per cent of Queensland, extends north to south over approximately six degrees of latitude (or more than 700 km). It extends westward to the Great Dividing Range (Figure 2.3). The rivers and streams of the Burdekin Region drain a diversity of tropical landscapes including semi-arid drylands, wooded grasslands, mountainous tropical rainforests, coastal plains and wetlands. The official marine extent of the Burdekin Region is defined by GBRMPA as a marine NRM boundary (Figure 1.1).

The Burdekin WQIP region includes five basins - the Black, Ross, Burdekin, Haughton and the Don (Australian Geospatial Fabric units 17-21 respectively www.bom.gov.au/water/about/image/basin-hi_grid.jpg) (see Figure 2.3). In this plan the Burdekin Region has been divided into eight major catchments and 52 sub-catchments for water quality analysis, reporting and management planning. The areas are the Townsville Coastal Plain (combining the Ross and Black Basins), and the Upper Burdekin, Belyando, Bowen Broken Bogie, Cape Campaspe, Suttor, Lower Burdekin (including the Haughton Basin) and Don "Catchments". There are both some major differences and important similarities between catchments in their areas and biophysical characteristics (see this Section and the WQIP Catchment Atlas for further information). The catchments have been further subdivided into the 52 sub-catchments for the purpose of spatially prioritising smaller, more manageable watersheds and pinpoint 'hot spots' or major sources of water pollutants. Marine areas and islands are treated spatially as if they were part of the nearest adjacent mainland sub-catchment.

Basins and catchments are listed in Table 2.1 and sub-catchments are identified in Figure 2.3.

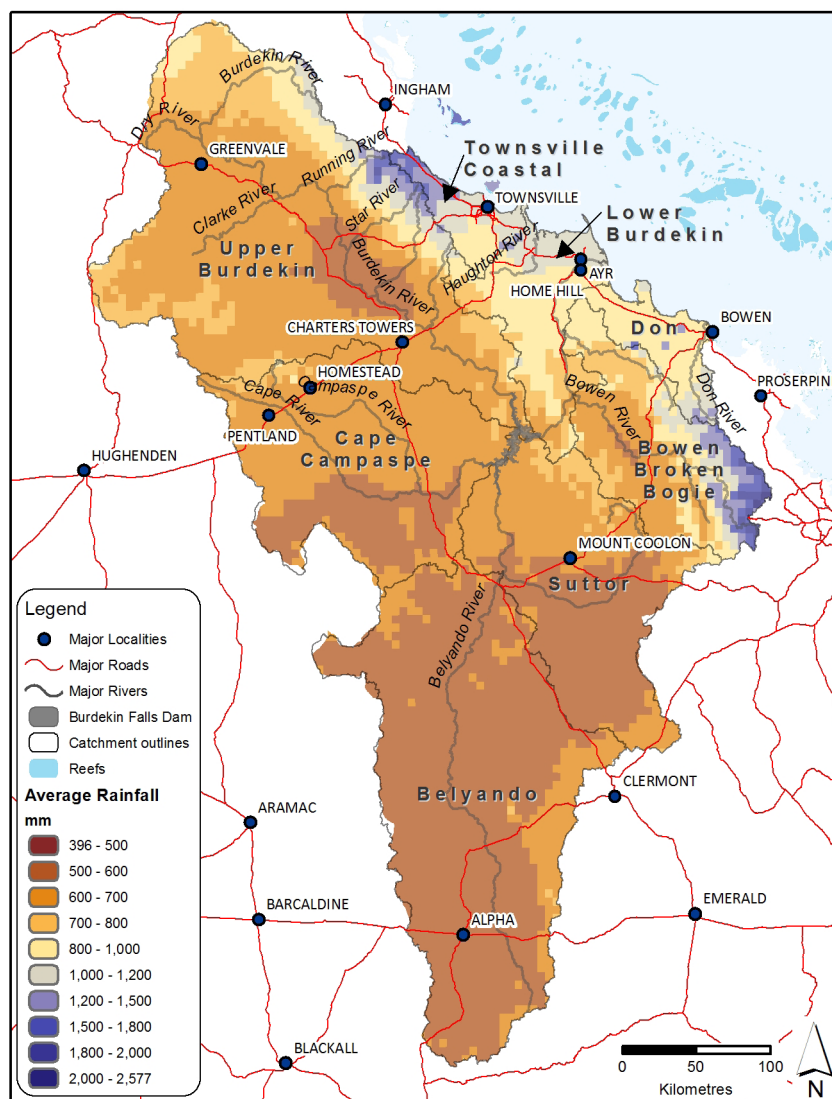


Figure 2.2. Rainfall distribution in the Burdekin Region. Source: Bureau of Meteorology

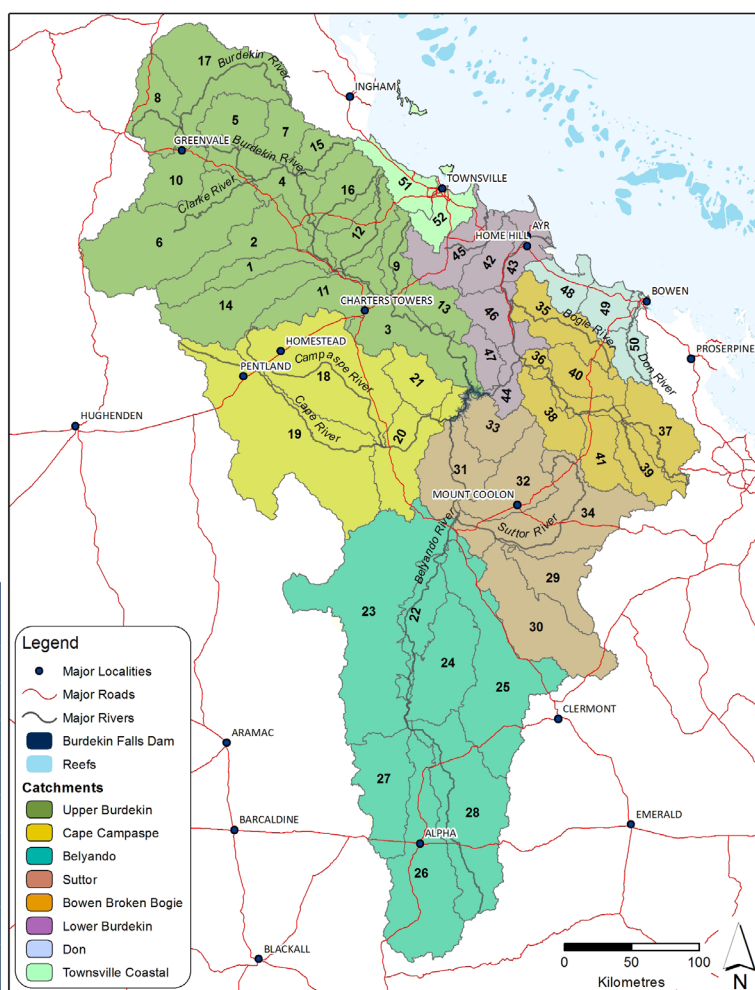


Table 2.1. Summary of basins, catchments and sub-catchments in the Burdekin Region.

Basin	Catchment	Sub-catchment (SC #)
Black	Townsville Coastal	Black River (51)
Ross		Ross River (52)
Haughton	Lower Burdekin	Barratta Creek (42)
		Burdekin Delta (43)
		Haughton River (45)
Burdekin	Lower Burdekin	Burdekin River (below Dam) (44)
		Landers Creek (46)
		Stones Creek (47)
	Upper Burdekin	Allingham Creek (1)
		Basalt River (2)
		Burdekin River (Above Dam) (3)
		Burdekin River (Blue Range) (4)
		Camel Creek (5)
		Clarke River (6)
		Douglas Creek (7)
		Dry River (8)
		Fanning River (9)
		Gray Creek (10)
		Hann Creek (11)
		Keelbottom Creek (12)
		Kirk River (13)
		Lolworth Creek (14)
		Running River (15)
		Star River (16)
		Upper Burdekin River (17)
	Belyando	Belyando floodplain (22)
		Carmichael River (23)
		Fox Creek (24)
		Mistake Creek (25)
		Native Companion Creek (26)
		Sandy Creek (27)
	Cape Campaspe	Upper Belyando River (28)
		Campaspe River (18)
		Cape River (19)
		Lower Cape River (20)
	Suttor	Rollston River (21)
		Diamond Creek (29)
		Logan Creek (30)
		Lower Suttor River (31)
		Rosetta Creek (32)
		Sellheim River (33)
	Bowen	Upper Suttor River (34)
		Bogie River (35)
		Bowen River (36)
		Broken River (37)
		Glenmore Creek (38)
		Little Bowen River (39)
		Pelican Creek (40)
		Rosella Creek (41)
Don	Don	Upstart Bay (48)
		Abbott Bay (49)
		Don River (50)

Figure 2.3. The Burdekin WQIP region showing the 8 major areas used as the primary management units in the WQIP, and the 52 sub-catchments.

Catchment	Sub-catchment NUMBER (SC #)	Sub-catchment NAME
UPPER BURDEKIN Catchment	1	Allingham Creek
	2	Basalt River
	3	Burdekin River (above Dam)
	4	Burdekin River (Blue Range)
	5	Camel Creek
	6	Clarke River
	7	Douglas Creek
	8	Dry River
	9	Fanning River
	10	Gray Creek
	11	Hann Creek
	12	Keelbottom Creek
	13	Kirk River
	14	Lolworth Creek
	15	Running River
	16	Star River
	17	Upper Burdekin River
CAPE CAMPASPE Catchment	18	Campaspe River
	19	Cape River
	20	Lower Cape River
	21	Rollston River
BELYANDO Catchment	22	Belyando Floodplain
	23	Carmichael River
	24	Fox Creek
	25	Mistake Creek
	26	Native Companion Creek
	27	Sandy Creek
	28	Upper Belyando River
SUTTOR Catchment	29	Diamond Creek
	30	Logan Creek
	31	Lower Suttor River
	32	Rosetta Creek
	33	Sellheim River
	34	Upper Suttor River



Catchment	Sub-catchment NUMBER (SC #)	Sub-catchment NAME
BOWEN BROKEN BOGIE Catchment	35	Bogie River
	36	Bowen River
	37	Broken River
	38	Glenmore Creek
	39	Little Bowen River
	40	Pelican Creek
	41	Rosella Creek
LOWER BURDEKIN Catchment	42	Barratta Creek
	43	Burdekin Delta
	44	Burdekin River (below dam)
	45	Haughton River
	46	Landers Creek
	47	Stones Creek
DON Catchment	48	Upstart Bay
	49	Abbott Bay
	50	Don River
TOWNSVILLE COASTAL PLAIN Catchment	51	Black River
	52	Ross River

Discharge from rivers and creeks in the Burdekin Region is characterised by seasonal pulses of water that are associated with wet season rains (event flows). Rapid runoff generated by intense rainfall on sparsely vegetated terrain generates high-magnitude, short-duration discharge events. Widespread soil erosion and the export of eroded material, including suspended sediment and particulate nutrients, into the Burdekin catchments and GBR have occurred historically and are continuing today. It is estimated that the export of suspended sediments and particulate nutrients to the GBR from the Burdekin Basin has increased six - fold since European settlement (derived from Waters et al. in review) and it is believed that these increases are reducing water quality and contributing to a decline in the health of coral reef ecosystems (see Coppo and Brodie, 2015; synthesis in Schaffelke et al. 2013). The Burdekin Basin is by far the major contributor to discharge in the region. The period from 2008 to 2012 represented a very wet period for the region, with several wet season discharges above the long term median for all of the major rivers (Table 2.2).

Table 2.2. Total wet season freshwater discharge (in ML per wet season, c.a. 1 November to 30 April) and the long-term (LT) median (c.a. from 1970-1971 to 1999-2000) for major gauged rivers in the Burdekin NRM region. Colour code: yellow 1.5 to 2 fold LT median; orange 2 to 3 fold LT median; red >3 fold LT median. Data supplied by the Department of Natural Resources and Mines (Queensland Government, <https://www.dnrm.qld.gov.au/water/water-monitoring-and-data/portal>). Source: Devlin et al. (2014).

River	Wet season long term freshwater discharge (ML)						
	Wet season long term median (ML)	2008 - 2009	2009 - 2010	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014
Black	44,391	295,934	140,705	334,160	167,434	41,904	99,478
Ross	20,719	230,202	143,836	242,779	147,173	30,443	125,630
Haughton	161,892	1,091,350	476,006	1,019,119	660,221	191,654	229,562
Burdekin	4,669,849	29,091,190	7,661,648	33,885,815	14,333,639	3,110,624	1,162,570
Don	51,062	229,896	127,202	785,986	197,426	151,384	85,851

Discharge exhibits high intra and inter annual variability. The historical discharge records for the Burdekin River (at Home Hill / Clare) highlight the extreme variability of the Burdekin River system discharge, illustrated in Figure 2.4. Average values of Burdekin River discharge poorly characterise the flow regime because of the extreme variability.

Mitchell et al. (2007) estimate that, on average, approximately 50 per cent of the water exported from the Burdekin mouth is derived from the Upper Burdekin catchment. The other five catchments in the Burdekin Basin (Belyando, Suttor, Cape, Bowen Broken Bogie and Lower Burdekin) each contribute around 10 per cent to the total discharge at the end of the Burdekin River. However, there is high variability in the relative contributions of the different basins between years (refer Lewis et al. 2015). Statistical analysis of Burdekin River discharge over the period 1987-2000 (Mitchell et al. 2006) identified that (i) the concentrations of suspended sediment and particulate nitrogen and phosphorus increase proportionally to the rate of river discharge; and (ii) disproportionately high loads of suspended sediment and particulate nitrogen and phosphorus are apparent following abnormally dry years. These two sources of variability need to be considered when assessing trends over time to enable comparisons between years or with model results to be interpreted correctly (Mitchell et al. 2006).

The Burdekin Falls Dam, completed in 1987, is located upstream of the Bowen Broken Bogie catchment and collects discharge from the Upper Burdekin, Cape Campaspe, Belyando and Suttor catchments. The Burdekin Falls Dam is traps around 65 per cent of incoming suspended sediments and particulate nutrients during wet season event flows (Lewis et al. 2013a; Bainbridge et al. 2007, 2008a, 2014, 2016). It is also evident that the fine (<16 µm) sediment fraction is the dominant particle size transported through the impoundment (Bainbridge et al. 2016) (see Section 3.1). The bulk sediment load to the coastal floodplain and wider coastal (GBR) environment is also reduced (Lewis et al. 2013a).

The dam significantly changes downstream flows and water quality outside of the flooding periods. These base flows are elevated (and more constant) to provide for irrigation demand and have created a constantly wetted margin, which has been colonised by dense recruitment of melaleuca seedlings and sedges (DEHP, 2016). The water also tends to be more turbid than they would under natural conditions (Davis et al. 2014), which presents an ongoing challenge for local water board and infrastructure maintenance. This elevated turbidity has resulted in a reduction in aquifer recharge rates and capacity, and increased pressure to move toward surface water supply of alluvial aquifer recharge (DEHP, 2016).

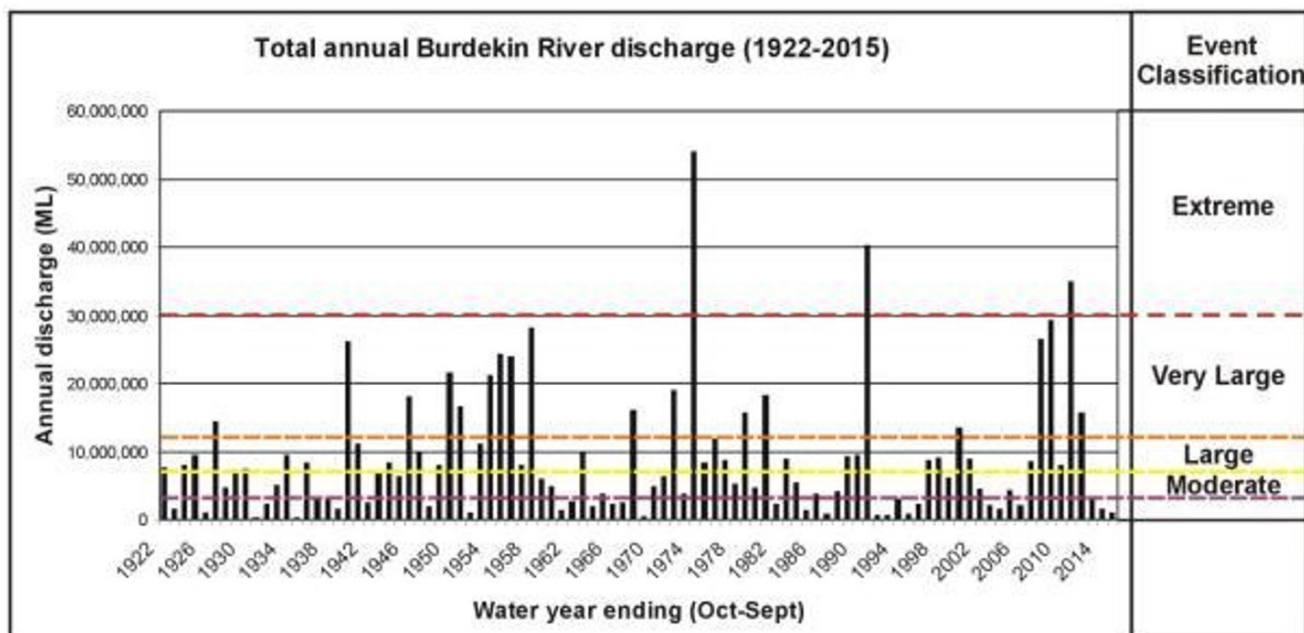


Figure 2.4. Annual and event discharge records for the Burdekin Basin with annual and event size classifications (classified in Lewis et al. 2006). Updated from Bainbridge et al. 2007 - based on flow data provided by DNRM, 2015).

Further documentation of the current understanding of the hydrological and ecological function of the catchments in the Burdekin Region has commenced through the 'Walking the Landscape' process developed by the Queensland Wetlands Program (DEHP, 2016). The process started with the Lower Burdekin catchment and was structured by questions relating to understanding of the system components (parts) and process, identification of freshwater, estuarine and marine wetland and catchment values, and the pressures (risk to values). This fundamental system understanding is very relevant to the WQIP, as system processes can have a significant bearing on water quality management options and choices.

The next phase of the process will address questions related to opportunities for management and the potential for reinstatement of values, e.g. restoration of connectivity, water quality improvement which is yet to be completed, and will be extended to other catchments in the Burdekin Region.

Important system processes for the Lower Burdekin catchment are considered in relation to sugarcane management which occurs in this area.

2.1.4 Natural assets relevant to the WQIP

The Burdekin Region has a variety of important natural assets that include groundwater dependent ecosystems, surface water, freshwater rivers, creeks and streams, wetlands, estuaries, coastal and marine systems.

Groundwater Dependent Ecosystems

Groundwater plays an important ecological role in directly and indirectly supporting terrestrial and aquatic ecosystems. Groundwater sustains terrestrial and aquatic ecosystems by supporting vegetation and providing discharge to channels, lacustrine and palustrine wetlands, and both the estuarine and marine environment. Aquifer ecosystems are inherently groundwater dependent (Queensland Government, 2014a).

Groundwater dependent ecosystems (GDEs) are ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011).

The Burdekin Region has four types of groundwater dependent ecosystems; alluvia, fractured rocks, permeable rocks and sedimentary rocks (Great Artesian Basin).

Environmental Values identified for groundwater are discussed in Section 4.1.1.

Wetlands, coastal and marine ecosystems

Coppo and Brodie (2015) have reviewed the status and trends, and threats to wetlands, coastal and marine ecosystems in the Burdekin Region.

Fourteen coastal ecosystems have been identified as important to the functioning of the GBR: coral reefs, lagoon floor, islands, open water, seagrasses, coastline, estuaries, freshwater wetlands, forested floodplain, heath and shrublands, grass and sedgeland, woodlands, forests and rainforests (GBRPM, 2012).

Wetlands are valuable for the environment, food, culture and help support Queensland's primary industries by providing nursery grounds for some species of fish and seafood to grow (Queensland Government, 2014a). Wetlands are also diversity hotspots for plants and animals, including threatened animals and aid in the connection of the landscape to allow animal and plant species to move and spread from place to place to maintain their populations (Queensland Government, 2014a). Some wetlands provide water for irrigation and farm animals and can be natural, artificial (ring tanks and dams), or a mixture of both (Queensland Government, 2014a).

The region includes Bowling Green Bay (346 square kilometres), a Ramsar-listed wetland of international significance, and 12 coastal wetlands of national significance. There are at least 4,970 lacustrine and palustrine wetlands located throughout the region and, of these, approximately 1,500 are located along the coastal catchments. These wetlands provide habitat for internationally and nationally important shorebirds, waterbirds, waders and seabirds particularly in the vicinity of the Bowling Green Bay Ramsar wetlands. Two species are considered Critically Endangered; Curlew Sandpiper and Eastern Curlew, three Near Threatened; Beach Stone-Curlew, Black-tailed Godwit and Grey-tailed Tattler and one Vulnerable; Great Knot. The Ramsar site seasonally supports both a wide variety of waterbird species, together with significant numbers. The site supports the largest populations of breeding and feeding brolgas (4,000) and magpie geese (10,000) in north-east Queensland. Of the 224 bird species known to occur in the site, 103 are known to breed within the site and at least 19 roosts have been identified. Approximately 30 species are listed under several international agreements (JAMBA, CAMBA and ROKAMBA) and the Bonn Convention.

The Burdekin Region contains extensive estuarine systems (mangroves, saltmarsh/saltflats and intertidal flats) which provide important habitat for many coastal and marine species. The region includes four declared Fish Habitat Areas: Bohle River, Cleveland Bay, Bowling-Green Bay and Burdekin with a total area of 187,491 hectares that includes many of the estuaries of the region and a significant area of the coast.

There are approximately 3,000 square kilometres of coral reefs in the region with approximately 340 hard coral species, 60 genera of soft corals and 1,500 species of fish. Reefs in the Burdekin Region (~20°S), together with reefs in the Far Northern region (~14°S), exhibit the highest hard coral species richness on the GBR. All reefs in the region are within the Great Barrier Reef Marine Park (GBRMP) and zoned General Use, Habitat Protection, Conservation Park, Marine National Park or Preservation Zones.

Seagrasses are a key ecosystem within the Burdekin Region supporting populations of dugong, turtle, seabirds and fisheries of commercial and recreational importance. A composite of seagrass monitoring surveys since 1985 indicates that there are 551 square kilometres of shallow seagrass areas (<15 m depth) in the region, which represent 45 per cent of the total shallow seagrass area in the GBR (excluding the Cape York region). No estuarine or deep water seagrass communities are monitored in this region, however, they are considered to be present.

The most significant species of conservation concern in the Burdekin Region are dugong, cetaceans, turtles and seabirds. The region includes four Dugong Protection Areas; Cleveland Bay, Bowling Green Bay, Cape Upstart Bay and part of Edgecumbe Bay. High priority cetaceans in the region include the humpback whale (vulnerable), dwarf minke whale (No Category Assigned (NCA) - insufficient information), Australian snubfin dolphin (NCA - insufficient information) and the Indo-Pacific humpback dolphin (NCA - insufficient information). The Australian snubfin dolphin and Indo-Pacific humpback dolphin are coastal species that are particularly vulnerable to water quality decline and populations are known to inhabit Cleveland Bay.

Five of the world's seven sea turtle species are likely to occur in the Burdekin Region. Scattered and periodic nesting of Flatback Turtles occurs on mainland and inshore islands between Townsville and Torres Strait. Cleveland Bay is considered an important foraging grounds and juvenile habitat for Green Turtles.

2.1.5 The people

The region has a population of approximately 240,000 people, predominantly located in the Greater Townsville area, Ayr, Home Hill, Bowen and Charters Towers. The population has grown approximately 20 per cent since 2005, and the Queensland Statistician's Office has predicted a regional population growth of approximately 50 per cent in the region over the next 20 years (Table 2.3). As urban areas and services expand, they are likely to encroach into rural lands and natural environments. Away from the main population centres the region is very sparsely populated, with most rural areas experiencing population decline. Approximately five per cent of the population is indigenous, with 16 recognised Traditional Owner groups.

The economy of the region is heavily reliant on natural resource dependent industries, particularly agriculture, which is by far the most important employer in the rural areas of the region. The estimated gross value of agriculture in the Burdekin region in 2012-13 was \$920 million (Australian Bureau of Statistics, 20143). There is a great diversity of agricultural enterprises across the region, with extensive grazing, sugarcane, horticulture, and both irrigated and dryland grain cropping. Other major industries include mining, metals refining (three major refineries on the coastal plain adjacent to Townsville) and aquaculture. Coal and gas industries and associated infrastructure are still being developed and are projected to boost population and economy while increasing pressures on water quality.

The GBR also provides substantial economic benefits to the Burdekin Region. It is difficult to distinguish the value of the GBR in the Burdekin Region from that of the whole GBR, however, this has been attempted to support the cost benefit analysis presented in Section 6.1.2 (Thomas and Brodie, 2015). Market value estimates of the economic contribution of three major reef-based industries were refined based on estimates provided in Deloitte Access Economics (2013) report and the peer-reviewed literature. The total tourism value-added estimate for the GBR Marine Park is \$5,175.4 million per year (Deloitte Access Economics, 2013). This value includes associated indirect income from tourism to the regional economy; the direct economic contribution of tourism in the Burdekin Region is estimated to be around \$29 million per year. Deloitte Access Economics (2013) estimates commercial fishing as the gross value product (2010-11) of line, pot, net and trawl fisheries, harvest, and aquaculture. The total annual gross value of production for commercial fishing businesses in the Burdekin Region in 2011-12 was \$66 million and the value of recreation was estimated to be \$81 million per year (Deloitte Access Economics, 2013). The total market value estimates (2011-12) of the economic contribution of the three main reef-dependent industries to the Burdekin Region (via direct value-add) and Australian (via indirect value-add) economies is \$176 million per year (Thomas and Brodie, 2015).

The Deloitte Access Economics (2013) report does not estimate non-market values associated with the GBR. It is not uncommon for non-market values to be considered more important than use or market values (Windle and Rolfe, 2006; Marré, 2014). However there are only two studies on the GBR's non-market values; Hundloe et al. (1988, cited in Stoeckl et al. 2011) estimate a non-use value of coral to 'vicarious users' of \$45 million per annum, and Windle and Rolfe (2006) report marginal values (the value of a one unit change) for different regional NRM improvements to soil condition, waterways and vegetation of between \$2.88 and \$5.80 for each one per cent improvement. Stoeckl et al. (2014) assess the total commercial (market) and wellbeing (quality of life) value of the entire GBR to be between \$15 billion and \$20 billion per annum, and while it is difficult to apply this at a regional scale, it demonstrates the high economic value of the GBR.

These are important issues for consideration when seeking to find a balance between land use and its impact on the broad range of regional values including other industries.

Table 2.3. Predicted population grown for the Burdekin region. Source: Queensland Statisticians Office, 2014.

Locality	Population (2014?)	Predicted Population, 2034
Townsville City Council Local Government Area	180,114	314,362
Charters Towers Regional Local Government Area	12,434	12,459
Burdekin Shire Council Local Government Area	17,775	19,467
Bowen Statistical Area Level 2	9,097	13,596
Collinsville Statistical Area Level 2	4,142	5,892
Palm Island Local Government Area	2,617	3,460
Jericho 2011 Statistical Local Area	965	

2.1.6 Land use

Land use in catchment areas adjacent to the GBRWHA has undergone extensive modification over the last 150 years since European settlement. This has led to significant increases in sediment, nutrient and chemical loads running off the land into the rivers and waters entering the GBR lagoon (e.g. Kroon et al. 2013; Waters et al. 2014, in review; Lewis et al. 2015). The main drivers of this change in land use and water quality have been identified as land clearing, extensive and intensive agricultural development, irrigation, urban and peri-urban settlements, and industrial development (GBRMPA, 2014a, 2014b). Runoff containing sediment, nutrients and pesticides from agriculture is viewed as the most important water quality threat to the health of inshore ecosystems of the GBRWHA (see Brodie et al. 2013a; GBRMPA 2014a, 2014b).

Land use characteristics of the Burdekin Region are shown in Table 2.4, and mapped in Figure 2.5. The spatial distribution of land uses across the region is also represented in Figure 2.6 (Basins) and (Catchments). The dominant land use in the Burdekin Region is extensive grazing of native pastures which accounts for approximately 90 per cent of the area (12,600,000 hectares) and contributes a large proportion of the soil erosion. The major intensive agricultural land uses in the region are sugarcane (90,000 hectares) in the coastal Lower Burdekin catchment and dryland cropping predominantly in the Suttor catchment (126,000 hectares). Currently, the Lower Burdekin is the largest sugar producing region in Australia; about 8.1 million tonnes of sugarcane are grown from which around 1.2 million tonnes of raw sugar is produced annually (Canegrowers, 2016a). Sugarcane from the area in 2010–11 was worth \$227.3 million (DAF, 2014).

Horticultural crops (~14,000 hectares) are also grown in the coastal areas, primarily in the Don Basin near Bowen. However, Lower Burdekin sugarcane farmers commonly (and increasingly) grow horticultural crops and cotton as part of a mixed commodity farming enterprise. Diversification of crops on sugarcane farms is likely to include a range of horticultural crops, plus rice and cotton in the future.

The region's cropping areas are heavily reliant on extraction of surface and groundwater for irrigation which has led to significant modification of the hydrology in the region (GBRMPA, 2012). These modifications have had flow on effects for system function and connectivity between the catchment and the coastal and marine areas.

The landscapes of the region also support a substantial mining industry which produces coal, mainly in the Bowen Broken Bogie and Belyando catchments, gold, silver and zinc in the Upper Burdekin and silver in the Suttor catchment. There are approximately 44 major mining sites currently operations in the region and 22 planned mines under assessment (DNRM Mines Online database – accessed 2015). Mining has also left an extensive 150 year legacy of impacts and risks associated with around 2,400 mine sites that are abandoned and in various stages of rehabilitation.

Urban expansion is occurring around the main regional centre of Townsville and may occur at new major mine sites. In addition to urban expansion there also continues to be aspirations to expand agricultural development throughout the catchment in the Lower Burdekin (cropping and aquaculture), Don (horticulture), Upper Burdekin (Pentland), Belyando and Suttor (via water harvesting), and Bowen (Urannah and Collinsville) areas (NQ Dry Tropics, public workshop consultation on NRM Planning issues, 2015).

While much of the growth in the agricultural sector is initially expected to take place in the Lower Burdekin irrigated cropping district (e.g. Marsden Jacobs Associates, 2013; Queensland Agricultural Land Audit, 2014), medium to longer term growth can also be expected in the Belyando and Suttor catchments, Charters Towers area and Cape River (Pentland bioethanol project). The horticultural industry in the Don River catchment near Bowen is also predicted to expand greatly in the medium and long term. The Burdekin Dam provides unique opportunities to accommodate expansion and diversification; however, it also has a number of high-profile constraints around the allocation of water resources and downstream impacts including issues with rising watertables, saltwater intrusion and pollutant runoff (Queensland Agricultural Land Audit, 2014). Only half of the water available for irrigation in the Burdekin Dam has been allocated to date (Commonwealth of Australia, 2015b).

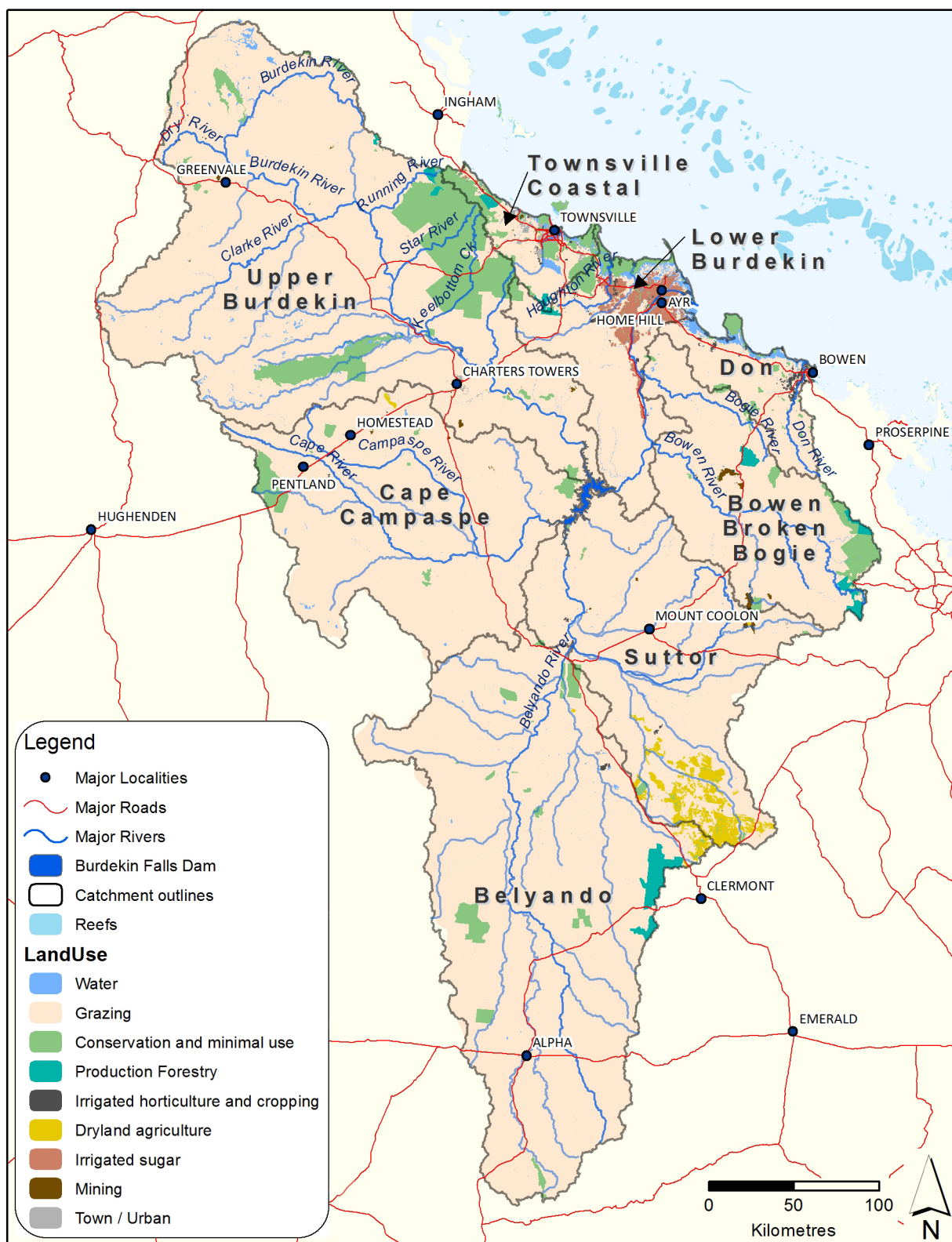


Figure 2.5. Land use in the Burdekin NRM region. Source: Derived from QLUMP land use mapping.

Catchment	Land use area (hectares)										Total
	Grazing	Sugarcane	Horticulture	Dryland Cropping	Irrigated Cropping	Urban	Conservation	Forestry	Other	Water	
Black	49,373	1,204	786	2	0	3,432	40,629	5,595	1,034	1,998	104,052
Ross	87,782	0	976	14	215	12,249	40,441	4,539	7,062	11,432	164,711
Houghton	239,703	74,640	3,187	116	2,785	2,126	61,640	3,218	1,405	24,419	413,239
Burdekin	11,950,139	22,857	330	125,808	5,387	5,387	678,558	83,029	18,890	115,757	13,005,970
Don	299,937	6,057	8,890	25	2,196	1,874	25,722	39	1,438	26,082	372,260
Total	12,626,934	104,759¹	14,168	125,965	10,411	25,067	846,990	96,421	29,829	179,687	14,060,231

¹ Note that the industry estimate is around 90,000ha.

Table 2.4. Estimated land use by area (hectares) in the Burdekin region (based on QLUMP 2009 data used in Source Catchments). Source: Dougall et al. (2014).

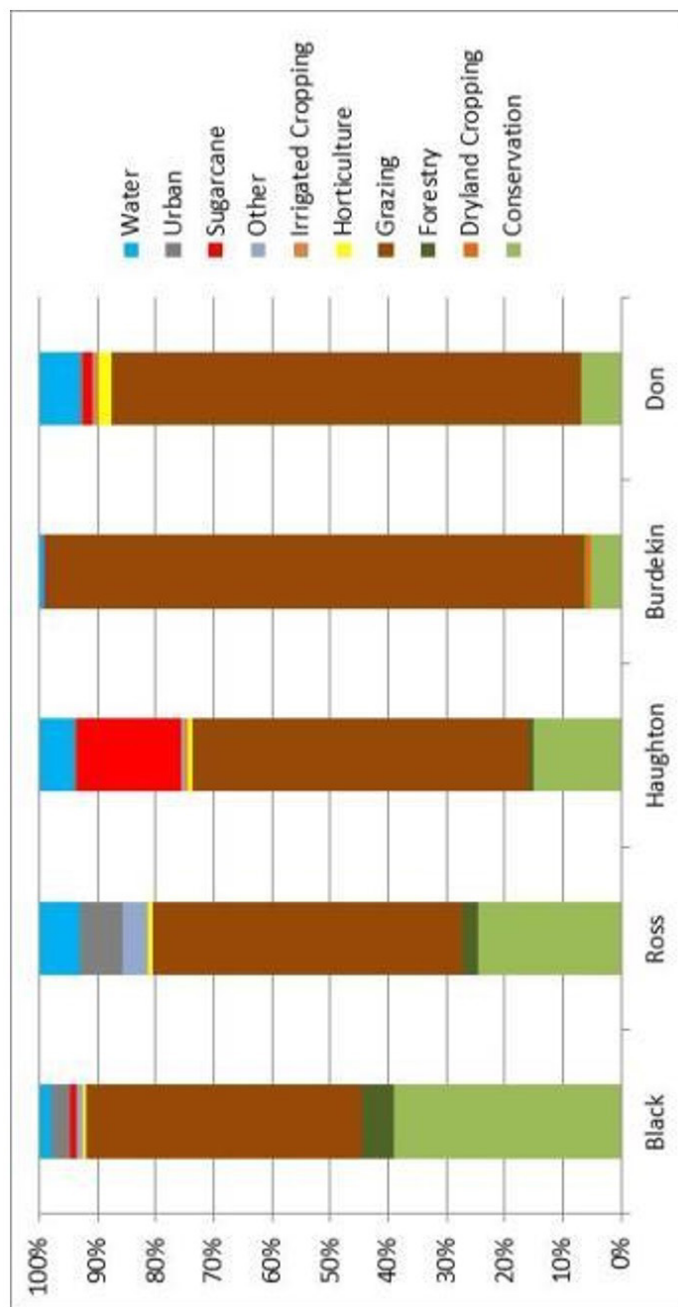


Figure 2.6. Land use characteristics in each Basin, showing the proportion of the area of each Basin in each land use. Source: Derived from Waters et al. (in review).

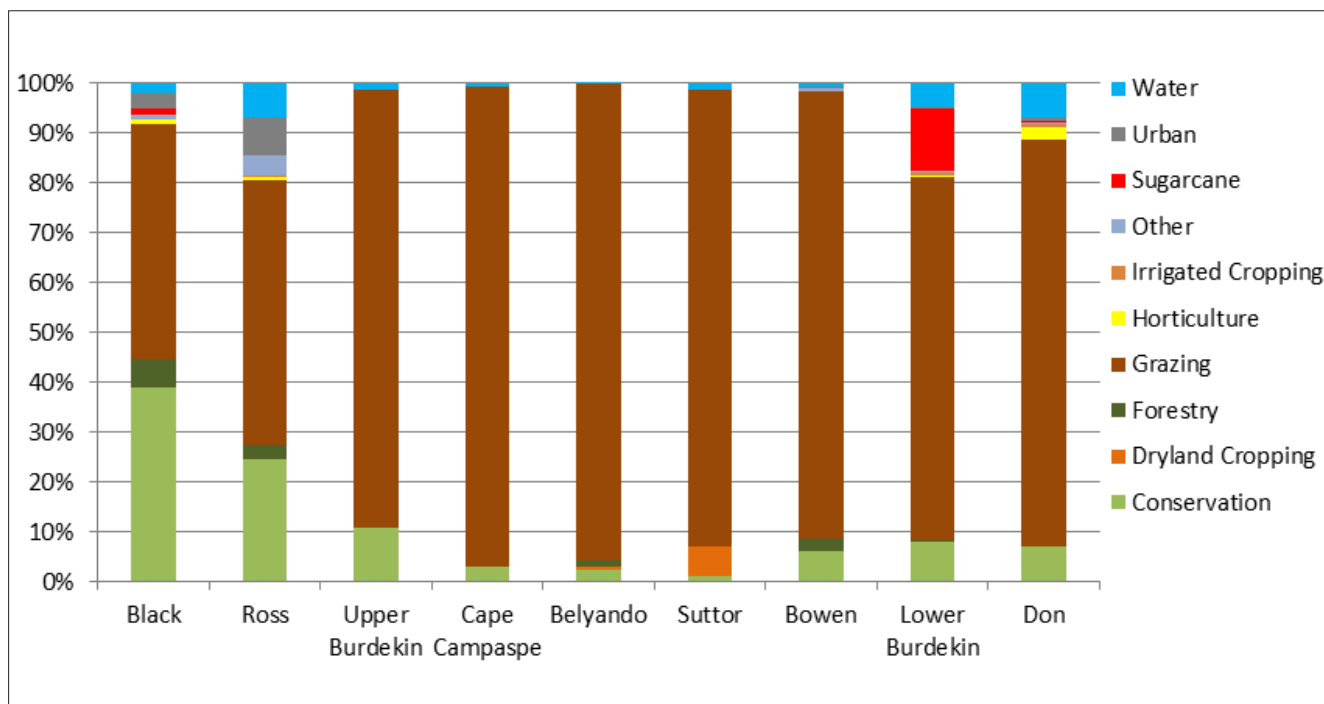


Figure 2.7. Proportion of land use in each catchment in the Burdekin NRM region. Source: Derived from QLUMP 2009 data. (Note: The Upper Burdekin, Cape Campaspe, Belyando, Suttor and Bowen catchments are in the Burdekin Basin, and the Lower Burdekin spans the Burdekin and Haughton Basins.)

2.2 Status of the Burdekin waterways and receiving waters

2.2.1 Coastal groundwater systems

Groundwater in the Burdekin Region and the Lower Burdekin catchment in particular, provide many services to ecosystems and industries in the region. The Burdekin coastal floodplain groundwater systems underlie a geographic area of about 1,600 square kilometres. The typical inland extent of the seawater wedge beneath the floodplain is estimated to occur where the groundwater table in the Lower Burdekin is 2 metres above mean sea level (Fass et al. 2007). In general, groundwater flows north toward the coast; however large fluctuations in groundwater levels due to extraction of large volumes of groundwater over many years and enhanced recharge of irrigation water make it difficult to construct and predict past and present groundwater flow paths.

Rising groundwater levels have been observed in areas since the inception of the Burdekin Haughton Water Supply Scheme (BHWSS) in the late 1980s. Shaw (1989) reviewed the likely response of the groundwater on the right and left banks of the Burdekin based on a salt and water movement model and concluded that problems with shallow watertables and salinity will undoubtedly occur in the irrigation area. Figure 2.8 shows the depth to groundwater in the Lower Burdekin area in October 2012. A considerable portion of the BHWSS area and the larger Burdekin Groundwater Management Area has a shallow groundwater mound less than 5 metres below ground level. Some of the Leichhardt section has much shallower levels than portrayed by the contours due to lack of inclusion of some bore data and the boundary conditions of the contouring algorithm. During the dry season, floodplain groundwater levels exceed surface water levels on both sides of the river up-stream of 'The Rocks' (Cook et al. 2004). During wet season high flow events, river water levels are higher than floodplain groundwater, resulting in a reversal in the direction of flow from the river to the groundwater. Similar changes now also occur into Barratta Creek downstream of Brown Road, where groundwater elevation is around 15 metres AHD and the bed of Barratta Creek is about 11 metres AHD (Shannon and McShane, 2013).

Groundwater quality issues in the Lower Burdekin include salinity, sodicity (a high proportion of sodium relative to calcium and magnesium which significantly affects soil properties) (Shaw, 2014) and elevated concentrations of nitrate and pesticides (Bristow, 2016).

The Burdekin groundwater management area has shown areas of increased groundwater salinity and sodicity since regular monitoring was introduced in the 1960s (Shaw, 2014), although there is high variability in these results between bores. In a detailed analysis of individual bores salinity is increasing in 44 per cent of bores, and 43 per cent of all bores have very high salinities; >3000 $\mu\text{S}/\text{cm}$ (Barnes et al. 2005). Of the remaining bores, some show a decrease in groundwater salinity and some show greatly fluctuating levels of salinity. The lowest salinity groundwater is found adjacent to the Burdekin River and within palaeochannels dissecting the floodplain (Figure 2.9). Tidal and near-shore marine sediments deposited during

Pleistocene and Holocene high sea level stands contain highly saline groundwater (Cl- 20,000–80,000 mg/l) up to 15 km inland.

There are limited data on pesticides in groundwater in the Lower Burdekin. Shaw et al. (2012) conducted a study of pesticides in groundwater in the Lower Burdekin showed that pesticides were present at detectable levels in 38 per cent of groundwater samples taken from bores in the Burdekin River Delta and BRIA. Four herbicides (atrazine, diuron, hexazinone and metolachlor) and two breakdown products of the herbicide atrazine (desethyl atrazine, desisopropyl atrazine) were detected in at least one of the 53 groundwater samples. The organophosphate insecticide, chlorpyrifos was detected in two of the groundwater bores sampled. The breakdown products of atrazine were the most commonly detected compounds, followed by atrazine itself.

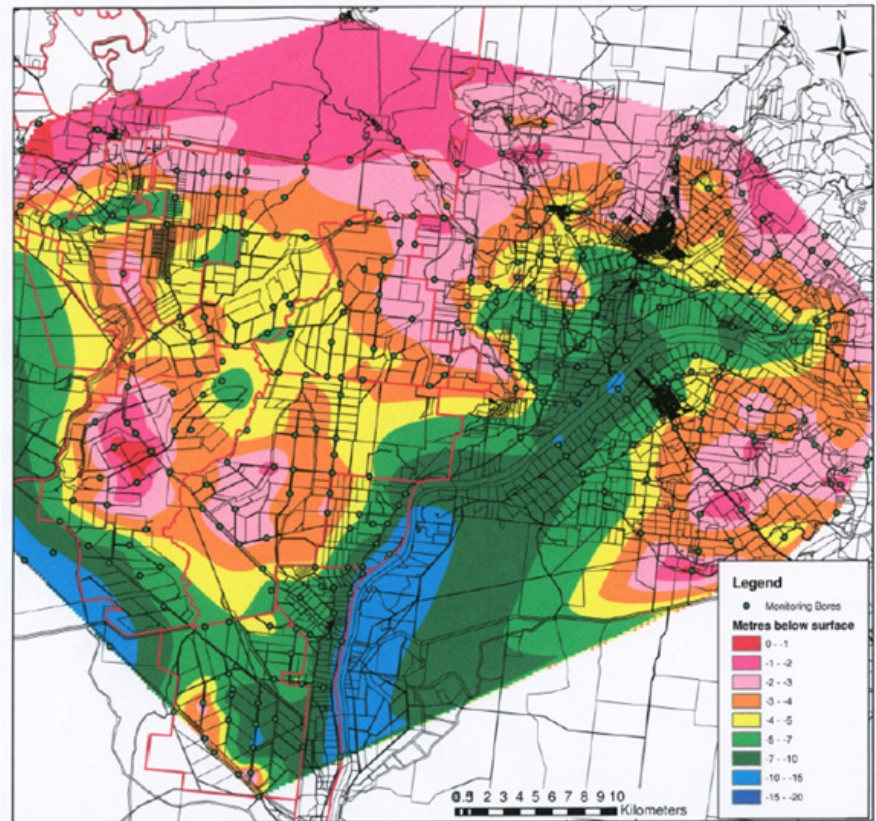


Figure 2.8. Lower Burdekin depth to groundwater in October 2012. Map produced by DNRM, 2012.

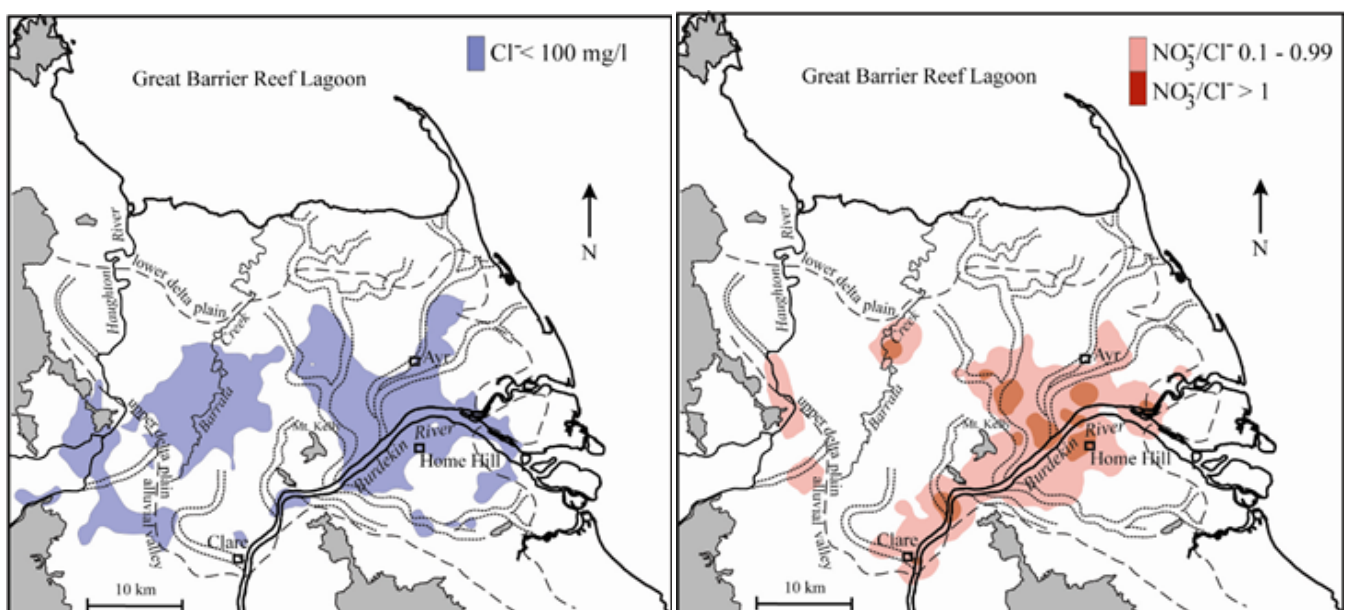


Figure 2.9. Location of fresh (Chloride (Cl-) < 100 mg/l) groundwater (left), and elevated nitrate (NO₃-)/Chloride (Cl-) mass ratios (right) in relation to the Burdekin River and Holocene palaeochannel network described by Alexander and Fielding (2006). Reproduced from Lenahan and Bristow, (2010). A net increase in nitrate concentration has been measured within the groundwater systems between 1985 and 2003, with 21 per cent of bores with statistically significant rising nitrate levels, and 13 per cent of bores with elevated nitrate levels (>20 mg/L). Source: (Barnes et al. 2005).

In a more recent study across the Lower Burdekin catchment (Vardy et al. 2015) found that concentrations of pesticides were present in the groundwater at all sites but were generally low, apart from the transect area of Barratta Creek at Northcote. This site showed a large temporal variation in pesticide concentration with peaks in concentrations following a flood event at the end of January 2013. This, along with a large decrease in specific conductivity following the flood event indicated that lateral exchange with the creeks surface water may be occurring. The pesticide concentrations decreased in these bores over a period of two months after the flood. Groundwater loads were estimated at Barratta Creek at Northcote and Burdekin River at Clare. The overall contribution of groundwater to the loads of pesticides, nitrates and phosphate at these sites were low during the study period. However, the contribution of ammonia from groundwater to ammonia loads was significant.

It is recognised that these studies represent limited sampling events and do not represent the range of concentrations present in groundwater of the Lower Burdekin over time. It is recommended that this sampling be conducted on a regular basis at selected bores to track the concentrations of pesticides through the year relative to times of pesticide application. Ongoing sampling across multiple years would be required to provide insights into long term trends in pesticide concentrations in Lower Burdekin groundwater.

2.2.2 Catchment waterway health

The aquatic ecosystems of the region are diverse and in many cases, are under threat from human influences (Davis et al. 2016). Key threats to catchment waterways are associated with altered hydrology, loss of connectivity, loss and disturbance of habitat, decline in water quality and soil chemistry, introduction of pest species and removal of native species through activities such as fishing. The interaction of multiple processes and the overarching influence of climate change also pose considerable threat to waterways in the Burdekin Region. Some of these threats, such as fishing, are managed through legislative mechanisms while others, such as those associated with disturbance of habitat, can be addressed through local government and non-statutory regional planning processes.

The current status of water quality in the region has been assessed as part of the process to establish local water quality guidelines in some catchments (See Section 4.1). This is underpinned by the establishment of Environmental Values through community consultation. Both of these processes reflect the modification of the region's freshwater systems over the last few decades, leading to degraded water quality in many locations.

Palustrine wetlands are the most modified wetland types with the following proportions of pre-clearing vegetation remaining in 2001: Bowen Broken Bogie (26 per cent), Lower Burdekin (35 per cent), Don River (51 per cent), Haughton River (61 per cent) and Barratta Creek (67 per cent). For estuarine wetland systems, only 60 per cent of pre-clearing vegetation remained in 2001 in the Lower Burdekin River. The riverine wetland systems are also affected, but to a lesser extent with the following proportions of pre-clearing vegetation remaining in 2001: Bohle Creek (66 per cent), Barratta Creek (67 per cent), Don River (74 per cent) and Ross River (75 per cent) (Queensland Government, 2014a).

The freshwater and estuarine wetlands of the Lower Burdekin are recognised as comprising the largest concentration in eastern Australia and are reported to provide food resources and an essential habitat in the lifecycle of up to 70 per cent of local marine fishery resources (Veitch and Sawynok, 2005). These wetlands contribute to the health of adjacent GBR waters and coral reefs. Furthermore, the estuarine and marine areas of Halifax, Cleveland, Bowling Green, Upstart and Abbot Bays, which constitute the immediate receiving waters of the region, are part of the GBRWHA. Wetland extent is reported as part of the Paddock to Reef Program every four years. In the period between 2009 and 2013, no net loss of wetlands was reported in the Burdekin Region. However, understanding wetland condition and ecological function is important for maintaining the diverse values of these systems.

The high value wetlands within the Lower Burdekin in and adjacent to the Ramsar wetlands of Bowling Green Bay are significantly impacted upon by changes in the landscape, particularly those changes associated with hydrological processes and pollutant inputs (Davis et al, 2016; O'Brien et al. 2016). Consequently, the capacity for these wetlands to continue to provide the services so important to the GBR is limited, and now many of these areas act as permanently inundated conduits for bulk water supply and runoff from sugarcane farms. This has contributed to a decline in wetland condition, habitat fragmentation and significant loss of productive coastal grazing land as weed chokes spread across the landscape due to constant inputs of eutrophic water.

Wetland condition decline and in particular, weed infestation in the Lower Burdekin catchment, has been well documented in recent years (Perna and Burrows, 2005; Veitch and Burrows, 2007; Veitch et al. 2008). Many of these reports focus on natural deepwater or lacustrine wetlands which have been seen to decline during living memory, with floating aquatic weeds heavily blanketing the surface (Perna and Burrows, 2005). These floating mats of weed (water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*), water lettuce (*Pistia stratiotes*) and para grass (*Urochloa mutica*)) are thick enough in places to allow woody vegetation to establish and to support the weight of people and even motorcycles (GBRMPA, 2013). Fish passage and habitat values of these heavily weed impacted wetlands are severely degraded in some locations

(Perna and Burrows, 2005). Attached emergent and semi-aquatic weeds cause similar problems with exotic grasses such as olive hymenachne (*Hymenachne amplexicaulis*), aleman grass (*Echinochloa polystachya*) and the robust native herb cumbungi (*Typha domingensis* and *T. orientalis*) establishing first as dense stands in shallower water. These infestations alter plant and animal (especially waterfowl) habitat, create physical and chemical changes (low flow and dissolved oxygen) conditions, and may restrict fish passage in the same way as floating weed mats do (Veitch et al. 2008).

It is predicted that the rising groundwater levels close to the ground surface which result in capillary rise and loss of the un-saturated zone, will result in water logging and soil salinisation in significant areas of the Lower Burdekin floodplain within the next decade without immediate action to manage groundwater levels (Shaw, 2014). This is discussed further in Section 4.1.4.

2.2.3 Catchment condition related to water quality

Groundcover

Ground cover consists of the non-woody plant cover near the soil surface and all litter including woody litter. The level and type of ground cover is important for land management as it affects soil processes including infiltration, runoff and surface erosion. In the GBR catchments, low ground cover can contribute to increased sediment loads reaching the GBR (Queensland Government, 2009). Maintenance of ground cover is essential for sustainable production, especially in rangeland environments where rainfall is highly variable. Ground cover also plays an important role in protecting valuable soil resources from wind erosion, and contributes to nutrient cycling and to maintaining biodiversity. The amount and distribution of ground cover can change in response to climate, land or soil type and land management, especially grazing intensity. For example, above-average rainfall can result in above-average ground cover, which helps the soil resist erosion by minimising raindrop impact, improving water infiltration and reducing surface runoff.

Ground cover is measured and reported annually as part of the Paddock to Reef Program using satellite imagery and the fractional vegetation cover method described by Scarth et al. (2010). The method measures the proportion of green cover, non-green cover and bare ground using reflectance information from late dry season Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) and Landsat 8 Operational Land Imager (OLI) satellite imagery. These data are calibrated using field observations. The spatial resolution of Landsat imagery is approximately 30 metres. Total ground cover is given by summing the green and non-green cover fractions (Queensland Government 2009a). It is important to note that averaging ground cover across the whole Burdekin Region can mask localised areas of lower cover, particularly where there is a strong rainfall gradient. The mean ground cover reported is therefore indicative of general levels of cover within the reporting catchment. It is important to consider the spatial distribution of cover when accounting for its impact on sediment generation.

The late dry season ground cover in 2013-14 for the Burdekin Region was reported as 73 per cent; however, there were significant areas of low ground cover within the region which were drought declared (Queensland Government 2015). This indicator is on track to meet the Reef Plan target of a minimum of 70 per cent late dry season ground cover by 2018, however, it is likely that this will decline if the relatively low rainfall recorded in the region over the last 2 years continues. The regional trend for the mean late dry season ground cover is shown in Figure 2.11.



Figure 2.10. Average ground cover in the Burdekin Region, 2008 to 2014. Data supplied by T. Beutel (DAF) through the Paddock to Reef Program.

Tree cover (an element of ground cover) also has an important role in the cycling of nutrients and water. Trees play a significant role in the water cycle taking up groundwater and releasing it to the environment, often described as ‘nature’s water pumps’. Marrying rehabilitation of riparian or even larger marginal productive areas with potential tree crops with rising groundwater areas may also be part of the long term solution to rising groundwater levels (GBRMPA, 2013).

Soil erosion

A soil erodibility map and dataset for the whole of the Burdekin basin has now been developed (Zund and Payne, 2014) showing how vulnerable a soil is to erosion. The map splits soils into 17 categories in 90m pixels based on soil attributes that are key drivers of soil erodibility (e.g. soil texture, soil sodicity, salinity and cation balance). The overall inherent soil vulnerability layer (Figure 2.12) shows that the most extensive areas of highest risk in the Suttor, Belyando and Cape Campaspe catchments, with smaller but also intensive areas of high overall erosion risk in the Upper Burdekin and Bowen Broken Bogie catchments.

This map is useful for refining target areas for intervention and prevention measures aimed at reducing all forms of erosion including gully erosion. However, the data should be combined with other available information and knowledge such as slope, land use, climate data and land cover data to fully assess risk of soil erosion occurring. For example, areas with a high vulnerability to erosion are unlikely to be eroded if they have low grazing pressures and consistently high ground cover, whereas areas of low vulnerability can still erode under sufficient grazing pressure. Inherent vulnerability to erosion does not equal erosion outcome necessarily (Zund and Payne, 2014).

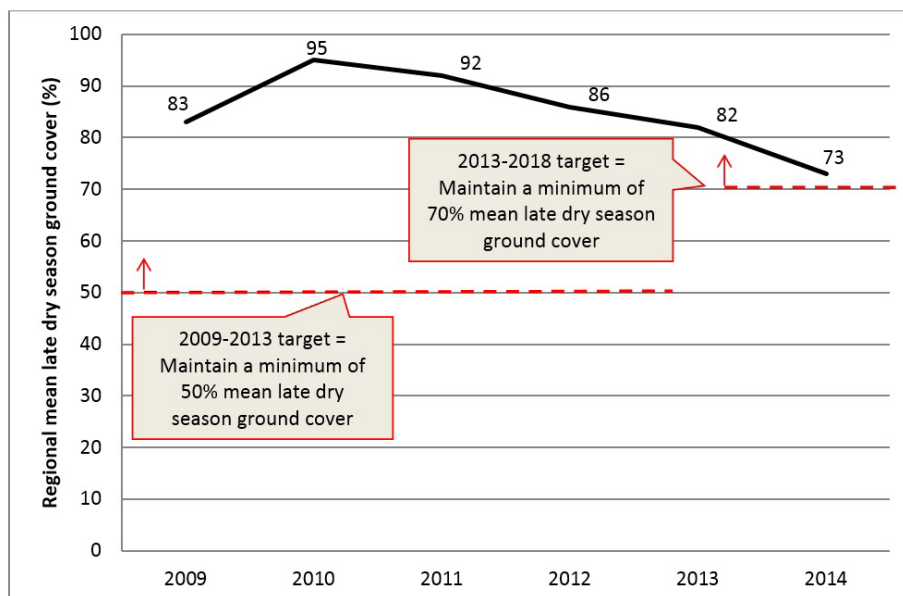


Figure 2.11. Regional mean late dry season ground cover in the Burdekin Region, 2009 to 2014. Source: Derived from Paddock to Reef Program reporting.

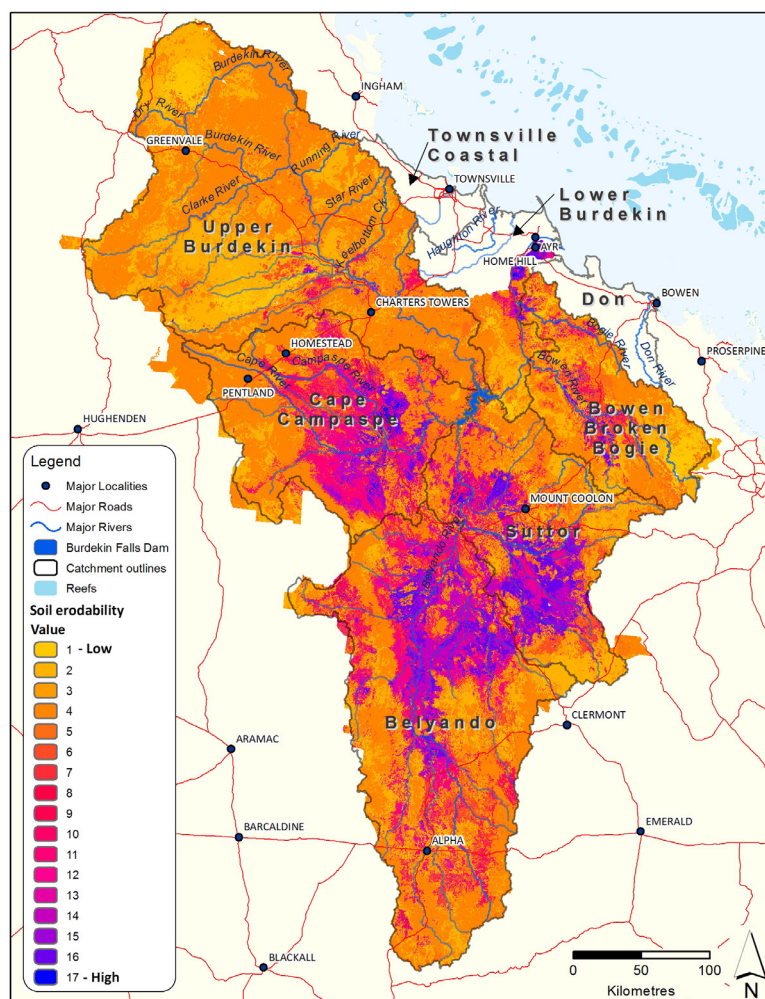


Figure 2.12. Overall inherent vulnerability to soil erosion in the Burdekin Basin, where soil erodability is classified from low (value = 1, yellow) to high (value = 17, blue). Note that the coastal catchments are not mapped. Source: Zund and Payne (2014).

Gully erosion

Gully features are the largest source of soil erosion in the Burdekin Region (see Section 3.1). The estimated contributions of gully erosion to Burdekin Region sediment export are documented in Wilkinson et al. (2015) showing that the Bowen Broken Bogie, Lower Burdekin (upper parts) and Don catchments have the highest contributions per hectare and per km of gully erosion relative to other catchments. This is supported by the most recent Source Catchments modelling (C. Dougall, DNRM). Environmental factors associated with gully frequency in the Burdekin Basin have been assessed, and suggest that lithology and soil data are the most useful predictors of gully erosion, and topographic data is also a moderately useful predictor of gully frequency (Bui et al. in review).

The current estimate of gully presence in the Burdekin Region is shown in Figure 2.13 (Tindall et al. 2014). Present records were based on visual assessment of high resolution satellite imagery and aerial photographs at test locations, along with subsequent predictive modelling for the remaining catchment. Gully presence was expressed in seven ordinal classes from very low to very high in 5km x 5km grid units. The mapping has not been completed for the coastal catchments. Using this data, it is estimated that 60 per cent of the Burdekin Basin has low or very low gully densities, and a large proportion of this area is in the Cape Campaspe and Belyando catchments and the southern half of the Suttor catchment. Only 3 per cent of the Burdekin Basin has high to very high gully density, with the majority of these areas are in the Upper Burdekin (54 per cent), Bowen Broken Bogie (22 per cent) and northern Suttor catchments (12 per cent). It is noted that most gullies occur within the first 1.5 metres elevation above drainage lines and gully changes tend to be episodic and event driven (Beutel et al. 2015).

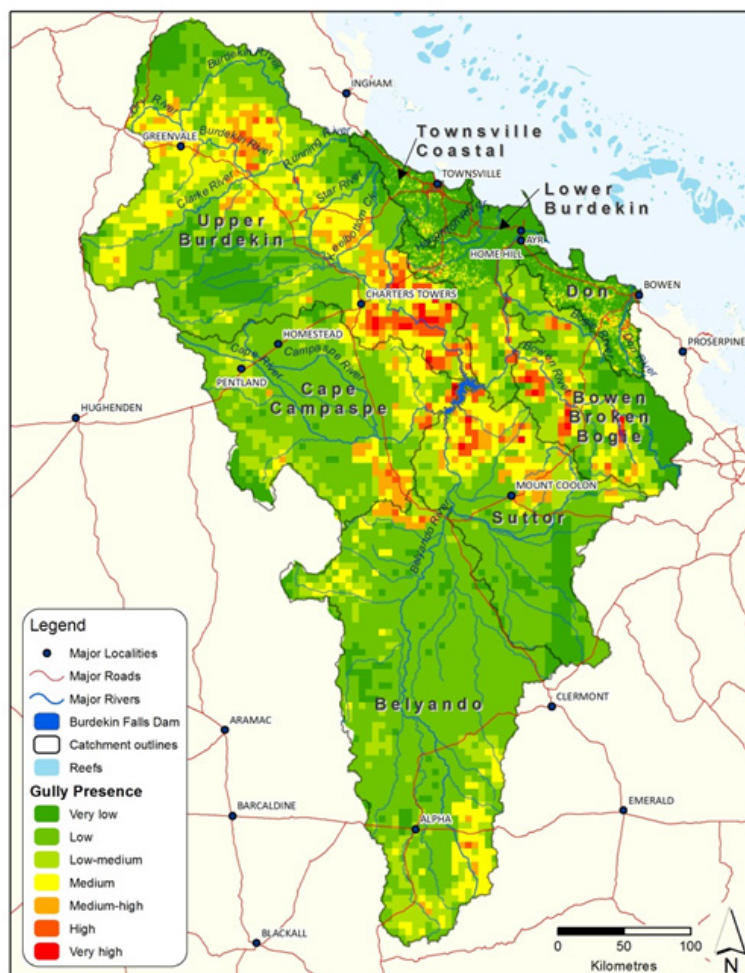


Figure 2.13. Gully presence mapping for the Burdekin Region.
Source: Tindall et al. (2014) and Darr et al. unpublished.

In an assessment of the areas most prone to gully erosion, Wilkinson et al. (2015) has identified that duplex soils classified as Chromosols were found to be most prone to gully erosion. The top layer is sandier than the subsoil, and the clay-rich subsoil impedes water infiltration into the deeper soil profile and thus promotes overland flow and lateral subsurface flow.

It is estimated that there are approximately 34,100 kilometres of gullies in the Burdekin Region (Wilkinson et al. 2015; Figure 4 based on Tindall et al. 2014, Darr et al. unpublished and NLWRA 2001; calculated using gully presence divided by 10 and multiplied by unit area). Analysis of the distribution between catchments shows that the Upper Burdekin catchment contains the greatest length of gullies (41 per cent), followed by the Don (12 per cent), Suttor (11 per cent), Belyando (9 per cent), Lower Burdekin coastal areas (9 per cent), the upper parts (East Burdekin) (2 per cent), Bowen Broken Bogie (8 per cent), Cape Campaspe (7 per cent), and the Ross and Black both less than 1 per cent.

Rill and scald erosion

Rilling and sheetwash erosion in scalded areas on hillslopes (degraded areas denuded of vegetation) are most extensive in the Belyando-Suttor catchments (Karfs et al. 2009), but also commonly surround gully networks in the Bowen (Wilkinson et al. 2013) and Upper Burdekin catchments (Bartley et al. 2010a, 2010b), where the rainfall erosivity and terrain slopes are higher than further inland from the coast.

Streambank erosion

Streambank erosion is considered to contribute ~20-40 per cent to end of catchment sediment loads in the Burdekin Basin (Hancock et al. 2013; Wilkinson et al. 2015; Waters et al. in review). However, it is not clear how much stream bank erosion has changed over time. Recent studies such as Brooks et al. (2014) suggest that the presence of woody vegetation, particularly on in-channel features is a major factor controlling bank erosion rates in Queensland rivers. In the Burdekin Basin, tree cover in riparian zones is largely intact in many areas (see below). Changes to the riparian zones in extensive rangeland areas have been more subtle, with riparian zones being influenced by stock access (grazing, trampling and compaction), weeds and feral animals, and not necessarily woody vegetation removal. In the more intensely farmed coastal areas, there are obvious and often dramatic changes to riparian zones. The Lower Burdekin was identified as a high priority catchment for further assessment of riparian zone impact and potential remediation (Bartley et al. 2014c). There is limited (<10 per cent) streambank erosion in the Belyando, Bowen Broken Bogie and Cape Campaspe catchments.

Riparian vegetation extent

The condition of riparian habitat has declined since the 1970s (when satellite imagery analyses were compared) in most of the Burdekin sub-catchments (Lymburner and Dowe, 2007) and currently varies greatly between catchments and sub-catchments. Significant deterioration can be seen to have occurred in the Cape Campaspe, Belyando and Suttor catchments in that period (Lymburner and Dowe, 2007). Many of the sub-catchments where the condition of riparian habitat was poorest in the 2007 assessments were also associated with high rates of stream bank and gully erosion.

The loss of riparian habitat since the 1970s is associated with a reduction in riparian ecosystem services that support healthy aquatic ecosystems (e.g. stream shading, leaf litter inputs, large woody debris generation, seed bank generation) and biodiversity (e.g. terrestrial habitat for reptilian, mammalian, and avian species (Lymburner and Dowe, 2007). The diversity of aquatic habitats and knowledge of their condition and ecology varies greatly between catchments and sub-catchments. Least is known about these attributes of aquatic health from the Belyando and Suttor catchments (Lymburner and Dowe, 2007; Maughan et al. 2007). The Upper and Lower Burdekin, and Bowen Broken Bogie catchments, where large permanent wetlands and waterholes, and perennially flowing rivers and streams are quite common, displayed the greatest diversity and ecological value of aquatic habitats in 2007 assessments (Maughan et al. 2007).

Riparian extent is reported as part of the Paddock to Reef Program every four years, with a selection of statistics presented in Table 2.5. It is estimated that 22 per cent of riparian forest in the Burdekin Region has been lost since pre-European conditions (Queensland Government, 2015). This varies between catchments with the highest losses in the Ross (34 per cent), Barratta Creek (32 per cent) and the upper parts of the Lower Burdekin (32 per cent). Note that the reporting boundaries used by the Paddock to Reef Program differ from the catchment boundaries used in this WQIP.

Current estimates of the total area of riparian forest and the riparian forest lost pre-clear to 2013 are shown in Figure 2.14. Current riparian forest extent in the region is greatest in the Black River catchment (excluding the Bohle River) (94 per cent), and areas of the Upper Burdekin (85 per cent), Bowen River (80 per cent) and Haughton River (74 per cent) catchments. The areas with lower riparian forest extent are Barratta Creek (57 per cent) and the Ross River (60 per cent). The Cape Campaspe, Belyando, Suttor, Don and upper parts of the Lower Burdekin catchments retain around 65-70 per cent riparian forest extent. The greatest losses in riparian forest extent between 1988 and 2013 have occurred in the area referred to here as the Bohle River catchment (~13 per cent) which is in the Black River Basin and around 11 per cent in the combined Cape Campaspe, Belyando and Suttor catchments. Losses in all other areas were less than five per cent.

In the most recent reporting period, between 2009 and 2013, it is estimated that approximately 0.3 percent (or 8,350 hectares) of riparian vegetation was lost in the Burdekin Region. Comparative losses in each four year reporting period are also shown in Figure 2.14. The greatest proportion of losses were reported in the Bohle River (1.2-3.6 per cent) in all periods, with the Don River showing comparatively larger losses between 2009 and 2013, however the absolute areas in these catchments are comparatively small overall.

Table 2.5. Riparian forest extent and losses in the Burdekin region. Data supplied by D. Tindall DSITI as an output of the Paddock to Reef Program. *Note that the boundaries differ from the catchments defined in this plan.*

Catchment	Catchment Area (ha)	Riparian Area (ha)	Riparian Area (%)	Riparian Forested Area (%)	Pre-Clearing-2013 Forest Loss (%)	2001-2005 (%)	2005-2009 (%)	2009-2013 (%)
Black River	105,890	31,297	30	93	5	0.5	1.1	0.4
Bohle River	36,777	7,863	21	67	27	1.3	3.6	1.2
Ross River	133,905	39,069	29	60	10	0.2	0.4	0.1
Upper Burdekin River	3,624,352	821,143	23	85	34	0.1	0.1	0.1
Haughton River	221,835	58,767	26	74	24	0.4	0.3	0.1
Barratta Creek	182,928	30,314	17	57	32	0.1	0.2	0.1
Don River	373,413	77,117	21	67	30	0.1	0.3	0.8
Lower Burdekin River	1,046,957	260,833	25	64	32	0.0	0.3	0.3
Bowen River	944,671	163,799	17	80	18	0.3	0.2	0.1
Suttor River (inc Suttor, Cape Campaspe, Belyando)	7,388,690	928,934	13	69	28	1.2	0.3	0.6
Burdekin region	14,059,417	2,419,135	17	75	22	0.5	0.3	0.3

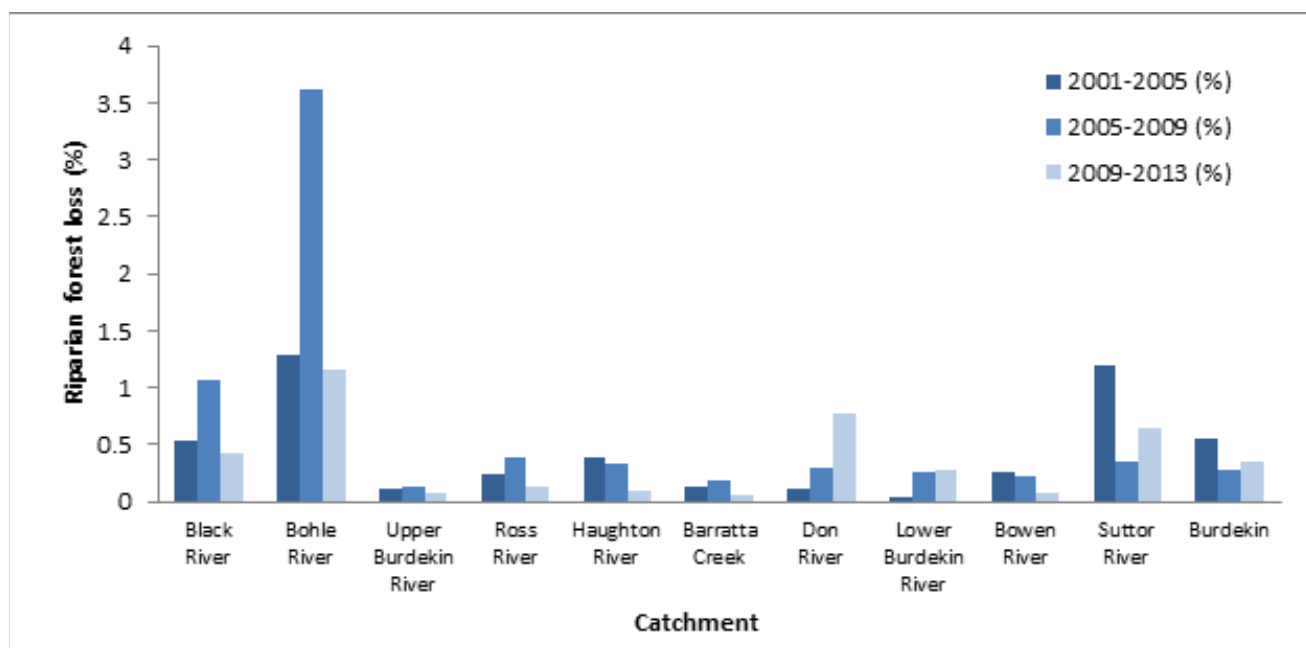


Figure 2.14. Estimated riparian forest loss in the Paddock to Reef Program reporting periods for the Burdekin Region. Data supplied by D. Tindall DSITI as an output of the Paddock to Reef Program. *Note that the boundaries differ from the catchments defined in this plan.*

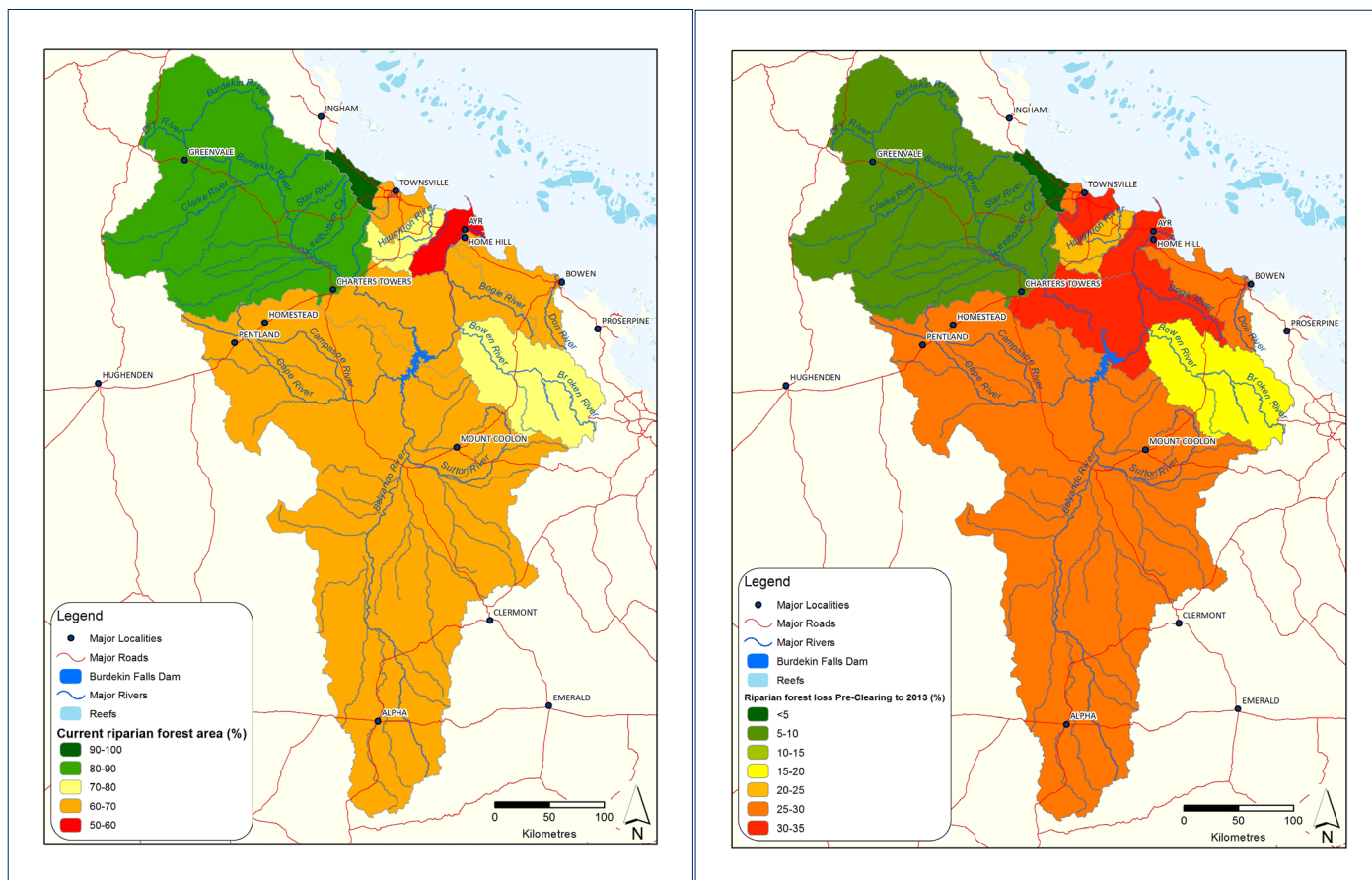


Figure 2.15. Current estimates of riparian forest extent (per cent) (left) and losses in riparian forest extent between 1988 and 2013 (right).

2.2.4 Coastal and marine ecosystems

As noted above, the Burdekin Region contains extensive areas of coastal and marine ecosystems including estuarine systems, seagrass and coral reefs. These ecosystems provide important habitat for a range of highly valued fish species, marine mammals and bird species.

The Burdekin Region contains approximately 280 square kilometres of estuarine systems (mangroves, saltmarsh/saltflats and intertidal flats); 26 of these were assessed as near pristine (30 per cent), largely unmodified (40 per cent) or modified (30 per cent) (Australian Government, 2015a). The modified estuaries are Barratta Creek, Burdekin River, Don River, Haughton River, Ross River, Bohle River and Sandfly Creek. Catchment modifying factors include altered catchment hydrology, effluent pollution, irrigation tailwater, groundwater extraction, sand extraction in estuaries and floodplains, dams, floodplain barrages and tidal weirs.

Regular seagrass monitoring through the Marine Monitoring Program has shown that the status of seagrass condition remains very poor in the Burdekin Region (McKenzie et al. 2014, 2015). Coastal intertidal seagrass abundance has remained low since 2011, whereas, seagrass abundance at intertidal reef sites has increased. Two monitoring sites, Shelley Beach and Bushland Beach near Townsville, were under minimum light thresholds more frequently than at any other sites on the GBR.

The AIMS Long Term Monitoring Program has conducted coral reef surveys in the region, at 27 sites for broad scale surveys, 18 sites for intensive surveys (AIMS, 2015) and the Marine Monitoring Program (MMP) monitors six inshore coral reefs in the region. Most surveyed reefs have very low hard coral cover (<20 per cent) and little improvement at surveyed locations over recent survey years, with the exception of some inner shelf reefs where higher coral cover is most likely due to a shift to species favouring more turbid and sheltered environments (Thompson et al. 2014a). The most significant threats to their viability are reduced water quality and increased storm damage due to climate change, with longer term effects associated with secondary outbreaks of COTS and coral bleaching also having important influence (Coppo and Brodie, 2015).

Dugong populations in Cleveland Bay and Upstart Bay had very high relative density in 2005 (>0.5 dugongs/km²), however, in 2011 both areas had significantly reduced dugong relative density. From aerial surveys in 2005 and 2011 there were too few dugong sighted in Bowling Green Bay to enable an abundance estimate to be made for that location. The Queensland Strandings Program estimates that, during 2011, 40 per cent of dugong strandings recorded along the Queensland coast

occurred between Cardwell and Bowen, and the main contributing factor to elevated dugong mortality was seagrass loss as a result of extreme weather events, most notably Cyclone Yasi in February 2011 which crossed the coast near Cardwell. The major pressures and threats to coastal and marine assets in the Burdekin Region include terrestrial pollutants (sediment, nutrients and pesticides), coastal development, shipping (and boating) and climate change, and to a lesser extent, fishing (Coppo and Brodie, 2015). Climate change, coastal development and increases in terrestrial pollutants are all considered serious threats to each coastal and marine asset, to varying degrees. The cumulative effect of all of these threats is likely to be significant.

A spatial assessment of the relative risk of degraded water quality to key coastal and marine assets in the Burdekin Region was conducted to support the update of this WQIP (see Waterhouse et al. 2015). In the combined assessment of the relative risk of marine water quality variables, the areas with the greatest potential influence from degraded water quality in the Burdekin Region (Very High relative risk class) are the inshore areas including the inner part of Halifax Bay, Cleveland Bay, Magnetic Island, Bowling Green Bay and Upstart Bay (Figure 2.16). The inner part of Edgumbe Bay is also in the highest relative risk class but this area is likely to be influenced by the rivers in the Proserpine Basin (Mackay Whitsunday NRM region). The High relative risk class extends into the central and northern parts of the region and reaches midshelf areas including Orpheus Island which is north of the Palm Island group. While some of this influence is driven by natural water quality conditions, a majority of the pollutants in this region are introduced from anthropogenic land uses including grazing, sugarcane and urban areas (see Section 3.1).

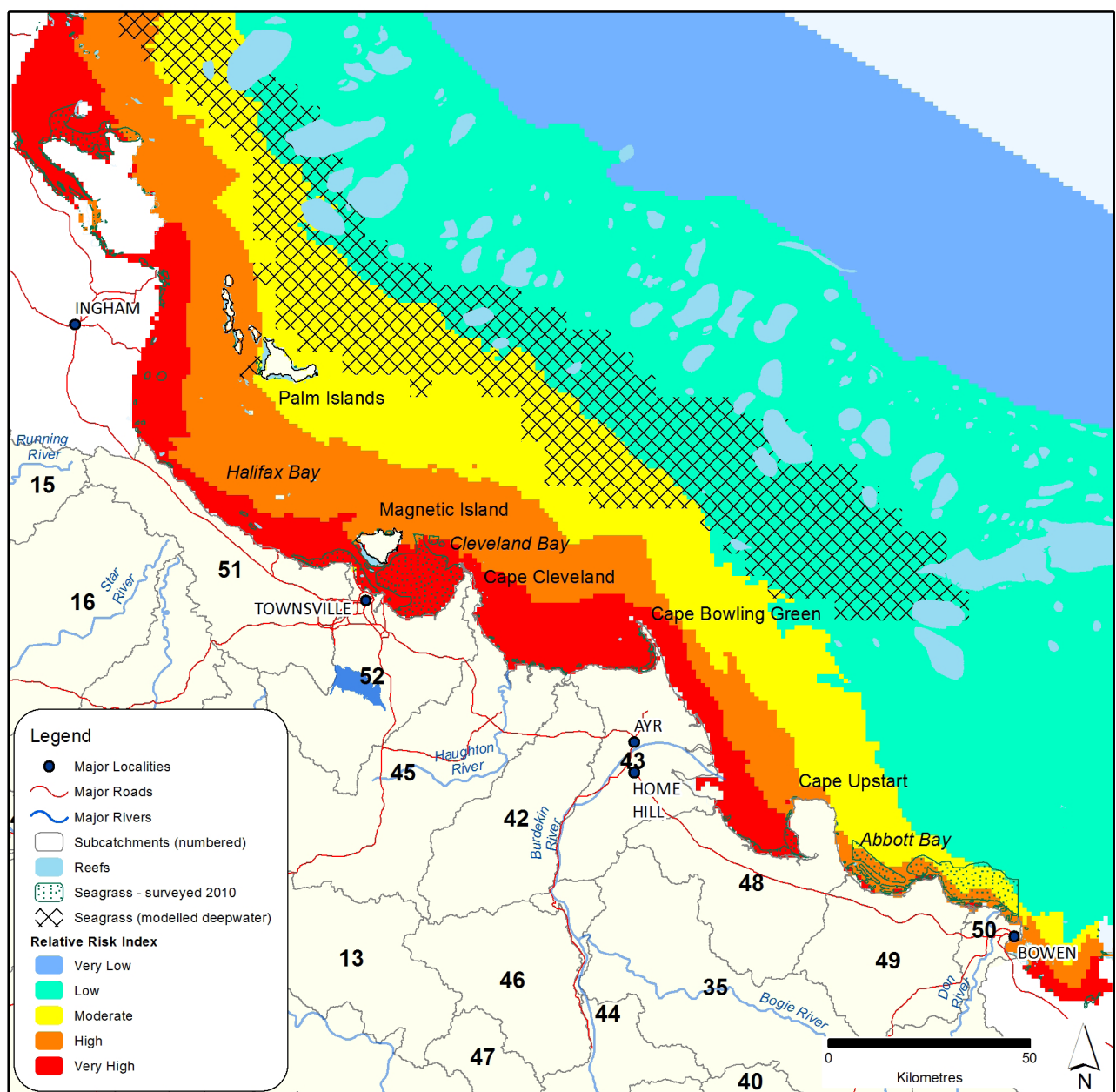


Figure 2.16. Combined assessment (1 km² resolution) of the relative risk of water quality variables. Reefs are shown in blue, surveyed seagrass (composite as at June 2010) shown in light green, deepwater modelled seagrass (>15m, 50 per cent probability) shown in green hatch. Source: Waterhouse et al. (2015).

Modelling of river plumes in the region between 2009 and 2013, and definition of 'zones of influence' in the wet season indicates that the Burdekin River has the greatest influence on these 'high risk' areas. The influence of the Haughton River appears to be confined to Bowling Green Bay and Cleveland Bay in the modelled years; however the modelling does not take into account realistic mixing of plumes from different rivers and the likely dynamics of the Burdekin River discharge, which may carry the Haughton River plume waters further north in large events. This modelling also suggests that the smaller Black and Don Rivers also influence the receiving embayments of Halifax Bay, and Upstart, Bowling Green and Abbot Bay respectively on a regular basis, although the relative load contributions from these rivers are small. Nevertheless, when considering combined and cumulative impacts, it is still important to ensure that the water quality from these rivers does not decline to exert additional pressures on these receiving environments (Waterhouse et al. 2015).

The areas around the Port of Townsville in Cleveland Bay are in the Very High relative risk classes. While the modelled area of influence from the Ross River was not included in the assessment, Cleveland Bay is in the receiving areas of the Black River in larger events, and will receive some runoff from the Ross River. While the influence of these rivers is small in comparison to the Burdekin River in the context of the whole region, the Black and Ross Rivers are important in terms of localised impacts on these receiving environments and as above, need to be managed to prevent increasing pressure from these rivers in the future.

The assessment shows that a large proportion of the seagrass area in the region is in the Very High and High relative risk classes (greater than 60 per cent and up to 99 per cent for all sediment and nutrient variables). While the areas of coral reef within the highest assessment classes are relatively small, the areas of greatest risk often include highly valued tourism and recreation sites of the GBR. Examples include Magnetic Island and the Palm Island group, including Orpheus Island.

Results for important habitat features in the Very High to Low relative risk areas of the Burdekin Region are summarised in Table 2.6. The areas in the Very Low relative areas include a majority of the offshore reefs where it is therefore important to maintain protection of these currently low water quality-impact areas.

It is important to recognise that the input variables represent longer term time series, and in most cases, represent average conditions. The response of coral reef and seagrass ecosystems to conditions in individual flood events, and the influence of repeated years of flood conditions, are also important and described further in Lewis et al. (2015) and Waterhouse et al. (2015).

The summarised status, trends and threats identified in Table 2.7 indicate that declines are likely to continue for some marine and coastal ecosystems due to the cumulative pressures of declining water quality, coastal development, COTS outbreaks, extreme cyclone and flooding events and climate change (Coppo and Brodie, 2015). Addressing chronic stressors, such as declining water quality, are important for maintaining and improving ecosystem condition in order to maintain ecological resilience and decrease the sensitivity of coral reefs and seagrass meadows to episodic disturbances, the frequency of which is likely to increase with the impact of climate change (e.g. Wiedenmann et al. 2012; Thompson et al. 2013). The events of recent years have shown that disturbances can occur every year in some locations for consecutive years, and that multiple events can even occur during the same year. As the return period between disturbances decreases, recovery will depend on maintaining ecological resilience and minimising chronic pressures such as poor water quality.

Table 2.6. Results of the relative risk assessment for important habitat features in the Very High to Low relative risk classes in the Burdekin Region. Reproduced from Waterhouse et al. (2015).

Habitat Feature	Description	Relative risk results	Likely rivers of influence
Outer Reefs – northern areas (from northern boundary to Cape Cleveland) e.g. Bramble, Trunk, Kelso, John Brewer, Lodestone, Keeper	Outer shelf coral reefs and deepwater modelled seagrass	Moderate - Low	Burdekin
Palm Island group (including Orpheus Island)	Midshelf island group, fringing reefs, coastal wetlands	Moderate	Burdekin
Halifax Bay	Herald and Rattlesnake Islands, coastal wetlands, fringing reefs	High - Very high	Black, Burdekin
Magnetic Island	Inshore island, coastal wetlands, fringing reefs, seagrass meadows	High - Very high	Burdekin, Ross (minor), Haughton
Cleveland Bay	FHA, DPA, coastal wetlands, extensive seagrass meadows	Very high	Black (minor), Burdekin, Ross (minor), Haughton
Outer Reefs – central areas (from Cape Cleveland to Cape Upstart) .g. Broadhurst, Davies	Outer shelf coral reefs and deepwater modelled seagrass	Low	Burdekin
Bowling Green Bay	FHA, Ramsar wetland, DPA, coastal wetlands, seagrass meadows	Very high	Haughton, Burdekin
Upstart Bay	FHA, DPA, coastal wetlands, seagrass meadows	Very high	Burdekin, Don
Outer Reefs – southern areas (from Cape Upstart to southern boundary) e.g. Old, Stanley	Outer shelf coral reefs and deepwater modelled seagrass	Low	Burdekin
Abbot Bay	DPA, coastal wetlands, seagrass meadows	Very high - High	Don, Burdekin
Edgecumbe Bay	DPA, coastal wetlands, seagrass meadows, fringing reefs	Very high - Moderate	Don, Proserpine Basin
Stone, Middle and Gloucester Islands	Gloucester Island NP, fringing reefs, seagrass meadows	High - Moderate	Don

Notes: FHA = Fish Habitat Area; DPA = Dugong Protection Area

Table 2.7. Assessment matrix summarising the value of coastal and marine assets in the Burdekin Region, their current status, trends of change, and future pressures and threats. This assessment is based on the best currently available information and in cases where information is limited, relies on expert judgment. All data is sourced in Coppo and Brodie (2015) unless specified here.

	Asset	Value/service	Status	Trends	Pressures/threats
Coastal assets	Estuaries	Critical habitat, coastal protection and stablization, nutrient cycling, Fishery nursery grounds.	Poor to very good	Localised impacts on easturine function; fisheries species	CD ↑, PD ↑, WQ ↓, fisheries impacts
	Coastal Wetlands and Mangroves	Critical habitat, coastal protection and stablization, nutrient cycling.	Poor to good (variable between wetlands)	Significant decline in wetland extent and function.	Modification of wetlands (vegetation removal, altered hydrological function), introduced pests and weeds, CD ↑, WQ ↓, EW ↑
	Coastal Islands	Critical habitat, (esp. for seabirds and turtle nesting), tourism income.	Good to very good	Changes to island vegetation and area	Human disturbance, introduced pests and weeds, EW ↑
Marine assets	Inshore coral reefs	Tourism, critical habitat, coastal protection and stablization	Poor*	Change in species composition, varibale coral cover up to 40%	CD ↑, PD ↑, WQ ↓, EW ↑, SST ↑, OA ↑
	Midshelf and offshore coral reefs	Reef tourism, critical habitat, coastal protetion, fisheries	Poor*	Declined, variable recovery, coral cover <20%	Crown-of-thorn starfish, EW ↑, SST ↑, OA ↑
	Inshore seagrass meadows	Critical habitat, (esp. for dugong), coastal stabilization, nutrient cycling	Poor*	Declining, signs of recovery	Elevated sediment, turbidity, low tide exposure, CD ↑, PD ↑, EW ↑
	Midshelf and offshore (reef) seagrasses	Critical habitat, nutrient cycling, poart of reef matrix	Poor*	Recent declines due to low tide exposure; signs of recovery	EW ↑
	Dugong	Tourism income, cultural importance, ecosystem function	Poor	Significant declines in 2010-13	Declining seagrass condition, human distrubance, vessel strikes
	Marine Turtles	Tourism income, cultural importance, ecosystem function	Poor to Good	Stable	Human distriburance, declining nesting island condition, increasing air/sand temperatures.
	Fish/sharks	Fisheries, apex predators, herbavores grazing macroalgae	Variable	Species dependent	Declining habitat condition, unsustainable fishing practices, SST ↑
	Cetaceans	Tourism income, iconic megafauna, apex predators	Variable	Stable	Human distrubance, reduced prey availability, declining habitat condition
	Seabirds	Tourism income, iconic fauna, apex predators	Variable	Most stable, some species in decline	Human distrubance, reduced prey availability, declining habitat condition

*Source: (Queensland Fivernment, 2015b).

Pressure/Threats: CD ↑ - increased coastal development, PD ↑ - increased port development, WQ ↓ - reduced water quality, due to catchment activities that increase nutrient, pesticide and sediment delivery to the coastal envrionment, ^EW ↑ - increased extreme weather events (i.e. tropcal cyclones, floods, storm surges), sea level rise, changing rainfall patterns, ^SST ↑ - increased sea surface temperure resulting in coral bleaching, ^OA ↑ - increased ocean acidification.
 ^ Considered beyond the scope of the WQIP.

3. What are the water quality issues in the Burdekin region?

3.1 Key pollutants and sources

Water quality is defined by associated use, values and affected ecosystems. While the focus of this WQIP is on protection of the coastal and marine ecosystems of the GBR, the connection and dependence of the GBR on coastal marine, estuarine and inland freshwater systems is recognised. Therefore catchment waterways including rivers, wetlands and estuaries need to be healthy too (GBRMPA, 2014a). Consideration must also be given to actions that may affect domestic, commercial or recreational water use beyond ecosystem values. For example, whether river water is safe for contact recreation (e.g. swimming), suitable for livestock to drink, or if the fish caught locally can be eaten safely.

Developing undisturbed land for agriculture and other purposes has had substantial impacts on the freshwater wetlands and riparian forests in the GBR catchment. In some areas of the GBR catchments, ~80 per cent of the naturally occurring floodplain wetlands have been destroyed (Johnson et al. 1999; GBRMPA, 2013). Most of the remaining 20 per cent are heavily impacted by aquatic weeds, changed hydrological conditions, poor water quality, altered fire regimes and/or loss of riparian vegetation (Arthington et al. 1997; Pusey et al. 2008). Associated ecosystem impacts are heterogeneous, direct and indirect, and vary greatly in spatial and temporal extent. Reduction in area and poor condition reduce the resilience of remnant aquatic ecosystems to the impacts of poor water quality, loss of habitat, weed invasion and future threats such as climate change (GBRMPA, 2013).

There has been considerable progress achieved on understanding the transport, fate and risk of pollutants transported from the Burdekin Region to GBR ecosystems since the 2009 WQIP was prepared. This is synthesised in Waterhouse et al. (2015) and summarised for each of the key pollutants below.

The modelled end-of-catchment pollutant load estimates (Waters et al. in review) and monitoring data for the Burdekin Region (Garzon-Garcia et al. (2015) indicate that the Burdekin Basin is the highest contributor of all total loads except for PSII herbicides, which is greatest from the Haughton Basin. The Haughton Basin also contributes the greatest proportion of anthropogenic DIN loads (61 per cent). The relative differences between the Black, Ross and Don Basins vary between constituents but are comparatively small.

Land use characteristics of the Burdekin Region were included in Section 2.1.6, and mapped in Figure 2.5. The dominant land use in the region by area is grazing. These areas generate large volumes of suspended sediment and particulate nutrients. Waters et al. (in review) estimates that on average the Burdekin Region contributes 3,695 million tonnes per year of suspended sediment at end of catchment, which is approximately 40 percent of total GBR TSS export. It is estimated 80 per cent of this load is derived from anthropogenic influences. The Burdekin Basin is recorded as contributing the majority (87 per cent) of the regional TSS load, with 76 percent of the load from grazing lands. The estimated total annual average load of particulate nitrogen is 3,530 tonnes per year and particulate phosphorus is 2,173 tonnes per year; approximately 76 percent of both constituents are exported from the Burdekin Basin. Approximately 80 per cent of the particulate nutrient loads are estimated to be from anthropogenic influences. It is estimated that 65 to 70 per cent of the regional particulate nutrient load is derived from grazing lands.

It is now clear from a range of monitoring and modelling that the bulk of fine sediment is delivered from the Burdekin Basin to the GBR is derived from a small proportion of the basin area, primarily within the Bowen Broken Bogie (43 per cent) and Upper Burdekin catchments (27 per cent) (Lewis et al. 2015; Bartley et al. 2014b; Waters et al. in review), with a large proportion of this load from grazing lands. This is supported by a variety of studies. The key points are:

- tracing data suggest that the Upper Burdekin and Bowen Broken Bogie catchments have the highest rates of accelerated erosion relative to pre-European rates at 3.6 and 7.5 times, respectively (Bartley et al. 2014c);
- the Burdekin Falls Dam traps a large proportion of the coarse particle fraction (>63 µm), about 50 per cent of the >16 µm fraction and 30 per cent of the fine <4 µm clay fraction (Bainbridge et al. 2016). The selective trapping efficiency of the Burdekin Falls Dam also highlighted that the <16 µm fraction became the dominant particle size transported through the impoundment (Bainbridge et al. 2016);
- the Upper Burdekin and Bowen Broken Bogie catchments also contribute the highest loads of the <4 µm, <16 µm and <63 µm sediment fractions to the end-of-catchment. Importantly, both the clay mineralogy and geochemical tracing data agree with the sediment budgets constructed for the catchment and highlight these two dominant sources (Bowen and Upper Burdekin) to the end-of-catchment sediment loads;
- the dominant erosion process driving this excess sediment delivery is gully erosion (Wilkinson et al., 2013; Hancock et al., 2013);
- the Bowen Broken Bogie catchment and other coastal streams in the region contribute more fine sediment per hectare than catchments upstream of the Burdekin Falls Dam; and

- within the Bowen Broken Bogie catchment, basalt and granitic areas contribute most per hectare and overall to clay and fine silt loads while the Upper Burdekin sources are largely derived from the sedimentary terrain (Bainbridge et al. 2014, 2016).

Spatial priorities for sediment management are discussed further in Section 5.1.5. However, it is noted here that TSS generation rates vary between land uses, and while the loads from grazing are highest overall (approximately 72 per cent of the regional TSS load), TSS contributions from other land uses including conservation and forestry, may also be important at local scales. It is also important to note that the export rates vary between catchments depending on landscape characteristics and management, for example, grazing export rates vary from less than 30 kg/ha/yr in the Cape, Belyando and Suttor catchments to ~1,200 kg/ha/yr in the Bowen Broken Bogie catchment, and 210 kg/ha/yr as the regional estimate (Waters et al. in review). Similar variances are modelled for export rates from conservation areas which highlights the importance of soil types and landscape characteristics in influencing erosion rates.

Sugarcane, dryland cropping and horticulture are the major agricultural intensive land uses in the region, with high concentrations and loads of DIN reported from sugarcane in streams and groundwater in the Lower Burdekin catchment (Bainbridge et al. 2008a). Most DIN (primarily nitrate) in streams that drain sugarcane areas is considered to come from fertiliser residue, with 90 per cent of the anthropogenic DIN attributed to this source (Dougall et al. 2014; Waters et al. in review).

The major source of herbicide loads from the Burdekin Region is the Lower Burdekin sugarcane area. The major PSII herbicides used and found in receiving waters are atrazine, ametryn, hexazinone and diuron (Davis et al. 2011, 2012; Smith et al. 2012; O'Brien et al. 2016). The herbicide tebuthiuron has been detected in runoff originating from grazing lands in the Burdekin River (Turner et al. 2012, 2013) but loads have been comparatively low when compared to the Fitzroy (Packett et al. 2009).

Due to the relatively small area of urban land use (<2 per cent of the region), urban areas are not a high priority at the regional scale, however, localised issues can be important. For example, sediment runoff from urban sources from specific developments have been issued with Protection Orders and penalty infringements and discharges into small embayments can also be significant to local ecosystems. In addition, outside of the Townsville area, monitoring information on urban stormwater quality is very limited. Areas of potential concern that remain undefined are the potential 'cocktail' of pesticides, gross pollutants in particular soft and micro plastics and the effects of disturbed groundwater in urban coastal areas.

Pollutant types, persistence and mobilisation vary between land uses and are described below.

3.2 Grazing in the Burdekin rangelands

3.2.1 Sources of pollutants

The area of grazing in the region is approximately 12,600,000 hectares (12,000km²), or 90 per cent of the region's area. Grazing lands occupy more than 50 per cent of the area of every catchment in the region and, in many cases, more than 80 per cent (Upper Burdekin, Belyando, Cape, Suttor, Bowen Broken Bogie and Don), although it is noted that not all of this area is actively grazed by cattle.

Historically, management of cattle grazing on the large, dry catchment of the Burdekin rangelands has involved localised tree clearing and, in many cases, the over-utilisation of pastures during drought conditions. With a summer rainfall pattern, pasture growth during the extended and often severe Burdekin dry season can be severely limited. Nevertheless, Coughlin et al. (2007) note an intensification of grazing pressure over the last 30 years that has included: (i) increases in stock numbers; (ii) a greater proportion of Brahman cattle and their crossbreeds that have a greater tolerance of arid conditions; (iii) use of nutritional supplements to maintain rumen microbes and enable cattle to browse on low energy and low quality pasture during the dry season. Supplements include urea, which adds available nitrogen to the environment, resulting in greater availability of utilisable pasture; (iv) sub-divisional fencing and the spreading of watering points away from natural sources; (v) improved pastures; (vi) woody weed and further tree clearing; and (vii) the confinement of cattle in smaller areas. In some cases, these developments have resulted in the localised loss of native perennial grasses and an increased vulnerability of rangelands and associated riparian areas to overgrazing and soil erosion.

The expansion of cattle production further accelerated the rates of soil erosion from grazing lands beyond natural levels. This is important when considering current erosion features and the influences of previous land uses including historical gold and tin mining. Sediment binds naturally with available nitrogen and phosphorus in the landscape providing a ready-to-move source of nutrients (Brodie et al. 2015). Following the long dry season, intense wet season rainfall generates high-magnitude, short-duration event flows that mobilises the soils and causes erosion. Rapid run-off across low ground

cover terrain transports high concentrations and large loads of sediment and nutrients through the catchments to the GBR lagoon.

As part of the 2009 WQIP, Coughlin et al. (2007) provided a comprehensive review of the impacts of livestock on water quality, which can vary greatly depending upon the terrain and the intensity and history of grazing. These effects are summarised and updated below.

Overgrazing reduces vegetation (ground cover) and exposes more vulnerable soils to erosion. Grazing in riparian areas can lead to changes in vegetation structure and increased light and the temperature of water bodies which, in combination with increased nutrients, increases algal growth and the dominance of exotic aquatic species. The potential for overgrazing increases in seasonally dry areas, when alternative waters in the landscape begin to dry up and stock congregate in sensitive areas. Riparian areas are particularly prone to disturbance from overgrazing and /or cattle pads because in the dry season, or in times between rain events, flowing rivers serve as the most reliable sources of water for cattle.

Trampling by livestock has an impact on soils by removing protective vegetation and loosening the soil, and physically breaking down the banks of gullies and streams (McIvor, 2012). The mobilisation and loss of disturbed soils is accelerated with the onset of wet season rains (Bartley et al. 2010a, 2010b, 2014a). The compaction of soils by grazing animals in the Burdekin catchment has also been shown to significantly reduce water infiltration (Roth, 2004), increase the proportion of low cover areas and increase surface runoff (Bartley et al., 2006, 2010a, 2010b, 2014a).

Direct fouling of waterways with faecal waste, and indirectly through increased runoff and soil movement, results in decreased water quality, foul smells, poor tasting water and increased growth of algae and aquatic weeds. The reduction of water levels in main river channels in the dry season amplifies this problem in the Burdekin, particularly towards the end of the dry season, when these sites concentrate cattle around waterholes. Collectively, sediment resuspension, defecation and urination, physical bank damage and vegetative disturbance from cattle loitering within riverine waterholes combine to reduce the water quality locally and downstream.

Weed infestation through soil disturbance, nutrient enrichment and an influx of seeds of exotic species is a common problem in grazing lands, particularly in riparian areas. Woody weeds within riparian areas are thought to reduce natural grass thickness and cover and reduce the filtering and infiltration role of riparian areas. The species composition of grass cover and soil type also influence water infiltration and soil erosion (Roth, 2004; O'Reagain et al. 2005; Wilkinson et al. 2014).

The formation of cattle pads can lead to the concentration of flows, increasing erosion and gullyng. Accelerated soil and stream bank erosion through reduced vegetation cover, trampling and bank collapse can result in the degradation of aquatic habitats.

The important link between upland grazing management and that of riparian and gullied areas is highlighted, and the subsequent influence this has on water quality. Degradation of upland pastures results in increased runoff, which in turn, can overload riparian areas, making them ineffective in retaining soil. Maintaining cover on areas above gullied landscapes has an important role in infiltration and reducing gully formation.

3.2.2 Grazing pollutant load contributions

Suspended sediments and associated particulate nutrients are the dominant water quality issues in grazing lands (Hunter and Walton, 2008; Kroon et al. 2013; Waters et al. 2014, in review). Most particulate nitrogen and particulate phosphorus is lost or mineralised from fine sediment following delivery to the GBR (McCulloch et al. 2003; Webster et al. 2006), and could be readily available for uptake in GBR ecosystems (Kroon et al. 2013). The estimated annual average anthropogenic load of TSS from grazing lands using the Source Catchments model (2013 baseline) is 2.8 million tonnes, or approximately 90 per cent of the regional anthropogenic load. The erosion sources of annual average anthropogenic TSS loads from grazing land are shown in Table 3.1 and Figure 3.1. The Bowen Broken Bogie catchment contributes 46 per cent of the TSS load from grazing lands (1.3 million tonnes/year), but only contains eight per cent of the grazed area. The Upper Burdekin is the next largest contributor at 27 per cent (0.8 million tonnes/year), the Lower Burdekin 14 per cent, and the Don six percent; all of the other catchments contribute less than two per cent each. Gully erosion dominates TSS sources in all grazing lands (50-73 per cent), with a regional estimate of 67 per cent of anthropogenic TSS in grazing lands from gully erosion. Hillslope and streambank erosion are estimated to contribute similar proportions, estimated at 19 per cent and 14 per cent respectively. These vary between catchments but in most cases, hillslope erosion is more significant than streambank erosion. While the Bowen Broken Bogie catchment dominates sediment delivery at a catchment scale, different 'hotspots' for sediment generation are evident at smaller scales. Sub-catchment assessments of the modelled TSS loads identify potentially important areas in other catchments including the Upper Burdekin, Lower Burdekin, Don and Black catchments, particularly when considering export rates (kg/hectare) (Waterhouse et al. 2016). This is discussed further in Section 5.1.5.

Table 3.1. Area of grazing in each catchment and modelled estimates of the proportion of anthropogenic TSS loads from gully, hillslope and streambank erosion in grazing lands in the Burdekin catchments. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

Catchment	Area of grazing (ha)	Proportion of grazing area	TSS contribution to regional grazing TSS load	Proportion of TSS from primary erosion sources		
				Gully	Hillslope	Streambank
Black	71,297	1%	1%	68%	26%	6%
Ross	68,115	1%	0%	50%	42%	8%
Upper Burdekin	3,515,498	28%	27%	71%	15%	14%
Cape	1,949,470	16%	2%	73%	21%	6%
Belyando	3,357,896	27%	2%	61%	32%	7%
Suttor	1,652,257	13%	2%	62%	28%	10%
Bowen Broken Bogie	1,047,127	8%	46%	71%	22%	7%
Lower Burdekin	579,323	5%	14%	52%	9%	39%
Don	302,556	2%	6%	59%	28%	14%
Total	12,543,540			67%	19%	14%

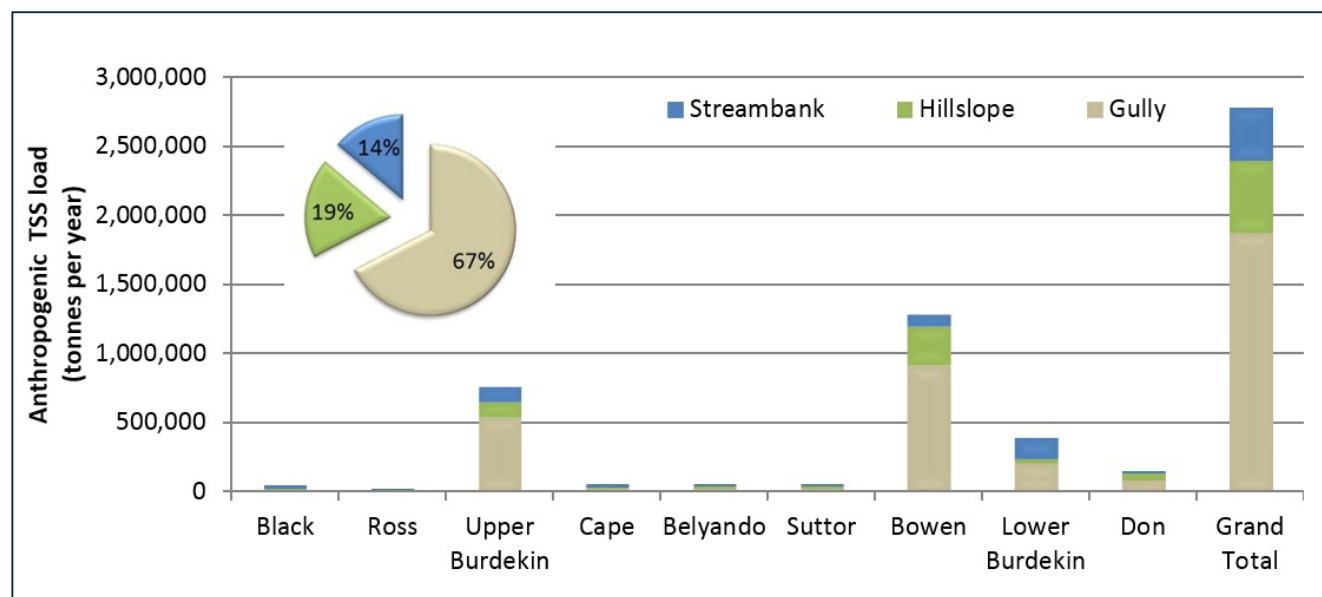


Figure 3.1. Modelled estimates of annual average anthropogenic TSS loads from gully, hillslope and streambank erosion in grazing lands in the Burdekin catchments. Inset pie chart shows regional contributions from grazing lands. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

Particulate nutrients are derived from soil erosion in grazing lands (Brodie and Mitchell, 2005; McKergow et al. 2005; Waterhouse et al. 2012). The estimated annual average anthropogenic load of PN and PP from grazing lands using the Source Catchments model (2013 baseline) is 2,322 tonnes and 2,173 tonnes respectively, or approximately 80 per cent of the regional anthropogenic loads.

The erosion sources of the annual average anthropogenic PN and PP loads from grazing lands are shown in Table 3.2 and Figure 3.2 and Figure 3.3. The Bowen Broken Bogie catchment contributes 54 per cent of the PN load and 49 per cent of the PP load from grazing lands, but only contains eight per cent of the grazed area. The Lower Burdekin and Upper Burdekin are the next largest contributors (around 17 per cent), and the Don (around eight per cent); all of the other catchments contribute less than three per cent each.

Table 3.2. Modelled estimates of annual average anthropogenic PN and PP loads from gully, hillslope and streambank erosion in grazing lands in the Burdekin catchments. Inset shows regional contributions from grazing lands. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

Catchment	Anthropogenic Particulate Nitrogen loads from grazing lands					Anthropogenic Particulate Phosphorus loads from grazing lands				
	Grazing load (t/yr)	Contribution to regional grazing load (%)	Erosion source (%)			Grazing load (t/yr)	Contribution to regional grazing load (%)	Erosion source (%)		
			Gully	Hillslope	Stream-bank			Gully	Hillslope	Stream-bank
Black	36	1	28	65	7	16	1	1	99	0
Ross	19	1	16	79	5	9	1	1	98	0
Upper Burdekin	352	13	57	35	8	302	18	11	81	8
Cape	32	1	50	49	2	28	2	23	73	4
Belyando	80	3	46	51	3	43	3	23	74	3
Suttor	73	3	43	54	3	38	2	22	71	7
Bowen Broken Bogie	1,506	54	58	39	3	824	49	8	87	5
Lower Burdekin	471	17	28	40	32	295	18	6	66	28
Don	211	8	21	71	8	114	7	5	93	3
Total	2,779	100	49	43	9	1,669	100	7	85	7

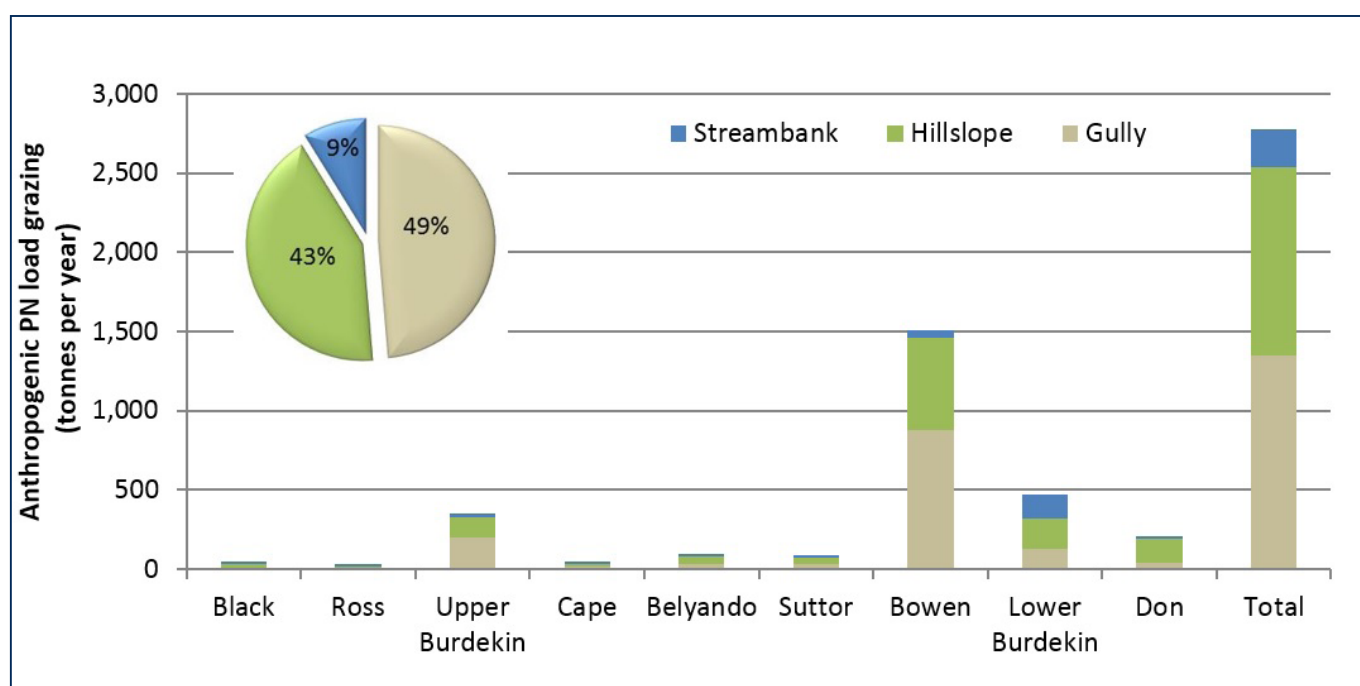


Figure 3.2. Modelled estimates of annual average anthropogenic PN loads from gully, hillslope and streambank erosion in grazing lands in the Burdekin catchments. Inset pie chart shows regional contributions from grazing lands. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

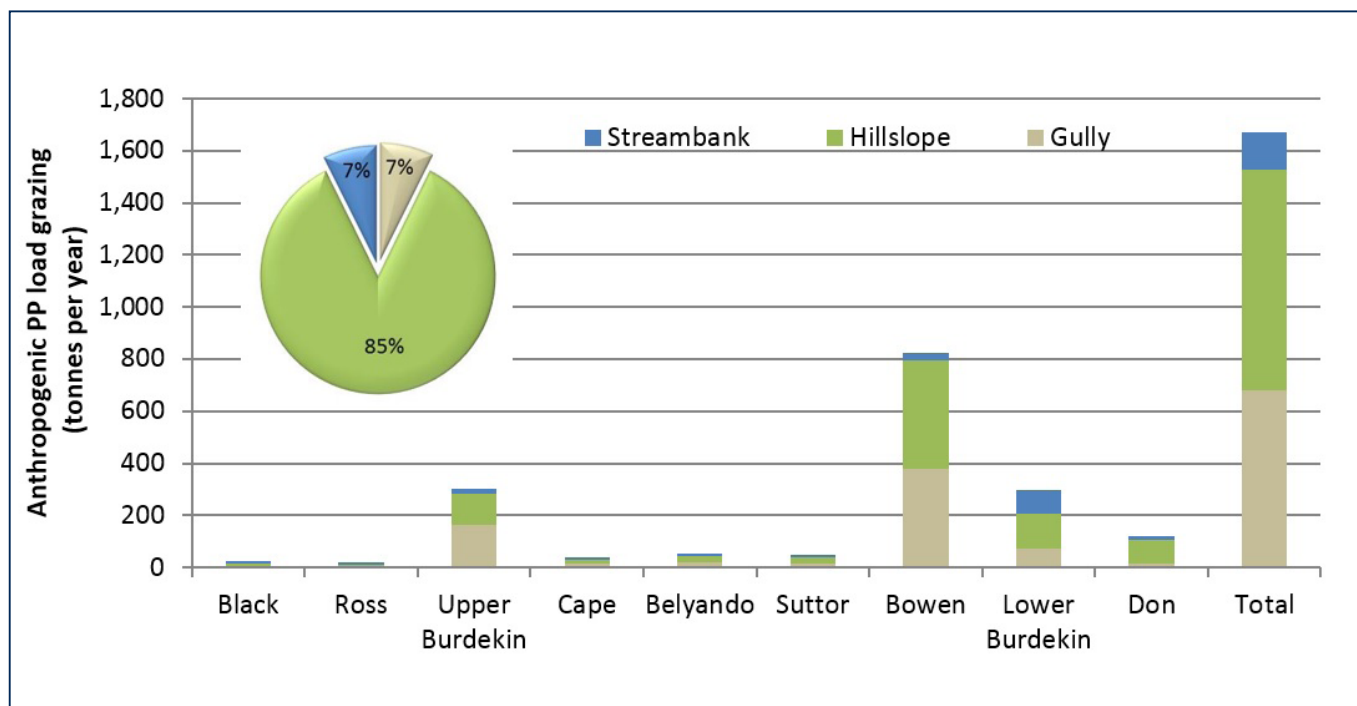


Figure 3.3. Modelled estimates of annual average anthropogenic PP loads from gully, hillslope and streambank erosion in grazing lands in the Burdekin catchments. Inset pie chart shows regional contributions from grazing lands. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

3.3 Sugarcane in the Lower Burdekin

3.3.1 Sources of pollutants

The area of sugarcane in the region is approximately 91,000 hectares (91 square kilometres), with approximately 80,000 hectares under production. Most of the region's sugarcane is located in the Lower Burdekin catchment, with small areas in the Don and Black catchments. The most practical boundaries for our discussion are the BRIA and Delta sugarcane growing areas (Figure 3.4).

The Lower Burdekin irrigated cropping area consists largely of the Burdekin River delta and floodplain ('the Delta'), of which sugarcane is by far the predominant crop. A substantial freshwater aquifer system underlies the Delta area which has largely supported agricultural, pastoral and domestic uses in the Lower Burdekin for over 100 years (Davis, 2006). The Burdekin Delta irrigation area as a whole is composed of predominantly porous, sandy and high permeability soils where over 1,800 groundwater pumps are reported to be in operation. The aquifer, which is in contact with the sea and various rivers and creeks, is managed by Lower Burdekin Water (formerly known as the North and South Burdekin Water Boards) whose key role is to control seawater intrusion into the coastal groundwater reserves and maintain good water quality for irrigation (Tait, 2013).

Groundwater for irrigation in the Delta area has been supplemented by discharge from the Burdekin Falls Dam since it was constructed in 1987. This water availability led to a major expansion of the sugarcane industry, into an area north of the Burdekin River extending to the Haughton River and Barratta Creek, which is known as the Burdekin River Irrigation Area (BRIA). Irrigation water is supplied to farms across the BRIA through a complex system of natural and artificial drainage channels. The soils of the BRIA are substantially different from those of the Delta area, and are composed of a mix of sodic / duplex and light to medium and heavy clays with high denitrification potential (McClurg et al. 1988). The Delta contains a mix of coarse sands, sandy loads to medium clays with low denitrification potential (DNRM, 2005). The supplemented water for irrigation from the Burdekin Falls Dam has resulted in a highly modified flow regime within the rivers and creeks that dissect the Lower Burdekin catchment. Flood or furrow irrigation is most common in the sugarcane areas, with over 95 percent of growers adopting this system to irrigate their crops (Queensland Government, 2015).

The water pricing arrangements for irrigators in the Burdekin are managed through the State Government Corporation, Sunwater and have implications for water use and runoff. The pricing structure utilised by Sunwater includes a two part (A and B) system which applies to both individual irrigators and bulk purchasers such as the lower Burdekin Water Boards. Part A of the price structure includes a fixed charge based on a client's allocation entitlement which must be paid for regardless of whether it is used, and Part B includes a variable volumetric component based on a client's actual water use. In practice, allocation entitlements are set at the higher end of the likely utilisation spectrum to provide a buffer against unforeseen circumstances that could necessitate higher than expected use levels. This structure results in an incentive

to use the full allocation entitlement that has “already been paid for” regardless of variability in actual needs particularly where individual irrigators have access to BHWSS channel water and gravity delivery.

The design of the bulk water distributor system results in the loss of considerable volumes of excess tailwater to streams and wetlands. In many areas, this has had a significant impact on ecosystem health and function (Tait, 2013). In light of these environmental, social and economic complexities within the Lower Burdekin sugarcane areas, a ‘whole of ecosystem’ approach to sustainable agriculture is required (Davis, 2006). Management must account for wet season event flows that deliver the greatest volume of surface water to the GBR, and recognise ambient water quality and tail-water runoff from irrigation throughout the year, the loss of nutrients and pesticides to groundwater and consideration of all sources of nitrogen and pesticides.



Figure 3.4. Map of the two distinctive sugarcane growing regions in the Lower Burdekin catchment, the BRIA and the Delta.

The scientific background to sugarcane management practices that improve water quality leaving the Lower Burdekin irrigated sugarcane area was reviewed by Davis (2006) as part of the 2009 WQIP. This still provides a strong basis for development of practical and relevant farming principles and guidelines that meet the social, economic and environmental aspirations of Lower Burdekin sugarcane farmers. These are summarised and updated below.

Average fertiliser (nitrogen) application rates in the Burdekin district are significantly above the Queensland sugarcane average (Queensland Government, 2015). While there are various contributing factors to this statistic, including higher yielding crops that require more nutrient inputs and naturally low soil organic matter, the sustainability of sugarcane-growing can be undermined by either over application or under application of fertilisers. Long term over or under application of fertilisers can result in loss of soil fertility and overall soil degradation leading to productivity declines and off-site environmental effects.

The aim of fertiliser application should be to match, but not exceed, crop demand. The application of a single set of fertiliser application guidelines, with minimal differentiation according to soil properties and organic matter content, can result in under or over supply of nutrients with consequences for productivity and nutrient loss. Understanding the variability in soil properties is fundamental to determining appropriate nutrient management practices for specific circumstances on individual farms as well as understanding yield constraints and developing crop yield targets. Fertiliser application in excess of crop demand may be recycled or lost as gas (through denitrification and volatilisation), by leaching into groundwater or through surface runoff into wetlands and coastal waters where they impact on the water quality (see Section 2.2). Tail-water recycling schemes ultimately reuse fertiliser losses, although improved understanding of nutrient content would make this practice more efficient.

The growing of fallow crops, particularly over the wet season, produces organic nitrogen for subsequent plant-cane crops and can benefit water quality by reducing crop requirements for fertiliser application (Schroeder et al. 2010).

Pesticide (including herbicide) application is a significant part of the overall farming system used by many growers to remain productive and competitive. Herbicides are the primary pesticide category used in sugarcane production but rates and practices are poorly documented with most knowledge coming from chemical sales data. Not all pesticides behave in the same manner and have notable differences in application, persistence, solubility and affinity for absorption to soil particles (Davis et al. 2012). This strongly influences the mobility and toxicity of a pesticide following application. The potential risk associated with losses via surface runoff or leaching is related to bioavailability and, consequently, concentrations in runoff can be high if rainfall or irrigation events occur shortly after application. The concentrations of pesticides measured in waterways in the Lower Burdekin sugarcane areas are known to frequently exceed water quality guidelines for ecosystem health (Davis et al. 2015; O'Brien et al. 2016).

Irrigation efficiencies influence the amount of surface runoff and drainage losses. Typically low irrigation efficiencies in the Lower Burdekin area have led to substantial modification of local hydrological regimes, resulting in significant impacts on freshwater and coastal ecosystems in the region (GBRMPA, 2012). Irrigation run-off from sugarcane can cause nutrient enrichment, water oxygen depletion, and fish kills in natural wetlands, and modification to the surface and ground water interactions and hydrological regimes (Davis et al. 2016). Furrow irrigation is common in the region and is one of the most widespread forms of irrigation worldwide. While the system typically has low pumping, labour and infrastructure costs and technical requirements, irrigation efficiency under furrow systems can vary significantly with potential for deep drainage losses and tail-water runoff. Lower water application efficiency is generally associated with deep drainage losses through highly permeable soils. Irrigation efficiencies may be gained by consideration of soil type, managing furrow length or irrigation water quality, optimising inflow rates and capturing and reusing irrigation induced runoff water. For example, tail-water recycling schemes can produce significant improvements in irrigation application efficiency for fine textured soils while retaining more fertiliser and pesticides on-farm.

Land management and tillage systems interact with fertiliser and pesticide application practices and irrigation. Together these practices influence productivity, water use efficiency and the off-site loss of nutrients and pesticides via surface waters and to groundwater. The adoption of practices such as reduced or zero tillage can result in reduction of sediment losses. However, this will increase reliance on pesticides making it imperative to manage surface runoff and deep drainage.

Rising water tables are evident in the Lower Burdekin irrigation areas (Shaw, 2014) with expression of groundwater at the surface in some locations (see Section 2.2.1). The difference in the rate of input of water to the irrigation area compared to natural recharge under rainfall and the rate of outflow of groundwater determines the groundwater imbalance and therefore the response of the watertable level to changed hydrology. As watertables approach the soil surface, water logging and increased salinisation of the root zone can occur, leading to reduced or complete loss of productivity. Importantly, the direct interface with the water table excludes the buffering capacity to absorb recharge during wet conditions, which poses a greater risk for fertiliser and pesticide losses via surface runoff. Shallow water tables and salinity are most common in catchments where the capacity for outflow is restricted by various features as outlined in the Salinity Management Handbook (2011).

3.3.2 Sugarcane pollutant load contributions

The dominant water quality issues from sugarcane areas are DIN and PSII herbicides (Waterhouse et al. 2012; Brodie et al. 2013a, 2013b; Thorburn and Wilkinson, 2013; Kroon et al, 2013; Waters et al. 2014). The estimated annual average anthropogenic load of DIN from the Lower Burdekin sugarcane area using the Source Catchments model (2013 baseline) is 1,046 tonnes per year, or 87 per cent of the regional anthropogenic load. These estimates correlate well with recent monitoring data (Turner et al. 2013; Garzon-Garcia et al. 2015).

Nitrogen losses in runoff and deep drainage vary according to soil type in both BRIA and Delta regions. The dominant loss pathway in the largely clay based soils of the BRIA is through surface water runoff whereas in the highly permeable light soils of the Delta the dominant loss pathway is through deep drainage (Thorburn et al. 2011). The amount of N leached from the BRIA soils is, on average, much less (<10 per cent of fertiliser applications) than the Delta soils (75 per cent) (Thorburn et al. 2011).

The current modelled estimate of the annual average PSII herbicide load from the Burdekin Region is 2,295 kg per year (Waters et al. in review). This equates to a Diuron Toxic Equivalent load of approximately 2,100 kg per year. Sugarcane is the greatest contributor of PSII herbicide exported load, contributing a majority (99 per cent) of this load. A small amount of atrazine is also modelled from cropping land uses in all of the catchments. At the catchment scale, the Lower Burdekin is the dominant contributor of PSII herbicides (>95 per cent) and nearly all (99 per cent) of this load is from sugarcane.

Nutrient and herbicide contributions from the BRIA and the Delta are shown in Figure 3.5. The BRIA and Delta regions contribute approximately equal loads of DIN (accounting for uncertainties in some of the model input data such as current management adoption), estimated at 460 tonnes/year (44 per cent) and 586 tonnes/year (56 per cent) respectively, with both areas occupying approximately equivalent proportions of the cane producing area (CPA) in the Lower Burdekin catchment. The DIN export rates are higher in the Delta (~14 kg/ha/yr) compared to the BRIA (~10 kg/ha/yr). The modelled PSII herbicide toxic equivalent load data for the region also shows that the modelled contributions from the BRIA and Delta are roughly equivalent (within the level of accuracy of the model), estimated at 693 kg/year (55 per cent) and 564 kg/year (45 per cent) respectively. The lack of distinction between regions is likely a result of the reporting of relatively homogenous farming practices across both BRIA and Delta, and the factors that influence pesticides loss processes do not vary significantly across regions. However, it is likely that more residuals are applied in the BRIA as standard practices use less cultivation and therefore weed pressure can be greater (E. Shannon, pers. comm.). In addition, the loss pathways are different, and a large proportion of the irrigation tailwater runoff in the BRIA discharges to Barratta Creek, compared to the Delta where the waterways are typically used as water transfer channels receiving surface and groundwater flows (Davis et al. 2012).

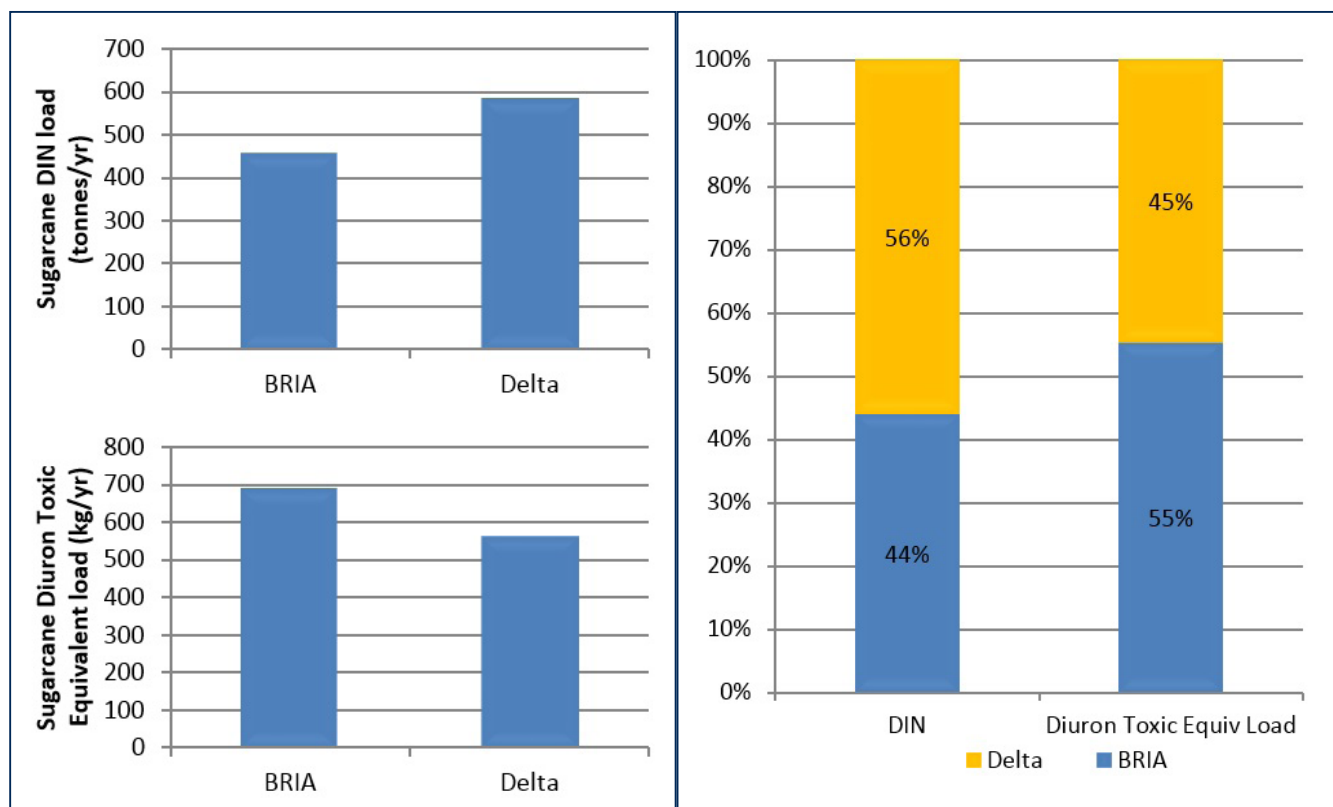


Figure 3.5. Modelled estimates of sugarcane contribution of DIN and PSII herbicide loads (Diuron Toxic Equivalent load) in the BRIA and Delta sugarcane regions. Derived from Source Catchments 2013 baseline estimates, DNRM 2015.

In addition to the figures presented above, it is estimated that around 130,000 tonnes of nitrate is present in the Burdekin coastal plain aquifer system (Barnes et al. 2005), but it is uncertain how much of this nitrogen reaches the GBR marine environment. The quantity of DIN in groundwater discharge (as NO₃⁻ or NH₄⁺) will depend on the groundwater chemical conditions that control the mobility of nitrogen in aquifers. Currently these conditions are largely unknown for GBR coastal plain aquifers making it difficult to estimate if any groundwater discharge of nitrogen is taking place, accumulating inland or being transferred into tributaries draining the coastal plain or via preferential pathways to the coast (Thayalakumaran et al. 2004, 2008), however Thayalakumaran et al. (2008) concludes that while there are nitrate 'hot spots' in certain areas, some or most of the nitrate is being consumed on its way to the ocean. If current estimates of groundwater discharge (Cook et al. 2004) are combined with existing groundwater nitrate data (Bristow, in review), it is possible that significant quantities of nitrogen could be discharged from the Burdekin coastal plain aquifer into the GBR lagoon. Current estimates suggest that the discharge of DIN from the aquifer ranges from 0 to 5,500 tonnes/year may be more than four times that of the Lower Burdekin sugarcane area (average of 1,100 tonnes/year) (Bristow, 2016). These uncertainties need to be resolved to provide a comprehensive understanding the total delivery of nitrogen to the GBR from the Burdekin Region.

3.4 Horticulture in the coastal areas

3.4.1 Sources of pollutants

The area of horticulture in the region is approximately 14,200 hectares (14 square kilometres). A majority (63 per cent) of the horticulture is located in the Don catchment with smaller areas in the Lower Burdekin (23 per cent), Ross and Black catchments (~5 per cent each).

The Don catchment includes the towns of Bowen, Gumlu and Guthalungra and is a major horticulture growing region producing vegetables (capsicum, beans, corn, pumpkin, zucchini and squash, chilli, eggplant, cucumber) and fruit (fresh and processed tomato, melons, fresh and processed mango), valued at \$450 million per year (Bowen Gumlu Growers Association, 2015). Irrigation water is sourced from a very seasonal Don River whilst ground water supply is the main source of water for many areas in this region.

3.4.2 Horticulture pollutant load contributions

The dominant water quality issues from horticulture areas in the Burdekin Region are DIN and, to a lesser extent, TSS and PSII herbicides (Waters et al. 2014, in review). Using the Source Catchments model (2013 baseline), the estimated annual average anthropogenic loads for the Don catchment horticultural area are 15 tonnes DIN and 1,740 tonnes TSS. These loads only represent ~0.1 per cent of the regional anthropogenic loads.

The TSS export rate from horticulture in the Lower Burdekin and Don catchments is 210-230 kg/ha/yr. The rates of TSS export from horticulture for the Black catchment, generated in the Source Catchments model, are comparatively higher (~900 kg/ha/yr and warrant further investigation. Estimates were not available for PSII herbicide loads from the horticultural areas in the Don catchment.

The main management factors influencing the pollutant sources in horticulture areas are similar to those for sugarcane noted above (Section 3.3.1): fertiliser application rates, pesticide application rates, irrigation efficiencies and land management and tillage.

3.5 Grain crops in the upper catchments

3.5.1 Sources of pollutants

There are approximately 44 growers managing 123,000 hectares (123 square kilometres) under grain crops in the Burdekin Region (Queensland Government, 2015). A majority (108,000 hectares or 86 per cent) of the dryland cropping is in the Suttor Catchment with smaller areas in the Belyando (15,000 hectares or 12 percent) and Cape Campaspe catchments (2,000 hectares or 2 per cent). The most commonly grown crops are sorghum, mung beans and chick peas. Wheat is also commonly grown in the Suttor during winter months. Barley, sunflowers and other cereal crops are less common. The type of crop grown largely depends on the commodity price and grain growers are known to opportunistically switch crops while profitability is high.

3.5.2 Grain crops pollutant load contributions

The dominant water quality issues from grain crops are TSS, and to a lesser extent, DIN and PSII herbicides (Kroon et al. 2013; Packett, 2014; Waters et al. 2014, in review). Using the Source Catchments model (2013 baseline), the estimated annual average anthropogenic loads for dryland cropping in the Suttor catchment are 5,800 tonnes TSS and 11 tonnes DIN. These loads represent ~0.2 per cent and ~1 per cent of the regional anthropogenic TSS and DIN loads respectively. The TSS export rate is estimated to be 56kg/ha/yr, which is relatively low compared to other agricultural land uses. Atrazine is used in grain crops and while the modelled estimates are small, elevated concentrations have been measured in some cropping areas (Packett, 2014).

The main management factors influencing the pollutant sources in grain crops include: land management and tillage, fertiliser application rates and pesticide application rates.

3.6 Urban areas

3.6.1 Sources of pollutants

The area of urban land use in the Burdekin region is currently estimated at 25,000 hectares, less than 1 per cent of Burdekin Region. Urban expansion is occurring around the main regional centre of Townsville.

Pollution of waterways from urban land uses generally follows one of three main interconnected pathways: stormwater runoff, sewage infrastructure or aerial drift. Gunn and Manning (2010) reviewed current urban water quality management practices within the Townsville area (Black and Ross catchments, which combine as the Townsville Coastal area) and the locally relevant environmental issues linked to these practices. This work has been selectively summarised and extended into the following summary of major urban water pollution processes for the Burdekin Region. Figure 3.6 shows some of the issues associated with urbanisation of natural land by comparing the processes which dominate each landscape. Urban environments generally contain many more 'hard surfaces' such as roofs, roads and paving than natural environments which change the runoff characteristics of catchments with lower infiltration and greater runoff volumes and rates. This means that flow peaks in downstream waterways tend to become higher in magnitude and shorter in duration, leading to increased risk of flooding, erosion and greater capacity to transport pollutants such as rubbish or sediment.

Water quality issues in urban areas can be differentiated by the stage and nature of development, and include new development areas, established suburban areas and peri-urban areas. The risk of mobilisation of contaminants is particularly high when land is under new development or where infrastructure is old and becomes either inadequate or subject to failures (Gunn, 2014). Exposed soils and landscaping activities greatly increase the risk of erosion and soil loss off construction sites.

Stormwater and sewage treatment systems can treat water to a high standard, however, regardless of the design and layout of these systems, their capacity to control pollutant discharges depends on how well they are operated and maintained. One critical risk is that there be cross contamination between water of different qualities or intended for different purposes. For example, during a storm, stormwater may enter sewers which in term may overload the capacity of the sewerage mains and sewage treatment plants (STP) resulting in overflows or bypasses. Sewage systems may also accept various types of industrial effluent under licence or be subject to unlicensed discharge of liquid wastes from industrial or domestic sources. Remaining vigilant about the quality of effluent being received and how this is managed through treatment, storage and ultimately reuse or discharge are critical to the impact on natural receiving waters.

Marine debris is also an important consideration for water pollution in the region and results from littering and dumping of plastics bags, rubbish, garden waste, oils and paints, pesticide, pet waste or other contaminants into sewers, drains or waterways. One clear example of a significant impact is the effect of plastic bags washed from storm drains on marine turtles. The turtles are known to mistake plastic bags for food (jellyfish), which may cause a slow death by starvation from ingestion (GBRMPA, 2014b).

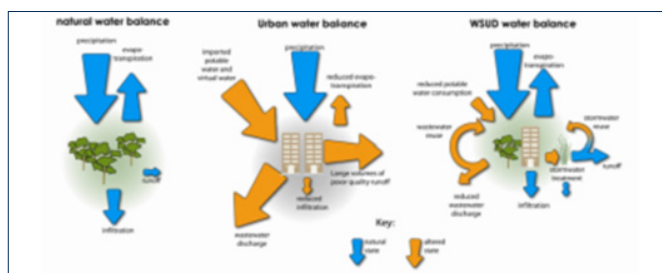


Figure 3.6. The effects of urbanisation on catchment hydrology and pollutant mobilisation contrasting natural, urban and urban with Water Sensitive Urban Design. Source: Healthy Waterways Limited.

3.6.2 Urban pollutant load contributions

Urban land uses contribute a large range of pollutants including TSS, nutrients, pesticides and other pollutants such as heavy metals, hydrocarbons, gross pollutants and pharmaceuticals (Kroon et al. 2013; Waters et al. 2014; Gunn, 2014). Overall, urban land uses contribute less than 10 per cent of the total regional load for the key water quality constituents affecting the GBR (Waters et al. 2014, in review). However, the nature and timing of urban water pollution is somewhat different to that of agricultural areas and impacts can be significant at local scales.

This section provides initial estimates of the relative contributions of major urban water pollution processes to pollutant loading of waterways. Estimations are based on information from numerous individual data sets, modelling and assessments made both within the region and across Australia (Gunn and Manning 2010; Gunn, 2014) and are documented further in Buchan (2016). However due to the complexity of factors influencing discharges and the lack of direct measurement data for most locations, the assessments must be considered preliminary rather than definitive.

The Black Ross WQIP provides information about diffuse source pollutant generation rates through event water quality monitoring (2006-2008), confirming anecdotal evidence and modelling. These results were combined with results from the Burdekin Region to provide comparative water quality pollutant generation rates for sediment (Gunn and Manning, 2010a). Figure 3.7 shows modelled results of TSS generation rate by land use, differentiating urban areas. The figure illustrates the disproportionate loading from developing urban areas in Townsville suggesting there is value in focusing management actions on this phase in urban land use.

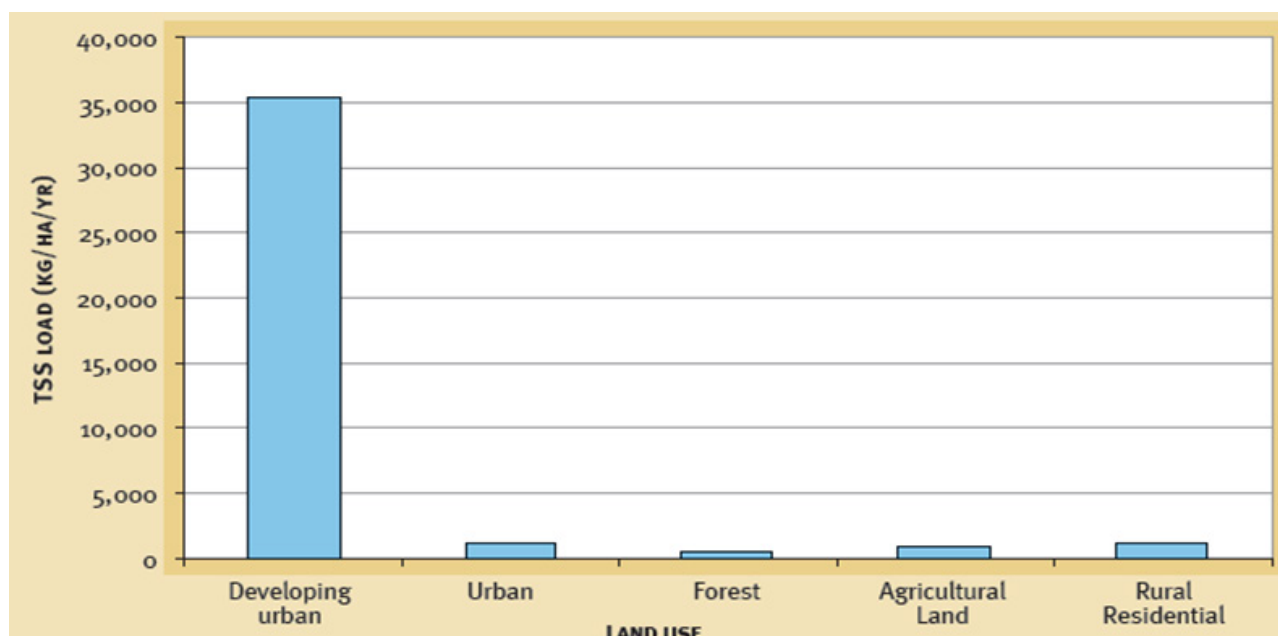


Figure 3.7. Relative annual sediment generation rate by land use on the Townsville Coastal area. Reproduced from: Townsville WQIP 2010, BMT WBM (2009).

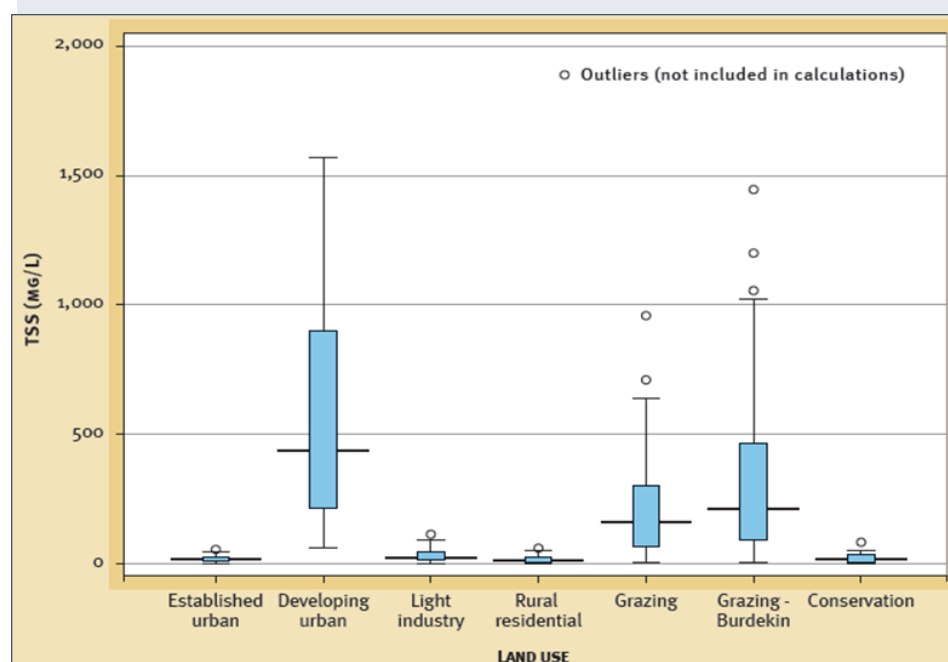


Figure 3.8. Sediment concentrations associated with land uses in the Townsville Coastal area and Burdekin Basin. Reproduced from: Townsville WQIP 2010, Bainbridge et al. (2008b).

Sediment concentrations measured in waterways of catchments associated with particular land uses are shown in Figure 3.8. These results confirm the observed high erosion rates and sediment movement associated with developing areas inferred in the modelled results.

Established suburbs and peri-urban areas

In established urban areas the infrastructure and landscape are largely stable, and there are typically few areas of soil disturbance or construction. However, there are still many sources of waterway pollutants and discharges of nutrients, chemicals, petrochemicals, organic materials and gross pollutants are still generally higher than natural areas. High nutrient loading may occur on turfed areas such as golf courses, race tracks, parks or domestic gardens. Adjacent hard, surface areas may also increase runoff rates and facilitate pollutant mobilisation.

Urban areas are small in all catchments other than the Ross and Black, and the pollutant export rates are typically lower than agricultural land use. However, high discharges can be locally or even regionally relevant and can impact specific ecosystems.

Table 3.3 shows the area of urban land in each catchment and the estimated total loads of key pollutants generated by surface runoff (stormwater) (and excluding sewage discharge). Insufficient data was available to establish different urban runoff generation rates for specific urban areas in the region. Most data is derived from, or fits well with, the Townsville and coastal centres. This accounts for over 85 per cent of the urban area. Estimates for Charters Towers and other inland towns in lower rainfall areas are more likely to be an over-estimate than an under-estimate.

Table 3.3. Estimated total urban land runoff for key pollutants by catchment.

Notes:

* Area data adjusted from 2009 maps using zoning and development data from local government (WRC, 2014, pers. comm. TCC & CCRC planning 2015).

¹ Based on generation rate of PN 1 kg/km²/yr; ² Based on generation rate of DIN 63 kg/km²/yr; ³ Based on generation rate of PP 0.5 kg/km²/yr; ⁴ Based on generation rate of DIP 1 kg/km²/yr; ⁵ Based on generation rate of TSS 23,200 kg/km²/yr.

Catchment	Urban areas	Area* km ²	Nitrogen PN ¹ t/yr	Nitrogen DIN ² t/yr	Phosphorus pp ³ t/yr	Phosphorus DIP ⁴ t/yr	Suspended Solids TSS ⁵ t/yr
Black	Townsville Palm Island	39	2,259	28	31	16	834
Ross	Townsville / Magnetic	123	7,717	95	105	55	2,851
Upper Burdekin	Charters Towers	25	1,568	19	21	11	579
Cape	Pentland	1	<0.01	<0.1	<0.01	<0.01	23
Belyando	Alpha	1	<0.01	<0.1	<0.01	<0.01	23
Suttor	Mines	1	<0.01	<0.1	<0.01	<0.01	23
Bowen	Collinsville	1	<0.01	<0.1	<0.01	<0.01	23
Lower Burdekin	Ayr, Home Hill	10	627	8	9	4	232
Don	Bowen	7	439	5	6	3	162
Total		205	12,861	158	176	91	4,752

The area of peri-urban land use in the region is estimated to be 45 square kilometres with a majority of these areas located around Townsville, Ayr and Home Hill, Charters Towers and Magnetic Island. Peri-urban or rural residential areas are often used for hobby farms. Many people living in peri-urban zones do so for lifestyle reasons and have urban based occupations. Where income and land management practice are not linked as for agricultural land, there is increased risk of a lack of expertise, time or equipment to manage the land for water quality protection. Rural residential properties may lack the infrastructure needed to deliver high quality sewage, or rubbish management.

The specifics of peri-urban expansion and the quality of land management in new and existing peri-urban areas were not quantified for this plan. Detailed data capture and complex analysis were considered unjustified with respect to catchment scale impacts of peri-urban area management on water quality, and preliminary pollutant load estimates are presented in Buchan (2016). The TSS load from peri-urban areas in the region is estimated to be approximately 2,000 tonnes/yr, and for all other parameters is predicted to be less than 1 tonne/yr. It is also noted that peri-urban areas are often not serviced with sewerage and rely on local land based sewage disposal processes which may be problematic for local waterways and groundwater resources.

The rates of pollutant generation in these areas is assessed as similar to developed urban, grazing and mostly not more than double land under minimal or conservation use.

Significant work is needed in the region to more accurately determine what the land uses actually are in areas classified as peri-urban and what the pollution risk is associated with these areas.

Urban sewage treatment

There are 11 STPs in the Burdekin Region that discharge into the GBRWHA or the catchment waterways. The estimated loads for these treatment plants are shown in Table 3.4. Data included in the table was obtained from discussions with Councils, the Queensland WaTERS database (DSITI, 2015) and the Source Catchments modelled data (Waters et al. in review) which estimates that approximately 79 per cent of the Total Nitrogen and Total Phosphorus is in dissolved inorganic form.

It is understood that sewage discharge has the potential to be a large contributor of nutrients leaving urban areas. For nutrients (PN, DIN, PP and DIP), current contributions are approximately 5 per cent of the current regional load, and for TSS less than 1 per cent of the regional load is from sewage effluent (Waters et al. in review). These estimates do not include the impact of sewage bypasses or connection of sewage to stormwater. Although STP contributions to nutrient and sediment loads are small at the regional scale, sewage discharges may still be highly relevant at a local scale in receiving areas such as Cleveland Bay.

Emerging pollutants from STPs such as pharmaceuticals, personal care products and pesticides are also of potential concern, although no specific studies have been conducted in the Burdekin Region to date. The results of a preliminary study in the Cairns region are relevant to Townsville (O'Brien et al. 2014), with detection of a range of chemicals including the artificial sweetener acesulfame, pesticides and pharmaceuticals (including antibiotics, analgesics, anti-convulsants, antidepressants, diuretics, and medical dyes). None of these chemicals were detected at concentrations known to cause environmental harm. It is recommended that an initial scoping study be carried out on the Cleveland Bay STP on these emerging pollutants to assess their risk in the Burdekin Region.

Table 3.4. Estimated average annual discharges for Burdekin Region sewage treatment plants. Source: Buchan (2016).

Catchment	Name of STP	Capacity Equivalent persons	Sub-catchment	Discharge point	Waste water Discharge	Dissolved Inorganic N	Particulate Nitrogen	Dissolved Inorganic P	Particulate Phosphorus	Total Suspended Solids
	Units				ML/Day	t/yr	t/yr	t/yr	t/yr	t/yr
Black	Palm Island	<3,000	Black	Halifax Bay	<0.5	<0.8	<0.2	<0.8	<0.2	<1
	Mt St John	<100,000	Black	Snaggy Ck	12	4	1	2.5	0.5	22
	Condon	10,000-50,000	Black	Bohle River	2.5	3	1	3.5	1	2.3
Ross	Magnetic Island	<3,000	Ross	Cleveland Bay	<0.5	<0.8	<0.2	<0.8	<0.2	<1
	Cleveland Bay	<100,000	Ross	Cleveland Bay	28	40	11	8	2	51
Upper Burdekin	Charters Towers	15,000	Burdekin above dam	Gladston Ck	1	3	0.5	2.2	0.5	4
Belyando	Alpha	<1000	Native/ Companion Ck	Alpha Ck	<0.5	<0.8	<0.2	<0.8	<0.2	<1
Bowen Broken Bogie	Collinsville	<5,000	Pelican Ck	Pelican Ck	0.33	0.8	0.2	0.8	0.2	1
Lower Burdekin	Ayr	10,000-15,000	Burdekin Delta	Kalamia Ck	2	7.5	1.5	5	1	11
	Home Hill	<5,000	Burdekin Delta	Burdekin R	0.7	6	1.6	1.7	0.4	3.4
Don	Bowen	<10,000	Don River	Don R	2	2.5	0.5	3	1	4.5
Whole Region	Total				49	67	17	27	7	99

Note: Data mostly represents the period 2010-2014 but site specific interpretation have been made to account for missing data or site operational upgrades or changes (Buchan, 2015 – supporting document).

New developments

It is well established that development sites have the potential to generate much higher pollutant loads than urban or, except for cropping areas, other established land uses (Gunn, 2014). However, sufficient local information to separate development site pollutant loading from urban and peri-urban stormwater could not be sourced for this plan. The modelling of TSS concentrations in runoff for the Black Ross WQIP (Bainbridge et al. 2008b; Gunn and Manning, 2010) suggest that fine particulate mobilisation is likely to be two orders of magnitude (>100 times) higher from development sites than other urban areas. The implications of this finding are that between 1 and 5 square kilometres of newly developing area may generate as much sediment load to waterway as the full 250 square kilometres of established urban and peri-urban land in the region. Areas planned for urban expansion in the region in the next few years are estimated to be around 5 square kilometres per year region-wide.

This information has further implications for other development or disruption areas outside of the urban context, including mine sites and linear infrastructure developments.

Further analysis of urban areas in Buchan (2016) has identified opportunities for reducing pollutant loads in the Burdekin region by targeting specific sources. It highlights the need to target new developments and improved sewage treatment standards.

3.7 Site and activity-specific impacts

As discussed in Section 3.5 there are generic impacts associated with any development involving urban site clearing, increased hard surface runoff and, in coastal zones, possible disruption of acid sulphate soils (Muller, 2006). This section discusses developments that may pose additional industry and site specific risks for water quality. It is recognised that each project can be complex by nature of its operation and local environmental context but more detailed assessment is outside the scope of this plan. More detailed information on individual potential water pollution hot spots is provided in catchment and sub-catchment summaries in the Catchment Atlas (2016).

3.7.1 Sources of pollutants

Intensive agriculture, aquaculture and food processing

The region has a number of sites associated with intensive agriculture, agricultural processing and aquaculture. These include:

- four sugarcane mills (all in the Lower Burdekin);
- one large active abattoir (Townsville), and two new sites under consideration (Lower Burdekin and Charters Towers);
- three feedlots 1,000-10,000 head, four feedlots of 500-1000 head and about 10 with <500 head (Crowley, G. 2015);
- several major aquaculture sites employing around 250 people, managing 240 hectares of ponds and producing >3000 tonnes of product worth >\$40 million/year (Wingfield, 2012). The Burdekin is among the most productive aquaculture areas in Queensland both in terms of total aquaculture production value and production output per hectare of ponds (Centre for International Economics, 2013); and
- one chicken farm.

Mining

Currently there are approximately 22 operational mine sites in the region, 44 sites under care and maintenance or active rehabilitation and 2,400 mines sites abandoned over the last 150 years (Figure 3.9; DNRM, Mines on line accessed October 2015).

The majority of mine sites are located in the Upper Burdekin catchment (gold and tin mining) where the greatest water quality risks are associated with heavy metal extraction and processing. The Belyando and Suttor catchments include parts of the Galilee Basin which include several very large development proposals for the rich coal and gas deposits. The Bowen Broken Bogie catchment, which includes parts of the Bowen Basin, has existing coal mines. Some sand mining occurs in coastal rivers near urban settlements, notably in the Lower Burdekin catchment.

Examples of key water quality and related hydrological issues associated with mining in the region include (drawn from mining and associated infrastructure EISs documentation Adani and Abbot Point 2010-2015):

- disruption of groundwater and surface water hydrology to land form changes;
- consumptive water use for dust suppression, on site processing or associated human settlement;
- disposal of water accumulating within the mine or diversion of water to prevent it entering the mine;
- potential failure of mine liquid waste holding ponds or leachate from above ground stockpiles;
- aerial transmission of mine dust onto local water bodies or land where they can be washed off;
- erosion of de-vegetated or disrupted sites;
- chemical and petrochemical spills;

- licensed wastewater discharges to waterways including disposal of intercepted groundwater and on-site retention basins during higher flow events; and
- the potential impacts of associated infrastructure including power, water supply, roads, rail, ports and urban development.

The water quality impact or risk associated with each of these issues is highly case specific and many issues are of minor significance at most sites. Where impacts or risks are high there is usually information in mine approval or operational management plans associated with licensing. However, comprehensive research into the cumulative effects and unlicensed risks of mines to waters in the region is yet to be undertaken.

Arguably the most significant mining related water quality issues for the region and the GBR are (GHD, 2012):

- the risk of gully development and stream bank erosion associated with abandoned mining sites;
- disruption of linked waterway and aquifer hydrology and quality through entrapment, diversion or use of water;
- the development and operation of associated infrastructure; and
- storm event driven mobilisation of toxic minerals or chemicals.

Only one mine has a registered discharge directly to waterways reported on the National Pollution Database (Accessed Sept 2015).

Heavy Industry

Much of the region's heavy industry is associated with mineral processing. The largest operations are Sun Metals (Zinc) which has a zero liquid discharge permit, Queensland Nickel and Xstrata Copper Refinery. Historically, tin mined in the region was processed near Townsville before export. In recent times nickel and cobalt ore has been imported for processing. Several other major industries have been established adjacent to the Port of Townsville and an industrial park is under consideration adjacent to the Abbot Point Port in the Don catchment.

The potential water quality risks from these industries are primarily associated with potential effluent holding dam failures in storm events and transfer of aerial pollutant emissions and particulates directly or through runoff into waterways or the ocean.

None of the industries had licensed continuous liquid discharge to waters registered on the national pollution database. However, there have been concerns over the risk of failure of waste containment ponds. Most have recorded potentially locally significant quantities of airborne particulate pollutants.

Military areas

There are significant areas of military base and training land in the region including Lavarack Barracks and RAAF Base Townsville (Airport), Townsville Field Training Area, Dotswood and Fanning River. Military training areas are treated as equivalent to conservation areas with respect to land use in this plan as they are not grazed by livestock, undertake controlled burns and remain largely undisturbed except for heavy vehicle and explosives field training activities.

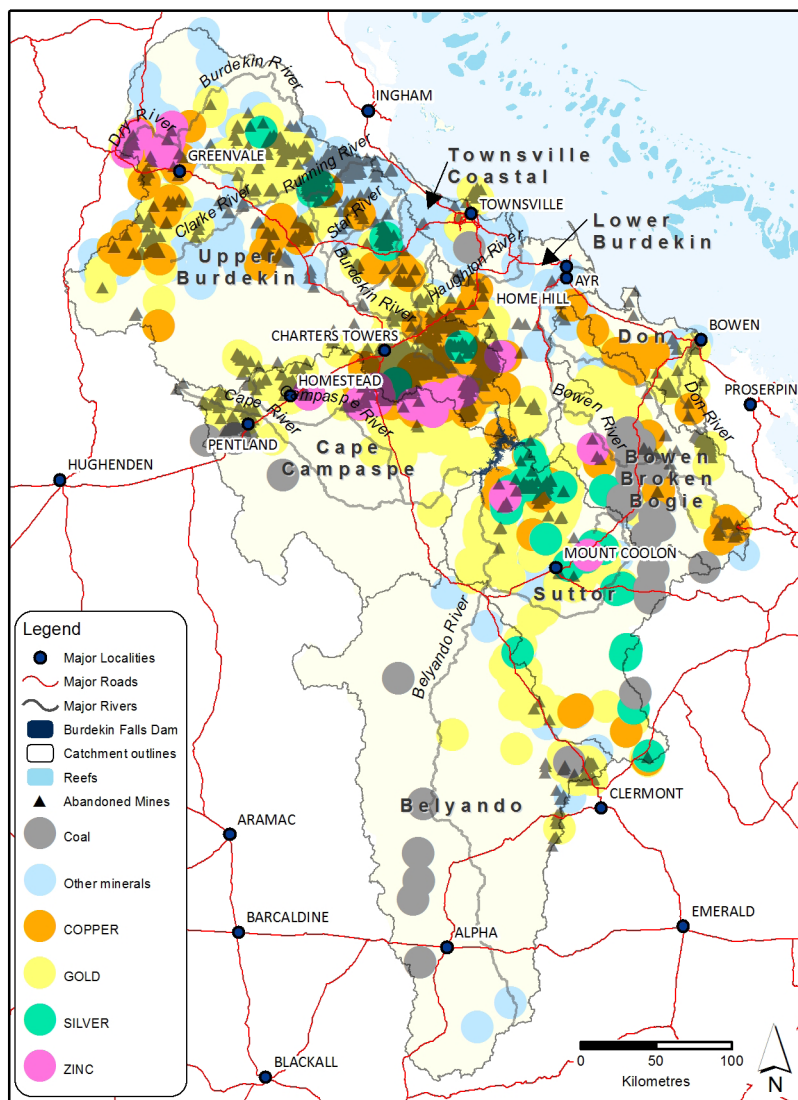


Figure 3.9. Current and past mining activity in the Burdekin Region. Source data: www.minesonlinemaps.business.qld.gov.au.

Ports and marine infrastructure

The major port facilities in the region include the Port of Townsville in Cleveland Bay, which is a mixed freight terminal at Townsville in the Ross catchment, and the Port of Abbot Point coal terminal in Abbot Bay in the Don catchment.

The Port of Townsville is a government-owned Corporation and seaport, and is the third largest seaport in Queensland after Port of Brisbane and the Central Queensland Port in Gladstone. Townsville is the largest port in Australia for exports in copper, zinc, lead and sugar (Port of Townsville, 2016). The port recently underwent an expansion in the Inner Harbour including construction of Quayside Terminal for cruise ships; further expansion of existing berths is proposed by 2017.

The Port of Abbot Point consists of a rail in-loading facility, coal handling and stockpile areas, and loading facilities located 2.8 kilometres offshore (NQBP Abbot Point, 2016). It is also adjacent to the Abbot Point State Development Area (APSDA), a 16,320 hectare site for dedicated industrial development. Further expansion of Abbot Point is proposed to provide export facilities for coal mined from the Galilee Basin. Current government policy requires dredge spoil from port expansion to be disposed of on land rather than in the GBR Marine Park and World Heritage Area. For Abbot Point dredge disposal into the local Caley Valley coastal wetlands has been ruled out in favour of an onsite bunded area. However, dewatering Abbot Point's dredge material may still generate significant local water quality impacts with an estimated 10,000m³ (32,000 tonnes) of fine sediment (0.1 per cent of 3 million tonnes dredged) to be returned into Abbot Bay in a 3-4 month period during the port expansion scheduled for 2016 (Abbot Point EIS). The impact of the ongoing dredging maintenance requirement for ports and their associated shipping channels remains undefined.

Both ports have Environmental Management Plans in place and conduct regular water quality and ecosystem health monitoring (Port of Townsville, 2016; NQBP, 2016).

A number of marinas also occur in the region including the Townsville Breakwater Marina in Cleveland Bay (325 berths), Townsville Motor Boat and Yacht Club in Ross Creek (165 berths), Magnetic Island Marina in Nelly Bay (106 berths), and the Bowen Boat Harbour in Bowen (~200 berths).

Ports and marinas can generate some potential risk to water quality, most likely at local scales, primarily through (GBRMPA, 2014b):

- stormwater runoff and management issues from land-based facilities;
- mobilisation of sediments from shorelines or the sea beds due to ship and boat movement, channel dredging or disruption of currents with breakwater structures;
- liquid waste discharge from shore loading facilities or shipping as licensed discharge, bilge water or spillage; and
- aerial contamination of water through dust or emissions from the freight handling area.

Arguably the most significant port related water quality risks for the region and the GBR are:

- the risk of maintenance dredging in resuspending of nutrients and fine sediments;
- importation or spreading of pest species from visiting ships or boats; and
- storm event driven spillage or leakage of toxic freight oils or fuels.

When measured in terms of volumes of suspended sediments and nutrient content, dredging has the potential to be significant to water quality wherever marine disposal options are considered (McCook et al. 2014). However, the volumes of suspended material in returned dewatering of land based dredge disposal sites is not likely to be significant at the regional scale. Definitive in depth research on these issues was beyond the scope of this plan (Waltham and Sheaves, 2015).

Dams and bunds

Any ponding or interruption of flow of waters in waterways and groundwater has the potential to significantly impact on water quality. Structures are regulated under the *Water Act 2000* [<https://www.legislation.qld.gov.au/legisln/current/w/watera00.pdf>] for ecologically sustainable planning, allocation and use of water and protecting the biological diversity and health of natural ecosystems. Pondered pastures are developed for grazing in some coastal areas.

It is important to recognise that water quality issues associated with structures may occur downstream rather than in the water body itself. For example, bottom release from dams, artificial channels (e.g. Haughton Main Channel) or modified natural systems / balancing storage. This may lead to release of acidic, salty, deoxygenated, nutrient rich, pesticide laden or turbid waters, or direct erosion of downstream river channels. For example, the Burdekin Dam provides a 'service' by capturing some of the sediment load from flooding rivers upstream. However, suspended sediment released from the dam during low flows results in the lower Burdekin River maintains high turbidity year round rather than clearing between flood events (Davis et al. 2014).

Further development of water infrastructure to facilitate agricultural expansion has the potential to have significant implications for downstream ecosystems (see Section 7).

Linear Infrastructure

Linear infrastructure includes all public systems for transport of people or goods, private roads and fence lines. This includes buried or overhead electricity lines, telecommunications, water, gas or fuel pipelines, roads and railways, tracks. The water quality risk from the development or maintenance of pipelines, power and communication lines, railways and roads reflects that for urban area development. However, this source of pollutants has not been quantified in the Burdekin Region or the GBR catchments more broadly. The primary risk is of land disturbance and clearing of vegetation which facilitates erosion and increased TSS and particulate nutrient loads.

All significant linear infrastructure development projects are regulated and require extensive environmental management plans which include provision for avoiding sediment movement or chemical spills which might affect waterways. The potential impacts on water quality associated with modification of the stream and shallow aquifer hydrology are also potentially significant. Development investigations always include detailed hydraulic analysis with respect to the engineering risk and integrity of the infrastructure, but information on the implications of changed water flow paths on the environment is usually less well documented. No specific analysis of water quality changes resulting from construction or operational phase of major linear infrastructure projects were undertaken for development of this plan. Analysis of the length and area of linear infrastructure and the rate of infrastructure expansion outside of urban areas also remains a knowledge gap which limits understanding of the significance of this issue in water quality risk assessment.

In order to get a broad indication of impacts it can be assumed that linear infrastructure only affects sediment runoff when it is under construction or maintenance, that easements are 10 metres wide and that sediment loading is similar to new developments in urban areas. On this basis, every 100 kilometres of new infrastructure or maintenance would have an equivalent potential sediment discharge to 1 square kilometre of new development or 100 square kilometres of existing urban area. Similarly, 250 kilometres of new linear infrastructure in the region would be expected to have similar impacts on sediment loading to all of the existing urban areas in the Burdekin Region.



4. What management goals & targets do we need to achieve for water quality?

4.1 Environmental Values and Water Quality Objectives

4.1.1 Environmental Values

A framework for identifying and setting Environmental Values (EVs) and Water Quality Objectives (WQOs) is established through the National Water Quality Management Strategy (NWQMS) and Queensland *Environmental Protection (Water) Policy 2009* (EPP Water). The *EPP Water 2009* includes a process for determining the EVs of waterways and corresponding WQOs, and identifies the need for appropriate consultation with the community, including industry and commerce sectors. This chapter outlines the process to identify EVs and derive WQOs, and results to date.

Environmental Values (EVs) are the qualities of waterways that need to be protected from the effects of pollution, waste discharges and other threats (such as runoff from agricultural lands) to ensure aquatic ecosystems are healthy and continue to provide essential ecosystem services, and waterways are safe for community use. All Queensland waters have EVs. Groundwater, surface water, freshwater rivers, creeks and streams, wetlands, estuaries and marine waters all have particular values that contribute to aquatic ecosystems and make them suitable for various human uses (e.g. drinking water, irrigation of crops, stock watering, recreation). Definitions of the various EVs of water are summarised in Table 4.1.

For aquatic ecosystems EVs, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) outline how aquatic ecosystems can be subdivided into three levels of protection related to their current condition. These are as follows:

1. High Ecological Value (HEV) ecosystems

These are essentially unmodified, highly valued aquatic ecosystems in which the ecological integrity is regarded as intact. Typically, these ecosystems are within national parks, conservation reserves or in remote and/or inaccessible locations. The management intent of HEV aquatic ecosystems is to protect the natural values to ensure that there is no detectable change beyond natural variability.

2. Slightly to Moderately Disturbed (SMD) ecosystems

These are aquatic ecosystems in which aquatic biodiversity may have been diminished to a small but measurable degree by human activity, but where the biological communities remain in a healthy condition. The management intent of SMD aquatic ecosystems is to maintain the existing natural values and improve or restore areas or components of the ecosystem that are disturbed towards natural condition.

3. Highly Disturbed (HD) ecosystems

These are degraded aquatic ecosystems with reduced and/or highly modified ecological values due to human activity. However, these ecosystems may still retain ecological or conservation values that should be protected. The management intent of HD aquatic ecosystems is to halt the decline and reverse the trend in water quality towards improvement.

In setting EVs for water, the following are considered, using stakeholder inputs and available datasets:

- the types of water uses and activities occurring (e.g. drinking water, agricultural, industrial, ecosystem protection and recreation);
- the number and location of these uses and activities;
- proposed future uses or activities;
- environmental, social and economic considerations that may influence the selected EVs; and
- any existing protection designations, (such as water bodies in a World Heritage area, National Park or Marine Park zones), technical studies etc. that may inform identification of aquatic ecosystem levels of protection (e.g. HEV).

As described earlier, EVs and WQOs for the Townsville region waters (Black and Ross River basins, Magnetic Island and adjacent coastal waters) are included in Schedule 1 of the EPP Water, following completion of the WQIP for that area (www.ehp.qld.gov.au/water/policy/townsville.html cited Nov. 2015).

Work to identify EVs throughout the Burdekin Region has been undertaken by or on behalf of NQ Dry Tropics in collaboration with community stakeholders, the Queensland Department of the Environment and Heritage Protection (formerly the Environmental Protection Agency) and GBRMPA. Draft EVs for the Burdekin Region were initially identified through literature review and collation from other sources of information (Greiner and Hall, 2006), surveys and workshops involving community groups, Traditional Owners, scientists and resource managers (Dight et al. 2007; Connolly et al. 2008) and specific community engagement activities. However, the extensive and diverse water resources of the Burdekin Region have posed a significant challenge in identifying the full suite of EVs that the community holds for water. Therefore, further consultation was undertaken for the whole region in 2013 which comprised all tidal and non-tidal waters and groundwaters of the Haughton, Burdekin and Don Basins, the eastern section of the Ross Basin, and the adjoining coastal waters to the limit of Queensland waters (Kerr, 2013). Recent work has been undertaken to spatially identify EVs, and derive aquatic ecosystem water quality guidelines in Don, Haughton and marine waters. Draft outputs are included in this WQIP for comment. Our current understanding of the EVs of water in the region is presented for each of the 52 sub-catchments within the Catchment Atlas (based on the 2013 work led by NQ Dry Tropics).

The main areas identified to date that are considered as “**essentially unmodified**” and contain HEV freshwater areas are presented for each of the 52 sub-catchments within the Catchment Atlas. Updated draft EVs/level of protection mapping to support draft aquatic ecosystem water quality guidelines is provided for the Haughton (Figure 4.1), Don (Figure 4.2) and downstream marine waters (Figure 4.3). Subject to community/stakeholder consultation and further review these would be considered for scheduling under the *EPP Water 2009*.

As a World Heritage Area and Marine Park, the desired state of the GBR is that all ecosystems be of high ecological value. While there are no aquatic ecosystems in Australia that are entirely without some human influence, the ecological integrity of high conservation/ecological-value systems is regarded as being intact. For GBR waters, the area affected by flood plumes with a high risk of impact on critical aquatic ecosystems such as coral reefs and seagrass meadows is acknowledged as being in a slightly to moderately disturbed state (shown on Figure 4.3 as the plume line). These waters are identified, with some adaptation, through modelled outputs of the risk assessment element of the Scientific Consensus Statement 2013 (Brodie et al. 2013a).

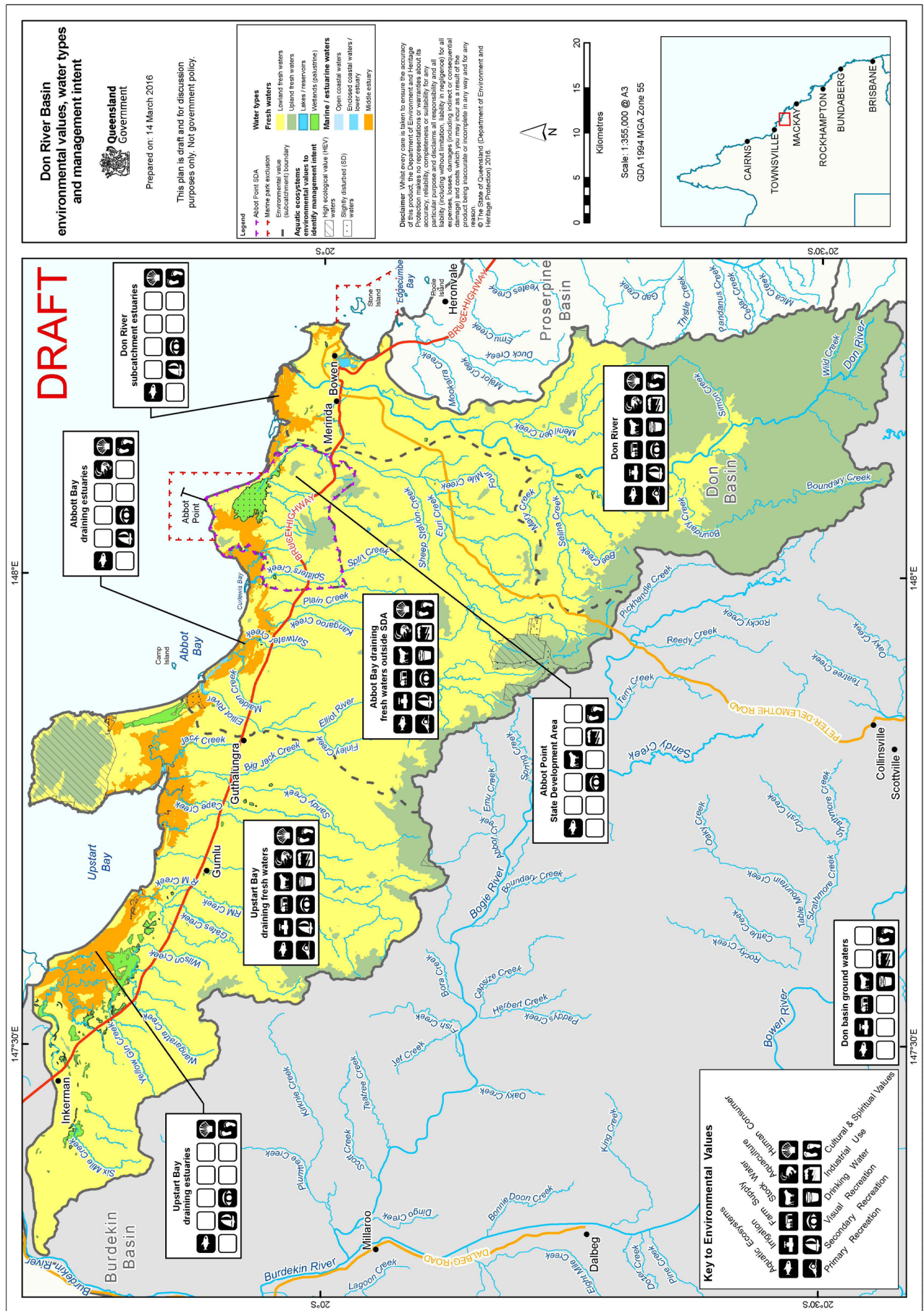
The flood plume impact area can only ever be indicative. At any one time the flood waters may or may not reach particular parts of the marine ecosystem depending on conditions, and may or may not carry above natural levels of pollutants. Care should be taken when comparing samples in waters near boundaries for assessment against guidelines.



Environmental Values	Supporting Details
Aquatic Ecosystems	 Supporting pristine or modified Aquatic Ecosystems - see details of three possible “Levels of Protection” below
High conservation ecological value systems (HEV)	These are systems that are largely unmodified or have undergone little change. They are often found within national parks, conservation reserves or inaccessible locations. Targets for these systems aim to maintain no discernible change from this natural condition (i.e. no physical, chemical and biological change).
Slightly to moderately disturbed systems (SMD)	These systems have undergone some changes but are not considered so degraded as to be highly disturbed. Aquatic biological diversity may have been affected to some degree but the natural communities are still largely intact and functioning. An increased level of change in physical, chemical and biological elements of these ecosystems is to be expected.
Highly disturbed systems (HD)	These are degraded systems likely to have lower levels of naturalness. These systems may still retain some ecological or conservation values that require protecting. Targets for these systems are likely to be less stringent and may be aimed at retaining a functional but highly modified ecosystem that supports other environmental values also assigned to it (e.g. primary industries).
Primary Industries	 Irrigating crops such as sugar cane, lucerne, etc.
	 Water for Farm Use such as in fruit packing or milking sheds, etc.
	 Stock watering
	 Water for Aquaculture such as barramundi or red claw farming
	 Human Consumption of wild or stocked fish or crustaceans
Recreation & Aesthetics	 Primary Recreation with direct contact with water such as swimming or snorkelling
	 Secondary Recreation with indirect contact with water such as boating, canoeing or sailing
	 Visual Recreation with no contact with water such as picnicking, bushwalking, sightseeing
Drinking Water	 Raw Drinking Water supplies
Industrial Uses	 Water for Industrial Use such as power generation, manufacturing plants
Cultural & Spiritual	 Cultural and Spiritual values.

Table 4.1. Definition of Environmental Values (from DEHP, 2015).

Figure 4.2. Don River Basin environmental values, water types and management intent (DEHP, 2016, reproduced with permission) .



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Some of the key points raised in the NQ Dry Tropics consultation report (Kerr, 2013) included:

- the EV's for farm and stock water use were consistently rated high, as was irrigation where this was reported. It is noted that groundwater was reported to have been used for irrigation of grass for livestock and drinking water, and it is probable that surface water is also used for this purpose in many sub-catchments;
- concern was raised about the impact of the mining and resources sector on EVs. Comment was made that it seemed pointless attributing EVs when a whole environment can be removed by large scale mining activity;
- feedback from one Regional Council included "the EVs of the region are unfortunately somewhat degraded due to grazing and mining activities. The full extent of this on aquatic values is yet to be determined";
- aquaculture was reported in the Allingham and Burdekin River (above dam) sub-catchments which may be related to red claw farming. Aquaculture was also reported in the Glenmore Creek sub-catchment but from information in the Burdekin WQIP the area does not seem conducive to aquaculture. A number of coastal sub-catchments also reported aquaculture; and
- community comment on the Environmental Values for coastal waters was focussed on the potential impacts of coastal development particularly dredging and port development.

Some general feedback from respondents included:

- the commercial fishing industry needs clean ocean waters to survive and we are most concerned about the impact of dredging for port development on the future of the industry;
- the cumulative impacts of runoff water quality, and siltation and dredging activities from coastal developments are having serious consequences on the ability of seagrass to recover over large areas of the region; and
- there are lots of turtles in our area but we are having problems with algal blooms affecting their feeding grounds while evidence has been found of elevated levels of cobalt in the turtles and we are worried about where that is coming from.

Traditional Owners emphasised that all freshwater, tidal and coastal waters have high cultural values for their people. The Traditional Owner group was concerned about:

- the permanent loss of EVs through mining and other development;
- continuous loss of habitat for aquatic species eg eels due to damming of rivers and creek; and
- the impact of water quality on turtles, dugongs, fish and other marine species.

The draft EVs for the region are documented in Table 4.2.

EVs for groundwater resources were also documented through a desktop study conducted by Dr Ian Dight (reported in Kerr, 2013). These findings are shown in Table 4.3. Some of the key points that were identified included:

- personal knowledge and communications with landholders has confirmed that most grazing properties, particularly those in drier, more remote areas of the region, rely on bore water (groundwater) for farm use and stock watering. While rain water collected in tanks is preferred for drinking water, this source is usually supplemented by groundwater sources (including the use of spikes within wet or dry water courses) as rainwater availability decreases towards the end of the dry season and/or during low rainfall years;
- the presence of bores in all sub-catchments, as ascertained by application of the DNRM Groundwater Database, reflects this widespread use of groundwater. It should be noted, however, that as licenses for the extraction of groundwater for farm use, small scale pasture irrigation and stock watering are not required outside prescribed areas along the coast (i.e. most of the Burdekin River Basin) information within the Groundwater Database on farm bores is incomplete;
- the high density of bores in areas of intensive agriculture for sugarcane, horticulture and grains (the coastal sub-catchments between Giru and Bowen, and in the Suttor Basin) strongly reflects the use of groundwater within these sub-catchments for irrigation;
- the majority of urban centres in the Charters Towers region utilise surface water supplies through direct pumping from rivers, dams, weirs or through spear points into nearby rivers or streams. However, some small townships such as Pentland rely completely on groundwater;
- Glenden is the main town within the Burdekin Catchment area of Isaac Council and is supplied via piped surface water sourced from the Bowen River;
- there is limited underground water used for urban purposes in the Whitsunday Council region with the majority of water for Bowen, for example, piped from the Proserpine River, although this is supplemented by groundwater from the Bowen GMA – Don River aquifer. This would therefore be integrated into the full suite of domestic and urban uses for the town. Collinsville is supplied from the Bowen River Weir;
- Alpha, in the Barcaldine Council area, is dependent on three bores for all domestic and urban uses, including drinking, parks and recreation e.g. the swimming pool, and light industrial use; and

- the towns and residential areas surrounding Ayr and Home Hill in the Burdekin Council region are supplied by a number of bores. The water is used for all domestic and urban uses but has treatment and infrastructure maintenance issues due to high levels of iron and manganese. The small township of Dalbeg also relies on groundwater supplies supplied from three bores managed by SunWater.

Through the community consultation process, generally, all sub-catchments recorded high and medium values for farm, stock and drinking uses for groundwater. Industrial uses were broadly reported and irrigation was also recorded outside of known irrigation areas. Other comments included *“Groundwater is also used to reduce the risk of saltwater intrusion into coastal aquifers from strategic recharge pits in the lower Burdekin”*. A comment from the Burdekin (Blue Range) sub-catchment was about the use of groundwater in mining camps (gold, diatomaceous earth, other heavy metals) and for use in mining from the Rollston River sub-catchment.

4.1.2 Water Quality Guidelines and Water Quality Objectives

Water quality guidelines define desirable ranges and trigger values / levels for certain measurable parameters that should be achieved to protect the EVs of particular waterways. Water quality guidelines are based on scientific evidence and judgement and may be defined for a range of physical (e.g. turbidity, suspended sediment), chemical (e.g. phosphorus, nitrogen, pesticides), and biological parameters (e.g. algae, macro-invertebrates and fish) as well as other measures of catchment condition (e.g. erosion levels, riparian vegetation, channel morphology).

Water quality guidelines are most frequently expressed as concentrations. For example, where toxic chemicals are polluting drinking water, then the water quality guideline will be the maximum permitted concentration of the toxicant, based on the best available knowledge, which will ensure no harm to consumers. Concentrations above the guideline value will indicate a possible health risk and trigger a response.

Water quality objectives (WQOs) are trigger values for the protection of both aquatic ecosystems and the human values and uses. They are therefore based on the EVs of water identified by the community and the existing water quality guidelines that are intended to protect these values. WQOs are set by identifying the appropriate indicators for the threats (e.g. sediment, nutrients and pesticides of concern) and EVs that need to be protected, then applying the corresponding water quality guideline values.

Human use EV guidelines

Water quality guidelines for **human use EVs** (e.g. irrigation, recreation) are based on relevant national guidelines. These include Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), Australian Drinking Water Guidelines (NHMRC, 2011), and Guidelines for Managing Risks in Recreational Water (NHMRC 2008), among others. Table 4.4 provides a summary of the proposed water quality guideline sources to protect human use EVs. Unless otherwise stated, these are based on relevant national water quality guidelines, and reference to those national guidelines or codes is essential to obtain comprehensive listings of all indicators and corresponding guideline values.

Table 4.2. Draft Environmental Values ascertained from published sources and community feedback. Source: Kerr, (2013).

Burdekin Catchments & sub-catchments													
Upper Burdekin Catchment													
Allingham Creek (1)	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
Basalt River (2)	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	
Burdekin River (Above Dam) (3)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Burdekin River (Blue Range) (4)	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
Camel Creek (5)	✓		✓	✓					✓			✓	
Clarke River (6)	✓			✓			✓	✓	✓	✓	✓	✓	
Douglas Creek (7)	✓			✓					✓			✓	
Dry River (8)	✓			✓					✓		✓	✓	
Fanning River (9)	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	
Gray Creek (10)	✓			✓					✓			✓	
Hann Creek (11)	✓		✓	✓			✓	✓	✓		✓	✓	
Keelbottom Creek (12)	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	
Kirk River (13)	✓	✓		✓		✓	✓	✓	✓		✓	✓	
Lolworth Creek (14)	✓			✓		✓	✓	✓	✓	✓		✓	
Running River (15)	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	
Star River (16)	✓			✓		✓	✓	✓	✓	✓		✓	
Upper Burdekin River (17)	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Cape Campaspe Catchment													
Campaspe River (18)	✓		✓	✓			✓	✓	✓	✓	✓	✓	
Cape River (19)	✓	✓	✓	✓					✓	✓		✓	
Lower Cape River (20)	✓	✓		✓					✓			✓	
Rollston River (21)	✓			✓					✓			✓	
Belyando Catchment													
Belyando floodplain (22)	✓	✓	✓	✓					✓	✓		✓	
Carmichael River (23)	✓		✓	✓					✓			✓	
Fox Creek (24)	✓			✓			✓		✓	✓		✓	
Mistake Creek (25)	✓	✓	✓	✓					✓	✓	✓	✓	
Native Companion Creek (26)	✓	✓	✓	✓					✓			✓	
Sandy Creek (27)	✓			✓					✓			✓	
Upper Belyando River (28)	✓	✓	✓	✓					✓	✓		✓	
Suttor Catchment													
Diamond Creek (29)	✓		✓	✓			✓	✓	✓			✓	
Logan Creek (30)	✓	✓		✓					✓			✓	
Lower Suttor River (31)	✓			✓		✓		✓	✓			✓	
Rosetta Creek (32)	✓	✓		✓					✓	✓	✓	✓	
Sellheim River (33)	✓			✓					✓			✓	
Upper Suttor River (34)	✓			✓		✓	✓	✓	✓	✓	✓	✓	
Bowen Broken Bogie Catchment													
Bogie River (35)	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	
Bowen River (36)	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
Broken River (37)	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	
Glenmore Creek (38)	✓		✓	✓		✓	✓	✓	✓			✓	
Little Bowen River (39)	✓		✓	✓			✓	✓	✓	✓		✓	
Pelican Creek (40)	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	
Rosella Creek (41)	✓			✓					✓		✓	✓	

Burdekin Catchments & sub-catchments												
Lower Burdekin Catchment												
Barratta Creek (42)	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Burdekin Delta (43)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Burdekin River (below Dam) (44)	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Haughton River (45)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Landers Creek (46)	✓	✓		✓					✓			✓
Stones Creek (47)	✓			✓			✓	✓	✓			✓
Coastal Waters	✓					✓	✓	✓	✓			✓
Don Catchment												
Upstart Bay (48)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Abbott Bay (49)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Don River (50)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coastal Waters	✓				✓	✓	✓	✓	✓			✓
Townsville Coastal Plain Catchment												
Ross River (Eastern section) (52)	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓

Table 4.3. Draft Environmental Values for groundwater for all sub catchments in the Burdekin region. Source: Kerr, (2013).

Burdekin Catchments & sub-catchments					
Upper Burdekin Catchment					
Allingham Creek (1)	✓	✓	✓	✓	✓
Basalt River (2)	✓	✓	✓	✓	✓
Burdekin River (Above Dam) (3)	✓	✓	✓	✓	✓
Burdekin River (Blue Range) (4)	✓	✓	✓	✓	✓
Camel Creek (5)		✓	✓	✓	✓
Clarke River (6)		✓	✓	✓	✓
Douglas Creek (7)		✓	✓	✓	✓
Dry River (8)		✓	✓	✓	✓
Fanning River (9)		✓	✓	✓	✓
Gray Creek (10)		✓	✓	✓	✓
Hann Creek (11)	✓	✓	✓	✓	✓
Keelbottom Creek (12)		✓	✓	✓	✓
Kirk River (13)	✓	✓	✓	✓	✓
Lolworth Creek (14)		✓	✓	✓	✓
Running River (15)		✓	✓	✓	✓
Star River (16)		✓	✓	✓	
Upper Burdekin River (17)		✓	✓	✓	✓
Cape Campaspe Catchment					
Campaspe River (18)		✓	✓	✓	✓
Cape River (19)		✓	✓	✓	✓
Lower Cape River (20)		✓	✓	✓	✓
Rollston River (21)		✓	✓	✓	✓
Belyando Catchment					
Belyando floodplain (22)		✓	✓	✓	
Carmichael River (23)		✓	✓	✓	
Fox Creek (24)		✓	✓	✓	
Mistake Creek (25)	✓	✓	✓	✓	✓
Native Companion Creek (26)	✓	✓	✓	✓	✓
Sandy Creek (27)		✓	✓	✓	
Upper Belyando River (28)		✓	✓	✓	
Suttor Catchment					
Diamond Creek (29)	✓	✓	✓	✓	
Logan Creek (30)	✓	✓	✓	✓	✓
Lower Suttor River (31)		✓	✓	✓	✓
Rosetta Creek (32)		✓	✓	✓	✓
Sellheim River (33)		✓	✓	✓	✓
Upper Suttor River (34)	✓	✓	✓	✓	✓
Bowen Broken Bogie Catchment					
Bogie River (35)	✓	✓	✓	✓	✓
Bowen River (36)		✓	✓	✓	
Broken River (37)		✓	✓	✓	
Glenmore Creek (38)		✓	✓	✓	
Little Bowen River (39)	✓	✓	✓	✓	✓
Pelican Creek (40)	✓	✓	✓	✓	✓
Rosella Creek (41)		✓	✓	✓	✓

Burdekin Catchments & sub-catchments					
Lower Burdekin Catchment					
Barratta Creek (42)	✓	✓	✓	✓	✓
Burdekin Delta (43)	✓	✓	✓	✓	✓
Burdekin River (below Dam) (44)	✓	✓	✓	✓	✓
Haughton River (45)	✓	✓	✓	✓	✓
Landers Creek (46)	✓	✓	✓	✓	✓
Stones Creek (47)		✓	✓	✓	✓
Don Catchment					
Upstart Bay (48)	✓	✓	✓	✓	✓
Abbott Bay (49)	✓	✓	✓	✓	✓
Don River (50)	✓	✓	✓	✓	✓
Townsville Coastal Plain Catchment					
Ross River (Eastern section) (52)	✓	✓	✓	✓	✓

Table 4.4. Proposed water quality guideline sources to protect human use EVs (those EVs other than the aquatic ecosystem, e.g. recreation, stock watering, aquaculture and crop irrigation). Provided by DEHP, February 2016.

Environmental value	Water type/area	Water quality guidelines to protect EV (refer to specified codes and guidelines for full details) ¹
Suitability for drinking water supply	All fresh waters including groundwaters	Note: For water quality after treatment or at point of use refer to the following guidelines and legislation: • Australian Drinking Water Guidelines (ADWG, 2011, updated Dec 2013) • <i>Public Health Act 2005</i> and Regulations • <i>Water Supply (Safety and Reliability) Act 2008</i>, including any approved drinking water quality management plan under the Act • <i>Water Fluoridation Act 2008</i> Quality of raw water (prior to treatment) to meet requirements of water supply operators.
Protection of the human consumer (including oystering)	Fresh waters, estuarine and coastal waters	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (herein referred to as AWQG) and Australia New Zealand Food Standards Code, Food Standards Australia New Zealand, 2007 and updates.
Protection of cultural and spiritual values	Fresh waters (including groundwaters), estuarine and coastal waters	Protect or restore indigenous and non-indigenous cultural heritage consistent with relevant government policies and plans.
Suitability for industrial use	Fresh waters, estuarine and coastal waters	Water quality requirements for industry vary within and between industries. The AWQG do not provide guidelines to protect industries, and indicate that industrial water quality requirements need to be considered on a case-by-case basis. This EV is usually protected by other values, such as the aquatic ecosystem EV.
Suitability for aquaculture	Fresh waters, estuarine and coastal waters	AWQG and Australia New Zealand Food Standards Code, Food Standards Australia New Zealand, 2007 and updates.
Suitability for irrigation	All fresh waters including groundwaters	AWQG (including algae, cyanobacteria, pathogens, ions, metals, salinity, sodicity, herbicides and other indicators).
Suitability for stock watering	All fresh waters including groundwaters	AWQG (including faecal coliforms, total dissolved solids, inorganic salts/ions, heavy metals, cyanobacteria and pathogens).
Suitability for farm supply/use	All fresh waters including groundwaters	AWQG.
Suitability for primary contact recreation	Fresh waters, estuarine and coastal waters	NHMRC (2008) Guidelines for Managing Risks in Recreational Water (including faecal contamination, physical hazards, toxic/irritating chemicals, venomous/dangerous aquatic organisms, cyanobacteria).
Suitability for secondary contact recreation	Fresh waters, estuarine and coastal waters	NHMRC (2008) Guidelines for Managing Risks in Recreational Water.
Suitability for visual recreation	Fresh, estuarine and coastal waters	Objectives as per NHMRC (2008) Guidelines for Managing Risks in Recreational Water.

¹ The water quality guideline source documents include: *Australian Drinking Water Guidelines* (NHMRC, 2011, updated February 2016); *Australia New Zealand Food Standards Code* (Australian Government); *AWQG - Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000); *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008).

Aquatic ecosystem guidelines

The primary guideline sources for aquatic ecosystems are the Queensland Water Quality Guidelines (DEHP, 2009), GBRMPA Water Quality Guidelines (GBRMPA, 2010) and Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). Table 4.5 and Table 4.6 summarise the WQGs for a selection of indicators based on Queensland Water Quality Guidelines, ANZECC and GBRMPA guidelines. These would apply in the absence of scheduled EVs/WQOs or local guidelines and are equivalent to HEV standing. The GBRMPA guidelines form the primary basis for identification of catchment-specific ecologically relevant targets in this WQIP.

Generally these guidelines should apply to the quality both of surface water and of groundwater since the environmental values which they protect relate to above-ground uses (e.g. irrigation, drinking water, farm animal or fish production and maintenance of aquatic ecosystems). Hence groundwater should be managed in such a way that when it comes to the surface, whether from natural seepages or from bores, it will not cause the established water quality objectives for these waters to be exceeded, nor compromise their designated environmental values. An important exception is for the protection of underground aquatic ecosystems and their novel fauna. Little is known of the lifecycles and environmental requirements of these quite recently-discovered communities, and given their high conservation value the groundwater upon which they depend should be given the highest level of protection (ANZECC/ARMCANZ, 2000).

In accordance with the national framework, the Reef Long term Sustainability Plan, and EPP Water, locally relevant water quality guidelines for **aquatic ecosystem EVs** are currently being developed in the Burdekin and other reef regions. Local draft WQGs are included in *Appendix 4. Draft local water quality guidelines (Aquatic Ecosystem Environmental Values)* for the Don and Haughton basins and downstream coastal/marine waters (Bowling Green Bay, Lower Burdekin coastal waters, Upstart Bay, Abbot Point Port core port waters outside GBR Marine Park, Abbot Bay waters within GBR Marine Park – outside of core port waters, Port Denison – Bowen Port and Edgumbe Bay midshelf waters near Holbourne Island). The guidelines are developed for particular levels of protection and water type. Additional work is underway for other waters of the Burdekin, anticipated by May-June 2016. Subject to stakeholder input and further review the guidelines may be submitted for inclusion in Schedule 1 of the *EPP (Water) 2009*.

Guidelines for GBR waters are derived with the management intent of maintaining waters of the GBR at high ecological value where it is already met. Where GBR water quality is classified as being in a slightly-to moderately-disturbed state, the management intent is to return the quality of this water to that of a high ecological value. The GBRMPA has derived, and applies, water quality guidelines based upon achieving:

- An annual mean concentration of Chlorophyll *a*.
- An annual mean concentration for total suspended solids, particulate nitrogen and phosphorus.

Annual mean guidelines were derived from empirical relationships that reflect the quality of the water required to support a healthy ecosystem state. Seasonal adjustments have been determined and should be applied where comparative (test site) data are collected within only one season. Other parameters have been derived from local source data where sufficient or have defaulted to the Queensland Water Quality Guidelines, or to the national Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) where appropriate. Details of the data and decision making are contained in DEHP supporting documents to catchment-level objectives being progressively implemented through schedules under *EPP (Water) 2009* for GBR waters.

For waters of the GBR that are outside state coastal waters the objectives from adjacent waters of the same type apply.

The GBRMPA also derived guidelines for a number of pesticides. These guidelines are under review at time of writing and are expected to be superseded by updated national guidelines. For toxicants the derivation is based upon effect concentrations and therefore applies regardless of flow. Toxicant concentrations that are protective of 99 per cent of species, derived in accordance with national protocols, apply unless otherwise specified.

The draft water quality guidelines for open coastal/marine waters included in this WQIP have been based on achieving the current water quality (as interpreted and analysed by GBRMPA), or GBRMPA Water Quality Guidelines. Where current water quality is better than the relevant GBRMPA guidelines, the local guidelines are set to maintain that current water quality. Where water quality is worse than GBRMPA guidelines the intent is to improve to the GBR guidelines.

Table 4.5. Draft Water Quality Objectives for freshwater streams, lakes and wetlands. Values are based on State and National Water Quality Guidelines for aquatic ecosystem protection, as follows: a = DEHP (2009); c = ANZECC/ARMCANZ (2000); d = proposed Guideline value to protect 99 per cent of organisms, Smith et al. (in prep.); nd = not determined (insufficient data).

Key Indicator of Pollution		Water Type			
		Upland Streams	Lowland Streams ^a	Lakes ^a	Wetlands ^c
Total suspended Sediment (TSS) (mg/L)		nd	10	nd	nd
Turbidity (NTU)		25	50	1-20	2-200
Ammonia-N (µg/L)		10	20	10	10
NOx-N (µg/L)		15	60	10	10
Organic N (µg/L)		225	420	330	nd
Total N (µg/L)		250	500	350	350-1,200
FRP (µg/L)		15	20	5	5-25
Total P (µg/L)		30	50	10	10-50
Chlorophyll a (µg/L)		Nd	5	3	10
Ametryn (µg/L)	Current ^c	nd	nd	nd	nd
	Proposed ^d	0.02	0.02	0.02	0.02
Atrazine (µg/L)	Current ^c	0.7	0.7	0.7	0.7
	Proposed ^d	3.7	3.7	3.7	3.7
Diuron (µg/L)	Current ^{c,1}	0.2	0.2	0.2	0.2
	Proposed ^d	0.2	0.2	0.2	0.2
Hexazinone (µg/L)	Current ^{c,1}	75	75	75	75
	Proposed ^d	0.2	0.2	0.2	0.2
Imidacloprid (µg/L)	Current ^c	nd	nd	nd	nd
	Proposed ^d	0.03	0.03	0.03	0.03
Tebuthiuron (µg/L)	Current ^c	0.02	0.02	0.02	0.02
	Proposed ^d	4.3	4.3	4.3	4.3
2,4-D (µg/L) ^c		140	140	140	140

¹ From ANZECC /ARMCANZ (2000): A freshwater low reliability trigger value of 75 µg/L was calculated for hexazinone using an AF of 1000. In the absence of marine data, this was adopted as a marine low reliability trigger value. These figures should only be used as indicative interim working levels. A freshwater low reliability trigger value of 0.2 µg/L was calculated for diuron using an AF of 200 on the lowest of a limited set of chronic data.

Table 4.6. Water Quality Objectives for end-of-catchment estuarine and marine waters. values are based on State and National Water Quality Guidelines, as follows: a = DEHP (2009); b = GBRMPA (2010); c = ANZECC/ARMCANZ (2000); d = proposed Guideline value to protect 99 per cent of organisms, Smith et al. (in prep.); nd = not determined (insufficient data).

Key Indicator of Pollution	Estuarine waters			Marine waters		
	Upper estuary	Mid-estuary	Enclosed coastal	Coastal ^b	Inshore ^b	Offshore ^b
Total suspended Sediment (TSS) (mg/L)	25 ^a	20 ^a	≤2 ^{a/b}	≤1	≤1	≤1
Secchi (m)	0.4 ^a	1.0 ^a	≥1.5a/b	Annual ≥10	≥11	Annual ≥17
Turbidity (NTU)	25 ^a	8 ^a	≤4 ^{a/b}	≤2	≤0.5	≤1
Ammonia- N (µg/L)	30 ^a	10 ^a	≤2 ^{a/b}	≤1	≤4	≤2
NOx-N (µg/L)	15 ^a	10 ^a	≤4 ^{a/b}	≤1	≤0.5	≤0.5
Organic N (µg/L)	400 ^a	260 ^a	180 ^{a/b}	≤70	≤60	≤70
Particulate N (µg/L)	nd	nd	nd	Annual ≤13 Dry ≤16 Wet ≤25	≤14	Annual ≤13 Dry ≤16 Wet ≤25
Total N (µg/L)	450 ^a	260 ^a	200 ^{a/b}	≤100	≤90	≤100
FRP (µg/L)	10 ^a	8 ^a	≤1 ^{a/b}	≤2	≤1	≤1
Particulate P (µg/L)	nd	nd	nd	Annual ≤ 2.1 Dry ≤ 2.3 Wet ≤3.3	≤2.0	Annual ≤ 1.9 Dry ≤ 1.5 Wet ≤2.3
Total P (µg/L)	40 ^a	25 ^a	≤12 ^{a/b}	≤12	≤10	≤12
Chlorophyll a (µg/L)	10 ^a	4 ^a	≤1 ^{a/b}	Annual ≤0.45 Dry ≤ 0.32 Wet ≤ 0.63	≤ 0.33	≤0.27
Ametryn (µg/L)	nd	nd	0.5 ^b	0.5	0.5	0.5
Atrazine (µg/L)	0.7 ^c	0.7 ^c	0.6 ^b	0.64 ^d	0.64 ^d	0.64 ^d
Chlorpyrifos (µg/L)	nd	nd	0.005 ^c	0.005 ^c	0.005 ^c	0.005 ^c
Diuron (µg/L)	1.8 ^{c,1}	1.8 ^{c,1}	0.9 ^b	0.9	0.9	0.9
Hexazinone (µg/L)	75 ^{c,1}	75 ^{c,1}	1.2 ^b	1.2	1.2	1.2
Tebuthiuron (µg/L)	0.02 ^b	0.02 ^b	0.02 ^b	0.02	0.02	0.02
2,4-D (µg/L)	140 ^c	140 ^c	0.8 ^b	0.8	0.8	0.8

¹ From ANZECC/ARMCANZ (2000): A freshwater low reliability trigger value of 75 µg/L was calculated for hexazinone using an AF of 1000. In the absence of marine data, this was adopted as a marine low reliability trigger value. These figures should only be used as indicative interim working levels. A marine low reliability trigger value of 1.8 µg/L was calculated for diuron using an AF of 1000. These figures should only be used as indicative interim working levels.

Further information and more recent updates on Environmental Values and Water Quality Objectives can be found from the following sites:

- fact sheet at www.ehp.qld.gov.au/water/pdf/factsheet-evs-wqos-faq.pdf
- Queensland Department of Environment and Heritage Protection www.ehp.qld.gov.au/water/policy/index.html
- National Water Quality Management Strategy www.environment.gov.au/water/quality/nwqms

4.1.3 Application of EVs and WQOs

Under the EPP Water, EVs and WQOs become part of the legislation by being included in Schedule 1. Once scheduled, local EVs and WQOs will inform planning and decision making for development under the *Environmental Protection Act 1994* (e.g. point source environmentally relevant activities); local government planning and decision making for urban land development under the *State Planning Policy State Interest - Water Quality (Sustainable Planning Act 2009)*; best practice management approaches to address diffuse emissions from rural lands; development of report cards on aquatic ecosystem health; and catchment scale management planning and decisions by non-statutory Regional NRM bodies.

The WQOs (defined by the Guidelines above) for downstream waters (e.g. end-of-catchment, receiving waters of the GBR) have been used in this plan to establish targets for pollutant load reductions that will protect the Environmental Values of estuarine and marine areas of the GBRWHA (Section 4.3).

4.1.4 Groundwater thresholds

Many years of work in the Lower Burdekin highlights the need to establish local and regional groundwater targets, in terms of quantity (water table depths) and quality (see for example, Shaw, 2014). While these need to be spatially specific, it is not yet clear whether a temporal component is required.

To successfully implement the water harvesting water licence system and to ensure that the groundwater resource is not put at risk, target water level thresholds have been developed by the Department of Natural Resources and Mines (DNRM, 2015a³) and water licences are conditioned to ensure that pumping under the water licence only occurs when water levels are above the target level. Pumping more than the nominal allocation is an offence under the Water Act 2000 and landholders are also required to record and report metered use. Existing DNRM monitoring bores have been assessed, and bores most representative of an area have been selected as representative monitoring bores. Based on aquifer characteristics, the representative monitoring bores have been mapped into Management Units (available from the department's Ayr office). Electrical Conductivity thresholds have also been established for some Management Units (Table 4.8).

Table 4.7. Target water level thresholds for the Lower Burdekin region. Source: DNRM (2015).

Management Unit	Representative Monitoring Bore	Target Water Level	
		Metres below reference point	Metres AHD
Coastal	11910186 (L)	7.8	2.4
	11910894 (L)	6.3	2.7
	119110191	4.8	2.1
Horseshoe Lagoon and Horseshoe Logoon North	11910186 (L)	7.8	2.4
	11900061	5.9	2.0
	11900218	11.2	3.4
	11900186	5.9	2.0
Giru	11900058	4.2	2.8
Jardine 1	11910933	7.0	5.1
	11910894 (L)	6.3	3.1
Selkirk 1	11900089	4.0	8.8
	11900209	11.6	4.4
	11911019	9.2	3.9
Northcote 1	11910985A	7.4	9.4
	11910923A	7.5	6.5
	11910980 (L)	8.2	7.1
	11910204 (L)	6.9	10.6
Northcote 2	12000197 (L)	7.4	12.5
	11910204 (L)	6.9	10.6
	11911006	7.0	11.6
	12000196	9.6	12.6
Mona Park	12000197 (L)	7.4	12.5
	12000190	9.7	11.7
Clare	12000040 (L)	10.8	14.2
	12000178	12.7	17.0
Mulgrave 1	12001282 (L)	13.6	13.7
	12001337	9.6	15.7
Mulgrave-Woodhouse	11910912	14.2	14.9
	11910856	10.8	19.6
	12001278	15.1	13.0
Haughton-Woodhouse	11900203 (L)	5.0	16.6
	11900217	3.9	18.5
	11911027	6.1	18.1
	19900220	10.7	18.4
	11911028	14.1	16.8
Haughton 1	11910881	13.9	4.8
	11900203 (L)	5.0	16.6
Haughton 2	11910904	11.5	12.1
	11911027	6.1	18.1

³ Disclaimer: The Burdekin Waterharvesting water licence Fact Sheet was current at the time of publishing this plan. It was developed based on the best available information at the time and aims to support growers to productively use groundwater from the 'artificially high' water table, while assisting to lower the water table. The document is subject to change. To view the most recent version of the fact sheet, please contact the Department of Natural Resources and Mines - Ayr office.

Table 4.8. Target Electrical Conductivity Thresholds for the Lower Burdekin region. Source: DNRM (2015a).

Management Unit	Representative Monitoring Bore	Threshold Electrical Conductivity Level ($\mu\text{S}/\text{cm}$)
Horseshoe Lagoon and Horseshoe Lagoon North	11910186 (L)	1500
	11900061	1500
	11900218	1500
	11900186	5000
Giru	11900058	5000

4.2 Land and catchment management targets

Reef Plan 2013 includes land and catchment management targets which address improved agricultural practices and the protection of natural wetlands and riparian areas. These targets recognise the important role of improved land management practices and catchment condition in meeting the end of catchment pollutant load reduction targets and are based on the conceptual understanding of the link between land condition, management practice standards and water quality outcomes. The land and catchment management targets to be achieved by 2018 are:

- 90 per cent of sugarcane, horticulture, cropping and grazing lands are managed using best management practice systems (soil, nutrient and pesticides) in priority areas;
- minimum 70 per cent late dry season ground cover on grazing lands;
- the extent of riparian vegetation is increased; and
- there is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.

This plan adopts these targets; however, the timeline for adoption of the best management practice target has been extended to align with the 2025 pollutant reduction targets. This is considered to be more realistic given the current levels of management practice adoption outlined in Section 3.

The Reef 2050 Plan also adopts these targets (WQT2), with a refined version of the wetland target (EHT3):

- There is no net loss of the extent, and a net improvement in the condition, of natural wetlands and riparian vegetation that contribute to Reef resilience and ecosystem health.

The following target is also included for non-agricultural land uses (WQT4):

- By 2020, Reef-wide and locally relevant water quality targets are in place for urban, industrial, aquaculture and port activities and monitoring shows a stable or improving trend.

These additional targets are also adopted in this plan.

4.3 End of catchment load reduction targets

4.3.1 Reef Plan and Reef 2050 Plan Targets

Water quality targets have been an important part of the framework for driving GBR water quality improvement over the last decade. Reef Plan 2013 sets targets designed to achieve the overarching goal of ensuring that *'by 2020 the quality of water entering the lagoon from broadscale land use has no detrimental impact on the health and resilience on the GBR'*. The Reef Plan 2013 targets to be achieved by 2018 include:

- at least a 50 per cent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas;
- at least a 20 per cent reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas; and
- at least a 60 per cent reduction in end-of-catchment pesticide loads in priority areas. The pesticides referred to are the PSII herbicides hexazinone, ametryn, atrazine, diuron and tebuthiuron.

The priority areas are referred to in *Reef Plan 2013 Appendix 1*, and identify the Burdekin Region as high risk (interpreted as high priority) for nitrogen, pesticides and sediments.

The Reef Plan 2013 targets built on the Reef Plan 2009 targets, which were primarily drawn from best available data and expert opinion at the time. These water quality targets quantify the amount of improvement to be achieved in loads of relevant water quality parameters, but are not linked to the Environmental Values of the coastal and marine environments, and hence are not necessarily ecologically relevant or based on natural physical processes (e.g. natural erosion rates).

Measurement of progress towards these water quality targets takes into account inter-annual variability in catchments to portray trends in water quality due to improved management practices, as distinct from natural variability in loads due to climatic factors. The load targets are modelled over the hydrological period 1986-2014 using management practice improvements starting in 2008, and calibrated using measured loads at end of catchment sites from 2005-2014.

The Reef 2050 Plan builds on the Reef Plan 2013 targets with the extended Reef 2050 Plan targets in bold:

- at least a 50 per cent reduction in anthropogenic end-of-catchment *dissolved inorganic nitrogen* loads in priority areas, **on the way to achieving up to an 80 per cent reduction in *nitrogen* in priority areas by 2025;**
- at least a 20 per cent reduction in anthropogenic end-of-catchment loads of sediment in priority areas, **on the way to achieving up to a 50 per cent reduction in priority areas by 2025;**
- at least a 20 per cent reduction in anthropogenic end-of-catchment loads of particulate nutrients in priority areas; and
- at least a 60 per cent reduction in end-of-catchment pesticide loads in priority areas.

In addition, the Queensland Government announced an election commitment in 2015 that adopted and extended these targets as follows:

- reduce nitrogen run-off by up to 80 per cent in key catchments such as the Wet Tropics and the Burdekin by 2025; and
- reduce total suspended sediment run-off by up to 50 per cent in key catchments such as the Wet Tropics and the Burdekin by 2025.

While the Reef Plan targets refer to reductions in ‘anthropogenic end-of-catchment’ loads, and define the pollutants as ‘dissolved inorganic nitrogen’ and ‘sediment and particulate nutrients’, the Reef 2050 Plan long term targets and the Queensland Government targets as they currently stand are less specific, using the term ‘up to’ and referring only to ‘nitrogen’ and ‘sediment’, and thus lend themselves to mixed interpretations. Both sets of targets refer to ‘priority areas’ or ‘key catchments’ which also requires further definition.

The Reef Plan 2013 and Reef 2050 Plan both include an action to undertake a mid-term review of the Reef Plan targets in 2016. Until this process has been completed, catchment-specific targets have been established for the Burdekin Region to assist in regional interpretation of these targets as part of the supporting work for this WQIP, and are described below. Catchment-specific targets have only been considered for TSS, nitrogen and PSII herbicides at this stage. While phosphorus is still considered to be an important water quality parameter, the current understanding is that the GBR is nitrogen limited (Furnas et al., 2005, 2011, 2013; Brodie et al. 2013a). In addition, there is limited understanding of the relationships between end of catchment phosphorus loads and marine water quality conditions, and further work is required to support the establishment of catchment-specific targets for phosphorus in the future.

While the progress toward pollutant load reductions in the Burdekin Region to date is positive (see Section 1.2), especially for TSS, it was agreed by stakeholders involved in the development of this plan that achievement of the 2018 targets is not realistic in the remaining timeframe (less than two years), particularly for DIN. The TSS targets may be met if funding levels over the last 8 years are continued. This plan is designed to target action towards achievement of 2025 targets as these take into account GBR ecological thresholds, however, progress reporting will still incorporate the existing Reef Plan targets.

4.3.2 Defining catchment-specific and ‘ecologically relevant’ targets

As described in Section 4.1, a set of aquatic ecosystem water quality guidelines have been established for the Burdekin Region that are intended to maintain the region’s Environmental Values. The GBR Water Quality Guidelines (GBRMPA, 2010) are the primary guidelines defined to support and maintain GBR ecosystem health, and have been used to establish catchment-specific targets for pollutant load reductions that will ensure that these guidelines are met. These targets, referred to as ‘ecologically relevant targets (ERTs)’ for the purposes of this WQIP, are necessary to achieve the overall long-term Reef Plan goal “*To ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental effect on the reef’s health and resilience*”. It is recognised that the GBR Water Quality Guidelines are mostly specific to coral and therefore further consideration of other factors of ecosystem health need to be incorporated in the future.

In establishing these targets it is important to recognise that the GBR Water Quality Guidelines are defined to maintain ecosystem health. Given that the near and in-shore areas of the GBR are already quite degraded, meeting the Guidelines is unlikely to allow for significant restoration of ecosystem health, but rather may promote system recovery. Restoration of ecosystems would likely be facilitated by lower Guideline values in some locations. The Guidelines are currently being reviewed by the GBRMPA to be regionally specific.

The methods for deriving the ecologically relevant catchment-specific targets are described in detail in Brodie et al. (2016) and summarised below.

Fine sediment end of catchment load reduction targets

Ecologically relevant targets for suspended sediments are derived from understanding the impacts of sedimentation and turbidity on coral communities and seagrass meadows, and the relationships between end of catchment loads and turbidity in the receiving environment (Brodie et al. 2016). The suspended sediment of most risk to the GBR is the fine fraction sometimes defined as that smaller than 15.7 μm , i.e. below the fine silt boundary and containing the clay and fine silt fractions (e.g. Bainbridge et al. 2012, 2014, 2015; Bartley et al. 2014b; Douglas et al. 2008; Brodie et al. 2013b) or of even more risk, just the clay particle size fraction, defined here as $<4 \mu\text{m}$. This component contains most of the nitrogen and phosphorus content (and other contaminants), is transported furthest in flood plumes rather than all depositing near the river mouth (Lewis et al. 2014a, 2015; Delandmeter et al. 2015), stays in suspension longest and is most effective at attenuating light when in suspension (Storlazzi et al. 2015), and drives increased turbidity on the inner- and mid-shelf of the GBR and results in the greatest degree of resuspension (Fabricius et al. 2013, 2014; Logan et al. 2014; Fabricius et al. 2016).

There is extensive evidence that the increased fine sediment supply from the Burdekin River and the potential increased turbidity and sedimentation can have severe impacts on GBR organisms.

This includes: reef fish (e.g. Wenger et al. 2011; Hess et al. 2015; Gordon et al. 2015) through effects on juvenile recruitment and feeding; corals through sedimentation (e.g. Weber et al. 2012; Pollock et al. 2014), decreased light (Fabricius et al. 2013, 2014, 2016) and increasing the competitive advantage of macro-algae and turf algae over corals (Gowan et al. 2014); and seagrass (Collier et al. 2012; Petus et al. 2014). Suspended sediment also interacts with other stressors to increase the overall impact of multiple stressors on coral reefs (Ban et al. 2014; Risk 2014; Graham et al. 2015). Resuspension of sediment in windy conditions or strong tidal currents in shallow waters ($<15 \text{ m}$) leads to conditions where suspended sediment concentrations are above the GBR Water Quality Guidelines (De'ath and Fabricius, 2008; GBRMPA, 2010), and this threatens coral reefs and seagrass meadows through reduced light for photosynthesis (Bartley et al. 2014b). In addition, it is now thought that the mineral type of fine particles is important in driving adverse effects offshore (Bainbridge et al. 2016). Some clay minerals are readily transported in suspension in the marine environment and form organic rich flocs (Bainbridge et al. 2012) which contribute to far field resuspension. This causes loss of clarity (Fabricius et al. 2014, 2016; Logan et al. 2014) and adverse effects on corals due to their organic content when deposited onto the coral surface (Weber et al. 2006, 2012).

It is estimated that 81 per cent of the total suspended load measured at the end of the Burdekin catchment (Home Hill) is $< 20 \mu\text{m}$ particle size fraction (Brodie et al. 2016; R. Turner DSITI pers. comm.). This fraction has been used to develop ERTs as a proxy for the $< 15.7 \mu\text{m}$ fraction, considered to pose most risk to GBR ecosystems. Source Catchments modelling also models all sediment delivery as being less than $20 \mu\text{m}$. The relevant GBR Water Guideline for this target is secchi depth which is a measure of water clarity, and is currently defined as >1.5 metres in Enclosed Coastal Waters, and >10 metres in Inshore Waters (see Figure 4.4). Secchi depth can also be reported with remote sensing as photic depth, a measure of the depth of light penetration, affected by turbidity or the amount of suspended material in the water column.

Relationships between sediment loads and photic depth in the Burdekin Region have been examined (Fabricius et al. 2014; Logan et al. 2013) to identify strong correlations in the coastal and inner-shelf areas, declining with increasing distance from the coast. It has also been demonstrated that with a 50 per cent reduction in fine sediment the photic depth would increase (i.e. turbidity decreases) with modest but still significant gains of approximately one metre, which is sufficient to meet the Water Quality Guideline values in some locations (Fabricius et al. 2014; Logan et al. 2013). The benefits of these gains will vary depending on the depth of the ecosystem. A case study of the relationship between photic depth and seagrass cover in Cleveland Bay demonstrates the strong correlation at a locally relevant scale, with a 50 per cent reduction in TSS load (approximately 1,600 tonnes) resulting in a predicted increase in seagrass cover in Cleveland Bay by approximately 40 per cent (Logan et al. 2013).

The process for setting the ERTs for TSS is illustrated in Figure 4.4.

As shown in Section 3.2.1, the influence of the Black, Ross, Haughton and Don Basins to the regional TSS loads is small compared to the Burdekin Basin, so catchment-specific ERTs have not been established for these rivers at this stage.

Smaller scale targets within the Burdekin Basin are also necessary to target management efforts between the individual catchments. These targets must take into account the long-term (> 100 year) erosion rates (because the long-term or natural sediment production and transport rates within catchments can vary by an order of magnitude), and consider differences in rainfall, geology, soil type and slope (Bartley et al. 2014c). This is particularly relevant as the need to demonstrate the effectiveness of on-ground remediation increases. Thus, even well-intentioned on-ground remediation in areas where erosion rates are naturally higher than other areas may yield costly, yet potentially ineffective improvements to erosion control.

Using accelerated erosion rate data from Bartley et al. (2014c) and the current end of catchment load estimates from the Source Catchments modelling, Brodie et al. (2016) have defined catchment-specific targets for the Burdekin Basin that meet the overall target of 1,600 kilotonnes per year, or approximately 50 per cent of the current TSS load (this is equivalent to approximately 60 per cent reduction in the current anthropogenic TSS load from the Burdekin Basin). These are shown in Table 4.9. To meet the targets, total annual average loads in the Upper Burdekin need to be reduced by approximately 475 kilotonnes (53 per cent reduction), in the Suttor by 20 kilotonnes (31 per cent reduction), in the Bowen Broken Bogie by 910 kilotonnes (57 per cent reduction), in the upper parts of the Lower Burdekin (commonly referred to as the 'East Burdekin') by 250 kilotonnes (57 per cent reduction), and in the Belyando and Cape Campaspe catchments no further reductions are required.

For context, the Reef Plan target for TSS in the Burdekin Basin is a 20 per cent reduction in the annual average anthropogenic end of catchment load by 2018. The modelled estimate of the anthropogenic load is approximately 2,710 kilotonnes (using the Source Catchments 2013 baseline), which gives a reduction target of 542 kilotonnes; this should be used as a progress target towards meeting the longer term ERTs. These reductions are shown in Figure 4.5, highlighting that significant effort is required to achieve the Reef Plan 2018 and ERTs, but that the achievements are on track to achieve the Reef Plan 2018 target.

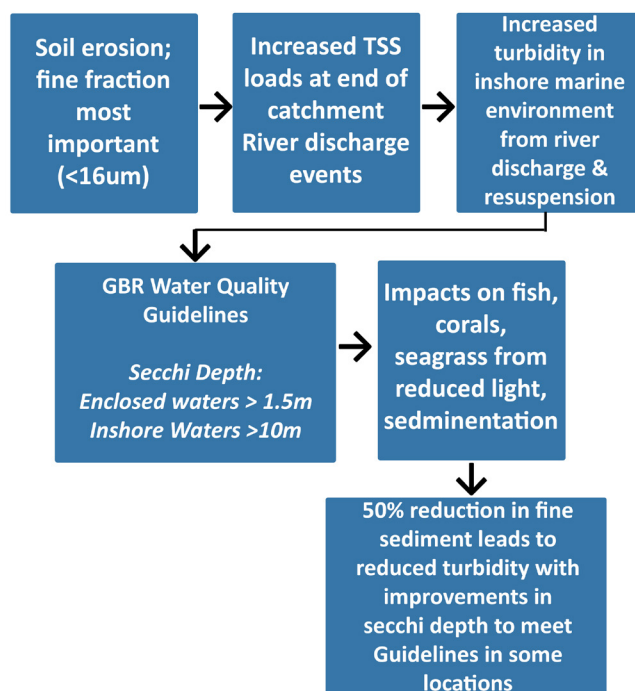


Figure 4.4. Conceptual representation of the steps and relationships used to define the TSS ecologically relevant targets.

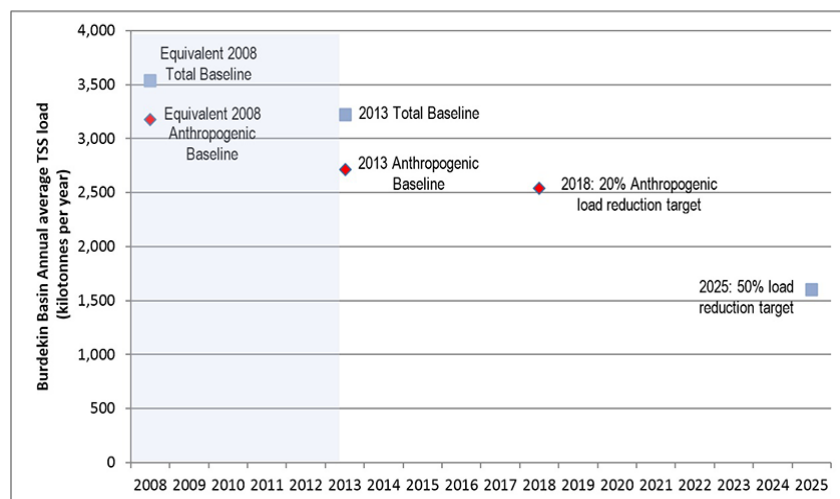


Figure 4.5. Modelled annual average estimates of current TSS loads for the Burdekin Basin and the reductions required to meet the Reef Plan targets (2018; red squares) and the ERTs (2025; blue squares). Note that the equivalent 2008 baseline for total and anthropogenic loads is a projection only and was back-calculated using the 2013 estimates and percentage reductions reported in the 2013/2014 Report Card.

Nitrogen end of catchment load reduction targets

Ecologically relevant targets for nitrogen are derived from understanding the impacts of increased nutrients on coral communities and seagrass meadows, and the relationships between end of catchment loads and Chlorophyll-a concentrations in the receiving environment (Brodie et al. 2016). Chlorophyll-a concentration is an indicator of phytoplankton abundance and biomass in coastal and estuarine waters and is a commonly used measure of water quality as an indicator of increased nutrient loads.

Excess nutrient pollutant export from the rivers in the Burdekin Region has been associated with several ecosystem impacts in the GBR. These include: reef degradation and overall reduced coral biodiversity between Townsville and Cooktown, including a reduction in species richness of 40 species, compared with the expected value, is evident in the area adjacent to the Tully River (Fabricius et al. 2005; DeVantier et al. 2006); enhanced vulnerability of reef corals to thermal bleaching stress (e.g. Wooldridge, 2009; Wooldridge and Done, 2009); increased presence of macroalgae on reefs which can affect coral cover and/or larval coral recruitment (De'ath and Fabricius, 2010); and reef damage from COTS outbreaks (Brodie et al. 2005; Fabricius et al. 2010; Wolfe et al. 2015; Uthicke et al. 2015; Wooldridge and Brodie, 2015; Wooldridge et al. 2015). For seagrass, nutrient effects are typically associated with the combined effects of fine sediment and nutrient to reduce water clarity which can lead to changes in the distribution of seagrasses to shallower waters (Collier et al. 2012) or when the reduced clarity is prolonged to seagrass mortality (Petus et al. 2014).

The health and ecology of coral reefs are very sensitive to DIN-enrichment. A threshold value of Chlorophyll-a $<0.45 \mu\text{g/L}$ has been identified as an important trigger value for the maintenance of a healthy reef status (De'ath and Fabricius, 2008) and has been adopted as the marine trigger value in the GBR Water Quality Guidelines, with a higher wet season value of $0.63 \mu\text{g/L}^{-1}$ (see Table 4.6). Corals are also known to be more vulnerable to thermal bleaching and mortality during summer heat stress conditions when also exposed to poor (ambient) water quality conditions, particularly nutrient-enrichment (Wooldridge and Done 2009; Wagner et al., 2010; Vega-Thurber et al. 2014; Wooldridge et al. 2016). The interaction between the COTS and nitrogen concentrations is also important. It is now known that outbreaks of COTS in the central GBR are associated with broad scale nutrient enrichment from land run-off and subsequent phytoplankton blooms of large phytoplankton species (Devlin et al. 2013; Uthicke et al. 2015; Wolfe et al. 2015) leading to enhanced survival of COTS larvae (Brodie et al. 2005). As chlorophyll concentrations (representing phytoplankton biomass) increase from about $0.4 \mu\text{g/L}^{-1}$ towards $0.63 \mu\text{g/L}^{-1}$, survival of COTS larvae increases dramatically. At chlorophyll concentrations near $1 \mu\text{g/L}^{-1}$ survival is high (Fabricius et al. 2010; Wooldridge and Brodie, 2015; Wolfe et al. 2015). These concentrations are common in wet season and flooding conditions in the GBR (Devlin et al. 2012).

For all of these nutrient effects, the nitrogen must be in a bioavailable form or be able to become bioavailable through, for example, bacterial action (Brodie et al. 2016). The DIN typically derived from fertiliser losses in sugarcane (see Section 3.3.2) is readily bioavailable. The PN derived from soil erosion in grazing lands and natural areas to the river mouths (see Section 3.2.2) is likely to become bioavailable through mineralisation within the lagoon waters or in the sediment (Furnas et al. 2005, 2011; Brodie et al. 2015); this assumption is based on knowledge of the long residence time of PN in the GBR lagoon (Brodie et al. 2012) and the evidence from international studies (e.g. Mills et al. 2004; Seitzinger and Harrison, 2008). Significant export of dissolved organic nitrogen (DON) also occurs from the Wet Tropics and Burdekin Rivers (Waters et al. 2014), and although most of this DON is 'natural' (Brodie and Mitchell, 2005) enhanced losses can occur from changed drainage regimes on floodplains and direct losses of urea. It is estimated that only a portion (20-30 per cent) of the DON is bioavailable (Brodie et al. 2015).

The term 'potentially reactive nitrogen (PRN)' (Wooldridge et al. 2015) is used to identify the proportion of the total nitrogen load from rivers that is likely to become bioavailable in the GBR lagoon (see Brodie et al. 2012, 2016). While the dissolved inorganic, particulate and dissolved organic nitrogen all ultimately contribute to the load of potentially bioavailable nitrogen discharged from rivers to the GBR lagoon (Brodie et al. 2013a), the DON loads are not considered in target setting here. While some of the DON is definitely bioavailable, the proportion in any specific instance is not known, and the sources of anthropogenic DON are not well understood. In addition, knowledge of methods to manage such anthropogenic DON has not been established (Brodie et al. 2015). Therefore, the total DIN load and the total PN load are used to estimate the combined nitrogen load reduction required to achieve the relevant Chlorophyll-a GBR Water Quality Guideline value. Note that these targets are set in terms of the total PRN load, not just the anthropogenic component as it is the total load that is reflected in the GBR water quality conditions.

To determine ecologically relevant PRN targets for Wet Tropics and Burdekin rivers, Wooldridge et al. (2015a) ran the decision support tool 'ChloroSim' (Wooldridge et al. 2006) with recent end of catchment monitoring data from the Paddock to Reef Program (Garzon-Garcia et al. 2015) to establish a quantitative relationship between the DIN-component of nitrogen discharge in event flows and the resultant Chlorophyll-a concentrations in the marine environment. While DIN can be used alone to satisfactorily parameterise the ChoroSim model, the model is used to set PRN reduction targets for both DIN and PN. The catchment-specific reductions in PRN concentrations that are needed to ensure compliance with the Chlorophyll-a wet season guideline of $0.63 \mu\text{g/L}^{-1}$ (GBRMPA, 2010) were then calculated to provide an end of catchment PRN load reduction target (Brodie et al. 2016).

The end of catchment target for DIN and PN combined in the Burdekin Region is a 60 per cent reduction in the total end of catchment load. Note that the targets will be required to be met in the Burdekin and Wet Tropics regions to ensure that the guideline values are met.

The process for setting the ERTs for DIN and PN is illustrated in Figure 4.6.

The annual average modelled estimate of the current total load of DIN and PN from the sugarcane and grazing areas in the region includes approximately 1,100 tonnes/year of DIN from the Lower Burdekin sugarcane area and 2,800 tonnes/year of PN (largely from grazing lands) in the Burdekin Basin, with a combined total of almost 3,900 tonnes of potentially reactive nitrogen (or bioavailable nitrogen) per year (note that these figures have been rounded to reflect accuracy). The target load reduction is a 60 per cent reduction, or approximately 2,340 tonnes/year to achieve a combined annual average load of 1,560 tonnes/year.

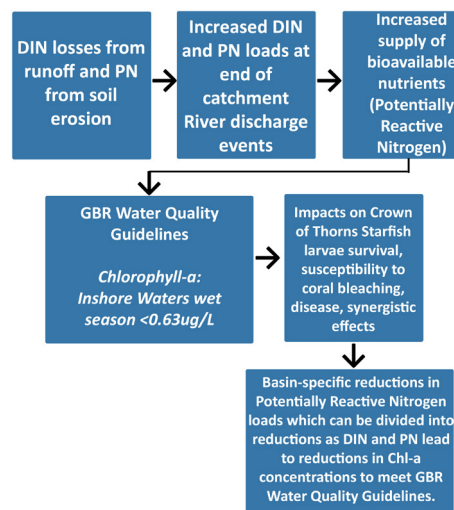


Figure 4.6. Conceptual representation of the steps and relationships used to define the ecologically relevant targets for bioavailable (Potentially Reactive) Nitrogen.

A number of combined DIN and PN scenarios can be used to address this reduction (see Brodie et al. 2016), and it is noteworthy that the required reduction in potentially reactive nitrogen cannot be achieved just out of sugarcane and thus it is necessary to address erosion of PN in the Burdekin Basin with a focus on grazing lands. The proposed reductions to meet the 60 per cent reduction in potentially reactive nitrogen (DIN + PN) are shown in Table 4.9 and are:

- 80 per cent (~880 tonnes) reduction in the total end of catchment load of DIN from sugarcane (all) (equating to approximately 70 percent reduction in the regional anthropogenic DIN load); and
- 52 per cent (~1,455 tonnes) reduction in the total end of catchment load of PN in the Burdekin Basin (equating to approximately 52 percent reduction in the regional anthropogenic PN load).

Reductions in pollutant loads from other land uses in addition to sugarcane and grazing such as horticulture, grains and urban areas could also contribute to these target reductions and should be considered. The Don, Ross and Black Basins are not considered in this assessment due to limited knowledge of specific marine impacts from these catchments at this time, and therefore it is recommended that further analysis is conducted to derive ERTs for these basins. It is recommended that the feasibility of further reductions in loads of DIN from STPs that discharge into the GBR are investigated, for example, an 80 per cent reduction in the DIN load from the Cleveland Bay STP could contribute an additional 30 tonnes per year to this reduction (see Table 3.4).

It is important to note that the Wet Tropics River loads also have to be reduced by the most recently proposed ERTs (Brodie et al. 2016) which range between basins (20 to 80 per cent) as well as the proposed Burdekin reductions to deliver the outcomes needed for GBR health.

Further research is required to improve the assessment of the sources and bioavailability of PN in the Burdekin Region, and GBR catchments more generally.

For context, the Reef Plan targets for DIN and PN in the Burdekin Region are a 50 per cent reduction and 20 per cent reduction respectively in the anthropogenic end of catchment loads by 2018. For DIN, the modelled estimate of the regional annual average anthropogenic load (using the Source Catchments 2013 baseline) is approximately 1,240 tonnes, which gives a reduction target (50 per cent) of 620 tonnes. For PN, the modelled estimate of the regional anthropogenic load is 2,800 tonnes, which gives a reduction target (20 per cent) of 555 tonnes. These reductions should also be used as progress targets towards meeting the longer term ERTs.

The 60 per cent reduction in potentially reactive nitrogen also satisfies the Reef 2050 Plan extended target of ‘up to 80 per cent reduction in nitrogen’.

The reductions are shown in Figure 4.7 and Figure 4.8, highlighting that significant and steady effort is required to achieve the Reef Plan targets and ERTs for Potentially Reactive Nitrogen.

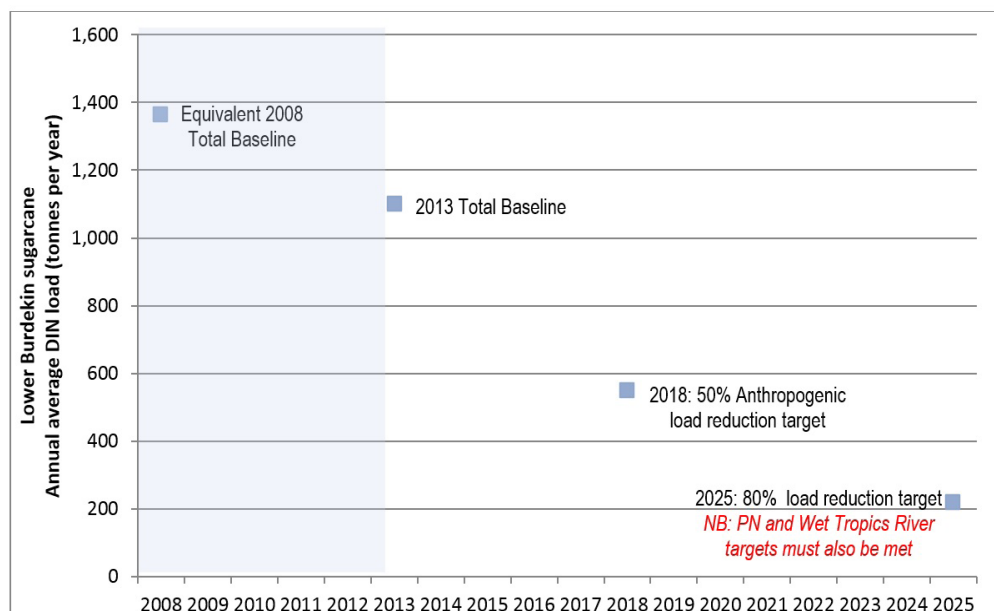


Figure 4.7. Modelled annual average estimates of current DIN loads from sugarcane in the Lower Burdekin catchment and the reductions required to meet the Reef Plan targets (2018) and the ERTs (2025). Note that the equivalent 2008 baseline for total and anthropogenic loads is a projection only and was back-calculated using 2013 estimates and percentage reductions reported in the 2013/2014 Report Card for the Haughton Basin.

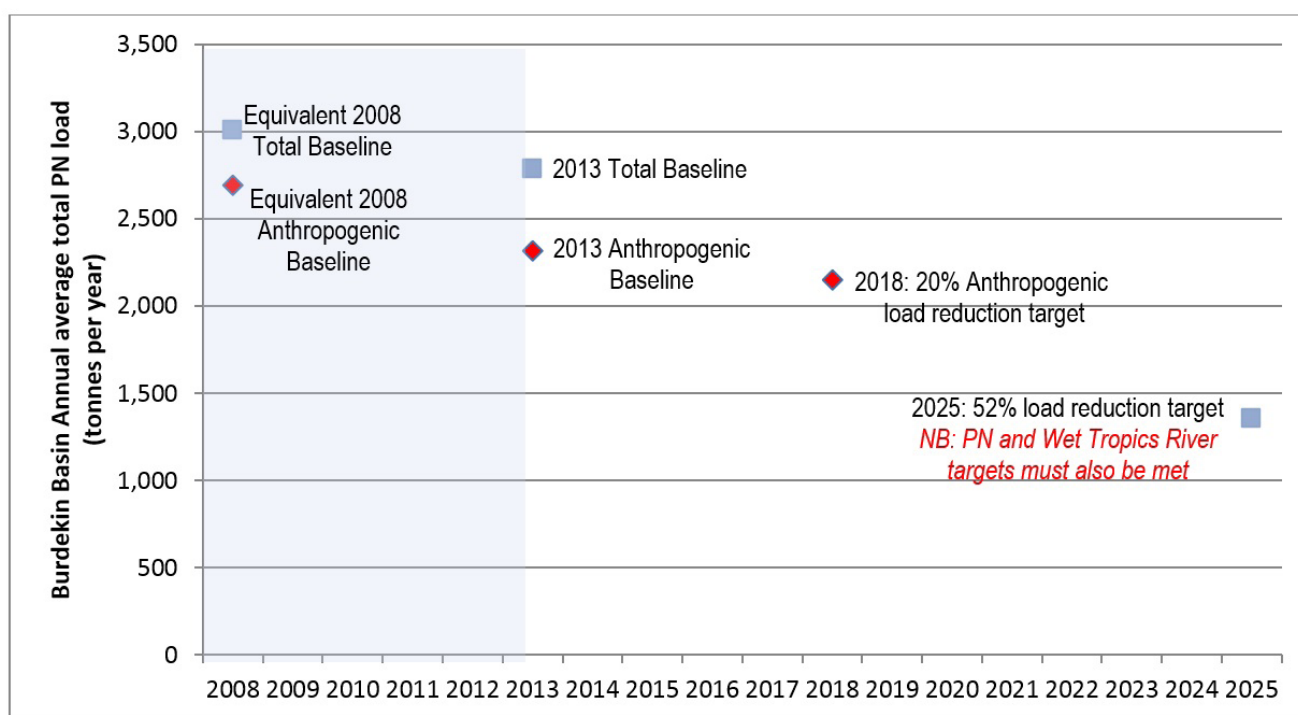


Figure 4.8. Modelled annual average estimates of current PN loads in the Burdekin Basin and the reductions required to meet the Reef Plan targets (2018; red squares) and the ERTs (2025; blue squares). Note that the equivalent 2008 baseline for total and anthropogenic loads is a projection only and was back-calculated using 2013 estimates and percentage reductions reported in the 2013/2014 Report Card.

PSII herbicides targets

Ecologically relevant targets for PSII herbicides are derived from understanding the impacts of specific concentrations of the five main PSII herbicides of concern to GBR ecosystems (ametryn, atrazine, diuron, hexazinone and tebuthiuron) (and are thus the only ones specifically addressed in Reef Plan although actions to minimise their loss are also likely to reduce loss of any other chemicals) (Brodie et al. 2016). It is the concentration of a particular herbicide that provides a measure of toxicity to non-target species. Recent studies have examined various components of the ecological risk of herbicides to GBR ecosystems (Lewis et al. 2009, 2012b; Davis et al. 2014; Kennedy et al. 2012a, 2012b; Smith et al. 2012; Devlin et al. 2015). Lewis et al. (2013b) showed that the ecosystems of highest risk from transient pesticide exposure are freshwater and coastal habitats including wetlands, estuaries, mangroves and seagrass which provide important ecological services to GBR biota, including nursery habitats, primary productivity and nutrient cycling. Concentrations in freshwater flood plumes have been detected in some parts of the GBR that are likely to cause temporal, reversible negative effects in the freshwater, estuarine and marine environments.

As identified in Section 4.1.2, a new set of ecotoxicity threshold values are proposed for marine environments (Smith et al., in prep-a) and have been used to set ERTs for PSII herbicides in the Burdekin Region (Brodie et al. 2015a). To reflect the different ecotoxicity of different PSII herbicides, 'toxic load factors' have also been developed to normalise the PSII herbicide loads / concentrations to a standard 'additive' concentration that can then be compared to a guideline value that represents for a range of PSII herbicides (Smith et al. in prep). This recognises that a mix of products is used for weed control with different toxicities in some industries, and that products may also be mixed in the receiving environment.

The current Reef Plan targets are based on annual PSII herbicide load reductions, but it is now emphasised that herbicide concentrations are most important when assessing their risk to receiving ecosystems (Lewis et al. 2013b; Smith et al. 2012; Davis et al. 2012, 2013; O'Brien et al. 2016). Hence to develop ecologically relevant targets for PSII herbicides, concentrations and toxic loads are the most relevant indicators. To set catchment specific targets for this WQIP, the predicted PSII herbicide concentration (normalised to diuron) and the diuron ecotoxicity concentration for coastal and marine waters ($0.08 \mu\text{g.L}^{-1}$) were used to examine the likely end-of-catchment PSII herbicide load reductions required to maintain concentrations below the guideline value (Brodie et al. 2016). Based on this analysis, a 90 per cent reduction in PSII herbicide loads is required for the Haughton Basin, and no further reductions are required for the other basins (i.e. no net increase) (see Table 4.9).

Further discussion with local experts has concluded that the reduction from the Haughton Basin was also applicable at the more relevant management scale of the Lower Burdekin sugarcane area. It is noted that a reduction in the PSII herbicides will also provide benefits to the freshwater ecosystems in the Lower Burdekin area, although an analysis of whether the reductions would produce concentrations that fall below the freshwater guidelines is still required.

The reductions are shown in Figure 4.9, highlighting that continued, steady progress is required to achieve the Reef Plan 2018 and ERTs for PSII herbicides.

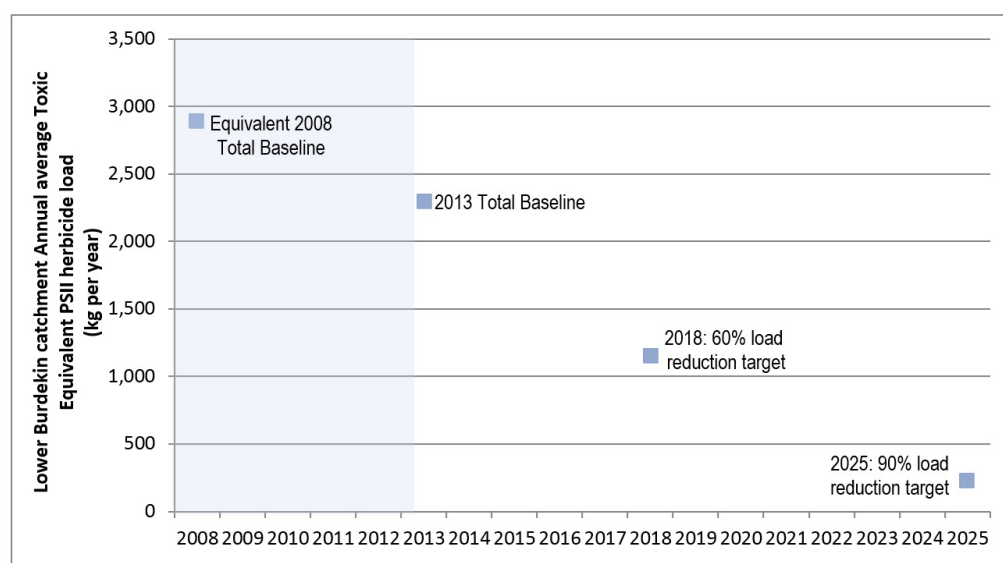


Figure 4.9. Modelled annual average estimates of current PSII herbicide loads from sugarcane in the Lower Burdekin catchment and the reductions required to meet the Reef Plan targets (2018) and the ERTs (2025). Note that the equivalent 2008 baseline load is a projection only and was back-calculated using 2013 estimates and percentage reductions reported in the 2013/2014 Report Card for the Haughton and Burdekin Basins.

Other pollutants

Pollutant reduction targets have been defined for PP, as it is recognised that PP loads are an important component of the nutrient budget of the GBR, although the relative biological role of nitrogen and phosphorus has not been fully quantified. Target reductions equivalent to those for TSS, i.e. 50 per cent reduction in the total load, have been set as preliminary targets in the Burdekin Basin as the management options for soil erosion are also likely to address PP reductions. Targets are not set for DIP at this stage due to a lack of understanding of the management options to reduce DIP loads, and also uncertainties of the relative importance of bioavailable phosphorus to aquatic ecosystem health in the GBR.

Catchment specific targets have not been set for all catchments or Basins in the region, however, adoption of the Reef Plan 2018 load reductions in these locations would be a suitable alternative until further assessment is completed.

Timeframes for meeting catchment-specific targets

Based on scientific evidence and input from industry experts in 2014 and 2015 it was proposed (e.g. Brodie et al. 2014) that a feasible timeframe for achievement of the ERTs is approximately 20 years from now, i.e. 2035. The GBR Outlook Report 2014 (GBRMPA, 2014a) defines climate change impacts as the single largest threat to the GBR ecosystem. Improved water quality improves the resilience of the GBR ecosystem to recover following cyclone damage and crown of thorn starfish outbreaks and improves the ability to cope with the impacts of increased temperature and ocean acidification. For example, temperature increases by 2018 are expected to result in coral bleaching events twice per decade and 2035 has been used as a critical climate change timeline within the Wet WQIP (Terrain NRM, 2015). Beyond 2035, the influence of water quality improvement in the context of other drivers of GBR health such as climate change is difficult to predict. Additional external factors such as agricultural expansion, intensification of agricultural land uses, or increased pressure from coastal development are also important but have not been factored into this timeframe. In light of the severe bleaching occurring on the GBR in 2016 (Normile, 2016) and the now-revealed urgency of managing water quality to provide the GBR resilience in the face of climate change, the assessment of the time period needed to provide this resilience is revised from 2035 to 2025.

With substantial increases in management efforts (and therefore increased investment) to reduce end of catchment pollutant loads, the Reef 2050 Plan timeframe of 2025 then becomes essential and may be possible.

It is important to note that all Reef Plan targets are based on **reductions in anthropogenic loads** while ERTs for sediment and nutrients are based on **reductions in total loads** as these are most relevant when assessing the requirements for ecological outcomes. However the sources of anthropogenic loads, for example, by sub-catchment, land use, land management and erosion type are relevant when targeting management options.

The recommended end of catchment pollutant load reduction targets for the Burdekin Region (shown in Table 4.9), are expressed as a percentage reduction from the Source Catchment 2013 modelled baseline estimates. The catchment-specific Reef Plan targets were set by adopting the overall 2013 Reef Plan GBR targets to each Basin in the Burdekin Region. The targets are consistent with the Reef Plan and Reef 2050 Plan targets and provide further interpretation of the Reef 2050 Plan targets and the Queensland Government election commitments (see above).

It is acknowledged that the Reef Plan targets will be updated in 2016 as part of the revision of the plan. Current efforts to refine the ecologically relevant targets using new evidence including the eReefs modelling, will provide greater confidence in the current targets and to establish ecologically relevant targets for the Basins where they are yet to be defined. Therefore, it is possible that there will be some adjustments to the targets recommended in this plan, and these should be revised in 2017.

Table 4.9. Summary of pollutant load reduction targets in the Burdekin Region, presented as per cent reductions. The table shows two sets of targets: Reef Plan Targets (RPT) to be achieved by 2018, and Ecologically Relevant Targets (ERT) to be achieved by 2025 for Total Suspended Solids (TSS), Dissolved Inorganic Nitrogen (DIN), Particulate Nitrogen (PN), Dissolved Inorganic Phosphorus (DIP), Particulate Phosphorus (PP) and PSII Herbicides (PSII). Derived from Brodie et al. (2015).

Basin / Catchment	TSS		PRN	DIN		PN		PP		DIP		PSII herbicides		
	RPT	ERT ¹	ERT ²	RPT	ERT	RPT	ERT	RPT	ERT	RPT	ERT	RPT (total PSII load)	ERT (diuron equivalent conc.) ³	ERT (toxic load)
Black	20	nd	nd	50	nd	20	nd	20	nd	NS	nd	60	<0.08 µg.L ⁻¹	No increase
Ross	20	nd	nd	50	nd	20	nd	20	nd	NS	nd	60	<0.08 µg.L ⁻¹	No increase
Haughton	20	nd	60	50	80 ⁴	20	nd	20	nd	NS	nd	6	<0.08 µg.L ⁻¹	90 ⁴
Burdekin*	20	50		50		20	52 ⁵	20	50	NS	nd	60	<0.08 µg.L ⁻¹	90 ⁴
Upper Burdekin	NS	53	See note ²	NS	See note ⁴	NS	See note ⁵	NS	nd	NS	nd	NS	<0.08 µg.L ⁻¹	No increase
Belyando		No increase												
Cape Campaspe		No increase												
Suttor		31												
Bowen		57												
Lower Burdekin ('East Burdekin')*		57												
Don	20	nd	nd	50	nd	20	nd	20	nd	NS	nd	60	<0.08 µg.L ⁻¹	No increase

Notes: The load targets are modelled over the period 1986-2014 using measured management practice improvements, and validated with measured loads from 2005-2014, to allow natural fluctuations observed in discharges over the modelled period to be accounted for and hence determination of the load reductions due to improved management. RPTs are reductions in anthropogenic end of catchment loads and ERTs are reductions in total end of catchment loads.

*The Burdekin Basin is defined here as per Figure 1.1. Here, the 'Lower Burdekin' refers to the part of the Lower Burdekin catchment that is in the Burdekin Basin, and excludes the area in the Haughton Basin. This is equivalent to the area defined as East Burdekin in Australian Government (2014), Wilkinson et al. (2015) or Bartley et al. (2014c).

nd = Insufficient evidence to develop catchment specific targets at this time; NS = not specified

¹ Reduction in fine sediment fraction, <20µm suspended sediment.

²The Potentially Reactive Nitrogen target (60 per cent reduction) is a combination of DIN reduction from the whole of the Lower Burdekin sugarcane area irrespective of Basin, and PN reduction from the Burdekin Basin above Home Hill. This is explained more fully in Brodie et al. (2016). Contributions from additional land uses could also be assessed through other reduction scenarios, but grazing and sugarcane are the dominant contributors of PRN in the Burdekin Region (Waters et al. in review; Waterhouse et al. 2016). The ERTs for DIN and PN must be met to achieve this target.

³Based on the proposed Water Quality Guideline value by Smith et al. (in prep).

⁴ Target sugarcane areas. This reduction is defined for the Haughton Basin but it is recommended that it is extended to cover all of the sugarcane areas in the Lower Burdekin, which is predominantly located in the Burdekin and Haughton Basins. The reduction will be assessed by modelling loads from a specific boundary for the BR1A and Delta sugarcane areas in the Lower Burdekin.

⁵ Target grazing areas. It could be assumed that the reductions in TSS that are achieved by managing soil erosion would deliver similar reductions in PN, however, it is known that different erosion processes generate different amounts of PN. For example, a larger proportion of PN is expected from hillslope erosion than channel erosion (streambank erosion and gully erosion). Therefore, rather than apply the same catchment specific reductions as those applied for the TSS ERT, the 52 per cent reduction is not divided between the catchments in the Burdekin basin at this time and further assessment is required.

5. What are the priority management options for meeting the targets?

The Reef 2050 Plan identifies a set of principles for decision making which have been taken into account in the development of priority management options for the WQIP. This WQIP adopts the following management principles which recognise the high ecological, economic and cultural values of the Burdekin Region:

- values and ecological processes in poor condition are restored and values and ecological processes in good condition are maintained;
- economic growth is sustainable and consistent with protecting the values of the region;
- decisions are based on the full range of knowledge, including scientific understanding, Traditional Owner and community knowledge;
- decisions take into consideration information on the current and emerging risks associated with climate change;
- management is adaptive and continually improving, informed by the outcomes of monitoring programs;
- decisions are underpinned by the principles of ecologically sustainable development, including the precautionary principle;
- impacts are avoided and residual impacts mitigated;
- offsets are considered only where impacts cannot be avoided or mitigated;
- actions that restore ecosystem health and resilience — delivering an overall improvement in the Reef's condition—are fostered. Governance arrangements are transparent and accountable;
- decisions continue to support a wide range of opportunities for sustainable economic, social and cultural activities, including traditional use;
- management is cooperative, fostering stewardship and strong community support; and
- innovation in management is fostered.

Management practice options for most land uses in the region are well developed and there is good evidence of the water quality benefits associated with those practices. Frameworks have been defined for the region through the Paddock to Reef Program which identifies the priority practices for improving water quality. There is also increasing confidence in priority areas for management at a sub-catchment scale. Priorities beyond this scale are less certain and require additional effort to refine. This chapter outlines the issues, actions and sub-catchments identified as a high priority for water quality management in the region for each of the major land uses contributing to the water quality issues in the region. The focus of management options to date has been on mitigation through adoption of best management practices, however, there is likely to be increasing pressure to consider treatment options and offsets in the future with increasing pressures on the GBR. These options are recognised but not considered in detail in this plan, and should be the focus of more detailed implementation plans.

5.1 Managing water quality in grazing lands

5.1.1 Principles for improving water quality from grazing lands

A vast amount of technical information is available for guiding grazing land management in the Burdekin Region. This is synthesised by McIvor (2012) in *Sustainable management of the Burdekin grazing lands: A technical guide of options for stocking rate management, pasture spelling, infrastructure development and prescribed burning to optimise animal production, profitability, land condition and water quality outcomes*. The guide contains detailed information and references for further reading, and is recommended for advisors working with producers to improve grazing management in the grazing lands of the Burdekin catchment. The key land management aims for the region are summarised in Table 5.1.

Substantial areas of the Burdekin Region grazing lands are considered to be in poor to very poor condition (Karfs et al. 2009; Abbott et al. 2008; Beutel et al. 2014), leading to reduced productivity, reduced ground cover, increased weed spread, increased run-off, increased erosion, and increased nutrient loss from soils that are already relatively infertile. This limits the productivity of the landscape and contributes to increased sediment discharge into the GBR.

Priority management practices have been established for the region through the Paddock to Reef Program and are summarised below and illustrated in Figure 5.1. Each of these practices is classified and weighted in terms of water quality risk for annual reporting (Table 5.2).

Table 5.1. Key land management aims for the Burdekin grazing lands. Source: McIvor (2012).

Aim	Situation	Factors to consider
1. Maintaining land in good (A and B) land condition	- Pastures are mainly in A or B land condition. - Such pastures will change in appearance depending on seasons, with ample feed for the whole year in good years, adequate feed for the whole year in average seasons and possibly inadequate feed towards the end of the year in poor years. - There may be a few overgrazed patches with low ground cover and the presence of less desirable species (C land condition). - Continued overgrazing of these C condition patches increases their size and frequency. If continued over a period of years, the average land condition goes from A-B to C.	- Indicates a history of good grazing management. - Temporal variability in pasture growth rates between years, during years and on different parts of the property leads to variation in feed supply. - Compounded by limited flexibility to vary cattle numbers within and between years; breeder enterprises have the least flexibility of all (also relevant to all Aims). - Increased vulnerability to erosion as a consequence of soil types, high surface slopes and runoff and soil saturation.
2. Improving land in poor (C) land condition	- Most of the paddock or preferred land type/s is in C condition. - There are still some 3P grasses but they are widely spaced and may be small with low vigour. - Persistent patch grazing is occurring. - Ground cover is highly seasonal and generally poor towards the end of the dry season with substantial loss of water through runoff. - There is a high proportion of annual grasses, forbs or undesirable species. - Highly nutritious feed may be available for short periods after rain, but feed shortages can develop quickly in dry periods.	- Drought. - Chronic and sustained excessive grazing pressure. - Selective use of land type or portion of paddock. - Can be exacerbated by intense wildfires. - Increased vulnerability to erosion as a consequence of soil types, high surface slopes and runoff and soil saturation
3. Stabilising and recovering land in very poor (D) land condition	- Significant soil erosion including gullying. - Substantial weed infestation. - Very low to no ground cover. - Very few or no 3P grasses. - Often approaching desertification in appearance.	- Chronic and continued overgrazing. - Loss of 3P grasses and ground cover. - Invasion of aggressive weeds.
4. Managing frontage country and wetlands currently	- Bare soils. - Gullies. - Poor vegetation including weeds. - Eroding streambanks. - Pugging. - Highly turbid water and/or algal blooms.	- Concentration of stock in these preferred areas. - Selective grazing. - Weed invasion. - Selective vegetation clearing or death through intense fires. - Feral pigs
5. Reducing grazing pressure in selectively grazed areas	- Heavily grazed areas and patches contrasting with other areas which are ungrazed and where the pasture has become rank. - Patches and ungrazed areas vary in species composition, morphology, structure and availability of forage.	- Animals graze more at locations with abundant quantities of preferred forages. - Animals avoid low quality forage, select high quality patches and regaze these preferred patches. - Past grazing has modified the plants present and their characteristics. - Current grazing determines available forage. - Distance to water is an important determinant of grazing distribution. - Patches may reflect different grazing use in the past and growth responses to dung and urine and burns.
6. Locating water points to even out grazing	Significant areas of the paddock receive little or no grazing pressure.	- Inadequate number and/or location of water points in relation to paddock size. - Avoidance of land types with less palatable pastures or limited accessibility.

Aim	Situation	Factors to consider
7. Minimising erosion when locating infrastructure e.g. fences	New forms or increased rates of soil erosion.	- Areas of reduced ground cover. - Altered water flows. - Problem soils. - Poor placement of infrastructure. - Gully formation.
8. Minimising woody plant problems	- Increased density of shrubs and trees, particularly on productive soil types. - Reduced pasture growth when woody vegetation is thick. - Encroachment into open land types.	- Sequences of very wet years. - Reduced competition from grasses due to heavy grazing. - Reduced frequency and/or intensity of effective fires
9. Managing chemicals – herbicides and fertilisers	- Excess vegetation growth in water ways e.g. algae. - Degradation of aquatic ecosystems.	- Herbicides, fertilisers and feed supplements carried in run-off to waterways. - Chemicals applied according to label and stored correctly. - Impact on the health of catchment waterways.

Gullies (contributes 67 per cent of anthropogenic TSS load from grazing lands)

Important determinants of management considerations for gully erosion rates include reducing runoff from areas upslope of the gully, increasing cover on gully walls and reducing the sediment transport capacity by reducing the slope gradient or increasing roughness (Thorburn and Wilkinson, 2013). Key practices:

1. linear features (roads, tracks, fences, firebreaks), and water points located and constructed to minimise their risk of initiating erosion;
2. strategies implemented, where practical and affordable, to remediate gullied areas; plus
3. Hillslope items 4-7.

Hillslope (contributes 19 per cent of anthropogenic TSS load from grazing lands)

The core grazing practice affecting hillslope erosion is stocking rate, and matching rates to carrying capacity, which together with recent climate and land condition affects utilisation rate, and consequently cover. Key practices:

4. retention of adequate pasture and ground cover at the end of the dry season, informed by (1) knowledge of ground cover needs and (2) by deliberate assessment of pasture availability in relation to stocking rates in each paddock during the latter half of the growing season or early dry season;
5. strategies implemented to recover any land in poor or very poor condition (C or D condition), where feasible;
6. stocking rates are based on pasture availability on paddocks are consistent with district long-term carrying capacity benchmarks for comparable land types, current land condition, and level of property development; and
7. the condition of selectively-grazed land types is effectively managed.

Streambank (contributes 14 per cent of anthropogenic TSS load from grazing lands)

Stock access to streambanks and riparian tree cover are the main factors that can be managed to reduce streambank erosion in grazing lands (Thorburn and Wilkinson, 2013). Key practice:

8. timing and intensity of grazing is managed in frontages of rivers and major streams (including associated riparian areas) and wetland areas.

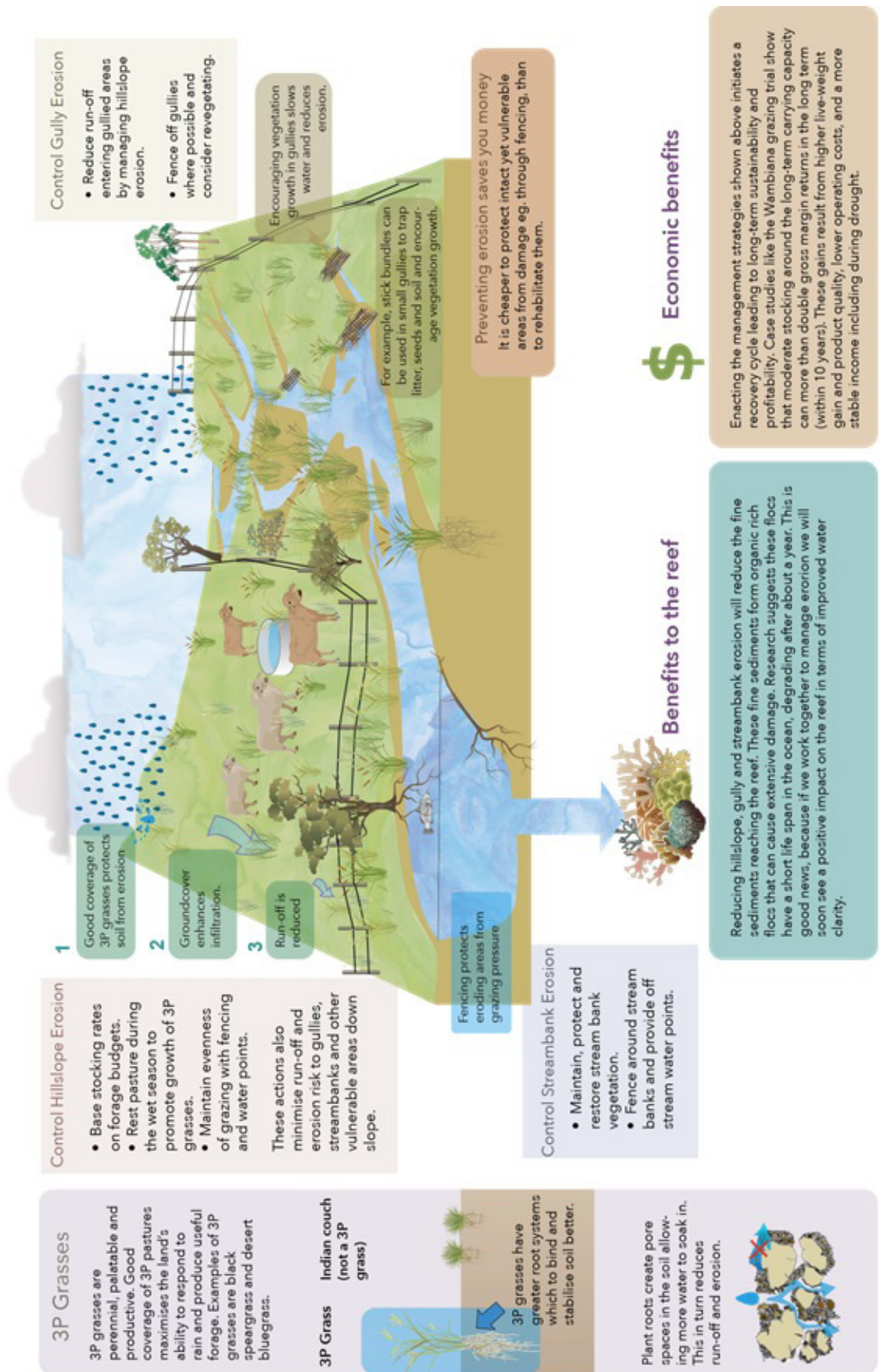
The relative priorities of the improved management practices for specific locations need to be assessed spatially and will depend on the dominant erosion processes and severity. This prioritisation should be based on catchment-scale fine sediment loads, proportional contributions from different erosion types and targeting of specific erosion control activities to areas within these priority sub-catchments (Wilkinson et al. 2014) and is described further in Section 5.1.5.

Table 5.2. Relative priorities of grazing management practices as per the Reef Plan Grazing Water Quality Risk Framework 2013.

Erosion process	Performance Indicator	Paddock to Reef program weighting (%)
Hillslope erosion		
1	Average stocking rates imposed on paddocks are consistent with district long-term carrying capacity benchmarks for comparable land types, current land condition, and level of property development.	25
2	Retention of adequate pasture and groundcover at the end of the dry season, informed by (1) knowledge of groundcover needs and (2) by deliberate assessment of pasture availability in relation to stocking rates in each paddock during the latter half of the growing season or early dry season.	35
3	Strategies implemented to recover any land in poor or very poor condition (C or D condition).	25
4	The condition of selectively-grazed land types is effectively managed	15
Streambank erosion		
5	Timing and intensity of grazing is managed in frontages of rivers and major streams (including associated riparian areas) and wetland areas.	100
Gully erosion		
6	Linear features (roads, tracks, fences, firebreaks, and water points located and constructed to minimise their risk of initiating erosion	30
7	Strategies implemented, where practical and affordable, to remediate gullied areas.	40
(see 1-4)	Hillslope erosion assessment.	30

Figure 5.1. Summary of cost effective erosion control in grazing lands in the Burdekin Region, derived from the synthesis of current understanding of sediment source, delivery, fate and impact in the Burdekin Region by Lewis et al. (2015). Prepared by L. Baskerville and S. Imgraben, 2015.

COST-EFFECTIVE EROSION CONTROL



5.1.2 Management practice framework for grazing lands

The framework for grazing management practices has been developed as part of Paddock to Reef Program, and was originally described using the 'ABCD' terminology and has more recently been described in terms of water quality risk (www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/assets/paddock-to-reef-grazing-water-quality-risk-framework.pdf). However, the ABCD terminology is still maintained in the Burdekin Region to maintain consistency in discussions with landholders. The framework provides a consistent description of the levels of management practice moving from D or dated practices at the lowest level (moderate to high risk), to C practices at a level that may meet code of practice or legal requirements (low to moderate risk), to B practice that is known and generally validated best practice (low risk) up to A practice which is above best practice in terms of water quality outcomes (very low risk). The framework has been adapted to be regionally specific and account for variation in specific practices that may be more relevant in a particular location or set of conditions (see *Appendix 5: The ABCD Frameworks for sugarcane, grazing and horticulture in the Burdekin region*).

5.1.3 Current adoption of improved management practices

There is considerable uncertainty in the knowledge of current adoption of improved management practices in grazing lands in the GBR catchments, including the Burdekin Region, largely due to poor spatial coverage of landholder surveys. The primary dataset is from the Paddock to Reef Program which reports adoption annually but only for a portion of the region (Table 5.3). This data is spatially extrapolated in the Source Catchments model to provide an estimate of management practice adoption across the Region by correlating it with remotely sensed ground cover data and therefore is important for the load estimates. Data was also collected through the technical workshops conducted for the development of the WQIP which used expert opinion and takes into account other data sources such as ground cover monitoring from remote sensing data and current land condition from on ground assessments to estimate current adoption in grazing practices for the Burdekin Region (Table 5.4). This data was used to assist in estimating the costs of specific practice changes and the proportions of adoption were not differentiated between catchments. Beutel et al. (2014) also reported land condition based on satellite imagery, however, this data was analysed in 2012 and was considered to be outdated for this plan.

Table 5.3. Current adoption of improved management practices in grazing lands in the Burdekin region from the Paddock to Reef Program, 2013-2015.

Catchment	A and B Class adoption 2013/14 (% of area)		
	Pasture	Riparian	Gully
Bowen Broken Bogie	9	44	24
Upper and Lower Burdekin	34	75	36
Suttor, Cape Campaspe, Belyando	29	52	17

Table 5.4. Current (2015) estimated adoption of management practices in grazing lands in the Burdekin Region, derived from discussions with grazing technical experts as part of the INFFER assessment (Section 6.1).

Principle	Practice	Proportion of area in practice class			
		D	C	B	A
Sustainable stocking rate	Matching stocking rate to forage availability	35	45	10	10
Pasture management	Pasture spelling	22	44	27	7
Managing grazing distribution	Accounting for land types, water distribution	20	60	19	1
	Riparian and frontage management	0	75	25	0
Prevention and stabilisation of erosion features including gullies, streambanks and scalds	Erosion prevention	0	98	2	0
	Erosion stabilisation	95	0	5	0

5.1.4 Estimated costs of improved grazing management practices

A synthesis of previous grazing economic analysis conducted in the Burdekin Region is presented in Waterhouse et al. (2016). The costs of soil management can be high depending on land type, productivity and erosion process, and given the limited private benefits of some practices such as streambank and gully stabilisation or remediation, and current constraints to government funding, the most cost effective actions should be promoted (McCosker et al. 2010). In addition, longer time frames may be required before graziers begin to realise economic returns from improved management such as lower stocking rates or stock exclusion on areas vulnerable to soil erosion. Despite this, economic analysis of grazing operations has shown that there are private benefits generated from shifting to B level management practices (Ash et al. 1995; McIvor and Monypenny, 1995; O'Reagain et al. 2011; Star et al. 2013) particularly in the long-term, as major land degradation events tend to occur during drought periods and there are economic benefits of maintaining lower stocking rates or reductions in utilisation rates (Landsberg et al. 1998; O'Reagain et al. 2011). Social factors then come into play that will influence the most effective policy to achieve sustainable grazing systems. Factors that affect the adoption of conservation practices by landholders include awareness of the problem, perception of risk, demographics, costs and impacts of profits and links between landholders (Pannell et al. 2006).

Hillslope erosion management

Recently, Star et al. (2015) completed an assessment of the opportunity cost per tonne of sediment reduction for scenarios shifting from B to A and C to B hillslope management practices (shown in Table 5.7). The costs for sediment reduction are higher for shifting from B to A practice than C to B practice, and range from less than \$10 per tonne in the Burdekin River (Dam) sub-catchment, to \$160 per tonne in the Burdekin River (Blue Range) sub-catchment, both in the Upper Burdekin catchment. The assessment predicts that the cheapest reductions would be achieved in the Bowen Broken Bogie catchment (typically less than \$30 per tonne), however, hillslope erosion is only part of the soil management issues and gully erosion dominates in these landscapes and is likely to require substantially higher costs for remediation to reduce soil loss (see Wilkinson et al. 2015).

Gully erosion management

The costs of gully erosion management vary considerably depending on the specific characteristics of the gully formation, and the combination of management options. Wilkinson et al. (2015) assessed a number of practice combinations in terms of cost and sediment reduction, shown in Table 5.5. The reductions in sediment yield were estimated by comparing the anticipated effects of specific techniques with those used in previous full remediation studies (see Wilkinson et al. 2015, Table 5). Generally, more intensive practices (combinations 4 and 5) are less likely to be cost-effective unless infrastructure is threatened, and one cost estimate for reshaping and associated revegetation is \$375 per tonne of sediment (Shellberg and Brooks, 2013). However, engineered check-dams can be cost-effective where they prevent small numbers of large but young gully heads incising large upstream areas (Star et al. 2015). This will more likely be the case in management units with large length-specific or area-specific gully contribution (t/km/yr or t/ha/yr).

In the context of the 'ABCD' management practice framework, practice combinations 2 and 3 are similar to 'B' management practice, or Low Risk in the Paddock to Reef WQ Risk Framework. The cost effectiveness of practice change was calculated for priority catchments including the Bowen Bogie Broken, Lower Burdekin (upper parts) and Don indicating that the cost of sediment reduction from gullies is around \$160 per tonne. Large gains in cost effectiveness can be achieved by targeting areas of intense gully erosion within priority management units, where each kilometre of fence isolates the largest possible length and area of gully erosion. Where the efficiency of fencing can be increased to 1 kilometre of fencing for 10 kilometre of gully feature, the cost of combination 3 becomes \$4,500 per kilometre of gully, and the cost-effectiveness becomes as low as \$81 per tonne. However, it is not known what proportion of all gullies can be managed at this fencing efficiency, which should be determined through evaluation and adaptive management (Wilkinson et al. 2015).

Table 5.5. Effectiveness of selected combinations of grazing practice changes to manage erosion of existing gullies. Reproduced from Wilkinson et al. (2015).

Practice combination	Description	Related WQ Risk Framework Performance indicators (Table 5.2)	Infrastructure cost to transition from C/D practices (Moderate– High Risk) (\$/km) ^a	Cumulative sediment reduction changing from C/D practices (Moderate–High Risk)
1	Destock the gullied paddock, for occasional dry-season crash-grazing.	1, 3, 6	\$0	10–20%
2	Fence gullied area, for occasional dry-season crash-grazing, and continuous spelling otherwise. Stocking rate in surrounding area managed within long-term carrying capacity and adequate pasture and groundcover retained at the end of the dry season.	1, 2, 3, 4, 6	\$5,000 per km of fence ^b	30%
3	As per 2 above, plus stabilisation using gully stick trap or other revegetation.	6	\$4,500–9,000 per km of gully ^c (\$5,000 + \$4,000)	50%
4	As per 3 above, plus hydroseeding.	6	\$4,500–9,000 per km as above + \$10,000–30,000 per ha ^d	70%
5	As per 2 above, plus gully reshaping earthworks or rock drop structures.	6	Drop structure: \$30,000–50,000 per gully head ^e Reshaping and seeding: \$10,000 per gully head	70%

^a Opportunity costs of de-stocking gullied paddocks are not included here.

^b Advice from NQ Dry Tropics, 2014.

^c Range depends on the fencing efficiency; 1 km fence per km of gully results in a total cost of \$9,000 per km, being \$5,000 fencing, and \$4,000 per km for check dams assuming 30 stick trap check dams per km (33 m spacing), 2 person-hours per structure at \$50 per person per hour plus materials and grass seed. \$4,500 equates to 1 km of fence for 10 km of gully, and \$4,000 for check dams.

^d Depending on scale of project (Shellberg and Brooks, 2013)

^e Condamine Alliance, Case study 1: Allora. Based on gully density of 4 km/km² and one rock drop structure at \$30,000 and reshaping of smaller adjacent features at \$10,000 (Little, 2014)

Streambank erosion management

The cost associated with bank erosion remediation varies between regions in the GBR and is reviewed in Bartley et al. (2014c). Table 5.6 provides an estimate for each of the primary remediation options which was based on conversations with staff at several of the NRM groups (specifically Burnett Mary Regional Group, Terrain NRM, NQ Dry Tropics and Fitzroy Basin Association) and published estimates from the region (e.g. Lovett and Price, 2001). It is assumed that for each of the more expensive options (e.g. bank battering and toe revetment) that fencing off and revegetation will also occur to provide additional support to the site in terms of long term tree root reinforcement. This extra vegetation is important insurance as Miller and Kochel (2013) found that 50 per cent of engineered structures (e.g. grade control structures and bend away weirs) showed signs of impairment after 5 years.

Table 5.6. Estimated costs of bank erosion remediation options assuming a 6 m high bank with a 1 km long, 100 m wide riparian buffer (~10 hectares) on a property in B condition. Reproduced from: Bartley et al. (2014c).

Activity	Costs		Fence off, natural vegetation regeneration and paddock management	Fence off and active revegetation	Bank battering	Rip-rap or rock revetment
Fencing		\$5000/km	\$5,000	\$5,000	\$5,000	\$5,000
Production loss (assuming highly productive treed land)	A condition	\$387/ha	\$3,870			
	B condition	\$203/ha	\$2,030	\$2,030	\$2,030	\$2,030
	C condition	\$100/ha	\$1,000			
Off-site watering		Tank \$2,500 Trough \$1,200 Polypipe \$5000/km	\$8,700	\$8,700	\$8,700	\$8,700
Maintenance (floods/pigs/weeds) ^a		\$250/annum	\$250	\$250	\$250	\$250
Revegetation ^b		\$27,900/km		\$27,900	\$27,900	\$27,900
Bank battering (generally for banks >260)		\$100,000/km			\$100,000	\$100,000
Rock-revetment for toes of bank (~6 m high)		\$5,000/m or \$5,000,000/km				\$5,000,000
Total (per km)			\$15,980	\$43,880	\$143,880	\$5,143,880
Risks			Low	Depends of frequency of overbank events	Depends of frequency of overbank events	Moderate (~50%) loss over 5 years

^{a,b} Based on data in Lovett, S., Price, P., 2001. Managing Riparian Lands in the Sugar Industry: A Guide to Principles and Practices. Sugar Research and Development Corporation/Land and Water Australia, Brisbane.
Revegetation data was adjusted for inflation i.e. cost in 2001 estimated at \$2,010 per 100 m is ~\$2,790 per 100 m in 2013.

^c Edwards and Star (2013).

5.1.5 Priority areas in grazing lands

A process to update the prioritisation of sediment management for the Burdekin Region has been completed to support this WQIP and involved the following steps, derived from Wilkinson et al. (2014) and Lewis et al. (2015):

1. a synthesis of current knowledge of sediment delivery processes, the importance of sediment types and how that influences the relative importance of material delivered from individual management units in the Burdekin Region (scale to be defined depending on accuracy of the data) (Lewis et al. 2015);
2. a spatial analysis of several primary variables that represent and reflect the status and drivers of sediment delivery from the catchment to the GBR from the Burdekin Region (Waterhouse et al. 2015, 2016);
3. a qualitative discussion on the combination of these components to identify sediment management priorities for the Burdekin Region (Waterhouse et al. 2016); and
4. representation of the outcomes of these steps in a series of conceptual diagrams for communicating the results to a range of stakeholders and in the WQIP (prepared by L. Baskerville and S. Imragden, 2015).

The assessment was conducted at a range of scales and based on modelled estimates of TSS loads and export rates from different land uses and erosion sources.

The catchment scale assessment for sediment management in grazing lands was largely summarised in Section 3.2.2 based on a combination of monitoring and modelling data, with the following conclusions):

- grazing land use, and associated loss of ground cover, is the dominant contributor to TSS loads in all catchments (72 per cent of the total load and 78 per cent of the anthropogenic TSS load in the region). This is not including the streambank contribution, a majority of which is likely to be located within grazing areas, increasing the contributions from grazing to be 89 per cent and 95 per cent respectively for total and anthropogenic loads;
- within grazing lands, gully erosion is the dominant erosion source in the region overall (67 per cent), and in all catchments;
- the Bowen Broken Bogie catchment generates the greatest TSS anthropogenic annual average load from grazing lands (46 per cent). The Upper Burdekin is the second largest contributor in the region (27 per cent), followed by the Lower Burdekin (14 per cent). The remaining catchments contribute less than 13 per cent of the regional grazing TSS load; and
- gully erosion dominates in all grazing lands (50-73 per cent), with a regional estimate of 67 per cent of anthropogenic TSS in grazing lands from gully erosion. Hillslope and streambank erosion are estimated to contribute similar proportions, estimated at 19 per cent and 14 per cent respectively. These vary between catchments but in most cases, hillslope erosion is more significant than streambank erosion.

Given the vast area of the Burdekin Region and the individual catchments, and the variability in the drivers of sediment delivery and landscape characteristics, it is necessary to assess sediment management priorities at smaller spatial scales. Waterhouse et al. (2016) have completed an assessment of sediment management priorities in grazing lands for the 52 sub-catchments in the region. The assessment was based on modelled estimates of anthropogenic TSS loads and export rates from grazing and erosion sources and cross checked with monitoring data where available. The number of properties and where possible, the costs of management practice improvement, were also assessed as factors likely to influence feasibility. The key findings were:

- **All of the highest ranking sub-catchments for anthropogenic TSS loads from grazing lands are in the Bowen Broken Bogie, Lower Burdekin or Upper Burdekin catchments.** All of the sub-catchments in the Bowen Broken Bogie catchment are ranked in the top quartiles, including the top 3 sub-catchments overall, the Bogie, Broken and Bowen Rivers. However, the results for the Broken River are considered to be an overestimate in the model due to limitations in estimating the cover factor in forested areas (C. Dougall, pers. comm.) and should not be ranked as a priority sub-catchment for sediment management;

All of the sub-catchments with the highest ranking anthropogenic TSS export rates (delivered to end of catchment) from grazing lands are in the Bowen Broken Bogie, Lower Burdekin and Don catchments (Figure 5.2). *(Note that the results for the Broken River are highly uncertain as the Source Catchments model does not accurately reflect erosion processes in rainforest catchments and therefore are shaded in this map, and the estimates of streambank erosion in the Burdekin River (below Dam) sub-catchment are likely to be an overestimate.)* Seven of the top 10 sub-catchments are in the Bowen Broken Bogie catchment. However, as noted above, the rates from the Broken River have low confidence and therefore were not ranked highly for this assessment.

Gully erosion is the dominant erosion type from grazing lands at a sub-catchment scale except in the Burdekin Delta where streambank erosion is the dominant source (inset graph Figure 5.2). The modelled estimates also show that the Burdekin River (below Dam) is dominated by streambank erosion, however, detailed assessments by Bartley et al. (2014c) identified that there is limited evidence of excessive bank erosion in the Burdekin River (below Dam) sub-catchment. Most of the reach is bedrock controlled (evident by the bedrock located on the banks and bed of the river) and well vegetated. Bartley et al. (2014c) reported evidence of alluvial gully erosion at the junction of the Burdekin and Bowen River systems, however, this is not classic bank erosion (i.e. has not resulted from lateral channel migration) and should be treated as alluvial gully erosion. An assessment of the Bowen River system found a similar result with very little evidence of high rates of bank erosion, matching the modelling results. Most of the channel was reasonably well vegetated on both sides of the river. There is some evidence of severe bank erosion (i.e. steep, bare banks with pipe erosion) at a number of abandoned mine sites in the upper section of the Little Bowen catchment, and there is considerable severe gully erosion in the Little Bowen. However, it seems that gully erosion, rather than stream bank erosion, is likely to be the dominant source of channel erosion in this catchment.

These results highlight the need to undertake on ground assessments before investing in erosion management at specific sites across the region.

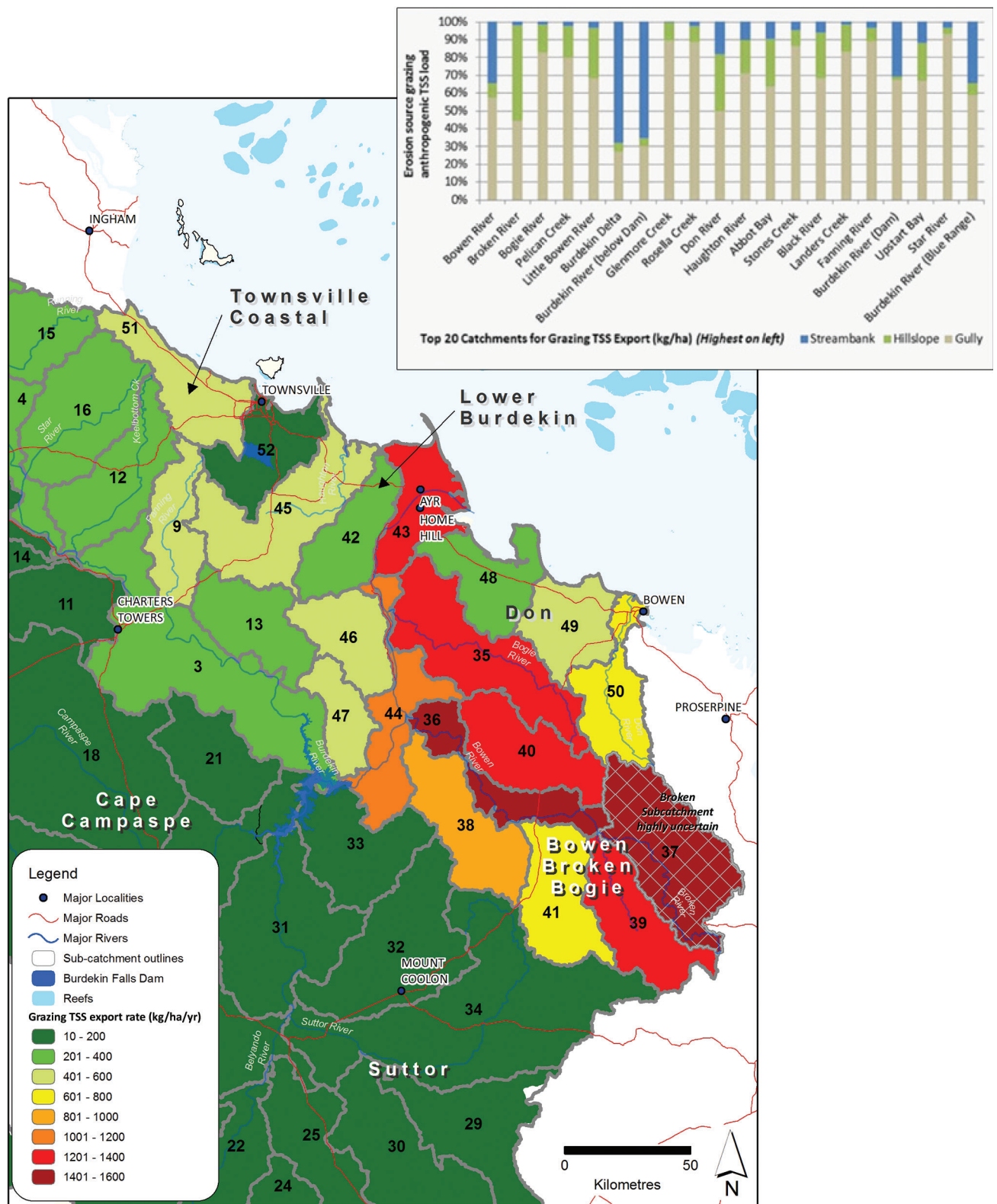


Figure 5.2. Modelled anthropogenic annual average TSS export rates from grazing lands in coastal sub-catchments below the Burdekin Falls Dam. Inset shows the erosion sources and the sub-catchments are ordered by anthropogenic TSS export rate in kg/hectare/year (highest on left). Catchment boundaries are shown in white. Derived from Source Catchments 2013 baseline estimates, DNRM 2015. Note that the results for the Broken River are highly uncertain as the Source Catchments model does not accurately reflect erosion processes in rainforest catchments and therefore are shaded in this map, and the estimates of streambank erosion in the Burdekin River (below Dam) sub-catchment are likely to be an overestimate.

Other factors can be used to assess priorities within sub-catchments including gully density mapping, analysis of current and historic ground cover data and assessment of changes in riparian vegetation cover and are included in the Catchment Atlas. Additional information associated with existing land condition and productivity, current management practices, the costs of management changes and social factors such as gender and age are also important to inform spatial prioritisation of sediment management (Star et al. 2015). However, much of this information is required at a parcel scale and is not uniformly available across grazing lands in the region. Future assessments should aim to progress this knowledge at property / parcel scales, some of which is pursued by Beutel et al. (2015) to prioritise extension activities for the Department of Agriculture and Fisheries (DAF).

For this assessment, the number of grazing properties and consideration of the costs of grazing management can be incorporated as indicative factors of management feasibility.

Table 5.7 summarises the characteristics assessed at sub-catchment scale for the 'top 10' sub-catchments in the Burdekin Region in terms of annual average sediment export from grazing lands to the GBR. This highlights that targeting a specific issue in prioritised sub-catchments has high potential for effective investment in water quality improvement.

It is recommended that a detailed implementation plan is developed to identify management strategies for these priority sub-catchments, focusing on the Bowen Broken Bogie catchment, as an immediate outcome of the WQIP.

Landscape protection and prevention of further erosion

In a highly modified landscape such as that of the grazing lands in the Burdekin, there is a need to protect those areas where soil erosion rates are relatively low, and to identify areas and prioritise actions to prevent further erosion. Methods for preventing further gully development are critical for reducing sediment loads delivered to the GBR. In some cases, it might be appropriate to encourage temporary retirement of marginal lands, or retire the land to alternative land uses such as conservation. However, some level of remediation is still likely to be required which needs to be factored into the assessment of management options.

Beutel et al. (2015) have established criteria for protection and prevention of soil erosion as part of the prioritisation of extension and education programs in grazing lands, coordinated by the Queensland Government. This assessment is available at a property scale but presentation of the data at this scale it is not considered to be appropriate for inclusion in this plan. Wilkinson et al. (2015) also identified the importance of preventing initiation of new gullies in the GBR catchments, which is substantially more cost effective than gully remediation.

Wilkinson et al. (2015) conducted a spatial assessment of vulnerability to future gully erosion in and around the Burdekin Basin. Vulnerable areas are defined as those with low levels of gully erosion that have similar environmental characteristics to areas usually containing high levels of gully erosion. These areas are identified by developing a model of mapped gully density, and then analysing the differences or 'errors' between the model and the input gully mapping. Areas where the mapped gully erosion is over-predicted by the model are vulnerable to future gully erosion. Factors considered in the assessment were current mapped gully presence and environmental variables known to influence gully development associated with soil, terrain, vegetation and climate. The variables most correlated with gully extent were dominated by soil properties, with the duplex soils classified as Chromosols found to be most prone to existing gullying.

Vulnerability to future gully erosion was most-correlated with the grazing-induced deficit in cover relative to nearby reference levels (Bastin et al. 2012). This indicated grazing management has had a significant impact on the development of gully networks. The area most vulnerable (at risk) to future gully erosion are those in duplex soil types (high surface soil water holding capacity) with relatively high historical cover levels. Maintaining ground cover on those properties is a priority for gully prevention, and is very cost-effective given the much higher costs of gully remediation.

Top 10 Sub-catchments	Catchment	Total TSS load		TSS export		Erosion source (%)			Dominant erosion source	No. of properties (>200ha)	Confidence (H/M/L)/ additional considerations
		tonnes	Rank	kg/ha	Rank	Gully	Hillslope	Stream			
Bowen River	Bowen	180,894	4	1,594	1	57	8	35	Gully	10	H; Bartley et al. (2014c)
Bogie River	Bowen	285,470	1	1,333	3	83	15	2	Gully	12	H; some monitoring data available to support model
Pelican Creek	Bowen	166,612	6	1,323	4	80	17	3	Gully	18	M; limited monitoring data support model – reasonable observational data
Little Bowen River	Bowen	177,594	5	1,272	5	69	28	7	Gully	6	H; some monitoring data available to support model
Burdekin Delta	Lower Burdekin	38,413	16	1,211	6	27	5	68	Streambank	10	H; some monitoring data available to support model
Burdekin River (below Dam)	Lower Burdekin	181,011	3	1,162	7	31	4	65	Streambank	9	H; Bartley et al. (2014c)
Glenmore Creek	Bowen	151,323	7	936	8	89	10	1	Gully	5	M; limited monitoring data support model
Rosella Creek	Bowen	101,485	9	737	9	88	9	3	Gully	4	M; limited monitoring data support model reasonable observational data
Don River	Don	67,218	12	652	10	50	32	18	Gully / Hillslope	19	H; some monitoring data available to support model
Houghton River	Lower Burdekin	80,555	11	524	11	71	19	10	Gully	38	H; some monitoring data available to support model

Notes: Red = Top quartile; Orange = Second quartile; light green = Third quartile; Dark green = Bottom quartile.

Total number of grazing properties in the region >200ha = 871; Total TSS load from grazing land use = 2,785,286 tonnes.

Table 5.7. Grazing TSS loads (based on modelled annual average anthropogenic estimates) and characteristics for the top 10 sub-catchments (determined by ranking loads per hectare and total loads). Note that the assessment for the Broken River is likely to be an overestimate due to limitations with the model accuracy in rainforest conditions.

5.2 Managing water quality from sugarcane

5.2.1 Principles for improving water quality from sugarcane

As illustrated in *Section 3.3.2 Sugarcane pollutant load contributions*, the biggest factor driving nitrogen losses in both runoff and deep drainage is fertiliser application rates and the timing of application. Managing irrigation efficiencies in the dry season is also important.

Optimising fertiliser use in sugarcane is about matching nitrogen supply to match crop nitrogen requirements, factoring in timing of application in proximity to wet season rainfall events and subsurface application of fertiliser. This is achieved through the development of nitrogen budgets based on the growers own yield expectations for specific blocks and ratoon numbers, and consideration of climate predictions, both seasonal (for rate) and weekly (for timing of application). Thorburn et al. (2011) have shown that aligning N fertiliser management with yields in individual blocks could reduce long-term nitrogen surpluses to 50 kg/ha/yr, and hence reduce DIN in runoff and deep drainage by approximately 70 per cent and 50 per cent, respectively, without reducing yields.

In the past five years new knowledge has been generated to improve our understanding of how irrigation management influences N losses. Improvements in water use efficiency are predicted to result in reductions in nitrogen loss especially in the dry season, and particularly in the heavier BRIA soils (Thorburn et al. 2011 and confirmed in recent data supplied by G. Fraser, DNRM through the Paddock to Reef Program). Therefore fertiliser and irrigation management are both required to reduce nitrogen losses from sugarcane in the region. Excess irrigation water also has implications for the volume of surface runoff which is greater if the soil profile is 'full'. Therefore irrigation efficiencies may be considered more important in the BRIA where there is comparably less deep drainage than in the Delta and greater capacity for surface runoff (Thorburn et al. 2011).

For pesticides the main factor that influences losses in both wet and dry seasons is the rate of application which is also linked to the application method (e.g. banded spraying) and timing of application. PSII herbicides (commonly atrazine, diuron, ametryn and hexazinone) are applied throughout the sugarcane crop growth and fallow periods to control weeds. Commonly these herbicides are applied uniformly over farms using standard spray rigs using combinations of various active ingredients targeting specific weed groups such as grasses and, broad-leaves and nutgrass vines. In recent years there has been a shift within the sugarcane industry towards the use of alternative herbicides such as metolachlor, impazipic, isoxaflutole, metribuzin and pendimethalin. These are perceived to have a reduced toxicity, mobility and persistence compared with PSII herbicides (Davis et al. 2014). However, relatively little is known about the long term acute and chronic effects when organisms in freshwater and marine environments are exposed to these alternative herbicides (Davis et al. 2014). In addition, the use of more environmentally benign knock down chemicals has been promoted, such as glyphosate that do not contain the same chemical properties that inhibit photosynthesis in corals and seagrasses (Flores et al. 2013) also further evaluation of the half-life of these products in marine ecosystems is required. Best practice herbicide management requires the strategic use of different modes of action herbicides to minimise risk of herbicide resistance developing within weeds.

In the Burdekin Region, the use of shielded spray rigs and other banded sprayers with multiple chemical mixes enables the targeted application of PSII herbicides away from water furrows is limiting the potential for offsite transport. Studies have shown that by using this method, PSII herbicides loads in irrigation induced runoff can be reduced by as much as 90 per cent compared to conventional blanket applications (Oliver et al. 2014). Banding applications are also shown to reduce wet season PSII herbicide losses by 47-60 per cent compared to conventional broadcast applications (Masters et al. 2013). Irrigation management was also found to be an important factor if herbicides are applied in a conventional method. Off-site herbicide losses are greatest in the first few irrigation events and taper off as irrigations continue throughout the crop growth period (Davis et al. 2014).

Improvements to the paddock scale modelling that have been incorporated in recent years include four regionalised scenarios that encompass a suite of traditional PSII herbicides and the alternative herbicides that are perceived to be less toxic to corals and seagrasses. The rate of applications is the dominant contributing factor, with limited differences associated with different irrigation techniques. Considering that the spatial risk of herbicide loss is largely homogenous, it is recommended that efforts be directed into the rate of PSII herbicide application, which can be improved by uptake of banded application methods across both BRIA and Delta regions.

The timing of losses is a critical factor in determining the relative risk of pollutants to the receiving environments. For example, the highest risk periods for pesticide impacts on freshwater ecosystems are (Davis et al. 2015):

- acute effects in main stream channels would be expected primarily during first flush events; occurring soon after herbicide application;

- the first flush generally washes away much of the instream plant biomass making detection of herbicide effects unlikely in the main stream. However, large events may be the main avenue for delivery of herbicides (and water) to off-channel floodplain wetlands that are recharged (but not necessarily flushed) by floodwaters;
- irrigation tailwater runoff events during the dry season may present a special case, acting like first flush events, especially in cases where the receiving stream does not have strong natural baseflow (see Davis et al. 2013); and
- for coastal and marine ecosystems, any risk from pesticide runoff delivered from the Lower Burdekin areas is only going to occur in wet season rainfall events, and is considered to be high to very low risk dependent on the distance of the ecosystem from the stream mouth (Lewis et al. 2013b; Brodie et al. 2013b). As an example for coastal seagrass in Bowling Green Bay directly in front of the mouth (within 5 kilometres) of Barratta Creek risk may be high from herbicides discharged in event flow. In contrast for coastal seagrass in Cleveland Bay, ~ 80 km from the mouth of Barratta Creek the risk will be very low from herbicide discharge due to dilution.

These concepts are summarised in Table 5.8.

Receiving environment	PSII herbicides ¹	Nutrients – DIN ²	Sediment ³
Groundwater	Uncertain (limited evidence and confidence in existing data)	Uncertain (limited evidence and confidence in existing data)	Low
Freshwater reaches of rivers and freshwater /coastal wetlands	Very High to Moderate (depending on location) <i>Dry season & first flush events</i>	Moderate (limited evidence of effects on aquatic plants in region) <i>Dry season & first flush (e.g. hypoxic events)</i>	Low – drain erosion limited
Estuarine reaches of the rivers	High to Low <i>First flush events</i>	Moderate to Low (limited understanding on effects on biota & WQ data; trophic interactions) <i>Dry season & first flush</i>	Low
Coastal intertidal & subtidal seagrass	High to Low <i>Wet season esp. first flush events</i>	High (high flow conditions only) <i>Interaction with sediment >> flocs and increased turbidity Wet season</i>	Low
Coral reefs – inner shelf	Low to very low <i>Wet season</i>	Locally high (high flow conditions only) <i>Interaction with sediment >> flocs and increased turbidity Wet season; irrigation tailwater nutrient loss is low to no risk</i>	Low
Seagrass – deepwater	Low to very low <i>Wet season only</i>	Low <i>Wet season only</i>	Low
Coral reefs – mid and outer shelf	Very Low to no risk <i>Large wet season events only</i>	Moderate (COTS & bleaching; relative to Wet Tropics) <i>Large wet season events only</i>	Low
Data sources:	¹ Lewis et al. (2013); Waterhouse et al. (2016a)	² Brodie et al. (2016); Waterhouse et al. (2016b)	³ Lewis et al. (2015); Davis et al. (2015)

Table 5.8. The relative risk of pesticides, DIN and suspended sediment runoff from sugarcane in the Lower Burdekin catchment to receiving aquatic environments. High risk indicates that the pollutant load/concentration is likely to exceed ecological health thresholds at levels that may lead to severe ecological damage over an extended area; Moderate risk indicates that the pollutant load/concentration is likely to cause degradation of ecosystems at local scales; and Low risk indicates that the loads/concentrations are not likely to result in measurable impacts on ecological health.

Taking these factors into account, the priority practices for improving water quality from sugarcane areas are summarised below, supported by the P2R Water Quality Risk Framework summarised in Table 5.9 and linked to the Burdekin framework in *Appendix 5: The ABCD Frameworks for sugarcane, grazing and horticulture in the Burdekin region*.

DIN: High Priority

1. Adoption of 'at industry standard' practices as outlined in Smartcane BMP framework as industry minimum standard. For fertiliser application this requires adoption of the Six Easy Steps nutrient management program.
2. Nitrogen budget developed for management zones, supported by Nutrient Management Plans.
3. Apply nitrogen fertiliser to match crop N requirements at times that avoid high risk periods for N losses and employ improved nutrient use efficiencies, e.g. improved subsurface application to minimise volatilisation. Irrigation management to minimise losses to runoff and deep drainage.
4. Extension and support for adoption of technology and understanding of local water quality issues.
5. Extension support to specifically promote the Six Easy Steps nitrogen management system using local productivity groups.

Residual herbicides including PSII: High Priority

1. The adoption of best practice technology for application of herbicide e.g. banded spraying, nozzle selection, products and rates.
2. Irrigation management to minimise losses to runoff and deep drainage and considers the timing of irrigation after herbicide application.
3. On farm water management systems (recycle pits) to store, capture and re-use irrigation induced run-off.
4. Adoption of fallow management to minimise weed pressure and reliance on herbicide application later in the crop cycle.
5. Extension and support for adoption of technology and understanding of local water quality and business issues.

Suspended Sediment / Particulate Nutrients: Low Priority

1. Promote controlled traffic farming.
2. Promote best practice drainage management.
3. Well managed fallow crop.

5.2.2 Management practice framework for sugarcane

The current management practice framework for sugarcane in the Burdekin Region is included in *Appendix 5: The ABCD Frameworks for sugarcane, grazing and horticulture in the Burdekin region*.

One of the challenges of basing much of the reporting and modelling on the ABCD framework is the differences in the definitions of the levels of practice between reporting schemes and industry frameworks. For example, in the sugarcane industry, current practices that will meet the Industry Standard under the Smartcane BMP framework (Canegrowers, 2016b) could be described as being roughly equivalent to C class practices under the ABCD framework.

The Smartcane BMP has a three- tier structure (Below /At / Above Industry Standard), which, though suiting its multi-regional and multi-themed (productivity, profitability and water quality) application, is different to both the Paddock to Reef Program and Burdekin Region four-tiered structure, making some comparisons difficult. It must be noted however, that all seven of the Smartcane BMP modules contain some detail relating to improving water quality and the cumulative effect is both significant and holistic. The Smartcane BMP is also the only system that requires proof of practice and this will be of immense use in long-term monitoring of practice change.

Table 5.9. Relative priorities of sugarcane management practices as per the Reef Plan Sugarcane Water Quality Risk Framework.

Priority	Management tactic	Weighting
Nutrient management		
1	Matching fertiliser rate to crop requirements	60%
2	Timing of fertiliser application	30%
3	Application method/form	10%
Irrigation management		
1	Irrigation water budgeting and management	80%
2	Managing surface runoff	20% (100% for non-irrigated cane)
Herbicide management		
1	Timing application of residual herbicides	40%
2	Targeted application of residual herbicides	40%
3	Residual herbicide use in ratoons	20%
Sediment management		
1	Ground cover management	75%
2	Controlled traffic farming	25%

Figure 5.3 illustrates the alignment of the description practice classes in the Burdekin Region. With co-operation between sectors, stronger alignment between systems should progress over time.

Another issue is continual improvement of the water quality benefits of practices as they evolve with better knowledge. For example, as an A class practice becomes proven and accepted, it is then adopted by industry and becomes a B class practice. The use of GPS for zonal-tillage / permanent beds in the sugarcane and multicrops industries is an example. Similarly some surface-fertilising practices that have been accepted as B practices are likely to move to C class practice as new methodologies are proven to be applicable and trials confirm water-quality impacts. It is important to recognise and capture this shift in evolving practices, and reflect what is actually happening on the ground rather than be constrained by categories. Hence, it is recommended that the framework is shifted into the context of water quality risk posed by management practices. This is being progressed through the Paddock to Reef Program for each region.

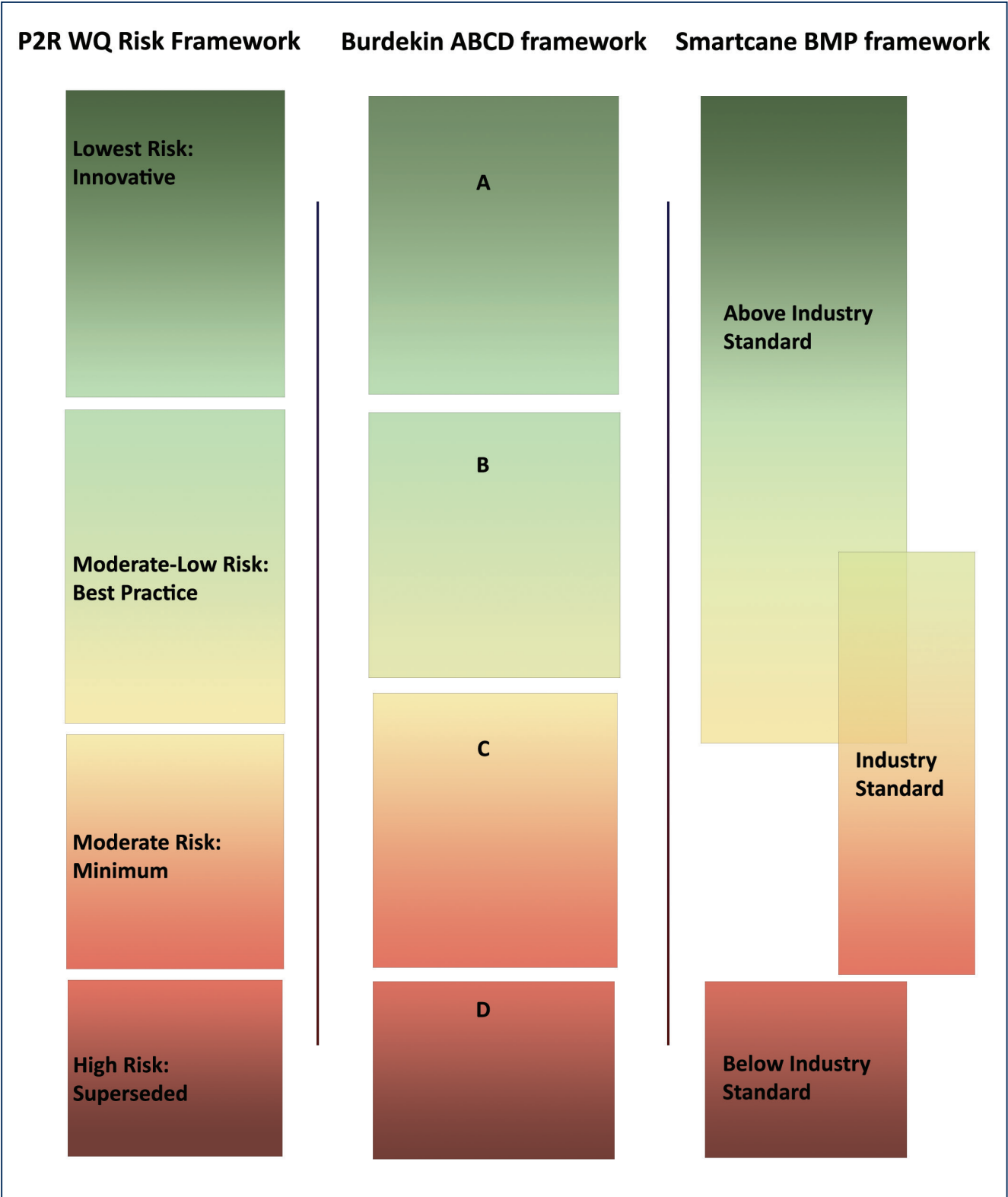


Figure 5.3. Alignment of the description in management practice classes under the Reef Plan Paddock to Reef Program, Burdekin ABCD framework and the Smartcane BMP framework.

The following key parameters are assumed for each management practice class in nutrient and irrigation management.

Average nitrogen usage in the Burdekin region over a full crop cycle is estimated at:

- A class: 157 kg N/ha/yr
- B class: 178 kg N/ha/yr
- C class: 219 kg N/ha/yr
- D class: 295 kg N/ha/yr

For irrigation management, the following assumptions were made for irrigation practices:

- A class: Not defined for this plan B class practices should achieve efficiencies > 90 percent.
- B class: Well designed and managed drip or overhead low pressure systems.
- C class: Well designed and managed furrow systems.
- D class: Poorly designed and managed furrow systems.

5.2.3 Current adoption of improved management practices

Management practice adoption data is available and interpreted through several sources in the region: 1) the Paddock to Reef Program; 2) the NQ Dry Tropics Reef Programme water quality grants database; and 3) industry technical advice from the INFFER workshops. Due to variations in the scope and detail of data sets, estimates of adoption characteristics vary between the sources. Anomalies are being identified and addressed through the Paddock to Reef Program. Estimates used for this WQIP were derived from industry experts as part of the INFFER process, taking into account all data sources, as are shown in Table 5.10. When taking into account management practice systems, it is important to recognise that a large proportion of the sugarcane area in the Burdekin Region is currently managed at or below C class practices. While it has been established that 95 per cent of the sugarcane area is irrigated using conventional furrow irrigation systems, there is a lack of data on how efficiently these irrigation systems are operating. Data on the adoption of Water Use Efficiency is important for understanding water quality influences from irrigation practices and is currently limited.

As an additional line of evidence, whole- of- industry nitrogen use can be considered using published annual Incitec Pivot sales data of nitrogen (and phosphorous). The data show that fertiliser use gradually declined between 1995 when average nitrogen application rates were in excess of 250 kg N/ha/yr, and recent years where application rates are around 220 kg N/ha/yr. Over the period 2011 to 2014, the average fertiliser sales per year from Incitec Pivot (produced annually as a useful baseline value) equated to an average application rate of 214 kg N/yr and varied from 227 kg N/ha in 2011 to 209 kg N/ha in 2014 (Agritech Solutions, 2015). Using this information, current adoption rates and the average nitrogen usage rates identified above, it is possible to calculate the contribution from each management class to the district average nitrogen use. The greatest contribution to regional use is in land managed under C class practice rates around 220 kg N/ha/yr (Agritech Solutions, 2015).

A third line of evidence is the aggregation of fertiliser usage data in the BRIA and Delta regions. The regulated Six Easy Steps fertiliser application rate in the Burdekin Region (under the Great Barrier Reef Protection Amendment Act 2009) is currently 170 kg N/ha/yr in plant-cane and 210 kg N/ha/yr in ratoon-cane, however, growers have had the ability to apply for an exemption to apply 240 kg N/ha/yr until further trials are completed this year and these rates may be reviewed. Farmer surveys of fertiliser application rates for plant and ratoon crops have been conducted across BRIA and Delta regions as part of the Paddock to Reef Program in 2015 (128 surveys). Fifty seven of the surveys were conducted in the BRIA, with respondents managing a total farm area of approximately 16,780 hectares (35 per cent of the BRIA region), and 71 surveys in the Delta, with respondents managing a total farm area of approximately 9,865 hectares (23 per cent of the Delta region); total area managed by the respondents equates to approximately 30 per cent of the Burdekin sugarcane production area.

Table 5.10. Current (2015) estimates for representative proportions of growers at each nutrient and herbicide management class. Derived from the Paddock to Reef program management practice adoption data and INFFER expert workshops.

Management class	Management practice adoption (% of area)			
	BRIA		Delta	
	Nutrient and tillage management	Herbicide management	Nutrient and tillage management	Herbicide management
D class	18	18	14	22
D-C class	12	10	12	13
C class	17	42	28	36
C-B class	18	8	18	10
B class	23	21	22	17
B-A class	0	0	0	0
A class	12	1	7	1

The data shows that 92 per cent of respondents in the BRIA and 82 per cent of respondents in the Delta are applying beyond 170 kg N/ha/yr in plant-cane. In ratoon-cane, 71 per cent of respondents in the BRIA and 62 percent of respondents in the Delta are applying more than 210 kg N/ha/yr.

Figure 5.4 shows this data represented as the nitrogen rate applied above (i.e. in excess of) the Six Easy Steps guideline, and the average value of nitrogen savings per hectare of application rates were as per Six Easy Steps. When assessed over a full crop cycle and extrapolated to the whole region, the N ‘surplus’ equates to approximately 1,760 tonnes per year in the BRIA and 360 tonnes per year in the Delta, with potential savings of up to \$187 per hectare in plant-cane and \$252 per hectare in ratoon-cane.

This data, along with, fertiliser sales records and modelled DIN loads (Section 3.3.2) point to **significant application of nitrogenous fertiliser beyond industry recommended Six Easy Steps guidelines in the BRIA and the Delta regions**. Reductions in fertiliser application will have environmental and economic benefits, as discussed further in Section 5.2.4.

The current estimates of the adoption of irrigation management practices and the assumed irrigation efficiencies are shown in Table 5.11. The adoption rates vary significantly between the Paddock to Reef program estimates and current industry advice, most likely because it is difficult to assess irrigation application efficiency given the high variability in site specific characteristics. The application efficiencies are also relatively low compared to national irrigation standards and it is recommended that best management practice rates defined in the Paddock to Reef program are reviewed. However, it is unlikely that the current B class efficiencies could be realised using furrow irrigation in all areas and methods such as well-designed drip and overhead low pressure irrigation systems are likely to be able to deliver 80 per cent application efficiencies in some locations (S. Attard, pers. comm.).



Figure 5.4. Estimates of nitrogen application above the nominal Six Easy Steps rate and potential cost saving for plant cane (top) and ratoon cane (bottom).

Table 5.11. Current (2015) estimates for representative proportions of growers at each irrigation management class from the Paddock to Reef program and industry advice (BRIA and Delta estimates provided by S. Attard, AgriTech Solutions December 2015).

Irrigation Management class	Total area Paddock to Reef program adoption data	BRIA		Delta	
		Application efficiency (%)	Current adoption (% area)	Application efficiency (%)	Current adoption (% area)
A	8	>85	2	>75	2
B	2	70-85	35	60-75	33
C	8	50-70	40	40-60	35
D	82	<50	23	<40	30

It is acknowledged that water use and therefore management of groundwater levels in the region is strongly influenced by water pricing, in addition to licensing requirements. Water costs were increased in year 2000 (Part A and Part B), which has discouraged conjunctive use of groundwater and is likely to have contributed to the rise in water tables in the region over the last 15 years (see Section 2.2.1). Legislative arrangements to restrict access to groundwater for conjunctive water use have also made a significant contribution to the rising groundwater issue (Shaw, 2014). The Queensland Government policy decision referred to as the 'one in eight rule' limits groundwater use to 1 part groundwater to every 8 parts of surface water applied, (12.5 per cent) (Petheram et al. 2008), limits the ability of individual BHWSS irrigators to address rising groundwater water levels. This has been difficult to achieve without growers having some certainty on investment and water yield, the lack of incentives in the water pricing policy to use groundwater, the difficulty of getting authorisation to use groundwater, the uncertain quality of groundwater and difficulty of extraction in some areas (Shaw, 2014).

There have been limited management arrangements that have made a change to groundwater use and a reduction in the rate of rise of groundwater levels. It will take a concerted effort to lower the water table because of leakage into streams, dewatering of the saturated zone as well as lowering the water table. The cost of infrastructure to do this and the costs and maintenance for pumping and the disposal of groundwater of poor quality or unacceptable pollutant load and appropriate monitoring will be high. Some irrigated areas may well go out of production in the time required to implement the recommendations and priority actions listed in Shaw (2014).

There are several factors that may affect a sugarcane farmer's management adoption decision. For example, in a recent study by Thompson et al. (2014b) (based on the results of 61 farmer surveys in Ayr (30), Ingham and Tully) potential constraints to adoption of variable nutrient rates within blocks included high capital investment and the requirement for new skills, and a perceived negative impact on farm profitability. Perceptions of the impact on farm profitability and compatibility with existing farming practices were critical factors impacting on the adoption decision. Socioeconomic factors as well farm characteristics were generally found to be insignificant in determining an adoption decision. However, a proportionally higher amount of younger farmers (aged 45 or less) were found to have adopted best management practices. It is also acknowledged that growers will be unlikely to adopt new practices that import high risks to farm production and profitability (see Smith et al. 2012; Smith et al. 2014; Poggio et al. 2014). Adverse weather conditions, incursions of disease, as well as increases in fixed costs have applied pressure on grower margins which is likely to influence management decisions (Smith et al. 2014).

Farm size can also influence management choices and has a bearing on the cost effectiveness of management practice changes. The characteristics of farm sizes and farm numbers (not enterprises) for the BRIA and Delta regions are shown in Table 5.12. It is estimated that there are 530 sugarcane farmers in the region (E. Shannon pers. comm.), operating 927 farms (provided by Wilmar, February 2016). The data indicates that:

- the **BRIA** includes 53 per cent of the Lower Burdekin cane production area, and 37 per cent of the number of farms in the region; and
- the **Delta** includes 47 per cent of the Lower Burdekin cane production area, and 63 per cent of the number of farms in the region.

This data highlights the multifaceted approach needed to achieve management practice improvements across the region and informs potential resource implications discussed in Section 6.

5.2.4 Estimated costs of improved sugarcane management practices

A synthesis of the literature on key agricultural economics studies involving sugarcane farm management systems and practices was completed as a component of the Reef Water Quality Protection Science Program (RP62c) project (Smith et al. 2014; Poggio et al. 2014; Thompson et al. 2014b). Many of the earlier economic studies mainly involved integrated approaches that included nutrient and pesticide management as a component within the suite of changes across the whole farming system (for example Roebeling et al. 2004, 2007; and Paddock to Reef program work within the Burdekin: Poggio and Page, 2010a, 2010b; van Grieken et al. 2010, but there is a growing body of recent research that has tended to focus upon changes to individual management practices (for example, Poggio et al. 2014; van Grieken et al. 2014). A summary of this work is provided in Waterhouse et al. (2016).

As part of the supporting studies for this WQIP, Smith (2015) has conducted a financial-economics analysis to evaluate the total weighted cost/benefits to transition between ABCD management classes using traditional capital budgeting methods. This analysis evaluated partial and whole transitions between 24 farming scenarios specifically developed to represent the nutrient, tillage and herbicide management classes that are consistent with the Burdekin ABCD framework. The scenarios included 12 different farm sizes within each of the Delta (25-300ha) and BRIA (50-2,000ha) cane districts. The data used to weight each farm size according to the proportion of farming area in each district was sourced from Wilmar (P. Larsen January 2016). Yield data used was based upon those provided by the APSIM modelling (G. Fraser, DNRM 2015). Further details of the methods and input data used is provided in Smith (2015) and an accompanying spreadsheet tool is available

Table 5.12. Characteristics of the area and number of sugarcane farms in the Lower Burdekin sugarcane area. Data supplied by P. Larsen, Wilmar January 2016.

Sugarcane region	Characteristic	Area classes (hectares)					
		<100	100-400	400-1000	>1000	Total	% of Region
Delta	No. of properties	479	106	2	1	588	63%
	% of properties	81%	18%	0.3%	0.2%	100%	
	Area (ha)	24,193	16,436	833	1,129	42,592	47%
	% of area	57%	39%	2%	3%	100%	
BRIA	No. of properties	181	141	11	6	339	37%
	% of properties	53%	42%	3%	2%	100%	
	Area (ha)	9,110	24,033	5,641	8,701	47,485	53%
	% of area	19%	51%	12%	18%	100%	
Regional total	No. of properties					927	
	Area (ha)					90,077	

from NQDT on request. In recognition that the yields produced from the simulations may or may not be representative of district cane production, cane yields presented in representative regional FEAT (Farm Economic Analysis Tool; see Cameron, 2005) file scenarios developed by DAF (DAF, 2015) were also evaluated indicating that further refinement of the yield data is necessary.

The Farm Gross Margin (FGM) was first estimated for each ABCD management class, and the changes to the FGM were subsequently used as approximations for the annual changes to farm cash flows as a consequence of transitioning between management classes. These cash flows were evaluated over a series of years (i.e. 5 years for this analysis) and discounted at an appropriate opportunity cost of capital to determine their present value. The present value of this cash flow stream was then compared to the capital expenditure requirements associated with the change in management practices to determine the Net Present Value (NPV). Importantly, all calculations were weighted by the number of growers estimated to be at each management class and representative farm size area.

The individual management practices that were costed for transitioning between management practice classes are shown in *Appendix 6: Management practice shifts and costs assumed in the INFFER cost benefit analysis*.

The results of the economics analysis presented below are calculated using a constant required rate of return of 5 per cent over a 5-year investment horizon. In Smith (2015) a more formal approach was developed and applied to assign appropriate discount rates for each management class transition. The Weighted Average Cost of Capital was estimated for Wilmar International Limited to be used as a base discount rate for the transition from C to B class management scenarios. Relative, risk-adjusted discount rates of return were subsequently calculated using the Capital Asset Pricing Model for changes between each management class scenario. Results of the weighted NPV of transitioning between management classes are shown in Table 5.13 for the region and then the BRIA and the Delta separately. The results are then broken down further between nutrient/tillage management and herbicide management transitions (Table 5.14). Capital expenditure costs for recycling pits have been excluded from these results.

Previous studies have typically found that moving from C to B class management practices (nutrient and herbicide) is generally profitable for sugarcane farmers. This data indicates that this is not the case, however shifts from D to C or D to B practice appear to be profitable.

For nutrients, moving farmers from D class nutrient management practices to C and B class management is deemed to be profitable across the region, with higher per hectare costs estimated in the Delta region than the BRIA for D to B shifts due to smaller farm sizes. All other changes (C to B, C to A and B to A) are expected to incur upfront costs to growers, with limited ongoing maintenance costs and in most cases, financial benefits within a full cropping cycle.

For herbicides, all practice class shifts are expected to cost growers across the region, except for shifting from C to B management practice in the BRIA. As for other practices the costs for herbicide management changes are typically higher in the Delta than the BRIA.

The results are more effective than previous studies at capturing the impacts of economies of scale across the sugarcane region. When taking farm size into account, the greater the area of smaller farms as a proportion of the total Burdekin area implies relatively larger upfront capital costs per hectare than if the farm size distribution was equally weighted across the region or skewed to the left towards a greater proportion of large farms. For instance, the data on representative farm sizes indicates that more than 50 per cent of farms in the Delta are 100 ha or smaller.

Table 5.13. Weighted Economic Analysis Totals using a constant Weighted Average Cost of Capital (WACC) and APSIM cane yields for the whole region), the BRIA and the Delta separately. *Profitable shifts are shaded green; shifts that are considered neutral within the possible margins of error are shaded light green; shifts that come at a cost to growers are shaded orange. Source: Smith (2015).*

Practice shift	Region (total)		BRIA		Delta	
	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹
Moving D to C class	19.9	50	10.2	50	9.6	50
Moving D to B class	8.3	20	9.5	45	-1.9	-5
Moving D to A class	-14.4	-35	4.3	20	-18.7	-100
Moving C to B class	-38.9	-100	-4.7	-25	-34.1	-185
Moving C to A class	-103.8	-265	-21.1	-100	-82.7	-450
Moving B to A class	-20.8	-50	-5.3	-25	-15.4	-85

¹ Rounded to the nearest 5.

Table 5.14. Weighted Economic Analysis Totals for nutrient/tillage management and herbicide management for each district using a constant Weighted Average Cost of Capital (WACC) and APSIM cane yields. *Profitable shifts are shaded green; shifts that are considered neutral within the possible margins of error are shaded light green; shifts that come at a cost to growers are shaded orange. Source: Smith (2015).*

Practice shift	Nutrient				Herbicide			
	BRIA		Delta		BRIA		Delta	
	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹	Weighted NPV over 5 years (million \$)	Per hectare annual totals (\$ per hectare) ¹
Moving D to C class	10.9	55	10.6	55	-0.6	-5	-0.9	-5
Moving D to B class	9.7	45	1.8	10	-0.3	0	-3.0	-15
Moving D to A class	5.0	25	-11.5	-60	-0.7	-5	-7.2	-40
Moving C to B class	-5.2	-25	-31.1	-170	0.4	0	-3.0	-15
Moving C to A class	-20.3	-100	-73.9	-400	-0.8	-5	-8.8	-50
Moving B to A class	-4.7	-25	-13.3	-70	-0.6	-5	-2.1	-10

¹ Rounded to the nearest 5.

For the purpose of generating specific input parameters for use in the INFFER analysis, results were further separated to isolate the upfront costs from the ongoing annual maintenance costs/benefits of all growers transitioning to B class or higher using a constant discount rate of the five per cent over a five year investment horizon. Scenarios were examined for cases inclusive and exclusive of recycle pits. These figures indicated that while progressive management practice adoption is expected to increase annual farm cash flows, the upfront capital expenditure costs required to implement these changes were considerably large by comparison.

Improved irrigation management is also expected to incur a cost to growers, and this can be significant when reaching B class irrigation efficiencies. These costs were considered after the above analysis for nutrients and pesticides was completed. Shifting D to C irrigation management is likely to require incorporation of automation systems for managing irrigation timing and rate. Current estimates indicate that the price to automate systems will widely vary from site to site depending upon farm layout and the type of hardware the individual farmers prefers. The early results of several trials indicate that the capital cost will be in the range \$600 to \$1,500 per hectare for instrumentation, with annual maintenance costs around \$50 to \$150 per hectare to support equipment maintenance and farmer training (S. Attard and M. Poggio pers. comm.). For the INFFER analysis, an upfront cost of \$1,000 per hectare, plus \$50 per hectare on-going annual maintenance costs were used for shifting from D to C irrigation practices.

The cost of shifting beyond C irrigation is likely to require a shift in management and scheduling of furrow irrigation methods or to higher efficiency systems such as drip or overhead low pressure irrigation. The costs of these systems also vary widely from site to site. Using data from the NQ Dry Tropics Reef Programme data associated with funding water quality grants, the estimated capital costs associated with drip irrigation have been reported between \$3,500 and \$12,000 per hectare, and between \$2,400 and \$7,500 per hectare for overhead irrigation. For the INFFER analysis, an upfront cost of \$5,000 per hectare, plus an estimate of \$1,000 per hectare for on-going annual maintenance costs was used for shifting from C to B irrigation practices.

5.2.5 Priority areas for sugarcane management

The Burdekin sugarcane growing area encompasses the Haughton River, Burdekin Delta, Barratta Creek, Burdekin River (below dam) sub-catchments, and a small proportion of the Upstart Bay sub-catchment. The most practical boundaries for spatial prioritisation are the BRIA and Delta.

The characteristics of the BRIA and Delta areas vary as summarised in Table 5.15.

Based on current knowledge of modelled and monitored DIN and PSII herbicide loads, pollutant loss pathways, and fertiliser usage and sales data, the following conclusions are drawn:

- fertiliser application rates recommended in the Six Easy Steps nutrient management program should not be exceeded in the Lower Burdekin sugarcane areas;
- improvements in water use efficiencies are also required to reduce nitrogen losses from sugarcane in the region. This may be considered more important in the BRIA where there is comparably less deep drainage than in the Delta and greater capacity for surface runoff and therefore direct discharge to waterways;
- there are marginal differences between the modelled PSII herbicide load in the BRIA and the Delta regions. However, it is likely that more residuals are applied in the BRIA as standard practices use less cultivation (E. Shannon, pers. comm.) and therefore weed pressure can be greater. While it is recommended that both the BRIA and Delta region have equal importance to reduce pesticide loads entering the GBR, greater attention may be placed on the BRIA in terms of application rates; and

Table 5.15. Key characteristics of the BRIA and Delta sugarcane growing areas in the Lower Burdekin.

Characteristic	BRIA	Delta
Establishment	Since 1980's	Since 1880's
Approx farm size ¹	up to 3,500 ha Median farm size: 94ha Average farm size: 140ha	up to 500 ha Median farm size: 56ha Average farm size: 72ha
Dominant soils	Sodic duplex/ and light to Medium Heavy clays (high denitrification)	Coarse sands, sandy loams and light to medium clays to sand (Low denitrification)
Nitrogen loss pathway	Large proportion of surface runoff	Large proportion of drainage
Average production ²	110 tonnes per ha	120 tonnes per ha
Fertiliser application rates ³	214 kgN/ha Plant 227 kgN/ha Ratoon	193 kgN/ha Plant 216 kgN/ha Ratoon
Water source	Surface water and ground water in Northcote, Jardine and Selkirk areas	Ground water and surface water from Water Board supply

Data sources:

¹ Wilmar (P. Larsen), January 2016

² Wilmar (P. Larsen), March 2016

³ Paddock to Reef program Survey data, NQ Dry Tropics 2015.

- The legacy of irrigation area management has resulted in a situation of rising watertable levels and emerging surface soil salinity that may increase over time, but now is at a critical stage requiring a concerted effort to attain a sustainable watertable regime. It is suggested that any further inaction in controlling groundwater levels will result in sugarcane lands being taken out of production (Shaw, 2014).

Given that the predominant pollutant loss pathway in the BRIA is by surface runoff (and therefore faster response times between pollutant reductions and responses in the receiving environment could be expected), there are less farms in the BRIA, the average farm is larger and practice changes are typically more cost effective, it could be concluded that improving sugarcane management actions in the BRIA may be a higher priority than in the Delta. However, due to variations in current practice adoption, specific site characteristics, proximity to sensitive freshwater waterways, and a range of complex social factors in the region, it may not be feasible to prioritise action in one area over another. Further discussion with industry experts is required before any strong recommendations along these lines could be adopted.

Spatial management prioritisation to a smaller scale is difficult at this point due to limitations in our understanding of the hydrological complexities of the system. More detailed information needed includes accurate block-scale yield mapping (to determine nitrogen requirement) and management practice adoption data including current fertiliser and PSII herbicide use (fertiliser use data is available for about one third of the industry). It would then be possible to identify areas with poor nitrogen and PSII herbicide use efficiency to target for management improvements. In addition to this, more frequent and intensive nutrient and PSII herbicide monitoring along major drainage channels and coastal creeks will inform finer scale spatial priorities in both BRIA and Delta regions and provide greater confidence of monitoring data for the local farming community.

Knowledge of current practice adoption, farm size and cost effectiveness of practice improvements should be used as a guide for targeting management until other knowledge is progressed. For example, as shown in Section 5.2.3, it is possible to target a smaller number of growers by focusing on larger farms; farms >1,000ha are recommended for targeting based on current data.

5.3 Managing water quality in horticulture

5.3.1 Principles for improving water quality from horticulture

The Growcom Horticulture Best Management Practice or Hort360 is a voluntary program developed by industry, science and growers to assist horticulture growers manage risk and identify opportunities for the growth and durability of their agribusiness. Underpinned by the long established Farmcare Code of Practice for Sustainable Fruit and Vegetable Production in Queensland (1998), Hort360 provides a structured risk based approach to assist in decision making that can have triple bottom line outcomes, long term benefits for grower capacity and also act as a benchmarking tool to measure improvements. Given the complexity of the fruit and vegetable industry Hort360 does not replace other quality assurance or environmental processes but complements and provides key knowledge and access to assistance.

Hort360 assists growers to develop action plans that address areas of opportunity that have a potential economic, social and or natural resource management outcomes. Action plans link growers to existing information sources, on farm assistance and services to assist them in implementing those actions. The data is stored in a database which can produce reports on a number of scales, although a key principle is guaranteeing data confidentiality to growers.

Based on grower feedback, Hort360 is primarily facilitated one-on-one by a Growcom extension officer so that a more effective outcome is reached and growers fully understand what they need to achieve. It also allows the field officer to initiate and be aware of further responses needed.

Hort360 greatly improves the specificity of the extension effort directed to growers enabling them to quickly see which aspects of their operation need improvement. Whilst the one-on-one facilitation is resource intensive it enables any follow up to be better targeted at the growers' risks and has streamlined Growcom's delivery activities.

From a Growcom perspective Hort360 enables them to benchmark the horticulture industry in terms of current practices at multiple scales, provide improved delivery targeting specific needs assisting growers to meet / exceed BMP and develop new projects specific to industry need. For growers the opportunity of increased profitability and sustainability are the major benefits of improved business management. However, voluntary adoption of the BMP process will also help ensure the most effective use of farm inputs and farm resources thus reducing environmental impacts, improving public perception of the horticultural industry and reducing the need for regulation or mandatory controls in the future.

Benefits of the Hort360 identified by the growers involved are:

- agreed information becomes a marketing opportunity;
- improved business efficiency;
- becoming more competitive as a grower in the market place;
- becoming more results driven - environmentally & economically (increase in farm profit);
- the availability of a Risk Assessment process;
- useful guidelines/checklist;
- decreased inputs, increase profit, increase efficiencies;
- benchmarking tools for your own business.

Hort360 Water Quality is the primary module delivered within the horticulture Reef Program. This module is used when forming a grower application to access reef incentives and an attempt is made to provide guidance as to how investment is made based on the action plan.

Data gathered through the delivery of Hort360 Water Quality is collated at multiple scales to assist Growcom deliver its extension program, provide growers with a benchmarking tool, provide NRM regions with practice change data and to inform the Reef Plan Report Card.

Precision Agriculture is promoted as a key principle behind progress towards the following practices:

Nutrient Management

- fertiliser use efficiency; and
- fertiliser application method - fertigation (automated).

Pesticide Management

- pesticide application - selection of agents and methodology; and
- Integrated Pest Management.

Sediment Management

- soil health;
- GPS control traffic permanent beds;
- grassed inter-rows;
- under tree mulch;
- improved fallow management;
- ground cover on non-productive areas (headlands);
- management of farm access tracks;
- controlled runoff diversion away from cropping areas; and
- buffers and traps.

5.3.2 Management practice framework for horticultural land uses

The identification and validation of better management practice guidelines for water quality in the horticulture industry was developed through a collaborative process that involved a comprehensive science and grower focus consultation including: NQ Dry Tropics, DAF, Bowen District Growers Association, Burdekin grower representatives, CSIRO and Growcom.

The Paddock to Reef Program WQ Risk Framework for management practices shown in *Appendix 5: The ABCD Frameworks for sugarcane, grazing and horticulture in the Burdekin region* has been designed to provide growers with guidance when establishing best management practices concerning the quality of water leaving their farms and entering the GBR lagoon. The ABCD framework defines improvement and provides a common scale of improvement from 'degrading' to 'cutting edge' practices.

The framework broadly categorises and describes improved farming practices according to their water quality outcomes. Over time, emerging technologies have become proven best management practices and the ABCD framework has been updated accordingly. This will continue into the future.

The A and B class farming practices described in the framework are designed to reduce water quality impact and increase the efficiency of on-farm operations in relation to:

- soil health;
- nutrient management;
- pesticide management;

- water and irrigation management; and
- planning and recording.

5.3.3 Current adoption of improved management practices

There are approximately 200 horticulture growers in the Burdekin Region, almost all located within the Don River catchment, with some in the Lower Burdekin catchment. The total area of horticulture reported 13,500 hectares (13.5 square kilometres).

Management practice adoption data is available and interpreted through several sources in the region: 1) the Paddock to Reef Program, 2) the NQ Dry Tropics Reef Programme water quality grants database, and 3) Growcom Hort360 (see Table 5.16). The Paddock to Reef Program reported that by June 2014, best management practice systems were used by approximately 60 per cent of horticulture growers for pesticides, 17 per cent for nutrients and 67 per cent for soil (Queensland Government, 2015). Due to variations in the scope and detail these datasets provide differing estimates of adoption characteristics, specifically in nutrient application where there is a 74 per cent difference between Paddock to Reef program and GrowCom estimates. These anomalies are currently being rectified through the Paddock to Reef Program with support from the Reef Programme. When taking into account management practice systems, a large proportion of horticulture area in the Burdekin Region is currently managed at or below B class practices, except in fallow management where a majority of the area is managed in A or B class. These practices are not necessarily equally distributed within the horticulture areas.

Figure 5.5 provides current management practices for growers in the Don River sub-catchment (a) and current management practices for growers across GBR catchment (b), extracted from Hort360. In comparing the level of current management practice adoption of growers in the Don catchment with growers across the GBR catchments, the Don catchment growers are performing equivalent or better than average.

Figure 5.5 (a). Horticulture grower performance data - Don Catchment. Source: Hort360.

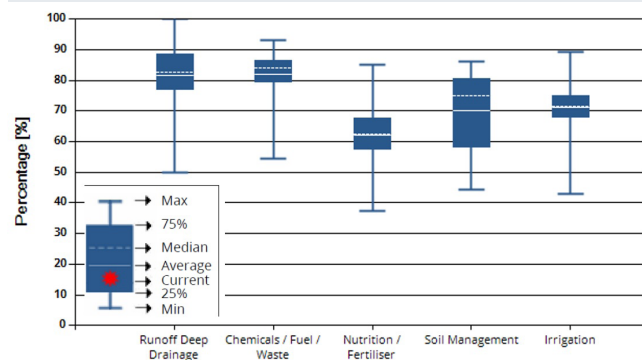
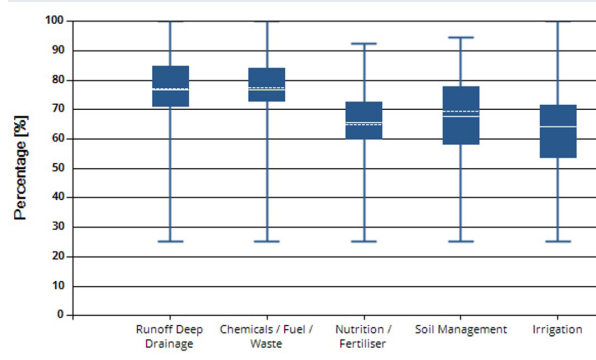


Table 5.16. Current adoption of priority management practices in horticulture in the Don catchment. Source: S. Wallace, GrowCom.

Practice (from P2R WQ Risk Framework)	% area in Practice class			
	D	C	B	A
1.3 Soil Management	0%	54%	45%	1%
1.4 Fallow Management	0%	33%	29%	38%
2.2-2.4 Nutrient application etc	0%	6%	91%	3%
4.3 Run off management	3%	19%	63%	15%

Figure 5.5 (b) Horticulture grower performance data - Great Barrier Reef catchments.



5.3.4 Estimated costs of improved horticulture management practices

The estimated costs of practice change vary widely between the wide range of horticultural crops in the Burdekin Region, and are not well documented. As part of the INFFER process, a workshop was convened with technical experts and stakeholders involved in horticulture management in the region to derive a set of cost estimates for the priority practice shifts for water quality improvement. The individual management practices that were costed for transitioning between management practice classes are shown in *Appendix 6: Management practice shifts and costs assumed in the INFFER cost benefit analysis*.

The assessment of management practice change in horticulture indicated that full adoption of best management practices is likely to come at a cost to growers (Roberts et al. 2016).

5.3.5 Priority areas for horticulture management

There is limited information on priority areas or characteristics that would guide prioritisation of improvements of horticultural practices in the Don River catchment, and therefore, regional industry and technical expertise is critical in

guiding future investment. However, based on the current adoption data provided by GrowCom, it is suggested that soil management may be a target area for improvement although compared to other land uses the TSS generation rates for horticulture are relatively low (~210 kg/ha/yr) (compared with grazing areas for example, ~500 kg/ha/yr).

5.4 Managing water quality in grain crops

5.4.1 Principles for improving water quality from grain crops

The main considerations for water quality outcomes from grain crops are associated with crop nutrition and soil fertility management, property design and layout and managing runoff, pesticide application, making best use of rainfall and integrated pest management.

5.4.2 Management practice framework for grain crops

Best management practices for soil and water management have been developed based on research and incorporated into the Grains BMP system. This system is centred on a self-assessment component which interrogates the level of practices used by the farmer in a number of areas of farm operation, and produces an action plan based on improving practices to the level desired by the farmer (at or above industry standard). Training is provided to help farmers achieve the action plan, and projects are implemented to change practices with the assistance of financial incentives where possible. Action plans developed through Grains BMP self-assessment identified areas for improvement. Growers were then encouraged to implement the action plan, with incentives targeted at eligible practices. Around 35 dryland farmers are located in the region.

The water quality risk framework for the grains farming industry is based on a range of key management areas selected from four modules of the Grains Best Management Practice (BMP) program. Eighteen management issues were assigned weightings according to their potential for influencing offsite water quality, shown in Table 5.17. These weightings were developed through a review process including Queensland Government scientists and experienced Central Queensland agronomists and agricultural consultants. Anonymous data from BMP program participants was analysed to develop management system ratings (from low to high) that reflect the water quality risk of the mix of individual practices on a farm. Where insufficient samples were available to discriminate management at the river basin level, the baseline for the entire region was used.

Table 5.17. Grains BMP program modules and management questions used in establishing relative priorities for grain crop management practices in the Paddock to Reef Program Water Quality Risk Framework. Source: Queensland Government, 2015.

BMP Module	Management category	Weighting
Sediment (runoff & soil loss)		
Property design layout	Use of contour & diversion banks in sloping cropping areas	15%
Property design layout	Sediment trapping devices	5%
Property design layout	Waterways & drainage lines	5%
Making best use of rainfall	Stubble volume & persistence	15%
Making best use of rainfall	Retain stubble during fallow	20%
Making best use of rainfall	Cropping frequency	10%
Making best use of rainfall	Need for tillage	20%
Making best use of rainfall	Wheel traffic	10%
Pesticides		
Pesticide application	Pest identification	5%
Pesticide application	Resistance management	10%
Pesticide application	Product selection	5%
Pesticide application	Risk of residual pesticide movement	40%
Property design layout	Pesticide & sediment movement	40%
Nutrients		
Crop nutrition	Records of crop yield & quality	10%
Crop nutrition	Frequency of soil testing for nitrogen	30%
Crop nutrition	Influence of stored soil moisture on yield & fertiliser decisions	30%
Crop nutrition	Impact of seasonal outlook on making fertiliser decisions	20%
Crop nutrition	Application timing to minimise potential losses & maximise uptake	10%

5.4.3 Current adoption of improved management practices

The Paddock to Reef Program reported that by June 2014, best management systems were used on approximately 91 per cent of grain farming land for pesticides (112,000 hectares), 48 per cent for nutrients (59,00 hectares) and 31 per cent for soil (39,000 hectares).

5.4.4 Estimated costs of improved grain management practices

There is limited data available for estimating the costs of management practice change in grain crops in the Burdekin Region. Collection of new information was considered to be outside of the scope of this plan.

5.4.5 Priority areas for grains management

There is limited information on priority areas or characteristics that would guide prioritisation of improvements of grains management practices in the Suttor River catchment, and therefore, regional industry and technical expertise is critical in guiding future investment.

Based on the current adoption data provided by the Paddock to Reef Program, it is suggested that soil and nutrient management may be a target area for improvement. However, compared to other land uses, the TSS generation rates for grain crops are relatively low (~56 kg/ha/year) compared to grazing areas (~500 kg/ha/year).

5.5 Managing water quality in urban areas

5.5.1 Principles for urban water quality management

The State Planning Policy State Interest - Water Quality (*Sustainable Planning Act 2009*) seeks to ensure that development is planned, designed, constructed and operated to protect the environmental values of Queensland waters (available from <http://www.statedevelopment.qld.gov.au/about-planning/state-planning-policy.html>). It also requires consideration of the construction and operational phases for proposed development assessed under the *Sustainable Planning Act 2009*, for areas generally greater than 2,500m². Activities including building and construction on lots smaller than this threshold must minimise impact under the general environmental duty provisions of the *Environmental Protection Act 1994*. The State Planning Policy Code - Water Quality requires reductions in the loads known to be generated as a result of urbanisation, by percentages specified for the relevant climatic region across Queensland, as identified on the SPP interactive mapping system ('Dry Tropics', 'Western Queensland', 'Central Queensland North' for Burdekin, Don and Haughton basins) for key pollutants of TSS, TN, TP and gross pollutants.' The State Planning Policy interactive Mapping System is at <http://www.statedevelopment.qld.gov.au/planning/state-planning-instruments/spp-interactive-mapping-system.html>.

The provisions of the State Planning Policy State Interest - Water Quality (*Sustainable Planning Act 2009*) allow for local governments to adopt alternative, locally appropriate, solutions to stormwater management in their planning schemes.

There are a broad range of urban water quality issues, each with a suite of feasible and practical management options. The suitability of these options is commonly highly site and situation specific. Fortunately the tailoring of urban water pollution management principles to local conditions has been well resourced and practiced by Townsville City Council for many years and the Black Ross WQIP (2010) and the Mackay Whitsunday Water Quality Improvement Plans (Drewry et al. 2008) have been used as a model for other urban water quality management practice in the GBR catchments. Gunn (2014) builds on this experience and provides a comprehensive analysis and referencing of the topic including the description and analysis of what constitutes: A class (aspirational); B class (best practice); C class (conventional practice meeting minimum standards); and D class (poor or dated practice) for different urban water quality management themes.

Key guidelines for good practice include the need for:

- a broad based, structured and adaptive, urban water quality management plan for each urban area;
- understanding of the relative risks and processes by which pollutants and hydrological modifications affect receiving water quality;
- integration of water quality considerations into all infrastructure development and refurbishment designs including both soft and hard engineering considerations;
- understanding of the extensive current legislative provisions for management and regulation;
- local government lead participation and active learning by industry; and
- public participation in urban water quality management issues.

For the purpose of this plan the following practice recommendations are made:

- make use of the work done by Townsville City Council, Whitsunday and Mackay Shire Councils as reported in Gunn (2014) guidelines (Chapter 4 and Appendix C) to understand the best management practice approach relevant to the urban issues you need to manage;
- note the regional context and relative importance of urban water quality management in reef management as defined in Section 3.6 of this plan; and
- consider the conclusions and recommendation made in this section when preparing local area specific urban water management plans.

5.5.2 A framework for urban water quality management

It is recommended that the general framework for GBR catchment urban area water quality improvement developed by Gunn (2014) is adopted for the Burdekin Region. The framework includes three primary categories directly relevant to the main water quality pollutant issues, defined by pollutant source and pathway as illustrated in Figure 5.6. This classification is used to identify and assign appropriate management practices that can be employed to improve water quality for each primary category. Figure 5.7 provides the pathway linkages to statutory requirements and the various components of urban land use.

All urban areas require significant awareness, behaviour change and capacity building programs to ensure the appropriate water quality improvement measures are imbedded in the cultures of local government, the development industry, stormwater managers and the wider community.

Water quality improvement actions for the main point source facilities are relatively simple and involve upgrades to STPs and/or appropriate land based disposal of treated effluent (irrigation). Best practice for sewage and water treatment plants includes provision for at least the following:

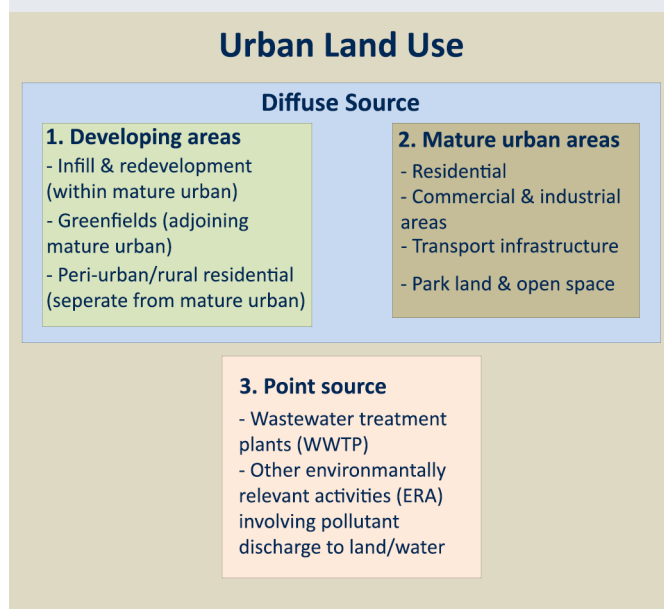
- control of contaminant inflows including legal and illegal discharge of a wide range of domestic and industrial pollutants;
- establishing and maintaining sewerage integrity by preventing direct or overflow connection with stormwater;
- water treatment to separate contaminants including solids, oils and grease, nutrients and pathogens;
- use or disposal of separated product streams; and
- managing to avoid bypass or failure by providing storage, backup and contingency capacity.

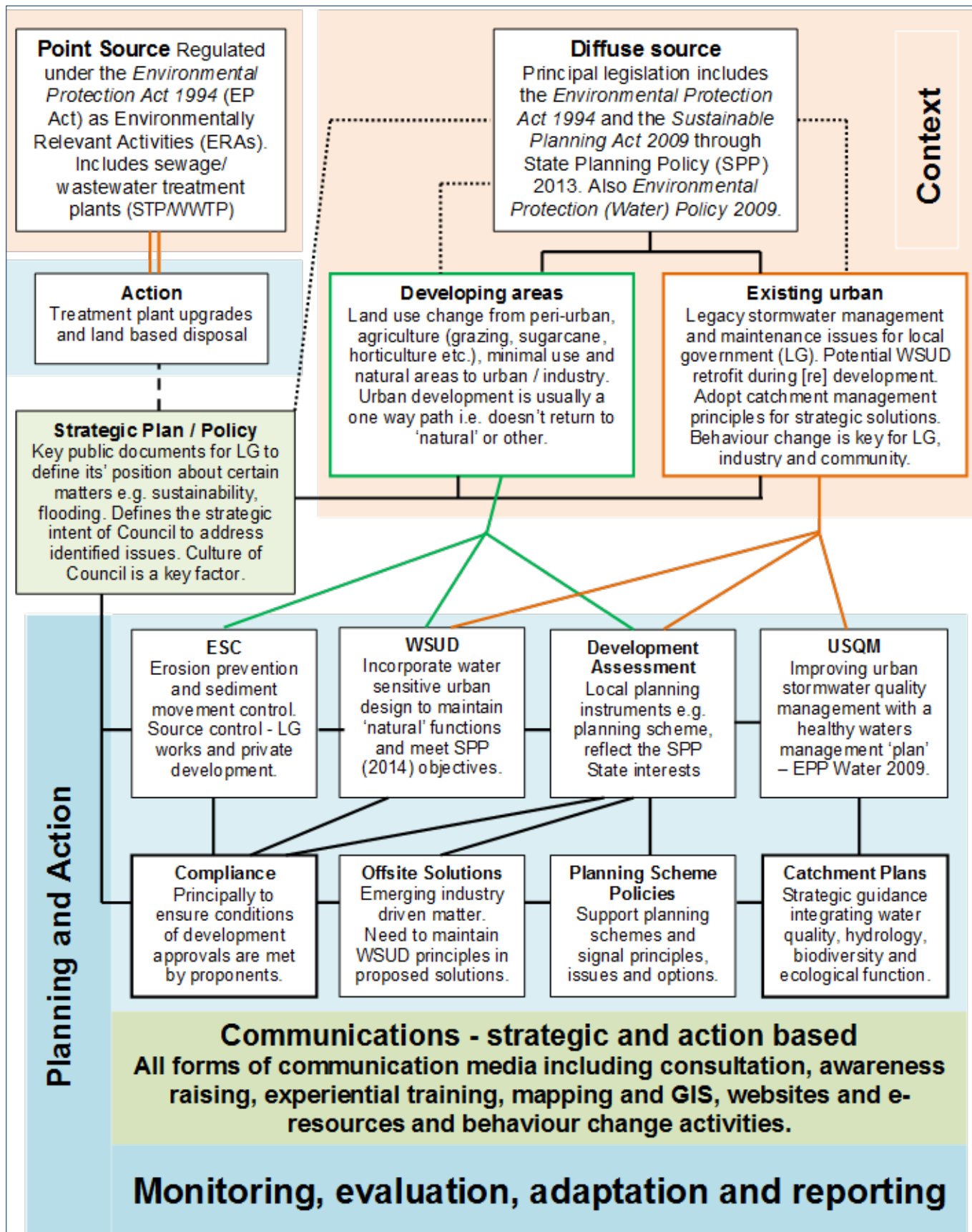
The impacts on local waterways should not be seen simply in terms of effluent volumes or nutrient loads. Rather the STP provides a service of liquid waste collection, treatment and product re-distribution to the time and place of greatest net benefit.

Diffuse source water quality improvement for urban land use is achieved through a combination of regulatory provisions, voluntary initiatives and the adoption of a flexible integrated catchment management approach to total water cycle management.

As highlighted in Section 3.6.2, developing urban areas are highly vulnerable to soil erosion during the land development and construction phases having the potential to generate significant amounts of sediment per hectare if appropriate management practices are not implemented. Therefore the principle management intent for developing urban areas is to prevent soil erosion and the subsequent movement of sediment to waterways and wetlands, which can largely be achieved through planning and development assessment. Planning and design for long term outcomes is also necessary during the land development phase, including the adoption of water sensitive urban design (WSUD). This is a critical to achieve maximum community and environmental outcomes and avoid unnecessary maintenance and refurbishment issues and post-development costs.

Figure 5.6. Components of water quality and other environmental outcomes in the urban setting. Source: Gunn (2014).





Notes: Urban includes: Residential – commercial –recreation (formal parks, sports grounds and walking/cycling paths) – industrial (includes transport infrastructure) – transport corridors – [environmental infrastructure is] natural areas – waterways – wetlands – connecting corridors– foreshore and estuaries – protected areas. LG is local government.

Figure 5.7. Pathway linkages to statutory requirements and the various components of urban land use. Source: Gunn (2014).

The management intent for mature urban areas revolves around maintaining good groundcover to improve water infiltration, and the maintenance of stormwater management infrastructure including the conversion from 'old school' infrastructure i.e. flood mitigation/water removal only, to WSUD measures, which incorporate water quality improvement and flood mitigation as integral components. Managing stormwater systems in mature urban areas is principally the responsibility of local government however there are instances where this will be the responsibility of the Queensland Government and/or Federal Government through government agencies or government owned corporations e.g. ports.

Incorporating WSUD in mature urban areas is usually more expensive than for developing urban areas as it has to be designed and executed after the development and construction phase i.e. retrofitting, rather than being an integral part of it.

5.6 Managing site and activity specific impacts

5.6.1 Principles for improving site specific water quality

The diversity of industries, scales of operation and water impact risks means there will always be exceptions to any generalised comment on what constitute good management practice for specific activities or sites.

In this region the capacity to minimise climatic event based failures of liquid waste discharges are particularly important.

Detailed assessment of what constitutes good mining and heavy industry practices with respect to water quality risks is beyond the scope of this plan. However, comprehensive legislative guidance is available and addresses water quality issues throughout the life of a development.

Good practice for port facilities with respect to water quality include due diligence with respect to at least the following issues:

- **spatially containing the development impact zones:** limiting the number and choosing low impact or already impacted sites to locate further port or marina development;
- **shipping:** legal, illegal and accidental pollutant discharge direct to waterways and ocean. Including effective capture or control of solid wastes, engine exhausts and oils, propeller strikes and underwater noise. Designing contingencies for extreme weather events;
- **dredging:** minimising the requirement for development and maintenance dredging. Low impact land site disposal of dredge material and 'treatment' of dewatering effluent to minimise fine sediment returns. Timing dredging operations to minimise ecological disruption;
- **controlling materials transfers:** minimising the time 'potential contaminants' (cargo) is on site and provisions for containment of waste or spillage during loading and off-loading; and
- **pollution containment and clean up capability:** at sea or on site vigilance including air pollution controls and response to spills, collisions or discharges of all likely materials. Including biosecurity risks for aquatic organisms. Wash down for trucks etc. and appropriate waste disposal facilities and procedures.

Good practice for rural linear infrastructure water quality issues is to mirror the legal requirements for development of the same infrastructure in urban locations. The principle risks are associated with potential mobilisation of soils from cleared land or construction material stockpiles. This means:

- **design for minimum hydrology and hydraulic disturbance:** minimise flow changes across the landscape and through natural channels, floodplains and shallow aquifers;
- **minimising the area cleared and time of disturbance:** minimum corridor width; tunnelling below drainage lines and rivers rather than cutting through banks and bed;
- **stormwater control and filtering:** including sediment curtains, pits and barriers or use of geo-fabrics and landscaping to control erosion temporary high erosion risks; and
- **rehabilitation:** post construction clean up, landscaping and revegetation including erosion monitoring.

5.6.2 A framework for high risk site specific water quality management

The discharge of pollutants from specific sites that are not within agricultural or urban land uses is regulated using the environmental and government planning legal framework outlined in Section 3.73.7. This approach is necessarily largely punitive and restrictive of what industries and developers might do on a site which may result in licensed discharge or the risk of unplanned pollution events. The legislation also makes some provision for water pollution trading and offsetting mechanisms which facilitate strategic management of site pollution at a larger scale. These arrangements also have the potential for site managers to invest in a broad range of diffuse pollution control measure not otherwise available to

their local operation. The framework includes obligatory and optional reporting in government (public) data bases including Queensland's WaTERS database (www.qld.gov.au/dsiti) and the National Pollution Inventory (www.npi.gov.au).

The Reef 2050 Plan promotes actions to avoid, mitigate or offset environmental impacts. It is recommended that this approach is adopted here.

5.6.3 Cost effectiveness of water pollution abatement in other land uses

Currently there is insufficient data to undertake a detailed economic analysis of the options for reducing pollutant loads from all land uses which would be comparable to the assessment completed for sugarcane, grazing and horticulture through Smith (2015) and INFFER (Roberts et al. 2016). Marsden Jacob and Associates (2013) have undertaken an assessment of the relative costs of nitrogen reduction options for a number of land uses in the GBR catchments, as shown in Table 5.8.

Table 5.8. Examples of relative costs of nitrogen abatement. Source: Marsden Jacob Associates (2013).

Source	Approximate costs (\$/kg/annum)	Comments
Rural diffuse – sugarcane BMPs	-31+38	Significant scope for reductions and enhancing industry commercial outcomes.
Urban diffuse - WSUD	360-450	Limited scope to contribute material reductions in loads.
Point sources - STPs	76-200	Implementation will form part of infrastructure provision for regional growth

This variability in pollutant abatement costs has a number of implications for planning, policy and program delivery for WQIPs in the Burdekin Region including demonstrating:

- there is high investment value in managing agricultural sources that represent the major sources of sediment, nutrient and pesticide loads;
- that some pollutant management can actually deliver commercial gains to the farmer, particularly in the longer term (i.e. a win-win situation); and
- there is variation in abatement costs for the same pollution type between sectors and land use categories.

It is also recognised that there is variation in the timeframes in which the benefits of the pollution abatement can be achieved. For example, point source pollution management such as STP upgrades would result in 'immediate' reductions in loads to receiving waters, as opposed to sugarcane management which may take a full crop cycle (~ 7 years) to realise benefits. A comparable example can be provided for reducing sediment loads from developing urban areas (which occurs within the development period) to grazing management, which may take 10-20 years to realise the benefits. Therefore, it is typically the amount of resources available that will drive the management choices.

This illustrates that significant gains could be made across all industries in the region with large scale investment to water quality improvement in the Burdekin Region over the next 5 to 10 years.

5.7 Restoring system function and coastal ecosystem health

5.7.1 Principles for system repair actions

There are a wide range of site-specific management options for delivering outcomes to restore ecological values and function in coastal ecosystems of the GBR. Full consideration of these outcomes is not within the scope of this plan, and the focus is on the actions that promote a whole of system approach to water quality management. Therefore the sugarcane areas and extensive wetland areas in the Lower Burdekin catchment are presented as a priority area for restoring system function and coastal ecosystems in the Burdekin Region.

As described in earlier sections, sugarcane production systems dominate the floodplain ecosystem in terms of area and biophysical processes in the Burdekin Region. The remaining remnant coastal ecosystems occur predominantly in areas not suitable for agricultural development, such as low lying and tidally influenced coastal margins. Remnant areas outside of the coastal margin include river and stream riparian corridors, intentionally retained vegetated corridors within the BRIA area, inland floodplain areas outside the footprint of existing irrigation infrastructure, and small isolated and degraded remnants within the agricultural landscape. These remnant coastal ecosystems retain important physical, biogeochemical and biological processes but are under pressure due to the influence of the irrigated agriculture system, system-wide alteration of floodplain hydrology and pervasive threats posed by weeds and hot fire regimes.

Manipulation of water supply to surface and groundwater systems in the region has a history dating back to the mid-1960s and impacts to the naturally seasonally dry wetlands are now widespread.

Restoring hydrological seasonality (periods of 'drying down') to some wetlands through controlling supplementary surface water is practically achievable without affecting water supply to croplands (Perna et al. 2012).

Hydrologic restoration should alter conditions to favour the predominantly native plants adapted to these regular wetting and drying regimes. Lower Burdekin Water has a modernisation plan in place to fund the installation of infrastructure to be used in better controlling flows and has a goal of developing a healthy ecology within and around hydrologically altered channels and wetlands in its region.

As identified in Section 5.1.5, it might be appropriate to encourage temporary retirement of marginal or unproductive lands, retire the land to alternative land uses such as conservation, or encourage wetland regeneration.

However, the cost of land conversion is likely to be a major factor in the assessment of management options.

It is acknowledged that these actions are not relevant to all coastal ecosystems in the region and full assessment of these options is considered to be outside of the scope of this plan.

5.7.2 Management framework for system repair

A whole of system framework for system repair is currently being developed by the Queensland Wetlands Program and GBRMPA. The framework recognises the importance of system understanding (parts and process) as the first step in planning for ecosystem outcomes. This framework can be adopted to guide strategic planning for system repair actions in the Burdekin Region in the near future.

It is difficult to report current adoption of system repair actions in the region until this framework is adequately defined.

5.7.3 Current adoption of system repair actions

Management actions are being implemented for strategic management of wetlands in the Lower Burdekin catchment. For example, NQ Dry Tropics is working in collaboration with Lower Burdekin Water, Burdekin Shire Council and farmers to implement landscape approaches in the Australian Government funded project "Restoring Burdekin Coastal Ecosystems for the Great Barrier Reef and Ramsar". The program has achieved great success with 340 ha of seasonal drying in lower Sheepstation Creek, an area that was permanently wet for over 10 years. The seasonal drying, which is a natural process, resulted in improved ecological functions (weeds managed and restored fish passage), stronger engagement with key stakeholders and increased community understanding of key wetland issues (P. Gibson NQ Dry Tropics, pers. comm.). The process was aided by infrastructure upgrades upstream allowing for more efficient control and conservative delivery of irrigation water and the current water restrictions.

More work is required in this area to further improve water delivery efficiency, including investigating the opportunity to install creek level sensors, monthly bore usage readings and measuring delivery volumes, accounting for seepage and evaporation versus usage. Groundwater bores must also be monitored for salinity to ensure the new delivery practice does not allow for saltwater intrusion. A grazier who lives on the system commented on the outcomes stating *"This is more like it. It's going back to how it used to be. Come the wet season we should now get a couple of years of seasonal open water before the cumbungi (Typha spp.) grows back, but then we can dry it out again."*

Other examples are presented on the NQ Dry Tropics website, <http://www.nqdrytropics.com.au/projects/waterways-wetlands-and-coasts-program/>.

5.7.4 Priority areas for system repair actions

The spatial prioritisation method used for protecting and restoring coastal ecosystems builds on extensive work already undertaken in the region to identify and prioritise actions for system repair outcomes.

Information used in the assessment included analysis of wetland extent, condition and threats (see Section 2.2), development of a typology to assess drivers of weediness in wetlands and a fish barrier prioritisation. This information can also be supplemented by the more recent 'Walking the Landscape' process (DEHP), and the GBRMPA Blue Maps and 'Ecological Calculator' which represents hydrological connectivity and system modifications.

Weeds assessment

A landscape scale approach to investigating drivers of weediness has been developed, incorporating both desktop data

collection using recent land unit mapping (Kahler, 2010), wetland mapping produced through the Queensland Wetland Program and field collection of various water and site specific parameters over one wet season (Connolly et al. 2012). The results are shown in Figure 5.9.

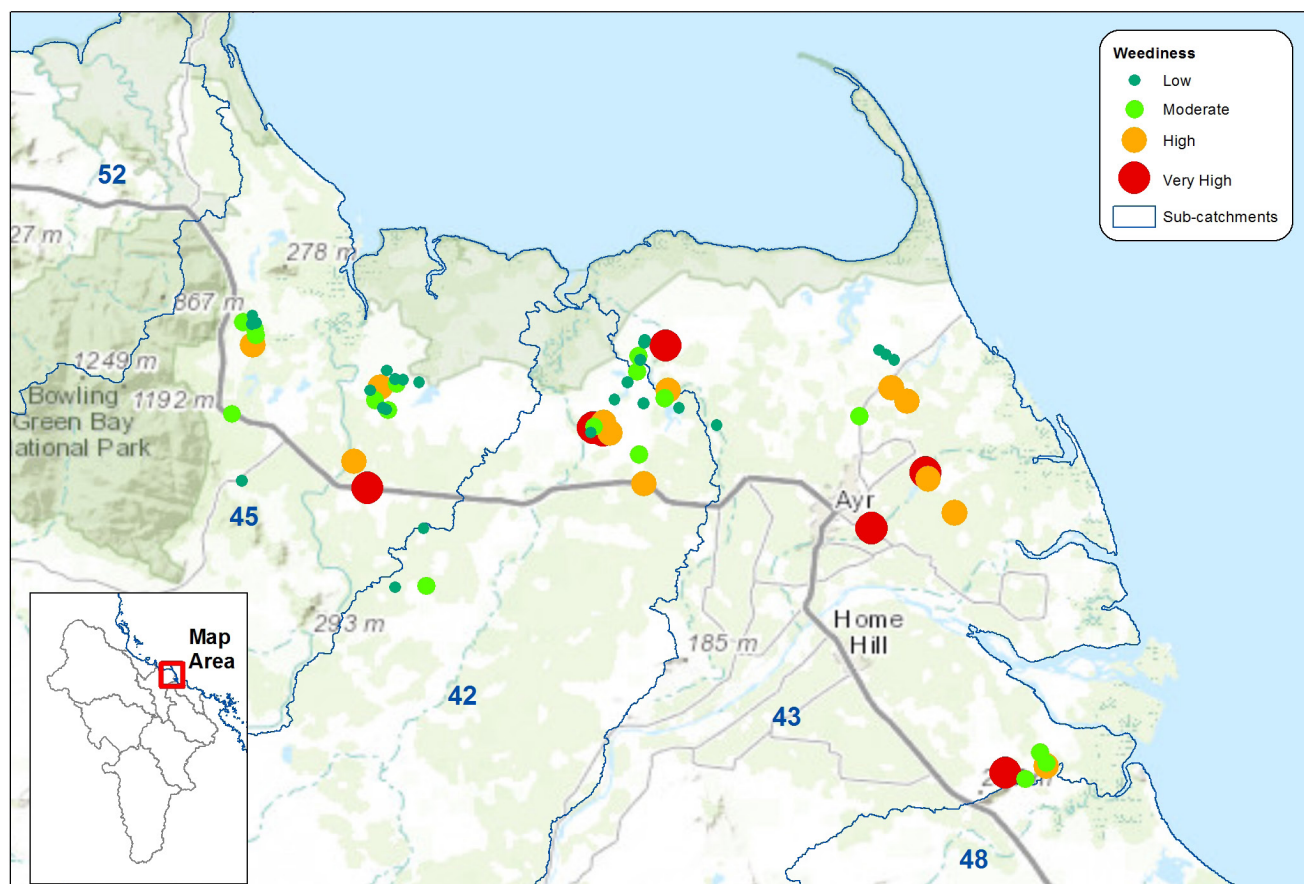


Figure 5.9. Wetlands assessed on weediness. Source: Connolly et al. (2012).

Results of this landscape level investigation confirmed the assumptions and site specific observations gathered by field officers and researchers in the past (Veitch et al. 2008) showing that landscape level approaches, in this case using Land Zones (Wilson and Taylor, 2012), wetting/drying and freshwater/salinity regimes can help predict a wetland's susceptibility to weediness.

The results showed that wetlands with naturally or artificially extended wetting periods were more likely to suffer invasion by floating weeds (deepwater or lacustrine wetlands) or emergent attached weeds (shallow or palustrine wetlands) (Connolly et al. 2012).

Floating weeds were more common in freshwater bodies than in brackish or saline areas.

While management interventions need to be considered closely prior to implementation, it is the systems with surfaces that are not inundated by tidal waters (Land Zone 5) that provide the greatest potential to strategically improve resilience to aquatic weeds and/or rehabilitate already infested areas through this landscape approach.

Examples of potential strategic management opportunities are presented in Connolly et al. (2012) and include:

- improved control of irrigation delivery system to ensure minimisation of excessive flows downstream of the last end-user e.g. Telemetry driven automated gates and replacement of old drop board system;
- the removal of a bund within inundated tidal flats or active alluvial systems may simply shift the weed problem further downstream (depending on the extent of water supplementation) making it an even bigger problem, while the removal of a bund within systems that are not tidally influenced may provide some resilience to aquatic weeds. The treatment of freshwater weeds active alluvial systems could be never-ending and resource-intensive due to abundance of both surface and ground waters. An example of this is the issues facing the Barattas or Plantation Creek. The focus of any effort under these circumstances should be directed at improving the irrigation delivery system;

- prevention or reduction of supplementation to systems that are not tidally influenced could be very effective in freshwater weed prevention or improved resistance e.g. pipeline to carry surface flows rather than using wetland system as part of the delivery system;
- improvement in irrigation management on farm to minimise tail water losses to wetland systems and groundwater; and
- bulkuru is recognised in the assessment as being important for migratory species found within the Ramsar wetlands of Bowling Green Bay (see Figure 5.10). Investigations found that Bulkuru has a defined range for both salinity and water regimes, so it might be possible to predict areas within the Lower Burdekin where these conditions occur and where they might have occurred prior to development. This could provide some measure of shift in Bulkuru habitat and the relative proportion that remains. It may also identify locations where Bulkuru (and other seasonal habitats) could be reinstated if desired.



Figure 5.10. Examples of impacted ↑ and intact → Bulkuru areas in the Burdekin Region. Photo supplied by S. Fry, NQ Dry Tropics.

Using the landscape approach, NQ Dry Tropics and Lower Burdekin Water have identified priority systems for undertaking infrastructure activities, shown in Figure 5.11. These wetlands comprise a mix of shallow coastal wetland and lagoon systems receiving perennial flows from irrigation schemes and surface water runoff from adjacent cane farms. All sites are currently being investigated for treatment options to restore seasonality and some of these options include improved control of irrigation delivery, bund removal, installation of diversion channels and improvement in irrigation management on farm.

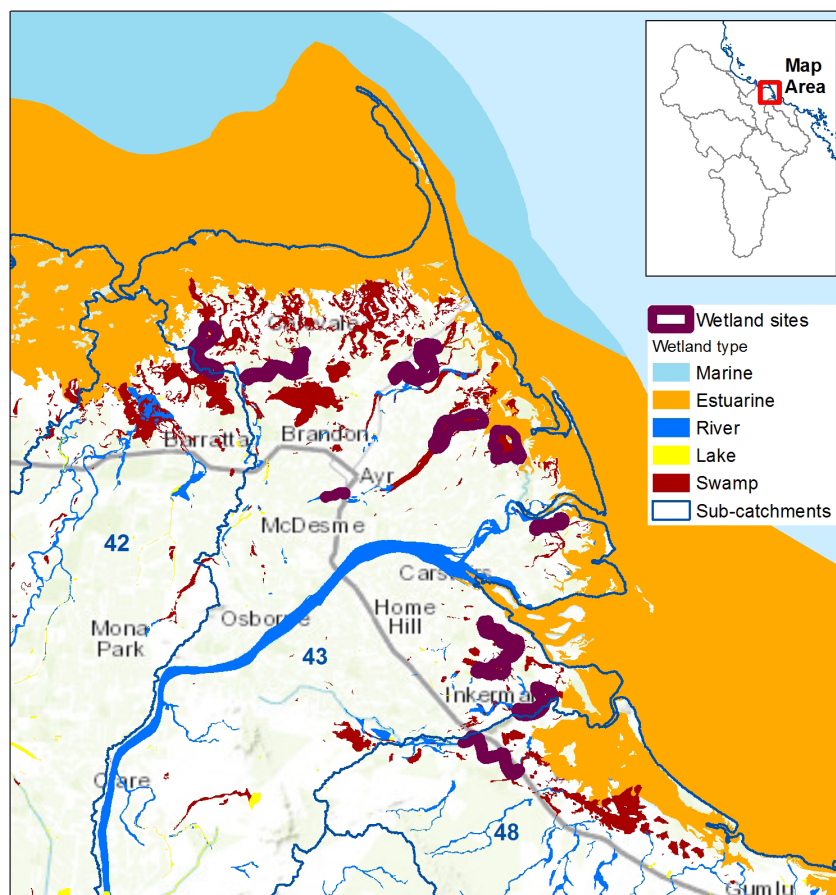


Figure 5.11. Selected sites for system repair based on prioritisation methodology. Polygons represent areas of potential improvement from infrastructure activities either within the area defined by the polygon or upstream activities.

Fish barrier prioritisation

Many fish species spend part of their lifecycle in freshwater ecosystems and migrate to coastal and marine environments. Fish populations are impacted upon by human activities, including degraded water quality, in their natural environment creating barriers to key ecological processes. More specifically, fish migration and dispersal are important natural ecological processes driving distribution and abundance for many populations, and yet, these natural processes are impacted upon by fish barriers (Eikaas and McIntosh, 2006; Agostinho, Pereira et al. 2007).

Restoring natural migration patterns and habitat connectivity is essential to promote optimum dispersal and to maintain the viability of populations in freshwater, coastal and marine environments (Bunn and Arthington, 2002).

Hence, it is argued that human activities in freshwater aquatic ecosystems can represent barriers to fish dispersal and migration and can contribute to overall decline of fish populations in the GBR.

Fish barriers and their impacts can be broadly categorised into four distinct groups including physical (e.g. dams, weirs, weed chokes and tidal barrages); hydrological (e.g. fast flowing water), chemical (e.g. poor water quality such as low dissolved oxygen or high acidity); and natural (e.g. natural landscape features such as mountain ranges and waterfalls).

Fish passage devices, commonly referred to as fish ways, are built to allow individual fish to move upstream and downstream by attempting to recreate natural hydrological conditions or modify hydrological conditions to a more tolerable level. By re-altering hydrological conditions to tolerable levels, it is possible for fish to access habitats previously made inaccessible by human activities (e.g. road construction). This can be achieved by utilising a variety of methods and approaches including vertical slot fishways, pool and weir methods, fish lifts / locks, rock ramps and trap and transfer methods.

A fish barrier prioritisation study was commissioned in 2007 (Carter et al. 2007) to identify all fish passage barriers and priorities for management including removal or establishment of in-stream structures, commonly referred to as fishways, that can be retrofitted to enable fish migration and dispersal to restore key ecological processes. Consultation with experts, regional communities and organisations that have ownership of or management responsibility for barriers was an integral component of this study which identified the top 30 priority barriers for further investigation. The outcomes are reported in Carter et al. (2007) and the 10 highest priority barriers are shown in Table 5.19.

Table 5.19. The highest priority fish barriers for remediation in the Burdekin region.

Rank	Barrier	Catchment	Comments/Recommendations	Current status 2016
1	Clare Weir	Burdekin River	Although a fish passage device (fish lift) is already installed on this structure its operation has been greatly restricted due to mechanical problems. The weir is a major barrier on the lower reaches of the main stem of the Burdekin main river channel, a habitat utilised by the broadest spectrum of migratory species.	Fish lift installed in 2007 but has limited operation due to on-going maintenance issues
2 & 3	2 Sand Dams on Lower Burdekin River	Burdekin River	These non-permanent barriers at Rita Island and "The Rocks" have high potential to be seasonally significant barriers to many species.	Rita Island Sand Dam fishway installed in 2009
4	Val Bird Weir	Haughton River	The weir is known to be fully drowned out during large flow events but nevertheless has been demonstrated to be a major barrier to fish movement upstream resulting in the loss of catadromous species including Jungle Perch from protected National Park tributary catchments (i.e. Majors, Spring and Double Creeks).	Still requires remediation
5	Aplins Weir	Ross River	Located below a large perennial waterbody, this potentially affects a large number of species.	Still requires remediation
6	Track crossing	Stuart Creek	Raised track crossing with a pipe culvert prevents the upstream movement of a range of fish species.	Barrier removed in 2008
7	Bowen River Weir	Bowen River	Major barrier on a large river that has high habitat values, and is already identified by SunWater as a priority for remediation for fish passage.	Fishway repaired in 2011
8	Giru Weir	Haughton River	The weir is fully inundated during large flow events but is thought to be a partial barrier to fish movement upstream. Existing structural features help facilitate some fish passage under a range of flows. The cost of options for modifying this structure are likely to be an order of magnitude lower than those for Val Bird Weir (see 5) and may be justified for servicing the upstream reach irrespective of a fish passage device being fitted to Val Bird Weir.	Still requires remediation
9	Alligator Creek Weir	Alligator Creek	The weir is fully inundated during large flow events, but is exposed on non-peak flows and anecdotal reports suggest that populations of catadromous species in the system, i.e. barramundi have been impacted by its presence.	Rock ramp fishway installed in 2012
10	Road and rail crossings, earth bunds and weed chokes	Sheepstation Creek system	There are a number of potential barriers on this system, which have been grouped together for a holistic assessment. The most effective approach to managing this and other barriers on the system is to work in cooperation with landholders, the North Burdekin Water Board and other stakeholders to examine options and an agreed order for the modification of barriers starting at the downstream end of the system and working progressively upstream.	2 vertical slot fishways installed: Bruce Highway, 2007; Toll Rd 2014 Rock Ramp fishway installed Fiveways Rd, 2011 Weed control works undertaken; further work required

GBRMPA Blue Maps hydrological connectivity and ecological functions

The suite of coastal ecosystem tools (Basin Assessments, Blue Maps and Ecological Process Calculator) developed by GBRMPA have been used to provide a better understanding of the ecological functions provided by natural and modified coastal ecosystems in the region (GBRMPA, 2013). These tools combine information about how natural coastal ecosystems functioned in a more natural state in comparison to how they are functioning now, which can be used to guide and prioritise where actions for maintaining, restoring and managing ecological function should be undertaken in the region.

The importance of ecological processes and the capacity of coastal and modified ecosystems to deliver these processes with benefits to the GBR are often dependant on the proximity of the service area to the GBR. The Blue Maps, developed by the GBRMPA, show the areas of strongest connectivity between the catchment and the GBR, through the mapping of wetter areas of the catchment. The data used in the assessment includes the extent of wetlands, wet vegetation, and floodplain areas, and factors in highest astronomical tide and storm surge. Although the whole catchment is connected to the GBR, and some processes such as sediment transport can originate from the top of the catchment, many more processes occur where connectivity is greatest. As illustrated in Table 5.20, the Blue Maps identify those areas with the greatest value for the delivery of ecological processes that benefit the GBR, with an example map output shown in Figure 5.12.

The Ecological Process Calculator has been developed by GBRMPA to estimate the changes to ecological functions in the Burdekin Basins. In this process, the ecological function of natural and modified coastal ecosystems is assessed by experts in terms of the ability to perform a range of biological, biogeochemical and physical processes. This was conducted for the Burdekin Region in a workshop setting, supplemented by published data where possible. A detailed description of each of the individual processes/services is available from GBRMPA and a summary of the processes is provided below.

Recharge-discharge processes:

- detains water; flood mitigation; potentially connects aquatic ecosystems; regulates water flow – groundwater; regulates water flow – overland flows.

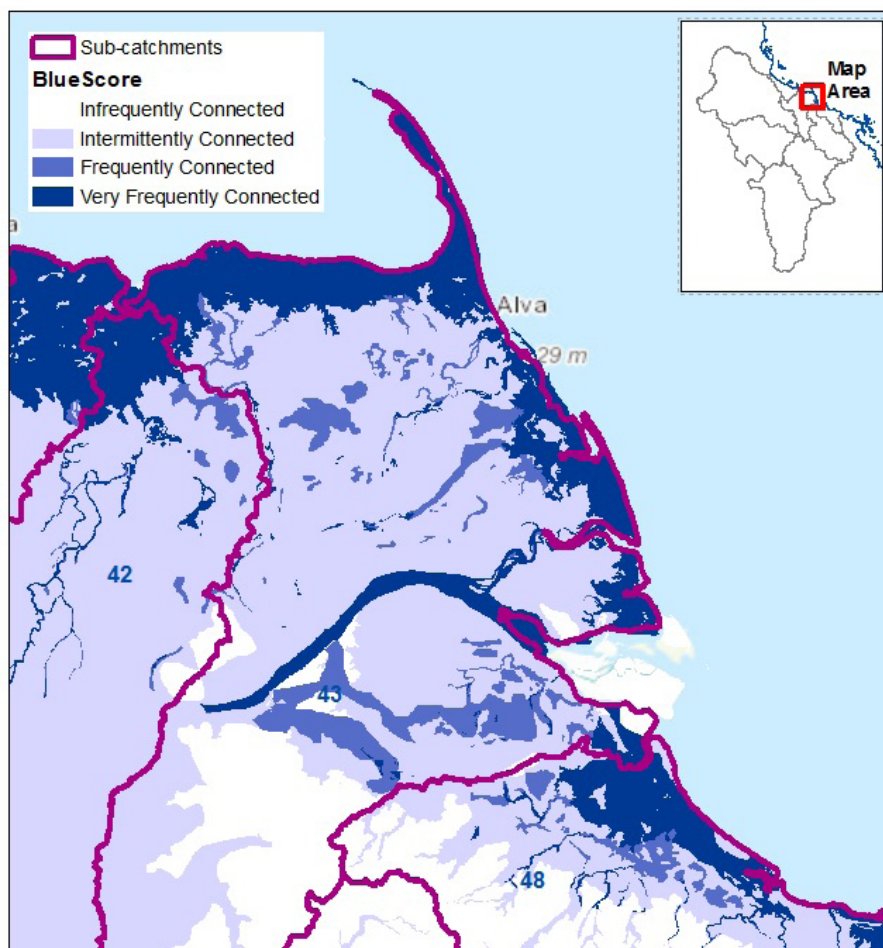


Figure 5.12. Example output of Blue Maps for part of the GBR catchment indicating the level of connectivity to waters of the GBR. Source: Map supplied by D. Audas, GBRMPA.

Table 5.20. Level of hydrological connectivity between catchment waterways and the Great Barrier Reef. Source: GBRMPA (2013).

Simplified Catchment Component Categories	Frequency of Hydrological Connection	Definition
Coastline and Estuarine Systems	Very frequently connected	Direct connections with the GBR occur on a diurnal basis
Freshwater wetlands and adjacent Floodplain Ecosystems	Frequently connected	Direct connections with the GBR occur on at least a monthly basis
	Intermittently connected	Direct connections with the GBR occur for extended periods during seasonal, tidal and flood events
Remaining Catchment	Infrequently connected	Direct connections with the GBR occur through groundwater and overland flows during rain events

Table 5.21. Results of the Ecological Process Calculator assessment for assessing the changes to ecological processes since pre-European times for each Basin in the Burdekin Region.

Basin	Recharge discharge processes	Physical processes	Biogeochemical and biological processes
Black	Moderate	Good	Good
Ross	Moderate	Good	Moderate
Haughton	Moderate	Moderate	Moderate
Burdekin	Poor	Moderate	Moderate
Don	Moderate	Moderate	Moderate

Physical Processes (Sediments):

- sedimentation – fine: trap fine sediments; retain fine sediments; release fine sediments slowly;
- sedimentation – coarse: trap coarse sediments; retain coarse sediments; release coarse sediment slowly; and
- material transport: transports material for coastal processes; particulate deposition and transport (sediments, nutrients, chemicals); material deposition and transport (debris, DOM, rock).

Biogeochemical processes:

- production: primary production; secondary production;
- nutrient: source of N, P; uptakes nutrients; regulates nutrients;
- carbon: carbon source; sequesters carbon; regulates carbon;
- decomposition: source of DOM; and
- regulation: salinity regulation; regulates temperature.

Biological Processes:

- survival: habitat refugia for aquatic spp with reef connections; habitat for terrestrial spp. connected to reef; food source; habitat for ecologically important animals;
- dispersal: replenishment/ecosystem colonisation; pathway for migratory fish;
- pollinate: pollination; and
- recruitment: habitat contributes significant recruitment.

The Ecological Process Calculator used the workshop assigned capacity scores, pre-clear and post-clear coastal ecosystem extents and Queensland Land Use Mapping Project (QLUMP) land use data (hectares) to calculate a percentage change score for each ecological process.

Percent change from pre-European times of ± 10 per cent were classified as “Very Good”, $\pm >10$ -25 per cent as “Good”, $\pm >25$ -50 per cent as “Moderate”, $\pm >50$ -75 per cent as “Poor”, and $\pm >75$ per cent as “Very Poor”. The results in Table 5.21 indicate that many of the ecological processes in the Burdekin Basins are considered to be in ‘Moderate’ condition. Further assessment is required to provide more definitive analysis at smaller spatial scales and can only be used as a guide for management prioritisation at this stage.

Blue Maps are combined with this assessment to highlight the hydrological connections between the coastal ecosystems and the GBR. Using the combined information, catchments are scored according to the ecological function provided by current natural and modified coastal ecosystems. This information can then be used to identify target management actions. An example of the Lower Burdekin catchment is provided in Table 5.22.

The Catchment Atlas presents the ratings for each hydrological connection zone and provides the areas of key land uses required to be targeted for improving functionality.

Table 5.22. Targets improving functionality within Hydrological Connection Zones in the Lower Burdekin catchment.

Frequency of Hydrological Connection	Target
Very frequent connection	Improve the capacity of these areas to manage biological and biogeochemical processes through: • priority barrier modification or removal; and • weed control.
Frequently connected	Improve the capacity of these areas to manage physical and biological processes through: • priority barrier modification or removal; • application of innovative technologies such as algal farms; • ongoing improvements to water quality; and • weed eradication or control.
Intermittently connected	Improve the capacity of these areas to manage physical, biological and biogeochemical processes through: • priority barrier modification or removal; • application of innovative technologies such as algal farms; • ongoing improvements to water quality; • weed eradication or control; • restoring riparian and catchment vegetation on areas of highly erosive soils; and • installing in-stream structures to reduce water flow velocities and streambank erosion, where assessed as appropriate.
Infrequently connected	Improve the capacity in these areas to manage physical and biogeochemical processes through: • addressing erosion in areas of highly erosive soils; and • slowing stream flows through installation of in-stream structures, where assessed as appropriate.

Estimated costs of system repair actions

It is difficult to assess the costs of system repair actions as they are very site specific and depend on the nature and scale of the works in different landscapes. NQ Dry Tropics has collated a number of examples of coastal ecosystem restoration including revegetation, restoration of bunded coastal wetlands and fish passage from past projects to derive the following ranges of costs:

- **revegetation:** cost range \$2,000 to \$13,500 per hectare. Range based on experience in previous projects. Minimal costs associated with seeding only. Maximum costs associated with planting of established trees in difficult areas and requiring significant maintenance e.g. weeding;
- **modernisation of irrigation delivery system:** cost ranges depending on specific circumstances but can be around \$100,000-\$250,000 per project. The intent is to improve water efficiency and reduce surplus water entering downstream wetlands. Examples include replacing drop-board systems with automatic gates that can be operated remotely for greater control of water supply (around \$180,000 each), which can also be combined with fish-ways (\$80,000 in these circumstances). Potentially replace delivery of water through natural systems to pipe networks;
- **removal or modification of bunds:** cost range \$3,000 to \$50,000 per bund. The minimum price is for simplest activity of using an excavator to remove part of the bund as was the case at Jerona bund. The higher end of the range is where landholder doesn't support complete removal and therefore requires more sophisticated actions such as bund modification to include a pipe and flap valve as well as an appropriate pre and post monitoring program. Given most landholders resistance to bund removal, the average is more likely towards the higher end; and
- **fish passage:** cost range \$50,000 to \$350,000 per fish passage. NQ Dry Tropics has significant experience in fish passage structures and estimates are based on actual costs for previous activities and costed activities. Smaller projects are more likely to gain traction i.e. with local government and water boards.

These cost ranges have been used to guide the budget estimates provided in Section 6.4.2, but it is recognised that additional scoping would be required prior to any allocation of funds. All in-stream barrier works (e.g. road and culverts) required a fish-way offset and approval is required from DAF.

6. How are we going to achieve the targets?

As described in Section 1.2, steady progress has already been made towards the Reef Plan targets. Modelling predicts that good progress has been made towards achievement of the Reef Plan TSS and PN load reduction targets for 2018 (85 per cent towards the 20 per cent anthropogenic TSS load reduction target and 75 per cent towards the 20 per cent PN anthropogenic load reduction target), and it is predicted that sustained progress supported by equivalent levels of investment to the last 8 years could achieve the Reef Plan target.

Progress towards the DIN and PSII herbicide targets has been slower and the 2018 targets are highly unlikely to be met in the next two years (32 per cent towards the 50 per cent anthropogenic load reduction target and 33 per cent towards the 60 per cent PSII herbicide load reduction target).

Given that there are two more years for delivery towards the 2018 targets identified in the Reef Plan, this WQIP focuses on implementation to meet the 2025 catchment-specific targets.

6.1 Analysis of options for achieving management goals and targets in agricultural land uses

The management goals and targets for water quality improvement in the Burdekin Region were outlined in Section 4. Spatial priorities for management were identified in Section 5.

A key element of developing the Burdekin WQIP is an integrated assessment of the benefits and costs of achieving water quality targets required to protect the values of the GBR.

This requires an understanding of the links between nutrient, sediment and pesticide targets and farm level management practice targets, and the level of ecosystem protection that will be achieved from meeting these water quality targets. Specifically this involved a detailed INFFER (Investment Framework For Environmental Resources) analysis to assess the cost-effectiveness of meeting ecologically relevant targets for pollutant reduction for the Burdekin NRM region (Roberts et al. 2016). INFFER is a seven-step process for prioritising and/or developing projects to address environmental issues such as reduced water quality, biodiversity, environmental pests and land degradation based on benefit:cost analysis principles. INFFER was used as it is the only framework available (in Australia and to our knowledge worldwide) that integrates all of the benefits, costs and risk factors associated with making informed environmental investment decisions. Further information on INFFER at www.inffer.com.au.

INFFER was used to assess the benefits and costs of a range of management scenarios involving grazing, sugarcane and/or horticulture. A base-case analysis was developed first and from this, other scenarios were explored. The agreed management goal used as the basis of the detailed analysis (called the base-case, conducted through the Project Assessment Form - PAF), was to achieve reductions in total loads through adoption of B practices (only practices from the ABCD framework that will have a direct impact on sediment, nutrient and pesticide loads were costed) hillslope grazing practices region-wide, streambank management in the Bowen Broken Bogie and Upper Burdekin catchments, basic gully management in the Bowen Broken Bogie, Upper and Lower Burdekin catchments, sugar cane in the Lower Burdekin), horticulture in the Don catchment) by 2035. It was not considered to be sensible to analyse achieving the goals in the 2018 timeframes specified in Reef Plan, given both the scale of the catchment and the lag times involved between adopting BMPs and achieving outcomes in the system.

The base-case analysis was costed based on the following actions:

- B practice adoption (nutrients, soil, pesticides, recycle pits and C class furrow irrigation systems) in sugarcane in the lower Burdekin catchment;
- B practice adoption in horticulture (nutrients, soil, pesticides and irrigation) in the Don catchment;
- B practice adoption of hillslope grazing management practices through the whole catchment;
- Gully stabilisation in grazing lands in the Bowen Broken Bogie, Upper and Lower Burdekin catchments; includes B practice gully management such as fencing and basic management such as stick traps; and
- Streambank management in grazing lands in the Bowen Broken Bogie and Upper Burdekin catchments (50% of streams fenced) (workshop and follow up discussions which suggest that most of the waterways in the Lower Burdekin that can be fenced have been).

The base-case analysis used what were considered to be the most realistic parameters to calculate the associated benefits and costs, integrated to a single number, that being the Benefit:Cost Ratio (BCR). Alternative scenarios were assessed through specifying changes in assumptions and modifying BCR parameters accordingly. These are described in full in Roberts et al. (2016).

The INFFER framework takes into account a range of factors including the estimated value of the asset (in this case the Burdekin marine NRM region), the effectiveness of the works (determined by the modelling scenarios outlined in Section 6.1.1), the time lags for the benefits of the project, technical feasibility, current and likely future adoption, adverse adoption (practices trying to prevent), socio-political risks, prospects of long term funding, and the upfront costs and maintenance costs of the project.

The practice shifts, estimated costs and assumptions for the scenarios are detailed in Roberts et al. (2016) and summarised in *Appendix 6: Management practice shifts and costs assumed in the INFFER cost benefit analysis*.

A number of additional scenarios were reported in Roberts et al. (2016) including:

- adoption of advanced irrigation systems in sugarcane;
- for grazing lands in the Bowen Broken Bogie catchment only:
 - a) B practice for hillslope erosion across the Burdekin region, B practice gully management in and waterways management in Bowen Broken Bogie catchment;
 - b) full gully remediation; and
 - c) land retirement;
- a modified base-case scenario assuming regulation of shifts from D to C practices; and
- a modified base-case scenario with a mix of options that is assumed to achieve the ecologically relevant targets.

6.1.1 The value of the asset

The INFFER assessment requires a monetary valuation of the asset being considered in the assessment, in this case the areas of the GBR associated with the Burdekin Region. This was agreed to be the Burdekin marine NRM region but was debated given the large area of influence of the Burdekin River plumes, and is therefore likely to be an underestimate. Market valuation work (direct and indirect) and non-market valuation studies initiated by David Pannell and refined by Thomas and Brodie (2015) were used to assess the value of the GBR valued the combined market and non-market values at \$1,460 million per year. This is relatively low compared to the reported GBR value of \$5 to 6 billion per year as it only factors in direct values to the GBR. The estimate for the Burdekin Region was \$209 million per year. Market values were estimated based on the value of reef-based tourism, recreation, commercial fishing and reef-dependent industries in the different NRM regions of the GBR catchments. Non-market values were based on estimates of the value of coral, seagrass and wetlands across the NRM regions and are likely to be an underestimate as there have been no specific studies on evaluation of ecosystem goods and services in the Burdekin Region. Using the combined market and non-market value of \$1,460 million per year, and taking a present value over 50 years using a real discount rate of 5 per cent gives a total value of \$28,100 million, or \$28 billion.

Further work is required to refine these estimates to be more comparable with international valuations, particularly for the non-market values (see Thomas and Brodie, 2015).

6.1.2 Benefits and of management options

Modelled load reductions for management scenarios

A number of management practices scenarios have been modelled with the Source Catchments model (2013 baseline) by C. Dougall, DNRM, including 'All A' and 'All B' scenarios. It is acknowledged that 100 per cent uptake of any practice is not realistic however these scenarios are used to demonstrate the relative benefits of different management options and are indicative only. The scenarios take into account current management practice adoption as reported under the Paddock to Reef Program, but it is recognised that there are gaps in knowledge of current adoption across industries.

The scenarios also assume that the management practice shifts are 'immediate' and do not factor in time lags or other barriers to adoption, but do provide an indication of the likely achievability of the end of catchment load reduction targets.

The modelling scenarios indicate that achieving almost full adoption of best management practices (B class) in sugarcane, grazing and horticulture will not achieve the ecologically relevant targets for TSS, DIN and PN.

However, the PSII herbicide reduction targets can be achieved if there was widespread adoption of best management practices in herbicide management in the Lower Burdekin sugarcane industry. Anticipated long term outcomes for 100 per cent uptake of specific management practices in priority catchment areas are shown in Table 6.1.

Table 6.1. Summary of the results of the management scenarios modelled to predict pollutant load reductions in the Burdekin Region using the ecologically relevant targets (4.3.2)

Pollutant	Targeted Total load (% reduction)	Modelled management scenario		Expected Total load (% reduction)	Progress towards ERT (%)
Total Suspended Sediment - fine fraction (<20 µm in model)	50	1	All grazing land was managed to B class AND All horticulture soils and nutrient managed to B class in the Don.	20	40
		2	Large scale gully remediation in the Bowen Broken Bogie catchment.	31	62
		1+2	All grazing land B class practices and large scale gully remediation in the Bowen Broken Bogie catchment.	42	82
Particulate Nitrogen	52	1	All grazing land was managed to B class.	10	18
		2	Large scale gully remediation in the Bowen Broken Bogie catchment.	19	37
		1+2	All grazing land B class practices and large scale gully remediation in the Bowen Broken Bogie catchment.	23	44
Dissolved Inorganic Nitrogen	80	3	All sugarcane land managed using B class nutrient management and C class irrigation methods.	42	52
		4	All sugarcane land managed using B class nutrient management and B class irrigation methods.	81	Achieved
Potentially Reactive Nitrogen DIN +PN	60	1+4	All grazing land was managed to 'B' class. AND All horticulture soils and nutrient managed to B class in the Don. AND All sugarcane land managed using B class nutrient management and B class irrigation methods.	30	49
		1+2+4	All grazing land was managed to 'B' class. AND Full gully remediation in the Bowen Broken Bogie catchment AND All horticulture soils and nutrient managed to B class in the Don. AND All sugarcane land managed using B class nutrient management and B class irrigation methods.	39	65
PSII Herbicides in Lower Burdekin	90	5	All sugarcane land managed using B class herbicide practices and C class irrigation methods.	87	97
		6	All sugarcane land managed using B class herbicide practices and B class irrigation methods.	90	Achieved

As an additional line of evidence for potential DIN reductions from sugarcane, Section 5.2.3 included a simple assessment of N surplus derived from survey data of fertiliser use. It was estimated that N surplus is currently approximately 1,760 tonnes per year in the BRIA and 360 tonnes per year in the Delta. The proportion of this nitrogen surplus that is lost in runoff varies on the soil type and location, however, it is reasonable to assume that adoption of the Six Easy Steps guidelines could result in DIN reductions that provide significant progress towards the target DIN reduction for the Lower Burdekin sugarcane area.

Estimated costs of management options

The estimated costs of practice change for grazing and sugarcane that were taken into account in this WQIP were summarised in Section 5 and are described specifically for the INFFER assessment in Roberts et al. (2016). These costs were derived from Smith (2015) for sugarcane, and industry experts through the INFFER workshops for horticulture and grazing.

Based on these assessments, the upfront costs are those associated with the on-ground payments needed to achieve B class management practices and do not take into account any cost sharing arrangements. **These costs are assumed to be allocated during an initial 5 year program.**

The extension effort required was based on suggestions from workshop participants. For context, the current effort in sugarcane in the Burdekin Region is estimated to be 6.6 FTE in extension with specific water quality focus, 5 FTE facilitating / administering water quality grants and 1 FTE facilitating BMP. Current effort in grazing is estimated to be 16 FTE in extension / facilitating BMP with specific water quality focus, 7 FTE facilitating / administering water quality grants. This data was collated by DAF as at June 2015 through discussions with NRM, industry, productivity services and government staff, based on the number of FTE's operating in 2014/15. Most of the FTE's included are on temporary funding and therefore their tenure is not secure. Total costs are therefore included in this estimate.

The upfront and maintenance costs over 20 years (on-going annual costs which would be required to ensure the benefits of the practice changes are maintained) are summarised in *Appendix 6: Management practice shifts and costs assumed in the INFFER cost benefit analysis*.

6.1.3 Benefit Cost Ratio

The results of the assessment can be used to guide the most cost effective management options for meeting the proposed pollutant load reduction targets. The base case presents a challenging outcome with a relatively low BCR. This is due to the scale of the effort required (currently relatively low adoption of best management practices), the current high capital investment required in large scale remediation works and advanced management practices that deliver the highest pollutant load reductions, and the fact that the mix of management options will not achieve the pollutant reduction targets. Recognition that agricultural pollution is not the only threat to the health of the GBR in the next 20 years (estimated through expert elicitation in this assessment as 50 per cent with climate change, storms and COTS as other factors) also reduces the overall benefit of the water quality management options considered, highlighted the need to take a holistic, and cumulative, management approach.

The alternative scenarios demonstrate that targeting practices will result in greater benefits. For example, the scenario of adopting B nutrient management practices and advanced irrigation in 70 per cent of the sugarcane area in the region is over 4 times more cost effective than the base-case, and the scenario of full gully remediation in the Bowen Broken Bogie catchment is 17 times more cost-effective than the base-case. This is useful for considering individual pollutants but does not deliver against all of the targets which are necessary for GBR outcomes. It is noted that the cost of remediation for both of these scenarios would vary depending on specific site characteristics and feasibility and that the cost information used here is the best available but should be considered 'back of the envelope'. Despite these assumptions, the scenario reinforces that widespread improvements in nutrient management and targeted adoption of advanced irrigation practices in sugarcane, and large scale gully remediation in the Bowen Broken Bogie catchment are likely to be some of the most cost effective options for nutrient and sediment management in the region.

The assessment of different policy options showed that the application of Regulation (supported by extension) to shift to C class practices for grazing, sugarcane and horticulture industries (with a lead in time of 10 years) is potentially 3 times more cost effective than using incentives and extension for all practice shifts (the base-case). A mixed scenario aiming to meet the ecologically relevant targets defined by the base-case plus large scale (70 per cent) adoption of advanced irrigation techniques in sugarcane, large scale gully remediation in the Bowen Broken Bogie catchment and Regulatory measures to shift to C practices is potentially the most cost effective scenario that meets the targets and is potentially five times more cost effective than the base-case.

The spatial resolution of management practice adoption in all industries in the region is poor, and therefore, considerable assumptions have been made about the areas of practice shifts required. In addition, as demonstrated in Section 5, many of the more intensive management options such as advanced irrigation, or streambank or gully remediation require site specific design and therefore the costs may have considerable spatial variation. However, it was outside the scope of this plan to undertake small scale assessment of these options and therefore, 'average' costs have been applied uniformly across the region for advanced irrigation, streambank restoration and gully remediation. This has most likely resulted in inflated costs for achievement of the targets. It was also challenging to develop estimates of the cost of Regulation without guidance of the approach and therefore, establishment, compliance and enforcement requirements. The costs were based on discussions with government policy officers and the current resource allocation of the Queensland Government.

There are two modelled scenarios which indicate substantial progress towards, or achievement of, the ecologically relevant targets with the following changes:

1. Sugarcane: Widespread adoption of B class practices in nutrient and irrigation management is modelled to achieve an 80 per cent reduction in DIN loads from the Burdekin sugarcane, which is sufficient to meet the DIN component of the ecologically relevant target for nitrogen of an 80 per cent reduction of DIN from sugarcane. This entails adoption of much more modest fertiliser application rates based on management zone yield potential, tailwater recycling (or treatment options) in some locations and considerable improvements in irrigation efficiencies. The methods of irrigation likely to be required to meet the efficiencies that will limit runoff or drainage include drip irrigation or overhead spray equipment, or

high efficiency furrow irrigation. It is recognised that these techniques may not be suitable in some locations and are not necessarily required everywhere so the costs are likely to be overestimated; further investigation is required of the most suitable options for improving irrigation efficiencies, particularly in the BRIA where surface runoff is a major contributor to the DIN losses. These changes are likely to come at a substantial total cost, estimated for this exercise at \$465 million upfront costs (first 5 years), and annual maintenance costs of over \$18 million per year. However, continuation of current irrigation practices is not sustainable and is likely to have financial implications for ongoing management of the rising water table in some locations.

2. Grazing: The scenario analysis indicated that it will be challenging to achieve the TSS reductions required to meet the ecologically relevant target of approximately 50 per cent reduction in fine sediment loads and the 52 per cent particulate nitrogen target from the Burdekin Basin without major remediation, land retirement or establishment of treatment options. However, the following scenario is predicted to achieve almost 80 per cent of the TSS target for the region:

- adoption of B class practices for hillslope management in grazing lands throughout the region plus ;
- gully fencing in the Bowen Broken Bogie, Lower Burdekin and Upper Burdekin catchments plus;
- 50 per cent streambank fencing in the Bowen Broken Bogie and Upper Burdekin catchments plus;
- an extreme scenario of full gully remediation in the Bowen Broken Bogie catchment.

It could be assumed that additional gully remediation in priority areas in the region could then achieve the target reduction. Again, these changes are likely to come at a substantial total cost, estimated for this exercise at \$573 million upfront costs (first 5 years), and annual maintenance costs of \$38 million per year. As for the sugarcane scenario, these costs are likely to be an overestimate due to uniform spatial application of management practice changes, particularly remediation options which are highly heterogeneous.

The assessment shows that the reductions required to meet the PN component of the ecologically relevant target for nitrogen (calculated to be 52 per cent) are also not likely to be met without major remediation or land retirement. However, the scenario was only assessed for PN contributions from grazing lands, and additional gains would be made from erosion management in all land uses. These benefits need to be quantified, and a better understanding of how to target PN management is necessary to guide future management to meet the PRN targets.

There are obvious practical challenges with respect to realising these scenarios in terms of costs, technical feasibility (particularly in improved irrigation practices in sugarcane), other barriers to adoption, time lags between management action and response, and the timeframes required to meet the targets and thus achieve the desired benefits for ecosystem health. There are also serious questions about shortfalls in meeting the targets and the implications to freshwater, coastal and marine ecosystems health. Discussion is required about the trade-offs between the level of management change considered politically and locally socially acceptable, and the desire to maintain the values of the receiving environments including the GBR. Given the already degraded state of the GBR, these issues need to be debated to facilitate water quality improvements beyond what may be considered to be 'business as usual' management. The role of restored floodplain and coastal ecosystem functions in ecosystem health recovery is likely to become more important as more extreme land use management options such as land conversion to other uses may be considered unacceptable by the community.

6.2 Delivery options

The complexity and scale of the management efforts required to meet the targets will require a mix of delivery mechanisms in the Burdekin Region. This includes regulation, extension, financial incentives and technology change supported by R&D as described below. This conclusion is supported by the benefit cost analysis which indicates higher BCRs for the mixed delivery option of regulation, financial incentives and extension and is reiterated through consultation with a wide range of stakeholders.

Regulation

Given that best available figures collected through the WQIP process suggest it is likely to be profitable for sugarcane and horticultural growers, and graziers to shift from D class to C class management practice then there should be no need to give incentives to such landholders. Given the urgent need to improve the health of the GBR, then it is recommended that regulatory approaches are introduced in these situations.

As described in Section 1.3 the Great Barrier Reef Protection Amendment Act 2009 (remains in place as producers transition to industry BMP systems and is currently being reviewed; as at February 2016 all cane farmers on > 70 hectares and graziers on > 2,000 hectares in the Wet Tropics, Burdekin and Mackay-Whitsunday regions are urged to adopt regulated standards and improve reef water quality outcomes. A number of other regulatory mechanisms are currently being explored by the Queensland Government's Great Barrier Reef Ministerial Water Science Taskforce, including permitting and licenses, compensation for temporary retirement of marginal land, and cross compliance. For example, cross compliance conditions provide financial incentives by linking payments to meeting environmental objectives.

Payments are forfeited where farmers are not compliant. For example grants, subsidies and tax relief issued under a different policy program, might be made conditional on the adoption of a process standard such as the BMP. For example, graziers' high capital costs, ability to service existing debt levels and variable cash flows have been identified as key barriers to practice changes. Government can directly influence the availability and cost of rural credit through encouraging the inclusion of criteria relating to the adoption of best management practice into government loan assessment criteria and conditions, for example through Drought Concessional Loans.

In addition to incentives, options for cross compliance might be identified through the objectives, implementation and assessment criteria in other legislative instruments. Possible instruments to explore further might include:

- *Vegetation Management Act 1999* as it relates to the management of land clearing and retention of ground wooded vegetation cover;
- *Sustainable Planning Act 2009* as it relates to planning approval, land uses and monitoring processes;
- *Water Act 2000* as it relates to ecosystem based management approaches for diffuse water pollution and regulates works within the bed and banks of defined watercourses (eg. system repair and streambank repair projects);
- *Land Act 1994* as it relates to duty of care provisions to the land by users of state leasehold land for example by conserving soil and water resources, preventing land degradation and protecting riparian vegetation; and
- *Sugar Industry Act 1999* as it relates to the sustainable production of sugarcane.

The socio political risk of the scenarios that were run in INFFER was assessed as being moderate to high and takes into account factors such as cooperation of other organisations, capacity for delivery, and social, administrative or political constraints such as support or opposition by local community groups and political resistance.

The likelihood of long term funding is also important for successful implementation of the project, which is essential for the options presented in this WQIP. The prospects for obtaining long-term funding was judged as possible, given that long-term plans such as the Reef 2050 Plan and institutional arrangements are in place, but the level of funding required is greater than what has historically been available.

Financial Incentives

Financial incentives may be required for sugarcane and horticultural growers and especially for graziers to shift permanently beyond C practice, but they should only be used in circumstances where the public net benefits of land management change are high (A or B practices) and the private net benefits are small or slightly negative. The level of these payments has been incorporated into the overall estimates of costs. Incentive delivery should be supported by ongoing extension.

The Australian Government has also recently released guidelines for investment priorities under Reef Trust 3. To expedite adoption of best management practices, this indicates that financial incentives, training and extension should only be targeted to landholders where the existing management practices are within the lower risk categories in the P2R WQ Risk framework, i.e. not poorly managed, degraded land with high suspended sediment erosion risk and nutrient loss.

Examples of financial incentives include approaches such as: grants for equipment, reverse auctions, concessional loans to implement improved practices, insurance mechanisms to underwrite risks, taxes or levies, stewardship payments for ecosystem services and compensation for temporary land retirement.

Extension

To support the adoption of B class practices in sugarcane, a targeted extension program will need to be delivered. Due to the large number of growers and sugarcane enterprises, estimates from local stakeholders (industry and Queensland Government staff) are that this program will require adequate ongoing resources. It is estimated that at least 11 FTE extension staff will be required to underpin this program. The greatest potential gains will come from working with larger farms (see Section 5.2.3).

For grazing, due to the large areas and number of farmers, this program will require adequate ongoing resources. It is estimated that at least 16 FTE extension staff will be required to underpin this program.

For horticulture, shifting to B class practices will also require a targeted extension program. There are a relatively small number of growers involved which is likely to be beneficial for resourcing.

Extension activities can include formal training, mentoring, peer to peer learning, agricultural economic advice, assistance complying with legal obligations, as well as advice on incentives to help land users trial, adopt, integrate, review, innovate and implement new practices.

As a general rule extension should only be used as the main policy tool in circumstances where the public net benefits of land management change are high, and the private net benefits of land management change are at least moderate.

Research and technology development

A number of A class practices, especially for DIN reduction in sugarcane, are associated with the adoption of new and unproven technologies. Examples include enhanced efficiency fertilisers and treatment systems such as algal ponds and floating wetlands in sugarcane and more holistic management in grazing. While these practices offer potentially significant environmental benefits, the private benefits are presently highly negative. It is recommended that ongoing R & D, including field trials be undertaken to investigate the commercial viability of these practices.

In addition, better understanding of the most cost effective techniques for large scale gully remediation are required if significant gains in controlling erosion from gullies in areas such as the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin catchments are to be made. This is currently being investigated through Reef Trust and NESP projects.

6.3 Strategies for delivering water quality improvement in the Burdekin region

Implementation of the WQIP will require actions across a range of land uses including agricultural and urban areas, and areas where ecological functions such as water retention, sediment trapping and hydrological connectivity have been modified.

The delivery mechanisms described in Section 6.2 involve a combination of:

- regulation to achieve minimum standards;
- financial incentives to encourage change;
- extension to facilitate technology transfer, education, communication, demonstrations and to provide support for community networks; and
- technology change including of improved land management options, such as through strategic research and design (R&D), participatory R&D with landholders, and provision of infrastructure to support a new management options.

There are also a number of factors affecting the choices of delivery mechanisms that are likely to change in the future. These are discussed in Section 7 and have implications for the longer term implementation strategy for meeting the proposed targets.

It is evident that it will be challenging to meet the 2018 Reef Plan targets and the longer term ecologically relevant targets with the current suite of agricultural management practices. Accordingly, the implementation of this WQIP will require BMP programs at a larger scale than has occurred previously, and with different levels of extension and incentives than current programs and research and development to investigate innovative practices. Large scale remediation and landscape restoration projects will also be required, in addition to consideration of land retirement in some locations that are no longer productive.

As described in Section 2.2, the implications of the current management challenges and the potential ongoing impacts on the health of freshwater, coastal and marine ecosystems must be considered seriously. Considerable trade-offs will be required between the level of management change that is considered to be acceptable politically and by the community, and the desire to maintain the values of the receiving environments including the GBR. Restoration of ecological functions in the floodplain and coastal ecosystems have a role in reducing pollutant loads; however, the likely benefits of these restoration activities are yet to be quantified and is a knowledge gap in this WQIP. Notwithstanding this, it is well known that the broader benefits to ecological health and biodiversity are significant.

This section presents the outcomes and targets required to achieve and maintain the desired goals outlined in Section 4 (reflected in the resource condition targets).

For all industries, the relevant Reef Plan target region-wide is applied which is that 90 per cent of area of each industry in each basin is managed using best management practice systems (soil, nutrient and pesticides). However, as outlined in Section 4.3.2, this WQIP adopts this as a more realistic target for 2025 to reflect the realities of the scale and complexity of the changes required to management in the region.

As stated earlier, it is recognised that the definitions (and hence, outcomes) of the industry ABCD classes will change as the water quality benefits and economic viability of new and innovative practices are proven and accepted over time. Therefore, the estimate of pollutant load reductions from practice shifts presented in the WQIP are essentially static, and do not take into account improvements in the magnitude of water quality benefits associated with each practice class over the five year period of the Implementation Plan (2020 to coincide with Reef Plan goal), towards the Reef 2050 Plan and ecologically relevant targets (2025, i.e. 10 years from now) and the Reef 2050 Plan goals (2050, i.e. 35 years from now).

Achievement of the ecologically relevant targets for pollutant load reductions can be viewed as a trajectory from baseline estimates in 2013, Reef Plan targets by 2018 and ecologically relevant targets by 2025.

The management targets related to protecting and maintaining values of catchment waterways, freshwater health and restoring ecological function of coastal ecosystems are also drawn from the Reef Plan 2013 targets. Drawing on the Reef Plan 2050 Plan Outcomes and Objectives, the Vision and Long Term Resource Condition Outcomes are:

OUTCOMES

vi. the status and ecological functions of ecosystems within the Great Barrier Reef World Heritage Area are in at least good condition with a stable to improving trend;

vii. reef water quality sustains the Outstanding Universal Value of the Great Barrier Reef World Heritage Area, builds resilience and improves ecosystem health over each successive decade;

viii. freshwater, estuarine and marine ecosystems are ecologically healthy, productive, resilient, enjoyed and valued;

ix. terrestrial ecosystems are sustainably managed for good water quality; and

x. surface and ground water resources are sustainably managed for good water quality.

LONG TERM RESOURCE CONDITION OBJECTIVES

v. the Great Barrier Reef World Heritage Area retains its integrity and system functions by maintaining and restoring the connectivity, resilience and condition of marine and coastal ecosystems (EHO2);

vi. trends in the condition of key ecosystems including coral reefs, seagrass meadows, estuaries, islands, shoals and inter-reefal areas are improved over each successive decade (EHO3);

vii. over successive decades the quality of water entering the Reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef (WQO1); and

viii. over successive decades the quality of water in or entering the Reef from all sources including industrial, aquaculture, port (including dredging), urban waste and stormwater sources has no detrimental impact on the health and resilience of the Great Barrier Reef (WQO2)

6.3.1 Agricultural land uses

LOAD REDUCTION TARGETS:

Sediment	Nutrients	PSII herbicides
TSS-1. By 2025, attain a minimum 50 per cent reduction in mean annual sediment load at end-of-Burdekin Basin from modelled 2013 baseline estimates. i.e. a reduction from approximately 3,200 t/yr to 1,600 t/yr. TSS-2. By 2025, attain a minimum 47 per cent reduction in mean annual sediment load at end-of-Upper Burdekin catchment from modelled 2013 baseline estimates. i.e. a reduction from approximately 1,000 t/yr to 526 t/yr. TSS-3. By 2025, attain a minimum 32 per cent reduction in mean annual sediment load at end-of-Suttor catchment from modelled 2013 baseline estimates. i.e. a reduction from approximately 63 t/yr to 43 t/yr. TSS-4. By 2025, attain a minimum 57 per cent reduction in mean annual sediment load at end-of-Bowen Broken Bogie catchment from modelled 2013 baseline estimates. i.e. a reduction from approximately 1,605 t/yr to 696 t/yr. TSS-5. By 2025, attain a minimum 57 per cent reduction in mean annual sediment load at end-of-Lower Burdekin catchment from modelled 2013 baseline estimates. i.e. a reduction from approximately 444 t/yr to 193 t/yr. TSS-6. By 2025, attain a minimum 20 per cent reduction mean annual sediment load from horticulture, dryland cropping and irrigated cropping areas in the Burdekin Region from modelled 2013 baseline estimates.	DIN-1: By 2025, attain a minimum 80 per cent reduction of DIN load entering the GBR from Lower Burdekin sugarcane areas from modelled 2013 baseline estimates - i.e. a reduction from approximately 1,098 t/yr to 220 t/yr. DIN-2: By 2025, attain a minimum 50 per cent reduction mean annual DIN load from urban, horticulture, dryland cropping and irrigated cropping areas in the Burdekin Region from modelled 2013 baseline estimates. PN-1. By 2025, attain a minimum 52 per cent reduction in particulate nitrogen load entering the GBR from grazing lands in the Burdekin Basin from modelled 2013 baseline estimates i.e. a reduction from approximately 2,802 t/yr to 1,345 t/yr.	PSII-1. By 2025, attain a 90 per cent reduction of PSII herbicide load entering the GBR from Lower Burdekin sugar lands from modelled 2013 baseline estimates - i.e. a reduction from approximately 2,295 kg/yr to 230 kg/yr.

MANAGEMENT ACTION OUTCOMES

- i. land managed sustainably (sediment, nutrient and pesticide losses minimised);
- ii. frontage country and riparian areas are maintained, improved or restored;
- iii. soil and pasture condition improved to minimise erosion; and
- iv. pests and weeds controlled.

MANAGEMENT ACTION TARGETS (note that these targets should be read in conjunction with the management practice frameworks outlined in Section 4). Current adoption rates are shown for context; 2013-14 adoption rates are derived from the Paddock to Reef Program for consistency; ranges represent variations between catchments.

Grazing

Graz-1. By 2020, retain a minimum of 70 per cent (dry season) ground cover in all years and a minimum of 80 per cent cover in years with above average rainfall in the preceding season.

Graz-2. By 2025, retain a minimum of 70 per cent (dry season) ground cover in all years and a minimum of 80 per cent cover in years with above average rainfall in the preceding season.

To reduce hillslope erosion:

Graz-3. By 2020, at least 50 per cent of grazing lands are managed to B class practice for pasture management with a focus in priority sub-catchments (2013/14 adoption of A or B is 10-35 per cent).

Graz-4. By 2025, 90 per cent of grazing lands in priority areas are managed using best management practice systems in pasture management.

Priority catchments for hillslope erosion are the Bowen Broken Bogie, Don and Lower Burdekin . Priority sub catchments include:

- Little Bowen River (Bowen Broken Bogie);
- Bogie River (Bowen Broken Bogie);
- Pelican Creek (Bowen Broken Bogie);
- Don River (Don);
- Glenmore Creek (Bowen Broken Bogie);
- Haughton River (Lower Burdekin);
- Bowen River (Bowen Broken Bogie);
- Abbot Bay (Don); and
- Rosella Creek (Bowen Broken Bogie);

To reduce stream bank erosion:

Graz-5. By 2020, at least 50 per cent of waterways are actively managed to maintain or increase the extent of riparian vegetation in the priority sub-catchments in the Bowen Broken Bogie, Upper Burdekin, Lower Burdekin and Don catchments, with specific areas identified for streambank remediation by 2018 (2013/14 adoption of A or B is 45-75 per cent).

Graz-6. By 2025, 90 per cent of grazing lands in priority areas are managed using best management practice systems in streambank management.

Priority catchments for streambank erosion are grazing lands in the Bowen Broken Bogie, Upper Burdekin, Lower Burdekin and Don. Priority sub-catchments include:

- Bowen River (Bowen Broken Bogie);
- Burdekin River (above dam) (Upper Burdekin);
- Burdekin River (Blue Range) (Upper Burdekin);
- Burdekin Delta (Lower Burdekin);
- Don River (Don);
- Haughton River (Lower Burdekin); and
- Little Bowen River (Bowen Broken Bogie)

To reduce gully erosion:

Graz-7. By 2020, at least 50 per cent of gullies in the priority Bowen Broken Bogie and Upper Burdekin sub-catchments are prevented and/or managed to B class practice, with specific areas identified for gully remediation by 2018 (2013/14 adoption of A or B is 25-35 per cent).

Graz-8. By 2025, 90 per cent of grazing lands in priority areas are managed using best management practice systems in gully management.

Priority Catchments are the grazing lands in the Bowen Broken Bogie and Upper Burdekin. Sub-catchments include:

- Bogie River (Bowen Broken Bogie);
- Glenmore Creek (Bowen Broken Bogie);
- Pelican Creek (Bowen Broken Bogie);
- Little Bowen River (Bowen Broken Bogie);
- Bowen River (Bowen Broken Bogie);
- Burdekin River (dam) (Upper Burdekin); and
- Rosella Creek (Bowen Broken Bogie)

Sugarcane

Cane-1. By 2020, at least 75 per cent of sugarcane areas are managed using Six Easy Steps Guidelines for management zone yield potential for determining fertiliser rates, or other innovative management regimes (2013/14 adoption of A or B is ~10-30 per cent).

Cane-2. By 2025, 90 per cent of sugarcane areas are managed using Six Easy Steps Guidelines for management zone yield potential for determining fertiliser rates, or other innovative management regimes.

Cane-3. By 2020, less than 20 per cent of sugarcane areas use low efficiency irrigation techniques (current D class irrigation practices).

Cane-4. By 2025, at least 60 per cent of sugarcane areas are managed using high efficiency irrigation techniques (B irrigation practices) (2013/14 adoption of A or B is ~10 per cent).

Cane-5. By 2020, at least 60 per cent of sugarcane areas are managed using best practice herbicide management (2013/14 adoption of A or B is ~20-30 per cent).

Cane-6. By 2025, 90 per cent of sugarcane areas are managed using best practice herbicide management.

Horticulture

Hort-1. By 2020, at least 50 per cent of horticultural lands in the Don catchment are managed using best management practice systems (soil, nutrient and pesticides) (2013/14 adoption of A or B soil is 67 per cent, nutrients is 17 per cent, pesticides is 60 per cent).

Hort-2. By 2025, 90 per cent of horticultural lands in the Don catchment are managed using best management practice systems (soil, nutrient and pesticides).

Grain Crops

Grain-1. By 2020, at least 50 per cent of grain crops in the Suttor catchment are managed using best management practice systems (soil, nutrient and pesticides) (2013/14 adoption of A or B soil is 31 per cent, nutrients is 48 per cent, pesticides is 91 per cent).

Grain-1. By 2025, 90 per cent of grain crops in the Suttor catchment are managed using best management practice systems (soil, nutrient and pesticides).

ON GROUND ACTION OUTCOMES – Practice and attitude change, including productivity and profitability:

- i. agricultural land managers implement recommended BMP for WQ improvement;
- ii. government and industry (non-government) extension services coordinated, expanded and strengthened in capacity and resources;
- iii. enhanced legislative framework (Fed., State, Local) to support WQ improvement including regulation of practices to achieve minimum industry standards;
- iv. financial incentives (using a range of delivery mechanisms) available to support agricultural land managers to move beyond BMP;
- v. agricultural land manager networks groups with the capacity to actively and effectively engage;
- vi. increased awareness, receptiveness and willingness to change practices;
- vii. research and Development organisations have increased knowledge and collaboration with land managers to bring about WQ improvement;
- viii. financial institutions embrace lending practices that lead to WQ improvements; and
- ix. greater Traditional Owner involvement & opportunity in land and water management.

ON GROUND ACTIONS

Grazing

Develop a Bowen Broken Bogie Catchment Action Plan (2016 to 2025) to establish a coordinated foundation for prioritised investment in the catchment that identifies the following detail: objectives, targets, priorities, actions, monitoring and evaluation, R&D requirements, delivery arrangements and establishes a budget for implementation over the next 10 years.

Develop and implement an extension and communication program to support shifts to whole of farm best management practice by:

- development and agreement of priorities for targeting farms, informed by this WQIP and the DAF Prioritisation process for extension activities;
- whole of industry information, capacity building and agreed clear messaging;
- small geographically based farmer groups;
- one-on-one extension; and
- establish, support & reinvigorate social networks of graziers (e.g. Landcare).

Extend water quality monitoring at a range of scales (on-farm, sub-catchment, end of catchment) to:

- improve understanding of TSS and particulate nutrient loss pathways and their fate;
- improve understanding of the impact of different management practices on water quality; and
- share and extend results among Government, industry and farmers.

Support improved pasture, frontage country and gully management with incentives (supported by long-term management agreements until improved technology improves practices to become profitable in their own right) as required.

Establish on-farm trials to support extension and communication program by validating science at a local level and to demonstrate the effectiveness and profitability of best management practices.

Auditing and reporting program to ensure compliance with management agreements.

R&D into cost effective gully remediation and streambank restoration techniques that align within existing regulations in the *Water Act 2000* and *Soil Conservation Act 1986*.

Support national sustainable product eco-beef labelling through awareness of WQ improvement and linkages to production, market value, and environmental value of product.

Sugarcane

Encourage farmers to move along a path where initially they use Six Easy Steps based on district yield potential, then with-in productivity groups, followed by farm yields, block yields then with-in block yields. This approach would be combined with the impact on yield of time of harvest, stage in crop cycle, irrigation management, proximity to the start of the wet season and age of crop.

Develop and implement an extension and communication program to support shifts to whole of farm best management practice by:

- development and agreement of priorities for targeting farms e.g. target the management units with farms greater than 1,000 ha which covers 15 per cent of the sugarcane area;
- whole of industry information, capacity building and agreed clear messaging;
- industry productivity group meetings (geographically based);
- one-on-one extension; and
- establish and implement the 'Bridging the Gap' framework for validating science at local level, demonstrate the effectiveness of BMP and communicating water quality science to growers.

Extend water quality monitoring at a range of scales (on-farm, sub-catchment, end of catchment) to:

- improve understanding of N and pesticide loss pathways and their fate;
- improve understanding of the impact of different management practices on water quality; Promote and demonstrate practices that reduce chances of losses; and
- share and extend results among Government, industry and growers.

Support improved irrigation practices and runoff management with incentives (supported by long-term management agreements) as required including:

- upgrade existing recycle pits and install infrastructure in strategically important locations, treatment and reuse;
- irrigation system change on soils where optimised furrow irrigation is inappropriate;
- irrigation scheduling tools; and
- riparian buffers, wetland restoration/construction.

Support groundwater management through:

- development of a groundwater management / dewatering strategy for the Lower Burdekin that proactively encourages conjunctive water use for irrigation in all areas where water quality is acceptable with sufficient incentives and certainty to make a significant difference to the rate of rise of the watertable within the shortest possible time. Lowering the watertable is an extremely high priority and can only occur in the short term by dewatering.

Establish on-farm trials to support extension and communication program by validating science at a local level and to demonstrate the effectiveness and profitability of best management practices.

Auditing and reporting program to ensure compliance with management agreements.

R&D into Enhance Efficiency Fertilisers, innovative fertiliser reduction use schemes, validation of management yield zones, improving soil health which has implications for nutrient use efficiency.

Horticulture and Grain Crops

Develop and implement a communication and extension program that promotes water quality improvement in horticultural crops including development of support materials and demonstration activities.

Establish water quality monitoring at a range of scales (on-farm, sub-catchment, end of catchment) and horticultural crops in the Don catchment to:

- improve understanding of nutrient, pesticide and sediment loss pathways and their fate;
- improve understanding of the impact of different management practices on water quality; and
- share and extend results among Government, industry and growers.

Support financial incentives programs that support growers to move beyond BMP.

Establish on-farm trials to support extension and communication program by validating science at a local level and to demonstrate the effectiveness of best management practices.

Establish collaborative arrangements amongst service providers (community, NRM, extension) for delivering improved water quality practices.

R&D to quantify the water quality benefits of a range of management practices across the horticulture industry.

6.3.2 Urban

The opportunity to address urban issues was mapped through the urban water quality improvement framework shown in Table 6.2. It is recognised that not all priorities will apply to every urban area. For example, many urban centres are not experiencing significant growth at present and don't have significant areas of construction. However, the timing and location of development will change over time and planning and design actions for these areas remain relevant in the interim. The priorities and recommendations presented here are based on principles and technical information rather than on statutory obligation. The legal framework and requirement for many urban water quality actions are summarised in *Appendix 2: Key legislation and policy considerations for regional water quality planning in Queensland* and detailed in Gunn (2014).

Procedural priorities identified for effective implementation of urban issues raised in the plan are to:

1. recognise the broad range of urban water quality impacts and issues;
2. focus on managing soil loss from active construction sites and development areas;
3. fund Local Government for water quality (research, education, infrastructure design and regulation); and
4. fully integrate urban water management as a theme within the regional INFER decision making process.

The following conclusions support strategic decision making for the region's urban water quality management:

1. Urban areas are small but important for regional water quality management and prioritisation of risks by the relative loading of key water quality pollutants is not adequate.

Urban impacts differ in the type, timing and location to those of the key rural land uses. Urban areas generate the risk of a broad range of water contaminants (including, petro and industrial chemicals, heavy metals, pathogens, nutrient, sediment, pesticide, plastics, micro-plastics and gross pollutants). These may enter waterways as stormwater, via sewage treatment facilities or as airborne particulates. Sewage discharges are broadly continuous regardless of season where as stormwater and aerial discharges are arguably even more event driven than discharges in rural landscapes.

2. The priority focus areas for urban issues should be on runoff control through construction site regulation and WSUD. Public and industry education are equally important.

Land under development is disturbed and the source of over 100 times more fine particulates than mature urban areas. There are well established regulatory standards and processes to control development site sediment and nutrient runoff. The most cost effective water quality management options involve preventing contamination in the first place and this requires public and industry education and incentive.

3. Local government needs funding for regulation, education and research/monitoring of local urban water quality issues.

While a rates base provides income this is insufficient for local government to fully participate in regional scale data capture, research, planning and delivery. In particular, smaller rural and regional councils have a small rate base and local priorities which may differ to those for maintaining GBR water quality.

The Reef 2050 Plan identifies a number of actions relevant to urban land uses. These are adopted in this WQIP as priority actions and include:

- review and set regionally relevant standards for urban and point-source discharges into the World Heritage Area and ensure licensees meet these standards (WQA10);
- increase adoption of leading practice in the management and release of point-source water affecting the Reef (WQA11);
- implement best practice stormwater management (e.g. erosion and sediment control, water sensitive urban design and capture of gross pollutants) for new development in coastal catchments (WQA12); and
- build capacity for local government and industry to improve water quality management in urban areas (WQA13).

These actions are aligned with the pollutant load reduction targets outlined in Section 4.3.1. Additional actions specific to the Burdekin Region are included in Table 6.2. Many of these actions are related to water quality management including the issues of land use design, integrated water management and waterway ecology.

Table 6.2. Urban water quality management opportunities and recommendations.

Issue	Consequence	Recommended Actions
Land use design	Avoid the most costly of pollutant control and remediation measures by appropriate land use design and development controls.	Continually research opportunities for re- zoning land uses to minimise the risk of water pollution or need for hard infrastructure. Protect natural assets and ecosystem service areas. Design for waterway use and amenity. Review of development guidelines in light of recent climate change driven extremes.
Areas under development	Construction and active earth works generate hundreds of times more sediment than established urban areas.	Local government to strictly control and regulate active urban development sites and areas. Practice WSUD and hard surface reduction/ minimisation. Investigate and manage for acid sulphate soils, shallow groundwater salinity risk and climate change issues.
Established areas	Complex suite of event driven mobilisation of nutrients, gross pollutants, litter, pesticides and petrochemicals.	Adopt a multi-staged management approach with emphasis on prevention and education, then regulation, then structural design (e.g. trash racks on drains) and clean up events which feed back into education programs.
Integrated water management	The quantity of stormwater and sewage effluent discharge to waterways is significant at local scales with opportunity for load reduction linked to reuse volumes and event control.	Increase integration of various sources of water supplies including stormwater and sewage reuse. Where practical, 'shandy' different water sources for quality control. Match use and reuse of water of different qualities for acceptable uses: Dust suppression, industrial use, parks and garden irrigation and potable supply.
Mix of pollutants	Urban water pollutants include a broader range of contaminants and typically discharge to highly frequented recreational waterways.	Fund local government regulation, compliance and monitoring. Fund coordinated public and industry specific water quality education.
Waterway ecology	The hydrology, mixing, drying cycles, vegetation structure and species composition (pests) are all important determinants of water quality in urban waterways, groundwater and downstream environments. Managing pollutants alone is not adequate to maintain waterway values.	Research the bio-physical characteristics of waterways within and passing through urban environments, to establish simple water body specific objectives and management plans. Establish clear 'custodial' arrangements of urban waterways (organisational or community) with scientific support, to underwrite monitoring and plan delivery.

6.3.3 High risk site specific issues

The opportunity to address site-specific issues was identified in Section 5.5.2. It is recognised that listed priorities will not apply to every site or site type. Many sites are not creating a significant water quality impact or risk and some are being managed to represent best practice outcomes. The listing of key sites will change over time and planning and design actions for the main categories remain relevant in the interim. The priorities and recommendations presented here are based on principles and technical information rather than statutory obligation.

Procedural priorities identified for effective implementation of site specific water quality issues raised in the plan are to:

1. recognise the broad range of point source water quality impacts and issues which require management independent of surrounding generic land uses;
2. focus on mining and ports, dams, bunds and linear infrastructure;
3. fund regional water quality impact research with respect to mining and water management infrastructure; and
4. use the site-specific action guidelines provided in Section 5.6 to assist with decision support in a complex regulatory environment.

The following conclusions are intended to support strategic water quality decision making for high risk site specific issues in the Burdekin Region.

1. Mines can be important at local scales.

Past, present and future mining activities all represent a significant but unquantified water quality risk. The impacts relate to: introduction of toxic materials to waterways e.g. heavy metals; gully and surface sediment erosion; disruption of surface and groundwater hydrology and significant dry area water extraction; aerial pollutant mobilisation pathways; potential event driven pollution control failures; and the very large scale of proposed new mines.

2. Expansion of the Abbot Point coal loading terminal is significant.

The planned expansions could generate about 1 per cent of the region's average annual anthropogenic discharge of suspended sediment to the GBR lagoon for one year (Abbot Point EIS). This may appear small, however, this is of similar magnitude to any one of the annual sediment discharges from the Black, Ross, Belyando, Cape Campaspe or Suttor catchments.

3. Regulation controls most of these impacts.

Generally point source water quality issues are regulated and already require compliance, education and monitoring. However, there is opportunity to go beyond obligation and examine the business opportunity in improving water quality outcomes through offsets.

The Reef 2050 Plan identifies a number of actions relevant to point source pollution listed above, in addition to specific port management. These are adopted in this WQIP as priority actions and include:

- restrict capital dredging for the development of new or expansion of existing port facilities to within the regulated port limits of Gladstone, Hay Point/Mackay, Abbot Point and Townsville (WQA14);
- develop and implement a dredging management strategy that includes (WQA15):
 - an examination and, where appropriate, a potential pilot program to evaluate different treatment and re-use options for managing dredge material;
 - measures to address dredging-related impacts on Reef water quality and ecosystem health; and
 - a 'code of practice' for port-related dredging activities;
- develop a State-wide coordinated maintenance dredging strategy which (WQA16):
 - identifies each port's historical dredging volumes and likely future requirements and limits;
 - identifies appropriate environmental windows to avoid coral spawning, seagrass recruitment, turtle breeding and weather events;
 - examines opportunities for the beneficial reuse of dredge material or on-land disposal from maintenance activities ; and
 - establishes requirements for risk-based monitoring programs (integrated with broader regional monitoring efforts).
- understand the port sediment characteristics and risks at the four major ports and how they interact and contribute to broader catchment contributions within the World Heritage Area (WQA17);
- mandate the beneficial reuse of port-related capital dredge spoil, such as land reclamation in port development areas, or disposal on land where it is environmentally safe to do so (WQA19);

- the Queensland Government will require all proponents of new dredging works to demonstrate their project is commercially viable prior to commencement (WQA20);
- support on-land disposal or land reclamation for capital dredge material at Abbot Point (WQA22); and
- expand 'nested' integrated water quality monitoring and report card programs at major ports and activity centres (e.g. Gladstone), in priority catchments (e.g. Mackay Whitsundays) and Reef-wide, to guide local adaptive management frameworks and actions (WQA23).

These actions are aligned with the pollutant load reduction targets outlined in Section 4.3.1. Additional actions specific to the Burdekin Region are included in Table 6.3.

Table 6.3. Water quality management opportunities and recommendations for site specific water quality issues.

Land use	Issues	Recommended Actions
Mining	• 22 large proposed mines; • 44 Mines operating or under care and maintenance; • 2400 Small to medium legacy sites.	1. Research: • erosion & ground / surface water interaction; • aerial pollutant mobilisation; • water extraction implications; and • positive benefits sites for sand extraction. 2. Register discharge data and management plans on public data bases (WaTERS) and use as a management tool. 3. Apply listed regional mining best practice tests and address practice gaps.
Port Dredging & Shipping	• Abbot Point expansion could mobilise 31 kilotonnes of fine sediment offshore in a short timeframe (4 months); • Abbot Point operation and maintenance dredging; • Expansion of Townsville port; and • Townsville port operation and maintenance dredging.	4. Manage dredge timing and dewatering processes. 5. Offset Abbot Point sediment impacts into Don or Burdekin Basin. 6. Apply/maintain an 'all dredge spoil to land' policy. 7. Strictly regulate ship movement. 8. Strictly regulate port and ship waste management. 9. Maintain high pollution emergency response clean up and containment capabilities.
Industrial	Aerial, overland and sewerage or waterway discharge (both licensed discharge and event driven capacity failures).	10. Manage through regulation. Strict monitoring and reporting requirements to State & Federal databases. 11. Promote wastewater reuse and innovation in researching and developing on sale opportunities.
Agricultural processing and aquaculture	Localised, overland and groundwater nutrient hotspot risks. The scale of aquaculture risks has not been quantified.	12. Research: • reuse opportunities for high value solid and liquid wastes streams; • energy recovery opportunities; and • aquaculture impacts and opportunities. 13. Subsidise advanced practice site management using region or GBR catchment wide market mechanisms such as tenders or trading systems.

6.3.4 Restoring catchment waterways and ecological function of coastal ecosystems

The first step in determining management actions for maintaining or restoring freshwater ecosystem health, catchment waterways and restoring ecological function in coastal ecosystems in the Burdekin Region is to collate knowledge about system processes, values and threats. This information is presented in Section 5.7. The most obvious management action for addressing water quality issues in these ecosystems is the application of the Water Quality Guidelines defined under the EPP (Water) and the recently scheduled EVs and WQOs for the Black, Ross, Haughton and Don Basins. This process is already well established in the region and incorporated into relevant policy and planning documents

The Reef 2050 Plan identifies a number of actions relevant to protecting and restoring coastal ecosystems. These are adopted in this WQIP as priority actions and include:

- prioritise functional ecosystems critical to Reef health in each region for their protection, restoration and management (EHA7);
- improve connectivity and resilience through protection, restoration and management of Reef priority coastal ecosystems including islands through innovative and cost-effective measures (EAH10);

- identify and prioritise key sites of high ecological value and implement recovery programs (Reef Recovery Plans) (EHA13);
- implement ecosystem health initiatives through the Reef Trust investment strategy (EHA14);
- improve mapping, modelling and monitoring of ecosystems important for the protection of the Reef to inform planning, assessment and decision making (EHA15);
- avoid, mitigate or offset impacts on marine and coastal ecosystems to restore Reef resilience and ecosystem health (EHA18);
- strengthen the Queensland Government's vegetation management legislation to protect remnant and high value regrowth native vegetation, including in riparian zones (EHA20); and
- work with local councils to build their capacity to effectively implement coastal planning laws and policies to protect the Reef (EHA24).

These actions are aligned with the catchment management targets outlined in Section 4.3.2.

Potential actions for improved management and protection of coastal ecosystem and functions in the Lower Burdekin catchment include (drawn from GBRMPA, 2013):

1. Development of a **Lower Burdekin Floodplain Action Plan** (building on Tait, 2013 and GBRMPA, 2013) that integrates water use and ecosystem function measures noted above to guide management effort, set priorities, identify dependent and rate determinant steps, recognising required trade-offs, and engagement of stakeholders.
2. Agreement of priority areas which will include significant areas of remnant floodplain coastal ecosystems set aside during the development of the BHWSS. Other key remnant coastal ecosystem assets include intact riparian systems, remnant delta habitats on the coastal fringe, coastal wetland buffers, remnant coastal ecosystem landscape corridor linkages and nodes, wetlands that have retained predevelopment ecological character and remnant floodplain habitats representative of areas developed to agriculture and potentially suitable for future development. Coastal ecosystem restoration priorities in the Lower Burdekin floodplain include revegetation of functional landscape elements, restoration of banded coastal wetlands and addressing major fish passage barriers.
3. Modification of some coastal ecosystems on the Lower Burdekin floodplain is irreversible or will be slow to respond to management interventions. In this case, the priority should be on reinstating ecosystem functions and values that are important to the health of the World Heritage Area within the modified landscape. Opportunities for improving ecosystem functions include:
 1. assessment of fluvial geomorphology and condition and works to restore natural river and coastal sand budgets and manage streambank erosion where necessary;
 2. reconfiguring the layout of agricultural production systems to emulate coastal ecosystem function outcomes (particularly interception and detention of run-off, and nutrient uptake);
 3. sustaining and expanding control programs for aquatic weed infestations in hydrologically modified stream systems. For example, establishment of Riparian Management Agreements with land holders. Adopting ecosystem restoration targets that suit modified floodplain conditions (i.e. the establishment of riparian rainforests on hydrologically modified drainage reaches);
 4. using seasonal distributary channels to bypass wet season flows around anoxic (low dissolved oxygen) stream reaches to facilitate fish movement and recruitment;
 5. restoring seasonal hydrological regimes in impacted high value wetland systems using hydrological isolation of selected wetlands or sub-catchments from irrigation tailwater base flows to reinstate hydrological seasonality at micro- or meso-scales;
 6. using pumped 'environmental flows' to replicate wet season river overbank flows down distributary creek systems to avoid critical wet season water quality "crashes" and enhance fish passage opportunities in floodplain distributary stream systems which have been hydrologically modified by river levees and non-seasonal flows;
 7. recognition programs that improve landholder ownership of wetlands e.g. Reef Guardians; and
 8. others include: Improved water delivery efficiency including infrastructure modernisation, reinstating fish passage (e.g. building fish ways), improved wader bird habitats, wetland condition monitoring, biodiverse plantings and enhancement of existing native vegetation, returned or mimicked seasonal dry down, riparian vegetation, water use efficiency on farm, pest control (e.g. pigs and tilapia), stewardship, community engagement, communications and education e.g. BBIFMAC water quality and water quantity extension for the Landscape Resilience project.

Implementation of these priorities needs to be brought into the context of a number of other planning processes. The Burdekin Regional NRM Plan is currently being updated and reviewed specifically to incorporate activities to mitigate and adapt to a changing climate. Estuaries, coastal floodplain and inshore ecosystems are important from both climate change mitigation and adaptation perspectives and will be prominent in the revision of the regional NRM Plan. From a climate change mitigation perspective, repairing the productivity and functionality of these ecosystems is a priority. Likewise with sea level rise and the likelihood of more extreme events, repairing coastal ecosystems to ensure foreshore buffering and resilience to extreme events is a priority (See Section 7.2).

6.4 Establishing a budget

6.4.1 Building on existing programs

A number of initiatives are already in place, and some of these have funding support for up to 3 years. The key programs have provided an estimated investment of almost \$35 million between 2013 and 2018, or approximately \$6.5 million per year. Importantly, there are no long term funding initiatives to support this Implementation Strategy beyond 2019 and a majority of the funding is only committed to 2016 or 2018.

6.4.2 Budget Estimate

It is challenging to provide a complete budget summary for the implementation of the WQIP, as a number of aspects still require further investigation, including system repair priorities, and it is recognised that cost estimates for management practice changes are dependent on many factors. Furthermore, knowledge of on-ground implementation of major works such as gully remediation in grazing lands and advanced irrigation in sugarcane has issues associated with skills and capacity and solutions can be site specific and will vary between locations. Accordingly, a large number of assumptions have been made in calculating the costs of progressing towards the targets over the next 5 years (Section 6.1).

It should be noted that a majority of the costs are associated with capital investments required to make changes in the first five years, and that annual maintenance costs will reduce significantly beyond 5 years (e.g. shifting sugarcane to B practice).

A number of tasks and roles are required to support delivery and implementation of the WQIP. While it is proposed that the implementation of this whole WQIP would be led by NQ Dry Tropics, the success of the plan will heavily rely on the maintenance, and in some cases establishment, of collaborative partnerships in the region. The main enabling actions, estimated annual costs, lead agency and partners are identified in Table 6.4. An indicative summary budget is also presented.

In deriving these estimates it is assumed that:

1. In the next five years management efforts will aim to achieve the following:

i. **Sugarcane:** 75 per cent adoption of B class nutrient management practices by 2020; requires shift of approximately 50 per cent of area in D or C class practices):

- fertiliser application rates in accordance with the 6ES Guidelines moving towards for management zone yield potential and sub-surface application;
- herbicide practices that primarily rely on knockdown herbicides and application using hooded/banded sprayers; and
- install instrumentation in furrow irrigation systems to improve irrigation efficiency, reduce tailwater losses and support automation of irrigation timing and rates.

ii. **Grazing:** 50 per cent adoption of A or B class hillslope, streambank and gully management practices by 2020; requires a shift of approximately 30 per cent of area for pasture management, 25 per cent of the area for streambank and gully management):

- matching stocking rate to forage availability and long term carrying capacity for land condition, managing grazing distribution by land type and watering points, pasture management (e.g. spelling);
- management of major watercourses, riparian zones and frontage country through fencing and off-stream watering points. Fencing has been costed for 25 per cent of waterways in the Bowen Broken Bogie and Upper Burdekin catchments at \$15,000 per km (Bartley et al. 2014c). Additional fencing has not been costed into the Lower Burdekin as it is understood that many of these areas have been fenced where practical; and
- restriction of stock access (and timing and access) to 25 per cent of gullied areas in the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin catchments. The cost ranges between \$2,000 to 10,000 per km (Wilkinson et al. 2015) but a figure of \$9,000 per km was allocated uniformly. Additional works will be required to target soil erosion from the worst gullies in priority areas (largely within the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin grazing lands). This will require large scale gully remediation works which vary in cost between locations (see Wilkinson et al. 2015). There is no additional allocation included in the budget as further evidence is required to target these areas, and this gully allocation should be distributed to target the most cost effective options. In addition, significant investment has recently been committed to these actions through Reef Trust and NESP.

iii. Horticulture depends on crop, but generally:

- cultivation, tillage and ground cover management;
- fallow management through cover crops;
- fertigation, variable rates and timing based on crop growth stage;
- targeted application of herbicides; and
- whole of farm runoff filtered via traps and buffers.

2. There will be funding to support the strategic installation of recycle pits in the BRIA at sites to be identified (drawing on the results of Shannon and McShane, 2013) (up to \$5 million), and that 5,000 hectares of sugarcane area will adopt advanced irrigation techniques (such as drip irrigation, low pressure overhead irrigation or high efficiency furrow irrigation) at a cost of approximately \$5,000 per hectare (\$25 million).

3. The level of investment in grain crops will be maintained to similar levels as previous investment.

4. That there will be more extension support and a level of financial incentives to support farmers and graziers to adopt best management practices.

5. That there will be sufficient skills and capacity to increase the extension services in the region across all industries, or that external funding will be provided to support training.

6. That there will be increased monitoring and evaluation at smaller scales to support the extension effort.

7. That a Lower Burdekin Floodplain Action Plan will be developed to guide strategic investment in the Region over the next 10 years. The system repair projects could be similar in scale to the existing projects in the region (see Section 5.7.2).

8. That the progress made in pollutant load reductions will contribute towards the catchment-specific pollutant load targets for the WQIP (Section 4.3.2) which are considered to take at least 10 years to achieve. This is due to time lags between on-ground management and improved water quality, but also realistic levels of capacity being available to implement actions in shorter timeframes. This progress would be dependent on continued improvement of the definition of best management practice systems, and implementation of large scale remediation works in grazing lands.

Table 6.4. Summary of indicative costs to implement the Burdekin WQIP over the first 5 years, 2016-2020. Note that these cost estimates factor in likely in-kind contributions equivalent to government investment for practice change actions based on previous incentive programs. No in-kind contributions are factored in for restoration or remediation programs.

Item	Description	Cost estimate per annum	Total Estimate over first 5 years (\$)	Lead agency and partners
ENABLING ACTIONS TO SUPPORT DELIVERY & IMPLEMENTATION				
Leadership	Overall responsibility for oversight of WQIP implementation including: - Overall project coordination - Undertake mid-term review of WQIP - Lead funding proposals - Maintain stakeholder networks 0.4 FTE plus operating	60,000	300,000	NQ Dry Tropics
Governance	In partnership with the Australian government, Queensland Government and industry, ensure implementation of the priorities and strategic engagement with the local community is well coordinated between partners. 4 x 1 day meetings	5,000	25,000	NQ Dry Tropics to coordinate
Project management and delivery and monitoring	Program Managers to supervise overall project management, coordination, external contracts and partnerships. 3FTE plus operating	350,000	1,750,000	NQ Dry Tropics and delivery partners

Item	Description	Cost estimate per annum	Total Estimate over first 5 years (\$)	Lead agency and partners
Communication and Engagement	Lead program communication and engagement activities including: - Develop a Communication and Engagement Strategy for the implementation of the Burdekin WQIP and annual work plans. - Develop science communication products. - Encourage community participation in activities e.g. citizen science programs, seminars to educate the community. - Hold stakeholder tours to highlight work sites, project outcomes and best management practices. 1FTE plus operating	160,000	800,000	NQ Dry Tropics and delivery partners
Technical synthesis of supporting knowledge	Overarching technical synthesis of the key messages and outcomes arising from the combined research and monitoring outputs. 0.2 FTE plus operating for technical workshops	50,000	250,000	Technical Group
DELIVERY & IMPLEMENTATION				
Urban				
Urban investigations and planning	Facilitate improved understanding of the nature, extent and location of future urban development and the capacity of runoff implications to be managed by development guidelines and local government processes. 0.2FTE plus operating	35,000	175,000	Collaborative position between NQ Dry Tropics and Councils

Item	Description	Cost estimate per annum	Total Estimate over first 5 years (\$)	Lead agency and partners
Sugarcane				
Shifting 50 per cent of sugarcane areas currently in D or C class practice for nutrient and pesticide practices (excluding recycle pits) to achieve 75 per cent adoption at B class practice	Refer to Section 6.1.2. Sourced from Smith (2015). Note that these costs already factor in farm profit. <i>The original cost estimate of \$45 million over 5 years was halved as these are likely to be achieved with matching in-kind farmer support.</i>	4,500,000	22,500,000	NQ Dry Tropics, Australian and Queensland Government and industry partners
Additional irrigation runoff management including shifting an additional 5,000ha to B class irrigation or strategic installation of recycle pits - <i>indicative only, further site specific assessment is required.</i>	Sourced from the INFFER workshops, see Roberts et al. (2016).	6,000,000	30,000,000	NQ Dry Tropics, Australian and Queensland Government and industry partners
Sugarcane extension	11 FTEs @\$150k/year, 1 FTE/50 growers ¹ Sourced from the INFFER workshops, see Roberts et al. (2016).	1,650,000	8,250,000	NQ Dry Tropics, DAF, BPS, Farmacist, BBIFMAC, industry partners
Demonstration projects to support extension	12 sites @ \$20,000 per site (operating cost only)	48,000	240,000	NQ Dry Tropics, BPS, Farmacist, BBIFMAC, industry partners, Australian and Queensland Government
Grazing				
Shifting 50 per cent of grazing lands in the region currently in D or C practice to B class pasture management practices	Sourced from the INFFER workshops, see Roberts et al. (2016). <i>Note: The original cost estimate of \$125 million over 5 years was halved as these are total cost estimates (do not factor in profit) and are likely to be achieved with matching in-kind farmer support.</i>	12,500,000	62,500,000	NQ Dry Tropics, DAF, AgForce, industry partners, Australian and Queensland Government
Development of Bowen Broken Bogie Action Plan	Develop stakeholder ownership and integrated approach to guide investment in the catchment to set priorities for large scale management of soil erosion and gully remediation. Includes staff costs for development and \$20,000 per year for update and review.	36,000	180,000	NQ Dry Tropics, Australian Government, Queensland Government, industry partners

Item	Description	Cost estimate per annum	Total Estimate over first 5 years (\$)	Lead agency and partners
Shifting 25 per cent of gullied areas in grazing in the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin catchment currently in D or C practice to B gully practices. Identification of priority areas for remediation. ²	Sourced from the INFFER workshops, see Roberts et al. (2016).	8,800,000	44,000,000	NQ Dry Tropics, DAF, AgForce, industry partners, Australian and Queensland Government
Shifting 25 per cent of waterways in grazing in the Bowen Broken Bogie and Upper Burdekin catchment currently in D or C practice to B streambank practices. Identification of priority areas for remediation. ²	Sourced from the INFFER workshops, see Roberts et al. (2016).	4,100,000	20,500,000	NQ Dry Tropics, DAF, AgForce, industry partners, Australian and Queensland Government
Grazing extension	16 FTEs @\$150k/year, 1 FTE/40 graziers ¹	2,400,000	12,000,000	NQ Dry Tropics, DAF, AgForce, industry partners
Horticulture				
Shifting 50 per cent of horticultural areas currently in C or D practice to B practice for sediments, nutrients, pesticides	Sourced from the INFFER workshops, see Roberts et al. (2016). <i>Note: The original cost estimate of \$7.8 million over 5 years has been halved as these are total cost estimates (do not factor in profit) and are likely to be achieved with in-kind farmer support.</i>	776,000	3,880,000	NQ Dry Tropics, DAF, GrowCom, industry partners, Australian and Queensland Government
Horticulture extension	0.7 FTE/year @\$150k/year ¹	105,000	525,000	NQ Dry Tropics, DAF, GrowCom, industry partners
Grain crops				
Shifting to All B practices in grains	Based on previous investment plus targeted extension for soil management.	70,000	350,000	NQ Dry Tropics, DAF, industry partners, Australian and Queensland Government
System repair				
Development of Lower Burdekin Floodplain Action Plan	Develop stakeholder ownership and integrated approach to guide investment (see below) and set priorities that take into account both water use and ecosystem function. Includes staff costs for development and \$20,000 per year for update and review.	36,000	180,000	NQ Dry Tropics, QLD Wetlands Program, GBRMPA, industry partners, Australian and Queensland Government

Item	Description	Cost estimate per annum	Total Estimate over first 5 years (\$)	Lead agency and partners
Restoration of bunds and fish passage	Guided by Action Plan but preliminary cost estimate provided for modification of 10 bunds @ \$40,000 per bund and 4 fish passage structures @ \$100,000 per structure (numbers will vary depending on total costs; these are relatively small project costs).	160,000	800,000	NQ Dry Tropics, QLD Wetlands Program, GBRMPA, industry partners, Australian and Queensland Government
Stewardship payments for ecosystem services	Pilot program to provide payments to a landholder for carrying out 'stewardship services' on their land to maintain or improve natural resource values and outcomes for public good (e.g. wetland restoration).	400,000	2,000,000	NQ Dry Tropics, QLD Wetlands Program, GBRMPA, industry partners, Australian and Queensland Government
Supporting actions				
Compliance and Auditing	Auditing of financial incentive payments. - Oversee compliance in the sugarcane, grazing and horticulture industries. - Farm visits and assessment of performance against management agreements for BMP implementation and stewardship payments. - It is important to have a person that is independent from the extension and incentive programs perform a proportion of landholder stewardship compliance assessments each year. 3FTE plus operating	480,000	2,400,000	Independent
Monitoring and Evaluation	Implementation of the monitoring and evaluation program outlined in Table 8.1 including combined reporting.	1,000,000	5,000,000	NQ Dry Tropics, Australian and Queensland Governments, CSIRO and/or universities, industry partners
	Site specific real time monitoring to track paddock scale and sub-catchment changes. 20 sites @ ~\$190,000 per site	760,000	3,800,000	
Priority Research Themes to Fill Knowledge Gaps (short term)	See Section 9.	750,000	3,750,000	NQ Dry Tropics, Australian & Queensland governments, CSIRO and/or universities, industry
Total		\$45,231,000	\$226,155,000	

Notes: See assumptions above.

¹ Current effort in sugarcane is estimated to be 6.6 FTE in extension with specific water quality focus, 5 FTE facilitating / administering water quality grants and 1 FTE facilitating BMP. Current effort in grazing is estimated to be 16 FTE in extension / facilitating BMP with specific water quality focus, 7 FTE facilitating / administering water quality grants. Source: DAF as at June 2015 from data collated through discussions with NRM, industry, productivity services and government staff, based on number of FTE's operating in 2014/15. Most of the FTE's included are on temporary funding and therefore their tenure is not secure. Total costs are therefore included in this estimate.

² Priority areas should be refined at a parcel scale using the prioritisation for grazing extension recently completed by Beutel et al. (2015).

These estimates indicate that significant investment of around \$226 million over the next five years, or \$45 million per year, is required to implement the actions identified within the Burdekin WQIP.

This assumes matching in-kind investment from land holders for management practice shifts, and is approximately 25 per cent of the INFFER scenario costed to come close to the ERTs by 2025 (which did not factor in in-kind support).

It is difficult to estimate the pollutant load reductions likely to be achieved with this scenario with confidence as the assumptions regarding sediment reductions from streambank and gully erosion would be highly dependent on specific locations and climate sequences.

A more detailed implementation plan should be developed to support this WQIP and identify these areas. Greater specification of actions will enable selection of the most cost effective options. While this uncertainty is acknowledged, some indicative conclusions regarding pollutant reductions can be made. If the 2025 targets are going to be met, it would be assumed that around half of the reductions should be achieved by 2020. Simple calculations from the modelled scenarios in Section 6.1.1 indicate that the changes above would achieve at least a further 10-15 per cent reduction in end of catchment TSS loads (at least 20 per cent towards ERT), 5-10 per cent reduction in PN (at least 9 per cent towards ERT) and 20-25 per cent reduction in DIN (at least 26 per cent towards ERT). Additional gains would be made from targeting investment in the highest pollutant generation areas identified in the sub-catchment prioritisations (Section 5). The INFFER analysis and previous assessments by Wilkinson et al. (2015) show that investment in large scale gully remediation techniques is the most cost effective management option for sediment management in the Bowen Broken Bogie catchment and therefore, this should be the focus of future efforts supported by R&D over the next 3 to 5 years.

While the current 'trajectory' of meeting the targets is not in line with the expected reduction towards the 2025 targets, it is expected that the rate of improvement could be accelerated beyond 2020 with the development of increased technical capacity in the region, expanded extension programs, implementation of a large scale communication and education programs, and improved knowledge of the optimal management practices for achieving pollutant load reductions.

The introduction of other delivery mechanisms such as regulation to shift farmers and graziers from D class practices may also be beneficial as illustrated in the INFFER analysis. As noted in Section 4.3.2, efforts to reduce DIN loads must also be implemented in the Wet Tropics region to ensure that the benefits of the load reductions are realised for the GBR.

Despite the uncertainties in the estimated costs of implementation, it is certain that significant investment, delivered in a focused and coordinated way, will be required to make substantial progress towards pollutant reductions for water quality outcomes in the Burdekin Region. It is acknowledged that this level of funding is currently not within the scope of the current Australian and Queensland Government commitments however, adjustments in the current level of investment will be required if the end of catchment load reduction targets to maintain, let alone improve GBR health, are to be met.



7. What challenges do we face in the future?

7.1 A changing landscape

Population projections and agricultural expansion

Population in the region is expected to grow over the next 20 years by approximately 50 per cent (DAF, 2014). In the next decade it is likely there will be increasing populations, market driven agricultural expansion and crop changes in areas already identified as suitable in terms of landform and climate and where irrigation water is available, and hotter more variable and event dominated weather. The WQIP has not taken into account potential land use change, or the influence of economic drivers on industries in the Burdekin Region beyond the next 3-5 years.

Governments have recently invested \$17million in a Northern Australia Sustainable Futures program including strategies around the future development of irrigated and mosaic agriculture, meat processing and infrastructure to further research and support northern development. A number of opportunities have been identified for agricultural industries in the region in the Queensland Agricultural Land Audit (DAF, 2014) which may affect the scope of agricultural land use in the Burdekin in the future.

Of greatest significance, there is the biophysical potential to significantly expand sugarcane and other crops in the Lower Burdekin catchment.

In particular only a little over half of the irrigation water potentially available from the Burdekin Dam is currently allocated to users. Plans by the Queensland Government to raise the Burdekin Falls Dam spillway could add 150,000 ML in supplemented strategic reserve for particular projects in the future (part of this may be available for agriculture). The audit concludes that sugarcane is currently grown in 10 per cent of the potential sugarcane area in the region.

Potential areas for all industries have been identified within the region (reported as the Charters Towers region which extends long the coast from just south of Home Hill to just north of Ingham and west to Greenvale, Pentland and Lake Buchanan) (DAF, 2014). These areas include where the majority of current production occurs as well as where production could potentially occur (based on biophysical parameters such as agricultural land classes 'A' and 'B' slope and temperature) and are not exclusive (the same areas have been assessed for each industry). However, while there is significant potential for expansion when considering the supply side of markets, opportunities will only arise where the region is competitive in key domestic and international markets.

A case study of the Water for Bowen expansion proposal that has the potential to convert large areas of grazing lands to sugarcane in the Don catchment (Thomas et al. in review) shows that DIN and PSII herbicide loads could increase by at least threefold even with the adoption of A class management practices in all expansion areas.

7.2 Managing water quality in a changing climate

This section describes the projected influence of a changing climate on regional water quality. This includes addressing contaminant generation, exposure and transportation issues for oceans, inland waterways and groundwater. Human and ecosystem vulnerability is then discussed in the context of the management implications for projected water quality changes. More detailed and technical supporting information is available in a supporting paper (Buchan, 2015).

For this discussion the International Panel on Climate Change (IPCC) definition of climate change is used. This has been summarised as: *"Any change in averages or variability of climate properties, whether natural or human caused identified to persist for decades or longer"* (IPCC, 2014).

Statistics on past climate conditions are used as a benchmark from which to measure change over time and modelling techniques are used to make complex projections of the trends likely to be experienced in the future (usually from the present until about 2100).

Climate change is important for water quality because it may affect four key processes:

- **generation** or accumulation of contaminants at source;
- **exposure** of water to sources of contaminants;
- **transportation** or persistence of substances in water; and
- **vulnerability** of human users or ecosystems to a particular set of water quality conditions.

7.2.1 The influence of climate change on water quality

The CSIRO and BOM reporting and projections for physical changes and trends to the Monsoonal North East Sub-cluster (including the Burdekin Region) for the next 50 years (www.climatechangeinaustralia.gov.au) identify the following key points related to climatic conditions:

- scientists are very confident that average temperatures will continue their rising trend in all seasons and very hot days and warm spells (weather events of a few days to a few weeks) will become more frequent;
- it is possible that there will be significant changes in total annual rainfall, but it is not entirely clear if there will be more or less rain. Scientists are highly confident that the rain that does fall will occur in more intense events and moderately confident that there will be fewer but more intense tropical cyclones. Stronger cyclones have a longer life so fewer more intense cyclones probably means increased risk of cyclone damage;
- global atmospheric Carbon Dioxide concentrations will 'inevitably' continue to increase in coming decades and there is no indication that our region might be an exception (IPCC, 2014; CSIRO, 2015); and
- natural variability may mask or enhance long-term human induced trends for 20 years. The current climate in the Burdekin Region is naturally highly variable year to year. This makes it difficult to differentiate and clearly represent small underlying trends (signals) from within very scattered (noisy) data points. It is important to recognise the dominance of transpiration and evaporation in catchments. In Australia generally approximately 2 per cent of rainfall goes to deep drainage, 9 per cent to runoff and 89 per cent to evapotranspiration (ABS, 2008). The dominant effect on freshwater quality and the quality of runoff may not be changes in rainfall, but changes in evaporation and the drying effect driven by the predictably higher temperatures expected in the region (Roderick, M. 2015).

Table 7.1 summarises information linking climate projections for the Burdekin Region to water quality and ecosystem impacts.

7.2.2 Implications for regional water quality improvement

Human water use

Human water use in the region includes irrigated agriculture, livestock watering, drinking water supply, and mining and industrial use. The risk of increased inter- and intra- annual rainfall variability and increased evaporative losses are likely, leading to greater uncertainty of supply. This may drive the desire or need to store more water for longer periods.

For irrigated agriculture more hot, dry spells are likely to increase water demand and make soils and crops more subject to water salinity issues. Livestock watering points are likely to be more subject to prolonged ponding and evaporation. This may exacerbate water quality problems associated with mineral concentration, algal toxicity or sediment and nutrient fouling by prolonged stock concentration at water points. For potable water supplies water quality issues are expected to be minor. However, increased use of shallower and more sediment laden drought reserves may increase the costs of both pumping and treatment of town water. This may become a significant issue locally in farming locations depending on these water sources.

The implications of climate change for industrial water users are highly industry-and site-specific. However, the increased risk associated with extreme climatic events and rainfall intensity generally increases the risk of failure for wastewater storage and treatment facilities. Dust suppression is a major use of water in mining. While quality standards for this water is low it is important in preventing aerial transportation of fine particulate matter, often containing heavy metals or other contaminants into nearby aquatic systems. The volume of water needed for dust suppression is likely to increase under climate change conditions, particularly during droughts. The impact of this on surface and groundwater hydrology may have significant secondary effects on local water quality.

The perception of coal mining as a significant global contributor to climate change is likely to have significant implications for the prospects of future coal mining in the region.

Proposed coal mining poses significant risks to water quality in the Belyando, Suttor and Bowen Broken Bogie catchments, however, it is possible that those risks may be avoided or mitigated by current regulations, environmental impact assessments and possibly a reduced rate or scale of open cut coal mine development in the next few decades.

Terrestrial ecosystems

Climate impacts on terrestrial vegetation cover may include:

- natural ecosystem structural changes including changes to species mix and dominance, and woodland thickening;
- increased susceptibility of riparian areas and loss of '3P' perennial grasses in drought conditions. Drought conditions are associated with eight major land degradation events across Australia since 1890;
- changes in burning patterns both from uncontrolled events, and from climate mitigation and wildfire risk management;
- changes to commercial imperatives for agricultural and livestock management practice including changes in vegetation clearing, pasture improvement, weed management and agricultural crop switching;

Table 7.1. Summary of evidence of the potential impacts of climate change on water quality in the Burdekin Region.

Environment	Change	Scale	Confidence	Impact	Evidence
Oceans	Average sea level rise	4mm/yr and increasing	Very High	Loss of beaches, mangroves & coastal wetlands. Increased bund walls affecting wetland dynamics.	CSIRO, (2014) WMO, (2015)
	Larger & more intense cyclones and associated river discharge	Events may occur annually Local and regional freshwater plumes Larger local runoff events	High	Coral & seagrass physical damage. Flood plumes larger in extent, greater risk from poor water quality. Potentially more maintenance dredging & shipping impact risks. Freshwater may bleach coral, increase susceptibility to other stressors.	GBRMPA (2014a)
	Ocean pH	Decrease 0.02pH units/yr	Locally uncertain Globally High	Within 25 years most Corals and Molluscs will not be able to form skeletons / shells	WHOI (2013) IPCC (2014)
	Increase sea surface temperature	Increase area and frequency of high temperature events of surface water >26°C	Locally high Globally Very High	Coral bleaching and stress. Disruption of synchronised spawning events.	Hobday & Hartog (2012).
Catchments	Average temperature rise	1-4°C in 85 years	Very High	More intense rain, higher evaporation, higher fire risk, more intense drought, more frequent flooding events.	CSIRO (2014).
	CO2 'fertilisation' of vegetation	Increased growth rate some plants	Uncertain	Only relevant in moisture surplus environments, rainforest and irrigated agriculture.	Webb et al (2012).
	More intense flooding	7% more moisture can collect in air per 1°C temp. Rise.	High	More severe gully and stream channel erosion. Greater capacity to transport pollutants downstream.	Wilkinson et al. (2015) Brodie, J. pers. comm. 2015
	More severe drought	Undefined	High	Higher fire risk and reduced vegetation cover, more erosion.	CSIRO (2014).
	Changed rainfall patterns	Increased variability, quantity & direction	High, Unknown	Possible change to tree & perennial grass cover. Will affect wind and water erosion	Dougall, C. pers. com. 2015
	Surface water temperature increases	Ponded or slow flowing waters subject to temp. Stratification. farm homestead, urban and livestock water supply dams.	Moderate	Favour phytoplanktonic or floating macrophytic production over rooted macrophytes changing light, nutrient, oxygen and pH dynamics. Potentially more toxic cyanobacterial algal blooms.	Australian Government (2015b)
Ground water	Changed aquifer recharge	Quantity & direction	Unknown	Found to be unpredictable elsewhere and driven by vegetation impact.	CSIRO & SKM (2010)
	Capillary rise	Shallow unconfined <3m mostly alluvial. Belanyo-Suttor and Lower Burdekin	Low	Drying and salinisation of wetlands / Groundwater dependent ecosystems	Costelloe et al. (2009) Overton et al. (2006)
	More variable hydrology	Shallow groundwater in costal and alluvial aquifers	Low - Moderate	Acid release from sulphate soils	Fitzpatrick and Shand (2008)

- woody vegetation dieback from severe droughts or destructive cyclonic winds; and
- runoff affected by frequency and intensity of wet season rainfall events.

The scale and relative significance of these processes for either event or long term pollutant loading of the rivers is not currently clear from research of the Burdekin Region, but historic records of past weather events leading to sediment losses from the Burdekin region found in coral cores in the Palm Islands and stretching back several hundred years would suggest that the predicted climate changes of extended dry periods followed by extreme rainfall will lead to significant flooding, erosion events and water quality decline in the Burdekin region (McCulloch et al. 2003).

Freshwater ecosystems

Many waterways in the Burdekin Region are already highly hydraulically dynamic due to extreme seasonality and spatial gradients of rainfall. Natural ecosystems already reflect this variability in their structure and biological function, and many have already been substantially modified (see Section 5.7.4).

In the space of a few decades climate change is unlikely to generate large scale changes to natural freshwater systems. However, it is clear that there will be a shift towards ecosystems characterised by more hydraulic variability. This makes it particularly important to recognise the dependence of systems on dry period 'permanent water' refuges, springs and groundwater recharge areas.

These are characteristically deep holes, springs, high altitude rainforest areas along coastal ranges such as Paluma and Mt Elliott or may be manmade water bodies such as dams and weirs. Managing these freshwater refuges to avoid mass deaths of populations of freshwater species will involve special consideration of water quality including the effects of chemical or thermal stratification and dissolved oxygen levels.

Increases in sediment loading of the rivers due to increased erosive capacity may lead to increased risk of smothering or relocation of species in deep water refuges upstream of major dams by mass in-channel bedload movement. Major flood events are known to have stripped soft sediment and riverine vegetation from river beds and banks leaving a 'rock armoured' surface in one location and new floodplain alluvial deposits in others (Baggs et al. 2015). Climate change projections suggest that this sort of structural disruption is likely to be increasingly common in the region's freshwater ecosystems.

Coastal aquatic ecosystems

The structure and function of coastal wetlands, estuaries and swamps are characterised by complex and dynamic interactions between fresh and marine water sources of different quality in the zone between low tide and a few meters above the high tide elevations. These systems are characteristically shallow (usually <2m) which makes local water quality conditions sensitive to surface effects such as heating, evaporation, wind mixing and groundwater interaction. Climate projections for sea level and storm surge increases, heat waves and stronger winds link directly to these coastal system vulnerabilities (Johnson and Marshall, 2007). Little research has been done on how these climate effects might play out in specific locations in the Burdekin Region.

Given the dynamic nature of beach and rocky shoreline habitat projected mean sea level changes may appear to be small and gradual with respect to species using these habitat areas. However, the vulnerability of beaches to erosion due to greater cyclone and storm intensity is of concern GHD (2012). Urban development and established cropping areas adjacent to beaches will prevent inland migration of beaches and coastal wetlands. Coastal erosion may also increasingly impact near-shore water quality condition (Department of Climate Change, 2010; Johnson et al. 2013).

It appears likely that during this century the increases in storm surge and wave turbulence will be of larger magnitude than progressive increases in sea level (Department of Climate Change, 2010). However, this is yet to be clearly quantified for local environments. If this assertion is correct, the key climate implications for shallow marine environments will be increased event-driven mobilisation of bottom sediment and eroded sediments. The potential implications are negative for the growth of seagrasses, near shore corals and dependent ecological communities and species. In turn, any loss of seagrass may facilitate mobilisation of shallow marine sediment during storm events. Importantly, the implications for coral reefs and seagrass include interactive (synergistic) effects of poor water quality from climate enhanced human land activities and the direct effects of climate change (Johnson et al. 2013).

Potential cumulative system responses

Climatic implications for water quality improvement are diverse and complex in that they involve feedback and inter-dependent processes. Management objectives must move from single parameters and areas, to discussion of system integrity and resilience with respect to overall values (Walker and Salt, 2006). For example, with respect to GBR ecosystems and potential climate influences, cumulative impacts may include:

- the increased susceptibility of corals to bleaching from warmer water when nutrient concentrations are higher (Wooldridge et al. 2009; Uthicke et al. 2012) and during periods of weaker ocean currents;
- increased incidence of coral disease in the presence of both poor water quality and warmer water (Haapkyla et al. 2011);
- combined effects of PSII herbicides and warmer water on corals (Negri et al. 2011); and
- combined effects of warmer water and more turbid water on corals (Pollock et al. 2014).

Individual species respond to the combination of stressors experienced simultaneously and thrive or survive depending on their overall resilience and tolerance of the suite of environmental conditions they experience (Uthicke et al., 2015).

Key system responses to climate change over the next few decades are likely to include:

- a loss of live coral cover due to increased temperature bleaching events, pH and cyclone mechanical damage;
- an increased total catchment pollution loads due to changes in vegetation, runoff variability and fire effects;
- increasingly event driven (acute) impacts with more incidents of extreme water quality values;
- reduced area and capacity of shallow marine and coastal wetlands to provide habitat for reef species;
- significant changes to agricultural and mining production approaches in the region;
- increased vulnerability of freshwater users to water quantity and quality issues; and
- loss of coral due to interactions between water quality effects (possibly increased turbidity, increased nutrients, more low salinity water in discharge events), and climate change effects (warmer water and low pH).

The capacity of the regional landscapes to moderate water quality is likely to decline with shifting climate due to:

- shallow marine and shoreline environments may be more physically damaged by storms;
- terrestrial vegetation may be more subject to fire and drought impacts;
- sediment deposition and trapping within catchments is less efficient during large runoff events; and
- ecosystems that are less diverse, productive and have a lower biomass perform diminished biological habitat functions.

The rapidly increasing scientific information and recognition of climate change issues is assisting to plan suitable climate adaptation actions. Inclusion of climate change considerations in this plan provides a more integrated approach to water quality management and the development of system resilience to retain environmental and natural resource values.



8. *How will we measure success?*

8.1 Adaptive management

An important part of the WQIP development and implementation process is the preparation of a supporting adaptive management strategy. Adaptive management is particularly appropriate in dynamic and complex systems that result in high levels of uncertainty in delivery of actions and achievement of outcomes. These characteristics typify environmental management systems, in both biophysical and socio-economic aspects, and are strong features of the GBR system (Eberhard et al. 2009).

It is important to acknowledge that the activities that are the focus of the WQIP occur within a broader socio-economic and ecological context. Other drivers, including possible land use intensification, demographic shifts, public land management and climate change will influence the elements described above and will need to be considered when addressing the key evaluation questions. Planning has a strong role in guiding and influencing the people that impact the environment through their everyday behaviour. Adaptive management needs to incorporate and reflect the human activity systems operating in the region and be designed to enable behavioural change in the relevant context.

Adaptive management involves learning from management actions, and using that learning to improve the next stage of management (Holling, 1978).

The process is started by strategic planning (the WQIP), managing the implementation process supported by a suite of targeted action plans, full review of the outputs and outcomes of the actions in 2020 supported by annual review of some indicators, learning from observation and evaluation of the results and incorporation of the lessons into the action plans and continued implementation. In some cases the learning may lead to the discontinuation of an action due to low levels of success and inability to reach targets or achieve outcomes. In reality this is not a failure of the plan, as plans are built using the best available information at the time; rather this is an example of the successful implementation of adaptive management. In terms of the overall plan this may lead to a revision of 'unrealistic' targets, investigation of innovative options or the creation of a totally new area of focus.

8.2 Water quality monitoring and modelling

Changes in water quality as a result of catchment management actions are only likely to be measurable at the smaller sub-catchment/land use scale in the shorter term (several years). Determining a change/trend in end of river catchment loads due to management within the catchment through the general "catchment noise" is not feasible, due to factors such as long time lags in the system, large inter and intra annual variability, rainfall intensity and distribution (Stow et al. 2001; Osidele et al. 2003 in Bainbridge et al. 2008b). As a result, a coupled monitoring and modelling approach is required. The extent of system "noise" will also vary depending on what water quality parameter is the focus, eg. sediment lag times will be significantly longer than reductions in dissolved inorganic nitrogen through reductions in fertiliser application. Pesticide concentrations in waterways as a result of management actions may be reduced within 1-2 years.

For this reason the most effective form of monitoring to determine improvements in water quality at the end of catchment will be long term and strategically focused. Short-term improvements may be detected through a well-planned program based around 'isolated' reaches and water bodies associated with small sub-catchments and relatively uniform land uses. Without this level of specificity there are too many variables and too much background 'interference' to derive any meaningful cause and effect information from water quality monitoring.

This Plan's monitoring and evaluation program should build on the framework of the Paddock to Reef Program, but it will require a dedicated role to ensure that the regional program is tailored to the needs of evaluating the actions in the WQIP or supporting action plans. The proposed integrated monitoring program should link with the Reef 2050 Integrated Monitoring and Reporting Program and includes four categories:

1. **Practice change:** Socio-economic indicator and practice uptake auditing and monitoring.
2. **Effectiveness of works:** Assessing the effectiveness of management actions by local research and regional modelling.
3. **Water quality and ecosystem health outcomes:** Freshwater, coastal and marine ecosystem health monitoring. Marine receiving waters incorporate inshore, midshelf and offshore monitoring locations.
4. **Enabling Actions:** Engagement, knowledge and empathy with issues.

The objectives, recommended indicators, opportunities for alignment and utilisation of existing programs, resources and gaps / future needs are outlined in Table 8.1.

Table 8.1. Summary of monitoring and modelling objectives, indicators, existing programs and gaps to support the Burdekin WQIP. *Note: Funding for the Paddock to Reef program is currently committed to 2018.*

Objective	Indicators	Existing Programs / Data Source	Recommended reporting frequency
1.PRACTICE CHANGE:			
Management action monitoring - agriculture	Adoption rates of management actions at a basin scale by industry in terms of level, percentage of participation and area of land.	Paddock to Reef program Management practice adoption monitoring program (NQDT, DAF) Reef Rescue water quality grants database (NQDT) Landholder surveys (NQDT / BPS)	Annual
	Landholder engagement in water quality grants programs	Reef Programme water quality grants database (NQDT, industry)	Annual
	Participation in training and extension programs	Reef Programme water quality grants database (NQDT, industry)	Annual
	Stocking rates Grass cover and biomass/pasture condition Tree cover	Paddock to Reef program Land Condition monitoring (DSITI)	Seasonal
	Riparian vegetation and wetland condition	Paddock to Reef program Land condition monitoring (DSITI) Paddock to Reef program Wetland condition and extent monitoring program (DEHP, DSITI)	Every 4 years
Monitoring management practice surrogates	Fertiliser and pesticide use	Reef Programme (NQDT, industry)	Annual
	Spatial analysis of land use change	SLATS (DNRM)	Every 5 years
Testing effectiveness of management practices	Field studies to quantify the water quality outcomes of particular management practices under a range of scenarios	Various R&D projects Paddock to Reef program case studies including gully remediation	One off studies that cover full crop cycle (where relevant) or longer term to assess grazing management response (5-10 years)
Monitoring landscape context (eg. climate)	Recording significant climatic events eg. drought and flood	P2R Report Card context (Office GBR) Bureau of Meteorology data	Annual
Monitoring socio-economic context (eg. profitability)	Costs of management practice change including opportunity costs and transaction costs	Reef Programme Game Changer, Project Catalyst Past studies: Smith (2015); Star et al. (2015); van Grieken et al (2010); Poggio et al (2014); Thompson et al. (2014b). Limited ongoing work.	Undertaken as part of field based assessments as needed
Management action monitoring - urban	Actions to be identified in consultation with local government		Annual
Testing effectiveness of management actions	Assess benefits and costs of measures to reduce urban water quality impacts, including water sensitive urban design and retrofitting options.		One off studies

Objective	Indicators	Existing Programs / Data Source	Recommended reporting frequency
2. EFFECTIVENESS OF WORKS			
Freshwater water quality	Groundwater monitoring	DNRM (2015); currently limited monitoring Various projects by researchers as project funds are available. Previous studies: Maughan et al. (2007); Lymburner and Dowe (2007). No ongoing monitoring. DSITI reports extent in Paddock to Reef program	Ambient and event
	Instream water quality monitoring.		
	Freshwater condition assessment.		
	Riparian condition assessment		Every 5 years
Paddock Scale Monitoring/Research	Property scale water quality monitoring to measure the impact of particular management practices. Input into catchment scale modelling that is specific to land use/land types in the Regions.	Paddock to Reef program Paddock scale monitoring sites (2 sugarcane) (QDAF, industry, NQ Dry Tropics, TropWATER)	One off studies to cover full crop cycle in cropping (if relevant) and longer term (at least 5 years) for grazing management response
Sub-catchment	Sub-catchment scale water quality monitoring to measure the longer term changes in water quality as a result of changes in land management practices and the impact of varying land uses. Input into catchment scale modelling that is specific to land use/land types in the region.	Paddock to Reef program GBR End of Catchment Loads program (DSITI, NQ Dry Tropics) e.g. Turner et al. (2013); Garzon-Garcia et al. (2015); Wallace et al. (2015).	Ambient and event
Whole of catchment	Monitoring of water quality at end of catchment sites. Modelling to estimate end of catchment pollutant loads to enable load calculations to assess progress against basin end of catchment targets	Paddock to Reef program GBR End of Catchment Loads program (DSITI, NQ Dry Tropics); e.g. Turner et al. (2013); Garzon-Garcia et al. (2015); Wallace et al. (2015). Paddock to Reef program Source Catchments modelling program (DNRM) e.g. Dougall et al. (2014); Waters et al. (in review)	Ambient and event monitoring Modelling could be reduced to every 2 years
Estuarine and marine	Water quality monitoring in inshore waters (i.e. within 20 km of the coast) of the GBR to assess long-term change in the concentrations of key biophysical water quality indicators.	Paddock to Reef program Marine Monitoring Program (AIMS, TropWATER, CSIRO); e.g. Thompson et al. (2014a); Devlin et al. (2014); McKenzie et al (2010, 2014, 2015); Coppo and Brodie (2015)	Ambient and event
River plumes	Water quality monitoring in river plumes to determine the composition of the material being transported in flood events to the inshore GBR, pollutant processing and comparison with GBR WQ Guidelines.	Paddock to Reef program Marine Monitoring Program (TropWATER) e.g. Devlin et al. (2014)	Event
3. WATER QUALITY & ECOSYSTEM HEALTH OUTCOMES			
Pressures and drivers	Cyclonic activity Sea Surface temperature Wind	Paddock to Reef program Marine Monitoring Program	Seasonal or events

Objective	Indicators	Existing Programs / Data Source	Recommended reporting frequency
Freshwater ecosystem health monitoring and assessment			
Status and trends of the health of freshwater and coastal wetlands	Freshwater instream biota and fish (indicators to be defined)	No regional program exists.	Annual
	Wetland extent and condition assessment	Paddock to Reef program Wetland Program (DSITI and DEHP)	Annual
	Estuarine and wetland (freshwater and coastal) ecosystem condition and connectivity Include modelled metrics for the high profile and high value species e.g. Mangrove Jack. Selected species are in essence surrogates for overall freshwater and marine biomass improvement.	No regional program exists.	Every 2-5 years
	Assessment of coastal ecosystem health indicators such as extent (e.g. salt marsh, mangroves), hydrological connectivity (to be defined)	GBRMPA, Queensland Wetland Program (DEHP & DSITI)	Annual
Receiving Waters Ecosystem Health Monitoring and Modelling	Link with Reef 2050 Plan, for example:		
Status and trends of the extent and health of mangrove communities	Inshore mangrove monitoring – mapping and assessment.	Queensland Wetland Program (DEHP and DSITI) Mangrove Watch (TropWATER)	Every 5 years
Status and trends of the extent and health of seagrass communities	Inshore seagrass monitoring – mapping and habitat assessment, plant reproductive and tissue nutrient status within seagrass beds.	P2R Marine Monitoring Program (GBRMPA, DAFF); McKenzie et al. (2015) TropWATER, Port of Townsville	Seasonal
Status and trends of the health of coral reef communities	Inshore coral reef monitoring – cover and diversity, demography and recruitment.	Paddock to Reef program Marine Monitoring Program (AIMS and others) e.g. Thompson et al. (2013, 2014a)	
Status and trends of the health of estuarine, coastal and marine fish communities	Fish population assessments – abundance and diversity of population relying on catchment and reef connections.	No specific program exists.	Every 5 years
4. ENABLING ACTIONS / STAKEHOLDER ENGAGEMENT			
Monitoring of socio economic indicators	Link with Reef 2050 Plan, for example:		
	Population and population projection	ABS Census Data	Every 5 years
	Economic and financial values of the GBR and catchments	No specific program exists. Various projects by researchers as project funds are available, e.g. Marsden Jacob Associates (2013), Thomas and Brodie (2015)	Every 5 years
	Community and visitor perceptions of the GBR	No specific program exists. Previous studies: Stoeckl et al. (2014)	Every 5 years
Knowledge and understanding of issues			
Stakeholder and community engagement	Surveys to benchmark and track knowledge and attitudinal change	No specific program exists. Previous studies: NQ Dry Tropics Landscape Resilience project (surveys to record changes in attitudes and behaviour change).	Every 2-5 years

8.3 Knowledge gaps and research needs

The development of the WQIP has highlighted many of knowledge gaps to be addressed by further research and investigation. As these gaps are addressed, improved knowledge and understanding will need to be integrated into monitoring and evaluation activities as appropriate.

The Plan identifies relationships between elevated pollutant loads on the condition and function of key ecosystem elements (e.g. seagrass, coral reefs, turtles and cetaceans, fish and bird populations), along with the supporting ecosystem processes. However, there are still substantial aspects of these relationships that require better understanding to guide management decisions. It is essential that the knowledge underpinning the anticipated cause- and effect relationships in the program logic is improved.

Knowledge gaps considered critical to improvement of the plan and the effectiveness and efficiency of its implementation include improved understanding of:

- **Ecosystem condition and recovery:** Cause and effect relationships between elevated pollutant loads and the condition and function of key ecosystem processes and elements (e.g. seagrass, coral, turtles, cetaceans, fish and birds). Ecosystem recovery from climate impacts, bleaching and reduced pollutant levels. Recovery from episodic events such as floods which may allow a derivation of event based stress – magnitude, duration and frequency.
- **Pollutant sources and ecological linkage:** Sources of pollutants and factors impacting on extent, condition and function of the asset area. This is needed to better link management options to outcomes with respect to effectiveness, reliability, feasibility and coverage.
- **Catchment and Industry management:** Catchment hydrology, and the relationship between management practice and water quality, bio-economic modelling. Urban planning, mining hydrology and pollutant impacts, intensive agriculture and processing opportunities and water infrastructure design and use for water quality outcomes.
- **Delivery and implementation:** The most effective delivery options for water quality improvement which requires good understanding of landholder behaviour, barriers to adoption and cost benefit analysis of management options.

These are presented in Table 8.2 to Table 8.5 and should also link with the Reef 2050 Integrated Monitoring and Reporting Program.

Table 8.2. Research priorities for understanding ecosystem condition and trend and recovery.

Major aim	Specific action	Review of previous studies
Improve understanding of the response of key marine ecosystem components to poor water quality and the value of ecosystem services.	• Refine the hydrodynamic modelling associated with the assessment of river discharges to the COTS outbreak initiation zone and the contribution of Burdekin Region river discharges to this area. • Development the framework to assess ecosystem services in the region, and influence of poor water quality on these values. • Investigate recovery and additive/ synergistic effect of multiple pollutants and freshwater.	Petus et al. (2014) Brinkman et al. (2014)
Seagrass condition and extent.	• Undertake further monitoring of the distribution and condition of seagrass habitats across the whole Burdekin marine Region.	McKenzie et al. (2014, 2015) Petus et al. (2014)
Coastal and estuarine ecosystem health assessments.	• Extend habitat assessments beyond coral reefs and seagrass to include wetlands, mangroves, estuaries and non-reef ecosystems, and particular species of fish, cetaceans and marine mammals. Improve understanding of ecosystem function, in particular the role of wetlands in water quality improvement and productivity.	Coppo and Brodie (2015)
Refine understanding of ecology and distribution of endemic freshwater fish species.	• Conduct targeted surveys to determine the distribution of endemic aquatic species such as fishes and turtles, particularly within impacted catchments.	
Evaluate condition of remnant palustrine wetlands; an ecosystem type that has been severely impacted in the Burdekin and plays an important ecosystem function.	• Undertake habitat assessments of remaining palustrine wetlands to determine their condition and ecosystem functionality. Include analysis of satellite imagery to identify wetting and drying regimes to establish the patterns of natural regimes.	Paddock to Reef Program DEHP Walking the Landscape Queensland WetlandInfo
Assess current and predicted future impacts from climate change on key asset values.	• Review current monitoring approaches to ensure these impacts can be adequately considered in future implementation and evaluation activities. • Improve understanding of the potential impacts of more frequent extreme events on asset values and recovery.	Review BoM data and CSIRO climate change predictions relative to Great Barrier Reef

Table 8.3. Research priorities for refining pollutant sources and ecological linkages.

Major aim	Specific action	Review of previous studies
Refine knowledge of the relative importance of particulate nutrients in driving ecological responses in the GBR.	Investigate primary sources of particulate nutrients, delivery pathways and bioavailability in the marine environment.	Brodie et al. (2015)
Improve understanding of risks to key ecosystem components from declining water quality, extended into freshwater, coastal and marine ecosystems.	- Scope the availability of, and acquisition of, more consistent temporal and spatial data for all water quality variables (including those not included in the most recent assessment such as phosphorus and particulate nutrients) and their ecological impacts to enable improved classification in terms of ecological risk and application of a formal risk assessment framework (which includes assessments of likelihood and consequence). - Recognise principles for protection of high value (low risk) areas in a revised regional risk assessment.	Waterhouse et al. (2015)
Improve understanding of the relative risk to different asset areas and values.	Refine the ability to link marine relative risk to end of catchment loads including improved techniques for defining zones of influence for each river. Expand scope of previous assessments to incorporate freshwater systems, coastal wetlands and mangroves.	Waterhouse et al. (2015)
Improve understanding of relationship between changes in water quality and ecosystem responses and recovery.	Review the appropriateness and adequacy of Reef Plan, Reef 2050 Plan and Ecologically Relevant Targets for maintaining and improving asset values.	Brodie et al. (2016)
Assess potential impacts of agricultural expansion in the region.	Model the implications of several agricultural expansion scenarios in the region in the context of pollutant loads.	Thomas et al. (in review)
Investigate the fate of nutrients and pesticides in groundwater in the Lower Burdekin catchment.	- Examine the fate DIN and PSII herbicides lost through deep drainage in the Lower Burdekin and establish whether these pollutants are delivered to the GBR through groundwater flow. - Quantify the capacity of the groundwater in the BRIA and Delta to denitrify nitrate.	Cook et al. (2004)
Develop a better understanding of function and processes in wetlands and waterways.	- Complete the system understanding process 'Walking the Landscape' process for priority sub-catchments to assist in the development of more detailed implementation plans. - Establish a specific program to support incorporation of system repair actions including riparian revegetation into future modelling to ensure a whole of catchment approach to improving water quality and ecosystem health.	GBRMPA (2012, 2013) Tait (2013) DEHP (2016) Walking the Landscape Queensland WetlandInfo

Table 8.4. Research priorities for improved catchment and industry management.

Major aim	Specific action	Review of previous studies
Improve understanding of catchment hydrological processes and relationships between land management practices and water quality.	• Synthesise surface and ground water quality monitoring data in the Lower Burdekin sugarcane areas. • Assess the relative contribution of DIN losses to the end of catchment in irrigation tailwater and rainfall runoff events. • Investigate the fate of pollutant losses via drainage in the Lower Burdekin catchment. Review and update modelling environment including: • Land use/constituent and process representation in Source Catchments • Integration of different paddock scale models. • Understanding of the effectiveness of practices on pollutant processes.	Review of assumptions in Source Catchments and Paddock to Reef program work for adequacy in assessing relationships between land management practices and water quality. Davis et al. (2012, 2013, 2014, 2016) Bristow (2016) Shaw (2014)
Establish smaller scale priorities for gully and streambank remediation, and the most cost effective techniques.	• Develop soil vulnerability and risk maps for high risk issues such as subsoil sodicity for difficult gully restoration. • Use high resolution imagery and site based assessments to identify the priority areas for gully and streambank and gully remediation at a property scale in the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin (East Burdekin) catchments. • Evaluate management options for gully and streambank remediation tailored to specific erosion features taking into account sediment generation rates, hydrological influences and costs.	
Establish smaller scale priorities for adoption of high efficiency irrigation techniques in sugarcane, and the most cost effective techniques.	• Use soil mapping, high resolution imagery and site based assessments to identify the priority areas for adoption of recycle pits or high efficiency irrigation techniques at a property scale in the Lower Burdekin sugarcane area.	Shannon and McShane (2013)
Continue to examine and trial management practices that reduce nutrient and herbicide losses from sugarcane areas.	Examples include: • Further innovative trials on N fertiliser application to reduce DIN (and possibly PN) loss from paddocks while maintaining crop productivity (also applies for P). • Evaluate the efficiency of recycle pits in removing DIN and PSII herbicides from irrigation tailwater. Use this information to develop design guidelines for maximum efficiency. • Examine ways to promote denitrification in the landscape (i.e. building soil microbial communities, possibility of denitrification walls, wetlands) – although note it is difficult during high flow events. • Trials on herbicide management (related to alternative herbicides and application procedures).	Numerous studies, many highlighted in this plan.
Improve understanding of the current practice in horticulture industries (vegetable and tree crops).	• Replicate approach used to assess sugar cane impacts for horticultural enterprises, including economic analysis of improved practice.	Few previous studies have been done. There will be a need for R&D if horticulture is to be better captured in terms of practice effectiveness.

Major aim	Specific action	Review of previous studies
Improve understanding of the current and potential future impacts of urban development on pollutant loads and subsequent water quality impacts.	• Assess benefits and costs of measures to reduce urban water quality impacts, including water sensitive urban design and retrofitting options. • Investigate likely future extent of peri-urban development and implications for achievement of WQIP targets and objectives. • Ongoing identification of opportunities for re- zoning land uses to minimise the risk of water pollution or need for hard infrastructure. • The bio-physical characteristics of waterways within and passing through urban environments • Community participatory research to establish simple water body specific objectives, management plans and governance. • Event based monitoring and modelling of stormwater discharges under local conditions. • Scoping study on emerging pollutants (including various pesticides, pharmaceuticals and personal care products from the Cleveland Bay STP to assess their risk in the Burdekin Region.	Buchan (2016) Gunn (2014) Marsden Jacobs Associates (2013) Urban efforts need to be able to be linked with agricultural sources through catchment modelling.

Table 8.5. Research priorities to improve delivery and implementation.

Major aim	Specific action	Review of previous studies
Improve understanding of landholder behaviour and barriers to adoption of improved management practices.	• Synthesise existing survey data to provide a consolidated understanding of barriers to adoption of improved management practices in sugarcane and grazing in the Burdekin Region.	Akbar et al. (2014) Coutts (2015) Rolfe and Gregg (2015) Thompson et al. (2014b)
Undertake further cost benefit analysis of management options.	• Synthesise existing knowledge of the costs and water quality benefits of priority practices and emerging practices in the Burdekin Region and identify priority gaps and limitations to full cost benefit analysis. • Establish a bioeconomic model for land uses in the Burdekin Region to incorporate: - Catchment modelling outputs and assumptions. - Economics across key contributing land uses/industries. - Extent of adoption of improved practices. • Evaluate the non-market values of the GBR and establish techniques to estimate regional contributions to the overall economic value of the GBR to assist in regional cost-benefit analysis.	
Establish smaller scale priorities for gully and streambank remediation, and the most cost effective techniques.	• Identify the priority areas for gully and streambank and gully remediation at a property scale in the Bowen Broken Bogie, Upper Burdekin and Lower Burdekin (East Burdekin) catchments using high resolution imagery and site based assessments. • Evaluate management options for gully and streambank remediation tailored to specific erosion features taking into account sediment generation rates, hydrological influences and costs.	Wilkinson et al. (2015) Bartley et al. (2014c) Waterhouse et al. (2016)

8.4 Assurance of outcomes

The science and economic analysis that underpins this WQIP has been undertaken to the best of our ability in the time available. We have used available published and unpublished information including technical expertise and local knowledge. We have engaged with many key scientists and economists involved in the collective Great Barrier Reef efforts in Queensland Government agencies, CSIRO and universities. A collaborative and participatory approach has been used and we have invited comment and review of the key component pieces of work.

Despite a large research effort being undertaken on the GBR, significant knowledge gaps and uncertainties remain. We have endeavoured to be transparent about assumptions made.

As knowledge improves, some aspects of the WQIP will change and be updated as part of adaptive management.

Adaptive management is a systematic process to improve management effectiveness by adopting an explicit approach to learning and review (Eberhard et al. 2009). In the context of a WQIP, reasonable assurance statements assess the uncertainty associated with the knowledge base around developing targets, and the capacity to deliver actions to achieve targets.

Qualitative estimates of the uncertainties associated with the major pieces of work that underpin the WQIP are outlined in Table 8.6.

Table 8.6. Estimate of the uncertainties associated with the major pieces of work that underpin the WQIP.

Topic	Issue Statement	Confidence in the data
Marine ecosystem status	Coral reefs are well mapped and current status across the region is well documented.	High
	The extent and status of seagrass beds in the region are not well mapped. There are limited locations where regular monitoring is undertaken.	Moderate
	Threats to the Reef have been well articulated through the Scientific Consensus Statement, Statement of Outstanding Universal Value and GBR Outlook Review Report 2014. However, there is high uncertainty around synergistic effects of climate change.	Moderate
	Relative risks of degraded water quality on seagrass and coral reefs are reasonably well understood. However, the influence of current ecosystem condition is not well accounted for which would provide progress towards assessing absolute risk.	Moderate
Targets	While there is good evidence of the link between pollutant loads and effects on ecosystem components, the relationship between changes in annual average loads and likely ecosystem response requires refinement as in reality, responses will be much finer scale or ecosystem-specific and influenced by other external factors. The role of PN in initiating COTS outbreaks requires better understanding for setting definitive nitrogen reduction targets.	Low-Moderate
Economic analysis	Sugarcane farm heterogeneity has been captured in size and costs. Heterogeneity relating to social factors (e.g. landholders' willingness to participate in programs and the impact on costs) has not been incorporated.	High
	Sugarcane farm profitability and cost estimates are reliable. Local expertise and work conducted in other regions was used, but significant variability in on-ground costs exist due to economic circumstances, perceptions of risk, capacity to change and other social drivers.	Moderate - High
	There is limited spatially explicit data for the economic analysis of practice change in grazing and horticulture.	Low – Moderate
	Considerable knowledge gaps remain in the ability to quantify the economic value of the natural assets and ecosystem services in the Burdekin Region, and the GBR more broadly. This affects the results of the benefit cost analysis if the economic value is underestimated.	Low
Pollutant load estimates	Modelling of land uses and constituent processes have been improved in recent years to represent local conditions.	Moderate
	Paddock and catchment scale modelling is well linked. Modellers have developed purpose built tools.	Moderate - High
Management practice adoption and effectiveness	Knowledge of the adoption of A, B, C, D practice suites is varied between industries and catchments.	Moderate - High
	The estimates of the effectiveness of A, B, C, D practice suites in modifying pollutant loads for agricultural industries are variable.	Moderate

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Appendix 1: Assessment of progress against Burdekin WQIP 2009 targets for the Burdekin Basin

Grazing land activities, outcomes & targets

RESOURCE CONDITION TARGET 1.

By 2058, attain a minimum 40% reduction in mean annual sediment load at end-of-Burdekin catchment (measured at Inkerman Bridge) from current (2008) – i.e. a reduction from approximately 3,700 kt/yr in 2008 to 2,220 kt/yr.

PROGRESS

In progress

Reduction to date = 404 kt/yr total sediment from the Burdekin Basin (~13% reduction since 2009 baseline).

The current (2013-2014) total annual average sediment load from the Burdekin Basin is estimated to be 3,183 kt/yr.

Note that additional sediment reductions are also expected as a result of the 2014-2015 investment in the region (to be reported in June 2016).

Note that the modelling platform has changed considerably since 2008, with the adoption of the Source Catchments model across all GBR catchments from 2008. The previous estimates were generated using SedNET. Source Catchments provides significant improvements in the ability to model the generation, delivery and fate of constituents and hydrology, and therefore the numbers are not directly comparable. However, the available data is presented here for reference.

RESOURCE CONDITION TARGET 2.

By 2058, attain a minimum 40% reduction in mean annual sediment load from the Belyando River Basin (measured at Mt. Douglas/Gregory Developmental Road) from current (2008) - i.e. a reduction from approximately 758 kt/yr to 455 kt/yr.

RESOURCE CONDITION TARGET 3.

By 2058, attain a minimum 40% reduction in mean annual sediment load from the Bowen - Broken River sub-basin (measured at Myuna from current (2008) by 2058 - i.e. a reduction from approximately 1,355 kt/yr in 2008 to 813 kt/yr.

RESOURCE CONDITION TARGET 4.

By 2058, attain a minimum 40% reduction in mean annual sediment load from the Cape Campaspe River Basin (measured at Taemas) from current (2008) – i.e. a reduction from approximately 325 kt/yr to 195 kt/yr.

RESOURCE CONDITION TARGET 5.

By 2058, attain a minimum 40% reduction in mean annual sediment load from the Suttor River Basin (measured at Mt. Coolon) from current (2008) - i.e. a reduction from approximately 175 kt/yr to 105 kt/yr.

RESOURCE CONDITION TARGET 6.

By 2058, attain a minimum 40% reduction in mean annual sediment load from the Upper Burdekin River Basin (measured at Sellheim) from current (2008) - i.e. a reduction from approximately 2,150 kt/yr to 1,290 kt/yr.

PROGRESS

In progress

Modelled data at the Catchment scale is current only available from 2013, and sub-catchment monitoring sites have not been continued throughout the reporting period.

Current loads are presented in the Catchment Atlas.

MANAGEMENT ACTION TARGET 1.

By 2013, attain a minimum of 40% cover (end of dry season) in all years and at least 50% cover (end of dry season) in 7 out of 10 years throughout the Burdekin rangelands.

MANAGEMENT ACTION TARGET 2.

By 2028, attain a minimum of 50% cover (end of dry season) in all years and at least 60% cover (end of dry season) in 7 out of 10 years throughout the Burdekin rangelands.

MANAGEMENT ACTION TARGET 3.

By 2058, attain minimum of 50% cover (end of dry season) in all years and at least 70% cover (end of dry season) in 7 out of 10 years throughout the Burdekin rangelands.

PROGRESS

Targets have been met

End of dry season cover (long term mean 1986-2013) = 76%

Assessment against Reef Plan Targets:

- 2009 = min. 50% late dry season cover by 2013;
- 2013 = min. 70% late dry season cover by 2018

There are 983 graziers managing 1,358,098ha of land in the Burdekin region (as at 2009).

Assessment against Reef Plan Target : 50% of graziers adopt improved management practices by 2013:

2013 Reef Plan Targets were met

Regional estimates of landholder engagement (based on number of landholders) (DPC, 2014):

- From 2009 to June 2013, 54 per cent of graziers (533) are known to have adopted improved land management practices.
- By June 2013, 70 per cent of graziers were using (A or B) practice systems that are likely to maintain land in good to very good condition or improve land in lesser condition.
- A total of 253 of the graziers who implemented improved practices completed Reef Rescue Water Quality Grants projects facilitated by NQ Dry Tropics. The Australian Government's FarmReady program supported 116 graziers (through provision of relevant training through AgForward and private sector consultants). Queensland Government extension projects resulted in management practice improvements in a further 164 grazing businesses.

To reduce hillslope erosion:

MANAGEMENT ACTION TARGET 4.

By 2013, 25 per cent (minimum) to 45 per cent of landholders undertake best management practice to control hillslope erosion in eight (8) priority sub-catchments.

MANAGEMENT ACTION TARGET 5.

By 2013, 20 per cent (minimum) to 30 per cent of landholders undertake best management practice within frontage country in all eight (8) priority sub-catchments.

MANAGEMENT ACTION TARGET 6.

By 2028, 25 per cent (minimum) to 45 per cent of landholders undertake best management practice to control hillslope erosion in all sub-catchments.

2013 Targets were met at regional scale

(note: assessment is not completed for individual priority sub-catchments)

By 2013, 26 per cent of landholders (254) were managed using best practice systems in pasture management.

By 2014, 30 per cent of grazing lands in the Burdekin Region were managed using best practice systems in pasture management (Queensland Government, 2014b).

Regional estimates of areas under improved management practices

From 2008 to 2013 (NQDT, 2014):

- 29 per cent of grazing lands (~392,000ha) were managed under changed soil practices.
- 59 per cent of grazing lands (~801,000ha) were managed under changed ground cover practices including gully erosion control.

To reduce stream bank erosion:

MANAGEMENT ACTION TARGET 7.

By 2013, 30 per cent (minimum) to 50 per cent of landholders undertake best management practice to control stream bank erosion in 10 priority sub-catchments (for stream bank erosion).

MANAGEMENT ACTION TARGET 8.

By 2028, 30 per cent (minimum) to 50 per cent of landholders undertake best management practice to control stream bank erosion in all sub-catchments.

MANAGEMENT ACTION TARGET 9.

By 2058, 50 per cent (minimum) to 70 per cent of landholders undertake best management practice to control stream bank erosion in all sub-catchments.

2013 Target was met (*note: assessment not available on priority sub-catchments only*)

By 2013, 12 per cent of landholders (116) were using best practice systems in streambank management.

By 2014, 62 per cent of grazing lands were managed using best practice systems in streambank management (Queensland Government, 2014b).

To support community (grazier) groups gain the capacity to actively and effectively engage:

MANAGEMENT ACTION TARGET 12.

By 2013, 20 per cent of landholders are involved in a community land management group.

MANAGEMENT ACTION TARGET 13.

By 2028, 50 per cent of landholders are involved in a community land management group.

2013 Target was met

Accurate figures on this involvement are not available. However, many landholders have been engaged through a range of extension workshops, training and demonstration activities as part of the Landcare Program and Reef Rescue/Reef Programme funding. In addition, the Australian Government's FarmReady program supported 116 graziers (through provision of relevant training through AgForward and private sector consultants). Queensland Government extension projects resulted in management practice improvements in a further 164 grazing businesses.

To reduce gully erosion and support sustainable land management:

MANAGEMENT ACTION TARGET 10.

By 2013, 20 per cent (minimum) to 40 per cent of landholders undertake improved management practice to control gully erosion in 4 priority sub-catchments (for gully erosion).

MANAGEMENT ACTION TARGET 11.

By 2028, 20 per cent (minimum) to 40 per cent of landholders undertake improved management practice to control gully erosion in all sub-catchments.

2013 Target was met
(*note: assessment not available on priority sub-catchments only*)

By 2013, <2 per cent of landholders (16) were using best practice systems in gully management.

By 2014, 26 per cent of grazing lands were managed using best practice systems in gully management (Queensland Government, 2014b).

Sugarcane activities, outcomes & targets

RESOURCE CONDITION TARGET 7.

By 2013, attain an 8 per cent (minimum) to 25 per cent reduction of nitrogen (nitrate) load entering the GBR from Lower Burdekin sugar lands from current (2008) - i.e. a reduction from approximately 3,000 t/yr to 2,250 t/yr*.

RESOURCE CONDITION TARGET 8.

By 2013, attain a 25 per cent (minimum) to 50 per cent reduction of pesticide (atrazine, diuron, ametryn, hexazinone) load entering the GBR from lower Burdekin sugar lands from current (2008).

RESOURCE CONDITION TARGET 9.

By 2018, reduce pesticide (atrazine, diuron, ametryn, hexazinone) concentrations in waters entering the GBR from Lower Burdekin sugar lands to below water quality objectives.

RESOURCE CONDITION TARGET 10.

By 2058, attain a 60 per cent (minimum) to 80 per cent reduction in nitrogen load entering the GBR from the Lower Burdekin irrigated cropping areas from current (2008) - i.e. a reduction from approximately 3,000 t/yr to 600 t/yr.

**Note that the modelling platform has changed considerably since 2008, with the adoption of the Source Catchments model across all GBR catchments from 2008. The previous estimates were generated using SedNET. Source Catchments provides significant improvements in the ability to model the generation, delivery and fate of constituents and hydrology, and therefore the numbers are not directly comparable. However, the available data is presented here for reference. The loads are now also reported for the Lower Burdekin Catchment.*

2013 Targets were met

Data for this period was only reported at a basin scale, therefore the results for the Haughton Basin are presented here.

Reduction to date (Haughton Basin) = 200 t/yr DIN (~29 per cent reduction since 2009 baseline) (note that this is calculated for all land uses but effort is targeted to sugarcane).

The current (2013-2014) total annual average load of DIN from the Haughton Basin is estimated to be 835 t/yr.

Data is now also reported for the whole sugarcane area for the Lower Burdekin catchment and estimated as 1098 t/yr DIN (modelled 2013 baseline).

Reduction to date (Haughton Basin) = 278 kg/yr PSII herbicide (~20 per cent reduction since 2009 baseline) (note that this is calculated for all land uses but effort is targeted to sugarcane).

The current (2013-2014) total annual average load of PSII herbicides from the Haughton Basin is estimated to be 1,500 kg/yr.

Data is now also reported for the whole sugarcane area for the Lower Burdekin catchment and estimated as 2,295 kg/yr PSII herbicide (modelled 2013 baseline).

Note that additional nutrient and pesticide reductions are also expected as a result of the 2014-2015 investment in the region (to be reported in June 2016).

There are 556 growers managing 90,000 ha of land in the Burdekin region (as at 2009).

Assessment against Reef Plan Target of 80 per cent of sugarcane growers adopt improved management practices by 2013:

Targets were not met

From 2008 to 2013, 55 per cent of sugarcane growers (306) are known to have adopted improved land management practices (Queensland Government, 2014b).

By June 2013, cutting-edge (A) or best management (B) practice systems were used by 21 per cent of sugarcane growers for nutrients, 38 per cent for herbicides and 4.1 per cent for soil (Queensland Government, 2014b).

The 306 growers who implemented improved practices completed Reef Rescue Water Quality Grants projects facilitated by NQ Dry Tropics. Of these, 166 improved nutrient management, 94 improved herbicide management, 78 improved soil management and 32 improved irrigation management. The Reef Rescue program improved management practices on over 65,000 hectares of sugarcane farm land in the Burdekin Region from 2009 to 2013.

MANAGEMENT ACTION TARGET 14.

By 2013, 16 per cent of sugar land is managed under 'Six Easy Steps' (B class management) or other innovative management regime (A class management e.g. N replacement).

MANAGEMENT ACTION TARGET 15.

By 2013, high nitrogen application rates of approximately 330 kg N/ha (plant) / 400 kg/ha (ratoon) are reduced to 190-210 kg N/ha (plant) / 270 kg N/ha (ratoon) or lower (i.e. e class management is improved to D class or better) on 11 per cent of sugar land.

MANAGEMENT ACTION TARGET 16.

By 2013, best practice herbicide management is adopted on 40 per cent of sugar land.

MANAGEMENT ACTION TARGET 17.

By 2018, best practice herbicide management is adopted on 80 per cent of sugar land

PROGRESS

2013 Targets were not met

As at 2014, approximately 10 per cent of sugarcane lands were managed using best practice nutrient management systems (Queensland Government, 2014b). Note that 6ES is now classed as 'C' class nutrient management practice.

Accurate data on fertiliser application rates is not available for the whole region.

As at 2014, approximately 26 per cent of sugarcane lands were managed using best practice herbicide management systems (Queensland Government, 2014b). management systems (ref: DPC 2014).

Other land uses

Horticulture

Assessment against Reef Plan Target of 80 per cent of horticulture producers adopt improved management practices by 2013:

2013 Reef Plan Targets were met

- From 2009 to 2013, 63 per cent of horticulture producers (120) are known to have adopted improved land management practices (Queensland Government, 2014b).
- By June 2013, cutting-edge (A) or best management (B) practice systems were used by 47 per cent of horticulture producers for nutrients, 80 per cent for herbicides and 81 per cent for soil. This was up from 45 per cent for nutrients, 80 per cent for herbicides and 77 per cent for soil in June 2012.
- All 120 horticulture producers who implemented improved practices did so with the support of Reef Rescue Water Quality Grants, facilitated by NQ Dry Tropics and the Growcom Farm Management System (FMS) program. Of these, 64 completed nutrient management projects, 21 completed herbicide management projects and 26 completed soil management projects.

As at 2014 (Queensland Government, 2015):

- Approximately 17 per cent of horticultural lands were managed using nutrient best management practice systems.
- Approximately 60 per cent of horticultural lands were managed using herbicide best management practice systems.
- Approximately 67 per cent of horticultural lands were managed using sediment best management practice systems.

Grains

As at 2014 (Queensland Government, 2015):

- Approximately 48 per cent of grain cropping lands were managed using nutrient best management practice systems.
- Approximately 91 per cent of grain cropping lands were managed using herbicide best management practice systems.
- Approximately 31 per cent of grain cropping lands were managed using sediment best management practice systems.

Appendix 2: Key legislation & policy considerations for regional water quality planning in Queensland

Legislation and policy considerations

WQIPs have had a focus on receiving waters, i.e. the Great Barrier Reef. The principal legislation relating to protection and management of the GBR is the Commonwealth *Great Barrier Reef Marine Park Act 1975* and its supporting *Great Barrier Reef Marine Park Regulations 1983* (the Regulations). The main object of this Act is to provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region.

In addition, there is a range of other Commonwealth and Queensland legislation relevant to management of the GBR. Management is also guided by Australia's obligations under relevant international conventions.

The legislation and conventions relevant to the Region are listed below:

Great Barrier Reef Marine Park legislation

Great Barrier Reef Marine Park Act 1975 is the primary Act in respect to the Great Barrier Reef Marine Park.

- *Great Barrier Reef Marine Park Regulations 1983* are the primary Regulations in force under the *Great Barrier Reef Marine Park Act 1975*.
- *Great Barrier Reef Marine Park (Aquaculture) Regulations 2000* regulate the discharge of waste from aquaculture operations outside the Marine Park which may affect animals and plants within the Marine Park.
- *Great Barrier Reef Marine Park (Environmental Management Charge–Excise) Act 1993* and *Great Barrier Reef Marine Park (Environmental Management Charge–General) Act 1999* govern operation of the environmental management charge.
- Great Barrier Reef Marine Park Zoning Plan 2003 is the primary planning instrument for the conservation and management of the Marine Park.
- The Hinchinbrook Plan of Management 2004 establishes more detailed management arrangements for specific areas of the Marine Park.

Other Commonwealth legislation

- *Environment Protection and Biodiversity Conservation Act 1999* regulates actions that have, will have or are likely to have, a significant impact on matters of national environmental significance, including responsibilities relating to fisheries.

- *Environment Protection (Sea Dumping) Act 1981* prohibits dumping of waste or other matter from any vessel, aircraft or platform in Australian waters unless a permit has been issued.
- *Historic Shipwrecks Act 1976* prohibits certain activities in relation to historic shipwrecks and relics and requires discoveries to be notified.
- *Native Title Act 1993* recognises and protects native title and includes a mechanism for determining claims to native title.
- *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* gives effect to Australia's commitments under the International Convention for the Prevention of Pollution from Ships.
- *Sea Installations Act 1987* regulates the installation of structures including tourism pontoons and power cables.

Queensland legislation

- *Coastal Protection and Management Act 1995*
- *Environmental Protection Act 1994*
- *Environmental Protection Policy (Water) 2009*
- *Fisheries Act 1994*
- *Local Government Act 1993*
- *Marine Parks Act 2004*
- Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004
- *Native Title (Queensland) Act 1993*
- *Nature Conservation Act 1992*
- *State Development and Public Works Organisation Act 1971*
- *Sustainable Planning Act 2009*
- *Transport Operations (Marine Pollution) Act 1995*
- *Transport Operations (Marine Safety) Act 1994*
- *Transport Infrastructure Act 1994*
- *Vegetation Management Act 1999*
- *Water Act 2000*
- *Workplace Health and Safety Act 1995*

International agreements

- Convention concerning the Protection of the World Cultural and Natural Heritage, 1972
- Convention on Biological Diversity, 1992
- Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973
- Convention on the Conservation of Migratory Species of Wild Animals, 1979
- Convention on Wetlands of International Importance

Especially as Waterfowl Habitats, 1971

- China–Australia Migratory Bird Agreement, 1986
- International Convention for the Prevention of Pollution from Ships, 1973
- Japan–Australia Migratory Bird Agreement, 1974
- Republic of Korea–Australia Migratory Bird Agreement,

2007

- United Nations Convention on the Law of the Sea, 1982
- United Nations Framework Convention on Climate Change, 1992

Selected relevant local plans, strategies and discussion papers

Name of the Plan	Geographic Coverage	Issues Covered	Reference, and/or document link
A Community based Natural Resource Management Strategy for the Burdekin-Bowen Floodplain Sub-Region of the Burdekin Dry Tropics 2000 Lead: BBIFMAC + other lead agencies identified in document	Lower Burdekin and Bowen	Priority resource management issues Key strategy summaries: 1. Water Management - Surface water issues, Irrigation Issues, Flooding and Drainage Issues, Ground water Issues 2. Nature Conservation - Remnant Vegetation Issues, Revegetation Issues, Fish Habitat Issues 3. Nature Conservation - Wildlife Issues 4. Nature Conservation - Wetland Issues 5. Nature Conservation - Environmental Weed issues, Feral Animal Issues, BRIA Conservation Area Issues 6. Sustainable Development and Land Use - On Farm / Property Practice Issues 7. Sustainable Development and Land Use - Production Sustainability Issues 8. Sustainable Development and Land Use - Sustainable Development Issues	Burdekin Bowen Integrated Floodplain Management Advisory Committee, 2000 - A community based natural resource management strategy for the Burdekin-Bowen floodplain sub-region of the Burdekin Dry Tropics, Ayr, Qld.
A Community based Natural Resource Management Strategy for the Burdekin-Bowen Floodplain Sub-Region of the Burdekin Dry Tropics Appendix B Strategy Implementation Manual September 2000 Lead: BBIFMAC + other lead agencies identified in document	Lower Burdekin and Bowen	Key Strategies: • Surface water • Irrigation • Flooding and drainage • Groundwater • Remnant vegetation • Revegetation • Fish habitat • Wildlife • Wetland • Onfarm/property practice • Production sustainability • Sustainable development • Social and economic	Burdekin Bowen Integrated Floodplain Management Advisory Committee, 2000, A community based natural resource management strategy for the Burdekin-Bowen floodplain sub-region of the Burdekin Dry Tropics Appendix B strategy implementation manual, Ayr, Qld.
Business and Communication Plan 2001-2003 for the Burdekin Bowen Floodplain Community Based Natural Resource Management 2001 Lead: BBIFMAC	Lower Burdekin and Bowen	• Implementation of the BBIFMAC NRM strategy • Stakeholders' project priorities • Communication and capacity building priorities • Guidelines for evaluation and review	Musso, B & Rickert, A 2001, Business and communication plan 2001-2003 for the Burdekin Bowen floodplain community based natural resource management, Ayr, Qld.
Freshwater Wetlands of the Barratta Creek Catchment Management Investment Strategy 2007 Lead: BBIFMAC	Barratta Creek Catchment	Management needs and recommended strategies: • Water resources • Woody weeds • Fire regime • Grazing regime • Nature conservation • Traditional owner NRM • Public access and recreational use • Strategy implementation	Econcern & Australian Centre for Tropical Freshwater Research, 2007, Freshwater Wetlands of the Barratta Creek Catchment Management Investment Strategy, Townsville.
Draft Sheep Station Creek Catchment Management Plan 2004 Lead: BBIFMAC	Sheep Station Creek Catchment	Plan not complete, chapters completed to date: Management Issues: • Aquatic weeds • Water Quality • Revegetation master plan • Remnant habitat complexes • Riparian and remnant vegetation	Tait, J 2004, Draft Sheep Station Creek catchment management plan, Ayr, Qld.

Name of the Plan	Geographic Coverage	Issues Covered	Reference, and/or document link
Guidelines for the Use of Grazing in the Management of Exotic Pasture Weeds in Wetland and Riparian Habitats 2011 Lead: Wetland Care	Coastal Floodplains of the North Queensland Dry Tropics Region	• Management/strategic grazing • Using grazing to manage dry season fire fuel loads in remnant native vegetation • Using grazing to reduce exotic pasture dominance in remnant native vegetation • Using grazing to promote native vegetation recruitment • To spell or not to spell • Type of grazing stock – ‘horses for courses’ • Lower Burdekin case studies and site investigations – key messages • Summary – grazing regime strategies & applications • Adaptive management – learning by trial (and error) • Managing wetlands within a property management planning context • Getting support for grazing based wetland management	Tait, J., 2011, Guidelines for the use of grazing in the management of exotic pasture weeds in wetland and riparian habitats, WetlandCare Australia, Ballina, NSW.
BBIFMAC Burdekin – Bowen Integrated Floodplain Management Advisory Committee Water Management Strategy Discussion Paper 3rd draft Lead: BBIFMAC		Detailed information i.e. existing data, strategies, works/ research projects needed: • Surface water issues • Irrigation Issues • Flooding and Drainage Issues • Ground water Issues	
BBIFMAC Burdekin – Bowen Integrated Floodplain Management Advisory Committee Wetland Management Strategy Discussion Paper D 1998 Lead: BBIFMAC	Lower Burdekin and Bowen	• Wetland Values • Heritage Values • Water Quality / Pollutants: • Weeds • Hydrology • Wetland Management • Protected Wetland Areas • Education and Extension	
A Community based Natural Resource Management Strategy for the Burdekin-Bowen Floodplain Sub-Region of the Burdekin Dry Tropics, For Review and Comment , Nature Conservation Strategy Part A, B, C 1998 Lead: BBIFMAC	Lower Burdekin and Bowen	Part A, B: Remnant vegetation, revegetation and fish passage issues Part C: Weeds, feral animals, BRIA Conservation Area Management Planning Issues	
A Community based Natural Resource Management Strategy for the Burdekin-Bowen Floodplain Sub-Region of the Burdekin Dry Tropics, For Review and Comment , Fish Habitat Issues Lead: BBIFMAC	Lower Burdekin and Bowen	Detailed information i.e. existing data, strategies, works/ research projects needed.	
Sub-Regional sustainable land use and development discussion papers PAPER 1.0 on farm / property practices Lead: BBIFMAC	Lower Burdekin and Bowen	Detailed information i.e. existing data, strategies, works/ research projects needed. • PAPER 1.0 On farm / property practices • PAPER 2.0 Production Sustainability Issues, impacts of further development on existing production • PAPER 3.0 Sustainable Development Issues	

Appendix 3: WQIP Technical Group Members

Name	Organisation	Role / Contribution to WQIP
NQ Dry Tropics Project team and staff		
Peter Gibson	NQDT	WQIP Coordinator
Jane Waterhouse	C2O, TropWATER	WQIP Coordinator, Water quality risk assessment, investment prioritisation
Paul Duncanson	NQDT	Water quality status & management, investment prioritisation
Alastair Buchan	NQDT	Urban and other and uses
Colleen James	NQDT	Agricultural management practices, past investment
Ian Dight		Advisory role
Project Leaders		
Jon Brodie	TropWATER JCU	Ecologically relevant targets, water quality risk assessment
Caroline Coppo	TropWATER JCU	Coastal and marine status assessment
Aaron Davis	TropWATER JCU	Agricultural impacts on freshwater systems
Michelle Dickson	Natural Decisions	INFFER analysis, NRM decision support systems
Cameron Dougall	DNRM	Source Catchments load modelling
Steve Lewis	TropWATER JCU	Ecologically relevant targets, pesticide risk assessment, pollutant analysis
Geoff Park	Natural Decisions	INFFER analysis, NRM decision support systems
Anna Roberts	Natural Decisions	INFFER analysis, NRM decision support systems
Marcus Smith	JCU	Sugarcane management practice economics
Colette Thomas	JCU	Economics values of coastal and marine areas
Donna Audas	GBRMPA	Coastal ecosystem assessment and BlueMaps
Mike Ronan	DEHP	Queensland Wetlands Program, Walking the Landscape
External experts		
Grazing management and water quality outcomes		
Rebecca Bartley	CSIRO	
Terry Beutel	DAF	
Paul Burke	AgForce	
Tim Moravek	DAF	
Peter O'Reagain	DAF	
Brigid Nelson	DAF	
Claire Rodgers	CHRUPP	
Alex Stubbs	AgForce	
Marie Vitelli	AgForce	
Scott Wilkinson	CSIRO	
Sugar cane management and water quality outcomes		
Steve Attard	Agritech Solutions	
Keith Bristow	CSIRO	
Terry Buono	DAF	
Matt Kealley	Canegrowers	
Tom McShane	BBIFMAC	
Rob Milla	BPS	
Mark Poggio	DAF	
Evan Shannon	Farmacist	
Wayne Smith	Canegrowers Burdekin	

Name	Organisation	Role / Contribution to WQIP
Horticulture management and water quality outcomes		
Scott Wallace	GrowCom	
Steve Tiley	GrowCom	
Urban management and water quality outcomes		
Chris Manning	Townsville City Council	
Mark Robinson	Townsville City Council	
Josh Dyke	Whitsundays Regional Council	
Adam Folkers	Whitsundays Regional Council	
Policy advice		
Chella Goldwin	Department of the Environment	
John Bennett	DEHP	
Rae Schlecht	DEHP	
Carla Wegscheidl	DAF	
Sean Hoobin	WWF	
Glen Holmes	WWF	
David Wachenfeld	GBRMPA	

Appendix 4: Draft local water quality guidelines (aquatic ecosystem EV) (DEHP, 2016)

Source: Department of Science, Information Technology and Innovation, Queensland (2016). Draft aquatic ecosystem water quality guidelines: Don and Haughton river basins, Mackay-Whitsunday estuaries, and coastal/marine waters (draft, 2016).

The draft guidelines in the following tables are for the aquatic ecosystem environmental value.

The following protocols are recommended for monitoring condition relative to the aquatic ecosystem guideline values (refer QWQG section 5, Appendix D for more detail):

- for the comparison of test site monitoring data against single value guidelines, the median water quality value (e.g. concentration) of a number (preferably five or more) of independent samples at a particular monitoring ('test') site should be compared against the applicable water quality guideline;
- where a range of values is provided for waters with an MD level of protection, the median water quality values of test samples is compared with the middle (typically median) value of the stated range;
- for single values specified as an annual (or seasonal) mean (rather than median) values, the mean water quality value of a number of independent samples at a particular monitoring ('test') site should be compared against the applicable water quality guideline. The sample number is preferably five or more samples for within season comparison, and five or more [preferably 24 or more over two years] samples taken during wet and dry seasons for annual mean comparisons; and
- where a range of values is provided for waters identified for HEV level of protection (e.g. total N:65-100-125), the 75 per cent confidence intervals around sampled 20th-50th-80th percentile distributions of the test site should meet the range of values. The sample number is a minimum of 24 test values over the relevant period (12 months if a continuous activity or alternatively a shorter period for activities where discharge occurs for only part of the year). For DO and pH, the test sample values should fall within the specified range.

Table: DRAFT Water quality guidelines for coastal and marine waters of the Don and Haughton coasts

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷																	
Water area/type (s1-s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
BOWLING GREEN BAY																	
BOWLING GREEN BAY SD Lower estuary/ enclosed coastal waters (s1, s2)	HEV	2-2-5 (s1)	1-4-8 (s1)	-	-	80-90-125 (s1)	1-1-3 (s1)	-	-	10-12-13 (s1)	≤1 (s1)	-	90-100 (s2)	2-4-14 (s1)	≥1.5 (s2)	≤1 (s1)	8-8.4 (s2)
BOWLING GREEN BAY Lower estuary/ enclosed coastal waters (s1, s2)	MD	≤2 (s1)	≤4 (s1)	-	-	≤90 (s1)	≤1 (s1)	-	-	≤12 (s1)	≤1 (s1)	-	90-100 (s2)	≤4 (s1)	≥1.5 (s2)	≤1 (s1)	8-8.4 (s2)
BOWLING GREEN BAY SD Open coastal waters (landward of GBR plume line) (s1, s2,s3,s4)	HEV	0-1-6 (s1, s4)	0-1-2 (s4)	8-13-20 (May-Oct) Wet:≤25 (Nov-Apr) (s3, s4)	50-70-90 (s4)	65-100-125 (s1, s4)	0-2-4 (s1, s4)	1.5-2.1-3.2 Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3, s4)	2-6-11 (s4)	8-12-20 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	60-110-320 (s4)	95-105 (s2)	≤2 (s1, s4)	≥10 (ann. mean) (s3)	0.5-1.2-2.5 Dry: ≤1.6 (May-Oct) Wet: ≤2.4 (Nov-Apr) (s1, s3, s4)	8.1-8.3-8.4 (s2)

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷												
Water area/type (s1-s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed										
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)
BOWLING GREEN BAY: All coastal waters (s1, s3, s5, s6))	All	Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. Levels specified here are derived to support the health of all seagrass species present either as the dominant species or as one of a suite of species that are known to occur in the region. It does not reflect requirements for macroalgae or other organisms. - Deep water areas (>10m): 2.5 mol m⁻² day⁻¹ over a rolling 7 day average * (Chartrand et al 2014; Rasheed et al 2014; York et al 2015) - Shallow inshore areas (<10m): 6 mol m⁻² day⁻¹ over a rolling 14 day average * (Chartrand et al, 2012) Note: # Absolute light requirements for seagrass may vary between sites. Values described here provide a conservative guide to the levels of light likely to support seagrass growth. Locally derived absolute thresholds ideally should be obtained for management of specific activities likely to impact on the light environment. Toxicants WQGs for all toxicants in these waters (except aluminium – specified below) as per GBRMPA (2010) and ANZECC (2000) water quality guidelines, to protect marine species at the HEV (99% species protection) level of protection. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted. <u>Pesticides/biocides</u> WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to): - Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L <u>Other toxicants</u> For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and other sources below: - Aluminium: <2.1 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] - Other toxicants in water: refer to ANZECC AWQG section 3.4 – ‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). Values correspond to protection of 99% of species - Toxicants in sediments: refer to ANZECC AWQG section 3.5 – ‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and ANZECC AWQG volume 2 (section 8) Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra Temperature (s3) Increases of no more than 1°C above long-term (20 year) average maximum. (GBRMPA, 2010)										
		Secchi (m)	Turb (NTU)	SS (mg/L)	pH							

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷																	
Water area/type (s1–s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
LOWER BURDEKIN COASTAL WATERS (extending up to boundary with Bowling Green Bay)																	
LOWER BURDEKIN Lower estuary/ enclosed coastal waters (s1, s2)	MD	≤2 (s1)	≤4 (s1)	–	–	≤90 (s1)	≤1 (s1)	–	–	≤12 (s1)	≤1 (s1)	–	90–100 (s2)	≤4 (s1)	≥1.5 (s2)	≤1 (s1)	8–8.4 (s2)
LOWER BURDEKIN Open coastal waters (s1,s2,s3,s4)	SMD	≤1 (s1, s4)	≤1 (s4)	≤20 (ann. mean) Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3)	≤70 (s4)	≤100 (s1, s4)	≤2 (s1, s4)	≤2.8 (ann. mean) Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3)	≤6 (s4)	≤12 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	≥110 (s4)	95–105 (s2)	≤2 (s1, s4)	≥10 (ann. mean) (s3)	≤2 (ann. mean) Dry: ≤1.6 (May-Oct) Wet: ≤2.4 (Nov-Apr) (s3)	8.1–8.4 (s2)
LOWER BURDEKIN All coastal waters (s1, s3, s5, s6)	All	Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. Levels specified here are derived to support the health of all seagrass species present either as the dominant species or as one of a suite of species that are known to occur in the region. It does not reflect requirements for macroalgae or other organisms. - Deep water areas (>10m): 2.5 mol m⁻² day⁻¹ over a rolling 7 day average [#] (Chartrand et al 2014; Rasheed et al 2014; York et al 2015) - Shallow inshore areas (<10m): 6 mol m⁻² day⁻¹ over a rolling 14 day average [#] (Chartrand et al, 2012) Note: [#] Absolute light requirements for seagrass may vary between sites. Values described here provide a conservative guide to the levels of light likely to support seagrass growth. Locally derived absolute thresholds ideally should be obtained for management of specific activities likely to impact on the light environment. Toxicants WQGs for all toxicants in these waters (except aluminium – specified below) as per GBRMPA (2010) and ANZECC (2000) water quality guidelines, to protect marine species at the HEV (99% species protection) level of protection. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted.															

Water area/type	Management intent /level of protection																
s1–s5: source for WQGs, listed after table)	DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ^{1–7} Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed <table><tr><th>Amm N (µg/L)</th><th>Oxid N (µg/L)</th><th>Partic N (µg/L)</th><th>Total Diss N (µg/L)</th><th>Total N (µg/L)</th><th>FRP (µg/L)</th><th>Partic P (µg/L)</th><th>Total Diss P (µg/L)</th><th>Total P (µg/L)</th><th>Chl-a (µg/L)</th><th>Silicate (µg/L)</th><th>DO (% sat)</th><th>Turb (NTU)</th><th>Secchi (m)</th><th>SS (mg/L)</th><th>pH</th></tr></table> Pesticides/biocides WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to): • Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L Other toxicants For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and other sources below: • Aluminium: <2.1 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] • Other toxicants in water: refer to ANZECC AWQG section 3.4 — ‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). Values correspond to protection of 99% of species • Toxicants in sediments: refer to ANZECC AWQG section 3.5 — ‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and ANZECC AWQG volume 2 (section 8) Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra Temperature (s3) Increases of no more than 1°C above long-term (20 year) average maximum. (GBRMPA, 2010)	Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
	Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷																	
Water area/type (s1-s5: source for WQGs, listed after table)		Management intent /Level of protection		Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed													
				Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)
UPSTART BAY																	
UPSTART BAY SD Lower estuary/ enclosed coastal waters (s1, s2)	HEV	2-2-5 (s1)	1-4-8 (s1)	-	-	80-90-125 (s1)	1-1-3 (s1)	-	-	10-12-13 (s1)	≤1 (s1)	-	90-100 (s2)	2-4-14 (s1)	≥1.5 (s2)	≤1 (s1)	8-8.4 (s2)
UPSTART BAY Lower estuary/ enclosed coastal waters (s1, s2)	MD	≤2 (s1)	≤4 (s1)	-	-	≤90 (s1)	≤1 (s1)	-	-	≤12 (s1)	≤1 (s1)	-	90-100 (s2)	≤4 (s1)	≥1.5 (s2)	≤1 (s1)	8-8.4 (s2)
UPSTART BAY SD Open coastal waters (landward of GBR plume line) (s1, s2, s3,s4)	HEV	0-1-6 (s1, s4)	0-1-2 (s4)	8-13-20 Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3, s4)	50-70-90 (s4)	65-100-125 (s1, s4)	0-2-4 (s1, s4)	1.5-2.1-3.2 Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3, s4)	2-6-11 (s4)	8-12-20 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	60-110-320 (s4)	95-105 (s2)	≤2 (s1, s4)	≥10 (ann. mean) (s3)	0.5-1.2-2.5 Dry: ≤1.6 (May-Oct) Wet: ≤2.4 (Nov-Apr) (s1, s3, s4)	8.1-8.3-8.4 (s2)
UPSTART BAY Open coastal waters (s1, s2,s3,s4)	SMD	≤1 (s1, s4)	≤1 (s4)	≤20 (ann. mean) Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3)	≤70 (s4)	≤100 (s1, s4)	≤2 (s1, s4)	≤2.8 (ann. mean) Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3)	≤6 (s4)	≤12 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	≥110 (s4)	95-105 (s2)	≤2 (s1, s4)	≥10 (ann. mean) (s3)	≤2 (ann. mean) Dry: ≤1.6 (May-Oct) Wet: ≤2.4 (Nov-Apr) (s3)	8.1-8.4 (s2)

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷												
Water area/type (s1-s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed										
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)
UPSTART BAY All coastal waters (s1, s3, s5,s6)	All	Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. Levels specified here are derived to support the health of all seagrass species present either as the dominant species or as one of a suite of species that are known to occur in the region. It does not reflect requirements for macroalgae or other organisms. - Deep water areas (>10m): 2.5 mol m⁻² day⁻¹ over a rolling 7 day average [#] (Chartrand et al 2014; Rasheed et al 2014; York et al 2015) - Shallow inshore areas (<10m): 6 mol m⁻² day⁻¹ over a rolling 14 day average [#] (Chartrand et al, 2012) Note: [#] Absolute light requirements for seagrass may vary between sites. Values described here provide a conservative guide to the levels of light likely to support seagrass growth. Locally derived absolute thresholds ideally should be obtained for management of specific activities likely to impact on the light environment. Toxicants WQGs for all toxicants in these waters (except aluminium – specified below) as per GBRMPA (2010) and ANZECC (2000) water quality guidelines, to protect marine species at the HEV (99% species protection) level of protection. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted. <u>Pesticides/biocides</u> WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to): - Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L <u>Other toxicants</u> For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and other sources below: - Aluminium: <2.1 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] - Other toxicants in water: refer to ANZECC AWQG section 3.4 – ‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). Values correspond to protection of 99% of species - Toxicants in sediments: refer to ANZECC AWQG section 3.5 – ‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and ANZECC AWQG volume 2 (section 8) Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra Temperature (s3) Increases of no more than 1 °C above long-term (20 year) average maximum. (GBRMPA, 2010)										
		pH SS (mg/L) Secchi (m) Turb (NTU)										

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) 1–7																	
Water area/type (s1–s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
ABBOT POINT PORT (core port waters outside GBR Marine Park)																	
ABBOT POINT PORT Lower estuary/ enclosed coastal core port waters outside GBR Marine Park (s1, s2)	MD	≤2 (s1)	≤4 (s1)	–	–	≤90 (s1)	≤1 (s1)	–	–	≤12 (s1)	≤1 (s1)	–	90–100 (s2)	1–3–7 (dry) 2–4–14 (wet) (s1)	≥1.5 (s2)	≤1 (s1)	8–8.4 (s2)
ABBOT POINT PORT Open coastal core port waters outside GBR Marine Park (s1, s2,s3,s4)	MD	2–2–4 (s1 port)	1–3–7 (s1 port) QWQG: <3	≤20 (ann. mean) Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3)	50–70–90 (s4)	80–100–125 (s1 port)	1–2–3 (s1 port)	≤2.8 (ann. mean) Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3)	2–6–11 (s4)	10–12–13 (s1 port)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	60–110– 320 (s4)	95–105 (s2)	1–2–4 (dry) 1–2–5 (wet) (s1 port)	≥10 (ann. mean) (s3)	1–1–1 (dry) 1–1–2 (wet) (s1 port)	8.1–8.4 (s2)
ABBOT POINT PORT Coastal core port waters outside GBR Marine Park; marinas; approved spoil grounds (s1, s3, s5, s6)	All	Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. This requirement is based on the listed species, from work by McKenna et al. (2015) <i>Initial light thresholds for modelling impacts to seagrass from the Abbot Point growth gateway project</i> . It does not reflect requirements for macroalgae or other organisms. - Deep water areas (>10m) dominated by <i>Halophila</i> species: 1.5 mol m⁻² day⁻¹ over a rolling 7 day average. * - Shallow inshore areas (<10m) dominated by <i>Halodule uninervis</i>: 5 mol m⁻² day⁻¹ over a rolling 7 day average (until further data is available) * Note: * These requirements are set as an initial threshold. Ongoing data collection on site is aimed at increasing certainty that these levels are sufficient to maintain seagrass at the desired level. Application of the thresholds should remain flexible to allow additional information from the ongoing data collection on site, or any additional new studies to be incorporated in refinement. Toxicants WQGs for all toxicants in these waters as per GBRMPA (2010) and ANZECC (2000) water quality guidelines. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted.															

Water area/type	Management intent /Level of protection	DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷															
(s1—s5: source for WQGs, listed after table)		Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
		Pesticides/biocides															
		WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to):															
		• Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L															
		Other toxicants															
		For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and sources below (corresponding to protection of 95% of species, except for toxicants with bioaccumulation risk, where ANZECC recommends 99% species protection)															
		• Aluminium: <24 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] • Other toxicants in water: refer to AWQG volume 1 section 3.4— ‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). AWQG values for the MD level of protection typically correspond to protection of 95% species (in a small number of cases where bioaccumulation may occur, the AWQG recommends 99% species protection level). • Toxicants in sediments: refer to AWQG volume 1 section 3.5— ‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and AWQG volume 2 (section 8)															
		Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.)															
		Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra															
		Temperature (s3) Increases of no more than 1 °C above long-term (20 year) average maximum. (GBRMPA, 2010)															

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ^{1–7}																	
Water area/type (s1–s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
ABBOT BAY (waters within GBR Marine Park – outside of core port waters)																	
ABBOT BAY Lower estuary/ enclosed coastal waters in GBR Marine Park outside core port waters: (s1, s2)	MD	≤2 (s1)	≤4 (s1)	–	–	≤90 (s1)	≤1 (s1)	–	–	≤12 (s1)	≤1 (s1)	–	90–100 (s2)	1–3–7 (dry) 2–4–14 (wet) (s1)	≥1.5 (s2)	≤1 (s1)	8–8.4 (s2)
ABBOT BAY Open coastal waters in GBR Marine Park outside core port waters: landward of GBR plume line (s1, s2, s3,s4)	SMD	≤1 (s1, s4)	≤1 (s4)	≤20 (ann. mean) Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3)	≤70 (s4)	≤100 (s1, s4)	≤2 (s1, s4)	≤2.8 (ann. mean) Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3)	≤6 (s4)	≤12 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	≥110 (s4)	95–105 (s2)	1–2–4 (dry) 1–2–5 (wet) (s1 port)	≥10 (ann. mean) (s3)	1–1–1 (dry) 1–1–2 (wet) (s1 port)	8.1–8.4 (s2)
ABBOT BAY Open coastal waters in GBR Marine Park outside core port waters: seaward of GBR plume line (s1, s2, s3,s4)	HEV	0–1–6 (s1, s4)	0–1–2 (s4)	8–13–20 Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s4)	50–70–90 (s4)	65–100–125 (s1, s4)	0–2–4 (s1, s4)	1.5–2.1–3.2 Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3, s4)	2–6–11 (s4)	8–12–20 (s1, s4)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	60–110– 320 (s4)	95–105 (s2)	1–2–4 (dry) 1–2–5 (wet) (s1)	≥10 (ann. mean) (s3)	0.5–1.2– 2.5 Dry: ≤1.6 (May- Oct) Wet: ≤2.4 (Nov-Apr) (s1, s3, s4)	8.1–8.3–8.4 (s2)

Water area/type (s1–s5: source for WQGs, listed after table)	Management intent /Level of protection	DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ^{1–7}															
		Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
		Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. Levels specified here are derived to support the health of all seagrass species present either as the dominant species or as one of a suite of species that are known to occur in the region. It does not reflect requirements for macroalgae or other organisms.															
		- Deep water areas (>10m): 2.5 mol m⁻² day⁻¹ over a rolling 7 day average " (Chartrand et al 2014; Rasheed et al 2014; York et al 2015) - Shallow inshore areas (<10m): 6 mol m⁻² day⁻¹ over a rolling 14 day average " (Chartrand et al, 2012)															
		Note: # Absolute light requirements for seagrass may vary between sites. Values described here provide a conservative guide to the levels of light likely to support seagrass growth. Locally derived absolute thresholds ideally should be obtained for management of specific activities likely to impact on the light environment.															
		Toxicants WQGs for all toxicants in these waters (except aluminium – specified below) as per GBRMPA (2010) and ANZECC (2000) water quality guidelines, to protect marine species at the HEV (99% species protection) level of protection. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted.															
		<u>Pesticides/biocides</u> WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to): Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L															
		<u>Other toxicants</u> For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and other sources below:															
		- Aluminium: <2.1 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] - Other toxicants in water: refer to ANZECC AWQG section 3.4—‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). Values correspond to protection of 99% of species - Toxicants in sediments: refer to ANZECC AWQG section 3.5—‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and ANZECC AWQG volume 2 (section 8)															
		Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.)															
		Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra															
		Temperature: Increases of no more than 1°C above long-term (20 year) average maximum. (s3 - GBRMPA, 2010)															

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷																	
Water area/type (s1–s5: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
PORT DENISON - BOWEN PORT (core port waters outside GBR Marine Park)																	
PORT DENISON Lower estuary/ enclosed coastal core port waters in outside GBR Marine Park (s1, s2)	MD	≤2 (s1)	≤4 (s1)	–	–	≤90 (s1)	≤1	–	–	≤12 (s1)	≤1 (s1)	–	90–100 (s2)	1–3–7 (dry) 2–4–14 (wet) (s1)	≥1.5 (s2)	≤1 (s1)	8–8.4 (s2)
PORT DENISON Open coastal core port waters outside GBR Marine Park (s1, s2,s3,s4)	MD	2–2–4 (s1 port) QWQG: <3	1–3–7 (s1 port)	≤20 (ann. mean) Dry: ≤16 (May-Oct) Wet: ≤25 (Nov-Apr) (s3)	50–70–90 (s4)	80–100–125 (s1 port)	1–2–3 (s1 port)	≤2.8 (ann. mean) Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr) (s3)	2–6–11 (s4)	10–12–13 (s1 port)	≤0.45 (ann. mean) Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr) (s3)	60–110– 320 (s4)	95–105 (s2)	1–2–4 (dry) 1–2–5 (wet) (s1 port)	≥10 (ann. mean) (s3)	≤2 (ann. mean) (s3)	8.1–8.4 (s2)
PORT DENISON Coastal core port waters outside GBR Marine Park; marinas; approved spoil grounds (s1, s3, s5, s6)	All	Seagrass Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. This requirement is based on the listed species, from work by McKenna et al. (2015) <i>Initial light thresholds for modelling impacts to seagrass from the Abbot Point growth gateway project</i> . It does not reflect requirements for macroalgae or other organisms.															
		• Deep water areas (>10m) dominated by <i>Halophila</i> species: 1.5 mol m⁻² day⁻¹ over a rolling 7 day average. * • Shallow inshore areas (<10m) dominated by <i>Halodule uninervis</i>: 5 mol m⁻² day⁻¹ over a rolling 7 day average (until further data is available) * Note: * These requirements are set as an initial threshold. Ongoing data collection on site is aimed at increasing certainty that these levels are sufficient to maintain seagrass at the desired level. Application of the thresholds should remain flexible to allow additional information from the ongoing data collection on site, or any additional new studies to be incorporated in refinement.															
Toxicants WQGs for all toxicants in these waters as per GBRMPA (2010) and ANZECC (2000) water quality guidelines. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted.																	

DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷

Water area/type	Management intent /Level of protection	DON AND HAUGHTON COASTAL AND MARINE WATERS: DRAFT Water quality guidelines (WQGs) ¹⁻⁷															
		Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
MIDSHELF WATERS HEV waters adjacent to Holbourne Island (s2, s4)	HEV	0–4–8 (s4)	0–0–1 (s4)	9–14–20 (s4)	40–65–90 (s4)	50–90–110 (s4)	0–1–3 (s4)	1.5–2.0–2.8 (s4)	2–6–10 (s4)	5–10–15 (s4)	0.18–0.33– 0.57 (s4)	30–50– 120 (s4)	95–105 (s2)	0.4–0.5– 0.7 (s4)	7–11–17 (s4)	0.5–0.8– 1.6 (s4)	8.1–8.3–8.4 (s2)
		Seagrass (Edgecumbe Bay) Light requirement is a photosynthetic active radiation (PAR) moving average, as specified below, depending on seagrass species. This requirement is based on the listed species, from work by McKenna et al. (2015) <i>Initial light thresholds for modelling impacts to seagrass from the Abbot Point growth gateway project</i> . It does not reflect requirements for macroalgae or other organisms.															
		- Deep water areas (>10m) dominated by <i>Halophila</i> species: 1.5 mol m⁻² day⁻¹ over a rolling 7 day average. * - Shallow inshore areas (<10m) dominated by <i>Halodule uninervis</i>: 5 mol m⁻² day⁻¹ over a rolling 7 day average (until further data is available) * Note: * These requirements are set as an initial threshold. Ongoing data collection on site is aimed at increasing certainty that these levels are sufficient to maintain seagrass at the desired level. Application of the thresholds should remain flexible to allow additional information from the ongoing data collection on site, or any additional new studies to be incorporated in refinement. WQGs for all toxicants in these waters (except aluminium – specified below) as per GBRMPA (2010) and ANZECC (2000) water quality guidelines, to protect marine species at the HEV (99% species protection) level of protection. Where pesticide values are specified in both the GBRMPA and ANZECC guidelines, the lower value will be adopted.															
EDGECCUMBE BAY and MIDSHELF coastal waters in GBR Marine Park outside core port waters; marinas; approved spoil grounds (s1, s3, s5, s6)	All	Toxicants Pesticides/biocides WQGs for pesticides/biocides specified in GBRMPA water quality guidelines (99% species protection) include (but not limited to): - Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Tebuthiuron: <0.02 µg/L <u>Other toxicants</u> For other toxicants not listed in GBRMPA guidelines, refer to ANZECC water quality guidelines and other sources below: - Aluminium: <2.1 µg/L (applies to the measured concentration in seawater that passes through a 0.45 µm filter) [Source: Golding et al. (2015)] - Other toxicants in water: refer to ANZECC AWQG section 3.4—‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). Values correspond to protection of 99% of species - Toxicants in sediments: refer to ANZECC AWQG section 3.5—‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and ANZECC AWQG volume 2 (section 8) Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013) Australian Government, Canberra															

Notes (where applicable):

Abbreviations: id: insufficient information; na: not applicable; –: WQG for indicator not available. Will be updated if guidelines become available.

1. Nutrients: Except where specified for event conditions, nutrient guidelines do not apply during high flow events in fresh and estuarine waters. During periods of low flow and particularly in smaller creeks, build-up of organic matter derived from natural sources (e.g. leaf litter) can result in increased organic N levels (generally in the range of 400 to 800 µg/L). This may lead to total N values exceeding the WQGs. Provided that levels of inorganic N (i.e. NH₃ + oxidised N) remain low, then the elevated levels of organic N should not be seen as a breach of the WQGs, provided this is due to natural causes. See QWQG (section 5 and Appendix D) for more information on applying guidelines under high flow conditions.

2. Suspended solids: Suspended solids (and hence turbidity and Secchi depth) levels in coastal waters are naturally highly variable depending on wind speed/wave height and in some cases on tidal cycles. The values in this table provide guidance on what the long term values of turbidity, Secchi depth or TSS should comply with. However, these values will often be naturally exceeded in the short term during windy weather or spring tides. They therefore should not be used for comparison with short term data sets. Where assessable coastal developments are proposed, proponents should carry out site specific intensive monitoring of these indicators (or equivalent light penetration indicators) and use these as a baseline for deriving local guidelines and for comparison with post development conditions.

3. Oxidised N = NO₂ + NO₃

4. Dissolved oxygen (DO): Dissolved Oxygen (DO) guidelines apply to daytime conditions. Lower values will occur at night in most waters. In estuaries, reductions should only be in the region of 10–15 per cent saturation below daytime values. In freshwaters, night-time reductions are more variable. Following significant rainfall events, reduced DO values may occur due to the influx of organic material. In estuaries post-event values as low as 40 per cent saturation may occur naturally for short periods but values well below this would indicate some anthropogenic effect. In freshwaters, post-event DO reductions are again more variable. In general, DO values consistently less than 50 per cent are likely to impact on the ongoing ability of fish to persist in a water body while short term DO values less than 30 per cent saturation are toxic to some fish species. Very high DO (supersaturation) values can be toxic to some fish as they cause gas bubble disease. DO values for fresh waters should only be applied to flowing waters. Stagnant pools in intermittent streams naturally experience values of DO below 50 per cent saturation.

5. Temperature: Temperature varies both daily and seasonally, it is depth dependent and is also highly site specific. It is therefore not possible to provide simple generic WQGs for this indicator for fresh or estuarine waters. (In open coastal/marine waters a WQG based on GBRMPA WQGs is provided.) The recommended approach is that local WQGs be developed. Thus, WQGs for potentially impacted streams should be based on measurements from nearby streams that have similar morphology and which are thought not to be impacted by anthropogenic thermal influences. From an ecological effects perspective, the most important aspects of temperature are the daily maximum temperature and the daily variation in temperature. Therefore measurements of temperature should be designed to collect information on these indicators of temperature and, similarly, local WQGs should be expressed in terms of these indicators. There will be an annual cycle in the values of these indicators and therefore a full seasonal cycle of measurements is required to develop guideline values.

6. Open coastal/marine waters – GBR plume line: The GBR plume discharge area is derived from a smoothed version of the 'high' and 'very high' risk classes of modelled outputs from the risk assessment element of the Reef Plan Scientific Consensus Statement 2013 (Waterhouse et al. 2013).

7. While seasonal means are estimated based on biotic responses the relationship is not as strong as it is for annual mean values. They are provided here as indicative objectives to allow comparison with single season collected data sets. Wet and dry seasons can start and end at different times of the year. Seasonal dates indicated are generally applicable. Applying these values for any management action should take both of these matters into account.

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Table: DRAFT Water quality guidelines for fresh and estuarine waters of the Don and Houghton river basins

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ¹⁻⁵													
Water area/type (s1-s4: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)
DON RIVER BASIN (listed Upstart Bay, Abbot Bay, Don River catchments)													
UPSTART BAY CATCHMENTS													
Mid estuarine waters of Upstart Bay catchments (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Mid estuarine waters of Upstart Bay catchments (s3 20-40-70 %ile, s2)	MD	2-4-9 (s3)	4-6-7 (s3)	180-250-355 (s3)	11-13-28 (s3)	19-24-40 (s3)	0.4-0.8-1.2 (s3)	85-100 (s2)	3-4-5 (s3)	1.4-1.5-1.6 (30-60-80 %iles) (s3)	I.D.	7-8.4 (s2)	N.A.
Lowland freshwaters of Upstart Bay catchments (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Lowland freshwaters of Upstart Bay catchments (s1 20-40-70 %ile, s2)	MD	2-3-8 (s1)	5-22-46 (s1)	240-350-625 (s1)	20-35-60 (s1)	40-60-100 (s1)	<5 (s2)	85-110 (s2)	2-4-7 (s1)	N.A.	5-6-13 (s1)	6.5-8.0 (s2)	250-490-1020 (s1)

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) 1-5														
Water area/type	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed												
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)	
Upland freshwaters of Upstart Bay catchments (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs												
Upland freshwaters of Upstart Bay catchments (s2)	MD	<10	<15	<250	<15	<30	na	90-110	<25	N.A.	-	6.5-7.5	<680	
ABBOT BAY CATCHMENTS														
Mid estuarine waters of Abbot Bay catchments (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.												
Mid estuarine waters of Abbot Bay catchments (s3 20-40-70% ile, s2)	MD	2-4-9 (s3)	4-6-7 (s3)	180-250-355 (s3)	11-13-28 (s3)	19-24-40 (s3)	0.4-0.8-1.2 (s3)	85-100 (s2)	3-4-5 (s3)	1.4-1.5-1.6 (30-60-80 %iles) (s3)	I.D.	7-8.4 (s2)	N.A.	
Lowland freshwaters of Abbot Bay catchments	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.												

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ^{1- 5}														
Water area/type (s1–s4: source for WQGs, listed after table)		Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
			Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)
Lowland freshwaters of Abbot Bay catchments (s1 20-40-70 %ile, s2)	MD		2–3–8 (s1)	5–22–46 (s1)	240–350–625 (s1)	20–35–60 (s1)	40–60–100 (s1)	<5 (s2)	85–110 (s2)	2–4–7 (s1)	N.A.	5–6–13 (s1)	6.5–8.0 (s2)	290–490–1020 (s1)
Upland freshwaters of Abbot Bay catchments (e.g. national park)	HEV		Insufficient data. Refer to QWQG for details on how to establish local WQGs											
Upland freshwaters of Abbot Bay catchments (s2)	MD		<10	<15	<250	<15	<30	na	90–110	<25	N.A.	-	6.5–7.5	<680
DON RIVER CATCHMENT														
Mid estuarine waters of Don River catchment (s3 20-40-70%ile, s2)	MD		2–4–9 (s3)	4–6–7 (s3)	180–250–355 (s3)	11–13–28 (s3)	19–24–40 (s3)	0.4–0.8–1.2 (s3)	85–100 (s2)	3–4–5 (s3)	1.4–1.5–1.6 (30-60-80 %iles) (s3)	I.D.	7–8.4 (s2)	N.A.
Lowland freshwaters of Don River (s1 20-40-70%ile, s2)	MD		3–5–19	16–25–64	165–200–295	35–45–70	80–100–135	<5 (s2)	85–110 (s2)	1–2–5	N.A.	4–5–10	6.5–8.0 (s2)	405–590–840

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ¹⁻⁵													
Water area/type (s1-s4: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)
Upland freshwaters of Abbot Bay catchments (s2)	MD	<10	<15	<250	<15	<30	na	90-110	<25	N.A.	-	6.5-7.5	<680

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ^{1- 5}													
Water area/type (s1-s4: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)
HAUGHTON RIVER BASIN (listed Haughton, Barratta, Burdekin delta)													
HAUGHTON RIVER CATCHMENT													
Mid estuarine waters of Haughton River catchments (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Mid estuarine waters of Haughton River catchment (s2)	MD	<10	<10	<300	<8	<25	<4.0	85-100	<8	>1	<20	7.0-8.4	n/a
Lowland freshwaters of Haughton River catchment (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Lowland fresh waters of Haughton River catchment (s1 20-40-70 %ile, s2)	MD	3-5-8 (s1)	3-6-18 (s1)	159-228-303 (s1)	8-10-13 (s1)	22-28-34 (s1)	<5 (s2).	85-110 (s2)	4-7-18 (s1)	N.A.	5.0-8.0-16.1 (s1)	6.5-8.0 (s2)	127-176-237 (s1)

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ¹⁻⁵													
Water area/type (s1-s4: source for WQGs, listed after table)	Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)
Upland fresh waters of Haughton River catchment (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Upland freshwaters of Haughton River catchments (s2)	MD	<10	<15	<250	<15	<30	na	90-110	<25	N.A.	-	6.5-7.5	<270
BARRATTA CREEK CATCHMENT													
Mid estuarine waters of Barratta Creek catchment (e.g. national park)	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Mid estuarine waters of the Barratta Creek catchment (s2)	MD	<10	<10	<300	<8	<25	<4.0	85-100	<8	>1	<20	7.0-8.4	n/a
Lowland freshwaters of Barratta Creek catchment	HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.											
Lowland fresh waters of Barratta Creek catchment (s1 20-40-70 %ile, s2)	MD	3-5-8 (s1)	3-6-18 (s1)	159-228-303 (s1)	8-10-13 (s1)	22-28-34 (s1)	<5 (s2).	85-110 (s2)	4-7-18 (s1)	N.A.	5.0-8.0-16.1 (s1)	6.5-8.0 (s2)	127-176-237 (s1)

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ¹⁻⁵															
Water area/type (s1-s4: source for WQGs, listed after table)		Management intent /Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3-4-5), lower and upper limits (e.g. pH: 7.2-8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed												
			Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH	Conductivity (µS/cm)	
Upland freshwaters of Barratta Creek catchments (s2)		MD	<10	<15	<250	<15	<30	na	90-110	<25	N.A.	-	6.5-7.5	<270	
BURDEKIN DELTA															
Mid estuarine waters of Burdekin Delta catchment		HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.												
Mid estuarine waters of the Burdekin Delta catchment (s2)		MD	<10	<10	<300	<8	<25	<4.0	85-100	<8	>1	<20	7.0-8.4	n/a	
Lowland freshwaters of Burdekin Delta catchment (e.g. national park)		HEV	Insufficient data. Refer to QWQG for details on how to establish local WQGs.												
Lowland fresh waters of Burdekin Delta catchment (s1 20-40-70 %ile, s2)		MD	3-5-8 (s1)	3-6-18 (s1)	159-228-303 (s1)	8-10-13 (s1)	22-28-34 (s1)	<5 (s2)	85-110 (s2)	4-7-18 (s1)	N.A.	5.0-8.0-16.1 (s1)	6.5-8.0 (s2)	127-176-237 (s1)	

DON AND HAUGHTON RIVER BASINS - Fresh and estuarine waters: DRAFT Water quality guidelines (WQGs) ^{1–5}												
Water area/type (s1–s4: source for WQGs, listed after table)	Management intent / Level of protection	Note: WQGs for indicators are shown as a range of percentiles (e.g. 3–4–5), lower and upper limits (e.g. pH: 7.2–8.2), or as a single value (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed										
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP(µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
Fresh waters: Toxicants (s4)	HEV and SD	WQGs for all toxicants and pesticides in these waters as per ANZECC AWQG, to protect species at the HEV level of protection. This corresponds to protection of 99% of species. Toxicants in water and sediment as per ANZECC AWQG: - Toxicants in water: refer to AWQG volume 1 section 3.4—‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). AWQG values for the HEV level of protection typically correspond to protection of 99% of species. - Toxicants in sediments: refer to AWQG volume 1 section 3.5—‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and AWQG volume 2 (section 8) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013)										
		WQGs for all toxicants and pesticides in these waters as per ANZECC AWQG, to protect species at the MD level of protection (except where noted). This corresponds to protection of 95% of species (except for toxicants with bioaccumulation risk, where protection of 99% species is used). Toxicants in water and sediment as per AWQG: - Toxicants in water: refer to AWQG volume 1 section 3.4—‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8). AWQG values for the MD level of protection typically correspond to protection of 95% species (in a small number of cases where bioaccumulation may occur, the AWQG recommends 99% species protection level). - Toxicants in sediments: refer to AWQG volume 1 section 3.5—‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and AWQG volume 2 (section 8) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013)										
Riparian	all	Refer to additional information after table										
Wetlands	all	Refer to additional information after table										
State Planning Policy	all	Refer to additional information after table										
Groundwaters	HEV	Where groundwaters interact with surface waters, groundwater quality should not compromise identified EVs and WQGs for those waters. Note: the AWQG recommends that the highest level of protection should be provided to underground aquatic ecosystems, given their high conservation value. Where groundwaters are in good condition the intent is to maintain existing water quality (20th, 50th and 80th percentiles).										

Sources: S1: Local datasets (e.g. DSITI, key stakeholder); S2: QWQG guidelines and /or data; S3: data collected by DSITI from Gregory River mid estuarine reaches. Data collection is ongoing and these WQGs will be updated as more data becomes available; S4: ANZECC (2000) AWQG

Notes to Table 3 (where applicable):

Abbreviations: id: insufficient information; na: not applicable; -: WQG for indicator not available. Will be updated if guidelines become available

WQGs have been derived using the percentiles specified. In general,

- WQGs for waters identified for MD management intent are based on 80th %ile of reference site data or, where no suitable reference site data is available, an alternative percentile range, as specified (e.g. 20-40-70th %iles). The middle value is suggested as the MD WQGs. The median concentration of n independent samples at the test site is to be compared with the values specified in the table. Refer to QWQG section 5 and Appendix D for further information on applying guidelines.
 - WQGs for SD and HEV waters are based on achieving the percentile range specified (typically 20-50-80th %ile of HEV waters or 20-40-70th %ile of best available WQ data where no reference sites were available). Refer to QWQG section 5 and Appendix D for further information on applying guidelines.
1. Nutrients: Except where specified for event conditions, nutrient guidelines do not apply during high flow events in fresh and estuarine waters. During periods of low flow and particularly in smaller creeks, build-up of organic matter derived from natural sources (e.g. leaf litter) can result in increased organic N levels (generally in the range of 400 to 800µg/L). This may lead to total N values exceeding the WQGs. Provided that levels of inorganic N (i.e. NH₃ + oxidised N) remain low, then the elevated levels of organic N should not be seen as a breach of the WQGs, provided this is due to natural causes. See QWQG (section 5 and Appendix D) for more information on applying guidelines under high flow conditions.
 2. Suspended solids: Suspended solids (and hence turbidity and Secchi depth) levels in coastal and tidal estuarine waters are naturally highly variable depending on wind speed/wave height and in some cases on tidal cycles. The values in this table provide guidance on what the long term values of turbidity, Secchi depth or TSS should comply with. However, these values will often be naturally exceeded in the short term during windy weather or spring tides. They therefore should not be used for comparison with short term data sets. Where assessable coastal developments are proposed, proponents should carry out site specific intensive monitoring of these indicators (or equivalent light penetration indicators) and use these as a baseline for deriving local guidelines and for comparison with post development conditions.
 3. Oxidised N = NO₂ + NO₃
 4. Dissolved oxygen (DO): Dissolved Oxygen (DO) guidelines apply to daytime conditions. Lower values will occur at night in most waters. In estuaries, reductions should only be in the region of 10–15 per cent saturation below daytime values. In freshwaters, night-time reductions are more variable. Following significant rainfall events, reduced DO values may occur due to the influx of organic material. In estuaries post-event values as low as 40 per cent saturation may occur naturally for short periods but values well below this would indicate some anthropogenic effect. In freshwaters, post-event DO reductions are again more variable. In general, DO values consistently less than 50 per cent are likely to impact on the ongoing ability of fish to persist in a water body while short term DO values less than 30 per cent saturation are toxic to some fish species. Very high DO (supersaturation) values can be toxic to some fish as they cause gas bubble disease. DO values for fresh waters should only be applied to flowing waters. Stagnant pools in intermittent streams naturally experience values of DO below 50 per cent saturation.
 5. Temperature: Temperature varies both daily and seasonally, it is depth dependent and is also highly site specific. It is therefore not possible to provide simple generic WQGs for this indicator for fresh or estuarine waters. (In open coastal/marine waters a WQG based on GBRMPA WQGs is provided.) The recommended approach is that local WQGs be developed. Thus, WQGs for potentially impacted streams should be based on measurements from nearby streams that have similar morphology and which are thought not to be impacted by anthropogenic thermal influences. From an ecological effects perspective, the most important aspects of temperature are the daily maximum temperature and the daily variation in temperature. Therefore measurements of temperature should be designed to collect information on these indicators of temperature and, similarly, local WQGs should be expressed in terms of these indicators. There will be an annual cycle in the values of these indicators and therefore a full seasonal cycle of measurements is required to develop guideline values.

References:

- ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality (AWQG)*.
- Australian Government (2013) *Anti-fouling and in-water cleaning guidelines* (June 2013), Department of Agriculture, Fisheries and Forestry, Canberra.
- Queensland Government (EHP; 2009, as amended) *Queensland Water Quality Guidelines*. (Refer to section 5 and Appendix D of the QWQG for more detail on compliance assessment protocols.)

Appendix 5: The ABCD Framework for cane, grazing & horticulture in the Burdekin region

Sugarcane - ABCD MANAGEMENT FRAMEWORK

NUTRIENT MANAGEMENT				A ASPIRATIONAL			
D DEGRADING		C CODE OF PRACTICE		B BEST PRACTICE			
Above industry recommended rates.		At industry recommended rates (Six Easy Steps based on district-wide yield potential for whole farm)		At industry recommended rates (Six Easy Steps based on individual block yield potential).		Variable rates within blocks based on field variability using Six Easy Steps. Use of emerging nutrient technologies.	
1.2 PLANNING	Future rates based on past application rates.	Soil test taken prior to planting. Not all blocks tested. Planning based on Six Easy Steps.		Soil test taken per plant block prior to planting. Planning based on Six Easy Steps.		Soil tests taken within management zones prior to planting. Planning based on Six Easy Steps.	
1.3 TIMING		Before first irrigation into dry soil.		Prior to mid-October in moist soil.		Split applications in ratoons.	
1.4 PLACEMENT	Granular fertiliser surface application. Any form of nutrient including mill mud applied in the furrow.			Sub-surface application of granular or solid fertiliser. Surface applied liquid nutrients on the hill.		Sub-surface application of liquid fertiliser. Banded mill mud.	
1.5 CALIBRATION	Fertiliser box rarely calibrated.	Fertiliser box calibrated for each block.		Rate controlled fertiliser box calibrated daily and between product changes.			
PESTICIDE MANAGEMENT							
2.1 USE OF RESIDUALS	Heavy reliance on residual products with no attempt made to minimise runoff losses.	Use of both residual and knockdown products. Minimised use and reuse of tail water.		Primary reliance on knockdown herbicides over residuals in ratoons.		Knockdown herbicides replace residuals.	
2.2 CHEMICAL RATES/ APPLICATION	Maximum label rates regardless of weed pressure	Chemicals applied at lowest rate for effective weed control.		Chemicals applied at lowest rate for effective weed control. Flow rate monitor, GPS guidance and dual/banded application systems utilised.		Implementation of new technology for improved placement and application efficiency (e.g. weed seekers).	
2.3 TIMING	Ad hoc.	Spray as per label recommendations.		Spray as per label recommendations with all weeds controlled before four leaf stage. Multiple weed control events during fallow.		Use of safe gauge tool.	
2.4 CALIBRATION	Once a year.			Continual calibration if using flow rate controllers.			
2.5 PLANNING	Reactive.	More than one weed management strategy for entire farm.		Weed management plan and variable weed strategies between plant blocks.		Weed management plan and variable weed strategies within management zones.	
SOIL HEALTH							
3.1 ROW SPACING & GUIDANCE	Conventional row spacing, no guidance.	Conventional row spacing, some machinery matched, not all.		Row spacing and all machinery wheel spacings are matched and are operated on GPS guidance for bed-forming, planting, and harvesting and haul out operations.			
3.2 PLANT CANE ESTABLISHMENT	Cultivated conventional.	Minimum tillage.		Zonal tillage during establishment of plant crop.		Zero till planting.	
3.3 RATOONS	Cultivated conventional.	Minimum tillage.		Zero tillage.			
3.4 FALLOW	Cultivated bare fallow.	Minimum tillage bare fallow with chemical weed control.		Well managed fallow crop.			
3.5 AMELIORANTS	No ameliorants.	Ameliorants applied based on soil test.		Variable rate ameliorants applied based on soil tests and prescription mapping.			
3.6 TRASH UTILISATION	Burnt crop and residual trash burnt.	Burnt.		Green cane trash blanket on suitable soils.			
3.7 HEADLANDS	Bare.			Ground cover maintained on headlands and drains.			
WATER AND IRRIGATION MANAGEMENT							
4.1 MATCHING WATER USE TO CROP REQUIREMENT	Irrigation applied with no evaluation of quantity.	Limited measurement of irrigation application.		Regular measurement / monitoring of volume supply with water meter and application rates matched. Pump audits conducted and outcomes incorporated into management plan. Irrigation matched with crop requirement, runoff and deep drainage are minimised.		Continual measurement of application volumes fed into automated control system.	
4.2 SCHEDULING	Scheduling by guesswork or set cycle.	Simple/limited soil moisture monitoring.		Soil moisture monitoring tools across irrigation management zones to determine irrigation timing.			
4.3 FURROW SHAPE & LENGTH	Inappropriate furrow shape and length for soil type.			Appropriate furrow shape and length for soil type and slope.			
4.4 RUNOFF MANAGEMENT	No laser levelling.	Laser levelling. Recycle pit on suitable soil types unable to capture all irrigation runoff.		Recycle pits on suitable soil types capable of capturing all irrigation runoff and sufficient pumping capacity to reuse. Meets approved design guidelines for recycle pits.			
4.5 TIMING	No consideration of timing of fertiliser and herbicide application relative to irrigation.	Herbicides delayed based on label recommendations.		Delaying irrigation application after fertiliser as long as possible.			
4.6 IRRIGATION APPLICATION EFFICIENCIES (%)*	<40 Delta	40-60 Delta		60-75 Delta		>75 Delta	
	<50 BRIA	50-70 BRIA		70-85 BRIA		>85 BRIA	
RECORD KEEPING							
5.1 ALL FARM RECORDS	No written/documented records.	Basic record keeping using a farm diary and spray log book.		BSES paddock journal or better and spray log book. Simple water quality monitoring of water leaving the farm.		Farm management software incorporating spray logbook. More detailed water quality monitoring of water leaving the farm.	

* Numbers are based on 20 years of accumulative project data including SIMROD runs and local knowledge. Irrigation efficiencies are a guide and may differ between blocks or between irrigations within blocks.

Table 5.12. Relative priorities for horticulture management practices in the Paddock to Reef Program Water Quality Risk Framework.

Horticulture- ABCD MANAGEMENT FRAMEWORK

SOIL MANAGEMENT		D DEGRADING	C COMPLIANT	B BETTER PRACTICES	A UNPROVEN
1.1 TREES (MANGOS, AVOCADOS, ORANGES, LYCHEES, BANANAS ETC.)	Cultivated establishment phase. Bare inter-rows.	Mulched bed, inter-rows maintained with as much ground cover as practicable.	Mulched bed, inter-rows maintained with as much ground cover as practicable.	Mulched bed, inter-rows with active management of groundcover, e.g. mulching and mowing. Contour planting.	Attracts multiple benefits for an ICM (Integrated Crop Management) program. E.g. ground cover management reduces erosion, improves soil health and provides alternative food to predatory mites.
1.2 PLANTATION (PINEAPPLES ETC.)	Cultivated establishment phase for plantation. Bare inter-rows.	Inter-rows maintained with as much ground cover as practicable.	Inter-rows maintained with as much ground cover as practicable.	Inter-rows maintained with as much ground cover as practicable.	
1.3 ANNUALS (TOMATOES, BEANS, CAPSICUMS, CORN, MELONS, PUMPKINS, EGGPLANTS ETC)	Cultivated bare fallow. Annual full cultivation in a non bed system.	Minimum tillage with less than three passes. Use of multi-task machinery to annually form beds, lay plastic and drip irrigation.	Minimum tillage with less than three passes. Use of multi-task machinery to annually form beds, lay plastic and drip irrigation.	Beds with minimum tillage and GPS guidance for all farming operations. No inter-row tillage.	Permanent beds with zonal tillage, use of control traffic farming (CTF) for whole of farming system.
1.4 FALLOW MANAGEMENT	Bare soil.	Cover crop planted/ opportunity crop maintained.	Cover crop planted/ opportunity crop maintained.	Cover crop planted for specific outcome. E.g. cover crops with deep roots that recover/harvest N in soil profile; or control plant parasitic nematodes.	Cover crop that attracts multiple benefits for an ICM (Integrated Crop Management) program.
1.5 HEADLAND MANAGEMENT	Bare access roads and headlands.	Grassed headlands, drains and waterways managed to minimise erosion.	Grassed headlands, drains and waterways managed to minimise erosion.	Permanent grassed headlands, drains and waterways managed to minimise erosion. Strategic herbicide use on these areas (E.g. rain forecasts considered in application)	
1.6 PLANNING AND MONITORING	No soil management plan.	Basic soil management plan.	Basic soil management plan.	Soil Management Plan developed for specific soil types.	Plan includes specific practices and monitoring that relates to slow but beneficial soil improvements in the future.
NUTRIENT MANAGEMENT					
2.1 PLANNING AND MONITORING	No nutrient management planning or monitoring.	Basic planning with nutrient monitoring undertaken annually.	Basic planning with nutrient monitoring undertaken annually.	Regular testing to inform nutrient management plan.	Post crop monitoring and review.
2.2 FERTILISER APPLICATION RATES	One application rate for whole crop based on potential yield.	Application rate based on industry recommendations and testing.	Application rate based on industry recommendations and testing.	Variable rates informed by testing against crop nutrient requirement and crop growth stage.	Block specific application based on monitoring movement of nutrients in the soil.
2.3 ACCURACY OF APPLICATION	Fertiliser application systems not calibrated.	Fertiliser application systems calibrated annually or in accordance with manufacturer recommendations	Fertiliser application systems calibrated annually or in accordance with manufacturer recommendations	Fertiliser application systems calibrated based on irrigated blocks.	System and management ensure uniformity or location specific delivery of planned nutrient application rates.
2.4 APPLICATION TIMING	Single fertiliser application. Crop development not considered.	Total nutrient requirement spread throughout the crop season.	Total nutrient requirement spread throughout the crop season.	Application timing based on crop growth stage (crop phenology), weather forecast, soil type and moisture levels.	
2.5 APPLICATION METHOD	Surface applied.	Mix of granular and liquid incorporated into soil.	Mix of granular and liquid incorporated into soil.	Fertigation. Automated fertigation systems, based on timer only.	Automated fertigation systems, based on crop nutrient requirement through monitoring of nutrient movement through the soil.
PESTICIDE MANAGEMENT					
3.1 PLANNING AND MONITORING	No pesticide management planning or monitoring.	Basic planning with pesticide monitoring undertaken annually.	Basic planning with pesticide monitoring undertaken annually.	Regular testing to inform pesticide management plan.	Post crop monitoring and review.
3.2 PESTICIDE APPLICATION	One crop protection strategy for each crop based on historic application rates or rules of thumb.	Pesticide application based on crop monitoring under an Integrated Pest Management program.	Pesticide application based on crop monitoring under an Integrated Pest Management program.	Block scale monitoring (once per week minimum) and pesticide application.	Management of "hot spots" with specific pesticides and maximum benefit from managing natural and introduced biological control agents.
3.3 APPLICATION TIMING	Routinely.	Timing pesticide applications with respect to weather conditions under an Integrated Pest Management program.	Timing pesticide applications with respect to weather conditions under an Integrated Pest Management program.	Decisions based on pest population and disease epidemiology; crop growth stage (crop phenology), weather forecast, soil type and moisture levels.	Management considers negative impacts on populations of several beneficial agents and acts accordingly.
3.4 APPLICATION METHOD	Non calibrated spray equipment.	Equipment is specific to managing the pest problem. Calibration is performed annually or as per manufacturer's instructions.	Equipment is specific to managing the pest problem. Calibration is performed annually or as per manufacturer's instructions.	Equipment has modifications that allow targeted application to specific crop, e.g. GPS and/or control droplet.	Use of targeted application technology, e.g. sensor controlled.
4. IRRIGATION & WATER MANAGEMENT					
4.1 APPLICATION RATE	Application rate based on historic rules of thumb. Unmeasured.	Application rate is determined by subjective tools based on crop water requirements. Measuring water use at a farm scale.	Application rate is determined by subjective tools based on crop water requirements. Measuring water use at a farm scale.	Application rate is determined by objective tools based on crop water requirements. Block scale measurement.	
4.2 SCHEDULING	Calendar scheduling.	Scheduling based on subjective information or tools.	Scheduling based on subjective information or tools.	Scheduling based on one or a few objective tools e.g. soil moisture monitoring, daily evaporation data, crop consumption, soil type, soil structure and crop stage.	Scheduling based on soil moisture monitoring, daily evaporation data, crop consumption, soil type, soil structure and crop stage.
4.3 RUN-OFF MANAGEMENT	No management.	Run-off is managed to minimise environmental harm	Run-off is managed to minimise environmental harm	Whole of farm run-off is filtered via properly designed and managed traps and buffers.	System monitors run-off and allows for a change in management.
4.4 UNIFORMITY	No monitoring.	Farm scale assessment of water distribution uniformity annually.	Farm scale assessment of water distribution uniformity annually.	Block scale assessment of water distribution uniformity.	

Grazing - ABCD MANAGEMENT FRAMEWORK

	Framework D practices	Framework C practices	Framework B practices	Framework A practices
Principle	Management Practice Category			
1. Sustainable stocking rate	1. Matching stocking rate to forage availability	Practices are highly likely to degrade land to poor (C) or very poor (D) condition.	Practices are likely to maintain land in good or fair (A/B) condition and/or improve land in lesser condition.	Practices are highly likely to maintain land in good (A) condition and/or improve land in lesser condition.
	2. Managing grazing distribution	Stocking rates that frequently exceed forage availability regardless of seasonal conditions.	Stocking rates adjusted reactively. Stock numbers reduced in dry conditions.	Stocking rates based on long term carrying capacity and adjusted according to forage budget and land condition. Innovative use of forecasting and forage budgeting tools.
2. Managing grazing distribution	2.1 Managing land types	No management for land types.	Limited management of land types. Land types not marked on property map.	Land types documented on property map. Land types defined and managed to prevent overgrazing of preferred land types. Targets for maintaining and improving land condition.
	2.2 Water distribution	Large paddocks under-watered or water points poorly located resulting in overgrazing in proximity to available water. Reliance on natural waters.	Limited watering infrastructure resulting in some uneven grazing pressure.	Watering points design and location prevent uneven patch grazing across all land types and paddocks. Utilising water points for rotational grazing.
	2.3 Riparian and frontage management	No off-stream watering points. Waterways not fenced. Frontage country frequently overgrazed.	Some strategically placed off-stream watering points away from pressure areas. Limited fencing of waterways.	Strategic waterbodies identified. All major water courses fenced to enable effective management of riparian area. Off stream watering points used to protect and manage frontage paddocks. Action taken to rehabilitate degraded riparian areas. Annual wet season spelling of frontage country.
	3. Pasture management	No spelling.	Infrequent and limited spelling.	Spelling of all paddocks at appropriate intervals according to pasture species and land type.
4. Prevention and stabilisation of erosion features including gullies, stream banks, and scalds	3.1 Pasture spelling	No spelling.	Infrequent and limited spelling.	Spelling of all paddocks at appropriate intervals according to pasture species and land type.
	3.2 Strategic fire management	No fire management strategy.	Opportunity burning. Not linked to improvement in land condition.	A fire management strategy implemented as a tool to improve land condition.
	4.1 Prevention	No identification of high hazard areas or management for erosion	No management plan for erosion or land degradation management. Practices being trialled	Soils with a high erosion hazard identified. Erosion control planning and measures in place across property, with ongoing monitoring and implementation of further mitigation options. Actively maintaining high levels of ground cover and good land condition.
	4.2 Management	No management.	Erosion features and erosion mitigation strategies identified. Stock exclusion.	Targeted erosion management plan with recommended interventions and techniques applied, and regular monitoring. Contributing catchment managed.
Monitoring	4.3 Infrastructure	Infrastructure is poorly located and not maintained. Relocated to adjacent areas as erosion expands. Firebreaks are only installed in a wildfire emergency with no consideration for strategic location or maintenance.	Location of infrastructure is not planned. Maintenance and implementation of erosion control works occurs only in areas where there is serious erosion.	Infrastructure well planned and located in accordance with a property management plan and marked on property map. Preventative erosion control practices implemented and well maintained. All roads and tracks are designed to minimise the chance of water flows concentrating into rills. Soil erosion is minimal.
	Groundcover monitoring	No monitoring.	Casual observation at end of dry season.	Quantitative data collection from specific sites used to inform property planning and land and livestock management.

Appendix 6: Management practice shifts assumed in the INFFER cost benefit analysis

Table 1. Description of required capital expenditure items for the nutrient, tillage and irrigation scenarios to transition to each management class in sugarcane. Source: Smith (2015).

Management class transition	Key practices	Description of nutrient & tillage management items
Nutrients		
D to C class	- 6ES based on district wide potential for whole farm. - Soil test prior to planting; not on all blocks.	Disc harrow; legume planter; bed former (hill up); recycle pits Note: assumed additional cost of \$1,000/ha upfront and \$50/ha ongoing added to capture upgrades from D to C practice irrigation in 23% of the BRJA area and 30% of Delta.
C to B class	- 6ES based on individual block yield potential - Soil test taken per plant block prior to planting - Sub-surface application of granular or solid fertiliser.	Zonal ripper/rotary hoe; wavy discs; double-disc open planter (stool splitter fertiliser box); GPS; flow rate monitor; harvester modifications; soil moisture monitoring tools, potentially alternative irrigation methods (drip, overhead low pressure) to achieve efficiencies. Note: assumed additional cost of \$5,000/ha on 70% of sugarcane area plus 5% maintenance to upgrade irrigation systems.
B to A class	- Variable rates within blocks based on field variability using 6ES. Use of emerging nutrient technologies. - Soil tests within management zones prior to planting. - Split applications in ratoons. - Sub-surface application of liquid fertiliser. - Banded mill mud.	Irrigation application volumes fed into automated control system
Herbicides		
D to C class	- Use of residual and knockdown products. Minimised use and reuse of tailwater. - Chemicals applied at lowest rate for effective control. - Spray as per label. - Weed Management Strategy for farm.	Octopus bars; tracking legs; air-induced nozzles; triplet air-induced nozzle heads and connections
C to B class	- Primary reliance on knockdown herbicides in ratoons. - Chemicals applied at lowest rate for effective control. Flow rate monitor, GPS guidance and dual/banded application systems utilised. - Spray as per label recommendations with all weeds controlled before four leaf stage. Multiple weed control events during fallow. - Continual calibration if using flow rate controllers. - Weed management plan and variable weed strategies between plant blocks.	Hooded sprayer and equipment modifications
B to A class	- Knockdown herbicides replace residuals. - New technology for placement and efficiency. - Use of Safe Guage tool for timing. - Weed management plan and variable weed strategies within management zones.	Weed-seeker technology

Table 2. Description of required capital expenditure items for the scenarios to transition to each management class in grazing. Source: Roberts et al. (2016).

Management class transition	Key practices	Description of items needed Upfront costs \$/farm ¹ , (\$/ha)	Description of items needed Maintenance costs \$/ farm/yr (\$/ha/yr)	Level of non-profit related barrier (Low, Medium, High)
Sustainable stocking rate	Matching stocking rate to forage availability			
C to B class ²	Adjust stock numbers based on forage availability (if they are overstocked). Monitor pasture and forage availability and think forward (seasonal weather forecasts).	Training and workshop costs - \$1,000 (\$0.05)	Three days of labour per year -\$720.00/farm/yr (\$0.04/ha/yr)	High
Pasture management	Pasture spelling			
C to B class ²	Need to have done a forage budget and requires fencing infrastructure. The management system has to be suitable.	Paddock subdivision - \$80,000 (\$4.37)	\$12,000 /farm/yr (\$0.66/ha/yr)	Medium
Managing grazing distribution	Managing land types and water distribution			
C to B class ²	Better property planning plus infrastructure. Realignment of fences and new fences. Watering points. Grazing management should be implemented also.	\$375,000 (\$20.50)	\$20,000 /farm/yr (\$1.09/ha/yr)	Low
Managing grazing distribution	Riparian and frontage management			
C to B class ²	Fencing both sides of the waterway and manage grazing pressure.	\$31,960/km/yr (assumed both sides need to be fenced, from Bartley 2014c)	\$3,196/km/yr	Medium-High
Managing grazing distribution	Prevention of erosion from gullies, scalds or other at risk areas			
C to B class ²	Training (workshops) most landholders will do this work themselves. Erosion Management Plan Measures implemented: -Road drains -Whoabouys -Infrastructure for spelling (covered elsewhere)	\$10,000/farm (\$0.55) based on discussion with Scott Wilkinson after workshop results deemed excessive	\$500/farm (\$0.03/ha/yr)	Medium
Managing grazing distribution	Erosion stabilisation			
C to B class ²	Fencing off as per discussion with Scott Wilkinson	\$9,000/km	\$450/km	Low

¹ Average farm size assumed to be 18,290 ha.

² D-C costs were not discussed at the workshop, so assumed to be the same as C-B in the absence of information.

Table 3. Description of required capital expenditure items for the scenarios to transition to each management class in horticulture. Source: Roberts et al. (2016).

Management class transition	Key practices	Description of items needed Upfront costs \$/farm ^A , (\$/ha)	Description of items needed Maintenance costs \$/ farm/yr (\$/ha/yr)	Level of non-profit related barrier (Low, Medium, High)
Soil management	Cultivation, tillage and ground cover			
C to B class ²	Changes to existing implements, tines, rippers, discs. 3 point linkage discs, changes to tines and GPS. In the future might need to purchase new equipment. - Control traffic - need to change row configuration and work out what suits implement and farming system.	\$110,00/farm (\$500/ha/yr) (\$20,000 to make changes to existing equipment and \$30,000 / GPS, assumed 3 per farm).	\$9,550/farm (\$43/ha/yr). Assumed as base station annual fee \$550/yr and \$9,000/yr to maintain 3 GPS systems including training.	High
Fallow management				
C to B class ²	Need to mulch 2 – 4 times per season. A mulcher rather than slashing is better.	\$20,000/farm for a mulcher (\$91/ha/yr)	\$16,000/farm (\$43/ha/yr)	Medium
Nutrient management	Application, rates, timing and calibration			
C to B class ²	Multiple fertiliser applications, base application and follow up application through fertigation based on soil and plant tests	No upfront costs	\$60,000/farm for fertilisers (\$273/ha/yr)	Low-Medium
Runoff management	Rates, scheduling and uniformity			
C to B class ²	Laser levelling, sediment traps. Drainage redirection	Assumed \$1.45 million/farm (\$6,600/ha/yr)	\$660/ha/yr assumed	Medium-High

¹ Average farm size assumed to be 220 ha

² D-C costs were not discussed at the workshop, so assumed to be the same as C-B in the absence of information.

Table 4. Upfront costs for the base-case Burdekin INFFER analysis. Source: Roberts et al. (2016).

Budget Item	\$ required in the first 5 years of the program	Annual maintenance \$ required
1. Incentive payments in horticulture to shift to B practices (nutrients, sediments, pesticides).	15,531,500	1,852,800
2. Incentive payments to sugarcane growers (Smith, 2015) to shift to B practice (nutrients, sediments, pesticides) plus recycle pits in 50% area in BRIA, 20% area in Delta.	112,602,800	0
3. Incentive payments for furrow irrigation in sugarcane to shift from D to C practice in 23% of the BRIA area and 30% of Delta.	23,700,000	1,185,000
4. Incentive payments to shift to B practice hillslope management in grazing lands throughout the region.	250,329,500	17,166,800
5. Gully stabilisation incentive payments in grazing lands in Bowen Broken Bogie, Upper and Lower Burdekin catchments (B practice gully management). Includes fencing and basic management such as stick traps, cost \$9,000/km). Applied to 60% of gully length in the whole region.	176,018,800	8,800,900
6. Waterway management incentive payments in Bowen Broken Bogie and Upper Burdekin catchments. Includes fencing on 50% of all streams in these catchments (3,439km waterways).	82,193,100	8,219,300
7. Program management: - Upfront: 4 FTEs @\$150k/year - Maintenance: 2 FTE/year @\$150k/year	3,000,000	300,000
8. Horticulture extension: - Upfront: 1.4 FTE @\$150k/year (1 FTE/50 growers - Maintenance: 0.7 FTE/year@\$150k/year	1,050,000	105,000
9. Sugarcane extension: - Upfront: 11 FTEs @\$150k/year (1 FTE/50 growers) - Maintenance: 5.5 FTE/year @\$150k/year	8,250,000	825,000
10. Grazing extension: - Upfront: 16 FTEs @\$150k/year (1 FTE/40 graziers) - Maintenance: 8 FTE/year @\$150k/year	12,000,000	1,200,000
11. Research to fill knowledge gaps and innovation	3,000,000	
Total costs	687,675,700	39,654,800



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