

Scoping land conversion options for high DIN risk, low-lying sugarcane, to alternative use for water quality improvement in Wet Tropics catchments

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ACRONYMS

BMP	Best management practice
CBA	Cost-Benefit Analysis
COTS	Crown of thorns starfish
DAF	(Queensland) Department of Agriculture and Fisheries
DEHP	(Queensland) Department of Environment and Heritage Protection
DIN	Dissolved Inorganic Nitrogen
DOE	Department of the Environment
DSS	Decision support system
ERT	Ecologically Relevant Targets
FHA	Fish Habitat Area
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GIS	Geographic Information System
GM	Gross margin
HCPSL	Herbert Cane Productivity Services Limited
HES	High ecological significance
JCU	James Cook University
LEG	Land evaluation guideline
MCA	Multi-Criteria Analysis
MIP	Major Integrated Project
N	Nitrogen
NESP	National Environmental Science Programme
NRM	Natural Resource Management
OGBR	Office of the Great Barrier Reef
PSII	Photosystem II inhibiting
RRRC	Reef and Rainforest Research Centre Limited
SDSS	Spatial Decision Support System
TPVGM	Total Present Value Gross Margin
TWQ	Tropical Water Quality
UK	United Kingdom
USA	United States of America
WTWQIP	Wet Tropics Water Quality Improvement Plan

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KEY MESSAGES

- This project scopes out a framework for land managers and government to consider towards achieving water quality improvements and long-term sustainability of coastal aquatic ecosystems, and the Reef.
- The framework is a decision support tool integrating spatial and economic information to assist with examining options for transitioning low-lying cane land, with a high risk of dissolved inorganic nitrogen (DIN) loss, to lower DIN-risk uses in the Wet Tropics.
- Economic analyses from both societal and private landholder perspectives are included in the framework. From a societal perspective land use transition can be a cost-effective option for reducing DIN loss, comparable to existing mechanisms for addressing DIN loss.
- Coastal wetland restoration (if sited on poorly performing cane land, with low conversion cost and high ecosystem service delivery) offers the greatest potential for cost-effective DIN reduction (\$7-9/kg DIN reduced). This transition option has multiple benefits, including extending available aquatic habitat for wildlife.
- Constructed treatment wetlands and grazing, when placed in appropriate locations (and where conversion costs are low and DIN reductions are high) can offer cost-effective DIN reduction in the range of \$15-17/kg DIN reduced, which is cheaper than that reported for extension-based approaches (c. \$50/kg DIN reduced).
- There is a paucity of quantitative information on the DIN removal capacity and conversion costs for wetland restoration or constructed treatment wetlands in the Wet Tropics. Therefore, there is uncertainty around the cost-effectiveness values and end users should be cognisant of the assumptions used in the framework. In general, wetland restoration or constructed treatment wetlands are most cost-effective when conversion costs are low and DIN removal capacity is high. Placing constructed wetlands within an integrated treatment train might further improve water quality, though this needs to be weighed against the additional costs incurred.
- Fruit tree crops appear to offer potential for cost-effective DIN reductions. The risk to return ratio for fruit tree crops, however, is likely to fall outside the acceptable range for many landholders whose farming experience is built around sugarcane cropping.
- Land use transition could be considered as part of a mix of mechanisms to address DIN loss. It complements other mechanisms, if targeted at the relatively small areas of poorly performing sugarcane land, while best management practice adoption initiatives should focus on the remaining, more productive sugarcane land.
- It is recommended that this framework be tested, evaluated and refined via a pilot as part of the Wet Tropics Major Integrated Project (MIP), or via alternative funding mechanism/s.

EXECUTIVE SUMMARY

The Reef 2050 Long-Term Sustainability Plan and Reef Water Quality Protection Plan 2013 have set ambitious targets for Great Barrier Reef (GBR) water quality improvement. The Wet Tropics Water Quality Improvement Plan identified that in order to meet the GBR Water Quality Guidelines the ecologically relevant target for reduction in Dissolved Inorganic Nitrogen (DIN) load is between 70-80% in the priority Wet Tropics catchments such as Russell/Mulgrave, Johnstone, Tully/Murray and Herbert. Even adoption of 'A-class' sugarcane management practices is predicted to only achieve around 30% reduction in DIN loads. There is a need for new, innovative approaches to achieve the load reduction beyond just 'A-class', and that are fully costed. This project explored one approach to further reduce nitrogen loads in the Wet Tropics catchments – *transitioning low-lying sugarcane land to an alternative land use requiring less or no nitrogen application*, and that, ideally, also *provides farmers with a long term alternative income that is better than sugarcane*.

Defining land use transition options

A review of the literature and consultation with experts in the related fields determined that a range of land transition opportunities exist with no, or lower, nitrogen application compared to sugarcane. The final land use options included: 1) grazing (grass-fed beef fattening); 2) tree crops; 3) construction of wetlands to provide water treatment in runoff before discharge to receiving waters; and 4) restoration of wetlands to provide services for aquatic ecosystems (such as fish habitat extension, or carbon sequestration).

Data acquisition and land use suitability analysis

Data to facilitate generation of the possible alternative land use areas was sourced from the Queensland Government, Terrain NRM and the Great Barrier Reef Marine Park Authority (GBRMPA). In this case, only data complete for the entire Wet Tropics region were used. Data not consistently available for the region, such as acid sulphate soils mapping, were excluded because of confounding problems with applying a consistent decision weighting during the land use suitability analysis (Multi-Criteria Analysis, MCA). In some cases, surrogate data sets were incorporated. A constraint here was (region wide) available local data, which generally provides additional fine scale details, but was excluded to avoid confounding problems.

The land use suitability analysis was used to assess sugarcane land in terms of the risks of DIN loss to the GBR, and the suitability for transition to another land use. Using GIS, the MCA was developed during a workshop with key end users, covering a range of local knowledge, industry, government and Natural Resources Management sectors. The MCA consisted of the following steps: 1) defining low-lying sugarcane areas with a high risk of DIN loss to the GBR; 2) determination of a ranking system of suitability following the four identified land uses suitable for transition; and 3) validation/vetting of the land suitability model and maps using expert and local knowledge. The outcome was a set of decision rules that defined the framework, which generated a series of maps outlining starting points for shortlisting possible areas for transition.

Economic analysis

Looking across the different land transition options (Figure ES-1), in appropriate locations (where conversion costs are low and DIN reductions are high) treatment wetlands and the grazing options offer cost-effective DIN reduction in the range 15–17 \$/kg DIN. This compares favourably with the cost-effectiveness reported for existing agricultural extension-based approaches (c. \$50/kg DIN reduction). Ecosystem service wetlands (i.e., wetland restoration) – again when appropriately situated – offer the prospect of even more cost-effective performance (7–9 \$/kg DIN reduction).

The key to cost-effective DIN reduction from transitioning to wetlands is to identify locations which offer a favourable combination of conversion cost and DIN removal rate. These locations will have to be identified at a site-specific level using appropriate local knowledge. Location is somewhat less critical to the cost-effectiveness of transitioning to grazing, but it will be much more cost-effective to convert to grazing on the soils that are 'leakier' with low sugarcane productivity (i.e., S4 in Figure ES-1). Figure ES-1 highlights the uncertainty surrounding the cost-effectiveness values for ecosystem service wetlands and treatment systems, compared to grazing. This is due to the limited published information on the costs and efficacy of these wetland systems in the Wet Tropics, and end users need to be cognisant of the assumptions used in the framework when interpreting the results.

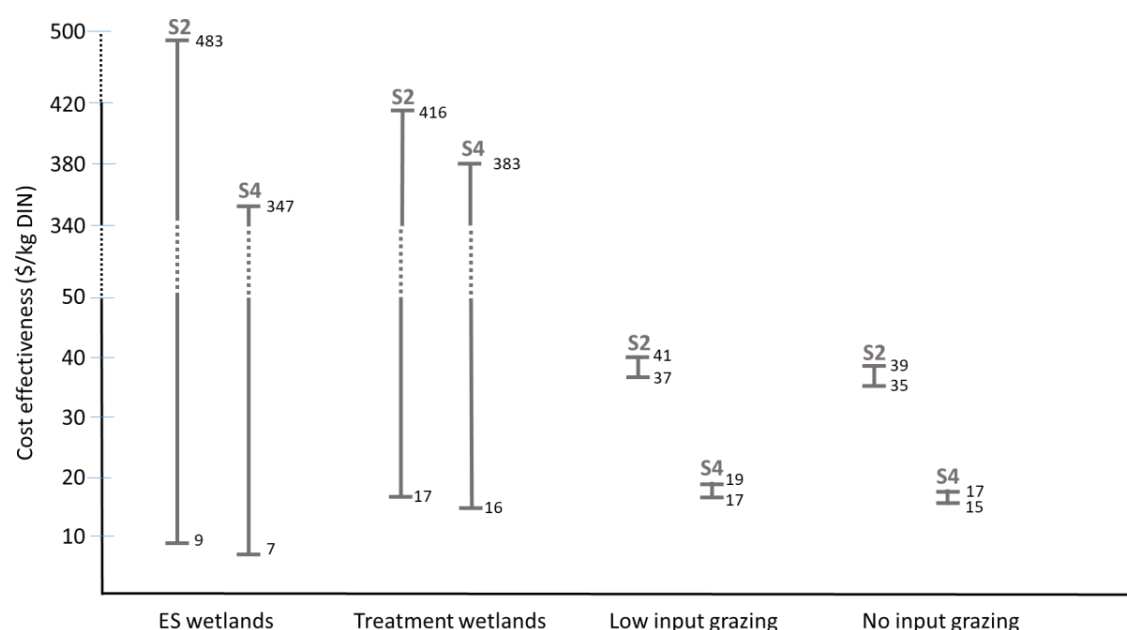


Figure ES1: Comparison of the range of cost-effectiveness for DIN reductions achieved by the different land use transitions from low-lying sugarcane land on S2 and S4 soil types. Cost effectiveness is expressed as total PV (Present Value) cost of land transition per kg reduction in DIN delivered. (ES denotes ecosystem service wetlands).

Of the land use transitions considered, only fruit tree crops deliver higher annuity gross margins than sugarcane. Cattle grazing can deliver a positive annuity gross margin from a private perspective, whereas the wetland options deliver negative annuity gross margins (i.e., incur annual costs, from a private perspective). This is because wetland maintenance costs are being incurred without (currently) any mechanism for generating revenues from DIN

reductions or enhanced ecosystem service flows. This situation would change if mechanisms such as nitrogen credit trading or nitrogen offsetting were available. The recent Discussion Paper on water quality regulations from the Queensland Department of Environment and Heritage Protection highlights and supports opportunities for movement in this direction.

Transitioning from sugarcane to ecosystem service wetlands can generate a total present value (PV) benefit from a societal perspective. Total PV benefits could be realised from locations where conversion costs are low and ecosystem service deliveries are high. Identifying such locations will require detailed and careful investigation at site-specific resolution, based on local data and local knowledge.

Extremely high PV benefits can potentially be obtained from transitioning to fruit tree crops, however, assessments are based on overly optimistic assumptions regarding year on year yields. In practice, other factors besides best-case annuity gross margins clearly affect land holders' decisions regarding transitioning to fruit tree crops. Net negative cash flows for several years after land transition, yields which are highly susceptible to weather variations and outbreaks of pests and diseases, and the vulnerability of sizeable up-front investments to catastrophic loss from extreme weather events such as cyclones, flooding and drought all act to push the risk to return ratio for fruit tree crops outside the acceptable range for many landholders whose farming experience is built around sugarcane cropping. Fruit tree crops do, however, appear to offer strong potential for cost-effective DIN reductions, so they should be considered alongside wetlands and grazing in the mix of possible land use transitions.

Constraints

This project highlights obvious information gaps in scientific knowledge and access to data. Access to consistently gathered data, and indeed local datasets, would improve and refine the framework presented here. For example, the framework assumes that low-lying, flood prone sugarcane land has poor production, though information on yield and gross margins in catchments, in combination with soil types and flow rates, would further refine these analyses. Similarly, more recent and comprehensive information on the costs and revenues from alternative land use would reduce uncertainty in the economic analysis.

There remains considerable debate about whether, for the Wet Tropics, almost all of the DIN load is transported during wet season peak event surface water flows or if a significant proportion of the DIN load to the reef is transported during ambient surface and groundwater flows (DEHP Constructed Treatment Wetlands Workshop web materials 2016, and the Alluvium Report 2016). This has major implications for the area of wetland which would be required to provide adequate retention time for effective DIN removal. If a considerable proportion of total DIN load is transported in ambient surface and groundwater flows then a network of modestly sized, appropriately situated treatment wetlands could provide effective DIN removal. If most of the total DIN load is transported during peak event surface flows then wetland area would have to be much larger to achieve the desired level of DIN reduction. The total present value costs of transitioning from cane production to wetlands would likely be very different in these two situations. This debate highlights the pressing need for robust scientific data on wetland performance and construction cost to be collected and made available at spatial and temporal scales relevant to end users, and for planning projects such as this one.

We have modelled a range of treatment efficiencies and costs of transitioning to wetlands to encompass the uncertainties and acknowledge the differences of opinion surrounding this issue. Modelling results suggest that in the right location, treatment wetlands might provide some local water quality benefits, particularly when considered as part of a treatment train using other emerging technologies.

Way forward

In low-lying, high DIN risk, sugarcane locations transition to a lower DIN risk land use will provide water quality benefits. The opportunity to test and refine the data presented herein via pilot projects in the Wet Tropics is necessary. Such pilot projects would also need targeted research to provide data to improve the knowledge base for the MCA and the economic analysis. Information on the costs and income from grazing in the Wet Tropics is more readily available than the other land use options, particularly wetland restoration and treatment systems. The current best opportunity to test and evaluate these transition options is possible via the Wet Tropics Major Integrated Project (MIP).

1.0 INTRODUCTION

1.1 Background and context

The World Heritage listed Great Barrier Reef (GBR) is recognised as having outstanding natural values. This iconic asset holds cultural and spiritual meaning, is a biodiversity hotspot, and has an economic, social and icon asset value of \$56 billion. It contributes \$6.4 billion (in 2015-16) to the economy and an estimated 64,000 jobs through tourism, recreation, fisheries and scientific activities (Deloitte Access Economics, 2017). In 2015, Tourism Australia found that 42% of international visitors rank the GBR as the most appealing tourist attraction in Australia (Stoeckl *et al.*, 2014). The future health and resilience of the GBR, and indeed its economic, environmental and social values, is under threat from climate change, poor water quality, coastal development and fishing (Great Barrier Reef Marine Park Authority, 2014).

The 2013 Scientific Consensus Statement (Brodie *et al.*, 2013a) concluded that the highest water quality risks to the GBR are: *Dissolved Inorganic Nitrogen (DIN) losses contributing to crown-of-thorns (COTS) starfish outbreaks, which are responsible for coral mortality on the mid-shelf and outer reefs; and fine sediment causing turbidity which impacts inshore coral reefs and seagrasses.* [Note that an updated Scientific Consensus Statement will be released late 2017]. As well as reef ecosystems, sediments, nutrients and pesticides also threaten the integrity of freshwater wetlands and some estuarine habitats that line the coast. There is strong scientific evidence to suggest that nitrogen runoff reaching the COTS ‘initiation zone’ (approximately between Lizard Island and Cairns) contributes to outbreaks, as higher nutrient levels sustain higher levels of phytoplankton and increase survival rates of the COTS larvae (Fabricius *et al.*, 2010). It is estimated that the rivers in the Wet Tropics region contribute around 80% of the DIN load to the COTS initiation zone (Terrain NRM, 2015). DIN pollution can also directly impact coral reefs through enrichment of organic matter in plankton and in sediments, leading to declining calcification, higher concentrations of photo-pigments (affecting the energy and nutrient transfer between zooxanthellae and the host) and potentially higher rates of coral disease (Waterhouse *et al.*, 2016). Terrestrially-sourced DIN has also been quantitatively linked to the upper thermal bleaching thresholds of symbiotic reef corals on inshore reefs (Wooldridge *et al.*, 2015). There is a strong relationship between the area of nitrogen-fertilised agricultural land and average DIN concentration in high-flow events (and reaching groundwater), therefore fertiliser residues from agricultural land are considered a key contributor to DIN entering the GBR lagoon (Terrain NRM, 2015).

The loss and modification of catchment ecosystems is also contributing to increased loads of nutrients and sediments entering the GBR. Broad scale vegetation clearing and catchment urban and industrial development (Waltham & Sheaves, 2015) has led to the widespread loss and degradation of freshwater wetlands, forested floodplains, woodlands, rainforests and other terrestrial and aquatic ecosystems in the catchment (GBRMPA, 2009; Brodie *et al.*, 2013a). These ecosystems are essential for a healthy, resilient GBR because they trap sediments and nutrients, slow surface water flow, connect coastal hydrology in some instances, and provide habitat for marine species (Great Barrier Reef Marine Park Authority, 2014).

Declining reef health will potentially have a significant impact on the environmental values and economic return generated by the GBR as an asset. Stoeckl *et al.* (2014) conclude that changes in the environment in the GBR would have a major impact on national and regional economies. Those authors found, through a major survey of visitors and residents, that degradation of environmental values would have real impacts in the tourism industry, including reductions in tourist satisfaction, reduced numbers of tourists visiting the region, reductions in the length of visits, and fewer repeat visits. Mustika *et al.* (2016) examined the potential implications of environmental deterioration for business and non-business visitor expenditures in the GBR. The authors concluded that nature-based tourism is an important source of income for the region. 90% of visitors came to the region for at least one nature-related reason, and that substantial environmental degradation could reduce visitor expenditure, and thus local tourism income, by at least 17%. Esparon *et al.* (2015) found that the greatest risk to tourism returns from environmental degradation was in the Wet Tropics region.

The impact of agricultural runoff on coral reefs is not limited to the GBR, with around a quarter of the total global reef area (Burke, 2011), and a range of other aquatic ecosystems impacted by agricultural pollution (Verhoeven *et al.*, 2006). These effects are compounded by vegetation clearing and wetland reclamation for agricultural development, which reduces the filtering and buffering capacity of natural ecosystems (Verhoeven *et al.*, 2006; Flanagan & Richardson, 2010). Countries around the world have implemented programs in an attempt to address the impact of agricultural pollution on aquatic ecosystems (Kroon, 2014). These have included the regulation of nitrogen fertiliser use on crops (Kronvang *et al.*, 2008), soil and water conservation (Chu *et al.*, 2009), reduced stocking density (Kronvang *et al.*, 2008) and conversion of agricultural land to alternative production systems or natural ecosystems (Frisvold, 2004). The management of diffuse pollutants from agricultural land uses is therefore a key issue throughout the world and management approaches implemented in other countries may also be applicable in the GBR.

There is a need for new, innovative approaches to reduce nitrogen loads that are cost effective and provide longer term viability for landowners. This project will explore land use transition options to reduce nitrogen losses from low-lying, high DIN risk sugarcane areas, in the priority Wet Tropics catchments. The Wet Tropics Water Quality Improvement Plan (WTWQIP) identifies that complete adoption of sugarcane best management practices would be insufficient to achieve the nitrogen load reductions needed to meet the GBR water quality guidelines and targets. This project, with project partners and end users, identifies possible suitable land uses that have a lower DIN risk, but also potentially provide on-going income for land holders. Constraints and opportunities within this project are also highlighted, which need further consideration to improve the framework presented here.

1.2 Management of water quality in the GBR

The key policy instrument to address GBR water quality is the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef WQ Plan), originally developed in 2003, updated in 2009, 2013, and again in 2017. The Reef 2050 Long-term Sustainability Plan (Reef 2050 Plan) was released in 2015 in response to the World Heritage Committee's recommendation for a long-term management plan for the GBR World Heritage Area (Commonwealth of Australia, 2015). It provides an overarching strategy for managing the GBR

and addressing a range of threats to the integrity of the GBR. The Reef 2050 Plan incorporates the water quality targets and actions from the Reef WQ Plan, which are (Commonwealth of Australia, 2015):

- At least a 50% reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas by 2018, on the way to achieving up to an 80% reduction in nitrogen by 2025;
- At least a 20% reduction in anthropogenic end-of-catchment loads of sediment in priority areas by 2018, on the way to achieving up to a 50 per cent reduction by 2025;
- At least a 20% reduction in anthropogenic end-of-catchment loads of particulate nutrients in priority areas; and
- At least a 60% reduction in end-of-catchment pesticide loads in priority areas.

The Reef 2050 Plan and Reef WQ Plan recognise the vital role of freshwater and coastal habitats in supporting a healthy GBR and include targets for riparian areas and natural wetlands, including (Commonwealth of Australia 2015): *There is no net loss of the extent and a net improvement in the condition of natural wetlands and riparian vegetation that contribute to Reef resilience and ecosystem health.*

The Reef WQ Plan is the primary instrument within the Reef 2050 Plan to address pollutant loss from broad-scale land use, notably agriculture (Department of the Premier and Cabinet, 2013; Commonwealth of Australia, 2015). The key programs to address agricultural pollutants include the voluntary, industry-led Best Management Practice (BMP) programs; grants to support adoption of best management practices; extension and education and more recently regulations on the use of fertilisers and pesticides in the sugarcane industry and grazing land management in the beef industry (Department of the Premier and Cabinet, 2013). The majority of investment in recent years has focused on facilitating adoption of best management practices. Ecosystem protection and restoration, referred to as ‘system repair’, and the use of treatment systems, such as constructed wetlands (Department of Environment and Heritage Protection, 2017), has been a relatively minor component of the Reef Water Quality Protection Plan (Department of the Premier and Cabinet, 2014).

1.3 Wet Tropics Region

The nine major river basins comprising the Wet Tropics NRM Region (Figure 1) have been highly modified since European settlement, with extensive vegetation clearing and hydrological modifications to facilitate agricultural production (Terrain NRM, 2015). Intensive agriculture dominates the coastal floodplain and grazing is the major land use in the drier, western parts of the region. Sugarcane production is the dominant intensive agricultural land use on the coastal floodplain and accounts for approximately 80% of the anthropogenic loads of DIN, and over 95% of the photosystem II (PSII) herbicide load to the GBR lagoon in the Wet Tropics region (Terrain NRM, 2015) (Figure 2). In terms of DIN load from sugarcane, the highest loads per unit area are from the Russell Mulgrave, Johnstone, Tully and Murray catchments (Hateley *et al.*, 2014; Waterhouse *et al.*, 2016).

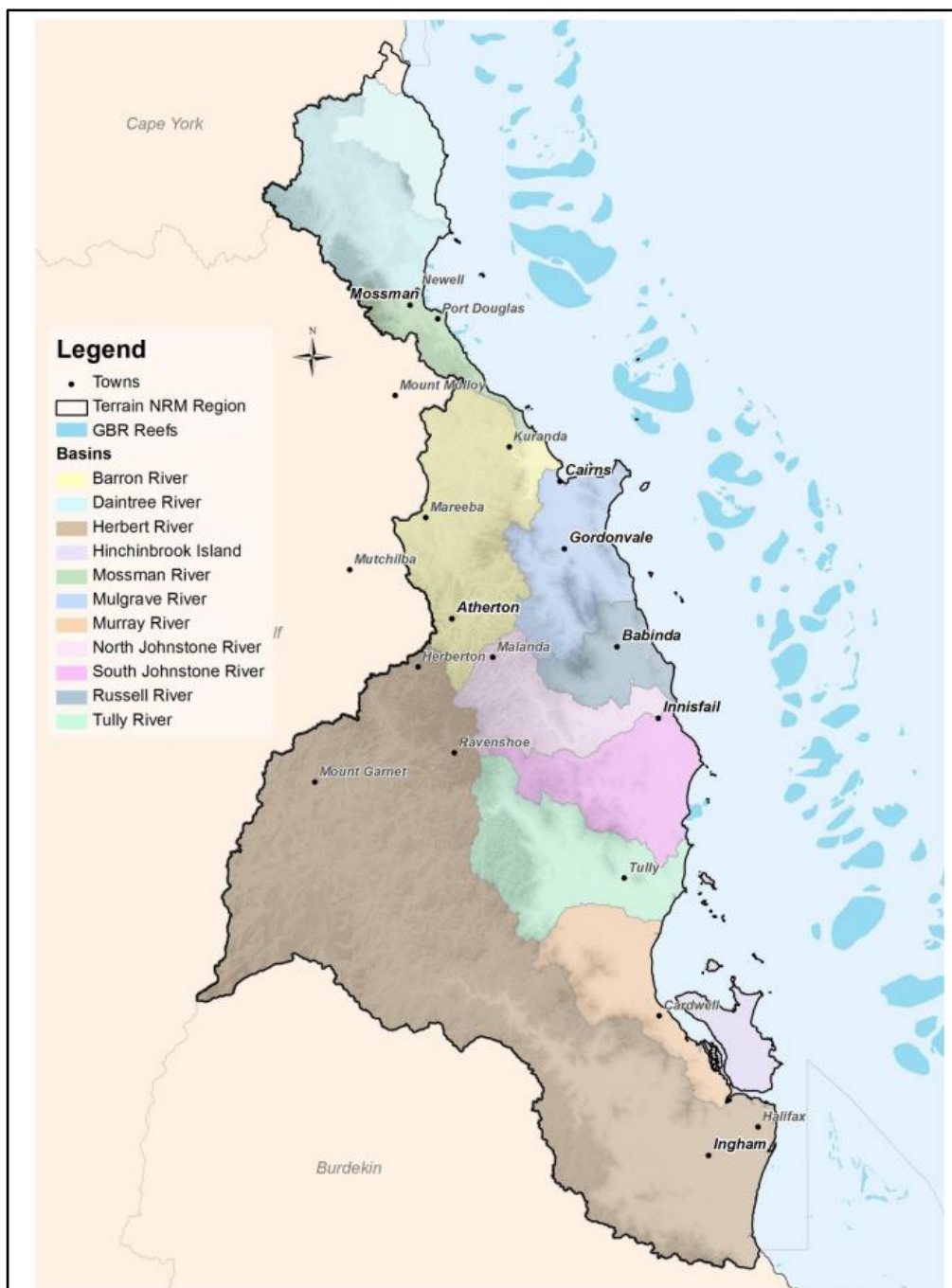


Figure 1: Map of the Wet Tropics and Great Barrier Reef World Heritage Areas (Terrain NRM, 2015)

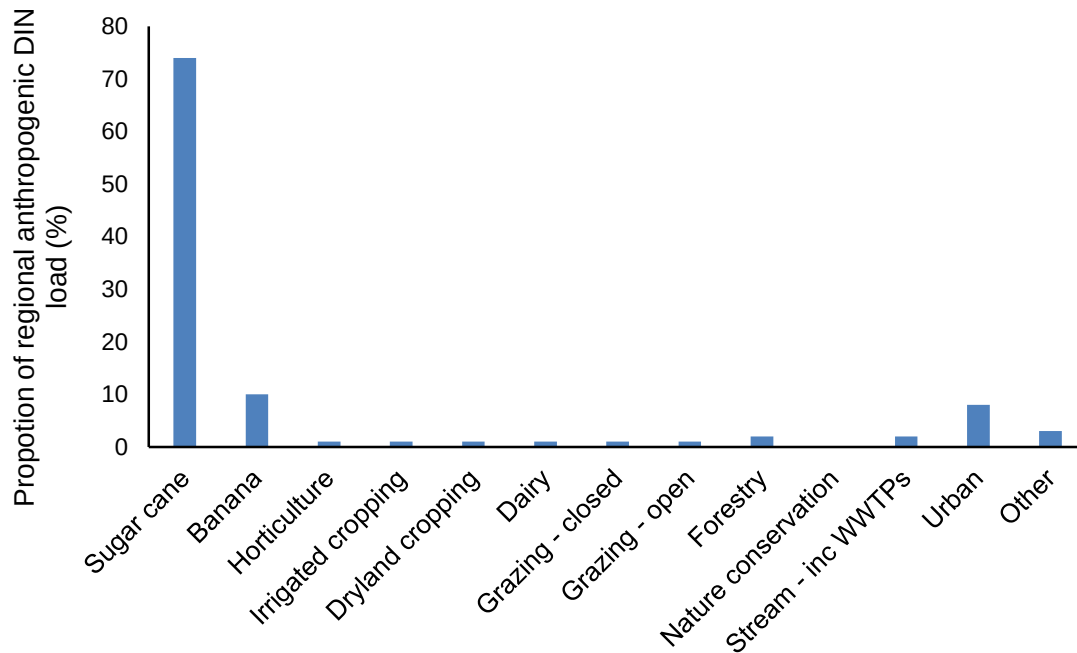


Figure 2: Land use contribution to anthropogenic DIN loads for the Wet Tropics region (2008 baseline data) (Hateley *et al.*, 2014)

The Wet Tropics Water Quality Improvement Plan 2015-2020 (WTWQIP) has been '*designed to identify the main issues impacting catchment waterways and the coastal and marine environment from land-based activities, and to identify and prioritise management actions that will halt or reverse the trend of declining water quality within the Wet Tropics region*' (Terrain NRM, 2015). The WTWQIP defined Ecologically Relevant Targets (ERT) for the pollutant load reductions needed to meet GBR water quality guidelines. These are defined for each river basin and vary from 50% to 80% reduction in DIN (from the modelled 2008 baseline estimate) by 2035 (Brodie *et al.*, 2016).

The WTWQIP also aims to restore the ecological function of the landscape through system repair, outlining values, threats and actions for managing freshwater and coastal ecosystems vital for the health of the GBR. Almost half of the palustrine wetlands in the Wet Tropics NRM region have been drained, filled and developed (Department of Environment and Heritage Protection, 2016a). Drains and levees have been constructed in many agricultural areas to drain or divert surface water and these have also impacted natural hydrological processes and connectivity (Bruinsma, 2001). These modifications have altered landscape processes and functions, reduced water detention time, and the trapping and filtering capacity of the floodplain and increasing water velocity, erosion and pollutant transport (Brodie *et al.*, 2004; Great Barrier Reef Marine Park Authority, 2014).

The WTWQIP identifies that the adoption of current best management practices in sugarcane will only go part of the way towards meeting the DIN water quality targets - it predicts 19% DIN load reduction for all B management practices (best practice) and 30% DIN load reduction, for A management practices (innovative/aspirational practices) (Hateley *et al.*, 2014). It explains that the restoration of ecological functions in coastal ecosystems and floodplains is needed, although the benefits of such actions are yet to be quantified (Terrain NRM, 2015). Similarly,

the Alluvium (2016) report examining the costs of meeting the Reef 2050 Plan water quality targets found that under current policy options the target for DIN reduction in the Wet Tropics Region could not be met and alternative policy responses would be needed (p.34). The WTWQIP did not assess alternative policy options such as land use change or land buy-back options in the cost-benefit analysis due to 'insufficient availability of information to make appropriate cost estimates, and the potentially high socio-political risk that is likely to be associated with these options at this time' (Terrain NRM, 2015). Alluvium (2016) investigated changing 50% of sugarcane land under D class management (i.e., poor management with high risk of pollutant loss (2,210ha) to either biodiversity conservation or grazing - no fertiliser application)). The modelling showed minimal DIN reduction from this land use change, due to the small area of D class management in the Wet Tropics Region. This suggests that limiting land use change to D class management land constrained the opportunity for this policy option to contribute more considerably to reducing DIN loads. For this reason, and the lack of commensurate information available on other agricultural industries in the Wet Tropics, DIN load reduction from sugarcane production is a key focus of the WTWQIP.

1.4 Transitioning low lying, high DIN risk, sugarcane land

Transitioning high DIN risk sugarcane land to an alternative land use that has a lower nitrogen input requirement or increased ability to process excess nitrogen is an alternative policy response outlined in the Reef 2050 Plan targets. Kroon *et al.* (2016) argue that long term reduction in nitrogen export to the GBR lagoon could be assisted by replacing current high-input crops with other crops suited to the climate and soils of the area which require lower nitrogen fertiliser input. These authors also identify that land-based pollution reductions can be achieved through hydrological restoration of landscapes (Kroon *et al.*, 2016).

There are several potential reasons why land use conversion may be an economically and environmentally rational response, particularly in low-lying, high DIN risk, sugarcane production areas. These areas are noted (but not in every case) for being unreliable from a production perspective and provide consistently difficult drainage and management challenges for landholders. Low-lying sugarcane lands generally have lower productivity and require greater inputs of fertiliser, and pesticide, to meet desired yield targets (Roebeling *et al.*, 2007, p15-17). It's also difficult to establish and harvest crops in these areas, high rainfall and inundation could potentially result in total crop loss, and they are likely to be significant sources of high nitrogen loss (Roebeling *et al.*, 2007, Figure 6 p17). Such sugarcane lands are commonly referred to as 'marginal'.

The report of the Great Barrier Reef Water Science Taskforce (The Great Barrier Reef Water Science Taskforce and the Office of the Great Barrier Reef Department of Environment and Heritage Protection, 2016) makes reference that the sugarcane industry could be facing greater regulatory burden in order to bring nutrient pollution levels in line with established targets. Transitioning low-lying, high DIN risk, lands that are comparatively difficult to farm, low yielding and leaky from a nitrogen perspective, with an alternative land use, could therefore be an option that is of benefit to the farmers, and to receiving waters in the GBR Lagoon.

Sugarcane cultivation and processing is a major industry in GBR catchments, with in the order of more than 350,000 hectares under production (Table 1). Reviewing available data illustrates that there exists inherent variability in the amount of land under production on a year-by-year basis as illustrated in Table 1. Productivity data available by Herbert Cane Productivity Services Ltd also outlines year-by-year variability (Table 2).

Table 1: Hectares of sugarcane under production by region. Sourced Australian Sugar Milling Council (2015), Sugarcane Statistics, ASMC, Brisbane

Region	2005	2010	2014
Northern	84,121	68,574	82,187
Herbert Burdekin	128,620	89,398	126,963
Mackay Proserpine	115,477	89,669	107,702
Queensland	381, 029	288,716	363,339

Table 2: Historical crop performance data presented in the Herbert Sugar Industry Report 2015. * standover left, ** standard harvested

Year	Tonnes	Ha Harvested
1996	5251285.67	53513.3
1997	5272421.61	57328.33
1998*	4191272.31	48669.9
1999**	4151741.51	59955.95
2000	2802049.39	58379.16
2001	3311004.97	56876.94
2002	4243591.27	54892.2
2003	4051558.05	56975.69
2004	4641372.86	56410.75
2005	5553359.05	57078.93
2006	4900084.45	57658.5
2007	4287010.73	57158.66
2008	4688595.64	55061.21
2009	3920941.21	51171.33
2010*	3274402.07	39567.98
2011**	2920400.98	52364.64
2012	3625680.08	50394.18
2013	4000685.4	54017.57
2014	4152315.8	55800.99
2015	4459593.6	56615.75

It is important to recognise that this project is only focusing on the proportion of land currently in production that is flood prone because it is low-lying. The inter-year variability evident in Table 1 and 2 presents the case that mill viability probably already experiences annual fluctuations. Reduction in sugarcane production associated with conversion of low-lying, high risk DIN sugarcane land could potentially be offset through improved and intensified production

on more viable production areas (that are not flood prone). The peak body for the sugar industry, Canegrowers, recognise this in their official policy, which states *that diversification of crops on spare, marginal or fallow land does not threaten mill viability*

(http://www.canegrowers.com.au/page/Industry_Centre/advocacy/policy-issues/, accessed 20 March 2017).

1.5 Land use change initiatives to mitigate agricultural pollutants

New agricultural product or land uses have been suggested as one mechanism to improve water quality entering the GBR (Alluvium, 2016; Kroon *et al.*, 2016; The Great Barrier Reef Water Science Taskforce and the Office of the Great Barrier Reef Department of Environment and Heritage Protection, 2016). Crops such as sugarcane and bananas with a high risk of nitrogen loss could be replaced with crops or grazing, requiring less fertiliser and consequently a lower risk of nitrogen losses (Kroon *et al.*, 2016). Alternatively, agricultural land can be converted to forest, grassland or wetland ecosystems. Converting agricultural land to alternative uses can have additional ecosystem service benefits by enhancing landscape buffering and filtering (Bernhardt *et al.*, 2005), providing wildlife habitat (Kaminski & Davis, 2014) and increasing carbon sequestration (Post & Kwon, 2000; McLeod *et al.*, 2011). The challenge is to identify alternatives that are environmentally sustainable and socio-economically feasible (Kroon *et al.*, 2016). Governments in China, United States of America (USA) and Europe have established large-scale land use change programs to address water quality, biodiversity decline and other environmental issues. Examples include the conversion of: cropping land to forest and grassland in China (Liu *et al.*, 2008); crops to wetlands in the USA (Frisvold, 2004); restoration of wetlands and providing buffers along waterways in Denmark (Kronvang *et al.*, 2008); and managed realignment of agricultural land to saltmarsh and mudflat in the United Kingdom (UK) (Luisetti *et al.*, 2011) (Table 3). The Migratory Bird Habitat Initiative in the USA enables both agricultural production and migratory bird habitat, through active management of crops to provide habitat and food for birds, including flooding after rice harvest, planting specific cover crops for feed (United States Department of Agriculture, 2012; Kaminski & Davis, 2014). There have been demonstrable improvements in water quality (Frisvold, 2004; Chu *et al.*, 2009; Windolf *et al.*, 2012) and biodiversity (Kaminski & Davis, 2014) as a result of these programs. Although land retirement has been suggested as a policy measure to address water shortage, land degradation and pollution in Australia (Department of Natural Resources and Environment, 2000; Fraser & Hone, 2003; Hamblin, 2009), there are few examples of structured transitioning of agricultural land to alternative uses for environmental purposes. Examples do, however, include:

- Retiring irrigated agricultural land and converting it to dryland agriculture, pastures or planting trees to combat salinity and acidity in the Murray-Darling Basin (Environment Protection Authority, 2014; Holland *et al.*, 2015);
- Reforestation to control salinity in south-western Australia (Bennett & George, 1995);
- Conservation covenants, such as the Nature Refuges program in Queensland (Department of Environment and Heritage Protection, 2014) and BushTender native vegetation agreements in Victoria (State of Victoria, 2016);
- Environmental non-government organisations such as Bush Heritage, Australian Wildlife Conservancy and Trust for Nature purchasing agricultural properties in strategic areas and instigating long-term restoration programs (Freudenberger, 2016);

- In the GBR catchments some producers voluntarily converted low productivity or abandoned cropping land into wetlands, with Government funding and technical assistance from the Queensland Government. Examples include the construction of wetlands on sugarcane farms, for example in the [Wet Tropics](#) and Burdekin and also on a [banana](#) farm in the Wet Tropics.

There are direct benefits to water quality from taking cropping land out of production and hence ceasing fertiliser and pesticide application. Constructed or restored wetlands have also been shown to reduce agri-pollutant loads (Mitsch *et al.*, 2001; Verhoeven *et al.*, 2006; Flanagan & Richardson, 2010), however, monitoring to date has not identified significant pollutant reduction in constructed or restored wetlands in the Wet Tropics and Burdekin regions (DeBose *et al.*, 2014). This may partly be due to a lack of comprehensive, long-term monitoring, or short residence times (McJannet *et al.*, 2012). Preliminary findings from research currently underway in natural wetlands in the wet tropics is showing significant levels of denitrification, in some wetlands over 500kg/ha/yr during the wet season. Wetlands with neutral pH, low C:N and high levels of nitrate in the water may have the highest denitrification rates (Adame pers. comm. 2017).

Table 3: Examples of land use transition outlining the primary objective of the initiative and the co-benefits in brackets

Land use prior to transition	Land use after transition	Objective	Initiative	Location	Reference
Cropland	Grassland, fruit trees or forest	Reduce soil erosion	Government funded Grain to Green Program, Sloping Land Conversion Program, Farm to Forest Program	Western China	Liu <i>et al.</i> (2008)
Rice field	Freshwater wetland	Water quality, bird habitat	Rice fields were abandoned	Ebro Delta, Spain	Comin <i>et al.</i> (2002)
Agricultural land	Non-production	Water quality (range of other ecosystem services)	Conservation Reserve Program	Throughout USA	Frisvold (2004)
Agricultural land	Wetlands	Range of ecosystem services	Wetlands Reserve Program	Throughout USA	Rewa (2005)
Agricultural land	Saltmarsh and mudflat	Flood defence (saltmarsh conservation, carbon sequestration, recreation, fish habitat)	Managed realignment Government program	Humber and Blackwater estuaries, United Kingdom	Mazik (2010); Luisetti <i>et al.</i> (2011); Luisetti <i>et al.</i> (2014)
Agricultural land	Wetlands, forests and buffer zones	Water quality	Several nitrogen Action Plans	Denmark	Kronvang <i>et al.</i> (2008); Windolf <i>et al.</i> (2012)

1.6 Frameworks for prioritising water quality and ecosystem health initiatives

Spatial prioritisation is widely used to inform investment in water quality initiatives and is recognised as a way to accelerate progress towards Reef water quality targets, e.g., Water Quality Improvement Plans, Water Quality Relative Risk Assessment (Brodie *et al.*, 2013b; Commonwealth of Australia, 2015; The Great Barrier Reef Water Science Taskforce and the Office of the Great Barrier Reef Department of Environment and Heritage Protection, 2016). Spatial assessment and prioritisation frameworks can also be used to assess multiple ecosystem services and the trade-offs between services, to support decision-making (Baral *et al.*, 2013). The assessment and valuation of ecosystem services has been undertaken in the UK (Luisetti *et al.*, 2011; Luisetti *et al.*, 2014) and Thailand (Sathirathai & Barbier, 2001), to enable comparison of the trade-offs between agriculture or aquaculture production, and natural ecosystems, such as wetlands. When ecosystem services are considered, retention or restoration of natural ecosystems are often shown to be economically viable from a societal perspective due to the range of services and benefits that are achievable, i.e., carbon sequestration, amenity and recreational value, and fish nursery (Luisetti *et al.*, 2011; Luisetti *et al.*, 2014). Ecosystem service valuation can help support a holistic approach to coastal management (Barbier, 2011), although it needs to be considered site-by-site, and in conjunction within a social context (Luisetti *et al.*, 2011). Assessing multiple ecosystem services enhances the capacity to achieve co-benefits (Zedler, 2003; Atkinson *et al.*, 2016), and there are a range of models and frameworks available to help (Adame *et al.*, 2015).

Wetland construction or restoration can be an effective approach to improving water quality and broader ecosystem service outcomes (Zedler, 2003), and a number of spatial assessment and prioritisation frameworks are available (e.g. Newbold (2005); White and Fennessy (2005); HLA-Envirosciences (2006); Flanagan and Richardson (2010); Comin *et al.* (2014)). For instance, Comin *et al.* (2014) developed a framework for the prioritisation of wetland restoration and creation to reduce nitrates from irrigated agriculture. Comin *et al.*'s (2014) framework integrated scientific-technical, social and economic elements via a five step process to identify cost-effective sites for wetland restoration for nitrate reduction at a catchment scale. Frameworks such as that outlined by White and Fennessy (2005) entail running different models with different weightings for criteria such as topography, land use, proximity to wetlands to identify solutions that meet project objectives.

For wetland management in the GBR catchments, the Queensland Government commissioned the development of a wetland prioritisation decision support system (DSS) that incorporates biophysical, socio-economic, community capacity and threat data, in addition to expert consultation, to identify higher priority wetlands for strategic investment. That wetland DSS involves a two stage multi-criteria analysis methodology, with the primary DSS to prioritise wetland aggregations within GBR catchments, and a secondary DSS for prioritising individual wetlands (HLA-Envirosciences, 2006). (The DSS is currently under review and could be informed by the data generated in this project).

The Queensland Government also developed the Walking the Landscape approach, which uses a combination of scientific information and expert knowledge to develop an understanding of landscape processes (Lammers *et al.*, 2012). Coppo (2016) reviews Spatial Decision

Support Systems (SDSS) and discusses their relevance to wetland restoration in the Wet Tropics, highlighting that the objective of the project, scale and socio-economic context dictates the SDSS used. Where the objective is water quality improvement, Coppo (2016) states that the SDSS should consider key indicators of wetland health, functionality and ecohydrological connectivity and their interrelationships, ideally at a catchment scale.

1.7 Project outline

This project specifically focuses on developing a framework in which available GIS spatial data are used in combination with technical input and advice from end user experts, to identify potential alternative land use options for high DIN risk, low-lying, sugarcane land in the Wet Tropics Region. In developing this project, it has been important to examine income opportunities which the alternative options offer to land holders in the long-term, after accounting for the costs of land use transition/ conversions and long-term viability of each.

This NESP project outlines the process completed in developing the framework (Figure 3), outlines where and how technical experts were involved in the project, and presents economic cost of transitioning from low return sugarcane land to alternative land uses. This project provides additional information for managers to consider, among the range of mechanisms (including for example, BMP, urban stormwater treatment, reverse auctions, nitrogen trading, incentive programs and policy/regulatory reform) that are already available and used to achieve DIN load reduction in GBR catchments. The framework presented here and information generated is a guide for land managers. Local data sets might exist which could further improve recommendations, these were, however, excluded from our analysis because equivalent data were not available for the entire study region. In addition, local landholder inputs to final transition projects are important and necessary.

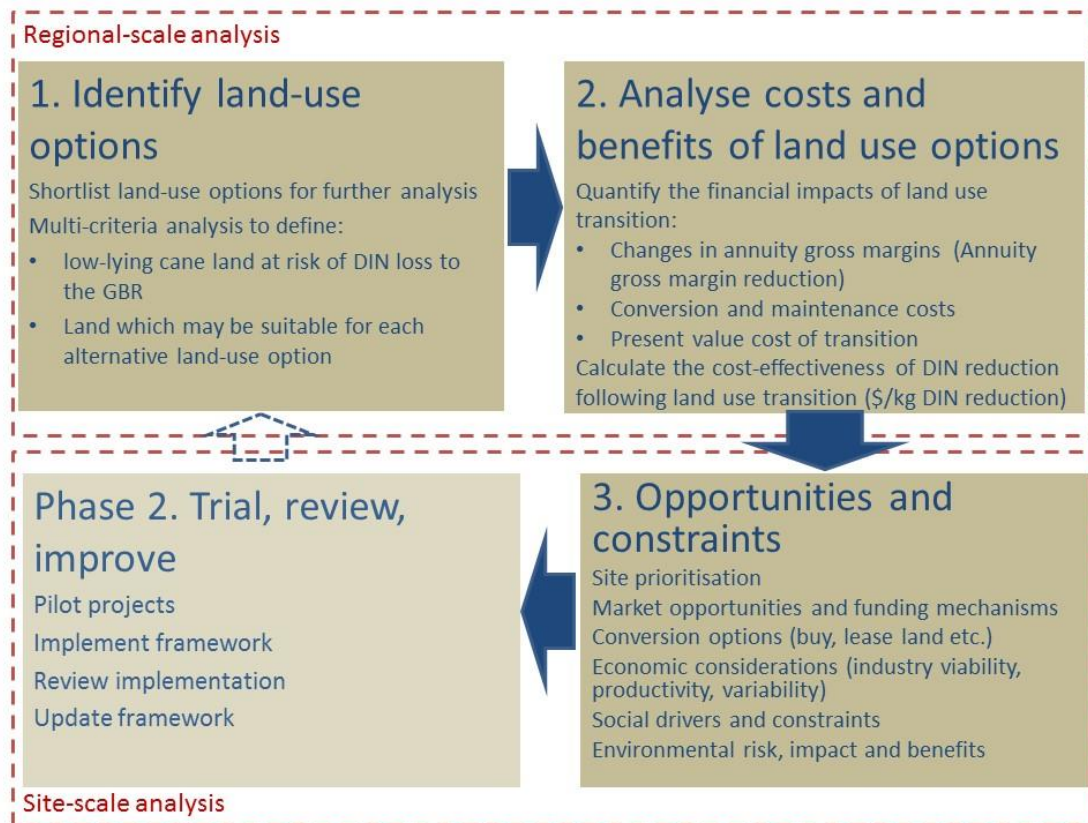


Figure 3: Conceptual outline of the project steps to develop the framework, in addition to implementation to review the benefits of this project and further refine for application in other GBR regions

2.0 IDENTIFYING OPTIONS FOR LAND USE TRANSITION

The approach to identifying options for transitional land uses are described below. In summary, this was achieved by engaging with a range of end users, completing a literature review for available published data and information, in addition to using a multi-criteria assessment platform to complete this assessment.

2.1 Stakeholder engagement

Stakeholder engagement has been a critical aspect in the project, to ensure that the framework is relevant to and readily adoptable by end users. End users and experts were identified from:

- Australian and Queensland government agencies implementing the Reef 2050 Plan;
- Regional NRM bodies, in particular Terrain NRM, however, discussions also occurred with North Queensland Dry Tropics NRM and Reef Catchments NRM;
- Industry including Canegrowers Australia and Herbert Cane Productivity Services Ltd;
- Individual farmers/land holders; and
- Environmental non-government organisations, such as WWF and Queensland Trust for Nature.

Additional stakeholders and interest groups were engaged at various points during the project to assist with identifying matters of interest and concern relating to industry, government and non-government organisations. This enabled the project team to consider and account broader priorities and issues of concern in undertaking this project. Thirteen stakeholder organisations were engaged (Appendix 3), in various forums, during the four phases of the project (Figure 3):

- Project planning and identifying land use options, via one-on-one and group meetings, phone and email correspondence;
- Multi-criteria analysis, via a stakeholder advisory group and follow up discussions;
- Economic analysis of land use options, via phone and email correspondence; and
- Final report, via one-on-one and group meetings, phone and email correspondence.

New initiatives to address pollutant runoff from agricultural lands in the GBR are often of concern to agricultural producers and the subject of land use transition is particularly sensitive. It has been important to involve representatives from the sugarcane industry to identify and understand the key concerns, obtain feedback on the framework, and to share the project learnings with industry and producers. A key aspect to communication with industry was an article published in the Canegrowers magazine (September 2016) describing the project and encouraging producers to contact the project team to test some of the ideas developed during the project, along with media coverage (Appendix 2). A follow up article is planned on completion of this report.

2.2 Defining land use transition options

The project needed to identify land use options for low-lying, high DIN risk, low productivity/profitability, sugarcane land that would achieve the goal of reducing DIN loads to the reef and, indeed, that would also benefit farmers economically. Land use options were identified via a process of discussions with stakeholders, along with an extensive review of available literature. Under advice provided by stakeholders and experts a range of alternative land uses to sugarcane were nominated, including: aquaculture, alternative crops (e.g., fruit trees, rice, and hemp), forestry (e.g., pine and mangroves for harvesting), wetlands for fish production or water treatment, and also leaving land to regenerate under its own process. Transitioning to an alternative, lower DIN risk, crop was assisted by accessing the Regional Land Suitability Frameworks for Queensland (Department of Natural Resources and Mines and Department of Science Information Technology Innovation and the Arts, 2013).

A desktop review of land use options was undertaken to identify climatic, market feasibility and nitrogen application requirements. Nitrogen application requirement is treated as a proxy for DIN loss risk. An important prerequisite was that nitrogen requirements had to be lower when compared with generic recommendations for sugarcane as outlined in Calcino *et al.* (2000): 120-150kg N/ha for fallow plant; 160-200kg N/ha for replant and ratoons. Those land use options requiring less than 150kg N/ha, tolerant to humid coastal wet tropical climate, and potentially feasible from a market perspective, were shortlisted to be considered in the Multi-Criteria Analysis (MCA), and economic analysis as prospective land use options for low-lying sugarcane land transition in the Wet Tropics (Table 4).

Table 4: Opportunities, constraints and nitrogen requirements of different land use options and whether they were shortlisted for consideration in the MCA and economic analysis

Land use option	Annual nitrogen requirement	Opportunities and constraints in the Wet Tropics	Consider in MCA and economic analysis	Reference
Banana	Up to 400kg N/ha for broadcasting, up to 25% less if fertigating	Requires more nitrogen than sugarcane	No	(Lindsay <i>et al.</i> , 1998)
Grazing: Grass-fed beef fattening	69kg N/ha	Currently undertaken. Generally not economically viable in their own right and often rely on other income, e.g. other grazing property or alternative income.	Yes	English (2016)
Aquaculture	Regulated to achieve Reef water quality objectives	Aquaculture discharges need to be managed consistent with Reef Plan water quality objectives. This requirement is deemed very restrictive, e.g. Guthalungra prawn farm approved after 13 years of negotiation and 'zero net discharge' requirement, which may be technically feasible but not economically viable. Aquaculture development areas to be designated. Profitability of aquaculture in QLD is similar to agriculture in that 60% of enterprises reportedly make a profit. Other constraints include economically viable markets and suitably skilled labour.	No	(Department Agriculture and Fisheries) (The Centre for International Economics, 2013)
Bamboo: Bamboo shoots (primary) Timber (secondary)	318kg N/ha	Suitable climate but no major market access currently.	No	(Kleinhenz & Midmore, 2001; Department Agriculture and Fisheries, 2011)
Timber: Exotic pines (<i>Pinus caribaea</i>)	Varies. Average 3.4kg/ha across softwood plantation estate	Exotic pines very sensitive to salinity and moderately intolerant to waterlogging. Minimum area 5ha. Cost structure of these plantations means that they do not	No	(Wilson, 1991; May <i>et al.</i> , 2009)

		compete well with imported product.		
Timber: Hardwoods e.g. Red mahogany <i>Eucalyptus pellita</i> and rainforest cabinet timbers	Varies average 9.7kg/ha across hardwood plantation estate	Grows well on coastal areas however Red mahogany plantations were severely affected in Cyclone Yasi. Impediments to forestry expansion in Nth QLD include market access and continuity of supply, cyclones, lack of forestry culture amongst landholders. Relatively low profitability of rainforest cabinet species. Opportunity for subsidising environmental services to encourage landholders to establish forestry plantations.	No	(Harrison & Herbohn, 2006; Harrison <i>et al.</i> , 2008; May <i>et al.</i> , 2009; Department Agriculture and Fisheries, 2013)
Maize	130-180kg N/ha	Similar nitrogen requirements to sugarcane	No	(Department Agriculture and Fisheries, 2010b)
Industrial hemp	150kg N/ha	Similar nitrogen requirements to sugarcane	No	(Sausserde & Adamovics, 2013)
Papaw	From 220kg N/ha in preharvest stage to 440kg N/ha in harvest stage, based on average practices	Requires more nitrogen than sugarcane	No	(Ross <i>et al.</i> , 2000)
Melons	30-100kg N/ha	Complementary crop with sugarcane, although generally only suitable for one year to manage pests and disease.	No	(Wright <i>et al.</i> , 1997)
Citrus	150-180kg N/ha/	Similar nitrogen requirement to sugarcane	No	(Department of Primary Industries, 2002)
Grape	20-40kg N/ha	Suited to sub-tropical and temperate climates.	No	(Oag, 2001)
Tree fruits (Avocado, coffee, custard apple, longan, lychee, macadamia, mango, persimmon,	Between 55kg N/ha and 120kg N/ha, 62kg N/ha (maintenance mature macadamia trees)	Lower nitrogen requirements than sugarcane. Some crops such as rambutan, mango, lychee and avocado are currently grown in the Wet Tropics. Climate	Yes	(Campbell <i>et al.</i> , 1998; Meurant <i>et al.</i> , 1999; O'Hare <i>et al.</i> , 2004; Thorburn & Wilkinson, 2013)

rambutan, stone fruit)	mango 55kg N/ha (based on 300g/tree 185 trees/ha) 60kg N/ha (low-chill stone fruit based on 25t/ha yield) 120kg N/ha (generic best management rate for tree crops)	variability and risk of cyclone damage.		
Potato	170kg N/ha	Requires more nitrogen than sugarcane	No	(Jackson <i>et al.</i> , 1997)
Sweetcorn	150kg N/ha	Similar nitrogen requirement to sugarcane.	No	(Wright <i>et al.</i> , 2005)
Sweet potato	100kg N/ha	Only suitable for dry season to limit pests and disease.	No	(Wilson, 1991; Loader <i>et al.</i> , 1999)
Tea	200-450kg N/ha	Requires more nitrogen than sugarcane	No	(Drinnan, 2008)
Rice	185-200kg N/ha	Requires more nitrogen than sugarcane	No	(Haifa, 2014)
Grain legumes: Peanut, soybean, mung beans	Up to 50kg N/ha (peanut), 15- 20kg/ha (soybean) but usually not needed.	Pest and disease problems in wet, humid areas and rain can make harvesting the grain difficult. Suitable for green manure. Used as a complementary crop with sugarcane during fallow. Therefore it would not replace sugarcane production.	No	(Department of Primary Industries and Fisheries, 2007; Department Agriculture and Fisheries, 2010a, 2011; Sparkes, 2016)

Following a review of available data and discussions with State Government experts, a refined land use options list was developed to explore during this project, including:

1. Grazing (grass-fed beef fattening – with and without fertiliser applied to pastures);
2. Tree crops; and
3. Wetlands:
 - a. Restore ecosystem services to provide additional, extended, habitat for wildlife (hereafter termed restore wetland ecosystem services); and
 - b. Treatment systems to provide runoff treatment before discharge to receiving waters (hereafter referred to treatment systems).

The reason for separating wetlands into two options is because wetland treatment provides water quality improvement benefits, while restoring wetland ecosystem services provides water quality and also additional available habitat for wildlife, and carbon sequestration.

2.3 Data acquisition

Data were sourced primarily from State Government, Terrain NRM and GBRMPA. Only data layers complete for the entire Wet Topics region were used in this project. For example, layers not consistently mapped for the study region, such as acid sulfate soils, were excluded because of confounding problems in applying decision rules consistently and fairly across the study region for the MCA; see Section 2.4. Instead the project team looked for appropriate surrogate data: in the case of acid sulfate soils, land zone mapping proved suitable.

2.4 Multi-criteria analysis

2.4.1 What is a multi-criteria analysis (MCA)?

A multi-criteria analysis (MCA) was used here. This decision-making approach is effective in situations where multiple criteria are involved and it's necessary for stakeholders to apply various decisions during the process – and particularly when reaching a general consensus is difficult to achieve. A full breakdown of the MCA for each stage in the project, including the four land use scenarios investigated, is presented in Appendix 4.

In this project, the MCA was completed using GIS processes, where mapping abilities to assess specific land for alternate and/or suitable use that is different to current use (Figure 4) (Malczewski, 2004; Chen *et al.*, 2010). MCA is a decision-making tool to solve problems using large amounts of complex data in a structured way (Koschke *et al.*, 2012). Combined with GIS, MCA synthesises spatial and non-spatial as well as qualitative and quantitative data, representing criteria known to affect land suitability, to produce a suitability map of the specific area (Walke *et al.*, 2012; MacMillan *et al.*, 2016). It allows assessment of multiple, often conflicting criteria and is suited to complex natural resource management decisions because it incorporates ecological, biophysical and social components, and enables stakeholders' judgement to be introduced into the decision system (Mendoza & Martins, 2006).

The advantage of using GIS-based MCA is that it offers the possibility to aggregate data from various disciplines (e.g., biological, environmental, social, economic factors) obtained from expert knowledge (Malczewski, 2004; Chen *et al.*, 2010; Koschke *et al.*, 2012). This lets managers identify alternative and/or preferred options for land parcels according to diverse suitability criteria. Land use suitability analysis is frequently used in ecological-economics (Huang *et al.*, 2011) due to its powerful and flexible approach to assess land for suitability (Chen *et al.*, 2010; Walke *et al.*, 2012), and has been applied to a number of mapping applications such as, soil suitability for cotton crops (Walke *et al.*, 2012), land suitability for prawn farming (Hossain & Das, 2010), and conservation effects on urban land use planning (Çelik & Türk, 2011).

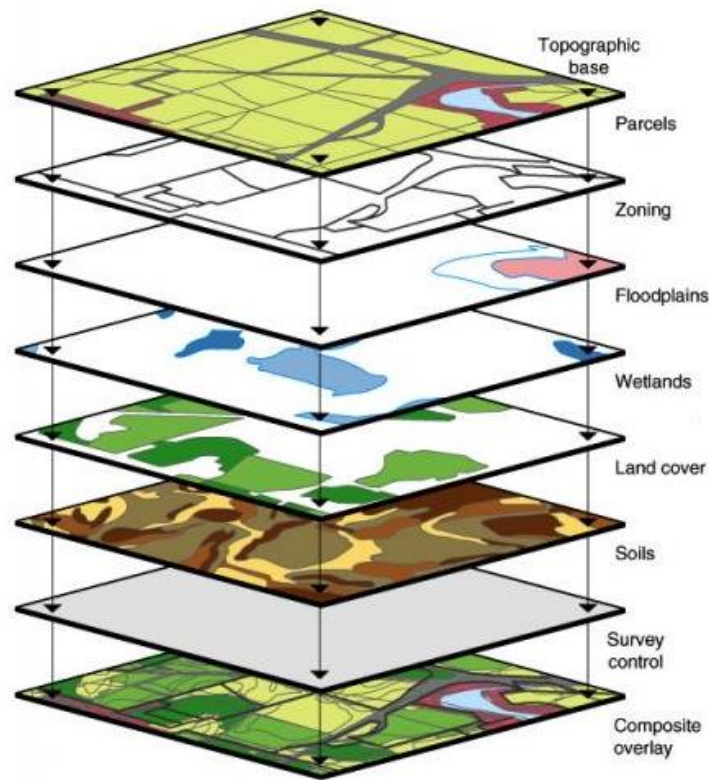


Figure 4: Schematic example of multi-criteria analysis incorporating spatial data to develop a composite overlay of the study area (Source, Dr Moloney, James Cook University, 2016)

2.4.2 The MCA process used in the project

A land use suitability analysis was used to assess sugarcane land in the Wet Tropics NRM region in terms of the risk of DIN loss to the GBR, and suitability for alternative land uses. The GIS-based MCA was developed in consultation with stakeholders and experts from Terrain NRM, Canegrowers, Department of Environment and Heritage Protection (DEHP) and GBRMPA via a stakeholder advisory group. Other stakeholders were engaged for input (see Section 2.1). The stakeholders and experts provided knowledge of the region, ensuring that the inputs and rankings applied were robust and locally relevant.

As determined through stakeholder engagement and the review of available data and literature, the GIS-based MCA consisted of the following steps: 1) defining sugarcane areas at risk of DIN loss, that were frequently connected to primary rivers; 2) determining a ranking system of suitability following four different land use scenarios using spatial analysis in ArcGIS Desktop 10.3.1 (ESRI 2015), i.e., rank the parcel to produce land suitability maps and provide summary statistics for each land use scenario, and 3) validating/reviewing the land suitability model using stakeholder and expert knowledge.

All the criteria/layers were clipped to the Wet Tropics region before use in the analysis. All outputs were saved as feature class within a file geodatabase feature dataset with a projection set to GDA_1994_Australia_Albers (this provides for a better representation of the large extent

of the region, so land parcel areas and perimeters are automatically calculated each time a dataset is saved).

2.4.3 Defining low-lying sugarcane lands at risk of generating and delivering DIN to the GBR

The first part of the MCA defined those sugarcane lands that are deemed low-lying and at risk of generating and delivering DIN to the GBR. This dataset is labelled DINrisk. Once defined, this dataset is used in the second part of the MCA to investigate different land use scenarios. DINrisk is generated in two stages: a) consists of defining the low-lying sugarcane areas within the Wet Tropics region; and b) adding information about connectivity to the coast, DIN generation rate and property boundaries to produce the DINrisk dataset (Table 5).

Table 5: Summary of data sources and their application in the MCA to define low-lying land

Dataset	Source	Attributes	Scale	Use in MCA
Drainage basins (2011)	Department of Natural Resources and Mines	Boundaries and sub-catchments	1:100,000	To define the Wet Tropics region, the focus for this project
LiDAR (2009-2015)	Department of Environment and Resource Management	Contour lines	1:50,000	To define lands <50m elevation, as the project focus is on low-lying sugarcane land
Regional Ecosystem (2016)	Queensland Government	Land zones 1, 2 and 3	1:50,000	To define land zones 1 (tidal flats and beaches), 2 (coastal sand dunes and beach ridges) and 3 (river and creek landforms), as these land zones are likely to have greater connectivity to watercourses and the GBR
QLD floodplain assessment overlay (2013)	Department of Natural Resources and Mines	Potential flood hazard areas	1:100,000	To define floodplain and flood hazard areas, i.e., those areas prone to flooding
QLUMP (2015)	Queensland Government	Sugarcane modified land	1:50,000	To define sugarcane land, the focus of this project

Low-lying sugarcane areas within the Wet Tropics region

Explicit sugarcane production data are not readily available for the Wet Tropics region and therefore low-lying, flood prone sugarcane areas were used as a proxy for generally low productivity sugarcane land (notwithstanding that in some low-lying areas that are flood-prone, sugarcane may in fact be more productive during dry years). In this study, the low-lying sugarcane areas (LLA) within the Wet Tropics region were defined as follows (also see Table 5):

1. Areas at altitudes less than 50m above sea-level (to exclude sugarcane in elevated areas, such as the Atherton Tablelands and elevated parts of the Johnstone River catchment), but to also constrain the study area comprising of Land Zone 1, 2, and 3;
2. Areas subject to flooding or within coastal or alluvial land zones, and
3. Areas mapped as sugarcane land use in the QLUMP 2009.

Areas at risk of DIN loss to the GBR, within the low-lying sugarcane areas

The second part of the MCA identifies the risk of DIN generation and delivery to the GBR from the low-lying sugarcane areas (Table 6, Figure 5). This enables low-lying sugarcane areas to be ranked in terms of water quality risk to the GBR. The low-lying sugarcane areas at risk of DIN loss to the GBR (DINrisk) are defined as:

1. Land which has frequent connectivity to the GBR using the GBRMPA blue maps outputs; and
2. Land that generates DIN, represented using average annual generation rates (kg/ha) of DIN using Source Catchment model outputs.

Sugarcane property boundaries were added at this stage to identify land at the property level, as negotiations and implementation of any of the scenarios would likely occur at a property scale.

Table 6: Summary of data sources and their application in the MCA to define low-lying land at risk of DIN loss to the GBR

Dataset	Source	Attributes	Scale	Use in MCA
Sugarcane properties (2015)	Department of Environment and Heritage Protection	Property boundaries	1:100,000	Define individual sugarcane properties
Catchments Load modelling (2015-2016)	Department of Natural Resources and Mines	DIN generation rate	1:100,000	Define DIN generation from sugarcane lands within source sub-catchments to indicate those areas with higher risk of DIN loss. Six categories of DIN generation rate are used following the data ranges from Hateley <i>et al.</i> , (2014).
Blue maps (2016)	Great Barrier Reef Marine Park Authority	Connectivity to the GBR	NA	Define areas that are very frequently, frequently or intermittently connected to the GBR, to indicate the likelihood of DIN being transported to the GBR

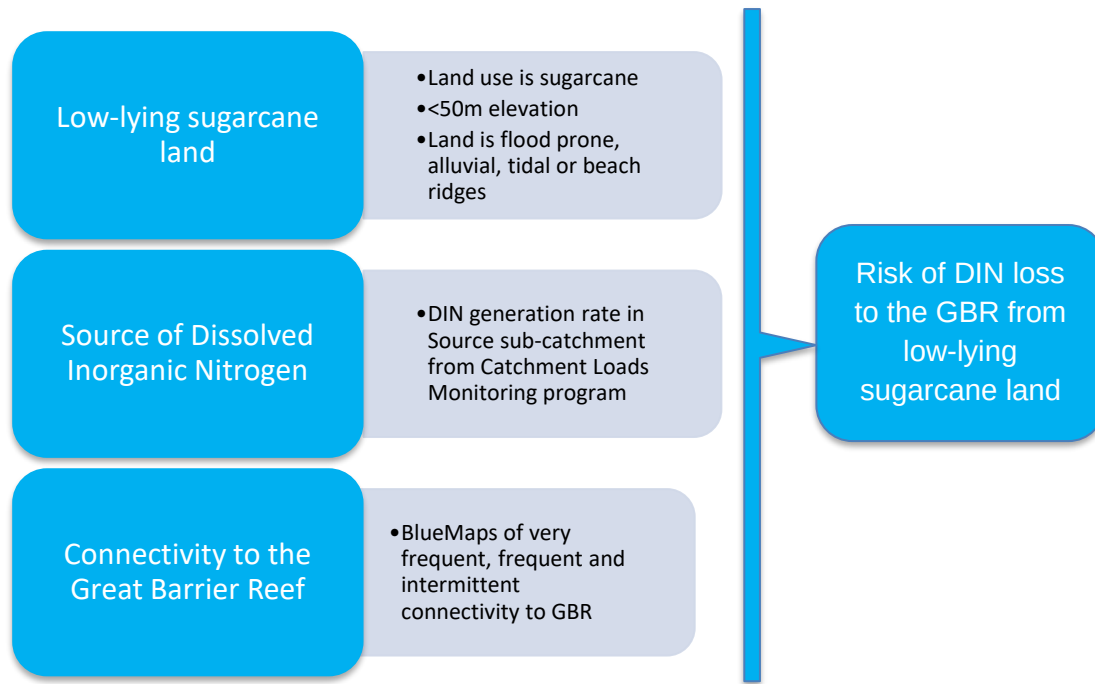


Figure 5: Spatial data and their application in the framework to define low-lying land with risk of high DIN loss to the GBR

2.4.4 Land use transition scenarios

Four land use scenarios were considered in the MCA based on the land use options identified in the review (refer section 2.2). Specific factors and parcel ranking systems for each land use scenario are described below. Rankings were systematically scored on a continuous scale from the least (i.e., 0 or 1) to the most (i.e., 3 to 6) suitable land use options. Scores were assigned in rank order according to the characteristic factors involved in the parcels' evaluation for each land use scenario without repetition. To verify generated scores, group discussion with stakeholders and experts was carried out for final score consensus.

Scenario 1: Grazing

The land parcels in the DINrisk dataset (Table 7) are ranked according to their suitability for grazing as defined by expert opinion (DAF Senior Beef Extension officer), as follows:

- Land within 10m of a stream or river was considered here to be unsuitable for grazing, in order to provide for a riparian buffer for erosion and sediment loss (based on recommended minimum buffer width for bank stabilisation in the Wetland Management Handbook (Department of Employment Economic Development and Innovation, 2011);
- Medium suitability was assigned to land at least 20 ha in size (minimum viable area for grazing based on personal communication with DAF Senior Beef Extension officer) but not adjacent to current grazing land; and
- Land adjacent to existing grazing land is deemed highly suitable because new grazing land could potentially be added to an existing grazing enterprise. It is assumed that

existing grazing properties are viable and that adding new grazing land would be possible.

Table 7: Summary of data sources and application in the MCA for grazing scenario

Dataset	Source	Attributes	Scale	Use in MCA
QLUMP (2015)	Queensland Government	Grazing native vegetation and grazing modified pasture	1:50,000	Define those areas currently used for grazing.
Ordered drainage	Department of Natural Resources and Mines	Water courses	1:100,000	Define water courses to be buffered, to exclude land within 10m of a stream or river.

Scenario 2: Tree crops

The land suitable for tree crops is based on the agricultural Land Evaluation Guideline (LEG). The agricultural LEG categorises land suitable for different crops and identifies management requirements for sustainable production. Five land suitability classes are determined by the guidelines:

- class 1 suitable land with negligible limitations,
- class 2 suitable land with minor limitations,
- class 3 suitable land with moderate limitations,
- class 4 low-lying land and
- class 5 unsuitable land.

Only class 1, 2 and 3 are considered suitable for specified land use (Table 8) (Department of Natural Resources and Mines and Department of Science Information Technology Innovation and the Arts, 2013). Tree crops are selected based on having lower nitrogen fertiliser requirements and potential to be grown in the Wet Tropics region (Section 2.2). Three types of tree crops (mango, rambutan and lychee) were selected for this evaluation as the agricultural LEG deems them suitable in parts of the Wet Tropics (note that these crops might not be suitable in all locations due to local site characteristics and constraints).

Table 8: Summary of data sources and application in the MCA for tree crop scenario

Dataset	Source	Attributes	Scale	Use in MCA
Agricultural Land Evaluation Guideline (2015)	Queensland Government	Lychee, mango and rambutan	NA	Identify suitable lands in classes 1,2 and 3 for each crop.

Scenario 3: Wetlands (restore ecosystem services or treatment system)

This scenario investigates two wetland use options: restoring wetland ecosystem services or installation of a treatment system to capture and treat runoff. These two options utilise similar

datasets (Table 9), and a suitability ranking system is used to determine the most suitable land parcels for each option.

Table 9: Summary of data sources and application in the MCA for wetlands (restore ecosystem services or treatment services)

Dataset	Source	Attributes	Scale	Use in MCA
Queensland Wetland (2013)	Queensland Government	Current wetlands	1:100,000	Define extent of estuarine and freshwater wetlands.
Wetland protection area - high ecological significance wetland (2011)	Department of Environment and Heritage Protection	High ecological significance wetland	1:50,000	Define those wetlands that are deemed 'high ecological significance'.
Fish Habitat Area (2014)	Queensland Government	Declared Fish Habitat Area	Varies	Identify those estuarine wetlands that are within declared Fish Habitat Areas.
QLUMP (2015)	Queensland Government	Conservation, protected estates and Natural Environment	1:50,000	Identify protected areas such as national park, state forest
Pre-clear Regional Ecosystem (2015)	Queensland Government Queensland Herbarium	Historic wetland	1:50,000	Define areas mapped as containing wetland ecosystems prior to catchment development.
Blue maps (2016)	Great Barrier Reef Marine Park Authority	Connectivity to GBR	NA	Define lands frequently or very frequently connected to the GBR (i.e., excludes intermittently connected areas)
Catchments Load modelling (2015-2016)	Department of Natural Resources and Mines	DIN generation rate	1:100,000	Define DIN generation from sugarcane lands within source sub-catchments.

This system ranks the values or features in each criterion as most suitable, moderately suitable, low suitability or unsuitable (Table 10) and the combination of values or features determines the suitability of a land parcel for either restoring ecosystem services or a treatment system.

Table 10: Ranking of data sources in the MCA for either restore wetland ecosystem services or treatment system

Criteria	Ranking for restoring ecosystem services	Ranking for treatment systems	Rationale for ranking and assumptions
DIN generation in the sub-catchment	Relatively low DIN (<13 kg/ha/yr) is ranked highest, moderate DIN (>13 - <21 kg/ha/yr) is ranked lower.	High DIN (>21 kg/ha/yr) is ranked highest, moderate DIN (>13 - <21 kg/ha/yr) is ranked lower.	In sub-catchments with high DIN generation, treatment systems are preferable to help capture and treat pollutants. Restoring ecosystem services should be limited to sub-catchments with low to moderate DIN to minimise eutrophication of restored ecosystems.

Proximity to wetlands, including those of high ecological significance (HES)	Adjacent to HES estuarine or freshwater wetland is ranked higher than non-HES wetlands.	Adjacent to HES wetland has the highest ranking. Within 50m of estuarine or freshwater wetland has a lower ranking.	To protect and enhance the values of HES wetlands, restoring ecosystem services and treatment systems adjacent to HES wetlands are ranked higher than non-HES wetlands. Estuarine wetlands are ranked higher than freshwater due to greater potential connectivity to the GBR. The model prioritises treatment systems located within 50m of a wetland, so that runoff is treated just prior to entering a wetland.
Proximity to protected areas, for management purposes	Adjacent to declared Fish Habitat Area is ranked highest. Adjacent to natural land or protected estates (e.g. national park) is ranked lower.	Not applicable	Land adjacent to a declared Fish Habitat Area or protected area is a priority for the restoring ecosystem services option, because the land could potentially be added onto the existing management unit. For example, if land was restored to estuarine wetland it could be included in an adjoining declared Fish Habitat Area. This is not applicable to treatment systems, as the intent and management of a treatment system is generally not commensurate with protected estates.
Connectivity to GBR	Very frequently and frequently connected	Very frequently and frequently connected	To improve GBR water quality and ecosystem function, the land should be regularly connected to the GBR.
Historic wetland (i.e., pre-clear)	Mapped as a wetland pre-clearing	Not applicable	Areas that were originally wetlands prior to catchment development are likely to be more suitable for restoring wetland ecosystem services.

Restore wetland ecosystem services

Land suitable for restoring wetland ecosystem services is defined as:

1. Adjacent to a freshwater or estuarine wetland, with a higher ranking given to those of high ecological significance or land within a 'historic wetland' (i.e., land mapped as being a wetland prior to catchment development/clearing);
2. Adjacent to a declared Fish Habitat Area (FHA) or natural land and protected estates;
3. Frequently or very frequently connected to the GBR; and
4. Having a low to medium DIN generation rate. (Table 10, Figure 6).

To determine those parcels of land that meet these criteria, land within the DINrisk dataset is ranked following this wetland ecosystem restoration definition. An example map of land for restoring wetland ecosystem services is presented in Appendix 5.

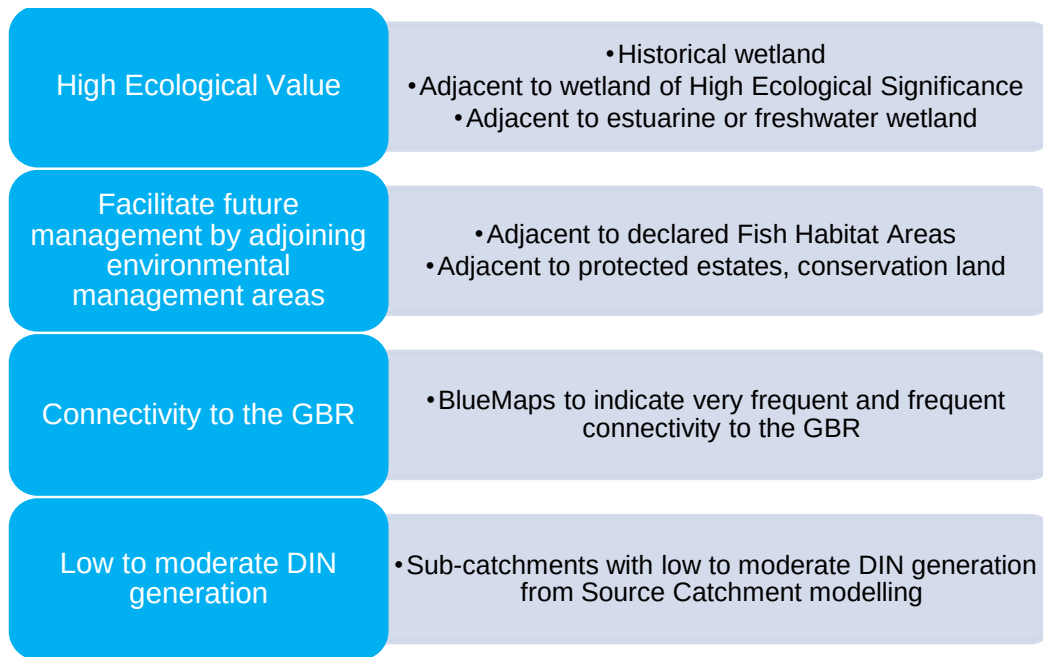


Figure 6: Spatial data and application in the framework to define land most suitable for restoring wetland ecosystem services

Treatment system

Land most suitable for a treatment system is defined as:

1. Within 50m of an existing wetland (i.e., freshwater or estuarine) consistent with buffer zones in the Wetland Management Handbook (Department of Employment Economic Development and Innovation, 2011), with a higher ranking for land adjacent to wetlands of high ecological significance;
2. Frequent or very frequent connectivity to the GBR; and
3. Has a medium to high DIN generation rate (Table 4, Figure 7).

To determine those parcels of land that meet these criteria, land within the DINrisk dataset is ranked following this treatment system definition. An example map of land most suitable for transition for treatment systems is presented in Appendix 6.

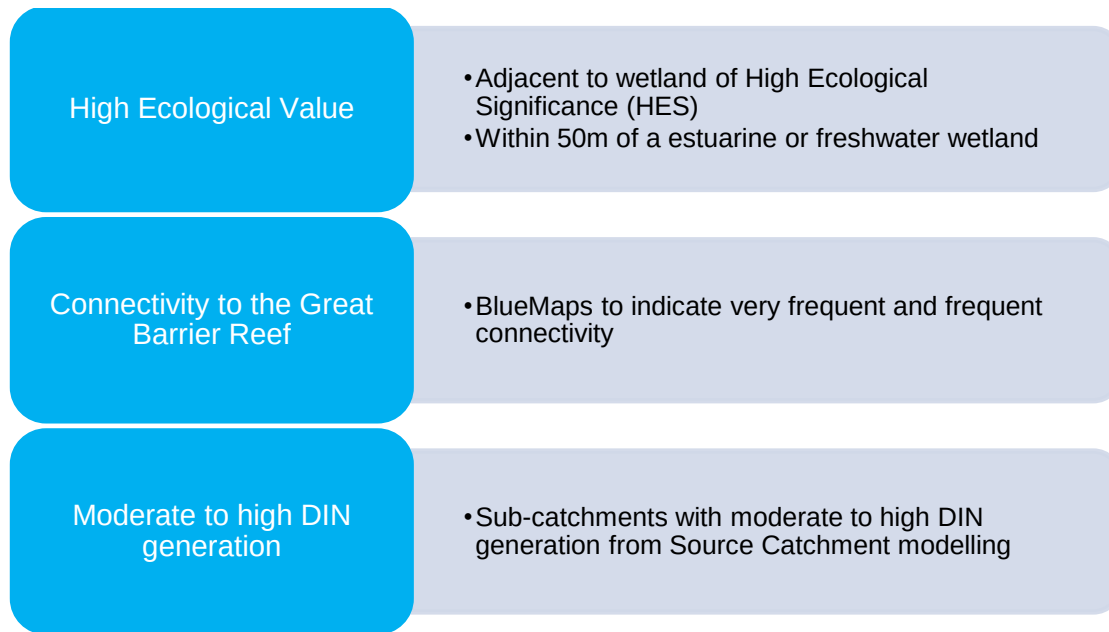


Figure 7: Spatial data and application in the framework to define areas most suitable for treatment systems

2.5 Limitations in the framework data analysis

All spatial data are subject to temporal and spatial uncertainty (Zhang & Goodchild, 2002), which needs to be considered when interpreting results. Data availability and extent were major limiting factors in running the land suitability model. The data used were the most up-to-date data available with temporal ranges from 2011 to 2016 (Table 5). LiDAR has the greatest temporal range (2009 to 2015), however, is only used to create the 50m contour line, having little impact on the resultant rankings. The river dataset (Ordered Drainage) is from 2007 however the potential for the rivers to have changed significantly is minimal and not anticipated to have a significant effect on the outcome of the analysis. Data extent is an important factor in obtaining a comprehensive land suitability model. Data needs to cover the entire area of interest otherwise there is a risk of excluding or including areas incorrectly. For this reason, acid sulfate soils data are not used as they cover only the Cairns and Halifax regions. Furthermore, due to inconsistencies in data extent and boundaries (see Figure 8), the use of a 1m buffer was needed to rank parcels' suitability in relation to their adjacency/proximity to specific criteria. Finally, some parcels overlapped multiple sub-catchment boundaries, in these cases the parcel was intersected and the portion contained within each sub-catchment was treated as a separate entity. The data used in the model were captured at ranges between 1: 100,000 to 1: 50,000. This indicates that the data are accurate when used at these scales and therefore the interpretation or interpolation of resulting data at finer resolutions should take this into consideration.

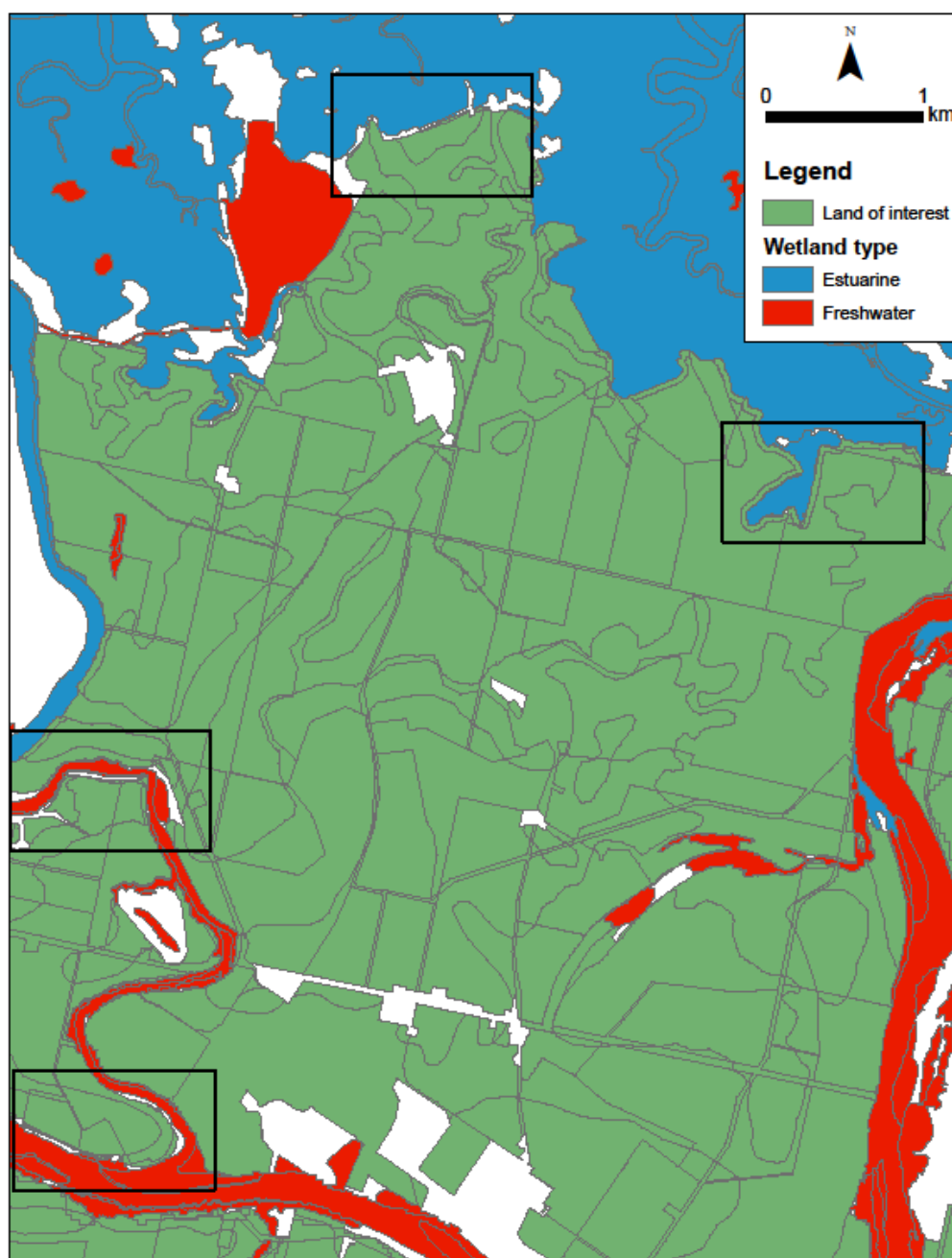


Figure 8: Example of spatial data inconsistencies in data extent and boundaries faced during this project

3.0 ECONOMIC ANALYSIS FOR LAND USE TRANSITION OPTIONS

This section describes the conceptual framework that underlies the economic analyses carried out for each of the transitional land use options. Economic analyses estimated the following economic outcomes from land use change:

- Annuity gross margin (Annuity GM) from the new land use;
- Annuity gross margin reduction (subtracting Annuity GM under the new land use from Annuity GM under sugarcane);
- Conversion cost (capital expenditures incurred to convert land from sugarcane production to the transitional land use);
- Total present value cost of conversion to the new land use over 12, 16 and 20 year time horizons, evaluated at a discount rate of 5% per annum. This calculation accounts for the difference in annuity GM following land use change and the one-off conversion cost; and
- Cost effectiveness of DIN reduction: expressed in terms of the total present value cost of transitioning from sugarcane to the new land use, per unit reduction in DIN emissions delivered.

Results from these economic analyses are reported per hectare of land converted.

3.1 Annuity Gross Margin (Annuity GM)

The different land uses have operating cycles that differ in length. Annual production revenues and costs typically vary within these operating cycles. For example, the sugarcane operating cycle starts with a planting sugarcane year in which cost inputs are high. Several ratoon cropping years (typically 3) then follow in which cost inputs are lower. Overall, a typical sugarcane production cycle might be five years in duration, comprising one plant sugarcane harvest 15 months after planting, followed by three ratoon harvests, each 13 months apart, followed by a six month fallow or legume-fallow period before sugarcane is planted again to repeat the cycle (note that there may be slight variants on these details).

Cattle fattening might typically operate on a 4-year production cycle, in which one year of heavier fertiliser input alternates with three subsequent years of lighter fertiliser input to maintain the pasture productivity required to support a particular level of fattening offtake. Constructed treatment wetlands after establishment might, in contrast, incur relatively constant annual maintenance costs and deliver relatively constant annual levels of DIN removal. In this case, the economic performance of constructed treatment wetlands could be modelled appropriately with a one year production cycle.

A method is therefore required to compare the economic performance of land uses with operating cycles of different lengths (e.g., 5 years for sugarcane, 4 years for cattle fattening and 1 year for constructed treatment wetlands). The annuity gross margin, calculated from the Total Present Value Gross Margin (TPVGM), allows this comparison to be made.

The Gross Margin (GM) calculation focuses on the difference ('margin') between production revenues and operating costs once the production process is up and running. Anticipated production revenues and operating costs may vary between years in the operating cycle as explained above. TPVGM calculation therefore discounts production revenues and operating costs from each year in the operating cycle via Eqn 1 to produce a 'total present value gross margin'.

Following Roebeling *et al.* (2007, p10-11), who used well-established principles of net present value calculation (Zerbe & Dively, 1994), the total present value of a land use is defined as the discounted sum of the differences between the revenues (R_t) and costs (C_t) which occur in each year t over the operating cycle T for the land use evaluated:

$$TPVGM = \sum_{t=1}^T \frac{R_t}{(1+r)^t} - \sum_{t=1}^T \frac{C_t}{(1+r)^t} \quad \text{Eqn 1}$$

where r is the time discount rate.

Discounting within the TPVGM calculation values more immediate delivery of revenues more highly and penalizes more immediate accrual of costs. Following Roebeling *et al.* (2007) and common practice, a discount rate of 5% per annum is used for TPVGM calculation in this report. A TPVGM > \$0 indicates that the discounted stream of annual revenues delivered by the land use exceeds the discounted stream of annual costs incurred.

Annuity gross margin is an economic measure, derived from TPVGM, which provides a straightforward mechanism for comparing gross margins from land uses with operating cycles of different lengths and different accrual trajectories for revenues and costs.

Following Roebeling *et al.*, (2007, p10), annuity gross margin (annuity GM) is defined as that gross margin which, delivered in each year of the operating cycle, discounted appropriately and summed, would produce the calculated TPVGM for the land use. Annuity GM can thus be thought of as annualized TPVGM, and is calculated by applying an annuity factor to TPVGM as follows:

$$\text{Annuity GM} = \text{TPVGM} \left(\frac{r}{1-(1+r)^{-T}} \right) \quad \text{Eqn 2}$$

where r is the annual discount rate, T is the operating cycle duration in years, and the term in brackets on the right hand side is the annuity factor.

Annuity GM accounts appropriately for inter-annual variations in operating revenues and costs within the operating cycle and thus provides a consistent basis for comparison of economic performance between land uses with operating cycles of different duration. It is important to remember that annuity GM compares performance of land uses once they are up and running; it does **not** take one-off start-up capital costs into account.

For consistency with standard definitions of annuity GM, and also to enable comparison with the annuity GMs for sugarcane production presented by Roebeling *et al.* (2007), our calculation of annuity GM does not include taxes or depreciation and maintenance of non-production system-specific fixed assets, or – as explained above – the capital costs of land use conversion.

Annuity gross margins are evaluated at a 5% annual discount rate over operating cycles of the relevant duration for each land use option, with revenue flows evaluated from private and societal perspectives, as described below.

3.2 Annuity GMs from land use options: private and societal perspectives

When evaluating land use options from the perspective of a private land holder, the annuity GM from the transition is the relevant net benefit stream to consider. When evaluating the transition from a societal perspective, however, the annuity GMs should be adjusted to account for societal costs arising from any accompanying DIN losses, and/or societal benefits arising from any active DIN removals or improvements in delivery of other ecosystem services (i.e., carbon sequestration or provision of nursery habitat for fisheries production).

Societal Annuity GM for land use

= Private Annuity GM for land use

– Cost of DIN losses + Value of improved ecosystem service delivery

Eqn 3

3.3 Annuity GMs from sugarcane production

Roebeling *et al.*, (2007) estimate annuity GMs from sugarcane production on four different soil classes in the Tully–Murray catchment in the Wet Tropics. Overlaying GIS maps of the locations of low-lying, high DIN risk, sugarcane land in the Tully–Murray catchment (Section 2) with the soil map from Roebeling *et al.*, (2007) study shows that most of the low-lying high DIN risk sugarcane locations are on soil classes S2 and S4. Following Murtha and Smith (1994), Roebeling *et al.*, (2007) define soil class S2 as ‘well drained medium to heavy clay soils from alluvial origin’, and soil class S4 as ‘poorly drained loam soils from alluvial origin’ (Roebeling *et al.*, 2007).

Annuity GM from sugarcane production on any particular soil class varies with fertiliser application rate. The plot-level annuity GMs reported by Roebeling *et al.*, (2007) for soil classes S2 and S4 at a fertiliser application rate of 150 kgN/ha are used as a basis for comparison with

the annuity GMs from the transitional land uses in this report (Table 2)¹. Roebeling *et al.*, (2007) annuity GMs are escalated from 2007 \$ to 2016 \$ using the 'all groups' consumer price index (CPI) for Brisbane (Australian Bureau of Statistics, 2016).

The plot-level annuity GMs on S2 and S4 soils in Table 11 are higher than the (2016 \$-converted) mean farm-level gross margin reported for the Wet Tropics by Van Grieken *et al.* (2014); Figure 7 page 32. This is somewhat surprising as a farm will typically cover several different soil types, for which annuity GM would likely be lowest for soil type S4 (Roebeling *et al.*, 2007, Figure 4 page 16). We retain (Roebeling *et al.*, 2007) 2016 \$-converted annuity GMs, however, because they are soil-type specific, and also because they provide some reflection of the recent strong rise in sugar prices (Table 11).

Table 11: Annuity gross margins from sugarcane production on soils classes S2 and S4 in the Tully-Murray catchment at a fertiliser application rate of 150 kgN/ha, as estimated by Roebeling *et al.*, (2007) escalated to 2016 \$ using the 'all groups' consumer price index for Brisbane (Australian Bureau of Statistics, 2016)

Soil class	Annuity GM from sugarcane (2016 \$/ha)
S2: well drained medium-heavy clay	1603
S4: poorly drained loam	1109

3.4 Annuity GMs from sugarcane production: private and societal perspectives

DIN losses arising from fertiliser applications to sugarcane impose external costs on society via negative impacts on water quality in the GBR. When evaluating sugarcane financial outcomes from a private perspective, the annuity GMs from sugarcane production are the relevant net benefit streams to consider. When evaluating sugarcane outcomes from a societal perspective, however, the annuity GMs from sugarcane production should be offset by the dis-benefits arising from the accompanying DIN losses. Roebeling *et al.*, (2007) estimate the DIN losses from sugarcane production on S2 and S4 soil classes at a nitrogen application rate of 150 kgN/ha. These results are shown in Table 12.

Table 12: DIN losses from sugarcane production with 150 kgN/ha nitrogen input on soil classes S2 and S4 in the Tully-Murray catchment, as estimated by Roebeling *et al.*, (2007, Figure 6 on p17)²

Soil class	DIN loss (kg DIN/ha)
S2: well drained medium-heavy clay	31
S4: poorly drained loam	50

¹ The mean nitrogen application rate on cane land in the Wet Tropics is reported to be 137 kgN/ha (Hateley *et al.*, 2014 Table 53, p172). Roebeling *et al.* (2007) annuity gross margin results for N applications of 150 kgN/ha are the closest publicly-available data for specific soil types S2 and S4.

² The DIN losses in Table 12 are soil-type specific, and therefore differ from the sub-catchment-specific DIN losses which were quoted earlier in Section 2.4.

A societal cost can be attached to these DIN losses using the DIN prices (\$/kg DIN), which are developed later in this Section. Annuity GMs from sugarcane from a societal perspective are calculated as follows:

$$\text{Societal Annuity GM sugarcane} = \text{Private Annuity GM sugarcane} - \text{Cost of DIN losses sugarcane}$$

Eqn 4

3.5 Reductions in annuity GM from private and societal perspectives

The reduction in annuity gross margin which the sugarcane producer would incur when switching to the new land use can be calculated by subtracting private-perspective annuity GM for the new land use from the annuity GMs from sugarcane production in Eqn 5.

$$\text{Priv Annuity GM Reduction} = \text{Priv Annuity GM sugarcane} - \text{Priv Annuity GM new land use}$$

Eqn 5

Reductions in annuity GM can also be calculated from a societal perspective (Eqn 6). Reductions in annuity GM from a societal perspective report the difference between societal annuity GM under sugarcane and societal annuity GM under the new land use:

$$\text{Soc Annuity GM Reduction} = \text{Soc Annuity GM sugarcane} - \text{Soc Annuity GM new land use}$$

Eqn 6

Reductions in annuity GMs from both private and societal perspectives are estimated for each transitional land use. These reductions in annuity GM are derived using Eqns 3,4,5 and 6³, drawing on the private and societal annuity GMs from sugarcane production on S2 and S4 soil types – based on (Roebeling *et al.*, 2007) modelling of sugarcane production in the Tully-Murray catchment escalated to 2016 \$.

The societal annuity GMs for some land uses (particularly wetlands and tree crops) may be higher than the societal annuity GMs from sugarcane. This is possible because societal valuations for active DIN removal and provision of other ecosystem services could be high if DIN prices are high, and/or if the new land use delivers high levels of DIN removal or other ecosystem services. In these circumstances the *reduction* in societal annuity GM (via Eqn 6) will be negative. This indicates that the new land use delivers a higher annuity GM than sugarcane, when viewed from a societal perspective. This is most likely to happen when considering conversion of land on soil class S4, where sugarcane annuity GMs are lower and DIN losses from sugarcane production are higher.

³ Note that none of these reductions in annuity GM account in any way for the capital costs of land conversion.

3.6 Conversion cost

Capital expenditures will be incurred to transition low-lying sugarcane land to a different land use. These capital expenditures occur once only, at the start of the conversion process. Capital expenditures differ for the different land uses. For cattle fattening, one-off capital expenditures could be required to construct a stockyard for livestock loading/unloading, and will be required to fence paddocks, prepare land and sow pasture. For tree crops, one-off expenditures will be required to prepare land and buy-in and plant tree stock. For constructed treatment wetlands, one-off capital expenditures will be required for excavations and/or earthworks, and for purchase and planting of appropriate nitrogen-processing vegetation. It is useful to estimate and report these one-off capital expenditures ('capex') of conversion separately from on-going operating expenditures ('opex') incurred regularly in the land use operating cycle.

The capital costs (per hectare) required to convert from sugarcane production to different land uses are estimated for each transitional land use.

3.6 Total present value cost of conversion to the new land use

The calculation of annuity GM and the reduction in annuity GM following land conversion regard any one-off capital investments required to set up the production process as 'sunk' or 'written off'. The calculated annuity GMs and reductions in annuity GMs (from both private and societal perspectives) therefore **ignore one-off capital costs of land use change**.

A full economic analysis of transitional land uses should account for these one-off capital costs of conversion as well as the reductions in annuity GM which follow from land use change. Net present value (NPV) calculation is designed to do exactly this.

Following Roebeling *et al.*, (2007, p10-11), who used well-established principles of net present value calculation (Zerbe & Dively, 1994), the net present value (NPV) of a land use is defined as the discounted sum of the differences between the benefits and costs (C_t) which occur in each year t over the defined time horizon T for which the land use is being evaluated, together with one-off costs of conversion which occur at the outset (C_0):

$$NPV = \sum_{t=1}^T \frac{B_t}{(1+r)^t} - C_0 - \sum_{t=1}^T \frac{C_t}{(1+r)^t} \quad \text{Eqn 7}$$

where r is the time discount rate.

Discounting within the NPV calculation values more immediate delivery of benefits more highly, and penalises more immediate accrual of costs.

Eqn 7 can be rearranged as:

$$NPV = \sum_{t=1}^T \frac{B_t - C_t}{(1+r)^t} - C_0 \quad \text{Eqn 8}$$

where $(B_t - C_t)$ expresses the net benefit delivered by the land use in year t .

When calculating NPV from a private perspective, the benefit terms B_t comprise market revenues from production (e.g., sale of fattened cattle, and the cost terms C_t comprise market costs incurred; e.g., purchase of livestock for fattening, fertiliser application, and transport costs). When calculating NPV from a societal perspective benefit terms are expanded to include any societal benefits from improved delivery of ecosystem services (if any), and cost terms are expanded to include the societal costs associated with DIN losses (if any).

Conventionally, when comparing two transitional land uses (e.g. sugarcane production and grazing), NPVs would be calculated according to Eqn 7 entirely separately for the separate land uses ($NPV_{\text{sugarcane}}$ and NPV_{grazing}). Each NPV would then be tested to determine whether it was greater than \$0, indicating that total present value benefits for that land use exceeded total present value costs. If the NPVs for both land uses exceeded \$0, then the NPVs would be compared with one another. The land use with the higher positive NPV would be the most advantageous land use option, showing a higher return on investment.

Direct NPV comparison in this way is not possible for sugarcane production in comparison with transitional land uses on low-lying, high DIN risk, sugarcane land. This is because the low-lying land is already being used for sugarcane production. The one-off capital costs of converting natural land to sugarcane production (e.g. costs of land clearance, drainage, access construction) are unknown and have effectively been written off decades ago. Consequently, NPV calculations hereafter focus on the **total present value cost of land use change (from current sugarcane production to a different land use)**.

From a private perspective, the choice facing the owner of low-lying sugarcane land is either to continue with sugarcane production, or convert to another land use. It is typically the case that the annuity GM from sugarcane would be higher than the annuity GM of the new land use. The landowner thus incurs a reduction in annuity GM when switching land use from sugarcane. This reduction in annuity GM will be regarded as an annual cost by land owners.

Land use transition will also incur one-off capital costs. The appropriate calculation to express the PV cost of land use change from the sugarcane producer's private perspective is:

$$PV\ Cost_{\text{Private}} = \sum_{t=1}^T \frac{\text{Reduction in Private Annuity GM}}{(1+r)^t} + C_0 \quad \text{Eqn 9}$$

where, again, r is the time discount rate, T is the time horizon over which PV cost is to be evaluated, and C_0 is the one-off cost of conversion to the new land use.

A similar calculation can be undertaken from a societal perspective:

$$PV\ Cost_{\text{Societal}} = \sum_{t=1}^T \frac{\text{Reduction in Societal Annuity GM}}{(1+r)^t} + C_0 \quad \text{Eqn 10}$$

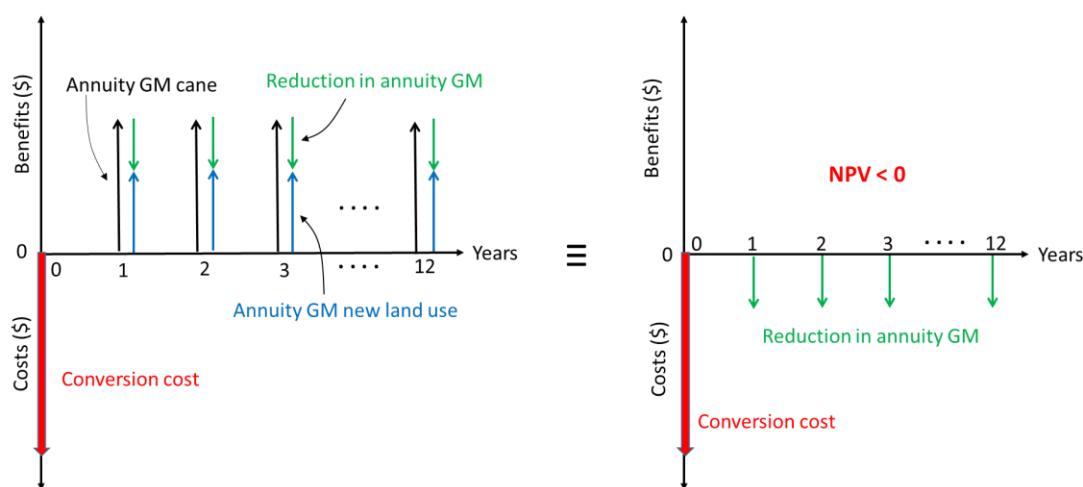
Here the inclusion of the reduction in societal annuity GMs accounts appropriately for both societal and private outcomes from land conversion.

Following Roebeling et al., (2007) and common practice, a discount rate of 5% per annum is used in this report for PV cost calculation. PV cost for conversion to new land uses will be calculated over 12, 16 and 20 year time horizons for conversion to wetlands and grazing. PV cost for conversion to tree crops will be calculated over a 20 year time horizon, recognising the longer time period required before tree crops achieve their full yield potential.

Figure 9 illustrates the components in the PV cost calculations of Eqns 9 & 10, indicating how land use change can potentially deliver an overall PV benefit if annuity GMs from the new land use exceed annuity GMs from sugarcane.

a)

Annuity GM after land use change < Annuity GM from cane



b)

Annuity GM after land use change > Annuity GM from cane

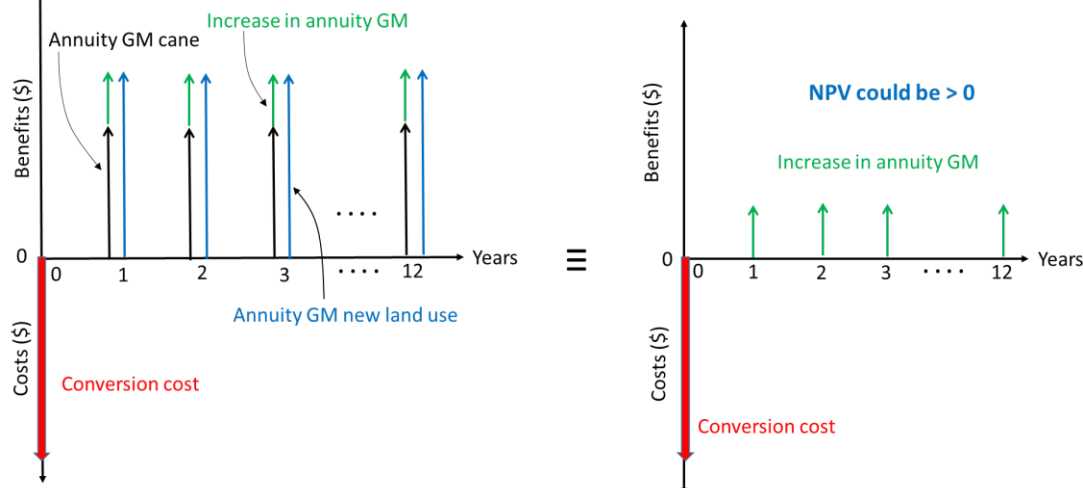


Figure 9: Diagrammatic representation of calculation of present value cost of land use conversion

3.7 Cost effectiveness of DIN reduction

The cost-effectiveness of DIN reduction provided by a particular change in land use is calculated by evaluating the total PV cost incurred per unit reduction in DIN loss delivered following land use change (\$ PV cost/kg DIN reduction) (Eqn 11).

$$\text{Cost effectiveness} = \frac{\text{PV cost of land use change}}{\text{Total reduction in DIN loss achieved}} \quad \text{Eqn 11}$$

PV cost and total reduction in DIN loss are both evaluated over a 12 year time horizon for conversion to wetlands and low input grazing. The cost-effectiveness of DIN reduction for conversion to tree crops is not reported in this study because the economic analysis show, under **optimal** conditions in **each year** of the 20-year time horizon, a PV **benefit** rather than a PV cost from land use change.

In practice, landowners will have to implement the land use changes required to deliver the desired reduction in annual DIN loss. It is therefore appropriate to calculate the cost-effectiveness of DIN reduction from the private landowner's perspective. Consequently, PV cost from a private perspective [Eqn 9] is used in the cost-effectiveness calculation [Eqn 11].

The cost element here accounts for the direct land conversion cost and the reduction in annuity gross margin which the private landowner incurs in switching from sugarcane to the alternative land use. In calculating the cost-effectiveness of DIN reduction in this way, we are assuming that the land conversion cost and the reduction in annuity gross margin are the only costs which the land owner will have to be compensated for in order to proceed with land use conversion. If other impediments are also present (e.g., the need to acquire a new set of farming skills), or other benefits arise (e.g., a reduction in the management time input required when switching from sugarcane production to the new land use) then the actual compensation required to persuade the land owner to proceed with land conversion may be higher or lower than we have assumed here. If this is the case, then the cost effectiveness of DIN reduction will be lower, or higher, than our estimate.

3.8 Valuation of improvements in ecosystem service delivery

3.8.1 Nutrient regulation

An indication of the value which society assigns per kg of DIN reduction in GBR catchments can be determined from society's willingness to pay to secure DIN reductions (\$/kg DIN abated/year). As the Government is regarded as representing the interests of society, the value of DIN reduction to society is determined by the Government's willingness to pay to obtain DIN reductions. Evidence of Government's willingness to pay for DIN reduction could be determined using:

- Current expenditures on agricultural extension activities to increase DIN abatement;

A range of values will therefore be used for DIN reduction in this report, ranging to a maximum of \$10/kg DIN reduced/year.

3.8.2 Carbon sequestration

A carbon price of \$10.23 per tonne CO₂ sequestered was obtained through the most recent Australian Government Direct Action auction process (Australian Government - Clean Energy Regulator, 2016).

Referring back to atomic weights, one tonne of CO₂ comprises 12/44 of a tonne of carbon. A valuation of \$10.23/tonne CO₂ sequestered is thus equivalent to a valuation of $(44/12 \times \$10.23) = \37.51 per tonne of carbon sequestered.

Carbon sequestration is therefore valued in this report at \$37.51/tonne of carbon sequestered.

3.8.3 Nursery habitat for fisheries

There is considerable variation in the literature regarding the value of coastal wetlands to fisheries production. The majority of estimations reviewed focused on an asset rather than production value. Similar to the analysis undertaken for nutrient reduction and carbon sequestration, the contribution which the different types of natural wetlands make to fisheries outcomes will vary depending on a number of factors.

Mangroves are identified in the literature as the wetland type that provides the greatest value to fisheries. A meta-analysis of global studies examining the value of mangroves found that the annual market value of capture fisheries supported by mangroves ranged from US\$750 to US\$16,750 per hectare of mangrove habitat (Rönnbäck, 1999). The lower bound of this figure converted to Australian dollars and updated to 2016 values (taking the value to AUD \$ 1573/ha) is used as a maximum for valuation to ensure a conservative and defensible basis for estimation. A nominal value of \$100 per hectare is used as a minimum valuation estimate for nursery services.

These figures are presented as a guide only. Further research beyond the scope of this project is necessary to estimate regional and wetland site-specific production values and contributions to commercial and recreational fisheries in the region.

A range of values will be used for fishery nursery habitat services in this report, ranging from a minimum of \$100/ha of coastal wetlands/year to a maximum of \$1573/ha of coastal wetlands/year.

3.9 Restore ecosystem services (coastal wetlands)

High Level Description: The definition of coastal wetlands used in this analysis is purposively broad and includes freshwater, brackish and saline wetland types reflecting the original landscape typology before conversion for agricultural purposes. There is a broad diversity of

wetland types in the Great Barrier Reef catchment. [Wetland/Info](#) (Queensland Government) identify the following types of wetlands in the GBR catchments:

- mangrove forests (estuarine)
- saltmarsh (saltpan/samphire) (estuarine)
- coastal saline swamps (palustrine)
- coastal non-floodplain tree swamps Melaleuca and Eucalyptus (palustrine)
- coastal non-floodplain wet heath swamps (palustrine)
- coastal non-floodplain grass, sedge and herb swamps (palustrine)
- coastal floodplain tree swamps – Melaleuca and Eucalyptus (palustrine)
- coastal floodplain wet heath swamps (palustrine)
- coastal floodplain grass, sedge, herb swamps (palustrine)
- coastal floodplain lakes (lacustrine)
- coastal non-floodplain rock lakes (lacustrine)
- coastal non-floodplain sand lakes – perched (lacustrine)
- coastal non-floodplain sand lakes – window (lacustrine)
- coastal non-floodplain soil lakes (lacustrine).

(WetlandCare Australia, 2008)

This section of the report details the high-level business case for the conversion of low-lying sugarcane land to a coastal wetland regardless of its type (in many cases this would be returning sugarcane land to its pre-existing form as a wetland). Significant differences are likely to exist in the restoration costs and benefits derived from each wetland type. Future work will be required to identify the restoration costs involved for each type of wetland, however, this analysis is beyond the scope of this preliminary assessment and therefore a range of potential costs and benefits are presented.

3.9.1 Economic evaluation

Annuity GMs

Annual benefits

Coastal wetlands are highly productive ecosystems providing a range of goods and services. Services identified for wetlands include supporting fisheries production, coastal protection, climate regulation (carbon dioxide sequestration), water purification, biodiversity protection and a range of cultural, recreational and educational values (Turner *et al.*, 2000). Three key ecosystem service values were identified for valuation in this study, as they are highly relevant to current management challenges confronting the Great Barrier Reef: nutrient regulation (water quality), carbon sequestration and fisheries production. An extensive range of literature was accessed to determine productive benefits and values. Similar to restoration costs, there is wide variation in the productive values and benefits delivered by coastal wetlands, dependent on wetland type and location. A range of benefit values are therefore provided. All of these benefits are regarded as societal benefits as there are currently no market mechanisms which enable landowners to accrue private revenues from provision of these public benefits.

Nutrient regulation

The extent to which natural coastal wetlands effectively trap and process nutrients is highly variable. Under appropriate conditions natural wetlands can be used to effectively treat polluted runoff from surrounding agricultural lands (Kroon et al., 2016). The amount of nitrogen reduction per hectare of natural wetland will be dependent on the load entering the wetland, residence time, system configuration, chemical properties (pH, C:N) and wetland vegetation type. An upper bound for annual nutrient reduction of 200kg DIN per hectare is used as this is at the lower end of estimates for constructed wetlands, which have been proven to remove between 200kg DIN per hectare per year and 1,200kg DIN per hectare per year (Department of Environment and Heritage Protection, 2016b). A minimum annual nutrient reduction value of 20kg DIN per hectare of wetland is used. Preliminary findings from research currently underway in natural wetlands in the wet tropics is showing significant levels of denitrification, in some wetlands over 500kg/ha/yr during the wet season (Adame pers. comm. 2017).

Therefore, range used here in the analysis is considered to be fairly conservative.

DIN removal via natural coastal wetlands: 20 – 200 kg DIN/hectare/year

Societal value of DIN removal⁴: \$133 - \$2,000/hectare/year

Carbon sequestration

Wetlands are per hectare one of the largest stores of carbon globally. Wetlands in coastal areas, particularly mangroves, have the greatest potential as carbon sinks. In these systems, biomass production is high but methane emissions are limited by salinity. Carbon storage has been estimated at ~240 tonnes C per ha to 1m depth in vegetated freshwater wetlands such as melaleuca forests, and ~550 tonnes C per ha to 1m depth in mangrove swamps (Australian Government, 2012).

The economic value of carbon stored in coastal wetlands will range between \$9,000 and \$20,630 per hectare [minimum: 240 tonnes C stored per ha, priced @ \$37.51 per tonne C; maximum 550 tonnes C stored per ha, priced @ \$37.51 per tonne C.].

Annual carbon sequestration rate in wetlands is conservatively estimated to be between 1 and 1.5 tonnes per hectare per year (Howe et al., 2009; Lovelock et al., 2014).

Carbon sequestration by coastal wetlands: 1 – 1.5 tonnes carbon/hectare/year

Societal value of carbon sequestration: \$37.51/tonne

Societal value of carbon sequestration by coastal wetlands: \$37.51 - \$56.27/ha/year

Fisheries habitat provision

⁴ DIN removal: minimum societal valuation 20kgDIN/ha @ \$6.67/kg DIN; maximum societal valuation 200kgDIN/ha @ \$10/kg DIN

Coastal wetlands can play a critical role in the lifecycle of many fish species that are important for commercial and recreational fishing. Over 75% of commercial fish catch and up to 90% of all recreational angling catch spend part of their lifecycle within estuaries and inshore wetlands (Creighton *et al.*, 2015). These authors identify that restoration of coastal wetlands will improve stocks of commercially important species such as Banana and Tiger prawns. Species important to both commercial and recreational fisheries such as mangrove jack and mud crab are dependent on coastal wetland areas. Barramundi post-larvae and juvenile phases feed and grow within estuarine to freshwater environments with juveniles being dependent on access to brackish coastal wetlands (Creighton *et al.*, 2015).

It is likely that all wetland sites identified through this project will be of at least some value to fisheries. Mangroves are identified in the literature as the wetland type that provides the greatest value to fisheries.

Societal value of fisheries nursery habitat: \$100 - \$1573/ha/year.

Recurrent annual costs

Maintenance costs for restored natural coastal wetlands are largely unknown. Given the uncertainty of information in natural wetland maintenance costs, coupled with the fact that natural coastal wetlands typically require minimal maintenance, a conservative value of \$750/ha/year is assumed for the maintenance cost of restored coastal wetlands.

Maintenance costs for restored coastal wetlands: \$750/ha/year

3.9.2 Annuity GMs of coastal wetlands

The private and societal annual benefits of nutrient regulation, carbon sequestration and fisheries habitat ecosystem services provision that could be derived from coastal wetlands, together with annual maintenance costs are outlined in Table 13. From the landholder's perspective, once the low-lying sugarcane land is converted into wetlands, the flow of private benefits in the form of revenues from the land ceases, and these benefits are replaced by maintenance costs. The situation is different from the societal perspective where the three ecosystem service flows deliver annual benefits to the society when low-lying sugarcane land is converted into coastal wetlands. In this report, the sum of ecosystem services values, net of maintenance costs, is regarded as the annuity GM for coastal wetlands from a societal perspective.

Table 13: Annuity gross margins from coastal wetlands (\$/ha), evaluated from private and societal perspectives

	DIN benefit (\$/ha)	Carbon benefit (\$/ha)	Fishery Benefit (\$/ha)	Maint. Cost (\$/ha)	Annuity GM (\$/ha)
Private min	0	0	0	750	-750
Private max	0	0	0	750	-750
Societal min	133	37.51	100	750	-480

Societal max	2000	56.27	1573	750	2879
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Annuity GMs reflect that, under current payment mechanisms, there are no marketable **private** returns for converting sugarcane land to coastal wetlands. Gross margins from a societal perspective report the value of the ecosystem services delivered, net of maintenance costs. The minimum to maximum variation in societal annuity GMs follows from valuing minimum and maximum ecosystem service deliveries at their minimum and maximum prices, respectively.

Costanza *et al.*, (1997) placed a value for ecological services of US \$9,990 per hectare per year on wetlands – specifically tidal salt marshes and mangroves and an annual global value of US\$1,648 billion. A 2006 meta-analysis of wetlands valuation studies around the world found that the average annual value is just over \$2,800 per hectare (Brander *et al.*, 2006). The only study of the value of wetlands in the GBR catchments estimates that one hectare of wetlands in the Lower Herbert region provides a community benefit of between \$1,915 and \$4,315, or an average of \$3,826 per year (Mallawaarachchi *et al.*, 2001). Against this broader background our valuation range of \$-480 - \$2,879 per hectare seems appropriate.

Total annual societal benefit of natural coastal wetland: \$-480 – \$2,879/ha/year

Reduction in Annuity GMs following conversion to coastal wetlands

Annuity GMs from sugarcane production on S2 and S4 land, from private and societal perspectives are shown in Table 14.

Table 14: Annuity Gross Margins from sugarcane production on soil classes S2 and S4 (\$/ha/year), evaluated from private and societal perspectives

	Annuity GM (\$/ha/year)
Private [S2 land]	1,603
Private [S4 land]	1,109
Societal min [S2 land]	1,293
Societal max [S2 land]	1,396
Societal min [S4 land]	609
Societal max [S4 land]	776

Annuity GMs from a societal perspective deduct the cost of DIN losses from the private annuity GMs⁵. Minimum societal annuity GMs value DIN losses at the highest DIN price (thus generating the largest loss), whereas maximum societal annuity GMs value DIN losses using the lowest DIN price (thus generating the smallest loss).

⁵ DIN loss from soil S2 is 31 kg DIN/ha and soil S4 is 50 kg DIN /ha (Table 12). This DIN loss is costed using DIN prices of \$6.67 / kg DIN and \$10/kg DIN, producing maximum and minimum damage cost of \$310 and \$207 for S2, respectively

The reduction in annuity GMs following restoration of low-lying sugarcane land to coastal wetlands are shown in Table 15, calculated using equations 5 and 6, and information collated in Tables 13 and 14.

Table 15: Reduction in annuity GMs following restoration of low-lying sugarcane land to coastal wetlands (\$/ha/year), evaluated from private and societal perspectives

	Reduction in Annuity GM* (\$/ha/year)
Private [S2 land]	2,353
Private [S4 land]	1,859
Societal min [S2 land]	-1,586
Societal max [S2 land]	1,876
Societal min [S4 land]	-2,270
Societal max [S4 land]	1,256

*Positive figures indicate *reductions* in annuity GM, negative figures indicate that annuity GMs increase (when viewed from the relevant perspective) following change of land use from sugarcane production.

Minimum reductions in societal annuity GM on a particular soil type arise when the maximum societal GM from coastal wetland is compared with the minimum societal GM from sugarcane, whereas maximum reductions in societal annuity GM arise from comparing the minimum societal GM from coastal wetlands with the maximum societal GM from sugarcane.

Reductions in annuity GM from a private perspective reflect the loss of annuity GM from sugarcane production on the relevant soil class, plus the additional maintenance costs associated with the wetlands, as no private benefits are produced following conversion. Reductions in annuity GM from a societal perspective offset the loss of annuity GMs from sugarcane and the wetland maintenance costs with the value of the ecosystem service flows produced, after adjusting sugarcane annuity GMs downwards to reflect the societal cost imposed by the associated DIN losses. When ecosystem service flows are valued using maximum prices, annuity GMs from a societal perspective can be higher than they were under sugarcane⁶.

Conversion costs

One-off restoration costs for coastal wetlands can be highly variable and dependent on a range of wetland type, site and time-specific variables. The simplest restoration strategies for areas of coastal wetland involve the restoration of flows following drainage or bund modification to enable natural processes to occur again (Wallace *et al.*, In Review). Other restorations can involve significant, costly earthworks and vegetation establishment. Bayraktarov *et al.*, (2016) in a major global examination of the costs of marine coastal restoration identified that mangrove wetlands had the lowest per hectare restoration cost of US\$2,500 per hectare.

⁶ Recall that calculations of changes in annuity GMs do not account for one-off capital costs of land use conversion.

Due to the extensive number of cost variables involved, a range of estimated restoration costs are used for the analysis. The lower bound adopted for restoration cost is \$5,000 per hectare, to reflect project implementation costs to landholders. The upper bound for restoration is considered to be similar to a constructed treatment wetland that involves significant earthworks and vegetation establishment at \$275,000 per hectare (Alluvium, 2016).

It should be noted that each potential restoration site would require different restoration activities and incur different maintenance costs. Further research will be required to develop a restoration and cost typology tool that can be used as part of a prioritisation and investment business case process.

Conversion Cost: \$5,000 to \$275,000/hectare

3.9.3 Present value cost of conversion

Total present value cost calculations incorporate changes in annuity GMs from private and societal perspectives, together with one-off conversion costs. The use of maximum one-off conversion cost would produce the largest total PV cost of conversion, whereas a minimum one-off conversion cost produces the lowest total PV cost of conversion. A range of total PV costs of conversion are therefore reported for each soil type. Here, Total PV costs of conversion are calculated over 12, 16 and 20 year periods using an annual discount rate of 5% per annum (Table 16).

Total Present Value Cost of wetland restoration

Table 16: Total Present Value Cost of wetland restoration (\$/ha) evaluated over 12, 16 and 20 year time horizons at an annual discount rate of 5%, evaluated from private and societal perspectives

	Tot PV Cost 12 years* (\$/ha)	Tot PV Cost 16 years* (\$/ha)	Tot PV Cost 20 years* (\$/ha)
Private min S2	25,855	30,501	34,324
Private max S2	295,855	300,501	304,324
Private min S4	21,477	25,147	28,167
Private max S4	291,477	295,147	298,167
Societal min S2	-9,057	-12,189	-14,765
Societal max S2	291,627	295,332	298,379
Societal min S4	-15,120	-19,602	-23,289
Societal max S4	286,132	288,612	290,653

*Negative Total PV costs indicate an overall benefit, from the relevant perspective.

Total PV costs of conversion calculated from a private perspective reflect the range of conversion costs, together with reductions in annuity GMs following land conversion.

Total PV costs of conversion from a societal perspective also reflect the range of conversion costs and reductions in annuity GMs, but these reductions are smaller than they were from a purely private perspective because of the DIN losses from sugarcane production and the societal benefits from ecosystem service flows from restored coastal wetlands.

In accordance with the earlier findings regarding reductions in societal annuity GMs, locations where conversion to coastal wetlands will produce high flows of ecosystem service benefits for low levels of conversion cost deliver a negative total PV cost of conversion from a societal perspective (i.e., conversion to coastal wetland provides a benefit from a societal perspective). All else being equal, total PV costs of conversion will be lower (and the potential to deliver a societal net benefit will be higher) when S4 land is converted because the reduction in annuity GM incurred is considerably lower.

Cost-effectiveness of DIN reduction

The cost-effectiveness of DIN reduction via conversion of low-lying sugarcane land to coastal wetland is reported in Table 17. Cost-effectiveness is reported in terms of Total PV cost from a private perspective (with the value of DIN reduction benefits excluded), over a 12 year time horizon, per unit DIN reduction delivered over the same time horizon.

Table 17: Cost effectiveness of removing DIN by converting sugarcane land to coastal wetlands (\$/kg DIN), evaluated from a private perspectives using the total PV cost of conversion approach and a 12 year time horizon

Cost effectiveness of DIN reduction	\$/kg DIN removed*‡
Private min [S2 land]	483
Private max [S2 land]	9.3
Private min [S4 land]	347
Private max [S4 land]	7.2

*A positive figure indicates that a cost is incurred per kg DIN removed

‡Cost effectiveness is calculated using the total PV costs of conversion and total DIN reductions over a 12 year time horizon

Cost-effectiveness results indicate that where conversion can be implemented at low cost, and where DIN removal can be achieved at levels approaching the lower end of the range for purpose-constructed treatment wetlands, conversion of low-lying, high DIN risk, sugarcane land to coastal wetlands can be highly cost-effective.

The variation in cost-effectiveness of restored coastal wetlands with DIN removal rate (kg DIN removed/ha) and total present value cost of conversion (k\$/ha) is shown in Figure 10.

3.9.4 Market for products and services

Potential demand for products and services (nutrient reduction and carbon sequestration) produced by natural coastal wetlands are strong in key areas of the GBR catchments with significant public investment occurring for these outcomes by Queensland and Australian Governments.

Commercial and recreational fishing is a key aspect of the regional economy although there is no readily identifiable and transparent market mechanism through which profits from these activities are currently re-invested in habitat maintenance, protection and restoration to enhance stocks.

3.9.5 Limitations and barriers to adoption

Markets for nitrogen and carbon reduction are emerging through public funding, however, there is a continued focus on best management practice rather than landscape restoration. There is currently no market mechanism for reinvestment in fisheries and an absence of policies and instruments to fund important habitat restoration. The absence of a nitrogen pollution cap and a nitrogen trading scheme limit the ability of markets to drive conversion of high DIN risk sugarcane land back to coastal and estuarine wetlands. Water quality offsets being considered by the Queensland Government as part of a new regulatory framework (Department of Environment and Heritage Protection, 2017) may provide a market for wetland restoration. Although this may require more definitive, local information on the DIN removal efficacy of restored wetlands.

Adoption and implementation of blue carbon projects has so far been limited. The capacity of landholders to participate in markets may be limited and there is a lack of aggregators in the market who would develop multiple funding and benefit projects. At the government level, combined and integrated policy outcomes across benefit categories are limited and usually focused on a single outcome.

3.9.6 Conclusion

Under appropriate circumstances, restoration of low-lying sugarcane land to natural wetlands is an appropriate policy option from a societal perspective. Low restoration cost – high benefit value wetland areas represent a ‘no regrets’ action that should deliver nitrogen reduction at a similar or lower cost than that currently incurred in supporting the shift towards best management practice in sugarcane production. Return is also delivered in a number of broader social goods rather than a single specific commercial private outcome.

The cost-effectiveness results presented are conservative, because they only include values from a private perspective. Carbon sequestration, provision of nursery habitat for fisheries and the values from the many other ecosystem services provided by natural coastal wetlands are excluded from this analysis.

The costs of coastal wetland restoration vary considerably, mainly because of the large variations in potential conversion cost. Where restoration can be delivered at low cost, an overall net benefit should be achieved in societal terms – i.e. when the societal values of DIN removal, carbon sequestration and fisheries benefits are accounted for, these benefits exceed the cost of conversion and reductions in annuity gross margin, as evidenced by the societal total PV cost results. The annuity GMs from ecosystem service flows at these locations exceed the annuity GMs which would likely be produced from sugarcane production, particularly on poorer draining S4 soil classes. This remains the case when only DIN removal and C

sequestration services are considered. These are the ecosystem service flows to which investment has already been committed through a range of public incentive schemes.

The key to cost-effective delivery of DIN reduction from coastal wetland restoration is identifying locations where wetland restoration costs are low and ecosystem service delivery rates are high.

Facilitating land use change and landholder participation can be achieved through a variety of business models. Purchase, restore and sell-on or lease of areas for restoration are potential implementation measures. A reverse auction process where landholders submit offers to restore wetland in return for an annual per hectare charge over a defined contract period (e.g., 12 - 20 years) would reveal the likely range of costings for a practical program.

Future work should include

- refinement of economic restoration costings for various wetland types
- estimation of location-specific fisheries production value
- development of a rapid assessment and prioritisation tool to assist the business case for wetland restoration
- implementation of a pilot project

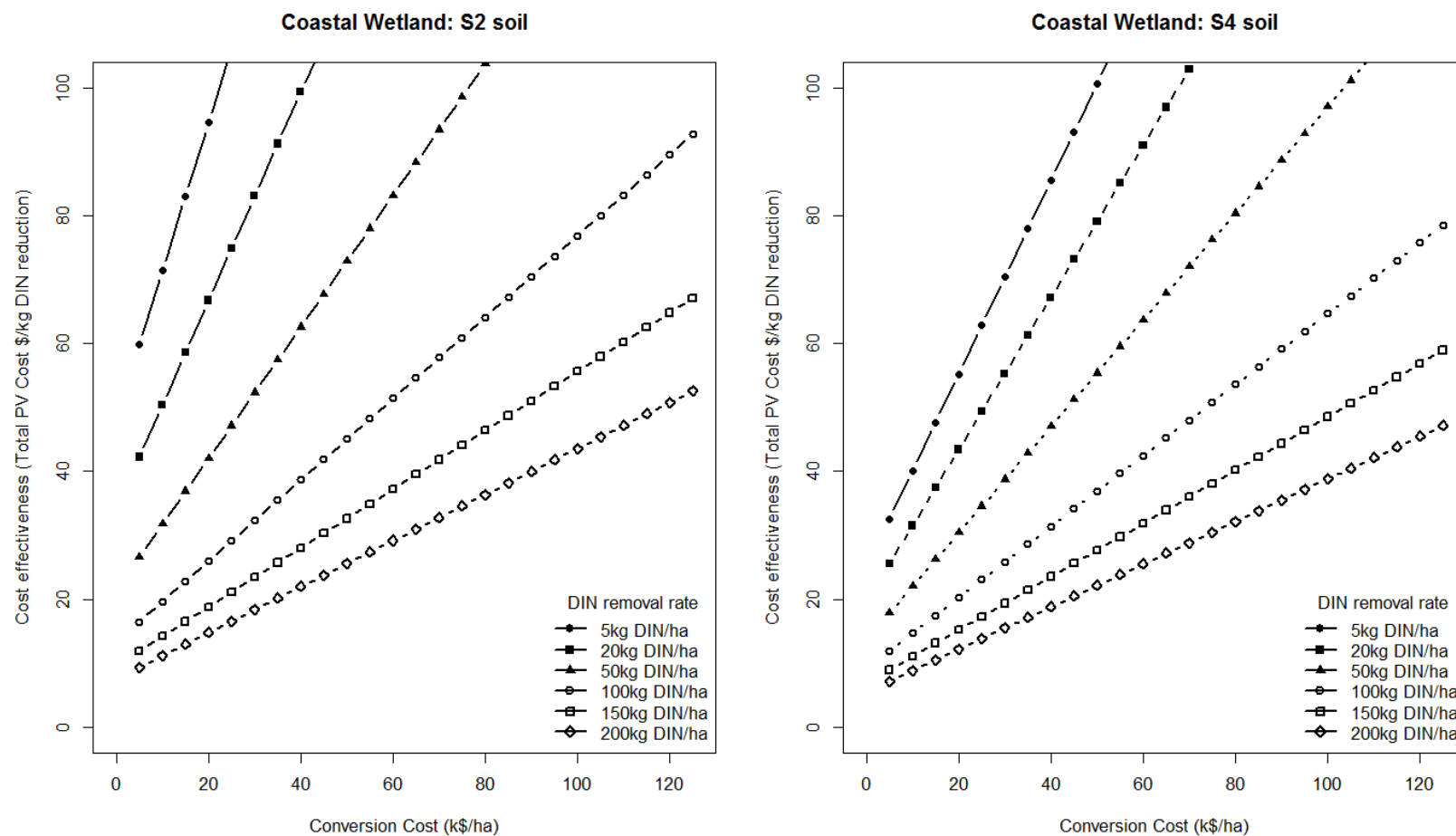


Figure 10: Cost-effectiveness of DIN removal following conversion of low-lying sugarcane land to coastal wetland, as a function of DIN removal rate in the wetland and the one-off cost of conversion

3.10 Constructed treatment wetlands

3.10.1 High level description

Constructed treatment wetlands have the potential to treat water pollutants, such as nitrogen and phosphorus, from agricultural runoff (Mitsch & Gosselink, 1993). Design guidelines have been presented for constructed wetland use in the wet and dry tropics (Breen *et al.*, 2012). In addition, emerging new water treatment technology is becoming available, that could be used as part of a treatment train with constructed wetlands (e.g., high rate macroalgae ponds), Department of Agriculture and Fisheries (2015). These new treatment technologies have yet to be trialled in a Wet Tropics agriculture context. For the purpose of reducing DIN loss from sugarcane paddocks, surface flow or free–water wetlands provide an appropriate water management option and have been trialled in the region (Department of Employment Economic Development and Innovation, 2011). These surface flow or free–water wetlands are therefore the focus of this study.

In high rainfall areas, for example, Tully catchment in the Wet Tropics, recent research indicates that a considerable proportion of total DIN load is delivered to the Reef lagoon under ambient flow conditions (Department of Environment and Heritage Protection, 2016b). Ambient flows include groundwater as well as surface water flows with N (or DIN) present in both (Department of Environment and Heritage Protection, 2016b). Constructed treatment wetlands, in the right location, and appropriately designed to remove nutrients under ambient water flows should therefore be able to make a contribution to DIN load reduction. This necessitates careful design of high flow bypass arrangements to ensure that DIN removal efficacy is not compromised during peak flow events, and also to ensure that the wetland does not dry out completely during drier spells (Breen *et al.*, 2012); it cannot be expected that constructed treatment wetlands could treat entire flow during high rainfall events (Department of Environment and Heritage Protection, 2016b). Constructed treatment wetlands are likely to be more effective at removing DIN if they have the following important features (Mitsch & Gosselink, 1993):

- Rich in organic carbon;
- Connected frequently to catchment nutrient flows via groundwater and/or surface water;
- Receive consistent and moderate amounts of nutrients (Verhoeven *et al.*, 2006);
- Adequate retention times; and
- Covered with appropriate types of vegetation.

To maximise cost effectiveness, constructed treatment wetlands should be located appropriately within catchment systems. Positioning constructed treatment wetlands near the outlet of medium / large sub-catchments, appropriately sized, is likely to be particularly effective (Department of Environment and Heritage Protection, 2016b), although optimum locations and sizing need to be determined following detailed catchment by catchment analysis (Queensland Wetlands Program pers. comm. 2016).

The constructed treatment wetlands considered in this study are assumed to meet the minimum design specifications widely used in the industry to treat nutrients in agricultural runoff. Relevant design specifications are detailed in *WetlandInfo* case studies (*Wetland* project search tool, *WetlandInfo* 2014). These wetland design features form the basis for economic evaluation of the feasibility of switching low-lying sugarcane land from sugarcane production to constructed treatment wetlands.

Minimum wetland size depends on the volume of runoff generated by a rain event size, soil type, existing moisture level in the soil and evaporation. In this study, it is assumed the wetlands are designed and sized following recommendations from the Queensland Wetlands Program (Fact Sheets, *WetlandInfo* 2014). The area of a constructed treatment wetland should be between 2% and 5% of its upstream drainage area (Department of Employment Economic Development and Innovation, 2011). Additional studies report that a constructed treatment wetland would need to be 20% of the upstream drainage area (Alluvium, 2016). There remains much debate relating to the relative size and efficacy of constructed wetlands in the Wet Tropics, and therefore limited quantitative information on the DIN removal capacity and conversion costs for wetland treatment. This debate has important ramifications on the uncertainty surrounding cost-effectiveness values and end users should be cognisant of the assumptions used here. In considering these differences, we provide a range in the efficacy and costings.

Constructed treatment wetlands considered in this study are assumed to meet the following criteria:

- The area available for wetland construction is at least 2% (though it could be as high as 20%, Alluvium (2016)) of the upstream catchment and at least 100m² in size to ensure adequate DIN removal performance;
- Best management farming practices are adopted on the sugarcane land within the catchment draining to the constructed treatment wetland; and
- Wetland is designed to accommodate natural water flows (i.e. through high-flow bypass) to avoid damage to existing natural wetlands or riparian vegetation.

Published information on costs of wetland establishment and maintenance, and on estimated levels of DIN removal, were used for economic evaluation of this land conversion option.

3.10.2 Economic evaluation

Annuity gross margin

Annual benefits

A systematic review of 203 wetlands from around the world (Land *et al.*, 2016) found a median total nitrogen removal rate of 93 g/m²/yr (i.e. 930 kg N/ha/yr) and a median nitrogen removal efficiency of 38% on a subset of 112 wetlands (i.e. wetlands with high sampling frequency for which all major water flow paths were quantified).

A 0.75 ha wetland constructed on a Wairarapa dairy farm in New Zealand is expected to remove 273 kg N/yr (364 kg N/ha/yr) (Praat *et al.*, 2015). These estimates of nitrogen removal

rate sit within the 200 – 1200 kgN/ha/yr range as reported in Department of Environment and Heritage Protection (2016b).

The modelling exercise conducted for the Gaia Farm case study concludes that 2.45 ha of constructed wetland could remove a third of the nitrogen run-off from more than 26 ha of banana production area and waste water from a banana packing shed (WetlandInfo, 2014). Gaia Farm is located south of Innisfail in the Wet Tropics. This design nitrogen removal efficiency of 33% is just below the median removal efficiency of 38% reported in Land *et al.* (2016).

A nitrogen removal rate of 400 kg N/ha/yr is considered a realistic moderate estimate of nitrogen removal rate for constructed treatment wetlands in sugarcane land (Department of Environment and Heritage Protection, 2016b). The same Summary Report indicates that nitrogen removal rates of up to 1200 kg N/ha/year can be achieved from suitably-located, high performance wetlands. We do not feel that appropriate data on the construction and maintenance costs of such high performance wetlands are available currently, so this high rate of N removal is not considered in this study. Therefore the upper range we considered appropriate for the study was 800 kg N/ha/year, comparable to the Land *et al.* (2016) review. The amount of DIN removed by treatment systems relative to total nitrogen removed is highly variable and depends on a range of factors. In lieu of any definitive TN:DIN ratio we assumed a 2:1 ratio.

Based on the preceding review of nitrogen removal rates and efficiencies, this study will use a minimum 200 kgDIN/ha/yr and a maximum of 400 kgDIN/ha/yr as the range of DIN removal rates for subsequent economic analyses.

DIN removal via constructed treatment wetlands: 200 – 400 kg DIN/hectare/year

Societal value of DIN removal⁷: \$1334 - \$4,000/hectare/year

Annual costs

Information on the annual cost of constructed treatment wetland maintenance is scarce. Taylor (2005) suggests annual maintenance costs are around 2% of construction costs. The Wetland Economic Assessment Tool (Department of Primary Industries and Fisheries n.d.) states annual operating expenses of \$5,636 for a 10ha wetland for which the construction cost was \$127,059. This suggests that annual maintenance cost is around 4% of construction cost. Taking the average of these two results, this study assumes that annual maintenance costs are approximately 3% of wetland construction cost⁸.

The range of annual maintenance costs for constructed treatment wetlands is assumed to be between \$1,800/ha/year and \$27,000/ha/year.

⁸ See following section for the estimated range of construction costs.

3.10.3 Annuity GMs of constructed treatment wetlands

Annuity GMs reflect that, under current payment mechanisms, there are no marketable private returns for converting low-lying sugarcane land to constructed treatment wetland, and thus currently no mechanism for covering on-going maintenance costs (Table 18). Gross margins from a societal perspective report the annual value of the DIN reductions delivered, offset by annual maintenance costs. The minimum to maximum variation in societal annuity GMs follows from minimum and maximum DIN reductions, valued at their minimum and maximum prices, offsetting maximum and minimum annual maintenance costs.

Table 18: Annuity gross margins of constructed wetlands (\$/ha), evaluated from private and societal perspectives

	DIN benefit (\$/ha)	Maint. Cost (\$/ha)	Annuity GM (\$/ha)
Private min	0	27,000	-27,000
Private max	0	1,800	-1,800
Societal min	1,334	27,000	-25,666
Societal max	4,000	1,800	2,200

Reduction in annuity GMs following conversion to constructed treatment wetland

Referring back to the annuity GMs from sugarcane production on soil classes S2 and S4, the reduction in annuity GMs following conversion of low-lying sugarcane land to constructed treatment wetlands are shown in Table 19.

Table 19: Reduction in annuity GMs following conversion of low-lying sugarcane land to constructed wetlands (\$/ha/year), evaluated from private and societal perspectives

	Reduction in Annuity GM* (\$/ha/year)
Private min [S2 land]	3,403
Private max [S2 land]	28,603
Private min [S4 land]	2,909
Private max [S4 land]	28,109
Societal min [S2 land]	-907
Societal max [S2 land]	27,062
Societal min [S4 land]	-1,591
Societal max [S4 land]	26,442

* Positive figures indicate reductions in annuity GM, negative figures indicate that annuity GMs increase (when viewed from the relevant perspective) following change of land use from sugarcane production.

Minimum reductions in societal annuity GM on a particular soil type arise when the maximum societal GM from constructed treatment wetland is compared with the minimum societal GM from sugarcane, whereas maximum reductions in societal annuity GM arise from comparing the minimum societal GM from constructed treatment wetlands with the maximum societal GM from sugarcane.

Reductions in annuity GM from a private perspective reflect the loss of annuity GM from sugarcane production on the relevant soil class, plus the annual wetland maintenance cost incurred following conversion. Reductions in annuity GM from a societal perspective offset the loss of annuity GMs from sugarcane with the value of the DIN reductions produced, after adjusting sugarcane annuity GMs downwards to reflect the societal cost imposed by the associated DIN emissions.

When DIN removals are valued using maximum prices, locations where DIN removal rates from constructed treatment wetland are high generate increased annuity GMs after land conversion⁹.

Conversion cost

The Queensland Department of Environment and Heritage Protection, through its *WetlandInfo* website, published several case studies on wetland construction and management in the GBR catchments. A case study on Gaia Farms in the Wet Tropics detailed a constructed treatment wetland to treat runoff from more than 26 ha of banana production area and wastewater from a banana packing shed (*WetlandInfo*, 2014). Ideally, economic analysis should be based on locally relevant and recent cost information on constructing and managing wetlands in intensive sugarcane production areas in the Wet Tropics; however, such data are rarely published. In addition to the costs reported in the Gaia Farm case study, cost information from other published sources is also reported for comparison.

This section summarises published information on the cost of constructing treatment wetlands (Table 20). All the cost figures are expressed in current 2015/2016 Australian dollars, escalated from original studies using the Consumer Price Index published by the Australian Bureau of Statistics. If the original cost figures were expressed in New Zealand dollars, costs were escalated to 2015/16 using the New Zealand Reserve Bank Calculator and then converted to Australian dollars (1 NZD = 0.96 AUD).

⁹ Recall that calculations of reductions in annuity GMs do not account for one-off capital costs of land use conversion.

Table 20: Cost information for constructed treatment wetlands in various locations

Gaia Farm Case Study (WetlandInfo 2014)	
Study area	Cowley Creek, south of Innisfail
Background information	A 2.45 ha wetland constructed on unproductive, flood-prone land to treat run-off from more than 26ha of banana production area and waste water from the banana packing shed. This constructed treatment wetland forms part of a treatment train following improved farming practices and vegetated swales, buffers and sediment traps.
Cost details	- wetland construction: \$41,404 - wetland plants: \$5,693 - planning, labour, machinery and equipment (in-kind): \$103,510 Total construction cost: \$150,607 Construction cost per ha: \$61,472/ha Annual operating & maintenance cost: not stated

Constructed treatment wetland on dairy farm (Praat et al., 2015)	
Study area	Lake Wairarapa, New Zealand
Background information	A wetland was constructed on a dairy farm located in the Lake Wairarapa drainage area. Construction started in 2014. 0.75 ha of wet pasture was transformed into a wetland with 0.5 ha of open water, which was subsequently planted with appropriate plants. The remaining area of 0.25 ha was appropriately vegetated with trees, flax, karamu and Manuka. An additional area was allocated to a specially-designed serpentine water flow path to slow down water flow and increase residence time.
Cost details	- Excavation: \$9,658 - Headworks and pipe installation: \$14,488 - Planting: \$16,419 - Fencing: \$2,898 Total construction cost: \$43,463 Construction cost per ha: \$57,951/ha Annual operating & maintenance cost: not stated

'Costs of achieving the water quality targets for the Great Barrier Reef' Wetland construction (Alluvium, 2016)	
Study area	Wet Tropics
Background information	An assessment of the installation costs for 25, 50 and 100 ha of constructed wetlands or recycle pits in sugarcane growing areas.
Cost details	- Installation cost for small wetlands: \$800,000/ha (low), \$900,000/ha (medium) and \$1,000,000 Construction costs per ha [Small wetlands]: \$900,000/ha - Installation cost for medium to large wetlands: \$275,130/ha (low), \$343,913/ha (medium), and \$412,696/ha in addition to establishment cost of \$738,607 Construction costs per ha [Medium/Large wetlands]: \$343,913/ha

Structural stormwater quality best management practice: cost/size relationship information from the literature (Taylor, 2005)	
Study area	Constructed wetlands in greenfield developments in South East Queensland
Background information	Collation of cost-related information on structural stormwater quality best management practices from all Australian states as found in relevant literature.
Cost details	- Construction and planting costs for 935m² (small) wetland with an inlet pond (85m²), macrophyte zone (850m²), bypass weir and channel: Construction costs per ha [small wetland] \$900,000/ha - \$1,000,000/ha - Construction and planting cost for large wetland to treat recirculated lake water with a 3,500m² macrophyte zone: \$650,000/ha Construction costs per ha [large wetland] \$650,000/ha

The costing information in Table 20 indicates that there is an order of magnitude difference in construction costs between surface-flow wetlands constructed for nutrient management on farms (Gaia Farms and Lake Wairarapa dairy farm) at c. \$61,500/ha and \$58,000/ha, and construction costs for stormwater management wetlands in urban/suburban residential settings (Taylor, 2005) @ \$650,000 - \$1,000,000/ha.

The range of construction costs for wetlands constructed on-farm for nutrient management in this study is \$60,000 - \$900,000 per hectare.

Total present value cost of conversion to constructed treatment wetland

Total present value cost of land use conversion calculations incorporate changes in annuity GMs from private and societal perspectives, together with one-off conversion costs (Table 21). Here, total PV costs of conversion are calculated over 12, 16 and 20 year periods using an annual discount rate of 5% per annum.

Total Present Value Cost of land conversion to constructed treatment wetlands

Table 21: Total Present Value Cost of conversion to constructed treatment wetlands (\$/ha) evaluated over 12, 16 and 20 year time horizons at an annual discount rate of 5%, evaluated from private and societal perspectives

	Total PV Cost 12 years (\$/ha)	Total PV Cost 16 years (\$/ha)	Total PV Cost 20 years (\$/ha)
Private min S2	90,162	96,881	102,409
Private max S2	1,153,516	1,209,993	1,256,457
Private min S4	85,783	91,527	96,253
Private max S4	1,149,137	1,204,639	1,250,300
Societal min S2	51,961	50,170	48,697
Societal max S2	1,139,857	1,193,292	1,237,252
Societal min S4	45,899	42,757	40,173
Societal max S4	1,134,362	1,186,572	1,229,526

Total PV costs calculated from a private perspective reflect the range of conversion costs, together with reductions in annuity GMs following land conversion.

Total PV costs from a societal perspective also reflect the range of conversion costs, but show the effects of accruing suitably discounted societal benefits from DIN reductions to offset the initial conversion costs, together with the effect of the lower reductions in annuity GM when land use conversion is viewed from a societal perspective. In all cases analysed, annuity GMs reduce following land conversion. Total PV costs of land conversion thus increase as time horizon lengthens.

Locations on S4 soils where conversion to constructed treatment wetlands will produce high levels of DIN removal for modest conversion costs deliver DIN reductions at the lowest total PV cost. Even in these locations on S4 soils, with the range of construction costs, DIN reductions and DIN pricing applied, conversion of low-lying sugarcane land to constructed treatment wetlands still incurs a cost from both private and societal perspectives.

Cost-effectiveness of DIN reduction

The cost-effectiveness of DIN reduction via conversion of low-lying sugarcane land to constructed treatment wetland is reported in Table 22. Cost-effectiveness is reported in terms of total PV cost incurred from a private perspective, as explained in the economics methodology section.

Table 22: Cost effectiveness of removing DIN by converting low-lying sugarcane land to constructed treatment wetlands (\$/kg DIN removed), evaluated using total present value cost over 12 years, from a private perspective

Cost effectiveness of DIN reduction	Total PV cost \$/kg DIN removed*‡
Private (min) [S2 land]	416
Private (max) [S2 land]	17.4
Private (min) [S4 land]	383
Private (max) [S4 land]	15.9

‡Cost effectiveness is calculated in terms of private-perspective total PV costs over a 12 year time horizon.

Cost-effectiveness results from a private, total PV cost perspective suggest that conversion of low-lying sugarcane land to constructed treatment wetlands can deliver DIN removal more cost effectively than existing extension-based policies.

The variation in cost-effectiveness of converting low-lying sugarcane land to a constructed treatment wetland with DIN removal rate (kg DIN removed/ha) and cost of conversion (k\$/ha) is shown in Figure 11.

3.10.4 Market for products and services

As mentioned previously, potential demand for the DIN removal service produced by constructed treatment wetlands is strong in key areas of the Great Barrier Reef catchments with significant public investment committed by Queensland and Australian Governments to reduce DIN emissions. Water quality offsets being considered by the Queensland Government as part of a new regulatory framework (Department of Environment and Heritage Protection,

2017) may provide a market for constructed treatment wetlands, even as part of a treatment train approach.

3.10.5 Limitations and barriers to adoption

- Locations must be identified carefully because the effectiveness of constructed treatment wetlands in removing water pollutants is dependent on the soil type, upstream drainage area, topography, hydrology and climate. High rainfall events on the hydrograph would need to be diverted around constructed treatment wetlands;
- Landowners require some form of financial support to switch land use from sugarcane to constructed treatment wetlands due to the public good nature of the DIN removal service provided and the sizeable opportunity costs of moving away from sugarcane;
- Cost effectiveness results suggest that whichever funding mechanism is used (subsidies, auction contracts or other forms of incentive), payments of the order of \$10/kg DIN removed should succeed in encouraging conversion of some low-lying sugarcane land to constructed treatment wetlands – particularly conversion of land on S4 soils; and
- The study focused on surface flow treatment wetlands, as there was some published information on the use of these systems in the GBR. New treatment system technologies, such as bioreactors or macroalgae, may be more cost-effective for DIN removal, however, trials are needed to determine their efficacy and feasibility in a Wet Tropics context.

Conclusion

Cost-effectiveness results suggest that for locations where construction costs are low and DIN removal potential is high, conversion of low-lying sugarcane land to constructed treatment wetlands should be achievable at considerably lower cost than that incurred under existing extension-based policies.

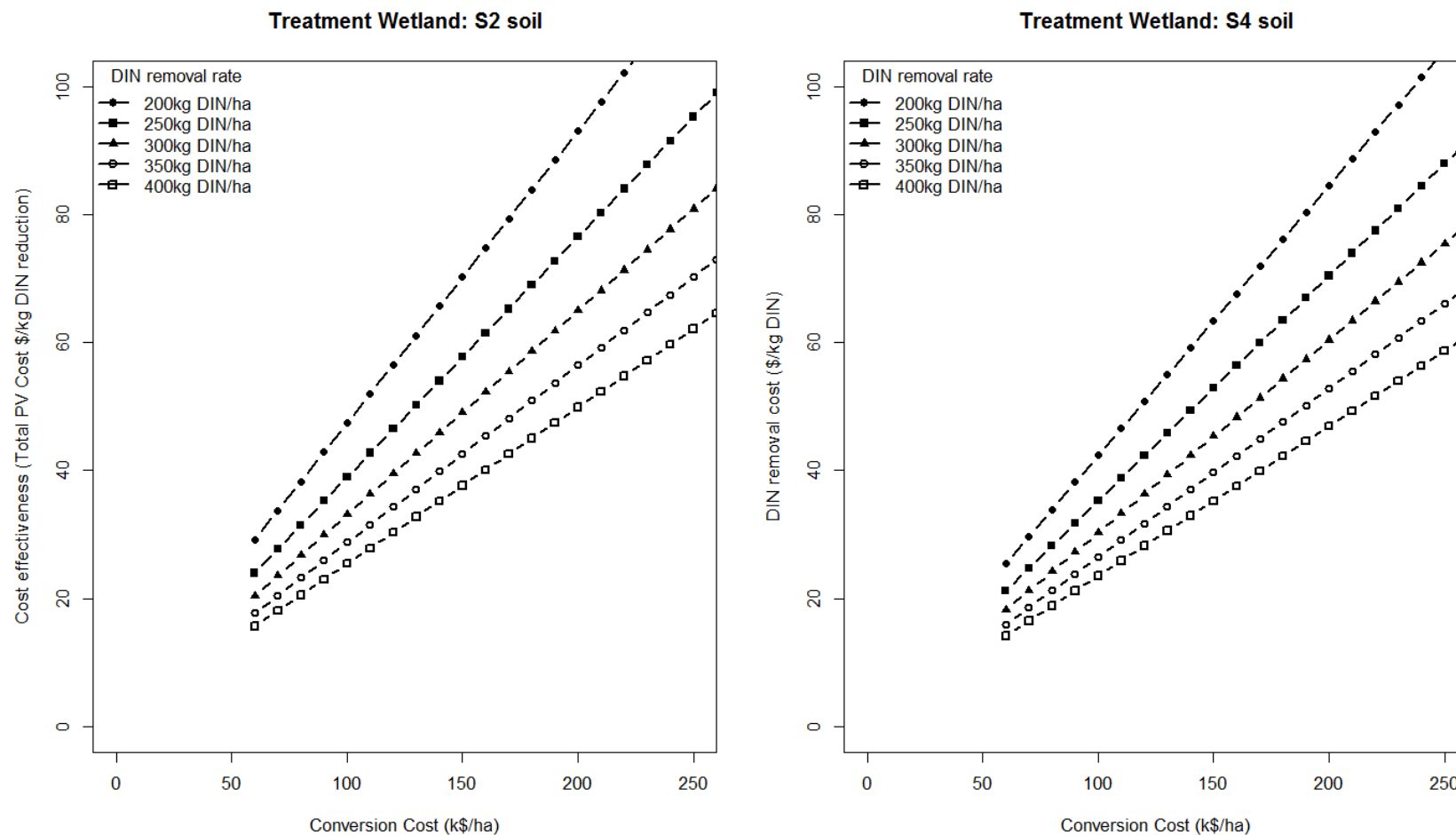


Figure 11: Cost-effectiveness of DIN reduction following conversion of low-lying sugarcane land to constructed treatment wetland, as a function of DIN removal rate in the wetland and the one-off cost of conversion

3.11 Grazing

3.11.1 High level description

Grazing has been identified as possible land use option for low-lying, high DIN risk, sugarcane land in the Wet Tropics. A DAF Senior Beef Extension Officer suggested low DIN impact grazing as a grass-finished cattle production system destined for live export or for slaughter. Data was kindly provided by DAF to this study, along with detailed explanations of the necessary management practices and current (2016) input costs for grazing in the Wet Tropics.

The study by Roebeling *et al.*, (2007) modelled the economic and environmental performance of beef grazing in the Tully-Murray catchment in the Wet Tropics. Roebeling *et al.*'s (2007) study estimated gross margins and DIN losses from beef grazing on different soil classes. Two of those soil classes, S2 and S4 predominate in locations where beef grazing could potentially replace sugar production on low-lying sugarcane land.

The analyses in this study utilise DIN loss estimates from Roebeling *et al.*, (2007), together with up to date information on management practices and input costs to model the economic and environmental performance of low-impact beef grazing as a conversion land use on low-lying sugarcane land in the Wet Tropics. Two variations of low-impact beef grazing system are considered:

- Grazing with fertiliser input for the pasture; and
- Grazing without fertiliser input for the pasture

For both grazing systems, restocker and feeder steers from inland Queensland are purchased in April at the end of the wet season. These cattle are fattened on grass paddocks converted from low-lying sugarcane land until the end of November or December and then sold. Outcomes from grazing are calculated for two different buy-in weights of animal (light and heavy), fattened on grass pasture between April and December:

- I. [Light] light-weight feeder steers for live export. Restocker steers with a buy-in weight of 250 kg per animal are purchased in April, fattened for 240 days, and then sold-out as light steers for live export from Townsville to Indonesia or Vietnam.
- II. [Heavy] heavy-weight slaughter cattle. Medium steers with a buy-in weight of 450 kg per animal are purchased in April, fattened for 240 days and then sold through the saleyard as grass-fed bullocks for slaughter.

Stocking densities differ between the two grazing systems. For the system with fertiliser input, stocking densities, and the fertiliser application rates necessary to support the pasture offtake required by those stocking densities in the long term, differ between the S2 (higher productivity) and S4 (lower productivity) soil types (Roebeling *et al.*, 2007). Under the system with no fertiliser input, stocking densities are adjusted downward for both soil types to match the lower pasture growth capacity without fertiliser applications.

Economic performance and cost-effectiveness outcomes for the two grazing systems are thus modelled for four production systems:

- L2: Light steer fattening on soil class S2
- L4: Light steer fattening on soil class S4
- H2: Heavy steer fattening on soil class S2
- H4: Heavy steer fattening on soil class S4

In the light and heavy production systems, brahman cattle (*Bos Indicus* spp) are fattened on a mixture of *Tully Humidicola* and *Setaria* grasses over a period of eight months. This particular combination of grass species and cattle genetics is deemed to be appropriate for the Wet Tropics (DAF pers. comm., 2016). The low-input grass-fed grazing system as suggested best matches the grazing system which Roebeling *et al.*, (2007) modelled on soil class S2. Buy-in and sell-out livestock prices are key drivers of profitability in a grass-finished cattle business.

Potential locations for conversion to grazing which are adjacent to existing grazing land are identified separately from potential conversion locations which are not adjacent to existing grazing land. Economic performance is modelled separately for these two categories of conversion because additional conversion costs will be incurred to construct a stockyard and loading facilities for land which is not adjacent to land that is already used for grazing.

3.11.2 Background information

Gross margin from cattle fattening varies with stocking rate. The primary mechanism for generating net revenue is weight gain per livestock head, following fattening on grass pastures from April to December. Advantageous variation in buy-in and sell-out prices can augment net revenues, but this variation is regarded as stochastic, i.e. it may or may not work out to the landowner's advantage to a particular extent in any particular year.

Grazing with fertiliser input

Economic modelling in this study assumes a weight gain of 0.5kg/head/day over a period of eight months (240 days), with a resulting total weight gain of 120 kg per head from fattening (DAF, pers. comm., 2016). For the light production system, restocker steers are bought in at a starting weight of 250 kg. The sell-out weight for these animals for live export will therefore be 370kg, and their mid-term weight will be 310kg. For the heavy production system, feeder steers are bought in at a starting weight of 450kg. The sell-out weight for these animals for slaughter as grass-fed bullocks will therefore be 570kg, and their mid-term weight will be 510kg.

Pasture offtake requirements are calculated for stocking densities expressed in mid-term weights as adult equivalents (AE). Roebeling *et al.*, (2007) suggest an economic optimum stocking rate of 2 AE/ha on soil class S2 and 1.75 AE/ha on soil class S4 (Roebeling *et al.*, 2007, p23). DAF suggest a stocking rate of one 450kg animal per 0.5 hectare for the grazing system in the Wet Tropics under current (2016) conditions, which is very similar to (Roebeling *et al.*, 2007) recommendations for soil class S2.

One AE is defined as a 450kg *Bos taurus* steer grazing at weight maintenance rate (Blakeley & McLean). Using Blakeley & McClean's AE equivalent table for *Bos indicus* (i.e., relevant for Brahman breeds):

- a 300 kg animal gaining 0.5 kg/day = 1 AE
- a 500 kg animal gaining 0.5 kg/day = 1.5 AE

Applying these AE figures to (Roebeling *et al.*, 2007) gross margin-maximising stocking rates produces the stocking densities (head/ha) in Table 23 for the four production systems.

Fertiliser applications are required to maintain the pasture offtake rates necessary to support these livestock weight gains in the long term. (Roebeling *et al.*, 2007) indicate that the fertiliser application rates shown in Table 23 are required to support gross margin-maximising stocking densities on soil classes S2 and S4 in the long term. DAF advised that cyclic fertiliser applications of 200 kg/ha/yr of Entec 67 fertiliser every 4th year, interspersed with applications of 150 kg/ha/yr of urea in intervening years would be appropriate to support gross margin maximising production. Given the nitrogen content of these fertilisers¹⁰, DAF recommendations equate to an average N application rate of 58.25 kgN/ha/year, which is almost identical to that recommended by Roebeling *et al.*, (2007) for soil class S2 (Roebeling *et al.*, 2007), p25). On soil class S4, higher fertiliser applications are required to enable pasture to support its economic optimum stocking density. Using Roebeling *et al.*, 's (2007) nitrogen application rate for soil class S4, and adopting DAF's 1:3 yearly cycle of Entec 67 and urea applications, recommended fertiliser application rates for soil class S4 are 300kg/ha/yr of Entec every 4th year, interspersed with 200 kg/ha/yr of urea in the intervening years. Overall this produces an average N application rate of 79 kg N/ha/yr (Table 23).

Table 23: Stocking rate, fertiliser requirements and DIN loss under L2, L4, H2 and H4 with fertiliser input

Case / scenario	DIN loss (kg/ha/yr)	Fertiliser requirement (kg N/ha/yr)	Stocking rate (heads/ha)
L2: Light feeders on soil class 2	2.7	58	2
L4: Light feeders on soil class 4	5	79	1.75
H2: Slaughter cattle on soil class 2	2.7	58	1.333
H4: Slaughter cattle on soil class 4	5	79	1.167

Roebeling *et al.*, (2007) model DIN loss as a function of stocking density and, presumably, the N application rates required to support those stocking densities in the long term (Roebeling *et al.*, 2007 p24). These predicted DIN losses for the relevant stocking densities and N application rates are also shown in Table 23.

¹⁰ Here we assume N content of 13% for Entec67 and 46% for Urea.

Grazing with no fertiliser input

Under this system with no fertiliser input to aid pasture growth, a weight gain of about 0.42kg/head/day is assumed, resulting in a total gain of 100kg/head over a period of 8 months (240 days) (DAF, pers. Comm., 2016). Similar to the light production system with fertiliser input, restocker steers are bought at a starting weight of 250kg. Gaining another 100kg during the eight-month fattening period, the sell-out weight for live export will be 350kg, and their mid-term weight will be 300kg. For the heavy production system, 450kg feeder steers are bought in and fattened to 550kg after 8 months ready for sale as grass-fed bullocks for slaughter. The mid-term weight for the heavy production system is 500kg/head.

Pasture offtake requirements are calculated for stocking densities expressed in mid-term weights as adult equivalents (AE). DAF suggest a stocking rate of one 450kg animal per 0.85 hectare for the grazing system without fertiliser input in the Wet Tropics under current (2016) conditions, assuming that this is for soil class S2. Blakely & McClean's AE equivalent table for *Bos indicus* indicates:

- a 300 kg animal gaining 0.42 kg/day = 0.95 AE
- a 500 kg animal gaining 0.42 kg/day = 1.4 AE

DAF's recommended stocking rate equates to a stocking density of 1.65 AE/ha for soil class S2. This is a 17.5% reduction on the stocking density which Roebeling *et al.*, (2007) recommend for soil class S2 when fertiliser is applied. Scaling down Roebeling *et al.*, 's (2007) recommended stocking density for S4 by the same proportion produces a stocking density of 1.45 AE/ha for grazing with no fertiliser application on soil class S4. Table 24 summarises DIN losses, fertiliser requirements and stocking rates for light and heavy animal production in the grazing system with no fertiliser input.

Table 24: Stocking rate under L2, L4, H2 and H4 with no fertiliser input

Case / scenario	DIN loss (kg/ha/yr)	Fertiliser requirement (kg N/ha/yr)	Stocking rate (heads/ha)
L2: Light feeders on soil class 2	0	0	1.737
L4: Light feeders on soil class 4	0	0	1.526
H2: Slaughter cattle on soil class 2	0	0	1.179
H4: Slaughter cattle on soil class 4	0	0	1.036

Grazing systems: summary

Table 25 summarises the information on the buy-in and sell-out weights under light and heavy production, with and without fertiliser input. For the grazing systems considered in this study, the information in Tables 23 and 24 provide the basis from which the economic performance and cost-effectiveness of low-input grazing as a mechanism for reducing DIN loss are assessed.

Table 25: Buy-in and sell-out weights, with and without fertiliser input

Case / scenario	Unit	Grazing with fertiliser input	Grazing without fertiliser input
Buy-in weight (Light production)	kg/head	250	250
Sell-out weight (Light production)	kg/head	370	350
Buy-in weight (Heavy production)	kg/head	450	450
Sell-out weight (Heavy production)	kg/head	570	550

3.11.3 Economic evaluation

All prices are expressed in 2016 dollars.

Annuity gross margins

Annual benefits

Revenues for the sale of fattened steers are the benefits obtained from a private perspective. A fixed livestock price of \$3/kg live weight is used to produce indicative revenues from sale of fattened steers. The sensitivity of the cost-effectiveness of DIN removal to the difference between sell-out and buy-in prices is indicated in Figure 12.

At the net-revenue-maximizing stocking rates, and assuming 120kg/head and 100kg/head weight gain during fattening with and without fertiliser input, respectively, annual revenues generated from each production system at a livestock sale price of \$3/kg live weight are shown in Tables 26 and 27.

Table 26: Revenues from sale of fattened steers from a 10 hectare paddock *with fertiliser input* under production systems L2, L4, H2 and H4, assuming 120kg/head weight gain and a sale price of \$3/kg live weight

Revenue	\$ per 10 ha
L2 @ 2 head/ha	22,200
L4 @ 1.75 head/ha	19,425
H2 @ 1.33 head/ha	22,800
H4 @ 1.167 head/ha	19,960

Table 27: Revenues from sale of fattened steers from a 10 hectare paddock *with no fertiliser input* under production systems L2, L4, H2 and H4, assuming 100kg/head weight gain and a sale price of \$3/kg live weight

Revenue	\$ per 10 ha
L2 @ 1.737 head/ha	18,279
L4 @ 1.526 head/ha	16,062
H2 @ 1.176 head/ha	19,476
H4 @ 1.036 head/ha	17,115

From a societal perspective, when fertiliser is applied to the pasture, the private revenues (Table 26) are offset to some extent by the DIN losses associated with grazing, as shown in

the first column of Table 23. These losses are valued using the \$6.67 - \$10 /kg DIN pricing established earlier. On the other hand, the private revenues from the grazing system without fertiliser input reflect the societal benefit, assuming zero DIN losses from this grazing system.

The per hectare revenues from grazing with fertiliser input, from private and societal perspectives are therefore:

Private perspective: Annual revenue

Annual revenue L2: 2,220 \$/ha

Annual revenue L4: 1,943 \$/ha

Annual revenue H2: 2,280 \$/ha

Annual revenue H4: 1,996 \$/ha

Societal perspective: Annual benefit

Annual benefit L2 minimum: 2,193 \$/ha

Annual benefit L2 maximum: 2,202 \$/ha

Annual benefit L4 minimum: 1,893 \$/ha

Annual benefit L4 maximum: 1,910 \$/ha

Annual benefit H2 minimum: 2,253 \$/ha

Annual benefit H2 maximum: 2,262 \$/ha

Annual benefit H4 minimum: 1,946 \$/ha

Annual benefit H4 maximum: 1,963 \$/ha

The per hectare revenues from grazing without fertiliser input, from private and societal perspectives are therefore:

Private perspective: Annual revenue

Annual revenue L2: 1,828 \$/ha

Annual revenue L4: 1,606 \$/ha

Annual revenue H2: 1,948 \$/ha

Annual revenue H4: 1,712 \$/ha

Societal perspective: Annual benefit

Annual benefit L2: 1,828 \$/ha

Annual benefit L4: 1,606 \$/ha

Annual benefit H2: 1,948 \$/ha

Annual benefit H4: 1,712 \$/ha

Annual costs

The main components of annual costs comprise costs for livestock purchase, livestock transport, veterinary costs, purchase and application costs for fertiliser (where relevant), and agents' fees. Livestock-related costs are estimated per head and then converted to per hectare costs using stocking densities. Fertiliser purchase and application costs are estimated per hectare and annualized across the four-year fertiliser application cycle (year 1: heavier application of Entec67; years 2, 3, 4: lighter application of urea). Fertiliser application rates vary with soil class as detailed in Table 30.

Livestock purchase costs

Restocker and feeder steers are purchased in April from saleyards in inland Queensland (e.g., Charters Towers or Mareeba). For the light production systems, restocker steers are bought in at a starting weight of 250kg. For the heavy production systems feeder steers are bought in at a starting weight of 450kg. A fixed livestock price of \$3/kg live weight is used to produce indicative costs for stock purchases, as shown in Tables 28 and 29.

Table 28: Cost for purchasing steers for fattening on a 10 hectare paddock under production systems L2, L4, H2 and H4 with fertiliser input, assuming buy-in weights of 250kg/head for the light production systems, 450kg/head for the heavy production systems and a purchase price of \$3/kg live weight

Purchase cost	\$ per 10 ha
L2 @ 2 head/ha	15,000
L4 @ 1.75 head/ha	13,125
H2 @ 1.33 head/ha	18,000
H4 @ 1.167 head/ha	15,800

Annual purchase cost L2: 1,500 \$/ha

Annual purchase cost L4: 1,313 \$/ha

Annual purchase cost H2: 1,800 \$/ha

Annual purchase cost H4: 1,580 \$/ha

Table 29: Cost for purchasing steers for fattening on a 10 hectare paddock under production systems L2, L4, H2 and H4 with no fertiliser input, assuming buy-in weights of 250kg/head for the light production systems, 450kg/head for the heavy production systems and a purchase price of \$3/kg live weight

Purchase cost	\$ per 10 ha
L2 @ 1.737 head/ha	13,026
L4 @ 1.526 head/ha	11,447
H2 @ 1.176 head/ha	15,911
H4 @ 1.036 head/ha	13,982

Annual purchase cost L2: 1,303 \$/ha

Annual purchase cost L4: 1,145 \$/ha

Annual purchase cost H2: 1,591 \$/ha

Annual purchase cost H4: 1,399 \$/ha

Fertiliser costs

Gross-margin maximizing fertiliser application rates vary between soil classes as detailed in Table 30. Fertilisers are assumed to be applied on a 1:3 annual cycle, with heavier application of Entec67 in year 1, followed by lighter applications of urea in years 2, 3 and 4, as shown in Table 30.

Table 30: Fertiliser application rates and costs per 10ha block. Total present value cost and annualized cost calculated across 4 year cycle at 5% annual discount rate

Cost description	\$/10 ha
Soil class S2	
Entec67: Year 1 @ 200kg/ha	
Entec67 fertiliser cost @ \$740/tonne	1,480
Entec 67 application cost @ \$20/ha	200
Urea: Years 2,3,4 @ 150kg/ha	
Urea cost @ \$528/tonne	3 x 792
Urea application cost @ \$20/ha	3 x 200
Total present value fertiliser cost (4 year cycle)	4,173
Annualised fertiliser cost	1,176
Soil class S4	
Entec67: Year 1 @ 300kg/ha	
Entec67 fertiliser cost @ \$740/tonne	2,220
Entec 67 application cost @ \$20/ha	200
Urea: Years 2,3,4 @ 200kg/ha	
Urea cost @ \$528/tonne	3 x 1,056
Urea application cost @ \$20/ha	3 x 200
Total present value fertiliser cost (4 year cycle)	5,562
Annualised fertiliser cost	1,569

Annualised fertiliser cost L2: \$118/ha**Annualised fertiliser cost H2: \$118/ha****Annualised fertiliser cost L4: \$157/ha****Annualised fertiliser cost H4: \$157/ha****Veterinary-related costs**

The costs of vaccination, fly control and copper supplement are shown in Table 31. These are assumed to be the same per head for all four production systems. Per hectare veterinary costs differ with and without fertiliser application in proportion to the difference in stocking densities.

Table 31: Vaccination and fly control costs per head

Cost description	\$/head
3-day vaccine	16
Fly control	5
Copper bullet	10
Total costs	31

Grazing with fertiliser input**Annual veterinary costs L2 @ 2 head/ha: \$62/ha****Annual veterinary costs H2 @ 1.33 head/ha: \$41/ha****Annual veterinary costs L4 @ 1.75 head/ha: \$54/ha****Annual veterinary costs H4 @ 1.17 head/ha: \$36/ha**

Grazing without fertiliser input**Annual veterinary costs L2 @ 1.737 head/ha: \$54/ha****Annual veterinary costs H2 @ 1.176 head/ha: \$36/ha****Annual veterinary costs L4 @ 1.526 head/ha: \$47/ha****Annual veterinary costs H4 @ 1.036 head/ha: \$32/ha**Transport costs

Freight costs include cattle transport cost to the farm and cartage to Townsville port for live export or a sale yard for slaughter (Table 32). These costs are assumed to be constant regardless of animal size.

Table 32: Freight costs per head

Cost description	\$/head
Freight in	20
Cartage to Port or saleyard	20
Total costs	40

Grazing with fertiliser input**Annual transport costs L2 @ 2 head/ha: \$80/ha****Annual transport costs H2 @ 1.33 head/ha: \$53/ha****Annual transport costs L4 @ 1.75head/ha: \$70/ha****Annual transport costs H4 @ 1.17 head/ha: \$47/ha**Grazing without fertiliser input**Annual transport costs L2 @ 1.737 head/ha: \$69/ha****Annual transport costs H2 @ 1.176 head/ha: \$47/ha****Annual transport costs L4 @ 1.526 head/ha: \$61/ha****Annual transport costs H4 @ 1.036 head/ha: \$41/ha**Agent's fees

Agents typically charge 5% commission (on sale value per head, by live weight) for livestock sold (QDAF pers. comm.). Agent's fees for the four production systems with fertiliser input are shown in Table 33, and the fees for system without fertiliser are shown in Table 34.

Table 33: Agent's fees per ha for production systems L2, L4, H2 and H4 with fertiliser input, assuming sale weights of 360kg/head for the light production systems, 570kg/head for the heavy production systems, sale price of \$3/kg live weight, and 5% agent's commission

Agent's fees	\$ per ha
L2 @ 2 head/ha	108
L4 @ 1.75 head/ha	95
H2 @ 1.33 head/ha	114
H4 @ 1.167 head/ha	100

Table 34: Agent's fees per ha for production systems L2, L4, H2 and H4 with no fertiliser input, assuming sale weights of 350kg/head for the light production systems, 550kg/head for the heavy production systems, sale price of \$3/kg live weight, and 5% agent's commission

Agent's fees	\$ per ha
L2 @ 1.737 head/ha	91
L4 @ 1.526 head/ha	80
H2 @ 1.176 head/ha	97
H4 @ 1.036 head/ha	85

Annual benefits and annual costs

Re-stating key annual revenue and cost results from the previous subsections, Tables 35 and 36 show annuity gross margins from the light and heavy production systems on soil classes S2 and S4 for with and without fertiliser input.

Table 35 Annual Revenues, Annual Costs and Annuity Gross Margins from L2, H2, L4 and H4 steer fattening production systems with fertiliser on soil classes S2 and S4 (\$/ha)

Revenues, Costs & Annuity GMs	\$/ha
<u>Soil class S2</u>	
Annual operating cost L2	1,868
Annual revenue L2 [private perspective]	2,220
Annual revenue L2 [societal perspective min]	2,193
Annual revenue L2 [societal perspective max]	2,202
Annuity GM L2 [private]	352
Annuity GM L2 [societal min]	325
Annuity GM L2 [societal max]	334
Annual operating cost H2	2,126
Annual revenue H2 [private perspective]	2,280
Annual revenue H2 [societal perspective min]	2,253
Annual revenue H2 [societal perspective max]	2,262
Annuity GM H2 [private]	154
Annuity GM H2 [societal min]	127
Annuity GM H2 [societal max]	136
<u>Soil class S4</u>	
Annual operating cost L4	1,689
Annual revenue L4 [private perspective]	1,943
Annual revenue L4 [societal perspective min]	1,893
Annual revenue L4 [societal perspective max]	1,910
Annuity GM L4 [private]	254
Annuity GM L4 [societal min]	204
Annuity GM L4 [societal max]	221
Annual operating cost H4	1,920
Annual revenue H4 [private perspective]	1,996
Annual revenue H4 [societal perspective min]	1,946
Annual revenue H4 [societal perspective max]	1,963
Annuity GM H4 [private]	76
Annuity GM H4 [societal min]	26
Annuity GM H4 [societal max]	43

Table 36: Annual Revenues, Annual Costs and Annuity Gross Margins from L2, H2, L4 and H4 steer fattening production systems with no fertiliser input on soil classes S2 and S4 (\$/ha)

Revenues, Costs & Annuity GMs	\$/ha
<u>Soil class S2</u>	
Annual operating cost L2	1,517
Annual revenue L2 [private perspective]	1,828
Annual revenue L2 [societal perspective]	1,828
Annuity GM L2 [private]	311
Annuity GM L2 [societal]	311
Annual operating cost H2	1,771
Annual revenue H2 [private perspective]	1,948
Annual revenue H2 [societal perspective]	1,948
Annuity GM H2 [private]	177
Annuity GM H2 [societal]	177
<u>Soil class S4</u>	
Annual operating cost L4	1,333
Annual revenue L4 [private perspective]	1,606
Annual revenue L4 [societal perspective]	1,606
Annuity GM L4 [private]	273
Annuity GM L4 [societal]	273
Annual operating cost H4	1,557
Annual revenue H4 [private perspective]	1,712
Annual revenue H4 [societal perspective]	1,712
Annuity GM H4 [private]	155
Annuity GM H4 [societal]	155

Annuity GMs show that the light steer fattening system generates higher margins than the heavy system, and that margins are higher on soil class S2.

Reductions in annuity gross margins

Referring back to the annuity GMs from sugarcane production on soil classes S2 and S4, the reduction in annuity GMs following conversion of low-lying sugarcane land to grazing are shown in Table 37. Results are only shown for the light production systems L2 and L4, as these systems clearly produce considerably higher gross margins than the heavy alternative on the equivalent soil class, irrespective of whether or not fertiliser is applied.

Table 37: Reduction in annuity GMs following conversion of low-lying sugarcane land to grazing production systems L2 and L4 with and without fertiliser (\$/ha/year), evaluated from private and societal perspectives

	Reduction in Annuity GM for grazing with fertiliser input (\$/ha/year)	Reduction in Annuity GM for grazing without fertiliser input (\$/ha/year)
Private L2 [S2 land]	1,251	1,291
Private L4 [S4 land]	855	836
Societal min L2 [S2 land]	968	982
Societal max L2 [S2 land]	1,062	1,085
Societal min L4 [S4 land]	405	336
Societal max L4 [S4 land]	555	503

Reductions in annuity GM from a private perspective reflect the difference between the annuity GM from sugarcane production and the annuity GM from light steer fattening on the relevant soil class. In all cases, steer fattening delivers lower annuity GMs than sugarcane production. The difference in annuity GMs is considerably lower on S4 land, and reduces further when the societal cost of DIN losses is included.

From a private perspective, on S2 land grazing with fertiliser input produces a lower reduction in annuity GM than grazing with no fertiliser input. On S4 land, however, the situation reverses, with the grazing without fertiliser input producing the lower reduction in annuity GM. This is a consequence of the additional fertiliser costs which are incurred on the lower quality S4 land.

From a societal perspective, reductions in annuity GM are considerably lower on S4 land than S2 land. This reflects the lower sugarcane revenues from S4 land and the accompanying higher DIN losses. From a societal perspective, the lowest reductions in annuity GM are produced from grazing without fertiliser input on S4 land.

Conversion cost

Estimated costs for converting a 10 ha land block to beef grazing are shown in Table 38. Conversion costs are assumed identical for all four production systems (L2, L4, H2 and H4).

Major costs in establishing cattle grazing are: watering infrastructure, fencing, land preparation, pasture preparation and establishment. These costs are assumed to be the same for all four production systems, with and without fertiliser. An additional cost of \$15,000 for constructing a stockyard and loading facilities is relevant for land blocks which are not adjacent to existing grazing land.

Table 38: Establishment costs for a 10 hectare paddock: L2, L4, H2 and H4 production systems

Cost item	\$ per 10 ha
Initial soil tests	160
Water infrastructure	5,625
Fencing	3,196
Weed clearing	450
Herbicide	370
Pasture preparation	1,350
Sowing pasture	3,300
Total cost [adjacent to existing grazing land]	14,451
Stock yard and loading facilities	15,000
Total cost [not adjacent to existing grazing land]	29,451

Conversion cost: \$1445/ha [adjacent to existing grazing land]

Conversion cost: \$2945/ha [not adjacent to existing grazing land]

Total present value cost of land conversion

Total present value cost of land conversion calculations incorporate changes in annuity GMs from private and societal perspectives, together with one-off conversion costs. Here, total PV costs of land conversion are calculated over 12, 16 and 20 year periods using an annual discount rate of 5% per annum (Table 39).

Total present value cost of land conversion to grazing system with fertiliser input

Table 39: Total present value cost of land use conversion to grazing (\$/ha), using the light steer fattening system with fertiliser input on soil classes S2 and S4 evaluated over 12, 16 and 20 year time horizons at an annual discount rate of 5%, evaluated from private and societal perspectives

	Total PV Costs 12 years (\$/ha)	Total PV Costs 16 years (\$/ha)	Total PV Costs 20 years (\$/ha)
Private L2 on S2 adj [‡]	12,533	15,003	17,035
Private L2 on S2 not adj	14,033	16,503	18,535
Private L4 on S4 adj	9,023	10,711	12,100
Private L4 on S4 not adj	10,523	12,211	13,600
Societal L2 on S2 min	10,025	11,936	13,508
Societal L2 on S2 max	12,358	14,455	16,180
Societal L4 on S4 min	5,035	5,834	6,492
Societal L4 on S4 max	7,864	8,960	9,862

[‡] 'adj' denotes converted land is adjacent to existing grazing land, so there is no requirement to construct a stock yard for livestock loading/unloading. 'not adj' denotes that the converted land is not adjacent to existing grazing, so additional stock yard construction costs are incurred.

Total PV costs will be incurred in converting low-lying sugarcane land to grazing with fertiliser input under all the scenarios investigated. This is a consequence of annuity GMs reducing, compared with sugarcane, for all the grazing production systems. The (modest) land conversion costs increase the total PV costs of conversion further. Total PV costs of

conversion increase as time horizons lengthen and the negative impacts on annuity gross margin (relative to sugarcane) accumulate further (Table 40).

Differences between total PV costs of conversion from private and societal perspective are larger on S4 land than on S2 land.

*Total present value cost of conversion to grazing system with **no** fertiliser input*

Table 40: Total present value cost of land use conversion to grazing (\$/ha), using the light steer fattening system with **no fertiliser input on soil classes S2 and S4 evaluated over 12, 16 and 20 year time horizons at an annual discount rate of 5%, evaluated from private and societal perspectives**

	Total PV Cost 12 years (\$/ha)	Total PV Cost 16 years (\$/ha)	Total PV Cost 20 years (\$/ha)
Private L2 on S2 adj [‡]	12,887	15,437	17,534
Private L2 on S2 not adj	14,387	16,937	19,034
Private L4 on S4 adj	8,855	10,505	11,863
Private L4 on S4 not adj	10,355	12,005	13,363
Societal L2 on S2 min	10,149	12,088	13,683
Societal L2 on S2 max	12,562	14,704	16,466
Societal L4 on S4 min	4,423	5,086	5,632
Societal L4 on S4 max	7,403	8,396	9,213

Total PV costs will be incurred in converting low-lying sugarcane land to grazing with **no** fertiliser input under all the scenarios investigated. This is a consequence of annuity GMs reducing, compared with sugarcane, for all the grazing production systems. The (modest) land conversion costs increase the total PV costs of conversion further. Total PV costs of conversion increase as time horizons lengthen and the negative impacts on annuity gross margin (relative to sugarcane) accumulate further.

Differences between total PV costs of conversion from private and societal perspective are larger on S4 land than on S2 land. This is because the higher DIN losses from sugarcane production on S4 land are assumed to reduce to zero when no fertiliser is applied to the grazing system.

Cost-effectiveness of DIN reduction

The cost-effectiveness of DIN reduction via conversion of low-lying sugarcane land to grazing, with and without fertiliser application, using the light production system on soil class S2 and S4 is reported in Table 41. Cost-effectiveness is evaluated in terms of the total PV cost of conversion from a private perspective over a 12-year time horizon, as explained in the economics methodology section.

Table 41: Cost effectiveness of removing DIN by converting low-lying sugarcane land to grazing (\$/kg DIN removed), evaluated using the total PV cost of conversion over 12 years, from a private perspective

Cost effectiveness of DIN reduction	\$/kg DIN removed*‡ (with fertiliser)	\$/kg DIN removed*‡ (with <u>no</u> fertiliser)
Private (min) [S2 land]	41	39
Private (max) [S2 land]	37	35
Private (min) [S4 land]	19	17
Private (max) [S4 land]	17	15

*A positive figure indicates that a cost is incurred per kg DIN removed.

‡Cost effectiveness in terms of the total PV cost of land use conversion, calculated from a private perspective over a 12 year time horizon.

Cost-effectiveness results from a private perspective suggest that conversion of S4 low-lying sugarcane land to grazing, with or without fertiliser, can deliver DIN reduction at lower cost than existing extension-based policies, but at somewhat higher cost than that projected for recently proposed incentive-based and regulation-based approaches¹¹.

From a DIN perspective, it is considerably more cost effective to convert S4 land, as opposed to S2 land, to grazing. As expected, grazing with no fertiliser input delivers DIN reductions more cost-effectively than grazing with fertiliser addition, but there is only a small difference in cost-effectiveness between the two systems (Table 41).

The impact of variation in the difference between sell-out to buy-in prices on the cost-effectiveness of converting low-lying S2 and S4 sugarcane land to grazing, with and without fertiliser applications, is shown in Figure 12. The plots in Figure 12 report cost-effectiveness over a 12-year time horizon, and assume that the converted land is adjacent to existing grazing land.

3.11.4 Market for products and services:

Description of key markets and demand

Supply and distribution chains for cattle fattening are already in place and markets are well established.

3.11.5 Limitations and barriers to adoption

None – other than the scale of reduction in annuity GMs and the high total PV cost of conversion, in comparison to continuing with sugarcane production – as currently configured.

3.11.6 Conclusion

Conversion of low-lying, high DIN risk, sugarcane land to beef grazing, with or without fertiliser application, does not appear to be an attractive alternative to sugarcane production from a

¹¹ DEHP 2016 indicates that existing extension-based programs deliver DIN reduction at around \$50/kg DIN removed. The regulatory and incentive-based policies proposed in the same document are modelled to deliver DIN reductions at around \$10/kg DIN removed.

private perspective. The reduction in annuity GM will be considerably lower if S4 land, rather than S2 land, is converted.

The cost-effectiveness of DIN reduction achieved by converting S4 land to either form of grazing (with or without fertiliser) is similar to that achieved by conversion to constructed treatment wetlands. Unless a fortuitously large sell-to-buy price differential is achieved, grazing, with or without fertiliser applications, appears to be less cost-effective as a method for DIN reduction than coastal wetland restoration – in locations where coastal wetland restoration can be implemented at low conversion cost and high rates of DIN removal can be achieved.

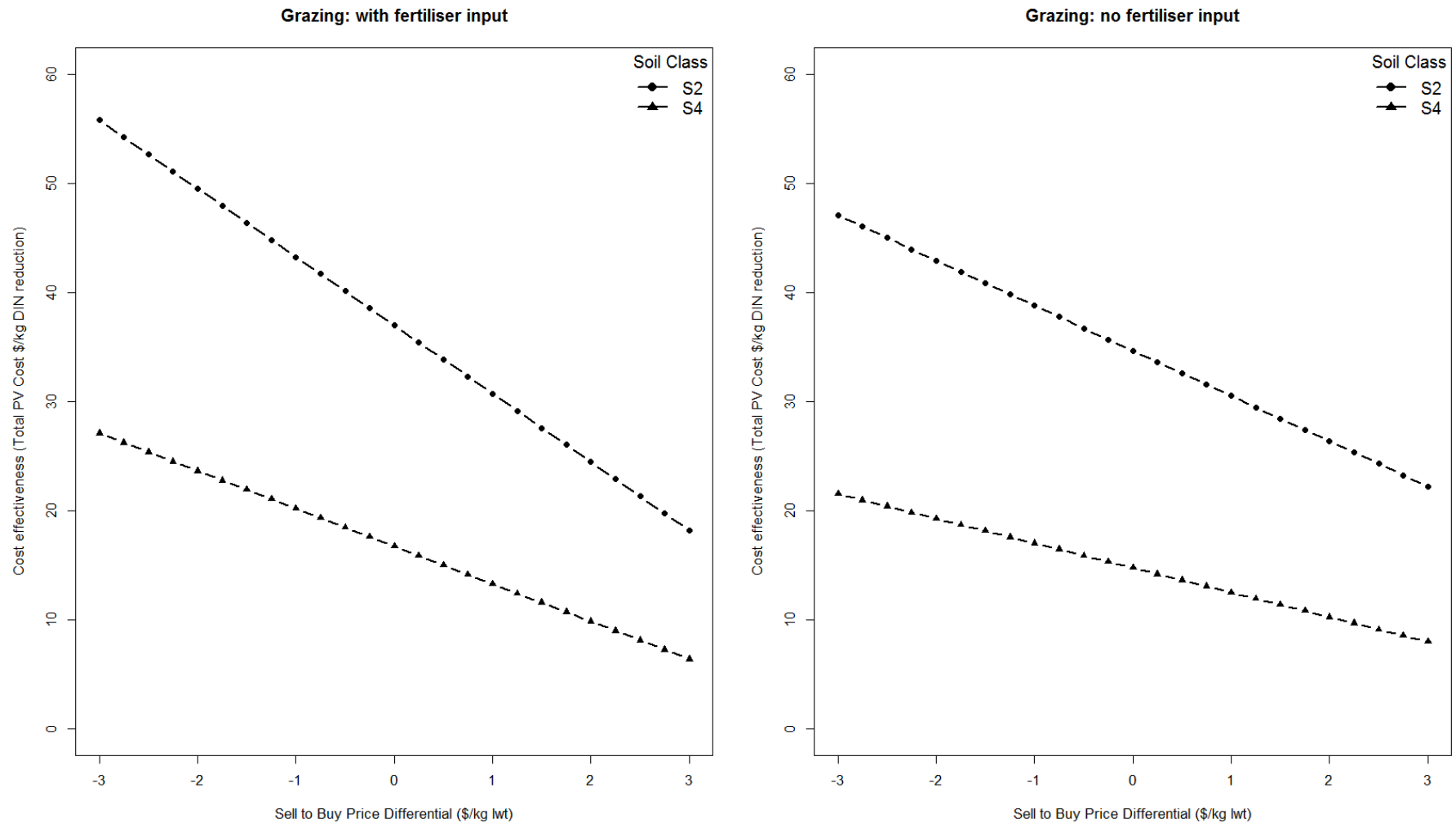


Figure 12: Impact of variation in the sell-to-buy price differential on the cost-effectiveness of DIN reduction achieved by converting low-lying sugarcane land to beef grazing, with and without fertiliser input. Cost-effectiveness is calculated over a 12 year time horizon, assuming that the land to be converted is adjacent to existing grazing land

3.12 Tree crops

3.12.1 High level description

Tropical fruits such as rambutan, lychee and mango present opportunities for landholders to switch from sugarcane production. High retail prices for these fruits provide promising prospects for profitable supply to domestic and international markets.

In the hot, wet, tropical coast of far north Queensland, a wide range of tropical tree fruits can be planted in selected locations where conditions are appropriate (The Archives of the Rare Fruit Council of Australia, 1988). Locations in the Wet Tropics such as Tully and Babinda, have the right climate for growing tropical fruits, as reported on ABC Landline 17 August 2003 (<http://www.abc.net.au/landline/stories/s923160.htm>, date accessed 18 March 2017). In the same ABC Landline programme, it was reported that in Babinda, Joe and Ivy Zapala, and their son Alan, converted some of their sugarcane fields to tropical fruit orchards more than 20 years ago.

Combined production of lychees, mangoes and rambutans was 1,609 tonnes for the Cairns ABS SA4 area, from more than 150 agricultural businesses in the vicinities of Atherton, Babinda, Daintree, Gordonvale-Trinity, Johnstone, Kuranda, Mareeba and Tully (Australian Bureau of Statistics, 2012). Table 42 summarises the production, yield and number of businesses by crop. Of the three fruits, the production of mangoes is highest, followed by lychees and then rambutan, consistent with the yield recorded per tree. There are considerably fewer areas that are suitable for growing rambutan compared to lychee and mango, which may explain the relatively low production of rambutan in the Wet Tropics.

Table 42: Production, yield and number of agricultural businesses for lychees, mangoes and rambutan in Cairns SA4

Crop	Production (kg)	Yield (kg/tree)	No. agri. businesses
Lychees	220,258	8	55
Mangoes	1,332,522	13	67
Rambutan	56,274	5	37

Source: ABS (2012)

Tropical fruit trees take years to mature sufficiently to bear commercial crops. Mango and lychee trees can take four or five years to start bearing fruit, however, full production is often not achieved until a few years later. Rambutan trees start fruiting slightly earlier, between the third and fourth year. Considering the long-term nature of investment in tropical fruit production, growers would encounter negative cash flows in the first few years of growing period, before cash flows become positive and increasing until the trees reach at least 10 years of age. Additionally, growers face other risks such as cyclones, pests and diseases, which could wipe out the entire crop for the season. The longer-term investment coupled with higher chances of losing the crop – and perhaps losing all previous investment, in the case of a cyclone – make switching from sugarcane to tree crops an unattractive business proposition from a risk perspective.

3.12.2 Agronomic information

Climate, growing conditions and orchard management

The tropical climate of north Queensland presents good growing conditions and an opportunity for landholders to grow high-valued tropical fruits such as lychee, mango and rambutan. Trees require well drained soils for maximum yields. Careful selection of sites with suitable climate and soil, and availability of infrastructure, labour and machinery are critical requirements in the conversion of existing sugarcane lands to fruit orchards.

A strong set of financial and managerial skills, in addition to full commitment of time and resources, are also required for a successful development of commercial orchards. Having established the orchards, which requires a high capital input, growers need to be committed to implementing a quality management program and joining a grower association for marketing activities (Department of Agriculture and Fisheries, 2012).

Basic equipment required for setting up tropical fruit orchards include an under-tree irrigation system, a tractor, spray equipment with separate units for pesticides and herbicides, a slasher or mower, a trailer and a farm vehicle, harvesting equipment, a packing shed, bird/bat netting, and a cold storage room (Menzel, 2002; Department of Agriculture and Fisheries, 2012). In the Wet Tropics, it is assumed that irrigation will not be required. Comparison of rainfall data from a region in Malaysia (where rambutan and mango grow well without irrigation), and Tully in the Wet Tropics show similar rainfall patterns and quantities.

A small, regular application of fertiliser throughout the year is typically recommended for these tropical fruit trees, thus a fertigation system together with a fertilizer spreader may also be required. To minimize the impact of DIN loss on water quality, it is recommended that fertiliser should be applied often in small quantities (such as via fertigation) in response to plant requirements, as determined by soil and leaf tests. If this is done properly, there should be minimal nitrogen surplus and therefore minimal loss of N to the environment (Thorburn & Wilkinson, 2013). Applying too much fertiliser would result in vegetative growth and low fruit yields, thus fruit trees are self-controlling with regard to N applications (Sing & Barron, 2014).

Tropical fruit trees require pruning after harvest to maintain manageable tree size and to promote flowering and cropping. Pruning can reduce canopy surface area by 30% compared to non-pruned trees, and this will reduce harvesting costs (Menzel *et al.*, 2000). Smaller trees are also easier to manage, and they allow higher density plantings to maximize returns to the grower (Menzel *et al.*, 2000). Typical planting densities range from 100 to 200 trees/ha.

Lychee, mango and rambutan trees are susceptible to a range of pests and diseases. Common pests include erinose mite (*Aceria litchi*), caterpillars, fruit borers, bugs, fruit piercing moths, birds and bats (Diczbalis, 2011). Spraying with pesticides is a standard practice by growers and the cost is small relative to the resulting returns through elevated yields and improved quality (Menzel, 2002).

Nets can be erected over the orchard to prevent birds and flying foxes from destroying the crops. Netting is expensive, however, with capital cost ranging from \$20,205 per hectare up to

\$85,576 per hectare (reported as \$17,000 per hectare and \$72,000 per hectare in 2008 \$) (Rigden, 2008). More expensive nets with smaller mesh can also keep the fruit piercing moths and rhinoceros beetles out, as well as birds and flying foxes. Other factors such as netting system, quality of structural materials, and orchard area, location and shape, affect the cost of orchard netting (Rigden, 2008). The different types of nets incurs different maintenance costs, with more expensive nets professionally designed and installed having a much lower maintenance cost (Rigden, 2008). Nets may need to be repaired or even replaced following severe weather or from photo-degradation.

Lychee

Lychee trees grow best on well-drained soils of medium to high fertility (Menzel, 2002). Trees should not be planted on heavy clay soils which become waterlogged as this may cause the trees to die (Menzel, 2002; Department of Agriculture and Fisheries, 2012). Lychees are suitable in areas that have a cool winter during flower initiation (June to September) followed by relatively humid and warm spring/summer periods when the fruits are growing (September to February) (Diczbalis, 2011; Department of Agriculture and Fisheries, 2012). Certain areas in the Wet Tropics may be suitable for lychee production because according to Diczbalis (2011), predominantly coastal/wetter areas with regular rainfall and high humidity – but the soil need to be well drained and of medium to high fertility.

An orchard with at least 2000 trees or a total area of 8-15 hectares is required in order to be economically viable (Department of Agriculture and Fisheries, 2012), with one person working on 5 to 7 hectares of mature trees except during harvesting and packing (Menzel, 2002). New orchards are typically established with marcots or air-layers (Menzel, 2002) which have been potted up for 3-4 months prior to field planting (Diczbalis, 2011). To save time and money, and in-line with recent commercial practices in Australia, air-layers can be directly planted into a pre-prepared site (Diczbalis, 2011).

Plantings generally range from 100 to 300 trees per hectare depending on the cultivars (140 trees/ha for Fay Zee Siu and Souey Tung; 280 trees/ha for Kwai May Pink and Wai Chee) (Menzel, 2002), and trees should be protected from south-easterly and westerly strong winds by planting windbreaks (DAF, 2012).

Rambutan and mango

Similar to lychee, rambutans require deep (i.e., 1m) well drained soils, with a good supply of water and protection from the wind (Ngo & Baker, 1990; The Archives of the Rare Fruit Council of Australia, 1988). Unlike lychees, rambutan are sensitive to cold temperatures (Ngo & Baker, 1990). Trees can still grow if temperatures are too low, but production and quality will be low (The Archives of the Rare Fruit Council of Australia, 1988).

Taller trees, such as mango, are typically planted at the same time as rambutan. The mango trees provide natural windbreaks for the rambutan trees and will protect the rambutan orchard for its entire lifespan (Ngo & Baker, 1990). Both rambutan and mango trees need to be optimally managed. A single orchard of this design can provide marketable harvests of both mango and rambutan.

A sugarcane farmer wishing to convert sugarcane land to rambutan, could consider a joint production system where the outputs are rambutan and mango. The two crops have different, but successive, harvesting periods. Mangoes are harvested from late December to mid-January, and rambutan from late January to May. This presents a better option than growing just a single crop, because farmers are able to diversify their production over a longer (joint) cropping period, thus reducing risks. For these reasons, this report considers a joint rambutan and mango production system, as an alternative land use to sugarcane production.

For commercial plantings, rambutan should be vegetatively propagated to minimize variation in quality and for earlier fruiting in three years after planter, instead of having to wait five or six years for the first viable crop. Rambutan should be planted with row spacing's in the range of 8-10m to allow tractor access for slashing and spraying (Ngo & Baker, 1990). A 5-ha commercial orchard can have approximately 900 rambutan trees and 80 mango trees (Ngo & Baker, 1990).

Harvesting, processing and packaging

Fruit handling in harvesting, grading and sorting, and packing is highly labour intensive, and needs to be completed in the shortest time possible to maintain fruit quality. It is crucial that growers have access to the necessary labour supply during this period. Fruit post-harvest technology is critical and fruits are best maintained at temperature between 5°C to 10°C (Ngo & Baker, 1990; Diczbalis, 2011). This necessitates growers the purchase or hire of cold rooms during the harvesting season. The refrigerated fruits are typically kept in 2.5kg crispy-wrap bags before they are marketed to ensure retention of high humidity around the fruits to retain their freshness (Menzel, 2002; Ngo & Baker, 1990; Diczbalis, 2011).

Estimates of DIN loss from tree crops

There is no published information on DIN loss from lychee, rambutan and mango tree crops in GBR regions. Thorburn and Wilkinson (2013) reviewed N fertilizer applications and crop N off-take for major crops in the GBR region: sugarcane, tree crops, banana, small crops, cotton and grains. The 94 kg N/ha/year N loss from tree crops at a fertiliser application rate of 150 kg N/ha/year reported in Thorburn and Wilkinson (2013) was derived from Macadamias. This rate of N application for tree crops stands in contrast to the findings summarised in Table 4 where the suggested N application rate is around 60 kg N/ha/year.

Estimates of N surplus from tree crops is obtained from Thorburn and Wilkinson (2013) review of literature which indicates that N surplus in mangoes and avocados are generally similar to that in macadamias. Thorburn and Wilkinson (2013) reported N loss of 94 kgN/ha/year from 150 kg N/ha/year applied, indicating 56 kg N/ha/year in crop off-take. In the absence of any other estimates of N loss from tree crops, the N loss rate of 63% (of N applied on the ground), as reported by Thorburn and Wilkinson (2013), is used in this analysis. Having obtained the link between N applied and N loss, the next piece of information required is what proportion of N loss is actually converted to DIN loss. This estimate of DIN loss in kg/ha/year will then be used in the subsequent economic analysis.

The conversion of N loss into DIN loss under appropriate climate and soil types for the Wet Tropics is estimated here by utilising the link between N application (kg N/ha/year), N surplus

or N loss (kg N/ha/year), and DIN loss (kg DIN/ha/year). This link can be deduced from two published studies, namely, 'Catchment modelling of nitrogen loads in the Tully-Murray basin' (Armour *et al.*, 2009) and 'N surplus by crop types in the Wet Tropics region' (Thorburn & Wilkinson, 2013).

Thorburn and Wilkinson (2013) summarised the information for sugarcane with N applied at 140 kg N/ha/year, N in crop off-take at 42 kg N/ha/year and the N loss at 98 kg N/ha/year, measured as the difference between N applied and N in crop off- take (see Table 2 on p.198). Armour *et al.*, (2009) modelled DIN export rates using SedNet/ANNEX for a range of land management scenarios. Armour *et al.*, 's (2009) Six Easy Steps for sugarcane scenario, under which the N application rate is 140 kg N/ha/year, produces a corresponding DIN export rate of 17 kg DIN/ha/year. This implies that about 17.35% of N loss is transformed to DIN loss for sugarcane.

Applying the same percentage of N loss to DIN loss for the **tree crops**, 94 kg N/ha/year of N loss (from Thorburn and Wilkinson 2013) would result in approximately 16 kg DIN/ha/year. Similarly, if N application rate is 60 kg N/ha/year as reported in Table 4, N loss would be 38 kg N/ha/year (calculated at 63% of N applied) and the consequent DIN loss is approximately 7 kg DIN/ha/year (calculated at 17.35% of N loss). This way of calculating the DIN loss from tree crops should be reasonable in this instance because we assume that the tree crops will be planted on the same land that had been used previously to produce sugarcane. Thus, the soil and climatic characteristics that give rise to the established conversion rate 17.35% between N loss and DIN loss under sugarcane should remain unchanged.

NRM region-specific estimates of DIN loss from different land uses have also been undertaken using the eWater Ltd Source Catchments water quantity and quality modelling framework (McCloskey *et al.*, 2017). Under this framework, the Source model was used to estimate DIN export load and areal rate by land use, based on the most recently available Queensland Land Use Mapping Program (QLUMP) data in each NRM region (McCloskey *et al.*, 2017). QLUMP was derived from the Australian Land Use and Management (ALUM) classification, in which, irrigated and non-irrigated tree fruits are categorised under horticulture. McCloskey *et al.*, 's (2017) estimate of DIN loss for horticulture in the Wet Tropics is approximately 1.78 kg DIN/ha/year.

Based on the limited information available on DIN loss from tropical tree crops, particularly lychees, rambutan and mango, in the Wet Tropics, this study uses **an upper limit of DIN loss at 16 kg/ha/year and lower limit at 2 kg/ha/year**.

Lychee, rambutan and mango trees should only be planted on well-drained soils (Menzel, 2002; Ngo & Baker 1990; The Archives of the Rare Fruit Council of Australia, 1988). Soil class S4 is defined as 'poorly drained loam soils from alluvial origin' and soil class S2 is as 'well drained medium to heavy clay soils from alluvial origin' (Roebeling *et al.*, 2007), p3). **This study therefore, considers lychee, rambutan and mango crops as a land use option only for soil class S2.**

Comparing this range of DIN loss figures (2 to 16 kg DIN/ha/year) against DIN loss from sugarcane on soil class S2 in Table 3, produces estimates of DIN reduction via conversion of low-lying sugarcane lands to tree crops (Table 43).

Table 43: DIN reduction from conversion of low-lying sugarcane land to tree crops

Soil class	DIN reduction from land use conversion (kg DIN/ha) ¹²
S2 (min)	15
S2 (max)	29

By converting sugarcane lands to tree crops, the DIN reductions range from 15 to 29 kg DIN/ha for soil class S2.

3.12.3 Economic evaluation

All prices are expressed in current 2016 dollars, unless otherwise stated.

Consistent with standard practice (e.g., Agbiz tools; Ngo & Baker, 1990), in this project, gross margin is calculated as the difference between revenue and variable costs. Fixed and overhead costs do not feature in gross margin calculations. Capital costs are initial costs incurred at the start of the business and these include the costs of purchasing tractors and vehicles, a slasher, a fertiliser box and spray machines, buildings and sheds, netting, land preparation and planting. The cost of land is excluded from our economic analysis consistent with the economic evaluation undertaken on the other land uses investigated.

Tropical fruit production comprises several variable cost components: fertiliser applications, canopy management, weed control, pest and disease control, harvesting, packing and marketing. Of these, the combined costs of harvesting, packing and marketing contribute to over 80% of the total variable costs (Menzel, 2002; Diczbalis, 2011), or 65% of total costs (Menzel *et al.*, 2000). Efforts should therefore be concentrated toward improving the efficiency of harvesting, packing and transporting the products to the domestic and/or overseas markets as the quality in which the fruits reach their final destination decreases rapidly as the time interval between harvesting and reaching supermarket shelves increases. This requires specific infrastructure to be in place such as a well-established system of marketing and transport network.

Yields are typically inconsistent from year to year, especially under changing climate. Tree crops, especially those in coastal areas, are sensitive to changing temperature and extreme events like cyclones. Flowering can be highly variable, thus impacting yields and returns to the farmers. ABC News Rural reported on 21st January 2016 that last year's lychee season was

¹² From Table 7.2, DIN loss from sugarcane in soil class S2 is 31 kg/ha and in soil S4 is 50 kg/ha. S2 min = 31 kg/ha from cane – 16 kg/ha from tree crops = 15 kg/ha of DIN reduction.
S2 max = 31 kg/ha from cane – 2 kg/ha from tree crop = 29 kg/ha of DIN reduction

tough for growers along the Queensland coast between Cairns and Townville and in parts of central Queensland, with crops down by more than 50% (ABC Rural 2016, <http://www.abc.net.au/news/2016-01-21/good-and-bad-in-queensland-lychee-picking-season/7103826>, date accessed 22 March 2017). Unpredictability in the climate will adversely affect growth, fruiting and flowering cycle for tropical fruit trees. These highly variable yields from season to season should be factored into the economic analysis.

Lychee

Information on the profitability of lychee production in Queensland is scarce. A search of the literature found two studies that looked at profitability in lychee (Diczbalis, 2011; Hassalls and Associates, (1999) quoted in Menzel *et al.*, 2000). Diczbalis (2011) quoted an earlier gross margin analysis conducted in Southeast Queensland in 2001, and Hassalls and Associates conducted a more in-depth financial analysis in December 1998 for lychee orchards in southern Queensland. Each of these studies used specific assumptions regarding average yield, price and variable costs. The reported gross margins were \$23,962/ha (\$21,814/ha in 2011 \$) (Diczbalis, 2011), and \$51,854/ha (33,987 in 2000 \$) (Menzel *et al.*, 2000).

Detailed data published in the Queensland Government's Agbiz budgeting tool for a Lychee Farm Model for Far North Queensland (<https://publications.qld.gov.au/dataset/agbiz-tools-plants-fruits-and-nuts/resource/c307a77b-335f-4b14-be6b-30542c304771>) can also be used for the economic analysis of this land use. These data were last updated in 2001. Ideally, more recent data would be preferred; however such data are not available at the time of writing, despite repeated attempts to secure such information from DAF. The information provided in the Agbiz tool is detailed and comprehensive and presents a good picture of the financial life cycle of a lychee orchard in North Queensland in each year of operation from year 1 to year 30 under optimal growing conditions. This project therefore, used the information from Agbiz to conduct the preliminary economic analysis of converting low-lying sugarcane land to lychee production, converting all the dollar values into current 2016/17 dollars.

Assumptions:

- Number of trees = 154 per ha
- Size of orchard = 13 ha
- Lychee price = \$11.69/kg (or \$8/kg, \$40 per 5 kg carton in 2001 \$)¹³
- Yields: 0 kg/ha (in Years 1, 2 and 3), 770 kg/ha (Year 4), 1155 kg/ha (Year 5), 1540 kg/ha (Year 6), 2310 kg/ha (Year 7), 2695 kg/ha (Year 8), 3080 kg/ha (Year 9), 3696 kg/ha (Year 10 onwards)

¹³ A wide range of prices are reported in the literature, ranging from \$7.63 per kg expressed in current \$ (reported as \$5 per kg in Menzel *et al.*, 2000) to \$22 per kg expressed in current \$ (reported as \$20 per kg in Diczbalis, 2011). The Agbiz tool reported a range of historical prices with a minimum price of \$10.81 per kg in current \$ (\$7.40 per kg in 2001) and a maximum price of \$22.65 per kg in current \$ (\$15.50 per kg in 2001). More recently in 21 Jan 2016, ABC News Rural reported the price of lychees averaging \$12-\$14 per kg (www.abc.net.au/news/2016-01-21/good-and-bad-in-queensland-lychee-picking-season/7103826, date accessed 16 March 2017). Given these variations in prices, the assumed price of \$11.69 (~\$12) is deemed to be consistent with those reported, and likely to represent the average price.

Rambutan and mango

A search for the publicly available reports on the economics of rambutan production in North Queensland returned with no results. Moreover, there is no Agbiz tool available for rambutan production in Queensland that can be used as a reference point for this analysis. To the best of the authors' knowledge, information on yields, farm gate price, capital costs and variable costs of rambutan production in Queensland are not readily available to the public at the point of writing.

There is, however, some information available in the form of reports and the 'Agnote' series from the Northern Territory Government, though these are rather dated. Given the extremely limited information on rambutan, this study used these documents as the basis for the economic analysis of converting low-lying sugarcane land to rambutan production in the Wet Tropics. In doing so, this study inherently assumes that yield, and the ratio of farm gate price to costs, which were reported for the Northern Territory, can also be realised in the Wet Tropics. Resulting gross margins have been escalated to 2016\$. These are clearly major assumptions. This does emphasise the need for further on-ground work and research to examine the profitability of commercial rambutan production in the Wet Tropics.

The economic analysis for the proposed joint production of rambutan and mango as an alternative to sugarcane, use the yield, and relative prices and costs as reported in Ngo and Baker (1990). Assumptions:

- Number of trees = 184 per ha (mixture of rambutan and mango providing wind protection) (840 rambutan trees on 4.2 ha and 80 mango trees on 0.8 ha);
- Size of orchard = 5 ha (4.2 ha for rambutan, 0.8 ha for mango);
- Price of rambutan = \$12.22/kg (or \$6/kg in 1989 \$, in Years 2,3,4 and 5), \$10.19/kg (or \$5/kg in 1989 \$ in Years 6 and 7), \$8.15/kg (or \$4/kg in 1989 \$ in Year 8 onwards);¹⁴
- Price of mango = \$1.83/kg (or \$0.90 /kg in 1989);
- Yields for rambutan: 0 kg/ha (in Years 1 and 2), 2,000 kg/ha (Year 3), 6,000 kg/ha (Year 4), 10,000 kg/ha (Year 5), 15,000 kg/ha (Year 6 onwards);
- Yields for mango: 0 kg/ha (Years 1 and 2), 500 kg/ha (Year 3), 2,000 kg/ha (Year 4), 6,000 kg/ha (Year 5), 12,000 kg/ha (Year 6), 19,000 kg/ha (Year 7), 22,000 kg/ha (Year 8), 24,000 kg/ha (Year 9), 25,000 kg/ha (Year 10 onwards).

Following Ngo & Baker (1990), long term prices of rambutan are expected to decline with the expectation of increasing supply as the trees mature to full production.

Annuity GMs

Tables 44a and 44b summarise the private and societal annual benefits, measured in terms of annuity gross margins, from the production of lychees and combined production of rambutan and mango. The annuity gross margins are calculated over the 20-year project lifespan. Similar

¹⁴ This price range is considered realistic even in current market conditions. ABC Rural reported on 8 December 2015 that rambutans were selling for between \$15 and \$18 a kilogram in Sydney (<http://www.abc.net.au/news/2015-12-08/northern-territory-rambutan-season-heats-up/7009534>, date accessed 21 March 2017).

to the analyses conducted for grazing and wetlands, the annuity GMs are reported from both private and societal perspectives.

From the landholder's perspective, once the sugarcane land is converted into fruit orchards, the flow of benefits in the form of annuity GMs is a private benefit. There is still some DIN loss from this land use, however small. The cost of this DIN loss is subtracted from the private annuity GMs to arrive at the societal annuity GMs.

The DIN loss from lychee, rambutan and mango trees is assumed to be in the range 15 to 29 kg DIN/ha on soil class S2. This is valued using DIN prices of \$6.67 per kg DIN (minimum) and \$10 per kg DIN (maximum), as established earlier in the report. The maximum societal cost of this DIN loss for S2 land is \$290/ha (= 29 kg/ha x \$10/kg) and the minimum societal cost is \$100/ha (= 15 kg/ha x \$6.67/kg).

Minimum societal annuity GM is calculated by subtracting the highest valuation of DIN loss from the private annuity GM, and the maximum societal annuity GM is calculated by subtracting the lowest valuation of DIN loss from private annuity GM, as summarised in Tables 44a and 44b.

Table 44a: Annuity GMs from production of lychee

	DIN loss \$/ha	Annuity GM \$/ha
Private	0	16,794
Societal Min (S2 soil)	290	19,504
Societal Max (S2 soil)	100	19,694

Table 44b: Annuity GM from a joint production of rambutan and mango

	DIN loss \$/ha	Annuity GM \$/ha
Private	0	28,115
Societal Min (S2 soil)	290	27,825
Societal Max (S2 soil)	100	28,105

Reduction in annuity GMs

The reduction (or increase) in annuity GMs following conversion of low-lying sugarcane land to lychee crop, or to rambutan and mango crops, are shown in Tables 45a and 45b.

Table 45a: Reduction (or increase) in annuity GMs following conversion from sugarcane land to lychee crop (\$/ha/year), evaluated from private and societal perspective

	Annuity GM sugarcane \$/ha/year	Annuity GM lychee \$/ha/year	Reduction in annuity GM* \$/ha/year
Private (S2 land)	1,603	16,794	-15,191
Societal Min (S2 land)	1,293	19,504	-18,211
Societal Max (S2 land)	1,396	19,694	-18,298

*Negative figures indicate that annuity GMs increase following change of land use from sugarcane production

Table 45b: Reduction (or increase) in annuity GMs following conversion from sugarcane land to combined rambutan and mango crops (\$/ha/year), evaluated from private and societal perspective

	Annuity GM sugarcane \$/ha/year	Annuity GM rambutan and mango \$/ha/year	Reduction in annuity GM* \$/ha/year
Private (S2 land)	1,603	28,115	-26,512
Societal Min (S2 land)	1,293	27,825	-26,532
Societal Max (S2 land)	1,396	28,105	-26,709

*Negative figures indicate that annuity GMs increase following change of land use from sugarcane production

The reduction in annuity GM is negative for all crops from both private and societal perspectives. This indicates that annuity GM from these tree crops is higher than that from sugarcane. However, despite the potential of high annuity GMs from these tree crops, this is not matched by evidence on the ground. Growing sugarcane remains the preferred land use option. This is likely to be due to a combination of the high one-off costs of conversion, negative cash flow during the early years of the production cycle and aversion to the risk of crop losses.

Conversion cost

Lychee

One-off land conversion costs for a 13-hectare lychee orchard are incurred in year zero. These costs are estimated from the information provided by the Agbiz tool spreadsheet. Land purchase cost and all irrigation-related costs are excluded. Table 46 reports the breakdown of conversion costs, expressed in 2016 \$. The netting cost of around \$80,000 per ha is assumed based on the information in Rigden (2008). Total cost of conversion for the orchard is \$1,415,557, about \$108,900 per hectare.

Table 46: Conversion costs from sugarcane land to a 13-hectare lychee orchard

Item	Cost (\$)
Land preparation and planting	140,285
Slasher, fertilizer box and spray machine	36,533
Buildings and sheds	154,900
Netting	1,040,000
Tractors and vehicles	43,839
Total	1,415,557

Rambutan and mango

Conversion costs for a joint production of rambutan and mango on former sugarcane land on soil class S2 were obtained from the Agbiz tool spreadsheet and Rigden (2008). Given the similarities between lychee and rambutan orchards, it is assumed that many of the conversion cost components in Table 46 were also applicable to rambutan and mango. The netting cost, and the costs of land preparation and planting were scaled down from 13 ha to 5ha. The cost of conversion for a 5ha rambutan and mango orchard is summarised in Table 47. Total cost of conversion is \$666,790, about \$133,358 per hectare.

Table 47: Conversion costs from sugarcane land to a 5-hectare rambutan and mango orchard

Item	Cost (\$)
Establishment cost	54,000
Slasher, fertilizer box and spray machine	14,051
Buildings and sheds	154,900
Netting	400,000
Tractors and vehicles	43,839
Total	666,790

Total present value cost of land conversion

One-off conversion costs are combined with annuity GMs to calculate the total present value cost of conversion. For lychee and rambutan (and mango), the total present value cost of conversion is calculated over a 20-year period using an annual discount rate of 5% per annum. Investments in rambutan, mango and lychee crops span a much longer time period compared to other land use options considered in this study. Lychee and mango take about 10 years to reach a full production, whereas rambutan takes about 6 years. The total present value cost of conversion from sugarcane to these tree crops is shown in Table 48.

Table 48: Total present value cost of land conversion to lychee, rambutan and mango crops (\$/ha) evaluated over 20 year time horizon at an annual discount rate of 5%, expressed from private and societal perspectives

	Total PV cost* (20 years) Rambutan & Mango \$/ha	Total PV cost* (20 years) Lychee \$/ha
Private	-197,040	-80,413
Societal min	-197.289	-118,049
Societal max	-199.495	-119,134

*Negative figures indicate that a total present value benefit is realised following land conversion from sugarcane production

The large present value benefits shown in Table 48 appear attractive, however, this is not matched by evidence on the ground. Growing sugarcane remains the preferred land use option. This suggests that aversion to risks surrounding potential crop failure, potential loss of investment and the uncertainty inherent in re-skilling to a completely different form of agricultural production typically outweigh the potential returns indicated by this form of deterministic analysis.

Cost-effectiveness of DIN reduction

The cost-effectiveness of DIN reduction for conversion to tree crops is not reported in this study because the economic analysis show, under **optimal** conditions in **each year** of the 20-year time horizon, a PV **benefit** rather than a PV cost from land use change.

Optimal conditions leading to optimal yield in each year of the 20-year cycle for tree crops is unlikely to occur in the future. Forecasts on future climate including frequency and intensity of cyclone occurrences, and knowledge on how varying climatic conditions would impact future yields, are not readily available during this study. Thus, the PV benefit reported for tree crops

in this study should be taken with caution, rendering direct comparison to other land uses in the form of cost-effectiveness measure inappropriate.

3.12.4 Market for products and services

- A harvest period (December to February) during the lucrative Christmas and Chinese New Year festivities when lychees are in high demand in both domestic and export markets. Demand for high quality lychee products exceeds the supply from Australia (Menzel *et al.*, 2000); and
- Australia has competitive advantage in the international markets due to its close proximity to the expanding Asian market, as well as supplying counter- seasonal tropical fruits to East Asia (Australian Trade and Investment Commission (<http://www.austrade.gov.au/australian/export/export-markets/countries/japan/industries/Fruit-and-vegetables>), date accessed 18 March 2017)

3.12.5 Limitations and barriers to adoption

Tropical fruit trees can be difficult to grow and consistent harvest levels are very difficult to achieve because of irregular flowering, poor fruit retention, susceptibility to pests and diseases, and the harvested fruits having a short shelf life. The Wet Tropics are also exposed to tropical cyclones which can completely destroy the crops and potentially also wipe out substantial prior investment in the tree stock. With more frequent extreme events anticipated under climate change, decisions to embark on tropical fruit production need to be weighted carefully against these risks.

3.12.6 Conclusion

Simple deterministic analysis suggests that conversion of low-lying, high DIN risk, sugarcane land to lychee or combined rambutan and mango production should deliver very large present value benefits to the landowner, as well as delivering reductions in DIN emissions. However, evidence on the ground appears to indicate that aversion to risks surrounding potential crop failure, potential loss of investment and the uncertainty inherent in re-skilling to a completely different form of agricultural production typically outweigh the potential returns suggested by this form of deterministic analysis.

3.13 Economic Analyses: Summary

Summarising findings from the economic analyses, transitions to alternative land uses can be compared in terms of:

- Annuity gross margin from a private perspective
- Present value cost of conversion from a private perspective
- Present value cost of conversion from a societal perspective
- Cost-effectiveness of DIN reduction

These outcomes will differ across soil types, with different assumptions regarding conversion costs, and with different assumptions for key parameters which affect annuity gross margins (e.g., difference between buy-in and sell-out prices for livestock).

Annuity gross margins for the different land use conversion are compared in Table 49. Present value costs of transition from private and societal perspectives are compared in Table 50. The cost effectiveness of DIN reduction achieved by the land use conversion are compared in Table 51 and Figure 14.

Table 49: Annuity gross margins (private perspective) for land use conversion from sugarcane production

Land use conversion	Soil Type	Annuity Gross Margin (\$/ha)	
		Min	Max
[Sugarcane]	S2	-	1603
[Sugarcane]	S4	-	1109
Ecosystem Wetlands	S2	-	-750
Ecosystem Wetlands	S4	-	-750
Treatment Wetlands	S2	-27,000	-1,800
Treatment Wetlands	S4	-27,000	-1,800
Low input grazing	S2	-	352
Low input grazing	S4	-	254
'No input' grazing	S2	-	311
'No input' grazing	S4	-	273
Lychee	S2	-	16,794
Rambutan & mango	S2	-	28,115

Of the land use conversions considered, only the fruit tree crops deliver higher annuity gross margins than sugarcane¹⁵. The other land use conversions are expected to deliver lower annuity GMs than sugarcane. Cattle grazing can deliver a positive annuity GM from a private perspective, whereas the wetland options deliver negative annuity GMs (i.e., incur annual costs, from a private perspective). This is because wetland maintenance costs are being incurred without (currently) any mechanism for generating revenues from the DIN reductions which the wetlands deliver. This situation would change if mechanisms such as nitrogen credit trading or nitrogen offsetting were available. The recent Discussion Paper on water quality regulations from the Queensland Department of Environment and Heritage Protection suggests opportunities for movement in this direction (Department of Environment and Heritage Protection, 2017). The wide variation in annuity GM for constructed wetlands follows directly from the wide variation in reported construction costs because annual maintenance costs (which impact on annuity GM) are assumed to comprise 3% of the cost of construction.

¹⁵ For fruit tree crops, the very high annuity gross margins reported here assume that the trees yield at the full potential for their age in each and every year of the 20 year timeframe. This is overly optimistic, but we did not conduct more sophisticated analyses because we were unable to source data from which to parameterise the probability and extent of yield reductions for stochastic simulation of annuity GM across a 20 year production cycle.

Table 50: Present value costs of land use conversion from private and societal perspectives

Land use conversion	Soil Type	Present value cost of conversion [Private]* (\$/ha)		Present value cost of conversion [Societal]* (\$/ha)	
		Min	Max	Min	Max
Ecosystem Wetlands	S2	25,855	295,855	-5,946**	293,701
Ecosystem Wetlands	S4	21,477	291,477	-10,325**	289,323
Treatment Wetlands	S2	90,162	1,153,516	51,961	1,139,857
Treatment Wetlands	S4	85,783	1,149,137	45,899	1,134,362
Low input grazing	S2	12,533	14,033	10,025	12,358
Low input grazing	S4	9,023	10,523	5,035	7,864
'No input' grazing	S2	12,887	14,387	10,149	12,562
'No input' grazing	S4	8,855	10,355	4,423	7,403
Lychee	S2	-80,413**	-	-119,134**	-118,049**
Rambutan & mango	S2	-197,040**	-	-199,495**	-197,289**

*Present value costs of land use conversion are calculated with a 5% discount rate over a 12 year timeframe for all land use conversions except fruit tree crops, for which a 20 year timeframe is used.

**Negative PV costs indicate that the land use conversion delivers a PV benefit.

The present value costs of conversion in Table 50 include the impact of the one-off costs of land conversion as well as the reductions in annuity GM compared with sugarcane. Maximum PV costs of land use conversion arise when the top-end estimates of the one-off costs of conversion are included, whereas the minimum PV costs of land use conversion arise when low-end estimates of one-off conversion costs are included. The difference between the minimum and maximum PV costs of conversion is high for wetlands – particularly for treatment wetlands – is because of the wide spectrum of conversion costs reported (\$60,000 - \$900,000 per hectare). PV costs of land use conversion are much lower for grazing because the start-up costs for grazing are much lower.

The PV costs of land use conversion from a societal perspective are always lower than from a private perspective. The societal benefits from sugarcane production are always lower than the private benefits because of the damage costs from the accompanying DIN losses. Furthermore, land use conversions which reduce DIN loss, and/or enhance delivery of other ecosystem services, are deemed to be beneficial from a societal perspective.

The extremely high PV benefits from converting to fruit tree crops should again be regarded with caution because of the overly optimistic assumptions regarding year on year yields. In practice, other factors besides best-case annuity gross margins clearly affect land holders' decisions regarding conversion to fruit tree crops. Net negative cash flows will be encountered for the first three to six years after planting. Anecdotal evidence suggests that yields are highly susceptible to weather variations and outbreaks of pests and diseases. Furthermore, sizeable up-front investments in fruit orchards are vulnerable to catastrophic loss from extreme weather events such as cyclones, flooding and drought. Overall, the risk to return ratio for fruit tree crops is likely to fall outside the acceptable range for many landholders whose farming experience is built around sugarcane cropping. Other potential impediments to converting from sugarcane to fruit tree crops are the high level of crop-specific management expertise required and the need to join grower associations to ensure access to marketing opportunities. For all of these reasons, only a small number of landholders have so far embarked on this conversion. Fruit tree crops do, however, appear to offer strong potential for cost-effective DIN reductions,

so they should be considered in the mix of possible land use conversions – and it might be appropriate to consider committing additional agri-extension effort in this direction.

Among the other land use conversions, the switch to ecosystem service wetlands can generate a total PV benefit from a societal perspective. Total PV benefit will be generated from locations where conversion costs are low and ecosystem service deliveries are high. Identifying such locations will require detailed and careful investigation at site-specific resolution.

Table 51: Cost effectiveness of DIN reduction delivered by land use conversions

Land use conversion	Soil Type	Cost effectiveness of DIN reduction*	
		(\$/kg DIN reduced)	
		Min	Max
Ecosystem Wetlands	S2	483	9
Ecosystem Wetlands	S4	347	7
Treatment Wetlands	S2	416	17
Treatment Wetlands	S4	383	16
Low input grazing	S2	41	37
Low input grazing	S4	19	17
'No input' grazing	S2	39	35
'No input' grazing	S4	17	15

*Cost effectiveness calculated using PV cost of land use conversion from a private perspective, over a 12 year timeframe with a 5% discount rate (Table 50).

The cost-effectiveness results in Table 50 and Figure 13 again reflect that the variation in the PV cost of land use conversion is considerably wider when converting to wetlands than to grazing. The most cost effective outcomes are achieved when land use conversion can be achieved at minimum cost and substantial reductions in DIN losses are delivered. For the grazing options, DIN loss reductions come from reductions in fertiliser input relative to sugarcane. For the wetland options, DIN loss reductions come from reductions in fertiliser input and active DIN removal by the wetlands themselves. The assumed higher rates of DIN removal enable treatment wetlands to deliver relatively cost-effective DIN reduction, even though the low-end conversion costs for treatment wetlands are considerably higher than those for ecosystem wetlands or cattle grazing. For grazing, it will be much more cost-effective to convert land on the leakier S4 soils.

Looking across the different land conversion options (Figure 13), in appropriate locations (where conversion costs are low and DIN reductions are high) treatment wetlands and the grazing options offer cost-effective DIN reduction in the range 15 – 17 \$/kg DIN reduction. This compares favourably with the cost-effectiveness reported for existing agricultural extension-based approaches (c. \$50/kg DIN reduction (Department of Environment and Heritage Protection, 2016c)). Ecosystem wetlands – again when appropriately situated – offer the prospect of even more cost-effective performance (7 – 9 \$/kg DIN reduction).

As already suggested, the key to cost-effective DIN reduction from converting to wetlands is to identify locations which offer a favourable combination of conversion cost and DIN removal rate. These locations will have to be identified at a site-specific level using appropriate local

knowledge. Location is somewhat less critical to the cost-effectiveness of conversion to grazing, but for grazing the actual PV cost incurred will depend on the returns achieved by cattle fattening – which are subject to risks around buy-in and sell-out livestock prices.

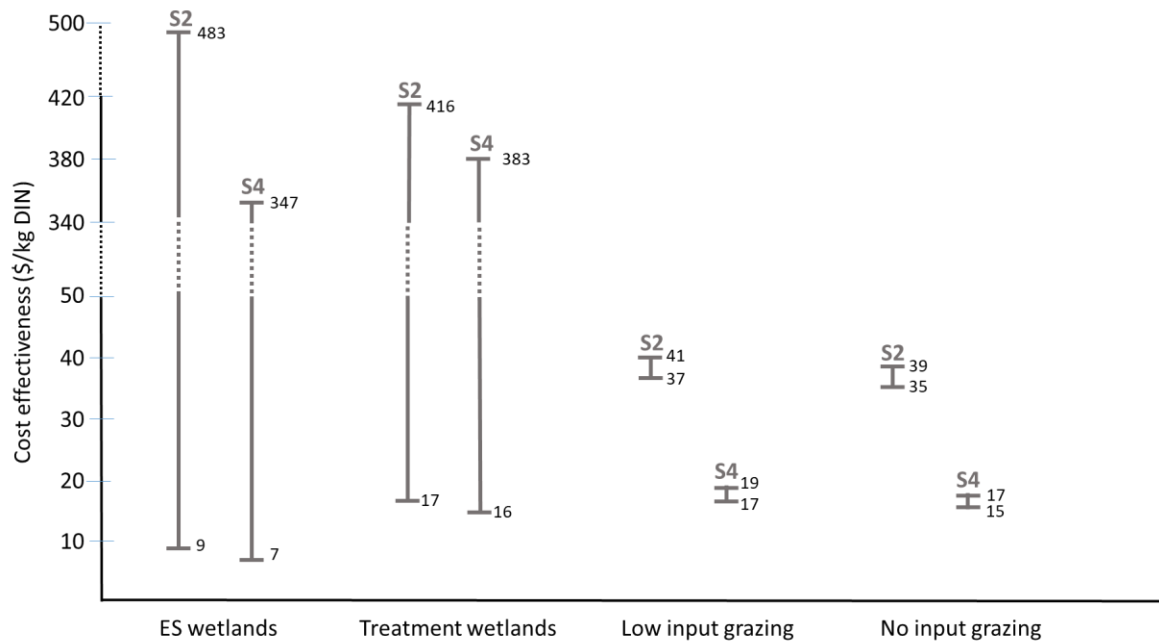


Figure 13: Comparison of the range of cost-effectiveness for DIN reductions achieved by the different land use conversion from low-lying sugarcane land on S2 and S4 soil types. Cost effectiveness is expressed as total PV cost of land conversion per kg reduction in DIN delivered (ES denotes ecosystem service wetlands)

4.0 FACILITATING ON-GROUND IMPLEMENTATION

4.1 Site-specific options analysis

The MCA identifies potential areas of land and land uses based on region-wide spatial information. This coarse level of assessment does not take into account site-specific social, economic and environmental implications of land use conversion. Similarly the economic evaluation shows that restoring wetland ecosystems, treatment systems, grazing and tree crops may be cost-effective mechanisms for reducing DIN. Their effectiveness depends on identifying the correct site with low conversion costs and high DIN reduction capacity. Therefore, these factors need to be considered on a site-by-site basis prior to any on-ground land use conversion. This site-specific options analysis is an essential part of the framework and needs to be undertaken following the identification of potential areas of land and land use options via the MCA and economic analyses. The site-specific options analysis consists of two parts:

1. Shortlisting sites;
2. Site assessment.

4.1.1 Shortlisting sites

Potential sites could be identified through an expression of interest process or by contacting landholders in areas identified in the MCA. Landowners should be provided up front with information on the financial impacts in terms of changes in gross margins, conversion and maintenance costs, and the present value cost of land conversion, including sources of funding, so that they can assess whether they wish to conversion all or part of their land to an alternative land use. In some cases, landowners may wish to conversion to another land use that offers a greater return, such as tree crops, based on economic analyses information alone, without any financial assistance. In other instances, conversion could involve government or private investment to support land use conversion. In this case, investors should thoroughly compare multiple sites to determine which is likely to be most cost-effective in reducing DIN loss. The findings in the economic evaluation (Section 3) and list of considerations for the site assessment (4.1.2 below) provide some guidance on how this could be conducted.

Once a site or sites have been shortlisted, a site assessment is required to ensure that land use conversion is suitable for the site and will not have any detrimental social, economic or environmental repercussions.

4.1.2 Site assessment

Decision support systems to assist in site assessment

There are existing decision support systems that have been used to assess and compare sites for management intervention in the GBR catchments. These generally focus on one objective, such as water quality (e.g., Reef Trust tender process and Water Quality Grants assessment) or wetlands (e.g., wetland decision support system (wetland DSS) and Walking the Landscape approach). No single existing DSS covers all potential investor priorities, which may be water quality improvement, wetland restoration or biodiversity improvement.

The wetland DSS and Walking the Landscape approach both consider multiple ecosystem services and can be configured based on investor priorities and management objectives. The wetland DSS (secondary DSS) is an interactive spreadsheet where values, threats and capacity can be weighted and values assigned for different sites (HLA-Envirosciences, 2006). The Walking the Landscape approach integrates scientific data with expert knowledge via a facilitated stakeholder workshop to develop a common understanding of landscape processes (Lammers *et al.*, 2012)

www.wetlandinfo.ehp.qld.gov.au/resources/static/pdf/ecology/connectivity/walking-the-landscape-15-02-13.pdf).

Due to their ability to consider multiple landscape processes and ecosystem services, these are useful tools that can help support on-ground land use conversion, particularly the 'restore ecosystem services' option. Although the DSS provides a framework for assisting in the analysis of site-specific options, it does not consider all possible factors and site nuances and therefore should only be used to support decision making, not to make decisions (HLA-Envirosciences, 2006). The following section outlines the range of factors that need to be considered for each site.

Process for assessing sites

The following steps should be taken to assess whether single or multiple sites are suitable for land use conversion and the most appropriate land use for the site/s:

1. Identify the management objectives and investor priorities (i.e., Water quality improvement, enhancing fish habitat, carbon sequestration);
2. Collate published biophysical, social and economic information on the site/s;
3. Elicit local landholder and stakeholder knowledge of the site/s; and
4. Workshop with landholders, investors and stakeholders to discuss available information, suitability of alternative land uses and implications of land use conversion.

The information that should be collated and assessed during this process is outlined below.

Production

- Current management system and likelihood (i.e., capacity and cost) of best management practices being adopted;
- Sugarcane production and economic viability under current and potential future management system;
- Sugarcane production in different years and the proportion of years site is economically viable;
- Size of the site and the proportion of the property it takes up and viability of remaining sugarcane enterprise; and
- Impact of land use conversion on mill viability.

Environment

- Landscape context (i.e., position in the landscape relative to natural features and agricultural production areas);
- Current and potential connectivity to waterways, including surface water and groundwater;
- Site opportunities and constraints to an alternative use, including waterlogging, soils, access, tenure, weeds, adjoining production systems and feral animals;
- Potential impact of land use change on adjacent or downstream production areas and natural areas;
- Vulnerability to predicted climate change impacts including rainfall, temperature and sea-level rise and impact this would have on the viability of future sugarcane production or alternative land use; and
- Legislative or planning constraints.

Socio-economic

- Landholder ambitions and future plans for the site (e.g., succession plan, planned expansion or intention to sell);
- Willingness of landowner to change land use, including desire to remain as custodian of the site;
- Capacity of landowner to implement changes required of an alternative land use (e.g., skills required to establish and run a grazing or tree crop enterprise); and
- Proposed development of the site or adjoining land, e.g., earmarked for urban expansion.

4.1.3 Local data

Integrating local datasets will be also a useful extension on the results presented in this project. Local datasets could include additional soils information, waterway barriers, land use, hydrology, or even water quality. Local governments, NRM or industry may hold such data, which could be accessed and used in further refining the starting points outlined in this project.

In addition, new knowledge or forecast of future climates, including intensity and frequency of cyclones, drought, climate projections, together with local data, could be incorporated into current planning. This is particularly important if planning to convert from sugarcane to tree crops. Consultations with landholders with experience already in converting sugarcane land to low-DIN alternatives uses would also be beneficial.

5.0 CONCLUSIONS

5.1 Framework

Research undertaken as part of this project has created an analytical framework capable of identifying areas of land currently used for the production of sugarcane that can be considered high risk from a nitrogen enrichment perspective and potentially suitable for conversion to alternative uses. The framework helps to identify candidate sugarcane land for conversion, and then provide an objective evaluation of the financial impact of converting high DIN risk sugarcane land to alternative land uses. The goal here is to choose land use that would result in DIN reduction at minimum cost to society.

A major advantage of this approach is that it takes a whole of system perspective and incorporates multiple benefits including valuable ecosystem service flows. In the pilot study region, only tree crops provided a higher rate of return than current use – and then only if yields achieve their full potential over multiple years. However, this may not be the case in alternative geographic locations with differing soil, climatic and economic conditions that may make alternative crops and land uses more viable. Conversion to treatment wetlands and/or restoration of wetlands could be a cost-effective approach for DIN reduction at locations where conversion can be achieved at low cost and DIN removal rates are high. Appropriate locations would have to be identified on a site by site basis.

The analysis has been constrained to a degree by the availability of both biophysical and economic data at an appropriate scale. The pilot has shown that further development will be necessary before the decision support tool is fully viable at a local scale. The utility of the framework lies in the fact that it allows spatial identification of high DIN risk sugarcane land suitable for conversion and also compares the value that different conversion options would deliver.

5.2 Key considerations

Conversion of low-lying, high DIN risk sugarcane land to alternative uses must be mindful and sympathetic to the broader biophysical, social and economic system in which these activities will occur. Some alternative land uses such as wetland restoration may introduce a number of new management challenges such as weed control that will need to be factored into action plans and costings (Burrows *et al.*, 2012). Tree cropping would require new skills and higher levels of investment and risk and many landholders may not be amenable to take on this risk. Land use conversion will present a significant challenge to the established ways of doing business and agriculture in those areas where there is a long history of dominant practice and an ageing farmer profile.

Returns from alternative uses of low-lying sugarcane land will in the beginning be somewhat uncertain in comparison to the long and stable history of sugarcane production and its associated and established system of transport, milling, business practices and support mechanisms. Consultation with landholders indicated that the issue of mill viability, because of volume throughput considerations, needed to be considered as part of the framework of

analysis. In the first iteration of this framework the impact of potential land use change on mill viability is not included in the economic analysis for a number of reasons. Primarily these are: 1) in the first iteration of any scheme the area likely to be converted will be small in relation to the overall area of production; 2) the productive potential and yield of the land which could potentially be converted is low and; 3) in comparison to other factors impacting on mill viability such as climatic conditions, the world sugar price, water, fuel and electricity costs and grower/miller relationships the impact of a small area of low-lying land use change will be immaterial.

5.3 Opportunities and constraints

5.3.1 Opportunities for implementing the framework

In a number of instances conversion of low-lying, high DIN risk sugarcane land to wetlands is a cost effective approach for DIN reduction. This is an important finding from a whole of GBR perspective as the ways in which low-lying, high DIN risk, sugarcane land are managed has major implications for water quality. The management practices currently implemented and the land use decisions regarding low-lying sugarcane land impose significant costs on broader society through their impacts on ecosystem functions that support economically valuable industries (for example tourism, commercial and recreational fisheries).

The supply of wetland services from private land typically goes unrewarded by the market forces because of missing markets. For example, in Queensland there is no mechanism for private landholders with wetlands on their property to gain benefit from the services they provide to other industries such as commercial and recreational fishing. No clearly defined funding stream derived from fisheries is available to maintain or enhance wetlands on private land, even though wetlands play an essential role in the life history of many desirable aquatic species (e.g., barramundi, *Lates calcarifer*, an iconic species, that has a diadromous movement ecology (needing to migrate between fresh and tidal waters to complete lifecycle stages, and a distribution across northern Australia rivers and estuaries James *et al.*, (2017)). The absence of such markets means that there are few economic incentives for landholders in appropriate areas to either protect or restore wetland function.

Restoring or retaining wetlands typically comes at an opportunity cost to landholders. Under its current structure the market generates too much wetland loss and too little wetland restoration.

Therefore, in this instance there is a clear need for government or third party intervention to address the current market failure and support wetland management and restoration on private land in the areas identified in this project. The following table (Table 52) suggests a number of forms intervention in the current market could take:

Table 52: Market interventions and approaches for wetland restoration

Approach		How it would work	Comment
Education and Information Campaigns		Engage landholders in relevant target areas and inform them of the value of wetland areas on their property to the broader ecosystem and reef.	May encourage some landholders to participate, though the fact that it will be at their own opportunity cost will be a significant dis-incentive.
Subsidies		Provide landholders with subsidies for goods and services for wetland restoration.	Reduces costs to landholders for wetland work. May be provided in conjunction with education but does not address opportunity cost impacts of taking land out of production.
Compensation		Compensation is paid to landholders to protect and restore wetland functionality.	In effect this rewards landholders who maintain and manage functional wetlands. Compensation would be paid on the basis of annual value of lost production from low-lying land.
Payments for Ecosystem Services	for	Landholders are paid on the basis of the amount of ecosystem services that the wetland system generates initially across the three benefits identified in the framework.	Provides an incentive in the market and will encourage investment in areas that provide the greatest ecosystem services. Will require the development of transparent supportive market mechanisms such as benefit calculators and capacity building.
Rate Relief		Landholders receive rate relief from Local Councils for participation in wetland restoration.	Will require local government participation.
Tax Relief		Landholders receive tax relief from Local Councils for participation in wetland restoration.	Will require Australian government participation.
Auctions		Auctions are a way that private landholders can effectively compete to provide environmental services. Auctions provide a means of revealing landholder willingness to participate and a mechanism for quantifying the perceived opportunity cost for providing environmental outcomes.	Auctions would be a suitable way of encouraging low-lying land use conversion, though will require a significant investment in regional capacity building.
Offsets		Conditioning environmentally damaging activities with offset requirements is a way of modifying existing market behaviours to ensure that the overall impacts are minimised and adequate environmental conservation is achieved.	Offset opportunities are emerging in Queensland that may potentially incentivise land use conversion.
Cap and Trade		Cap and trade is a market-based approach that sets a maximum limit on an environmentally damaging outcome (e.g., total DIN emissions)	A cap on the amount of available nitrogen pollution in each catchment would incentivise wetland restoration.

	in a geographically-defined area (e.g., a specific river catchment). Tradable permits in emissions are issued to landholders by the government. Permits can be bought and sold (e.g., online) between landholders under the total cap. Trading occurs when landholders can realise a benefit by buying or selling. Wetland banking in America is an example of a cap and trade approach where a cap on wetland loss has been implemented with tradeable credits being generated through wetland restoration elsewhere.	See (Smart <i>et al.</i> , 2016) for further information.
Land Acquisition	Under this model land could be purchased for the purposes of wetland restoration. Outright purchase of private properties by public authorities is a form of direct intervention in the market place to ensure conservation outcomes. Various private and quasi-private organisations have recently come into existence with the express purpose of buying and protecting high value conservation land. The Bush Heritage Trust and Queensland Trust for Nature are examples of such organisations.	A variation on this model is the purchase of land, wetland restoration and then resale of commercially important areas of land to reduce overall costs. Appropriate mix of land repurposing, boundary realignment, and sale of alternative land parcels may be commercially attractive and also deliver a conservation outcome.
Conservation Easements	Conservation easements are a tool of property law that is used in other countries. They grant a right to a public authority to restrict land use on properties not in their ownership. Easements are commonly used for linear infrastructure in Australia. In the United States conservation easements have become the most popular conservation tool.	Could be an appropriate, though potentially controversial, approach and may have to mix with other approaches to be socially viable.
Conservation Leases	Conservation leases are an alternative to outright land purchase and involve temporary long-term leases over properties or strategic areas of properties. Conservation leases are increasingly being used in Great Britain and France to enhance conservation outcomes on private land.	Reduces overall purchase costs while still allowing land access and conversion potential.

5.3.2 Constraints

The potential market interventions identified to encourage land use conversion all face significant implementation barriers under the current policy and investment frameworks. A significant stream of funding will need to be identified to allow the market interventions described above to be implemented. However, in comparison to approaches that involve supporting current production practices through best management rather than land retirement or conversion there may be significant gains in outcomes versus dollars spent. Land conversion is likely to be a more permanent and lasting approach.

Significant gaps exist in the knowledge of alternative land use performance in terms of their environmental and economic performance. However, this pilot study has demonstrated that large and productive gains from a whole of society perspective can potentially be achieved. Further work including a pilot project is required to inform the further development of the framework.

6.0 TRIAL, REVIEW AND IMPROVE – PHASE 2

6.1 Improved information for framework

There is a need for targeted research and updated datasets to improve the knowledge base for the MCA and economic analyses. The datasets used in the MCA were generally captured at ranges between 1:100,000 to 1:50,000 and therefore results should be interpreted at this scale, limiting the confidence of results at finer resolutions. The spatial extent and availability of some datasets precluded their use in the MCA. Datasets, such as Acid Sulfate Soils, were not available throughout the whole Wet Tropics region and therefore could not be used in this MCA. In addition, there are datasets such as groundwater dependent ecosystems that would be useful for assessing suitability for wetland restoration or treatment systems, which are available in other regions but not the Wet Tropics. Although BlueMaps was deemed the best available dataset on connectivity to the GBR, it does not account for interrupted connectivity from bunds, infrastructure etc. Updating and expanding these datasets would make the framework more robust. The framework can easily be updated to include updated or additional datasets when they become available.

In lieu of spatially referenced sugarcane production data, the framework assumed that low-lying, flood prone sugarcane land has poor productivity. Information on sugarcane yield, CCS and gross margins in multiple catchments and soil types would enhance the MCA and help refine the economic analyses. Similarly, more recent and comprehensive information on the costs and revenues from alternative land uses would reduce uncertainty in the economic analyses. Additional information regarding which factors influence the costs of wetland conversion, and which factors influence the efficiency of DIN removal would be particularly useful to better quantify the cost effectiveness of ecosystem service wetlands and treatment systems as options for DIN loss reduction.

There remains debate in relation to the efficacy of constructed wetlands for treatment, with very different levels of efficacy presented which has major implications on the cost effectiveness examined here. However, the opportunity to integrate constructed treatment wetlands into a broader treatment train (i.e. using devices like paddock scale bioreactors, or high rate macroalgae ponds), in the right location, might deliver additional benefits for water quality improvement and may still be cost effective. There is a real need for additional data and research in this area, so that more informed decisions can be made and thereby costed.

6.2 Pilot projects

It is recommended that the framework be tested via a pilot project/s in the Wet Tropics, involving wetland restoration or a treatment system. Pilots could be modelled on previous wetland restoration or constructed treatment wetland projects conducted on sugarcane farms, which have demonstrated that poorly performing low-lying sugarcane land can be taken out of production without impacting farm productivity. Overall farm production can actually be improved, as highlighted in some of these case studies:

- Burnside (Herbert): Five hectares of wetlands were re-established on the sugarcane and grazing property south of Ingham. The soil that was excavated as part of the wetland rehabilitation was used to raise paddock height. Which, along with best

management practices, improved yields in previously poor productivity areas by five tonnes per hectare.

wetlandinfo.ehp.qld.gov.au/resources/static/pdf/resources/reports/farming-case-studies/cs-cane-15-04-13.pdf

- Papale's wetland (Burdekin): Four hectares of previously poorly performing low-lying sugarcane land was converted to a wetland to capture and reuse water runoff and provide habitat for wildlife. As part of this work, the sugarcane paddock was reconfigured to help maintain the same sugarcane yield on less land.
www.smartcane.com.au/CaseStudies/NatSysMgmCs2.aspx
- Mungalla bund wall removal (Ingham): A wetland ecosystem services project site in Ingham where a section of an earth bund wall constructed in the 1940's was removed to reinstate tidal exchange above the wall, to improve water quality, destroy invasive aquatic weeds and to also reconnect the wetlands downstream. This project has demonstrated some of the benefits offered in removing bund walls to improve water quality and fisheries habitat value (Figure 15).
www.mungallaaboriginaltours.com.au/2016-07-20-04-14-12/wetlands-restoration-project



Figure 14: Mungalla wetland before bund wall removal (September 2013) with invasive aquatic weed choke, and after bund wall removal and saltwater ingress (September 2015) with native aquatic vegetation returning (photos provided by B. Abbott)

In addition to the economic and environmental benefits, these projects benefited the landowners by providing recreational opportunities, improving aesthetics or for other altruistic reasons. A wetland restoration or treatment system pilot project could also achieve social, economic and environmental benefits and therefore is recommended to test and refine the framework and achieve DIN reductions.

The Queensland Government-funded Wet Tropics Major Integrated Projects (MIPs) is an ideal opportunity for a pilot project. The MIP has the thesis to improve water quality from sugarcane and banana farms in the Tully and Johnstone River catchments by integrating water quality solutions across all activities in the catchments. Regional and local stakeholders and landowners would need to be involved in the site-specific analysis to shortlist sites and identify the most appropriate site for a pilot.

A structured monitoring and evaluation program would be required as part of a pilot project to:

- Evaluate the success of wetland restoration or treatment system construction on sugarcane land;
- Quantify the DIN reductions and the economic costs and benefits of wetland restoration or a treatment system;
- Identify any unintended social, economic or environmental consequences, whether positive or negative; and
- Determine what improvements should be made to the framework.

A pilot project is an ideal opportunity to fill some of the key knowledge gaps pertaining to the treatment capacity of restored wetlands and treatment systems in a wet tropics context. These knowledge gaps are currently constraining the implementation of wetland restoration or treatment system projects due to an inability to quantify the water quality benefits of such projects.

6.3 Other NRM regions and industries

This framework could be readily adapted for use in other sugarcane growing regions in the GBR. This would involve updating the datasets in the MCA and revising the economic analysis based on local information. Different agricultural land use options would need to be explored, as the viability of alternative crops will vary between regions because of different climates, markets and infrastructure availability (i.e., irrigation systems).

The framework was developed for sugarcane in the Wet Tropics, however, it could be adapted to other intensive agricultural industries, such as banana, where DIN loss is also an issue. At this stage, this framework is unlikely to be applicable in a rangelands grazing context to manage sediment loss, because the risk factors, inputs and possible options are very different to sugarcane.

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APPENDIX 1: PROJECT FACT SHEET



National Environmental Science Programme

Project 2.1.2 Scoping options for low lying, marginal cane land to reduce DIN in priority wet tropics catchments

Project Summary

This project will scope alternative land use options and income streams that will deliver reduced nitrogen loads from marginal sugarcane land in priority wet tropics catchments. The Wet Tropics Water Quality Improvement Plan (WTWQIP) identified that complete adoption of sugarcane best management practices would be insufficient to achieve reductions outlined in the Great Barrier Reef (GBR) Water Quality Guidelines. There is a need to explore new, innovative mechanisms to achieve water quality targets. By working with community and industry partners, this project will map low-lying land with a high-risk of nitrogen loss, identify possible alternate uses, quantify the economic costs and benefits of land transition, and identify constraints/opportunities for alternative land uses. Such land use options might include restoring coastal wetland function and habitat values, through to alternative farming enterprise development including aquaculture, cattle grazing, cropping, or carbon offset enterprise.

Problem

The Reef 2050 Long-Term Sustainability Plan and Reef Water Quality Protection Plan 2013 have aspiring water quality improvement targets. The WTWQIP identified that to meet the GBR Water Quality Guidelines a target reduction (70 to 80%) for dissolved inorganic nitrogen (DIN) is necessary in the priority wet tropics catchments. The challenge is that complete adoption of 'A-class' sugarcane management practices in the wet tropics catchments will only achieve a 30% reduction; additional cost-effective innovative approaches to reduce nitrogen loads are needed.

How Research Addresses Problem

This research focuses on marginal, low-lying cane lands, and will provide a framework for identifying alternative land use options that targets, explicitly, reducing nitrogen loads. In identifying these new levers for encouraging change, options proposed will be economically feasible for implementation. Overall this research will provide an additional set of management actions necessary to deliver on a commitment to protection of the Great Barrier Reef.



Tidal floodplain area and channel adjacent to sugar cane farm

Photo: Chris Wigghead



Freshwater wetland are critical habitat for range of wildlife species

Step 1 - Identify low-lying, high-risk production areas

Using GIS mapping and other data sets available, low-lying, marginal sugarcane land in the priority wet tropics catchments will be identified in the Russell-Mulgrave, Johnstone, Tully/Murray or Herbert catchments.

Step 2 – Site options assessment

Alternative land use options (e.g. grazing, other crops, conversion to wetlands) will be determined for suitable sites identified. Different site typologies will be identified based on existing information on vegetation, geology, agricultural production, elevation, flooding, saline intrusion, and alternative land use options for different site typologies selected.

Step 3 – Economic analysis

Costs will be estimated using location-specific data on foregone gross margin from the existing sugarcane production, conversion cost (e.g. earthworks) and on-going maintenance cost. Revenues from alternative land uses will be obtained from agricultural economic and extension literature and landholders where possible. Estimated conversion and maintenance costs for representative sites based on published literature and stakeholder experience will be presented, across a relevant range of prices for at-source N-credits, C-credits and incomes from alternative food or fibre production.

Step 4 – Feasibility of implementation

Social, economic and environmental constraints and opportunities will be identified through consultation with community, industry and government stakeholders. Market options, industry viability and mechanisms to facilitate change (e.g. buy-back, lease land) will be explored and discussed in the context of viable alternative land uses.

Further information

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Australian Rivers Institute



This project is supported through funding from the Australian Government's National Environmental Science Programme

APPENDIX 2: COMMUNICATION PRODUCTS – ARTICLE IN CANGROWERS MAGAZINE (OCTOBER 2016)

Industry news

Getting the lowdown on what to do with low-lying cane land

Do you have flood-prone, low-lying cane land that struggles to be productive? A new study is aiming to identify what alternatives might exist for making some income from it.

The issue of farming these areas came to light recently with a report commissioned by the Queensland Government, called Alluvium.

It looked at changes to sugarcane land use as one option to improving water quality for the Great Barrier Reef.

Alternative uses for cane land has been a sensitive topic and it's been felt there is a need for more information so that growers, the industry and government can assess both the opportunities and the risks in any strategy.

So, what land use options do cane farmers have that will provide an income and also reduce nitrogen from reaching the Great Barrier Reef?

James Cook University (JCU) and Griffith University scientists and economists are investigating this question.

Their scoping study will collate relevant information on options for low-lying cane land in the Wet Tropics region.

It will assess the costs and benefits of different land use options and identify income streams.

The study is being funded through the Australian Government's National Environmental Science Programme.

The lead researcher is Dr Nathan Waltham from JCU.

"We understand that this is a sensitive topic for the cane industry," he said.

"The implications of land use change on production, mill viability and regional communities are issues that have been raised by industry and this is forefront in the scoping study.

"Our study will provide a step by step process, backed by the best available information, that will help identify alternative income streams for low-lying land."

The study needs growers in the Wet Tropics region who may be interested in alternatives for their low lying land and would be willing to discuss their situation.

If this is you, and you're interested in being involved in the study please contact Dr Waltham at Nathan.waltham@jcu.edu.au or phone 4781 4191.



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APPENDIX 3: STAKEHOLDER ENGAGEMENT

Record of stakeholder engagement throughout the project. The number of crosses (x) indicates the level of involvement (xxx indicates where stakeholders have been involved in multiple discussions, attended meetings and provided information; x indicates stakeholder has been involved in a discussion or meeting).

Organisation engaged	Phase of project				
	Project planning and identifying options (Jan-Jun 2016)	Multi-criteria analysis (Jul-Oct 2016)	Project progress update (Nov 2016)	Economic analysis (Nov-Dec 2016)	Project progress update (Jan-Mar 2017)
Canegrowers	xx	xx	x	x	xx
Terrain NRM	xx	xxx	x	x	xx
HCPSL	xx	x	x		
Queensland Wetlands Program, EHP	xxx	xxx	x	xxx	xx
Reef Water Quality, EHP	xx		x		x
GBRMPA	xxx	xxx	x		
DOE	x		x		
GBR Foundation	x		x		x
Queensland Trust for Nature	x		x		x
Agriculture, DAF	xx		x	xxx	
Fisheries, DAF	x		x		x
Wilmar	x		x		
WWF	x		x		x
Mungalla	x		x		
Greening Australia	x		x		

APPENDIX 4: MULTI-CRITERIA ANALYSIS

This section outlines the datasets (Table S4.1), ranking system (Table S4.2) and process used in the multi-criteria analysis. The flowchart diagrams illustrate the process, with blue representing the inputs used for the processes, pink indicating the processes used and yellow the outputs from each process. The text indicates how the specific process was achieved.

Table S4.1: Sources of datasets used in the land suitability model

	Dataset (Barnthouse <i>et al.</i>)	Source	Attributes	Scale	Comments
Low lying areas	Drainage basins (2011)	Department of Natural Resources and Mines	Boundaries and sub-catchments information	1:100,000	Wet Tropics Region
	LiDAR (2009-2015)	Department of Environment and Resource Management	Contour lines	1:50,000	
	Regional Ecosystem (2016)	Queensland Government	Landzones 1, 2 and 3	1:50,000	Version 9
	QLD floodplain assessment overlay (2013)	Department of Natural Resources and Mines	Potential flood hazard areas	1:100,000	
	QLUMP (2015)	Queensland Government	Sugarcane modified land	1:50,000	
DIN risk	Blue maps (2016)	Great Barrier Reef Marine Park Authority	Connectivity to Great Barrier Reef	NA	Baseline from sugarcane only (2013) and within source sub-catchments
	Catchments Load modelling (2015-2016)	Department of Natural Resources and Mines	DIN generation rate	1:100,000	
	Sugarcane properties (2015)	Department of Environment and Heritage Protection	Parcel boundaries	1:100,000	
Scenario 1: Grazing	QLUMP (2015)	Queensland Government	Grazing native vegetation and grazing modified pasture	1:50,000	

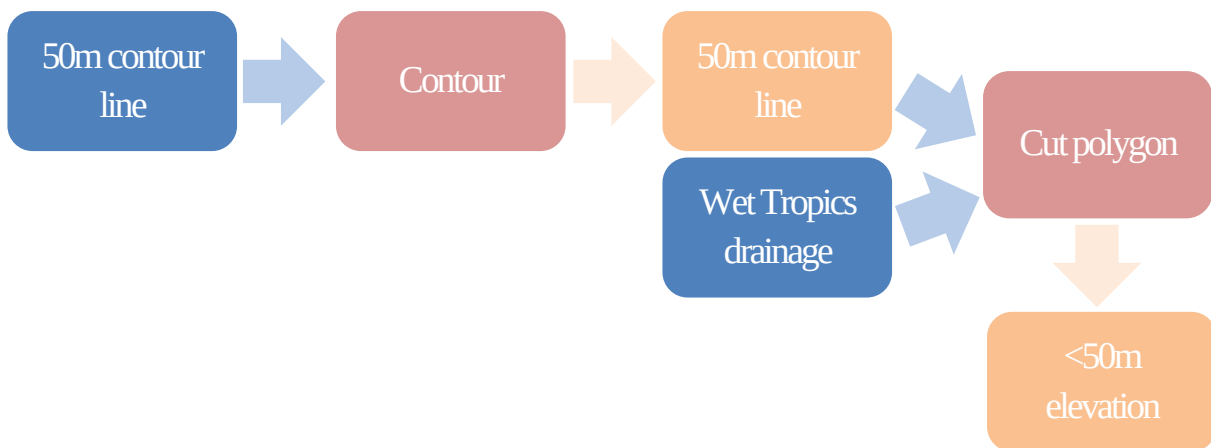
	Ordered drainage (2007)	Department of Natural Resources and Mines	Rivers and streams	1:100,000	Version 6.13
Scenario 2: Tree crops	Agricultural Land Evaluation Guideline (2015)	Queensland Government	Land suitability for lychee, mango and rambutan production	NA	
Scenario 3 & 4: Restore ecosystem services or treatment system	Queensland Wetland (2013)	Queensland Government	Current wetlands	1:100,000	Version 4
	Wetland protection area - high ecological significance wetland (2011)	Department of Environment and Heritage Protection	High ecological significance wetland	1:50,000	Scale along the coast
	Fish Habitat Area (2014)	Queensland Government	Declared Fish Habitat Area	Varies	
	QLUMP (2015)	Queensland Government	Conservation, protected estates and natural environment	1:50,000	
	Pre-clear Regional Ecosystem (2015)	Queensland Government Queensland Herbarium	Historic wetland	1:50,000	Broad Vegetation Group (2014) version 1.1. Broad Vegetation Groups 34, 16d, 22a and 22b for wetland classification.

Table S4.2: Land suitability model ranking system

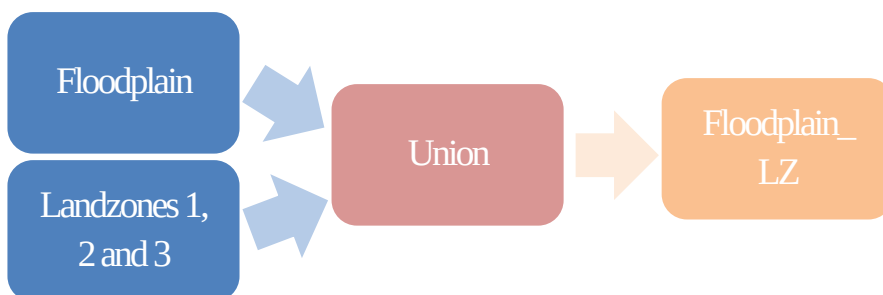
Scenario	Criterion	Unit	Suitability ranking system				References
			Most suitable (score)	Moderately suitable (score)	Low suitable (score)	Unsuitable	
a: Grazing	-	-	Adjacent to current grazing (1)	Land >20ha (1)	-	<10m around rivers (0)	English pers. comm DEEDI 2011
b: Tree crops	LEG (for each crop)	-	Class 1 suitable land with negligible limitations (1)	-	-	Class 4 land (0)	Queensland Government 2015
			Class 2 suitable land with minor limitations (1)	-	-	Class 5 unsuitable land (0)	
			Class 3 suitable land with moderate limitations (1)	-	-	-	
c: Restore ecosystem services	Ecological value	-	Historic wetland (5)	Adjacent to HES Freshwater wetland (3)	Adjacent to Freshwater wetland (1)	-	Queensland Government 2011, 2013, 2015
			-	Adjacent to HES Estuarine wetland (4)	Adjacent to Estuarine wetland (2)	-	
	Management value	-	Adjacent to declared Fish Habitat Area (2)	Adjacent to natural land and protected estates (1)	-	-	Queensland Government 2014, 2015
	BM	-	Very frequently connected (3)	Frequently connected (2)	-	Intermittently connected (0)	
	DIN	kg/ha/yr	< 8 (4)	> 13 - < 18 (1)	-	> 21 - < 27 (0)	Hateley et al (2014)
			> 8 - < 13 (3)	> 18 - < 21 (2)	-	> 27 (0)	
d: Treatment system	Ecological value	-	Adjacent to HES wetland (3)	Within 50m of estuarine wetland (2)	Within 50m of freshwater wetland (1)	-	GBRMPA (2016) Hateley et al (2014)
	BM	-	Very frequently connected (3)	Frequently connected (2)	-	Intermittently connected	
	DIN	kg/ha/yr	> 21 - < 27 (3)	> 13 - < 18 (4)	-	< 8	
			> 27 (4)	> 18 - < 21 (5)	-	> 8 - < 13 (5)	

Flowchart 1 - Low-lying sugarcane areas (LLA) within the Wet Tropics region

- a. Define the areas <50m above sea-level. The areas less than 50m above sea-level are generated using LiDAR and drainage basins datasets (Table S4.1). First, the 50m contour line is created from the LiDAR dataset (Spatial Analyst – ArcMap™ 10.3.1 - ArcGIS), then using the “cut polygon” tool (Editor toolbar – ArcMap™ 10.3.1 - ArcGIS), the areas >50m above the sea-level are removed from the Wet Tropics region to produce the <50m elevation dataset.

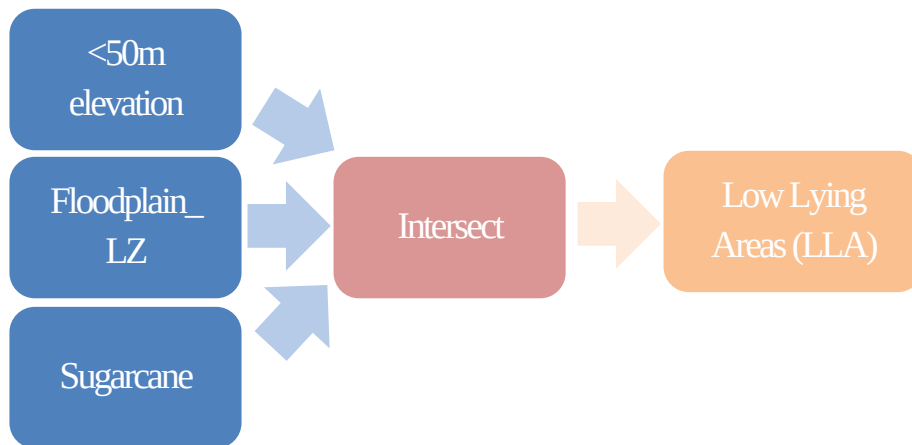


- b. Define the areas prone to flooding and coastal and alluvial land zones. The areas prone to flooding are created (floodplain LZ dataset) by combining the following two datasets using the union tool (Analysis Tools – ArcMap™ 10.3.1 - ArcGIS):
- coastal or alluvial land zones i.e. land zones 1 (tidal flats and beaches), 2 (coastal sand dunes and beach ridges) and 3 (river and creek landforms) from the Regional Ecosystem dataset (Wilson and Taylor 2012)
 - potential flood hazard areas from the Queensland (QLD) Floodplain Assessment Overlay.



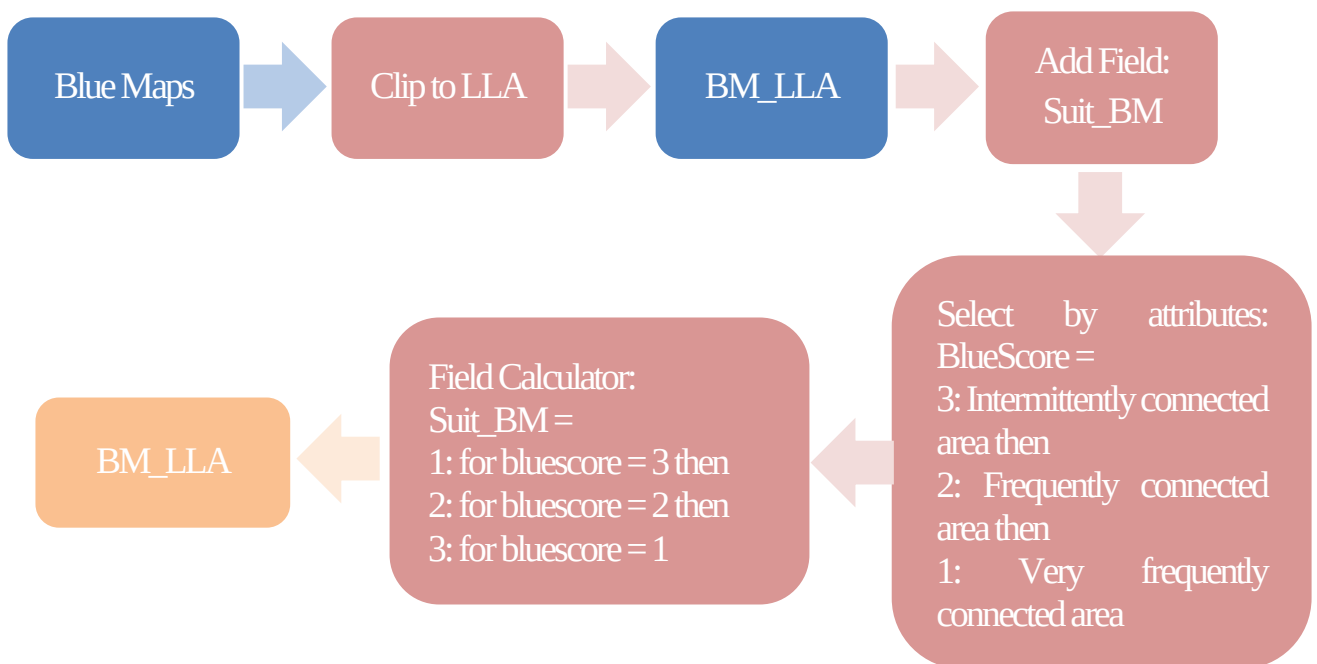
- c. Define the low-lying areas under sugarcane production. The sugarcane modified lands are extracted (Data Management – ArcMap™ 10.3.1 - ArcGIS) from the Queensland Land use Mapping Project dataset (QLUMP - Table 1).
- d. To produce the low lying areas dataset, the areas less than 50m above the sea level, prone to flooding and with sugarcane production are intersected (Analysis Tools –

ArcMap™ 10.3.1 - ArcGIS) to only keep areas that fit all three factors; the output is called Low Lying Areas (LLA).

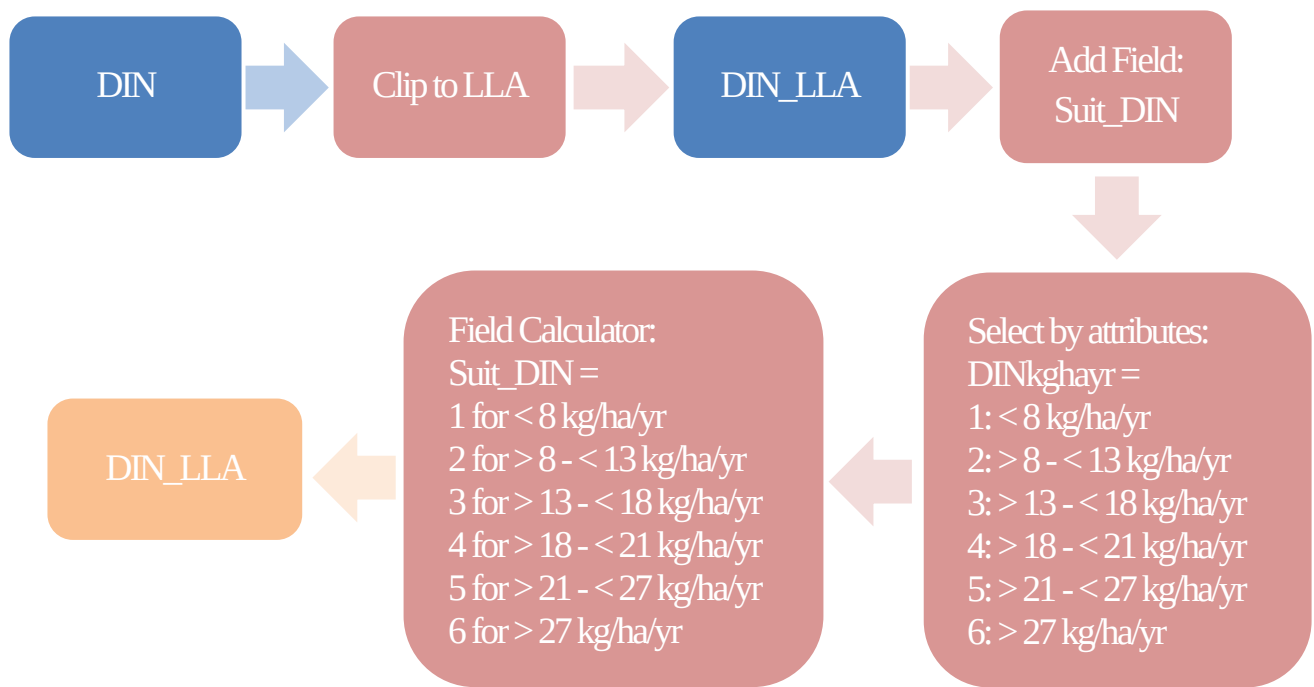


Flowchart 2 - Area at risk of DIN loss to GBR, within the low lying sugarcane areas (LLA)

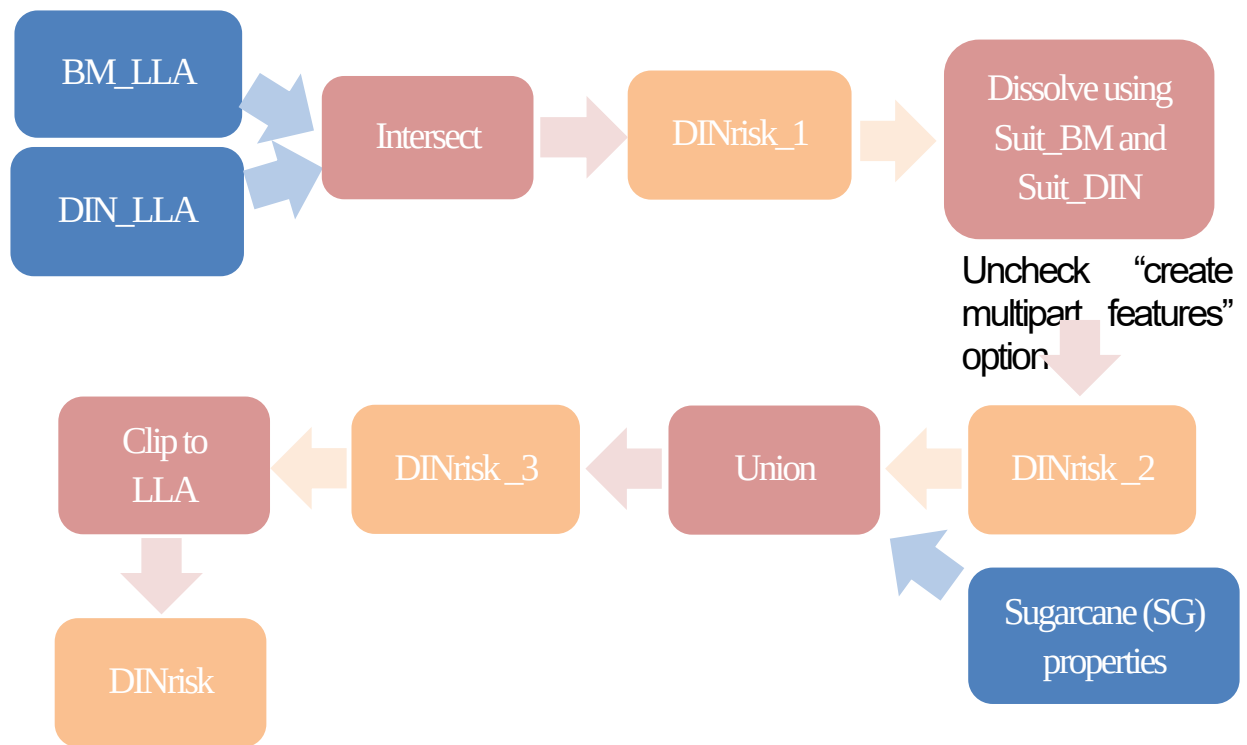
- a. Define the areas with connectivity to the GBR. Information regarding land connectivity to the GBR is found in Blue Maps dataset (Table S4.1). The BM dataset is first clipped (Analysis Tools – ArcMapTM 10.3.1 - ArcGIS) to the LLA dataset; the output is called BM_LLA. A suitability field is added to the BM attribute table to score the land parcel from 1 to 3 (i.e. from intermittently (1) to very frequently connected to the GBR (3) so that very frequently connected is ranked higher than intermittently connected as per Table S4.2).



- b. Define the areas with the greatest loss of dissolved inorganic nitrogen (DIN). Information regarding DIN generation from sugarcane land is found in the Catchments Load modelling dataset (Table S4.1). Only DIN generated from sugarcane land is used. The Catchments Load modelling dataset is first clipped (Analysis Tools – ArcMapTM 10.3.1 - ArcGIS) to the LLA dataset; the output is called DIN_LLA. A suitability field is added to the DIN attribute table to score the land parcel from 1 (low DIN generation rate) to 6 (high DIN generation rate) following the data ranges from the technical report by Hateley *et al.* (2014).

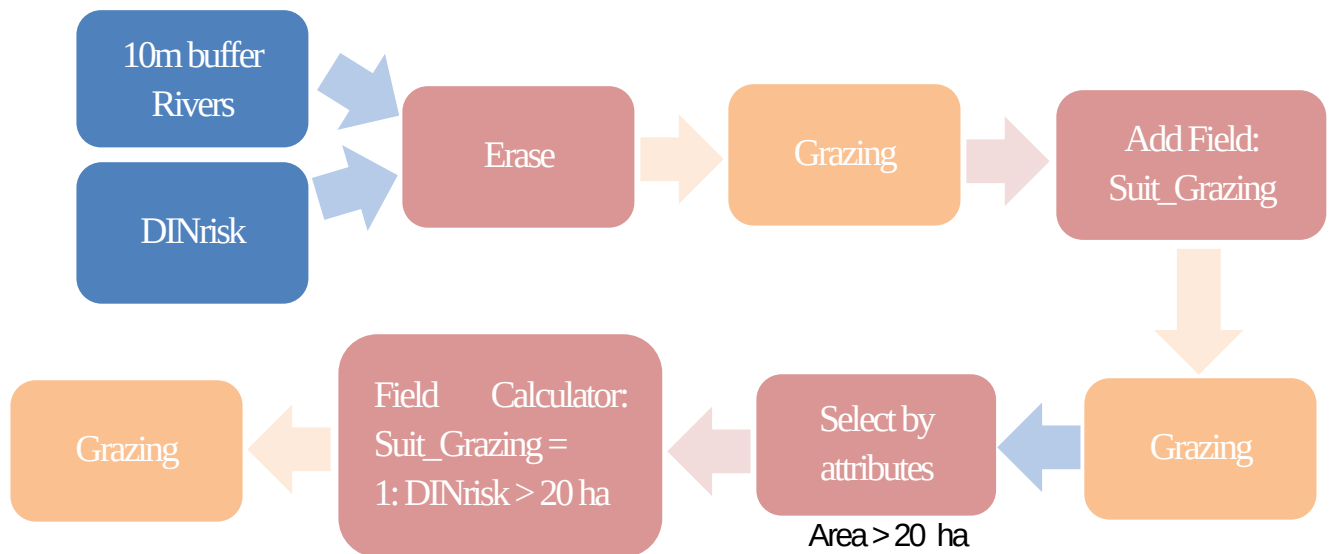


- c. Identify areas with different levels of risk of DIN loss to the GBR (DINrisk) within the low-lying sugarcane areas (LLA). The BM_LLA and the DIN_LLA datasets are intersected to generate an intermediate land of interest (DINrisk_1) feature class containing information on both connectivity to the GBR and the DIN generation rate for each land parcel. Parcels within DINrisk_1 are then dissolved (Data Management–ArcMap™ 10.3.1 - ArcGIS) using both parcel's connectivity to the GBR and DIN generation rate attributes (i.e. adjacent parcels with same attributes are aggregated - DINrisk_2). Finally, the DINrisk_2 and sugarcane properties dataset (Table 1) are unioned to delimit parcels for conversion (DINrisk_3). The “union” tool combines both layers in their entirety and therefore a clip is performed to remove those sugarcane properties that fall outside of the LLA. The output, called DINrisk, is then used in each land use scenario to rank land parcels.

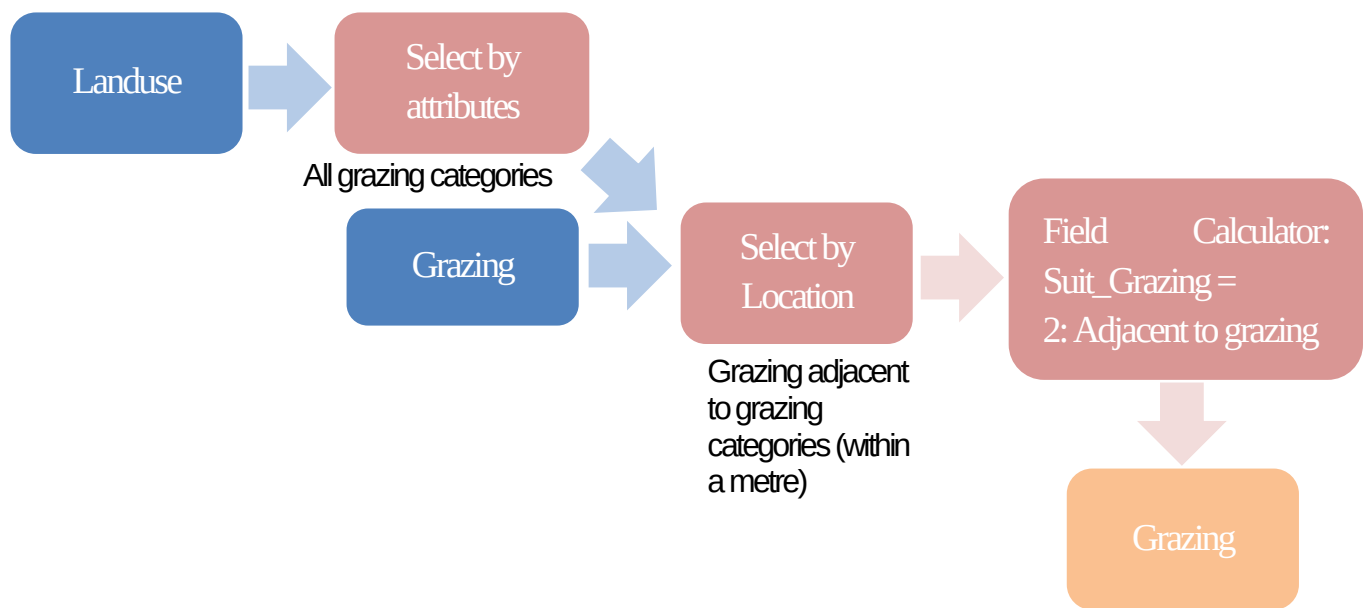


Flowchart 3 - Grazing scenario

- a. To remove the DINrisk areas within 10m of streams or rivers, we first create a 10m buffer around the ordered drainage dataset (Table S4.1). This 10m buffer is then erased (Analysis Tools – ArcMap™ 10.3.1 - ArcGIS) from the DINrisk dataset; the output is called Grazing. A suitability field is added to the Grazing attribute table to score each land parcel depending on their suitability level (Table S4.2).
- b. Define the suitable land parcels within the DINrisk dataset based on their size (> 20ha) and proximity to existing grazing land. First, land parcels with an area greater than 20ha are selected (Data Management – ArcMap™ 10.3.1 - ArcGIS) and given a medium suitability level.

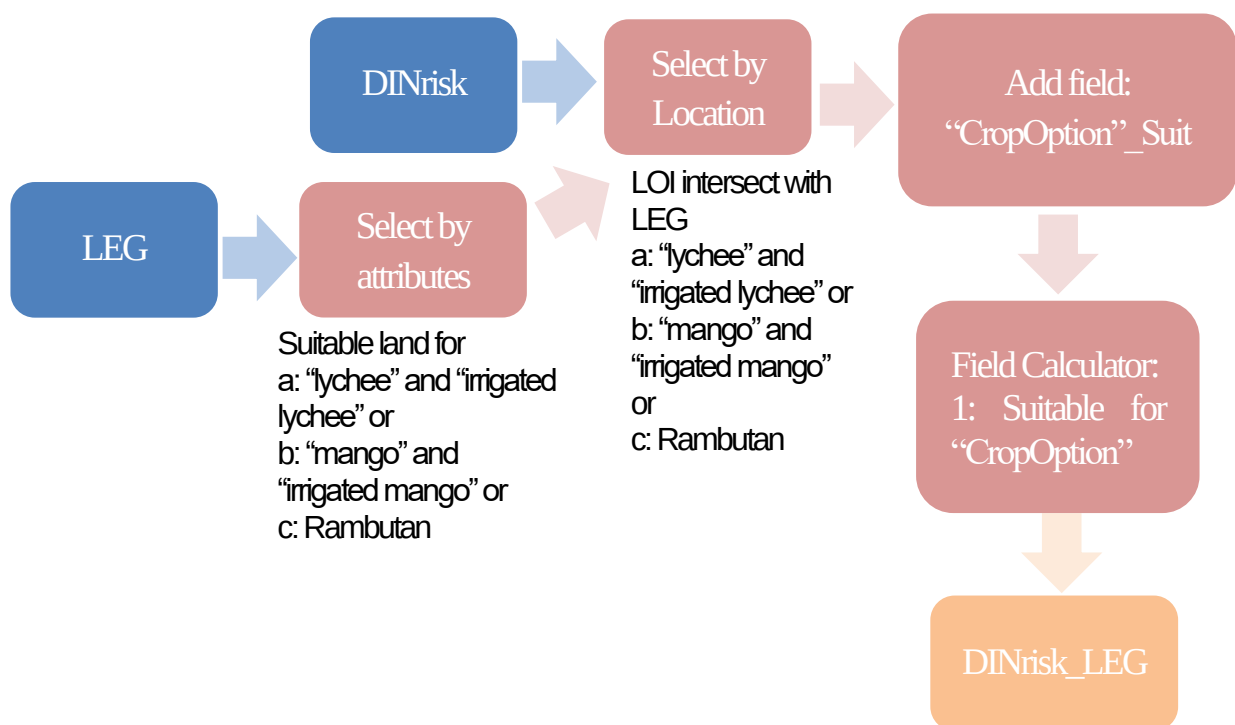


- c. The grazing modified lands are then selected (Data Management – ArcMap™ 10.3.1 - ArcGIS) from the Queensland Land use Mapping Project dataset (QLUMP - Table 1), and used in the select by location tool with “are within a distance of 1m of source layer” as option (Data Management – ArcMap™ 10.3.1 - ArcGIS), to select parcels adjacent to grazing land. The selected parcels are given a high suitability level. Finally, a grazing suitability map is produced, each parcel within the land of interest is coloured based on their level of suitability (i.e. from the suitability field).



Flowchart 4 - Tree crop scenario (crops with lower nitrogen fertiliser requirements than sugarcane)

- a. A copy of the DINrisk dataset is created and called DINrisk_LEG. A suitability field for each tree crop is added to DINrisk_LEG attribute table to give each land parcel a cropping suitability score based on the selected crop. Each tree crop is individually selected from the LEG dataset (i.e. class 1, 2 and 3), then multiple selections by location using “intersect source layer with a search distance of 1m” option (Data Management – ArcMap™ 10.3.1 - ArcGIS) are performed to select DINrisk_LEG parcels that are suitable for each tree crop. These parcels are given a suitability score. Three maps are produced, i.e. one map for each tree crop and each parcel within the land of interest is coloured based on each cropping level of suitability (i.e. from each cropping suitability field).

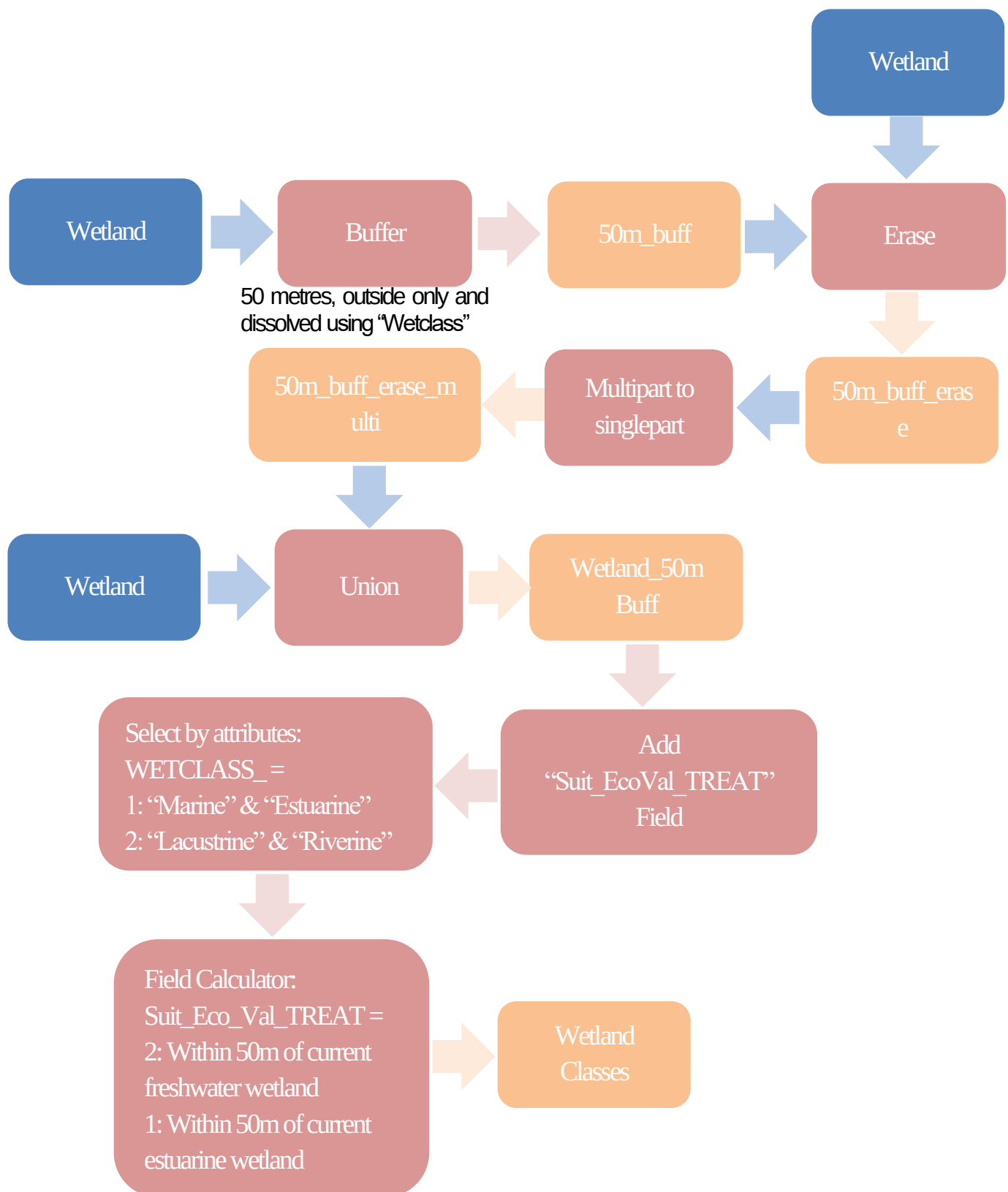


Flowchart 5 - Non-agricultural land use scenarios (restore ecosystem services or treatment system)

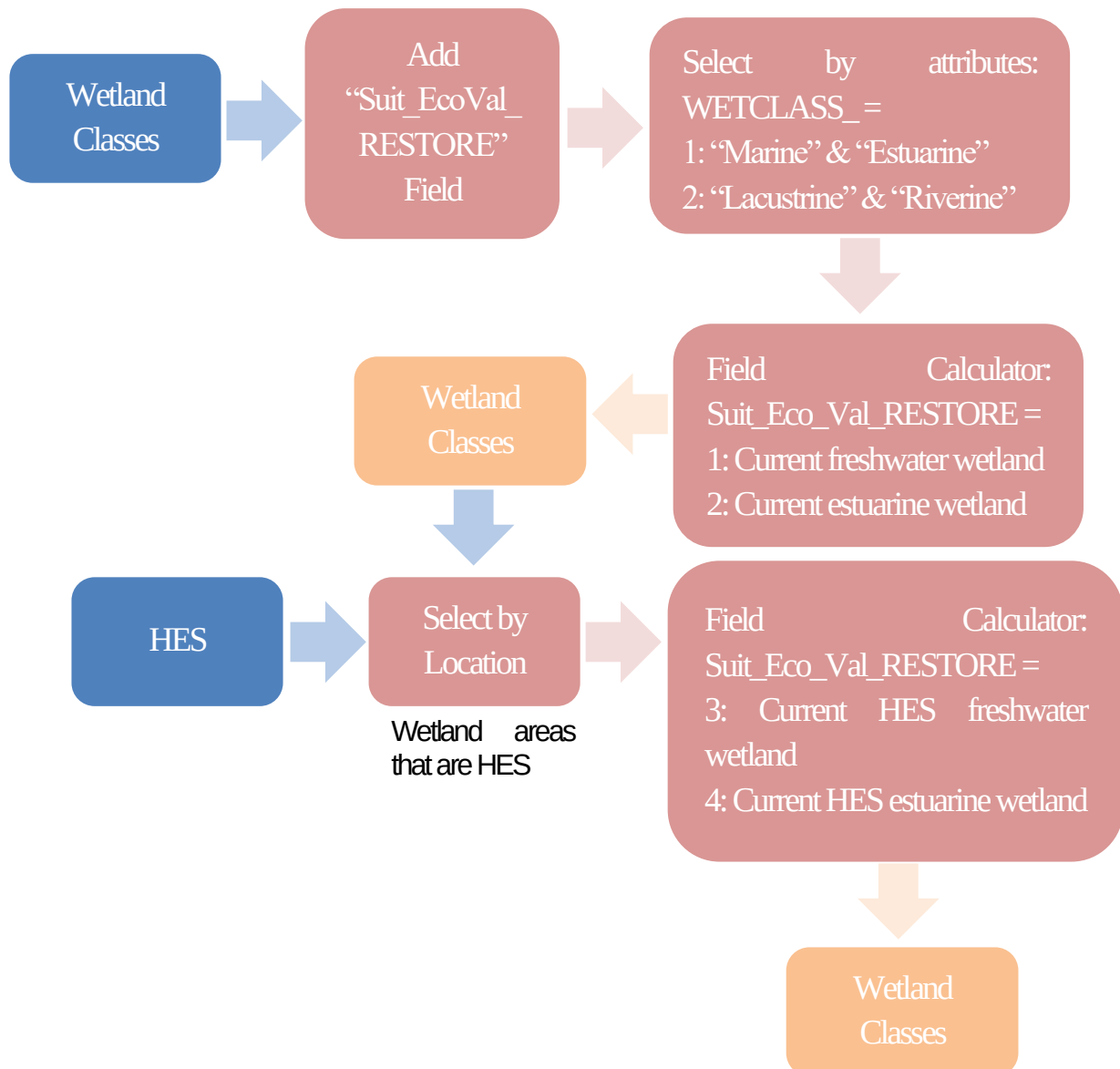
- a. Define the different wetland classes based on their proximity (within 50m) to estuarine and freshwater wetlands. Create a 50m buffer around the current wetlands.
- b. The different wetlands from the Queensland Wetland dataset (Table S4.1) are first classified according to their ecological and management characteristics (i.e. marine, freshwater, of high ecological significance and/or adjacent to a declared Fish Habitat Area). Management value and ecological value RESTORE (for restore ecosystem services) and ecological value TREAT (for treatment systems) are added to the Wetland datasets attribute table to give each wetland parcel an ecological and management value score (Table S4.3). Freshwater (i.e. lacustrine, palustrine and riverine categories) and estuarine (i.e. estuarine and marine categories) wetlands are first selected and given an ecological value of 1 and 2, respectively.

Table S4.3 Ecological and management values and their ranking for restore ecosystem services and treatment system options

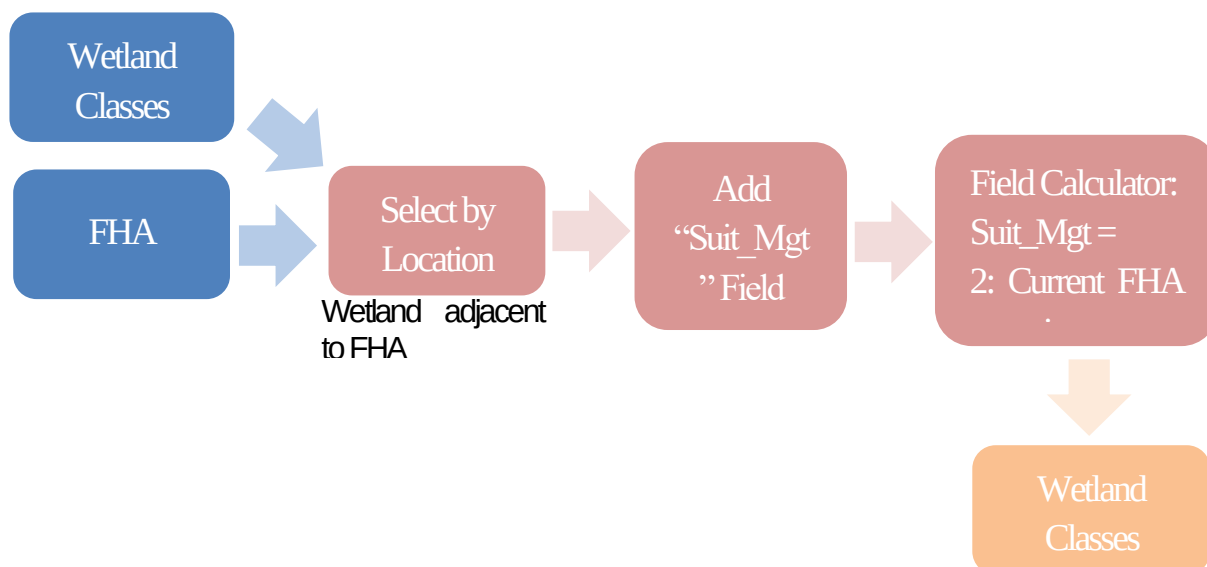
Option	Value categories used	Ranking (in decreasing order of priority, 1=lowest ranking)
Restore ecosystem services	Ecological value - RESTORE	5: within historic wetland 4: adjacent to HES estuarine wetland 3: adjacent to HES freshwater wetland 2: adjacent to estuarine wetland 1: adjacent to freshwater wetland
	Management value	2: adjacent to declared Fish Habitat Area 1: adjacent to natural land or protected estate
Treatment system	Ecological value - TREAT	3: adjacent to HES wetland 2: within 50m of estuarine wetland 1: within 50m of freshwater wetland



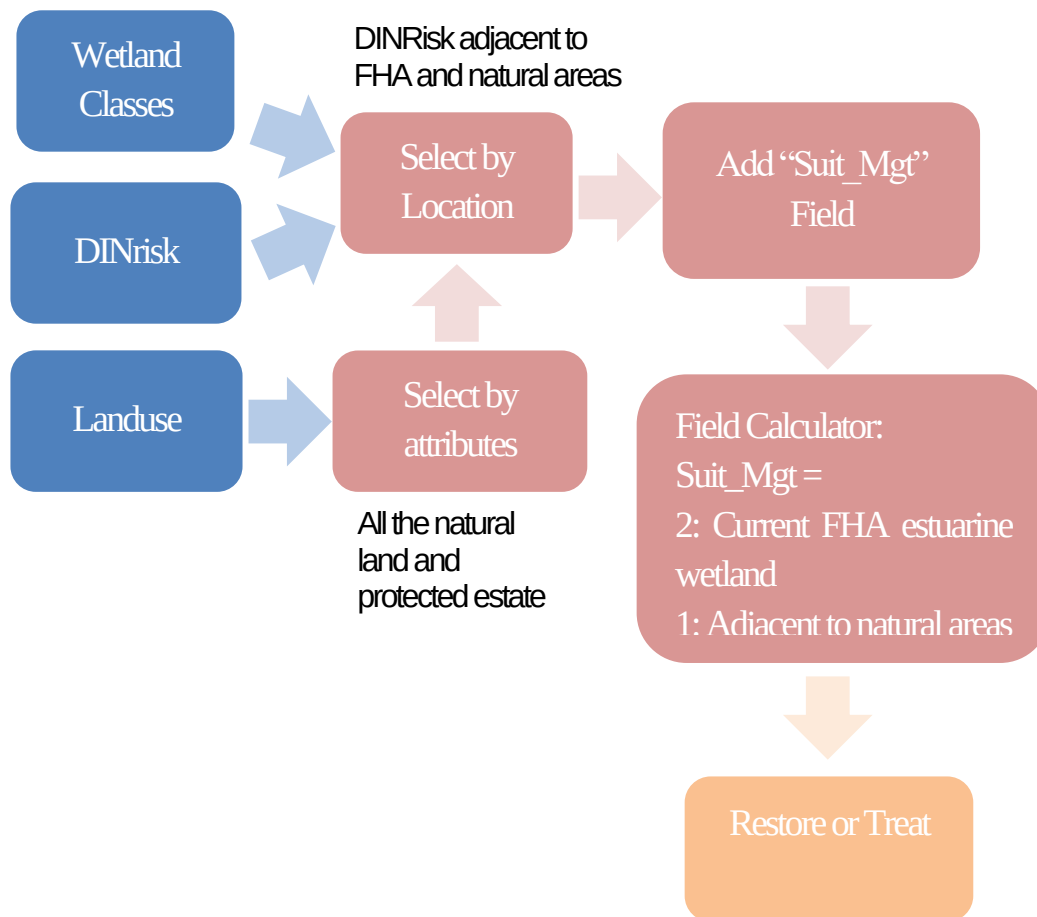
- c. Define the different wetland classes based on if the existing wetland is of high ecological significance. The Wetland protection area - high ecological significance wetland dataset (Table S4.1) is used to select freshwater and estuarine wetlands that are HES. The selection is made using “intersect source layer with a search distance of 1m” as option (Data Management – ArcMap™ 10.3.1 - ArcGIS). Wetland parcels are given an ecological value score of 3 (HES freshwater wetland) and 4 (HES estuarine wetland), respectively (Table S4.3).



- d. Define the different wetland classes based on their proximity to a declared Fish Habitat Area. A selection by location using “are within a distance of 1m of source layer” as option (Data Management – ArcMap™ 10.3.1 - ArcGIS) is performed to select estuarine wetlands that are adjacent to declared Fish Habitat Areas, based on the Fish Habitat Area dataset (Table S4.1) and given a management value score of 2 (Table S4.3).

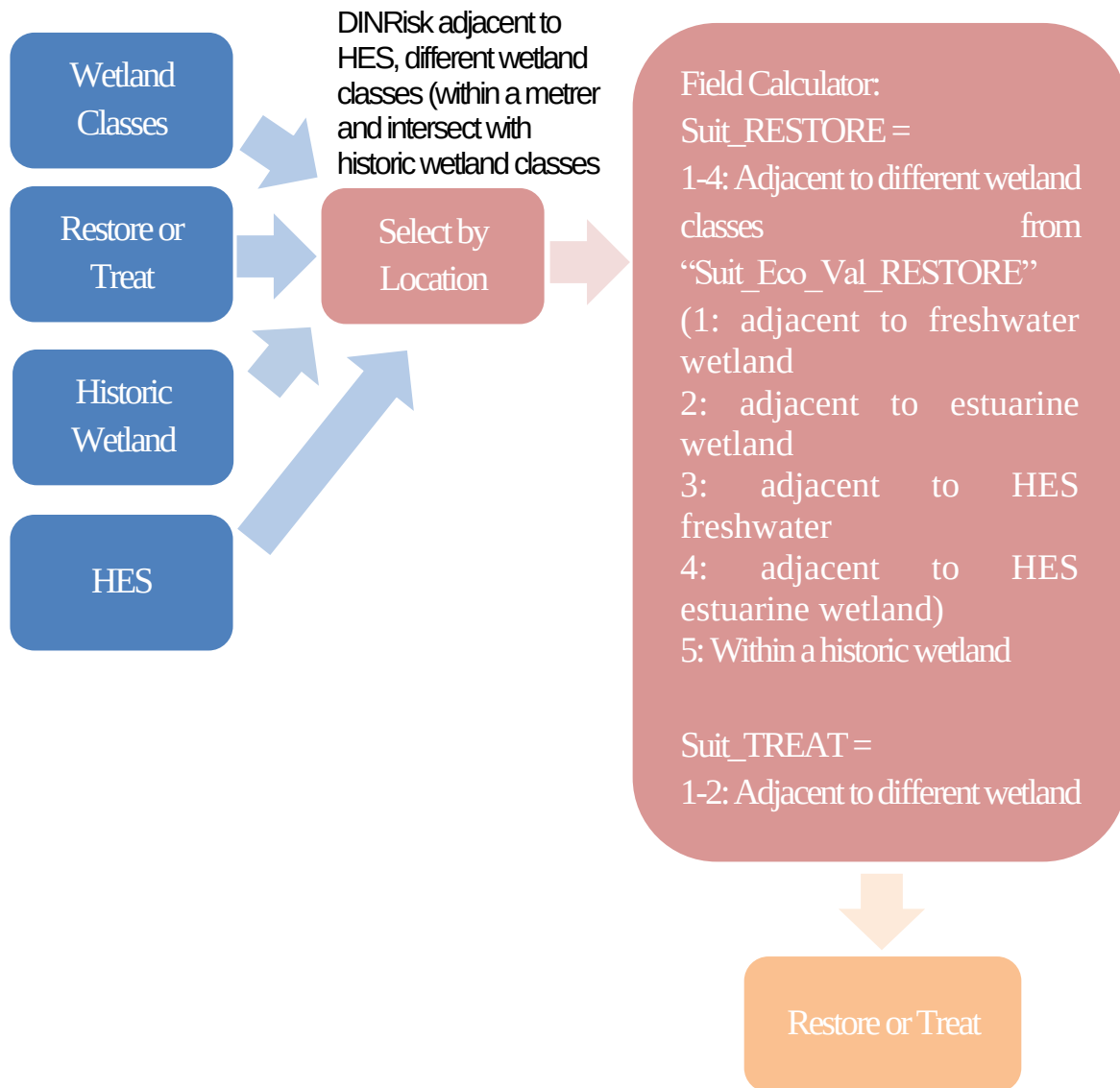


- e. Using the new wetland classification, DINrisk parcels are ranked according to their features (Table S4.2). Ecological value RESTORE, ecological value TREAT and management value fields are added to the DINrisk attribute table, to give each parcel an ecological and management value score (Table S4.3). Multiple selections by location using “are within a distance of 1m of source layer” as option (Data Management – ArcMap™ 10.3.1 - ArcGIS) are performed to select parcels. DINrisk parcels adjacent, or within a metre, to wetland classes with an ecological value RESTORE score of 1 to 4 (i.e. based on the classified wetland dataset ecological value RESTORE field) are given the same ecological value score (i.e. 1 to 4).

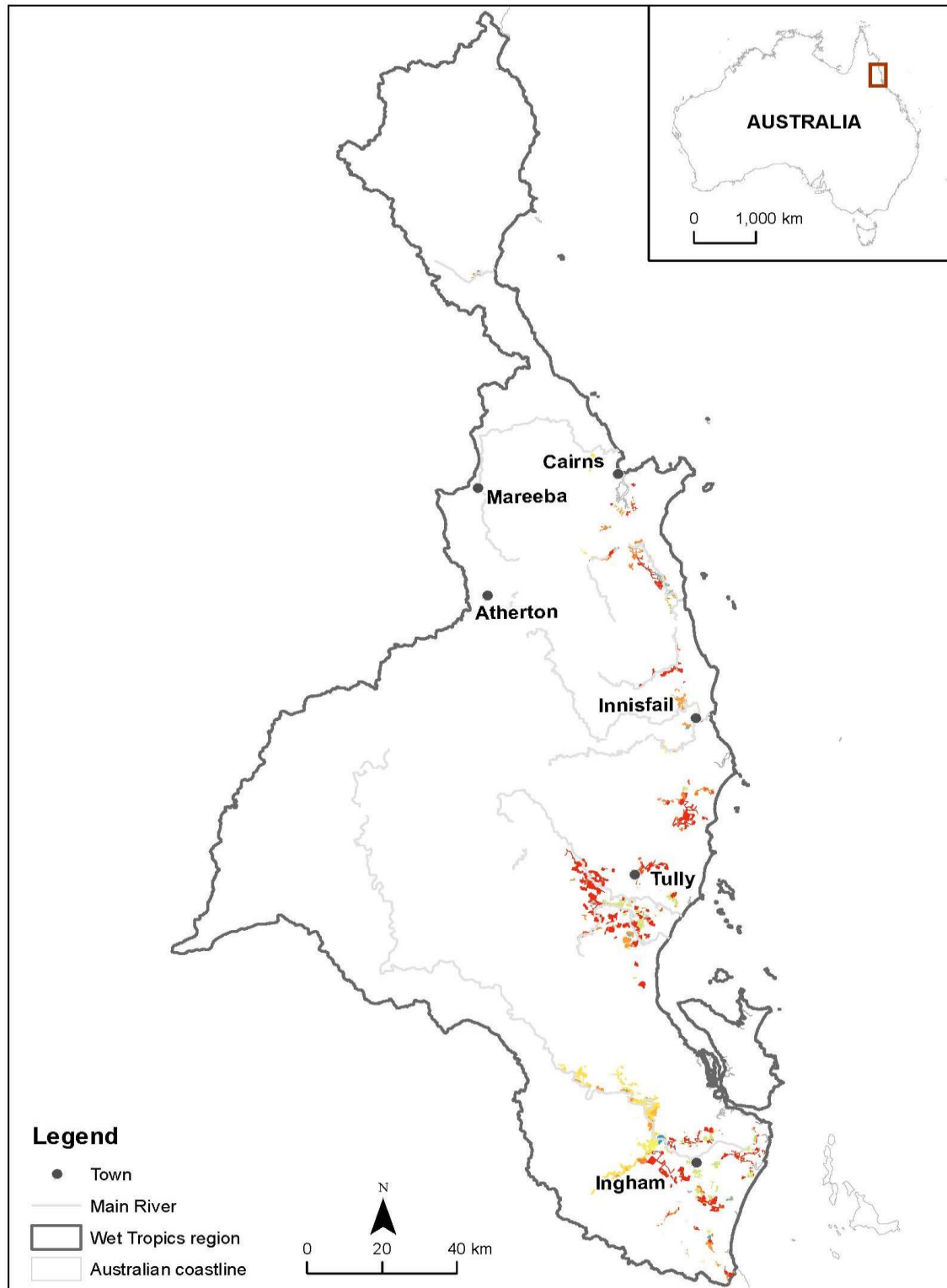


- f. Define the suitable land within the DINrisk dataset based on their proximity to the wetland classes and areas that are mapped as having been wetlands prior to catchment development/clearing, referred to as 'historic wetlands'. These 'historic wetlands' are extracted from the Pre-clear Regional Ecosystem dataset following broad vegetation groupings (Table 1) from Appendix 2 in Neldner *et al.* (2014). DINrisk parcels that "intersect with a search distance of 1m" the historic wetlands are selected and given an ecological value RESTORE of 5 (Table S4.3).
- g. DINrisk parcels adjacent, or within a metre, to wetland classes with an ecological value TREAT score (i.e. in ecological value TREAT field) of 1 to 2 are given the same ecological value score (i.e. 1 to 2). A selection by location using "intersect source layer with a search distance of 1m" as option (Data Management – ArcMap™ 10.3.1 - ArcGIS) are performed to select DINrisk parcels that are adjacent to a high ecological significance wetland and given an ecological value TREAT of 3.
- h. Define the suitable land within the DINrisk dataset based on their proximity to a declared FHA and natural land and protected estates. The DINrisk parcels adjacent, or within a metre, to wetland classes with a management value score of 2 are given the same management value score (i.e. 2). The natural land and protected estates are extracted (Data Management – ArcMap™ 10.3.1 - ArcGIS) from the Queensland Land use Mapping Project dataset (QLUMP - Table 1), then a selection by location using "are within a distance of 1m of source layer" option (Data Management – ArcMap™ 10.3.1 - ArcGIS) is performed to select DINrisk parcels adjacent to natural areas and give them a management value score of 1.

- i. Maps showing the attributes of different land parcels for restore ecosystem services and treatment systems are produced. Each land parcel is coloured based on their ecological and management suitability level using a colour ramp from least to most suitable.



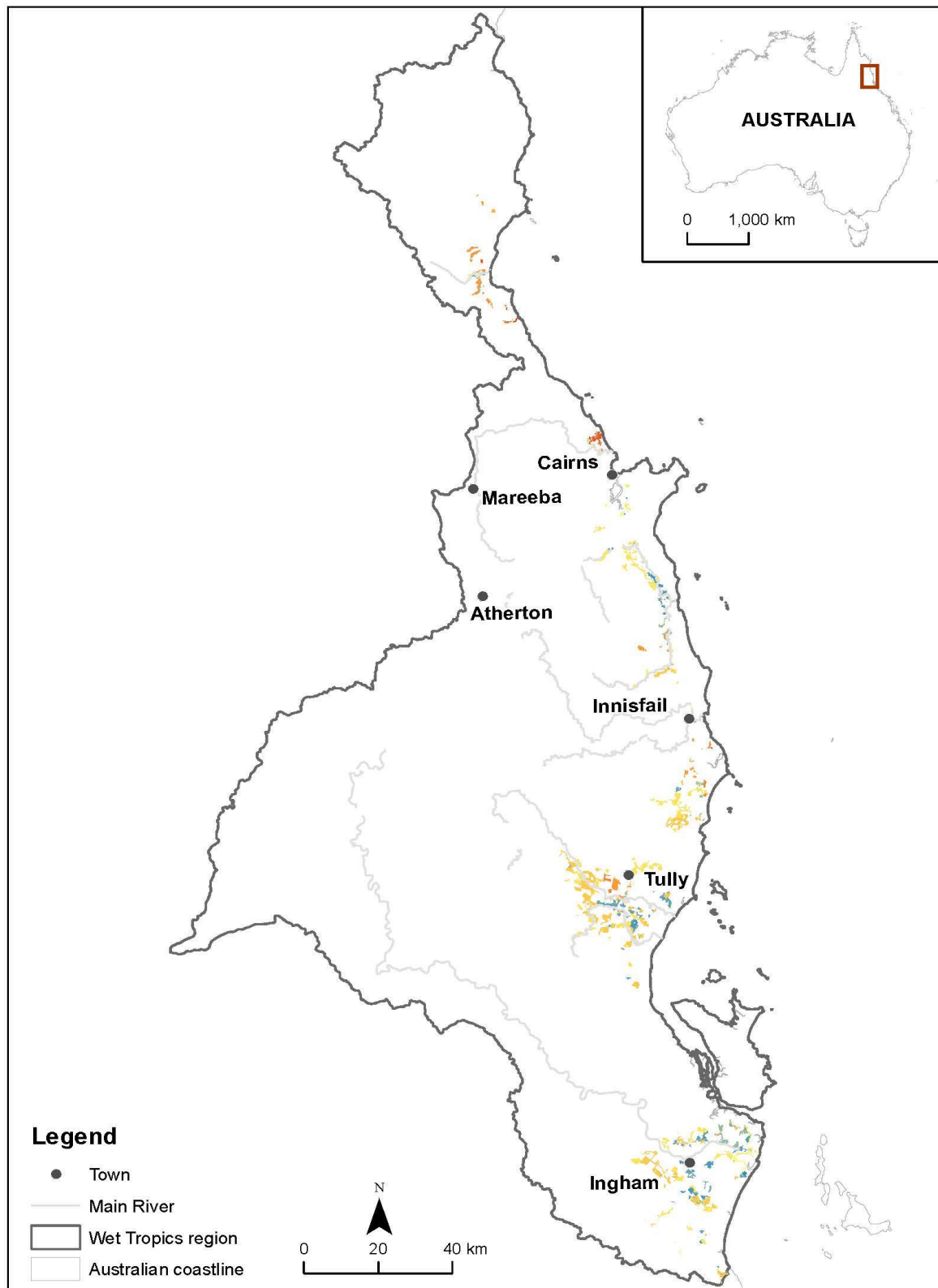
APPENDIX 5: SPATIAL MAP SHOWING SUITABLE LAND FOR RESTORING WETLAND ECOSYSTEM SERVICES IN THE MCA



Legend for Appendix 5

Potential connectivity	DIN (kg/ha/yr)	Ecological value	Management value
2: Frequently Connected	1: < 8	1: Adjacent to freshwater wetland	 1: Adjacent to natural land and protected estate
		2: Adjacent to estuarine wetland	 1: Adjacent to natural land and protected estate
		4: Adjacent to freshwater HES wetland	 3: Adjacent to FHA
		5: Adjacent to estuarine HES wetland	 1: Adjacent to natural land and protected estate
		6: Historic wetland	 3: Adjacent to FHA
			 1: Adjacent to natural land and protected estate
	3: > 13 - < 18	1: Adjacent to freshwater wetland	 1: Adjacent to natural land and protected estate
		2: Adjacent to estuarine wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
		4: Adjacent to freshwater HES wetland	 1: Adjacent to natural land and protected estate
		5: Adjacent to estuarine HES wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
		6: Historic wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
3: Very Frequently Connected	1: < 8	1: Adjacent to freshwater wetland	 1: Adjacent to natural land and protected estate
		4: Adjacent to HES wetland	 1: Adjacent to natural land and protected estate
		6: Historic wetland	 1: Adjacent to natural land and protected estate
	2: > 8 - < 13	1: Adjacent to freshwater wetland	 1: Adjacent to natural land and protected estate
		2: Adjacent to estuarine wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
		4: Adjacent to freshwater HES wetland	 1: Adjacent to natural land and protected estate
		5: Adjacent to estuarine HES wetland	 3: Adjacent to FHA
		6: Historic wetland	 1: Adjacent to natural land and protected estate
	3: > 13 - < 18		 3: Adjacent to FHA
		1: Adjacent to freshwater wetland	 1: Adjacent to natural land and protected estate
		2: Adjacent to estuarine wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
		4: Adjacent to freshwater HES wetland	 1: Adjacent to natural land and protected estate
		5: Adjacent to estuarine HES wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA
		6: Historic wetland	 1: Adjacent to natural land and protected estate
			 3: Adjacent to FHA

APPENDIX 6: SPATIAL MAP SHOWING SUITABLE LAND FOR TREATMENT SYSTEM IN THE MCA



Legend for Appendix 6

Potential connectivity	DIN (kg/ha/yr)	Ecological value
2: Frequently Connected	4: > 18 & < 21	1: Within 50m of freshwater wetland
		2: Within 50m of estuarine wetland
		3: Adjacent to HES wetland
	5: > 21 & < 27	1: Within 50m of freshwater wetland
		2: Within 50m of estuarine wetland
	6: > 27	2: Within 50m of estuarine wetland
3: Very Frequently Connected	4: > 18 & < 21	1: Within 50m of freshwater wetland
		2: Within 50m of estuarine wetland
		3: Adjacent to HES wetland
	5: > 21 & < 27	1: Within 50m of freshwater wetland
		2: Within 50m of estuarine wetland
	6: > 27	1: Within 50m of freshwater wetland 2: Within 50m of estuarine wetland

