FINAL REPORT

Costs of achieving the water quality targets for the Great Barrier Reef

July 2016

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Foreword

The Great Barrier Reef (GBR) is arguably Australia's most iconic natural asset. But virtually all of the relevant science indicates that the GBR is in decline.

While there has been a significant increase in resources dedicated to the protection of the GBR in recent years, particularly in addressing rural runoff with voluntary practice change programs, it is recognised that these alone will not be enough to meet the water quality targets. Therefore, there is an urgent need to better understand the broad magnitude of investment required and the actions and approaches that are most likely to be cost effective, in order to inform changes to the long-term management of the GBR.

This document summarises the key findings from a project to:

- Estimate the costs of undertaking a number management action based solutions sets designed to make significant progress towards the 2025 reef targets (i.e. a 20 per cent reduction in anthropogenic end-of-catchment fine sediment loads for Mackay Whitsunday and Burnett Mary with a 50 per cent reduction in the Fitzroy, Burdekin and Wet Tropics catchment by 2025; a 50 per cent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen (DIN) for Mackay Whitsunday and Burnett Mary catchments and an 80 per cent reduction in the Burdekin and Wet Tropics catchments by 2025)
- Identify potentially more efficient pathways to achieve those targets using total and marginal abatement cost curve approaches.

We have undertaken a review of the project and are pleased to provide our comments on this version of the report. We note that our review complements an internal peer review by DEHP (completed) and a second national and international peer review process planned prior to the report's release in July.

We comment on four aspects of the project: the uniqueness of the project, the project team, the methodology adopted, and the emerging results.

1. The project is ground breaking in that it represents the first detailed attempt to establish comprehensive and robust estimates of the range of potential costs to meet the 2025 GBR targets.
2. A very strong multi-disciplinary team has been assembled to work on this project. It is noteworthy that they have built on the significant data, models and knowledge already generated by many professionals working on GBR management in numerous organisations, all of whom have been so willing to contribute their own pieces of the puzzle to this ambitious, internationally-significant attempt to synthesise and then prioritise so many different policy options and locations.
3. Our review of the methodology adopted by the project team concludes it is relevant, robust and world's best practice.
4. Our review suggests the results from the project are well supported by evidence, and will be of great use to the Queensland and Federal governments, including in future costing and planning exercises.

We urge that the range of cost estimates in this report not be treated as definitive. They are based on the best available information at this time, but the real cost of achieving the targets will also be dependent on the decisions government, businesses and communities make to address the current and future challenges facing the GBR.

We also note that while the costs of achieving the targets may appear daunting at first, they are likely to be insignificant when compared to the long-term benefits of maintaining the resilience of the GBR.

Professor Barry Hart

Dr Neil Byron

July 2016

Executive Summary

This project was funded by the Queensland Government's Department of Environment and Heritage Protection (DEHP). The purpose of the project was to estimate the range of costs of achieving two key regional water quality targets for the Great Barrier Reef (GBR) catchments as set out in the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) (Commonwealth of Australia 2015). This has been done through an assessment of seven policy solution sets identified by DEHP for evaluation, their abatement contributions in meeting the regional targets, and their associated costs.

The targets selected were those needing to be met by 2025 for anthropogenic end-of-catchment fine sediment loads and dissolved inorganic nitrogen (DIN). These are:

- A 20 per cent reduction in anthropogenic end-of-catchment fine sediment loads for Mackay Whitsunday and Burnett Mary with a 50 per cent reduction in the Fitzroy, Burdekin and Wet Tropics catchment by 2025.
- A 50 per cent reduction in anthropogenic end-of-catchment DIN for Mackay Whitsunday and Burnett Mary catchments and an 80 per cent reduction in the Burdekin and Wet Tropics catchments by 2025.

In addition, this report also estimates the costs of achieving a number of interim targets (i.e. 50% and 75% of the stated targets).

The seven policy solution sets selected by DEHP for investigation were land management practice change, improved irrigation practices, gully remediation, streambank repair, wetland construction, changes to landuse (including conversion to conservation uses) and improvements in urban stormwater management.

A consistent process has been used across GBR catchments to evaluate the cost effectiveness of alternative investments for delivering specific regional water quality targets. The process builds on and extends approaches used in recent evaluations of the cost-effectiveness of narrower ranges of policy options to achieve water quality targets in GBR catchments. The approach uses physical modelling approaches typically used for estimating reduction in pollution loads attributable to policy solution sets and economic analysis based on marginal abatement cost curve (MACC) and total abatement cost curve (TACC) approaches. By bringing these two sets of quantitative analyses together it is possible to determine a least cost pathway to achieving regional targets. Given the inherit uncertainties in input data, a range of costs has been established for actions within each policy solution set and the total costs of achieving regional targets.[1]

The evaluation provides a strong science based approach, based on the best information available, upon which future impact and cost-effectiveness evaluations can be built. The study also highlights the need for greater innovation and research and development to validate new practices that could reduce the overall economic cost for society. The accuracy of the estimates is constrained by available data, resource constraints on this project, and the impact that policy design and implementation will have on the final costs. It is therefore suggested that the results are viewed as being indicative and illustrative only in any future application for policy work and investment towards meeting the Reef 2050 Plan targets. Furthermore, the variance in cost estimates reinforces the need to establish a cohesive suite of innovative policies that can ensure the targets are met at the lowest economic cost.

[1] The costs included are the capital costs, operational and management costs, transaction costs, program management costs and enforcement costs of each action, net of any increase in revenue.

Why are the figures in this report different to the figures in the Draft for Comment Report produced in May 2016?

In developing the final costings for this project, we first considered the completion of the full set of solutions and costed these accordingly against an agreed 2013 baseline linked to the Reef Source Catchments Models.

Subsequent to the Draft for Comment Report, further analysis was then undertaken to add in all of the relevant reported achievements in the period of 2009 to 2013 (State of Queensland 2014). This reduced the total volume of abatement required, and hence, the cost.

In addition, in the Draft for Comment Report, we included the full cost of the last step of policy solution set actions needed in each region to meet the relevant regional Reef 2050 Plan, even where this would result in overshooting the target. We have now adjusted the modelling so that regional targets are met exactly. This has significantly reduced the need for some of the very expensive abatement actions, particularly streambank and gully erosion actions in the Fitzroy, and therefore the cost.

These adjustments in the modelling result in a total estimated cost of $8.2 billion. Importantly these adjustments reinforce the need to ensure regional targets are robust and not set in isolation. Our research has found that in virtually all regions, the final few percent of abatement often account for a very high percent of the total cost of abatement.

Headline results

Key headline results from the analysis are:

- Our analysis indicates a clear investment pathway, which is consistent with, and extends recent work linked to the policy solutions sets.
- Our analysis indicates the policy solution sets assessed in this analysis can meet the two water quality targets in most of the GBR catchments. In some areas such as the Wet Tropics (fine sediment and DIN) the relevant policy solution sets and the actions contained within them (as currently defined) cannot be applied widely enough, or they simply cannot address the scale of load reductions required to meet the targets. Meeting targets in this region will require an expansion of the scope of possible policy solution sets and/or actions.
- This analysis only considered a relatively narrow suite of policy solution sets. Other variations and combinations of the current policy solution sets, and indeed other policy solution sets or actions outside the scope of this analysis, also warrant further investigation.
- The cost estimate of the current policy solution sets to meet the regional Reef 2050 Plan targets for the GBR requires a significant increase in investment from current levels. The project sought to estimate the costs out to 2025 to meet the fine sediment and DIN regional targets for the GBR using the current policy solution sets. The total costs for the regions investigated is estimated at $8.2B. This includes $7.8B for achieving the fine sediment targets in four of the five regions investigated. For DIN, the total cost is estimated at $0.4 billion to achieve the targets, also in four of the five regions investigated. For the Wet Tropics, the current solution sets only achieve 75% of the DIN target and 80% of the fine sediment target, and will require additional solutions. The relative breakup of these across the regions evaluated is indicated in Summary Table 1.
- In addition, the costs of meeting 50% and 75% of the regional Reef 2050 Plan targets have been calculated and these are also presented in Summary Table 2. The cost of achieving 50% of this load reduction is $623M and the cost of achieving 75% of this target is $3.86B. These are significantly lower than their proportional contribution to the full target would suggest. This is because the lower targets can be met through a broader selection of lower unit cost actions.
- It should be realised that there is significant uncertainty in the costs estimates due to the availability, variability and quality of data used to generate these estimates.
- Failure to increase current levels of investment could result in costs that are higher than the most likely estimate. Efficient policies should result in costs closer to, or potentially lower than, the most likely estimate.

- There is significant variance on the marginal abatement costs for the different policy solution sets and their actions. For most regions, significant progress towards targets could be achieved at a relatively low cost. However, as the abatement targets are approached, policy solution sets with significantly higher marginal costs are often required, and the total cost of achieving the target increases significantly. This reinforces the need to implement low cost investments now and identify how we can enhance the efficiency of other measures as policies and programs are rolled out. This is a prudent strategy.
- Our analysis shows that the efficient policy solution sets are actually regionally specific. Therefore, policies, regulations and decisions need to be cognisant of regional circumstances and the efficient pathway to achieve targets for specific regions and loads. Generic Reef-wide and inflexible policies may inadvertently increase the cost of meeting the targets.
- Marginal costs of poorly managed future development are very high. All of the cost curves developed show sharp inclines as the targets are approached. Poorly managed development that creates a net increase in loads increases the volume of abatement required to meet the targets, forcing the community to invest into a circumstance where either the targets are less likely to be met, or the cost of meeting the targets is significantly higher. This reinforces the need to ensure policies are in place to avoid and mitigate the impacts of future development.

The table below (Summary Table 1) shows the high-level region estimates of targets, loads, and the costs of meeting desired reductions in loads for both fine sediment and DIN. The costs for achieving 50 %, 75 % and 100 % of the target load reductions is also presented in Summary Table 2 and Summary Figure 1.

Summary Table 1. Cost of achieving the targets (100%) per region

	Fine sediment			DIN			Total Cost
Region	**Target Load to reef by 2025 (tonnes/yr)**	**Load delivered to reef at 2025 with policy solution sets in place (tonnes/yr)**	**Costs of policy solution set**	**Target Load to reef by 2025 (tonnes/yr)**	**Load delivered to reef at 2025 with solution sets in place (tonnes/yr)**	**Costs of policy solution set**	
Wet Tropics*	1,170,000	1,270,000	$242,000,000	3,280	3,740	$56,100,000	$298,000,000
Burdekin	2,160,000	2,160,000	$1,090,000,000	1,460	1,460	$304,000,000	$1,390,000,000
Mackay Whitsunday	539,000	539,000	$8,290,000	770	770	$28,800,000	$37,100,000
Fitzroy	1,030,000	1,030,000	$6,460,000,000				$6,460,000,000
Burnett Mary	1,110,000	1,110,000	$11,600,000	616	616	$1,730,000	$13,300,000
Totals	**6,009,000**	**6,110,000**	**$7,820,000,000**	**6,130**	**6,590**	**$391,000,000**	
Grand total						**$8,210,000,000**	

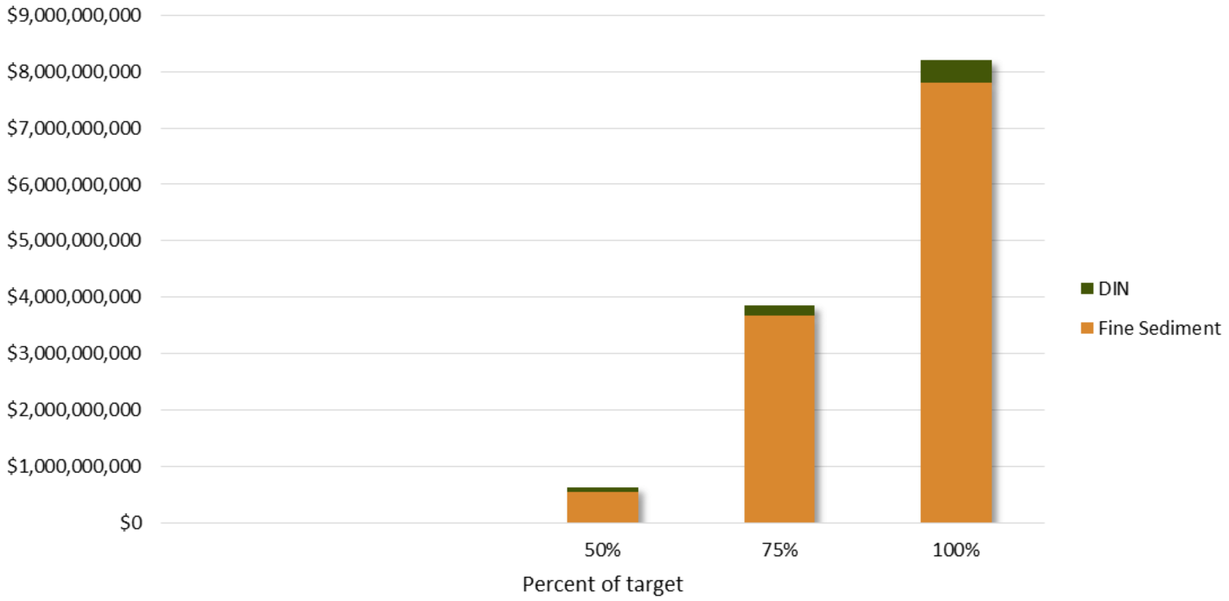
* In the Wet Tropics only 75 percent of the DIN target and 80 percent of the fine sediment target can be achieved based on the policy solution sets modelled

Summary Table 2. Costs of meeting 50%, 75% and 100% of the targets in each region

Fine Sediment	**Total Cost**	**Total Cost**	**Total Cost**
Region	**50% of target**	**75% of target**	**Full target**
Wet Tropics *	$48,600,000	$126,000,000	$242,000,000
Burdekin Dry Tropics	$8,240,000	$553,000,000	$1,090,000,000
Mackay Whitsunday	$660,000	$3,960,000	$8,290,000
Fitzroy	$476,000,000	$2,980,000,000	$6,460,000,000
Burnett Mary	$4,760,000	$8,160,000	$11,600,000

DIN	**Total Cost**	**Total Cost**	**Total Cost**
Region	**50% of target**	**75% of target**	**Full target**
Wet Tropics *	$29,200,000	$56,100,000	$56,100,000
Burdekin Dry Tropics	$55,900,000	$126,000,000	$304,000,000
Mackay Whitsunday	$55,800	$2,770,000	$28,800,000
Burnett Mary	$0	$741,000	$1,730,000
Total for 5 regions	**$623,000,000**	**$3,860,000,000**	**$8,200,000,000**

* In the Wet Tropics only 75 percent of the DIN target and 80 percent of the fine sediment target can be achieved based on the policy solution sets modelled



Summary Figure 1. *Steps to target – fine sediment and DIN costs whole of GBR (except Cape York)*

The scale of investment required is commensurate with the scale of the challenge. The catchments flowing into the GBR lagoon are some of Australia's largest, with the Burdekin catchment alone almost double the size of Tasmania. Across catchments like the Burdekin, the extent of ecological repair work required is extensive. And as with any asset management program, the costs of delivering successful asset management, asset repair, asset renewal and asset maintenance is both expensive and ongoing. Natural assets are no different. The necessary science and implementation techniques required to deliver this asset management program do exist, although further effort is required to improve current investment processes and policy choices that minimise the cost of meeting the targets. Furthermore, the scale of investment required will also be dictated by the policies and investment approaches adopted to meet the regional targets.

Importantly, the key tools developed during this project (a meta-model based on the outputs from the Department of Natural Resources and Mines' Reef Source Catchments Models and the abatement curves) will be able to support future policy and investment decision making processes linked to the long-term protection of the GBR. Key project learnings can also inform other GBR planning, prioritisation and investment-related processes.

The regional capacity required to deliver the necessary on-ground works within the timeframe is also considered to be a key issue. This project has not assessed whether it is technically or politically feasible or socially acceptable to implement the policy solution sets. Further work is required to consider what can be practically achieved within the required timeframes, current governance structures and existing capacities of program delivery partners.

It should be noted that the policy solution sets investigated here only address some of the catchment-based issues placing pressures upon the GBR. Clearly other significant issues such as climate change (warmer water, increased extreme weather events) and other catchment-based factors such as landuse intensity and land clearing all impact the Reef's health. However, these were not the focus of this costings project.

In completing this work, we have identified some key findings, which we believe should be considered in relevant future works within the GBR catchments. These are:

- For some regions and their respective targets, achieving the final few percentage of the abatement target accounted for a significant proportion of the cost. Therefore, the targets need to consider cost-effectiveness and the marginal abatement gains as targets are approached. It also reinforces the need to ensure targets are robust and reflect regional assimilative capacities for loads into the marine environment and likely thresholds.
- Land practice improvement was nearly always the most cost-effective solution and should be considered first in most cases. However, in many regions, land management improvements alone are insufficient to meet the targets and more costly actions are also required.
- When implementing any actions, it is very important to consider the sequence they are delivered in, as the most cost-effective solution may not be the one that needs to be delivered first. In some circumstances more expensive on-ground actions are required as prerequisites to more cost effective actions later. Furthermore, to actually achieve stated abatement targets, the sequencing and packaging of actions and overall policy solution sets becomes vital as the inclusion of some actions may exclude the opportunities to adopt others (e.g. there is no point in enhancing nutrient practices on land that would need to be retired in order to actually meet the abatement target). This requires a slight departure from the typical use of abatement curves when designing efficient policies as the policy solution sets are not mutually exclusive.
- There are likely to be trade-offs between regions where more cost-effective actions could be delivered in one region in preference to another, but only if looking across the whole of the GBR. This would require considering the implications of what those trade-offs mean in terms of local and regional outcomes, as well as impact to the GBR.

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Abbreviations

Alluvium	Alluvium Consulting Australia Pty Ltd
AEB	Annualised Equivalent Benefit
DEHP	Department of Environment and Heritage Protection
DIN	Dissolved Inorganic Nitrogen
DNRM	Department of Natural Resources and Mines
DSITI	Department of Science, Information Technology and Innovation
ERT	Ecologically Relevant Target
GBR	Great Barrier Reef
LTSP	Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan)
MACC	Marginal Abatement Cost Curve

NRM	Nature Resource Management
OGBR	Office of the Great Barrier Reef
P2R	Paddock to Reef Program
RSCM	Reef Source Catchment Models
TACC	Total Abatement Cost Curve
WQIP	Water Quality Improvement Plan
WST	Water Science Taskforce

1 Introduction

1.1 Project background and objectives

A consortium led by Alluvium Consulting Australia Pty Ltd (Alluvium) was engaged by the Department of Environment and Heritage Protection (DEHP) to provide an assessment of the marginal as well as total costs and water quality benefits (effectiveness) for different policy interventions (or actions within seven policy solution sets) to achieve regional Great Barrier Reef (GBR) water quality targets. The targets adopted for this project are based on the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) for Dissolved Inorganic Nitrogen (DIN) and fine sediment only (Commonwealth of Australia 2015). These were defined by DEHP as:

- A 20 per cent reduction in anthropogenic end-of-catchment sediment loads for the Mackay Whitsunday and Burnett Mary regions with a 50 per cent reduction in the Fitzroy, Burdekin and Wet Tropics regions by 2025. This study focussed on the fine fraction (<16µm) of Total Suspended Sediment (TSS) and is referred to throughout this report as fine sediment.
- A 50 per cent reduction in anthropogenic end-of-catchment DIN loads for the Mackay Whitsunday and Burnett Mary regions and an 80 per cent reduction in the Burdekin and Wet Tropics regions by 2025.

The Reef 2050 Plan is the overarching strategic document for GBR water quality outcomes, which has been adopted by both the Queensland and Australian governments. Figure 1 shows the geographic area of the Reef regions. Cape York was not included in this assessment as it was considered by DEHP to be of relatively low risk in relation to the two pollutants assessed.

Figure 1. *Catchments of the Great Barrier Reef (State of Queensland, 2013)*

The project used a bio-economic modelling approach (integrated economic-ecological models, see for example Knowler, 2002) to initially determine the costs and effectiveness for all the actions within the seven policy solution sets for fine sediment and DIN abatement. The project then sought to determine the most cost effective combination of actions from across the policy solution sets (represented by total abatement and marginal cost curves) to meet the regional Reef 2050 Plan targets for fine sediment and DIN within each of the Reef regions. The costs to meet the targets in their entirety (100%) are calcualted, as well as the costs to reach key steps (50% and 75%) towards the targets. The original Terms of Reference (ToR) for this project are outlined in Attachment A1.

DEHP identified that the information developed during this project would be used to:

- Inform required investments over the next 10 years by governments, the community and industry
- Improve the understanding of the cost effectiveness of the various interventions included in the policy solution sets
- Inform the prioritisation of interventions to provide further support for the work that has already been done
- Provide a shared understanding of the types of actions that could be required to meet the Reef 2050 Plan targets for all level of governments and the Natural Resource Management (NRM) bodies.

The intent of the project was to provide an understanding of the estimated total investment required to meet the regional Reef 2050 Plan targets based on the assumption that the actions within the policy solution sets achieve their full adoption success and full pollution abatement impact by 2025. It is recognised that in reality, there are numerous constraints to meeting the targets, such as existing technological and implementation capacity, delivery arrangements, and time lags between on-ground actions and pollution abatement. Additionally, while the best available biophysical and costings information has been used, there are a range of uncertainties and necessary assumptions that underpin this work, particularly given that this is the first time this type of assessment has been attempted at this scale. As such, it is suggested that the results are viewed as being indicative and illustrative only in relation to any future application for policy work and investment towards meeting the Reef 2050 Plan targets.

In addition, a focus for the project was to provide information to the GBR Water Science Taskforce (Taskforce). The Taskforce provided its Final Report to the Queensland Government in May 2016. This report provided recommendations on the best possible approach and investment priorities for an additional $90 million over the next four years towards meeting the Reef 2050 Plan water quality targets for DIN and fine sediment. The results of this project have shown that the funding required to meet the regional Reef 2050 Plan targets is well beyond what is currently allocated.

The seven policy solution sets used to guide the assessment in this project were:

- Policy solution set 1: Land management practice change for cane and grazing
- Policy solution set 2: Improved irrigation practices for cane
- Policy solution set 3: System repair - Gully remediation
- Policy solution set 4: System repair - Streambank repair
- Policy solution set 5: Wetland construction in cane growing areas
- Policy solution set 6: System repair - Changes to landuse
- Policy solution set 7: Urban stormwater management.

An example of the actions from within the policy solution sets defined for certain geographic areas, include moving landholders from D to C, then C to B, then B to A class practice change for policy solution set 1. Other actions, for example, under policy solution set 3, are reducing gully erosion by 10%, 25%, 50% and 100%. For the policy solution set 5, the actions were installing 25, 50 and 100 hectares of constructed wetlands/pollutant traps.

1.2 Report structure

This report is divided into two main sections. The main body of the report (sections 1-6) is designed to be read as a stand-alone, high-level summary of the overall project approach, results and conclusions. The Attachments section of the report provides greater detail on the approach taken in relation to the regional Reef 2050 Plan targets, the policy solution sets (including the costs and pollution abatement efficacy for actions within the policy solution sets), and the bio-economics meta-modelling approach including the determination of the most cost effective combination of actions (represented by cumulative cost curves) to meet the regional Reef 2050 Plan targets. A brief description of each section of the report is provided below:

- **Section 1** provides an introduction to the project
- **Section 2** provides an overview of the project management approach
- **Section 3** provides an overview of the project methods and the key project components
- **Section 4** provides an overview of the results and a narrative of the major findings
- **Section 5** provides a summary of the conclusions reached as a result of the project work
- **Section 6** provides a list of the references utilised in the main body of the report (sections 1-5). References used in the development of each policy solution set are contained within each relevant document in Attachment B.
- **Attachment A** outlines the Terms of Reference for the project
- **Attachment B** outlines in detail the seven policy solution set statements
- **Attachment C** provides supporting information on the process utilised to develop both the Marginal Abatement and Total Abatement Cost Curves.

2 Project management

2.1 Project governance

The project was overseen by a DEHP Internal Review team, involving key Office of the Great Barrier Reef (OGBR) staff, as well as staff from other areas within the Department including Environmental Policy and Planning (Reef Water Quality) and the Queensland Wetland Program. This team provided overall project governance, with a smaller core team from within the OGBR providing day to day project management. A project implementation plan was developed. This included weekly meetings with DEHP, regular project team meetings, and peer review of the project methodology and outputs as they were developed.

The project was also subject to two formal peer review processes. The first involved comments on a draft report by members of the DEHP Internal Review team, as well as other Queensland Government staff from the Department of Natural Resources and Mines (DNRM), the Department of Agriculture and Fisheries (DAF) and the Department of Science, Information Technology and Innovation (DSITI). The second peer review process involved comments on a subsequent version of the report by national and international experts. Economists from the Taskforce also provided highly valuable input and guidance throughout the project, including during both peer review processes.

Additionally, as part of providing information to the Taskforce, the following engagement occurred with the Taskforce, which also helped inform the project:

- An initial project presentation to the Taskforce in March 2016. This provided a general outline of the seven policy solution sets (and their actions) and the proposed approach to modelling and costing.
- A project progress workshop held in April 2016. This workshop involved both interested Taskforce members and the DEHP Internal Review Team. It provided a presentation of the seven policy solution sets including the approaches used to determine the pollution efficacy and costs of actions within the policy solution sets.
- Additional discussions sessions with the Taskforce economists in April 2016.
- A presentation to the Taskforce in early May 2016. This provided a high-level presentation on preliminary project results and also provided an opportunity to discuss the peer review processes for the project.

2.2 Project milestones and tasks

The key project stages and their major outputs are outlined in Figure 2 below and were structured as follows:

1. Stage 1 - Project Inception: This stage commenced in February 2016. It produced a project implementation plan. This included a project inception workshop with DEHP and the Alluvium project team resulting in refined definitions for each of the policy solution sets, agreement on the targets to be used, the baseline for the cost and pollutant reductions to be assessed against, the meta-modelling approach and related costing process. Key outcomes from the project inception workshop are outlined below in *Section 2.3*.
2. Stage 2 - Main Project Part A: This involved the preparation of detailed overviews of each policy solution set, as well as papers outlining the approaches to the targets, modelling and costings. This included the determination of the costs and effectiveness of the actions (within the policy solution sets) and the approach to be used for the cumulative cost curves for the selected actions to meet the regional Reef 2050 Plan targets at the region scale. This stage involved work from March through to May 2016.
3. Stage 3 - Main Project Part B: This stage produced the meta-model outputs, including the cumulative cost curves to provide the total cost to meet the regional Reef 2050 Plan targets, which resulted in the final project report. This stage included the two peer review processes and concluded in July 2016.

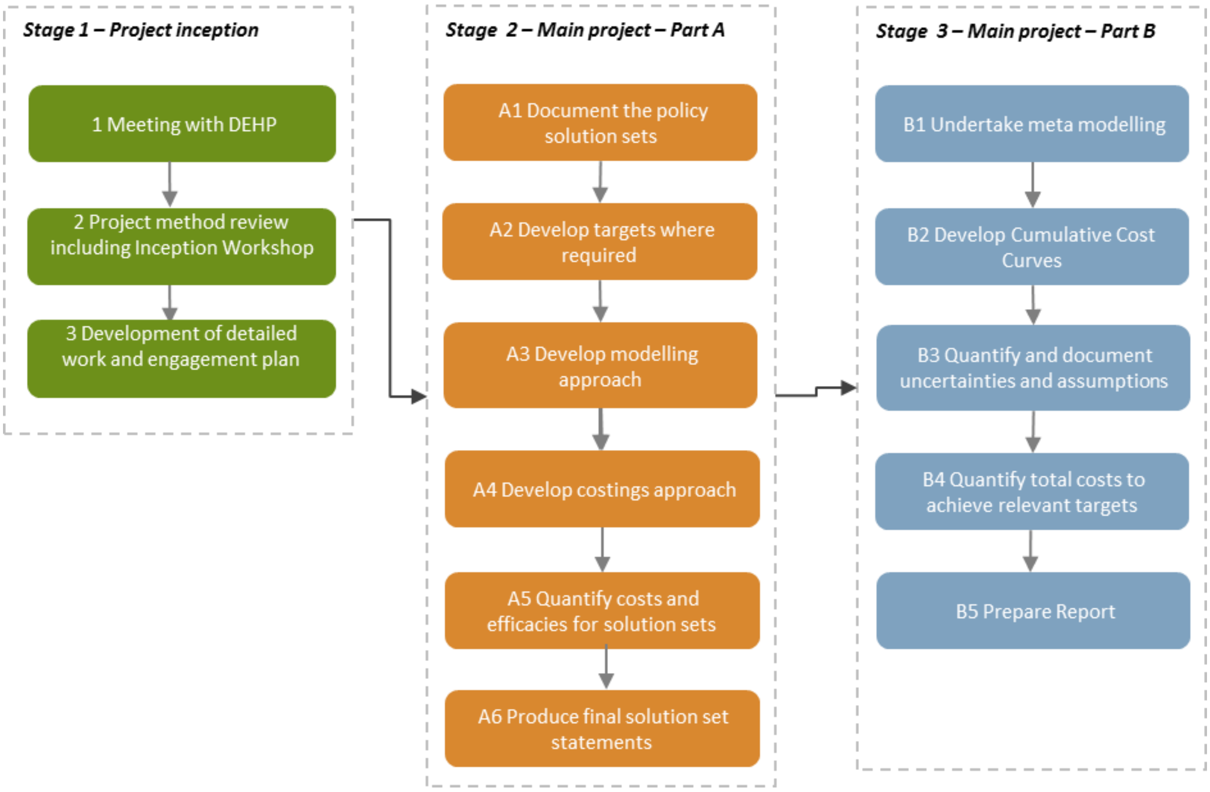


Figure 2. *Key project milestones*

2.3 Project inception workshop

The project used a bio-economic modelling approach incorporating the best available biophysical, costings and pollution abatement information for actions within the seven policy solutions. The modelling approach involved the development of a meta-model to capture relevant bio-physical and pollution abatement information. The costings process and meta-model were integrated into a single platform which was used to determine the marginal and total costs (represented by cumulative cost curves) of actions across the policy solution sets to meet the regional Reef 2050 Plan targets.

A project inception workshop was held in February 2016 to provide clarity around the following related project areas:

- The actions within the seven policy solution sets that were initially provided by DEHP were refined based on expert opinion including their geographic extent. The policy solution sets are summarised in Section 3.3 of this report and outlined in detail in Attachment B.
- To provide greater clarity and a clear end point for costing purposes, DEHP provided the following interpretation of the regional Reef 2050 Plan water quality targets, which were to be compared to a 2009 baseline:
    1) A 20 per cent reduction in anthropogenic end-of-catchment sediment loads for the Mackay Whitsunday and Burnett Mary regions with a 50 per cent reduction in the Fitzroy, Burdekin and Wet Tropics regions by 2025. As previously indicated, this study focussed on the fine fraction (<16µm) of Total Suspended Sediment (TSS) and is referred to throughout this report as fine sediment.
    2) A 50 per cent reduction in anthropogenic end-of-catchment DIN loads for the Mackay Whitsunday and Burnett Mary regions and an 80 per cent reduction in the Burdekin and Wet Tropics regions by 2025.
- Cape York was not included as it was considered by DEHP to be of relatively low risk in relation to the two pollutants assessed for this project.

- Importantly it was agreed that the project must appropriately acknowledge the achievements that have previously been made in relation to progress towards the GBR water quality targets since 2009, as reported by the Queensland and Australian Governments in the 2012 and 2013 GBR Report Cards (State of Queensland, 2014). These achievements are based on the Reef Source Catchments Models, which have been adopted and developed by the Queensland Government to generate information on a range of biophysical processes across the Reef regions related to landuses and pollutant loads.
- While a 2009 baseline has been used to incorporate previous achievements, a modelling baseline of 2013 was selected based on advice from the custodians of the Reef Source Catchment Models (DNRM and DSITI). The 2013 baseline superseded previous assessments of the baseline condition and is unlikely to change significantly in the future even with further modelling improvements (Waters pers comm, 2016). The 2013 baseline for other relevant conditions (water resource management, gully density, etc.) was assumed to remain constant for these assessments with relevant changes included only where they were associated with a policy solution set (e.g. land management practice change).
- Given the timeframes available for the project, it was not possible as originally intended to base the biophysical modelling component of the project on a modification and re-run of the Reef Source Catchment Models. It was therefore determined that the best way to utilise the models would be to produce "meta-model" spreadsheets utilising the results from the Reef Source Catchment Models, which allowed the project to incorporate information consistent with outputs from the models.

The objectives, proposed calculation basis and estimation approach for the cumulative cost curves were also agreed to. As the process was further refined, the integration of the costings process with the meta-model was also resolved. It was agreed the project would estimate cumulative curve cost ranges (confidence intervals) for reductions in anthropogenic fine sediment and anthropogenic DIN load reductions, with separate cost curves developed for each pollutant.

3 Project Method and Components

3.1 Project overview

An overview of the bio-economic modelling approach (and the integration of this approach with the costings process) is outlined in Figure 3. This project converted the percentage regional Reef 2050 Plan targets into tonnes per annum to cost abatement in terms of dollars per tonne removed per annum to meet the regional Reef 2050 Plan targets.

Sections 3.2 and *3.3* provide information on the regional Reef 2050 Plan targets as well as the seven policy solution sets, which includes costs and pollution abatement efficacy for actions within the policy solution sets. *Section 3.4* provides an overview of the meta-model used for capturing relevant biophysical data and pollution abatement efficacy. *Section 3.5* provides an overview of the costings process, which was integrated with the meta-model. *Section 3.6* outlines the process utilised to sequence policy solution sets and the actions within them to meet the relevant targets.

The integration of the meta-model and costing model allowed for the determination of the costs and effectiveness for all the actions within the seven policy solution sets for both fine sediment and DIN abatement. This can be used to determine the most cost effective actions for fine sediment and DIN abatement. The costing process also includes the development of the marginal and cumulative cost curves for meeting the regional Reef 2050 Plan targets within each of the GBR regions assessed.

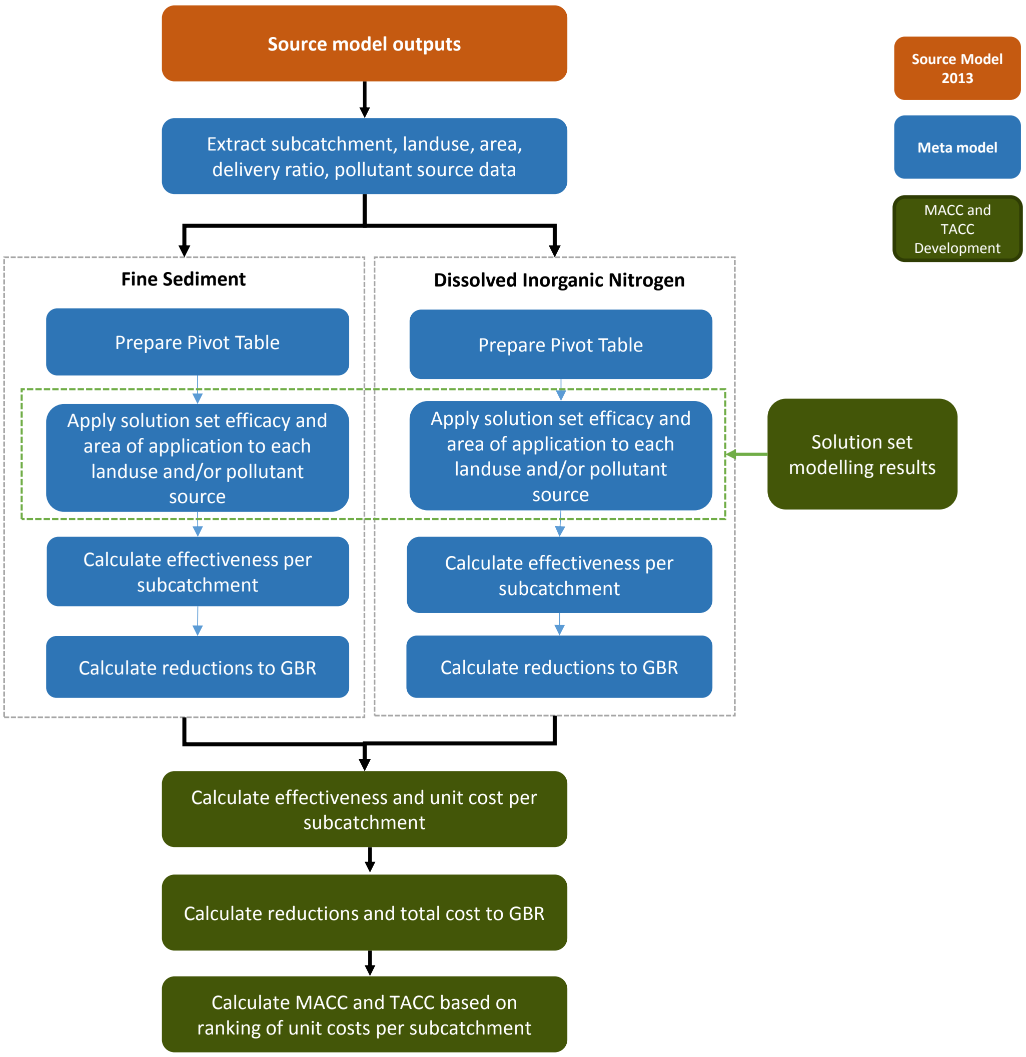


Figure 3. *Overview of modelling and costings approach adopted in this project*

3.2 Water quality targets

As outlined in *Section 1*, DEHP provided a definition of the regional Reef 2050 Plan targets for this project, shown below in Table 1. The scope of this project only includes the assessment of fine sediment and DIN. Other pollutants such as Particulate Phosphorus, Particulate Nitrogen and herbicides were not included in the ToR for the project.

Table 1. Percentage reductions of DIN and Fine sediment to be achieved by 2025 in this project

Region	DIN % reduction	Fine sediment % reduction
Wet Tropics	80	50
Burdekin	80	50
Mackay Whitsunday	50	20
Fitzroy	N/A	50
Burnett Mary	50	20

The following clarification was also provided by DEHP:

- Cape York was not included as DEHP considered this region relatively low risk in relation to fine sediment and DIN export.
- The targets are a combination of the Reef Water Quality Protection Plan 2009 targets and the Queensland government's election commitments as reflected by the Reef 2050 Plan targets. The information provided in the plans has been interpreted as:
    - DIN: The Reef Water Quality Protection Plan 2009 identifies the priority catchments as the Burdekin and the Wet Tropics. Therefore, it is assumed that the higher target will apply to those areas. The lower target will apply to the remaining relevant catchments – Mackay Whitsunday and Burnett Mary.
    - Fine sediment: The Reef Water Quality Protection Plan 2009 identifies the priority catchments as the Burdekin and Fitzroy. The government's election commitment also included Wet Tropics as a priority catchment for suspended sediment. Therefore, it is assumed that the higher target will apply to those three regions. The lower target will apply to the remaining relevant catchments – Mackay Whitsunday and Burnett Mary.

Calculating the target reductions from 2009 requires consideration of the estimated load reductions achieved between 2009 and 2013 (note that the 2013 baseline is used for all other calculations, so only achievements to this point are taken into account). The achievements reported in each region for DIN and fine sediment between 2009 and 2013 are included in Table 2 and Table 3, expressed as the annual average reduction in the anthropogenic load between 2009 and 2013. The following steps were taken to account for these achievements:

- Subtraction of the percentage reduction from the target reductions defined for the purposes of this project. For example, for Wet Tropics DIN, the target defined by DEHP is an 80% reduction in the anthropogenic DIN load. Given that a 13% reduction in the anthropogenic load was reported between 2009 and 2013, this would assume that the reduction required is 80-13 = 67%.
- Calculation of the reduction required in tonnes from the anthropogenic load.

The load reductions used in this assessment are shown in Table 2 and Table 3.

The ToR for this project outlined the following task relevant to the targets:

- *Decide the targets for each catchment. Most WQIP's are setting their own ecologically relevant targets except for Mackay-Whitsunday. These can be used as the basis for assessment. An ecologically relevant target will need to be developed for Mackay-Whitsunday.*

This work related to this task is covered in an Addendum to this report entitled "Defining basin-specific targets and ecologically relevant targets for the Great Barrier Reef".

Table 2. Calculation of the DIN load reductions required, accounting for modelled achievements 2009 to 2013. Reductions were published in the Reef Report Card 2012-2013 (State of Queensland, 2014)

Region	2013 baseline modelled total DIN load (tonnes/yr)	2013 baseline modelled anthropogenic DIN load (tonnes/yr)	DIN target reduction amount	Total reduction required (tonnes/yr)	New baseline to meet DIN target (tonnes/yr)	Reduction 2009 - 2013 (%)	Revised DIN load reduction required (tonnes/yr)
Wet Tropics	5,050	2,210	80%	1,770	3,280	13%	1,490
Burdekin	2,450	1,240	80%	988	1,460	14%	818
Mackay Whitsunday	1,240	935	50%	468	770	24%	245
Fitzroy	1,840						
Burnett Mary	874	516	50%	258	616	31%	98
Total				3,480			2,650

Table 3. Calculation of the fine sediment load reductions required, accounting for modelled achievements 2009 to 2013. Reductions were published in the Reef Report Card 2012-2013 (State of Queensland, 2014)

Region	2013 baseline modelled total fine sediment load (tonnes/yr)	2013 baseline modelled anthropogenic fine sediment load (tonnes/yr)	Fine sediment target reduction amount	Total reduction required (tonnes/yr)	New baseline to meet fine sediment target (tonnes/yr)	Reduction 2009 - 2013 (%)	Revised fine sediment load reduction required (tonnes/yr)
Wet Tropics	1,670,000	990,000	50%	495,000	1,170,000	13%	371,000
Burdekin	3,690,000	3,070,000	50%	1,530,000	2,160,000	16%	1,050,000
Mackay Whitsunday	611,000	357,000	20%	71,400	539,000	9%	38,200
Fitzroy	1,790,000	1,530,000	50%	765,000	1,030,000	4%	701,000
Burnett Mary	1,260,000	782,000	20%	156,000	1,110,000	3%	134,000
Total				3,020,000			2,290,000

3.3 Policy solution sets

The geographical extent of each of the policy solution sets is shown in Figure 4. A summary of the key elements of each policy solution set is provided in Table 4. Attachment B provides detailed information on each of the seven policy solution sets including:

- Policy solution set description and context – background information and definition of the solution set.
- Method – how the policy solution set and the actions within it were assessed.
- Management actions (or practices) within each solution set including their costs and efficacy.
- Assumptions and limitations – to enable any future costing processes to be more robust, each policy solution set documents the key assumptions and limitations the project team encountered developing the policy solution set and its associated costs. These relate to issues including data availability and consistency across the GBR catchments, as well as the short project timeline, the relatively short timeframe to meet the targets and the initial definition of the current policy solution sets.

- References – a summary of the literature drawn on during the development of the policy solution sets.

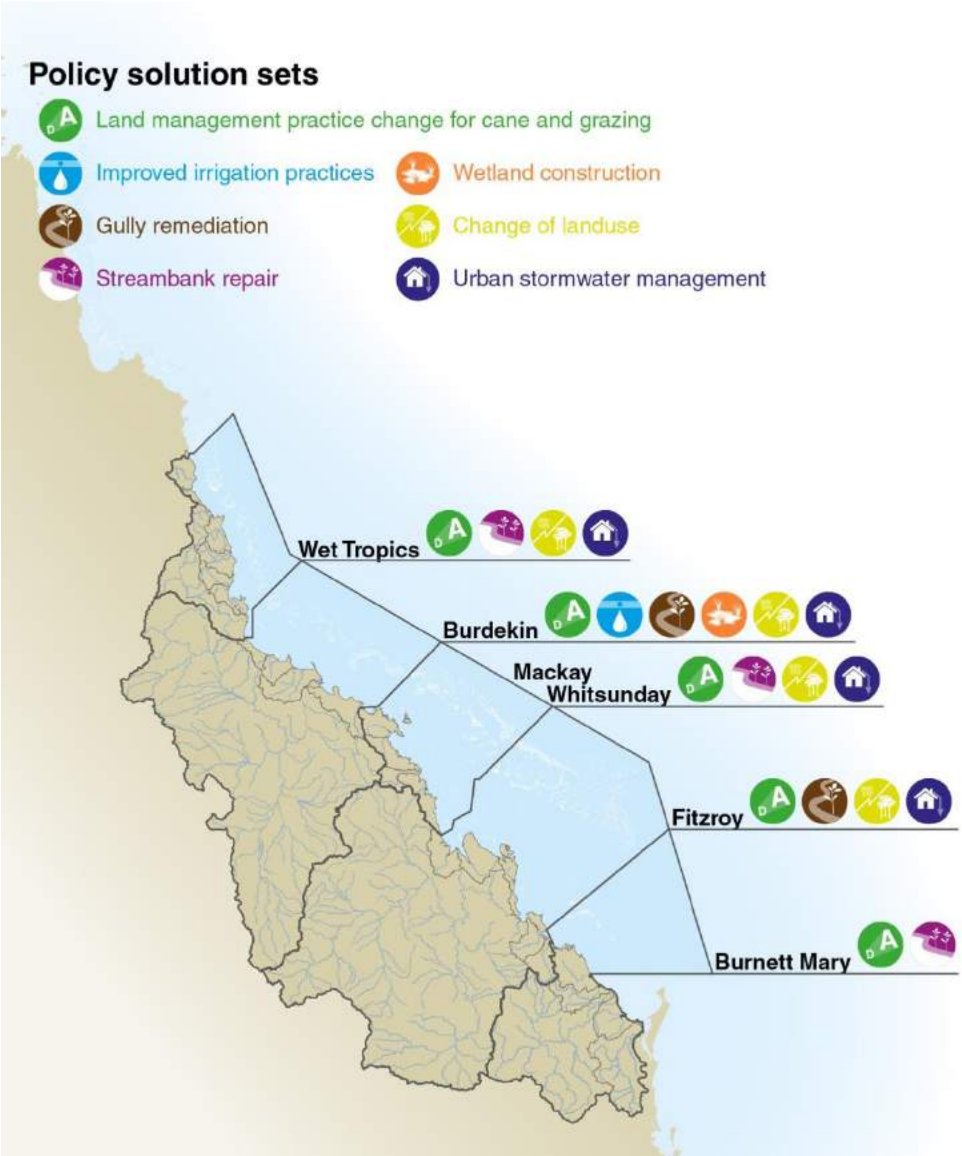


Figure 4. *The seven policy solution sets selected for investigation and their geographic extent across the relevant GBR NRM regions*

Table 4. Policy solution set summary

Policy solution set	Definition	Key management actions	Key costing parameters	Key assumptions/limitations
1. Land management practice change for cane and grazing	Achieving: a) 100% adoption of A level management practices across all catchments with grazing (Burnett Mary, Burdekin, Fitzroy, Mackay Whitsunday, Wet Tropics) b) 100% of cane growers to meet B class practice across all catchments with a sugarcane industry (Burnett Mary, Burdekin, Mackay Whitsunday, Wet Tropics) Target pollutant: Fine sediment and DIN	Management of hillslope erosion in grazing lands and nutrient management in sugarcane Utilising the P2R Program process for assessing progress toward the targets, and the levels of management practice adoption derived from the 2013-2014 Report Card (Queensland Government, 2015)	Private costs - cost to landholders for purchasing capital equipment and modification of production system Impact on farm profit Extension cost - costs of achieving reductions in sediment and nutrients instigated through government provided extension services	Changes of economic costs, discount rates and time period for analysis between regions Estimating minimum and maximum private and extension costs does not reflect the diversity and complexity of the individual catchments included in this assessment
2. Improved irrigation practices	Adoption of higher efficiency irrigation practices in 10%, 20%, 50%, 70% and 100% of the Lower Burdekin sugarcane area Target pollutant: DIN only	Utilising the P2R Program Water Quality Risk Framework Adoption data is available and interpreted through several sources: a) P2R b) NQ Dry Tropics Reef Programme water quality grants database c) Industry technical advice from the INFFER workshops undertaken for the Burdekin WQIP	Capital expenditure items for the nutrient, tillage and irrigation transitions The program costs include, extension, regulation and monitoring and evaluation	Differences between cost effectiveness, farm size, loss pathways and current adoption between the BRIA and Delta areas of the Lower Burdekin Fertigation, although a highly efficient fertiliser application technique has not been costed in this policy solution set as there is limited data on the economics of these practices in sugarcane in the Lower Burdekin
3. System repair: Gully remediation	Reducing gully erosion by 10%, 25%, 50% and 100% in the Burdekin and Fitzroy River catchments Target pollutant: Fine sediment only	a) Revegetate gully feature, reduce concentrated surface runoff and stock management b) Stick traps c) Rock chute grade control d) Check dams grade control e) Gully Plug dams f) Earthworks	On-ground project cost – capital and maintenance Impact on (farm) profit e.g. reduced stocking rates Program cost – cost to government, regional NRM bodies and industry that is incurred via incentives, extension, regulation and monitoring and evaluation	Accuracy of the gully mapping - rapid assessment indicates both underestimation and overestimation of gully lengths No trajectory information so difficult to determine if gully erosion is accelerating or decaying

Policy solution set	Definition	Key management actions	Key costing parameters	Key assumptions/limitations
4. System repair: Streambank repair 	Remediating 5% and 10% of streambank length in the Mary, O'Connell, Tully and Herbert Rivers Target pollutant: Fine sediment only	a) Creation of buffer zone (50m) b) Revegetation c) Monitoring and maintenance d) Other engineering approaches*	Opportunity costs: Foregone production Management costs: Fencing, revegetation, Maintenance, Off-site watering	Recognised limitations of the Dynamic SedNet model within Source modelling to assess erosion rates at the reach scale * These have not been costed as part of this exercise although they can be highly important to reduce project risks – requires improved understanding of hydraulic and geomorphic processes
5. Wetland construction 	Installation of 25, 50 and 100 hectares of constructed wetlands/pollutant traps in suitable areas of sugarcane Target pollutant: DIN only	a) Vegetated wetland constructed to capture surface runoff from cropping lands b) Recycle pit to trap irrigation tailwater in dry season conditions from cane lands in the Lower Burdekin region. c) Recycle pit downstream of cropping lands sized to treat surface runoff from the upstream catchment. d) A combination of (b) and (c)	Site preparation Establishment of new plants Maintenance for exotic plants Property management for site establishment	Very little relevant data from actual monitoring and evaluation for the likely end of system water quality benefits in the GBR region of constructed wetlands and recycle pits
6. System repair: Changes to landuse 	Voluntary retirement of: (a) 10%, 30%, 50% of small cane properties operating at D class practice or in flood zoned areas in the Burdekin, Wet Tropics and Mackay Whitsunday Catchments. (b) 5%, 10%, or 20% of grazing lands in the Bowen, Fitzroy, and Burdekin regions as identified in the WQIPs. Target pollutant: Fine sediment and DIN	a) Retiring cane lands to grazing lands with A level management to reduce the quantity of DIN b) Shift cane and grazing lands to a level of biodiversity conservation management with weed and pest control but no remediation works. c) As for (b) but including remediation works (primarily aimed at reducing sediment loss as quickly as possible)	Market value of land Management costs including upfront costs of land rehabilitation On-going maintenance costs	Assumptions include: a) Opportunity cost is assumed as the price of land based on a combination of its market value and DNRM globe mapping valuations There is no difference between freehold and leasehold land b) Land is permanently retired from agricultural landuse c) Landholder retains the land albeit with a binding covenant for biodiversity conservation purposes for grazing land and low density grazing for retired sugarcane land.

Policy solution set	Definition	Key management actions	Key costing parameters	Key assumptions/limitations
7. Urban stormwater management 	Urban growth pollutant loads in the local government areas of Cairns, Townsville, Mackay and Rockhampton. Permutations include: a) Policy solution set 7a: Greenfield development with no mitigation b) Policy solution set 7b: Greenfield development mitigated by effective Erosion and Sediment Control (ESC) and Water Sensitive Urban Design (WSUD) c) Policy solution set 7c: Residual loads from 7b offset by investment in rural diffuse treatments Target pollutant: Fine sediment and DIN	For ESC this includes including establishing drains, sediment basins, sediment fences, topsoil and hydromulch, rocks/gravel for driveway access, kerb inlet protection For WSUD this could include combinations of bioretention basins / pods, underground detention tanks and detention basins as modelled using MUSIC	Urban growth: Qld Government estimates for detached and attached dwelling growth For ESC costings determined for small and large projects For WSUD Capex and Opex figures for detached and attached dwellings Transaction and administration costs linked to design, assessment and approval	Key assumption include: Historical (previous 10 years) development patterns are a reasonable representation of future development patterns. The suite of WSUD and ESD solutions identified and previously modelled are an effective urban response. The modelling parameters in MUSIC are a reasonable reflection of the efficacy of on-ground practices. Transaction, management and regulatory costs previously calculated for SEQ are a reasonable reflection of those costs in the GBR. Key data gaps include: Lack of location-specific soil types, slopes etc Information on compliance is very limited

3.4 Meta-modelling approach

The catchments draining to the GBR have been modelled biophysically through various iterations of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (P2R program). The P2R program is a collaboration involving governments, industry bodies, regional NRM bodies, landholders and research organisations. It is jointly funded by the Queensland and Australian governments. A significant level of investment has been made in this program and the resultant modelling is identified as being best practice in the catchment modelling industry. As part of the efforts to bring this modelling into this project, we have had to consider how best to represent and use the outputs of the P2R work to quantify the likely effectiveness of management interventions and the costs associated with their implementation.

This section outlines the approach used for both understanding how effective the actions within the policy solution sets were, and how to determine the least cost in achieving the regional Reef 2050 Plan targets.

Method

The modelling undertaken as part of the P2R program has been constructed in the Source modelling framework. This framework, developed by the former eWater Cooperative Research Centre, has the ability and flexibility to represent a range of landscape processes and simulate their interaction with rainfall and runoff. The complexity of the models is considerable in order to capture the range of processes across the GBR region and such models require a high degree of skill and resources to construct, run and analyse. An example screenshot of one of the P2R models provides an indication of the model complexity (Figure 5).

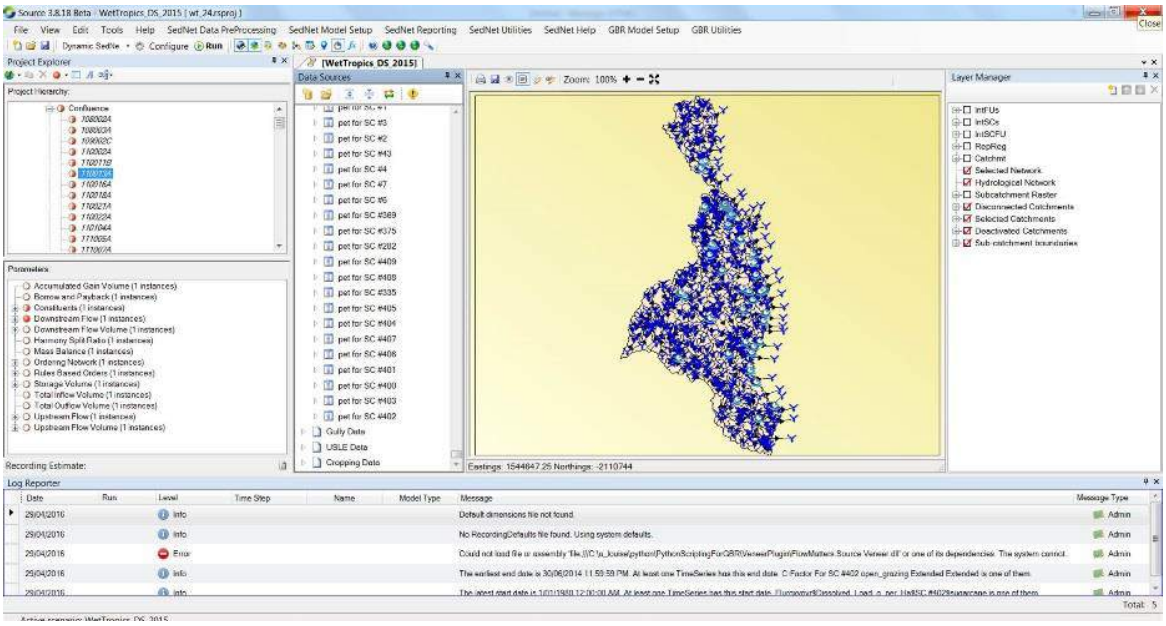
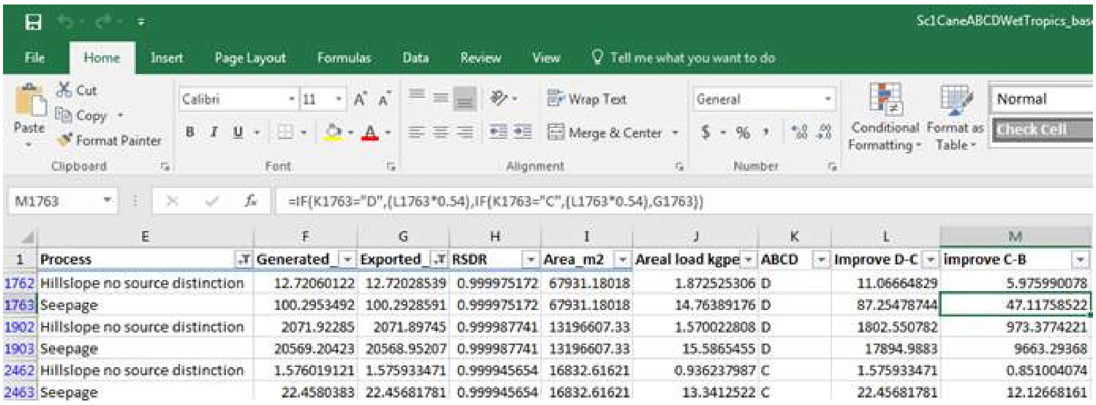


Figure 5. *A Paddock to Reef Source catchment model*

Given the timeframes available for this project, it was determined early on that it would be unlikely that the relevant Reef Source Catchment Models for the GBR region could be modified and run before the project was due to be completed. We therefore considered that the best way to utilise the models would be to produce "meta-models" of the results from the Reef Source Catchment Models so that we could interact with the results without having to re-run the models each time.

The meta-model is basically a spreadsheet of results from the Reef Source Catchment Models that contain model outputs categorised by individual sub-catchments and the source of pollution. This was generated by extracting the constituent of interest (fine sediment or DIN) from the model results into a separate data file. An example of the output is shown in Figure 6.



=IF(K1763="D",(L1763*0.54),IF(K1763="C",(L1763*0.54),G1763))

	Process	Generated_	Exported_	RSDR	Area_m2	Areal load kgpe	ABCD	Improve D-C	improve C-B
1762	Hillslope no source distinction	12.72060122	12.72028539	0.999975172	67931.18018	1.872525306	D	11.06664829	5.975990078
1763	Seepage	100.2953492	100.2928591	0.999975172	67931.18018	14.76389176	D	87.25478744	47.11758522
1902	Hillslope no source distinction	2071.92285	2071.89745	0.999987741	13196607.33	1.570022808	D	1802.550782	973.3774221
1903	Seepage	20569.20423	20568.95207	0.999987741	13196607.33	15.5865455	D	17894.9883	9663.29368
2462	Hillslope no source distinction	1.576019121	1.575933471	0.999945654	16832.61621	0.936237987	C	1.575933471	0.851004074
2463	Seepage	22.4580383	22.45681781	0.999945654	16832.61621	13.3412522	C	22.45681781	12.12668161

Figure 6. *Example Meta-model*

From this meta-model, we then manipulated the loads from each sub-catchment by the change in area of a specific landuse, or a change in load from a particular pollutant source within a particular sub-catchment for a specific landuse. This gave us the flexibility to model the actions within the policy solution sets without having to re-run the Source models.

A flow chart of the process has been previously discussed (see Figure 3) to illustrate how the meta-model worked, including in relation to other components of this project.

This process allowed us to provide information that was consistent with the Reef Source Catchment Model outputs, was straight-forward to modify or change, and with some minor adjustments, is suitable for use beyond this project if further work is required to further assess policy solution set performance. Separate meta-models were developed for the Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary regions.

Data availability

We have been very fortunate to work closely with the P2R modellers to obtain the Reef Source Catchment Model results. These outputs are based on the 2013 (baseline) model runs and as such are bound by the same data limitations that are present for the Reef Source Catchment Models. We extracted the model results for the Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary into separate meta-models and used each of these to inform the overall effectiveness and ability of each policy solution sets (and their actions) to achieve the regional Reef 2050 Plan targets.

Assumptions and limitations

The meta-model outputs are assumed to be representative of the Reef Source Catchment Model outputs but are not to be used as a replacement for them. By necessity, we simplified the Reef Source Catchment Model outputs and applied management practice efficacy to loads from each pollutant source. This is not the same as within the Reef Source Catchment Model, where the effects of the management practice on a particular pollutant generation and/or transport process would be simulated to determine a change in load, rather than just applying a percentage change to the load.

3.5 Abatement costing process

The abatement costings estimate the costs of the investments needed to deliver the actions within each of the policy solutions sets. Abatement costs are the cost that are incurred to achieve the fine sediment and DIN pollution reduction. The cost modelling estimates two types of abatement cost curves that are useful for informing investment decision making and prioritisation in GBR catchments:

- Marginal abatement cost curve (MACC): The marginal cost of abatement measures the additional cost that is incurred to abate an additional amount of pollution (fine sediment or DIN). A MACC is graphical representation of the marginal cost of abatement for different investments. The graph is ordered left to right from the lowest cost to the highest cost opportunities. Investments that fall below the horizontal axis are cost savings, while investments above the line involve net costs (see for example Figure 3 in Department of Environment and Heritage Protection (2016)).
- Total abatement cost curve (TACC): A TACC is simply a graphical representation of the total costs incurred to abate pollution. It is calculated by adding together the total cost of abatement for each investment, i.e. by multiplying the marginal cost per unit of abatement by the total amount of abatement achieved for each policy solution set. The graph is ordered left to right from the lowest cost to the highest cost opportunities. Investments that fall below the horizontal axis are cost savings, while investments above the line involve net costs.

Marginal Abatement Cost Curves (MACCs) have previously been developed for sugarcane and grazing in the GBR Catchments (Beher, Possingham, Hoobin, Dougall, & Klein, 2016; DEHP, 2016; Star, et al., 2013). The approach in this project builds on elements drawn from these and earlier evaluations (such as the WQIPs) as well as the project teams' experience. The basis of the calculations for both the MACCs and TACCs developed for this project is outlined below. It should be noted that in reality when the relevant programs are rolled out the MACCs and TACCs achieved will not be step-wise changes as shown in this project, rather the curves will show a continuous increase in marginal costs.

TACC calculation basis

As stated above, a TACC is simply a graphical representation of the total costs incurred to abate pollution calculated by adding together the total cost of abatement for each investment, i.e. by multiplying the marginal cost (MAC) per unit of abatement by the total amount of abatement achieved for each solution set. As a result our discussion in this method section focuses on the calculation basis of the MAC and MACC.

MACC calculation basis

We have estimated MACC ranges (minimum, most likely and maximum values) for reductions in anthropogenic fine sediment and anthropogenic dissolved inorganic nitrogen (DIN) load reductions achieved by 2025. We have developed separate MACCs for fine sediment and DIN.

The MACCs measure incremental abatement at sink – e.g. the cost per unit of anthropogenic sediment load abated (not delivered) to the reef lagoon from sub-catchments in the regions defined in the solution sets and by 2025. This approach means the MACCs provide directly relevant insight to the costs of achieving Reef 2050 Plan targets, and the approach takes into account proximity effects and the role of water regulation infrastructure on sediment and DIN delivery ratios.

Adapting the notation in Star, et al. (2013) we are measuring for each solution set and each land unit the Annualised Equivalent Benefit (AEB):

$$\overline{\mathrm{CC}} = \frac{1}{N}\sum_{n=0}^{N}\left(\frac{\mathrm{Cost}\alpha\mathrm{CC}_{s,L,U_{1-0},b_{1-0}}}{\alpha\mathrm{CC}_{s,L,U_{1-0},b_{1-0}} * a * f * \mathrm{E}_{cl,dr,ae}} * \frac{1}{(1+r)^n}\right)$$

$\overline{\mathrm{CC}}$	**This is the Annualised Equivalent Benefit (AEB) – the average incremental abatement cost per unit (likely tonne) for the solution set and land area under examination over the assessment period over the 10 year period 2016-25.**

αCC	Is the land unit – this is the area that the condition change occurs (measured in a common unit of measurement such as hectares or length of streambank).
S	Sub-catchment, as defined the sub-catchment boundaries within the relevant Paddock to Reef Source model.
L	Land type as defined by the relevant Paddock to Reef Source model (hillslope, gully, streambank, direct).
U	Land with a particular landuse and $_{1\text{-}0}$ indicates change in land type (e.g. cane to grazing).
b	Is land condition and $_{1\text{-}0}$ indicates change in land condition (e.g. land class C to B or un-remediated and remediated gully).
a	Adoption success achieved as at 2025. This is the probability of adoption occurring by 2025 – i.e. the required practice change is adopted, given the type of practice change required and the likely policy tool that would be used, aggregated at $\alpha CC_{S,L,U_{1-0},b_{1-0}}$. For the solution sets in this report DEHP requested that adoption success was set at 100% - i.e. the value is set to 1. This means we assume full adoption and compliance by landholders who are required to change practices and behaviours. We have retained the adoption parameter in the final model and the MACC Excel spreadsheets so that these parameters can be varied in future work to examine the impact of changes in adoption success on marginal abatement costs and total abatement achieved. Adoption success / compliance is linked to the policy tool being used. As a guide where there are legally binding contracts attached to land title (e.g. a covenant) a score closer to 1 should be assigned in future evaluations. For all other riparian management contracts and for regulation a default score of around 0.8 could be assigned, unless there is a compelling reason to vary this based on knowledge of factors such as likelihood of landholder's non-compliance with standard conditions (e.g. a landholder area with a known poor 'track record' (suggested score of 0.5) or areas with predicted high ownership turnover (score of 0.6). For voluntary adoption the value can range from 1-0, and should be based on the private benefits that accrue to the landholder as a result of adoption. Where superior data or information is available for some solution sets and regions (e.g. from INFERR analysis from WQIPs, alternative scores could be used).
f	Practice efficacy success by 2025. This is the probability that the practice will be implemented with a defined policy framework but still not demonstrate the anticipated benefits (i.e. the efficacy risk), aggregated at $\alpha CC_{S,L,U_{1-0},b_{1-0}}$. Success here is distinct from adoption / compliance success. For example, a producer may fully comply with their practice change requirement but the expected outcomes may not occur could be because of technical reasons, farmer capacity or good ability to maintain the works or structures after they are put in (for reasons other than contract compliance). Programs could fall short of anticipated benefits for socio-political reasons, or program governance and delivery arrangements. For the solution sets in this report DEHP requested that practice efficacy success was set at 100% - i.e. the value is set to 1. This means we assume full efficacy. We have retained the practice efficacy parameter in the final model and the MACC Excel spreadsheets so that these parameters can be varied in future work to examine the impact of changes in practice efficacy success on marginal abatement costs and total abatement achieved. As a guide f=.1 (10%) for very low probability of practice efficacy success, f=.9 (90%) for very high probability of success for any of the specified reasons. The main reasons for the f value assigned should be clearly stated for each solution set. Where superior data or information is available for some solution sets and regions (e.g. from INFERR analysis from WQIPs) alternative scores could be used and calibrated to this rating scale.
E	Is the change in load per hectare (fine sediment or DIN) associated with the condition change. Sediment: is the unit of anthropogenic delivered fine sediment load. This is the fine sediment (<16µm) load derived under modern land management (as opposed to background longer term runoff) that reaches the reef lagoon, as modelled in Source. DIN: Dissolved inorganic nitrogen which is defined as the soluble, non-organic nitrogen transported from a range of sources such as direct surface runoff, groundwater, and processing of other components of the nitrogen cycle and delivered to the reef lagoon.
cl	Constituent load (tonne) represents the modelled load of fine sediment or DIN as derived by the relevant Paddock to Reef Source model.

dr	Delivery ratio describes the constituent load actually delivered to the GBR lagoon divided by that generated in the catchment. This accounts for processing that may occur as the constituent is transported down the river system network such as deposition, resuspension, decay and/or enrichment.
ae	Assumed efficacy the assumed performance of the management practice or restoration technique as defined by literature, monitoring, or expert knowledge in respect to the reduction of constituent load. Note this could take a value +/-1 because it is being modelled off the average in Source.
Cost	Is the total cost of improving the condition of each land unit. The total cost includes: (1) on-ground project cost – this is the cost of project work (capital and maintenance). (2) impact on (farm) profit – this is distinct from the on-ground project works cost. The profit impact could be positive, negative or nil. It measures the change in farm profit arising from the project going in – for example changing stocking rates may change farm input costs and revenue. For example van Grieken et al., (2011) for the Tully and Pioneer catchments found improving cane from D and C Class to B Class can improve profitability by reducing input costs. (3) transaction cost – this is the additional cost that the landholder incurs collecting their own information and in peer consultation about changing management practices. It includes direct costs and opportunity costs (of information time). It does not include technical advice from external parties. It includes time in extension and regulatory compliance activities. Extension is defined as: The additional cost the landholder incurs seeking and participating in agronomic, economic, construction or maintenance technical advice or capacity building. Regulatory compliance is the additional cost incurred by the landholder in complying with regulation, above and beyond the direct and indirect costs already identified. Given the complexities of costing this consistently across the other policy solution sets they have not been considered further here (and as a result set to zero where necessary in the costings approach), except for Policy solution set 7 where these costs are well known and documented. (4) program cost – this is the additional cost incurred because of implementing the project / program. For the solution sets in this report DEHP requested that program costs are the costs to achieve *the highest possible uptake of the required actions*. The costs include incentives, extension, regulation and monitoring and evaluation. Note here that the costs to achieve the highest possible uptake of required actions may not be the most efficient investment that will maximise environmental benefits for a fixed budget. This is because one action may achieve a higher level of uptake than another, but the costs of achieving additional actions are likely to rise over time, making achieving additional action progressively more expensive. DEHP may want to relax the highest possible uptake requirement in future evaluations. Note also that in the case of incentives, it is any incentive that needs to be paid to induce landholder participation above and beyond on-ground project cost and full compensation for change in farm profit. For example, incentives such as subsidised training can be offered in higher priority areas.
r	Is the real discount rate, which will be set at 7% based on Treasury guidelines[2].
n	The number of time periods that the AEB is calculated over. For this evaluation DEHP has requested that the AEB is calculated for 10 years from 2016-25. Achieving long-term abatement needs up-front capital investment. This means costs are front loaded but abatement benefits will, in many cases, continue beyond the 10 year window requested by DEHP. It also means that the AEB is higher than if the AEB was based on a longer timeframe, such as 30 years. For the purpose of this evaluation, the approach provides a correct estimate of the total cost of delivering the investments needed to achieve the policy solution sets by 2025.

The costing approach used in this evaluation includes four main types of cost that are discussed in more detail in Attachment C.1:

- On-ground project cost – this is the cost of project work (capital and maintenance).
- Impact on (farm) profit – this is distinct from the on-ground project works cost. The profit impact could be positive, negative or nil. It measures the change in farm profit arising from the project implementation. For example, changing stocking rates may change farm input costs and revenue. For example, van Grieken et al. (2010) for the Tully and Pioneer catchments found improving cane from D

[2] https://www.treasury.qld.gov.au/publications-resources/project-assessment-framework/paf-cost-benefit-analysis.pdf

and C Class to B Class can improve profitability by reducing input costs. For the purposes of this evaluation and in agreement with the Taskforce economists we have only included negative impacts on farm profit in the MACC and TACC presentation, as this highlights the costs that will be incurred. Where farm profit is modelled as improving due to shifting between D and C Class to B class in cane we note these in the discussion of the results.

- Transaction and administration cost – this was assessed for Policy solution set 7 only (Urban stormwater management) as the costs are well known and documented (see Attachment B.7). Given the complexities of costing this consistently across the other policy solution sets they have not been considered further here (and as a result set to zero where necessary in the costings approach).
- Program cost – this is the additional cost that is incurred from implementing the project / program. It was requested by DEHP that the program costs should be the costs to achieve the highest possible uptake of the required actions. The costs include incentives, extension, regulation and monitoring and evaluation.

Our approach explicitly recognises and assesses the variability in the potential efficacy of actions and their lifecycle costs (represented by MACC and TACC ranges). The aim is to provide some consistency with earlier approaches, transparency so backward calculation can be performed, and clear insights into where uncertainty and variability in the potential efficacy of actions and their abatement costs have greatest impact (on the marginal and total costs of pollution abatement for actions within each of the policy solution sets, and by region).

Importantly, this project allows for policy solution sets (and regions) with different levels of data and knowledge to be incorporated into a common analytical framework (see Figure 3). The MACCs and TACCs were built up using the Annualised Equivalent Benefit (AEB) using an adapted version of the approach in Star, et al. (2015). The process calculates the AEB for each policy solution set and region over a 30 year time horizon and measures incremental pollution abatement at sink (the GBR lagoon). We present separate MACCs and TACCs for fine sediment and DIN.

In this report the AEB for each policy solution set and region are presented graphically along with the annual quantity of pollution abatement achieved by 2025, assuming all investments occur as soon as possible, preferably within the next 24 months. Attachment C.1 includes discussion on why this is the preferred approach.

Our approach extends on the MACC developed previously for sugarcane and grazing in the GBR Catchments (DEHP, 2016; Beher, Possingham, Hoobin, Dougall, & Klein, 2016) and uses the best available data. The MACCs and TACCs in this report are underpinned by assumptions set out in Attachment C.1. The abatement cost curves address some of the limitations identified with earlier MACC assessments in the GBR, in particular that abatement is measured at the GBR lagoon rather than the farm gate, that abatement is evaluated at 2025, and that abatement includes the opportunity cost of land. Key limitations that remain include issues identified in earlier evaluations (DEHP, 2016). These include:

- Adoption success: the MACC and TACC assessment evaluates the likelihood of adoption of the required practice change occurring by 2025 and then 2035 given the economics of the practice, and the likely policy tool that would be used. Based on DEHP guidance, in all policy solution sets we assume that investments achieve their full adoption success by 2025. In reality, success could be less than this assumed level.
- Practice efficacy success by 2025: the MACCs and TACCs are based on progress towards achieving load reductions against the 2025 targets. Based on DEHP guidance, in all policy solution sets we assume that investments achieve their full pollution abatement impact by 2025. In reality, success could be reduced due to technical and implementation delivery constraints, socio-political reasons, project governance arrangements, farmer capacity, compliance with policies and programs, the ability to maintain works or structures after they are implemented, and because of exogenous risks e.g. cyclones or major flood events.

- Regional aggregation: the abatement costing and curves are based on the concept of 'representative farms' and 'representative actions' within regions and policy solution sets – i.e. the MACCs and TACCs are constructed based on estimated abatement costs that would be incurred to deliver works and measures within regions on average. This assumes away significant regional and farm enterprise heterogeneity (Star, et al., 2013; van Grieken, et al., Cost-effectiveness of management activities for water quality improvement in sugarcane farming., 2014). We know from earlier work that this heterogeneity means actual on the ground costs within regions for programs will deviate (potentially significantly) from these representative averages.
- Current costs and adoption success: the MACCs and TACCs are based on understanding of the current costs of investments required to deliver each of the policy solution sets and their adoption success, drawn from recent literature and experience in delivering these types of projects in the GBR previously. The significant scale and scope of the investments required to deliver the GBR water quality targets mean that economies of scale and scope could be achieved. Conversely, future program costs may be higher and adoption success lower than historically if current investment is securing the 'low hanging fruit' and future gains from practice change are not sufficiently large to motivate change (van Grieken, et al., Cost-effectiveness of management activities for water quality improvement in sugarcane farming., 2014). These issues have not been factored into the current evaluation. Because of the variability in costs across the actions we have deliberately used an informed range of input values and have then undertaken a sensitivity analysis to establish defendable estimates for the most likely, optimistic (best case) and pessimistic costs (worst case).
- The assumption that A,B,C,D land management practice leads to A,B,C,D land condition (due to time lags) has not yet been confirmed (DEHP, 2016).

Deriving costs for achieving 50% and 75% of the Reef 2050 Plan targets

To determine the costs of achieving 50% and 75% of the regional Reef 2050 Plan targets, each of the policy solution sets within each region was reviewed to determine how achieving 50% or 75% of the total load reductions required will change both the actions that may be needed and the costs of doing so.

The 50% and 75% points have been treated as distinct targets in themselves, not just a linear transition from 0% to 100% of the full regional Reef 2050 Plan target. This is an important distinction, as the costs to achieve a portion of the full targets may change significantly in some regions as some of the most cost-effective options could not be included as they were either incompatible with other options, or they would result in shortfalls in meeting the actual targets.

A good example of this is in the Burdekin region, where achieving the full regional Reef 2050 Plan target was achieved through irrigation efficiency improvements. While the cost-effectiveness of improving cane practice from D to C was better, the load reduction from doing this was too small (approximately $1/10^{th}$ of the irrigation improvement), and was no longer needed if irrigation improvement was implemented. To achieve 50% of the full regional Reef 2050 Plan target, a much smaller amount of improvement is needed after taking into account achievements to date, so the D to C improvements in cane practice now become appropriate. We have illustrated this conceptually below (Figure 7).

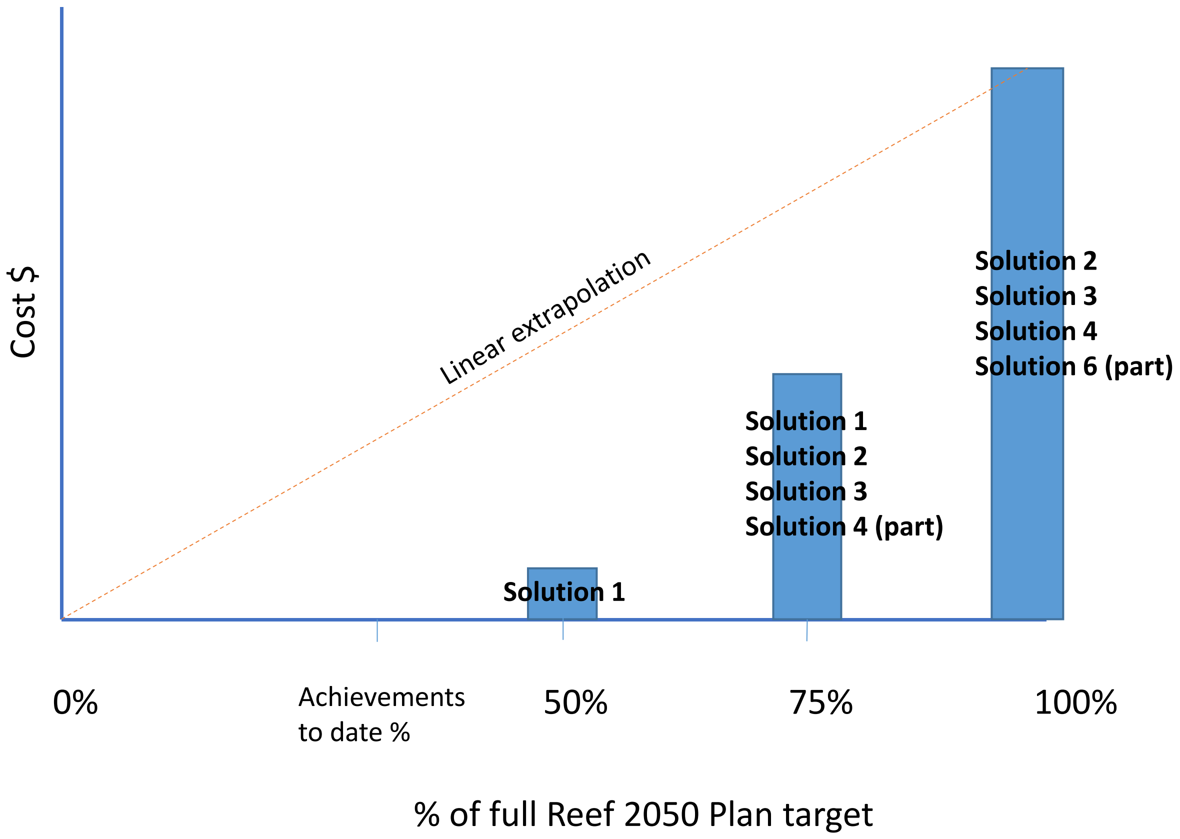


Figure 7. *Achieving 50% and 75% of Reef 2050 Plan targets*

This can have a significant impact on overall costs. Another issue that may also arise is that only delivering the policy solution sets and the actions within them to achieve 50% or 75% of the target may actually increase the overall costs to achieve 100% of the regional Reef 2050 Plan target if they are progressed sequentially. For example, if 50% and 75% of the target could be achieved through practice change only, but to achieve 100% would require retiring poor practice land, if the practice change had already occurred achieving 50% or 75%, then it would either no longer be worth retiring land and more expensive options may be needed, or the money expended in practice change may be wasted if the land is then retired. These issues all need to be accounted for in the revisiting of the policy solution sets and the actions required to achieve the targets.

To derive the costs, we therefore:

1. Reviewed the full list of policy solution sets and their actions in each region for both fine sediment and DIN.
2. Chose the most cost-effective suite of policy solution sets/actions to meet 50% and 75% of the regional Reef 2050 Plan target.
3. Considered the logical sequencing of these to reduce potential impacts on the costs to achieve the full target.
4. Pro-rata the last step to ensure that the 50% or 75% is achieved exactly, consistent with the approach used to achieve the full (100%) target.

3.6 Sequencing of actions across the policy solution sets

To determine the best group of least cost actions (from across the policy solution sets) to achieve the regional 2050 Plan targets, we had to look at the cost-effectiveness of individual actions in terms of the dollars per tonne removed, and then combine the actions into a logical sequence that actually achieved the relevant regional target. From this, we were then able to develop both performance curves that showed a logical sequence of actions, and the lowest cost package of actions and solutions to achieve the targets. It sometimes meant that in selecting a group of options, the cheapest option was not the first one to be accounted for. For example, in most catchments, the most cost-effective option was moving producers to a better land management practice. In terms of decision rules for identifying the list of solutions, the following approach was used:

- All options were ranked from most cost-effective to least cost-effective.
- Actions from the most cost-effective end were added until the load reduction target was achieved.
- In some cases, where the most cost-effective options did not achieve the targets, we had to select a more expensive option that then resulted in no longer needing some of the more cost-effective ones, because the lower cost ones did not provide enough load reduction. For example, if the most-cost effective option was practice change of D to C class practice, but the load reduction was minimal, then if the next most-cost effective option was land retirement and this delivered the full load reduction needed, then the first one would not be required.
- The actions were sequenced so that where landuse change was identified in the sets of actions to achieve the targets, it would be assumed to occur first, prior to improving the management practice of the original landuse. For example, if the result was to change a proportion of D class practice cane lands to conservation, then this was sequenced to occur first, with any remaining D class land then changed to improved land practice if that was part of the group of actions.

The final list of adopted actions was added together to determine both the cost and efficacy of the adopted actions for each region. Note that all options were treated as individual actions addressing either fine sediment or DIN. While it is highly likely that some options may result in reductions in both pollutants of interest, in most cases the loads predicted by the Source model were not significant for the other pollutant. An example of this is in the reduction of DIN for sugarcane through improved farm practice. Some of these practices would also result in a reduction in fine sediment, but the resulting reduction of the total load was minimal and was therefore not considered in the overall calculation.

4 Results and discussion

The following sections provide an overview of the key results from both the modelling and the abatement cost curve development exercises. They also provide links to the relevant regional Reef 2050 Plan water quality targets for the GBR.

The results outlined in *Section 4.2* of this report for each region are the minimum efficient suite of policy solution sets to meet the targets for that specific region based on the assessment of abatement efficacy and costs. If a specific policy solution set is not included for a region, that is because it is not part of the most cost-effective way to meet the targets in that particular region.

The results outlined in *Section 4.3* are the total policy solution sets required to meet both the regional targets and the broader GBR targets. These results are essentially the aggregate of the regional analyses. No trade-offs between regions have been assessed in this project as this is outside the project's scope. Furthermore, while trading off regional targets within a multi-regional target could be considered and would reduce overall costs, this would result in targets not being met in some regions. This would be inconsistent with the broader objectives of the Reef 2050 Plan and this project's ToR.

4.1 Meta-Model results

The Reef Source Catchment Models results were first divided up into fine sediment and DIN constituents, with specific sub-catchments, landuses, pollutant sources, generated load, exported load and a delivery ratio listed for each constituent. From this, a range of contextual information was derived which assisted in analysing the data further. This information is outlined below.

Contextual information for regions

Landuse areas

Using the meta-model, pie charts were created showing the proportion of landuses within the catchment as included in the Reef Source Catchment Model (Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12). Note that these landuse classes are combinations of those defined in the relevant landuse mapping (e.g. QLUMP) and then refined as determined by the regional stakeholders. As can be seen from these pie charts, the regions vary quite considerably in landuse proportions, though the Burdekin and the Fitzroy are broadly similar in being so dominated by grazing. It is these area proportions that have a large influence on how effective an action and/or policy solution set will be. For example, if there is a larger landuse proportion being acted on such as grazing, it would be expected to have a larger effect, although some landuses such as intensive agriculture (e.g. cane or horticulture) can have an impact much larger than their area might suggest within a region for particular pollutants.

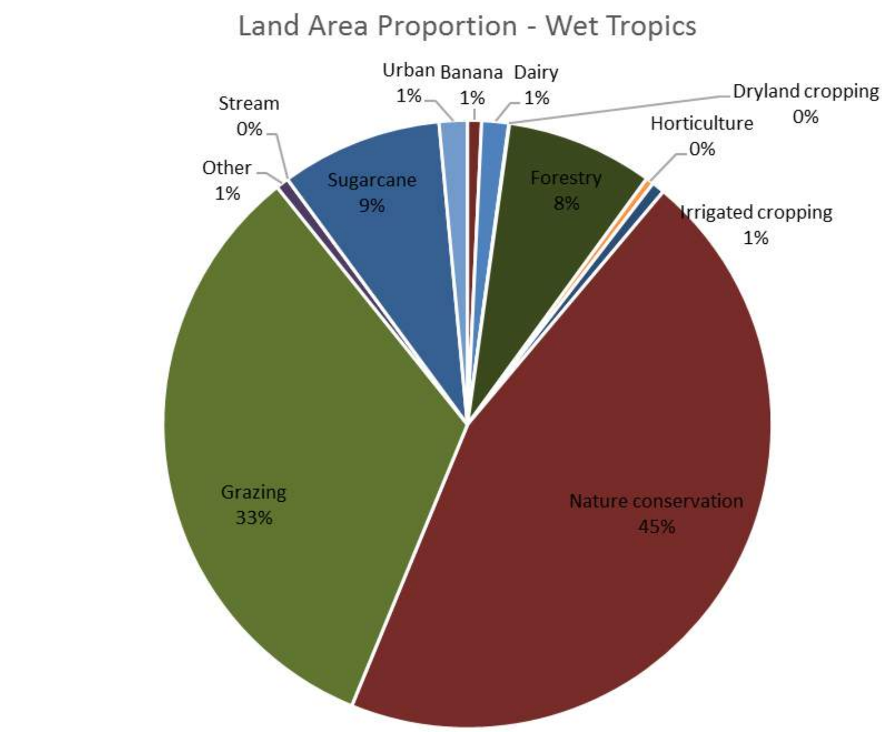


Figure 8. *Landuse proportions - Wet Tropics*

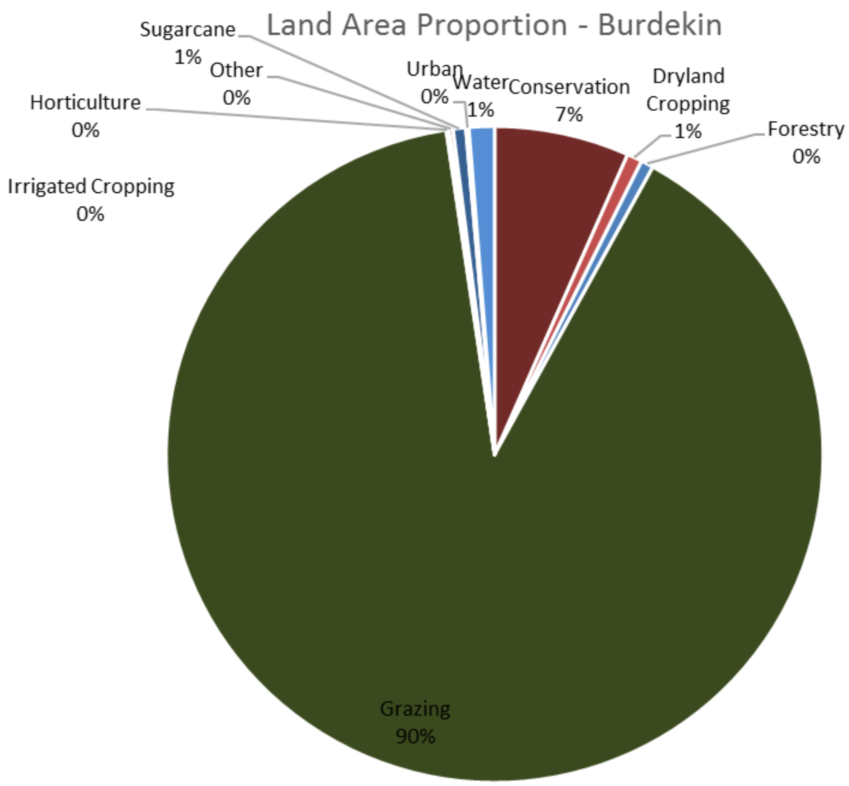


Figure 9. *Landuse proportions - Burdekin Dry Tropics*

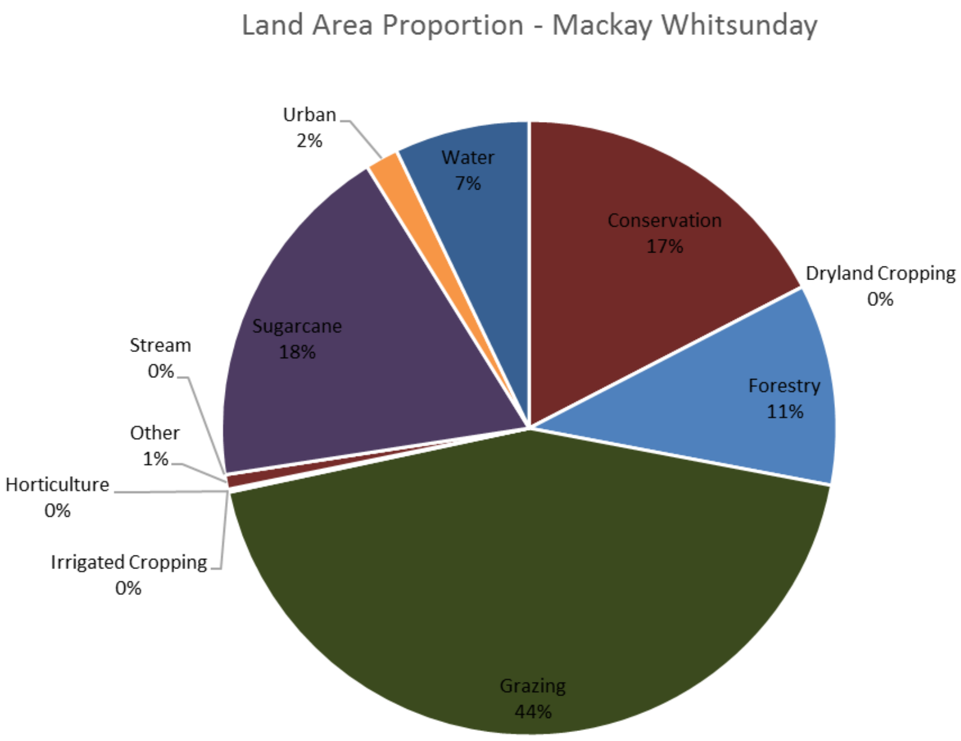


Figure 10. *Landuse proportions - Mackay Whitsunday*

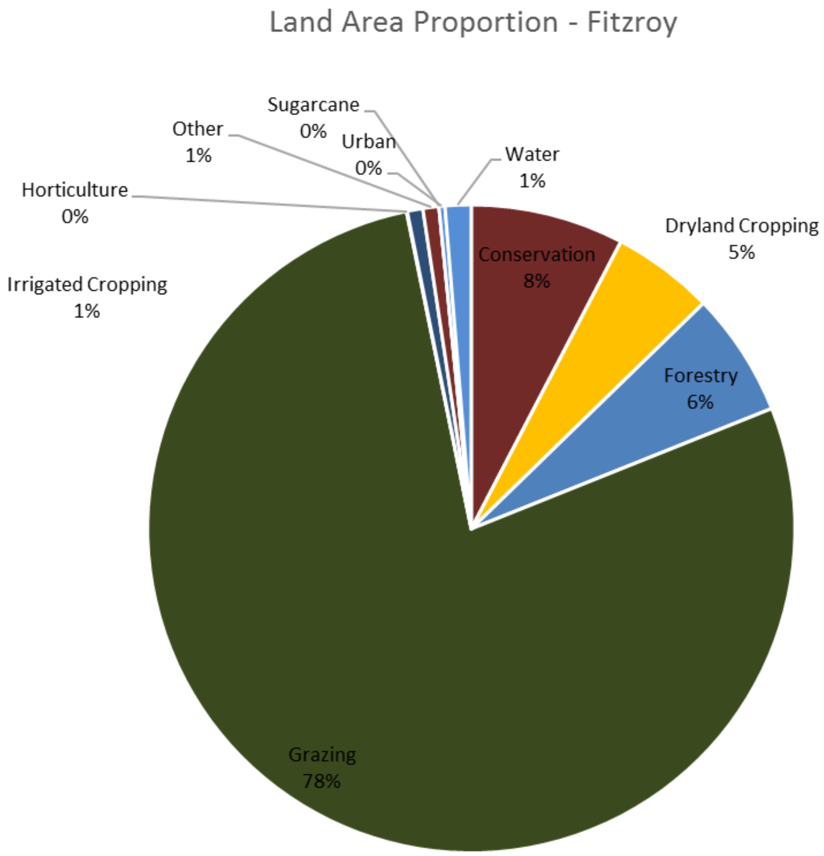


Figure 11. *Landuse proportions - Fitzroy*

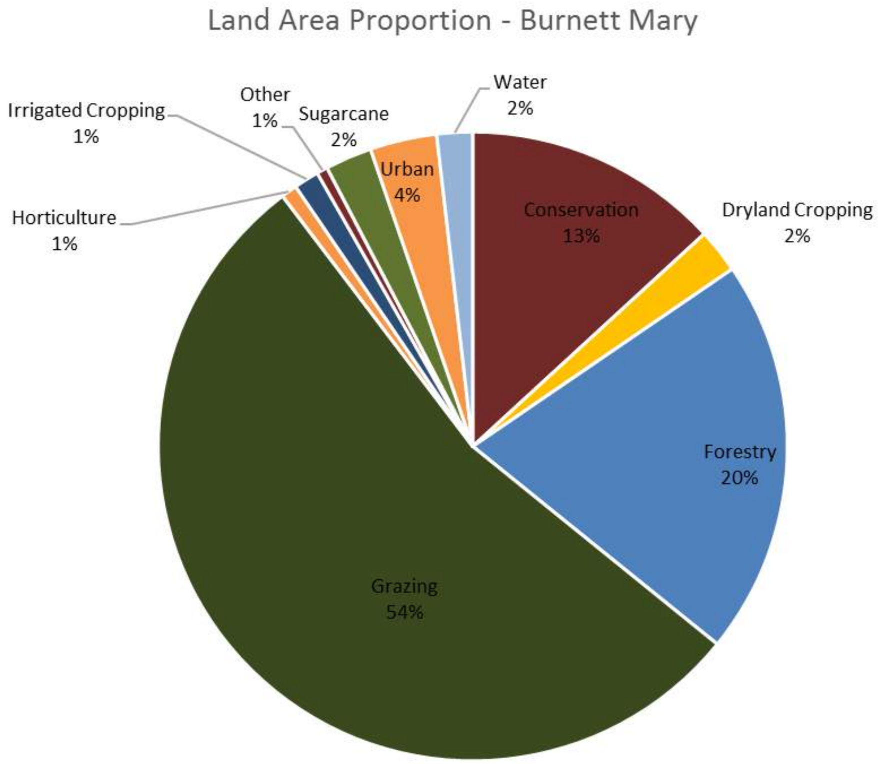


Figure 12. *Landuse proportions - Burnett Mary*

Dominant pollutant processes

In terms of targeting policy solution sets within particular regions, it is important to understand the processes of pollutant generation and export so that it is possible to focus in on those which are causing the most problems. From the Reef Source Catchment Model, we can split up the contributions by the source of pollution process in terms of mean annual loads delivered to the reef (in tonnes per year). These are shown in the graphs below (Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, Figure 21 and Figure 22).

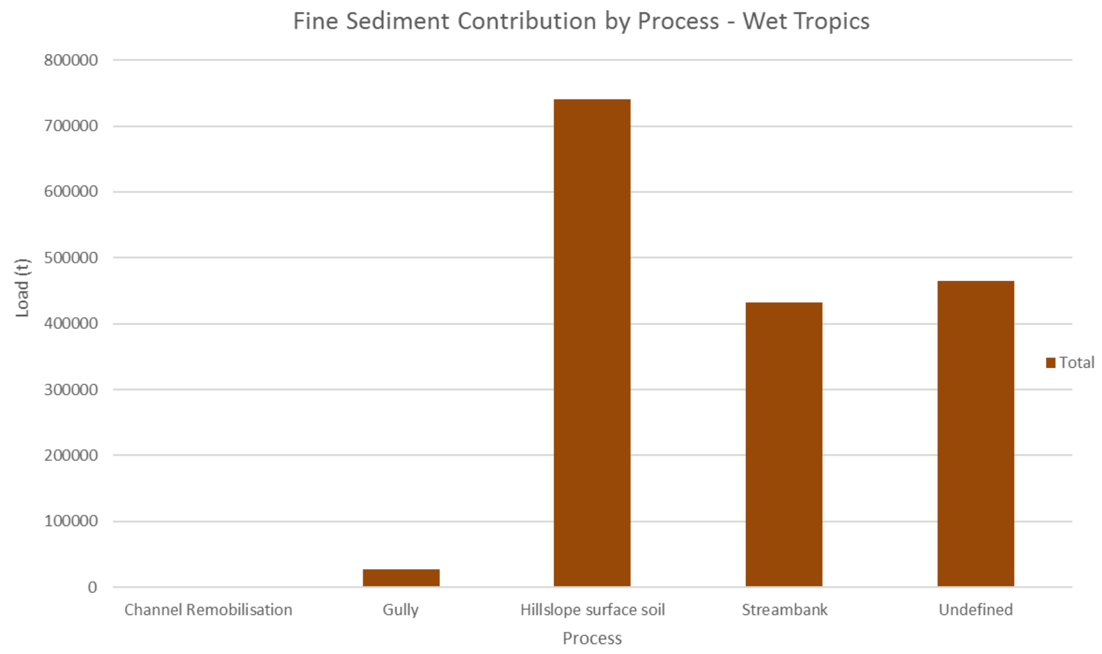


Figure 13. *Fine sediment contributions - Wet Tropics*

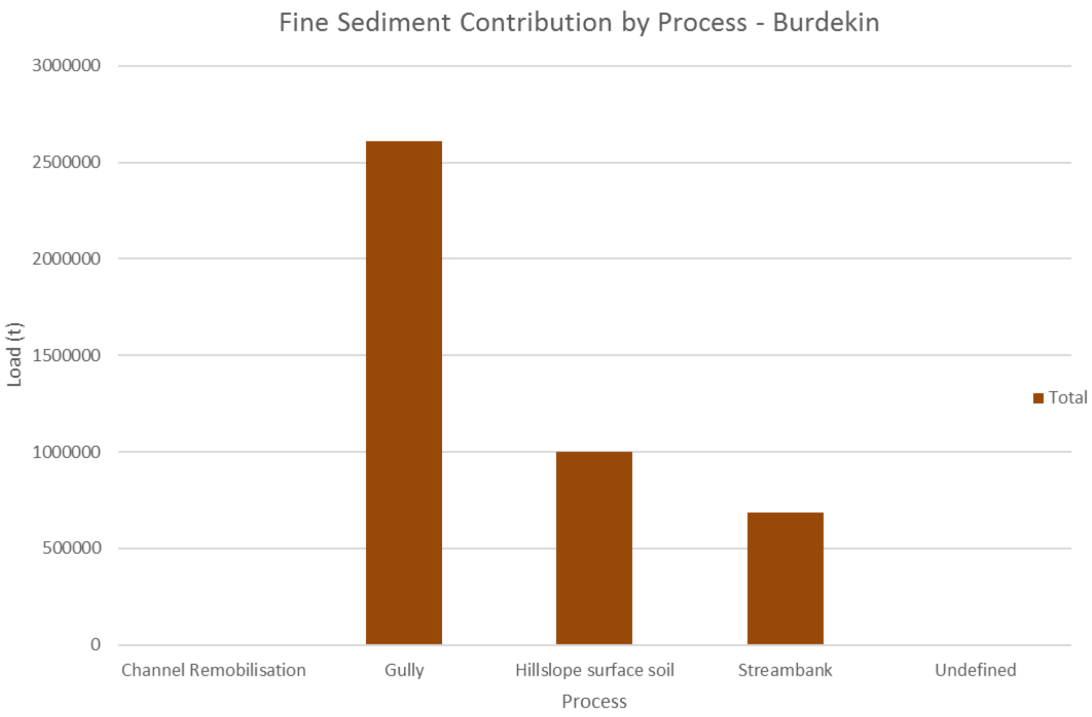


Figure 14. *Fine sediment contributions - Burdekin Dry Tropics*

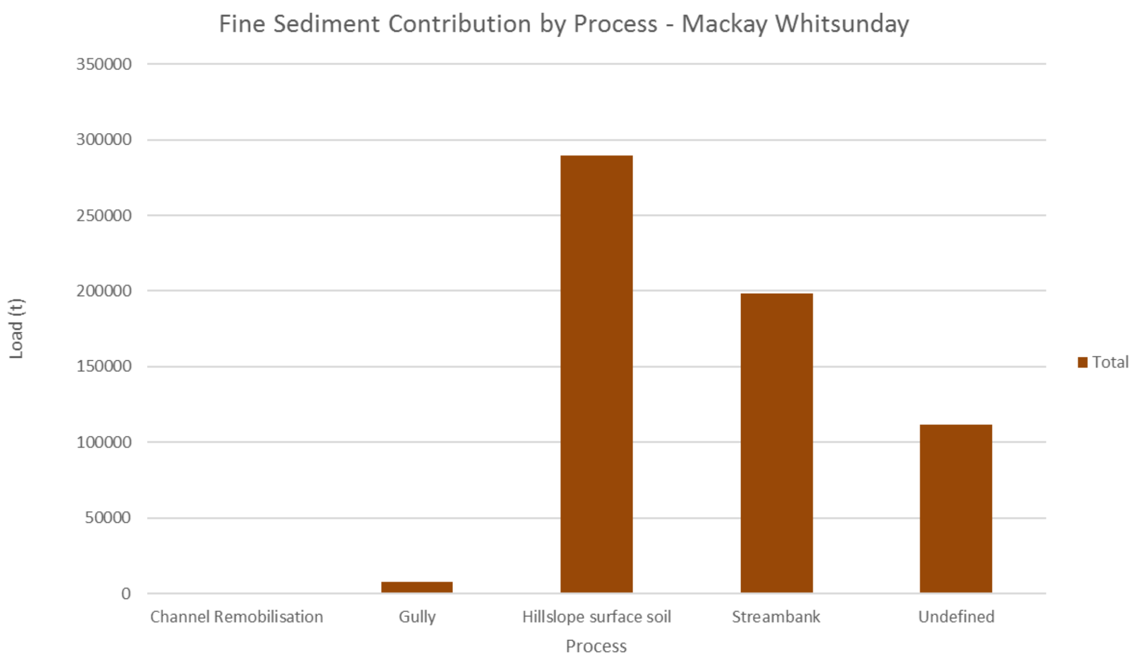


Figure 15. *Fine sediment contributions - Mackay Whitsunday*

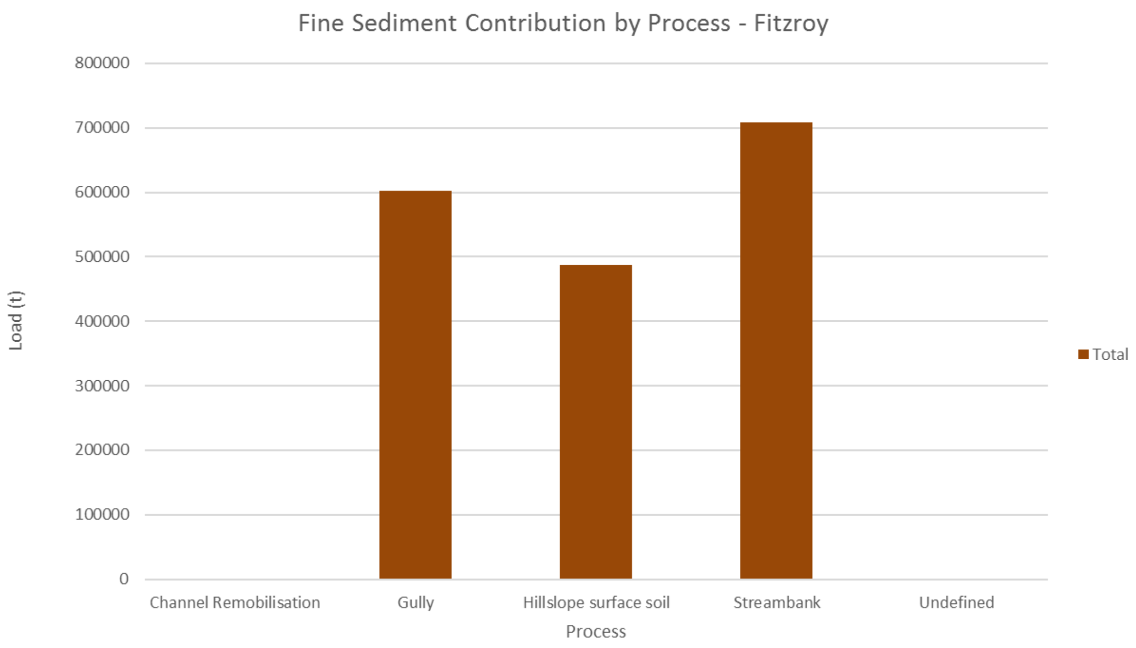


Figure 16. *Fine sediment contribution – Fitzroy*

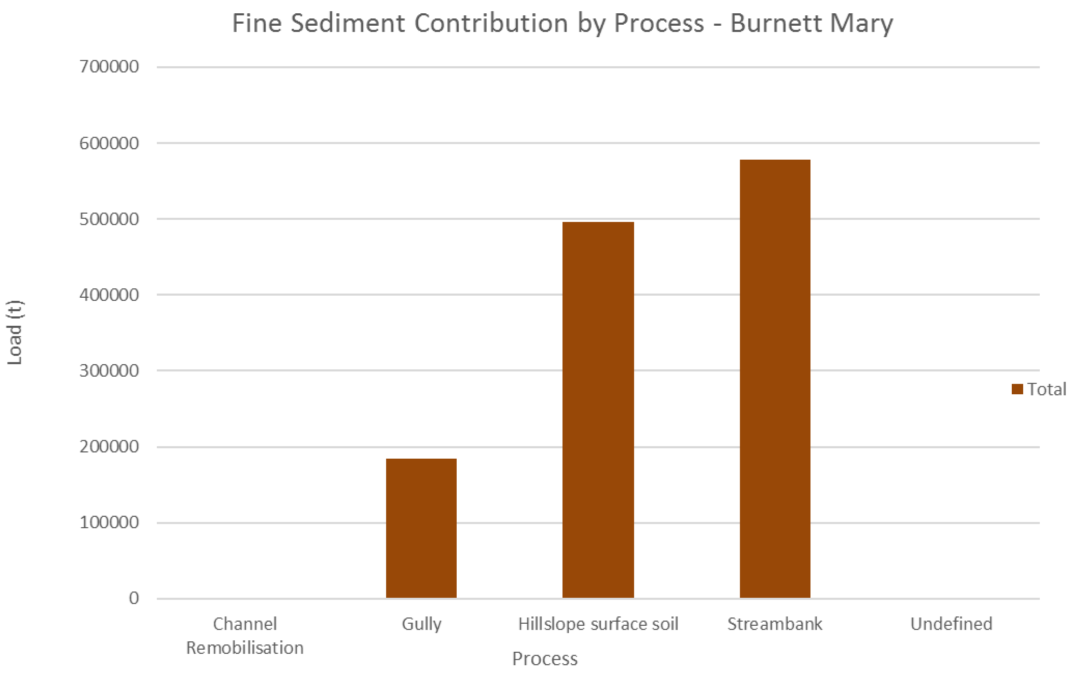


Figure 17. *Fine sediment contributions - Burnett Mary*

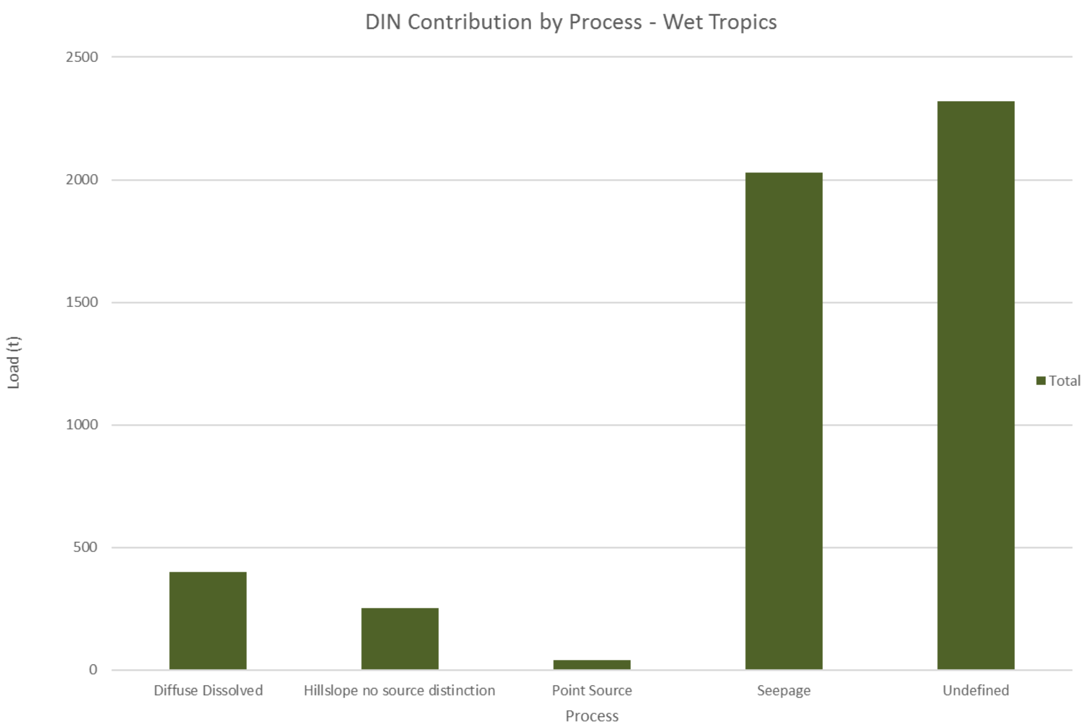


Figure 18. *DIN Contributions - Wet Tropics*

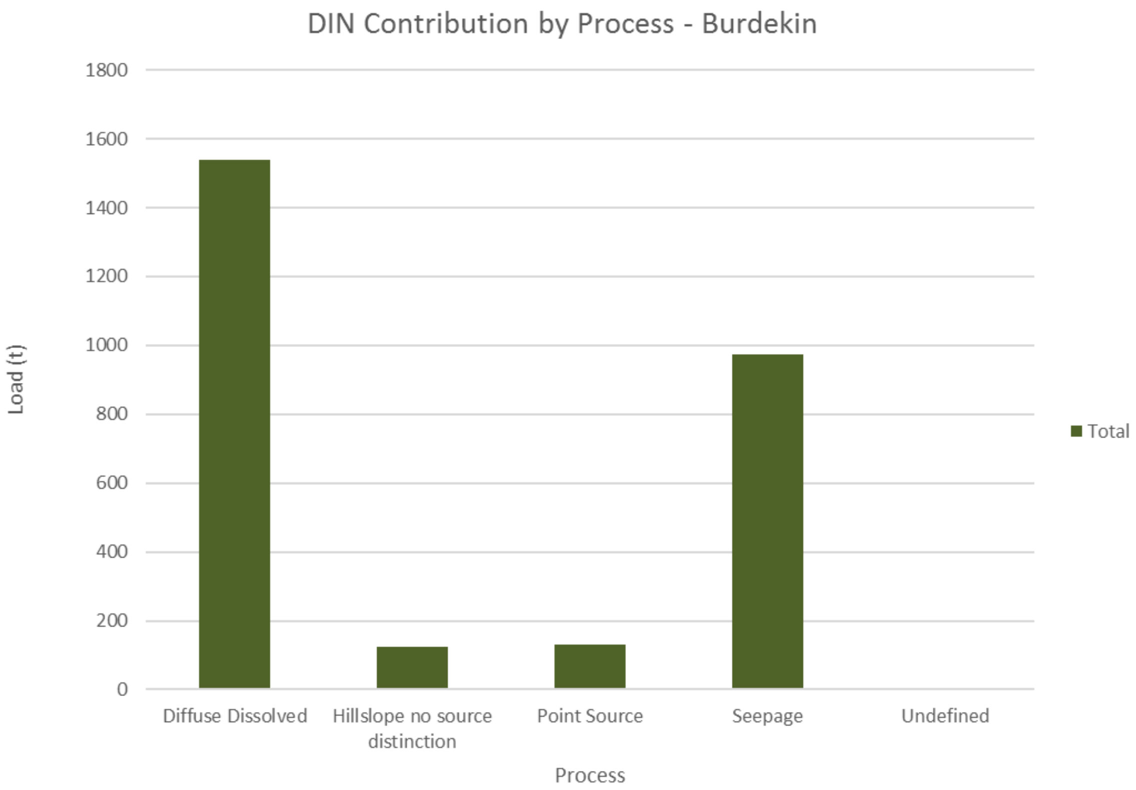


Figure 19. *DIN Contribution - Burdekin Dry Tropics*

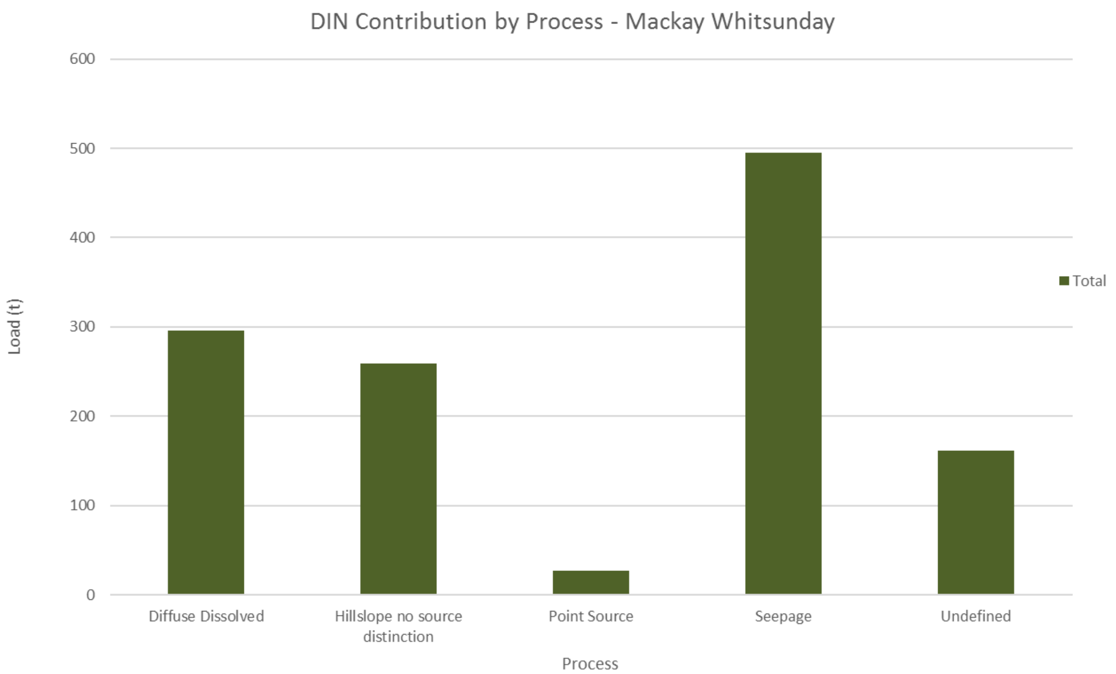


Figure 20. *DIN Contribution Mackay Whitsunday*

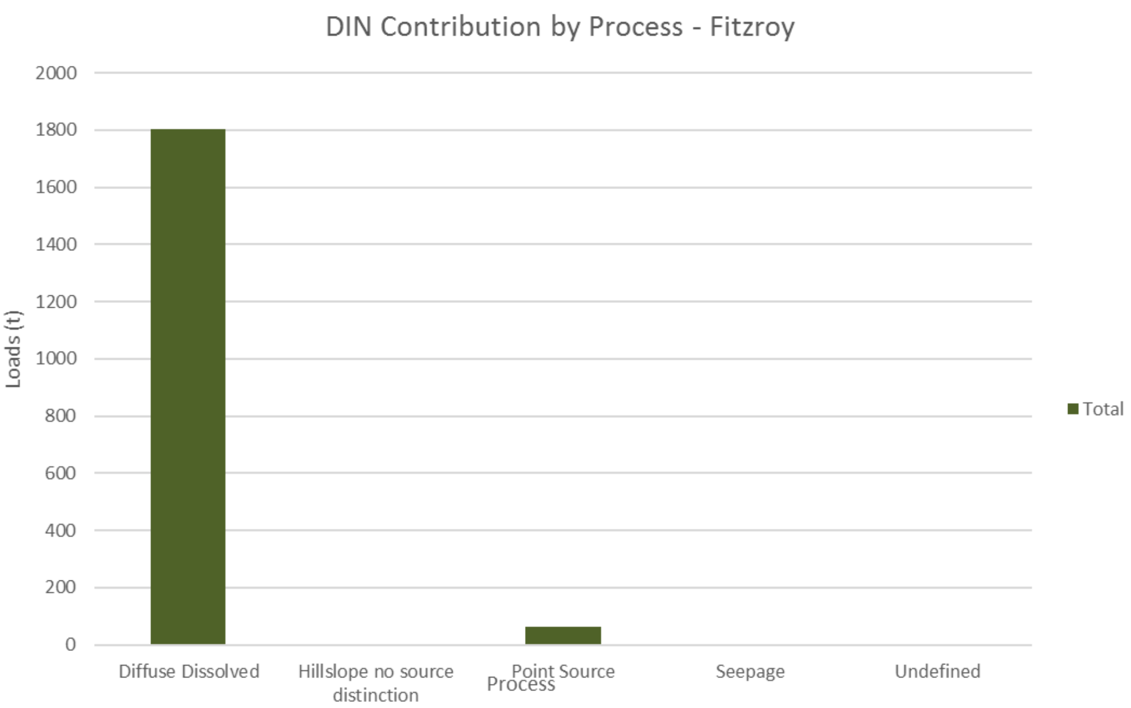


Figure 21. *DIN Contributions - Fitzroy*

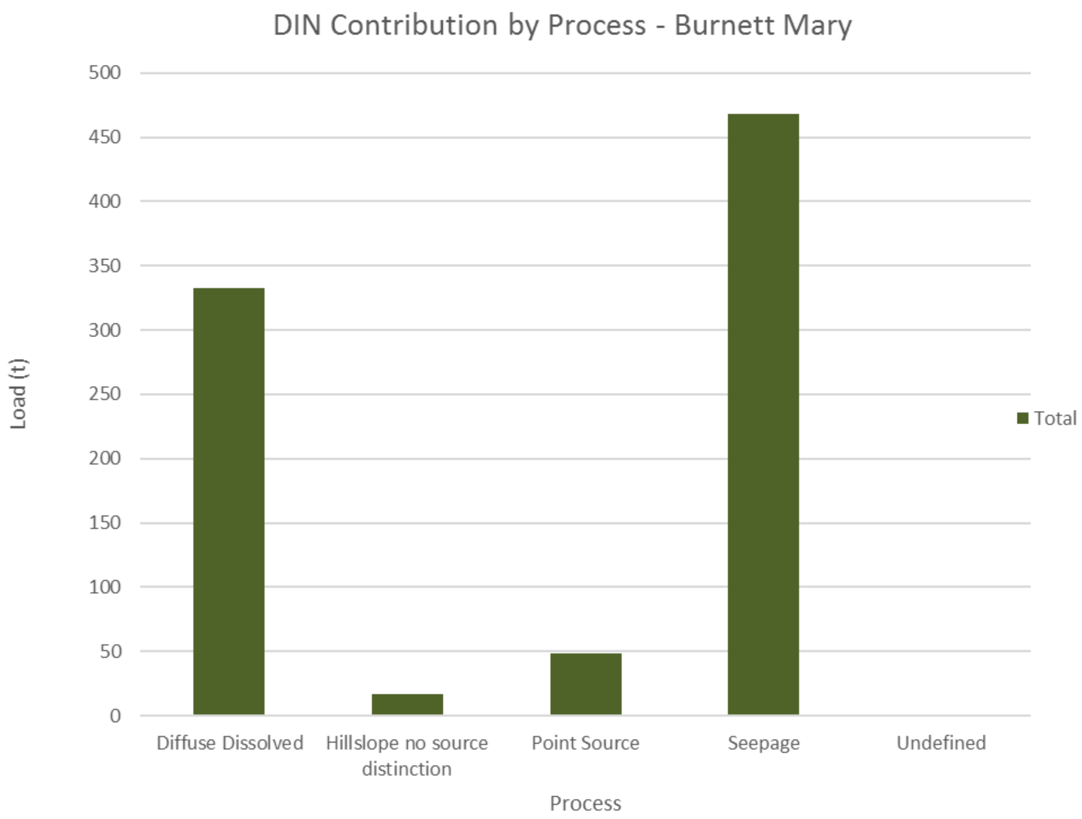


Figure 22. *DIN Contributions - Burnett Mary*

What the above graphs show is the complexity of each of the regions in terms of the sources of pollution, in that some regions the fine sediment processes are dominated by gully erosion (e.g. the Burdekin Dry Tropics), whereas others are more influenced by hillslope and streambank erosion (e.g. Mackay Whitsunday and Burnett Mary region). For DIN, those catchments with areas of sugarcane show a dominance of seepage delivered DIN, whereas the Fitzroy, with only minimal amounts of sugarcane, the dominant source of DIN is from diffuse contributions. This has a significant bearing on the effectiveness of the selected actions within the policy solution sets, in that some actions may be effective at treating a particular source, but this is only part of the overall contribution. The above graphs also do not distinguish between anthropogenic load and total load; these represent total loads only.

4.2 Adopted solutions for each region

Based on the sequencing of actions (from across the policy solution sets) as noted in *Section 3.6*, we prepared regional groups of actions, that when combined, provided the most cost-effective, logical actions for the pollutant of interest to meet the relevant regional Reef 2050 Plan targets. As noted earlier, the last step in each of these groups was adjusted by a pro-rata method such that the target was achieved exactly and not exceeded. The validity of doing this is that through progressive implementation, investments would be made until the targets were achieved, and no further increase in investment would then be needed.

The final list of adopted actions was added together to determine both the cost and efficacy of the adopted actions to meet the regional Reef 2050 Plan targets. These are presented below.

Wet Tropics Region

The results for fine sediment in the Wet Tropics region are presented in Table 5 and Figure 23. The results show that in the Wet Tropics, the full list of actions that we assessed weren't able to achieve the fine sediment Reef 2050 Plan target even if they were all fully implemented. This shows the challenge of both the climatic conditions in the region (very high rainfall) and the limitations of the actions within the solutions sets we were asked to assess. For example, only 10% of streambanks within the Herbert and Tully regions were assumed to be treated, whereas it may be possible to increase this further if suitable erosion prone areas could be identified. It may well be that despite all of these measures, the regional Reef 2050 Plan target may not be achievable and this might mean that the targets may not be appropriate to the region, or that we should look to reduce fine sediment in other regions where it may be more cost-effective, to make up for the shortfall that we think is likely.

Table 5. Adopted actions - Wet Tropics fine sediment

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef[1] (t/yr)	Long-term load to reef required to meet target[2] (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		1,670,000	1,170,000			
Load reductions to date (2009-2013)	129,000	1,540,000	1,170,000			
Streambank Repair Herbert 5% of Stream Length	71,000	1,470,000	1,170,000	$18,800,000	$18,800,000	$26
Streambank Repair Herbert 6-10% of Stream Length	56,800	1,410,000	1,170,000	$29,900,000	$48,600,000	$53
Grazing Practice Change D to C	6,750	1,400,000	1,170,000	$686,000	$49,300,000	$10
Grazing Practice Change C to B	37,800	1,370,000	1,170,000	$58,800,000	$108,000,000	$155
Grazing Practice Change B to A	88,400	1,280,000	1,170,000	$23,000,000	$131,000,000	$26
Streambank Repair - Tully River 5% of stream length	1,420	1,280,000	1,170,000	$5,070,000	$136,000,000	$358
Streambank Repair - Tully River 6% to 10% of stream length	987	1,280,000	1,170,000	$5,620,000	$142,000,000	$569
Urban stormwater new development-Wet Tropics - Cairns	80	1,270,000	1,170,000	$101,000,000	$242,000,000	$125,000

1 – Total load exported to reef is the load being delivered after all the actions to that point have been implemented
2 – Long-term load to reef required to meet target is the mean annual load that would be exported to the reef if the LTSP targets were met.

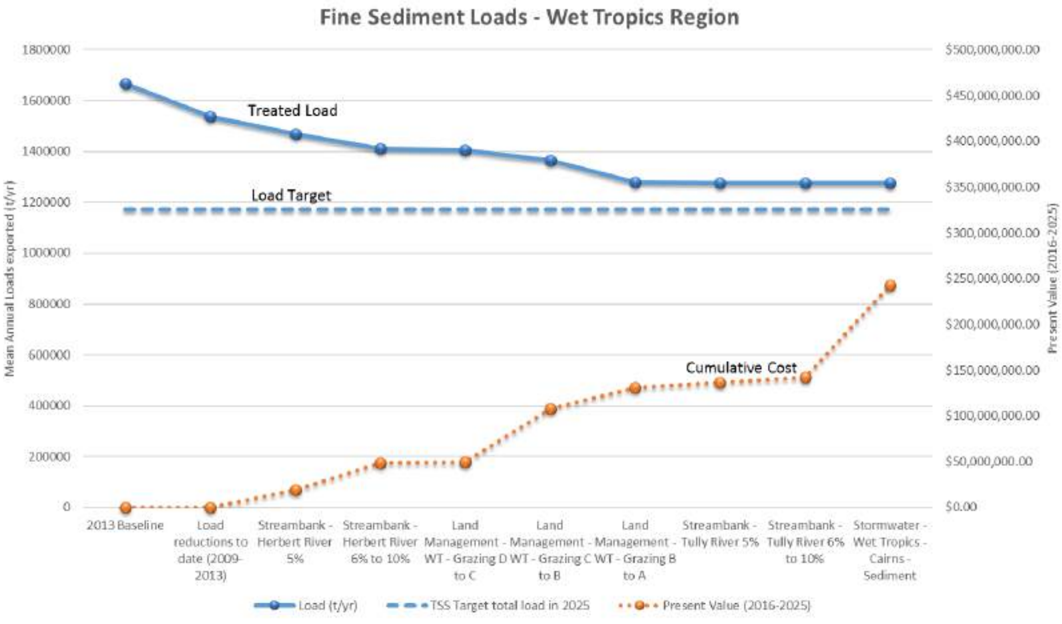


Figure 23. *Fine sediment efficacy and costs - Wet Tropics*

The results for DIN in the Wet Tropics region are presented in Table 6 and Figure 24. It is clear from Table 6 and Figure 24 that the majority of actions provide little DIN reduction until we improve cane land management practice from C to B. This relates to the fact that there is only a very small amount of D class cane land in the Wet Tropics (around 5%), whereas around 90% of cane is in C class. That means the change of practice from C to B is predicted to result in a large reduction in DIN loads. Overall though, the DIN target can't be achieved with all of the relevant management actions included in the policy solution sets and this again suggests that the target needs to be reconsidered, the extension of some of the actions modelled could be re-examined (e.g. changing C class cane practice through to A, or converting the poorest performing C class cane lands to conservation or grazing), or other technologies and solutions need to be evaluated. From the pollution process charts presented earlier, it may also be that other policy solution sets may also need to be targeted to reduce the overall anthropogenic load.

Table 6. Adopted actions – Wet Tropics DIN

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline	5,050	5,050	3,280			
Load reductions to date (2009-2013)	287	4,760	3,280			
10% Retirement of D Class Practice Cane to Conservation	12	4,750	3,280	$1,710,000	$1,710,000	$14,500
11-30% Retirement of D Class Practice Cane to Conservation	24	4,730	3,280	$3,420,000	$5,130,000	$14,500
31-50% Retirement of D Class Practice Cane to Conservation	24	4,700	3,280	$3,420,000	$8,550,000	$14,500
Cane Practice Change D to C	9	4,690	3,280	$947,000	$9,500,000	$11,100
Cane Practice Change C to B	953	3,740	3,280	$46,600,000	$56,100,000	$4,890

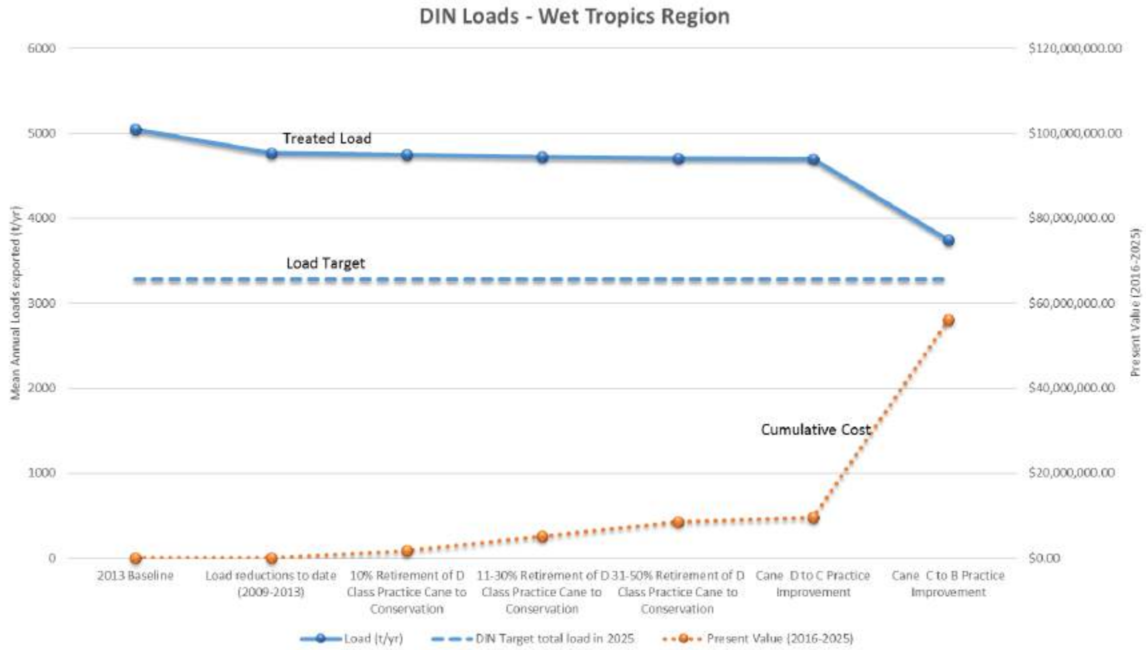


Figure 24. *DIN efficacy and costs - Wet Tropics*

Burdekin Region

The results for fine sediment in the Burdekin region are shown in Table 7 and Figure 25. Fine sediment reduction in the Burdekin is predicted to achieve the targets with the solutions assessed though the costs climb considerably when gully remediation is part of the policy solution set. This is because the extent of gullies is large within key areas of the catchment downstream of the Burdekin Falls Dam, and the cost of remediation is also large. This is shown by the pollution process graphs, which demonstrate the dominance of gully erosion. Also, given that grazing is by far the largest landuse within the region, further focus on improved grazing practice, and combining this with gully remediation may result in lowering overall costs through economies of scale.

In looking at which solutions to group together for Burdekin fine sediment, changing D class land to conservation within the Bowen River was actually more cost-effective than treating 10% of gullies, however if the D class grazing land had already implemented the improved practice (which was the most cost-effective solution), then there would be no D class land left to change to conservation and hence these actions were not required.

Table 7. Adopted actions - Burdekin fine sediment

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		3,700,000	2,160,000			
Load reductions to date (2009-2013)	491,000	3,200,000	2,160,000			
Grazing Practice Change D to C	300,000	2,900,000	2,160,000	$8,960,000	$8,960,000	$3
Grazing Practice Change C to B	230,000	2,670,000	2,160,000	$364,000,000	$372,000,000	$158
Gully - Burdekin 10% of gullies full repair (pro-rata)	513,000	2,160,000	2,160,000	$717,000,000	$1,090,000,000	$140

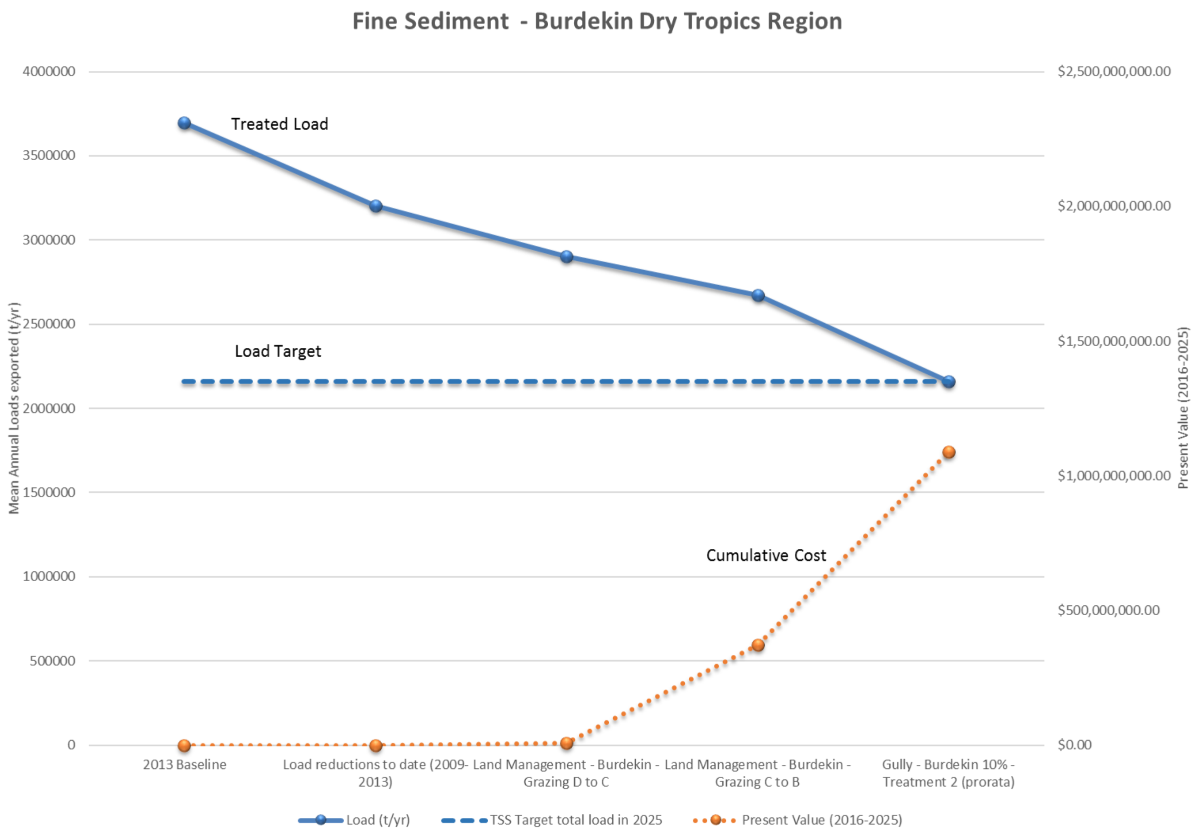


Figure 25. *Fine sediment efficacy and costs – Burdekin Dry Tropics*

The results for DIN in the Burdekin region are shown in Table 8 and Figure 26. Achieving the DIN targets within the Burdekin is also predicted to be possible from the meta-model results, though this is heavily reliant on the performance of improved irrigation practice. As previously outlined, the order of these actions on the graphs presented is sometimes different to what might have to be done in practice. In order to avoid double counting, however, the irrigation practice was assumed to occur first followed by improved land management practice. In reality, it should probably be the opposite and in terms of the model outputs, we think that further work is needed to properly understand what improved irrigation practice can actually achieve.

Table 8. Adopted actions - Burdekin DIN

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		2,450	1,460			
Load reductions to date (2009-2013)	173	2,270	1,460	$-	$-	$-
Irrigation - Burdekin - 20% - Level 2	165	2,110	1,460	$20,200,000	$20,200,000	$12,300
Irrigation - Burdekin - 21 to 50% - Level 2	247	1,860	1,460	$80,900,000	$101,000,000	$32,700
Irrigation - Burdekin - 51 to 70% - Level 2	165	1,700	1,460	$103,000,000	$204,000,000	$62,500
Irrigation - Burdekin - 71 to 100% - Level 2 (pro-rata)	240	1,460	1,460	$99,800,000	$304,000,000	$41,700

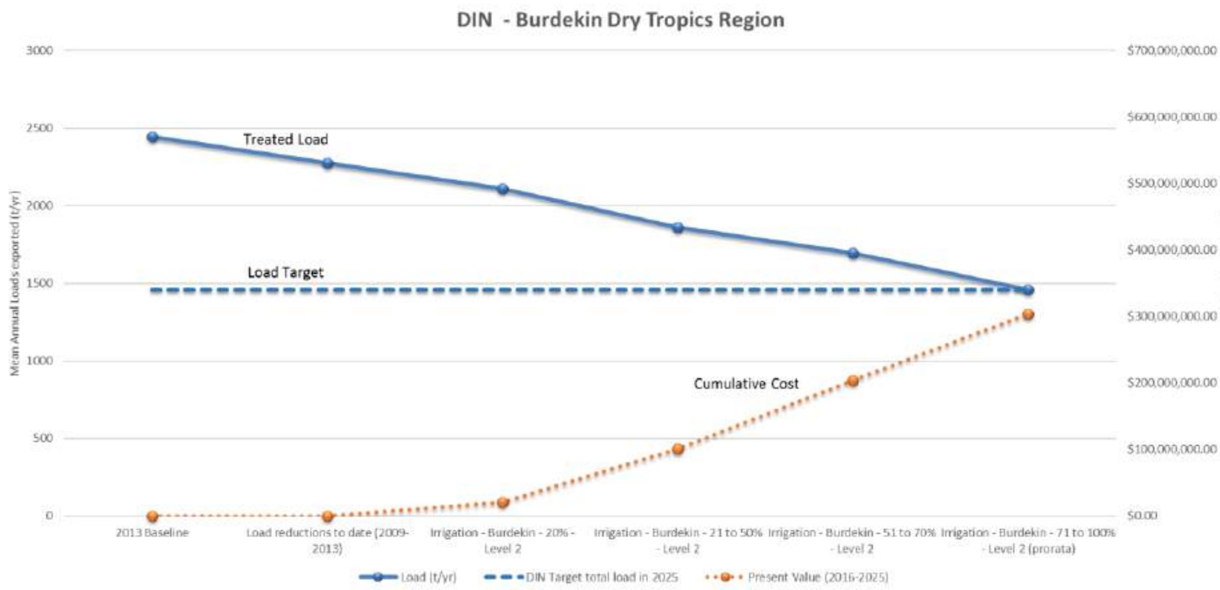


Figure 26. *DIN efficacy and costs - Burdekin Dry Tropics*

Mackay Whitsunday Region

The results for fine sediment in the Mackay Whitsunday region are shown in Table 9 and Figure 27. The results show that the fine sediment target could be readily achieved with land management practice improvements and the overall cost-effectiveness in terms of $ per tonne is very good (less than $100/tonne). In nearly all of the catchments assessed, moving land management practice from D to C (assumed to incur regulation and extension costs only) was typically the most cost-effective option.

Table 9. Adopted actions – Mackay Whitsunday fine sediment

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		611,000	539,000			
Load reductions to date (2009-2013)	32,100	579,000	539,000			
Grazing Practice Change D to C	38,000	541,000	539,000	$7,020,000	$7,020,000	$19
Grazing Practice Change C to B (pro-rata)	1,890	539,000	539,000	$1,270,000	$8,290,000	$67

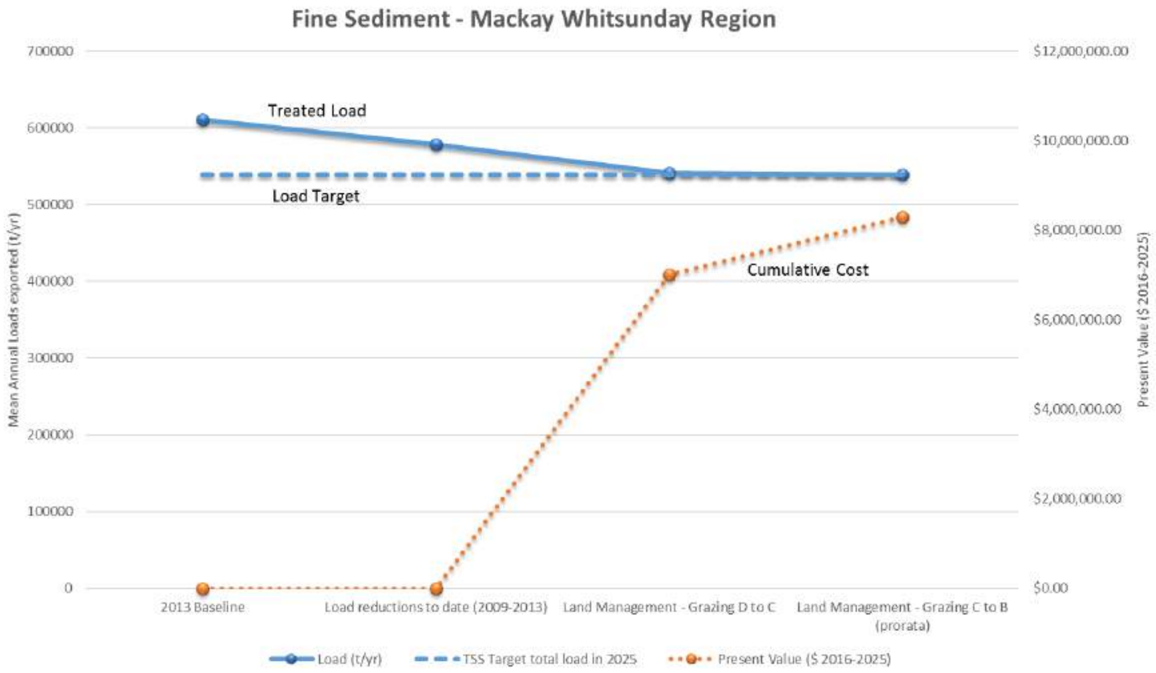


Figure 27. *Fine sediment efficacy and costs - Mackay Whitsunday*

The results for DIN in the Mackay Whitsunday region are shown in Table 10 and Figure 28. The results indicate that the target can be achieved however the last step requires a significant increase in investment. In terms of combining the options to achieve the target, we assumed that landuse change of D class land to a passive landuse would need to occur first, followed by improvement of the remaining D class land to C and then to B. Again, this may not be the most cost-effective sequence, but in terms of all the actions considered, these are the four most cost-effective options that logically group together.

Table 10. Adopted actions – Mackay Whitsunday DIN

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		1,240	770			
Load reductions to date (2009-2013)	224	1,010	770			
Land Repair - 10% D class cane to conservation	12	1,000	770	$741,000	$741,000	$6,280
Land Repair - 11% to 20% D class cane to conservation	24	977	770	$1,480,000	$2,220,000	$6,290
Cane Practice Change D to C	102	875	770	$609,000	$2,830,000	$597
Cane Practice Change C to B (prorata)	105	770	770	$26,000,000	$28,800,000	$24,700

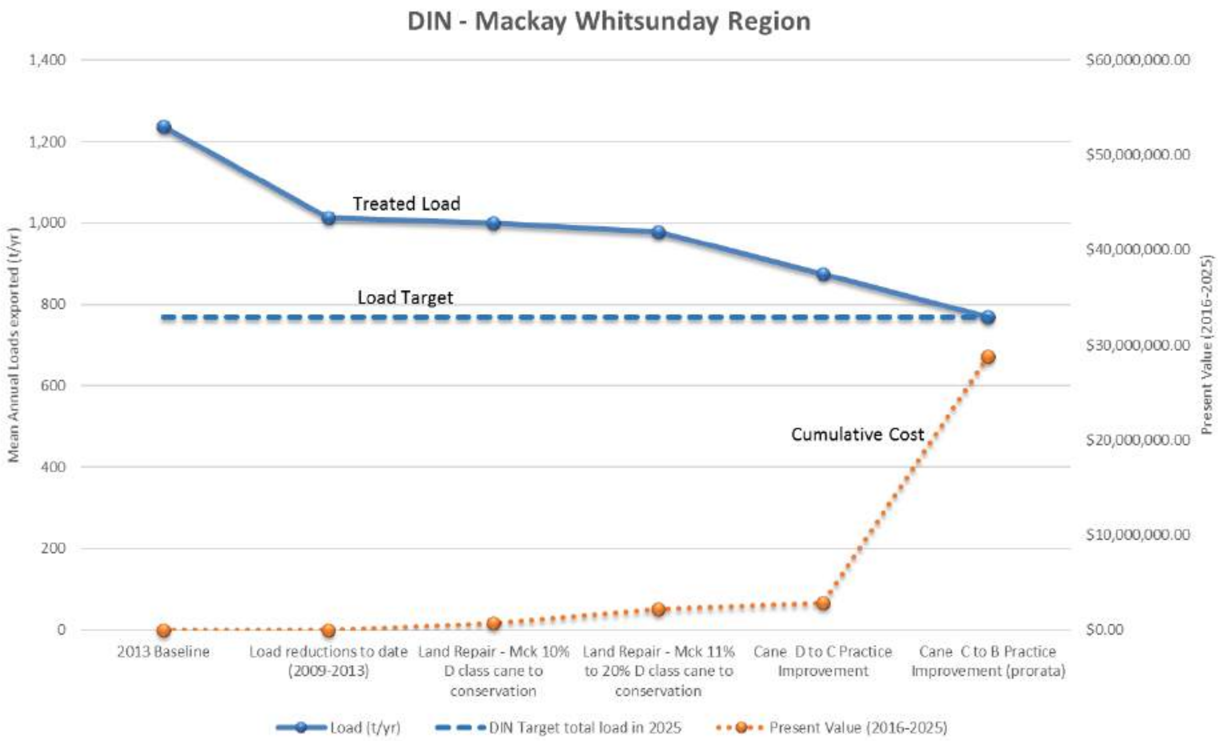


Figure 28. *DIN efficacy and costs - Mackay Whitsunday*

Fitzroy Region

The results for fine sediment in the Fitzroy region are shown in Table 11 and Figure 29. The results show one of the classic features of natural resource economics, that of diminishing returns. The progress towards the load target for the adoption of the proposed solutions is relatively constant for the policy solution set chosen, however the costs demonstrate an exponential increase as the reductions get closer to the target load. The cumulative cost rises significantly when gully remediation is added. We also did not explore the effectiveness of stream repair in this region. The significance of streambank erosion is significant though when reviewing the pollution processes graphs for the Fitzroy, as seen in Figure 16. This shows that streambank erosion is the highest contributor of fine sediment within the region, though what proportion of this is anthropogenic is not defined.

Table 11. Adopted actions – Fitzroy Fine Sediment

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		1,790,000				
Load reductions to date (2009-2013)	61,200	1,730,000	1,030,000	$-	$-	$-
Grazing Practice Change D to C	248,000	1,480,000	1,030,000	$51,500,000	$51,500,000	$3.47
Grazing Practice Change C to B	75,800	1,410,000	1,030,000	$440,000,000	$491,000,000	$31
Grazing Practice Change B to A	22,900	1,380,000	1,030,000	$388,000,000	$880,000,000	$28
Gully - Fitzroy 10% of gullies - full repair	104,000	1,280,000	1,030,000	$1,260,000,000	$2,140,000,000	$98
Gully - Fitzroy 11% of gullies - full repair	140,000	1,140,000	1,030,000	$1,930,000,000	$4,060,000,000	$169
Gully - Fitzroy 26% of gullies - full repair (pro-rata)	113,000	1,030,000	1,030,000	$2,400,000,000	$6,460,000,000	$233

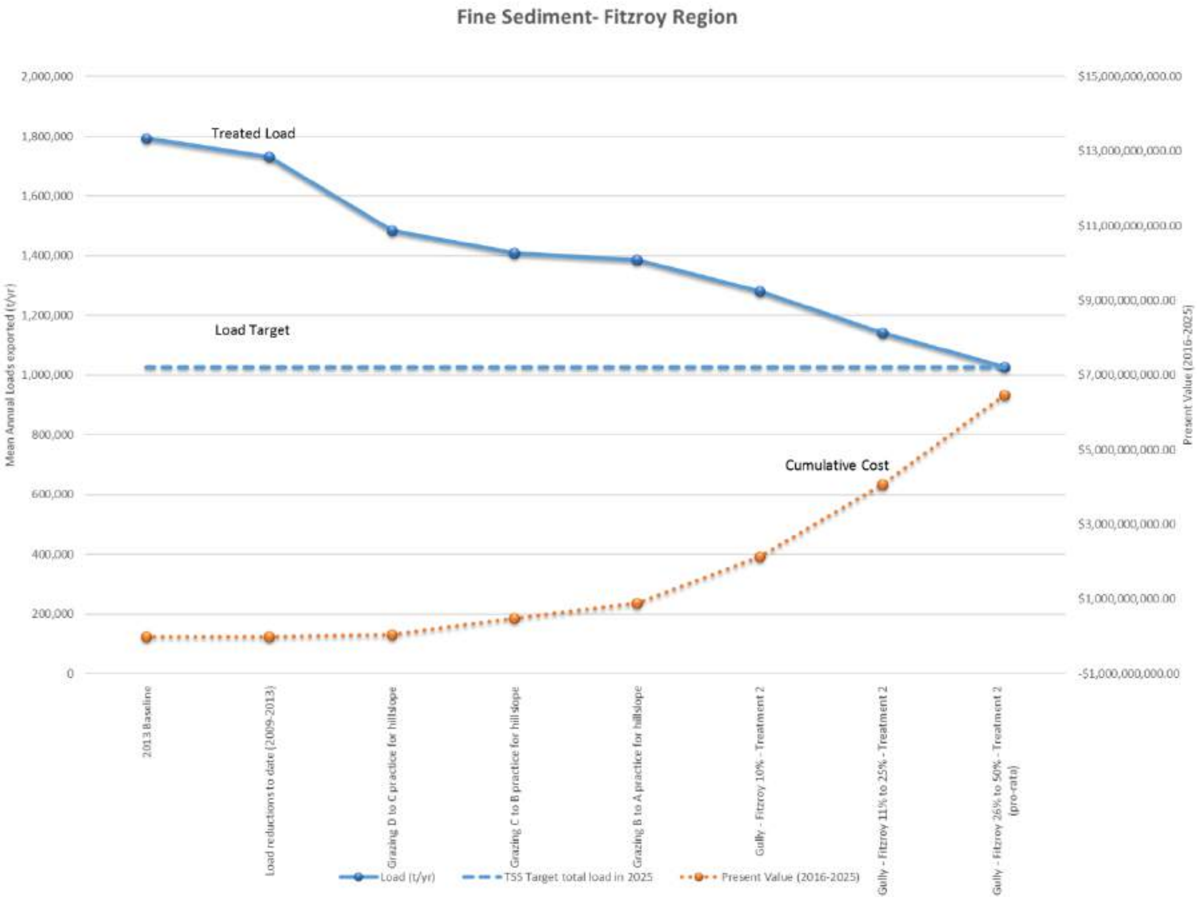


Figure 29. *Fine sediment efficacy and costs – Fitzroy*

Burnett Mary Region

The results for fine sediment with the Burnett Mary region are shown in Table 12 and Figure 30. The fine sediment target in the Burnett Mary is predicted to be achievable by just a single step of land management practice change, moving D class grazing to C practice. We applied these practice improvements to just hillslope sediment export in the meta-model, so it may well be that a combination of improved practices may not just lead to hillslope fine sediment reduction, but other sources such as gully and streambank erosion might also be reduced.

Table 12. Adopted actions – Burnett Mary Fine Sediment

Adopted actions	Reduction in load by solutions (t/yr)	Total load exported to reef (t/yr)	Long-term load to reef required to meet target (t/yr)	Present Value ($total 2016-2025)	Cumulative Present Value ($total 2016-2025)	$/tonne
2013 Baseline		1,260,000	1,110,000			
Load reductions to date (2009-2013)	23,500	1,240,000	1,110,000			
Cane Practice Change D to C Practice (pro-rata)	134,000	1,110,000	1,110,000	$11,600,000	$11,600,000	$8.69

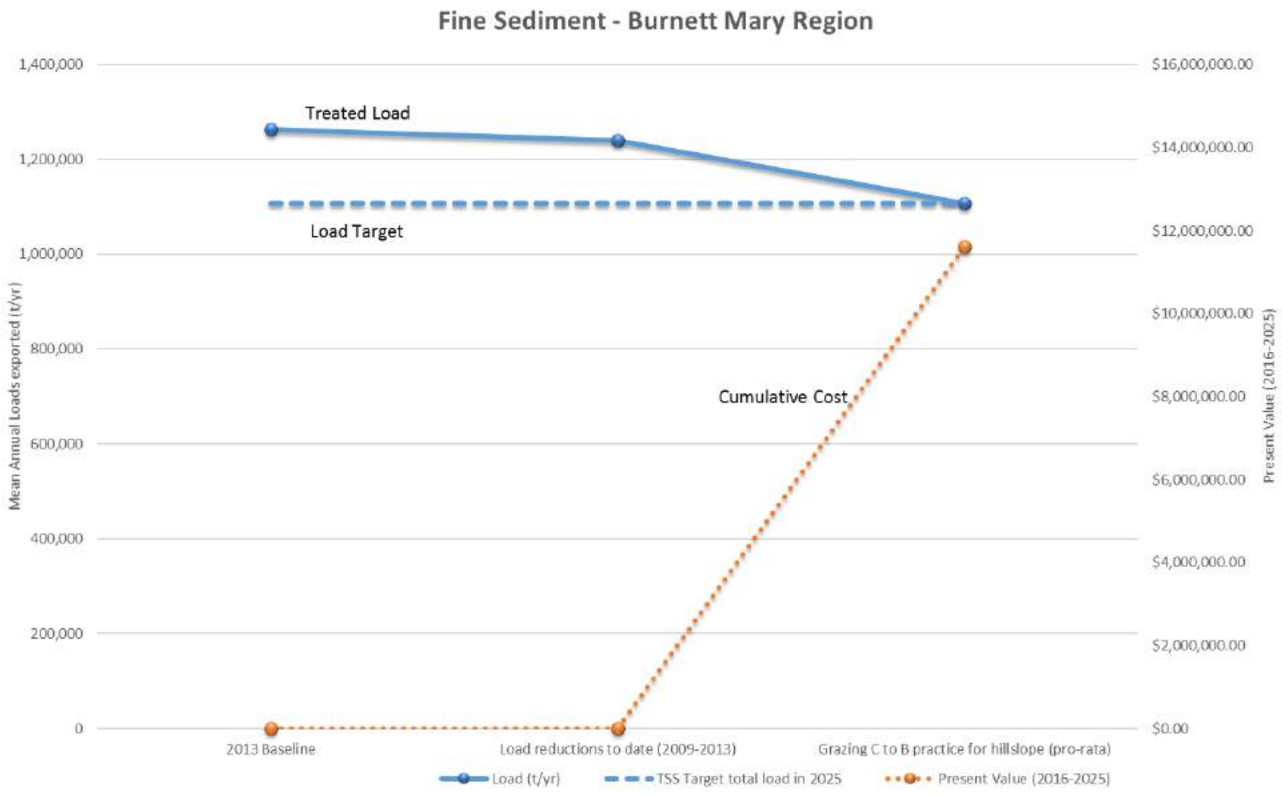


Figure 30. *Fine sediment efficacy and costs - Burnett Mary*

The results for DIN within the Burnett Mary Region are shown in Table 13 and Figure 31. As we have shown in the previous regions, land practice change can be very effective at moving towards the DIN targets and in the Burnett Mary, moving all cane to at least C class practice is predicted to achieve the target.

Table 13. Adopted actions – Burnett Mary DIN

Adopted actions	Load reduced (t/yr)	Load exported (t/yr)	TSS Target total load in 2025	Present Value ($/yr)	Cumulative Present Value ($/yr)	$/tonne
2013 Baseline		874	616			
Load reductions to date (2009-2013)	160	714	616			
Cane Practice Change D to C (pro-rata)	98	616	616	$1,730,000	$1,730,000	$1,770.00

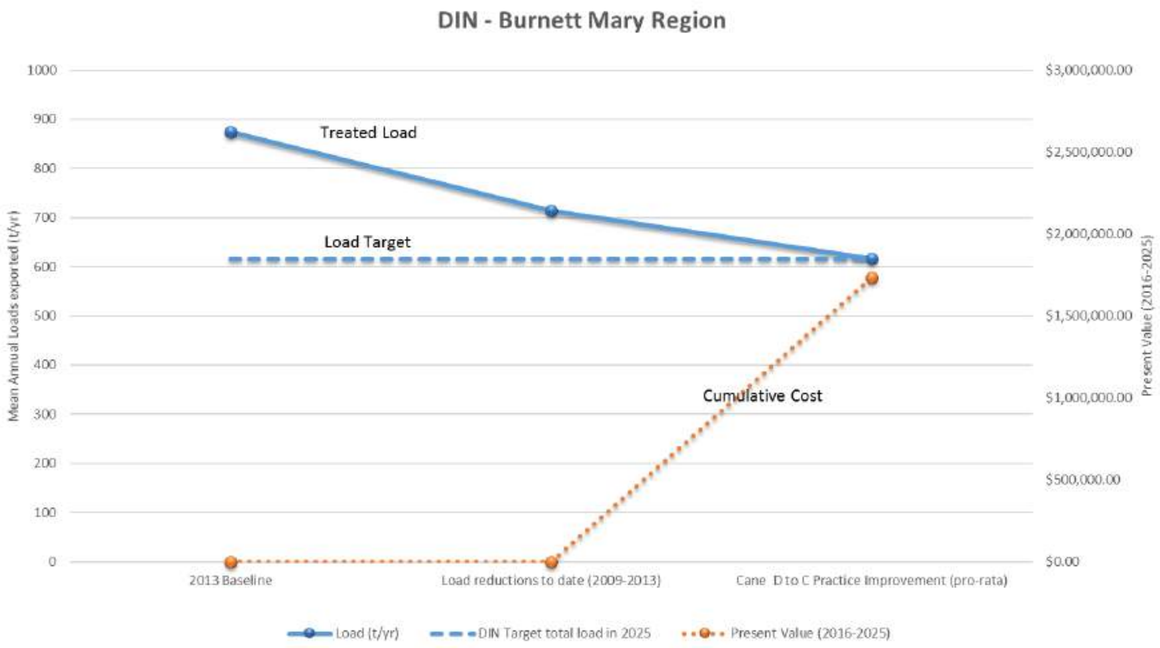


Figure 31. *DIN efficacy and costs - Burnett Mary*

4.3 Total costs to meet the regional Reef Plan 2050 targets

The total costs and the relative contributions of particular policy solution sets required to meet the regional Reef 2050 Plan targets in each NRM region are further summarised in Figure 32 and Figure 33 below. For fine sediment (Figure 32) the most significant costs are associated with the two largest catchments, the Burdekin and the Fitzroy. These larges costs reflect the extent and expense associated with systematically addressing gully remediation over huge geographic areas. Conversely, land management practice change is sufficient to drive the necessary reductions in fine sediment in both the Mackay Whitsunday and the Burnett Mary regions. For DIN, whilst change in landuse plays a role in both the Wet Tropics and Mackay Whitsunday, land management practice change is by the far the most effective way to reach the relevant regional Reef 2050 Plan targets across the regions assessed for this project (Figure 33).

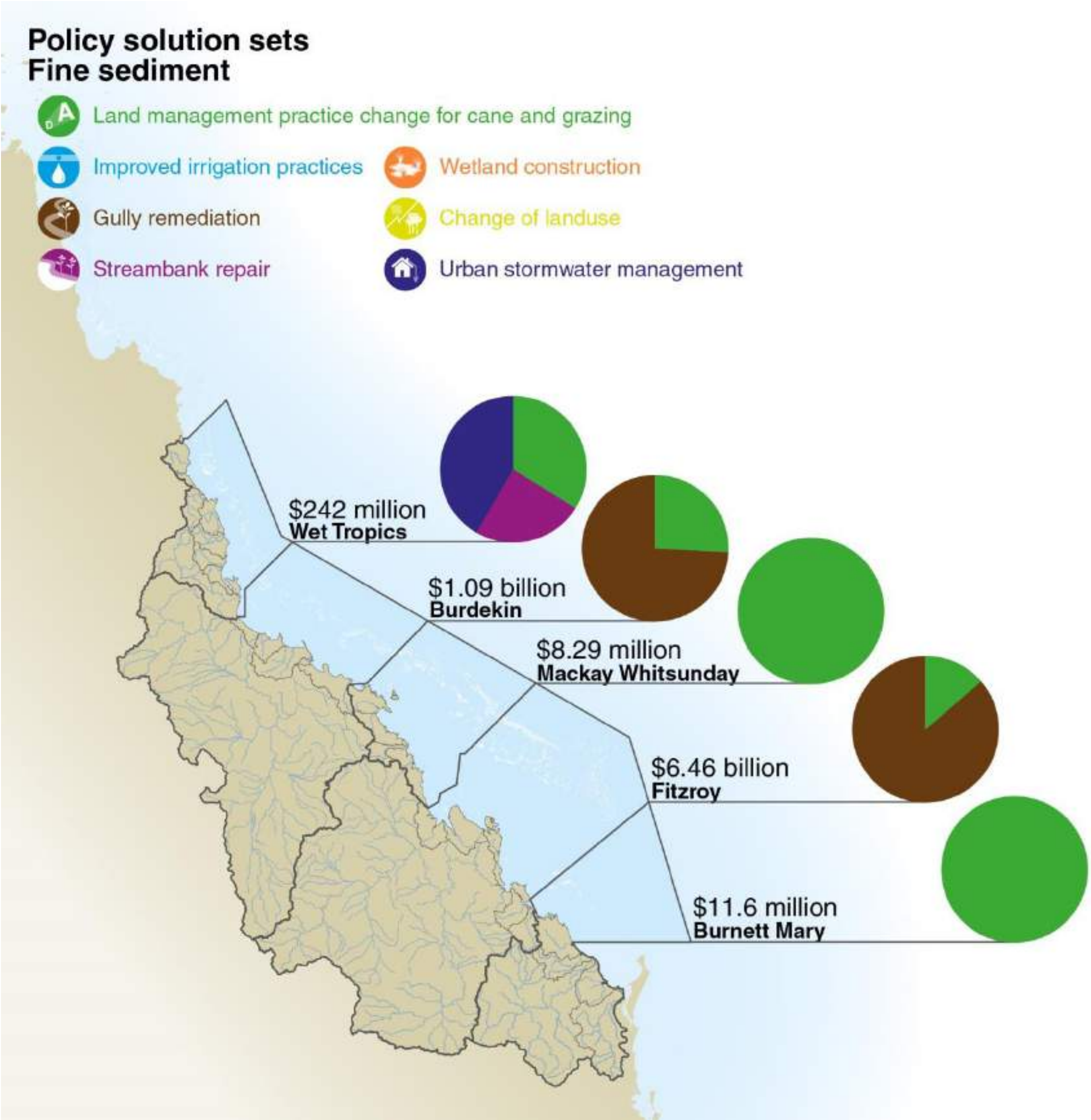


Figure 32. *Contribution of each policy solution set to load reduction and the relative level of investment required to meet Reef 2050 targets in each NRM region – Sediment*

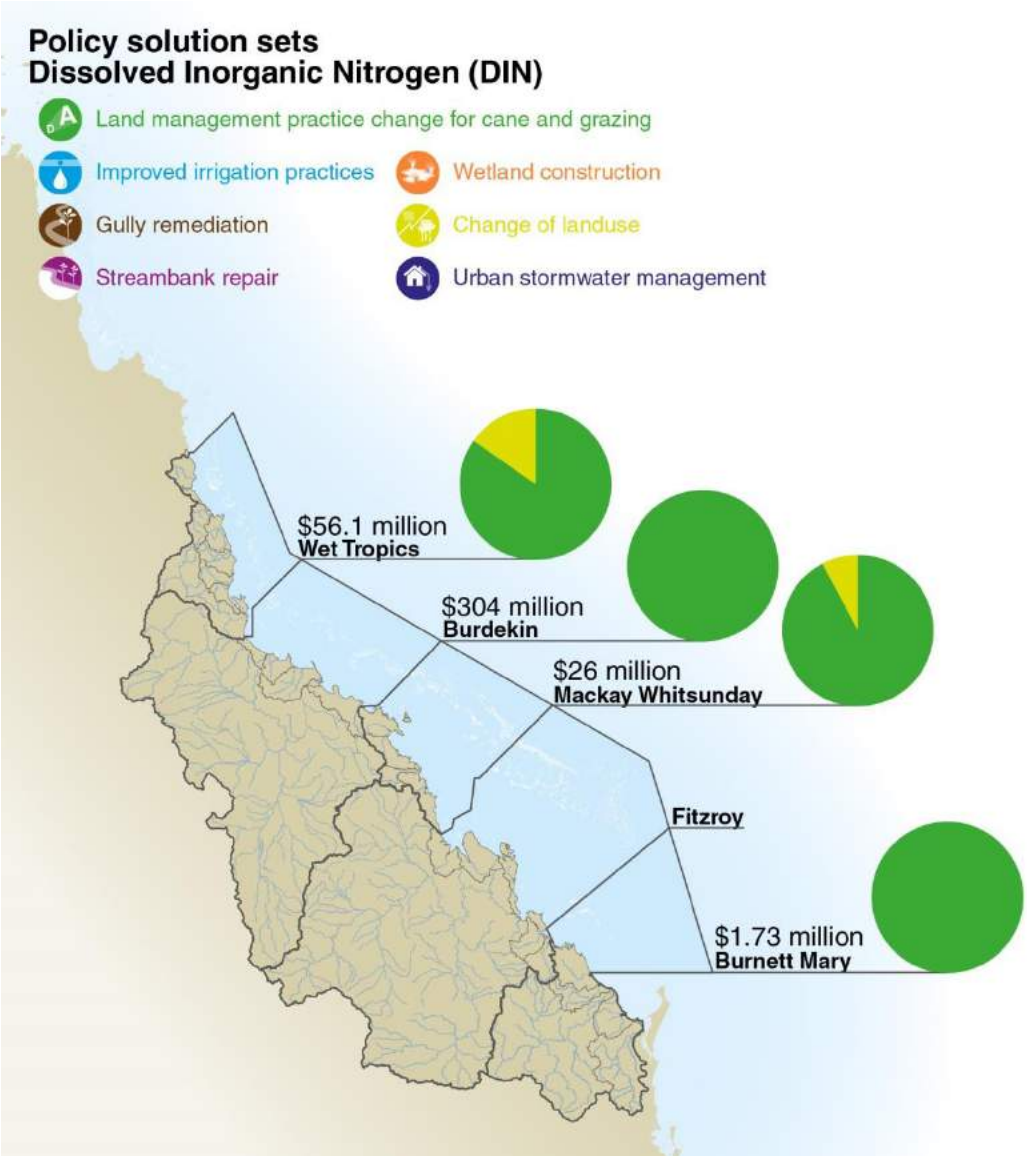


Figure 33. *Contribution of each policy solution set and the relative level of investment required to meet Reef 2050 targets in each NRM region – Dissolved Inorganic Nitrogen*

4.4 Deriving costs for achieving 50% and 75% of the reef 2050 Plan targets

This section summarises the findings from the derivation of the efficient costs to achieve 50% and 75% of the Reef 2050 Plan targets.[3]

Wet Tropics

The total costs for fine sediment in the Wet Tropics are shown in Figure 34.

[3] Consistent with the terms of reference, this analysis has been presented for 50%, 75% and 100% of the targets. Effectively this is an optimisation exercise (i.e. the lowest cost solution set to meet a pre-determined load abatement target). This approach could be repeated for other targets (e.g. 90%), but would involve significantly more calculation time.

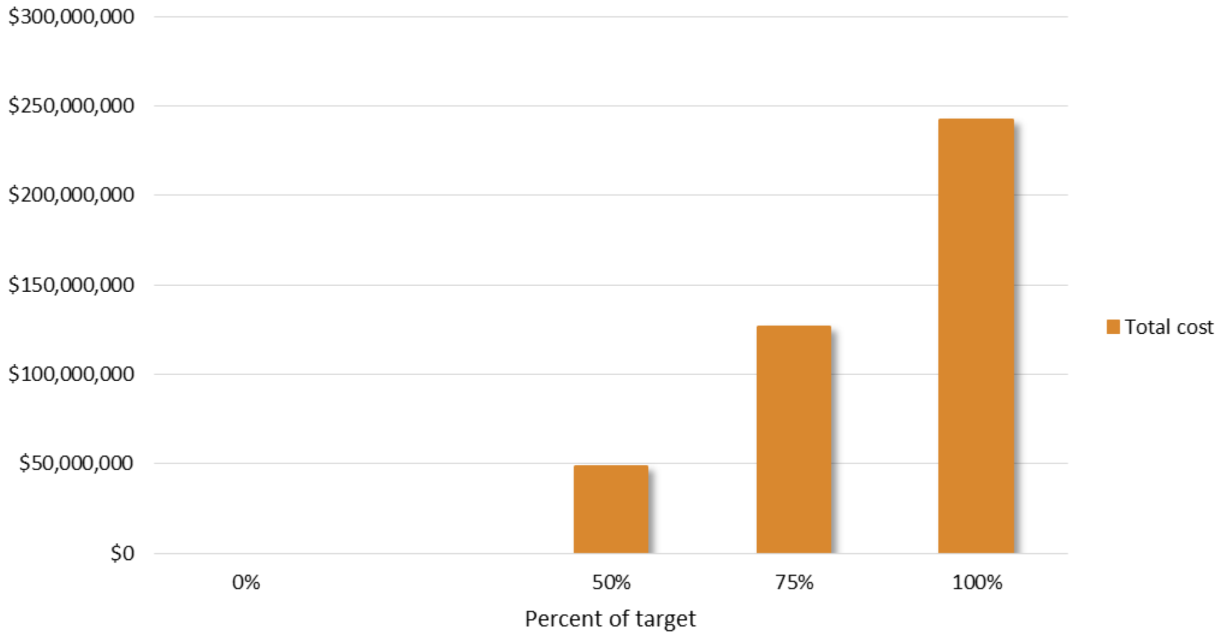


Figure 34. *Steps to Target - Wet Tropics - Fine Sediment*

The summary results from the modelling are shown in Table 14. The key points to note are:

- The total cost of meeting 50% of the fine sediment target is around $49 million. This can be achieved through streambank works on the Herbert River.
- The cost of meeting 75% of the target is around $125 million. This can be achieved through streambank management on the Herbert River and progressive improvements in grazing practices. It should be noted that the sequence of policy solution sets could involve actions with higher unit costs being undertaken before actions with cheaper unit costs. However, overall, the cost of meeting the target is minimised.
- To meet the full target requires a comprehensive policy solution set including streambank repair, grazing practice change and urban stormwater management in Cairns, with a total estimated cost of around $242 million.
- The costs of meeting the lower targets (e.g. 50% of the Reef 2050 Plan targets) are significantly below their proportional load reductions as the lower target enables exploitation of a greater set of low cost actions that still meet the overall target. However, following a progressive pathway of 50%, 75% and 100% of the target will probably result in an overall higher cost to meet the 100% target as some progressively lower-emission actions may be required on the same land that may not be complementary.

Table 14. Cost of fine sediment targets – Wet Tropics

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Streambank Repair Herbert 5% Stream Length	$18,783,000	$26
Streambank Repair Herbert 6-10% Stream Length	$48,637,000	$53
Grazing D to C	$49,323,000	$10
Grazing C to B	$108,087,000	$155
Grazing B to A	$131,135,000	$26
Streambank - Tully River 5%	$136,209,000	$358
Streambank - Tully River 6% to 10%	$141,828,000	$569
Stormwater - Wet Tropics - Cairns	$242,377,000	$125,061

Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Streambank - Herbert River 5%	$18,783,000	$26
Streambank - Herbert River 6% to 10% (pro-rata)	$48,637,000	$62

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Streambank - Herbert River 5%	$18,783,000	$26
Streambank - Herbert River 6% to 10%	$48,637,000	$53
Land Management - WT - Grazing D to C	$49,323,000	$10
Land Management - WT - Grazing C to B	$108,087,000	$155
Land Management - WT - Grazing B to A (pro-rata)	$126,364,000	$26

The total costs for fine sediment in the Wet Tropics are shown in Figure 35.

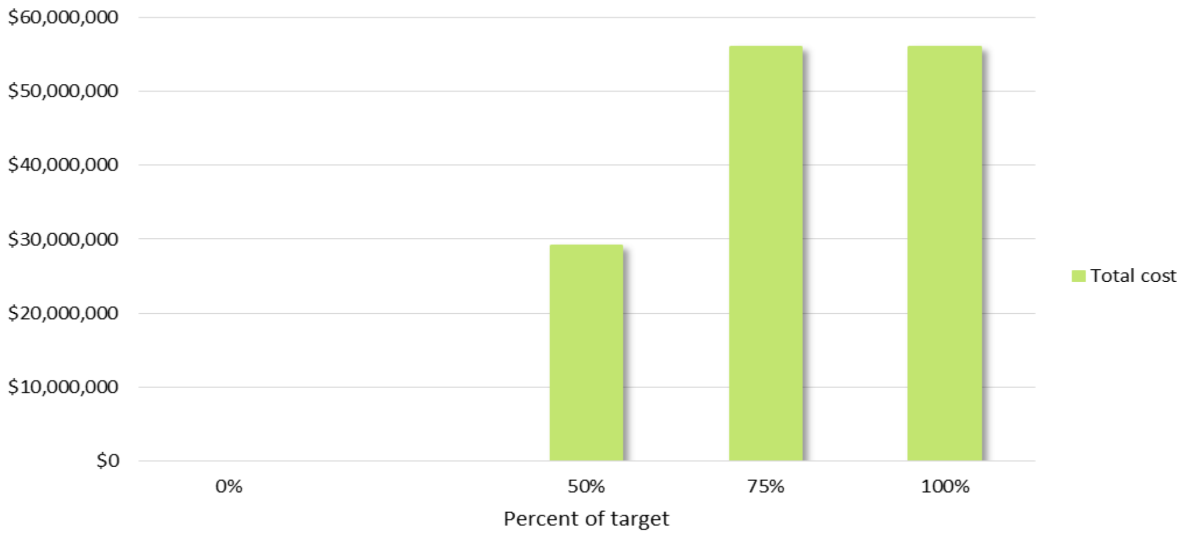


Figure 35. *Steps to Target - Wet Tropics - DIN*

The summary results from the modelling are shown in Table 15. The key points to note are:

- The total cost of meeting 50% of the DIN target is around $29 million. This can be achieved through practice change (C to B).
- The cost of meeting 75% and 100% of the target are around $56 million (the same because the target cannot actually be achieved). This will require significant actions including land retirement to conservation and improvements in management practice on other land. It should be noted that the sequence of policy solution sets could involve actions with higher unit costs being undertaken before actions with cheaper unit costs. However, overall, the cost of meeting the target is minimised.

Table 15. Cost of DIN targets – Wet Tropics

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
10% Retirement of D Class Practice Cane to Conservation	$1,712,000	$14,467
11-30% Retirement of D Class Practice Cane to Conservation	$5,131,000	$14,451
31-50% Retirement of D Class Practice Cane to Conservation	$8,554,000	$14,467
Cane D to C Practice Improvement	$9,501,000	$11,147
Cane C to B Practice Improvement	$56,074,000	$4,888

Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Cane C to B Practice Improvement (pro-rata)	$29,180,000	$4,888

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
10% Retirement of D Class Practice Cane to Conservation	$1,712,000	$14,467
11-30% Retirement of D Class Practice Cane to Conservation	$5,131,000	$14,451
31-50% Retirement of D Class Practice Cane to Conservation	$8,554,000	$14,467
Cane D to C Practice Improvement	$9,501,000	$11,147
Cane C to B Practice Improvement	$56,074,000	$4,888

Burdekin

The total costs for fine sediment in the Burdekin are shown in Figure 36.

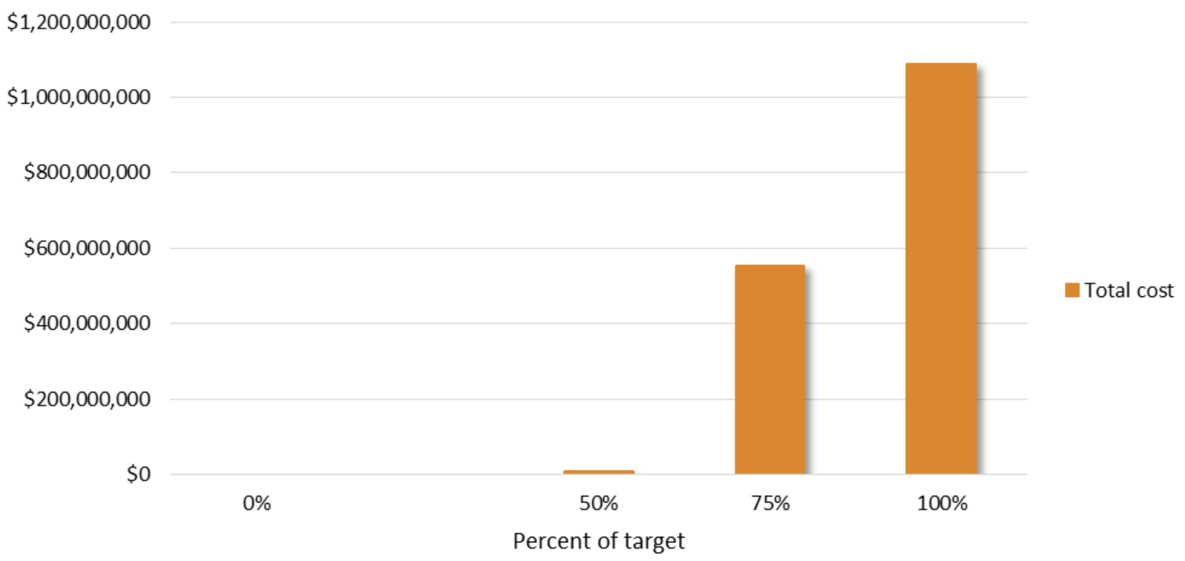


Figure 36. *Steps to Target - Burdekin - Fine Sediment*

The summary results from the modelling are shown in Table 16. The key points to note are:

- The total cost of meeting 50% of the fine sediment target is around $8 million, largely due to the significant progress in recent years. This can be achieved through enhanced grazing management.
- The cost of meeting 75% of the target is significantly higher (around $550 million) as a suite of higher unit cost actions are required including moving significant areas to B practice grazing and large investments in gully repair.
- To meet the full target requires a comprehensive policy solution set including, grazing practice change and significantly more gully treatment, with a total estimated cost of around $1.1 billion.
- The costs of meeting the lower targets (e.g. 50% of the Reef 2050 Plan targets) are significantly below their proportional load reductions as the lower target enables exploitation of a greater set of low cost actions that still meet the overall target.

Table 16. Cost of fine sediment targets – Burdekin

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Burdekin - Grazing D to C	$9,000,000	$3
Land Management - Burdekin - Grazing C to B	$372,000,000	$158
Gully - Burdekin 10% - Treatment 2 (prorata)	$1,089,000,000	$140
Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Burdekin - Grazing D to C (pro-rata)	$8,000,000	$3
Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Burdekin - Grazing D to C	$9,000,000	$3
Land Management - Burdekin - Grazing C to B	$372,000,000	$158
Gully - Burdekin 10% - Treatment 2 (prorata)	$553,000,000	$140

The total costs for DIN in the Burdekin are shown in Figure 37.

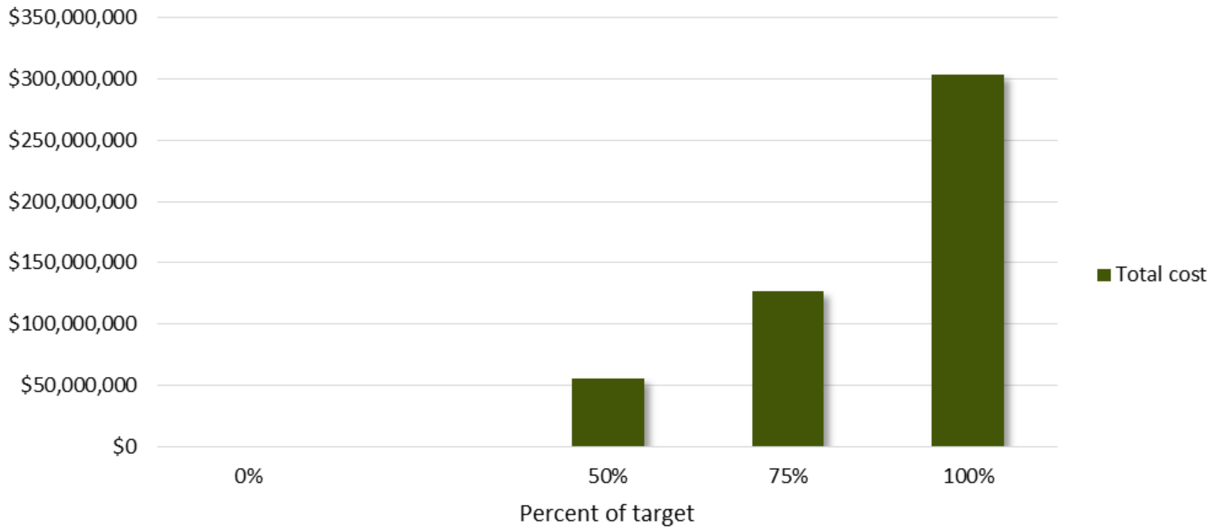


Figure 37. *Steps to Target - Burdekin - DIN*

The summary results from the modelling are shown in Table 17. The key points to note are:

- The total cost of meeting 50% of the DIN target is around $56 million. This can be achieved through practice change (C to B) and irrigation enhancements. In addition, change in D class practice is also required.
- The cost of meeting the 75% target is significantly higher (around $126 million) as very major investments are required in irrigation. In addition, major investment is also required to move all C practice to B practice.
- The cost of meeting the 100% target is over twice the cost of meeting the 75% target, estimated at around $304 million. Because practice change alone will be insufficient to meet the targets, this target actually triggers fundamental change to irrigation practices.

Table 17. Cost of DIN targets – Burdekin

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Irrigation - Burdekin - 20% - Level 2	$20,000,000	$12,264
Irrigation - Burdekin - 21 to 50% - Level 2	$101,000,000	$32,744
Irrigation - Burdekin - 51 to 70% - Level 2	$204,000,000	$62,463
Irrigation - Burdekin - 71 to 100% - Level 2 (prorata)	$304,000,000	$41,650

Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Burdekin - Cane D to C	$2,000,000	$11,045
Irrigation - Burdekin - 20% - Level 2	$23,000,000	$12,264
Land Management - Burdekin - Cane C to B (pro-rata)	$56,000,000	$24,726

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Burdekin - Cane D to C	$2,000,000	$11,045
Land Management - Burdekin - Cane C to B	$68,000,000	$24,726
Irrigation - Burdekin - 20% - Level 2	$88,000,000	$12,264
Irrigation - Burdekin - 21 to 50% - Level 2 (prorata)	$126,000,000	$32,744

Mackay Whitsunday

The total costs for fine sediment in the Mackay Whitsunday region are shown in Figure 38.

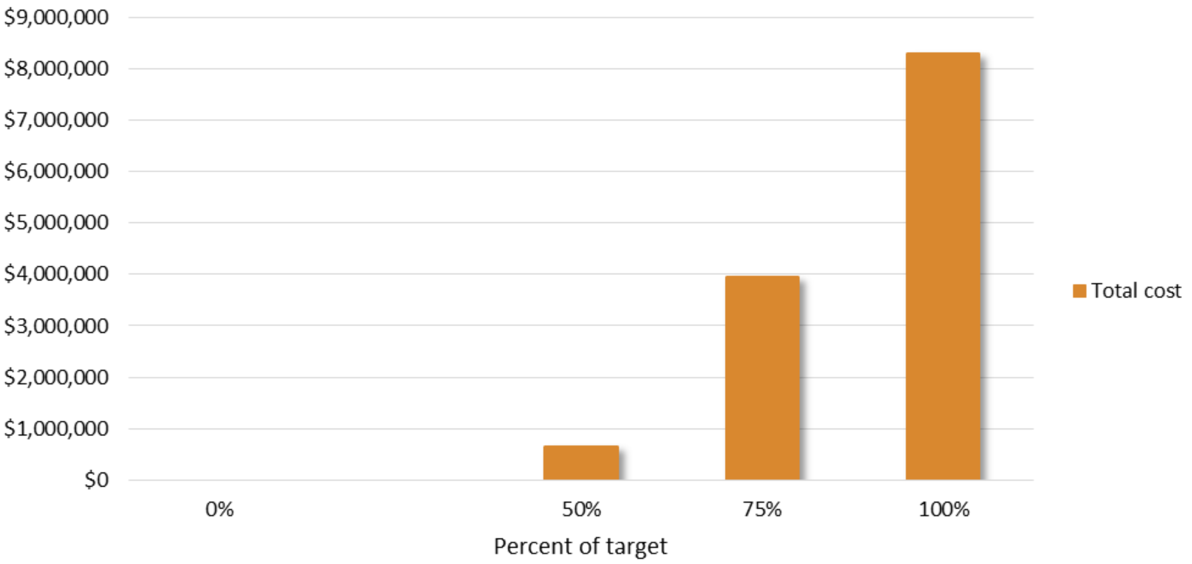


Figure 38. *Steps to Target - Mackay Whitsunday - Fine Sediment*

The summary results from the modelling are shown in the table below (Table 18). The key points to note are:

- The total cost of meeting 50% of the fine sediment target is around $1 million, largely due to the significant progress in recent years. This can be achieved through enhanced grazing management on land currently under D practices.
- The cost of meeting 75% of the target is higher (around $4 million), but is largely similar to achieving the 50% target, albeit with change required over a wider area.
- To meet the full target requires a comprehensive policy solution set including grazing practice change, incorporating some areas from C to B practice, while all areas under D would need to improve. We estimate the cost of this target at around $8 million.
- The costs of meeting the lower targets (e.g. 50% of the Reef 2050 Plan targets) are significantly below their proportional load reductions as the lower target enables exploitation of a greater set of low cost actions that still meet the overall target. This is particularly the case for achieving the 100% target.

Table 18. Cost of fine sediment targets – Mackay Whitsunday

Full target		
Scenario	**Cumulative Present Value ($ 2016-2025)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Grazing D to C	$7,000,000	$18
Land Management - Grazing C to B (prorata)	$8,000,000	$67

Stack for 50% of target		
Scenario	**Cumulative Present Value ($/yr)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Grazing D to C (prorata)	$1,000,000	$18

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Management - Grazing D to C (prorata)	$4,000,000	$18

The total costs for DIN in the Mackay Whitsunday region are shown in Figure 39.

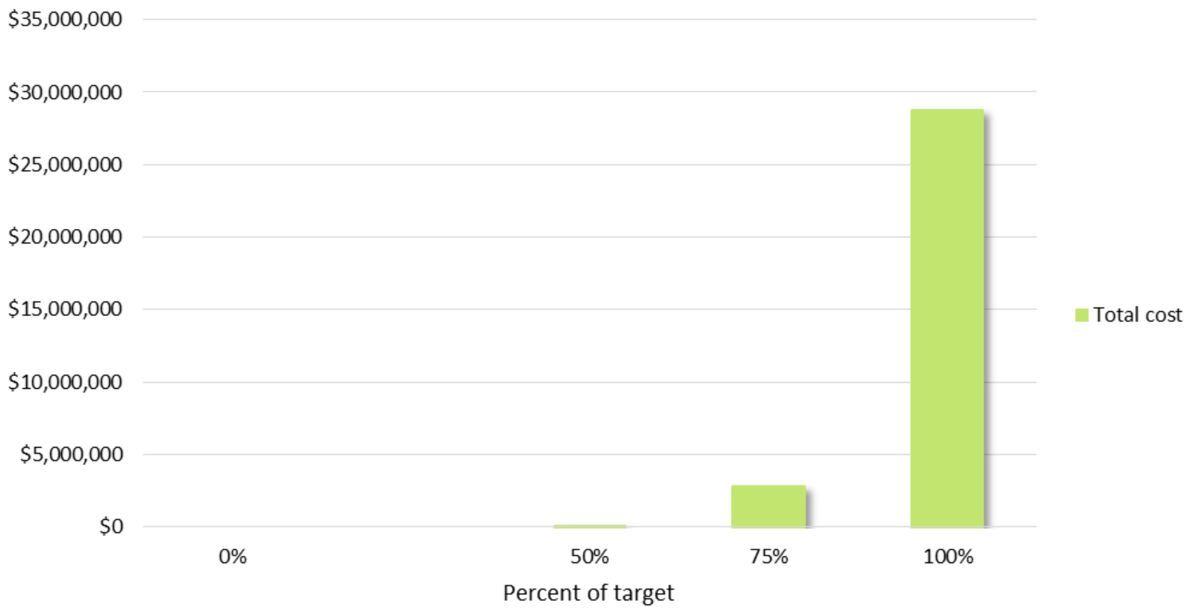


Figure 39. *Steps to Target - Mackay Whitsunday - DIN*

The summary results from the modelling are shown in Table 19. The key points to note are:

- The total cost of meeting 50% of the DIN target is negligible, around $0.1 million due to previous practice change and because this involves the cheapest practice change (C to B).
- The cost of meeting the 75% target is higher (around $3 million). Achieving this target would require both practice change and some land retirement.
- The cost of meeting the 100% target is almost 10 times the cost of meeting the 75% target, estimated at around $29 million. Because practice change alone will be insufficient to meet the target, this target also requires the retirement of some land.

Table 19. Cost of DIN targets – Mackay Whitsunday

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Repair - Mackay 10% D class cane to conservation	$1,000,000	$6,283
Land Repair - Mackay 11% to 20% D class cane to conservation	$2,000,000	$6,294
Cane D to C Practice Improvement	$3,000,000	$597
Cane C to B Practice Improvement (prorata)	$29,000,000	$24,671

Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Cane D to C Practice Improvement (prorata)	$100,000	$597

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Land Repair - Mackay 10% D class cane to conservation	$1,000,000	$6,283
Land Repair - Mackay 11% to 20% D class cane to conservation	$2,000,000	$6,294
Cane D to C Practice Improvement (prorata)	$3,000,000	$597

Fitzroy
As per the ToR for this study, no DIN targets have been assessed for the Fitzroy. The total costs for fine sediment in the Fitzroy region are shown in Figure 40.

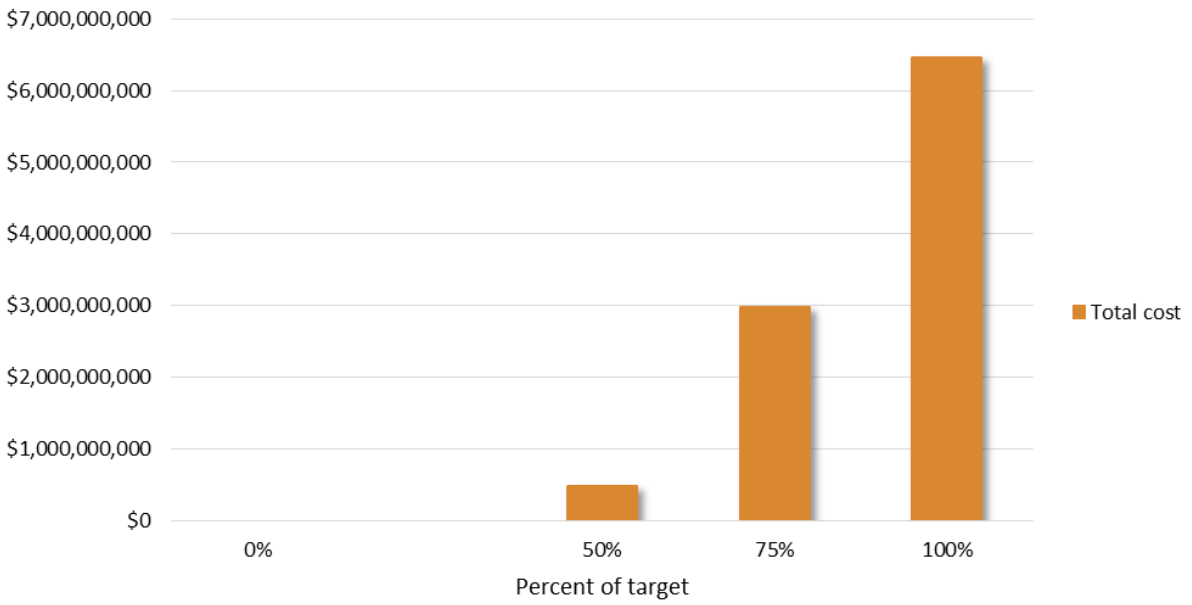


Figure 40. *Steps to Target - Fitzroy - Fine Sediment*

The summary results from the modelling are shown in the table below (Table 20). The key points to note are:

- The total cost of meeting even the 50% of the fine sediment target is very significant, at around $480 million. Significant areas of grazing D to C practice for hillslope, and grazing C to b on hillslopes will be required.
- The cost of meeting 75% of the target is around 6 times higher than meets the 50% target, with a total cost of almost $3 billion. Significant areas of improved practices on hillslopes are required and significant gully repair (which has a relatively high unit abatement cost).
- To meet the full target requires a very comprehensive investment comprehensive policy solution set including, grazing practice change (some to A class) and significant gully repairs. We estimate the cost of meeting this target at around $6.5 billion, almost 14 times the cost of meeting the 50% target.

Table 20. Cost of fine sediment targets – Fitzroy

Full target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing D to C practice for hillslope	$51,000,000	$3
Grazing C to B practice for hillslope	$491,000,000	$31
Grazing B to A practice for hillslope	$880,000,000	$28
Gully - Fitzroy 10% - Treatment 2	$2,135,000,000	$98
Gully - Fitzroy 11% to 25% - Treatment 2	$4,063,000,000	$169
Gully - Fitzroy 26% to 50% - Treatment 2 (pro-rata)	$6,463,000,000	$233

Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing D to C practice for hillslope	$51,000,000	$3
Grazing C to B practice for hillslope (prorata)	$476,000,000	$31

Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing D to C practice for hillslope	$51,000,000	$3
Grazing C to B practice for hillslope	$491,000,000	$31
Grazing B to A practice for hillslope	$880,000,000	$28
Gully - Fitzroy 10% - Treatment 2	$2,135,000,000	$98
Gully - Fitzroy 11% to 25% - Treatment 2 (prorata)	$2,984,000,000	$169

Burnett Mary

The total costs for fine sediment in the Burnett Mary are shown in Figure 41.

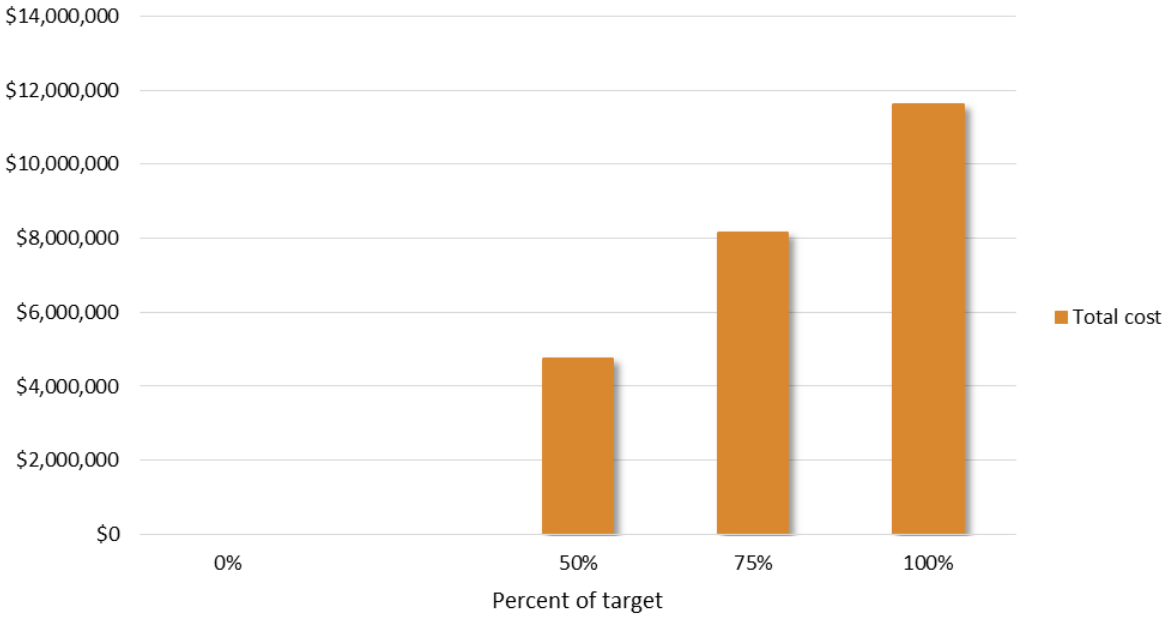


Figure 41. *Steps to Target - Burnett Mary - Fine Sediment*

The summary results from the modelling are shown in Table 21. The key points to note are:

- The total cost of meeting 50% of the fine sediment target is around $5 million, achieved through enhanced management on hillslopes.
- The cost of meeting 75% of the target is higher (around $6 million), and the cost of meeting 100% of the target is around $12 million, all achieved through enhanced management on hillslopes.
- Unlike all other policy solution sets modelled, the cost of progressively meeting the targets for this region is relatively linear, as the same generic action is required.

Table 21. Cost of fine sediment targets – Burnett Mary

Full target		
Scenario	**Cumulative Present Value ($/yr)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing C to B practice for hillslope (pro-rata)	$12,000,000	$9
Stack for 50% of target		
Scenario	**Cumulative Present Value ($/yr)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing C to B practice for hillslope (pro-rata)	$5,000,000	$9
Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Grazing C to B practice for hillslope (pro-rata)	$8,000,000	$9

The total costs for DIN in the Burnett Mary are shown in Figure 42.

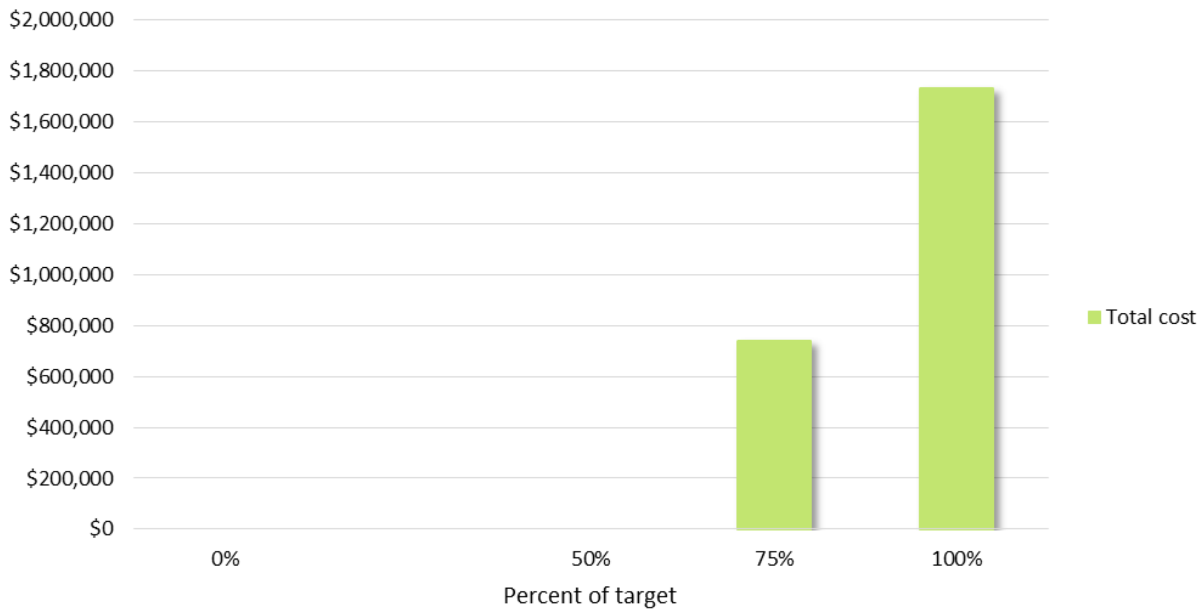


Figure 42. *Steps to Target - Burnett Mary - DIN*

The summary results from the modelling are shown in Table 22. The key points to note are:

- There are no further costs associated with meeting the 50% of the DIN target as it has already been met.
- The cost of meeting the 75% target is estimated at around $0.7 million, primarily for improvements in cane practice.
- The cost of meeting the 100% target is estimated at around $1.7 million.

Table 22. Cost of DIN targets – Burnett Mary

DIN		
Full target		
Scenario	**Cumulative Present Value ($/yr)**	**$/tonne**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Cane D to C Practice Improvement (pro-rata)	$1,700,000	$1,767
Stack for 50% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Stack for 75% of target		
Scenario	**Cumulative Present Value ($)**	**$/tonne/yr**
2013 Baseline	$0	$0
Load reductions to date (2009-2013)	$0	$0
Cane D to C Practice Improvement (pro-rata)	$700,000	$1,767

4.5 Whole of GBR results – cost effectiveness

We have compiled two sets of tables outlining the list of actions selected into the policy solutions sets and the totals associated with those (Table 23 and Table 24), then the full list of actions evaluated.

The list of actions for the final selected policy solution sets is split on a region by region basis so that comparisons can be made of the costs and load reductions between regions, and the cost-effectiveness of similar actions in different regions.

When considering the policy solution sets, there were a large number of potential actions that were evaluated. These have been compiled to present a complete list of options that were evaluated in this project, in addition to the final sets of actions chosen (noted by either FS1,2,3 or DIN1,2,3 etc). We have tabulated these for information purposes (Table 25 and Table 26) but the cumulative figures do not represent any overall cost to protect the Reef, only the full costs of the all actions (within the policy solution sets) evaluated. In some cases, the actions were extraordinarily expensive and may never be used, but it is important that we show they have been considered to support any future activities that may require such data.

Table 23. Selected actions required to achieve fine sediment targets across the whole of GBR

Policy solution set and actions	Load reduced (t/yr)	Load exported (t/yr)	Present Value ($/yr)	$/tonne
2013 Baseline (whole GBR)		9,031,000		
Wet Tropics				
Load reductions to date (2009-2013)	129,000	8,902,000		
Streambank Repair Herbert 5% Stream Length	71,000	8,831,000	$18,800,000	$26.4
Streambank Repair Herbert 6-10% Stream Length	56,800	8,774,200	$29,900,000	$52.5
Grazing Practice Change D to C	6,750	8,767,450	$686,000	$10.2
Grazing Practice Change C to B	37,800	8,729,650	$58,800,000	$155
Grazing Practice Change B to A	88,400	8,641,250	$23,000,000	$26.1
Streambank - Tully River 5% of stream length	1,420	8,639,830	$5,070,000	$358
Streambank - Tully River 6% to 10% of stream length	987	8,638,843	$5,620,000	$569
Urban Stormwater new development - Wet Tropics - Cairns	80.4	8,638,763	$101,000,000	$125,000
Burdekin				
Load reductions to date (2009-2013)	491,000	8,147,763		
Grazing Practice Change D to C	300,000	7,847,763	$8,960,000	$3
Grazing Practice Change C to B	230,000	7,617,763	$364,000,000	$158
Gully - Burdekin 10% of gullies - Full Treatment (pro-rata)	513,000	7,104,763	$717,000,000	$140
Mackay Whitsunday				
Load reductions to date (2009-2013)	32,100	7,072,663		
Grazing Practice Change D to C	38,000	7,034,663	$7,020,000	$19
Grazing C to B Practice Change (pro-rata)	1,890	7,032,773	$1,270,000	$67
Fitzroy				
Load reductions to date (2009-2013)	61,200	6,971,573		
Grazing Practice Change D to C	248,000	6,723,573	$51,500,000	$3.47
Grazing Practice Change C to B	75,800	6,647,773	$440,000,000	$31
Grazing Practice Change B to A	22,900	6,624,873	$388,000,000	$28
Gully - Fitzroy 10% of gullies - Full Treatment	104,000	6,520,873	$1,260,000,000	$98

Policy solution set and actions	Load reduced (t/yr)	Load exported (t/yr)	Present Value ($/yr)	$/tonne
Gully - Fitzroy 11% to 25% of gullies - Full Treatment	140,000	6,380,873	$1,930,000,000	$169
Gully - Fitzroy 26% to 50% of gullies - Full Treatment (pro-rata)	113,000	6,267,873	$2,400,000,000	$233
Burnett Mary				
Load reductions to date (2009-2013)	23,500	6,244,373		
Grazing Practice Change C to B (pro-rata)	134,000	6,110,373	$11,600,000	$8.69
All GBR	**2,920,000**	**6,110,000**	**$7,820,000,000**	**$268**
TSS Target total load in 2025		**6,009,000**		
Deficit		**101,000**		

Table 24. Selected actions required to achieve DIN targets across the whole of GBR

Policy solution set and actions	Load reduced (t/yr)	Load exported (t/yr)	Present Value ($/yr)	$/tonne
2013 Baseline (whole GBR)		9,610		
Wet Tropics				
Load reductions to date (2009-2013)	287	9,323		
10% Retirement of D Class Practice Cane to Conservation	12	9,311	$1,710,000	14500
11-30% Retirement of D Class Practice Cane to Conservation	24	9,288	$3,420,000	14500
31-50% Retirement of D Class Practice Cane to Conservation	24	9,264	$3,420,000	14500
Cane Practice Change D to C	9	9,255	$947,000	11100
Cane Practice Change C to B	953	8,302	$46,600,000	4890
Burdekin				
Load reductions to date (2009-2013)	173	8,129		
Irrigation - Burdekin - 20% - Level 2	165	7,964	$20,200,000	$12,300
Irrigation - Burdekin - 21 to 50% - Level 2	247	7,717	$80,900,000	$32,700
Irrigation - Burdekin - 51 to 70% - Level 2	165	7,552	$103,000,000	$62,500
Irrigation - Burdekin - 71 to 100% - Level 2 (pro-rata)	240	7,312	$99,800,000	$41,700
Mackay Whitsunday				
Load reductions to date (2009-2013)	224	7,088		
Land Repair - 10% D class cane to conservation	12	7,077	$741,000	$6,280
Land Repair - 11% to 20% D class cane to conservation	24	7,053	$1,480,000	$6,290
Cane Practice Change D to C	102	6,951	$609,000	$597
Cane Practice Change C to B (pro-rata)	105	6,846	$26,000,000	$24,700
Burnett Mary				
Load reductions to date (2009-2013)	160	6,686		
Cane Practice Change D to C (pro-rata)	98	6,588	$1,730,000	$1,770
All GBR	**3,022**	**6,590**	**$390,557,000**	**$12,900**
TSS Target total load in 2025		**6,130**		
Deficit		**460**		

Table 25. Full list of actions evaluated for fine sediment

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
FS1	Land Management - Burdekin - Grazing D to C	Burdekin	Sediment	300,000	300,000	$8,960,000	$8,960,000	$3
FS3	Land Management - Wet Tropics - Grazing D to C	Wet Tropics	Sediment	6,750	307,000	$686,000	$9,640,000	$10
FS1	Land Management - Mackay - Grazing D to C	Mackay	Sediment	38,000	345,000	$7,020,000	$16,700,000	$19
FS4	Land Management - Fitzroy - Grazing D to C	Fitzroy	Sediment	248,000	593,000	$51,500,000	$68,100,000	$21
FS1	Streambank - Herbert River 5%	Wet Tropics	Sediment	71,000	664,000	$18,800,000	$86,900,000	$26
FS2	Streambank - Herbert River 6% to 10%	Wet Tropics	Sediment	56,800	721,000	$29,900,000	$117,000,000	$53
FS1	Land Management - Burnett Mary - Grazing C to B	Burnett Mary	Sediment	134,000	855,000	$77,900,000	$195,000,000	$58
FS5	Land Management - Wet Tropics - Grazing B to A	Wet Tropics	Sediment	37,800	892,000	$23,000,000	$218,000,000	$61
FS4	Land Management - Wet Tropics - Grazing C to B	Wet Tropics	Sediment	88,400	981,000	$58,800,000	$276,000,000	$67
FS2	Land Management - Mackay - Grazing C to B	Mackay	Sediment	1,890	983,000	$1,270,000	$278,000,000	$67
	Streambank – O'Connell River 6% to 10%	Mackay	Sediment	2,400	2,190,000	$1,690,000	$7,880,000,000	$71
	Streambank – O'Connell River 5%	Mackay	Sediment	1,610	2,190,000	$1,200,000	$7,880,000,000	$75
	Streambank - Mary River 6% to 10%	Burnett Mary	Sediment	37,200	2,230,000	$41,700,000	$7,930,000,000	$112
FS3	Gully - Burdekin 10% - Treatment 2	Burdekin	Sediment	513,000	1,500,000	$717,000,000	$994,000,000	$140
FS2	Land Management - Burdekin - Grazing C to B	Burdekin	Sediment	230,000	1,730,000	$364,000,000	$1,360,000,000	$158
	Land Management - Mackay - Grazing B to A	Mackay	Sediment	13,900.0	2,240,000	$22,200,000	$7,950,000,000	$159
	Streambank - Mary River 5%	Burnett Mary	Sediment	31,100.0	2,270,000	$51,100,000	$8,000,000,000	$164
	Land Management - Burnett Mary - Grazing B to A	Burnett Mary	Sediment	63,800.0	2,330,000	$194,000,000	$8,190,000,000	$305
	Land Repair - Bowen 11% to 20% D class grazing to conservation	Bowen	Sediment	88,700	2,420,000	$283,000,000	$8,480,000,000	$319
	Land Repair - Bowen 5% D class grazing to conservation	Bowen	Sediment	44,200	2,470,000	$142,000,000	$8,620,000,000	$320
	Land Repair - Bowen 6% to 10% D class grazing to conservation	Bowen	Sediment	44,100	2,510,000	$142,000,000	$8,760,000,000	$321

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
FS6	Streambank - Tully River 5%	Wet Tropics	Sediment	1,420	1,730,000	$5,070,000	$1,360,000,000	$358
	Gully - Burdekin 11% to 25% - Treatment 2	Burdekin	Sediment	403,000	2,910,000	$1,590,000,000	$10,300,000,000	$394
	Gully - Burdekin 26% to 50% - Treatment 2	Burdekin	Sediment	582,000	3,500,000	$2,610,000,000	$13,000,000,000	$448
FS7	Streambank - Tully River 6% to 10%	Wet Tropics	Sediment	987	1,730,000	$5,620,000	$1,370,000,000	$569
FS5	Land Management - Fitzroy - Grazing C to B	Fitzroy	Sediment	75,800	1,800,000	$440,000,000	$1,810,000,000	$581
	Land Management - Burdekin - Grazing B to A	Burdekin	Sediment	74,600	3,570,000	$538,000,000	$13,500,000,000	$722
	Land Repair - Burdekin 6% to 10% D class grazing to conservation	Burdekin	Sediment	17,500	3,590,000	$145,000,000	$13,600,000,000	$826
	Land Repair - Burdekin 5% D class grazing to conservation	Burdekin	Sediment	17,500	3,610,000	$145,000,000	$13,800,000,000	$826
	Land Repair - Burdekin 11% to 20% D class grazing to conservation	Burdekin	Sediment	35,100	3,640,000	$290,000,000	$14,100,000,000	$826
FS1	Land Repair - Fitzroy 5% D class grazing to conservation	Fitzroy	Sediment	16	1,800,000	$134,000	$1,810,000,000	$836
FS2	Land Repair - Fitzroy 6% to 10% D class grazing to conservation	Fitzroy	Sediment	16	1,800,000	$134,000	$1,810,000,000	$836
FS3	Land Repair - Fitzroy 11% to 20% D class grazing to conservation	Fitzroy	Sediment	32	1,800,000	$267,000	$1,810,000,000	$836
FS7	Gully - Fitzroy 10% - Treatment 2	Fitzroy	Sediment	104,000	1,910,000	$1,260,000,000	$3,070,000,000	$1,210
FS8	Gully - Fitzroy 11% to 25% - Treatment 2	Fitzroy	Sediment	140,000	2,050,000	$1,930,000,000	$4,990,000,000	$1,370
	Gully - Burdekin 10% Treatment 1	Burdekin	Sediment	13,800	3,650,000	$191,000,000	$14,300,000,000	$1,390
FS6	Land Management - Fitzroy - Grazing B to A	Fitzroy	Sediment	22,900	2,070,000	$388,000,000	$5,380,000,000	$1,700
	Gully - Burdekin 51% to 100% - Treatment 2	Burdekin	Sediment	294,000	3,950,000	$5,110,000,000	$19,400,000,000	$1,740
FS9	Gully - Fitzroy 26% to 50% - Treatment 2	Fitzroy	Sediment	113,000	2,180,000	$2,400,000,000	$7,780,000,000	$2,130
	Gully - Burdekin 11% to 25% - Treatment 1	Burdekin	Sediment	6,870	3,960,000	$268,000,000	$19,600,000,000	$3,910
	Gully - Burdekin 26% to 50% - Treatment 1	Burdekin	Sediment	9,920	3,970,000	$441,000,000	$20,100,000,000	$4,450
	Gully - Fitzroy 51% to 100% - Treatment 2	Fitzroy	Sediment	98,300	4,060,000	$6,070,000,000	$26,200,000,000	$6,180

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
	Gully - Fitzroy 10% - Treatment 1	Fitzroy	Sediment	1,770	4,070,000	$212,000,000	$26,400,000,000	$12,000
	Gully - Fitzroy 11% to 25% - Treatment 1	Fitzroy	Sediment	2,390	4,070,000	$326,000,000	$26,700,000,000	$13,600
	Gully - Burdekin 51% to 100% - Treatment 1	Burdekin	Sediment	5,010	4,070,000	$864,000,000	$27,600,000,000	$17,200
	Gully - Fitzroy 26% to 50% - Treatment 1	Fitzroy	Sediment	2,370	4,080,000	$501,000,000	$28,100,000,000	$21,100
	Gully - Fitzroy 51% to 100% - Treatment 1	Fitzroy	Sediment	1,680	4,080,000	$1,030,000,000	$29,100,000,000	$61,300
FS8	Stormwater - Wet Tropics - Cairns - Sediment	Wet Tropics	Sediment	80	2,180,000	$101,000,000	$7,880,000,000	$125,000
	Stormwater - Reef Catchments - Mackay - Sediment	Mackay	Sediment	26.3	4,080,000	$63,500,000	$29,200,000,000	$241,000
	Stormwater-- Fitzroy - Rockhampton - Sediment	Fitzroy	Sediment	10.6	4,080,000	$32,700,000	$29,200,000,000	$308,000
	Stormwater - Burdekin - Townsville - Sediment	Burdekin	Sediment	28.6	4,080,000	$120,000,000	$29,300,000,000	$419,000

Table 26. Full list of actions evaluated for DIN

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
DIN3	Land Management - Mackay - Cane D to C	Mackay	DIN	102	102	$609,000	$609,000	$597
DIN1	Land Management - Burnett Mary - Cane D to C	Burnett Mary	DIN	98	200	$1,730,000	$2,340,000	$1,770
DIN5	Land Management - Wet Tropics - Cane C to B	Wet Tropics	DIN	944	1140	$46,600,000	$48,900,000	$4,930
DIN4	Land Management - Wet Tropics - Cane D to C	Wet Tropics	DIN	17	1160	$947,000	$49,900,000	$5,570
DIN1	Land Repair - Mackay 6% to 10% D class cane to conservation	Mackay	DIN	11.8	1170	$741,000	$50,600,000	$6,280
DIN2	Land Repair - Mackay 11% to 20% D class cane to conservation	Mackay	DIN	23.6	1200	$1,480,000	$52,100,000	$6,290
	Land Repair - Mackay 31% to 50% D class cane to conservation	Mackay	DIN	23.6	2560	$1,480,000	$510,000,000	$6,290
	Land Management - Burdekin - Cane D to C	Burdekin	DIN	22	2590	$2,430,000	$513,000,000	$11,000
DIN1	Irrigation - Burdekin - 20% - Level 2	Burdekin	DIN	165	1360	$20,200,000	$72,300,000	$12,300
DIN2	Land Repair - Wet Tropics 11% to 30% D class cane to conservation	Wet Tropics	DIN	23.7	1380	$3,420,000	$75,700,000	$14,500
DIN1	Land Repair - Wet Tropics 10% D class cane to conservation	Wet Tropics	DIN	11.8	1400	$1,710,000	$77,400,000	$14,500
DIN3	Land Repair - Wet Tropics 31% to 50% D class cane to conservation	Wet Tropics	DIN	23.7	1420	$3,420,000	$80,800,000	$14,500
	Irrigation - Burdekin - 70% - Level 1	Burdekin	DIN	576	3450	$116,000,000	$1,120,000,000	$20,100
DIN4	Land Management - Mackay - Cane C to B	Mackay	DIN	105	1530	$26,000,000	$107,000,000	$24,700
	Land Management - Burdekin - Cane C to B	Burdekin	DIN	264	2850	$65,300,000	$578,000,000	$24,700
	Land Management - Burnett Mary - Cane C to B	Burnett Mary	DIN	363	2540	$119,000,000	$509,000,000	$32,700
DIN2	Irrigation - Burdekin - 21 to 50% - Level 2	Burdekin	DIN	247	1770	$80,900,000	$188,000,000	$32,700
DIN4	Irrigation - Burdekin - 71 to 100% - Level 2	Burdekin	DIN	240	2010	$99,800,000	$287,000,000	$41,600
DIN3	Irrigation - Burdekin - 51 to 70% - Level 2	Burdekin	DIN	165	2180	$103,000,000	$390,000,000	$62,500

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
	Land Repair - Mackay 10% D class cane to A class grazing	Mackay	DIN	11.2	3460	$7,910,000	$1,120,000,000	$70,900
	Land Repair - Mackay 11% to 20% D class cane to A class grazing	Mackay	DIN	22.3	3490	$15,800,000	$1,140,000,000	$71,000
	Land Repair - Mackay 31% to 50% D class cane to A class grazing	Mackay	DIN	22.3	3510	$15,800,000	$1,150,000,000	$71,000
	Land Repair - Wet Tropics 11% to 30% D class cane to A class grazing	Wet Tropics	DIN	26.1	3540	$24,600,000	$1,180,000,000	$94,300
	Land Repair - Wet Tropics 10% D class cane to A class grazing	Wet Tropics	DIN	13.1	3550	$12,300,000	$1,190,000,000	$94,400
	Land Repair - Wet Tropics 31% to 50% D class cane to A class grazing	Wet Tropics	DIN	26.1	3570	$24,700,000	$1,220,000,000	$94,400
	Land Repair - Burdekin 10% D class cane to conservation	Burdekin	DIN	4.42	2850	$5,000,000	$583,000,000	$113,000
	Land Repair - Burdekin 31% to 50% D class cane to conservation	Burdekin	DIN	8.84	2860	$10,000,000	$593,000,000	$113,000
	Land Repair - Burdekin 11% to 30% D class cane to conservation	Burdekin	DIN	8.84	2870	$10,000,000	$603,000,000	$113,000
	Irrigation - Burdekin - 71 to 100% - Level 1	Burdekin	DIN	247	3820	$495,000,000	$1,710,000,000	$200,000
	Wetlands - Recycle Pit for Wet Weather 2% of Farm Area	Burdekin	DIN	193	4010	$440,000,000	$2,150,000,000	$228,000
	Wetlands - Recycle Pit for Wet Weather 3% to 5% of Farm Area	Burdekin	DIN	220	4230	$659,000,000	$2,810,000,000	$300,000
	Wetlands - Recycle Pit for Wet Weather 6% to 10% of Farm Area	Burdekin	DIN	323	4560	$1,100,000,000	$3,910,000,000	$340,000
	Wetlands - Wetland 6% to 10% of Farm Area	Burdekin	DIN	419	4980	$1,610,000,000	$5,510,000,000	$384,000
	Wetlands - Recycle Pit for Irrigation Tailwater - Burdekin	Burdekin	DIN	22	5000	$96,300,000	$5,610,000,000	$438,000

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
	Land Repair - Burdekin 10% D class cane to A class grazing	Burdekin	DIN	4.47	5000	$23,800,000	$5,630,000,000	$533,000
	Land Repair - Burdekin 31% to 50% D class cane to A class grazing	Burdekin	DIN	8.93	5010	$47,700,000	$5,680,000,000	$534,000
	Land Repair - Burdekin 11% to 30% D class cane to A class grazing	Burdekin	DIN	8.93	5020	$47,700,000	$5,730,000,000	$534,000
	Wetlands - Wetland 3% to 5% of Farm Area	Burdekin	DIN	174	5190	$1,220,000,000	$6,950,000,000	$700,000
	Wetlands - Recycle Pit for Irrigation Tailwater	Burnett Mary	DIN	9.7	2880	$79,400,000	$683,000,000	$818,000
	Wetlands - Recycle Pit for Wet Weather 11% to 20% of Farm Area	Burdekin	DIN	242	5440	$2,190,000,000	$9,130,000,000	$903,000
	Wetlands - Wetland 11% to 20% of Farm Area	Burdekin	DIN	203	5640	$2,630,000,000	$11,800,000,000	$1,300,000
	Wetlands - Wetland 2% of Farm Area	Burdekin	DIN	87.9	5730	$1,390,000,000	$13,200,000,000	$1,580,000
	Stormwater - Reef Catchments - Mackay	Mackay	DIN	-1.2	2880	$63,500,000	$999,000,000	$5,290,000
	Stormwater - Fitzroy - Rockhampton	Fitzroy	DIN	-0.6	2880	$32,700,000	$936,000,000	$5,450,000
	Stormwater - Burdekin - Townsville	Burdekin	DIN	-1.6	2880	$120,000,000	$903,000,000	$7,490,000
	Stormwater - Wet Tropics - Cairns	Wet Tropics	DIN	-0.9	2880	$101,000,000	$783,000,000	$11,200,000

* Stormwater solutions for urban lands will actually not prevent an increase in DIN loads as a result of future development, therefore the cost effectiveness is actually negative, in that if the money is expended on these options, a net increase in DIN would still occur, though obviously this would limit the overall increase compared to no treatment of stormwater from future urban development.

Estimated costs of achieving targets
The MACC modelling output comprises a summary of DIN and fine sediment abatement at the GBR lagoon achieved by 2025 and the average cost of abatement per tonne for the seven policy solution sets. These results are also presented as separate MACCss and TACC for DIN and fine sediment and by region. MACCs and TACCs for joint DIN and fine sediment abatement are not presented as the bulk of actions considered in this report are primarily aimed at a single target (e.g. reducing fine sediment loads).

Figure 43 through Figure 46 summarise the estimated costs of achieving the regional water quality targets shown in aggregate, excluding Cape York which is not included in this assessment. Table 27 and Table 28 provide the project and cost data that underpins these figures, and ranks projects in the order presented in the figures.

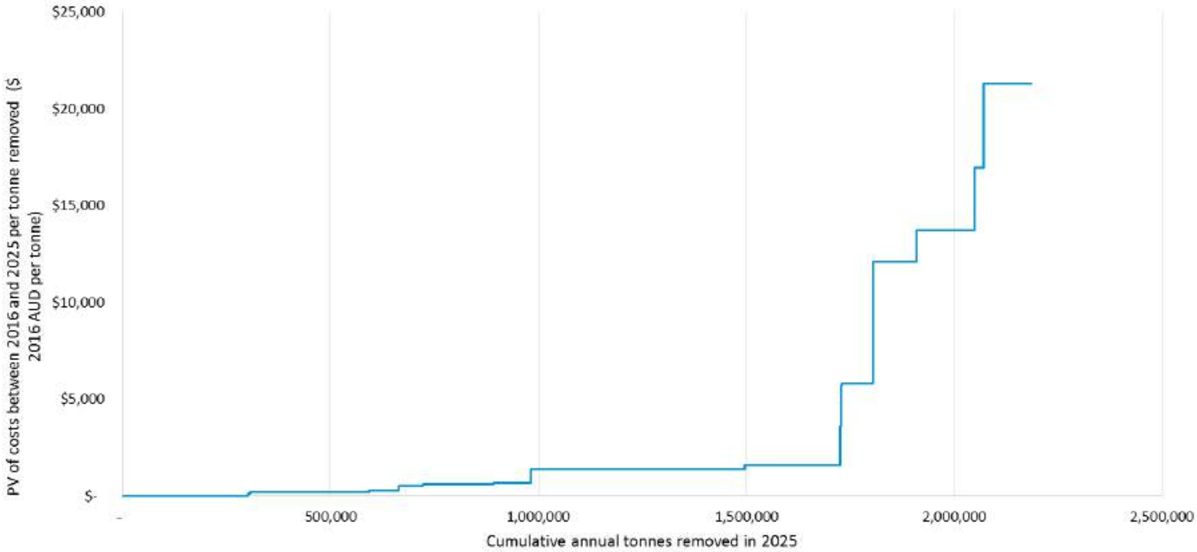


Figure 43. *Estimated MACC of achieving fine sediment targets for each region in aggregate (excluding Cape York) by 2025*

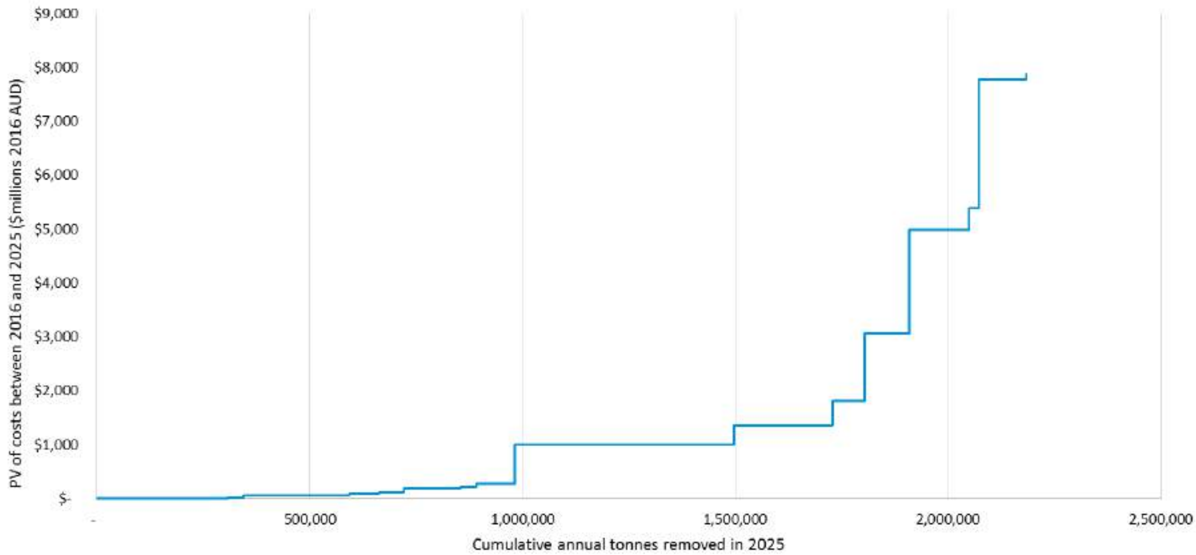


Figure 44. *Estimated TACC of achieving fine sediment targets for each region in aggregate (excluding Cape York) by 2025*

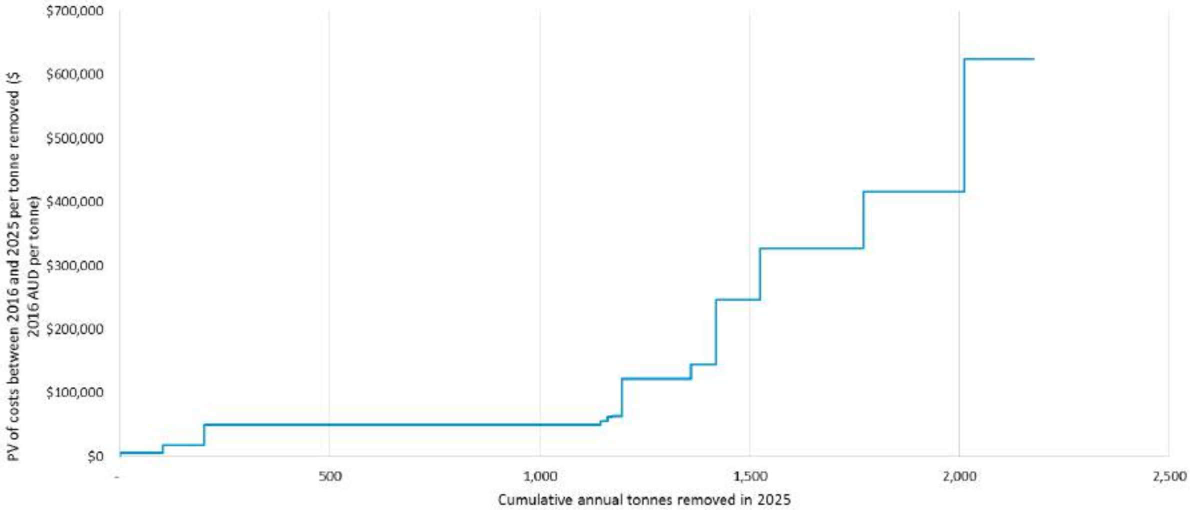


Figure 45. *Estimated MACC of achieving DIN targets for each region in aggregate (excluding Cape York) by 2025*

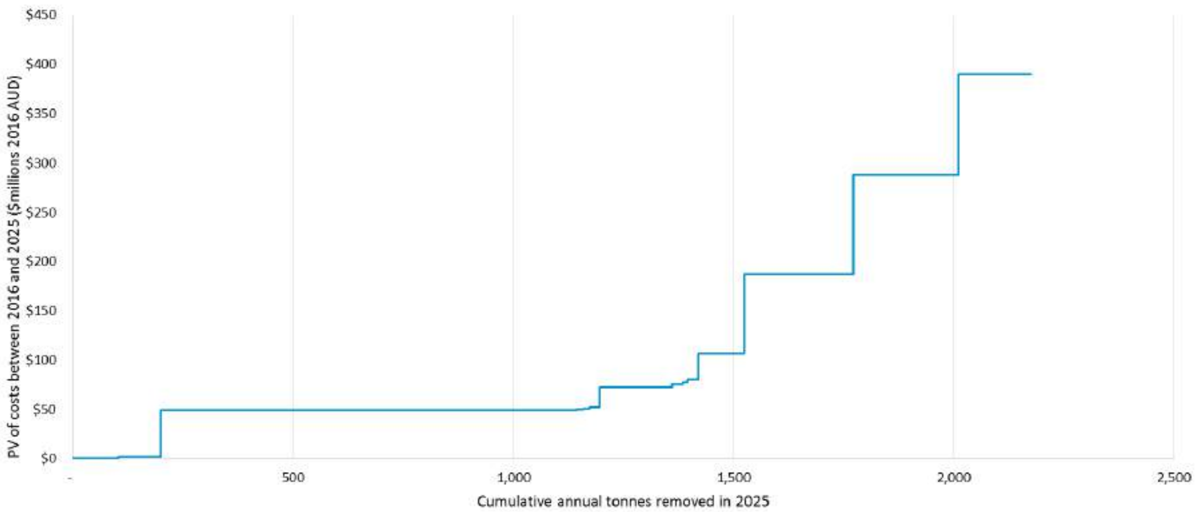


Figure 46. *Estimated TACC of achieving DIN targets for each region in aggregate (excluding Cape York) by 2025*

Table 27. Estimated cost of achieving fine sediment targets for each region in aggregate (excluding Cape York) by 2025

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
FS1	Land Management - Burdekin - Grazing D to C	Burdekin	Sediment	300,000	300,000	$8,960,000	$8,960,000	$3
FS3	Land Management - Wet Tropics - Grazing D to C	Wet Tropics	Sediment	6,750	307,000	$686,000	$9,640,000	$10
FS1	Land Management - Mackay - Grazing D to C	Mackay	Sediment	38,000	345,000	$7,020,000	$16,700,000	$19
FS4	Land Management - Fitzroy - Grazing D to C	Fitzroy	Sediment	248,000	593,000	$51,500,000	$68,100,000	$21
FS1	Streambank - Herbert River 5%	Wet Tropics	Sediment	71,000	664,000	$18,800,000	$86,900,000	$26
FS2	Streambank - Herbert River 6% to 10%	Wet Tropics	Sediment	56,800	721,000	$29,900,000	$117,000,000	$53
FS1	Land Management - BURNETT MARY- Grazing C to B	Burnett Mary	Sediment	134,000	855,000	$77,900,000	$195,000,000	$58
FS5	Land Management - Wet Tropics - Grazing B to A	Wet Tropics	Sediment	37,800	892,000	$23,000,000	$218,000,000	$61
FS4	Land Management - Wet Tropics - Grazing C to B	Wet Tropics	Sediment	88,400	981,000	$58,800,000	$276,000,000	$67
FS2	Land Management - Mackay - Grazing C to B	Mackay	Sediment	1,890	983,000	$1,270,000	$278,000,000	$67
FS3	Gully - Burdekin 10% - Treatment 2	Burdekin	Sediment	513,000	1,500,000	$717,000,000	$994,000,000	$140
FS2	Land Management - Burdekin - Grazing C to B	Burdekin	Sediment	230,000	1,730,000	$364,000,000	$1,360,000,000	$158
FS6	Streambank - Tully River 5%	Wet Tropics	Sediment	1,420	1,730,000	$5,070,000	$1,360,000,000	$358
FS7	Streambank - Tully River 6% to 10%	Wet Tropics	Sediment	987	1,730,000	$5,620,000	$1,370,000,000	$569
FS5	Land Management - Fitzroy - Grazing C to B	Fitzroy	Sediment	75,800	1,800,000	$440,000,000	$1,810,000,000	$581
FS1	Land Repair - Fitzroy 5% D class grazing to conservation	Fitzroy	Sediment	16.0	1,800,000	$134,000	$1,810,000,000	$836
FS2	Land Repair - Fitzroy 6% to 10% D class grazing to conservation	Fitzroy	Sediment	16.0	1,800,000	$134,000	$1,810,000,000	$836
FS3	Land Repair - Fitzroy 11% to 20% D class grazing to conservation	Fitzroy	Sediment	32.0	1,800,000	$267,000	$1,810,000,000	$836
FS7	Gully - Fitzroy 10% - Treatment 2	Fitzroy	Sediment	104,000	1,910,000	$1,260,000,000	$3,070,000,000	$1,210
FS8	Gully - Fitzroy 11% to 25% - Treatment 2	Fitzroy	Sediment	140,000	2,050,000	$1,930,000,000	$4,990,000,000	$1,370
FS6	Land Management - Fitzroy - Grazing B to A	Fitzroy	Sediment	22,900	2,070,000	$388,000,000	$5,380,000,000	$1,700
FS9	Gully - Fitzroy 26% to 50% - Treatment 2	Fitzroy	Sediment	113,000	2,180,000	$2,400,000,000	$7,780,000,000	$2,130

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
FS8	Stormwater - Wet Tropics - Cairns - Sediment	Wet Tropics	Sediment	80.4	2,180,000	$101,000,000	$7,880,000,000	$125,000

Table 28. Estimated cost of achieving DIN targets for each region in aggregate (excluding Cape York) by 2025

Identified actions for regions	Description	Catchment	Pollutant	Efficacy (tonnes per year removed by 2025)	Cumulative efficacy (tonnes per year removed by 2025)	Present Value of Costs (2016-2025 $)	Cumulative Present Value of Costs (2016-2025 $)	Cost effectiveness ($/tonne/yr)
DIN3	Land Management - Mackay - Cane D to C	Mackay	DIN	102	102	$609,000	$609,000	$597
DIN1	Land Management - Burnett Mary - Cane D to C	Burnett Mary	DIN	98	200	$1,730,000	$2,340,000	$1,770
DIN5	Land Management - Wet Tropics - Cane C to B	Wet Tropics	DIN	944	1,140	$46,600,000	$48,900,000	$4,930
DIN4	Land Management - Wet Tropics - Cane D to C	Wet Tropics	DIN	17	1,160	$947,000	$49,900,000	$5,570
DIN1	Land Repair - Mackay 6% to 10% D class cane to conservation	Mackay	DIN	11.8	1,170	$741,000	$50,600,000	$6,280
DIN2	Land Repair - Mackay 11% to 20% D class cane to conservation	Mackay	DIN	23.6	1,200	$1,480,000	$52,100,000	$6,290
DIN1	Irrigation - Burdekin - 20% - Level 2	Burdekin	DIN	165	1,360	$20,200,000	$72,300,000	$12,300
DIN2	Land Repair - Wet Tropics 11% to 30% D class cane to conservation	Wet Tropics	DIN	23.7	1,380	$3,420,000	$75,700,000	$14,500
DIN1	Land Repair - Wet Tropics 10% D class cane to conservation	Wet Tropics	DIN	11.8	1,400	$1,710,000	$77,400,000	$14,500
DIN3	Land Repair - Wet Tropics 31% to 50% D class cane to conservation	Wet Tropics	DIN	23.7	1,420	$3,420,000	$80,800,000	$14,500
DIN4	Land Management - Mackay - Cane C to B	Mackay	DIN	105	1,530	$26,000,000	$107,000,000	$24,700
DIN2	Irrigation - Burdekin - 21 to 50% - Level 2	Burdekin	DIN	247	1,770	$80,900,000	$188,000,000	$32,700
DIN4	Irrigation - Burdekin - 71 to 100% - Level 2	Burdekin	DIN	240	2,010	$99,800,000	$287,000,000	$41,600
DIN3	Irrigation - Burdekin - 51 to 70% - Level 2	Burdekin	DIN	165	2,180	$103,000,000	$390,000,000	$62,500

Key outcomes of the marginal abatement cost modelling are the following:

- Costs shown in the MACC and TACC figures are the estimated least cost pathways for achieving the regional water quality targets shown in *Section 3.2* of the main body of this report. The investment pathway shown is based on the logical sequencing of investments, as described in the section titled *Integration with metamodeling and estimating cost curves* within Attachment (C.1).

- Not all investments in the policy solution sets are needed to achieve the targets. Table 27 and Table 28 show all of the potential investments from the policy solutions sets. Investments that are included in the cost curves in Figure 43 through Figure 46 are shown with the alphanumeric notation in the column on the left of both Tables. A total of 23 out of 52 investments are required to meet the fine sediment target, and 14 of 47 DIN investments.

- Fine sediment: the total cost of achieving regional and GBR fine sediment abatement targets is estimated to be in the order of $7.8 billion in the most likely case, and $5.3 billion under best-case assumptions and $18.4 billion under worst case assumptions. There is significant differential between unit abatement costs of land management and practice change compared to streambank and gully repair. Around 85% of total regional fine sediment targets (1.8 million tonnes) are achieved through land management and repair activities at a total cost of around $1.8 billion, an average cost per tonne of $1,000. The remaining 0.4 million tonnes of abatement comes mainly from a combination of streambank and gully repair at an estimated total cost of $6 billion, i.e. an average cost per tonne of around $16,000. This reinforces the need to prioritise investments based on cost-effectiveness to ensure targets are met at the lowest cost to the community and industry.

- DIN: The total cost of achieving regional and GBR DIN abatement targets by 2025 is estimated to be in the order of $390 million between now and 2025, based on best estimates. Around 70% of total regional DIN targets (1,500 tonnes) are delivered mainly through a land management (shifting from D to C and C to B in cane production areas) and land repair activities at a cost of around $105 million. Land management activities (1,160 tonnes abatement) are yield positive returns in the order of $65 million, as farm profitability improves from shifting cane practices from C to B in Burdekin and Wet Tropics.

  The remaining 650 tonnes of DIN abatement come from three irrigation efficiency investments in the Burdekin with a total cost of close to $280 million – shifting irrigation in the Burdekin - 21 to 50% - Level 2; Irrigation - Burdekin - 71 to 100% - Level 2; and Irrigation - Burdekin - 51 to 70% - Level 2.

- Uncertainty is a significant feature of the MACC results, and is more significant for some investments than others. Figure 47 through Figure 50 highlight where uncertainty is the greatest of the cost-effective sequence of investments. This shows that there is significant uncertainty around some of the cost estimates. This implies there is significant economic value in undertaking work to reduce this uncertainty as this will enable truly efficient investments to be made.

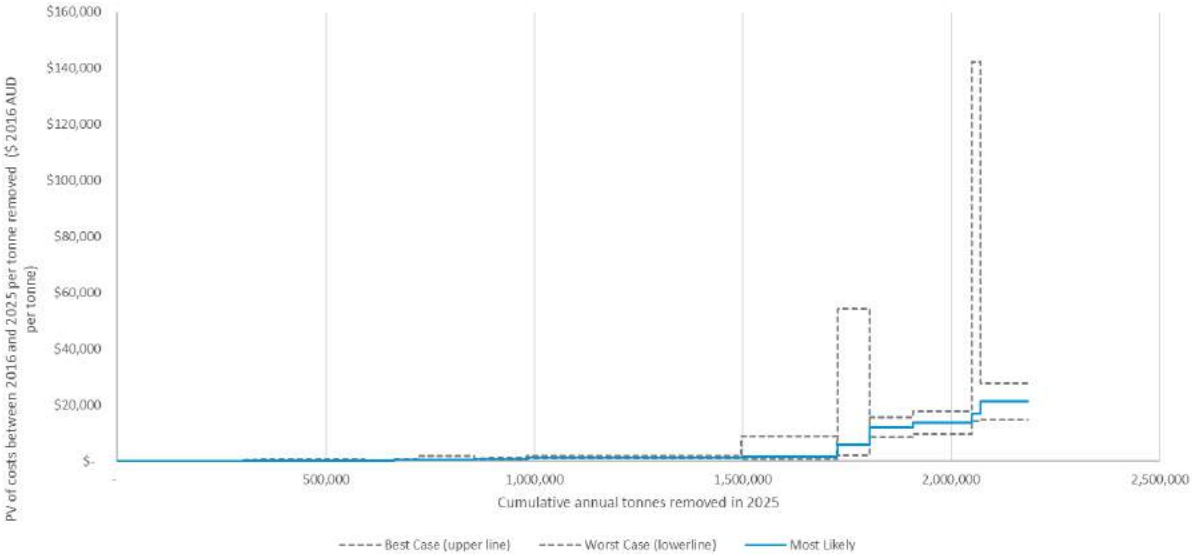


Figure 47. *Estimated MACC of achieving fine sediment targets for each region in aggregate including uncertainty (excluding Cape York) by 2025*

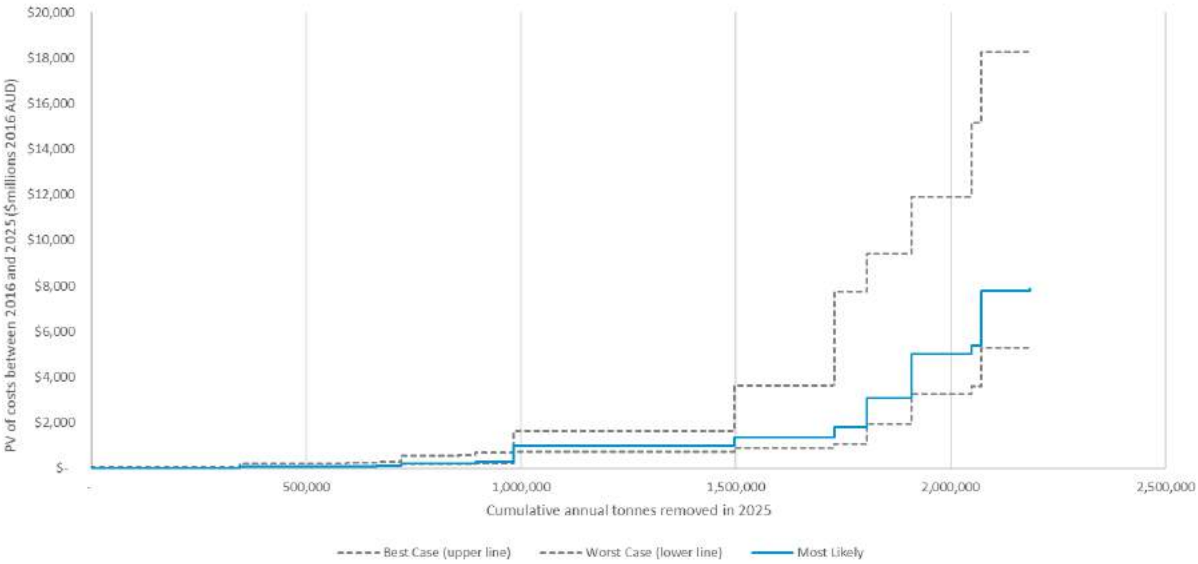


Figure 48. *Estimated TACC of achieving fine sediment targets for each region in aggregate including uncertainty (excluding Cape York) by 2025*

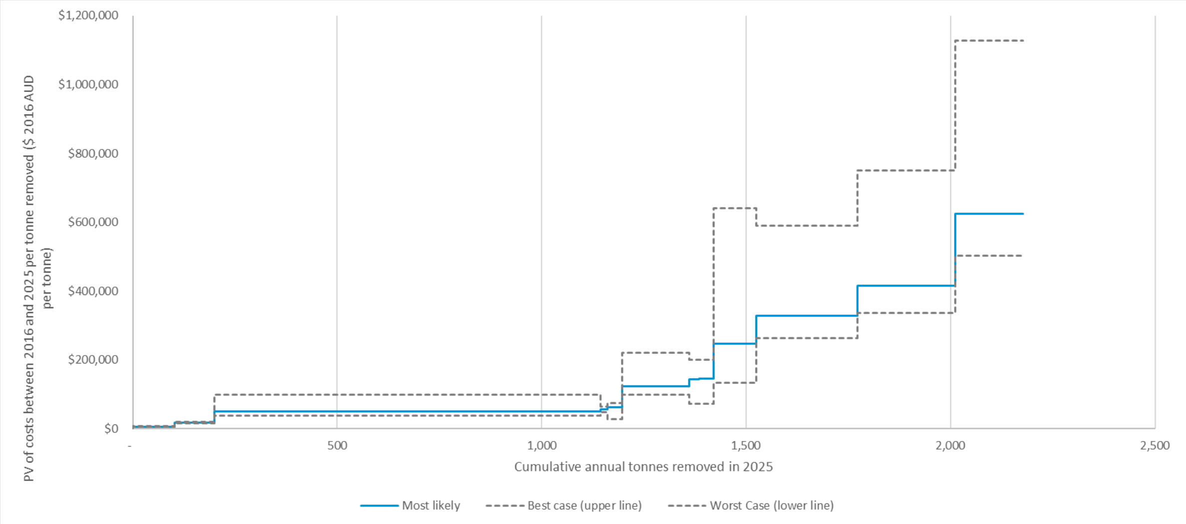


Figure 49. *Estimated MACC of achieving DIN targets for each region in aggregate including uncertainty (excluding Cape York) by 2025*

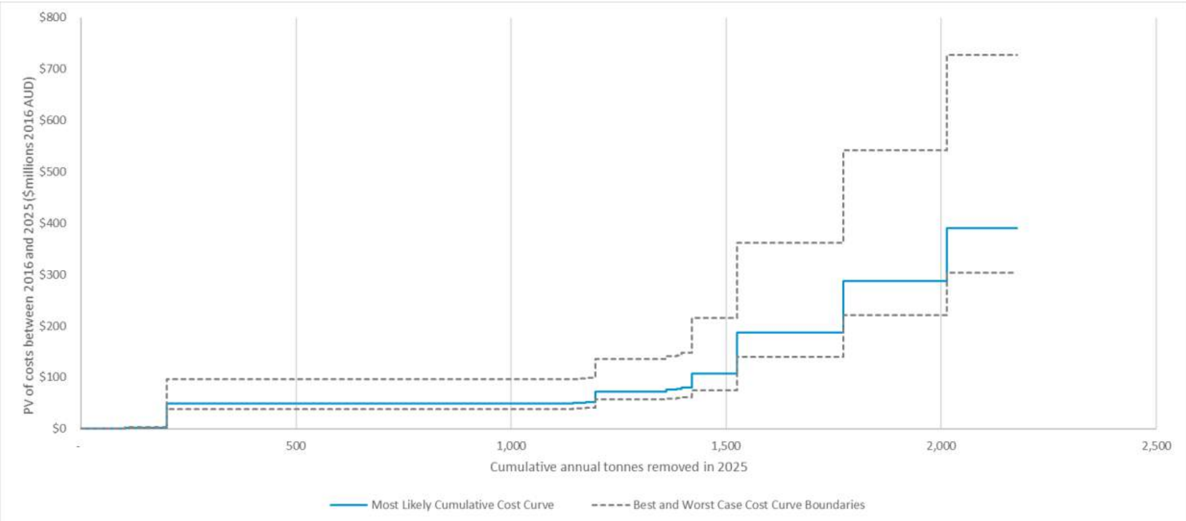


Figure 50. *Estimated TACC of achieving DIN targets for each region in aggregate including uncertainty (excluding Cape York) by 2025*

Marginal abatement costs and TACCs in this report are not directly comparable with earlier estimates for the GBR (Department of Environment and Heritage Protection, 2016; van Grieken, et al., Cost-effectiveness of management activities for water quality improvement in sugarcane farming., 2014; Star, et al., 2013; Beher, Possingham, Hoobin, Dougall, & Klein, 2016) for one or more of the following reasons:

1. The MACC and TACC pollution abatement is estimated based on the quantity received by the GBR, not at the paddock or farm edge. This approach takes into account proximity effects and the role of water regulation infrastructure on sediment and DIN delivery ratios. It also means MACC and TACC will generally be higher than cost effectiveness assessments which have evaluated pollution abatement at the farm scale – i.e. evaluations that have the quantity DIN reduced at edge of paddock or farm rather than estimated the quantity of DIN received by the GBR (Whitten, Kandulu, Coggan, & Marinoni, 2015).
2. Our evaluation includes transaction and administration costs (Policy solution set 7 only), program costs and opportunity costs, which have not been included in some earlier assessments (Department of Environment and Heritage Protection, 2016; van Grieken, et al., Cost-effectiveness of management

activities for water quality improvement in sugarcane farming., 2014; Beher, Possingham, Hoobin, Dougall, & Klein, 2016).

4.6 Discussion

The choices of actions within the policy solution sets that were used were dictated by the need to achieve the regional Reef 2050 Plan targets on a region by region basis. This means that for the whole of the GBR, trade-offs between regions were not included and each region was evaluated independently.

The analysis we have undertaken shows that when ranked in order of cost-effectiveness as shown in the tables above, there are some actions chosen in particular regions that are far less cost-effective than those in other regions that were not required. It therefore strongly suggested that a whole of reef cost-effectiveness assessment should be conducted to identify if trade-offs between regions could be undertaken, including the impacts that such trade-offs could have on local stream and reef areas. Such an assessment is beyond the scope of this project, but the data and analyses completed would be able to inform a future project of this nature.

As noted above, in many cases, land management practice change was the most cost-effective in terms of both fine sediment and DIN and this should continue to be a focus of actions within the reef catchments. We also did not evaluate all possible combinations of actions from across the policy solution sets, such that in some regions, combining actions such as grazing practice change and gully remediation may actually be considerably more cost-effective when conducted in parallel. Also, in some catchments, other sets of actions may be worthy of exploring, especially streambank erosion reduction in the Fitzroy, as the dominant source of pollution was not always the focus of particular policy solution sets and their actions.

We also did not consider the potential of some actions having effects for both pollutants of interest. For example, improving sugarcane management practice may also have the effect of reducing fine sediment contributions, and improving grazing land management practice may lead to reductions in DIN. It is also important to realise that we did not consider the effects of these management practices on other related pollutants, especially for DIN, where reductions in particulate nitrogen may be just as important in reducing overall DIN loads because of the transformation of particulate nitrogen to DIN in some systems.

Overall, this project shows that a combination of options is required to meet the regional Reef 2050 Plan targets and that the choice of the target and the actions used has a large bearing on the overall costs. These actions and policy solution sets also represent those that we were specifically asked to evaluate. There may be others that represent the best overall solutions to achieve the regional Reef 2050 Plan targets.

5 Conclusions

This section briefly outlines some of the key conclusions from our analysis.

This project represents the first major attempt to assess the real costs of meeting load abatement targets for fine sediment and DIN in the GBR. However, it should be acknowledged that this assessment is not entirely comprehensive. Not all regions are included, not all potential policy solution sets are explored, and we have necessarily assumed the volumetric targets based on 2013 data are the perfect basis for target establishment in 2016. Furthermore, there is significant uncertainty and variability in the input data used in the project and assumptions that have been made across scientific, management and economic factors.[4]

The estimates summarised in this document should not be treated as definitive. They are based on the best information available at this time, and they will change over time as information is enhanced, technologies change, economic circumstances change, and a more sophisticated approach is taken to GBR policy. There are a number of important sets of information that are derived from this analysis:

- **Marginal and total abatement cost curves.** The suite of costs curves for each policy solution set (and the actions within them) for each region show the significant differences in the cost-effectiveness of different on-ground actions, including some actions that are actually profitable. This provides a clear message that the consideration of the cost effectiveness of actions to reduce loads into GBR investment is fundamental. These curves provide a guide towards an efficient pathway of investment within each region.

- **Costs of achieving regional targets.** The second suite of information from this project specifically outlines what is likely to be the least cost suite of actions required to actually meet the load abatement targets. In some cases, this necessarily requires some of the more expensive actions/policy solution sets (e.g. land retirement), as the suite of cheaper actions/policy solution sets are insufficient to meet the targets. It should be noted that the final cost is also highly reliant on the decisions, policies and investment approaches adopted. It is also important to note that there is significant uncertainty in the cost estimates due to the availability, variability and quality of data used to generate these estimates.

- **Policy solution sets and their costs are regionally specific.** Our analysis shows that the efficient policy solution sets are actually regionally specific. Therefore, policies, regulations and decisions need to be cognisant of regional circumstances and the efficient pathway to achieve targets for specific regions and loads.

- **Revisiting targets.** Often the costs of achieving the final few % of the load abatement targets account for much of the total cost of achieving the targets. This reflects the increasing marginal abatement costs. Therefore, it would be prudent to periodically revisit targets to ensure they are robust and reflect the regional assimilative capacity of the GBR and relevant thresholds.

- **Marginal costs of poorly managed future development are very high.** All of the cost curves developed show sharp inclines as the targets are approached. Poorly managed development that creates a net increase in loads increases the volume of abatement required to meet the targets, forcing the community to invest into a circumstance where either the targets are less likely to be met, or the cost of meeting the targets is significantly higher. This reinforces the need to ensure policies are in place to avoid and mitigate the impacts of future development.

- **Potential future use of this work.** The data, tools and knowledge developed in this program can be further developed (new regions, new policy solution sets and actions) and used for broader GBR policy design and investment prioritisation.

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[4] Data sources and assumptions are clearly outlined for each policy solution set in their respective attachments.

6 References

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Attachment A
Project Terms of Reference

A.1 Project Terms of Reference

The Project Terms of Reference are outlined in the Department of Environment and Heritage Protection Request for Quote (Reference Number: EHP15044). The relevant sections are shown below:

1.2 Goods/Services Required

The marginal cost effectiveness and the cumulative cost and effectiveness is required for each of the seven scenarios (subsequently called policy solution sets in the project) listed below.

1) **Land management practice change for cane and grazing**

   Improving land management practice has been the predominant response to improving water quality in the GBR. There are Reef Plan water quality risk frameworks for grazing and sugarcane which rate differing land management activities according to their risk to the reef. These ratings are generally referred to as A practice (very low risk), B practice (low risk), C practice (low to moderate risk) and D practice (moderate to high risk). The costs and effectiveness of moving land managers from one class of practice to the next has been a focus of the WQIPs and estimated costs and effectiveness over five years are included in these plans. However, these do not extend to fully achieving the water quality targets.

   Further work has been undertaken which assesses the costs of moving all graziers in the Burdekin and Fitzroy catchments to A class practice and moving all cane growers in the Burdekin and Wet Tropics catchments to B class practice. (A class practice is still only aspirational for cane and has not been demonstrated to be cost effective). Further costing effectiveness work will only need to be undertaken where studies do not currently exist.

   The scenarios to be costed and modelled are:

   - 90% cane growers to meet B class practice in the Burnett Mary and Mackay Whitsunday catchments
   - All graziers to meet A class practice in the Wet Tropics and Burnett Mary catchments.

   To achieve this outcome, the costs and effectiveness of a number of enabling mechanisms (for example, incentives, extension and regulation) will also need to be considered.

   The customer will work with the successful offer to build the scenarios for the enabling mechanisms.

2) **Improved irrigation practices**

   The largest irrigated sugarcane growing region in Queensland is in the Burdekin catchment and includes the Burdekin Regional Irrigation Area (BRIA) and the Burdekin Delta. Studies have shown that moving from overhead to drip irrigation can reduce the amount of dissolved inorganic nutrients by up to 80%. However, there are very few economic studies demonstrating the costs of changing irrigation practices particularly in light of changes to allocations and pricing in the water market.

   This scenario assesses the costs and effectiveness of moving 50% of growers in the Burdekin Regional Irrigation Area and the Burdekin Delta to alternative irrigation practices. These would include moving from flood or overhead to drip irrigation, telemetry and recycle pits with sufficient pumping capacity to re-use stored water.

3) **System Repair: Gully remediation in Bowen and Upper Burdekin and Fitzroy catchments**

   Recently released synthesis reports estimate that gully erosions contributes approximately 40% of the total suspended sediment (TSS) load to the GBR. It is also estimated that 50% of the TSS exported comes from the Bowen catchment and 27% from the Upper Burdekin catchments.

   Priority gully management techniques include revegetation of gully features by porous check dams supported by fencing, watering points and grazing pressure that that can improve land condition and reduce runoff. These techniques can lead to a reduction in gully sediment yields of 50-90% within 10 to 40 years.

This scenario will assess the costs and effectiveness of reducing the area of gully erosion in the Bowen Bogie, Upper Burdekin and Fitzroy by 10%, 20% and 30%.

The precise location of the areas to be included in the hypothetical remediation will be refined based on the priority gully areas identified in the Fitzroy and Burdekin WQIPs.

4) System Repair: Streambank repair

Streambank erosion is the erosion of the channel boundary in river systems and is estimated to contribute 30-40% of end of catchment TSS loads in GBR catchments. The Mary and Pioneer Rivers are predicted to be a major source of sediment in the Burnett Mary and Mackay Whitsunday catchments. Other major contributors are the East Burdekin, Lower Burdekin and Herbert Rivers in the Burdekin and Wet Tropics catchments. Repair works include fencing off and revegetating riparian zones with associated offsite watering points to more mechanical interventions such as rock revetment.

This scenario assesses the costs and effectiveness of repairing 5% and 10% of streambank length in the Mary, Pioneer, East Burdekin, Lower Burdekin and Herbert Rivers. The precise location of the areas to be included in the hypothetical remediation will be refined based on relevant information in the WQIPs.

5) Systems repair: Wetlands repair

Wetlands provide a range of ecosystem services included nutrient assimilation and sediment trapping. The reinstatement and repair of current wetlands in strategic locations in the landscape could further improve the quality of water reaching the GBR. The priority locations for wetlands are identified during the development of the WQIPs.

This scenario will assess the costs and effectiveness of installing 25, 50 and 100 hectares of wetlands in priority areas as identified in WQIPs.

6) System Repair: Voluntary retirement of marginal land from production

In the cane growing regions there are farms with low productivity and high costs of moving to better standards of land management practice. For these farms the best environmental outcomes may be to change the type of production or retire land completely particularly when located in a strategic location in the landscape.

Similarly, some grazing lands are on poor country with low rates of groundcover which exacerbates erosion, reduces resilience and leads to high sediment losses. Some of these types of properties could be taken out of production either temporarily or permanently to improve the level of groundcover.

The scenario to be costed for cane is the voluntary retirement of 10% of small cane properties (under 50 hectares) operating at D class practice in the Burdekin, Wet Tropics and Mackay Whitsunday catchments. The cost of on-going management of the land will also need to be considered. This will include a change to a lower polluting activity (for example, changed to grazing) or it may be long-term remediation. The effectiveness will be the estimated change in loads noting that there will be lags in response.

The scenario to be costed for grazing is the voluntary retirement of 5% of highly erosive properties in the Bowen, Fitzroy and Burdekin as identified in WQIPs. The on-going costs of management and/or remediation will also need to be included. The effectiveness will be the estimated change in loads noting that there will be lags in response.

7) Urban stormwater management

Urban stormwater run-off potentially contributes to adverse water quality in waterways which impacts on aquatic ecosystem health and limit human water uses. Unless well managed, urban stormwater can release contaminants such as nutrients, sediment and solid waste to waterways. Local governments are responsible for approving urban development and to ensure development is planned, designed, constructed and operated to manage stormwater and wastewater in ways that support the protection of environmental values. There are two elements; one requires an erosion and sediment control plan during construction and the second is stormwater management post construction.

The potential scenarios for urban stormwater for the major centres of Cairns, Townsville, Mackay and Rockhampton are:

(a) Business as usual plus Water Sensitive Urban Design and Erosion and sediment control (during construction).

(b) Business as usual plus Water Sensitive Urban Design and Erosion and sediment control plus offset of residual loads following Water Sensitive Urban.

The general methodology that will need to be followed is:

(a) Decide the targets for each catchment. Most WQIPs are setting their own ecologically relevant targets except for Mackay-Whitsunday. These can be used as the basis for assessment. An ecologically relevant target will need to be developed for Mackay-Whitsunday.

(b) Decide which management actions, rehabilitation techniques, etc are required.

(c) Define the exact location for the action.

(d) Define the business as usual scenarios.

(e) Model the cost of the actions including rehabilitation, system repair and land retirement.

(f) Estimate the program costs to achieve the highest possible uptake of the required actions – these will include the costs to landholders, incentives, extension, regulation, monitoring and evaluation.

(g) Model the effectiveness of actions at the paddock scale using agreed modelling platforms.

(h) Model the effectiveness of the actions as delivered to the end of catchment.

(i) Where costs have been assessed at the individual level, extrapolate costs to each catchment depending on current uptake of practices.

Note that the necessary model to assess the effectiveness of the actions as delivered to the Great Barrier Reef lagoon is the Paddock to Reef Source Catchment Model which is owned by the Queensland Department of Natural Resources and Mines. The successful tenderer will be provided with access to the relevant modelling to be undertaken by the Queensland Department of Natural Resources and Mines within the timeframes of the consultancy.

1.4 Deliverables

The results of the assessment are to be provided in a draft report and a final report.

The reports are to include:

- The full details of the scenario assessed in terms of the actions, scale and location of the activity.
- The methodology/s used to assess the costs.
- The methodology/s used to assess the effectiveness at the local scale (e.g. paddock) and at the end of catchment.
- The assumptions used in assessing the costs.
- The assumptions and scenarios used for any policy interventions which have been included in the analysis (e.g. costs of incentives and regulation).
- The strengths and weaknesses of the approach taken.
- The acknowledgment of any time lags in delivering the estimated reduction in nutrients and sediments.

- The confidence range for any estimates provided.
- Any discount rates used for the economic analysis.

For each of the required scenarios the following is to be supplied:

- The marginal cost and effectiveness of achieving the action for the nominated area (for example, $/tonne of TSS abated in the Bowen sub-catchment). For some activities this is likely to be a range of costs with an associated confidence range.
- The marginal costs should include:
    - any opportunity costs incurred including transaction and administrative costs.
    - any policy, program and regulatory costs incurred in supporting the required action.
- The cumulative cost of achieving the scenario and the total load of pollutants abated. For example, the total cost of achieving x tonnes of TSS abated in the Bowen sub-catchment.

Consideration will also need to be given to the underlying activities needed to support the implementation of the actions, governance and monitoring and evaluation.

The Eligible Customer will work with the successful offer to determine these costs.

Attachment B
Policy solution statements

B.1 Policy solution statement 1: Land management practice change for cane and grazing

Policy solution set description and context

This policy solution set aims to assess the cost and efficacy of achieving 100% adoption of A level management practices across all regions with grazing and 100% cane growers to meet B class practice across all catchments within the sugarcane industry. The focus is on management of hillslope erosion in grazing lands and nutrient management in sugarcane. Gully and streambank components are accounted for in Policy solution sets 3 and 4 of this project. The costs have been defined as the private costs (the opportunity cost and capital expense) for landholders to adopt these management practices, the cost of extension services to support the implementation of capital inputs and management practice changes and regulation.

Funding arrangements in the Great Barrier Reef (GBR) catchments from government programs such as the Reef Program and industry Best Management Practices (BMP) programs has been directed towards achieving the 2013 targets under the joint Australian and Queensland Government Reef Water Quality Protection Plan. These programs have sought to achieve pollutant reductions through providing extension and financial incentives for improvements towards best management practice. An extensive Paddock to Reef Integrated Monitoring Modelling and Reporting Program (P2R Program) has been designed to assess progress towards the targets through integrating information about adoption of agricultural management practices, groundcover, riparian vegetation and natural wetland extent, and end of catchment pollutant loads (e.g. http://www.reefplan.qld.gov.au/measuring-success/report-cards/2014/).

For each industry there is a suite of specific management actions used to describe the water quality risk relevant to sediment management in grazing lands and farm system processes such a nutrient, soil, pesticide and water management in sugarcane (P2R Water Quality Risk Framework http://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/management-practices/). The framework is used to define and report management practices and the predicted water quality improvements at a paddock scale. The framework aligns with the previously adopted A, B, C, D management framework classification, which generally ranges from D practices as high water quality risk to A practices with very low water quality risk. B class is best management practice, or low water quality risk.

Changes in land management practices may come at a significant cost to landholders. The on-ground benefits from management changes to improve water quality may only be minor, e.g. improvements in pasture yield (short term) and less soil erosion (long-term). However, the (short term) opportunity costs, e.g., lower stocking rates or stock exclusion on buffer areas of affected sites, coupled with high capital and maintenance costs, may outweigh the benefits to landholders. These are some reasons why soil conservation adoption rates by landholders are generally low in the GBR catchments and worldwide (Rolfe and Gregg, 2015; Valentin et al. 2005).

Over the past two years each of the NRM regions in the GBR catchment has completed Water Quality Improvement Plans (WQIP). Part of the WQIP process has been to assess the changes in land management required to achieve end of catchment pollutant load reduction targets, and the associated costs of these changes, which have been reported in a number of reports (Terrain NRM, 2015; Bass et al. 2014; Park and Roberts, 2014; Smith, 2015; Roberts et al. 2016; Folkers, et al. 2015; Park et al. 2014; Pannell et al. 2014; Star et al. 2015). The WQIPs vary in the spatial scale of the assessments, the actions that are costed, the sources of adoption data and the suite of mechanisms assessed to achieve the targets. However, all WQIPs provide insights to the costs that are likely to be required to increase the level of adoption of agricultural management practices to an improved management level, and the private and public trade-offs.

Management practices that present lower risks to water quality have complex and uncertain economic and environmental outcomes (Rolfe and Gregg, 2013). Predicting the consequences of management changes at the enterprise level is difficult and typically requires detailed knowledge of both enterprise and biophysical characteristics (Pannell and Roberts, 2010). Variance across the catchments of achieving these changes was highlighted by Rolfe and Windle (2016) in assessing the cost per reduction in pollutants.

Scope of Works
The scope of works for this solution set involved an assessment of the costs of changing management practices in sugarcane and grazing across all catchments in the Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary NRM regions. The costs were assessed based on the paddock scale changes required (such as implementation of machinery, changed infrastructure and the maintenance cost to ensure capital is fully operational and does not deteriorate) and the changes that occur in farm profit. Following this, the different policy mechanisms of extension and regulation were costed, based on extension providing education and capacity building for landholders to fully adopt the different management practices, and regulation setting a minimum standard for all landholders. A range was estimated for each cost indicating a best case (cheapest case), most likely case (average cost) and worst case (most expensive option).

Method
The overall method to assess the costs of changing management practices involved a number of steps which varied between the two industries (sugarcane and grazing). To understand the marginal costs for each change, the capital costs of the change, the costs to maintain the capital, extension costs and regulation costs were estimated and combined into a stream of benefits and costs over the ten-year period to 2025. These benefits and costs were then brought back into today's dollar terms at a discount rate of 7%, consistent with discount rates recommended by Queensland Treasury (Queensland Treasury 2015). These are then translated into an annual cost and expressed as Annual Equivalent Benefits.

The costs of practice changes were based on past economic work and used an incremental step change (i.e. D to C, and C to B etc.) between management practice classes. As a first step, the baseline case was identified and the current level of adoption and pollutant loads were estimated across the GBR catchments. Documented upfront capital costs, on-going maintenance costs and change in profit were assessed, along with the subsequent pollutant reductions based on the areas of management practice shifts required to achieve 100% practice adoption. The extension costs expected to be required to support the practice shifts were also defined to provide a total cost estimate of adoption. Given the limited amount of work completed on transaction costs across the GBR catchments to date and the variability of these between landholders (Coggan et al. 2015), these were assumed to be zero. A summary of the method is shown in Figure 51.

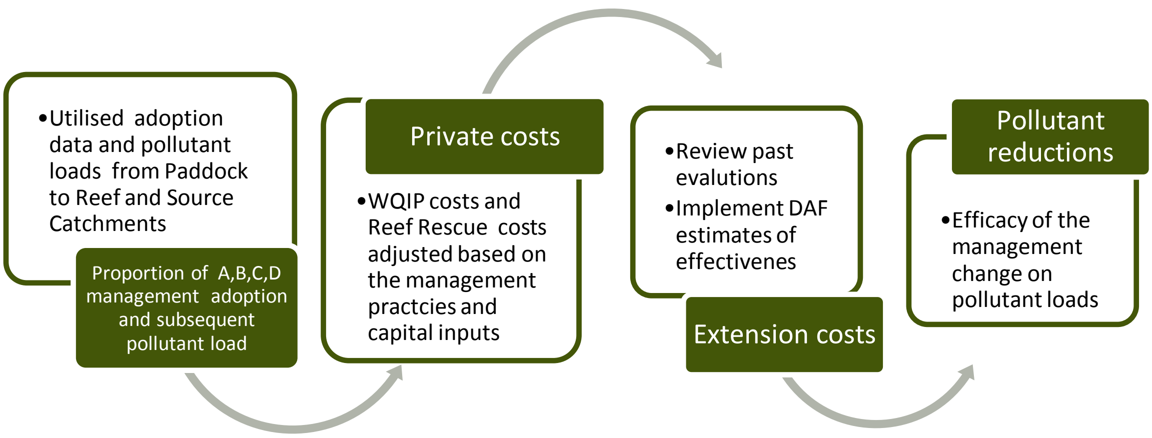

Figure 51. *The four stage methodology for assessing progress toward the targets*

Assumptions
In completing this work a number of assumptions were made. Previous work in different regions has had a range of differing assumptions in the way costs were assessed, and starting points along with the specified changes in machinery for the required management practices. This results in an inconsistency in

disaggregating past work to be comparable. Some catchments had considerably large bodies of work to draw upon and therefore a larger difference occurs between the best case and the worst case costing.

For this study it was important to standardise assumptions across regions and the time period of the study. A relatively simplistic approach was used, namely assumptions of a single minimum and maximum private cost and extension cost per region. No transaction costs were considered in this analysis due to limited work completed and the variance in how Natural Resource Management groups support landholders to change management. Due to the approach being stepwise, further efficiencies that could be achieved from shifting from D through to A have not been considered. The approach has focused on incentives, extension and regulation. Mechanisms such as tenders and auctions have not been considered.

Specific Assumptions include:

1. The Paddock to Reef Management Practice Framework aligns to the classified A, B, C, D from low risk to high risk management for sugarcane practices.
2. The Paddock to Reef Management Practice Framework aligns to the classified A, B, C, D land condition framework.
3. Private costs and benefits were assessed through changed practices in nutrient and soil management for sugarcane.
4. Private costs and benefits were assessed through changed land condition for grazing.
5. Transaction costs were assumed to be zero for landholders.
6. Regulation was the mechanism selected for shifting from D to C management in both cane and grazing.
7. Extension is assumed to be delivered by Queensland Government departments and continues to achieve the current level of adoption.
8. Regulation is enforced, which requires legally defensible monitoring and reporting through multiple lines of evidence.
9. Although it is acknowledged that there will be time lags between implementation and realising the full biophysical benefit of the change in management practice, these lags were considered out of the scope of work and therefore it has been assumed that management is effective immediately.
10. The time period for achieving the reduction was 2025 (in line with the Reef 2050 Plan targets, as interpreted for this project).
11. A discount rate of 7% was used to bring the costs and benefits back into today's dollar terms.

Management practices
To understand the private implications of adopting different management practices and the associated costs, clear specifications of the on-ground changes were required. These were based on the P2R Water Quality Risk Framework (http://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/management-practices/). The selection of sugarcane and grazing practices considered the weightings of importance for improved water quality outcomes. Selected sugarcane practices considered the weightings based on nutrient and soil management practices and the selection of grazing practices considered the weightings based on soil management.

In sugarcane, the costs were assessed for specific changes in management practices, including the economic transition for: 1) from a high risk sugarcane farming nutrient practice (D) to a moderate risk practice (C); and 2) from a moderate risk practice (C) to a low risk practice (B). The policy mechanism for a shift from D to C management in both sugarcane and grazing was assumed to be regulation. Table 29 details the major changes required for each practice shift.

Table 29. Changes in management practices for nutrient management in sugarcane

D to C (High risk to Moderate risk)	C to B (Moderate risk to low risk)
Rule of thumb N rates now based on soil tests and 6ES	Better timing of nutrient applications
Investment in a stool splitter for sub-surface nutrient application rather than surface applied	Electronic record keeping and calibration undertaken regularly
Written records are undertaken	Geo referenced soil testing with hand held GPS
Soil tests are undertaken and fertiliser is based on District Yield Potential (DYP)	Include legume and mill mud application in N budget
Calibration of fertiliser boxes at the start of season	Drop N rates to farm yield potential (FYP) – below 6ES industry standard
Risk assessment before applying nutrients	Apply different nutrient regimes between paddocks
Legume N contribution recognised in N budget	Develop a nutrient management plan

In grazing, the focus was on hillslope erosion management: 1) Moderate to High risk (D) to Low to Moderate risk (C); 2) Low to Moderate risk (C) to Low risk (B); and 3) Low Risk to Very Low Risk (A) (Table 30). It must be noted that the practices in the framework are weighted on importance and are focused predominately on stocking rate and pasture management for improved groundcover and regenerating low groundcover areas.

Table 30. Changes in management practices for sediment management in grazing lands

Land management practice category	Changes in management practice
Moderate to High risk to Low to Moderate risk (D-C)	Long-term stock and stocking rate records documented in diaries, paddock records etc. Land condition is assessed based on pasture yield, and of dry season cover.
	Numbers in each paddock recorded annually. Use common sense and rules of thumb to account for effects of animal class and size/age.
	Some land types are managed separately.
	Residual cover is managed by observed amount of pasture and groundcover at the end of the dry season and try to keep enough residual pasture for stock.
Low to Moderate risk to Low risk (C-B)	Most of the different land types are managed separately. Numbers in each paddock recorded at each muster. Account for different animal class and size/age.
	Objective measure of safe stocking rate calculations, including property map and based on historical data, subjective assessment of resource condition.
	Use long-term experience to look at stock numbers and pasture available in each paddock after the wet season. Cattle numbers adjusted to ensure adequate residual pasture and groundcover at break of season.
	Regularly observe groundcover, density of 3P grasses and land condition. Aim to maintain paddock and groundcover specific to region, rainfall and land type.
	Fencing is implemented to manage selectively grazed areas also use wet season spelling and use of fire and `lick' to even out grazing.
	Pastures/paddocks wet seasoned spelled on a regular basis.
	Stocking rates and frequently used pasture spelling are used to recover degraded country.
Low risk to Very Low risk (B-A)	Most of the different land types are managed separately.
	Numbers in each paddock recorded every time there is a change in numbers within a paddock. Use AE or LSU to account for different animal class and size/age.
	Land condition is asset based on the A, B, C, D GLM framework.
	Documented records, including property map and safe stocking rate calculations based on land type, property infrastructure and objective assessments of land condition.
	Routinely use forage budgets and paddock/stock records for each paddock and adjust cattle numbers to ensure adequate residual pasture and groundcover at break of season.

Land management practice category	Changes in management practice
	Residual groundcover is managed through photo monitoring at end of dry season.
	Selectively grazed areas are fenced and regenerated through wet season spelling. Use fire, lick and water points to even out grazing.
	Wet season management is implemented through annual pastures/paddock spelling determined by pasture monitoring.
	Spelling and frequently used pasture spelling are used to recover degraded country.

Management Practice Adoption

The 2013-2014 management practice adoption data from the P2R program was used to understand the current level of management. The P2R Water Quality Risk framework was used to align management practice to a range of likely risk states, shown in Table 31 for sugarcane and Table 32 for grazing.

Table 31. P2R program classification of management practices in the sugarcane industry

Water Quality Risk	Lowest	Moderate-Low	Moderate	High
Previous "A, B, C, D" nomenclature	A	B	C	D
	Innovative	Best Practice	Minimum	Superseded

Table 32. P2R classification of management practices in the grazing industry

Water Quality Risk	Very Low	Low	Low to Moderate	Moderate to High
Resource condition objective	Practices highly likely to maintain land in good (A) condition and/or improve land in lesser condition	Practices are likely to maintain land in good or fair condition (A/B) and/or improve land in lesser condition	Practices are likely to degrade some land to poor (C) condition or very poor (D) condition	Practices are highly likely to degrade land to poor (C) or very poor (D) condition

The current adoption data for cane and grazing are shown in Table 33 and Table 34. In sugarcane (Table 33) the largest changes are required in the Burdekin and the Wet Tropics Regions.

Over 95% of all graziers in the GBR catchments would be required to adopt a suite of improved management practices and shift to a new classification to achieve 100% adoption of A class practices (Table 34). The largest change in landholder adoption was required from C management to B management, with the Burnett Mary and Burdekin Region having the largest portion of graziers required to shift to A management.

Table 33. Current percentage of sugarcane lands required area to adopt improved nutrient management across the GBR catchments

Management classification shift	A	B	C-B	D-B
Wet Tropics	2%	3%	92%	3%
Burdekin	3%	5%	82%	10%
Mackay Whitsunday	0%	19%	79%	2%
Fitzroy		N/A		
Burnett Mary	1%	12%	74%	13%

Table 34. Current percentage of graziers adopting A class practices and those required to adopt improved hillslope management across the GBR catchments

Management classification shift	A	B-A	C-A	D-A
Wet Tropics	7%	14%	77%	2%
Burdekin	1%	29%	58%	12%
Mackay Whitsunday	8%	31%	25%	36%
Fitzroy	8%	14%	48%	30%
Burnett Mary	2%	44%	54%	0%

Sugarcane private costs

The change in management costs for sugarcane are focused predominately around changes that require modifications or changes to machinery or infrastructure. Three aspects that are considered, which are costs or benefits borne by the landholder, are the capital cost of the machinery, and repairs and maintenance over the life of the machinery. There are also the variable cost implications that have an overall impact on landholder farm profit. The subsequent sections will step through each of these.

Capital costs

The capital costs accounted for the required machinery or infrastructure to implement the new management classification. To allow for the variance between farm characteristics, the ability to modify existing machinery or source second-hand machinery, a range of capital costs were accounted for in each region. The values were estimated as most likely (average), best case (cheapest) and worst case (most expensive). The sources of information used to underpin cost assumptions are shown in Table 35.

There are essentially two approaches taken in the literature. One involves modelling a hypothetical farm system based on the management practice framework. The other is based on actual capital costs of a particular grower or group of growers which often involves a capital cost to make the change. This indicates the variance in starting point for assessing costs and the approach to achieve the change (i.e. modification of equipment as opposed to the purchasing of new capital). Farm size was also critical, as it gave perspective regarding the scale of properties and the required capital. The approach taken to this varied across the literature with some studies assuming different capital required and others assuming the same capital would be required and greater economies of scale to be achieved as the farm size increases. As separate farm sizes were not explored directly in this study, the range of farm sizes were taken into account in the costs for the best case, most likely and worst case costs per hectare. The literature provides insights to costing and the farm system implications to consider, with regions that have further economic information having more detailed insights.

Table 35. Review of capital cost for shifting from C to B management

Reference	Capital	Capital best case ($/farm)	Capital Best case $/ha	Capital most likely ($ /farm)	Capital most likely ($/ha)	Capital worst case ($/ farm)	Capital worst ($/ha)	Farm Size (ha)
				Wet Tropics				
Whitten et al (2015)	Assumed that most farmers would already have suitable equipment although there would be a capital cost of approximately $10,000 for those who did not, along with some reduction in fertiliser application	10,000	33	10,000	50	10,000	100	Small (<100 ha), medium (100 ha-200 ha) and large (>200 ha)
Smith et al (2014) WQIP	Stool Splitter fertiliser box* costing based on van Grieken	47,000	134	47,000	188	47,000	313	Small <100 ha, >100 ha medium <250 ha; and large >250 ha.
Rolfe and Windle (2016)	Modification of variable rate stool splitting sub-surface fertiliser applicator	997	1	9,380	38	59,500	397	Small 150ha, medium 250 ha large 930 ha
Catalsyt Growers Forum (2015)	Modify stool split fertiliser box			5,200	43			A 120 ha grower
van Grieken et al (2014)* capital items costed 2012	Stool Splitter fertiliser box, harvester modifications	42,773	143	50,000	250	57,000	570	Small (<100ha), medium (100ha-200 ha) and large (>200 ha) based off Van Greiken et al. (20014)
				Burdekin				
Smith WQIP	Zonal ripper/rotary hoe; wavy discs; double-disc open planter (stool splitter fertiliser box); GPS, flow rate monitor, harvester modifications	125,000	63	125,000	1,276	125,000	1,506	BRIA Maximum up to 3,500 ha, Average 140 ha and Median 94 ha and the Delta is max 2,000 ha, Average, 98 ha, and Median 83 ha
Rolfe and Windle (2016)	Wavy disc cultuers, GPS, Bedformer, variable rate fertiliser box	2,240	2	14,735	50	44,500	1,483	Small 30ha, medium 297 ha, large 1059 ha
Whitten et al (2015)	Assumed that most farmers would already have suitable equipment although there would be a capital cost of approximately $10,000 for	10,000	40	10,000	67	10,000	100	Small (<100 ha), medium (100ha-200 ha) and large (>200 ha)

Reference	Capital	Capital best case ($/farm)	Capital Best case $/ha	Capital most likely ($ /farm)	Capital most likely ($/ha)	Capital worst case ($/ farm)	Capital worst ($/ha)	Farm Size (ha)
	those who did not, along with some reduction in fertiliser application							
Poggio and Page (2010)	Stool Splitter fertiliser box	40,000	333	40,000	333	40,000	333	Farm size 120 ha
Poggio and Page (2010) BRIA	Stool Splitter fertiliser box bed renovator	62,000	258	62,000	258	62,000	258	Farm Size 240 ha
van Grieken et al (2014)	Stool Splitter fertiliser box, harvester modifications	47,273	189	50,000	250	57,000	570	Not actually specified assumed small (<100 ha), medium (100 ha-200 ha) and large (>200 ha)
				Burnett Mary				
van Grieken (2014)	Change fertiliser box and tillage equipment, zonal till implements	115,000	460	115,000	920	115,000	1,533	75 ha, 125 ha, 250 ha
				Mackay Whitsunday				
Rolfe and Windle (2016)	Nutrient management plans, variable rate controller	13,922	28	26,242	116	48,032	1,144	42 ha, 226 ha, 490 ha
East et al (2012)	Bed Renovator, GPS, modification to double disc planter			72,000	300			240 ha
East et al (2011)	Variable rate controller	26,500	88	26,500	177	26,500	177	50 ha, 150 ha and 300 ha
Law and Star (2015)	GPS, Bed renovator and ripper, Rate controller, SMS software, widen existing equipment	30,000	200	79,810	532	85,000	567	150 ha

The private costs capture the cost to landholders for purchasing capital equipment and then modifying their production system to implement the improved management practices. The costs have been assessed from past multiple sources across the catchment work completed under a number of programs (Table 35).

The change in farm profit is the income received from the change in management practice derived from the crop minus the direct costs of growing the crop. Cane growing enterprises differ significantly to other broadacre crops due to the ability to harvest the crop multiple times before replanting costs are again incurred. Therefore, the growing costs in the first year 'the plant cane' year are always higher than the growing costs of the 'ratoons' due to the additional machinery operations involved in preparation of the soil for cane planting (Table 36).

A standard farm size was implemented to account for the detailed information regarding their specific cane, land preparation, fertiliser, legume crops, fallow management and irrigation. Average farm sizes for sugarcane were assumed to be 150ha for the Wet Tropics, 106ha for Burdekin and 125ha for Mackay Whitsunday. The change in farm profit considered the grower's machinery, implements and irrigation soil type, scale, and production system. A range of costs were estimated to implicitly account for aspects such of economies of scale, enterprise heterogeneity and farm layout.

To focus the analysis on the specific changes in question, a number of variables have been standardised so that the results are not influenced by changes in prices of inputs. The economic analysis has used a six year (2005-2016) average net sugar price of $410. All fertiliser and chemical prices were catchment specific. All labour was costed at $30 per hour for a farm hand. The change in farm profit was then calculated resulting in a before practice change gross margin and an after practice change gross margin, which were then entered into an investment analysis. Maintenance costs were then estimated at a value of 10% of the capital cost, which is estimated to be the on-going repairs over the period of analysis. It must however be acknowledged that the large variance in starting point of growers was not accounted for and therefore the options in the catchments represent one aspect of the number of ways to shift to the next management class.

For each representative farm, cane yields were set at average yield (tonnes per hectare) and Commercial Cane Sugar (CCS), the actual sugar content within the cane, according to the historical data available (Table 36). Yield data for Mackay reflects the average yield on an irrigated cane farm and has been estimated from aggregated data including both irrigated and non-irrigated farms.

Table 36. Average yields of the five regions (2005-2014). Source: Collier and Holligan (2016)

Region	Crop	Yield (t/ha)	CCS	Historical Data Range
Burdekin (Delta)	Plant	142	14.51	2005-2014
	Ratoon*	115	14.53	
Burdekin (BRIA)	Plant	130	14.90	2005-2014
	Ratoon*	105	14.72	
Tully	Plant	90	13.08	2006 - 2014 (excluding 2011)
	Ratoon**	81	12.56	
Mackay	Plant	94	14.34	2005, 2007-2009, 2012-2014
	Ratoon**	82	14.05	
Burnett Mary	Plant/Ratoon***	90	13.8	N/A
Herbert	Plant	95	14.13	2005 - 2014 (excluding 2011)
	Ratoon**	79	13.56	

*Average of 3 ratoons; **Average of 4 ratoons ***APSIM yields were used.
[1] The average yield of a property with access to irrigation was estimated based on the assumption that 2 megalitres of irrigation will boost yield by 16 tonnes per hectare.

A wide and varied range of management items can be used to shift management classes. Past studies have used different starting points and therefore different management items have been required. The capital costs are based on the range of capital expenditure items implemented that could be used (Table 37). It has been assumed that presenting a range captures the different approaches to obtaining the capital outcome; i.e. amending existing machinery or purchasing outright new machinery.

Table 37. Description of the range of capital expenditure items for the nutrient, scenarios to transition to each management class in sugarcane. Source: Law (2015) and Smith (2015)

Management class transition	Description of nutrient and tillage management items
D to C class	Disc harrow; legume planter; bed former (hill up); double-disc open planter (stool splitter fertiliser box)
C to B class	Zonal ripper/rotary hoe; variable rate fertiliser box, wavy discs; GPS

Grazing Private Costs

For grazing the average property size was assumed as 20,000 ha for the Bowen and Upper Burdekin catchments, and 7,000 ha in the Fitzroy catchment. The average property size estimates were based on a combination of work completed under the WQIPs and other programs such as Reef Rescue, Reef Program and Property Identification Codes. It is acknowledged that there is large variance in property size, however for the purposes of this study they were standardised to a regional average.

A key aspect of the management is reducing stocking rate to improve land condition, which leads to increased perennial, productive and palatable pasture species slowing water runoff and leaching. Estimation across the catchment provides an understanding of the reduction in stocking rate required. The method to estimate this involved a number of different data sets, such as land type mapping integrated for each of the catchments, however spatial heterogeneity was not well accounted for (Star et al 2015). It must be noted that for the scope of this study it was assumed that land condition has the capacity to improve in alignment with the management practice. In reality, the time periods for regeneration are not well understood and are based on particular land type characteristics. For D to C management it is assumed that regulation costs will be applied with the mechanical works required to improve land condition that are captured in the gully remediation and streambank remediation sections of this report (related to calculating total regional costs).

Accounting for the variation in land condition provides information on the proportions of land that are able to be improved or the scope of change required, and also allows estimation of the stocking rates currently being used by landholders. Although there are no specific targets for land condition, there are targets that represent groundcover and adoption of practices by landholders. The premise of the P2R Water Quality Risk Framework is that the low risk management practices will maintain or improve land condition. Therefore, understanding the areas in the catchments with the greatest capacity for improvement, and the associated cost per tonne of sediment reduction is important to consider.

Productivity was measured in this work as AE/Ha. This is the hypothetical number of 400kg cattle that can be sustainably supported per hectare according to the GRASP model (Mackayeon et al 2000). GRASP takes into account rainfall, land type, tree cover and land condition to determine this long-term carrying capacity. Table 38 refers to the four products that were combined to estimate productivity in any sub-catchment.

Table 38. Parent layers of sub-catchment productivity data

Data set	Description
Spatialised GRASP raster	This raster estimates AE/ha across the landscape assessing average land condition and taking into account local tree cover, GLM land type and long-term average rainfall.
GLM land type boundaries	GLM land type mapping for the study area. Polygons were assigned to the dominant land type where multiple land types were mapped in a polygon.

In theory, estimating AE/ha at pixel scale from the spatialised GRASP A raster and A, B, C, D rasters is relatively simple. B, C and D condition land has 75%, 45% and 25% respectively of the AE/ha of land in A condition.

So AE/ha adjusted for likely land condition equates to:

$$(P(A) + .75 \times P(B) + .45 \times P(C) + .25 \times P(D)) \times AE/Ha.$$

However, our A, B, C, D raster included significant pixel numbers unassessed by the A, B, C, D modelling due to the FPC mask. To patch these data at pixel scale the following process was used:

1. Sub-catchment and land type boundaries were intersected to create a combined sub-catchment x land type vector layer.
2. The A, B, C, D rasters were converted to a single draft aggregate A, B, C, D raster, null where A, B, C, D land condition was unassessed, and where present, equal to:

$$(P(A) + .75 \times P(B) + .45 \times P(C) + .25 \times P(D))$$

3. The mean value of pixels in the draft aggregate A, B, C, D raster were calculated for each catchment, and for each combination of sub-catchment x land type.
4. Where a pixel was unassessed for land condition but there were some assessed pixels within that land type x sub-catchment area, the pixel was assigned the mean aggregate pixel value for the land type x sub-catchment combination. Alternatively, the pixel was assigned the mean aggregate pixel value for the sub-catchment. This produced the final aggregate A, B, C, D raster.
5. The final aggregate A, B, C, D raster was multiplied by the Spatialised GRASP A raster to provide pixel-by-pixel estimates of AE/Ha, and these were averaged per sub-catchment to provide estimates of sub-catchment productivity.

Capital costs, maintenance and changes in farm profit were defined for each region. The changes in farm profit represented the forgone income for landholders removing cattle out of production. For the Burdekin and Fitzroy regions (the two largest catchments), previous work completed by Star et al. (2015) was integrated to estimate the changes in farm profit based on land type and condition. For the Burnett Mary, Mackay Whitsunday and the Wet Tropics regions previous work was used to align land types and approximate locations for each of the catchments mix of land types (Whish 2013), which influence the productivity(Star et al. 2015) and subsequent changes to farm profit. A high productivity land type was selected to estimate the worst case (most expensive), a low productivity land type was selected for the best case (cheapest) and the dominant land type in most likely (average) (Table 39).

Table 39. Land productivity types assumed to represent best, most likely and worst case scenarios

Region	Low Productivity land type-grouping	Average/Dominant land type -grouping	High Productivity land type - grouping
Wet Tropics	Coastal flats with mixed eucalypts on grey clays-5	Alluvial-2	Red Basalt-2
Burnett Mary	Ironbark spotted Gum-4	Blue Gum-3	Softwood Scrub-1
Mackay Whitsunday	Cypress pine on deep sands-4	Eucalypts hills and ranges-3	Alluvial Flats and plains-2

The land type groupings then allowed a gross margin per adult equivalent (AE is a 400kg steer) (Table 40) and the subsequent average carrying capacity to be calculated to estimate the change in farm profit per hectare. There is obviously significant variation regarding enterprise, and operations that have not been accounted for in standardising the gross margin per AE.

For shifting landholders from D to C management requires mechanical intervention which was costed separately. It must be noted that the costings for D to C are mutually exclusive.

Table 40. Gross margins per AE of productivity groupings

Productivity Grouping	Beef CRC template	2015 GM$/ AE
1	R322 Central Qld Brigalow	$312.55
2	R313E Basalt (Dalrymple, Flinders) & Downs (Flinders, Richmond, McKinlay)	$241.98
3	R313C Goldfields (eastern half of Dalrymple Shire)	$199.30
4	R332B Lower Burdekin & Bowen	$197.43
5	R331 Coastal speargrass	$182.32

Extension Costs

The extension cost estimates the costs of achieving reductions in sediment and nutrients based on landholder improvements in management practices instigated through government provided extension services. The method to estimate the extension cost involved several data sets integrated to allow for spatial heterogeneity between the regions, and was costed at a landholder level and extrapolated to a per hectare basis based on the average farm size. Extension in this context was costed based on the current model where incentives are offered parallel to extension, i.e. Grazing BMP and Reef Program.

Estimating the level of extension effectiveness is difficult as there may be significant time lags in both landholder adoption and achievement of outcomes. It is inevitable that there are diminishing returns to extension expenditure. This is because extension services tend to engage with the more willing landholders first and over time the extension services are working with less willing landholders and therefore are more costly to engage with. However, there is very limited data providing insights into the rate of diminishing returns or the cost required to continue to change landholder management practices. Therefore, for this exercise it has been considered linear.

A significant challenge in understanding the effectiveness of past extension programs is the poor alignment of the BMP programs to the P2R WQ Risk framework. Therefore, the DAF one-on-one extension program, which included a landholder survey aligned to the P2R Water Quality Risk Framework, was evaluated in this cost estimation.

In sugarcane, the DAF extension report showed that on average 62% of landholders had shifted a level of management as a result of extension services with a confidence bound of 10 (Department of Agriculture and Fisheries 2015). Therefore, for estimation of the extension costs, a most likely estimate of 62% of landholders and best case being 72% and worst case being 52%. These efficiencies were used to provide an indication of the potential outcomes that may be expected from future expenditure on extension and the range of costs, based on the past DAF extension investment.

In grazing, the DAF extension report showed that on average 78% of landholders had shifted a level of management as a result of extension services with a confidence bound of 8.5. It is likely that there were many other landholders who may have taken smaller steps towards improved management practices; however, these small changes are impossible to quantify (Department of Agriculture, 2015). Therefore, for an estimation of the extension costs, an adoption of a most likely estimate of 78% of landholders, best case 86.5%, and worst case 69.5%. These efficiencies were used to provide an indication of the potential outcomes that may be expected from future expenditure on extension and the range of costs, based on the past DAF extension investment. Figure 52 shows the method used to calculate the extension cost curve.

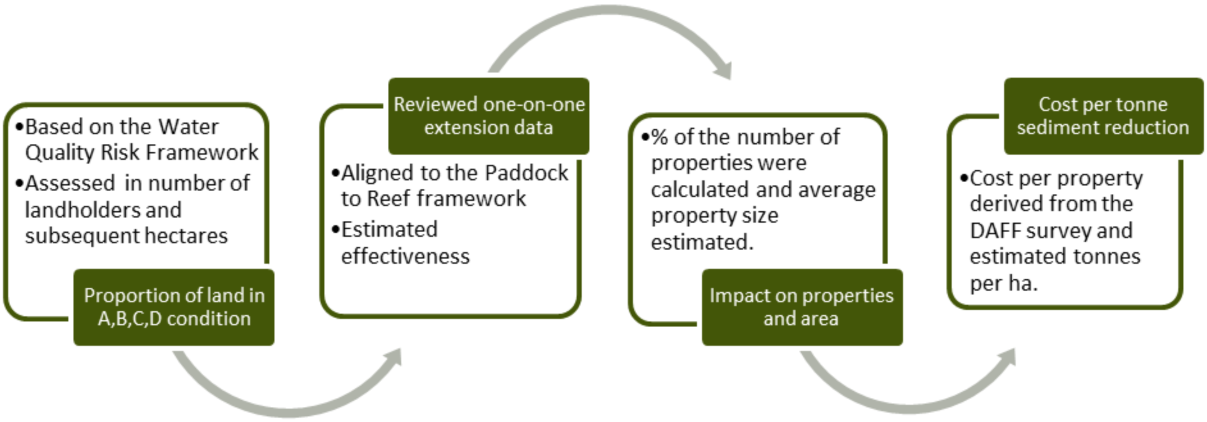

Figure 52. *Shows the method used to calculate the extension cost curve*

Regulation costs

The purpose of a regulation is to set a minimum standard for all landholders that can be enforced. Figure 53 provides a framework for a potential model. There are many costs associated with the imposition of regulation, some of which would be borne by landholders and some of which likely to be borne by government (and hence, taxpayers). Although these costs would be borne by different entities, for simplicity it is assumed that the government would bear all the costs associated with regulation. The regulation costs have been estimated using total costs, and overhead costs have not been considered (Table 41).

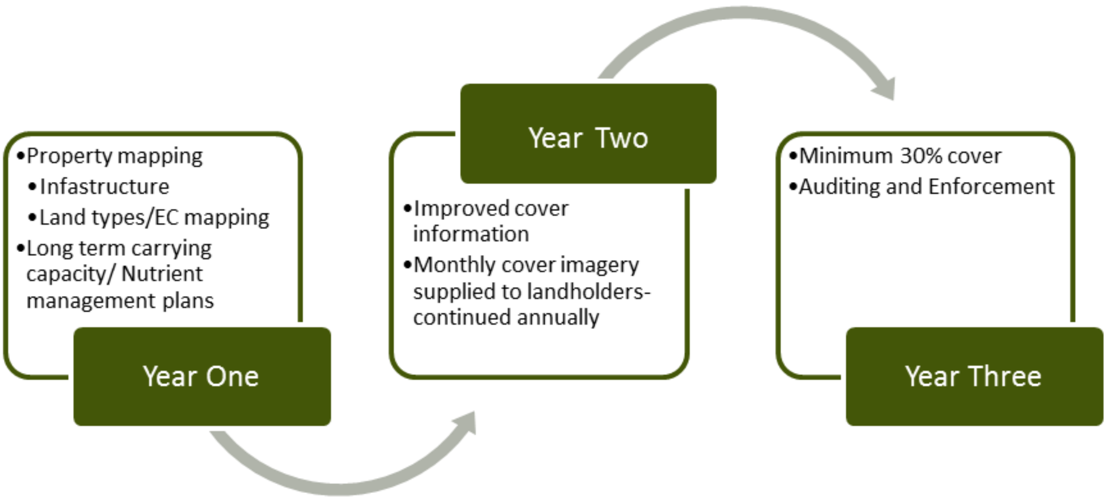

Figure 53. *Framework for a potential model to set minimum standards for landholders*

As a regulation sets a minimum standard, all properties must comply and be checked for compliance. The estimated costs do not include the cost of pursuing a property through the legal system or the program costs associated with regulation. The calculated cost is based on a per property basis (on the average farm size) and then disaggregated to a per hectare cost.

For sugarcane, regulation was assumed to provide a minimum standard for property planning, and nutrient management at a block level. Initially, it was assumed that the initial cost to complete soil testing, mapping, and nutrient management plans would be significantly high at $8,000 per farm. However, a lesser amount ($2,000) would be required over the growing cycle of the sugarcane (Table 41). To estimate the worst case and best case scenario these costs were varied by 10% to provide a range for the costs.

Table 41. Assumed actions and costs associated with regulation for sugarcane

Regulation Includes	Actions	Costs over 5 years
Property Plan	Includes mapping of soil type, nutrient management plan and EC mapping - completed through extension.	
Enforcement	Auditing	$2,000 per year per property

Table 42 shows the assumed total cost incurred per grazing properties and the sediment reductions costs calculated on the basis of a total property shift from D condition land to C condition land over five years. To estimate the worst case and the best case this cost was varied by 8.5% in line with the advice provided by DAF staff experienced in extension. It was assumed the same variance would occur in grazing.

Table 42. Cost incurred per property for a regulated D-C land condition shift in grazing lands over five years

Regulation Includes	Description	Cost over 5 years ($)
Property Plan	Includes mapping of land types, cover, calculation of LTCC, infrastructure and current erosion issues. Completed through extension.	
Improved information	Provision of monthly cover changes and the trend over time.	$12,000
Minimum cover relative to rainfall	30% cover required at all times throughout the year.	$20,000
Enforcement	Enforcement officers.	$10,000

Results

The results are initially presented on a per hectare basis. For sugarcane, the private costs of capital, maintenance and change in farm profit are presented followed by the extension and regulation costs. Grazing results are presented in the same order.

The results from the sugarcane analysis (Table 43) demonstrate the wide range of costs that occur across regions, based on how the machinery is obtained and the requirements for practice change. Where there were greater information sources such as in the Burdekin region, the range was smaller than in the regions where limited information was available, such as the Burnett Mary region. The shift from C to B practice in all cases had higher capital costs associated with it. The per hectare differences also account for the fact that different average farm sizes were used across the regions and therefore the same machinery costs per farm are lower on a per hectare basis when the average farm size is larger. Although changes in farm profit in many cases are positive, poor years or the risk premium landholders would expect to receive has not been accounted for. Therefore, the change in farm profit in many cases is so small relative to the total farm gross margin that other factors in the production system may mask the impact of the change in management practice.

The grazing results (Table 44) reflect the ranges in the dominate productivity types of the regions and the subsequent enterprises that are operated. The larger property sizes reflect the inherit productivity and therefore lower costs per hectare to achieve the change. The higher costs of shifting to an A management practice is reflected across all regions with the higher opportunity cost to de-stock to meet A management practice standards (Table 44).

The regulation and extension costs for both sugarcane and grazing are reported in Table 45. The higher the number of properties in the catchment, the higher the cost to regulate or provide extension as each landholder is engaged. The costs are provided separately for each mechanism (extension and regulation). As such these costs do not reflect the costs if they were implemented together (Table 45).

Table 43. Sugarcane practice change costs for shifting on a per hectare basis

Region	Management Practice change		Most Likely (Average Cost $/ha)			Best Case (Cheapest cost $/ha)			Worst Case (Most Expensive $/ha)		
	Current practice	Future practice	Capital cost	Maintenance cost (annual cost)	Change in farm profit	Capital cost	Maintenance cost (annual cost)	Change in farm profit	Capital cost	Maintenance cost (annual cost)	Change in farm profit
Wet Tropics	C	B	114	11.4	60	78	7.8	73	345	34.5	47
Burdekin	C	B	372	37.2	74	148	14.8	133	709	70.9	15
Mackay Whitsunday	C	B	281	28.1	294	106	10.6	86	692	69.2	-76
Burnett Mary	C	B	920	92	245	460	46	316	1533	153.3	245

Table 44. Grazing practice change costs for shifting on a per hectare basis

Region	Management Practice change		Most Likely (Average Cost $/ha)			Best Case (Cheapest cost $/ha)			Worst Case (Most Expensive $/ha)		
	Existing practice	Future practice	Capital cost	Maintenance cost (annual cost)	Change in farm profit	Capital cost	Maintenance cost (annual cost)	Change in farm profit	Capital cost	Maintenance cost (annual cost)	Change in farm profit
Wet Tropics	C	B	27	2.7	-3.1	18	1.8	-2.1	35.1	3.51	-3.9
	B	A	84.6	8.46	-9.4	58	5.8	-6.4	95	9.5	-10.6
Burdekin	C	B	5.54	0.554	-0.6	2.5	0.25	-5.5	49.41	4.941	-22.61
	B	A	22.62	2.262	-13.6	7.4	0.74	-13.6	122	12.2	-122.03
Mackay Whitsunday	C	B	27	2.7	-3	18	1.8	-2.2	49.5	4.95	-5.5
	B	A	59.4	5.94	-6.6	52	5.2	-5.8	105	10.5	-11.6
Fitzroy	C	B	5.54	0.554	-0.6	3.4	0.34	-9.6	86.79	8.679	-86.79
	B	A	30.95	3.095	-27.3	10.1	1.01	-27.3	245	24.5	-245
Burnett Mary	C	B	10	1	-2.1	7.2	0.72	-2.1	44.1	4.41	-4.9
	B	A	37	3.7	-5.2	36.9	3.69	-7.9	107	10.7	-11.9

Table 45. Extension and regulation costs for each of the catchments in setting a minimum standard across both sugarcane and grazing

		Most Likely (Average Cost $/ha)		Best Case (Cheapest cost $/ha)		Worst Case (Most Expensive $/ha)	
		Regulation program cost	Extension Program cost	Regulation program cost	Extension Program cost	Regulation program cost	Extension Program cost
Wet Tropics	Cane	13.33	21.82	12.00	18.79	14.67	26.01
	Grazing	5.0	3.1	4.6	2.2	5.4	19.7
Burdekin	Cane	18.9	30.9	17.0	26.6	20.8	36.8
	Grazing	0.50	0.31	0.45	0.22	0.54	1.97
Mackay Whitsunday	Cane	13.3	21.8	12.0	18.8	14.7	26.0
	Grazing	5.0	3.1	4.6	2.2	5.4	19.7
Fitzroy	Grazing	1.4	0.9	1.3	0.6	1.6	5.6
Burnett Mary	Cane	10.0	16.4	9.0	14.1	11.0	19.5
	Grazing	2.0	1.2	1.8	0.9	2.2	7.9

For grazing practice change, the assumption was made that this would only affect the generation of fine sediment, as the most likely outcome of improved practice was an improvement in cover and therefore a reduction in hillslope sediment generation. There may be some small reductions in DIN, however the contribution of DIN (in terms of total load) from grazing is very low compared to other landuses and therefore those changes, if present, were not likely to change the overall DIN loads from the region.

With the change of cane land practice, the assumption was made that these would be changes in nutrient management that would affect the export of DIN only. This was because if practice change had resulted in changes in fine sediment, given that the cane industry is mostly confined to the lowlands and relatively flat country, changes in fine sediment load from those areas would be minimal in terms of overall loads delivered to the reef. If further evidence exists that this is significant in some catchments, then it could be changed, however for this analysis, changes were attributed to affecting DIN only.

In modelling terms, the practice change was based on the distributions outlined in Table 33 and Table 34.

Grazing A, B, C, D was distributed according to the rank percentiles of areal loads (in kg/ha/yr) of hillslope export to simulate the approach used in the P2R modelling which distributes A, B, C, D according to cover outcomes. While not identical to the approach used in the P2R modelling, it was assumed that cover outcome would be strongly related to hillslope areal load.

In cane, the practice distributions were related to nutrient management only and averaged across all catchments in the region.

For these distributions, efficacies were provided in Shaw and Silburn 2016 for grazing. For sugarcane, the efficacies were derived from model runs undertaken by DoSITI staff in support of Report Card 7 (Fraser pers comm 2016). In this study, we assumed that both the years to deliver full efficacy, and the likely adoption/compliance rate were not used, such that the practice change was immediately effective and applied to all the relevant practice area.

The efficacies quoted are for each practice change step and applied to all of the particular pollutant source related to the landuse (Table 46 and Table 47). For example, in grazing, a 46% reduction was applied to hillslope fine sediment from a sub-catchment which had been classed as D class grazing practice. Subsequently, an additional 61% reduction was applied to the resultant load out of the D to C, then a further 76% reduction was applied to the result of the C to B change to give the final load if the D class land moved through all the steps to A.

Table 46. Assumed efficacy - grazing practice change

Area of application			Applies to			Efficacy		
Region	Catchment	Sub-catchment	Landuse	Practice class	Pollutant source	Assumed Efficacy	Years to deliver full efficacy	Likely adoption/ compliance rate
ALL	ALL	ALL	Grazing	D to C	hillslope	46	8	1
ALL	ALL	ALL	Grazing	C to B	hillslope	61	8	1
ALL	ALL	ALL	Grazing	B to A	hillslope	76	8	1

Table 47. Assumed efficacy - cane practice change

Area of application			Applies to			Efficacy			
Region	Catchment	Areal change	Landuse	Practice class	Pollutant source	Assumed Efficacy		Years to deliver full efficacy	Likely adoption/ compliance rate
Wet Tropics	ALL	4,427	Cane	D-C	Seepage and hillslope no distinction	13	%	9	1
Wet Tropics	ALL	119,42 2	Cane	C-B	Seepage and hillslope no distinction	46	%	9	1
Burdekin Dry Tropics	ALL	8,023	Cane	D-C	Seepage and hillslope no distinction	48.6	%	8	1
Burdekin Dry Tropics	ALL	74,429	Cane	C-B	Seepage and hillslope no distinction	24.5	%	8	1
Mackay Whitsunday	ALL	2,844	Cane	D-C	Seepage and hillslope no distinction	35	%	9	1
Mackay Whitsunday	ALL	138,25 6	Cane	C-B	Seepage and hillslope no distinction	37	%	9	1
Burnett Mary	ALL	11,231	Cane	D-C	Seepage and hillslope no distinction	25	%	9	1
Burnett Mary	ALL	75,042	Cane	C-B	Seepage and hillslope no distinction	35	%	9	1

These were applied within the relevant meta-model for each region and the results graphed to show the reduction in total load, the target load for the region and the degree of compliance with the Reef 2050 Plan target. Tables and graphs for fine sediment are presented first, followed by DIN.

Wet Tropics grazing practice change

Table 48 and Figure 54 show the meta-model results for grazing land practice change. These results show the magnitude of change of moving all grazing landuse (both open grazing and forested grazing) to a minimum land practice class as outlined in the Table. That means the table line "2013 with all grazing to C" means moving all D class grazing to C practice, but no other change, whereas moving all grazing to A means that D has moved to C, then both the converted C (from D) and the existing C class moves to B, then all converted D and C, plus existing B moves to A. The difference between each one shows the step change performance, but the mass load reduction and the percent reduction shows how much the total loads (not just the anthropogenic) would be reduced.

These results show that with full grazing practice change, we can reduce the overall loads of fine sediment by around 8% within the Wet Tropics. This is due to both the small areas of grazing land within the Wet Tropics and lower hillslope erosion due to the good groundcover present.

Table 48. Results for fine sediment load reductions - Wet Tropics grazing D to A

Scenario	loads (t/yr)	mass load reduction (t)	% reduction*
2013 Load	1,660,000	-	
2013 with all grazing to C	1,660,000	6,750	0%
2013 with all grazing to B	1,570,000	95,100	6%
2013 with all grazing to A	1,530,000	133,000	8%

*** this is the reduction in overall load, not anthropogenic load. This allows equal comparisons between regions in terms of effectiveness.**

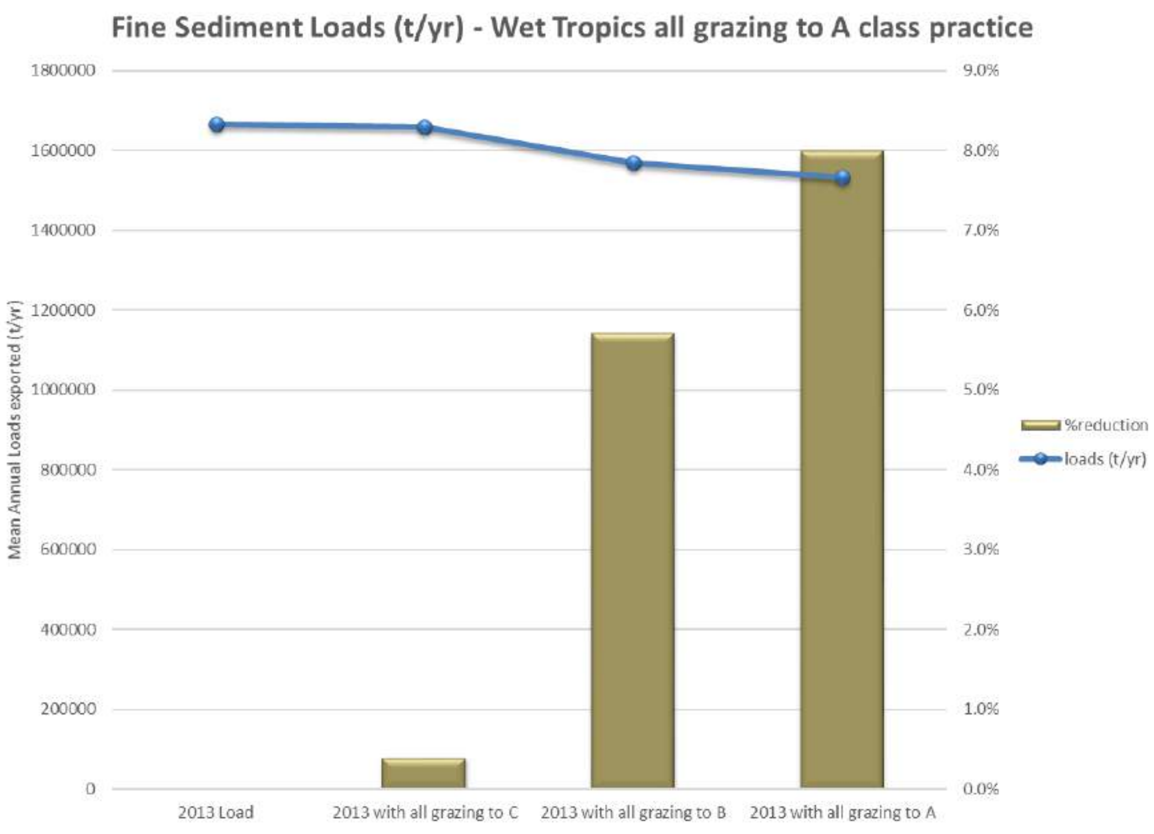

Figure 54. *Results for solution set 1 - Wet Tropics grazing practice change*

Burdekin grazing practice change
Table 49 and Figure 55 show the meta-model results for grazing land practice change. The Burdekin catchment is dominated by grazing lands, covering over 90% of the total catchment, so improvements in practice in the catchment would be expected to lead to a significant reduction, however this is complicated by the sources of pollution which is discussed further below.

In the Burdekin, grazing practice change appears to be more effective in reducing fine sediment loads, because the area of grazing lands is a far larger overall proportion of the total area in this catchment. We also thought that this would result in a greater effect of land practice change, however because we were assuming that practice change would only affect hillslope erosion, and gully erosion is also a big contributor to fine sediment loads, the overall effect as we have modelled it is not as significant. In reality, we would expect that changes in practice would reduce fine sediment loads from both gullies and hillslope, but as part of this analysis, we have "decoupled" them so we can measure the effect of gully remediation separately to practice change.

Table 49. Results for fine sediment load reductions - Burdekin grazing D to A

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	4,300,000	-	
2013 with all grazing to C	4,000,000	300,000	7%
2013 with all grazing to B	3,770,000	531,000	12%
2013 with all grazing to A	3,690,000	605,000	14%

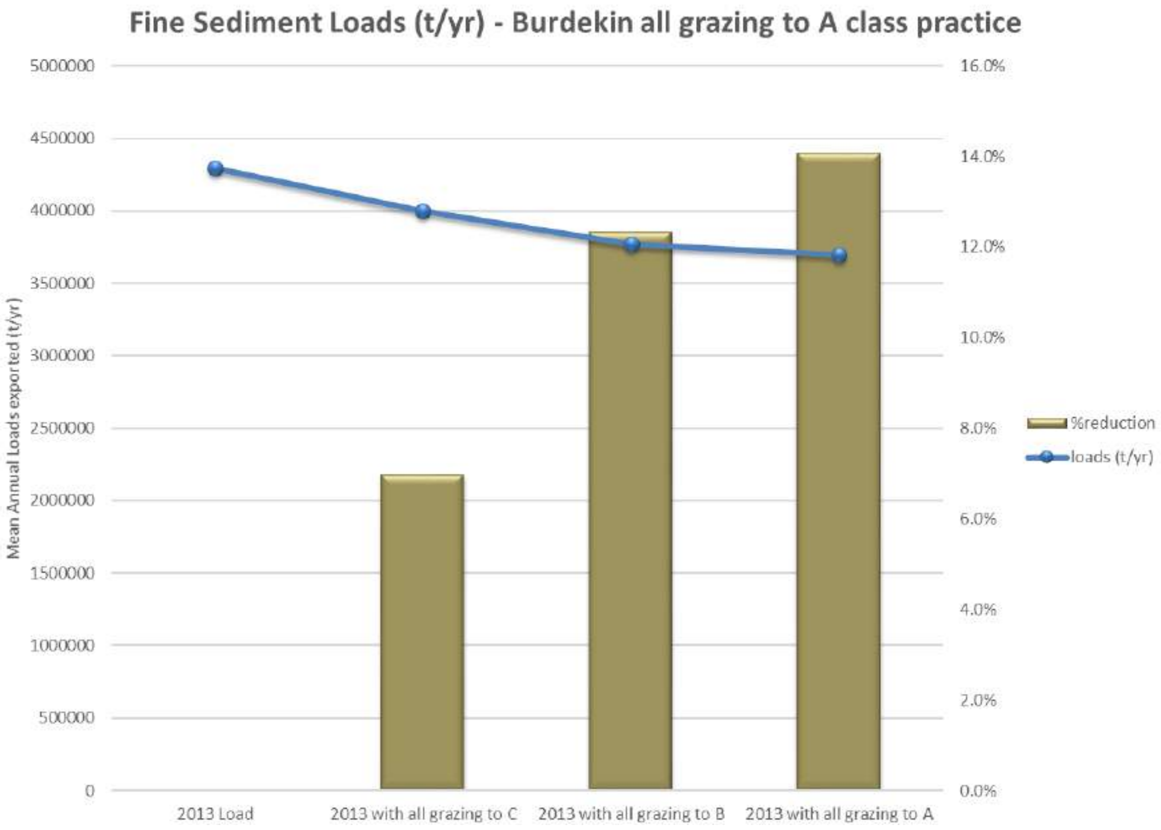

Figure 55. *Results for solution set 1 – Burdekin grazing practice change*

Mackay Whitsunday grazing practice change

Table 50 and Figure 56 show the meta-model results for grazing land practice change. The Mackay Whitsunday region has a lower proportion of grazing landuse as well as a lower overall area compared to other regions and this is shown in a slightly lower overall effect of land practice change for grazing.

In the Mackay Whitsunday region, the percentage load reductions are similar to those in the Burdekin, however the actual amounts are around 1/10th of the tonnages in the Burdekin. This is simply a factor of the overall area of the region. We do note that hillslope erosion is the most dominant source of fine sediment in the Mackay Whitsunday region, so we expected that grazing practice change may have been more significant, however the lower proportion of grazing within the region means that the percentage total load reductions are not quite as large as in other regions like the Burdekin where grazing is more dominant.

Table 50. Results for fine sediment load reductions Mackay Whitsunday grazing D to A

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	611,000	-	
2013 with all grazing to C	573,000	38,000	6%
2013 with all grazing to B	557,000	54,000	9%
2013 with all grazing to A	543,000	67,900	11%

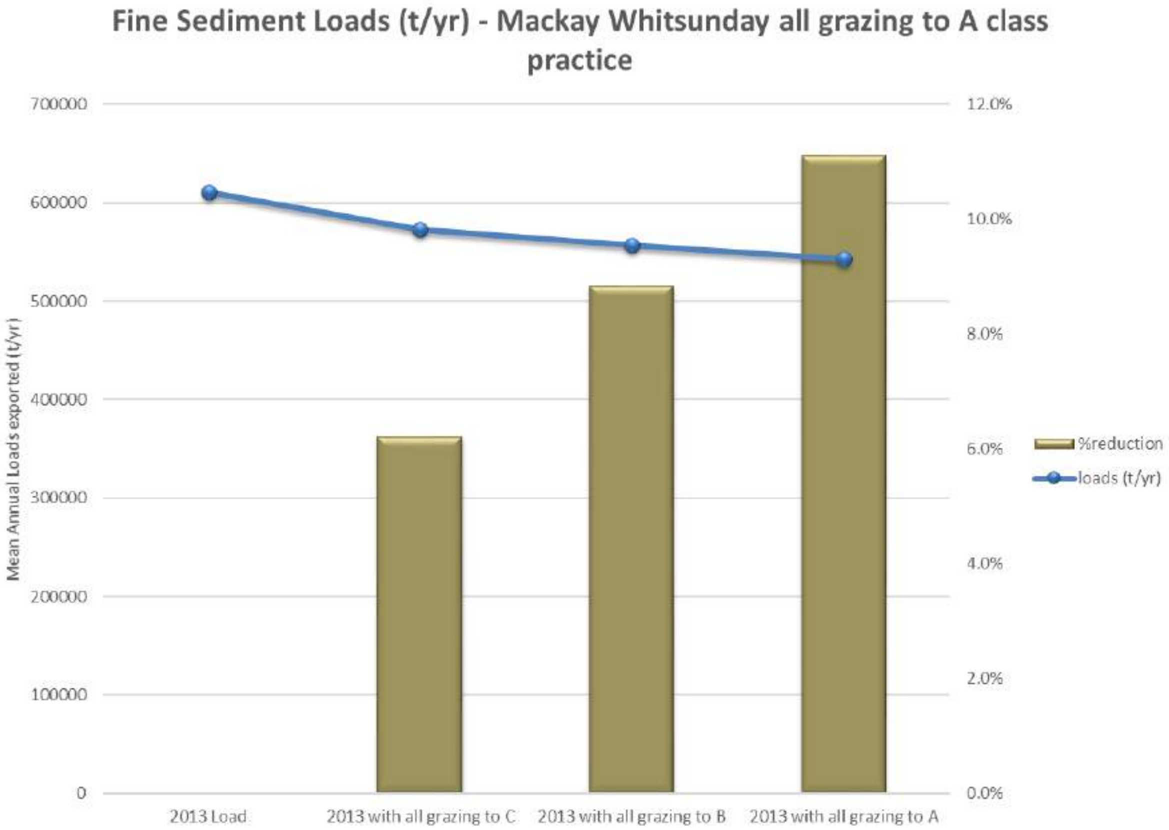

Figure 56. *Results for solution set 1 – Mackay Whitsunday grazing practice change*

Fitzroy grazing land practice change

Table 51 and Figure 57 show the meta-model results for grazing land practice change. The Fitzroy is the second largest region in the GBR catchments, with a contributing area of 156,000 km^2. It is also a region dominated by grazing, so land practice change is an important method of reducing fine sediment loads as shown below.

The results show how effective the land practice change is, with a nearly 20% reduction in total fine sediment loads. This indicates that in the Fitzroy, hillslope erosion is a bigger overall contributor to the loads, and, in combination with the dominance of grazing landuse in the catchment, therefore changes to practices that then result in reductions in hillslope erosion are going to have a bigger impact.

Table 51. Results for fine sediment load reductions Fitzroy grazing D to A

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,800,000	-	
2013 with all grazing to C	1,550,000	248,000	14%
2013 with all grazing to B	1,480,000	324,000	18%
2013 with all grazing to A	1,450,000	347,000	19%

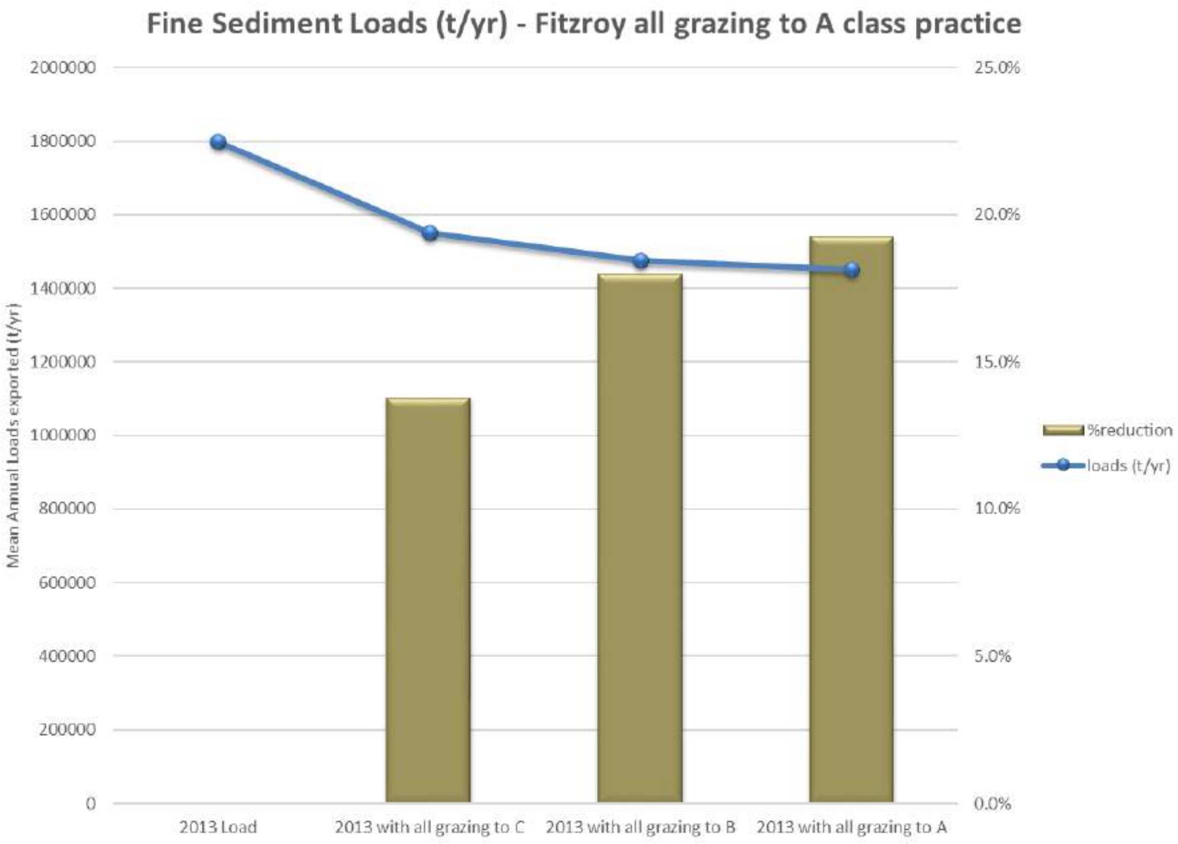

Figure 57. *Results for solution set 1 – Fitzroy grazing practice change*

Burnett Mary grazing land practice change

Table 52 and Figure 58 show the meta-model results for grazing land practice change. The Burnett Mary region has a broader distribution of landuses, though grazing is still an important contributor to fine sediment loads. These loads and the effects of land management practice change are shown below.

These results show us that changing land practice has the potential to reduce fine sediment loads by 18%, and also shows that the biggest impact would be from moving grazing to at least B class practice. There is no change in terms of moving grazing to C as all grazing within the Burnett Mary is considered to be at C class practice already. Also, because this practice change is only applied to hillslope erosion in the model, the impacts are not quite as large as would be expected, but as noted in the previous regions, this is so we can separately account for land practice change and gully and streambank remediation. In reality, we would likely see that improvements in land practice would also reduce loads from gullies and streambanks, however we have not modelled this within the project.

Table 52. Results for fine sediment load reductions Burnett Mary grazing D to A

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,260,000	-	
2013 with all grazing to C	1,260,000	-	0%
2013 with all grazing to B	1,100,000	162,000	13%
2013 with all grazing to A	1,030,000	225,000	18%

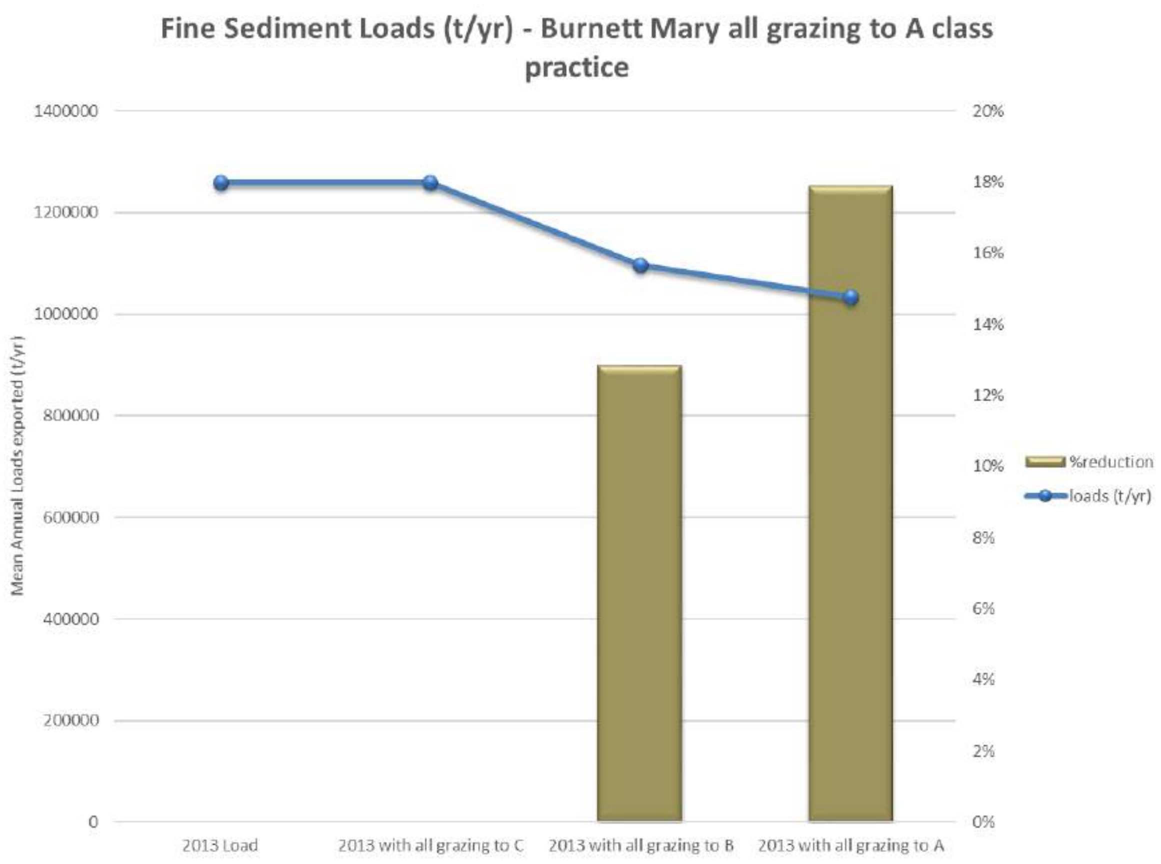

Figure 58. *Results for solution set 1 – Burnett Mary grazing practice change*

Wet Tropics cane practice change

Table 53 and Figure 59 show the meta-model results for cane practice change. The Wet Tropics region has around 8% of the catchment in sugarcane, however while its overall area proportion is low, the DIN contribution is dominated by that landuse. For that reason, one of the solution sets investigated was to improve cane practice to at least a B class standard. Given that the majority of cane lands are considered in C class practice within the region, the potential reduction in DIN loads with improving practice to B was expected to be substantial.

The results show that moving all cane lands to at least C class practice will not lead to much improvement in DIN loads from the region as the majority of cane lands are already in C and only around 3% are in D. The substantial reduction in overall DIN loads would be possible through the implementation of practice change so that cane lands were all in B class practice at least, with a nearly 1000 tonne per year reduction possible.

Table 53. Results for DIN load reductions Wet Tropics Cane D to B

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	5,040	0	0%
2013 with all cane to C	5,020	17	0%
2013 with all cane to B	4,080	961	19%

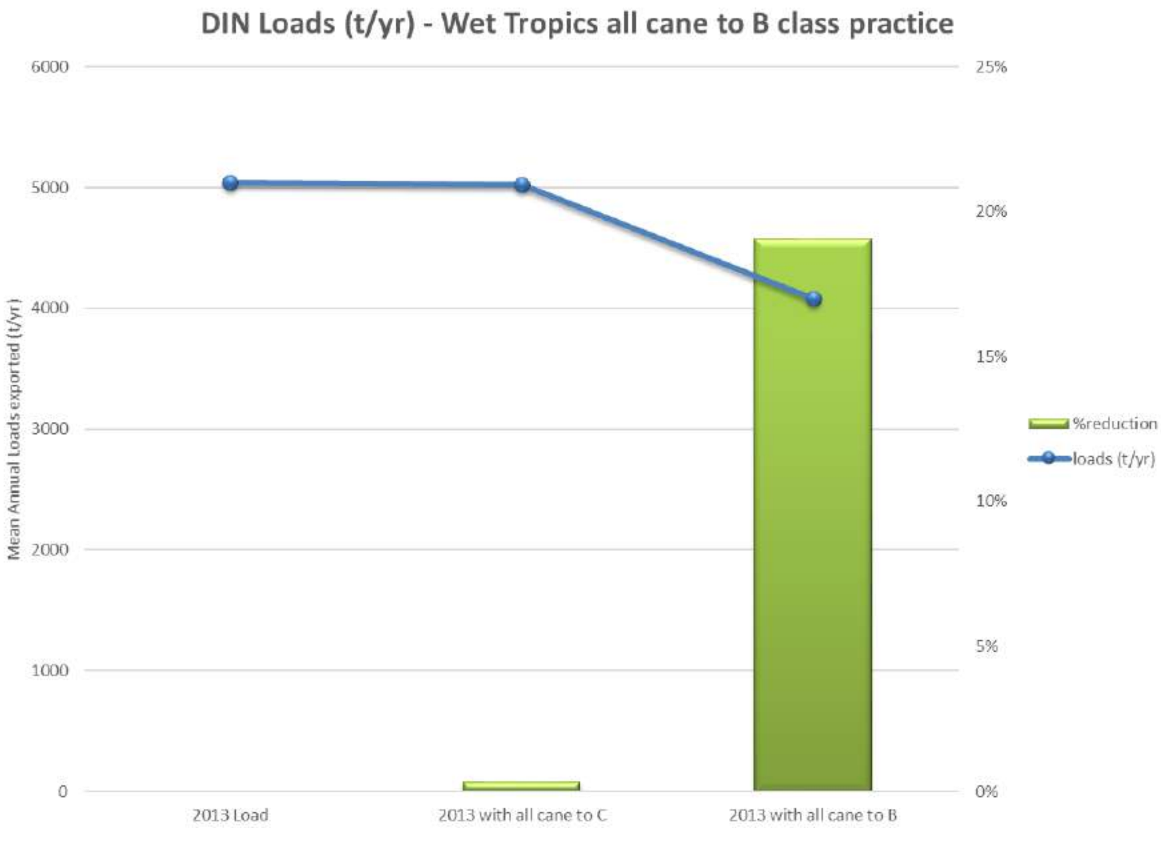

Figure 59. *Results for solution set 1 – Wet Tropics cane practice change*

Burdekin cane practice change

Table 54 and Figure 60 show the meta-model results for cane practice change. Sugarcane landuse in the Burdekin is only a small proportion of the overall landuse, around 1%, but it is concentrated in the key agricultural areas of the Burdekin River Irrigation Area (BRIA) and the Burdekin Delta. Both of these areas are immediately adjacent to the GBR lagoon and therefore any contributions from those areas would be delivered straight to the reef. This means that any actions implemented to the cane industry in those areas is likely to have a significant effect on DIN reductions.

As for the Wet Tropics, more of the cane landuse is in C class practice than in other practice classes, so the most substantial improvement is moving all sugarcane to B class practice though given that there are other contributors to the overall DIN load in the Burdekin, and that sugarcane is only a very small proportion of the overall catchment area, the load reductions are still substantial. It does suggest that other practices may also be needed to reduce DIN loads even with the potential reductions possible through practice change.

Table 54. Results for DIN load reductions Burdekin Cane D to B

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	2,770	0	0%
2013 with all cane to C	2,740	22	1%
2013 with all cane to B	2,480	286	10%

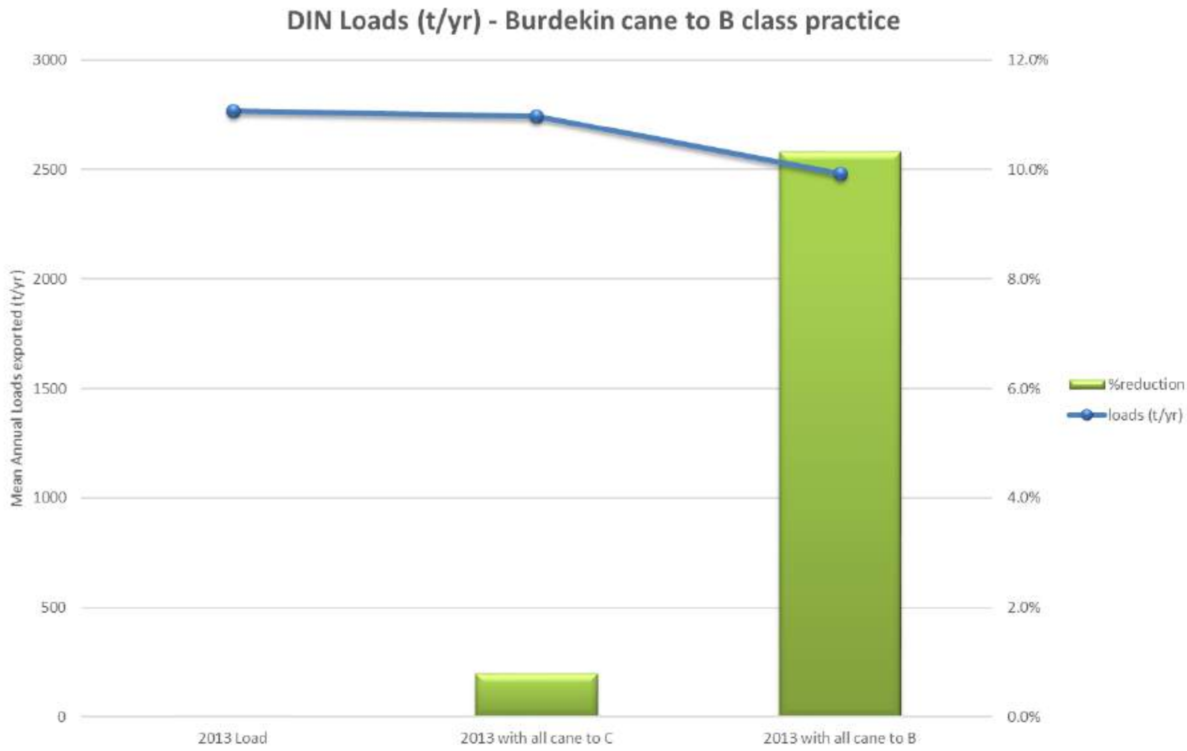

Figure 60. *Results for solution set 1 – Burdekin cane practice change*

Mackay Whitsunday cane practice change

Table 55 and Figure 61 show the meta-model results for cane practice change. The Mackay Whitsunday region is one of the smaller regions in the GBR but is dominated by sugarcane landuse, with it taking up 18% of the overall catchment area. For that reason, the likely performance of management actions targeting sugarcane practice can have a big effect on reducing DIN loads.

The potential load reductions of DIN in the Mackay Whitsunday region from putting changed land practices in place on sugarcane areas is quite large. We think that these reductions will be more than enough to meet the targets for DIN in the region, and it might be that these reductions might actually be able to offset some of the loads from other regions where their performance is not able to meet the overall targets.

Table 55. Results for DIN load reductions Mackay Whitsunday Cane D to B

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,240	0	0%
2013 with all cane to C	1,140	102	8%
2013 with all cane to B	775	465	38%

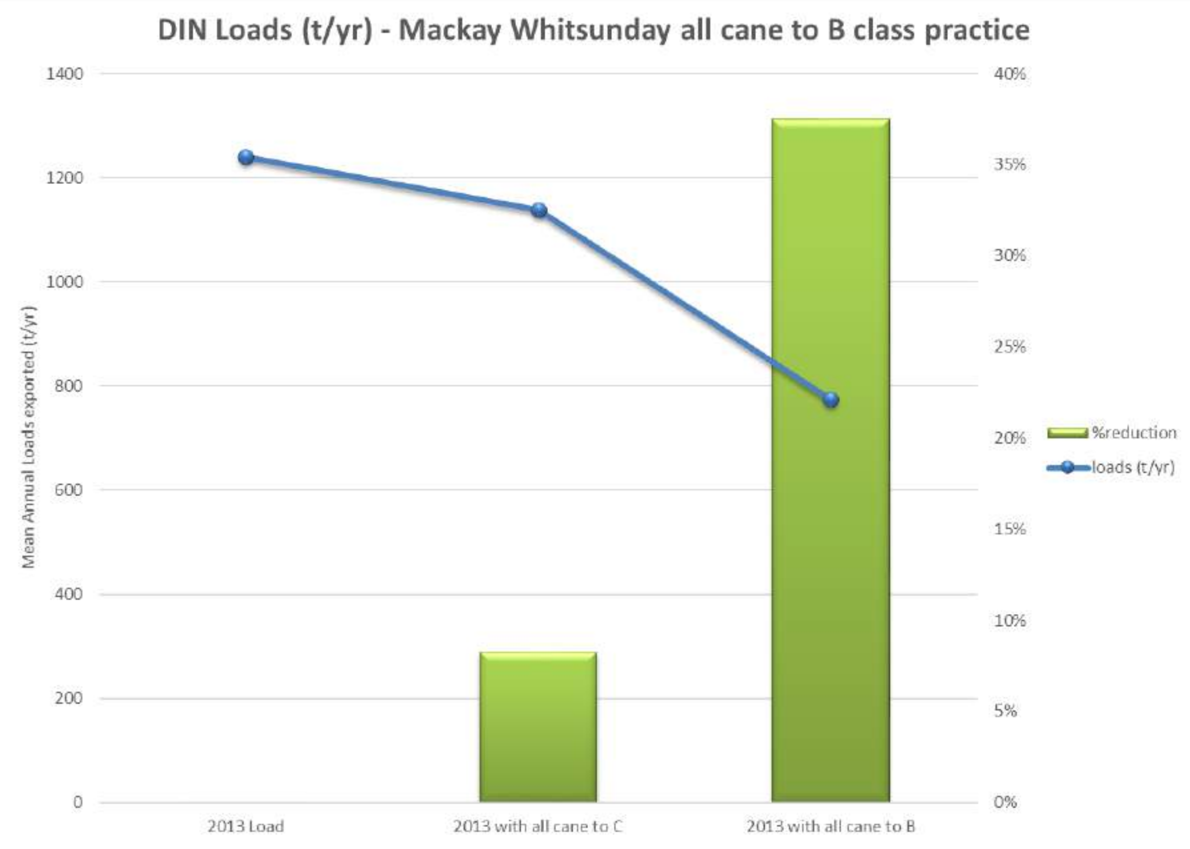

Figure 61. *Results for solution set 1 – Mackay Whitsunday cane practice change*

Burnett Mary cane practice change

Table 56 and Figure 62 show the meta-model results for cane practice change. The Burnett Mary system has a range of landuses in the region, and is dominated by grazing lands with sugarcane areas again mostly confined to the coastal catchments. Even so, sugarcane contributes more than half of the overall DIN load and so is worth considering in terms of changing sugarcane practices to reduce that load.

The results show us that the reductions from moving all cane to at least C class practice are reasonable, though not as large as moving it all to B class.

Table 56. Results for DIN load reductions Burnett Mary Cane D to B

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	866	0	0%
2013 with all cane to C	815	52	6%
2013 with all cane to B	727	140	16%

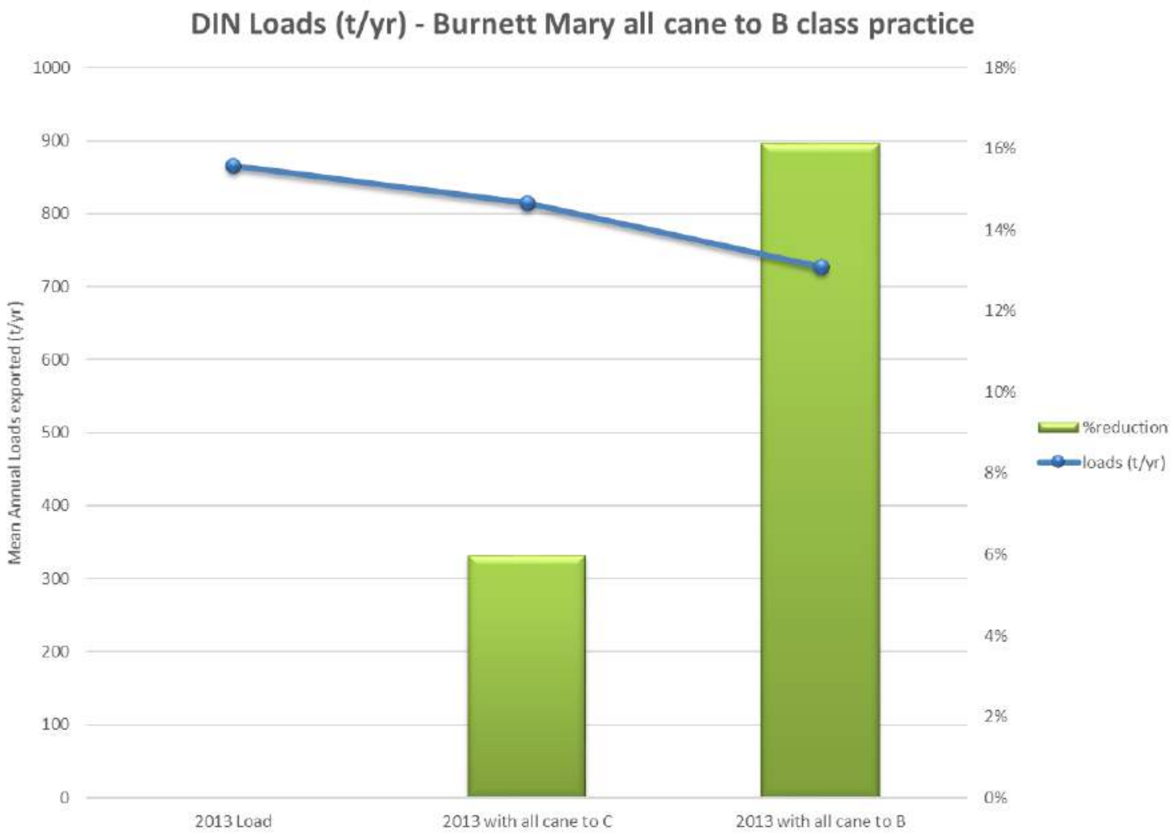

Figure 62. *Results for solution set 1 – Burnett Mary cane practice change*

In all of these assessments for this policy solution set, the most substantial reductions will be from improving to B class practice, with minor gains to be made to moving to at least C. This is likely to be the result of previous investments in practice change, such that in some regions there are only a few areas still in D class practice. The tonnage reductions in DIN are also quite substantial by doing so, with up to a nearly 50% reduction in the loads coming from cane lands in some catchments with the changes as we have modelled them. We think that this is not the end of those improvements though, and while we have been able to look at the effects of our current thinking in terms of improving practice, newer approaches and technology could mean even higher reductions might be possible.

Limitations

For this study it was important to standardise assumptions across regions and the time period of the study. A relatively simplistic approach was used, namely assumptions of a single minimum, average and maximum private, extension and regulation cost per region. It is acknowledged that the approach does not reflect the heterogeneity and diversity of the individual catchments included in this assessment (Thompson et al. 2015; Star et al. 2013). To achieve 100% adoption of all A in grazing and all B in sugarcane will result in diminishing marginal returns that relate to the level of adoption over time, particularly given that a high percentage (95% in the Burnett Mary) are required to change. The current costs associated with the change have not considered this, which is a limitation of the study. Similarly, it is acknowledged that climate is a significant driver of the costs, however these have not been considered well in the context of this study.

The approach has focused on the mechanisms of incentives, extension and regulation. It is a limitation of the study that mechanisms such as tenders and auctions have not been considered, and the implications that information asymmetries still exist. Specific farm changes and paddock scale heterogeneity has not been accounted for well. Project selection is critical in achieving cost effective management change and limited consideration has been given to the most critical aspects of the management practice. Instead the grouping of the classification has been considered (Rolfe and Windle, 2016). It must also be noted that the farming system changes have only focused on the high priority pollutants of fine sediment and dissolved inorganic nitrogen. The cumulative impacts on the farming system from adopting practices outside of this scope have not been considered.

In grazing the inference that A, B, C, D land management practices leads to A, B, C, D land condition has not yet been correlated due to time lags in management changes and system response. Similarly, the inference that shifting from D to C by 2025 may not be fully realistic. The costs and production changes did not capture all of the biophysical factors, such as site-specific effects, or adequately reflect cumulative and threshold effects (Wu and Skelton-Groth, 2002) and impacts of poor management long-term on production. The assumptions that landholders were always profit-maximising and have perfect knowledge are not realistic as many have different aspirations and levels of management capacity and debt.

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B.2 Policy solution statement 2: Improved irrigation practices

Policy solution set description and context

The largest irrigated sugarcane growing region in Queensland is in the Burdekin catchment and includes the Burdekin River Irrigation Area (BRIA) and the Burdekin Delta (Figure 63). Paddock scale modelling in the Paddock to Reef Program (P2R) has shown that moving to higher efficiency irrigation techniques (such as drip, overhead or high efficiency furrow irrigation for example, optimising furrow in-flow rates, surge irrigation, optimising cut-off times using telemetry and automation, skip-row irrigation or combinations) combined with at least best management practice nutrient management can reduce the amount of dissolved inorganic nitrogen (DIN) lost to the environment by at least 80%. There are very few field studies to establish whether these reduction estimates are robust and also very few economic studies demonstrating the costs of changing irrigation practices, particularly in conjunction with nutrient management.

This solution set assesses the costs of moving to high efficiency irrigation practices in the Lower Burdekin sugarcane area, including representation of at least 10%, 20%, 50%, 70% and 100% of the suitable sugarcane area adopting high efficiency techniques. High efficiency irrigation techniques are reliant on particular biophysical characteristics such as soil type and pollutant loss pathways, and are only suitable in certain cases such as less permeable soils where surface runoff dominates. This was taken into account when considering the adoption rates, i.e. different sorts of high efficiency techniques will not be suitable everywhere and thus a 100% adoption solution set is highly unlikely. Irrigation improvements are costed separately in this Policy solution set (nutrient management is costed in the land management Policy solution set 1), but it is recommended that they should be considered in conjunction with a shift to B class nutrient management practices. The consideration of irrigation and nutrient management together also recognises the influence of wet season runoff in DIN loads given that the majority of irrigation tailwater runoff occurs during the dry season.

Figure 63. *The Lower Burdekin sugarcane area, typically divided into the BRIA (≈47,500ha) and Delta (≈42,600ha) irrigation areas.*

The characteristics of the BRIA and Delta areas are quite distinct and are shown in Table 57, highlighting the following key points:

- Analysis of paddock scale monitoring and modelling data indicates that a larger proportion of DIN loss occurs via surface runoff in the BRIA area than in the Delta.
- Much of the runoff from the BRIA is directly discharged to Barratta Creek, compared to the Delta where the waterways are typically used as water transfer channels (Davis et al. 2012). Recycle pits are also used in the BRIA to capture and recycle irrigation tailwater.
- The soils in the Delta are also more permeable than in the BRIA, making them less suitable for achieving efficient furrow irrigation techniques.
- In the Delta, the majority of irrigators are groundwater irrigators, where water irrigation water recharges the aquifer and is subsequently reused to maintain soil moisture requirements.
- Delta growers apply more water per unit of area (e.g. 20+ML/ha) than BRIA growers (e.g. 10-12ML/ha). Reasons include high soil permeability (irrigation water leaches quickly) in the Delta and most of the irrigation water is charged via area ($/ha – not a volumetric charge) in the Delta. These factors affect the relative economic benefit accrued from improvements in water application efficiency.
- The average farm size in the BRIA is 140ha (with areas up to 3,500ha) compared to 72ha in the Delta (with areas up to 500ha). Previous economic analysis conducted by Smith (2015) indicates that it is more cost effective to implement improved nutrient and irrigation management practices on the larger farms as fixed costs are spread across a larger production base.

These factors were considered when assessing the distribution of adoption between the two areas (Table 57).

Table 57. Key characteristics of the BRIA and Delta sugarcane growing areas in the Lower Burdekin. Reproduced from Waterhouse et al. (2016).

Characteristic	BRIA	Delta
Area:	47,485 ha	42,592 ha
Establishment	Since 1980s	Since 1880s
Approx. Farm size[1]	Up to 3,500ha Median farm size: 94ha Average farm size: 140ha	Up to 500ha Median farm size: 56ha Average farm size: 72ha
Dominant soils	Sodic duplex/and light to medium and heavy clays (high denitrification potential)	Coarse sands, sandy loams and light to medium clays (Low denitrification potential)
DIN loss pathway	Large proportion in surface runoff	Large proportion in drainage
Modelled annual average DIN load[3]	460t/yr	586t/yr
Average production[2]	110 tonnes per ha	120 tonnes per ha
Fertiliser application rates[4]	214 kgN/ha Plant 227 kgN/ha Ratoon	193 kgN/ha Plant 216 kgN/ha Ratoon
Water source and use	Surface water and groundwater in Northcote, Jardine and Selkirk areas 10-12 ML/ha Volumetric charge for water Gravity fed systems leading to lower electricity costs	Groundwater and surface water from Water Board supply 20+ ML/ha Largely area based charges for water Pumping leads to higher electricity costs
Irrigation systems	Predominantly furrow irrigation	Predominantly furrow irrigation

Data sources:
[1]Wilmar, January 2016.
[2]Wilmar, March 2016.

[3] Based on modelled estimates of DIN loads from sugarcane areas using the Paddock to Reef Source Catchments model, DNRM (2015).
[4] P2R Survey data, NQ Dry Tropics (2015).

The relevant target for the Lower Burdekin sugarcane area in this project is an 80% reduction in anthropogenic DIN from the Burdekin region by 2025.

Approach

The assessment involved a desktop analysis of costs and pollutant load reductions associated with progressively shifting 10%, 20%, 50%, 70% and 100% of the irrigated area to B class irrigation practices, which is essentially adoption of higher efficiency techniques such as drip irrigation, overhead low pressure or automated and optimised furrow irrigation. The selection of irrigation management practices was guided by the P2R Water Quality Risk Framework for sugarcane[5]. It is noted that the irrigation methods adopted for A class practices are likely to remain the same, but better operational efficiencies would lead to greater application efficiencies.

Current adoption rates were drawn from the P2R program reporting for 2013/2014 (Queensland Government, 2015) for consistency with other solution sets. However, refined adoption rates are also presented (but not costed) following further discussions with industry experts (e.g. Steve Attard, Evan Shannon). Source Catchments modelling outputs for DIN loads (2013 baseline) from the Lower Burdekin sugarcane area were used to assess the efficacy of improvements in irrigation practices.

Key pieces of work that have been used to assess this solution set include:

- The draft Burdekin Water Quality Improvement Plan (currently awaiting Australian Government sign off, June 2016);
- Smith (2015) financial economic analysis of sugarcane management practice changes;
- NQ Dry Tropics Reef Rescue and Reef Programme grants data;
- Source Catchments modelling scenarios (Grant Fraser, DSITI and Cameron Dougall, DNRM); and
- Discussions with or review by local experts including Steve Attard (AgriTech Solutions), Mark Poggio and Matt Thompson (DAF) and Evan Shannon (Farmacist).

More detailed methods and results are presented in the sections below.

Management practices, adoption, costs and effectiveness

Management practices considered in the assessment
Irrigation practices are defined in the P2R WQ Risk Framework in terms of: 1) calculating the amount of water to supply, 2) managing surface runoff, and 3) optimising the irrigation system; refer to Table 58. Within this framework, calculating the amount of water to supply is the most important management tactic for water quality outcomes with best management practice requiring that the amount of irrigation water applied to each block is less than or matches the soil water deficit. The APSIM modelling does not model an irrigation system (e.g. furrow, drip, overhead low pressure) but rather irrigation management (amount applied and how often), and scenarios are created that mimic typical management situations seen in the field.

While it has been established that 95% of the sugarcane area in the Lower Burdekin is irrigated using conventional furrow irrigation systems (S. Attard, pers. comm.), there is a lack of data on how these irrigation systems are operating in terms of application efficiency and total water usage versus losses. Data on the range of irrigation application efficiencies (i.e. the proportion of the water applied that is used by the crop and not lost to runoff or drainage) is important for understanding water quality influences from irrigation practices and

[5] http://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/assets/paddock-to-reef-sugarcane-water-quality-risk-framework.pdf

is currently limited in the GBR. The P2R program defines a set of application efficiencies for different practice levels in the BRIA and the Delta, shown in Table 59. This indicates that the application efficiencies expected to be achieved in the BRIA are likely to be higher than those in the Delta.

Worldwide, average application efficiencies of different systems are reported as: surface irrigation 60-90%, sprinkler 65-90% and drip 75-90% (Fairweather et al. 2000). However, these efficiencies can be misleading and depend on soil type, moisture conditions before irrigation, depth to groundwater, the crop being grown, management practices, and quality of irrigation water. Conceptually, it may be expected that a drip system would be a more efficient way of applying water, but due to variability in these characteristics, can be very site dependent (Hodgson et al. 1990). It is the management of the system for a particular soil and crop combination that is the important input to improve irrigation efficiency. A technology that can lead to potentially high efficiencies, such as drip irrigation, still has to be well designed and managed to take full advantage of that potential and is likely to require substantial technical support.

It is unlikely that the current B class efficiencies could be realised using conventional furrow irrigation across the Lower Burdekin (Attard, 2014; Raine and Bakker, 1996) and only methods such as well-designed and well-managed automated furrow irrigation systems and well-designed drip or overhead low pressure irrigation systems are likely to be able to deliver 80% application efficiencies across the entire irrigated sugarcane area (Bakker et al., 1997; S. Attard, pers. comm.).

Table 58. Management tactics related to irrigation management in the P2R WQ Risk Framework for sugarcane management.

Priority	Management tactic	Weighting (Water quality assessment)		Indicative practice levels 2013			
				Lowest risk, commercial feasibility may be unproven	Moderate-low risk	Moderate risk	High risk
		Irrig	No Irrig	Innovative	Best Practice	Minimum	Superseded
Water							
1	Calculating the amount of water to apply	70	0		Amount of irrigation water applied to each block is less than or matches the soil water deficit.	Amount of water applied to each block exceeds the soil water deficit by **less than** 50%.	Amount of water applied to each block exceeds the soil water deficit by **more than** 50%.
2	Managing surface runoff	20	100	All drainage lines are designed to minimise erosion, are maintained with grass cover, and filter sediment before entering trap or pit. Farm layout directs all runoff safely to these structures. Runoff from the first 15 mm of rainfall is captured and retained on farm. All irrigation runoff is able to be captured and stored on-farm. Recycle pits have sufficient pumping capacity to re-use stored water.	Crop row orientation and surface topography ensures runoff is directed from all blocks without causing soil loss or waterlogging. All drainage lines are designed to minimise erosion, are maintained with grass cover, and filter sediment before entering trap or pit. Recycle pits have sufficient capacity to capture all irrigation-induced runoff. Recycle pits have sufficient pumping capacity to re-use stored water.	Crop row orientation and surface topography ensures runoff is directed from most blocks without causing soil loss or waterlogging. The majority of drainage lines are designed to minimise erosion and are maintained with grass cover. Recycle pits have insufficient capacity to capture all irrigation induced runoff.	Headlands and drains are not specifically designed to prevent erosion and are sprayed out and/or cultivated. No on-farm water capture.
3	Optimising the irrigation system	10	0		Irrigation system performance assessments occur on a regular basis.	Irrigation system performance assessments occur on an irregular basis.	Irrigation system performance assessments have not occurred.

Based on this advice, three main methods of irrigation have been identified for costing in this assessment. These are:

- Level 1 - well-designed and managed drip and overhead low pressure systems;
- Level 2 - well-designed and managed automated furrow systems; and
- Level 3 - well-designed and managed conventional furrow systems.

Level 3 systems will be the cheapest to operate and therefore, are represented in the assessment with the maximum possible area. However, the labour requirement may be significant on a daily basis depending on site specific characteristics. These systems are likely to be most effective in the BRIA where there are lower infiltration soils therefore, less loss to deep drainage during irrigation events. Importantly, leaching losses on highly permeable soils can be very high, which makes 80% application efficiencies unobtainable on these types of soils when using furrow irrigation without very expensive (in some cases implausible) changes to the overarching design of farms (e.g. row lengths) (M. Thompson, DAF pers. com.). Level 2 systems require more costs to acquire instrumentation for automation and scheduling (capital) but there may be greater labour savings in the longer term; a higher level of skill is required than in Level 3. The use of telemetry and automation enables irrigators to monitor their irrigation systems and maintain continuous management over irrigation events. Telemetry allows growers to communicate with their irrigation systems remotely, while automation enables them to control particular operations such as opening and closing valves and stopping pumps. Additionally, growers are able to monitor field status, which improves their ability to make decisions in real time (DAF, 2016). Level 1 systems, such as drip irrigation, are the most costly method and require a high level of skill to operate. As described in the section titled *Management practice adoption*, these systems are constrained to the Delta in this assessment where infiltration rates are high and therefore, furrow irrigation systems are likely to be less efficient, requiring adoption of more advanced techniques to achieve best management practice application efficiencies.

Table 59. Application efficiencies for Irrigation management classes in the BRIA and Delta sugarcane areas from the Reef Rescue A, B, C, D framework Sugar Growers Burdekin Region 2013[6]

Management class	Application efficiency (%)	
	BRIA	Delta
A	>85%	>75%
B	70-85%	60-75%
C	50-70%	40-60%
D	<50%	<40%

In the BRIA, installation of recycle pits to capture irrigation runoff will also reduce surface runoff which can be beneficial with lower application efficiencies. While current adoption rates for recycle pits are reasonably well known, there is less knowledge of the efficiency of the pits. It has been agreed to treat recycle pits separately in Solution set 5 Wetland Construction as assumptions regarding the effectiveness of the pits for each practice class are being addressed explicitly in that solution set.

If drip or overhead low pressure irrigation systems were installed, then there would be several additional impacts and benefits which could be significant. Examples are listed below, but these additional benefits are not factored into in this assessment (e.g. farm profit) due to time and resource constraints:

- There would be limited or no surface irrigation runoff (thereby reducing nutrient runoff and delivery to receiving environments). This may involve lower (or different) electricity and water costs.
- Green cane trash blanketing could be implemented on suitable soils which assists in reducing surface runoff and soil erosion.
- Nutrient management could be improved with potentially reduced application rates due to greater delivery efficiencies, increased ability to move from single to split or multiple applications (e.g. weekly as is possible with drip fertigation). This would result in lower fertiliser costs and potential yield (and revenue) improvements. and
- In drip systems herbicide usage could also be dramatically reduced (no wetting of the soil surface) which may result in lower weed control costs.

Management practice adoption
Management practice adoption data is available and interpreted through several sources in the region: 1) the P2R program, 2) the NQ Dry Tropics Reef Programme water quality grants database, and 3) industry technical advice from the INFFER workshops undertaken for the Burdekin WQIP (see Roberts et al. 2016) and additional discussion. Due to variations in the scope and detail of the data sets, estimates of adoption characteristics vary widely between the sources. Anomalies are being identified and addressed through the P2R program. For

[6] https://drive.google.com/file/d/0B2eYGb5_l-adX2FVNTNBUE9uSUE/view

this project the P2R adoption data from 2013/2014 will be used so that the exercise can be readily repeated in the future, however, an alternative set of adoption data is also presented for comparison. Discussions with industry experts indicate that given the lack of understanding of current application efficiencies (regardless of method) across the region, that the P2R adoption rates provide a conservative perspective of current adoption and that more site based assessments would reveal better application efficiencies in some locations. Future investment is warranted to identify current application efficiencies in the Burdekin as this would greatly improve the ability to identify current status and potential benefits of practice change. This would also enlighten growers and make them aware of potential opportunities.

The P2R program adoption data is reported for the whole Lower Burdekin sugarcane area and report that as at 2013/2014, 10% of the area was managed under A or B class practice irrigation, 8% at C class and 82% at D class. For this exercise we have split the A and B adoption into 8% A practice and 2% B practice (based on discussion with technical experts). More recent adoption data was also collated for the Burdekin WQIP, which is quite different to these estimates, as shown in Table 60. These differences are likely to be due to interpretation of the irrigation efficiencies achieved for each class and possibly reflects the spatial variation in biophysical characteristics. It is recommended that further work is required to resolve these differences and to ensure that the water use assessment between the BRIA and the Delta (including technologies adopted) are compatible, as these will have significant implications for these desktop cost assessments. The P2R Program adoption figures noted above are used in this assessment for consistency with other Policy solution sets.

Table 60. Current (2015) estimates for representative proportions of growers at each irrigation management class. Prepared in conjunction with S. Attard, AgriTech Solutions and M. Davies, SRA December 2015 as part of the Burdekin Region WQIP update.

Irrigation management class	BRIA		Delta	
	Application efficiency (%)	Current adoption (% area)	Application efficiency (%)	Current adoption (% area)
A	>85%	2	>75%	2
B	70-85%	35	60-75%	33
C	50-70%	40	40-60%	35
D	<50%	23	<40%	30

To work out the areas required to shift irrigation practices, it is recognised that the maximum area that can achieve best practice irrigation application efficiencies using different methods varies between the BRIA and the Delta. This is determined by local characteristics, and has been estimated with advice from AgriTech Solutions, shown in Table 61. This is a very simplistic assessment and would need to be supported by detailed field assessment and industry consultation for actual application of these proportional estimates. It would also require external assistance in many cases to cover the high capital costs to growers. However, it recognises that there will be areas where cheaper methods can be applied to achieve the B class irrigation application efficiencies if well-designed and managed, and has been applied in allocating costs. These estimates assume that growers maintain a certain standard and do not shift back to previous practices which is highly dependent on technical capacity, and the provision of adequate support services, and realistically would be variable between growers.

Table 61. Estimated proportion of the potential Application Efficiencies at B practice irrigation management that could use each method in this assessment.

Irrigation Method	Proportion of the potential proportion of area in each region that could adopt irrigation method			
	BRIA	Area (ha)	Delta	Area (ha)
Level 1 - well-designed and managed drip and overhead low pressure systems	30%	14,246	60%	25,555
Level 2 - well-designed and managed automated furrow systems	65%	30,865	35%	14,907
Level 3 - well-designed and managed conventional furrow systems	5%	2,374	5%	2,130

These factors are then applied to the scenarios for 10%, 20%, 50%, 70% and 100% of the irrigated area to B class irrigation practices to estimate the area of the practice shifts required in the BRIA and the Delta (Table 62).

Table 62. Estimated proportion of the area of practice shifts required using particular irrigation methods in the Lower Burdekin sugarcane area based on the maximum potential areas identified in Table 61

Adoption of advanced irrigation	Irrigation method	% shift required across region (assume 10% at A or B)	Area shift req'd across region	BRIA area (ha)[2]	% of total BRIA area	Delta area (ha)[3]	% of total Delta area	Regional total[4]	% of total area
10%[1]	Level 3	0	-	0	0%	0	0%	0	0%
20%	Level 2	10	9,000	9,000	19%	0	0%	9,000	10%
50%	Level 2	40	36,000	31,000	65%	5,000	12%	36,000	40%
70%	Level 2	60	54,000	31,000	65%	15,000	35%	46,000	51%
	Level 1			0	0%	8,000	19%	8,000	9%
100%	Level 2	90	81,000	31,000	65%	15,000	35%	46,000	51%
	Level 1			10,000	21%	25,000	59%	35,000	39%

Notes: Level 1 = well-designed and managed drip and overhead low pressure systems; Level 2 = well-designed and managed automated furrow on a portion of the area; Level 3 = well-designed and managed conventional furrow on a (very) small area.

[1] It is assumed that the current adoption of 10% at A or B class irrigation management eliminates the need for any action in this policy solution set.

[2] *BRIA total area 47,485ha*

[3] *Delta total area 42,592ha*

[4] *Total area 90,077ha*

Cost estimates of management practice changes

Upfront costs and annual maintenance costs

As identified above, the costs of the three main methods of irrigation management can vary significantly, and will be influenced by site specific characteristics – so there will also be a range within each method.

For this exercise we have assumed that well designed and managed furrow irrigation (Level 3) in suitable areas will not incur any new additional costs as no new equipment is likely to be required. However, it is recognised that this may require many more labour hours being attributed to irrigation duties depending on the site characteristics, although that is not factored in here as it is very site and grower-specific. As noted in Table 61, it is expected that these are only likely to achieve B practice application efficiencies in 5% of the BRIA and Delta areas. It was also assumed that these systems contribute to the existing 10% of the area in A or B class practices.

Automated furrow irrigation (Level 2) is likely to require incorporation of instrumentation 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 prefer. The early results of several trials indicate that the capital cost will be in the range $600 per hectare (DAF, 2016) to around $1,500 per hectare for instrumentation (in extreme cases, costs could be as high as $2,500) (S. Attard, Agritech Solutions, pers. com.). Annual maintenance costs and training through extension is estimated to be around $50 to $150 per hectare to support equipment maintenance and farmer training (S. Attard, AgriTech Solutions and Burdekin WQIP INFFER workshops.). 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 in the Burdekin WQIP INFFER analysis. These systems are less likely to achieve the B class irrigation efficiencies in the Delta due to the highly permeable soils. Higher infiltration leads to the need for relatively short furrow lengths, which can become too short to be practical to manage at these levels of efficiency.

The costs of drip or overhead low pressure irrigation systems (Level 1) also varies 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. 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 Burdekin WQIP INFFER analysis. We have applied varied costs across different proportions of the adoption scenarios, with greater adoption of advanced irrigation practices in the BRIA where surface runoff is a significant issue for the downstream receiving environments (e.g. Bowling Green Bay Ramsar site). It is recognised that the capital costs may reduce over time as adoption increases, although this has not been factored into the assessment.

The cost estimates are presented as ‘most likely’, ‘best case’ and ‘worst case’ scenarios, based on the ranges identified above and shown in Table 63. The overarching analysis is for a 10 year life of capital (these are not discounted). Given the timeframe of the study and widely ranging estimates of costs, we have assumed that there is no cost variation between the BRIA and Delta regions, as there is limited data to support any other conclusions. It is recognised that in reality, soil types and economies of scale are likely to have large impacts on costs between the BRIA and Delta, but this has not been reported explicitly for irrigation practices to date. An example of a main cost difference here may be the higher cost of sand filters in the BRIA, whereas the average Delta farm may be able to use disc filters.

Table 63. Cost estimates for irrigation methods ($/ha).

	Most likely		Best case		Worst case	
Method	Capital costs ($)	Annual maintenance costs ($/yr)	Capital costs ($)	Annual maintenance costs ($/yr)	Capital costs ($)	Annual maintenance costs ($/yr)
Level 3 well-designed and managed conventional furrow systems	0	0	0	0	0	0
Level 2 well-designed and managed automated furrow systems	$1,000	$50	$600	$30	$2,500	$125
Level 1 well-designed and managed drip and overhead low pressure systems	$5,000	$1,000	$3,500	$700	$12,000	$2,400

Shifting from D class irrigation management to more efficient techniques requires a higher level of skill and understanding. Extension costs have been accounted for in the maintenance of $50 to $150 per hectare for Level 2 irrigation, and then $1,000 per hectare for Level 1 irrigation.

Change in farm profit

The private costs capture the cost to landholders for purchasing irrigation capital equipment and then modifying their production system to implement it. The costs have been assessed from past multiple sources across the catchment work completed under a number of programs and consideration of the changes to labour, water (as per Lower Burdekin pricing structure) and electricity efficiencies have been accounted for. The change in farm profit is the income received from the change in management practice derived from the crop minus the direct costs of growing the crop. Cane growing enterprises differ significantly to other broadacre crops due to the ability to harvest the crop multiple times before replanting costs are again incurred. Therefore, the growing costs in the first year 'the plant cane' year are always higher than the growing costs of the 'ratoons' due to the additional machinery operations involved in preparation of the soil for cane planting (Table 64).

A standard farm size was implemented to account for the detailed information regarding their specific cane, land preparation, fertiliser, legume crops, fallow management and irrigation. The change in farm profit considered the grower's machinery, implements and irrigation soil type, scale, and production system. In reality growers have different starting points and changes in implementing the new management practice implemented the practice change forecast the impact of the changes on their production which they believe will occur. The analysis takes into account the changes in electricity, water and labour costs from irrigation system improvements as these factors may have a considerable impact on farm profitability. However, other factors that may be important but are not considered here are increased ratoonability, fewer weed control operations, less cultivation and potentially reduced nutrient use when splitting fertiliser applications.

To focus the analysis on the specific changes in question, a number of variables have been standardised so that the results are not influenced by changes in prices of inputs. The economic analysis has used an average net sugar price of $410 (2005-2016) (see Policy solution set 1). All labour was costed at $30 per hour for a farm hand. The change in farm profit was then calculated resulting in a before practice change gross margin and an after practice change gross margin, which were then entered into an investment analysis. It must however be acknowledged that the large variance in starting point of growers was not accounted for and therefore the scenarios represent one aspect of the number of ways to implement irrigation practices. To estimate the change in farm profit, cane yields were set at average yield (tonnes per hectare) and Commercial Cane Sugar (CCS) according to the historical data available, however it is acknowledged that these can be highly variable.

Table 64. Average yields of the Delta and BRIA regions of the Burdekin (2005-2014). Source: Collier and Holligan (2016)

Region	Crop	Yield (t/ha)	CCS	Historical Data Range
Burdekin (Delta)	Plant	142	14.51	2005-2014
	Ratoon*	115	14.53	
Burdekin (BRIA)	Plant	130	14.90	2005-2014

Extension costs

The extension costs were derived from the assessment in Policy solution set 1 which was based on the current DAF extension program. It is estimated that 1FTE costs approximately $150,000 per year, and this is divided by an average farm size of 140 hectares in the BRIA and 72 hectares in the Delta (area data provided by P. Larsen, Wilmar in January 2016 as part of the Burdekin WQIP). In Policy solution set 1, DAF data indicates that the 'most likely' case delivers extension that is 62% effective in influencing growers. For this policy solution set, it is assumed that the extension staff will be specialised in irrigation management and therefore would deliver greater efficiencies, more like 80%. This equates to a range of $16 per hectare to $21 per hectare for the BRIA and $31 per hectare to $40 per hectare for the Delta between the best and worst cases. These costs have been applied to the areas adopted from each cane district in the calculations.

It should be noted that this level of extension service may not be required if Policy solution set 1 was implemented at the same time, with significant cost efficiencies likely to be delivered thereby reducing the estimated extension costs. Targeting large farms in the BRIA would also provide cost savings by working with fewer growers. However, a higher level of technical capacity is required to adopt high efficiency irrigation systems, and with a large increase in adoption, growers may be unable to get the desired support. There would need to be a significant increase in the support services currently available with specialist advice for furrow automation, telemetry and drip irrigation systems.

Regulation costs

Regulation has not been considered in this solution set as it is considered to be highly unlikely in the context of current and historic water allocation policy.

Program costs

The estimated additional program costs associated with this policy solution set are shown in Table 65, and take into account project coordination and management, communication and engagement and compliance and auditing (i.e. incentive payments are treated separately). Site specific investigations and planning are included in the upfront costs. Program implementation would also need to include a monitoring and evaluation program and supporting research and development to fill key knowledge gaps, but these are not factored into these solution sets. While this will result in minor underestimates in costs for this solution set, the costs may not be significant (e.g. water use data is available from existing metering, or the bulk of the monitoring needs would be met by monitoring of practice change). The program costs range from approximately $4 per hectare for the best case scenario to $6 per hectare for the worse case.

Table 65. Estimated program costs to support delivery and implementation.

Items	Description	Cost estimate per annum	Cost per hectare		
			Most likely	Best case	Worst case
Project management and delivery and monitoring	Project Manager to supervise overall project management, coordination, external contracts and partnerships *Total of 1.5 FTE plus operating*	$225,000	$2.50	$2.00	$3.00
Communication and Engagement	Lead communication and engagement activities. • Develop a Communication and Engagement Strategy for the implementation of the program. 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. *0.5 FTE plus operating*	$100,000	$1.11	$0.89	$1.33
Compliance and Auditing	Auditing of stewardship payments – involves 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. *1 FTE*	$120,000	$1.33	$1.07	$1.60
Total		**$445,000**	**$4.94**	**$3.95**	**$5.93**

Management practice effectiveness
Due to the large variation (and therefore the assumptions applied) regarding irrigation efficiencies in each management class, the project team agreed to assume that a majority of the practice shifts will be from D class management which is basically conventional furrow irrigation (and currently reported as 92% adoption under the P2R program), to B class irrigation management which can be either Level 1, 2 or 3 methods. It is assumed that growers would shift from D to B class practices but it is acknowledged that this will not always be the case.

A number of management practice adoption scenarios have been modelled using Source Catchments and APSIM through the P2R program to support the Burdekin WQIP (C. Dougall, DNRM and G. Fraser, DSITI). Draft revised model runs from the APSIM model (G. Fraser, DSITI) which factor in more detailed climate and soil combinations were also provided to the project team and were considered in this assessment.

The modelling predicts that in the Lower Burdekin sugarcane area, the DIN reduction from shifting from D class to A class nutrient management under D class irrigation management is estimated to be 75% or approximately 88% reduction under A class irrigation management. If sugarcane shifted from D class irrigation management and D class nutrient management to A class irrigation management and A class nutrient management, the modelling predicts that this would result in a 98% reduction in downstream DIN load. This indicates that moving from D to A class nutrient management would deliver a 75% reduction in downstream DIN, but improving irrigation practice on top of that would deliver an additional 23% reduction in downstream DIN loads.

If it is assumed that nutrient management from D to B (Solution set 1) would take place before irrigation management, then irrigation gives an additional 23% reduction in downstream DIN. If irrigation improves from D to B class but nutrient management stays at D class, then a 62% reduction is predicted. If no nutrient management improvement occurred, then improving irrigation efficiency would lead to a considerable improvement because the load in the downstream drainage in dry weather is reduced, but if nutrient management was also improved to a high level, there would be minimal residual DIN in the downstream drainage.

It is therefore assumed that shifting from D class to B class irrigation management will result in a 62% reduction in DIN loads (assuming a large proportion of sugarcane in the Lower Burdekin is at D class practice for nutrient management). When this policy solution set is combined with Policy solution set 1, which shifts all sugarcane to B class practice (a 73% reduction) and irrigation efficiency is added, an extra 22% reduction is delivered to give a 95% total DIN reduction.

It is assumed that the water quality benefits of this policy solution set could be realised in a relatively short timeframe, estimated to be three years to establish efficiently operating irrigation systems.

Assumptions and limitations

There are many issues associated with costing this policy solution set as the selection of optimal irrigation techniques is site specific. Major assumptions have been made (with industry advice) on current adoption and site suitability. There are also significant differences between the current adoption of irrigation management practices reported through the P2R program and industry expert opinion (with the former being much poorer).

The main assumptions made in this assessment are outlined in Table 66.

Table 66. Key assumptions made in Policy solution set 2 for advanced irrigation systems

Factor	Key assumptions
Farm size	Average (mean) farm size is derived from data supplied by Wilmar for the Burdekin WQIP and is: BRIA 140 hectares; Delta 72 hectares.
Irrigation method and application efficiency	The methods have been classified into three main types and application efficiencies which does not recognise the large variability in application efficiencies based on site specific characteristics. Application efficiencies are derived from the P2R program APSIM modelling framework which is also represented in the Burdekin A, B, C, D Management Practice Framework (2013[7]). It is assumed that there are no limitations in the capacity of industry to adopt alternative irrigation methods in the next two to five years in terms of technical capacity and equipment supply.
Current management practice adoption	Based on P2R program reporting for 2013/2014 to be consistent with other solution sets and provides consistent approach if the assessment is repeated.
Differences between site characteristics in the BRIA and Delta	The site characteristics of the BRIA are considered to be more conducive to cheaper methods that deliver B class irrigation application efficiencies due to greater opportunity for more efficient furrow irrigation due to less permeable soils than in the Delta. The allocation of these methods has therefore been 'weighted' to the BRIA in the area calculations. There are large assumptions about the maximum potential areas where each irrigation method can be applied which could be rectified through more intensive expert consultation and site specific investigations.
Upfront costs	There is limited data on the costs of changing irrigation methods and differences will be heavily influenced by site specific conditions. A range of costs has been applied to each irrigation method, resulting in uniform application of upfront costs over large areas which are unlikely to be realistic. However, it is the based on the best information available at the time and does try to take into account the variation between the BRIA and Delta to some extent. Estimates are based on indicative estimates provided by industry experts and preliminary results from DAF and SRA field trials.
Maintenance costs	Maintenance costs take into account machinery maintenance and technical training for growers. Estimates are based on indicative estimates provided by industry experts and preliminary results from DAF and SRA field trials.
Farm profit	The change in farm profit is the income received from the change in advance irrigation techniques derived from the crop minus the direct costs of growing the crop. These costs encompass changes such as pumping costs (electricity) and labour efficiencies. Overheads or fixed costs were considered. Further work is required to refine the yield estimates associated with these practice changes in the APSIM modelling as this has implications for costs which are not fully quantified at this stage.
Extension costs	Derived from extension cost and efficiency data provided by DAF and calculated on a per hectare basis using average farm size in the BRIA and Delta. It is assumed that there are no limitations to expanding the current extension capacity. In sugarcane, the DAF extension report showed that on average 62% of landholders had shifted a level of management as a result of extension services with a confidence bound of 10 (Department of Agriculture and Fisheries 2015). Therefore, for estimation of the extension costs, an adoption a most likely estimate of 74% of landholders and best case being 52% worst case being 62%. These efficiencies were used to provide an indication of the potential outcomes that may be expected from future expenditure on extension and the range of costs, based on the past DAF extension investment.
Regulation costs	Regulation is not included in this solution set as it is not considered to be likely in the context of current water use policy.
Effectiveness of irrigation methods	An efficacy of 74% reduction in DIN loads is assumed in moving from D class irrigation management practice to B class irrigation management practices. D to C class shifts or C to B class shifts were not assessed separately due to the uncertainty in the knowledge of the application efficiencies of the selected methods in these intermediary steps. It is assumed these benefits could be realised in a relatively short timeframe, estimated to be three years.

[7] https://drive.google.com/file/d/0B2eYGb5_l-adX2FVNTNBUE9uSUE/view?pref=2&pli=1

Results

The assumed efficacies used to undertake the meta-modelling came from results provided by DoSITI and DNRM modellers from a series of runs undertaken to evaluate various irrigation practices on reducing residual DIN in drainage. These gave us the efficacies for moving each class of nutrient management practice to improved irrigation (i.e. D class nutrient management was assumed to stay the same, with only irrigation improvements leading to nutrient reduction) (Table 67).

The performance of improved irrigation practice could provide a reasonable reduction in DIN loads, up to a maximum of a 30% reduction in overall load coming from the catchment, which is greater than the predicted reductions from changing all cane to at least B class practice in the region. When developing the models for this policy solution set though, we did note that the performance attributed to just irrigation practice improvement seemed to be quite high. The efficacies that we calculated were based on finer scale paddock models (APSIM and HowLeaky) results and discussions with the modellers indicated that they think this level of reduction may be possible.

Table 67. Assumed efficacy – irrigation improvement change

Area of application		Applies to			Efficacy	
Region	Catchment	Landuse	Nutrient Management Practice class	Pollutant source	Assumed Efficacy	
Burdekin Dry Tropics	BRIA Only	Cane	D	Seepage and hillslope no distinction	74	%
Burdekin Dry Tropics	BRIA Only	Cane	C	Seepage and hillslope no distinction	75	%
Burdekin Dry Tropics	BRIA Only	Cane	B	Seepage and hillslope no distinction	79	%

The results from applying these efficacies are shown in Table 68 and Figure 64.

Table 68. Results for DIN load reductions Burdekin improved irrigation practice

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	2,770	0	0%
10% uptake	2,770	0	0%
20% uptake	2,600	165	6%
50% uptake	2,350	412	15%
70% uptake	2,190	576	21%
100% uptake	1,940	823	30%

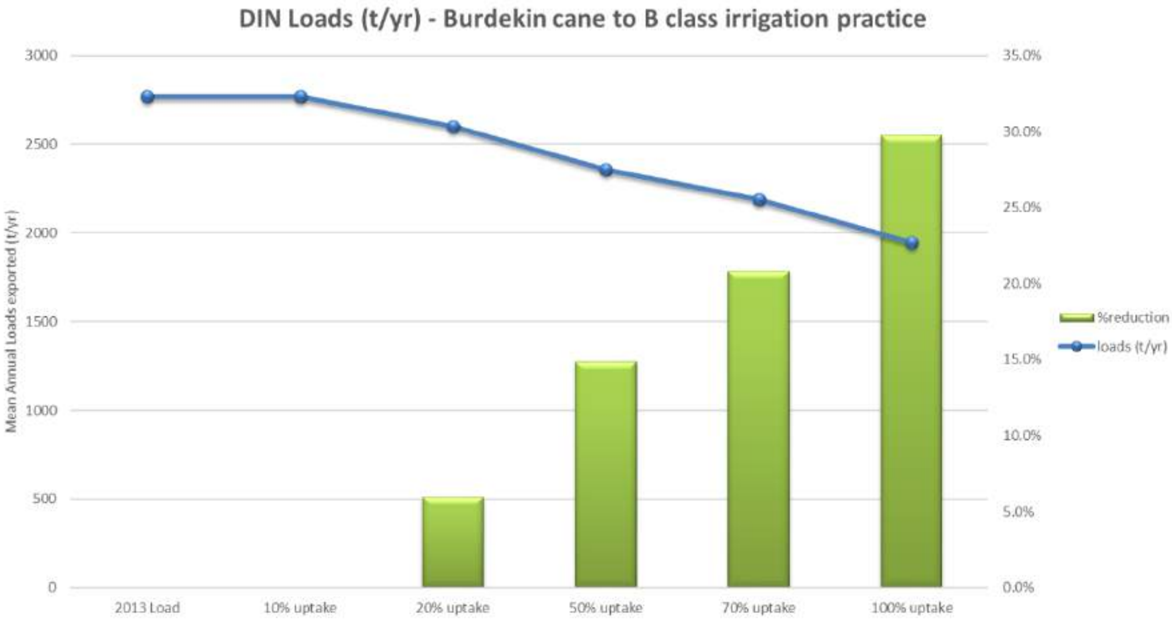

Figure 64. *Results for solution set 2 – Burdekin improved irrigation practice*

Policy solution set implementation

There are implementation issues with broadscale adoption of advanced irrigation techniques in terms of capacity to design, install and operate these more sophisticated systems, let alone the comparatively high costs. While we are running high adoption solution sets to demonstrate the level of change likely to be required to meet the targets, feedback from industry in the development of the Burdekin WQIP indicated that the most suitable options will be site specific, and will range from optimised/automated furrow irrigation, low pressure overhead irrigation, drip irrigation and in some cases, methods combined with recycle pits. The latter are considered in Policy solution set 5.

It is recognised that when drip irrigation is adopted, fertigation then becomes an option for nutrient application. Fertigation is a highly efficient fertiliser application technique and is likely to deliver added benefits. This is not costed in this solution set as there is limited data on the economics of these practices in sugarcane in the Lower Burdekin.

The large upfront costs associated with adopting higher efficiency irrigating practices are likely to provide challenges for large scale adoption of these techniques until further information is available to demonstrate benefits to farm profit. The uncertainty associated with selecting the most suitable irrigation methods for achieving B class irrigation methods could be overcome with more site specific assessments, although these could become costly. However, if developed in conjunction with other management improvements such as nutrient management identified in Policy solution set 1, the efficiencies and benefits are likely to be substantial. Before any substantial investment was considered towards this solution set, further investigation of the relative proportion of dry season and therefore irrigation tailwater losses of DIN, compared to wet season runoff would be required to confirm the potential benefits for the GBR receiving environment in addition to freshwater and coastal ecosystems.

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Much of the work in this policy solution set built on the cost assessments undertaken for the recent update of the Burdekin WQIP (February 2016). The previous contributions of individuals involved in those assessments are also recognised here.

B.3 Policy solution statement 3: System repair – gully remediation

Policy solution set description and context

This policy solution statement aims to assess the costs and efficacy of treating gully erosion for 10%, 25%, 50% and 100% of the gully lengths in the catchments of the Burdekin and Fitzroy Rivers. These catchments were selected as they represent catchments across the GBR where substantial reductions in gully erosion could be realised with appropriate management. The approach adopted for the assessment involved:

1. Determining the extent of gullying comprising assessments to identify the:
    a. Length of gullying within the Burdekin and Fitzroy catchments, and hence the amount of work required to treat 10%, 25%, 50% and 100% of gullies.
    b. Priority sub-catchments within which treatments should be applied.
2. Identifying and costing the alternate approaches to control gullying and/or the impacts of gullying. This included investigations into the efficacy of these treatments in reducing sediment supply.

Gully types and sediment supply

There are two distinct types of gullying in the Burdekin and Fitzroy catchments requiring consideration. These are terrace gullies and hillslope gullies. Current available information including the modelling available for this project does not differentiate between the two types. The two gully types have different impacts on sediment supply and hence this can impact on priorities for management.

Geographic extent

The Burdekin River catchment lies within the NQ Dry Tropics natural resource management region. The Fitzroy River catchment lies within the Fitzroy Basin Association natural resource management region. Hillslope gully erosion is prevalent through much of these two very large catchment areas. Terrace gully erosion is found along the major waterways in these catchments where weathered Tertiary age alluvial deposits are present.

Terrace gullies

Terrace gullies, also referred to as alluvial gullies in recent literature (Brooks, et al, 2009), consist of active incision and subsequent widening into older (Tertiary) weathered alluvial deposits that form a terrace (high level and infrequently engaged floodplain) adjacent to larger waterways.

The erosion process in these gullies leads to a broad scale deflation (hence they are sometimes also termed terrace deflation amphitheatres) of the landscape (refer Figure 65). These features are not solely driven by local catchment runoff or direct rainfall. These gullies can undergo substantial development, driven by larger flood events in the adjacent larger waterway (as shown in Figure 65).

The old subsoils exposed in terrace gullies are often hostile to the establishment of vegetation (these soils can be sodic/saline and lack critical elements and nutrients used in vegetation growth), hence many of these gullies have remained devoid of groundcover over decades of observation by the author (Figure 66).

Figure 65. *Terrace or alluvial gully adjacent Burdekin River (image courtesy R. Lucas) and left in moderate flood (image courtesy B. Sheppard)*

Figure 66. *Margin of a terrace gully adjacent Burdekin River. Photo courtesy of B. Shephard*

Terrace gullies can provide an immediate and direct source of sediment to stream systems. However, these are unlikely to fundamentally change the hydrology of a catchment.

Hillslope gullies

Hillslope gullies are formed through the process of incision of a channel (where a channel generally did not previously exist) into valley fills. These valley fills can be a mixture of alluvial and colluvial deposits and can be typically found in lower order (smaller) waterways as shown in Figure 67. These gullies undergo the more typical incision process, whereby;

1. an erosion head or knick point migrates upstream in the valley fill
2. the channel then undergoes a process of evolution comprising:
    a. deepening
    b. widening
    c. eventual recovery (if there is sufficient upstream sediment supply) through development of a compound cross-section (benches) and meander migration.

This form of gullying is generally linear, however as they occur in valleys with varying width, the width of the gully can also vary considerably. While the process is linear, the incision in one waterway can lead to the establishment of a knick point at the confluence of tributaries and the subsequent incision of these tributaries.

The incision into valley fills is a natural process. However, the rate and occurrence of incision with the GBR is well in excess of any natural rate of gullying. The initiation of hillslope gullies in the GBR can be linked to anthropogenic influences that cause concentration of flow such as linear infrastructure, cattle tracks or furrow lines.

The management of incision into valley fills is highly important for a number of whole of system outcomes. Valley fills are both long-term sediment stores and catchment 'sponges' reducing peak flows and attenuating runoff.

Sediment stores

Valley fills serve as large scale sediment sinks within a catchment. Incision at the lower end of a 2nd order watercourse can lead to extensive sediment release through that watercourse and all valley fill tributaries located upstream from that watercourse.

Hydrologic sponge

Valley fills also serve to store rainfall in the form of soil moisture. The process of infiltration and slow release of this shallow groundwater results in reduced downstream peak flows and prolonged base flows. Incision of valley fills reduces the extent of infiltration, increases the rate of release of water to stream systems and increases downstream flood peaks.

Small 1st and 2nd order watercourses and hence valley fills, can make up over 70% of the length of a stream network. The loss of valley fills through a catchment (via gullying) can lead to a fundamental change in the hydrology of a catchment, increasing sediment transport capacity and increasing downstream flood peaks. This increase in peak runoff can increase the adverse impacts associated with sediment release and impacts on the GBR. However, the process can also result in increased streambank erosion and hence additional adverse impacts on the Reef and adjoining asset managers (e.g. landholders). The process can also result in a reduced permanence of stream flow and loss of aquatic habitat availability in ephemeral waterways.


Figure 67. *Hillslope gully (incision of valley fill) in Burdekin River catchment in a confined setting (left) and unconfined setting (right)*

Key pieces of previous work

Research organisations and government agencies have undertaken significant research and modelling directly related to gully erosion across the selected catchments for well over a decade. Much of this work is published in *Managing gully erosion as an efficient approach to improving water quality in the Great Barrier Reef lagoon* (Wilkinson S.N., Bartley R., Hairsine P.B., Bui E.N., Gregory L., Henderson, A.E., 2015).

The gully mapping data available for this cost estimation process is based on the National Land and Water Resources Audit information generated in the late 1990s, with additional, more recent intensely mapped information in areas of high gully density.

The Queensland Government's Reef Source Catchment Model outputs form the baseline for sediment generation and export estimates. The gully erosion rates from the Source Modelling, utilises the National Land and Water Resources Audit data sets together with the additional more recent intensive data sets.

This investigation has used the same data sets as those used for the Source modelling 2013 baseline assessment of sediment generation (gully mapping and gully density) and export. In addition, this investigation has also relied on additional information gathered from the literature and from the Burdekin Water Quality Improvement Plan (Dight, 2009) and Fitzroy Catchment Water Quality Improvement Plan (Fitzroy Basin Association, 2015).

Method

For the purpose of this project, the costs of gully control have been established based on rates per kilometre of gully length. To reflect this approach and to enable the costs of gully control to be estimated, this investigation has sought to identify the length of gully within each of the subject catchments. In addition, the investigation has sought to identify priority sub-catchments to which the treatment actions are to be applied, i.e. if 10% of gullies were to be treated, which gullies should be treated to provide the best return on investment in terms of reduced fine sediment load to the GBR? Similarly, if 25% of gully length was to be treated, which gullies would be treated?

The broad steps for this assessment have included:

1. Identify the length of gullying and priority catchments for gully treatment.
    - The length of gullying has been estimated based on a GIS analysis of available gully mapping.
    - The priority sub-catchments have been identified based on the modelled outputs of fine sediment generated from gullies and other information provided in the WQIPs.
2. Identify and cost the activities and works required to halt or manage the impact of gullying.
    - Develop high and low cost treatments for both hillslope and terrace gullies and estimate the efficacy of these treatments.
    - Estimate portion of hillslope and terrace gullies in each region.
    - Determine overall cost and efficacy of treating 10%, 25%, 50% and 100% of the gully lengths in the catchments of the Burdekin and Fitzroy Rivers.

More details of the method adopted for this assessment are provided below.

The extent of gullying

Length of gully analysis

The gully erosion rate is simulated in the Source modelling by estimates of Annual Average Sediment Supply (AASS). The source modelling AASS was developed by dividing the volume of sediment lost from the gully network by the number of years since the gullying was assumed to have commenced whereby:

1. The volume of the gully has been estimated by multiplying gully density (metre length of gully divided by catchment area, i.e. m/m^2) by the typical cross-section area of the gully:
    - Gully density: The length of gully per catchment area is estimated by density mapping based on the National Land and Water Resources Audit data set. The rate of erosion is considered static and as a result the modelling doesn't account for the stage of incision or decaying and accelerating gully erosion at locations across catchments.

- Gully cross-section area: a cross-section area of 10 m^2 is used for both the Burdekin and Fitzroy models.

2. The number of years since gully initiation has been based on the assumption that gullying commenced at some time following European settlement of the area.

Note: The AASS average annual gully rate annual supply is runoff weighted at the yearly scale hence wet years generate more sediment than dry years, with the average annual sediment supply preserved.

Within the Reef Source Catchments Model, the gully erosion rate for the Business as Usual scenario, is adjusted based on the land management class. Erosion rates are adjusted by the factors 0.75, 0.90, 1.0 and 1.25 for land condition class A, B, C and D respectively.

Burdekin Catchment: Data provided for the Burdekin catchment from DNRM modellers, within the NQ Dry Tropics NRM region, provides linear (30 X 30m square pixels) gully mapping within 1,718 variable size sub-catchments from 46,458 ha down to 2 ha. The total catchment area is 133,000 km^2 (13.3M ha), with a total mapped gully length of 127,214 km. This equates to approximately 1 km of gully for every 1 km^2 of catchment area.

Using GIS analysis, the sub-catchments were overlain on the gully mapping data to calculate total length of gully within each sub-catchment and the ratio of gully length to area expressed as metres per hectare (m/ha). The length of gullies was calculated based on the number of pixels multiplied by 30 m (i.e. the size of each pixel). While it is recognised that this is not a highly accurate method of calculating the length of the mapped gullies, it is considered fit for purpose given the overall accuracy of the gully mapping.

Using the data and method described above, the density and length of gullies were calculated and mapped (refer Table 69 and Figure 68). For the purposes of illustration, the density is mapped in groups of 5 m/ha in a range from 0 to 33.7 m/ha. The analysis revealed the highest density of gullies in the Burdekin catchment to be in the upper Burdekin River catchment. The top 20 sub-catchments (as mapped) are shown in Table 69 and in Figure 69. There were three small, minor sub-catchments ranging from 19 to 40 ha and with gully densities of 41.3 to 51.3 m/ha that were considered too small to be a useful representation for the purposes of this assessment. These are not included in the list of top 20 gully density sub-catchments. A full set of sub-catchment based gully densities and gully lengths has been complied into a MS excel spreadsheet. Gully mapping for SC#648 in the Star River catchment is provided as Figure 70. This figure illustrates the scale of gullying through the sub-catchment and the scale of the gulling issue to be addressed in the catchments of the GBR.

Table 69: Burdekin NRM Region – sub-catchments with highest mapped density of gullies per hectare

Sub-catchment	Within the larger sub-catchment of	Catchment area (Ha)	Total length of gully (m)	Density m/Ha
SC #648	Star River	12,138	409,290	33.7
SC #653	Upper Burdekin River	5,201	176,280	33.9
SC #414	Douglas Creek	9,874	304,800	30.9
SC #642	Star River	6,278	196,500	31.3
SC #632	Star River	176	5,370	30.5
SC #320	Keelbottom Creek	10,405	325,680	31.3
SC #281	Fanning River	15,314	473,100	30.9
SC #274	Fanning River	5,836	182,670	31.3
SC #700	Kirk River	11,464	351,210	30.6
SC #395	Upper Burdekin River	227	6,750	29.7
SC #650	Star River	5,666	167,670	29.6
SC #271	Upper Burdekin River	6,201	184,470	29.7
SC #413	Douglas Creek	5,167	151,500	29.3
SC #344	Basalt River	8,565	247,230	28.9
SC #321	Keelbottom Creek	1,535	44,010	28.7
SC #693	Upper Burdekin River	6,129	180,090	29.4
SC #701	Kirk River	16,542	474,540	28.7
SC #702	Kirk River	6,665	194,640	29.2
SC #704	Upper Burdekin River	10,187	290,580	28.5
Total for selection shown		143,570	4,366,380	
Totals for catchment/region	Burdekin	13,299,314	127,213,950	

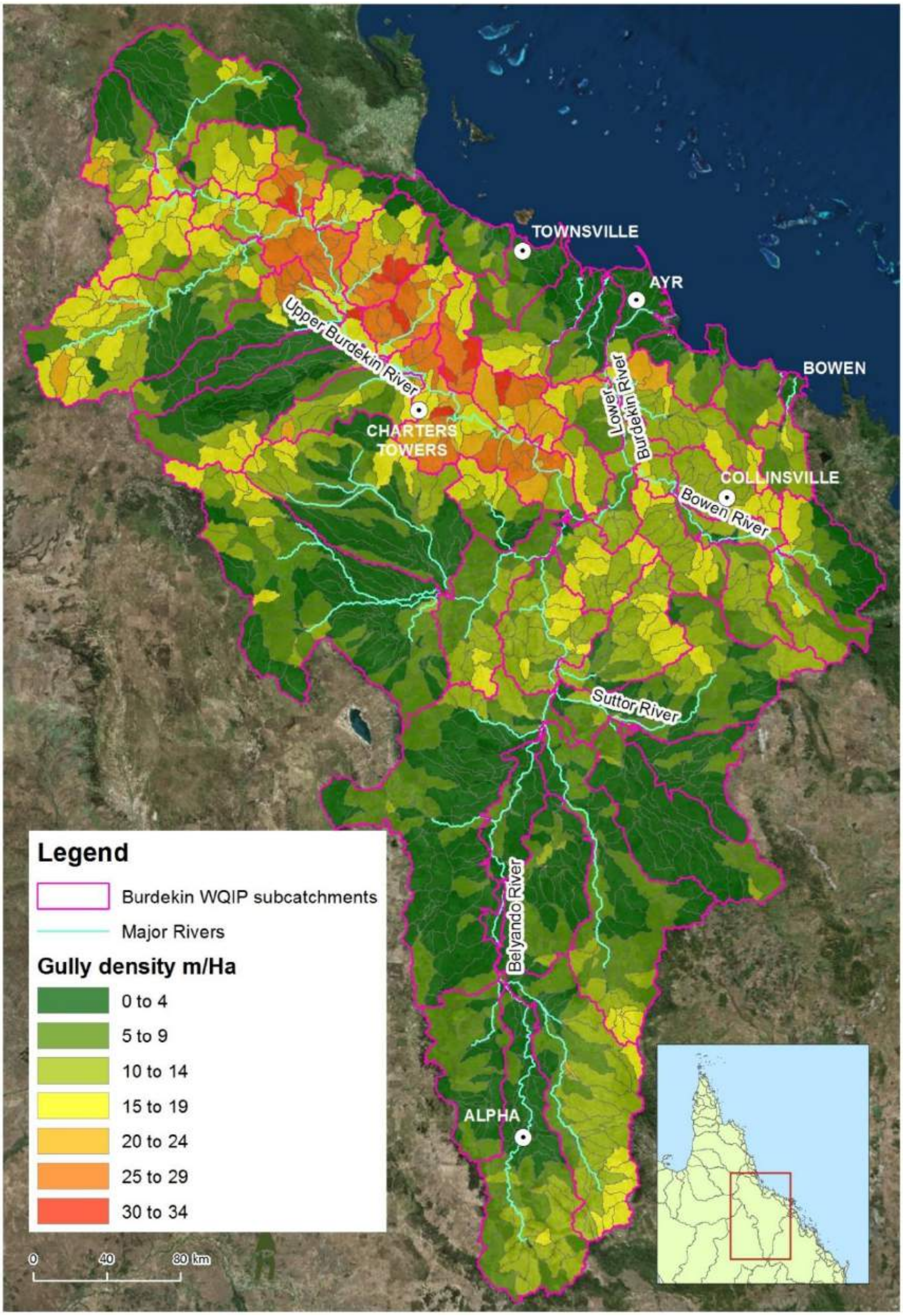

Figure 68. *Gully density by sub-catchment within the NQ Dry Tropic NRM region*

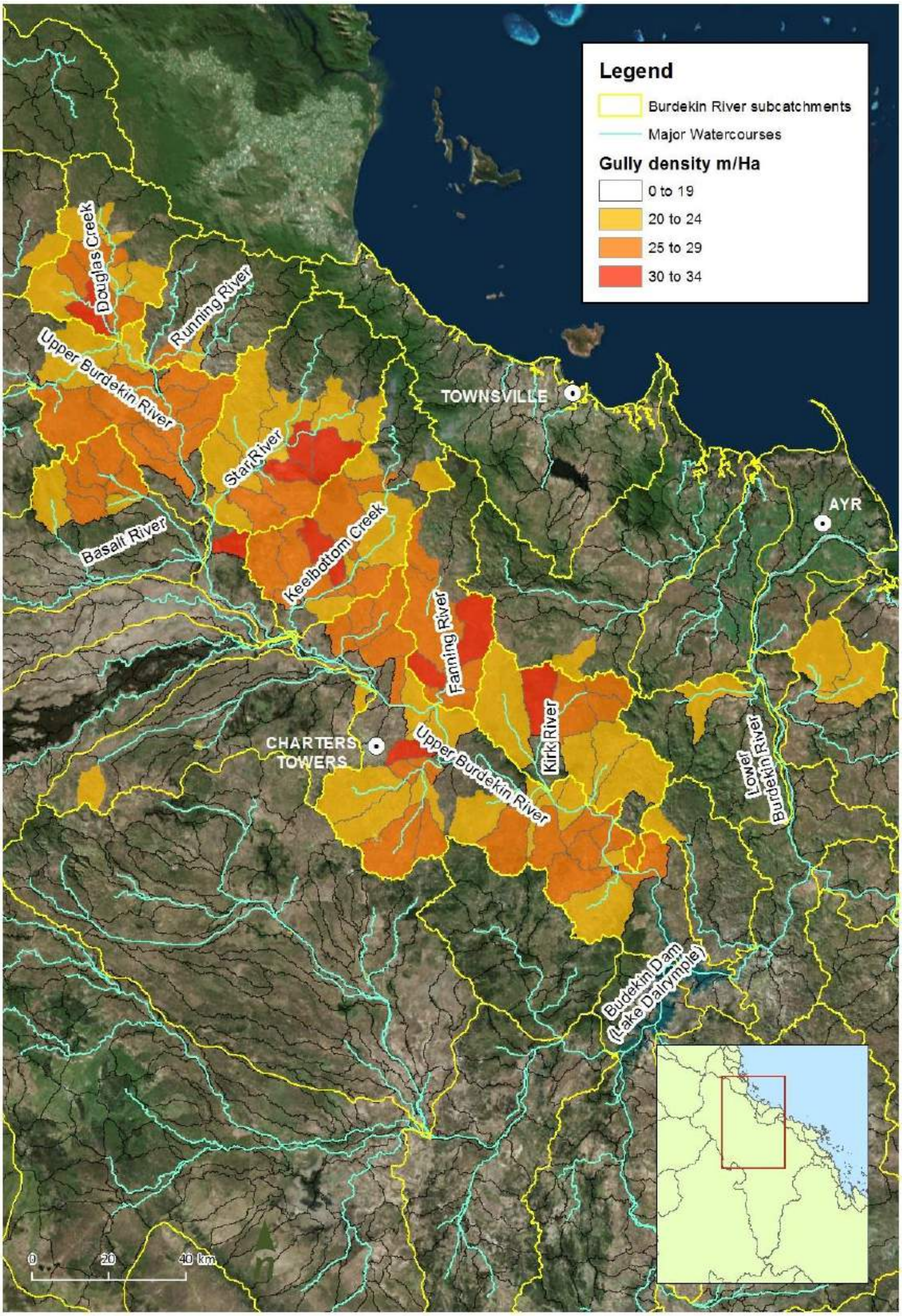

Figure 69. *Sub-catchments with the highest mapped gully density in the NQ Dry Tropic NRM region - all in the upper Burdekin River*

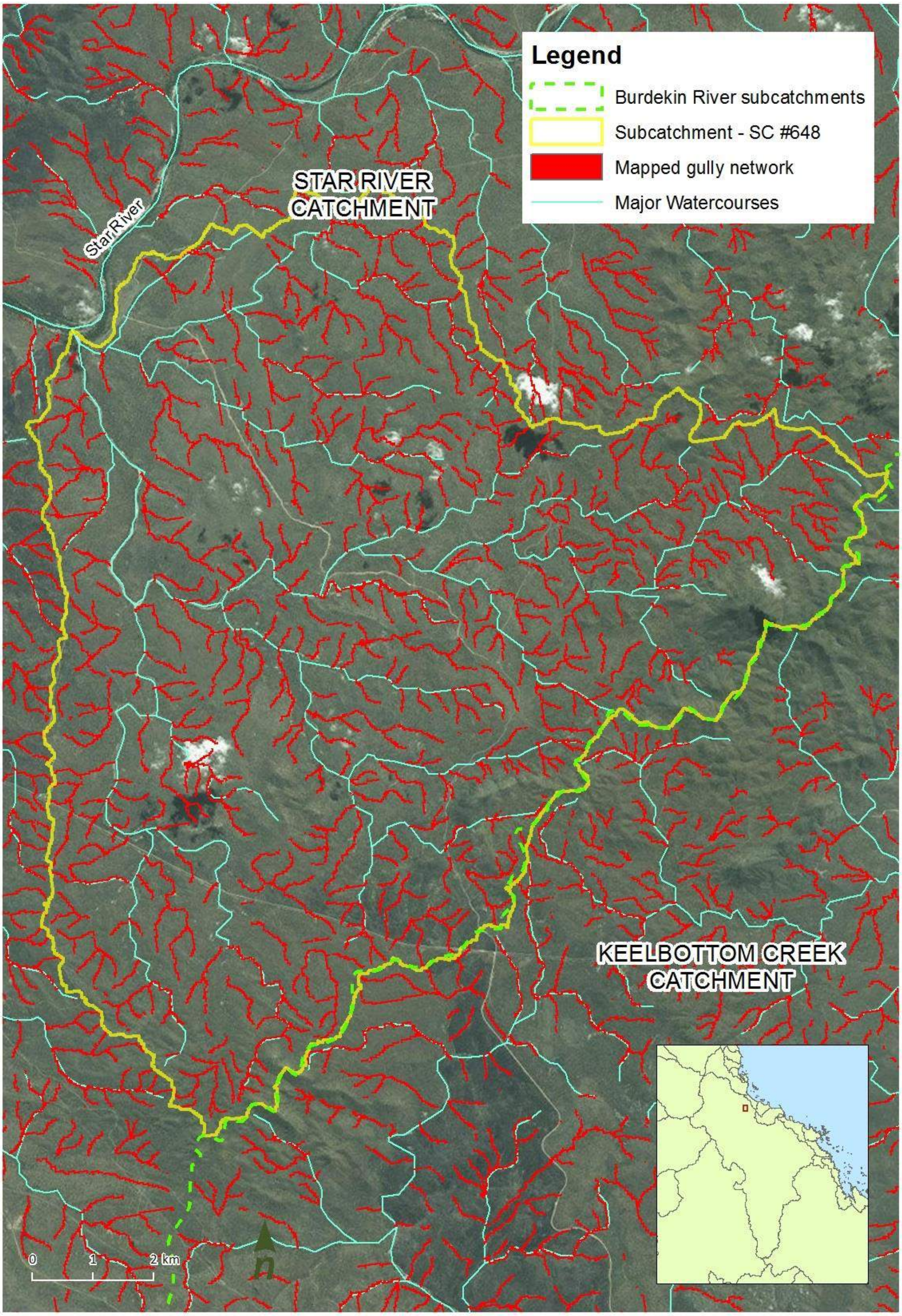

Figure 70. *Gully density within sub-catchment SC#648*

Fitzroy catchment: Data provided for the Fitzroy Basin Association NRM region included gully mapping within 1,917 variable size sub-catchments from 46,458 ha down to 2 ha. The gully mapping density data was provided as pixels with a ratio of kilometres of gully per square kilometre area, which was then processed to express gully density as total metres and m/ha for each of the 1,917 sub-catchments. The total catchment area is 147,000 km^2 (14.7M ha), with a total mapped gully length of 148,961 km. The Fitzroy was found to have a similar mapped ratio of gully length to area as the Burdekin of approximately 1 km of gully for every 1 km^2 of catchment area.

The density and length of mapped gullies for the Fitzroy catchment have been estimated using the method described earlier. The density of mapped gullies is shown in Figure 71. For the purposes of illustration, the density is mapped in groups of 5 m/ha in a range from 0 to 29.6 m/ha. The top 20 sub-catchments, with highest gully densities, are listed in Table 70. There were three small, minor sub-catchments ranging from 4 to 59 ha and with gully densities of 25.4 to 29.6 m/ha that were considered too small to be a useful representation for the purposes of this assessment and are not included in the list of top 20 sub-catchments.

Figure 72 illustrates typical gully erosion in the north of the Fitzroy with modelled high density gullying. This high gully density is verified by the authors on-ground knowledge of those sub-catchments.

Table 70. Fitzroy Basin Association NRM Region – sub-catchments with highest density of gullies per hectare

Sub-catchment	Within the larger sub-catchment of	Catchment area (ha)	Total length of gully (m)	Density m/Ha
SC #403	Dawson River	1,921	53,202	27.7
SC #1464	Nogoa River	33,377	917,567	27.5
SC #827	Isaac River	14,061	382,611	27.2
SC #1580	Theresa Creek	6,711	181,007	27.0
SC #1467	Nogoa River	6,416	171,507	26.7
SC #1465	Nogoa River	18,568	494,255	26.6
SC #1466	Nogoa River	15,478	411,941	26.6
SC# 1701	MacKenzie River	5,867	149,917	25.6
SC #242	Dawson River	333	8,422	25.3
SC #234	Dawson River	1,663	41,990	25.3
SC #399	Dawson River	17,503	437,154	25.0
SC #813	Isaac River	5,286	131,466	24.9
SC #1524	Theresa Creek	7,730	192,187	24.9
SC #250	Dawson River	2,450	60,648	24.8
SC #1463	Dawson River	6,522	160,196	24.6
SC #1131	Nogoa River	13,499	329,387	24.4
SC #1600	Comet River	11,409	277,971	24.4
SC #1133	Comet River	12,602	304,013	24.1
SC #616	Dawson River	868	20,893	24.1
SC #496	Dawson River	2,151	50,821	23.6
Total for selection shown		182,264	4,726,334	
Totals for catchment/region		14,377,129	148,961,236	

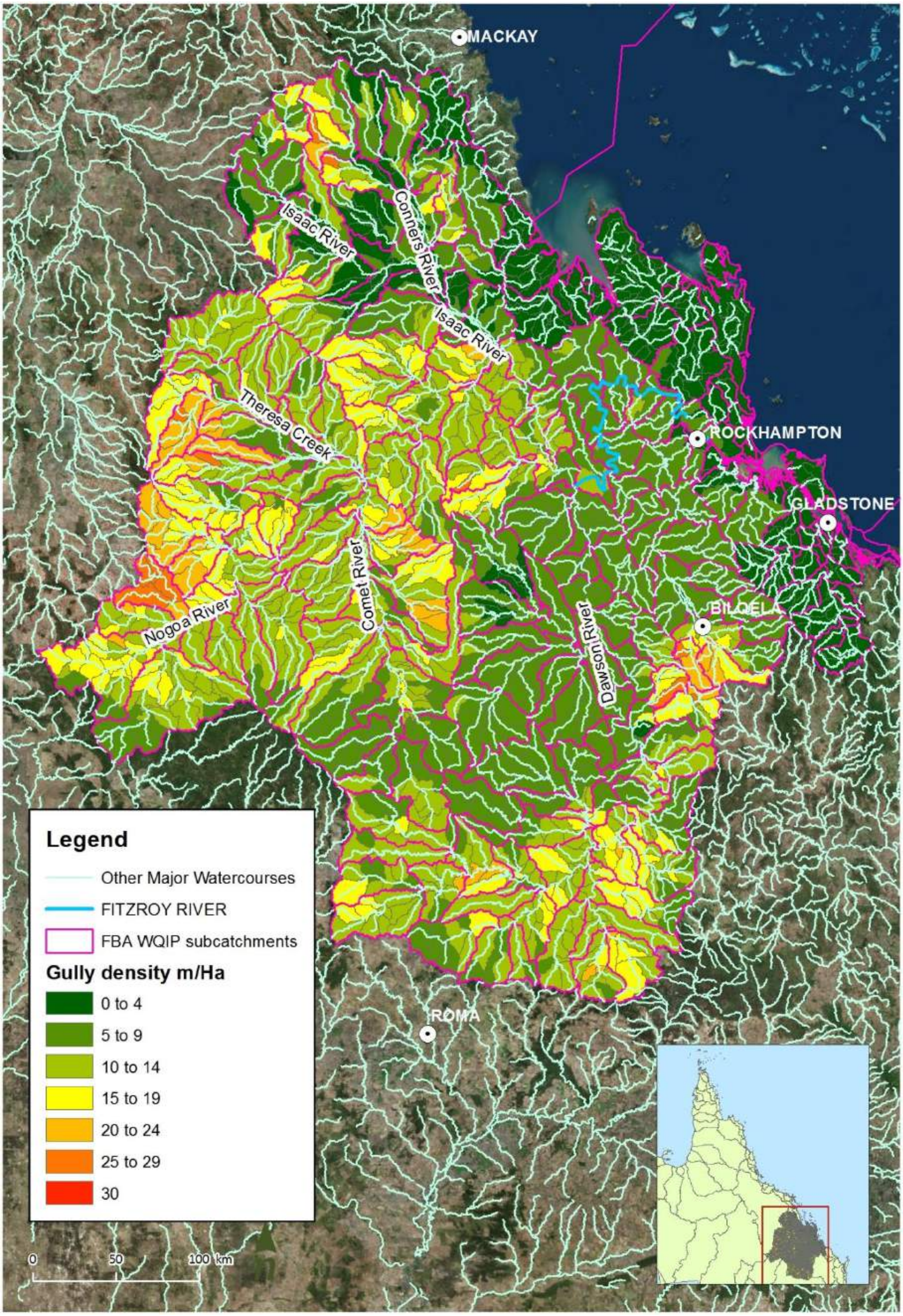

Figure 71. *Gully density across the Fitzroy region*

Figure 72. *Typical terrace gully in Walker Creek catchment*

Priority sub-catchments for gully treatment

Burdekin Catchment

The sub-catchments of the Burdekin catchment were identified for attention. The prioritisation of the Burdekin catchment has been based on the information used in the Burdekin Water Quality Improvement Plan (Dight, 2009), being updated (NQ Dry Tropics, 2016) at the time of preparing this report. Reef Source Catchment Model outputs have been used to identify the top 10%, 25%, 50% and 100% of gully length for treatment. The 1,587 Source modelling sub-catchments are lumped up into 52 major sub-catchments.

Table 71 shows that the top 10% of gully length, based on TSS rankings in the WQIP, is contained within eight of the major sub-catchments.

Table 71. Top ~10% of Burdekin gullies ranked based on the TSS loads in WQIP

WQIP Sub-catchment	No. of Source sub-catchments	GrazRate_Ranking (WQIP)	Total Gully Length (km)
Bowen River	20	1	1,299
Broken River	25	2	1,515
Bogie River	29	3	3,322
Pelican Creek	19	4	1,859
Little Bowen River	15	5	1,717
Burdekin Delta	14	6	303
Burdekin River (below Dam)	22	7	1,620
Glenmore Creek	38	8	2,147
Totals	182		13,783

Fitzroy catchment

The sub-catchments of the Fitzroy catchment were identified for attention. The sub-catchments of the Fitzroy have been 'prioritised' based on the information provided from the Source modelling outputs. Source modelling outputs have been used to identify the top 10%, 25%, 50% and 100% of gully length for treatment.

The 1,891 Reef source catchment model sub-catchments can be lumped into the six major catchments and 195 sub-catchments utilised in the Fitzroy WQIP. The top 10% of gully length identified for management attention are set out in Table 72.

Table 72. Top ~10% of Fitzroy gullies ranked based on the exported weight of fine sediment in Source model

WQIP major catchment	No. of Source sub-catchments	WQIP sub-catchments	Total Gully Length (km)
Lower Dawson River	44	D1, D26, D32	3,135
Upper Dawson River	15	D56	1,584
Fitzroy River	32	F11, F23, F28	1,649
Mackenzie River	83	T26, T27, T30, T32, T39, T40	8,943
Total			15,311

Assumptions and limitations related to identifying gully lengths

Gully mapping

An assessment of the accuracy of the gully mapping has been made across the Burdekin and Fitzroy catchment where gully lines were provided. The examination included a review of aerial photography against the gully mapping.

It was found that there was a disconnect between the mapped gullies in the GIS layers provided and current aerial photography. Our review has confirmed the mapping data associated with the National Land and Water Audit is too coarse for the investigations required for this project and more detailed assessments (like those currently being undertaken by DNRM and DSITI) are required. As a result of the data limitations, the gully lengths set out in this report are a first estimate and should not be used for purposes beyond this.

Priority sub-catchments

It was found that the priority sub-catchments set out in the WQIPs do not correlate with those with the highest mapped gully density. This is not unexpected. While the highest priority sub-catchments within the WQIPs are identified as those that deliver the greatest fine sediment loads to the GBR, some catchments may not be a priority. As an example, the Bogie River catchment is dominated by Granitic bedrock and is observed to be exporting large volumes of sand size sediment. The Bogie catchment and similar catchments in granitic landscapes, with high rankings as exporters of fine sediment, may warrant further investigation.

Cost and efficacy of management practices

A typical gully of the GBR

There are a range of different management practices (treatment actions) that could be applied to the range of gully types in the GBR. The most appropriate management practices for any particular gully will be a function of the valley setting, gully type, and the phase of incision (trajectory) of the subject gully. A review of the mapping data available for this investigation reveals no discrimination on the gully type present, and an absence of information suitable to establish the trajectory of gully evolution and development. As a consequence, it has not been possible to develop and apply gully management options to the range of gully types and evolution in the GBR catchments. For the purpose of this investigation a 'typical' GBR gully has been envisaged and treatment options developed for that 'typical' gully. Each kilometre of that typical gully is assumed to:

- Be actively deepening with a number of 'knick' points
- Be actively widening
- Have a more significant headcut at the upstream extent
- Be transporting coarse and fine sediment from upstream erosion processes.

Management options

1. The gully tool box (Wilkinson et. al., 2015b) provides a good starting point for the identification of management options to address gullying.
2. Effective gully management requires vegetation management. However, the quality and suitability of vegetation for erosion control is impacted by stock access and grazing. As a consequence all options for management will require some level of stock management. Stock management will require fencing and exclusion of stock for periods of time. The vegetation requirements and hence the vegetation establishment requirements for each gully will be a function of factors including the soils and subsoils present, the availability of seed sources and the extent to which additional structural works will be required to assist vegetation establishment.

The effectiveness of treatments will also be enhanced by management of areas that are not only subject to current gullying, but are yet to be gullied. Effective management will require protection and management of the vegetation to protect intact valley fills upstream of existing gullies.

A range of gully management practices are available and documented in the Gully toolbox (Wilkinson S., Hawdon A., Hairsine P., Austin J., 2015) and elsewhere including:

- **Passive management** – Revegetate gully feature, reduce concentrated surface runoff and stock management.
- **Stick traps** – 0.5 m high constructed from bundling local fallen timber with wire mesh which lies within the eroded gully feature.
- **Rock chute grade control** – Rock chute grade control structures on erosion heads/knick points in valley fills and within incising gully lines.
- **Check dams grade control** – Low cost log or geotextile check damn style grade control program.
- **Gully Plug dams-** A dam with a syphon (not a storage) at the end of terrace gullies.
- **Earthworks program** – Reshape to 1V:4H, topsoil, rip and seed and manage overland flow entry.

Other techniques include cross ripping of the land surface to increase infiltration and reduce runoff and the use of short intensive stocking of sites to trample down banks.

In reality, a combination of a number of known and potentially new practices would be employed to treat any given gully based on environmental, social and economic factors. Each individual practice would be applied in particular locations within the gullies where they will be most effective. For example, stick traps and check dams are only likely to be of use for gullies with very small contributing catchment areas (<2 ha) and only in systems where the gullies have reached the bottom of their condition trajectory and started to recover. They are likely to be complimentary to the more effective works such as rock chutes on erosion heads or earthworks. Gully plug dams would only be contemplated in terrace gully systems or larger hillslope gully systems.

Implementation issues and efficacy considerations for the practices

The type of intervention selected needs to take into consideration the geomorphic processes, objectives and site constraints. Some higher level broad implementation issues are discussed in Table 73. In addition to these broad issues in any catchment there are likely to be local constraints relating to soils, riparian vegetation condition, farm management constraints, pests, weeds and maintenance access.

Table 73. Implementation issues and efficacy considerations with different types of interventions

Type of intervention	Implementation issues	Efficacy considerations
1. Passive management	Often the best grazing areas (upstream of a gully head in more fertile alluvial soils) will require long narrow areas to be fenced.	Efficacy will be close to 0 in systems that are beyond the threshold that groundcover can mitigate. Simply fencing terrace gullies has been shown by observation across a number of catchments to be

			ineffective in the first 5 years. The period until fencing would abate any fine sediment is unknown.
3.	Stick traps	Risk of undermining and outflanking causing periodic acceleration of sediment export.	Only applicable where contributing catchment areas are small (<2ha) and where condition trajectory has reached the bottom.
4.	Rock chute grade control	The distance from the gully to a source of competent rock will substantially impact cost, this may affect prioritisation. Potential for upskilling contractors/farmers to manufacture the rock in the paddock. Requires experience to be developed in the region from practitioners (design and construction elements) who have successfully delivered these in many regions with dispersive soils.	The most highly effective tool for preventing future increases in sediment inputs through gully heads incising through valley fills.
5.	Check dams grade control	Issues very similar to stick traps.	See Stick Traps.
6.	Gully Plug dams	Risk of pipe/tunnel failure if built with the dispersive local material.	These are a sediment management measure, not an erosion control.
7.	Major earthworks program	Need for skilled operators and earth moving equipment of appropriate scale.	An integral component in accelerating the efficacy of many management options by faster establishment of adequate groundcover on surfaces.

The range of costs associated with each practice

The recent CSIRO gully stabilisation (Wilkinson S., Hawdon A., Hairsine P., Austin J., 2015) publication outlines the costs and effectiveness of various treatments (Table 74). These costs and efficacies have been used as a guide in developing costs and efficacies for the application of management practices to certain gully management scenarios. This information has been supplemented with costs supplied by the NRM regional bodies (NQ Dry Tropics, 2016a).

Table 74. Effectiveness of selected combinations grazing practice changes to manage erosion of existing gullies (Wilkinson et. al. 2015)

Practice combination	Description	Related Water Quality Risk Framework Performance indicators (McCosker, 2013)	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%

These costs do not include or account for all the costs of the gully remediation. These costs have not been independently validated and their applicability and efficacy are not universally applicable.

The cost for each element of practice change is the total cost of improving the condition of each land unit to achieve the sediment abatement outcome. The total cost includes:

1. On-ground project cost – this is the cost of project work (capital and maintenance).

2. Impact on (farm) profit – this is distinct from the on-ground project works cost. The profit impact could be positive, negative or nil. It measures the change in farm profit arising from the on-ground implementation of the project (e.g. changing stocking rates may change farm input costs and revenue). van Grieken et al., (2011) for the Tully and Pioneer catchments found improving cane from D and C class to B class can improve profitability by reducing input costs. Similarly pasture (groundcover) and production can both be achieved through improved grazing practice.

3. Program cost – this is the additional cost to government, regional NRM bodies, and industry that is incurred to implement the project/program. It was agreed with DEHP that the program costs should be those that achieve the highest possible uptake of the required actions. The costs include incentives, extension, regulation and monitoring and evaluation. Note that in the case of incentives, it is any incentive that needs to be paid to induce landholder participation above and beyond on-ground project cost and full compensation for farm profit. For example, incentives such as subsidised training can be offered in higher priority areas.

Proposed treatments for typical gullies

For the purpose of this investigation, gully erosion techniques have been bundled into typical treatments that could be applied to the control and management of gullies. These treatment arrangements have been developed to address the 'typical' issues found in the gullies of the GBR. The details of these treatment arrangements are shown in Table 75, Table 76, Table 77 and Table 78.

Table 75. Treatment 1: Low efficacy and long lag – all gullies

Item	Cost	Notes
Fencing (and total) cost	$9,200 per/km	Assuming double fence per km at $4,600 per km of fence
10 stick traps per km on minor side gullies	$2,000 per km	
Total	$11,200/km	
Efficacy rate of	15% reduction of fine sediment	Mid-range as per Table 74

Table 76. Treatment 2a: High efficacy, short lag – hillslope gullies

Item	Cost	Notes
1 rock chute per km	$25,000 per km	
10 stick traps per km on minor side gullies	$2,000 per km	
Fencing (and total) cost	$9,200 per/km	Assuming double fence per km at $4,600 per km of fence
Revegetation	$30,000 per km	Direct seeding and some soil amelioration with hydromulch/gypsum/fertiliser) of 3ha per/km assuming an average width of 30m between fences. Cost $10,000 per Ha: of gully
Total	$66,200 per/km	
Efficacy rate of	80% reduction in fine sediment	Estimated based on expert opinion consistent with the gully toolbox (Wilkinson et al 2015)

Table 77. Treatment 2b: High efficacy, short lag, no revegetation - hillslope gullies

Item	Cost	Notes
1 rock chute per km	$25,000 per km	
10 stick traps per km on minor side gullies	$2,000 per km	
Fencing (and total) cost	$9,200 per/km	Assuming double fence per km at $4,600 per km of fence
Total	$36,200 per/km	
Efficacy rate of	65% reduction in fine sediment	Estimated based on expert opinion consistent with the gully toolbox (Wilkinson et al 2015)

Table 78. Treatment 3: High efficacy, short lag - terrace gullies

Item	Cost	Notes
Earthworks	$250,000 per km	Assumes 50,000m3/km earthworks @ $5/m3 (4:1 batter and deep rip on contour)
10 stick traps per km on minor side gullies	$2,000 per km	
Fencing (and total) cost	$9,200 per/km	Assuming double fence per km at $4,600 per km of fence
Revegetation	$30,000 per km	Direct seeding and some soil amelioration with hydromulch/gypsum/fertiliser) of 3ha per/km assuming an average width of 30m between fences. Cost $10,000 per Ha: of gully
Total	$291,200 per/km	
Efficacy rate of	80% reduction in fine sediment	Estimated based on expert opinion consistent with the gully toolbox (Wilkinson et al 2015)

Adopted treatments

As terrace gullies are not distinguished in the gully mapping, only the typical treatments relevant to hillslope erosion are to be adopted for the purposes of this project. It is proposed that Treatments 1 and 2a be applied to 10%, 25%, 5% and 100% of gully lengths in the costing assessment.

1. Treatment 2b is provided as an example of a high efficacy, low $/t sediment abatement treatment that could be applied immediately and provide multiple other ecological, social and economic benefits.
2. Treatment 3 is for terrace gullies and cannot be readily applied to this project.

The costs associated with mitigating gully and streambank erosion are driven by local circumstances (works required, access, materials required, scale of actions required etc.). Furthermore, there will be a range of estimates around the average to represent what are reasonable upper and lower bounds for the estimates used in this report.

For the purposes of this report we have used upper and lower bounds of +/- 30% around the mean estimates. This is consistent with previous studies in the GBR catchments (Wilkinson et al 2015, Shelberg and Brooks 2013).

Results

As discussed in this section, eroding gullies have previously been identified as a big overall contributor of fine sediment to the GBR. The challenge in dealing with them is that they are so extensive in some catchments. It makes sense therefore to focus in on those which are discharging more than their fair share of pollution to the GBR. To do that, we took the results of the gully erosion at each sub-catchment, and divided that by the area of the sub-catchment, so that we could rank the gullies by their loads per hectare. From this, we then selected the top 10%, 20% and 50% of eroding gullies to treat first, then also looked at a scenario where we treated all gullies. Obviously, treating all gullies is unlikely to be practical in any catchment, both because of the extent of gullies, and also that where a gully is already present, it may no longer be active and works may be better directed to stop new gullies from forming. Because of this, our results are indicative of the extent of present gullies only, not of sediment that may be coming from new gullies that potentially have a much higher sediment export. The results are presented in Table 79, Table 80, Table 81 and Table 82 and Figure 73, Figure 74, Figure 75 and Figure 76.

We looked at two options for remediating gullies, one where just fencing was used, and another where full repair of the gully was assumed. This was for the Burdekin Dry Tropics and Fitzroy regions only and for fine sediment. It is also likely that repairing gullies may reduce DIN, or particulate nitrogen that then also may be transformed to DIN, however this was not simulated in this project.

Table 79. Results for fine sediment load reductions Burdekin gully repair with fencing only

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	4,300,000	0	0%
top 10% of gullies	4,150,000	152,000	3.5%
top 25% of gullies	4,070,000	227,000	5.3%
top 50% of gullies	3,960,000	336,000	7.8%
all gullies	3,910,000	392,000	9.1%

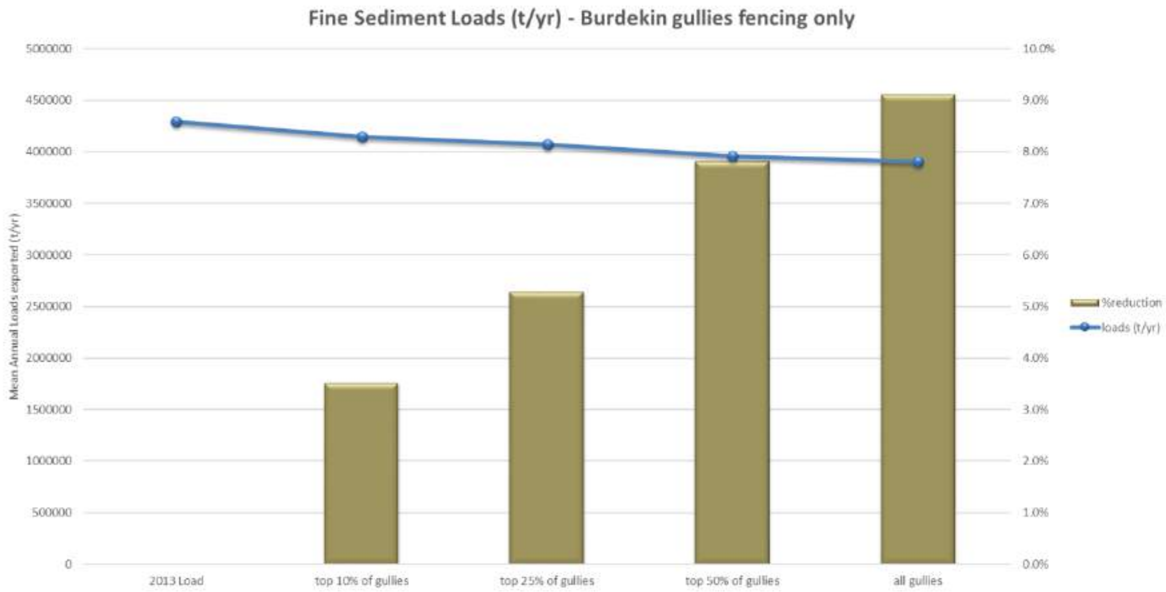

Figure 73. *Results for Policy solution set 3 – Burdekin gully repair through fencing*

Table 80. Results for fine sediment load reductions Burdekin gully repair with full remediation

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	4,300,000	0	0%
top 10% of gullies	3,490,000	810,000	18.8%
top 25% of gullies	3,090,000	1,210,000	28.2%
top 50% of gullies	2,500,000	1,790,000	41.7%
all gullies	2,210,000	2,090,000	48.6%

Figure 74. *Results for Policy solution set 3 – Burdekin gully repair with full remediation*

Table 81. Results for fine sediment load reductions Fitzroy gully repair with fencing only

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,800,000	0	0%
top 10% of gullies	1,780,000	19,500	1.1%
top 25% of gullies	1,750,000	45,800	2.6%
top 50% of gullies	1,730,000	71,900	4.0%
all gullies	1,710,000	90,300	5.0%

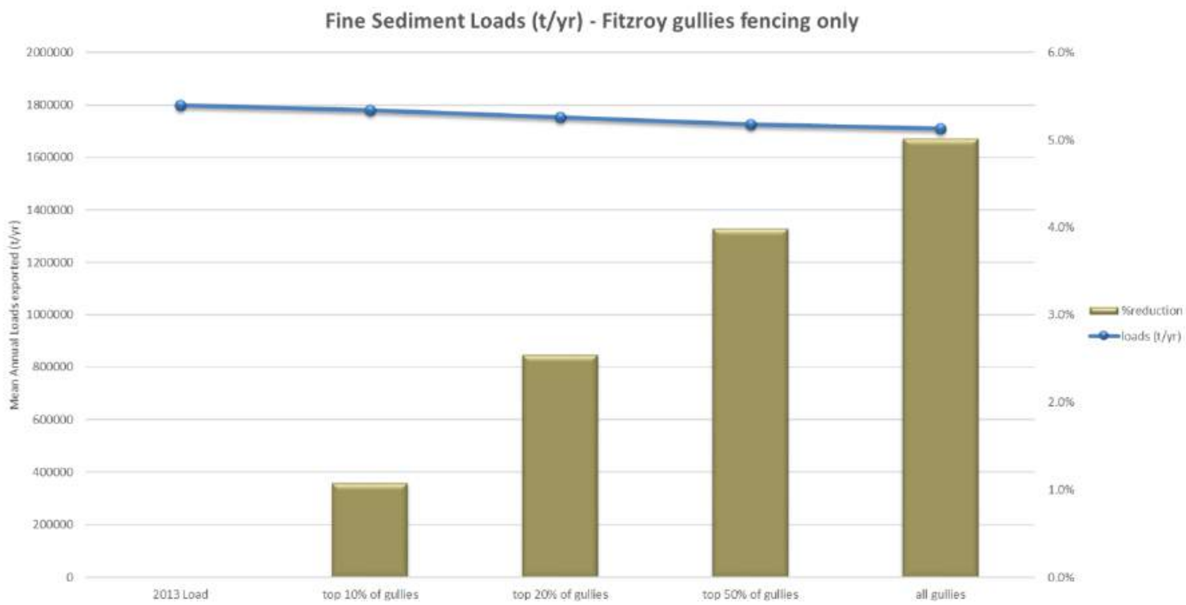

Figure 75. *Results for Policy solution set 3 – Fitzroy gully repair through fencing*

Table 82. Results for fine sediment load reductions Fitzroy gully repair with full remediation

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,800,000	0	0%
top 10% of gullies	1,700,000	104,000	5.8%
top 25% of gullies	1,550,000	244,000	13.6%
top 50% of gullies	1,420,000	383,000	21.3%
all gullies	1,320,000	482,000	26.8%

Figure 76. *Results for Policy solution set 3 – Fitzroy gully repair with full remediation*

What is very interesting about these results is firstly that fencing alone for remediating gullies does not appear to lead to a substantial reduction in fine sediment export, with a maximum of only 9.1% reduction in overall fine sediment load. Secondly, that in the Burdekin, full repair of gullies is predicted to lead to a nearly 50% reduction in overall sediment load, but the same level of treatment in the Fitzroy leads to just over 25% reduction. This is due to the fact that in the Burdekin gullies are the dominant source of fine sediment with more than 60% of the overall contribution, but in the Fitzroy gullies are predicted to be only one third of the fine sediment load, so even with full repair, the maximum reduction would be far less than in the Burdekin. This has implications for the costs to reach the fine sediment target in the Fitzroy as the treatment of streambank fine sediment, which is the dominant source in the region, was not one of the policy solutions we were asked to assess as part of this project.

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B.4 Policy solution statement 4: System repair – streambank repair

Policy solution set description and context

This policy solution set aims to assess the costs and effectiveness of remediating 5% and 10% of streambank length in the Mary, O'Connell, Tully and Herbert Rivers. These locations were selected as they represent catchments across the GBR region where substantial reductions in streambank erosion could be realised with appropriate management.

A higher desktop geomorphic assessment of waterways within the Mary River, O'Connell River, Herbert River and Tully River catchments was undertaken utilising Google Earth (more detailed spatial data was not available for the assessment) along with outputs from the Reef Source Catchments Models to identify the areas for streambank remediation for the purposes of this assessment.

The cost data for riparian revegetation for the GBR catchments is varied and in most cases dependant on local site conditions, access to materials/labour and climatic conditions. Local data from NRM groups has been used in each catchment where it was available to reflect regional differences. In the absence of local data from the NRM groups, more general costing data has been used (Bartley et al. 2015).

Geographic extent

The areas selected for streambank remediation include:

1. 15 km of the Tully River upstream of the Bruce Highway (5% scenario) and 14 km of the Tully River upstream of the Bruce Highway and 13 km of Bulgan Creek between Tully township and Tully River confluence (10 % scenario) (see Figure 77).
2. 74 km of the Herbert River upstream of the Stone River confluence (5% scenario) and 117 km of the Herbert River upstream of Ingham and 31 km of Stone River upstream of the Stone River confluence (10% scenario) (see Figure 78).
3. 6 km of the O'Connell River upstream of the Andromache River confluence (5% scenario) and 4.5 km of the O'Connell River upstream of the Andromache River confluence and 10 km of the O'Connell River upstream of the Boundary Creek confluence (10% scenario) (see Figure 79).
4. 77 km of the Mary River downstream of Kenilworth (5% scenario) and 140 km of the Mary River downstream of Conondale (10% scenario) (see Figure 80).

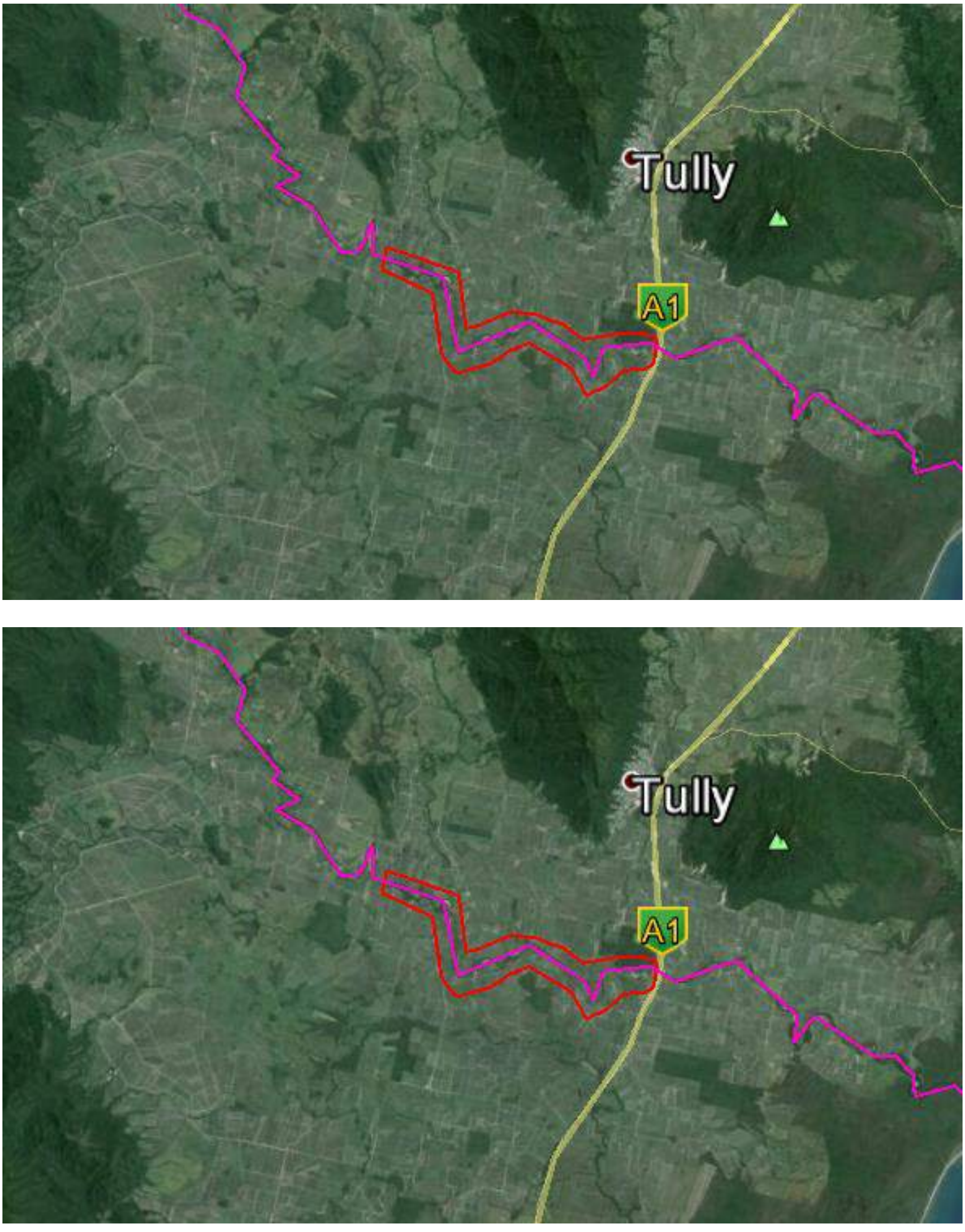

Figure 77. *The area of streambanks to be remediated in the Tully River - 5% (top), 10 % (bottom). Existing vegetation coverage in the proposed restoration zone was estimated to be 20% and 30% respectively.*

Figure 78. *The area of streambanks to be remediated in the Herbert River - 5% (top), 10 % (bottom). Existing vegetation coverage in the proposed restoration zone was estimated to be 40% and 20% respectively.*

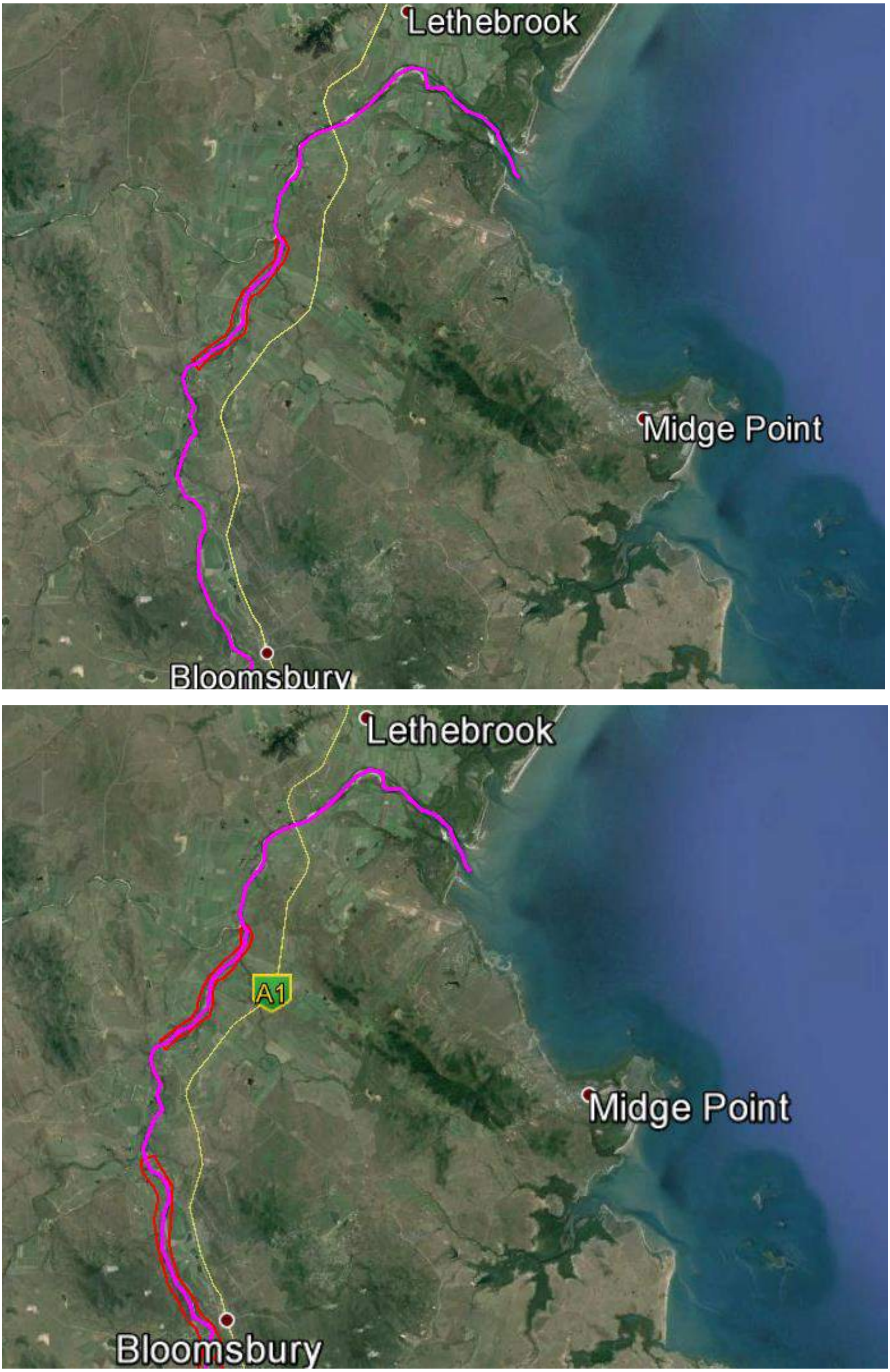

Figure 79. *The area of streambanks to be remediated in the O'Connell River - 5% (top), 10 % (bottom). Existing vegetation coverage in the proposed restoration zone was estimated to be 30% and 30% respectively.*

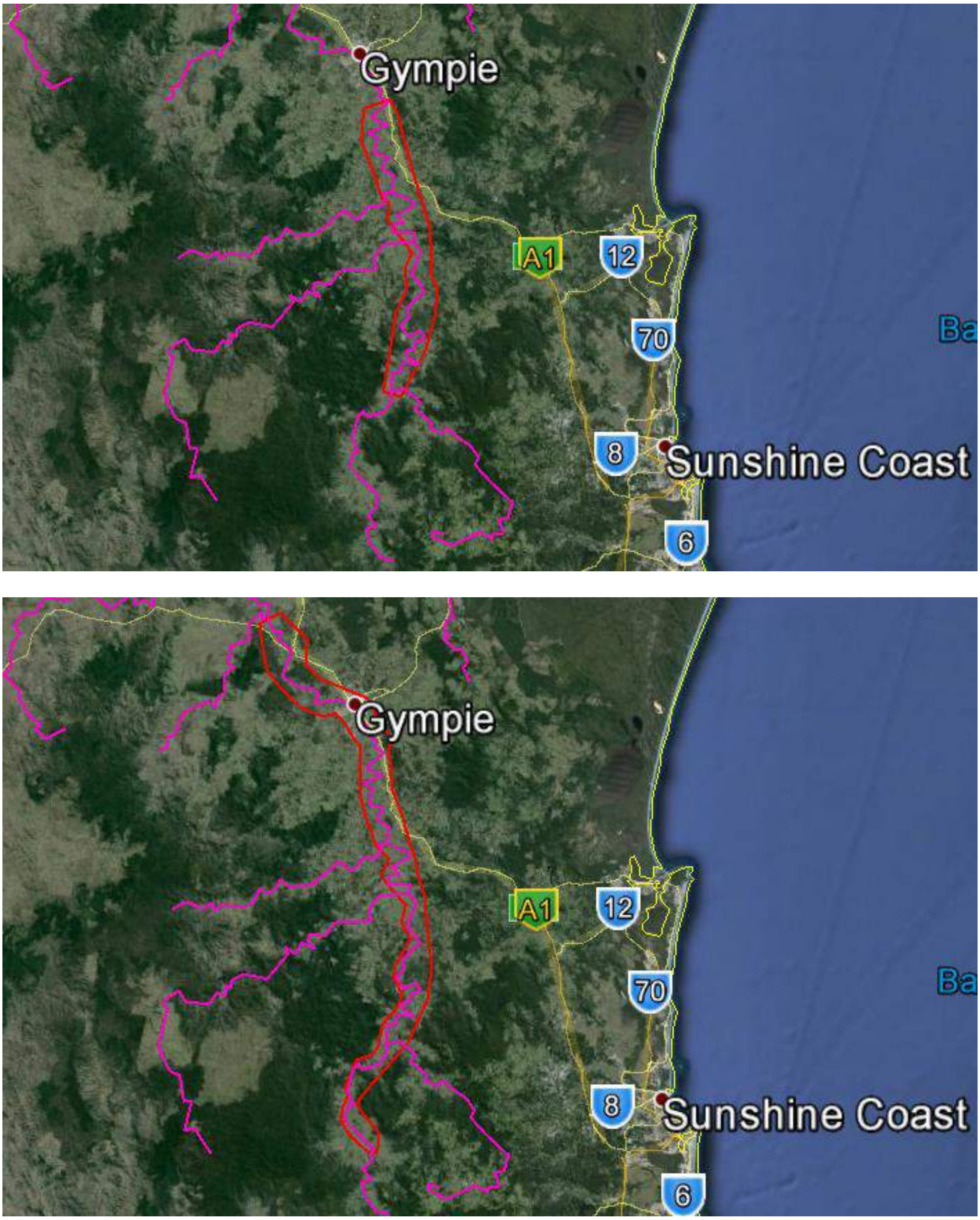

Figure 80. *The area of streambanks to be remediated in the Mary River - 5% (top), 10 % (bottom). Existing vegetation coverage in the proposed restoration zone was estimated to be 20% and 20% respectively.*

Method for selecting the areas for streambank remediation

The areas selected for streambank remediation within this policy solution set had to meet the following two key criteria:

1. No significant issues with the Source modelling assumptions, and the Reef Source Catchments Models predicting accelerated rates of streambank erosion. This was checked via a desktop assessment and a review of the Source modelling outputs at the sub-catchment scale.
2. The reaches selected have the capacity to laterally adjust (i.e. not confined by bedrock) and there is degraded riparian vegetation coverage (i.e. limited riparian buffer width and/or density). As a result these reaches have the greatest capacity for streambank erosion.

To complete the assessment of these criteria the following steps were utilised:

- An assessment of the degree of channel confinement from aerial imagery (i.e. is the channel confined by the bedrock valley margins or does the channel abut erodible alluvial floodplains or terraces?).
- An assessment of riparian vegetation width and density from aerial imagery.
- An assessment of recent evidence of bank instabilities using Google Earth historical imagery.
- Within the Mary River and O'Connell River catchments the assessments were supplemented by more detailed geomorphic assessments as additional studies by the project team had been undertaken in these areas.
- Outputs from the Reef Source Catchments Models were compared to the reaches identified as being susceptible to bank erosion. This included an assessment of the spatial distribution of streambank erosion rates, stream power, soil information (i.e. % fine sediment, erodibility etc.) and riparian vegetation condition.

Within each of the four nominated catchments approximately 5% and 10% of the total modelled river links were selected for remediation. The Reef Source Catchments Models adopt a 30 km^2 drainage threshold to identify the major stream network and contributing sub-catchments. As a result, the links used to estimate channel erosion do not begin until the contributing catchment is 30 km^2. Links must also begin at a confluence. As a result, many of the links will have contributing catchments which are significantly greater than 30 km^2. This means that many of the lower order streams in the Mary River, O'Connell River, Herbert River and Tully River catchments are not included in the modelling. Furthermore, the total modelled river links includes bedrock controlled reaches which cannot be remediated.

Assumptions and limitations

- The method adopted relies on the Source modelling estimates of streambank erosion within each link modelled. The efficacy of management practices related to remediation will be estimated as a percentage reduction of the modelled streambank erosion estimates. As a result, the cost benefit ratio for streambank management is heavily reliant on the Source modelling streambank erosion estimates at the reach scale.
- Streambank erosion is estimated within the Source modelling using the Dynamic SedNet model. The model, and the data inputs currently utilised, is a reasonable tool for estimating the relative contribution of bank erosion at large whole catchment scales. However, its applicability at smaller spatial scales (i.e. reach or sub-catchment) to estimate erosion rates and undertake prioritisation is limited due to the coarse data sets used, size of the model links and sub-catchment areas and modelling assumptions. The limitations of the Dynamic SedNet model have been outlined in the document 'Streambank management in the Great Barrier Reef catchments: a handbook' (Bartley et al, 2015). Some of these issues include:
    - The bank erosion equation in the SedNet model was based on the empirical relationships presented in Walker and Rutherfurd (1999) and Rutherfurd (2000) that used meander migration rate as a surrogate for bank erosion. Many rivers in Queensland have a macro channel configuration which are confined by resistant floodplain/terrace material, which in

turn limits lateral adjustment. Most of the channel erosion occurs on inset benches and floodplains within the macrochannel. The modelling currently cannot account for the differing erodibility of benches, inset floodplains and terraces.

- There is the potential for large systematic errors without sufficient model calibration (De Rose et al., 2005). Furthermore, calibration of end of catchment loads can result in significant under/over prediction of sediment sources within the catchments, including streambank erosion rates (Brooks, et. al. 2013). However, it is understood the current modelling does use upland monitoring where possible for calibration.
- The models provide a reach averaged estimate, which doesn't consider the explicit erosion process (e.g. incision/widening vs meander migration) that can often vary within a reach, and even vary on different banks within the same reach. As a result, there could be large zones of concentrated sediment loss within a broader reach (links can be tens of kilometres in length).

Management practices

Erosive processes and the role of riparian vegetation
Streambank erosion is a natural and essential process in alluvial systems. Human activities, such as land clearing and stripping of riparian vegetation, can however result in accelerated rates of erosion. Accelerated rates of erosion in the GBR has major impacts on catchment sediment loads. Other impacts include damage to public assets (bridges, culverts, road embankments, power lines etc.) and degradation of, and damage to, river health through, for example, infilling of pools by large sediment loads, erosion of bank habitat niches (e.g. under cut banks) and loss of large wood.

There are a range of erosional processes that can occur independently or in unison resulting in streambank erosion. Abernethy and Rutherfurd (1999) define three erosion categories as:

1. Subaerial erosion – erosion by processes external to the stream (i.e. cattle pugging, desiccation, groundwater seepage)
2. Fluvial scour – erosion resulting from the entrainment of bed and bank sediments due to hydraulic forces exceeding the resistance force (e.g. cohesion, gravity etc.)
3. Mass failure – erosion caused when large volumes of bank material slide or topple from the bank into the channel.

Riparian vegetation plays an important role in minimising the rates of streambank erosion in each of these three erosional categories. However, for each category different types of vegetation impact on the processes differently. Furthermore, as highlighted by Abernethy and Rutherfurd (1998), the means by which different types of vegetation impact on erosional channel change is also dependant on the location within the catchment. A summary of how different vegetation types limit each of the three erosion categories is given in Table 83.

Table 83. Vegetation and its influence on each of the three erosional processes (adapted from Abernethy and Rutherfurd, 1998)

Erosion process	Vegetation interaction
Mass failure	Root reinforcement – Riparian trees strengthen bank substrate and tend to resist mass failure. The extent of reinforcement is dependent on root strength and the density of the root structure. The effect of the roots is to increase the effective cohesion of the sediments. The longer and more extensive the root network the greater the degree of reinforcement. As a result, smaller shrubs and grasses are less effective at limiting mass failure. (Abernethy and Rutherfurd 2000). Bank moisture – Saturated banks are less stable than unsaturated banks as water increases the weight of the bank, encouraging mass failure. All vegetation types decrease the level of bank saturation by intercepting precipitation and by transpiration (Abernethy and Rutherfurd 2000).
Fluvial scour	Resistance of bank material – Vegetation on the bank increases cohesion and bank strength through the root networks. Smaller shrubs and grasses, which have limited impact on mass failure processes, are more effective at limiting the ability of bank sediments to be entrained due to their more extensive coverage of the bank surface area (Blackham 2006). Near bank velocities – Vegetation increases hydraulic roughness, which reduces near bank velocities. The shear force exerted against the bank is thus reduced. The impact of vegetation on hydraulic roughness is complex and varies with type of vegetation and discharge. At low flow, grasses and shrubs that stand rigid have a high wetted surface area and provide hydraulic resistance (Blackham 2006). As discharge increases, the herbaceous vegetation often cannot withstand the force and is flattened against the bank. Hydraulic resistance is reduced but the vegetation protects the bank substrate from erosion (Abernethy and Rutherfurd 1999). Large trees provide minimal resistance during low flow but as discharge increases their large trunks and branches provide the majority of the resistance once the herbaceous vegetation has been flattened.
Sub-aerial preparation	Piping – Seepage of water can lead to leeching and softening of the bank material making the bank more susceptible to mass failure. Vegetation can reduce the onset of saturated flow through evapotranspiration. However, cavities from decomposed roots can encourage subsurface flow. The risk of this can be reduced with an appropriate suite of riparian vegetation.

Erosion process	Vegetation interaction
	Desiccation – Dry and cracking banks are more susceptible to mass failure. Vegetation can reduce desiccation by binding the substrate together (Wynn and Mostaghimi 2006).

Importantly, and as outlined in Table 83, for these different forms of erosion, vegetation plays two critical roles in limiting channel change:

1. Hydraulic (frictional) resistance: According to Anderson and Rutherfurd (2003) riparian vegetation adds additional resistance elements in the main channel and on the floodplain of waterways such that flow velocity and conveyance are reduced. As a result:
    a) inchannel stream power is lower in vegetated reaches compared to systems with bare banks, and
    b) near bank stream velocity is lower in vegetated reaches compared to systems with bare banks.
2. Structural protection to the streambank: The vegetation provides structural reinforcement to the bank material increasing the cohesive properties of the soil.

These roles in limiting streambank erosion are rarely provided by a single species. A suite of vegetation types is required to fulfil these various roles in limiting channel change. This suite of vegetation includes instream vegetation, streambank groundcovers, shrub species and trees. This suite of vegetation is typical of remnant native riparian vegetation communities within the GBR. As a result, remediation of streambanks in the GBR needs to remove landuse pressures (i.e. grazing, sugarcane etc.) from the riparian zone and restoration of a native riparian vegetation community.

Relevant management practices

The specific practices to remediate streambanks include:

1. Creating a sufficient buffer from adjacent landuses. For grazing areas this will require fencing and offsite watering. The width of the buffer zone should be a minimum of 50 m from the top of bank in lower order rivers unless there is evidence of active channel migration. Determining an appropriate buffer width is complex and reliant on a number of factors (Bartley et al. 2015). For this project a 50 m buffer is considered sufficient to achieve stability and water quality benefits while providing a sufficient set back from the adjacent landuse.
2. Revegetating the riparian zone with a suite of appropriate native species. Revegetation plans should be developed appropriate to the local area, which should consider erosion risk, appropriate zones and planting densities and infill planting schedules.
3. An appropriate monitoring and maintenance regime for the local environment, which considers weeds, feral animals and watering requirements.

There are a range of other engineering approaches which can be implemented to assist native vegetation establishment. These include bank toe protection, bank re-profiling, alignment training and grade control. While these engineering approaches may be required at specific locations within each of the identified regions to increase the likelihood vegetation establishment, it is difficult to determine the required extent without a more detailed understanding of the hydraulic and geomorphic conditions.

Rock armouring of river banks (without accompanying riparian vegetation establishment) is a common practice implemented across the GBR river systems. Rock toe protection can be effective at increasing the likelihood of riparian vegetation establishment on the upper bank. However, rock armouring alone can have a range of negative secondary impacts, including increasing rates of downstream erosion (Florsheim et. al., 2008). As a result, rock armouring has not been considered as an appropriate management practice.

Costs

This assessment focused on the cost of revegetating streams which have degraded riparian zones. The cost estimates have been modified by +/-30% for best and worst case estimates to produce the three cost ranges for this policy solution set. The costs associated with mitigating gully and streambank erosion are driven by local circumstances (works required, access, materials required, scale of actions required etc.). Furthermore, there will be a range of estimates around the average to represent what are reasonable upper and lower bounds for the estimates used in this report. We have therefore used upper and lower bounds of +/- 30% around the mean estimates. This is consistent with previous studies in the GBR catchments (Wilkinson et al 2015, Shelberg and Brooks 2013).

The implementation of the riparian buffers in the four catchments has the following costs:

1. Opportunity costs (foregone production)
2. Management costs (fencing, revegetation, off-site watering, maintenance).

These are discussed below.

Opportunity costs

The majority of the riparian buffers in the four catchments are within private land which is used for agricultural production. Landuses in each catchment adjacent the identified reaches are outlined in Table 84.

Table 84. Landuses in each catchment

Catchment	Landuse
Tully River	Sugarcane
Herbert River	Sugarcane
O'Connell River	Sugarcane/Grazing
Mary River	Grazing

For grazing areas, it is assumed that the opportunity costs are negligible assuming appropriate offsite watering has been provided (included as part of the management costs). In addition to offsite watering, specific farm management plans (i.e. provision of shade etc.) may need to be developed with landholders to limit stock access to the riparian zone (which has not been costed as part of this study). For sugarcane areas there will be some foregone production. Determining forgone production is difficult. As a result, the opportunity cost to the landholder from foregone production has been estimated based on the land value. An assessment of real estate costs indicates sugarcane land is approximately $9-11K per ha (realestate.com.au. 2016). For a 50 m wide buffer on each side of the channel, the opportunity costs for sugarcane areas is $90-110,000 per linear kilometre of river.

Management costs

Some indicative management costs are provided in Table 85. The adopted costs for each catchment are shown in Table 86.

Table 85. Range of management costs for each activity

Activity	Cost
Fencing (only applied in grazing lands)	$9,200/km (both banks) Bartley et al. (2015) $15,000-20,000 /km (both banks) (per comm. Sunshine Coast Council) $30,000 / km both banks) (per comm. Mary River Catchment Coordinating Committee)
Revegetation including initial years of maintenance and infill planting	$27,900/km (assuming 10 ha per kilometre for both banks) (Bartley et al. (2015)) $825,000/km (pers. comm. Mary River Catchment Coordinating Committee) $150,000 /km (pers. comm. Sunshine Coast Council) $200,000/km (pers. comm. Reef Catchments) $330,000/km (pers. comm. Terrain NRM)
Maintenance	$500/km/ annum (Bartley et al. (2015)) Field officer $800/day (including vehicle) (pers. Comm. Queensland Trust for Nature).
Offsite watering	$18,000 /km (Bartley et al. (2015))

Table 86. Adopted costs for each catchment

Catchment	Opportunity cost	Fencing	Revegetation works including initial years of maintenance	Offsite watering	Maintenance (post vegetation establishment period)
Mary River	N/A	$10,000/km based on information provided by Mary River Catchment Coordinating Committee and Sunshine Coast Council	$825,000/km (which includes extensive three-year maintenance program) based on information provided by Mary River Catchment Coordinating Committee	$18,000 /km based on Bartley et al. (2015)	$1600/km assumes two days' time for field officer per km
O'Connell River	$10,000/ha for sugarcane areas (assumed to be 50% of land)	$4,600/ km based on Bartley et al. (2015) assumed 50 % grazing areas which require fencing	$200,000/km based on information provided by Reef Catchments	$18,000 /km based on Bartley et al. (2015)	$1600/km assumes two days' time for field officer per km
Herbert River	$10,000/ha	N/A	$330,000/km based on information provided by Terrain NRM	N/A	$1600/km assumes two days' time for field officer per km
Tully River	$10,000/ha	N/A	$330,000/km based on information provided by Terrain NRM	N/A	$1600/km assumes two days' time for field officer per km

Effectiveness
The scientific understanding of the role riparian vegetation plays in limiting streambank erosion is relatively advanced. However, there are limited studies which quantitatively evaluate the effectiveness of revegetating streams which have degraded riparian zones (Bartley et al. 2015). Bartley et al. (2015) found 12 published peer reviewed studies from around the world documenting the response of riparian vegetation based streambank remediation on sediment yields, water quality or erosion rates. Five of the studies did not result in improved sediment yields, water quality or reduced erosion following remediation. Seven studies showed restoration of riparian vegetation has a positive impact on sediment loads, with a reduction in erosion rates of between 40% to 80%. The response time for improved water quality following remediation was quite variable, ranging between two and 18 years.

In the GBR catchments, high quality, structurally diverse native riparian vegetation will be required to maximise the erosion resistance of streambanks. It is likely that the establishment of high quality, structurally diverse native riparian vegetation through a revegetation program is likely to take five to ten years. As a result, based on the studies above, the 80% efficacy in the GBR catchments will not be reached until approximately ten years following implementation.

Results

Specific sub-catchments were identified from the Source sub-catchment layers that aligned with 5% and 10% of total streambank length in the relevant rivers where erosion was taking place, and to those, an 80% reduction in fine sediment was assumed to apply.

The results of the application of the above parameters are given below in Table 87, Table 88, Table 89 and Figure 81, Figure 82 and Figure 83.

Table 87. Results for fine sediment load reductions Wet Tropics stream repair

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,660,000	0	0.0%
2013 with 5% streambank repair	1,590,000	72,400	4.4%
2013 with 10% streambank repair	1,530,000	130,000	7.8%

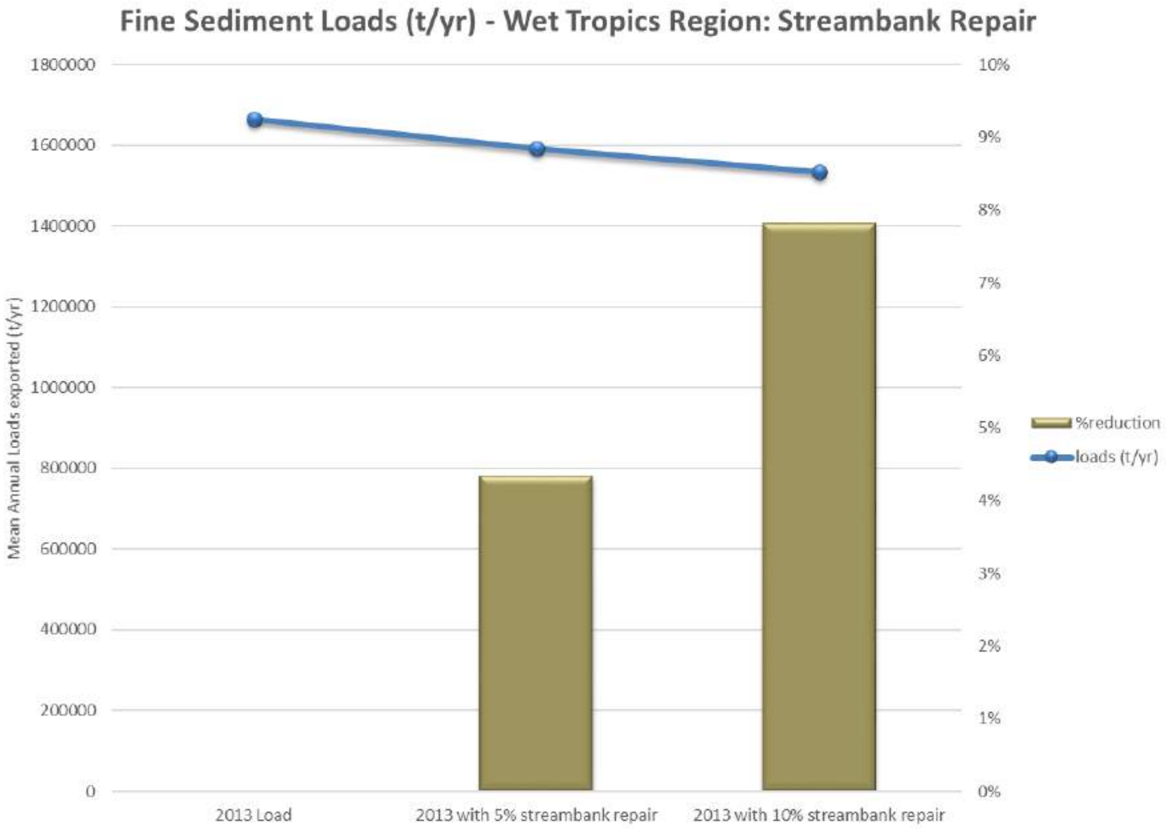

Figure 81. *Results for solution set 4 - Wet Tropics streambank repair*

Table 88. Results for fine sediment load reductions Mackay Whitsunday stream repair

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	200,000	0	0.0%
2013 with 5% streambank repair	198,000	1,610	0.8%
2013 with 10% streambank repair	196,000	4,010	2.0%

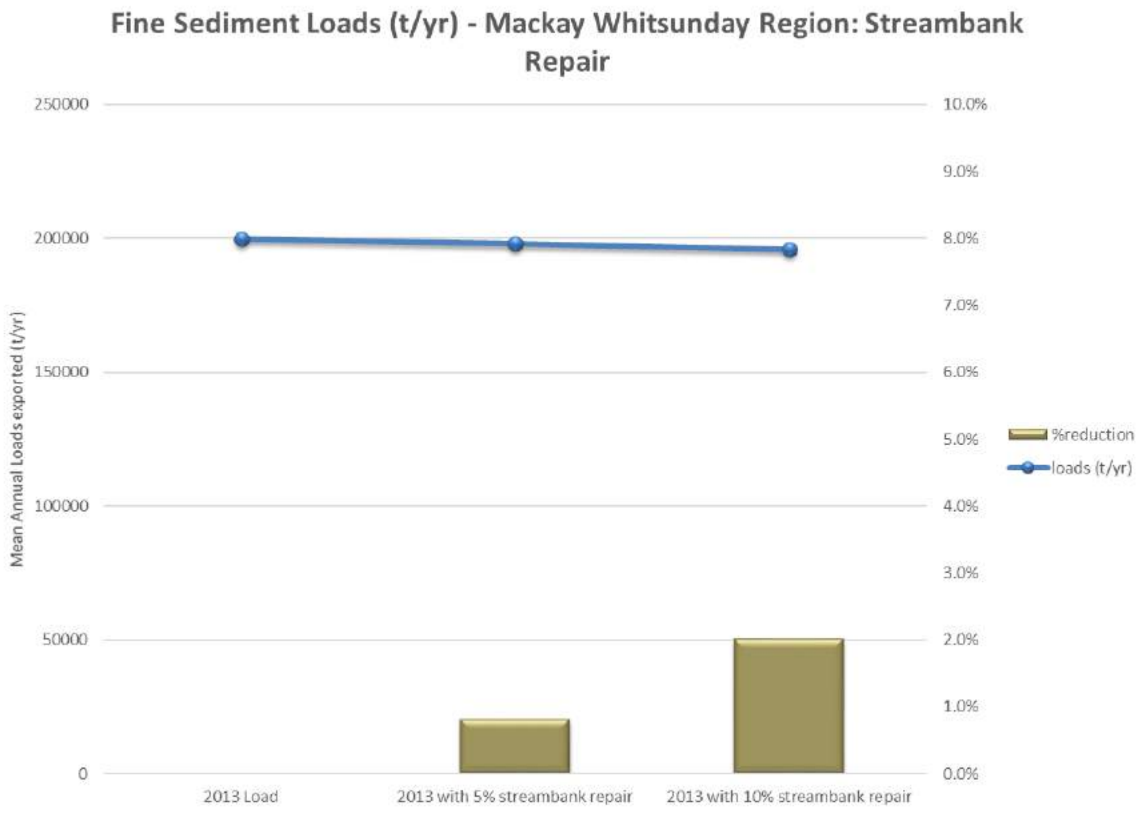

Figure 82. *Results for solution set 4 - Mackay Whitsunday streambank repair*

Table 89. Results for fine sediment load reductions Burnett Mary stream repair

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,260,000	0	0.0%
2013 with 5% streambank repair	1,230,000	31,100	2.5%
2013 with 10% streambank repair	1,190,000	68,300	5.4%

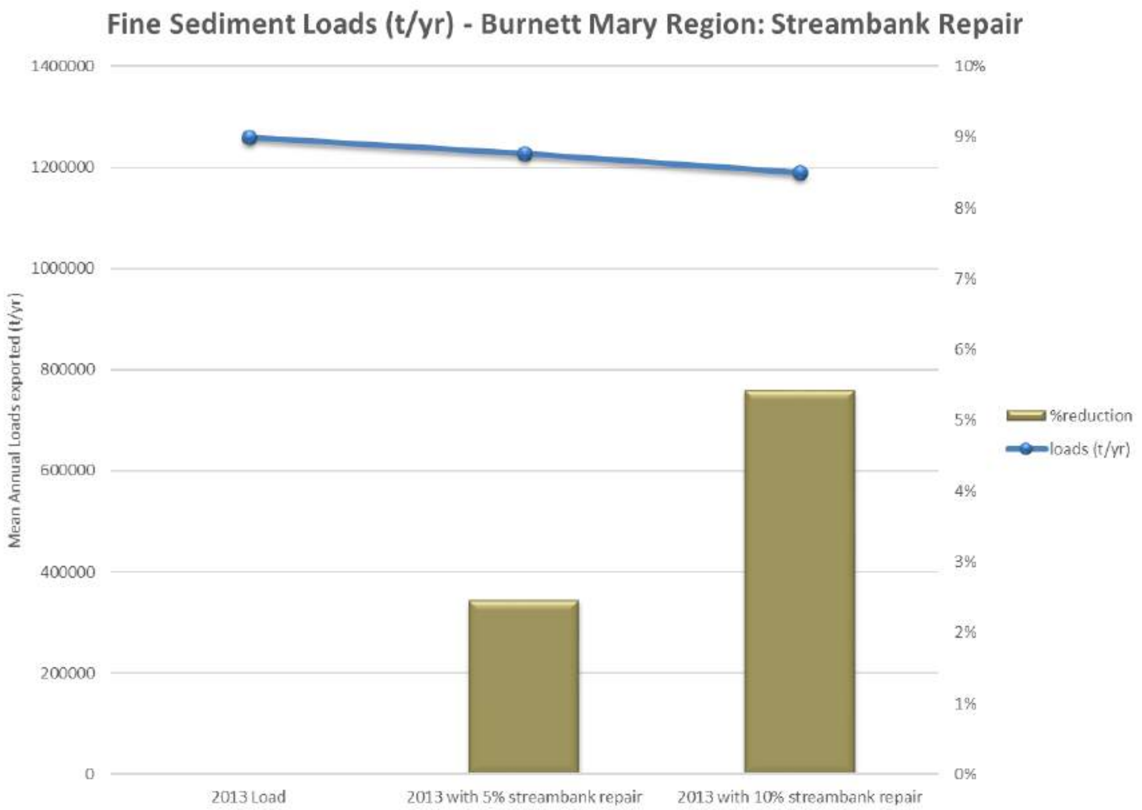

Figure 83. *Results for solution set 4 - Burnett Mary streambank repair*

These results show that in the Wet Tropics, streambank repair can result in a reasonable level of fine sediment reduction given the small area of application and by focussing on those areas that are actively eroding. A similar result was predicted for the Burnett Mary system, but in the Mackay Whitsunday, the load reduction was relatively minimal.

Implementation issues

The major implementation issue is the lag time required for the vegetation to reach a level of maturity required to provide protection against erosion. This can take between five and ten years. There are also risks that flow events will scour the bank prior to the vegetation reaching maturity. This could result in damage and loss of the revegetation works and significant additional maintenance costs. In high risk locations appropriate toe protection (rock, large wood, pile fields etc.) could be utilised to increase the likelihood of vegetation establishment. To determine the level of risk to the revegetation works and the costs associated with appropriate works to reduce the risk of loss and damage to the works, requires a more detailed understanding of the hydraulic and geomorphic conditions in each river. The risk to establishing vegetation and the degree of structural toe protection required to alleviate the risk has not been assessed as part of this project.

Key pieces of previous work that have been used to assess this policy solution set include:

- Streambank management in the Great Barrier Reef catchments: a handbook (Bartley et. al., 2015)

- Mary River Restoration Plan (Alluvium, 2014a)
- O'Connell River Stability Assessment (Alluvium, 2014b).

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B.5 Policy solution statement 5: Wetland construction

Policy solution set description and context

Solution set definition
Wetland construction: This policy solution set assesses the costs and effectiveness of installing 25, 50 and 100 hectares of constructed wetlands/pollutant traps in suitable areas of sugarcane cultivation given current knowledge of likely effective locations and, in contrast, likely ineffective locations. Consideration of a larger range of area of constructed wetland/pollutant traps will be examined to refine the solution set. The possibility of quantifying pollutant trapping effectiveness separate from biodiversity gain effectiveness will be considered although quantifying biodiversity gains in dollar terms is not possible at the present. From the initial analysis it is clear that in terms of pollutant trapping, recycle pits can be more effective than constructed wetlands (as each is defined below) in some catchments. However, constructed wetlands have considerable potential biodiversity gains compared with recycle pits which are specifically designed to be regularly drained.

Solution set geographic extent
The primary region where constructed wetlands and treatment facilities such as recycle pits (sumps) have been proved to have value in pollutant trapping is in the lower Burdekin cropping lands (sugarcane mostly) for trapping dissolved inorganic nutrients and herbicides (the pollutants of concern in this area). The solution sets focus in that region but provide quantitative evidence that the sizing of constructed wetlands needs to be at least 100% greater than a recycle pit to have a similar level of treatment. In other regions like the Wet Tropics, due to in the volumes of rainfall runoff events, constructed wetlands are somewhat effective for sediment but have lower effectiveness for dissolved nutrients and herbicides. In the majority of areas of sugarcane, fine sediment is not a priority because the areas are typically flatter and therefore have lower sediment generation potential. However, in some catchments, particularly the Mackay-Whitsunday, sediment from cane lands can be a dominant source and therefore wetlands may be worthy of consideration.

Key pieces of previous work – literature review

Constructed wetlands
Constructed wetlands (including vegetated drains and swales) for agricultural run-off are usually situated 'on-farm', in areas that had previously yielded low to marginal crop production and were often former wetlands. For water quality improvement services, they are located downstream of tailwater or irrigation discharge areas, or down-land of overland flows of run-off. The ideal size is dependent on the size of the catchment area, or the number of hectares which drain into the wetland and how much water the wetland will generally be treating, while maintaining a steady and moderate inflow. Constructed wetlands also require an impermeable bottom layer, either clay or man-made material, to protect the groundwater from infiltration of pollutants. They are normally vegetated (as distinct from recycle pits) (Figure 84) but also require an area of sufficient size to allow biogeochemical processes to occur by having a sufficient residence time. The primary pollutant removal processes of constructed wetlands are through enhanced sedimentation for fine particulates, and through biological uptake by bacterial and fungal films (biofilms) adhering to plants and sediments (Pollard 2010, Kadlec and Wallace 1996).

Constructed wetlands usually have a built-in high flow bypass design, driven by hydraulic/backward flow into an attached sediment basin. Bypass designs redirect large flows around the wetland to avoid flushing of the wetland downstream. Design options for adaptive management, such as water level gauges, and pumps, etc., can also be included in constructed wetlands. Important issues that are considered when designing wetlands, other than upstream catchment area, include hydraulic efficiency, vegetation composition, bathymetry, hydraulic grade changes in the land (i.e. direction of water flow) and watertable depth. They may also have other features like an initial sediment detention basin and are usually installed as part of a treatment train approach.

Design principles in Queensland are available (e.g. Resources, WetlandInfo 2013) but most of these are based on urban examples. They are not necessarily entirely suitable for design in agricultural areas, and in particular areas of potentially short period extreme rainfall which includes almost all of the coastal GBR catchments.

Figure 84. *Constructed wetland on a banana farm in the Johnstone River basin (from DeBose et al. 2014)*

Numerous studies have been conducted on the effectiveness of constructed wetlands for the mitigation of high nutrient wastewater in temperate areas, sub-tropical areas and in urban catchments, however very little work has been conducted in tropical areas which are prone to seasonal high flow events and flooding. Many factors influence the ability of constructed wetlands to reduce pollutants and improve water quality exiting the system. These factors include climatic conditions (e.g. amount of rainfall, surface temperature), background levels of organic matter, age, type and distribution of vegetation in the wetland, nutrients and solids generated within the wetland (such as dissolved organic nitrogen and phosphorus, and detritus), and overall residence time of the water within the wetland.

Recycle Pits (reclamation sumps)

Recycle pits are ponds or basins or drains that supply captured irrigation tailwater back to the surrounding agricultural land (Figure 85). While they are not designed primarily to trap nutrients, sediment and pesticide runoff from the paddock (but rather capture excess irrigation water for reuse), in practice they are very effective traps in that the captured water with its loads of fine sediment, nutrients and pesticides can be passed across the paddock again with strong opportunities for these materials to be removed during passage. Sumps are found in irrigation areas where the tailwater from irrigated land is collected and stored. They are common in the lower Burdekin sugarcane area, as the predominant form of irrigation is furrow, which as used in this region leads to large volumes of tailwater leaving the farm after irrigation events. Irrigated (often supplementary) sugarcane in other districts (e.g. Herbert, Mackay, Proserpine, and Bundaberg) occurs via overhead irrigation which results in far smaller volumes of tailwater. This tailwater is often high in nutrients and pesticides which is then used again to irrigate agricultural land (generally on the same farm). Recycle pits are constructed to provide an on-farm water resource point; to receive irrigation tailwater and runoff; and be used to irrigate out of. They are often just expanded farm drains with a control structure (weir) and a pumping system to return captured tailwater to the "top" of the farm (Figure 86) (Shannon and McShane 2013).

Recycled pits do not normally have planted vegetation and are easily able to be excavated regularly to remove trapped sediment and particulate nutrients. When operated effectively they can capture near 100% of irrigation tailwater, with its contained fine sediment, nutrients and pesticides, and returned onto the farm. They have little or no direct biodiversity benefits. They may also be effective at reducing off-farm event runoff (especially small first flush events which may occur in October or November before the main wet season events) if they are sufficiently sized to capture a significant proportion of runoff events, though the sizing of these pits will be similar to that of wetlands. They are often used in combination with constructed wetlands – see Resources, WetlandInfo 2013) and thus form part of a treatment train approach (see below).

Figure 85. *On-farm recycle pit (reclamation sump) in the lower Burdekin River catchment. Photo credits: J. DeBose and D. O'Brien*

Figure 86. *Pumping from a recycle pit – lower Burdekin*

Treatment trains

A treatment train uses several treatment types in conjunction to maximise local and downstream outcomes. Many pollutants such as nutrients and fine sediments require a number of measures used in sequence for treatment to be effective. In the case of nutrient runoff from sugarcane cultivation it is well recognised that the most effective steps in management are carried out on farm, e.g. fertiliser management, and that after-farm measures such as constructed wetlands are a final polishing process and in general less effective than on-farm management measures. Designs for treatment trains are also available in Queensland (Resources, WetlandInfo 2013).

Treatment trains are often utilised for treating runoff, and consist of a series of nutrient and sediment trapping mechanisms, such as grassed/vegetated drains, recycle pits and sediment basins prior to entering the constructed wetland. The full treatment train will include the primary steps in on-farm management as well as the after-farm steps such as sumps and constructed wetlands. After-farm treatment trains are often effective, especially when they include different types of flow regimes (e.g., deep pools with slower flow, subsurface flow, turbulent flow through shallow marsh areas, etc.). In the treatment train approach, the final 'polishing' of the treatment train is the smaller step following on-farm management steps such as fertiliser management systems.

An example of a treatment train approach is the Constructed Wetlands Development for the Barratta Creek Catchment being constructed by WetlandCare Australia. In this project (Figure 87) irrigation tailwater runoff from several large cane farms in the Burdekin-Haughton Water Supply Scheme in North Queensland is being diverted from the current tailwater drain system through a constructed wetland via a remediation pond.

Figure 87. *WetlandCare Australia sediment detention pond and constructed wetland under construction*

Costings
With respect to the costs of constructing recycle pits and constructed wetlands we have reviewed the information from Marsden Jacob Associates: Financial & Economic Consultants 2013 Draft report (Report prepared for Queensland Department of Environment and Heritage Protection). The report covered the economic and social impacts of protecting environmental values in GBR catchment waterways and the GBR lagoon. As an example, initial summarised draft findings for this solution set from Marsden Jacob are as follows:

- Establishing replacement (constructed) wetlands—small size (cost per ha)
- $800,000 (low estimate) $900,000 (med.) $1,000,000 (high).

Costs should include site preparation, removal of exotic plants, establishment of new plants and property management for the establishment of the site. Cost will vary depending on size, prior condition of site, location of site (especially the choice between urban or rural land) need for water re-routing and availability of necessary plants and expertise. Likely to be significant costs over a fairly long period, as plants are progressively introduced.

- Establishing replacement (constructed) wetlands - medium to large size (cost per ha) + establishment cost of $738,607
- $275,130 (low) $343,913 (med) $412,696 (high).

Shannon and McShane (2013) evaluated the possibilities and costs of establishing new recycle pits in the Burdekin Haughton Water Supply Scheme (BHWSS). The need for increased tailwater recycling was the realisation that the Barratta Creek drainage system is now recognised as a very disturbed system (Davis et al. 2013; O'Brien et al. 2016). The changed hydrology and contaminated tailwater loss has serious local and downstream environmental implications. Farm tailwater runoff, overflow from SunWater infrastructure and rising groundwater have all contributed to the change in hydrology in the system.

They note that: "*Irrigation tailwater capture is commonplace within the BHWSS; with around 100 recycle pits identified in this scoping study. The proportion of irrigated area with tailwater capture in the Burdekin River Irrigation Area is around 70% of total irrigated area. Grower investment within the BHWSS in irrigation tailwater capture is conservatively estimated to be $15-20 million, of which $1 million has come from the Australian Government's Reef Rescue 1 Incentive Program. Despite these tailwater recapture efforts, significant surface water is still being discharged into Barratta Ck from drains within the BHWSS area. This surface water is generally a result of irrigation runoff water from farms without tailwater recycling (such as the original Clare scheme); from SunWater balancing storages and channel overflows and from farms with sub-optimal tailwater capture systems.*"

Their study resulted in the identification of: "*15 potential sites for further extraction of surface water from SunWater drains and directly from Barratta Ck base flow studies have shown that SunWater drains such as RB3 and RB5, which flow into the Barratta Ck carry volumes of up to 35 ML/day and 55 ML/day respectively, although the base flow readings show large daily fluctuations. The additional tailwater extraction sites would effectively reduce the base flow in the Barratta Ck system to a minimum.*"

We have used their costings in preference to the Marsden Jacob report as the Shannon and McShane (2013) figures are based on actual examples.

Effectiveness - Summary of the reviewed studies

The ability of wetlands to improve the quality of water has long been recognised and has led to the proliferation of wetlands as a means to treat diffuse and point source pollutants from a range of landuses. However, much of the existing research has been undertaken in temperate climates with a paucity of information on the effectiveness of wetlands in tropical regions. The effectiveness of some wetlands for trapping sediment is moderate but for trapping dissolved nutrients is very low (Hunter and Lukacs 1999, 2000; McJannet et al. 2011, 2012; DeBose et al. 2014; Reef Catchments 2016) in typical Burdekin and Wet Tropical areas of the GBR catchment.

Most of the many recycle pits and constructed wetlands built over the last 20 years in the GBR catchment have never been adequately tested for their pollutant trapping effectiveness in the period of high risk – the wet season. Even recent studies such as the recently released National Environmental Science Program study (Smart et al. 2016) did not use high risk period rainfall in their scenarios. The analysis was based on wetland performance in a 30mm rainfall event. Once again this is a low risk event and not really relevant to effective trapping in the Tully situation (or other key areas in the GBR catchments) where high risk rainfall events are likely above 100mm events as in our modelling below.

DeBose et al. (2014), in a review investigating the effectiveness of a variety of vegetated systems at sites within the South Johnstone, Tully, Herbert and Burdekin catchments, conclude that "*the residence time of contaminants in vegetated systems, especially for dissolved and fine particulate material, is the most important factor in determining trapping effectiveness. As particulate material is generally easier to trap than dissolved matter, properties of contaminants which predispose them to be present in a particulate form or to adsorb onto particulate matter will strongly regulate trapping effectiveness. Thus large hydraulic volume traps or systems with relatively low input volumes will be the most effective at trapping agricultural pollutants*".

A principal finding of the DeBose et al. (2014) study is that *"the residence time of water in trapping mediums is an important measure of likely effectiveness of any vegetated area. Long residence times lead to effective trapping while short residence times are unlikely to trap anything."*

In field studies in constructed wetlands and recycle pits across the Wet Tropics and Burdekin regions in cane and bananas, DeBose et al. (2014), found some trapping of sediment and nutrients in the dry season but very little (effectively zero) trapping in the wet season in times of maximum pollutant delivery but short residence times.

McJannet et al. (2011, 2012) in studies on the Tully – Murray floodplain on a small natural wetland (but of large area in terms of most constructed wetlands) found small net imports and exports of sediment to/from the wetland in individual years, but over the longer term this kind of wetland was neither a sink nor source of sediment. In contrast, phosphorus was continually removed by the wetland with an overall net reduction of 14%. However, it should be noted that there is no 'permanent' gaseous loss mechanism for phosphorus, and its removal from the water column is equal to its accumulation in the wetland soil. They found very little removal of nitrogen by this type of wetland from several analyses including: (i) Surface and groundwater fluxes, (ii) Estimation of water column and soil denitrification rates, (iii) Wetland residence times, and (iv) Hydraulic loading. They also found no clear evidence for transformation of nitrogen to more or less bio-available forms. Hence, while the benefits of using wetlands to improve water quality in controlled environments have been demonstrated in the literature, these benefits may not always be directly translated to wetland systems in the tropics when there is strong seasonality inflows and short residence time during the periods of maximum sediment and nutrient load.

McJannet et al. 2012 also found that water retention times in this type of wetland are very short, particularly when most of the flow and any associated materials are passing through it (i.e. 1–2 h), so there is little time to filter most of the annual flux of water through this wetland. Longer retention times occur at the end of the dry season (up to eight days); but this is when the lowest fluxes of water pass through the wetland.

Similar results were found by Hunter and Lukacs (1999, 2000) in studies of constructed wetland trapping in the lower Burdekin: "*where the potential for using constructed wetlands to improve the quality of irrigation drainage waters (tailwater) was assessed at an experimental site in the Burdekin River Irrigation Area in north Queensland. Two detailed performance trials were undertaken in 1999 to quantify changes in concentrations and loads of suspended solids, phosphorus and nitrogen between wetland inlets and outlets. Intake water to the wetlands during the trials contained mean concentrations of suspended solids of < 95 mg L-1, total phosphorus < 0.09 mg L-1, and total nitrogen < 0.63 mg L-1. The wetlands removed 60-70% of the suspended solids load (compared with 16-49% from a control bay without vegetation) and concentrations at bay outlets were significantly lower than at inlets. However, there was a net increase (ranging from 0.4% to 67%) in total phosphorus loads, and concentrations at the outlets of vegetated bays were significantly higher than at inlets. Changes in total nitrogen loads were relatively small and variable (within the range ± 22%), and concentrations at outlets were generally not significantly different from those at inlets. The wetlands at the time of these trials had been established for five years. Results from monitoring in 1994/95 indicated a much greater ability of the wetlands to remove phosphorus, although results for suspended solids and nitrogen were comparable. Reasons for the diminished phosphorus removal in 1999 may have been due to the changed condition of the wetlands as well as differences in the phosphorus composition of water entering the wetlands."*

Overall it is clear that constructed wetlands would only trap dissolved nitrogen in the time of maximum input, i.e. the wet season if they were of sufficient size to provide an effective residence time for biological processes to operate. Recycle pits can trap dissolved nutrients from irrigation tailwater in the dry season and as the water is returned to the farm be very effective in removing this component of paddock nitrogen loss. However, this really only applies to the lower Burdekin where there is a surplus of irrigation delivery due to furrow irrigation and this is the least critical time for delivery of nitrate to the GBR. In other catchments, recycle pits are being used where they may be acting as a runoff harvesting scheme and providing both an irrigation source and pollutant trapping mechanism.

Cost effectiveness

Roebeling et al. (2015) note *"Water pollution delivery reduction costs are, however, not equal across abatement and treatment options. In this paper, an optimal control approach is developed and applied to* *explore welfare maximizing rates of water pollution abatement and/or treatment for efficient diffuse source water pollution management in terrestrial-marine systems. For the case of diffuse source dissolved inorganic nitrogen water pollution in the Tully-Murray region, Queensland, Australia, (agricultural) water pollution abatement cost, (wetland) water pollution treatment cost and marine benefit functions are determined to explore welfare maximizing rates of water pollution abatement and/or treatment. Considering partial (wetland) treatment costs and positive water quality improvement benefits, results show that welfare gains can be obtained, primarily, through diffuse source water pollution abatement (improved agricultural management practices) and, to a minor extent, through diffuse source water pollution treatment (wetland restoration)".*

Our initial analysis of the constructed wetlands to date in the region is that overall they rate very poorly in terms of cost effectiveness in reducing end-of-catchment loads of dissolved inorganic nitrogen.

Method

How the key project tasks are being approached
The following section outlines the steps required to run the solution set and a range of potential constructed wetlands and recycle pits that have been considered as outlined below.

1. Construction of a vegetated wetland downstream of cropping lands sized to treat surface runoff from the upstream catchment.
2. Construction of a recycle pit to trap irrigation tailwater in dry season conditions from cane lands in the Lower Burdekin region.
3. Construction of a recycle pit downstream of cropping lands sized to treat surface runoff from the upstream catchment.
4. A combination of 2 and 3.

This has been undertaken through some desktop and modelling analyses.

Data availability
Considerable data exists as to the costs of building pits and wetlands although separating the costs of the farmer's own time inputs from the fixed costs is more difficult. Very little relevant data from actual monitoring and evaluation exists for the likely water quality benefits in the GBR region of constructed wetlands and recycle pits. We will have to rely heavily on modelling and estimation techniques to quantify the nutrient trapping effectiveness of these structures.

Targeted geographic areas for more detailed analysis
We will use the lower Burdekin as our targeted area given the history and knowledge in that area regarding these structures (e.g. DeBose et al. 2014; Shannon and McShane 2013). We also use the modelling (see below) to extend the analysis to the Wet Tropics.

Effectiveness modelling
The stormwater model MUSIC was used to model effectiveness of the proposed treatment systems operating through both wet and dry climates.

In MUSIC, wetland performance is largely dictated by residence time, the universal stormwater model parameters and the ability of the wetland to bypass high flows. We therefore used a 72-hour residence time in the wetlands and sumps to simulate the period needed for biogeochemical processes to operate. From previous studies on the performance of urban stormwater wetlands, we know that 72 hours is an optimal period for removal of soluble nitrogen (typically based on measurements of NOx and NH3, though sometimes Org-N has been also monitored). Most of the losses do not occur through the vegetation or denitrification (only about 10-20% of the total removal), the majority is through consumption by epiphytic organisms in the biofilms on the surface of the vegetation or in the sediment-water interface.

After preliminary modelling in MUSIC, the model was re-parameterised to model DIN (not just TN) (and fine sediment) by adjusting the performance of the wetlands to reflect minimal reduction by any physical processes (e.g. enhanced sedimentation), and used previous monitoring data for two wetlands in Brisbane (Cressey St Wetland and Bowies Flat Wetland) for which we had good speciated nutrient data (BCC 2006). This should reflect performance for NOx and NH3 based on real data for sub-tropical and tropical environments. This adjustment was to reduce the k and C* parameters in the wetland node within MUSIC to better simulate both the potential slower decay rates in tropical wetlands, and background concentrations noted in the sub-tropical wetlands noted above.

For costings, we used the life cycle costing module in MUSIC which was updated to 2016 dollars. For the wetlands, we used the native life cycle costs (LCC) functions in MUSIC which we know are an underestimate for urban wetlands, but we think are likely to be a reasonable approximation for farm based systems given that a lot of the machinery for constructing and shaping a wetland would already be on-site. For the recycle pits, we took the approximate dollar estimates from Shannon and McShane (2013) and scaled those to a per ha capital cost (Table 90). We used that cost in the MUSIC LCC module to then derive the maintenance and other costs and come up with full LCC costs.

Table 90. Operational effectiveness of six recycle pits during a 7-week study period during the dry season of 2013 (from Shannon and McShane (2013))

Pit name	Pit area(m^2)	Loss rate Evaporation + deep drainage (mm/day)	Recycled Volume over the monitoring period (ML)	Monitoring period (days)	Water reuse (ML/week)
Lot 266	8,000	10.14	15.35	48	2.2
Lot 248	8,400	6.80	22.31	48	3.2
Lot 252	10,600	3.50	57.69	48	8.2
Woodhouse 2A	34,000	NA	295.9	41	47.4
Lot 28	4,400	8.00	7.92	41	1.3
Lot 31	7,000	6.4/7.7/17.4	13.34	41	2.2

Assumptions and limitations

Assumptions were made to take data from the Burdekin (fully irrigated cane with furrow irrigation) and to hence apply in other regions such as Mackay Whitsunday (supplementary irrigation with overhead) or the Wet Tropics (rainfed sugarcane).

Management practices

What are the relevant practices that can deliver the solution set?
Comparison of recycle pits and constructed wetlands.

What is the geographic extent of each of the practices?
Can be used throughout the GBR sugarcane regions but recycle pits more effective in some locations such as the lower Burdekin due to rainfall regimes and to residence time factors.

What is the range of costs associated with each practice?
We can obtain cost information from a range of sources and published material on the costs of building constructed wetlands/pollutant traps of various designs and sizes in the lower Burdekin and some other GBR regions, for example, the Wet Tropics and Mackay Whitsunday.

From a review of existing costs, e.g. from Marsden Jacobs (above) these can range from $800,000 - $1,000,000 per hectare for small constructed wetlands to $200,000 to $500,000 per hectare for medium to large ones.

What is the likely efficacy of each practice?
Some data exists for the efficacy of recycle pits in the Lower Burdekin region and this was used directly in the modelling. To quantify the likely performance of wetlands and recycle pits, modelling was undertaken in the MUSIC modelling software (see above). While typically applied in urban environments, MUSIC can easily be configured to provide simulations of non-urban catchments. Previous work undertaken in the region to model wetlands (DPI 2009) had identified relevant modelling parameters to use and these were applied to representative wet tropics and dry tropics climatic conditions.

The modelling results show both the wetlands and recycle pits need to occupy significant areas to have any real efficiency. It is obvious from the results that there is a threshold size for the pits that needs to be achieved to have both sufficient volume, to support the reuse rates, and to ensure that they are sufficiently drained to capture the next runoff event. From the wetland side of things, it appears that you need around twice the area of wetland to get the same removal rate of a recycle pit, once the pit reaches that threshold, but this holds only for the dry tropics, in the wet tropics, both the recycle pit and a constructed wetland seem to have similar performance, but again, this is without any optimisation of either. Recycle pits are not used in the Wet Tropics as there is minimal tailwater in these basically rainfed systems or even when supplementary irrigation (overhead) is used, thus consideration of recycle pits in the Wet Tropics was discarded. The recycle pits really need to have sufficient reuse demand to process the inflows and create storage for the next event. The wetlands need to be configured to process each event more efficiently by reducing detention time and optimising treated volumes and overall reduction.

Lower Burdekin wetlands and recycle pits
The results of the analysis for Lower Burdekin wetlands and recycle pits are shown in Figure 88, Figure 89 and Table 91.

Modelling Assumptions

Assumes 200 ha cane farm (DIN parameterised as per Rohde et al 2006)

- Uses Ayr rainfall for period 1980-2009 for Burdekin wetlands and Tully rainfall for the same period for approximating wet tropics
- Wetland parameters
  - 0.5m extended detention depth
  - average depth below standing water level 1m
  - sediment basin 10% of total area
- Recyle Pit parameters
  - reuse 2600 kL per year (25mm/week irrigation)
  - 1m extended detention depth
  - average depth below standing water level 2m
- Average size 0.876 ha (for all except Woodhouse 2A)
- Average cost: $175,000 per storage (Shannon and McShane 2013 - p17 $150-200k per storage)
- Assumed capital cost $199,771.69 per ha (say $200k/ha)

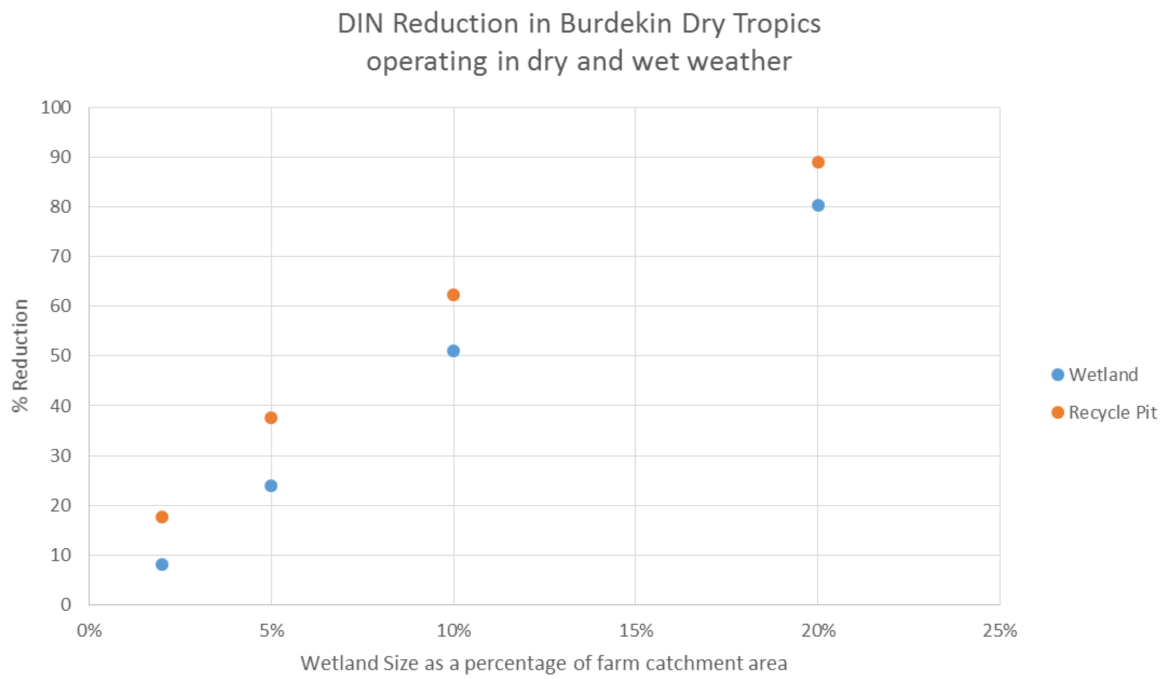

Figure 88. *Wetland and Recycle Pit Performance for Event Runoff for DIN in Burdekin*

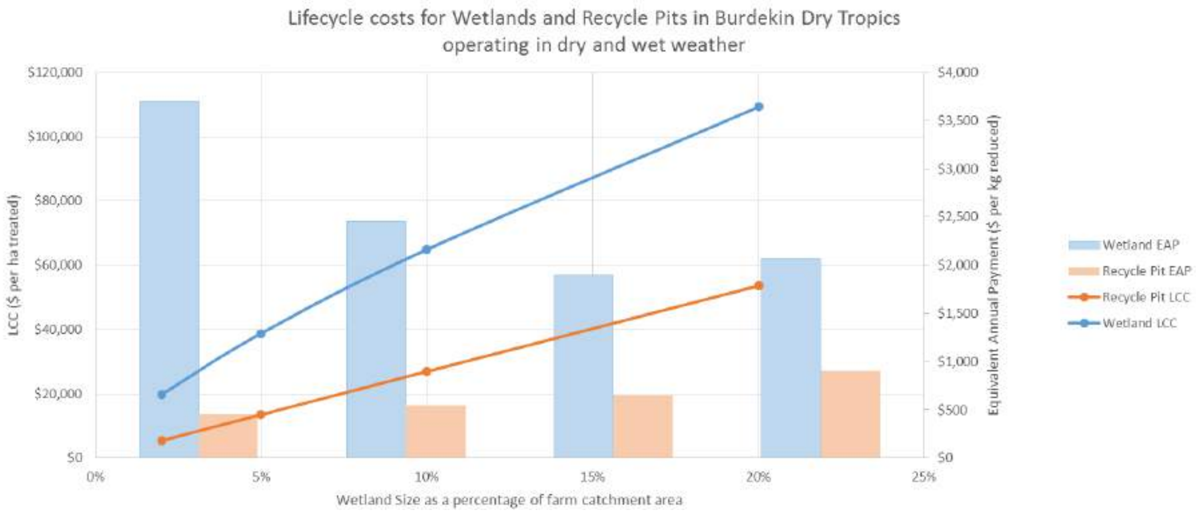

Figure 89. *Lifecycle costs for the Burdekin*

Table 91. Estimated costs and efficacy for Burdekin wetlands and recycle pits

Area of treatment device	Wetland LCC			Recycle Pit LCC		
	DIN reduced	Life Cycle Cost	Equivalent Annual Payment	DIN reduced	Life Cycle Cost	Equivalent Annual Payment
(% of farm area treated)	%	($2016/ha treated)	($/kg reduced)	%	($2016/ha treated)	($/kg reduced)
2%	8	$19,786	$3,702	18	$5,417	$461
5%	24	$38,757	$2,456	38	$13,507	$545
10%	62	$64,879	$1,897	67	$26,923	$653
20%	80	$109,241	$2,071	89	$53,613	$906

Wet Tropics wetlands
The results of the analysis for Wet Tropics wetlands are shown in Figure 90 and Figure 91 and Table 92.

Assumptions

- Assumes 200 ha cane farm (DIN parameterised as per Rohde et al 2006)
- Wetland parameters
  - 0.5m extended detention depth
  - average depth below standing water level 1m
  - sediment basin 10% of total area

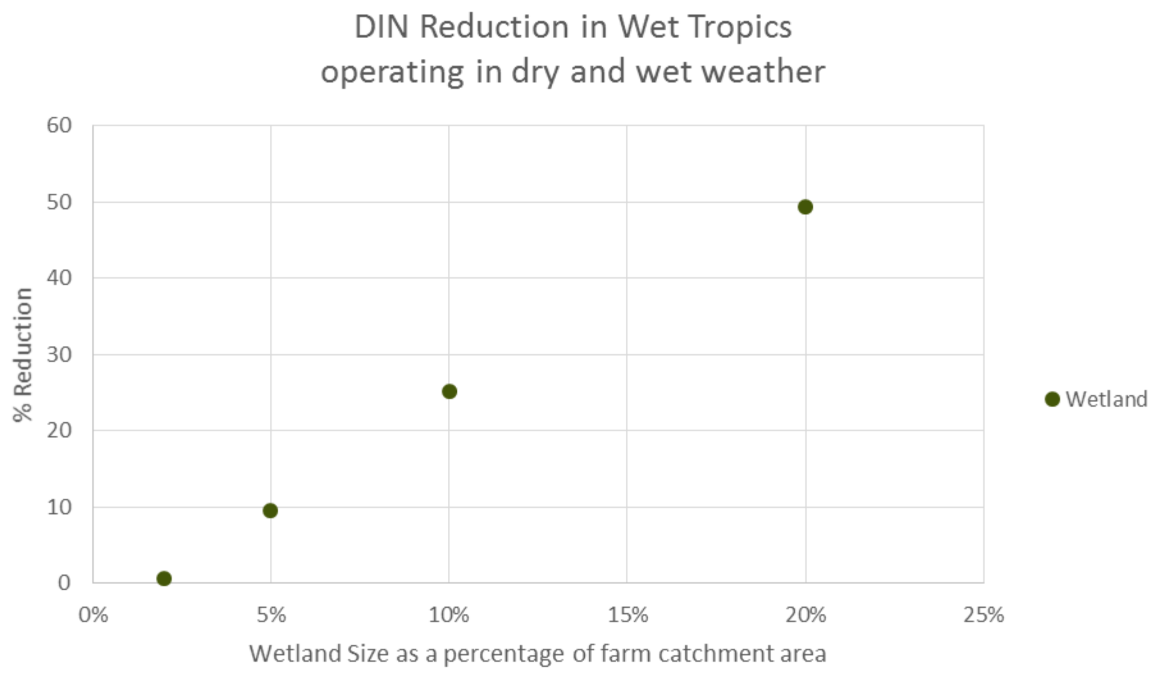

Figure 90. *DIN reduction in Wet tropics*

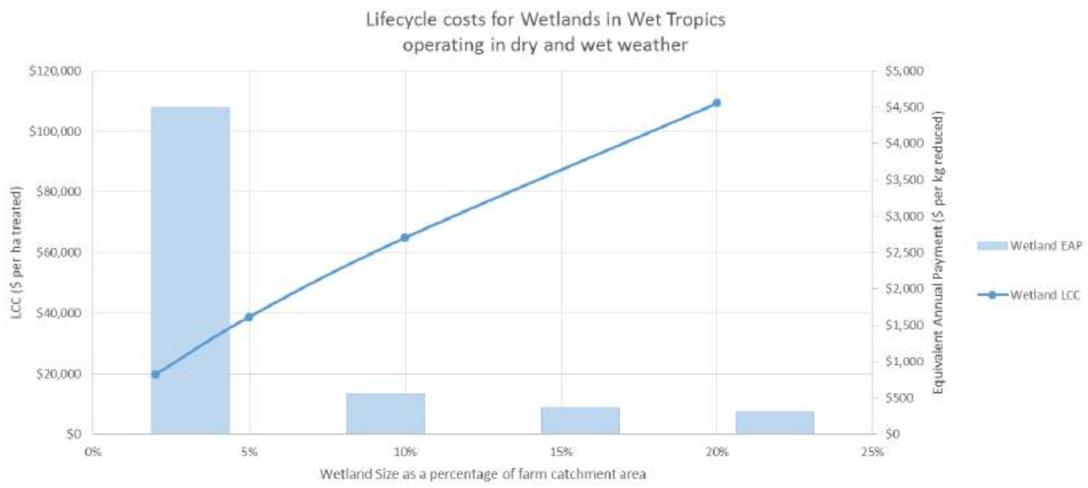

Figure 91. *Lifecycle costs for the Wet tropics*

Table 92. Estimated costs and efficacy for Wet Tropics wetlands

Area of treatment device	**Wetland LCC**		
	DIN reduced	Life Cycle Cost	Equivalent Annual Payment
(% of farm area treated)	%	($2016/ha treated)	($/kg reduced)
2%	1	$19,786	$4,489
5%	10	$38,757	$560
10%	42	$64,879	$361
20%	49	$109,241	$313

Overall results

In addition to investigating recycle pits being used for wet weather, we also looked at their current application in treating irrigation tailwater runoff during dry weather. The performance of these was modelled by DNRM and DSITI modellers using APSIM and HowLeaky to simulate the capture and reuse of irrigation tailwaters in the Burdekin and Burnett Mary regions. We used these results in the meta-model to obtain performance of the 'dry weather' recycle pits in addition to the wetlands and recycle pits treating both dry and wet weather. These results are shown in Table 93 and Figure 92.

Table 93. Results for DIN reductions Burdekin recycle pits and wetlands

Solution set action	**loads (t/yr)**	**mass load reduction (t)**	**% reduction**
2013 Load	2770	0	0%
Dry weather recycle pit	2740	22	1%
Wet weather recycle pit at 2% of farm area	2570	193	7%
Wet weather recycle pit at 5% of farm area	2350	413	15%
Wet weather recycle pit at 10% of farm area	2030	736	27%
Wet weather recycle pit at 20% of farm area	1790	978	35%
Wetland at 2% of farm area	2680	87.9	3%
Wetland at 5% of farm area	2500	262	9%
Wetland at 10% of farm area	2090	681	25%
Wetland at 20% of farm area	1880	884	32%

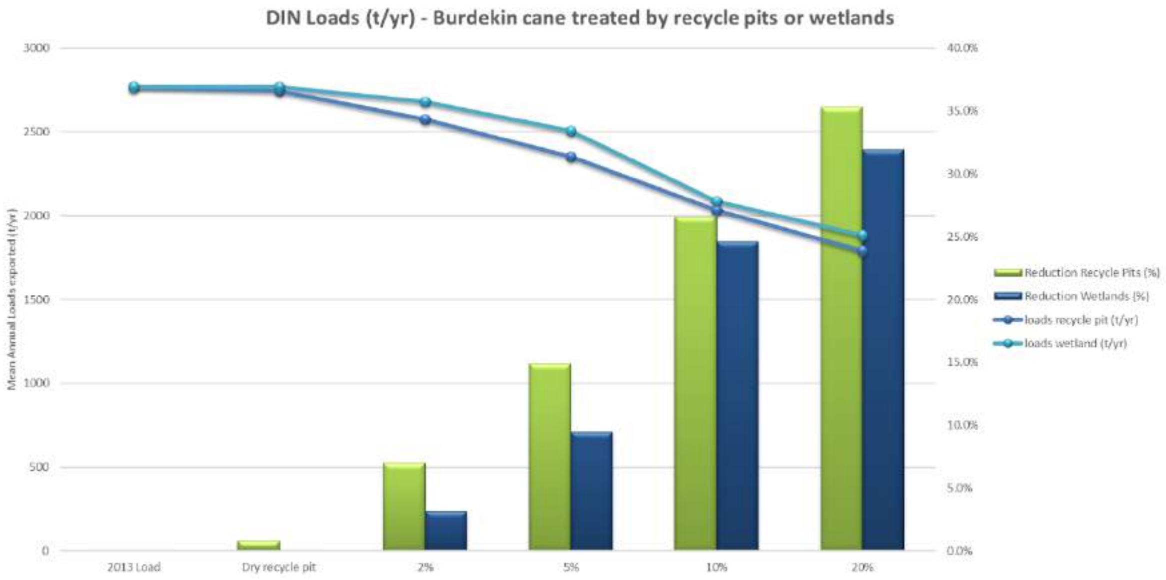

Figure 92. *Results for solution set 5 – Burdekin constructed wetlands and recycle pits*

In the Burnett Mary, the results for the dry weather recycle pits are shown in Table 94.

Table 94. Results for DIN reductions Burnett Mary dry weather recycle pits

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	866	0	0
Dry weather recycle pit	857	10	1.1%

These results show that both wet weather recycle pits and wetlands can be effective for reducing DIN loads, however they need to be of considerable size to achieve a significant reduction, and obviously, this will be reflected in the costs of the treatment. Dry weather recycle pits are not very good at reducing DIN loads to the GBR, however they may play a role in both managing the dry weather loads of nutrients into downstream creeks and wetlands and also in pesticide treatment, both of which were not examined in this project.

The costs and effectiveness data derived from the above analysis was entered into the overall cost/effectiveness spreadsheet.

Implementation issues

The type of wetland constructed needs to take into account rainfall and irrigation regimes, objectives, e.g. trapping fine sediment, dissolved nutrients and/or dissolved herbicides; biodiversity gains; long-term effectiveness, degree of protection the GBR versus other high value ecosystems, for example, Ramsar sites. In addition to these broad issues in any catchment there are likely to be local constraints relating to land ownership and tenure, existing wetland condition, location with respect to existing cropping areas, local drainage and hydrology, access, presence of irrigation, distance to valued ecosystems, issues of disturbing Potential Acid Sulphate Soils, land area availability and hydrological factors.

Conclusions

The modelling shows (see section *Lower Burdekin wetlands and recycle pits*) that if wetlands or recycle pits are of sufficient size compared to the catchment drainage area (to provide adequate retention time), these systems can provide moderate capacity to trap DIN. However, these outcomes are not reflected in experimental results in the GBR catchments to date (most results show little or no trapping of DIN), which may be an indication that the wetlands tested were not optimally designed to have sufficient capacity to trap significant amounts of DIN. The number of constructed wetlands installed in the GBR catchment over the last 20 years (when funding has been provided by governments to build them) which are of sufficient size to be effective in the wet season is not known.

Overall there is evidence of some trapping in the dry season (low risk period) but limited trapping during larger rainfall events in wet season (the high risk to end-of-valley loads period based on the size of most existing constructed wetlands) when well-designed constructed wetlands are bypassed.

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B.6 Policy solution statement 6: System repair - changes to landuse

Policy solution set description and context

This policy solution set aims to assess the costs and efficacy associated with changes to landuse as follows:

Sugarcane: voluntary retirement of 10%, 30% and 50% of sugarcane area under D class management in priority regions in each of the Wet Tropics, Burdekin and Mackay Whitsunday regions to the following alternative landuses:

- Biodiversity conservation management (land purchased by the government) and maintained through on-going weed and pest control.
- Conversion to grazing lands assumed to be purchased by government, covenanted to only enable low impact grazing (no nitrogen fertiliser) and then resold as unimproved grazing land.

Grazing land: Voluntary retirement of 5%, 10% and 20% of grazing land under D class management in the priority regions of Bowen, Upper/Lower Burdekin and the Lower Fitzroy catchments to biodiversity conservation through land purchase.

The declining health of the Great Barrier Reef (GBR) from increased loads of sediments and nutrients which are predominantly attributed to agricultural landuses has resulted in a number of programs since 2009 to improve water quality (Waterhouse et al. 2012; Brodie et al. 2013; Thorburn and Wilkinson 2013).

In major Australian agri-environmental programs including Queensland, the predominant methods used for encouraging change in farm management are extension and small, temporary incentive payments, reflecting Australia's reliance on low-cost voluntary approaches (Pannell and Roberts, 2015). Although considerable investment in changing agricultural management has occurred, it is becoming more well recognised that voluntary approaches will be insufficient (Craig and Roberts, 2015), particularly in the context of the substantial water quality targets which need to be achieved to protect the GBR.

Changing agricultural landuse affects the mix of benefits produced with inevitable trade-offs (DeFries et al. 2004). Such changes may be controversial, (Kim and Dale, 2011), due to the impact on competing resource uses (Gordon et al., 2010), agriculture and biodiversity conservation (Barraquand and Martinet, 2011). Although historically politically unpopular, there is at least some recent interest in assessing the need for land retirement (defined as the process of taking agricultural land out of production; United States Department of Agriculture, 2016) of some agricultural land.

The concept of land retirement is not new. Retirement of erodible land in the United States has occurred since the 1930s and for decades in Europe (Hone et al. 1999; Land & Water Australia, 2009). In Australia there have also been various pilot programs involving small scale and voluntary land retirement. Amongst the most notable Bushtender, a Victorian voluntary auction-based approach (Land & Water Australia, 2009) and also land purchase and covenanting through the Trust for Nature (http://www.trustfornature.org.au/).

Several factors are required for land retirement programs to be successful. These are clear objectives and the mechanisms for targeting land for retirement based on environmental benefit (such as use of metrics such as an Environmental Benefits Index), and the cost of retirement. One of the key issues of land retirement is calculation of the compensation for changing landuse and secondly where the land retirement should occur.

The mechanism used for land retirement has large implications on the cost and landholder participation. Mechanisms range from a non-binding voluntary agreement with landholder retaining full property rights but agreeing to manage the land differently (Comerford, 2014), a binding voluntary agreement such as through BushTender (Stoneham 2002), to covenanting or outright purchase and external management such as resumption for a public park. There is also significant heterogeneity in terms of landholder willingness to voluntarily retire land as well as problems of information asymmetry (landholders know the costs of land retirement on production and profit greater than the government, and the government understands the environmental values more than landholders).

Under the current legislative framework, there are a number of different land tenures and types of leases which have different conditions under the *Land Act 1994*. Rural leasehold land which has terms of 30 and 50 years with a maximum term of 100 years required renewal of the lease agreement under the Delbessie Agreement. The Delbessie Agreement is a framework of legislation, policies and guidelines supporting the environmentally sustainable, productive use of rural leasehold land for agribusiness. In 2012 it was repealed and replaced by the State Rural Leasehold Land Strategy which again builds on the principles of the statutory duty of care and provisions relating to land degradation (Parliamentary Committees 2013). This includes soil erosion, riparian management, biodiversity conservation and any process that results in declining water quality (DNRM 2013).

Scope of work

Although there is an existing legislative framework, the scope of this study is to understand the costs for landholders to be incentivised to retire land from agricultural production to remediate land to reduce fine sediment and DIN from entering into the GBR. For the purposes of this study it is assumed that land retirement is voluntary and targeted to areas of high environmental benefit (significant pollutant impact into the GBR).

The scope of work for the voluntary retirement of D class sugarcane and grazing land was based on the market value of land which was assumed to be purchased by the government. It was assumed that the required amount of land to be retired would be achieved voluntarily (100% participation of affected landholders). Changes to farm profit were not relevant for this solution set as land was purchased. No costs for extension or regulation have been costed as these mechanisms are not relevant to the retirement of land. The approach has also only considered incentivised land retirement and has not considered other policy options such as tenders or stewardship agreements.

This piece of work is assumed to be considered in conjunction with other policy solution sets such as gully and stream management in particular. Land retirement would reduce the pressures on streams and gullies and could substantially reduce costs for these solution sets.

Method

The method involved identifying the costs for different land retirement options in the sugarcane and grazing industries. The costs that were then estimated in this method were the market purchase of land and the future management of the land. Costs were estimated on a property basis and then disaggregated to a per hectare basis to estimate the cost over a number of hectares. Due to spatial heterogeneity in the landscape and the variance in climatic influences (van Grieken et al 2014, Star et al 2015) a best case cost, worst cast cost and most likely cost estimates were developed for each of the land retirement percentages and cost parameters.

The selection of focus catchments in the grazing lands was informed by the original policy solution statement from DEHP, and modified with further information on specific areas with high total suspended sediment loads and nutrient loads in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy Water Quality Improvement Plans (Star et al. 2015; Waterhouse et al. 2016).

Estimating the cost of land retirement involved a number of components. This included the management practice adoption data from the Paddock to Reef (P2R) Water Quality Risk Frameworks as well as the estimation of market values for land to retire were then derived and subsequent management costs (Figure 93).

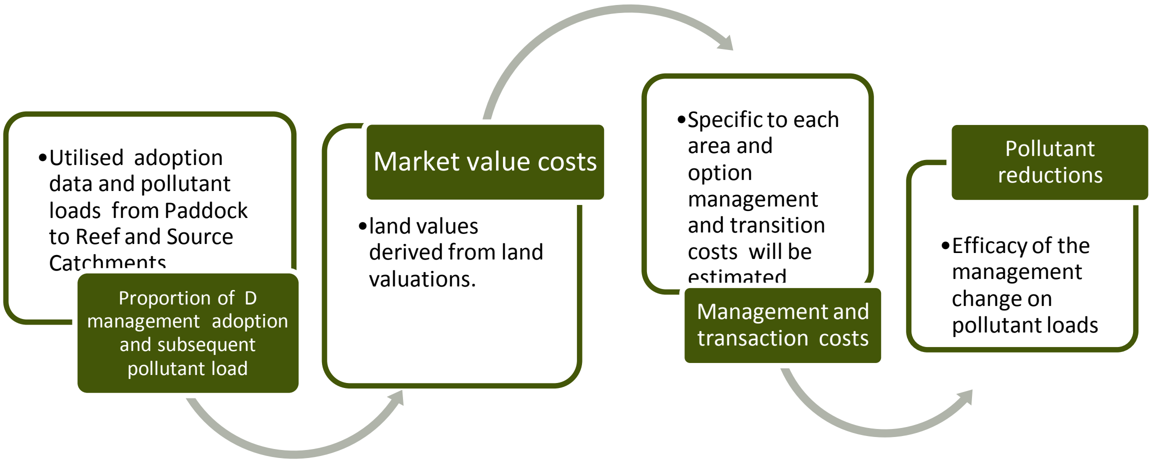

Figure 93. *The four stage methodology for assessing process toward the targets.*

The area in D management was derived from the 2013-2014 Great Barrier Reef Report Card (Queensland Government, 2015). The subsequent proportions to have voluntary land retirement in each of the catchments were then calculated out (Table 95).

Table 95. Management Areas in D management practice

Catchment	Industry	Area (ha)
Wet Tropics - 10%	Cane	443
Wet Tropics - 30%	Cane	1,330
Wet Tropics - 50%	Cane	2,210
Burdekin - 10%	Cane	802
Burdekin - 30%	Cane	2,410
Burdekin - 50%	Cane	4,010
Mackay Whitsunday - 10%	Cane	284
Mackay Whitsunday - 30%	Cane	853
Mackay Whitsunday - 50%	Cane	1,420
Bowen - 5%	Grazing	34,600
Bowen - 10%	Grazing	69,100
Bowen - 20%	Grazing	138,000
Upper Burdekin - 5%	Grazing	28,700
Upper Burdekin - 10%	Grazing	57,300
Upper Burdekin - 20%	Grazing	115,000
Lower Fitzroy - 5%	Grazing	98
Lower Fitzroy - 10%	Grazing	196
Lower Fitzroy - 20%	Grazing	392

Farm size

Average farm sizes for sugarcane were assumed to be 150 ha for the Wet Tropics, 106 ha for Burdekin and 125 ha for Mackay Whitsunday. For grazing average property size was assumed as 20,000 ha for the Bowen and Upper Burdekin catchments, and 7,000 ha in the Lower Fitzroy catchment. The areas were based on a combination of work completed under the Water Quality Improvement Plans and other programs such as Game Changer, Reef Rescue and Property Identification Codes it is acknowledged that there is large variance in property size, however for the purposes of this study they were standardised.

Costs

The costs of land retirement were estimated based on land values, transaction and management costs. These costs are calculated based on the assumption that the State Government would incur all of the costs in the retirement of the land.

Land Values

The costs considered in each of the sugarcane and grazing solution statements were based on market values, although different land titles exist given that leasehold leases are bought and sold on the open market at values approximately equivalent to the value of freehold property no cost differential was estimated (Parliamentary Committee 2013).

A number of data sources were used to estimate market land values including Herron Todd White Rural Market Update (2015), current rural real estate listings and Department of Natural Resources and Mines unimproved land valuations (2015) which do not include the value of any capital improvements including fencing, troughs, sheds or houses.

Estimation of annual on-going maintenance costs

It was assumed that sugarcane land would need revegetation for cattle pasture as natural regeneration is unlikely to occur (or would occur very slowly). The upfront revegetation costs assumed:

1. $7,500/ha – based on the Queensland Trust for Nature estimates of $5,000 ha initial revegetation upfront and $1250/ha;
2. $2,790/ha – from a report by Lovett and Price (2001) adjusted for inflation to 2016 valuation;
3. $33,000/ha - which includes upfront and maintenance costs provided by natural resource management groups; and
4. $20,000/ha – which includes upfront and some maintenance costs.

Based on this information, it was assumed that the upfront costs for the 'best case' estimate were based on (1), the Queensland Trust for Nature estimate; the 'worst case' estimate based on (3), Wet Tropics figure; and the 'most likely' estimate was intermediate between the two. It was assumed that maintenance costs in the Mackay Whitsunday region has been under-estimated, based on the Wet Tropics figures outlined above, the same costs were assumed for the three catchments.

For the grazing it was assumed that given the land is under D management, upfront improvements would be required including some remediation of scalded bare areas. It was assumed that 20% of each property would need treatment. For the 'worst case' estimate, chisel ploughing and seeding was assumed to be required at a cost of $260/ha, for the best case crocodile seeding was assumed ($150/ha) with the most likely being the average of the two ($210/ha) (Moravek and Hall, 2014). Unlike on sugarcane properties, regeneration of native vegetation on grazing properties was assumed to occur naturally (no need for revegetation planting) based on the fact that land has not been cultivated under grazed landuse. The total upfront costs were estimated as the sum of purchase price plus remediation of scalded areas. On-going pest and weed maintenance was assumed as uniform for the three catchments. Maintenance was assumed to include spot spraying of woody weeds.

Results

The cost estimates for each of the three land retirement options are shown in Table 96, Table 97 and Table 98. For sugarcane conversion to biodiversity (Table 96) and grazing conversion to biodiversity (Table 98) the upfront costs were assumed as the land purchase price plus upfront initial improvements. For the conversion of sugarcane to low impact grazing, the upfront costs were lowered due to the resale of unimproved land for grazing (Table 97).

<u>Conversion of sugarcane areas managed using D class management practices to biodiversity conservation</u>

The market values in sugarcane reflected the high productivity of the Burdekin irrigation areas with a smaller range of $10,000 per hectare (best case) to 17,000/ha (worst case). This region had the highest values and the smallest range. The Wet Tropics and Mackay had the largest range of the best case being $7,000/ha and the worst case $12,000/ha (Herron Todd White 2015).

Maintenance costs were assumed as $250/ha as 'worst case' (Bartley et al. 2015) based on potential flood, weed, and feral pest issues. Most likely was estimated to be $160/ha calculated from assumptions made for the streambank restoration solution set (two days maintenance per year at $800/day to maintain 10 ha and half this ($80/ha) assuming that it does not occur only on streambank and therefore has easier application and lower weed density.

<u>Conversion of sugarcane areas managed using D class management practices to low impact grazing land</u>

This solution set assumed that sugarcane land managed using D class management practices would be purchased by the government, with covenant conditions only allowing low impact grazing (zero fertiliser application, low stocking rates). It was also assumed that land would be resold as unimproved grazing land, noting that fences and infrastructure costs would need to be borne by the purchaser. Assumptions for the initial land purchase were as for the conversion of sugarcane land to biodiversity.

Conversion of grazing land managed using D class management practices to biodiversity conservation

Land values for D management land in the Bowen catchment had a range of $300/ha to $600/ha. The Fitzroy had the largest range reflecting the lower productivity woodlands to high productivity brigalow scrub of $800 to $1,600 per hectare respectively. The Upper Burdekin had a range of $500/ha through to $800/ha reflecting the large sized properties and medium productivity land types (Herron Todd White 2015).

On-going pest and weed maintenance was assumed as uniform for the three catchments. Maintenance was assumed to include spot spraying of woody weeds. The figures were based on estimates from central Queensland grazing properties ($10/ha and doubled to $20/ha on the basis that costs would be higher for conservation than where grazing was permitted). The 'best case' scenario was assumed to have costs reduced by 25% and for the worst case a 25% increase in costs, there being no hard information to base the figure on.

Table 96. Estimated costs for conversion of sugarcane areas managed using D class management practices to biodiversity conservation

	most likely			best case (cheapest)			worst case (most expensive)		
	Wet Tropics	Burdekin	Mackay Whitsunday	Wet Tropics	Burdekin	Mackay Whitsunday	Wet Tropics	Burdekin	Mackay Whitsunday
Average estimated farm size (ha)	150	106	125	150	106	125	150	106	125
cost of land to purchase ($/ha)	10,000	1,2000	10,000	7,000	10,000	7,000	12,000	17,000	12,000
upfront initial improvement costs ($/ha) - revegetation of cane land	18,750	18,750	18,750	7,500	7,500	7,500	33,000	33,000	33,000
cost of maintenance ($/ha)	160	160	160	80	80	80	250	250	250

Table 97. Estimated costs for conversion of sugarcane areas managed using D class management practices to low impact grazing land

	Most likely			Best case (cheapest)			Worst case (most expensive)		
	Wet Tropics	Burdekin	Mackay Whitsunday	Wet Tropics	Burdekin	Mackay Whitsunday	Wet Tropics	Burdekin	Mackay Whitsunday
Cost of land to purchase ($/ha)	10,000	12,000	10,000	7,000	10,000	7,000	12,000	17,000	12,000
Income from sale as grazing lands	5,866	5,324	7,209	4,927	4,360	5,729	6,289	6,289	8,689

Table 98. Estimated costs for conversion of grazing lands managed using D class management practices to biodiversity conservation

	Most likely			Best case			Worst case		
	Bowen	Upper/Lower Burdekin	Lower Fitzroy	Bowen	Upper/Lower Burdekin	Lower Fitzroy	Bowen	Upper/Lower Burdekin	Lower Fitzroy
Average property size	20,000	20,000	7,000	20,000	20,000	7,000	20,000	20,000	7,000
Cost of land ($/ha)	400	600	1,300	300	500	800	600	800	1,600
Cost of initial improvements - costs from land remediation paper on scalds ($/ha) year one	30	30	30	42	42	42	52	53	52
Cost of maintenance ($/ha) - pests and weeds	20	20	20	15	15	15	30	30	30

To simulate the changes in pollutant loads of converting landuse from D class sugarcane to either conservation or A class grazing, we took an average of the pollutant export rate (in t/ha/yr) for conservation and A class grazing in terms of DIN and applied this to the area of sugarcane to be converted. This, in effect, 'turned off' the DIN loads from the D class sugarcane as the pollutant export rates for DIN from both conservation and A class grazing were very low. The final solution set looked at converting 10, 30 and 50% of D class cane to either conservation or A class grazing in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday regions.

A very similar process was used for D class grazing lands being converted to conservation areas, where we used the pollutant export rate for conservation (in t/ha/yr) and multiplied that by the area being converted. The solution sets examined the conversion of 5, 10 and 20% of D class grazing lands to conservation in the Upper and Lower Burdekin Rivers and the Bowen River within the Burdekin Dry Tropics region and 5, 10 and 20% of grazing lands in the Lower Fitzroy catchment within the Fitzroy region.

The results for these scenarios are presented below.

Table 99. Results for fine sediment reductions Burdekin Dry Tropics grazing landuse change

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	4,300,000	0	0.0%
2013 with 5% D class grazing to conservation	4,270,000	29,700	0.7%
2013 with 10% D class grazing to conservation	4,240,000	59,300	1.4%
2013 with 20% D class grazing to conservation	4,180,000	119,000	2.8%

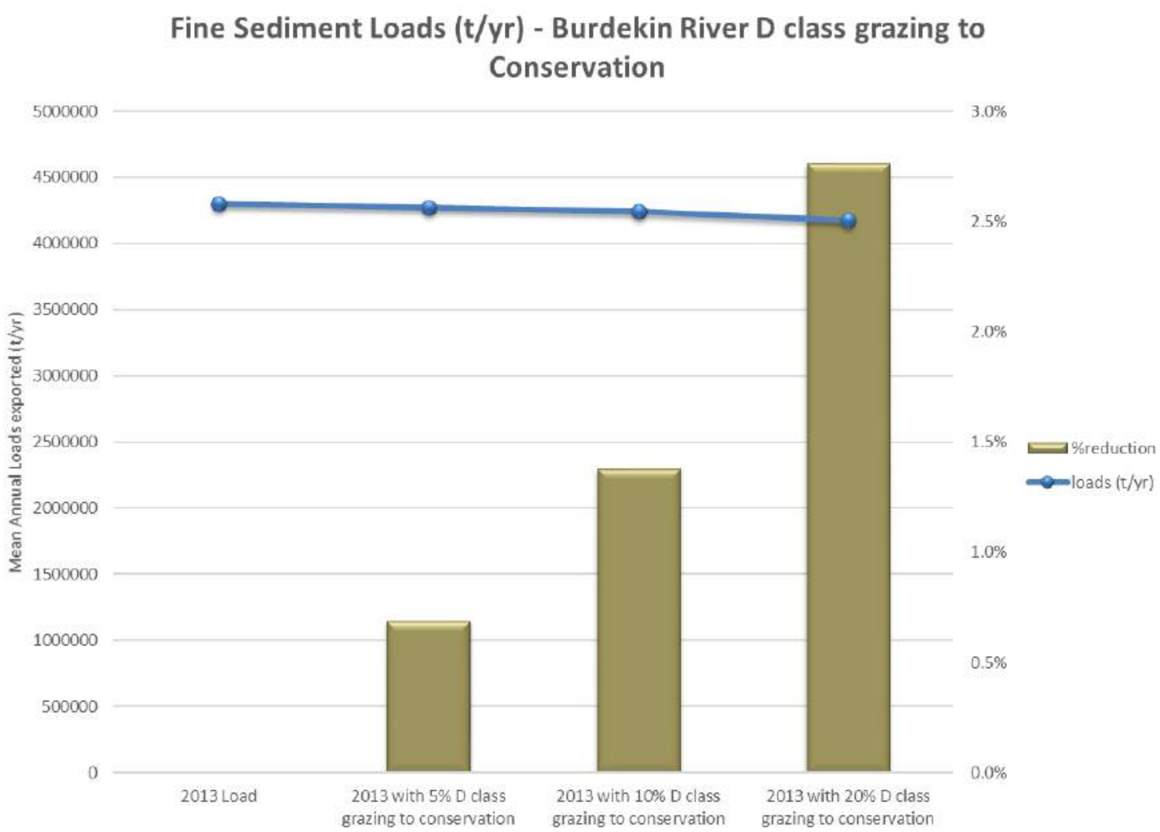

Figure 94. *Results for solution set 6 – Burdekin grazing landuse conversion*

Table 100. Results for fine sediment reductions Fitzroy grazing landuse change

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,800,000	0	0.0000%
2013 with 5% D class grazing to conservation	1,800,000	16	0.0009%
2013 with 10% D class grazing to conservation	1,800,000	32	0.0018%
2013 with 20% D class grazing to conservation	1,800,000	63	0.0035%

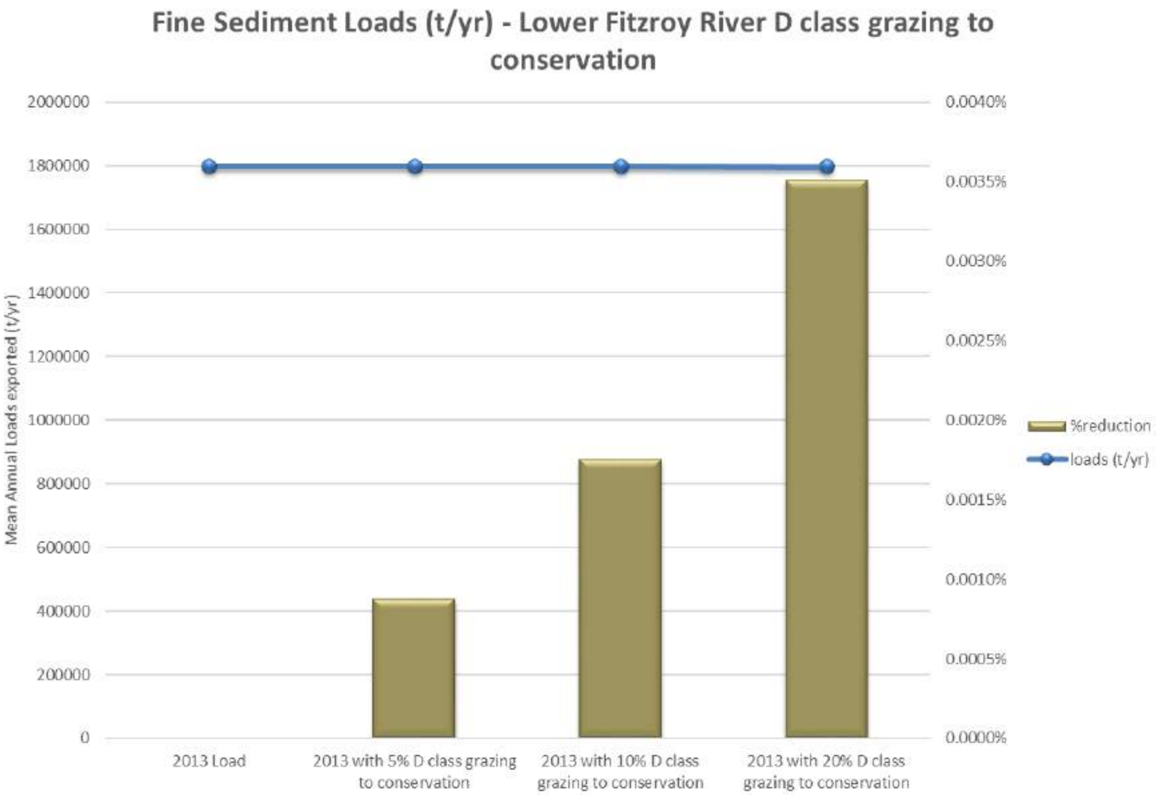

Figure 95. *Results for solution set 6 – Fitzroy grazing landuse conversion*

We can see from the above results that landuse change in the Fitzroy doesn't provide much (if any) real reduction in fine sediment and that is simply because the only areas of change were confined to the Lower Fitzroy catchment where there is only a small area of D class grazing. For this policy solution set to be more effective in reducing fine sediment loads, a broader area of land conversion would need to be considered.

In the Burdekin, there is some fine sediment reduction, but again, this is not very high because both the area of D class land being changed in the Bowen and Upper/Lower Burdekin Rivers is not very large, and that there are other catchments in the region where no landuse change is proposed. Still, this has targeted the highest exporting D class grazing lands and within the catchments of the Bowen and Upper/Lower Burdekin Rivers, the reductions are quite reasonable with an estimated 14% reduction in fine sediment from the Bowen River being predicted by the meta-model.

For sugarcane, the areas considered were larger, with up to 50% of D class cane areas being converted in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday regions being simulated in the meta-model. These results are given below.

Table 101. Results for DIN reductions Wet Tropics sugarcane landuse change

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	5,040	0	0.0%
2013 with 10% D cane to Conservation	5,030	12	0.2%
2013 with 30% D cane to Conservation	5,010	36	0.7%
2013 with 50% D cane to Conservation	4,980	59	1.2%
2013 with 10% D cane to A class Grazing	5,030	13	0.3%
2013 with 30% D cane to A class Grazing	5,000	39	0.8%
2013 with 50% D cane to A class Grazing	4,980	65	1.3%

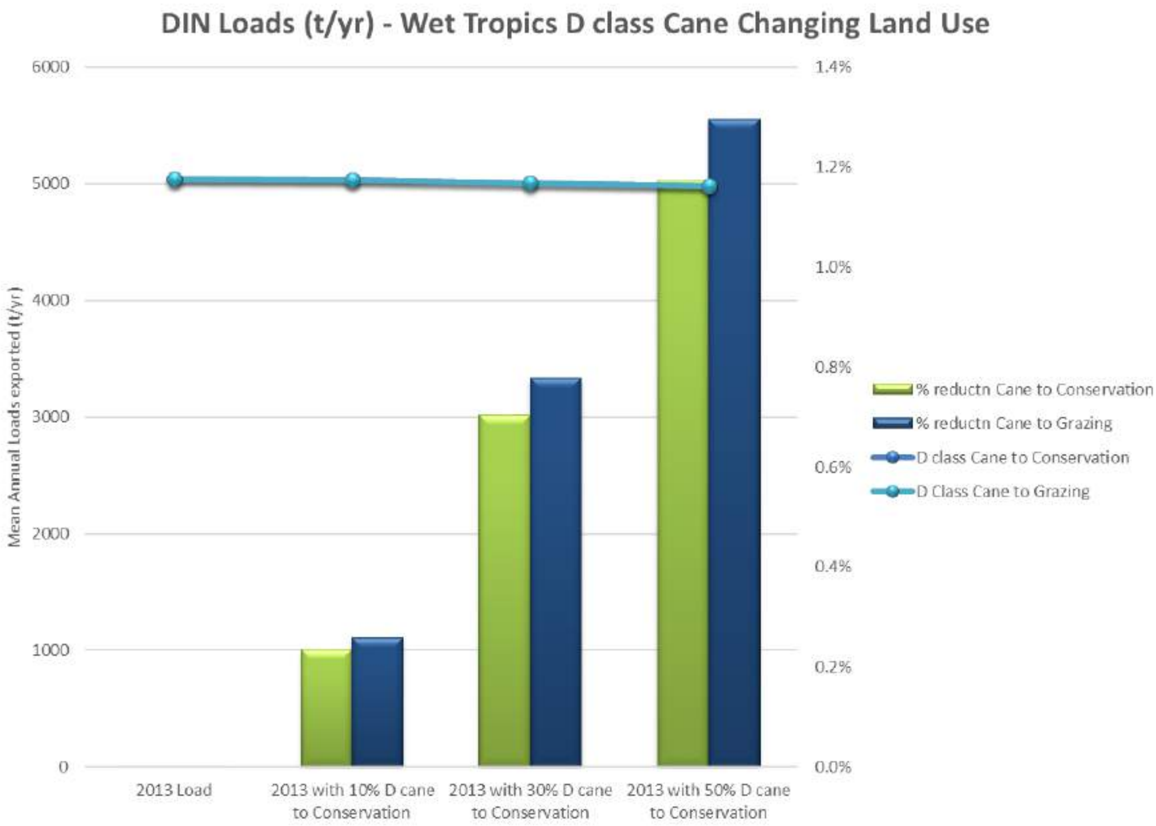

Figure 96. *Results for solution set 6 – Wet Tropics sugarcane landuse conversion*

Table 102. Results for DIN reductions Burdekin Dry Tropics sugarcane landuse change

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	2,770	0	0.0%
2013 with 10% D cane to Conservation	2,760	4	0.2%
2013 with 30% D cane to Conservation	2,750	13	0.5%
2013 with 50% D cane to Conservation	2,740	22	0.8%
2013 with 10% D cane to A class Grazing	2,760	4	0.2%
2013 with 30% D cane to A class Grazing	2,750	13	0.5%
2013 with 50% D cane to A class Grazing	2,740	22	0.8%

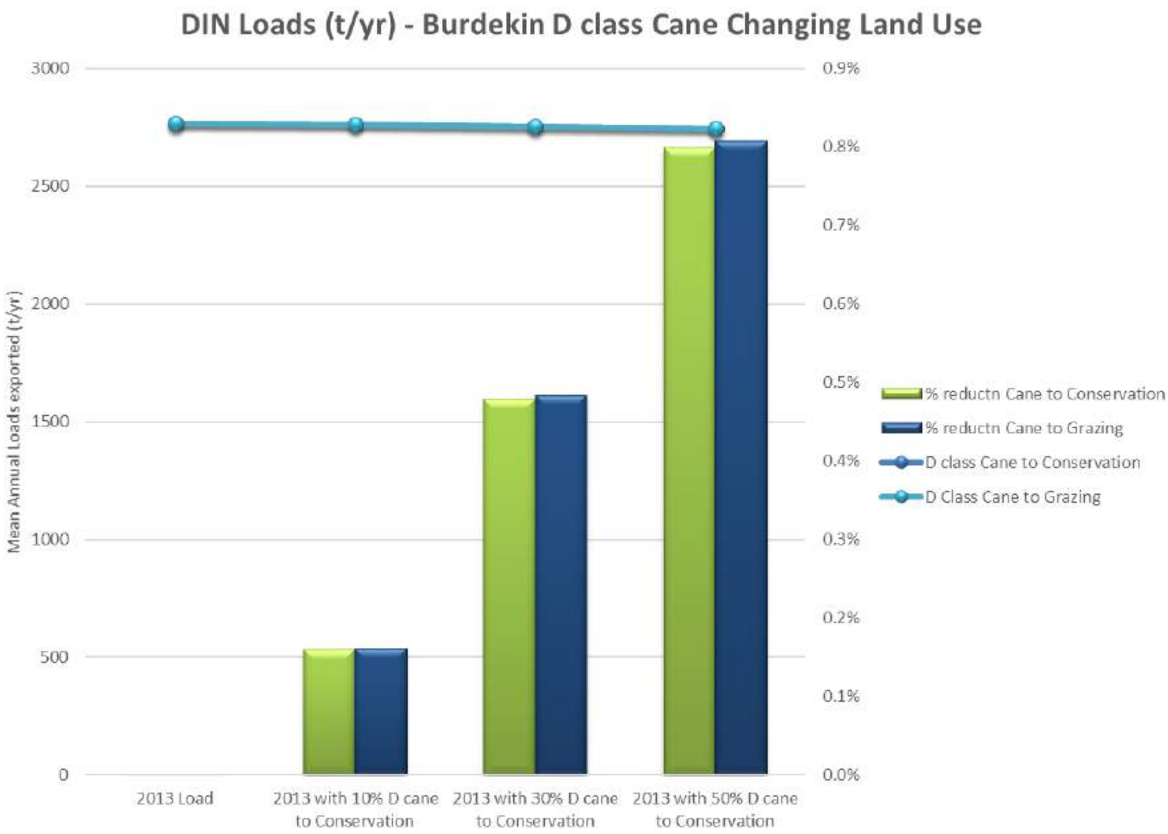

Figure 97. *Results for solution set 6 – Burdekin Dry Tropics sugarcane landuse conversion*

Table 103. Results for DIN reductions Mackay Whitsunday sugarcane landuse change

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
2013 Load	1,240	0	0.0%
2013 with 10% D cane to Conservation	1,230	12	1.0%
2013 with 30% D cane to Conservation	1,200	35	2.9%
2013 with 50% D cane to Conservation	1,180	59	4.8%
2013 with 10% D cane to A class Grazing	1,230	11	0.9%
2013 with 30% D cane to A class Grazing	1,210	33	2.7%
2013 with 50% D cane to A class Grazing	1,180	56	4.5%

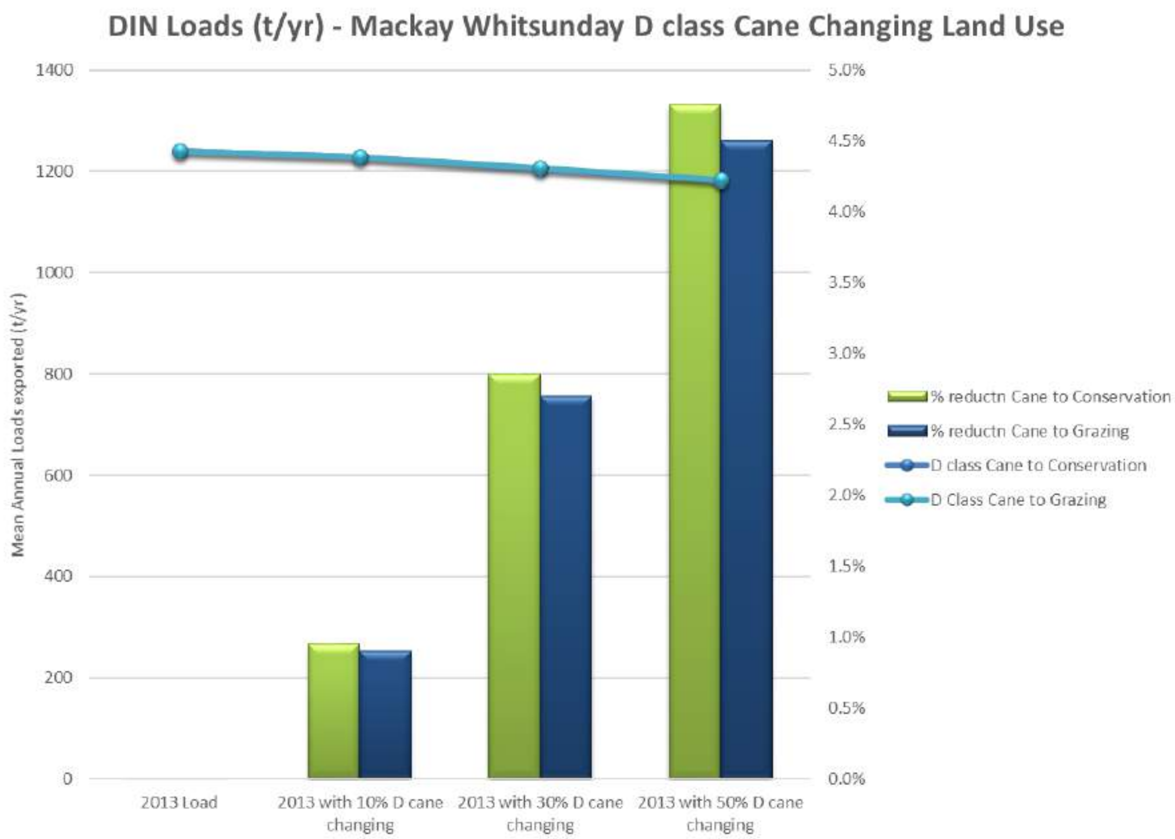

Figure 98. *Results for solution set 6 – Mackay Whitsunday sugarcane landuse conversion*

These results show that for the Wet Tropics and Burdekin, there is only a minimal reduction in DIN loads predicted by the meta-models and this is simply a function of the small area of D class cane in both regions. In the Mackay Whitsunday, there is a greater area of D class cane, so the conversion of it results in a better level of performance.

Time-lags

Three estimates of time-lags were made:

1. Maximum years that efficacy would last after project implementation (set at 20 years for all the land retirement options, which is the time period for this solution set analysis).
2. Estimated number of years before water quality benefits commence. For sugarcane, one year was assumed because although nitrogen fertiliser application was assumed to cease upon land purchase,

rundown of residual nitrogen is likely to take several years. For grazing, a one year time lag was assumed based on the fact that it would take several years for D class land to gain sufficient groundcover to reduce sediment loss and is highly dependent on climatic conditions.

3. Number of years until the maximum benefits are realised. For sugarcane, this was assumed to be one year as sugarcane would stop producing further dissolved inorganic nitrogen. For grazing, a time lag of nine years was assumed based both on grazing lands being typically further away from the GBR and that recovery of land condition from D class can take many years (Moravek and Hall 2014, Star et al 2011).

Additional assumptions and limitations

Key assumptions and limitations are outlined below.

Assumptions

- The opportunity cost, assumed as the price of land based on market value is extremely simple. It does not capture premiums landholder may seek in voluntarily retiring land (Kirwan et al 2005).
- The capture of additional upfront and maintenance costs is very simple and homogeneous. Overall there is extremely limited information on costs to achieve landuse change or practice change.
- The lack of capture of heterogeneity overall (single farm sizes assumed in each region, simple assumptions of upfront, transaction and maintenance costs on a combination of its market value).
- It is assumed that there is no difference between freehold and leasehold land.
- That the land is permanently retired from agricultural landuse.
- No consideration was given to the major socio-economic issue of properties which are too small for viable agriculture.
- Differences in the interest and capacity of landholders to move from the current to the desired state are ignored.
- For the conversion of sugarcane to low impact grazing land we have assumed that a binding covenant (registered on the title in perpetuity and dictates landuse) outlining the permitted use is imposed.
- The areas of land managed using D class management practices are based on modelled information through the P2R program. Through previous experience in WQIPs, landuse areas in sugarcane and also areas in both grazing and cane attributed to particular A, B, C or D management practices is highly contested. There is very limited and integrated information available to enable areas to be estimated with high confidence at this stage, and the level of understanding of current status varies considerably between industries and regions.
- Efficacy assumptions are very simple and have only focused on the change in dissolved inorganic nitrogen loads for sugarcane, and fine sediment loads for grazing lands.
- A single time-lag and linear response has been considered for grazing and sugarcane areas for 1) estimated number of years before water quality benefits commence; 2) number of years until the maximum benefits are realised; 3) maximum years that efficacy would last after project implementation. This assumption ignores heterogeneity in space and time. It assumes that implementation occurs immediately (which is not possible particularly due to the large areas of grazing).
- The management changes have been confined largely to hillslope management practices. Gully and streambank remediation have been considered in policy solution statements 3 and 4. In reality there will be a more complex interaction than the logical sequencing of policy solution sets (to meet the LTSP targets) that has been considered here.

Limitations

This analysis should be considered as a very simplistic 'first-pass' analysis. Land conservation approaches in this context are relatively new and require further implementation considerations before further costings can be considered. To be most effective for informing environmental planning and policy, agricultural landuse information needs to be of high spatial resolution. High spatial resolution, reliable and dynamic landuse information is necessary for integrating with biophysical data which commonly displays significant heterogeneity across the landscape. The costs associated with land retirement could have much higher variance than reported here.

- The logical sequencing of policy solution sets (gully and stream management in particular) (to achieve the regional Reef 2050 Plan targets) meant that these solution sets were considered in isolation from land retirement. Land retirement would reduce the pressures on streams and gullies and could substantially reduce costs for these solution sets.
- The areas considered were based on proportions set under the policy solution set from DEHP. In reality this may not reflect on-ground changes required or the location that is most practical, i.e. areas of sugarcane that occur on flood plains.
- Selection of land retirement projects and the pollutant reductions are location specific and therefore different approaches will be required to be developed, this has not been considered in this analysis.
- D level management is defined as the management practices that will further degrade land condition and subsequently increase loads per unit area. This is a significant limitation of the study as the areas may differentiate based on management or condition.
- There are likely to be substantial additional biodiversity and potentially wider community benefits through land retirement which have not been accounted for. Such benefits have not been considered in this land retirement analysis (and also for other policy solution sets) and are a major limitation of the current project.

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B.7 Policy solution statement 7: Urban stormwater management

Policy solution set description and context

- Whilst the bulk of the solution sets assessed in this report relate to the 'legacy' loads from past development, one of the emerging risks to the Reef is the growth in loads attributable to urban diffuse loads. The urban stormwater solution set relates to the implementation of efficient actions to address urban diffuse loads from *new* developments. All future urban development in the targeted local government areas would implement erosion and sediment control and water sensitive urban design (WSUD) actions to mitigate the growth in loads attributable to urban development. Performance requirements would be in line with those outlined in the Single State Planning Policy requirements for urban stormwater management in the region of interest.

- This policy solution set focuses on urban growth in the local government areas of Cairns, Townsville, Mackay and Rockhampton only. Therefore, they do not capture all of the risks associated with urban development, or the costs of mitigating that development.

- There are a number of permutations of urban loads that need to be addressed within this solution set and these are as follows:

    - 7a Urban loads are increased through greenfield development with no mitigation. This creates two distinct set of risks. Firstly, the significant loads attributable to the construction phase of development as land is cleared prior to the development of built structures, etc. Secondly the on-going increase in loads attributable to the operational phase of development.

    - 7b Urban loads are increased through greenfield development, but mitigated by effective Erosion and Sediment Controls (ESC) (construction phase) and Water Sensitive Urban Design (WSUD) (operational phase) at full compliance with the relevant best practice. Whilst ESC and WSUD will mitigate increases in loads, there will still be a residual increase in loads.

    - 7c Residual loads from the developed mitigated case (when compared to the predeveloped case) are offset by investment in rural diffuse treatments. In effect, this solution set increases the size of regional rural diffuse abatement targets to include the growth in residual loads from urban development.

This solution set draws on a reasonable body of previous relevant work which includes:

- Healthy Waterways (2010) A Business Case for Best Practice Urban Stormwater Management.
- Water by Design (2014). Benchmarking Erosion and Sediment Control Performance in South East Queensland - 2013. Healthy Waterways Ltd. Brisbane.
- Water by Design (2014). Off-site Stormwater Quality Solutions Discussion Paper (Version 1). Healthy Waterways Ltd. Brisbane.
- Healthy Waterways (in preparation) A Business Case for Erosion and Sediment Control.
- Unpublished results from the on-going Reef Urban Stormwater Management Improvement Group.
- In addition, various technical consultancies and modelling projects have been undertaken for specific urban development projects in the target council areas.

- It should be noted that this previous work has included loads modelling and abatement costing for WSUD relevant to the case study Local Government Areas (LGAs), with the exception of Rockhampton. Because the resources for this project do not allow for substantial new modelling, we have assumed the unit rates for efficacy and costs for Rockhampton are the same as Townsville.

Method

The basic method for the urban solution set and data sources is shown in the table below (Table 104). This was repeated for each LGA.

Table 104. Overview of approach

Step	Data / information sources / key assumptions
Estimate future development patterns (number and dwelling type). This step is required to estimate the amount of ESC and WSUD activity required for scenario 7b. It is necessary to separate the development into detached and attached dwellings as the actions and costs are vastly different depending on the development type.	Queensland Government forecasts of new dwellings by LGA, Building approvals data. In estimating the mix of future development, we have assumed the relative proportions of detached and attached dwellings over the past 10 years is a reasonable guide to future development patterns.
Determine appropriate ESC and WSUD management actions.	Based on 'deemed to comply' solutions the former SPP 4/10 Urban stormwater management and model runs.
Modelling efficacy (load mitigation).	Use of MUSIC.
Establish unit costs. This included all relevant planning and design, capital, operational and maintenance, regulation and extension costs.	Based on previous business cases and other technical reports. Figures have been updated to current values. Note: GBR-specific data is available for WSUD on-ground actions. However, for ESC and all relevant planning, design and regulation costs are inferred from work previously conducted in SEQ.
Estimate range of abatement costs. Modelling costs have been estimated as per the approach outlined in *Section **4*** This includes the estimation of a range of costs to reflect variance in input costs.	This is primarily a modelling exercise. The variance in the range of input costs is based on variances used in previous work (e.g. Business Case for WSUD).
Estimate costs of offsetting residual loads. This represents the gap between loads abated by ESC and WSUD and the estimated change in loads attributable to urban development. This would be secured via a rural diffuse offset in the same region. In effect, Scenario 7c provides an indication of the likely cost of achieving future urban development that is relatively benign to the GBR (excluding loads outside the scope of the scenario such as wastewater treatment costs).	Modelled exercise based on residual loads estimated from MUSIC and costs of abatement from other scenarios. The offset cost is estimated as the marginal cost of the next most cost effective action after the regional targets have been met. This cost is added to the cost to scenario 7b. We have used the action after the targets have been met, as we assume cheaper actions are already fully exhausted in meeting their specific scenarios (e.g. rural landuse practices).

Assumptions and limitations in modelling

Key assumption in our estimations include:

- State dwellings forecasts for the target LGAs are the series developed in 2013. It should be noted that these estimated growth rates are higher than actual growth rates over the past two years due to a slowdown in the resources sector.
- The historical development patterns (average % detached, % attached over the past 10 years) are a reasonable representation of future development patterns.
- Detached dwelling density is 13.2 lots per hectare (consistent with previous modelling).
- The suite of WSUD and ESC solutions identified and previously modelled are an effective urban response.
- The modelling parameters in MUSIC are a reasonable reflection of the efficacy of on-ground practices.
- The unit costs established in previous projects (adjusted for inflation using the non-housing construction price index) are a reasonable reflection of actual costs.

- In the absence of specific costing data for Rockhampton, we have assumed that unit costs for Rockhampton are the same as Townsville.
- Transaction, management and regulatory costs previously calculated for SEQ are a reasonable reflection of those costs in the GBR.
- The variance in costs (outlined in Table 108 and Table 109) are assumed to be normally distributed around the median (most likely) cost for each input cost included in the modelling.

Key data gaps and limitations include:

- There is not sufficient information and resources to differentiate assessments based on location-specific soil types, slopes, etc.
- While we have assumed full compliance as the base case, information of actual compliance is very limited. However, anecdotal information suggest compliance levels are currently very low for ESC, while the effectiveness of much of the WSUD investment is compromised due to deficient design and implementation.

We have also assumed that the key policy mechanisms for this solution set will be:

- For Scenario 7b, we have assumed this would be a regulatory requirement for all new developments. While the costs of ESC and WSUD establishment costs would initially be borne by developers, these costs would be passed onto consumers (e.g. purchasers of new dwellings). The on-going operations and maintenance costs for WSUD would be incurred by local governments and recovered through minor net increases in rates.[8]
- For Scenario 7c, we have assumed that the offset would be secured in a similar means to other rural diffuse abatement (e.g. reverse tender to purchase on-farm abatement). The cost of this offset would be capitalised into the price of land and ultimately borne by consumers.

Management practices

Number of dwellings
We have estimated the total number of dwellings based on the Queensland Government's estimates of new dwellings for each LGA (last updated in 2013). We have then estimated the new developments by type (detached dwellings, attached dwellings) based on the average split of building approvals for each LGA over the past 10 years. Midpoint estimates are shown in the table below (Table 105).

Table 105. Estimated annual new dwellings by type

	Cairns	Townsville	Mackay	Rockhampton
Detached dwellings	1,340	1,786	979	494
Attached dwellings	468	562	239	139
Total dwellings	1,808	2,348	1,218	633

Using the assumed densities within the modelling undertaken for the development of SPP4/10, (13.2 dwellings per ha for detached dwellings, 37.5 dwellings per ha for attached), the total areal change of landuse through urbanisation (assuming development occurs at the rate in Table 2 for the period 2016-2025) is shown in the table below (Table 106).

[8] The implementation of ESC and WSUD *could* result in net savings to councils due to reduced expenditure required to manage downstream stormwater infrastructure.

Table 106. Urbanisation areal change for period 2016-2025

	Cairns	Townsville	Mackay	Rockhampton
Total areal change (ha)	1024	1350	723	369

On-going management practices

On-ground management practices are outlined in Table 107. While there would be variance in the scale and mix of the management practices depending on specific development site characteristics, the practices outlined below are dominant practices.

Table 107. Implementation issues with different types of interventions

Type of intervention	Implementation issues
ESC actions by developers	A suite of actions during construction including establishing drains, sediment basins, sediment fences, topsoil and hydromulch, rocks/gravel for driveway access, kerb inlet protection.
WSUD actions by developers	A combination of bioretention basins/pods, underground detention tanks and detention basins as modelled using MUSIC.

Indicative ESC costs

We have estimated unit costs based on the previous work underway for the Business Case for ESC (currently under development). Initial estimates (mid points) are in the table below (Table 108). Note there is no data available specific to each of the regions for some cost items. In this analysis we have assumed specific variances around the mean (most likely) input costs to establish a range for our modelling. In the absence of any formal studies, this variance is based on industry consultation.

Table 108. Indicative costs of WSUD interventions ($ per new dwelling)

Cost item	Cairns	Townsville	Mackay	Rockhampton	Assumed variance around the mean cost (%)
Minimal approach (small developments)					
Install sediment fence	$60	$60	$60	$60	50%
Temporary downpipes to stormwater	$200	$200	$200	$200	50%
Rock/gravel access driveway	$215	$215	$215	$215	50%
Supply and install turf strip (including preparation and watering)	$177	$177	$177	$177	50%
Kerb inlet protection	$8	$8	$8	$8	50%
Total	$660	$660	$660	$660	50%
Comprehensive approach (larger projects)					
Drainage					
Form drains	$141	$141	$141	$141	50%
Lining of drains	$85	$85	$85	$85	50%
Sediment control					
Sediment basins	$869	$869	$869	$869	50%

Sediment fence	$5	$5	$5	$5	50%
		Erosion control			
Ameliorate topsoil subject to Nutrient testing	$239	$239	$239	$239	50%
Apply hydromulch in accordance with specification	$596	$596	$596	$596	50%
Total	$1,934	$1,934	$1,934	$1,934	50%
Council inspections ($ per lot developed)	$365	$365	$365	$365	30%

Indicative WSUD costs

We have estimated unit costs based on the previous work undertaken for the Business Case for WSUD. Initial estimates (mid points) are in the table below (Table 109). In this analysis we have assumed specific variances around the mean (most likely) input costs to establish a range for our modelling. This variance is based on previous analysis for the WSUD Business Case and industry consultation.

Table 109. Indicative costs of WSUD interventions ($ per new dwelling)

Cost item	Cairns	Townsville	Mackay	Rockhampton	Assumed variance around the mean cost (%)
WSUD – detached dwellings					
Capex					
Bioretention basins/pods	$4,192	$3,407	$3,407	$3,407	20%
Underground detention tanks	$1,691	$1,691	$1,691	$1,691	20%
Detention basins	$201	$171	$184	$171	20%
Total	$6,085	$5,270	$5,282	$5,270	20%
Annual Opex					
Bioretention basins/pods	$41	$34	$34	$34	15%
Underground detention tanks	$6	$6	$6	$6	15%
Detention basins	$8	$7	$7	$7	15%
Total	$55	$46	$47	$46	15%
WSUD – attached dwellings					
Capex					
Bioretention basins/pods	$1,018	$1,110	$1,018	$1,110	20%
Underground detention tanks	$926	$1,009	$926	$1,009	20%
Detention basins	$38	$23	$38	$23	20%
Total	$1,982	$2,142	$1,982	$2,142	20%
Annual Opex					
Bioretention basins/pods	$10	$11	$10	$11	15%
Underground detention tanks	$3	$3	$3	$3	15%
Detention basins	$2	$1	$2	$1	15%
Total	$15	$15	$15	$15	15%

Cost item	Cairns	Townsville	Mackay	Rockhampton	Assumed variance around the mean cost (%)
Transaction and admin costs (once off)					
Design	$23	$23	$23	$23	60%
Assessment & approval	$250	$250	$250	$250	20%

Efficacy

The efficacy of operational WSUD derived through MUSIC model runs completed as part of the original WSUD Business Case assessments. To determine reductions for fine sediment and dissolved inorganic nitrogen, the pollutant reductions extracted from MUSIC were adjusted to reflect the proportions of those constituents typically found in urban stormwater. The most suitable data set with information on these components was the Brisbane City Council's former Urban Stormwater Monitoring Program. In this program, the particle size distribution analysis showed that 8% of the Total Suspended Solids across nine events was <24 microns, so this was assumed to be fine sediment (usually considered that fraction <16 microns). The fractions of ammonia and oxides of nitrogen were found to be 58% of the total nitrogen concentration across the same nine events so this value was used to represent DIN.

In the table below (Table 110), two different case study results were assessed and these should be applied to the increase in urban residential development within the appropriate region.

Table 110. Assumed Efficacy

		Scenario 7a	Scenario 7a	Scenario 7a	Scenario7b	Scenario 7c (to offset)
Urban Development		**Pre development**	**Developed**	**Load Increase**	**Developed mitigated**	**Residual Load**
Fine Sediment Loads (tonnes/yr)	Rockhampton	28.5	60.7	32.3	10.6	-17.9
	Mackay	59.5	121.2	61.7	26.3	-33.2
	Townsville	77.0	164.5	87.4	28.6	-48.5
	Cairns	124	221	96.1	44.1	-80.4
Urban development		**Pre development**	**Developed**	**Load Increase**	**Developed mitigated**	**Residual Load**
DIN Loads ((tonnes/yr))	Rockhampton	1.87	4.48	2.61	2.46	0.59
	Mackay	4.11	8.92	4.81	5.34	1.23
	Townsville	5.07	12.12	7.05	6.67	1.60
	Cairns	8.42	16.18	7.76	9.35	0.94
Developing urban (in transition)		**Pre development**	**Developed**	**Load Increase**	**Developed mitigated (ESC)**	**Residual Load**
Fine Sediment Loads (tonnes/yr)*	Rockhampton	28.5	57.9	29.5	2.9	-25.6
	Mackay	59.5	230	171	11.5	-48.0
	Townsville	77.0	157	79.8	7.8	-69.2
	Cairns	124	341	216	17.0	-107

*assumes 1/9th of load due to 1/9th of total area exposed per year for 9 years

Summarising these on a city by city basis are the results for the new urban landuse only, then how they change the overall fine sediment and DIN loads coming from the regions (Table 111). These results are aggregated for the years to 2025 to account for the gradual increase in new urban areas and then calculated as tonnes per year result (Figure 99 and Figure 100, Table 112 and Table 113).

Table 111. Policy solution set 7 results for each city within the GBR region

			Fine Sediment			
	Predevelopment (t/yr)	**Developed (t/yr)**	**Load change (t/yr)**	**Developed mitigated (t/yr)**	**load reduction (t/yr)**	**Residual Load (t/yr)**
Rockhampton	28.5	57.9	29.5	2.9	-25.6	-17.9
Mackay	59.5	230	171	11.5	-48	-33.2
Townsville	77	157	79.8	7.84	-69.2	-48.5
Cairns	124	341	216	17	-107	-80.4

			DIN			
	Predevelopment (t/yr)	**Developed (t/yr)**	**(t/yr)**	**Developed mitigated (t/yr)**	**(t/yr)**	**Residual Load (t/yr)**
Rockhampton	1.87	4.48	-2.61	2.46	-0.592	0.592
Mackay	4.11	8.92	-4.81	5.34	-1.23	1.23
Townsville	5.07	12.1	-7.05	6.67	-1.6	1.6
Cairns	8.42	16.2	-7.76	9.35	-0.935	0.935

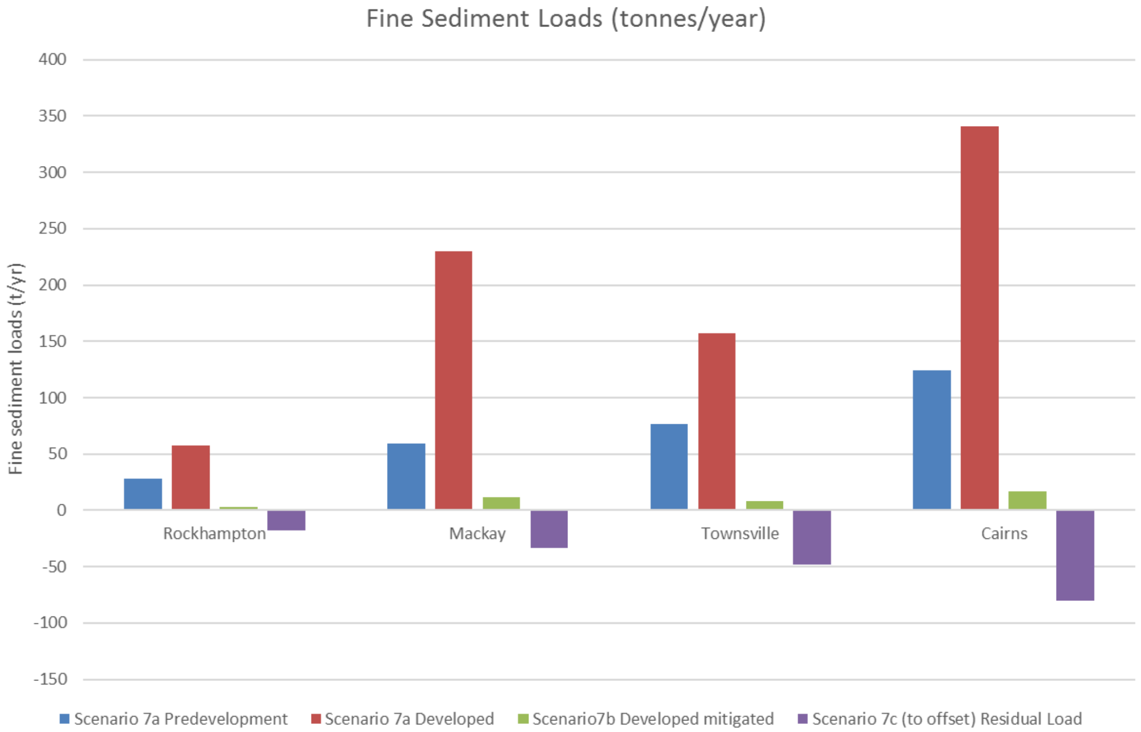

Figure 99. *Fine sediment loads from new urban areas*

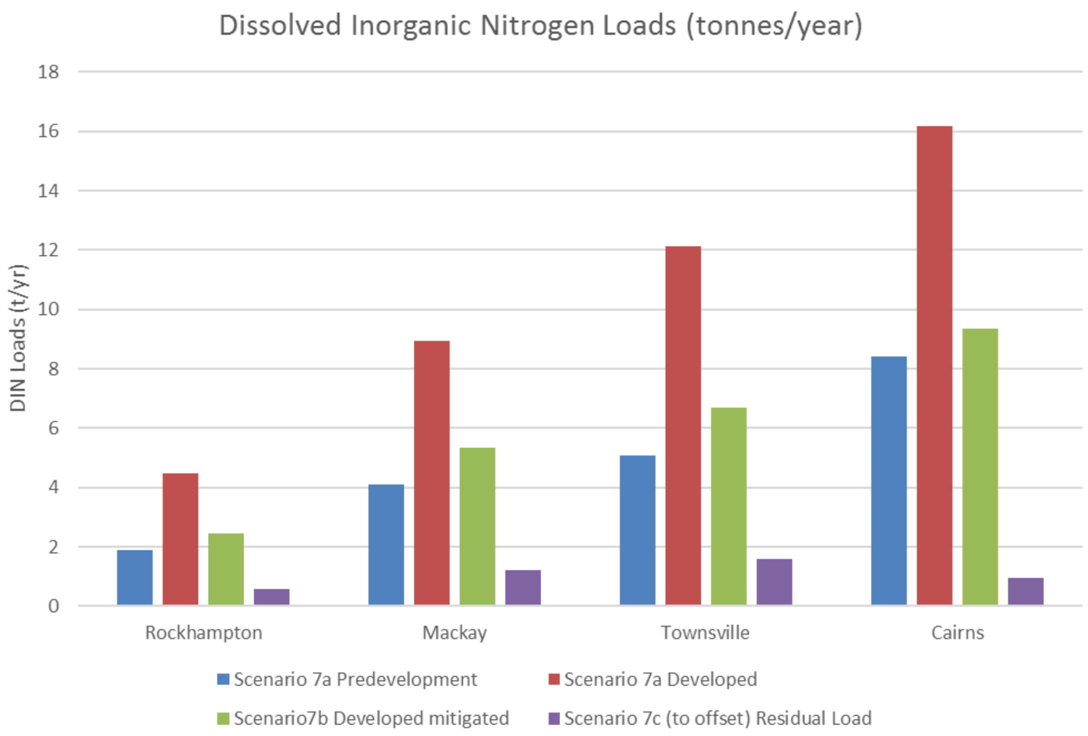

Figure 100. *DIN loads from new urban areas*

Table 112. Results for fine sediment reductions for new urban development

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
Wet Tropics - Cairns	1,660,000	80.4	0.005%
Burdekin - Townsville	4,300,000	28.6	0.001%
Reef Catchments - Mackay	611,000	26.3	0.004%
Fitzroy - Rockhampton	1,800,000	10.6	0.001%

Table 113. Results for DIN reductions for new urban development

Scenario	loads (t/yr)	mass load reduction (t)	% reduction
Wet Tropics - Cairns	5040	-0.935	-0.019%
Burdekin - Townsville	2770	-1.6	-0.058%
Reef Catchments - Mackay	1240	-1.23	-0.099%
Fitzroy - Rockhampton	1870	-0.592	-0.032%

These results show that if full treatment of new urban areas is implemented, then the overall loads of fine sediment are likely to reduce slightly, however for DIN loads, even with full treatment, some increase in loads would be predicted. This increase would need to be offset by investing in a low cost rural treatment to ensure that there was no overall load increase.

For erosion and sediment control, we have assumed that future greenfield development will apply appropriate measures that will achieve at least 95% TSS reduction (conservative estimate of effective sediment basins), though no DIN reduction will be assigned.

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Attachment C
Abatement costs

C.1 Abatement costs

Background

This attachment provides a technical summary of the Marginal Abatement Cost Curves (MACC) and Total Abatement Cost Curves (TACC) developed for this project.

The MACC and TACC approach developed for this project was based on our understanding of the project objectives as defined by DEHP. These were to evaluate the marginal and total costs and water quality benefits for seven well defined policy solution sets for GBR catchments to achieve the regional water quality targets as set out in the Reef 2050 Plan. The target date to achieve these objectives was set as 2025.

The approach estimates the costs of the investments needed to deliver each of the policy solution sets for the GBR. Abatement costs are the costs that are incurred to achieve the fine sediment and DIN pollution reduction. The cost modelling estimates two abatement cost curves that are useful for investment decision making and prioritisation in GBR catchments:

- Marginal abatement cost curve (MACC): The marginal cost of abatement measures the additional cost that is incurred to abate an additional amount of pollution (fine sediment or DIN). A MACC is graphical representation of the marginal cost of abatement for different investments. The graph is ordered left to right from the lowest unit cost to the highest unit cost opportunities. Investments that fall below the horizontal axis are cost savings, while investments above the line involve net costs (see for example Figure 3 in (Department of Environment and Heritage Protection (2016)).
- Total abatement cost curve (TACC): A TACC is simply a graphical representation of the total costs incurred to abate pollution. It is calculated by adding together the total cost of abatement for each investment, i.e. by multiplying the marginal cost per unit of abatement by the total amount of abatement achieved for each policy solution set. The graph is ordered left to right from the lowest cost to the highest cost opportunities. Investments that fall below the horizontal axis are cost savings, while investments above the line involve net costs. In effect, the curve shows the cumulative costs of moving towards the abatement targets.

MACCs have previously been developed for sugarcane and grazing in the Great Barrier Reef Catchments (Department of Environment and Heritage Protection, 2016; Beher, Possingham, Hoobin, Dougall, & Klein, 2016). Our MACC and TACC approach builds on elements drawn from these and earlier evaluations (WQIPs) plus our own experience. Our approach also explicitly recognises and assesses the variability in the potential efficacy of actions and their lifecycle costs (represented by MACC and TACC ranges). Our aim in developing the MACCs and TACCs for the policy solution sets has been to provide some consistency with earlier approaches, and also transparency so backward calculation can be performed.

Importantly, this project allows for policy solution sets (and regions) with different levels of data and knowledge to be incorporated into a common analytical framework.

Method

Additional information on the method to develop the costs curves (to that outlined in section *3.5*) is discussed further below:

Annualised equivalent benefit (AEB)	**The annualised equivalent benefit is the preferred measure for the MACC analysis because it takes into account: (1) time lags between investment and when abatement occurs; (2) that some activities will involve investing in new equipment to undertake some management practice transitions. The AEB approach is consistent with the use of AEB for cane in (Department of Environment and Heritage Protection, 2016). As noted above, based on DEHP guidance the AEB is an annualised cost over ten years.**
MACC ranges	Our approach has estimated MACC and ranges (minimum, maximum and most likely MACC). MACC ranges are the preferred approach given the uncertainty around many of the cost and impact

	parameters that will be estimated, the existence of within and between region heterogeneity, and the likelihood of non-linearity in costs and impacts. We discuss these issues further below and how we estimated the MACC ranges. We have used the approach as MACC ranges can support the Department's GBR investment prioritisation work on a number of fronts. The MACC ranges: • Clearly identify AEBs that have more certainty in terms of the cost per unit of abatement. This will be clearly seen on graphs by these AEBs having smaller ranges compared to AEBs for other actions. • Highlight the value of reducing uncertainty, which can be measured in terms of the change in expected AEB and expected total abatement that can be achieved by reducing the range on the AEBs. • Highlight that, after accounting for uncertainty, the actions that have the same expected abatement costs between and within regions.
Baseline	The incremental cost and incremental abatement is measured against the same static baseline used in the Source meta-modelling work – which is set at 2013 to align with the Reef Water Quality Protection Plan 2013 investment baseline. This baseline represents the loads that would be expected from the relevant sub-catchment if current landuse practice continues unchanged as it was in 2013. In principle, the preferred approach would be to use a dynamic baseline for evaluating MACC and contribution towards meeting targets, because it shows the net change in movement towards achieving the Reef 2050 Plan targets, accounting for additional impacts from changing landuse and condition, positive and negative. The dynamic baseline would be determined by assuming that the current business practice continues unchanged, but takes into account possible changes in landuse and intensity, and how these will impact on sediment and nutrient loads reaching the reef lagoon if these intensified landuses continued using the current (2013) business practices. In practice, the dynamic baseline is challenging to get 'right' because we don't know what will happen in the future. There is merit in this approach being adopted in future evaluations by DEHP or other parties. Initial thoughts in establishing the key parameters for the baseline are: • Sugarcane. We assume no growth in production areas due to lack of competitive advantage. The exception may be an expansion of the Lower Burdekin Delta production area Burdekin on back of State subsidies currently being considered by State Development. • Horticulture. Recent growth rates apply, but assume no material developments in processing/manufacturing due to lack of competitive advantage. • Beef. Potential for growth in intensification on back of market growth in SE Asia. The timing of this potential intensification is highly uncertain as most SE Asian countries have policies to expand their own production. • Urban. Based on population forecasts for key centres (Cairns, Townsville etc.).
Highest possible uptake program cost	As discussed above, we note that the MACC will be based on program delivery mechanism(s) (incentives, extension, or regulation) that will achieve *the highest possible uptake of the required actions*. Also, we note that maximum uptake does not necessarily imply best value for money to the Government – for example program A may achieve 90% uptake of a practice for $1 million in program costs, and program B may achieve 95% uptake for $30 million in program costs. With a limited budget an approach of maximising uptake may deliver *less* total abatement than a program that delivers the most cost effective possible uptake of the required actions. Future evaluations may consider relaxing this requirement.

Data sources and unit costs
The data sources and unit costs are all described within the relevant solution set statements and these should be read in conjunction with this section.

Integration with meta-modelling and estimating cost curves
A flow chart of the process for integrating the unit costs for the actions with the meta-modelling results is shown below (Figure 101). Key steps in the process involved:

- **Developing an Excel based database of each potential action.** Each action was defined by scenario, region, and the costs of the action. This is shown in Figure 102. We defined most likely, minimum and maximum values for all parameters, and assigned probability distributions. We generally assigned Pert distributions unless there was maximum uncertainty, in which case we assumed a uniform distribution.
- **Integrating estimate of 2025 Efficacy (tonne removed at GBR in 2025)**. Using outputs from the Source meta-modelling. These efficiency values were total tonne abatement achieved at reef in 2025, aggregated at the catchment level. These values are shown in the far right of Figure 102.
- **Calculating the present value of costs for each policy solution set, scenario and catchment per 2025 tonne using the input data.** This was done by adding the one-off capital costs of investments, and one-off transaction and administration costs (urban stormwater management policy solution set only) and policy costs, and recurring operating and maintenance costs for each policy solution set, scenario and catchment over the ten year investment horizon. These solution set costs were then discounted using a 7% real discount rate to obtain the present value of each policy solution set, scenario and catchment combination at 2025. The present value of these costs was then divided by the annual abatement for the same policy, solution set, scenario and catchment at 2025 to derive the MAC for that policy solution set.
- **Prioritising actions based on logical sequencing and then cost-effectiveness**. To determine what was the best group of least cost solutions to achieve the target, we had to look at the cost-effectiveness of individual solutions in terms of the dollars per tonne removed, and combine the solution sets into a logical sequence that actually achieved the relevant target in each region.

From this, we then were able to develop MACCs that showed a logical sequence of actions, and the lowest cost package of solutions to achieve the targets. The approach sometimes meant that in selecting a group of options, the cheapest option was not the first one to be accounted for. For example, in most catchments, the most cost-effective option was moving producers to a better land management practice. From a pure cost perspective, moving them from C to B class may be most logical, however it also makes sense that you first need the more expensive option of moving the D class producers to a C where producers are not already at C class.

In terms of decision rules for identifying the list of solutions, the following approach was used:

- All solutions from most cost-effective to least cost-effective were ranked.
- Solutions from the most cost-effective end were added until the load reduction target was achieved.
- The Reef 2050 Plan decision principles were used to group the options into logical sequences, so that we looked at avoidance before mitigation wherever this was the least expensive.
- In some cases, where the least cost options did not achieve the targets, we had to select a more expensive option that then resulted in no longer needing some of the lower cost ones, because the lower cost ones did not provide enough load reduction.
- The final list of adopted solutions was added together to determine both the cost and efficacy of the adopted solutions for each region.

Assumptions and limitations

Our approach extends MACCs developed previously for sugarcane and grazing in the Great Barrier Reef catchments (Department of Environment and Heritage Protection, 2016; Beher, Possingham, Hoobin, Dougall, & Klein, 2016) and uses best available data. The MACCs address some of the limitations identified with earlier MACC assessments in the GBR, in particular that abatement is measured at the GBR lagoon rather than the farm gate, more complete representations of costs are included, that abatement is evaluated at a common end-point of 2025, and that the evaluation includes opportunity costs. Key limitations that remain include issues identified in earlier evaluations (DEHP, 2016). These include:

- **Adoption success.** The MACC assessment evaluates the likelihood of adoption occurring by 2025 given the economics of the practice and the likely policy tool that would be used. Based on DEHP guidance, in all solution sets we assume that investments achieve their full adoption success by 2025. In reality, success could be less than this assumed level.
- **Practice efficacy success by 2025.** The MACCs are based on progress towards achieving load reductions against the 2025 targets. Based on DEHP guidance, in all solution sets we assume that investments achieve their full pollution abatement impact by 2025. In reality, success could be less than this because of technical and implementation delivery constraints, socio-political reasons, project governance arrangements, farmer capacity or good ability to maintain the works or structures after they are put in for reasons other than contract compliance).
- **Regional aggregation.** The MACCs are based on the concept of 'representative farms' and 'representative actions' within regions and solution sets, i.e. the MACCs are constructed based on costs that would be incurred to deliver works and measures within regions on average. This assumes away significant regional and farm enterprise heterogeneity (Star, et al., 2013; van Grieken, et al., Cost-effectiveness of management activities for water quality improvement in sugarcane farming., 2014). We know from earlier work that this heterogeneity means actual on the ground costs within regions for programs will deviate (potentially significantly) from these representative averages.
- **Current costs and adoption success.** The MACCs are based on understanding of the current costs of investments required to deliver each of the solution sets and their adoption success, drawn from experience in delivering these types of projects in the GBR previously. The significant scale and scope of the investments required to deliver the GBR water quality targets mean that economies of scale and scope could be achieved. Conversely, future program costs may be higher and adoption success lower than historically if current investment is securing the 'low hanging fruit' and future gains from practice change are not sufficiently large to motivate change (van Grieken, et al., Cost-effectiveness of management activities for water quality improvement in sugarcane farming., 2014) These issues have not been factored into the current evaluation.
- **The assumption that A, B, C, D land management practice leads to A, B, C, D land condition** (due to time lags) has not yet been confirmed (Department of Environment and Heritage Protection, 2016).

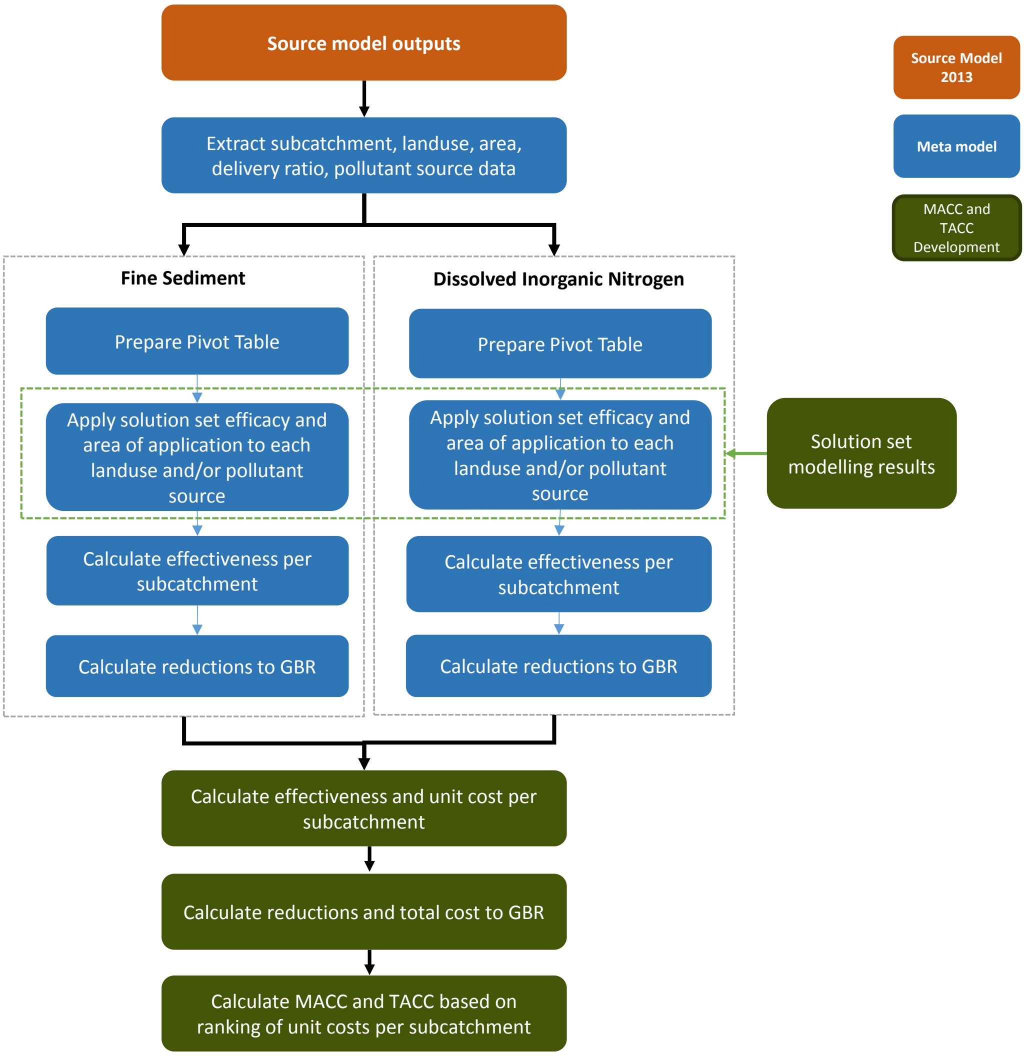

Figure 101. *Diagram illustrating how costings are integrated with the modelling*

Scenar	Description	Catchmen	Sediment/D	Capital cost (one-off cost	Operating and maintenance cost (annual	Impact on (farm) profit (annual cost	Transaction cost (one-off cost)	Regulation program cost (one-off cost	Extension Program cost (one-off co	2025 Efficacy (tonne removed at GBR in 202	PV of Costs (2016-2025)	PV of Costs per 2025 tonne
1	Land Management - BM - Cane C to B	Burnett Mary	DIN	$ 69,038,640	$ 6,903,864	$ -	$ -	$ 750,420	$ 1,227,837	363.0	$118,605,348.14	$326,736.50
1	Land Management - BM - Cane D to C	Burnett Mary	DIN	$ -	$ -	$ -	$ -	$ 112,310	$ 183,762	102.0	$1,802,780.73	$17,674.32
1	Land Management - BM - Grazing B to A	Burnett Mary	Sediment	$ 59,065,700	$ 5,906,570	$ 12,645,502	$ -	$ 2,929,275	$ 1,387,276	63,771.3	$194,448,676.72	$3,049.16
1	Land Management - BM - Grazing C to B	Burnett Mary	Sediment	$ 19,644,911	$ 1,964,491	$ 4,125,431	$ -	$ 3,928,982	$ 2,449,720	161,712.0	$94,281,214.54	$583.02

Figure 102. *Excel file showing costings are integrated with the modelling (2025 efficacy)*

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