An effective landscape restoration approach to improving water quality on the Great Barrier Reef

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Abstract. The Great Barrier Reef (GBR) and agriculture are closely connected through shared environmental impacts and economic dependencies. Increased sediment loads exacerbated by inappropriate land use changes are impacting the health and resilience of the GBR. In the grazing lands of the GBR catchments, more than 75% of the land-based sediment load comes from eroding gullies and streambanks. Landscape restoration of extensive gullies and degraded streambanks can restore ecological function and provide rapid reductions in sediment lost from grazing lands in GBR catchments. The Reef Trust Partnership (RTP) implemented additional governance layers when delivering such restoration activities to maximise water quality investment outcomes. As a result, the RTP Landscape Restoration Program prevented an estimated 75.9 kilotonnes of sediment from entering local waterways and the GBR lagoon. This paper outlines the lessons learned and provides recommendations for delivering similar landscape restoration activities for water quality improvement outcomes.

Key words: landscape restoration, sediment reduction, water quality.

Introduction

A global icon and the world's largest living organism, the Great Barrier Reef (GBR) is home to a quarter of all known marine species. UNESCO World Heritage-listed since 1981, the GBR has an economic, social, and cultural value of $56 billion (Deloitte 2019). Since the arrival of Europeans in 1840, widespread landscape modification has occurred in GBR catchments to meet societal needs through urban development, agriculture, forestry, and mining (Lewis et al. 2021). The interdependence between GBR ecosystems and agriculture is shaped by shared water use, land pressures, and economic entanglements (Cinner et al. 2022). Agricultural production is the dominant land use in over 80% of the 423,000km^2 GBR catchment area (Waterhouse et al. 2024). Extensive cattle grazing on native and cleared pastures occurs in over 70% of the GBR catchment area (Waterhouse, et al. 2024) supporting approximately 20% of Australia's beef herd (MLA 2022). However, broader agricultural production including grazing is contributing to pollutant loads impacting the quality of water in the GBR lagoon (Lewis et al. 2021).

Anthropogenic sediment export

Degraded landscapes caused by land use change, overgrazing, vegetation loss, increasingly intense rainfall, and poor soil health contribute to soil erosion (Nesa et al. 2024). Extensive soil erosion in GBR catchments has resulted in increased fine sediment in the GBR lagoon (Thorburn et al. 2023). Prosser and Wilkinson found that since pre-development, fine sediment exports from GBR catchments have increased by 1.4 to 3 times across catchments (cited in Waterhouse et al. 2024). Elevated turbidity from terrestrial runoff is degrading marine ecosystems (Lewis et al. 2021).

Current research and modelling outcomes show that around one fifth (22%) of the sediment generated in GBR catchments is attributed to hillslope erosion, while gully erosion contributes 54% and streambank erosion 24% (Waterhouse et al. 2024). Small hotspots have been identified as producing significant sediment loads. For example, in the Bowen catchment 2% of gullies are contributing 30% of sediment losses (Daley et al. 2024). While erosion is a natural process, intensified gully erosion in the GBR catchments with altered land use is widely recognised as a key driver of elevated sediment yields, contributing approximately 40% of terrestrial fine suspended sediment pollution to downstream ecosystems (Bartley et al. 2020).

In grazing lands, activities that increase groundcover and reduce hillslope erosion are necessary to mitigate future erosion risks. Interventions to restore ecological function are required where end of dry season cover is consistently <10% (Bartley et al. 2020). Landscape restoration can be achieved through large-scale remediation of degraded land to restore ecological function. However, with grazing land management, the time delay between mitigation actions and recovery is strongly influenced by climate and can be 15 to 20 years before sediment outcomes are realised (Koci et al. 2020). Results can be achieved earlier by mitigating gully and streambank erosion. Landscape restoration activities such as extensive streambank restoration and gully remediation require significant investment and long-term scales to achieve results. However, where engineering and vegetation measures are combined; sediment reduction outcomes can be realised in a relatively short period (Brooks et al. 2021).

Landscape Restoration Program

Improving water quality is essential to increase the GBRs ability to withstand the escalating impacts of climate change (Queensland 2018). A six-year partnership (the Reef Trust Partnership, RTP) (2018-2025) between the Australian Government's Reef Trust and the Great Barrier Reef Foundation (GBRF) invested $64.3 million into sediment reduction programs across Queensland's Herbert, Burdekin, Fitzroy, and Mary regions within its $200 million RTP Water Quality Program.

Two general approaches were used to contribute to the ambitious sediment reduction targets – grazing practice change and landscape restoration. Hillslope erosion was addressed primarily through grazing practice improvement, small-scale earthworks, and low-cost interventions such as leaky weirs to stabilise soil and slow sediment transportation. In contrast, the Landscape Restoration Program (LRP) was designed to deliver large-scale reconstruction of extensive gully networks and eroded streambanks. To maximise the efficiency of the investment, projects were selected based on cost-effectiveness (C/E). A 7-step delivery approach (Figure 1) was designed to meet technical demands, mitigate risks, and ensure the most effective use of RTP funding. Throughout the delivery program, this approach was refined to be more robust and effective, the steps are expanded below.

Figure 1. RTP Landscape Restoration Program 7-step delivery approach

Site identification

Delivery providers identified priority gullies with large and recent baseline sediment yields using the methods of the Reef Trust Gully and Streambank Toolbox (Wilkinson et al. 2022) which included utilising high resolution repeat LiDAR (Light Detection and Ranging) digital elevation models datasets (DEMs) and the guided Gully and Stream Bank Erosion Control Assessment Tools (GECAT and SECAT) to determine historical erosion rates, baseline erosion rates, and baseline sediment yields. In the Bowen, Broken, Bogie (BBB) and Fitzroy catchments, the above was complemented with a priority list of gullies developed by Daley et al. (2021).

During prioritisation and planning stages, delivery providers identified a number of challenges when engaging with landholders responsible for the highest priority sites. Barriers included: active erosion extending across property boundaries; actual sediment savings available being less than anticipated thus reducing the C/E of the site; remote locations and extensive property sizes limiting access and availability of materials; and landholder disinterest resulting in no access or commitment to ongoing management of the site. As a result, the site identification process was adapted to address these challenges and include this broad range of considerations beyond maximum sediment savings when identifying and planning potential remediation sites.

Planning - feasibility report to detailed design

To ensure technically robust and cost-effective projects, a Technical Advisory Group (TAG) consisting of independent gully and remediation specialists was established for the LRP. The TAG provided technical and practical expertise to the LRP through review and endorsement of sediment abatement calculations and assessment of the appropriateness of proposed rehabilitation works. The planning process included three steps, the feasibility report, concept design and detailed design.

An initial feasibility report identified the maximum sediment abatement potential of a proposed remediation site. To ensure consistency, sediment abatement figures were calculated using a formal process. Delivery providers submitted the report for review by the TAG. Feedback was provided, and when appropriate, the maximum sediment abatement figure was endorsed prior to the development of remediation designs. This approach ensured that money was not invested into developing concept or detailed designs for sites that were deemed too costly to remediate based on potential sediment savings. Ultimately, the C/E of the proposed project ($/t of sediment saved) led to approval to proceed or not.

Based on the endorsed feasibility report, a concept design incorporating the proposed remediation approach, estimated sediment reduction, indicative budget, and proposed site management was submitted to the TAG for review and assessment of its suitability. Often further information was required as part of the assessment process, including identification of areas of the site with potential high risk of failure which required a more detailed investigation to produce a plan which lowered that risk.

The final step in the design process was the detailed design that incorporated site maps and design diagrams, detailed earthworks, geotechnical analysis, schedule of quantities, statement of approvals, identified co-benefits, monitoring plan, land management agreement, project budget and estimated final sediment reduction. A TAG review confirmed C/E and sediment load reduction.

Onground work

Onground work was completed as per the schedule with delivery provider oversight of construction and an 'as-built' report submitted by contractor when completed. Monitoring and maintenance were completed as per detailed design.

Gully remediation works were delivered in the Fitzroy, Burdekin and Herbert regions (detailed in Table 1 below). Alluvial gully remediation site interventions (example in Figure 2) included a mix of land reshaping, diversion banks and associated rock chutes, porous rock check dams, batter drains, soil amelioration, revegetation (native endemic to the area), fencing, and grazing management.

Figure 2. Example of LRP alluvial gully site before (May 2023) and after (March 2024) remediation. Actions included reshaping, diversion bank and associated rock chutes, porous rock check dams, soil amelioration, revegetation, fencing, and grazing management.

Streambank restoration works were delivered in the Mary, Fitzroy, Burdekin, and Herbert regions (detailed in Table 2 below). Interventions included reshaping, pile field installation, rock beaching, fencing, revegetation, irrigation systems, and grazing management (example in Figure 3).

Figure 3. Example of LRP streambank site before (Nov 2024) and after (March 2025) rehabilitation. Actions included vertical bank battering and construction of rock chute, batter drains, bunds, rock beaching, and pile fields; soil amelioration, revegetation, fencing, and grazing management.

Verification

An onsite review process for completed landscape restoration works was developed to ensure that reported outputs were being achieved and to provide lessons for adaptive management within the program. Independent technical advisors with relevant expertise were engaged to review and evaluate hard and soft engineered remediation works. The technical advisors assessed detailed design plans and completed an onsite evaluation of works to determine consistency with those plans. Throughout 2023-2024, independent onsite reviews were completed on a total of eight streambanks and 31 gullies at 15 project sites (investment per site ranging from $250,000 to $5 million) across four regions. Post review, observations on the practical on-ground efficacy of works, identification of risks and site-specific recommendations were provided in reports which were distributed to the appropriate delivery providers for action. Overall, the review found that the completed works used accepted industry practices and techniques and were achieving the reported sediment reductions in the short term. Summary results and lessons learnt are documented in Landloch (2025).

Maintenance

A rapidly changing climate is affecting the GBR catchments through increased severity and frequency of weather events, with compounding effects over time (Ortiz et al. 2018). For example, between 2018-2024, more than 10 tropical cyclones (TCs) impacted the GBR. This included TC Jasper in late 2023 and TC Kirrily in early 2024 which caused widespread flooding and erosion in GBR catchments (BOM, 2025). After drought conditions from 2019-2021 (Queensland Government, 2024), the Mary River experienced a peak flood of 22.9 metres in 2022, the highest level since 1893 (GRC, 2025). Weather impacts contributed to LRP maintenance requirements.

Erosion control efficacy for LRP activities ranged from 30% to 90%. The verification found that regardless of the efficacy of erosion control measures, all remediated sites required some form of maintenance (detailed in Tables 1 and 2 below). In the highly sodic and dispersive soils of the BBB, maintenance investment averaged approximately +24% across gully sites. In contrast, on the better soils in the Mary catchment, across 14 streambank restoration sites there was an average additional investment of 7% required for maintenance which was predominantly revegetation. This highlights the challenges of working with dispersive soils as compared to the better streambank soils. All LRP streambank sites required ongoing management of revegetation during the initial 2-year establishment phase with the level of input dependent on seasonal conditions. Additional RTP investment supported the early maintenance of LRP sites to achieve sediment reduction outcomes.

Outcomes

Gully remediation outcomes varied between sites with a range in sediment reduction from 173 t/y (tonnes per year) to 4,617 t/y. Investment per site ranged from $300,000 to $4.2 million. Erosion control measures varied in modelled/calculated effectiveness from 33% to 90%, with efficacy at most sites around 85%. Detailed information on remediated gully sites is provided in Table 1.

Table 1. Efficacy and maintenance requirements for individual RTP Landscape Restoration Program gully remediation sites

Regional program	Recent average rainfall (mm/yr)	Sediment reduction reported (tonnes)	Erosion control efficacy	Approved $ per tonne[1]	# wet seasons post works	Maintenance % additional $ increase	Actual $ per tonne
Herbert	757	173	33%	$1,526	2	6%	$1,616
BBB	522	2,078	80%	$749	2	72%	$1,290
BBB	670	1,057	87%	$427	2	25%	$539
BBB	597	462	87%	$1,043	1	19%	$1,263
BBB	522	4,617	80%	$899	1-2	2%	$921
BBB	522	258	87%	$601	2	211%	$1,924
BBB	635	1086	90%	$1,008	1	-	-
Fitzroy	675	1,623	80%	$470	1	-	-
Fitzroy	-	226	47%	$470	2	-	-
Total/ Average		**11,580**	**75%**	**$803**	**1-2**	**21%**	

[1]Cost effectiveness (C/E) is related to investment in site-specific planning and onground work and does not include administration, approvals, salaries etc. Maintenance data not available for three sites.

Calculated/modelled sediment abatement outcomes on streambank restoration sites varied from 850 t/y to 19,152 t/y. Investment across sites ranged from $100,000 to $5.3 million. Erosion control measures varied in effectiveness from 40% to 87%, with an average effectiveness of 63%.

Cost-effectiveness ranged from 539 to 1,616 $/t sediment abated. On average all streambank sites incurred an additional 7% increase in total cost for maintenance resulting in an average C/E of 363 $/t. Detailed information on efficacy and maintenance requirements are provided in Table 2.

Table 2. Efficacy and maintenance requirements for RTP Landscape Restoration Program streambank restoration sites broken down by regional program

Regional program	# sites restored	Sediment reduction reported (tonnes)	Erosion control efficacy	Approved $ per tonne[1]	# wet seasons post works	Maintenance % additional $ increase	Actual $ per tonne
Herbert	1	1,982	60%	$493	3	6%	$501
BBB	1	9,157	63%	$578	1	-	-
Fitzroy	5	27,050	40-82%	$241	1-3	-	-
Mary	13	26,091	67-87%	$338	1-3	7%	$362
Total/ Average	**20**	**64,280**	**63%**	**$336**	**1-3**	**7%**	

[1]Cost effectiveness is related to investment in site-specific onground works and associated sediment abatement only. No maintenance data available for BBB and Fitzroy sites.

Learnings

Onsite reviews of on-ground works at both gully and streambank sites found that in most cases significant dieback was experienced where revegetation activities did not include monitoring and watering (particularly for tube stock). Sites with implemented monitoring, management and irrigation had strong vegetation recruitment (example in Figure 4). This indicates that during the vegetation establishment phase, investment in monitoring and irrigation is essential.

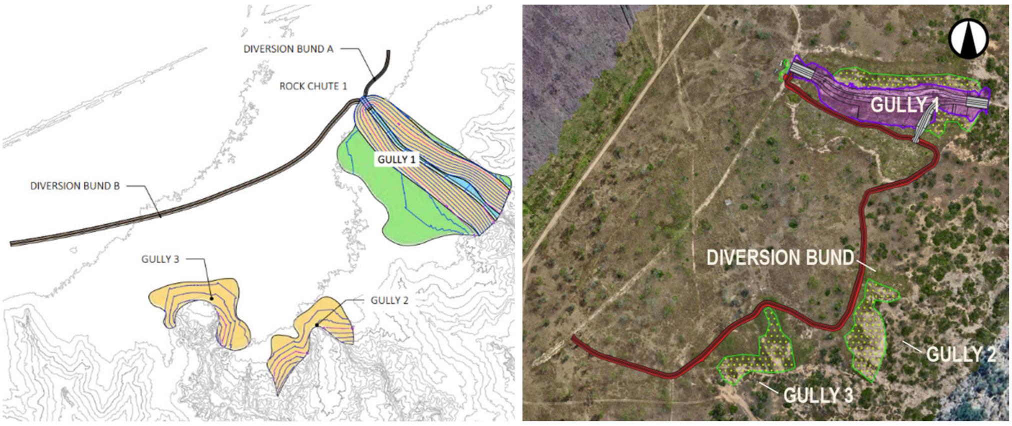
Specialist skills are required for the construction of works as per detailed designs. Specifically, this applies to the installation of rock chutes that provide a stable flow transition to a lower bed level and the temporary porous rock check dams (PCD)s used in low velocity channels to trap sediment and encourage vegetation growth. When designed, constructed, and maintained appropriately, these interventions are effective (Abbasi, et al., 2019). However, onsite verification of a semi-randomised selection of on-ground works found that all rock chutes (13/13) and most PCDs (30/39) reviewed had some form of departure from design. A common issue was the mismatch between specified and available rock sizes during construction. Any departure from design during construction can lead to potential failure in the short to medium term (example in Figure 5). Specialist oversight and supervision of construction should be provided to achieve the design intent. Where project investment is large (>$250,000), construction works should be audited by a suitably qualified person at control points during construction for compliance to design specification.

Figure 4. Quality of vegetation establishment. Image left; poor recruitment of vegetation (cattle onsite). Image right; strong groundcover establishment (comprehensive soil testing and cattle exclusion).

Figure 5. Poor and good porous rock check dam implementation. Image left; outflanking of PCD abutments. Image right; constructed as per design with no outflanking.

Failures occurred where hydraulic modelling of the 'works-in-place' to identify residual risks was not completed. When combined with a lack of knowledge of the soil type, issues were exacerbated by rainfall events that occurred soon after construction and before vegetation had been established. As a result, a site that was impacted by intense rainfall events over two wet seasons required significant maintenance works and reinvestment. The redesign process included additional soil testing and 'works in place' modelling prior to earthworks, amelioration, and revegetation (Figure 6).

Figure 6. Works-in-place modelling significantly changes bund placement at gully remediation site. Image left; original design resulted in failure. Image right; changes to bund placement in maintenance design.



Key learnings associated with the delivery of the RTP Landscape Restoration Program are shared with recommendations that can be applied to future water quality programs in Table 3.

Conclusion

The Reef Trust Partnership (RTP) Landscape Restoration Program (LRP) focused on remediation of prioritised hot spots characterised by large alluvial gully networks and highly erosive streambank sites. The RTP developed and refined a consistent and robust process when delivering the LRP, to ensure cost-effective and appropriate interventions for required sediment reduction outcomes. These landscape restoration activities have prevented an estimated 75.9 kilotonnes of sediment from entering local waterways and the GBR lagoon. Adaptive learning during the delivery of the program was applied to maximise investment outcomes. Key learnings for landscape restoration activities that can be applied to future water quality programs include the need for appropriate governance and independent technical advice to minimise risk and ensure cost-effective interventions. Long-term planning and actions beyond project cycles (monitoring, management and maintenance) are essential to maximise the impact of significant investments and ensure the durability of sediment reduction outcomes. Finally, maintenance will be required and therefore should be included in restoration budgets, with recommendations actioned early to mitigate the risk of intervention failures.

Table 3. Summary of learnings and recommendations associated with the delivery of the RTP Landscape Restoration Program

Component	Issue	Learning	Recommendation
Selection of restoration sites	Use of cost-effectiveness (C/E) as the main metric for works approval	Providers sometimes miscalculated sediment calculations to maximise sediment savings and/or maximise C/E	A consistent and robust process including independent technical advice is required to ensure sediment baselines and C/E calculations are robust
		A high level of technical skill is needed for accurate and consistent sediment calculations and design-modelling; outsourcing increases costs	Technical training is required to increase regional delivery provider capacity
Improving designs	Insufficient modelling	Hydraulic modelling of the 'as is' situation was completed as a standard practice; 'works-in-place' modelling to identify residual risks was not routinely conducted	Hydraulic model runs for gully and streambank sites and geotechnical slope stability and shear stress calculations for streambanks sites with 'as-built' structures in place are required
	Insufficient soil testing	Where only basic soil testing was completed on gully remediation sites with sodic and/or dispersive soils, vegetation re-establishment was poor or inconsistent, resulting in renewed erosion	Analysis of soil materials that will be exposed or used during site works to be conducted at a scale of 1:5,000 or less as described in McKenzie et al. (2008)
			Gully-specific amelioration, fertilisation, and plant selection and analyses, should consider issues of soil fertility, hostility to plant growth, and stability
	Accounting for future climate change	Increased severity and frequency of weather events impacted works	Future designs must consider the current and future predicted impacts of climate change
Implementation of works	Adherence to design	Small departures from designs of large restoration projects (>$250,000) resulted in increased potential failure in the short to medium term	A suitably qualified person to undertake audits at control points during construction for compliance with design specifications
Post-project maintenance	Planning maintenance to minimise risks for potential failure	All landscape remediation projects regardless of efficacy/season required maintenance	Maintenance should be included in restoration budget, and must be actioned early to mitigate failure
		Maintenance requirements identified early mitigated failure risks	Independent onsite review of post works completion is recommended
	Ongoing cattle exclusion	Cattle were detected inside exclusion fencing with detrimental effects on revegetation and earthworks observed at a majority of LRP sites	Delivery provider and landholder commitment to maintain fencing and cattle exclusion/management during and beyond the project end should be formalised through a written agreement
	Long-term commitment	Landscape restoration activities require considerable investment to achieve significant sediment load reduction outcomes	Before engaging in rehabilitation activities, the funding providers, delivery providers and landholders must be committed to long-term monitoring, management, and maintenance

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