Innovative Gully Remediation Project

FINAL PROJECT SYNTHESIS REPORT

Report prepared for Greening Australia Ltd and Queensland Department of Environment and Science

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Report prepared by Damon Telfer
Fruition Environmental Pty Ltd

This report has been written and compiled by Damon Telfer, FRUITION Environmental Pty Ltd, Townsville QLD.

E: office@fruitionenvironmental.com.au
M: 0419 882 984

The Innovative Gullies Remediation Program initiative has been funded by the Queensland Government and Greening Australia to identify more innovative and cost-effective gully remediation techniques.

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Acknowledgements

The Innovative Gully Remediation Project has been funded through the Queensland Government's Reef Water Quality Program and Greening Australia's Reef Aid program. Reef Aid receives donations from a number of Australian and overseas based philanthropic organisations and individuals and acknowledgement is given to those persons and organisations that support on-ground actions to control sediment and nutrient export to the Great Barrier Reef lagoon.

The project described within this document was undertaken on the traditional lands of the Juru people. Respects are paid to the Juru traditional custodians, their elders past, present and emerging.

The assessment of the project's cost-effectiveness was greatly assisted by the knowledge and expertise of the team led by Andrew Brooks of the Griffith University Centre for Coastal Management.

More than fifty locally based businesses have also supported the on-ground implementation of the Strathalbyn Station remediation works.

Thanks go to Fruition Environmental Pty Ltd for applying their expertise in developing and managing the on-ground implementation of the works program, installation of the water quality monitoring equipment, and to their team for the wet-season collection of water samples.

Particular thanks go to the construction crews, whose practical experience and tireless dedication to quality conservation earthworks facilitated the success of this program.

The landholders, the Hughes family and particularly Bristow and Uriesha Hughes, are gratefully acknowledged for their support in facilitating the implementation of such a vast remediation project on their property.

This report has been improved by incorporating the recommendations from technical and editorial reviewers, thanks to all those who provided valuable feedback.

Executive Summary

The Innovative Gully Remediation Project commenced in 2017 and was completed in late 2020. The overarching objective of the project was to develop cost-effective and scalable options for the reduction of sediment and particulate nutrient export to the Great Barrier Reef lagoon.

The $4 million project used a unique public / private funding model where 50% of the funding was provided by the Queensland Government and 50% was provided through Greening Australia's Reef Aid initiative. The funds provided through Reef Aid were sourced from philanthropic donations from individuals and corporations from around the world.

The project site was Strathalbyn Station, a beef cattle grazing enterprise located 45km north-west of Collinsville and 60km due south of Ayr, owned by the Hughes family as part of the Wentworth Cattle Company.

The site was selected in consultation with the property owners after being flagged as a potential trial site due to the number of large active gully systems on the property, many of which had been in existence for many decades.

Preliminary investigations by Griffith University revealed that the proposed target gullies had a baseline fine sediment yield of almost 8,000 tonnes per annum.

In consultation with land remediation experts, and under the guidance of the project steering committee, 17.41ha of direct gully remediation trials were implemented between November 2017 and August 2019. An additional 44ha of contributing gully catchment was also managed for groundcover retention. More than 50 local businesses were involved in the construction phase which included the establishment of an on-site quarry and multiple phases of earthworks and revegetation. The design and implementation of the remediation trials were overseen by Greening Australia in partnership with Damon Telfer of Fruition Environmental Pty Ltd.

The trials built upon recently completed smaller scale remediation trials on Cape York and elsewhere to assess which techniques were the most likely to be successful and cost-effective at scale.

Cost-effectiveness of each trial was measured through an intensive water sampling and landform analysis effort by Greening Australia, Fruition Environmental Pty Ltd and Griffith University, assisted by the National Environmental Science Program and Queensland Government's Office of the Great Barrier Reef. Data was collected to determine the net and percentage reduction in fine sediment and particulate nutrient export to the reef lagoon over the period 2017-2020.

The results revealed that large alluvial gullies in remote locations can be remediated very effectively. The average effectiveness of the 10 treatment trials implemented was 98%. This represents a remarkable achievement given that the site experienced its 6th wettest wet season in record (based on 120 years of rainfall data) when the majority of the works had been completed less than 6 months previously.

Through careful targeting of the works, it was possible to achieve a net annual fine sediment reduction of 4,428 tonnes (equivalent to approximately 370 truckloads per year) through remediation of just 51% of the target gully area. This represents a 92% reduction in the baseline annual fine sediment export to the reef from the treatment areas of the gullies.

The upfront cost for all treatments implemented was $2.37 million for an annual estimated fine sediment saving to the Great Barrier Reef lagoon of 4428 tonnes. This equates to an upfront investment of $536 per tonne. Using an expected lifespan of the project works of 25 years and a discount rate of 7%, the average cost-effectiveness, annualised in line with the CE_1 method, was $58 per tonne (2019 value).

The total maintenance costs for all years and all treatments were $34,214 (excluding materials costs). This figure represents 1.4% of the total on-ground works budget.

These outcomes are impressive and have demonstrated that the gully remediation techniques used in this project are capable of achieving immediate and sustaining large reductions in point source sediment and associated particulate nutrient export to the Great Barrier Reef lagoon. Given that large alluvial gullies are a major contributing source of fine sediments and nutrients, it is likely that treatments such as those demonstrated through this project will play an important role in achieving the Reef 2050 water quality targets.

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Introduction

This report is the final report of the Innovative Gully Remediation Project. The project commenced in 2017 and was completed in late 2020.

It presents a synthesis of the findings of almost four years of applied research aimed at assessing the cost-effectiveness of one of the largest gully remediation programs implemented in Queensland.

The report outlines the background to the project before documenting the processes and investigations undertaken to develop the program prior to the implementation phase. This has been presented to provide details on project setup which may be relevant to future large-scale gully remediation programs.

The remediation treatments are documented including the detail of which techniques and materials were used and where, with observations and data on the effectiveness of each treatment type presented. Again, it is hoped that this information is of some value to future programs.

Of particular significance, and the main objective of the project is the cost-effectiveness analyses. The report provides the necessary data and statistics to quantify the fine sediment and associated particulate nutrient reductions achieved in each treatment, and quantify the annualised cost per tonne of sediment abated. The methodology and assumptions used in this analysis are scientifically robust and have been externally reviewed from technical experts.

Where information is provided as a summary, the source of the data is identified and referenced in the report. Many of the referenced documents are available on the Greening Australia website (https://www.greeningaustralia.org.au/projects/rebuilding-eroding-land-2/) enabling the reader to seek out further detail if desired.

Lastly, this report serves as a wrap-up of what was an extremely ambitious and ultimately successful project.

Background

The Innovative Gully Remediation Project

The Innovative Gully Remediation Project was commenced in 2016 as a collaborative project supported by the Queensland Government's Reef Innovation Fund and Greening Australia's Reef Aid Program.

The purpose of the collaboration has been to develop cost-effective and scalable options for the reduction of sediment and associated particulate nutrient export to the Great Barrier Reef lagoon ecosystem from alluvial gullies in grazing landscapes. The program has been specifically focussed on trialling methodologies that can be replicated in or transferred to other areas of the Burdekin and within other Great Barrier Reef catchments.

The project site is located at Strathalbyn Station, 45km north-west of Collinsville and 60km due south of Ayr, located in the Burdekin-below-dam catchment on the eastern bank of the Burdekin River (*Figure 1*) in the North Queensland Dy Tropics region. The property is owned by the Hughes family and the Wentworth Cattle Company.

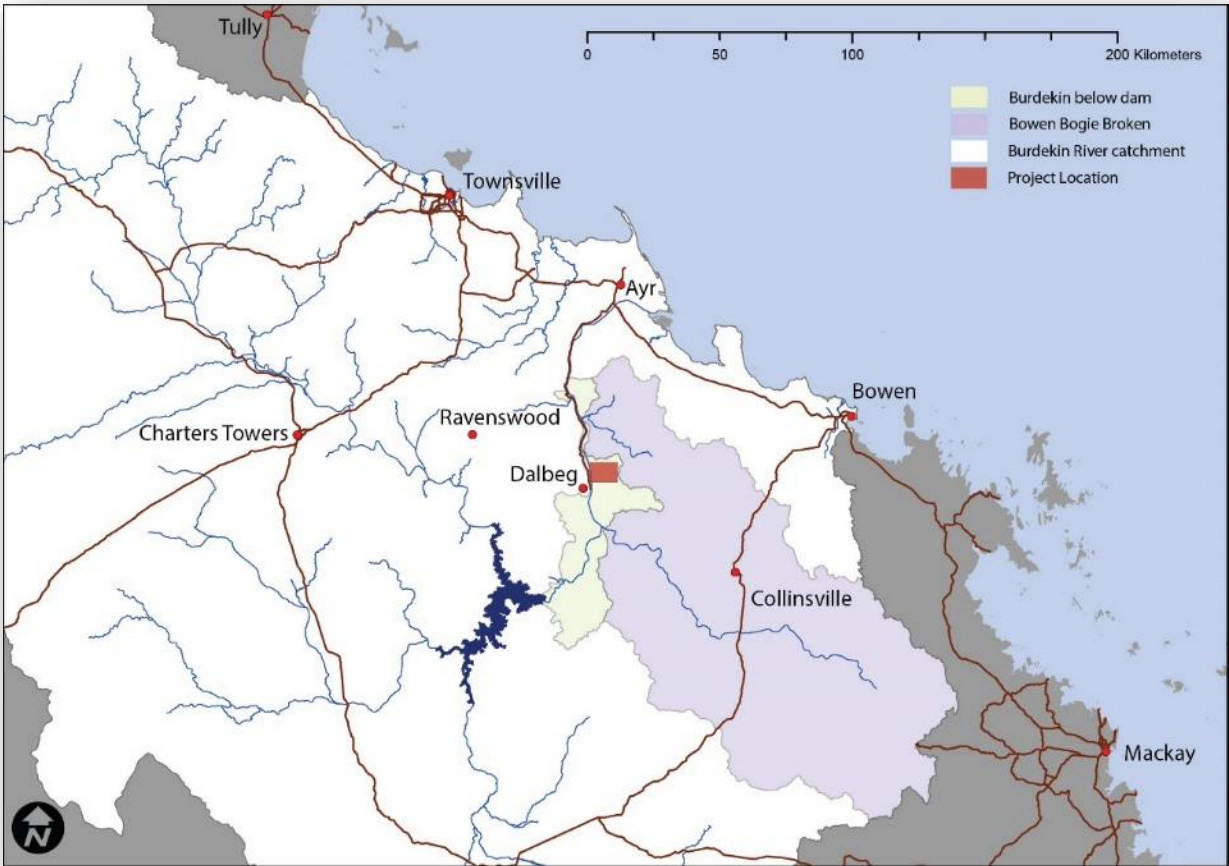

Figure 1 Strathalbyn Station, the site of gully stabilisation trials implemented under the Innovative Gully Remediation Project.

The Collaborative Agreement

The collaborative agreement between Greening Australia Ltd and the Queensland Government was the key document guiding the delivery of the project. The document contained the governance arrangements for the project, the objectives and milestones to be achieved, the project timelines, and the funding arrangements.

The agreement established a project steering committee which consisted of representatives of the two parties to the agreement and other key project contributors as required. The steering group met quarterly to assess the project's progress against the project's milestones and to make decisions on the project's implementation as required.

Regular steering group meetings ensured that there was continuous interaction between the project sponsors and implementors as the project was developed and delivered. This contributed strongly to the project's success as well as ensuring a shared understanding of the technical and logistical issues associated with delivering large scale gully remediation projects.

The total funding for the project was four million dollars ($4M), half of which was provided through the Queensland Government's Reef Innovation Fund and half which was raised through Greening Australia's Reef Aid program via private donations.

Project Objectives and Milestones

The Innovative Gully Remediation Project collaborative agreement set out seven objectives for the program:

1. To trial different techniques for gully remediation on at least 5 treatment sites (across 150ha) to deliver more cost-effective solutions that can be applied across regions.
2. Trial innovative monitoring techniques to determine reduction of sediment and particulate nutrient loads to the Great Barrier Reef and the costs of achieving those reductions based on different interventions.
3. Harness innovative ideas and facilitate cross boundary interaction and fresh thinking to tackle the challenge of gully erosion.
4. Engage innovative individuals and organisations with a history of success but not necessarily in the Reef catchments and industries to borrow learnings and successes from other fields.
5. Engage with scientists and remediation experts to ensure the project builds upon the latest scientific understanding.
6. Build upon and integrate with existing and new gully remediation projects being delivered by Queensland and Australian governments and other partner organisations.
7. Communicate the outcomes of the trials broadly, particularly in Reef catchments, to ensure broad uptake of best practice gully remediation techniques.

Sixteen Milestones were also documented in the collaborative agreement. These are outlined in *Table 1*.

Background

Table 1 Innovative Gully Remediation Project milestones from the collaborative agreement

No.	Milestone	Milestone date
1	Hold forum to explore innovative remediation techniques	28 February 2017
2	Agree on remediation techniques to be trialled in consultation with the Sediment Working Group	15 March 2017
3	Produce a work program for the Project	30 March 2017
4	Produce a communication and engagement strategy	30 March 2017
5	Agree on sites and landholder agreements for trials	30 March 2017
6	Agreed monitoring and evaluation plan in place	1 May 2017***
7	Agreed economic evaluation plan in place	1 July 2017***
8	Undertake fine scale mapping and gully classification/prioritisation	1 March 2017
9	Agree on site plans and delivery arrangements, including options for traditional owner engagement and native seed production	1 June 2017
10	Commence trials and monitoring on 150ha with at least 5 treatment sites	1 July 2017
11	Provide advice to Great Barrier Reef Foundation (GBRF) on establishing a complimentary demonstration site on Cape York	March 2018
12	Ongoing communication of outcomes from Project, including visualisations, videos, demonstration days, etc	Six-monthly commencing March 2018 until June 2020
13	Assess the opportunities for innovative financing for future remediation	1 June 2018
14	Synthesise initial outcomes and develop draft best practice guide to innovative gully remediation techniques in consultation with the Sediment Working Group	December 2019***
15	Produce an economic report on the cost effectiveness of different techniques in reducing sediment runoff	December 2019***
16	Synthesise final outcomes of the Project	31 August 2020***
*** The collaborator should also seek peer reviews on draft reports and products in consultation with the Department		

This report addresses Milestone 16 of the collaborative agreement and has been compiled to bring together the project results and learnings to assist future programs going forward.

Key Evaluation Questions

In essence the project objectives focus on four main evaluation criteria: measured sediment reduction, measured treatment effectiveness, calculated treatment cost effectiveness over the Project's trial sites, and level of project collaboration.

These criteria have formed the Key Evaluation Questions for the project which are:

- What are the measurable reductions in fine sediment export (measured in tonnes of sub-20µm particles delivered to the Great Barrier Reef lagoon) from treatment gullies compared to baseline measured sediment export rates and/or the control gully sites.
- Which treatment options or combinations are the most effective in reducing the export of sub-20µm particles from treatment sites.
- Which treatment options are the most cost-effective in terms of $ cost per tonne of sub-20µm delivered to the GBR lagoon.
- How have the methodologies used, including new and emerging monitoring and evaluation techniques and equipment, improved our understanding of how to treat alluvial gully systems and monitor those treatment's effectiveness and cost efficiency in reducing sediment export.

The structure of this report reflects these key questions and much of the material presented herein is framed in the context of answering these questions.

Project Collaborations and Linkages

The project has relied on a great number of contributing partners including the landholders, land remediation experts, contractors, QLD government departments, research institutions, and local small businesses to bring the program to fruition.

Outside the Department of Environment and Sciences Office of the Great Barrier Reef and Greening Australia, the following collaborations assisted greatly in the delivery of the program:

- The National Environmental Science Program's 3.1.7 project coordinated by Griffith University
- Expert land remediation advice and on-ground project delivery and monitoring support by Fruition Environmental Pty Ltd
- Informal advice from QLD Department of Environment and Science (DES) Water Quality & Investigations and CSIRO Land and Water with respect to monitoring equipment setup
- Soil analyses and field support from QLD DES Soil and Land Resources, Science Division and specifically Peter Zund

Development of the Remediation Trials

Milestone 5

Agree on sites and landholder agreements for trials

The agreement to proceed with the remediation trials at Strathalbyn Station was finalised in September 2017 with the signing of the landholder agreement. This was the culmination of almost 10 months of potential site investigations, site assessments and landholder consultation. A broad outline of the project development activities is presented in *Table 2*.

Table 2 Summary of project development activities undertaken in the first year of the Innovative Gully Remediation Project

	Description	When undertaken
Collaborative Agreement	The agreement documenting the project objectives, milestones and responsibilities between Greening Australia and QLD Office of the Great Barrier Reef	October 2016
Site selection process	Assessment of 24 potential project sites against documented criteria	November 2016 – September 2017
Landholder engagement	Discussions and site visits at proposed sites	October 2016 – September 2017
Investigations of logistics, resources and access	Desktop assessments, landholder consultation, and site investigations	March 2017 – August 2017
Steering group meetings	Between the project co-funders, project managers and remediation experts as required	Quarterly from January 2017
Landholder agreement	Between the Hughes family at Strathalbyn Station and Greening Australia	September 2017
Co-funding updates	From the Greening Australia Reef Aid program to the steering group	Steering group meetings
Resource development	Development of the on-site quarry at Strathalbyn Station to provide materials for the remediation trials	September 2017
Preliminary Site Investigations	Preliminary analyses of soils, gully processes, and estimated sediment yields	December 2016 - May 2017

Project Site Selection

The selection of the Strathalbyn Station northern gully complex as the project site for the Innovative Gully Remediation Project trials was the end result of a multi-stage process undertaken by Greening Australia in close collaboration with the Queensland Department Environment and Science, Office of the Great Barrier Reef, Queensland Department of Agriculture and Fisheries, NRM bodies and key researchers (Greening Australia, 2016).

Twenty-four properties were assessed against a set of selection criteria which gave priority to properties based upon:

1. property tenure,
2. occurrence of gully erosion,
3. willingness of the landholder to be involved and to allow access
4. whether existing projects were already being undertaken at the potential project sites
5. degree of remoteness and difficulty of access
6. size and type of the gully complex and its suitability for remediation

A breakdown of the set of assessment criteria utilised is outlined in *Table 3*.

Table 3 Site selection criteria considered during the assessment of potential project locations for the Innovative Gully Remediation Project

	Criteria
Location/Gully Characteristics	Discrete (within a smaller subcatchment) of the Lower Burdekin catchment
	Accessible (for logistic purposes)
	Representative of broader GBR gully erosion issues (for replicability and scaling considerations)
	Tenure
	Manageable (ie. not over multiple areas or properties)
Strategy/Approach	Delivers positive outcomes aligned to Reef 2050 targets/Great Barrier Reef Water Science Taskforce 2016
	Leverage: building on other projects successes/learnings
	Measurable impact/outcomes
	Multiple environmental benefits (water quality/biodiversity/productivity)
	Potential for site to respond rapidly to treatments/interventions
Time	Achievable within project timeframe
	Quick start up time
	Has longevity/legacy post project completion
Financial	Cost-effective/value for money
	Focussed activities on proven interventions
	Achievable within budget
Stakeholders	Engaged/supportive landholders
	Local interest/support
	Aligned with NRM priorities/ other projects
	Aligned with other QLD government projects
	Positive existing NRM-landholder relationship/engagement
Communications	Suitable for case studies
	Adds to scientific knowledge
	Promotable (tells a good story)

Development of the Remediation Trials

Landholder Engagement and Agreement

Strathalbyn Station has been owned by the Wentworth Cattle Company and the Hughes family since 2006. The property is run by Bristow and Uriesha Hughes.

Discussions between Greening Australia and the Hughes family commenced in late 2016 and progressed until mid-2017. The Hughes family has been particularly interested in the sustainable and holistic management of their grazing enterprise and were from the out start open to finding a solution to the gully erosion issues occurring on the property. The family was already engaged in NRM programs through the Department of Agriculture and Fisheries (DAF) and NQ Dry Tropics and there had been some attempts to stabilise gullies in the north of the property through a Paddock to Reef program and through their own private efforts around road infrastructure.

An agreement to proceed with remediation trials on terms suitable to all parties was reached in September 2017. The agreement was put in place for the life of the project (August 2020) and covered access arrangements, project responsibilities, worker accommodation facilities, and other practical matters.

Investigation of Logistical Factors

Logistical factors that affect large scale remediation works that were investigated as a part of the trial development phase included:

- site access for machinery, equipment, and materials
- worker accommodation,
- availability of materials for treatments
- requirements around existing land use (in this case, related to a cattle grazing enterprise)
- workplace health and safety.

As a result, the following actions were identified as requirements prior to the commencement of the trials:

- Access arrangements were to be negotiated to ensure impacts to existing property roads were minimised and roads and tracks were returned to their pre-works state prior to each wet season
- A site office and container storage would be required for the duration of the works to assist with WHS requirements and materials and equipment storage
- Workers accommodation was to be located on-site for the duration of the works, leased from the landholder
- Due to the scale of the trials, and to reduce cartage costs and impacts to public and private road infrastructure, an on-farm quarry should be established prior to the commencement of works to ensure a cost-effective supply of materials for the treatments

Suitability for Treatment Trials

The intention for the project was to utilise a Before After Control Impact (BACI) design, in part informed by previous trial programs undertaken under the National Environmental Science Programme (NESP) and Reef Trust programs.

Early investigations into the proposed Strathalbyn site indicated that although the gullies appeared to represent a set of highly comparable gullies (for experimental purposes), closer analysis indicated that there was considerable complexity and variability within individual gullies, let alone between gullies. It was not practically possible to have a control gully for every treatment gully, however the variability in gully processes, soil types and sediment export yields provided an opportunity for tailoring remediation designs and establishing a variety of treatment types and repetitions.

A partial BACI study design was eventually selected, in which a single untreated control gully would be monitored for the life of the project and the treated gullies monitored to provide baseline data where possible, with comparison to the control gully for trends available at the end of the project.

Project Work Plan

Once the site was selected a project work plan was produced that set out how the project's objectives and milestones were to be achieved in accordance with the timeframes documented in the collaborative agreement.

The work plan was developed by Greening Australia and approved by the Project steering Committee in March 2017.

The cashflow and co-funding timetable within the collaborative agreement had some impact on the on-going delivery of works and it was necessary to structure the work plan accordingly. As a consequence, the implementation of on-ground treatments was split into three phases covering the 2017, 2018 and early 2019 North Queensland dry seasons.

Milestone 3

Produce a work plan for the project

Milestone 8

Undertake fine scale mapping and gully classification/prioritisation

Preliminary Site Investigations

To an extent, the preliminary site investigations at Strathalbyn Station had commenced prior to the site being ratified as the agreed trial site for the Innovative Gully Remediation Program by the Project Steering Committee. This was to assist with the site selection process. Additionally, the engagement with the landholder necessitated some level of understanding of the gully erosion issues at the site and the level of interest in addressing them before more detailed investigations ensued.

Once the Strathalbyn site was ratified by the Steering Group and agreed to by the Hughes family, further investigations were undertaken. Between November 2016 and May 2017 investigations focussed on undertaking gully mapping and classification over the proposed project area (see *Figure 2*), defining landscape scale factors and processes that influence gully erosion (soils, vegetation, landuse), estimating historical sediment export rates, and the collection of basic water flow data using water level loggers, rain gauging and time lapse photography. The results of these investigations are reported in the *Preliminary Assessment of Alluvial Gully Systems on Strathalbyn Station* document (Brooks et al., 2017).

The preliminary site investigation phase of the project was essential to determining the initial priorities for the gully remediation trials.

Primary Datasets

To a large extent the datasets collected reflected the lessons learnt from the gully remediation trials undertaken by Cape York NRM and Griffith University and reported in Brooks et al. (2016a).

The primary datasets included:

- historical air photo analyses
- LiDAR data over the Strathalbyn Station property which allowed the accurate mapping of the gully systems and assisted the baseline assessment of erosion rates
- a classification of gully type based on morphology and process
- detailed soil sample analyses
- vegetation functional groups and groundcover
- land condition assessments and land use
- local rainfall and gully flow characteristics
- regulations and approval processes that may affect the works
- cultural heritage considerations

A summary of key information derived from these datasets is provided below.

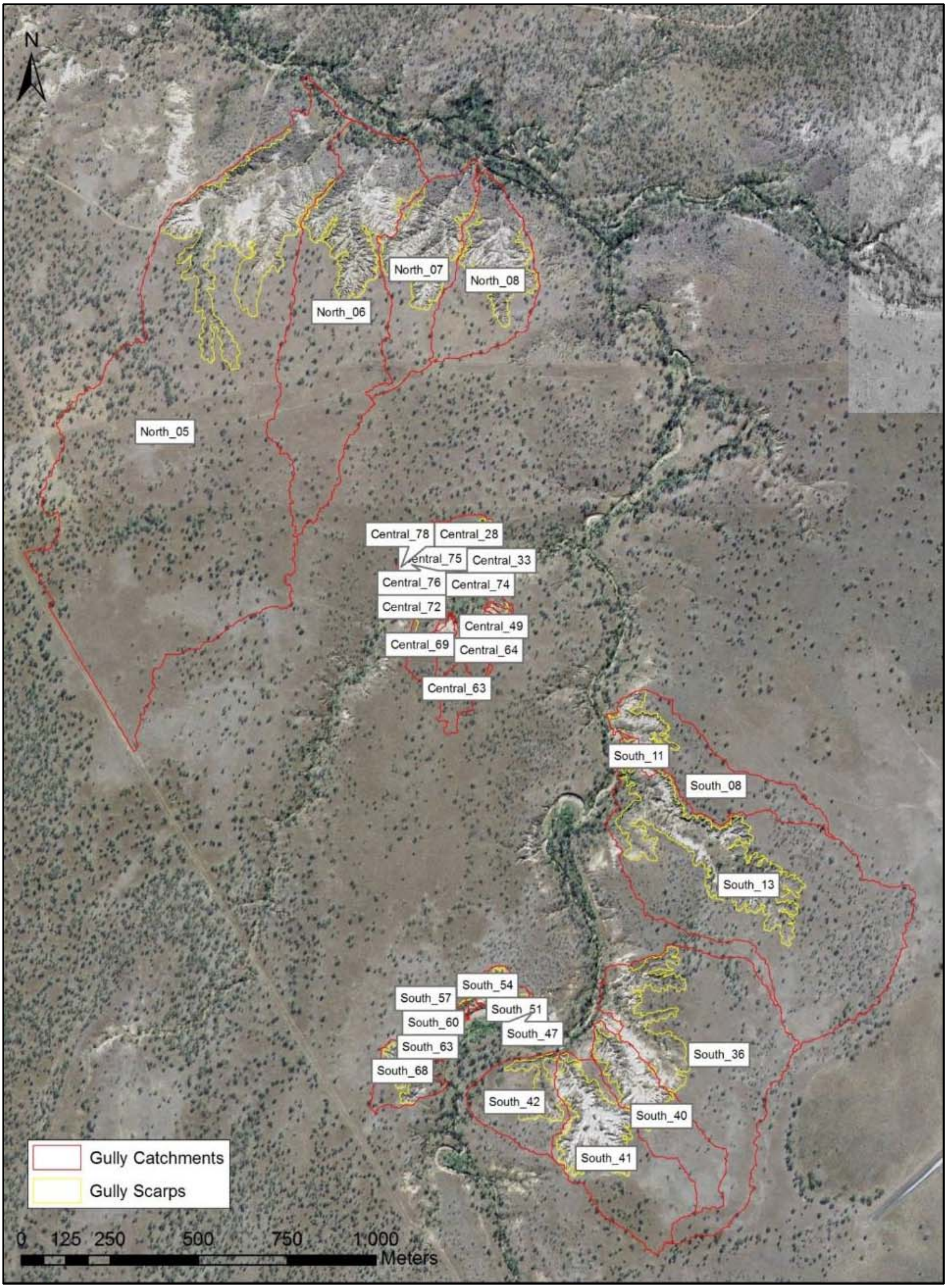

Figure 2 Area of preliminary site investigations undertaken to facilitate prioritisation of gullies for remediation under the Innovative Gully Remediation Project (Source: Brooks et al., 2017).

Gully evolution 1945-2016

The temporal analyses of historical aerial photography revealed the extent of gully expansion over the analysis period, 1945-2016 (*Figure 3*).

Also revealed was the effect of soil type on gully morphology. Specifically, the lower reaches of each gully outlet (which were bounded by more recent and erosion resilient alluvial sediments from the local catchment) were significantly less prone to gully expansion compared to areas of gully that had expanded into older terrace materials with highly sodic sub-soils.

This information was used to prioritise which gully lobes were targeted for intensive treatment in the subsequent trials and also how much of each gully required treatment to significantly reduce fine sediment export.

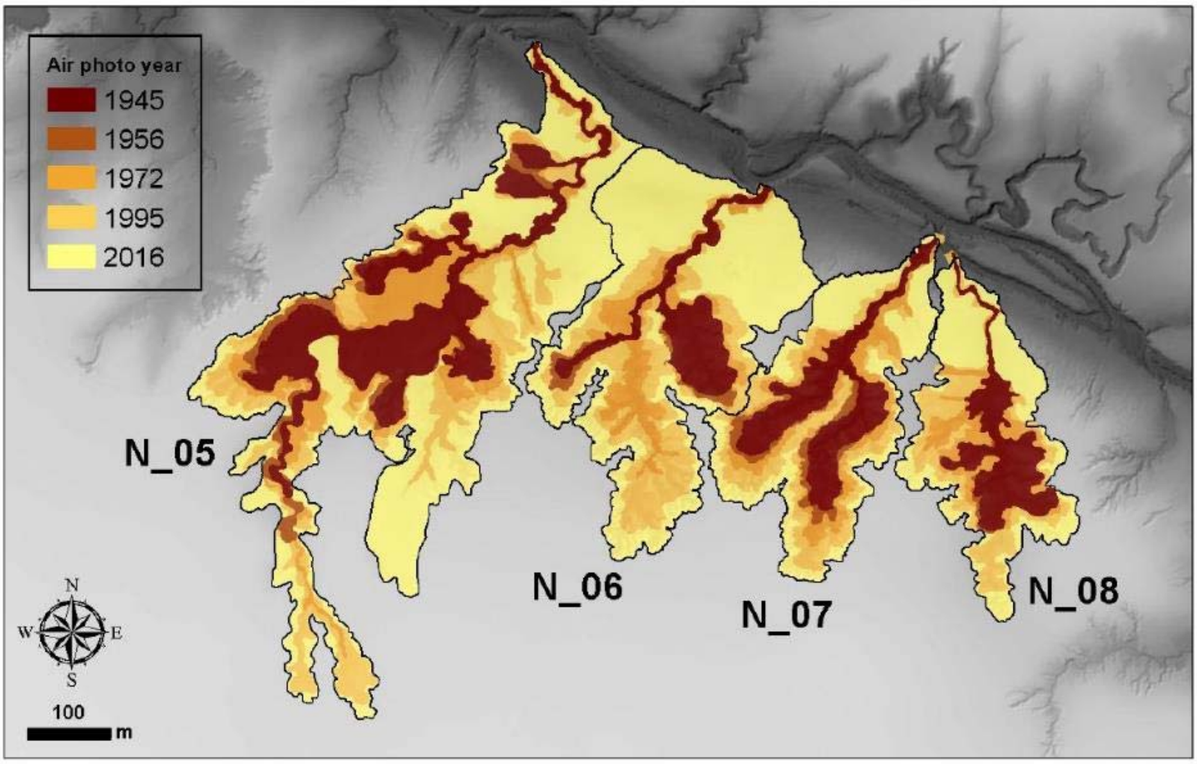

Figure 3 Gully growth progression as mapped from historical air photos (Source: Brooks et al, 2017)

Baseline assessment of erosion rates

Brooks et al. (2017) estimated historical sediment yield from gully complexes within the project area. This initial estimate was calculated based upon a modelled difference in digital elevation data by estimating the volume of sediment exported at selected time points guided by the availability of historical aerial photography series, and extrapolating remnant and relic surfaces identified in the field and in the LiDAR dataset (Brooks et al., 2017). The difference between time series in m^3 was then converted to tonnes (using bulk density estimates derived from soil testing) and the yearly rate of export per hectare determined (see *Figure 4*).

Net fine sediment yield ranged from 176 to 370 tonnes per hectare per year with a total estimated annual export of some 7,700 tonnes per year. The total estimated volume of erosion from the 4 target gullies between 1945 and 2016 was estimated at 322,249 m^3.

This showed that the Northern Gully complex, when compared to sediment yields derived from multitemporal LiDAR analyses over other gullies in the project area, contained a cluster of the highest fine sediment yielding gullies within the project area.

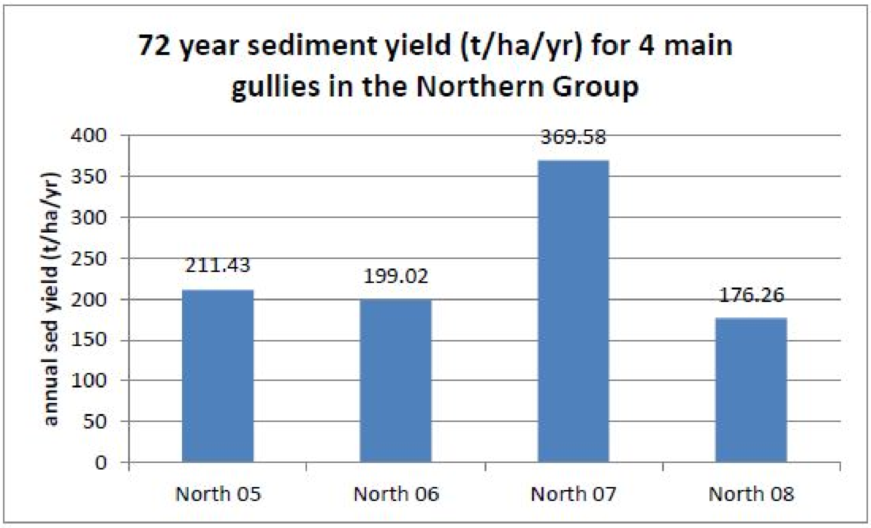

Figure 4 Initial estimates of per unit area sediment yields from the Northern gully complex on Strathalbyn Station between 1945-2016 (Source: Brooks et al, 2017)

This confirmed the Northern Gully complex as the highest priority for remediation and enabled subsequent investigations relating to logistics, resourcing, treatment options, and trial design to proceed in a more focussed effort.

Soils baseline data

Soil samples collected during the preliminary investigations were fundamental to the assessment of the erosion processes on the site. Assistance provided through the NESP 3.1.7 project and the Queensland Government's Office of the Great Barrier Reef allowed considerably more soil samples to be taken than would generally occur in a land remediation project (74 from within the project area).

The information gained from the soil sample analyses revealed that the soils within the targeted gullies exhibited high to very high sodicity, high dispersibility, were slaking, and contained very high percentages of fine sediments (averaging 72.5% less than 20 µm). Topsoils, where occurring, were also dispersive but depending upon soil type may be useful for remediation if treated with gypsum and organic matter to reduce dispersion and fertiliser and organic matter to improve fertility. Consequently, there was a need to find appropriate materials for the remediation program from other sources if capping of regraded batters was to be a technique utilised in the trials.

The analyses of samples within the proposed treatment area were particularly useful for determining levels of various soil ameliorants required under the remediation program.

Site vegetation and land condition

Baseline vegetation assessments were conducted in September 2017 by Greening Australia Ltd. Ground cover, slope angle, surface condition and relative dominance of functional groups were measured due to their relationship with erosion, and so their responses to gully remediation could be tracked over time.

The baseline study showed ground cover to be very poor with only one gully catchment having ground cover over 70%, the minimum recommended ground cover to control detrimental impacts of erosion (Land & Macdonald, 2005). All other gullies had far below the recommended quantity of ground cover and were therefore vulnerable to erosion. The most common surface category identified during the baseline study was “Eroding”, indicating gully instability and sediment output. This identified the need to significantly increase vegetative land cover in the gully systems at Strathalbyn as an erosion prevention tool. Further details on the baseline studies and impacts of gully remediation on surface category can be found in the *Innovative Gullies Remediation Project - Vegetation Monitoring Report 2021* (Greening Australia, 2021).

A negative correlation between ground cover and slope angle was identified. The low ground cover on steeper slopes highlighted the need for reduced slope angles to allow for erosion control through the establishment of vegetation and stabilizing root systems.

There was poor functional group diversity with exotic perennials representing over 85% of vegetative ground cover. No other functional groups, such as annual natives, native and exotic forbes and native legumes, were present by more than 5% across all sites. This lack of functional group diversity identifies the need to increase the dominance and variety of native functional groups to achieve greater biodiversity and landscape resilience.

The findings from the study including overall poor ground cover, unstable and eroding surfaces, steep, unvegetated slopes and a lack of functional group diversity provide the baseline from which to compare future monitoring of these variables. It also identified priority goals for the Gully Remediation project at Strathalbyn as increasing ground cover, increasing diversity and proportional shifts in functional groups, decreasing prevalence of unstable surfaces, and decreasing slope angles, as this will enhance gully stability and greatly reduce erosion rates.

Regulations and approvals processes

A number of actions were required to ensure that the treatment trials were undertaken in compliance with Queensland Government legislation and regulations. The primary requirements were under the Queensland Vegetation Management Act 1999 (VMA).

As all areas proposed for remediation in the northern gully complex area were classified as Category X under the VMA, they were therefore not subject to regulation. However, areas of the lower sections of the gullies within 50m of Bonnie Doon Creek were classified as Category R and consequently remediation work in these areas were avoided.

A further search was required to investigate the requirements of the VMA in relation to the potential on-farm quarry which was being investigated as a possible source of remediation materials. In this regard, the Extractive Industry Clearing Code was used, and the Department Natural Resources and Mines was notified of an area of approximately 2ha of Category B to be cleared for development of an on-farm quarry.

Under the Forestry Act 1959 (QLD), the use of Queensland Government-owned quarry materials is permitted provided the material is used on the same lease land parcel from which it is sourced and the material is not sold. As the area proposed for both the on-farm quarry and the remediation trials were on the same parcel, the proposed quarry complied with the Act.

Cultural Heritage

Given that the remediation works were likely to involve excavation and significant disturbance of the land surface (despite the area already having been subject to Significant Ground Disturbance), in accordance with the Queensland Government's Duty of Care Guidelines (2004), a search of the Aboriginal Cultural Heritage Database and Register was undertaken. The search revealed no records of Aboriginal cultural heritage within the project area.

Nevertheless, in accordance with the guidelines, protocols were put in place for the management of any cultural heritage finds should any occur during construction or related activities.

Milestone 1

Hold forum to explore innovative remediation techniques


Greening Australia and Department of Environment and Science
Innovative Gully Remediation Project
Forum Outcomes Report
March 2018

Milestone 2

Agreement of techniques to be trialled

Milestone 9

Agree on site plans and delivery arrangements, including options for traditional owner engagement and native seed production

Review of Gully Remediation Techniques

Gully erosion has been a long-term soil degradation and water quality issue in many of the northern Great Barrier Reef catchments. Research into the sources of fine sediments has revealed that up to 90% of all fine sediments reaching the reef lagoon are from eroded subsoils associated with gully erosion (Wilkinson et al., 2013). This had led to an increasing focus on how to tackle these sources of sediment.

In this context, the Innovative Gully Remediation Program commenced at a time when several trials specifically targeting alluvial gully erosion were nearing their completion or being evaluated. Additionally, the focus on determining the most appropriate methods for remediation of eroding gullies was being facilitated by a number of government sponsored funding programs (eg. Reef Trust and the National Environmental Science Program) and research institutions including CSIRO and Griffith University.

The starting point for many of the techniques investigated and trialled in these programs have been in some respects industry-standard approaches to soil conservation and erosion control which have been practiced for many years.

The challenge for the Innovative Gully Remediation Program has been how to develop erosion mitigation strategies and gully remediation techniques which address the underlying causes of alluvial gully erosion, which are appropriate to rangeland grazing enterprises, and that can be replicated at a scale which matches the targets of the Reef 2050 plan.

To ensure that the Innovative Gully Remediation Program furthered the contemporary understanding of alluvial gully remediation techniques, a review of recently completed research and trials was undertaken. These included a review of:

- the Soil Conservation Guidelines for Queensland (Carey et al., 2015)
- the gully slope stabilisation treatment trials documented in Shellberg and Brooks (2013) and updated in Brooks et al (2016)
- the summary document covering the alluvial gully systems erosion control and rehabilitation workshop held in Collinsville in August 2016 (Brooks et al., 2016b)

Additionally, a Gully Remediation Forum was convened in 2017 to bring together researchers and experts in landscape remediation to discuss approaches used in other disciplines and industries (eg. mine site remediation approaches, sodic soil amelioration) and explore potential innovative techniques which may have relevance to alluvial gully remediation.

Gully Remediation Forum 2017

As part of the review of techniques relevant to alluvial gully remediation, a gully remediation forum was held in Townsville in May 2017. Eighteen (18) people attended the forum, representing a broad spectrum of remediation/rehabilitation practitioners, research scientists, project coordinators, and government stakeholders (*Plate 1*).

The forum used the joint Greening Australia/QLD government alluvial gully remediation trial site at Strathalbyn Station as a focal point for discussions. However, it was not an objective of the forum to resolve the specific issues of gully erosion on Strathalbyn per se. Rather, it provided an opportunity to share information and past experiences relevant to alluvial gully remediation generally in the context of an actual remediation site which had the benefit of significant background information and data.

The key concepts, points of discussion, preliminary learnings and subsequent responses to the forum are documented in the Innovative Gully Remediation Project "Forum Outcomes Report" document.

A summary of the forum outcomes and the actions adopted after the forum are provided in *Communique 1 – The Innovative Gully Remediation Forum Outcomes* at https://www.greeningaustralia.org.au/wp-content/uploads/2018/04/Communique-One-new.pdf

Plate 1 Participants of the Innovative Gully Remediation Forum in Townsville

Remediation Technique Selection

Following the review of remediation techniques and the forum, a program of potential remediation treatments for trialling under the project was developed and reviewed by the project steering committee.

The factors influencing the potential treatment options included:

- availability of resources for use in the treatment works (eg. quarry rock, topsoil, mulches, water supply etc)
- implications of the above to the project budget
- desire to trial treatments not yet trialled at whole of gully scale
- potential to be successful, given previous remediation experience and demonstrations/trials
- likely potential to be cost-effective
- desire to test some treatments that are less intensive in terms of resource requirements but which are still likely to have acceptable levels of long-term success
- requirement to meet the project's objective of trialling innovative solutions
- requirement of meeting the project's objective of having at least 5 treatment types

The material resource requirements for a project the scale of the proposed trials was a significant practical, logistical and budgetary consideration.

In July 2017, after a thorough investigation of the above factors and consultation with the landholder, the Steering Committee agreed to commence the trials utilising an on-farm quarry resource which was capable of providing sufficient quarry materials to complete the remediation trial.

The Remediation Treatments

The Innovative Gully Remediation Project on-ground works program commenced in October 2017 after 11 months of project planning and setup. The program was implemented over the period September 2017 to July 2019, in three phases aligned to the North Queensland dry season.

In summary, the project has resulted in 17.41 ha of direct gully remediation treatments over 10 trial sites with an additional forty-four hectares (44 ha) of surrounding grazing area fenced and managed by the landholders in accordance with regenerative holistic grazing principles.

The range of treatments and the implementation timetable are detailed in the *Strathalbyn Station Gully Remediation Works Update, July 2019* (Telfer, 2019). The information in that report is updated and summarised here, along with information on the project's approach to treatment design and factors influencing implementation for individual treatments.

Milestone 10

Commence trials and monitoring on 150ha with at least 5 treatment sites

Gully Remediation Design Approach

The type and scale of works required to successfully remediate large-scale gullies in remote locations, and costs associated with these styles of works, necessitates a considerable preconstruction effort to determine the nature and specifications of each component of the works.

The design process must carefully consider the most efficient end landform not just in terms of soil conservation and land remediation principles, but also in terms of available on-site resources, access, earthworks efficiencies, the existing land use, and other practicalities.

This project relied on experts in soil conservation and land remediation for treatment design, civil designers and surveyors for determining earthworks quantities, and experienced earthworks contractors for nuancing the design approaches on the ground.

The following factors are considered important considerations:

- using the best available landform data to allow accurate modelling of surface features and earthworks quantities
- balancing the cut-fill ratio of earthworks to reduce the need to import/export materials
- managing flow concentration by careful consideration of the end landform and installing flow dissipation structures where design can not eliminate flow concentration down batters or within the channel
- careful retention of topsoils and native vegetation wherever possible
- designing critical structures to a minimum average exceedance probability (AEP) of 5%, considered appropriate for agricultural settings with no threat to infrastructure or life

Treatments Implemented under the Trials

As discussed previously, the considerable variability in the character and sediment yields both between gullies and within gullies both complicates and provides opportunities for trialling alternative approaches to remediating large alluvial gully systems.

Ten (10) treatments were implemented within the project area over the period September 2017 through to July 2019, involving three phases of works. Table 4 shows the implementation timetable (including maintenance works undertaken) with Figures 5- 8 showing the location and summary of the treatments implemented in each implementation year. Table 5 provides a comparison of each treatment implemented over the project. *Plate 2* shows an example of the remediation works and different treatments undertaken in 2018.

Table 4 Completion dates of on-ground works activities under the Innovative Gully Remediation Program at Strathalbyn (Telfer, 2019)

	2017				2018								2019			2020
	September	October	November	December	May	June	July	August	September	October	November	December	May	June	July	August
Quarry development	■	■														
Treatment 1		■	■	■												
Treatment 1 maintenance works															■	
Treatment 2							■	■								
Treatment 2 maintenance															■	■
Treatment 3						■	■									
Treatment 3 maintenance works															■	
Treatment 4					■	■										
Treatment 4 maintenance works															■	■
Treatment 3-4 Extension Area							■									
Treatment 3-4 Extension maintenance												■			■	■
Treatment 5 Diversion bund & rock chute			■													
Treatment 5 maintenance															■	
Treatment 6													■	■	■	
Treatment 6 Diversion bunds & rock chute														■	■	
Treatment 6 maintenance																■
Treatment 7								■	■							
Treatment 8									■	■						
Treatment 8 maintenance works															■	
Treatment 8b										■						
Project site stock management fencing												■				
Control Gully Remediated under subsequent GBRF project												■				■
				End 2017 Works								End 2018 Works			End 2019 Works	End 2020 Works

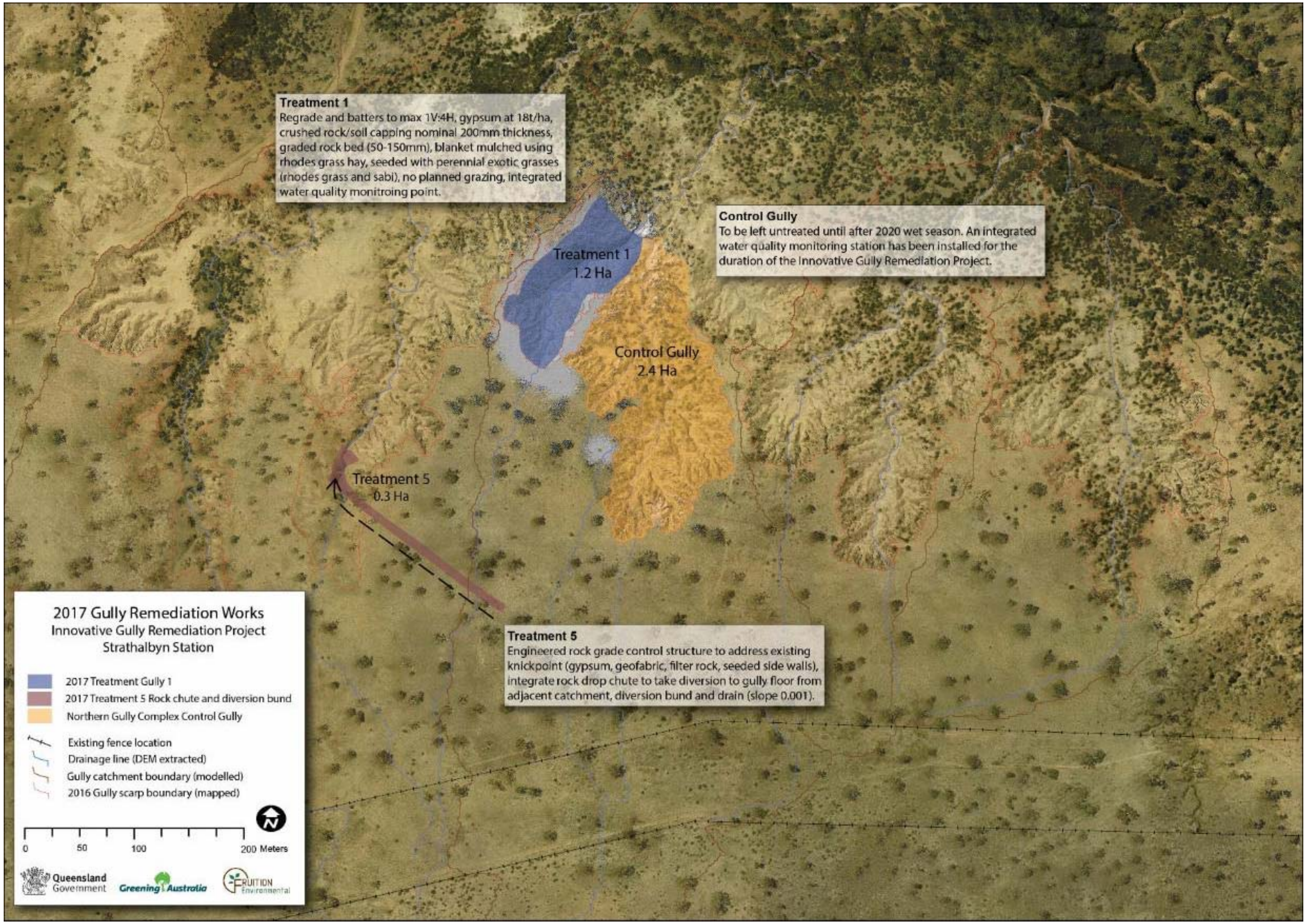

Figure 5 Overview of remediation treatments implemented in 2017 under the Innovative Gully Remediation Project.

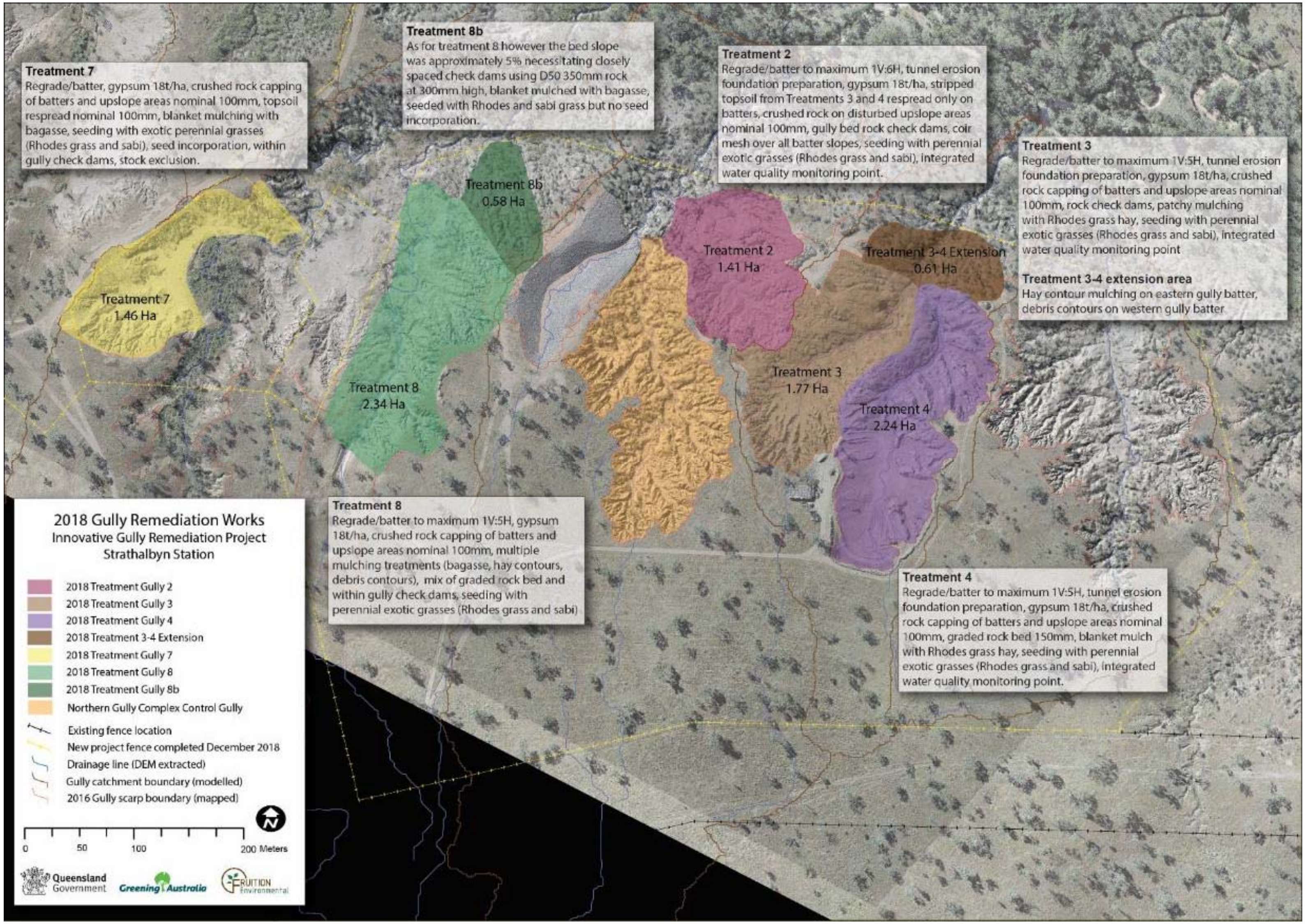

Figure 6 Overview of remediation treatments implemented in 2018 under the Innovative Gully Remediation Project.

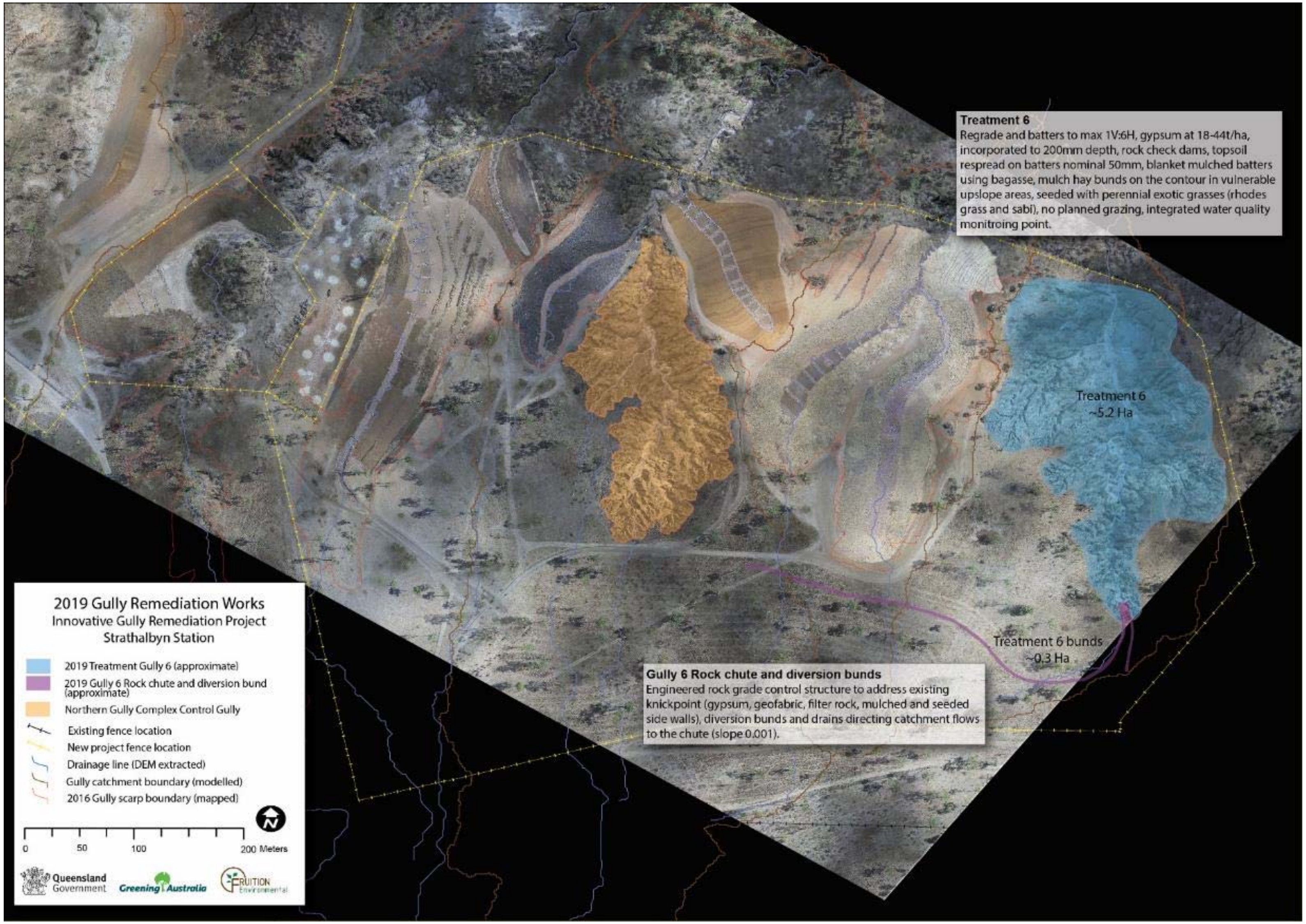

Figure 7 Overview of remediation treatments implemented in 2019 under the Innovative Gully Remediation Project.

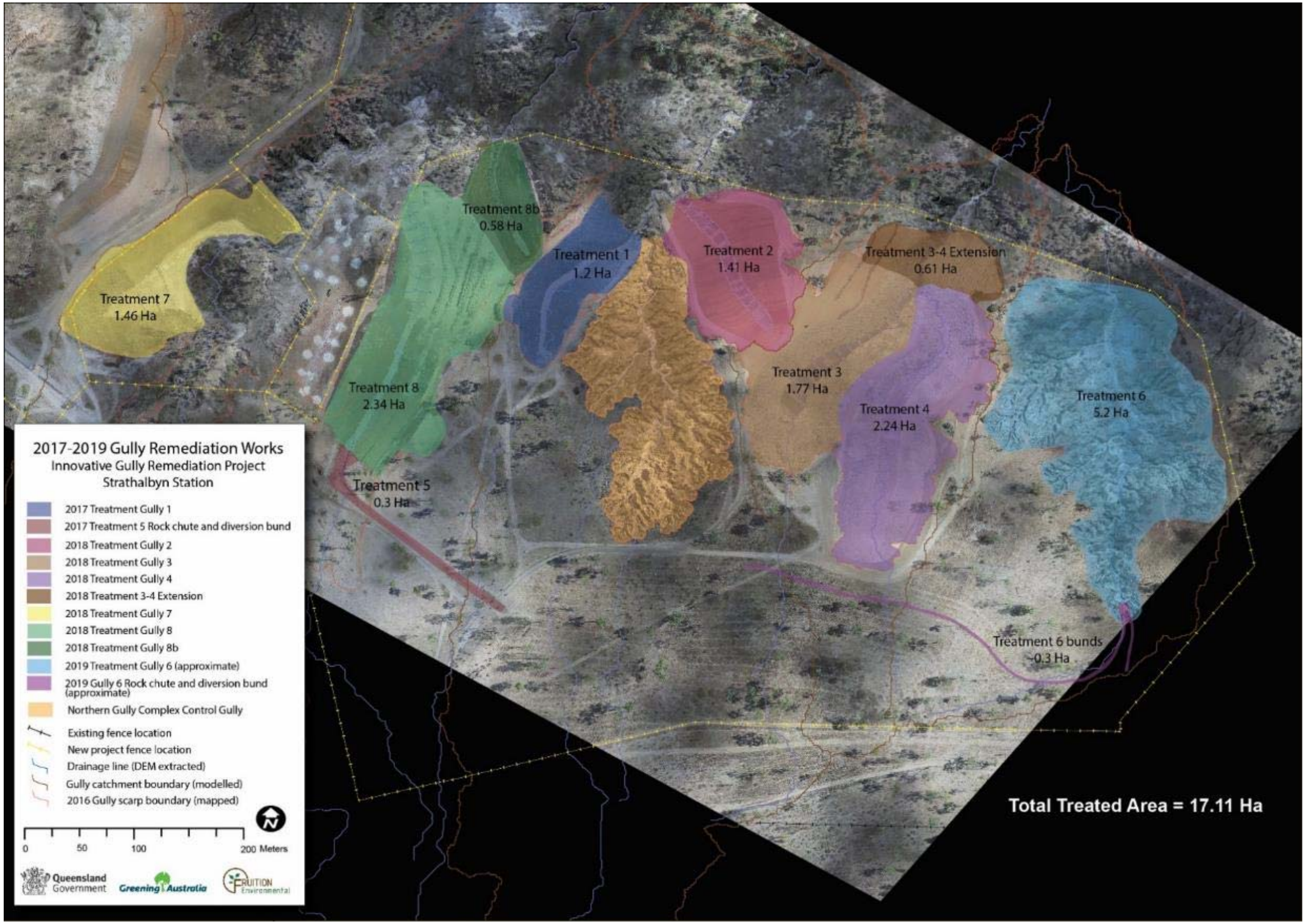

Figure 8 Innovative Gully Remediation Project works overview 2017-2019.

Table 5 Comparison of works undertaken at each trial site under the Innovative Gully Remediation Project at Strathalbyn Station (Telfer, 2019)

Site	Works implemented																		
	Catchment treatments			Gully Scarp treatments				Gully bed treatments			Regraded batter treatments								
	Fenced for managed stock access	Diversion bund to intercept catchment flows	Rock chute to control diverted flows to gully bed	Earthworks to reshape/regrade	Gypsum application and incorporation to 0.15m	Capping with gravel materials nominal 100mm	Capping with borrowed topsoil	Graded rock bed	Porous Rock check dams	Gypsum application and incorporation	Coir mesh applied over batters	Blanket mulching - Hay	Patchily spread hay mulch	Blanket mulching - Bagasse	Bagasse applied with a spreader or blower	Hay bunds on the contour	Debris bunds on the contour	Direct seeding – exotic grasses	Direct seeding with sub-surface incorporation
Treatment 1	×	×		×	×	C		×		×			×					×	
Treatment 2	×			×	×		×			×	×							×	
Treatment 3	×	×		×	×	×			×	×			×					×	
Treatment 4	×	×		×	×	×		×		×		×				E		×	
Treatment 3-4 Extension Area	×	×		×	×	×			×	×			×				F	×	
Treatment 5	×	×	×	×	×					×									
Treatment 6	×	×	×	×	B				×							×	×	G	
Treatment 7	×	A		×	×	×			×	×				×					×
Treatment 8	×	×	×	×	×	×		D	×	×					H	I	J	×	
Treatment 8b	×	×		×	×	×			×	×				×				×	

A – diversion bund implemented under an adjacent Greening Australia – Australian Government funded Reef Trust 4 program: B – incorporated to 0.2m depth: C – nominal 200mm thick: D – upstream half of Treatment 8 bed has been treated with graded rock: E – on north east batter only: F – on north west batter only: G – to be undertaken in September 2019: H – bagasse spread with a semitrailer mounted blower on parts of the eastern and all of the western batter: I – hay bales spread on the contour on the north eastern batter only: J – Debris spread on the contour in the inter-rows of the hay contours on the north eastern batter.

Plate 2 Innovative Gully Remediation Project works underway in 2018 – Strathalbyn Station

Monitoring and Evaluation

The project's monitoring and evaluation strategy was developed progressively between November 2016 and December 2018, based on core monitoring and evaluation principles. This reflected the need to determine the remediation trial site, designs and implementation plan prior to formalising the monitoring strategy.

Although the plan was not finalised until December 2018 (Telfer, 2018), much of the groundwork had commenced under the guidance of the project steering committee and with expert input. This included the collection of baseline information, the selection of the likely control gully to be used for treatment effectiveness comparisons, and the choice of methodology for collection of landform, soil, topographic, vegetation and water quality data.

The progressive development of the strategy has allowed the project a degree of flexibility, including the ability to integrate developing areas of interest such as bioavailable nutrient sources associated with remediation and new collection technologies (e.g. innovative sampler designs and improved LiDAR capture methodologies).

Monitoring and Evaluation Plan

The objectives of the M&E Plan stem from the overall project objectives, specifically:

- To trial different techniques for gully remediation on at least 5 treatment sites (across 150ha) to deliver more cost-effective solutions that can be applied across regions.
- To trial innovative monitoring techniques to determine reduction of sediment and particulate nutrient loads to the Great Barrier Reef and the costs of achieving those reductions based on different interventions.
- To engage with scientists and remediation experts to ensure the project builds upon the latest scientific understanding.

In essence these objectives focus on four main evaluation criteria:

- measured sediment reduction
- measured treatment effectiveness
- calculated treatment cost effectiveness over the Project's trial sites
- and level of project collaboration.

Milestone 6

Agreed monitoring and evaluation plan in place

https://www.greeningaustralia.org.au/wp-content/uploads/2019/09/IGRP_ME_Plan_Report_20181126.pdf

The full list of monitoring and evaluation activities undertaken under the program are detailed in the *Strathalbyn Innovative Gully Remediation Project Monitoring and Evaluation Plan* (Telfer, 2018).

Key Monitoring and Evaluation Metrics

The Plan identifies the monitoring metrics which have been collected throughout the project. Adaptive strategies have been used to progressively implement the monitoring program as the construction phases of the remediation trials were completed over several years. This was necessary as the implementation timetable was linked to the co-funding timetable of the project.

The metrics include datasets covering landscape scale, catchment scale, individual gully scale, and specific attributes scale data (such as water quality sample sediment concentrations and particle size distributions), all of which are relevant to answering the evaluation criteria.

The collection of these data in remote locations poses technical and logistical challenges. For these reasons, there has been a strong reliance on expert advice and assistance and collaborations with complimentary research programs. In particular, the following contributions have assisted the monitoring and evaluation objectives of the project:

- Additional contributions by the QLD Department of Environment and Science (DES) towards the NESP 3.1.7 project[1] which assisted with baseline soil investigations by making Departmental staff (Peter Zund) and soil sample analyses (through the DES Science Laboratory) available
- Preliminary investigations into gully classification and priorities for erosion control were undertaken by Griffith University under contract from Greening Australia
- Baseline sediment yield estimates were undertaken by Griffith University's Precision Erosion & Sediment Management Research Group under contract from Greening Australia
- The monitoring equipment design, installation, maintenance and sample collections were undertaken by Fruition Environmental Pty Ltd under contract from Greening Australia
- Analyses of samples were assisted through the Griffith University NESP 3.1.7 program
- The evaluation of cost-effectiveness of the trials was undertaken by Griffith University's Precision Erosion & Sediment Management Research Group under contract from Greening Australia
- The collection of high-resolution LiDAR from 2017 through to 2020 was undertaken by Airborne Research Australia, with funding contributions from Queensland Government and the Australia Government's Reef Trust program.

The key monitoring metrics which have been collected under the Plan are outlined in *Table 6*.

A summary of the timing of collection of these datasets and brief description of the methodologies used are contained in the Monitoring and Evaluation Plan document (Telfer, 2018).

[1] NESP 3.1.7: effectiveness of alluvial gully remediation in Great Barrier Reef catchments, Griffith University

Table 6 Key monitoring metrics and methods used in the Innovative Gully Remediation Program monitoring and evaluation strategy

Key Monitoring Metric	Sub-category	Methods of collection used
Gully erosion rate	Estimated historical rates	Temporal analyses of aerial imagery
	Contemporary rates versus post-remediation treatment	LiDAR derived digital elevation models (DEM) using DEM of difference method
Sediment export load[2]	Estimated historical rates	Reconstructed landform surface compared to LiDAR derived DEM using DEM of difference method combined with soil analyses for bulk density and particle size fractions
	Contemporary rates versus post-remediation treatment	LiDAR derived digital elevation models (DEM) using DEM of difference method, water quality suspended sediment concentrations and water flow modelling
Change in vegetation[3]	Within gully: pre-treatment versus post-treatment	Monitoring of ground cover, surface categories and functional group diversity and relative dominance undertaken in gullies
	Land condition assessments: pre and post land management/land use change	Land Condition Assessments (LCA's) conducted according to Chilcott et al 2003
Treatment effectiveness	Effectiveness in reducing fine sediment export over time	LiDAR derived digital elevation models (DEM) using DEM of difference method, water quality suspended sediment concentrations and water flow modelling
Treatment cost	Cost of treatment per tonne of fine sediment saved[4]	Annual estimated tonnes of fine sediment abated divided by the annualised total up-front costs of treatment after a applying a discount rate and assuming a treatment lifespan of 25 years
	Maintenance costs of treatments	Annual and total maintenance costs attributed to each treatment

Monitoring and Evaluation Design

The monitoring and evaluation design utilises a partial Before After Control Impact (BACI) study design. A single untreated control gully was monitored for the duration of the project (November 2016- May 2020) for comparison with the trial treatment gullies. This design was adopted as it was considered impractical to have a control site for each treatment site as generally the remediation designs involved some element of change to gully catchment inflows and adjacent gully systems. For this reason, monitoring of the control gully was ceased in May 2020 as it became necessary to remediate the control to prevent it affecting adjacent treatments through rapidly progressing erosion.

2 proportion under 63µm and under 20µm
3 cover, biomass, and functional group (end-of-dry and end-of-wet survey)
4 as measured against the specific gully baseline or control gully trend

All gullies within the Northern gully complex were monitored using annual repeat airborne LiDAR survey or terrestrial LiDAR surveys (QLD DSITI and Griffith University) from 2016 (RPS Pty Ltd) through to 2020 (Airborne Research Australia). High resolution airborne LiDAR was collected between 2017 and 2020. This data was the primary data source for monitoring baseline and post-treatment erosion rates over the full gully and treatment surfaces.

Baseline water quality data was collected in gullies prior to treatment between 2016 and 2018, although the dataset was limited to rainfall and water level in 2016. Baseline data was collected where possible in all gullies scheduled for remediation, with the intention to collect at least some baseline sediment concentration data prior to remediation works. Additionally, water quality data was collected within Bonnie Doon Creek at a location downstream of the remediated gullies via a permanent telemetered DES Gauging Station installed in 2018.

Figures 9 to 12 show the 2016-2020 water sampling monitoring locations. For budgetary reasons and due to practical constraints, full-suite water quality monitoring stations were confined to 5 of the 10 treatment areas (Figure 12). An example of one of the full-suite water quality monitoring station setups is provided in *Plate 3.*

The suite of monitoring techniques used at both study sites is summarised in *Table 6.*

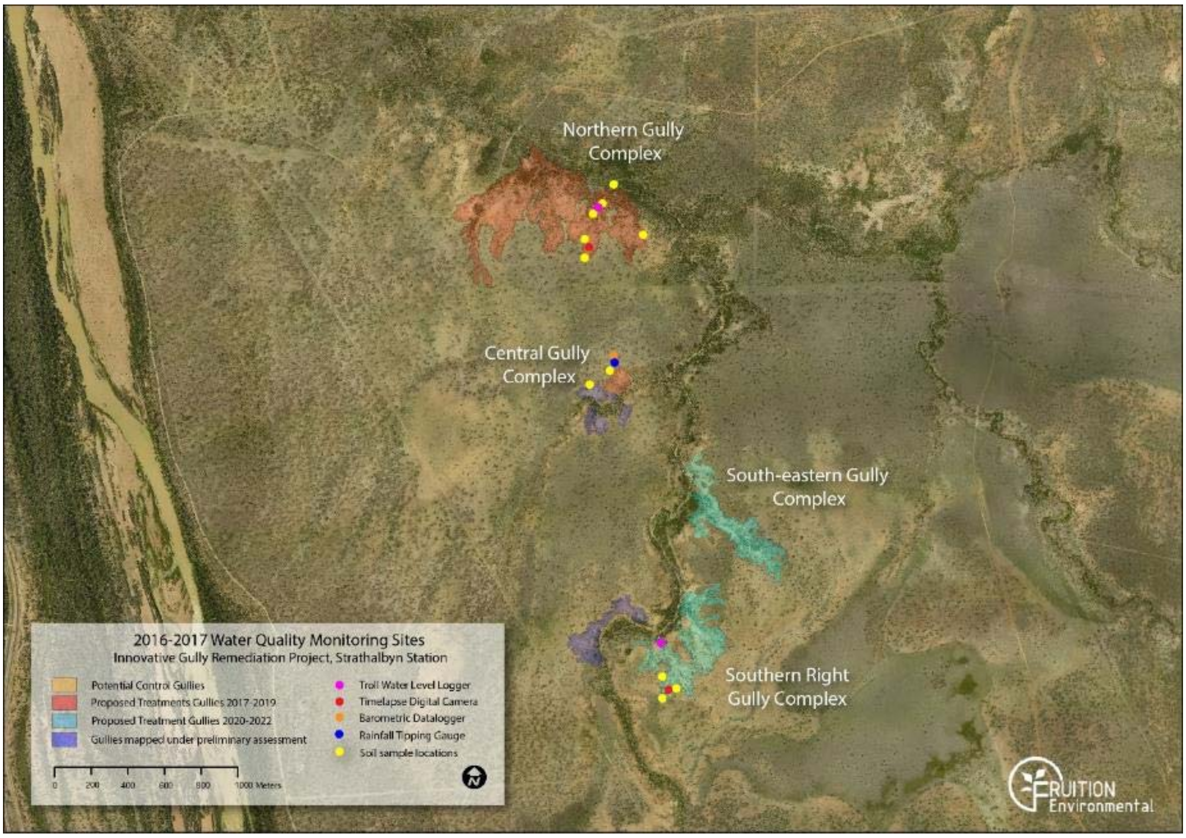

Figure 9 2016-2017 monitoring locations and instrumentation for pre-works baseline water quality and rainfall event data collection.

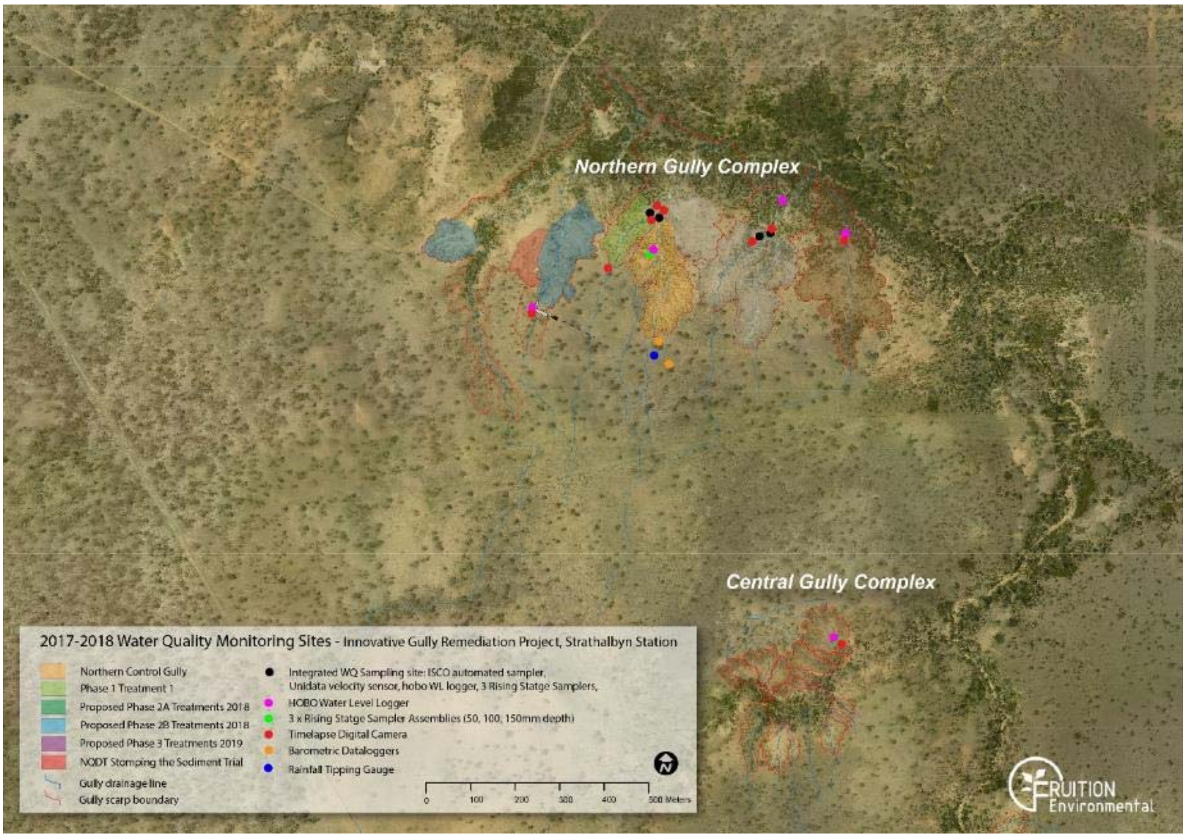

Figure 10 2017-2018 monitoring locations and instrumentation for pre-works baseline water quality and rainfall event data collection.

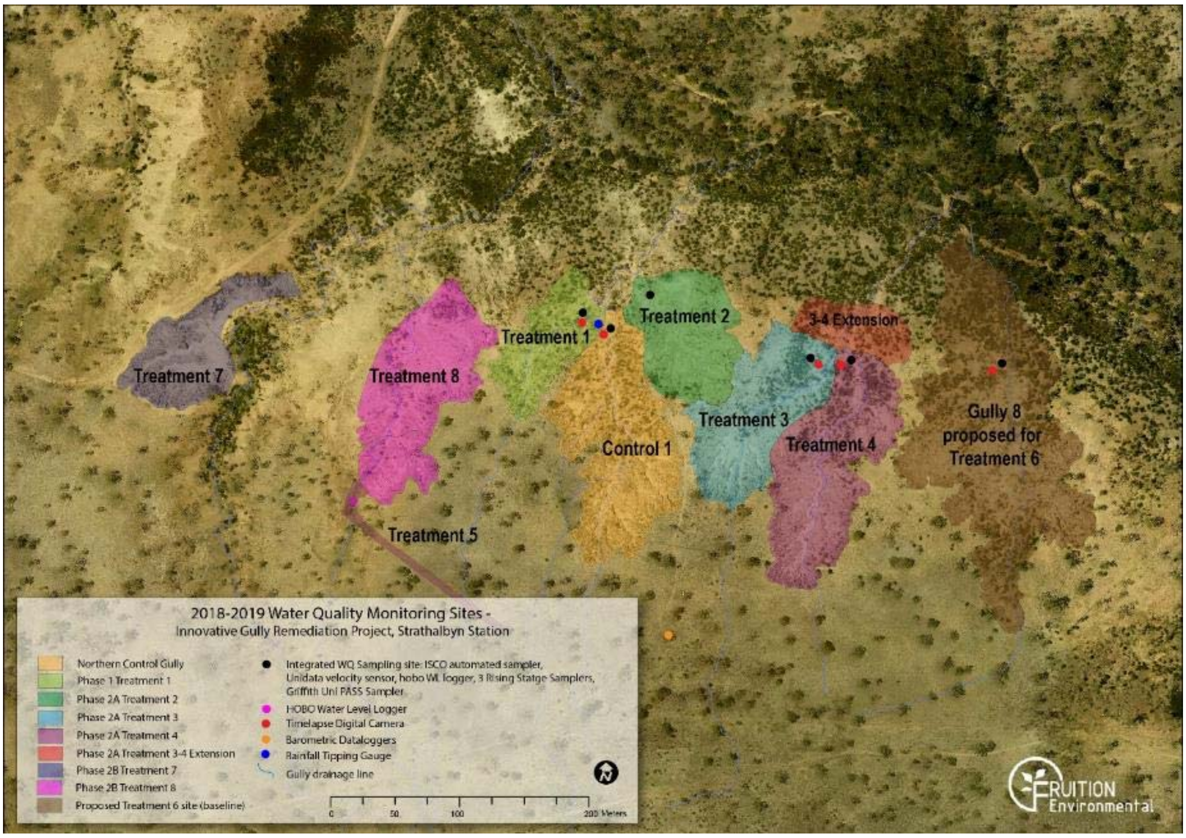

Figure 11 2018-2019 monitoring locations and instrumentation for pre-works baseline water quality and rainfall event data collection.

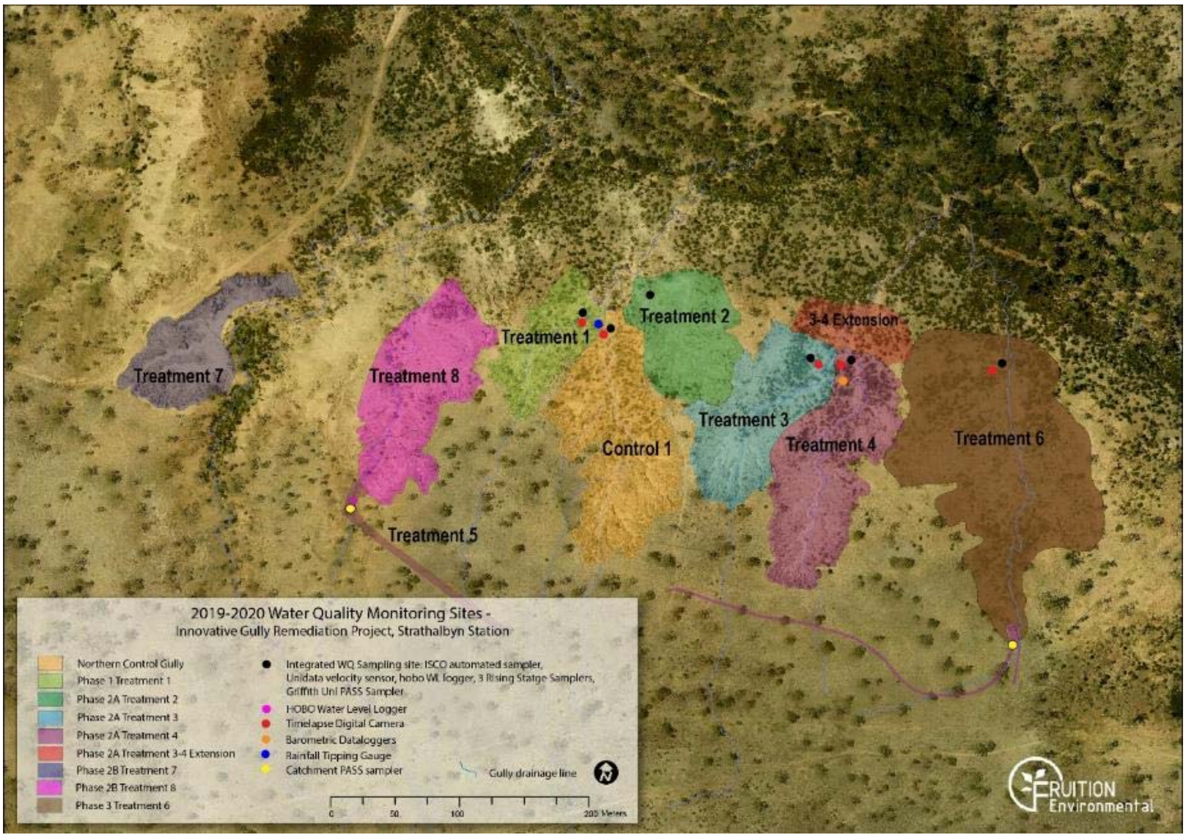

Figure 12 2019-2020 monitoring locations and instrumentation for pre-works baseline water quality and rainfall event data collection.

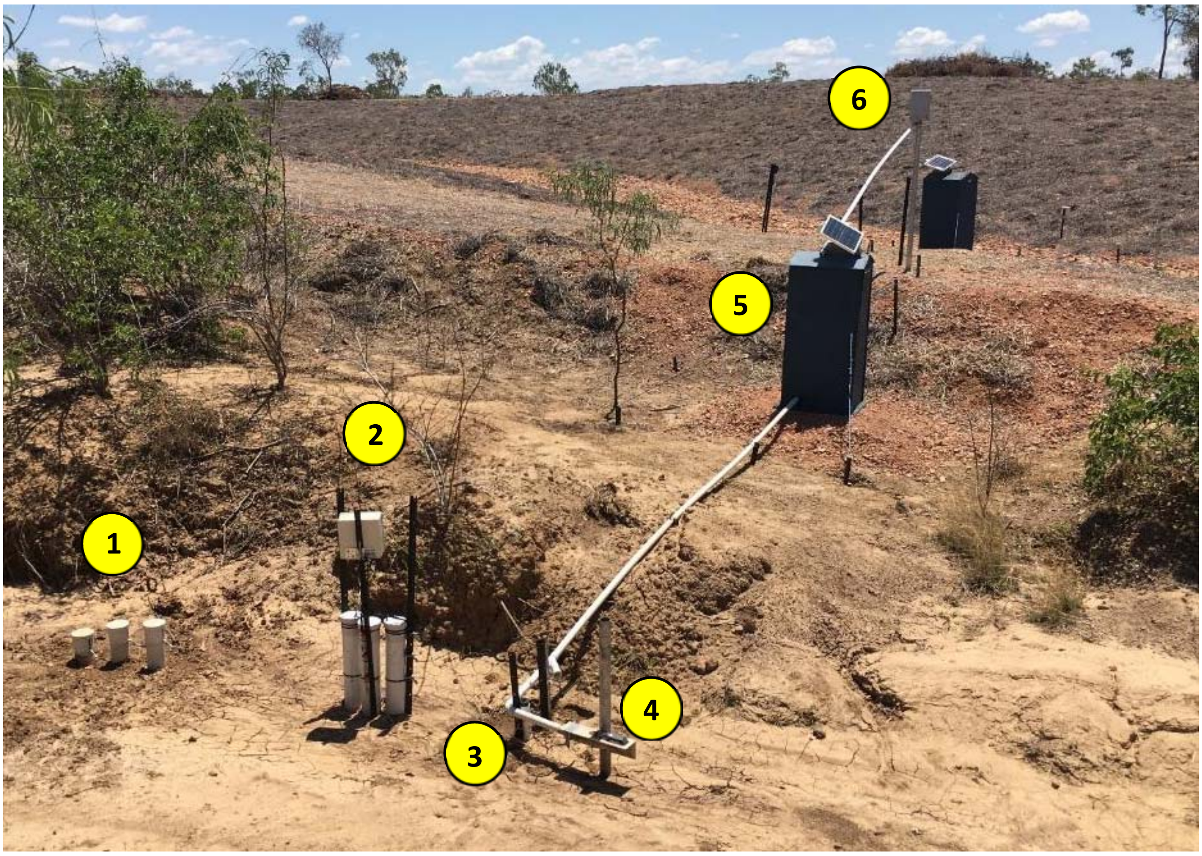

Plate 3 Water quality monitoring station installed at the control gully including (1) rising stage samplers with intakes set at 50mm, 100mm and 150mm above the bed; (2) PASS sampler assembly; (3) water level logger; (4) bracket containing the velocity sensor and autosampler intake hose; (5) cabinet housing the datalogger, modem, autosampler and power supply; and, (6) rain gauge mounted on an extension pole.

Table 6 Innovative Gully Remediation Program water quality sampling program equipment and purposes

Equipment/method	Purpose	When used
Tipping rain gauge	Records rainfall quantity and intensity	All year
Pressure transducer datalogger	Records water depth at deployment location when compensated with a barometric dataset	All year
Barometric pressure transducer	Collects barometric pressure to allow compensation of the water level loggers deployed on site	All year
Rising stage sampler	Collects a 1L sample on the rising stage of a flow event at the height of the bottle intake	All year
PASS sampler	A pump activated suspended sediment sampler, capable of collecting a composite sample over one or more events	Wet season only
ISCO automated water sampler	Collects up to 24x1L samples on a set time interval	Wet season only

Equipment/method	Purpose	When used
Liquid level actuator	Triggers the ISCO sampler to collect samples upon water contact and discontinues sampling when flow recedes	Wet season only
Velocity sensor	Collects flow velocity at the deployment location, logged at a predetermined interval	Wet season only
Time-lapse camera	Takes digital photographs on a set interval to document flow processes	Wet season only
High resolution LiDAR dataset	Allows modelling of stream discharge using a derived DEM, rainfall and calibration readings where available	Post wet analyses

Information Sharing and Data Storage

The Monitoring an Evaluation Plan also identifies the methods of collection, responsibilities, and timeframes for collection of monitoring data. The custodians of each dataset are identified along with proposed access to data rules. It is envisaged that most data will be accessible to third parties under Creative Commons licencing to facilitate further research and analyses of the data beyond the life of the Innovative Gully Remediation Project. To this end, currently collaborating or linked projects that may benefit from data sharing arrangements are listed in the plan.

Reporting on the Data

The data and information collected under this program will be reported in line with the requirements of the project collaborative agreement. This includes reporting on the outcome of the monitoring program against the key evaluation questions, producing recommendations for monitoring of future large scale gully remediation programs, and synthesising the monitoring and evaluation outcomes into the project Final Report in 2020. Importantly, the data will also be used to feed into other related Queensland Government evaluation frameworks such as the Paddock to Reef Program and the Reef Water Quality MERI evaluation template (DES, 2018).

Gully Remediation Treatment Effectiveness

In the context of this program, effectiveness has primarily been measured in terms of the post-treatment reduction in fine sediment and particulate nutrient export to the Great Barrier Reef lagoon that is attributable to the remediation works. This is in line with the first three of the four key evaluation questions outlined in the introductory chapters of this report. The majority of the monitoring program actions designed under the project are focussed on this question.

However, a number of other elements of effectiveness are relevant to the objectives of the project. These include:

- The robustness of the treatment, in this case measured by the cost and regularity of maintenance required to maintain the remediation works and lock in the associated fine sediment reductions
- The longevity of the effect of the treatments which is again a function of maintenance requirements but also of the success of vegetation establishment on the site and the improvement in land condition and land management associated with the remediation actions

This section outlines the results of the evaluation of effectiveness by:

- Providing updated baseline fine sediment yield information to reflect the yield coming from each treatment area as opposed to the overall gully systems.
- Summarising the results of the water quality monitoring program undertaken between 2016 and 2020.
- Summarising the results of the volumetric analyses of treatment sites using change detection based on LiDAR derived digital elevation models (DEMs)
- Summarising maintenance statistics for each treatment gully.
- Overviewing the response of the treatment areas to revegetation trials and documenting changes in land condition associated with land management changes being implemented by the landholder.

Gully and Treatment Area Baseline Sediment Yield

Gully Baseline Yield

The initial assessment of fine sediment yield completed for the northern gully complex in 2017 (Brooks et al., 2017) estimated yield from the four gully systems within the Innovative Gully Remediation Project trial area at 7,716 tonne per year.

Milestone 14

Synthesise initial outcomes and develop draft best practice guide to innovative gully remediation techniques in consultation with the Sediment Working Group

Milestone 15

Produce an economic report on the cost effectiveness of different techniques in reducing sediment runoff

In 2020 the baseline sediment export rates were updated using an improved prediction methodology for the former land surface and more refined bulk density estimates (see Daley et al., 2020 for details of the method). The more recent estimations introduce an error margin for the calculations. In total, the fine sediment export estimate have increased marginally to 7,922 tonnes per year if the most conservative estimate is used taking into account the error margins. The updated 2020 baseline yield estimates have been used in the assessment of treatment effectiveness (see Brooks et al., 2020).

Table 7 compares the updated estimates undertaken in 2020 with the former estimates from 2017.

Table 7 Updated fine sediment (<20 µm) yields for the Innovative Gully Remediation Project's target gullies (adapted from Daley Et al., 2020). Red emboldened are the updated yield figures.

Gully	Gully area	Estimate	Volume eroded (m^3)	Net fine sediment export (t/yr)	Fine sediment export per hectare (t/yr/Ha)
North-05	14.13	Former 2017	126,529	3,030	211
		Updated 2020	**150,707**	**3,500 ± 240**	**251**
North_06	8.67	Former 2017	73,079	1,750	199
		Updated 2020	**98,438**	**2,300 ± 160**	**267**
North_07	5.67	Former 2017	88,750	2,125	370
		Updated 2020	**75,002**	**1,760 ± 120**	**311**
North_08	4.54	Former 2017	33,891	811	176
		Updated 2020	**40,271**	**947 ± 65**	**209**
TOTAL	33.01	Former 2017	322,249	7,716	n/a
		Updated 2020	**364,418**	**7,922 minimum (8371)**	**n/a**

Treatment Area Baseline Yield

The treatment areas within each of the four northern gully systems targeted do not cover the entire gully systems that were analysed for gully baseline yield. Consequently, in order to determine the effectiveness of each treatment it has been necessary to attempt to quantify the baseline fine sediment yields attributable to each area of treatment.

The results of this analysis are presented in Table 8 [5].

Overall, the analysis indicates that an average of 6000 t of fine sediment per year has eroded from the Innovative Gully Program treatment areas over the baseline period. This equates to 126,000 tonnes of fine sediment to the reef over the last 21 years, roughly 10,500 truck loads to the reef.

The analysis highlights the variability in erosion activity between lobes of gullies. For example, Treatment 8b has an area of just 37% of the Treatment 7 area but a 32% higher baseline sediment

[5] Note that these figures differ from those presented in the Daley et al. report as they exclude gullies not treated under the Innovative Gully Remediation Program

yield. Similarly, Treatment 2 and Treatment 7 have a similar area, however Treatment 7 has almost twice the baseline sediment yield.

Table 8 Estimated fine sediment (<20 µm) yields for the Innovative Gully Remediation Project's treatment sites and control gully (in red) over the baseline period from 1995 to 2016 (adapted from Daley et al., 2020).

Gully	Treatment	Gully area treated (Ha)[6]	Volume eroded (m^3)	Baseline net fine sediment export (t/yr)	% of gully area treated	% Total potential yield reduction
North-05	**Treatment 7**	1.58	6,300	**430 ± 140**	32%	65%
	Treatment 8	2.34	17,900	**1,280 ± 190**		
	Treatment 8b	0.58	4,960	**569 ± 85**		
North_06	**Treatment 1**	0.96	4,870	**283 ± 42**	27%	23%
	Treatment 2	1.41	4,010	**240 ± 96**		
	Control	2.42	18,600	**1,180 ± 180**		
North_07	**Treatment 3**	1.77	9,140	**490 ± 160**	81%	69%
	Treatment 4	2.24	10,900	**620 ± 200**		
	Treatment 3-4 extension	0.61	2,090	**98 ± 33**		
North_08	**Treatment 6**	3.57	15,500	**810 ± 240**	79%	86%
TOTAL/AVERAGE for all Treatments		**16.97[6]**	**94,270**	**6,000 ± 1506**	**51.4%**	**72%**

Treatment Effectiveness – The Monitoring Results

As outlined previously, the analysis of the effectiveness of the treatments in terms of fine sediment reduction has utilised two methodologies (Brooks et al., 2020):

- direct sampling of runoff at the gully outlets and analyses of samples collected for suspended sediment concentration, followed by modelling of the gully flows to estimate sediment loads in tonnes of fine sediment per year
- comparison of high resolution lidar derived digital elevation models (DEM of difference) to determine net changes between periods of analysis and the use of soil analyses to derived net export of fine sediment from the treatment areas (volumetric analyses).

The combined analyses result in an estimated annual fine sediment reduction of 4,430 tonnes per year, representing 92% of the annual estimated baseline annual fine sediment export from the treatment areas of the gullies (4,820 tonnes per year: from *Table 7* total minus the control gully export).

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[6] This is the area of treated gully as opposed to the treatment area. The treatment area is generally a larger area as the remediation works often extend above the area of existing gully scarp in order to achieve the required batters when regrading or to deal with catchment flow considerations and includes diversion bunds installed within the gully catchment.

Water Quality Results Summary

A combination of water quality monitoring and DEM of difference was used to estimate treatment effectiveness in Treatments 1,3,4, and 6 and the Control area. Although a water quality station was located on Treatment 2, there was insufficient flow into the treatment area to record any automated samples and only 2 rising stage samples were recorded over the entire monitoring period.

A detailed description of the sampling results including number of samples tested, particle size analyses and suspended sediment concentration methods and results are provided in Brooks et al. (2020)

In summary, the analyses revealed that all of the sampled treatments had significantly reduced suspended sediment concentration (SSC) compared to their respective baseline SSC and compared to the control gully SSC (*Table 9*).

Table 9 Geometric mean (mg/L) and maximum suspended sediment concentration (mg/L) for the control and instrumented treatment areas (adapted from Brooks et al., 2020). Red emboldened figures are post treatment results. Black emboldened are the control gully results for comparison.

Treatment	Geometric Mean (mg/L)			Maximum SSC (mg/L)		
	2017-18	2018-19	2019-20	2017-18	2018-19	2019-20
Control	**57,925**	**69,451**	**66,192**	**128,975**	**172,176**	**116,800**
Treatment 1	**972**	**511**	**344**	**1,948**	**3,191**	**610**
Treatment 3	82,265	**2,613**	**1,589**	420,148	**6,504**	**2,030**
Treatment 4	105,436	**762**	**852**	164,148	**2,578**	**9,680**
Treatment 6	-	59,377	**10,755**	-	87,826	**44,484**

The particle size of samples collected did not vary significantly from the baseline samples after treatment and there was no significant variation between treatment gullies and control site observed. This would be expected as the D90 of the control and baseline samples was generally less than 60µm (Brooks et al., 2020).

Comparison of the suspended and fine sediment yield from each treatment, normalised for gully catchment area, indicate that the remediation measures applied at gullies T1, T3, and T4 all had similar effectiveness, with fine sediment export reduced to less 15 t/ha/year in the first year after treatment and less than 3 t/ha/year the second year after treatment. All three of these treatment areas had maintenance works completed before the second year of water quality monitoring. Fine sediment yield from T6 reduced from 182 t/ha/yr to 22/t/ha/yr after treatment and maintenance works were completed in 2020. These results are detailed in *Table 10*. Whether a similar reduction in fine sediment export after the second year will be achieved unfortunately is outside the timeframe for this project.

Normalised to modelled water discharge volume per cubic metre (to account for variations in runoff between the 2018/19 and 2019/20 wet seasons), sediment yields were very low for all treatments compared to the control or baseline yields where available (*Table 10*). The lowest yield was less than 0.5kg per m^3 for T1, followed by less than 0.9kg per m^3 for T4, less than 2.6kg per m^3 for T3, and less than 10kg per m^3 for T6. These yield estimates represent a reduction in fine sediment export ranging from 96.2-99.5% depending upon the year. Comparatively, T6 was the least effective with a reduction of only 83.8%, although this figure was derived from only a single sampling year. Possible explanations for these results are outlined in *Specific Treatment Response* sub-section later in this chapter.

Table 10 Suspended sediment yield and fine sediment yield (sub 20µm), total and by treatment area, for the control and instrumented treatment areas (adapted from Brooks et al., 2020). Red emboldened figures are post treatment results. Black emboldened are the control gully results for comparison.

Treatment	Suspended Sediment Yield				Fine Sediment Yield < 20µm			
	Total (t/yr)		By Treatment Area (t/ha/yr)		Total (t/yr)		By Treatment Area (t/ha/yr)	
	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Control	**5232**	**1775**	**473**	**161**	**4114**	**1256**	**373**	**114**
Treatment 1	**4**	**1**	**3**	**1**	**4**	**1**	**3**	**1**
Treatment 3	**162**	**35**	**18**	**4**	**132**	**27**	**15**	**3**
Treatment 4	**11**	**4**	**5**	**2**	**10**	**4**	**5**	**2**
Treatment 6	3310	**213**	354	**26**	2423	**182**	259	**22**

Volumetric Analyses Results Summary

Change detection using LiDAR derived DEMs of difference was utilised as the primary method of evaluating treatment effectiveness where water quality data was not collected, that is on Treatments 2, 3-4 extension, 7, 8, and 8b[7]. The method was also applied to the Control, T1, T3, T4, and T6 remediation areas.

The sites were all monitored using annual repeat high resolution airborne lidar survey (~ 0.1m resolution). The results of the volumetric analyses were then adjusted to quantify the total yields in tonnes of fine sediment. This was achieved by accounting for the modelled sediment delivery ratios to the reef lagoon (based on Paddock to Reef modelling), the average bulk density of soils in the Northern gully complex, and the average proportion of soil particles below 20µm from the soil sample analyses.

Details of the method and results are contained in the Daley et al. (2020) and Brooks et al. (2020) documents. A summary of the results are contained in *Table 11*.

[7] Treatment 5 consisted of a rock chute and diversion bund which truncated catchment flows to Treatment 1 and diverted them to Treatment 8. Consequently, the effects of that treatment are accounted for in the assessments of Treatments 1 and 8 and are not reported individually.

Table 11 Sediment abatement estimates for gullies treated under the Innovative Gully Remediation Program 2017-2020 (adapted from Brooks et al., 2020)

Treatment	Gully area treated (Ha)[6]	Volume eroded (m³)	Baseline net fine sediment export (t/yr)	Treatment effectiveness ratio[8]	Total abatement[9] (tonnes <20µm at GBR)	Average annual abatement (tonnes <20µm at GBR)
Control	2.42	18,600	**1,180 ± 180**	n/a	n/a	n/a
Treatment 1	0.96	4,870	**283 ± 42**	99%[10]	841 ± 125 (3)	280 ± 42
Treatment 2	1.41	4,010	**240 ± 96**	78%[11]	376 ± 151 (2)	188 ± 75
Treatment 3	1.77	9,140	**490 ± 160**	98%[10]	960 ± 314 (2)	480 ± 157
Treatment 4	2.24	10,900	**620 ± 200**	99%[10]	1,228 ± 396 (2)	614 ± 198
Treatment 3-4 extension	0.61	2,090	**98 ± 33**	96%[10]	192 ± 65 (2)	96 ± 32
Treatment 6	3.57	15,500	**810 ± 240**	84%[10]	680 ± 202 (1)	680 ± 202
Treatment 7	1.58	6,300	**430 ± 140**	99%[11]	851 ± 277 (2)	426 ± 139
Treatment 8	2.34	17,900	**1,280 ± 190**	97%[11]	2,476 ± 367 (2)	1238 ± 184
Treatment 8b	0.58	4,960	**569 ± 85**	75%[11]	852 ± 127 (2)	426 ± 64
				TOTAL ABATEMENT	**8,456 ± 2024**	
					AVERAGE ANNUAL ABATEMENT 2018/19 to 2019/2020	**4,428 ± 1093**

The results show that for treatment areas where only volumetric analyses were undertaken, the treatment effectiveness ranged from 75% for Treatment 8b through to 99% for Treatment 7. Note that the treatment effectiveness ratios utilised for treatment areas that also had water quality data reflect the measured change in fine sediment yield through the water quality analyses.

Table 11 shows that overall the treatment trials delivered a net fine sediment export reduction of 8456 ± 2024 tonnes across the study period, or a mean annual abatement of 4428 ± 1093 tonnes.

Treatment Effectiveness - Particulate Nutrients

In addition to sediment sample concentrations, total nutrient and bioavailable nutrient data were analysed from the collected water samples where possible. The nutrient sample data indicate that, in comparison to the control gully data, the gully remediation measures applied have reduced particulate nutrient concentrations by approximately 80% (Brooks et al., 2020). The reduction in

[8] Averaged of calculated effectiveness in 2018/19 and 2019/20
[9] Number of years since treatment in brackets
[10] Based on observed Suspended Solids Concentration data
[11] Based on temporal analyses of high resolution LiDAR (DEM of Difference)

particulate nutrients was an expected result of the soil erosion controls significantly reducing the amount of suspended sediment flowing through the remediated gullies.

In contrast dissolved and bioavailable nutrient sample concentrations from the remediated gullies were significantly higher than the Control gully sample data two years post-treatment.

Comparison of SSC and nutrient data indicate there is a moderate to strong relationship between particulate nutrients and suspended sediment. Whereas, there appears to be little to no relationship between dissolved and bioavailable nutrients and suspended sediment, except for dissolved phosphorus, which showed a moderate relationship with suspended sediment.

Possible sources of the increased dissolved nutrient concentrations measured at the gully outlet may be the soil ameliorants used in the remediation process (including gypsum and organic matter imported to use as surface mulches or soil improvers). This possibility is supported by preliminary sample data collected from the gully catchments which had very low particulate and dissolved nutrient concentrations compared to the samples collected from the gullies. Further investigation regarding the source of elevated dissolved nutrients and their persistence in the gully system is underway under a further innovative program funded by the Great Barrier Reef Foundation and QLD Office of the Great Barrier Reef.

Further details are available in the Brooks et al. (2020) report.

Treatment Effectiveness – The Vegetation Response

Vegetation monitoring undertaken periodically by Greening Australia at the Strathalbyn Project site showed substantial improvements in vegetation cover, diversity and relative dominance of functional groups, surface stability, and Land Condition Assessment (LCA's) ratings in response to gully remediation. At treatment sites three and four (for which the most reliable before and after data was available) vegetation cover increased by 47% and 40% respectively (*Figure 13*).

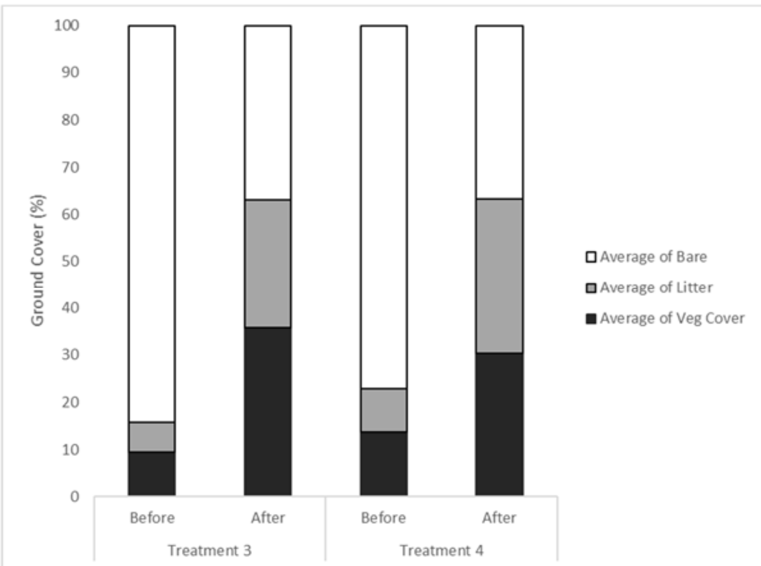

Figure 13 Average ground cover proportions before and after gully remediation at Treatment 3 and 4 (Source: Greening Australia)

Diversity of functional groups increased and relative dominance shifted in response to gully remediation, evident in the reduced proportional dominance of exotic perennials and the appearance and proportional increase of functional groups not present by more than 5% until 2019, such as annual natives, native and exotic forbes and native legumes. At both treatment sites three and four, annual native species accounted for approximately 0.2% before gully remediation but afterwards, increased to 21% and 19% respectively (*Figure 14*). *Table 12* provides a key to the function groups abbreviations used in *Figure 14*.

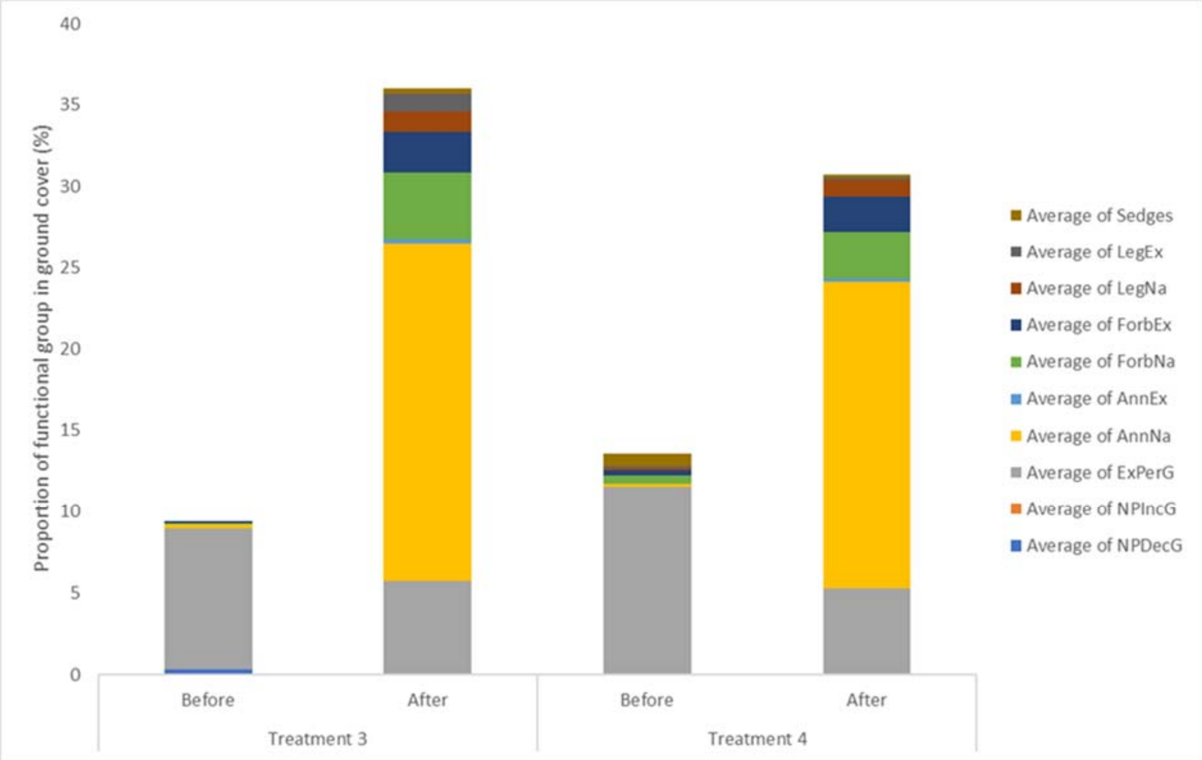

Figure 14 Diversity and relative dominance of functional groups before and after gully remediation at treatment sites three and four (Source: Greening Australia)

Table 12 Key to the functional group abbreviations used in Figure 14.

Code	Functional Group	Code	Functional Group	Code	Functional Group
NPDECG	Native Decreaser Grasses	AnnEx	Annual Exotic Grasses	LegEx	Exotic Legumes
NPIncG	Native Increaser Grasses	ForbNa	Native Forbes	Sedge	Sedges
ExPerG	Exotic Perrenial Grasses	ForbEx	Exotic Forbes	Bare	Bare Ground
AnnNa	Annual Native Grasses	LegNa	Native Legumes	Litter	Organic Litter

Surface category surveys showed gullies were mostly comprised of eroding surfaces prior to remediation works but increased in stability in response to gully remediation. By 2020, eroding categorisations at treatment sites decreased on average by 33% and stable categorizations (including stable/aggrading) increased by 57%. The control site continued to have high rates of eroding surfaces throughout monitoring.

Land Condition Assessments conducted in gully catchments showed improved land condition ratings after implementation of gully remediation. Variables identified by Chilcott et al 2003 including dry matter (DM) yield, tree cover, palatable plant species, tree basal density, sapling diameter, tree count etc. were used to generate an overall land condition rating. Treatment sites three and four were both rated as “poor condition” prior to gully remediation, but received “good condition” and “excellent condition” ratings respectively, after gully remediation (*(Plate 4).* The locations of the LCA monitoring points for Treatment 3 and Treatment 4 are shown in *Figure 15*. The LCA’s also provide a visual representation of the changes in landscape over time, such as the increase in ground cover and establishment of mid-storey vegetation. LCA’s were developed for use by landholders so these results are indicative of grazing potential and are useful for communication with landholders and graziers.

Plate 4 LCA monitoring points in gully catchment of treatment three (above) and four (below) before gully remediation in 2018 (left) and after gully remediation in 2020 (right). Source: Greening Australia, 2021.

Monitoring of ground cover, functional groups, surface categories and LCA's conducted by Greening Australia at Strathalbyn identified improvements across all components in response to gully remediation. The increase in stable surfaces and vegetation cover show that gully remediation has been successful in stabilising gully systems and ensuring long-term stability through vegetation establishment. The increase in functional group diversity and shifts in relative dominance toward more native species show an improvement in biodiversity and landscape resilience as a result of gully remediation works. Futher details on this monitoring are available in *Innovative Gullies Remediation Project - Vegetation Monitoring Report 2021* (Greening Australia, 2021).

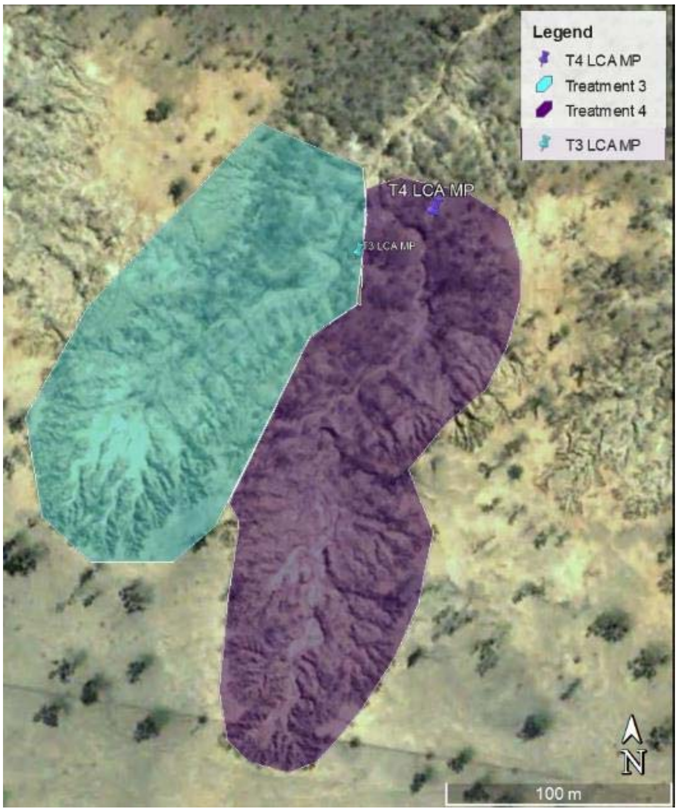

Figure 15

Locations of LCA Monitoring Points in Treatment 3 and Treatment 4 (Source: Greening Australia, 2021)

Treatment Effectiveness – Measured by Maintenance Cost

Maintenance requirements and associated costs are not a direct reflection of the effectiveness of the remediation treatments in reducing fine sediment or particulate nutrient export. However, the degree of post-works maintenance required on the different treatment gullies does provide a surrogate measure of both the resilience of the treatment approaches and the likelihood of the initial measured yield reductions being maintained in future years.

The maintenance actions required over the project period and associated on-ground costs for each treatment are summarised in Table 12. The total maintenance cost for each treatment over the project period is also provided.

The total maintenance costs for all years and all treatments was $34,214 (excluding materials costs). This figure represents 1.4% of the total on-ground works budget.

Maintenance costs in this project have been kept low by undertaking the repair works when equipment, resources and personnel were already on site, but also through the use of experienced remediation contractors for both design and implementation. Additionally, the high standard of remediation work undertaken has reduced the scale and frequency of required maintenance actions.

Nevertheless, it is evident from Table 12 that some treatment sites required a higher degree of maintenance than others. This has important implications for the cost-effectiveness of individual treatment as it can be expected that sites requiring more frequent or costly maintenance will be either more expensive over the presumed life project or will not attain the predicted sediment abatement figures over that period.

Repair works were most frequently required where there was concentration of flows down batters. Flow concentration was generally associated with three primary factors:

- Concentration of flows in the convex corners where two batter alignments transitioned together such that flow concentrated midway down the batter
- Concentration of flows on batters below minor drainage depression
- Concentration along stock pads and vehicle access tracks, particularly associated with wet season access

Table 12 Maintenance actions undertaken and costs in Innovative Gully Project treatment gullies between January 2018 and July 2020

Treatment	Maintenance actions required	Year Maintenance completed	On-ground cost [12] ($ ex GST)	Total cost ($ ex GST)
Treatment 1	Repair of stock damage after wet season grazing	2019	415	**935**
	Porous check dams in an area of flow concentration where batter alignments merged	2019	521	
Treatment 2	Repair of rill erosion in areas of undermined jute mesh	2019	415	**1,772**
	Repair of rill erosion in areas of undermined jute mesh	2020	1,350	
Treatment 3	Porous check dams in an area of flow concentration where batter alignments merged	2019	415	**415**
Treatment 4	Minor repairs of re-initiated tunnel erosion on the boundary with Gully 8	2019	831	**2,721**
	Repairs of minor rilling on batters	2020	1,890	
Treatment 3-4 ext	Temporary diversion bunds	Late 2018	4,493	**10,074**
	Batter chute to address concentrated flow from an upslope drainage depression	2019	3,756	
	Repair of stock damage after wet season grazing	2019	415	
	Minor repairs of batter chute and construction of a diversion bund above repaired stock damage on the western batter	2020	1,410	
Treatment 5	Minor repair of rilling on eastern bund on the rock chute to prevent outflanking	2019	415	**431**
Treatment 6	Repair of batters in several locations	2020	4,845	**13,945**
	Repair of rock check dams within the channel	2020	2,585	
	Addition of a batter chute and diversion banks to deal with flow concentration down the north western batter	2020	6,515	
Treatment 7	None required	n/a	nil	**nil**
Treatment 8	Batter chute on the eastern batter to address concentrated flow down the batter	2019	3,921	**3,921**
Treatment 8b	None undertaken	n/a	-	**nil**
			TOTAL MAINTENANCE COSTS, ALL TREATMENTS	**$34,214**

[12] Excludes materials costs. Note also there were no mobilisation costs for maintenance in 2019 or 2020 as plant and equipment were already on-site.

Treatment Effectiveness - Specific Treatment Responses

Observations of the early responses of the treatments to the 2018-2019 wet season storm events have been previously documented in the *Strathalbyn Works Update Report* (Telfer, 2019) and summarised in *Communique 4* in May 2020. This section presents additional information based on a further year of data and observations from the 2019-2020 wet season.

After now having three years of data, it appears that a feature of the treatments thus far is that they have a high degree of stability and, with some exceptions, have generally improving vegetative cover. As detailed in the previous sections, only relatively minor maintenance was required on most treatments with some requiring little or no maintenance. However, analyses of the post-construction LiDAR derived DEMs (Digital Elevation Models) reveal that there are some common themes around the treatments that provide important information on common pressure points in large-scale gully remediation designs and construction.

The fact that these treatments have been designed as trials has allowed an element of testing of treatment approaches. As such, the treatments implemented at any one site do not necessarily represent the most effective or least-cost treatment option available. This has allowed testing of multiple approaches and combinations of treatment. Generally, these revolve around changes to treatments applied in the gully catchments to control catchment flow into the gullies, treatments of the gully scarp and resulting batter surfaces, and treatments of the gully floor or drainage channel.

With the benefit of multiple years of analysis, it is possible to identify a number of common issues with the remediation treatment types that affect the longer-term stability of the post-remediation landform. Examples of the main observations are documented below.

Concentration of catchment flows

The catchment areas of the northern gully systems are generally very flat with a general downslope trend towards Bonnie Doon Creek. In such low relief environments depressions as shallow as a stock pad or vehicle track can alter the catchment flow paths resulting in flow concentration and often erosion.

There are two primary areas of flow concentration that are identifiable in the DEMs of difference generated from the repeat high-resolution LiDAR:

- Concentration of flows down natural flow paths or vehicle or machinery access tracks to the remediated gully heads
- Concentration of flow in concave bends in the batter alignment which causes flow to concentrate midway down the batter slope
- Concentration of flow from slight depressions with relatively small catchments areas (0.2-0.5ha) in areas above the batters and which drain to the batters.

Figure 13 shows an example of rill erosion caused by vehicle and machinery access tracks to the Treatment 1 gully head. The 2020-2019 LiDAR comparison shows the repairs undertaken in the 2019 maintenance year which included porous rock check structures on the batter and flow spreading whoa-boys on the access track.

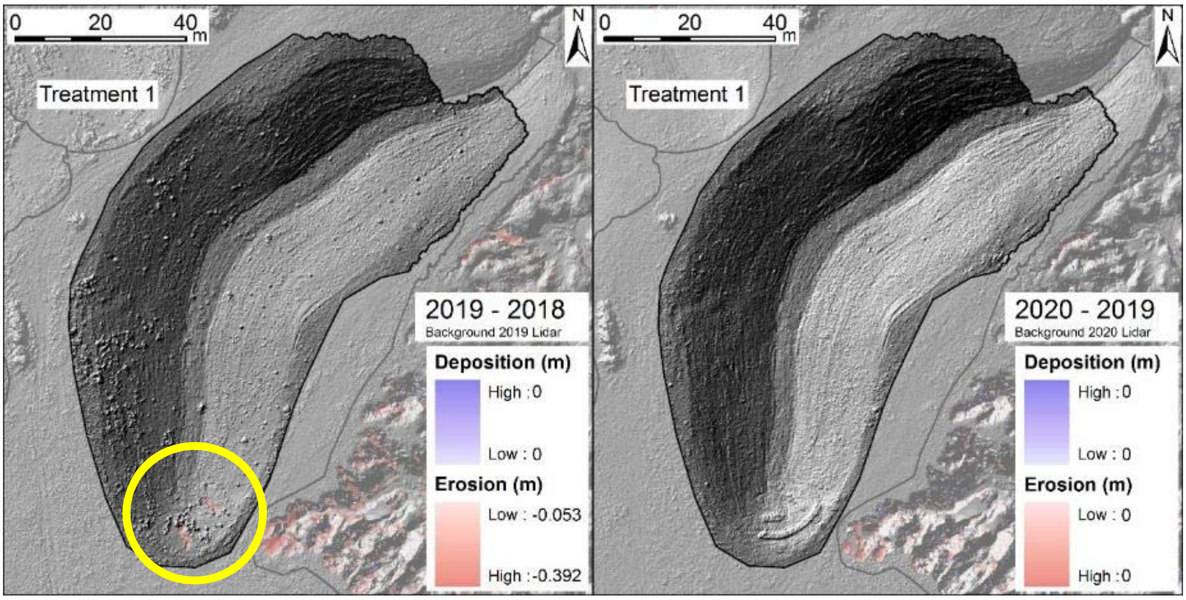

Figure 13 *Treatment 1 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)*

Figure 14 shows rill erosion at Treatment 3 on the lower batter below a concentration point where the batter forms a concave bend. The remediation/maintenance response was to again install porous rock check structures on the contour to dissipate the batter flows without causing pooling. *Plate 3* shows the maintenance works immediately after completion.

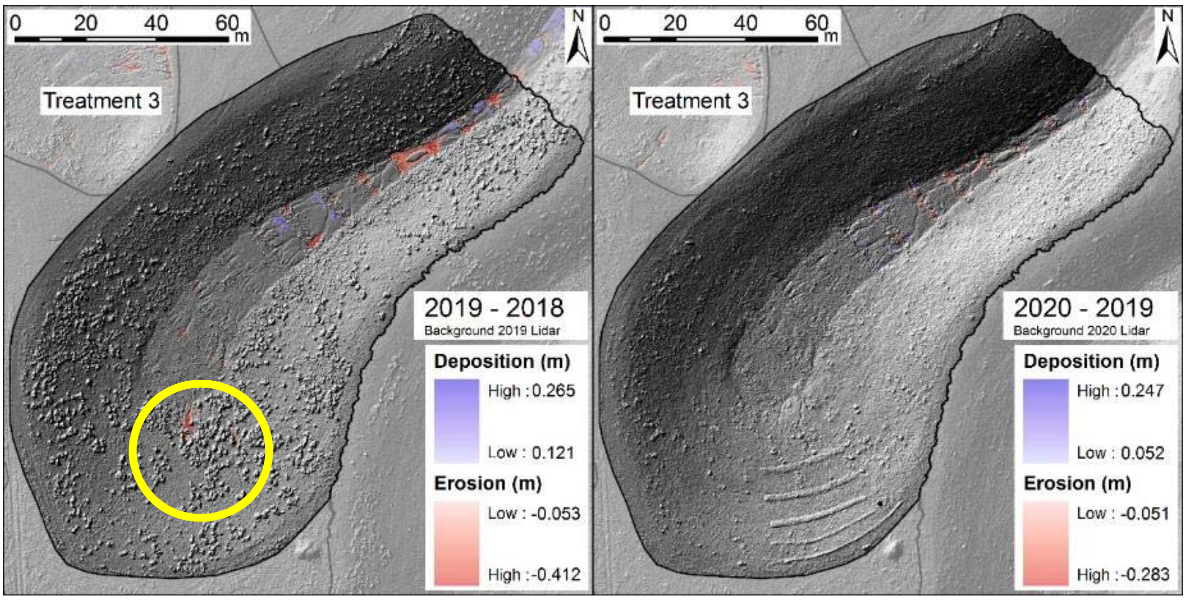

Figure 14 *Treatment 3 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)*

Plate 5
Cobble (50-150mm quarry rock) and bagasse checks installed at the location of rilling on the batter face caused by concentration of flow during intense rainfall events.

Figure 15 shows concentration of flow down long batters from a depression in the upslope surface above the batters (yellow highlight). This most often occurs where the landform design model does not adequately deal with above batter drainage slopes. If untreated this type of erosion can result in significant rills and potentially reinitiate the gully by exposing the sodic subsoil below the capping materials. The 2019-2018 image shows emergency bunds installed in December 2018 which were overtopped and failed during the intense 2019 wet season, exacerbating the issue. The problem was eventually resolved by installing adequate diversion bunds which controlled surface runoff safely down a batter chute to the gully floor (*Plates 6-8*).

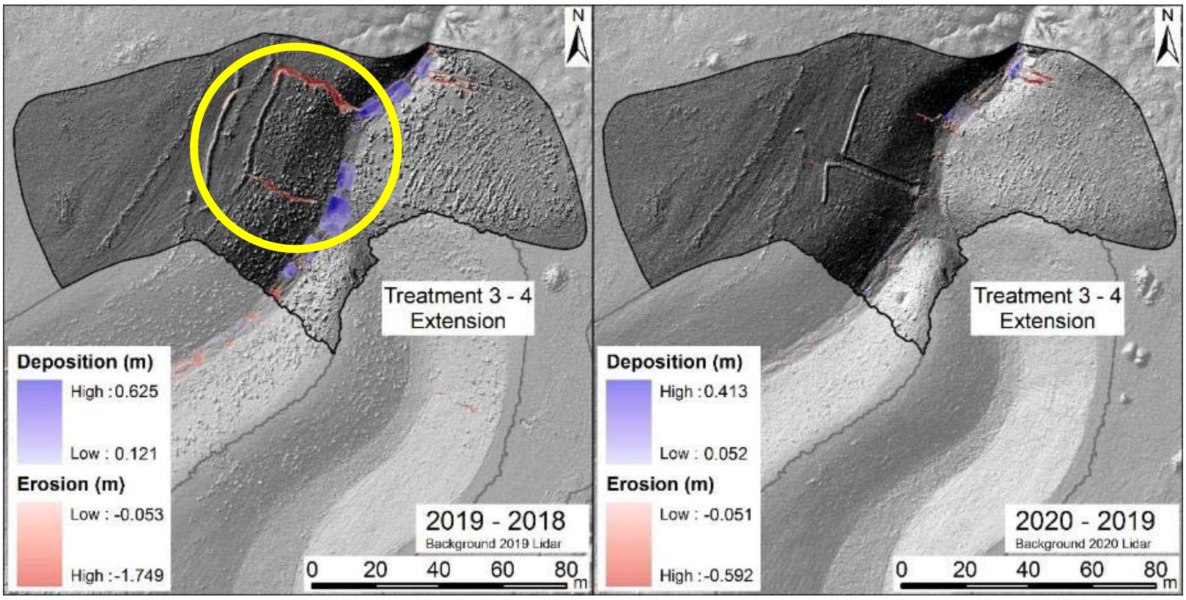

Figure 15 Treatment 3-4 extension LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)

Plate 6
Erosion on the batter face caused by failure of diversion bunds intended to disperse concentrated flow caused by a small drainage depression after earthworks.

Plate 7
Repairs of the above site underway involving the regarding of the eroded area and construction of a batter chute to take flows (diversion bunds to the throat of the batter chute not yet installed at the time of photo).

Plate 8
Repairs upon completion in August 2019

Gully floor treatments

Efforts to stabilise the catchment areas and the eroding gully scarp can affect sediment transport and, where diversions are used, increase gully flows in receiving gullies. In addition, the post-remediation flow paths are sometimes, through necessity (ie. the cut fill balance model), steeper than pre-remediation flow paths. All of these processes can result in the initiation of secondary headcuts in the channel floor as the gully system compensates.

For this reason, treatments such as porous check structures or installation of a cobble lined bed are utilised to dissipate flow energy and entrap fine sediments eroded from the catchment or batter surfaces. Over the longer term, the establishment of vegetation within the channel is also desirable and having some structural stability encourages this process.

Rock check dam structures were utilised in Treatments 2, 3, 6, 7, and 8b. The graded rock bed treatment was used in Treatments 1 and 4. Treatment 8 had a graded rock bed until midway down the channel followed by rock checks. In this case the graded rock bed was installed to deal with increased gully flows associated a diversion of catchment flows to this gully.

Of the treatments that have rock capped batters, the greatest source of ongoing erosion identified through the LiDAR analyses is that associated with scour downstream of rock check dams, or complete failure of the check dams altogether. Examples of downstream scour of the check dams are shown in Figures 16 to 18.

In Figure 16, the comparison between the 2019 and 2018 LiDAR shows erosion immediately downstream of the interface between the graded bed and the commencement of the checks, and aggradation immediately downstream The subsequent comparison between 2020 LiDAR and the 2019 data shows that the system was stable in the next season. It is typical that there is some re-organisation of sediments between rock checks that results in a stepped profile if they are functioning correctly (see Plates 9 and 10).

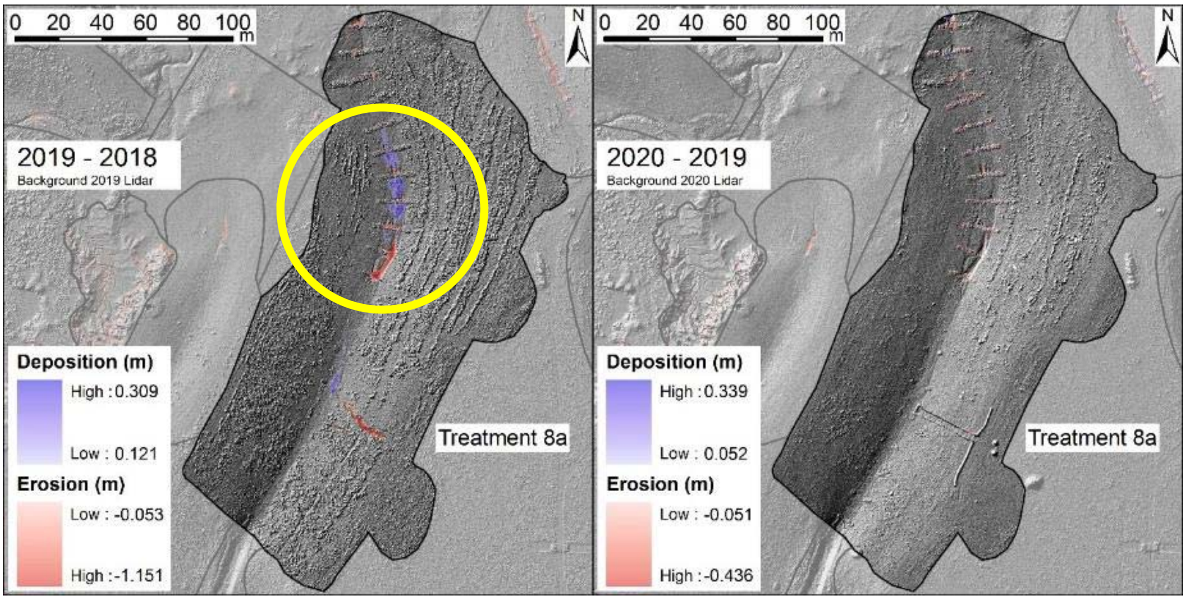

Figure 16 Treatment 8 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020).

Plate 9
Porous check dams installed in the bed of Treatment 3.

Plate 10
Approximately 200mm depth of sediment deposition behind porous check dams in Treatment 3, creating the typical stepped profile (flow from photo left to right)

Figure 17 shows the changes in the observation period at Treatment 8b. The channel here has a slope approaching 5% so the checks were spaced closely and made of larger sized rock than at any other site. Erosion has occurred over both years of observation with the primary failure of the checks being associated with undermining of their foundations (gypsum treated sodic sub-soils). Check dams may not be appropriate in such circumstances.

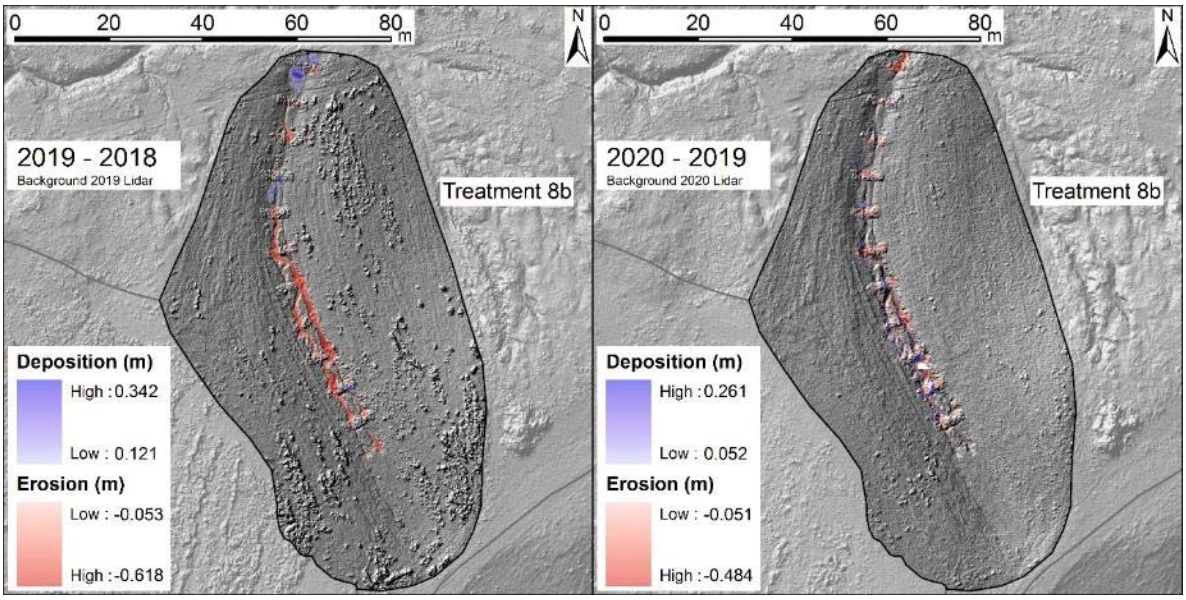

Figure 17 Treatment 8b LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)

Figure 18 shows the pre-remediation gully in May 2019 and a comparison of the post-remediation form in late 2019 and 2020. Post-remediation this gully received the catchment flows from the adjacent gullies through a diversion bund and rock chute structure. The check dams show numerous areas of erosion and deposition, associated with both scour and settlement of the structures themselves. The highlighted area is where outflanking has occurred, undermining the check dams' purpose of dissipating flows and trapping sediments and resulted in a cut to the lower batter which before repair threatened to reinitiated erosion on the batter (Plate 11).

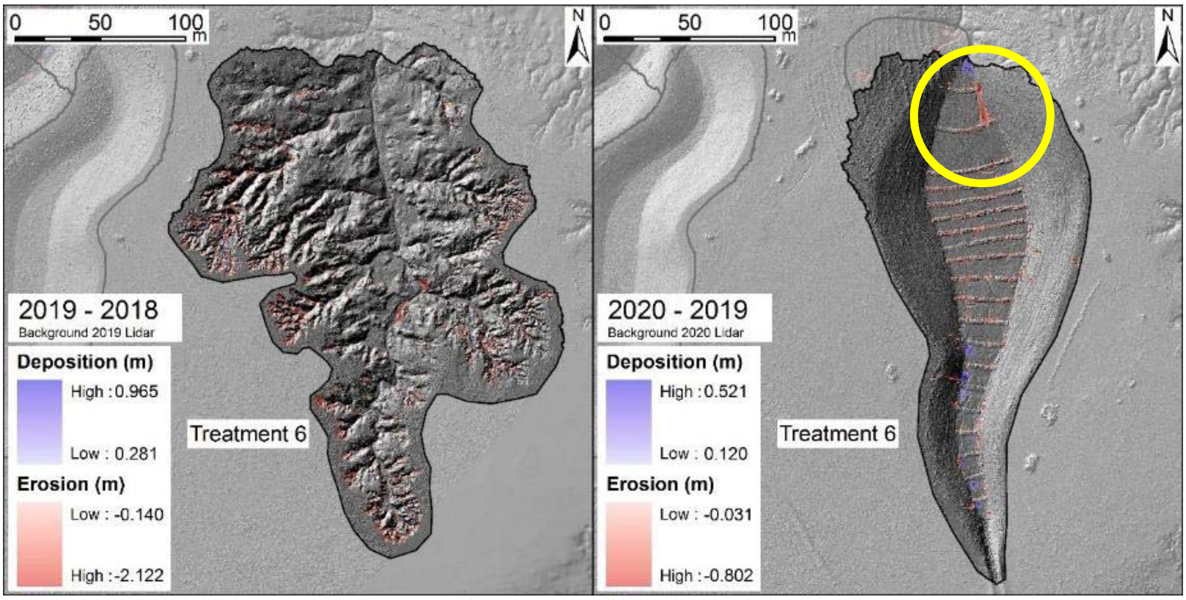

Figure 18 Treatment 6 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)

Plate 11
Outflanking of check dams at the downstream end of Treatment 6

Figure 19 shows the graded bed installed in Treatment 4. This approach is inherently stable and very efficient at trapping fine sediment. In construction terms, the cost of this treatment under this trial was only 30% more expensive than installing check dams but had the benefit of reduced long term maintenance costs. Two years post-treatment vegetation is starting to naturally recruit in the bed, including several native grass and forb species (Plate 12).

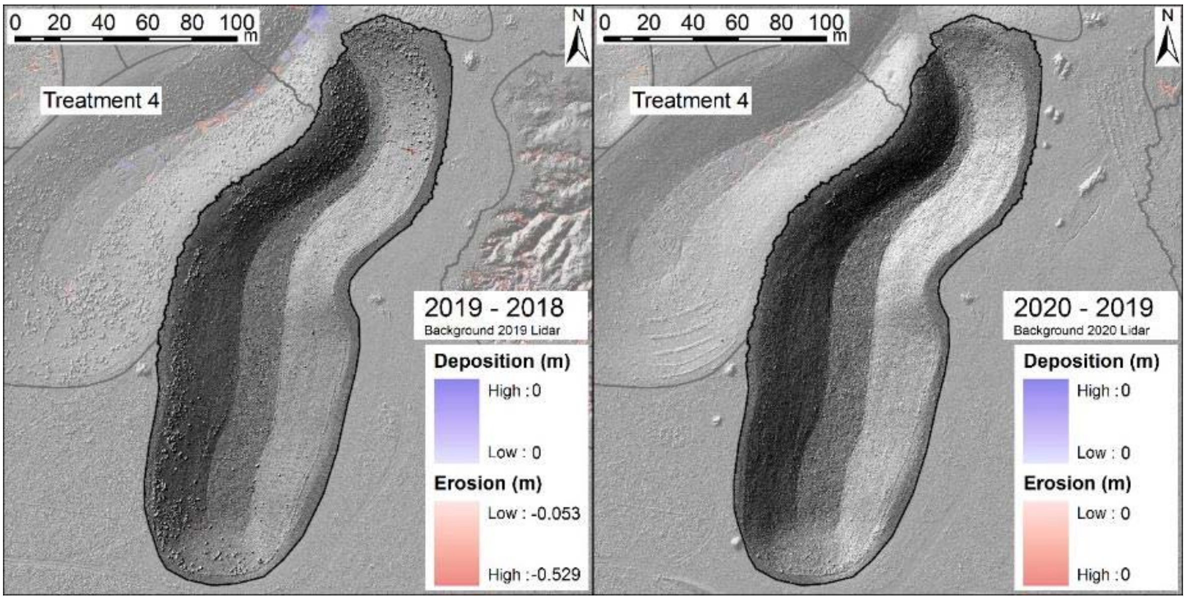

Figure 19 Treatment 4 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020)

Plate 12
Graded rock bed in Treatment 4, showing early stages of natural colonisation of vegetation

Capping material and thickness

Treatments that do not include rock capping on the batters and relied on soil amelioration using gypsum and organic matter alone, were more likely to have rills and small gullies forming on the batters. This was evident in Treatment 2 which utilised jute mesh over gypsum treated soil, and Treatment 6 which utilised gypsum treated soil and organic matter only.

Although it is early in the assessment in terms of the number of wet seasons observed, it is already evident that these treatments will require significant on-going maintenance going forward if they are to continue to abate sediment at the levels reported here. Neither the coir matting on Treatment 2 or the blanket mulch and debris and hay bunds on Treatment 6 prevented rill erosion on the batters (see Figure 20 and Plate 13 for Treatment 2).

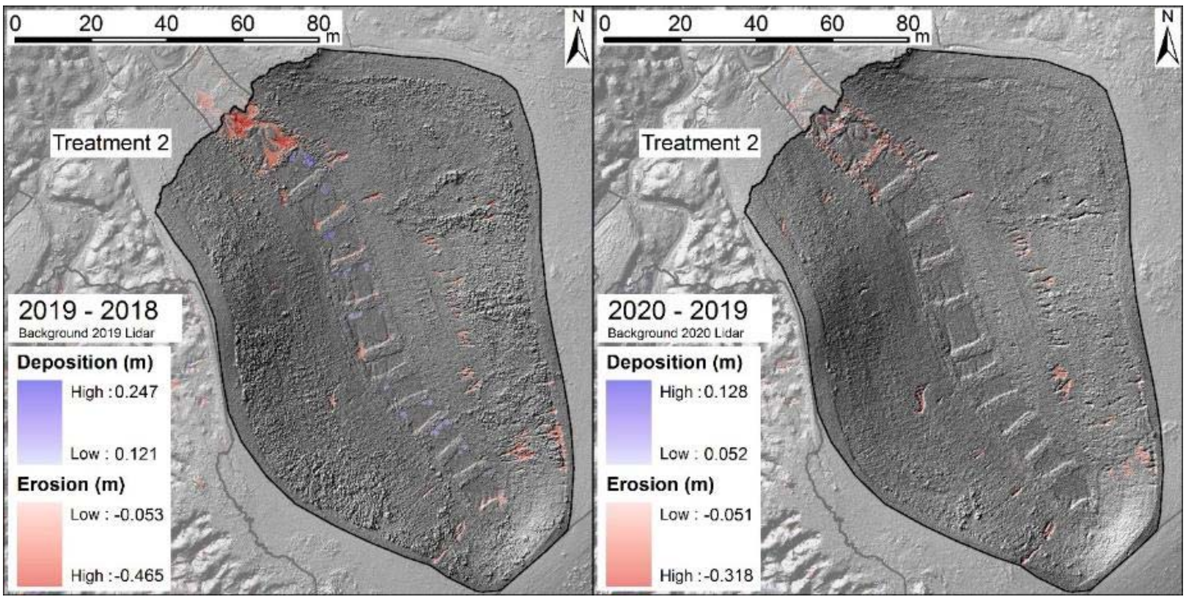

Figure 20 Treatment 2 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020).

Plate 13
Rill erosion underneath the jute mesh covers installed on the Treatment 2 batters

In contrast, the sites capped with crushed gravel (sub 50mm in size), which included Treatments 1, 3, 4, 7, 8, and 8b, were inherently stable over the monitoring period with only the previously discussed issues relating to controlling flow concentration requiring minor maintenance.

The main differentiation in the rock capped batter treatments were in Treatment 1, which had a 200mm thickness of gravel capping applied, and Treatment 7 which had the standard 100mm of gravel capping but with a further addition of 100mm of topsoil added over the top. Both these treatments are extremely stable with 99% effectiveness (see Figure 21 for Treatment 7 DEM comparisons). Both treatments had catchment inflows truncated by diversion banks. Vegetation cover is more diverse on Treatment 1 but less consistent than Treatment 7 which has almost 100% cover of exotic perennial grasses with some native and exotic herbs and forbs (Plates 14 and 15).

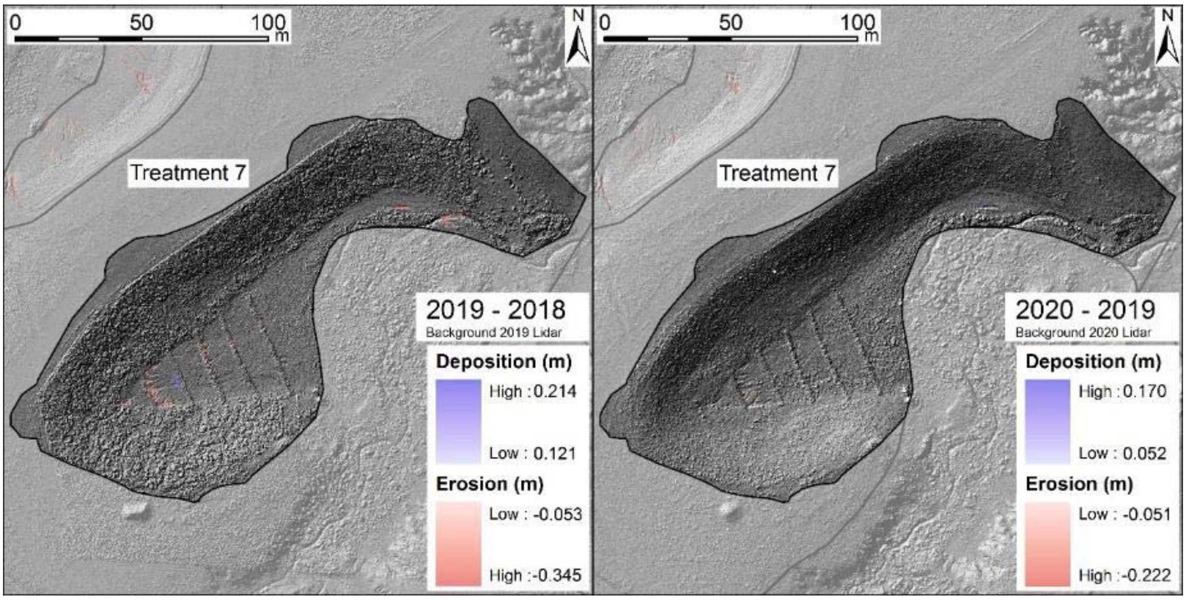

Figure 21 Treatment 7 LiDAR derived DEM of Difference showing changes over the observation periods 2018-2019 and 2019-2020 (Source: Brooks et al., 2020).

Plate 14
Treatment 7 three months after construction in December 2018

Plate 15
Treatment 7 in April 2020, 18 months post-construction

Surface Treatments

The differences in surface treatments used on the remediated gullies are sometimes subtle and to an extent represent practical trials related to applying soil ameliorants of different types over complex post-remediation landforms. The range of surface treatment trials involved the following:

- Practical methods of incorporating gypsum into regraded landforms
- Different sources of organic matter including hay mulches, compost, bagasse, and debris from gully clearing
- The uses of mulches and organic matter as flow dissipation on batters including in bunds and as blanket applications (Plates 16 and 17)
- Methods of seeding and of countering factors relating to variable germination on the final landform

Plate 16
Debris and hay bunds installed on the contour in Treatment 8

Plate 17
Grass growth in the seeded area between hay bunds

The importance of the establishment of a self-sustaining perennial vegetation system on the remediated gullies cannot be understated and it is in a large part the final amelioration of the reformed landform that will secure the sediment yield reductions associated with the earthworks. This requires attention to the soil constraints which in most cases at this site relate to very high sodicity, lack of organic matter, low fertility, and very low soil biological activity.

The treatments that have performed the best in this regard have been Treatment 7, Treatment 1, and to a lesser extent Treatments 3 and 4. It should be noted that all sites treated received gypsum incorporated to a minimum of 150mm at the rate determined through soil sample analyses, so differences in vegetation were generally related to the surface applications of mulch materials, the direct seeding methodology, and whether topsoil was utilised as part of the batter capping materials.

Interestingly, provided the substrate is stable, older treatment sites tended to exhibit significant recruitment of additional exotic and native species (see *Plates 18* and *19*). It is hypothesised therefore that the initial vegetation establishment goal should be to ensure rapid cover of the ground surface with perennial species (generally grasses but legumes and forbs are also useful) without too much concern for initial diversity.

Plate 18
Treatment 1 in August 2017 prior to treatment

Plate 19
Treatment 1 in August 2020 showing recruitment of native trees and a diversity of shrubs, forbs and some native grasses. Only exotic Sabi grass and Rhodes grass was sown at this site.

Some further observations are provided below:

- Blanket mulching with hay, though effective at reducing rill erosion on batters, can impede direct seeding success. It is also expensive to implement.
- Mulch and debris bunds are effective flow dissipation structures on long batters and allows dense ground-cover to be achieved in the interrow (Plates 16 and 17).
- Incorporation of seed into a thin mulch bed (eg. Bagasse) greatly increases direct seeding germination and establishment success (Plate 15).

Cost-effectiveness of Remediation

Economic Evaluations of Treatment Effectiveness

Milestone 7

Agreed economic evaluation plan in place

There is no currently accepted or standardised approach to the economic evaluation of alluvial gully remediation works. At the “Strathalbyn Shared Learnings” meeting organised by Department of Environment and Science in 2018 it was agreed that a standard needed development.

At the time of writing this report a number of methodologies were being developed and assessed to determine the cost-benefits of large-scale gully remediation programs in terms of their sediment reduction efficacy.

The development of these methodologies was being assisted by staff at the Queensland Department of Environment and Science, Queensland Department of Agriculture and Fisheries, CSIRO, regional NRM bodies (eg. under the Burdekin MIP project), research institutions, and the Great Barrier Reef Foundation. These are works in progress.

The consistent evaluation of projects being undertaken to reduce fine sediment export to the reef lagoon is an important component of the prioritisation of projects targeting the GBR water quality objectives. During the life of this project the focus of remediation has expanded to include bioavailable nutrient export also and the Strathalbyn water quality program has evolved to seek to answer questions in this regard. The results of the bioavailable nutrient monitoring is outside the scope of the original project brief so is not summarised here but is reported in Brooks et al (2020). The data measured during these investigations may be valuable for selecting remediation techniques which are highly successful but also least costly and which do not exacerbate other issues of importance.

There are potentially further benefits of gully remediation that are currently not being assessed but which nevertheless are tangible. These include increased land productivity, improved biodiversity and better land stewardship amongst others. These factors are outside the scope of the objectives set for this program and so are not considered further in this report.

Cost-effectiveness of the Strathalbyn IGRP Trials

The independent evaluation of the cost-effectiveness of the remediation trials at Strathalbyn has been completed by Griffith University and is reported in Brooks et al. (2020).

Cost-effectiveness of Remediation

The evaluation is based on dividing the upfront costs of each gully-specific treatment by the gully-specific fine sediment reduction (at end of system ie. potentially delivered to the reef lagoon) attributed to the remediation treatment.

“Upfront costs” are the direct costs of implementation of the treatment trials including materials, site survey, earthworks, mobilisation and demobilisation, infrastructure, water provision, works supervision, and revegetation. Total upfront costs for the ten trial sites was $2.37M in 2019 dollars.

On-going maintenance costs are not included in upfront costs but for reference purposes averaged 1.4% of total upfront costs across all treatments (*Table 12*, page 43).

The fine sediment reduction figures were determined via water quality sample data and/or, where no water quality data was available, by comparison of digital elevation data derived from high resolution repeat LiDAR. These figures are reported in tonnes of fine sediment reduced per year.

The Brooks et al. (2020) assessment uses two methods to calculate cost-effectiveness:

- CE_1 which annualises the upfront cost by dividing the total upfront costs by the expected lifespan of the treatment (estimated at 25 years for all trials undertaken) and applying a discount factor to reduce to 2019 values, and then dividing that figure by the annual fine sediment reduction. This produces a cost-effectiveness estimate expressed in $/tonne of fine sediment export reduced.
- CE_2 which simply divides the total upfront cost by the annual fine sediment reduction and produces a cost-effectiveness estimate expressed in $/tonne of fine sediment export reduced *per year*.

The CE_2 method is the most commonly used method at present being the primary method for determining cost-effectiveness in the Australian Government’s Reef Trust program amongst others.

The Griffith University assessment of the Strathalbyn gullies suggests that the use of the CE_1 method is preferable as it allows for comparisons between remediation treatments that have different lifespan expectancies. However, the prediction of the lifespan of any single treatment option is currently still somewhat speculative until longer term data on the treatments is available. Further, the cost-effectiveness values are dependent upon the choice of discount rate used.

Another variable that affects the estimation of cost-effectiveness over the predicted lifespan of the remediation trials is whether the sediment reductions measured over the initial 2-3 year monitoring period translate to the same reduction over the 25 year assessment period. Only longer-term monitoring can answer that question.

Finally, it is probable that the upfront costs associated with the Strathalbyn trials are higher than if the sites were not treated as “trials”. The necessity of maintaining a control site in the middle of the gully complex, multiple mobilisations and demobilisations over a number of years, the imperative to trial new and innovative treatment methodologies, and the focus on achieving maximum sediment reductions for each treated gully have contributed to likely higher costs than if all the gullies were treated at once with a single methodology.

Results of evaluation

The estimated cost-effectiveness of seven of treatments undertaken at Strathalbyn using both the CE_1 and CE_2 metrics is provided in Table 13. A comparison of treatments is also shown in Figures 22 and 23.

Table 13 Cost effectiveness of seven of the gully remediation treatment trials undertaken at the Strathalbyn Station Northern gully complex (adapted from Brooks et al., 2020)

Treatment	Area (ha)[13]	Upfront cost (2019 $)	Fine sediment load reduction[14]	Treatment effectiveness (%)	Cost Effectiveness CE_1[15] $/tonne	Cost Effectiveness CE_2 $/t/yr
Treatment 1	1.2	192,197	282	99.5	**65**	752
Treatment 2	1.41	183,666	187	78	**87**	1018
Treatment 3	1.77	230,893	478	97.6	**43**	501
Treatment 4[16]	2.85	323,433	708[17]	98.7	**47**	546
Treatment 5	0.3	146,055	-[18]	n/a	**n/a**	n/a
Treatment 6	5.5	633,964	679	83.8	**85**	986
Treatment 7	1.46	240,680	426	99	**50**	582
Treatment 8a	2.34	422,913	1242	97	**30**	350
Treatment 8b	0.58	-[19]	426	n/a	**n/a**	n/a
TOTALS	**17.41ha**	**$2,373,801**	**4428 t/yr**			

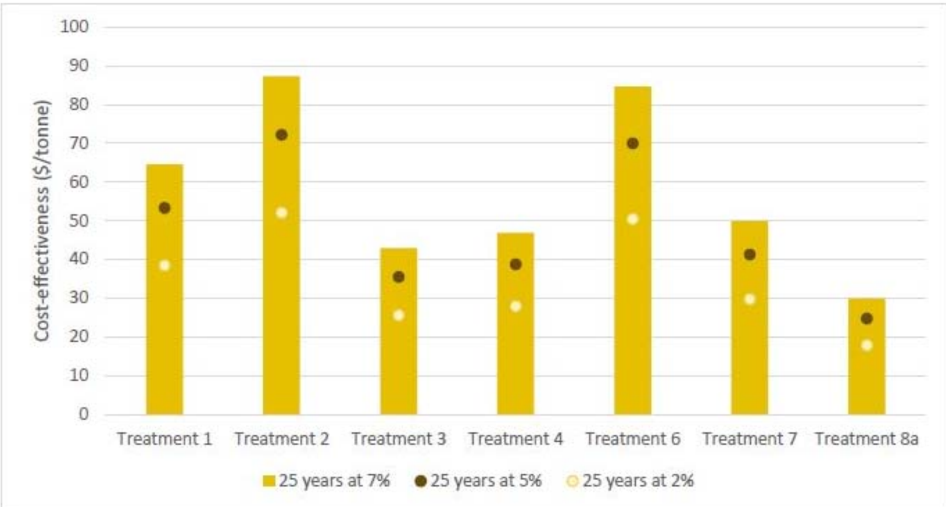

Figure 22 The end of system (GBR Lagoon) cost-effectiveness for all treatments calculated using the CE_1 methodology (Source: Brooks et al., 2020).

[13] Actual area of treatments implemented
[14] Tonnes per year at end of system ie. GBR lagoon
[15] Assumed 25 year lifespan and 7% discount rate
[16] Includes the treatment 3-4 extension area
[17] Includes reduction from T3-4 extension area
[18] Included in Treatment 8 analyses
[19] Included in T8b costs

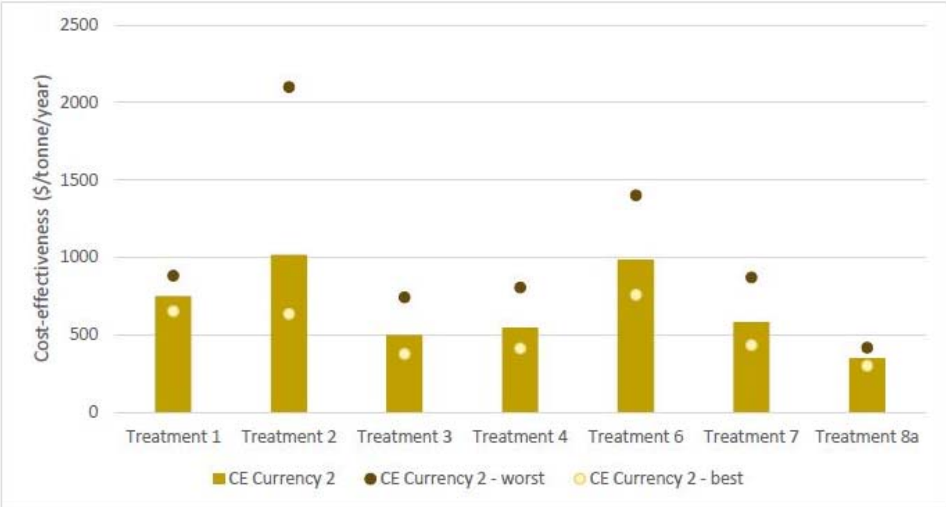

Figure 23 The end of system (GBR Lagoon) cost-effectiveness for all treatments calculated using the CE_2 methodology, analgous to the current Reef Trust method for calculating cost-effectiveness (Source: Brooks et al., 2020).

The upfront cost for all treatments implemented was $2.37 million for an annual estimated fine sediment saving to the reef lagoon of 4,428 tonnes. This equates to an upfront investment of $536 per tonne. Using an expected lifespan of the project works of 25 years and a discount rate of 7%, the average cost-effectiveness, annualised in line with the CE_1 method, was $58 per tonne (2019 value).

Least cost-effective

The data reveals some interesting anomalies. For instance, both Treatment 2 and 6 were trialed as lower-cost treatment approaches which, after earthworks, utilised only gypsum treated soils for capping and lower cost mulch and seed applications on the surface. As could be expected for lower cost trials, these two treatments have been shown in this analysis to be the two least effective treatments (between 78-84% effective). Paradoxically though, T2 and T6 are also the two most expensive trials on both the CE_1 and CE_2 cost-effectiveness measures. The explanation for this result is found in the particular circumstances of each gully.

For example, T6 was the only trial site undertaken under the program in 2019 and so contains a high proportion of mobilisation costs in its upfront cost. Additionally, the baseline sediment yield was low per hectare compared to other higher producing sediment gully systems remediated. Additionally, the gully was multi-lobed, deep, extensive and with significant tunnel erosion which increases earthworks and remediation costs.

In terms of T2, the trial was designed as a low-cost treatment that did not utilise rock capping, however topsoil had to be imported from an adjacent gully. In addition, post-earthworks labour costs associated with jute mesh installation significantly increased costs of surface treatments. Again, that gully had low base yield and combined with lower treatment effectiveness has consequently a low cost-effectiveness ratio.

This is quickly demonstrated by a comparison of T2 to T7. Both T2 and T7 were remediated under the same mobilisation in 2018. T2 is roughly equivalent in size but had almost half the base sediment export load of T7. Both trial sites have had catchment inflows diverted from the gully. T2 was designed as a low-cost treatment, but T7 was designed as an optimal treatment trial involving rock capping covered with topsoil, seeded and blanket mulched with bagasse. Although the T2 implementation cost was 76% of the implementation cost of T7, the quantity of sediment abated was only 44% of that under the T7 trial. Due to the lower base sediment yield and less effective treatment, the T2 trial was 74% less cost-effective than the T7 trial.

The lesson from these two gully treatment trials is that cost of treatment must be equated to baseline fine sediment yield with lower likely treatment effectiveness taken into account when determining the remediation budget. This may in turn affect the priority of treating low base sediment yielding gullies against higher contributing gully systems.

Other factors that affect the cost-effectiveness data relate to how costs such as mobilisation/demobilisation are spread across treatment trials in any one works year. In years where only a single site was treated (Treatment 1 in 2017 and Treatment 6 in 2019) the higher mobilisation/demobilisation costs and reduced efficiencies have made the costs of those treatments higher on average than treatments undertaken in 2018 (Treatments 2,3,4,7, and 8). This fact has implications for future work on remote sites as costs can be reduced by targeting clusters of gullies during a single mobilisation and thus improving the cost-effectiveness of all works undertaken.

Most cost-effective

In terms of the most cost-effective trial, the analyses suggests that T8 was the most cost-effective treatment undertaken ($30/tonne), followed by Treatments 3,4 and 7 ($43-50/tonne).

Essentially in each of these treatment trials was very similar with 100mm of rock capping over regraded batters treated with gypsum (including an additional 100mm topsoil on T7), mulching and seeding. The main trial differentiations at these sites were in application methods for surface ameliorants, mulching and seeding, and differentiation in bed channel treatments. All four treatments had very high effectiveness ratios over the monitoring period (97-99%) and per hectare upfront costs ranging from $113,485/Ha (T4) to $130,448/Ha (T3) to $164,849/Ha (T7) up to $180,732/Ha (T8a).

The main differentiating factor which brought the T8a treatment down to the most cost-effective treatment again was the baseline fine sediment yield from this gully. This again emphasises the importance of prioritising high baseline sediment yield gullies for large-scale alluvial gully remediation works.

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Milestone 11

Provide advice to the Great Barrier Reef Foundation on establishing a complimentary demonstration site on Cape York

Project Learnings

The most important outcome of the project is that it is clear that the gully remediation techniques demonstrated in this project are capable of achieving large reductions in point source sediment and associated particulate nutrient pollution of the Great Barrier Reef lagoon. Given that large alluvial gullies are a major contributing source of fine sediments and nutrients, it is likely that treatments such as those demonstrated through this project will play an important role in achieving the Reef 2050 water quality targets.

This section summarises some of the specific learnings from the Innovative Gully Remediation Project that may be of relevance to future projects.

Site selection and Prioritisation

This project has demonstrated that site selection influences cost effectiveness. Selecting gully systems that have high fine sediment yields will provide the greatest opportunity for sediment abatement.

Further, although gully baseline yields may broadly be related to gully area, targeting the highest yielding lobes of gullies can reduce actual treatment areas and associated costs whilst still achieving a high proportion of fine sediment abatement.

The complexity in gully systems means that attempts to attribute a cost per hectare remediation cost is too simplistic and unlikely to be useful as a prioritisation metric.

Pre-works investigations

There are some critical baseline data sets that are crucial to designing and implementing cost-effective large-scale gully remediation programs.

The following datasets are considered essential pre-works datasets:

- Soil sample analyses and field analyses in the proposed treatment area to generate nutrient, organic matter, cations, exchangeable sodium percentage, particle size distribution and bulk density information which are of use in the sediment export estimations and the remediation designs
- Ground-controlled LiDAR or drone land surface models to assist in estimating erosion rates and gross sediment export, and of later use in designing earthworks cut and fill programs

Design

The design of the earthworks component of large scale remediation programs is an iterative process whereby the cut and fill quantities are balanced to avoid having an excess stockpile or insufficient soil to construct the design (necessitating importing material often a great cost). This is a specialist field of remediation design in which skilled surveyors or engineers are often indispensable.

The main factors which affect costs in the design are the bulk quantities, the proximity of the cut to fill locations, and the final shape and steepness of the batters and channel (which affect subsequent costs which surface amelioration and treatments).

It stands to reason then that careful attention is paid to these three factors if cost-effective designs are to be implemented.

The designs used in this trial have all been site specific and based upon resources available at this site. They are not recipes for use at other project sites with different constraints and opportunities.

Monitoring

Monitoring water quality parameters in runoff in remote and generally inaccessible gullies has significant challenges, is expensive, often frustrating, and gives mixed results. It is however important for determining baseline sediment concentration estimates for post- treatment concentration comparisons. Deriving accurate stormwater discharge though is difficult and this program has shown some of the limitation of trying to collect this information in both control and remediated gully environments. It is possible that utilising flumes or specifically tailored designs at the outlets of gullies will resolve some of the sampling issues. Flumes are currently being trialled under GBRF funded programs at Strathalbyn.

The assessment of volumetric change using multitemporal LiDAR derived DEMs is in comparison inexpensive and considerably easier. Issues related to noise in the LiDAR datasets can be resolved using expert approaches developed during this project, however some of the changes that occur between time periods are within the limits of detection of the technology. These analyses are however very good at picking up changes in the gully bed and rilling of the batter surfaces which can assist in identifying maintenance issues and also help quantify the changes to the actual fine sediment abatement over time.

The volumetric analyses are likely to be extremely useful over time. Longer term datasets may help to validate the assumptions of how long these treatments will actually last, what level of maintenance is required and how frequently, and whether the estimated fine sediment abatement figures are enduring or overestimated.

Treatment Efficiencies and Logistics

The treatments undertaken in this project were experimental and due to factors related to project governance were required to be implemented over three successive dry seasons. The staged implementation has affected cost-effectiveness by allocating higher mobilisation costs against the years where fewer treatments were implemented (two treatments in 2017, one treatment in 2019) as opposed to 2018 where seven treatments were implemented.

To improve cost-effectiveness, it is generally more efficient to undertake gully remediation in close clusters with as few mobilisations as possible.

This project also made use of an on-farm quarry resource. This was not a quick decision and was the result of assessing several alternative options. In the end the steering committee settled on the quarry option as it was able to provide the best quality materials for remediation, with the lowest impact, and at a very low development cost compared to the alternatives.

The availability and use of on-site materials is a very important factor to consider during site investigations and design as the costs associated with importing materials to site can markedly increase construction costs and thus reduce cost-effectiveness.

Cost-effectiveness

The cost-effectiveness methodologies used to evaluate the treatments in this program add to the pool of knowledge on cost-effective approaches to fine sediment abatement to improve water quality of the GBR.

The CE_1 approach is an improvement on the standard methodologies used in many existing programs as it annualises the upfront costs based on assumed lifespans of the treatments. This contrasts with other methodologies which simply state the upfront cost divided by the estimated fine sediment abatement (however calculated). However, for the CE1 approach to be useful as a comparative tool, it would be necessary to adopt a standardised discount rate and standardised expected lifespan for certain treatment options or combinations. This data is not currently available and is unlikely to be available for at least another decade.

The other assumption in all current cost-effectiveness measures is that the sediment abatement continues at the same rate as measured in the initial period. This obviously dependent on many factors including sympathetic land management, maintenance and other legacy issues.

Maintenance/Legacy Issues/Future funding programs

The maintenance costs incurred under this program are to date very low at 1.4% of overall implementation costs. However, it is clear that some treatments require more frequent and more interventionist maintenance than others.

Given that the project has assessed its cost effectiveness on a 25 year time scale, it is appropriate to consider which treatments will require the most maintenance over that period. The maintenance costs in Table 12 give some indication.

Landholder agreements, funding programs, and even NRM organisations typically do not cover periods anywhere near the project lifespans assumed in the cost-effectiveness calculations.

For this reason, any new innovations in environmental markets that provide mechanisms for incentivising the maintenance of completed remediation treatments are a useful development, provided that is what they achieve.

Communications and Media

Communication of the project's progress and outcomes has been guided by the *Communications and Engagement Strategy 2017-2020* (Greening Australia, 2017). The strategy was adopted by the project steering group in June 2017.

It has been an important component of the project to engage with and communicate to stakeholders and the broader community about the project's objectives. In general, the approach has been to explain the rationale for the project, the approaches being implemented to resolve the problem, the contributions of the parties involved, and the outcomes of the project particularly any learnings from the techniques used to rehabilitate eroding gullies and methods used to evaluate their cost-benefit.

The mechanisms used included:

- Project reports, documents and communiques, many available online at https://www.greeningaustralia.org.au/projects/rebuilding-eroding-land-2/
- Field days, conferences, symposiums and workshops
- Traditional media releases
- Online content including web links and social media updates
- Donor tours
- Project Awards

Project Reports and Documents

A summary of the main reports and documents produced as part of the Innovative Gully Remediation Project is provided below:

- *Preliminary Assessment of Alluvial Gully Systems on Strathalbyn Station*. Brooks et al, 2017
- *Innovative Gully Remediation Project Communications and Engagement Strategy 2017-2020*. Greening Australia 2017
- *Innovative Gully Remediation Project Forum Outcomes Report*. Telfer 2018
- *Innovative Gully Remediation Project Monitoring and Evaluation Plan*. Telfer 2018
- *Innovative Gully Remediation Project – Strathalbyn Station Gully Remediation Works Update Report*. Telfer 2019
- *An assessment of gully sediment yields on Bonnie Doon Creek, Strathalbyn Station*. Daley et al., 2020.
- *Monitoring the effectiveness of Alluvial Gully Erosion Remediation at Strathalbyn Station*. Brooks et al, 2020
- *Innovative Gully Remediation Project Final Synthesis report* (this document), Telfer 2021

Milestone 4

Produce a communication strategy

Milestone 12

Ongoing communications of outcomes from the project, including visualisations, videos, demonstration days, etc.

Milestone 12

Ongoing communications of outcomes from the project, including visualisations, videos, demonstration days, etc.

Please see the Reference section for further detail. A number of these documents are available on the Greening Australia website. Links are provided in the References where available.

Apart from these publicly available documents, a number of internal documents were produced relating the project governance and delivery. These included an internal project delivery plan, numerous documents prepared for the project steering group to help guide the implementation of project, and regular updates on the project's progress against the milestones.

Communiques

The regular release of Communiques was a primary method of keeping stakeholders informed of the project's progress during the implementation phase. These included:

- *Communique #1: Innovative Gully Remediation Project Forum Outcomes*. April 2018
- *Communique #2: Project Update.* May 2018
- *Communique #3: Post Works Monitoring Outcomes.* November 2019
- *Communique #4: Project Update.* June 2020
- *Communique #5: Best Practice in Large-scale Gully Remediation* (in development)

Communiques have been distributed in PDF format via an email list and also made available from the Greening Australia website.

For the first three communiques, the mailing list exceeded 85 recipients, with an excellent open rate above 52% for all three. The audience increased for Communique 4 to more than 120 recipients.

Further communiques will summarise results from the monitoring and evaluation plan and this report.

Field days, Conferences, Symposiums and Workshops

- 8th International Symposium on Gully Erosion 21-27 July , 2019: hosted 37 delegates from across the world on a tour of the Strathalbyn field site as part of the post-conference field trip
- Presentation/demonstration to the Stomping the Sediment Field Day (NQ Dry Tropics)
- Innovative Gully Remediation Project Forum, 2017
- Strathalbyn Shared Learnings Workshop in Townsville, 2018
- Presentations to the Reef Trust Erosion Control Forum in Cairns, 2018; in Mackay, 2019, and on-line in 2020.

- 8th International Symposium on Gully Erosion 21-27 July, 2019 'Innovative Gully Project – finding cost effective and scalable solutions to reduce sediment into the Great Barrier Reef'
- 9th Australian Stream Management Conference 12-15 August, 2018 (also peer reviewed published paper) 'Innovative Solutions to alluvial gully remediation: a case study from the Great Barrier Reef Catchments'
- GBR Reef Restoration Conference – Cairns 16-19 July 2018. Reef Aid – 'Innovative restoration techniques in priority catchments to improve water quality on the Great Barrier Reef
- Society of Ecological Restoration Conference: Brisbane 25-28 September 2018. 'Reef Aid Restoration of wetlands and gullies in priority catchments to improve water quality in the Great Barrier Reef'
- Private Landholders Conservation Conference – Brisbane – joint presentation with landholder Bristow Hughes 24-26 October 2018 'Reef Aid Innovative Solutions for alluvial gully remediation to improve water quality onto the Great Barrier Reef'

Media Releases

Over the life of the project, more than 80 media items referenced the Strathalbyn project. There was coverage in publications such as The Guardian, Sydney Morning Herald, The Age, Brisbane Times, WAtoday, and the Canberra Times; on ABC Radio National, SBS Radio; on television on Nine Queensland and Channel 7; and on CNN television in America. Web analytics predicted a potential reach of 71 million viewers.

The project also gained mentions in key regional and agriculture-focused publications including Queensland Country Life, Stock Journal, The Land, Farm Online, Beef Central and the North Queensland Register.

Online Content

The main online content supporting the project has been the landing page on Greening Australia's website: https://www.greeningaustralia.org.au/projects/rebuilding-eroding-land-2/

This page has received over 2,800 pageviews in its lifetime, and has been gradually updated with links to publications (such as the communiques) as works have progressed.

Social media posts (Facebook, Instagram, Twitter, LinkedIn), owned web articles and items in Greening Australia's monthly newsletter, The Leaf, have featured updates on the gully works at Strathalbyn and assisted in driving traffic to the website, together with the dedicated communique mailing list.

Donor tours

Donor Tour Monday 15th May 2017 – 6 donors and stakeholders visited the Strathalbyn site together with Greening Australia board directors and staff. They met landholder Bristow Hughes and inspected the project site. Donors were given a tour of the project site by Damon Telfer and Greening Australia CEO Brendan Foran.

Donor Tour Wednesday 16th May 2018 - 12 donors and stakeholders visited the Strathalbyn site, spoke to landholder Bristow Hughes and inspected the project site. Donors were given a tour by Damon Telfer and Greening Australia CEO Brendan Foran and Reef Aid Director Lynise Wearne.

Donor Tour Monday 20th May 2019 - 10 donors and stakeholders toured the Reef Aid projects site including Strathalbyn Station. Donors again were given a tour by Reef Aid Director Lynise Wearne, Damon Telfer and Greening Australia CEO Brendan Foran and met the landholder Bristow Hughes and his family on site.

Sukin and Greening Australia Influencer Tour 15-16 August 2019 – Reef Aid Director and other Greening Australia staff took three 'eco' social influencers and Sukin staff on a tour of Reef Aid project sites, including the gully works at Strathalbyn Station. The three Instagram influencers shared posts on their experiences with their large online followings.

Project Awards

- Banksia Sustainability Awards - Minister's Award for the Environment 2018 – Reef Aid – while the award was for the Reef Aid program overall, the achievements at Strathalbyn Station were a significant part of the successful nomination and a presentation on the project was given at the awards ceremony
- Premier's Awards for Excellence 2019 – Create jobs in a Strong Economy - Commendation (2nd place)
- Premier's Awards for Excellence 2019 – Protect the Great Barrier Reef - WINNER
- Premier's Awards for Excellence 2019 – Premiers Award for Excellence - WINNER (overall winner)

Plate 20 The Innovative Gully Remediation Project team with the Premier at the Queensland Government's Premier's Awards for Excellence. Photo credit Queensland Government.

Co-funding Outcomes

A key deliverable of the Innovative Gully Project was the cofounding requirement of $2M to be provided from Greening Australia. Through Greening Australia's philanthropic team, a total of $2,024,696.79 was raised from a variety of national and internal private foundations and corporation as well as individual donors, all of whom without this funding the project would not have been possible. This included:

- Prior Family Foundation
- Sukin
- Tiffany and Co Foundation
- Portland house
- Yulgibar foundation
- PurryBurry Trust
- Give2Asia USA
- Garry White Foundation
- Norman Family
- Paul. M. Angell Family Foundation
- over 100 web donors.

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Supporting documents

- The Innovative Gully Remediation Project Plan which details the essential delivery steps required to meet the project objectives as agreed by the funding parties in the collaborative agreement, unpublished, Greening Australia, 2017.
- The requirements of the Paddock to Reef program as detailed in the Grazing WQ Risk Framework 2018
- The Innovative Gully Remediation Project Collaborative Agreement.
- DES (2018) *Department of Environment and Science Appendix B MERI Plans v1* (dated 29 June 2018), unpublished guideline produced by the Queensland Government Office of Great Barrier Reef.