Innovative solutions to alluvial gully remediation: a case study from the Great Barrier Reef Catchments

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Key Points

- A key conclusion from the Scientific Consensus Statement (2017) is that fine sediment is one of the greatest water quality threats to the Great Barrier Reef(GBR)
- Almost half of the suspended sediment load to the GBR comes from the Burdekin catchment
- Significantly almost 2/3rd of this load is contributed from the Bowen and Bogie catchments, which represent less than a 10th of the Burdekin catchment area
- For this reason, tackling alluvial gully erosion in the East Burdekin, Bowen, and Bogie catchments is essential if fine sediment export from gullies to the reef is to be reduced
- There is a need to develop cost effective and scalable options for the remediation of alluvial gully systems that can be replicated in other areas of the Burdekin and within other Great Barrier Reef catchments.

Abstract

The Innovative Gully Remediation Project is a collaborative project supported by the Queensland Government's Reef Innovation Fund and Greening Australia's Reef Aid Program. The purpose of this collaboration is to develop cost effective and scalable options of alluvial gully systems that can be replicated in other areas of the Burdekin and Great Barrier Reef catchments. Priority alluvial gully areas in the East Burdekin are the focus of the current project. These gullies have been found to have exported on average 956 tonnes per hectares since 1945, equating to 550,000 tonnes of sediment, of which 65% is capable of suspension and delivery to the reef lagoon. The Innovative Gully Remediation Project is trialing different techniques for gully remediation on at least 8 treatment sites (across 150ha). A range of monitoring techniques have been implemented 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. Phase 1 works were competed in 2017, and the initial results showed a great than 97% reduction in suspended sediment concentration between treated and untreated alluvial gullies. The current paper presents these initial findings and discusses the implementation of Phase 2 works to be undertaken as part of Greening Australia's Reef Aid program.

Keywords

Alluvial gully erosion, suspended sediment load, Burdekin catchment, Great Barrier Reef

Introduction

The Great Barrier Reef (GBR) Marine Park covers 34 million hectares in area along a 2,300 km stretch of the Queensland coast. The Great Barrier Reef Catchment, comprising 35 separate drainage basins, covers an area of 42 million hectares and drains directly into the Great Barrier Reef lagoon. As detailed in the 2017 Scientific Consensus Statement, many of the Great Barrier Reef ecosystems continue to be in poor condition caused by

an interaction between climate and other stressors. While climate change remains the most serious threat to the Great Barrier Reef as demonstrated by recent large scale coral bleaching events in 2016 and 2017, it is the cumulation of stressors which can influence the resilience and recovery of the reef (Waterhouse *et al*. 2017).

Of all these stressors, poor water quality is understood to be the greatest local threat to the future of the Great Barrier Reef beyond climate change. There is considerable evidence that sediment and associated nutrients can affect the recovery potential of inland coral reef communities following storms, floods and bleaching events (Woolridge 2009). In the face of global climate change, improvement in water quality is one stress which can be managed within the timeframes required to enable the GBR time to adapt to the impacts related to climate change (Woolridge *et al.* 2009).

While there has been considerable investment in improving water quality and land management practices. According to the 2017 Scientific Consensus Statement on the Great Barrier Reef, the current business as usual approach to land management practice change will not be sufficient to address the poor water quality issues facing the Reef. There needs to be an acceleration and targeting of restoration efforts. Extensive research and mapping has been undertaken over many years to determine the highest priority sediment and nutrient hotspots that contribute the majority of sediment and nutrients to the Reef. From this information it has been determined that large alluvial gullies are one of the most connected sources of fine sediment, delivering sediment in many cases directly into the mainstream channels of the largest rivers draining to the reef (Wilkinson *et al.* 2013; Garzon-Garcia *et al*., 2016). The two largest drainage basins, the Fitzroy and the Burdekin, represent 64% of the total Great Barrier Reef Catchment Area. These two catchments contribute the greatest amount of fine sediments and nutrients to the Great Barrier Reef's shallow waters and is the core focus area for the Reef Aid initiative.

The Burdekin River (catchment area ~ 130,000 km2), the focus of the current Project, is estimated to deliver about 47% of the total suspended sediment load to the GBR (Waters et al., 2013), some of which is contributing directly to the Crown of Thorns Starfish (COTS) initiation zone to the north of Cairns. It is documented that around 2000ha of alluvial gullies adjacent to the lower Bowen River in the Burdekin catchment are responsible for an estimated 30% of the entire fine sediment load to the GBR lagoon (A. Brooks pers comm., 2017). These priority areas are considered to be 'hotspots' as sources of sediment, but also key areas to focus gully remediation works be deliver the biggest sediment reductions.

Previous studies have demonstrated through a series of plot-scale trials within the Normanby catchment that erosion rates can be reduced by as much as 80% over a few years with the appropriate treatment of the dispersive alluvial soils (Shellberg and Brooks., 2013; Brooks *et al.*, 2016). However, these plot scale trials now need to be upscaled to complete alluvial gully complexes and different treatments tested at the whole of gully scale to ensure that the sort of results achieved at the plot scale can be replicated at the gully complex scale. The current Project is focused within the Burdekin catchment, and trialing a range of gully remediation treatments at the whole of gully scale. The focus of the Project is on Strathalbyn Station which alone has contributed approximately 300,000 tonnes of sediment to the reef, significantly reducing water quality.

Work completed by Cape York NRM, Queensland Department of Environmental and Science (DES), Griffith University and others have identified the current gaps in knowledge with regards to stabilising alluvial gully systems in the GBR catchments. This project will address these knowledge gaps and will assist in communicating innovative approaches, mechanisms, and techniques that are cost-effective and able to be delivered at scale.

The Innovative Gully Remediation Project

Greening Australia is leading a systems repair innovation project in the Burdekin / Bowen Catchment to develop a 150ha gully restoration permanent demonstration site. The demonstration site is located at one of the most downstream and largest alluvial gully sites in the Burdekin River catchment. This project is trialing restoration of heavily eroded alluvial gullies at a large scale with the outcome of confirming the most cost-effective methodologies for wider gully repair across the catchment, one of the major contributors of sediment to the reef. The project commenced in 2017 and will be completed in 2020.

The *Innovative Gully Remediation Project* (referred to as the Project) is a collaborative project supported by the Queensland Government's *Reef Innovation Fund* and Greening Australia's *Reef Aid*™ Program.

Specific objectives to be undertaken during the project include:

- Trialing different techniques for gully remediation on at least 8 treatments sites (across 150ha);
- Trialing innovative monitoring techniques to determine sediment and particulate nutrient loads to the Great Barrier Reef and the costs of achieving those reductions based on different interventions;
- Harness innovative ideas and facilitate cross boundary interactions and fresh thinking to tackle the challenge of gully erosion

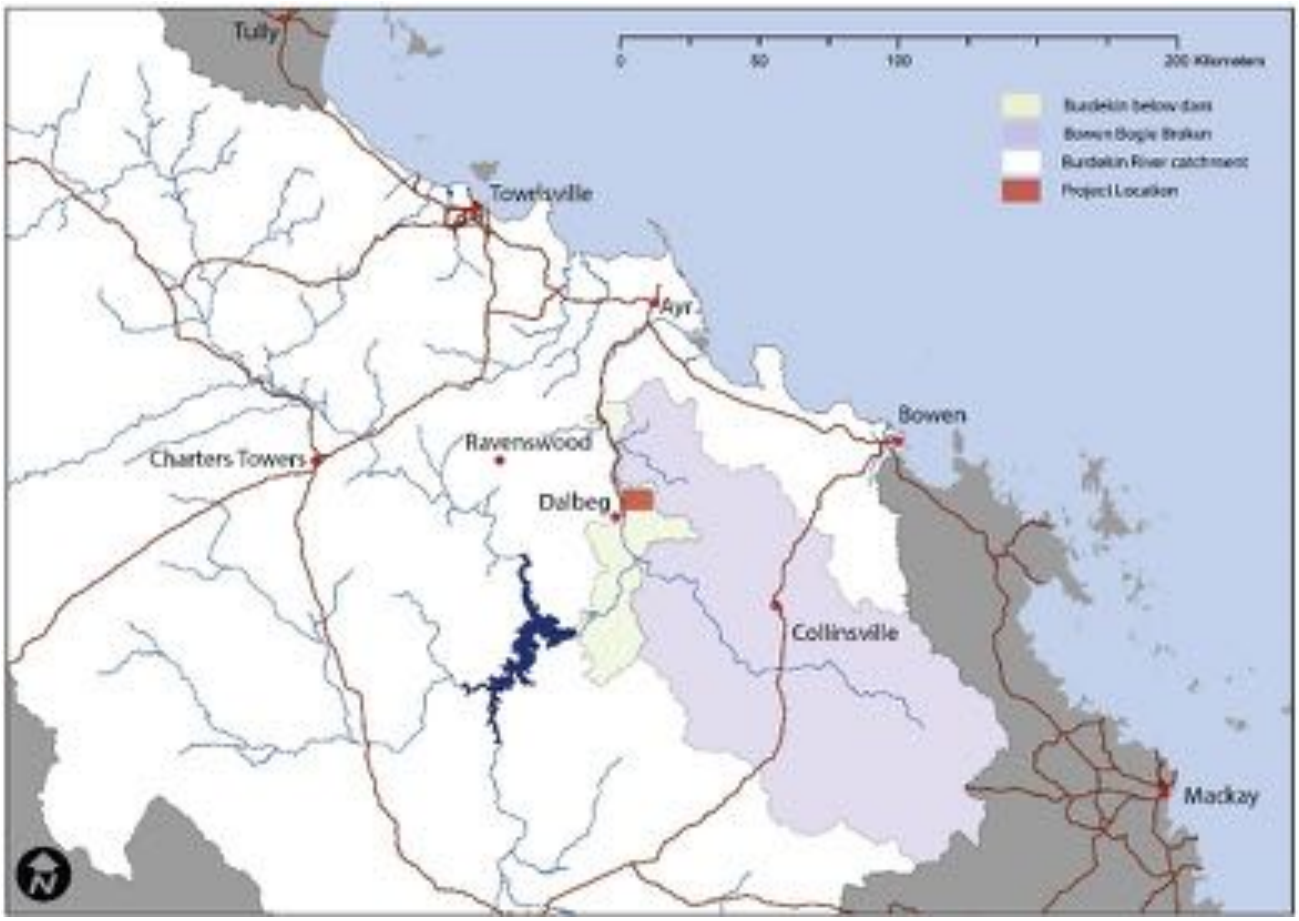
Project location and background

The Project site is at Strathalbyn Station, 45km north-west of Collinsville and 60km due south of Ayr, located in the East Burdekin catchment on the eastern bank of the Burdekin River (**Figure 1**). The Strathalbyn Station project area contains 64.68 ha of gullies, 32.44 km of gully scarp and 8.66 km of gullies in length. An analysis of gully scarp area to catchment size as derived from the LiDAR generated DEM reveals that gully area is not directly related to gully catchment area. The size of gully complexes ranges from 1-5ha with some systems occupying almost the entire catchment area.

Gullies have likely initially evolved by eroding laterally away from the Bonnie Doon Creek drainage line. A reconstructed surface investigation revealed that gullying has heavily incised the 'paleo-swales' on the terrace adjacent to Bonnie Doon Creek. Some lobes are more incised than others within the same gully network.

Analysis of sub-set of 52 gully complexes within the Bonnie Creek catchment on Strathalbyn Station demonstrated that these gullies have clearly been initiated within the last 100 – 150 years, coincident with the commencement of grazing in this region. Recent research reveals that in the vicinity of 300,000 tonnes of sediment has been exported to the reef from the 60 hectares of alluvial gullies that make up the Strathalbyn project area (Brooks *et al*. 2017).

Figure 1 Project Location



Methods

Gully Classification and defining

Initial analysis undertaken through Griffith University as part of the Project (Brooks *et al*. 2017) involved the analysis of high resolution aerial LiDAR data, soil analysis and the identification and classification of major gully complexes within the Project area. This resulted in the identification of the main gully systems which have the highest potential for demonstrating the success of potential treatments in reducing fine sediment export form the Project Area.

From this work, three distinct groups of alluvial gully systems were identified (**Figure 2**):
1. The Northern Gully Complex
2. The Central Gully Complex
3. The Southeast Gully Complex
4. The Southern Gully Complex

Only the works being undertaken within the Northern Gully Complex form the basis for the current paper. An example of these gullies is shown in **Plate 1**. According to the existing soil mapping, the northern gully complex is eroding into both the duplex and cracking clays, and the fifth gully on the Northern Gully Complex is eroding into the cracking clays.

Figure 2 Gully Complex Classification – Project Sites

Plate 1 Example of the Northern Gully complex the focus of the current Project

On ground works

Eight eroded farmland trial sites with different soil erosion treatments and two eroded farmland control sites have been established on Strathalbyn station within the Northern Gully Complex (**Figure 3**). The eight different treatments include:

Treatment 1: Earthworks to reshape and regrade approximately 1.2ha of heavily incised alluvial gully, followed by soil amelioration using 18t per hectare of gypsum, construction of a graded rock bed, capping of disturbed soils and batters, mulching using Rhodes grass hay, and seeding (Completed December 2017)

Treatments 2: Earthworks to reshape and regrade approximately 1.41ha of heavily incised alluvial gully, gypsum, rock capping upslope and lower 1.5m of batters only, placement for stripped topsoil from Treatment 3 and 4 on batters, compost application, Jute mesh, mulch batters and upslope areas, seed, grazing management as part of the exiting paddock rotation

Treatments 3: Earthworks to reshape and regrade approximately 1.8ha of heavily incised alluvial gully, gypsum, rock/soil capping of batters 100mm, seeding, mulching, short duration high intensity grazing once per year, within gully check dams. Integrated water quality monitoring point.

Treatment 4: Earthworks to reshape and regrade approximately 2.5ha of heavily incised alluvial gully, gypsum, rock/soil capping of batters and upslopes 100mm, graded rock bed, seeding, mulching, stock exclusion. Integrated water quality monitoring point.

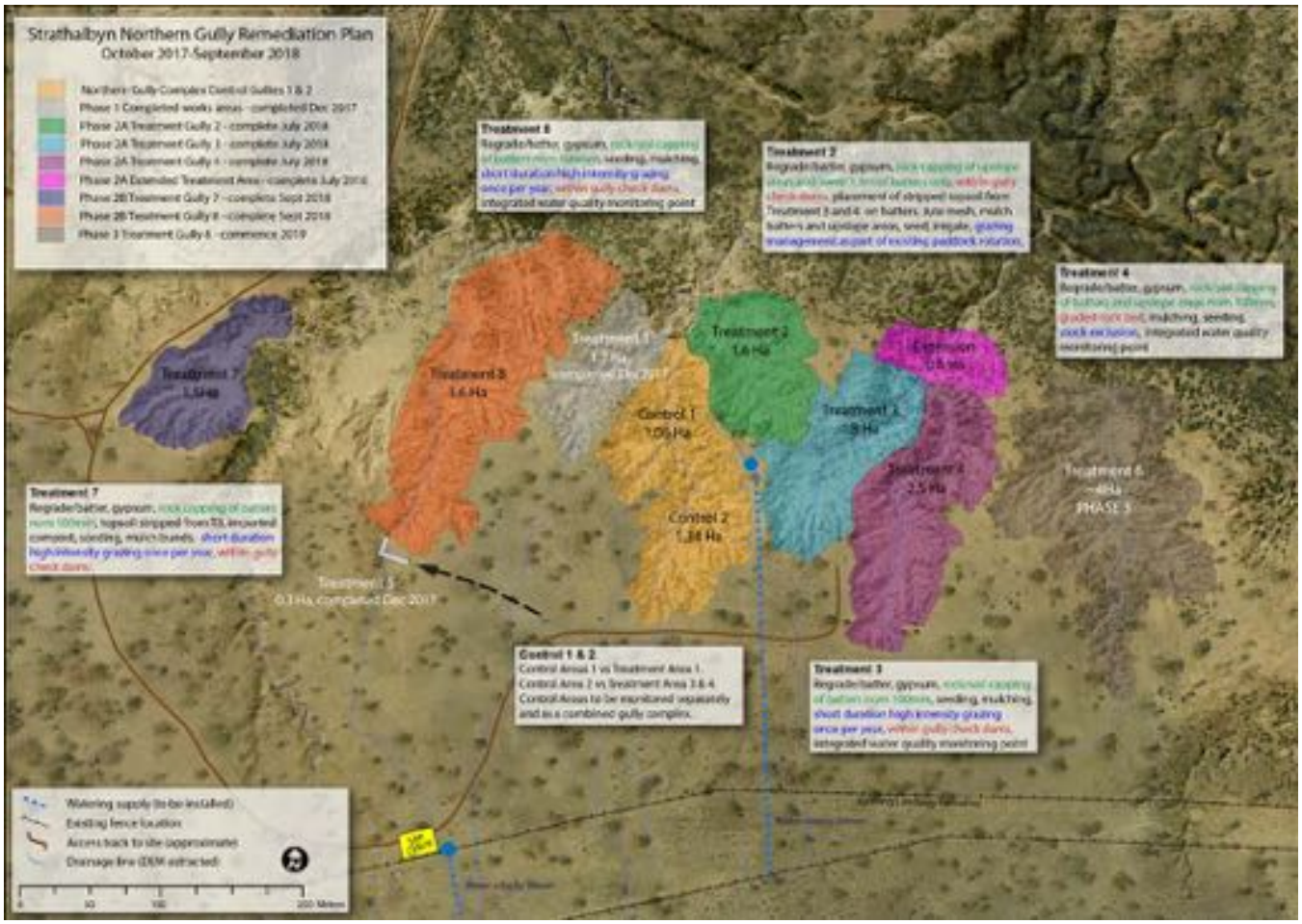
Treatment 5: Construction of a rock chute over a rapidly retreating gully knickpoint and partial diversion of catchment flows from Treatment 1 down through the chute structure (Completed December 2017)

Treatment 6: To be determined based on completed work at the end of 2018

Treatment 7: Earthworks to reshape and regrade approximately 1.5ha of heavily incised alluvial gully, gypsum, rock/soil capping of batters 100mm, topsoil stripped from Treatment 8, imported compost, seeding, mulch bunds, short duration high intensity grazing once per year, within gully check dams.

Treatment 8: Earthworks to reshape and regrade approximately 3.6ha of heavily incised alluvial gully, gypsum, rock/soil capping of batters 100mm, seeding, mulching, short duration high intensity grazing once per year, within gully check dams. Integrated water quality monitoring point.

Figure 3 Innovative Gully Project Treatments and sampling locations



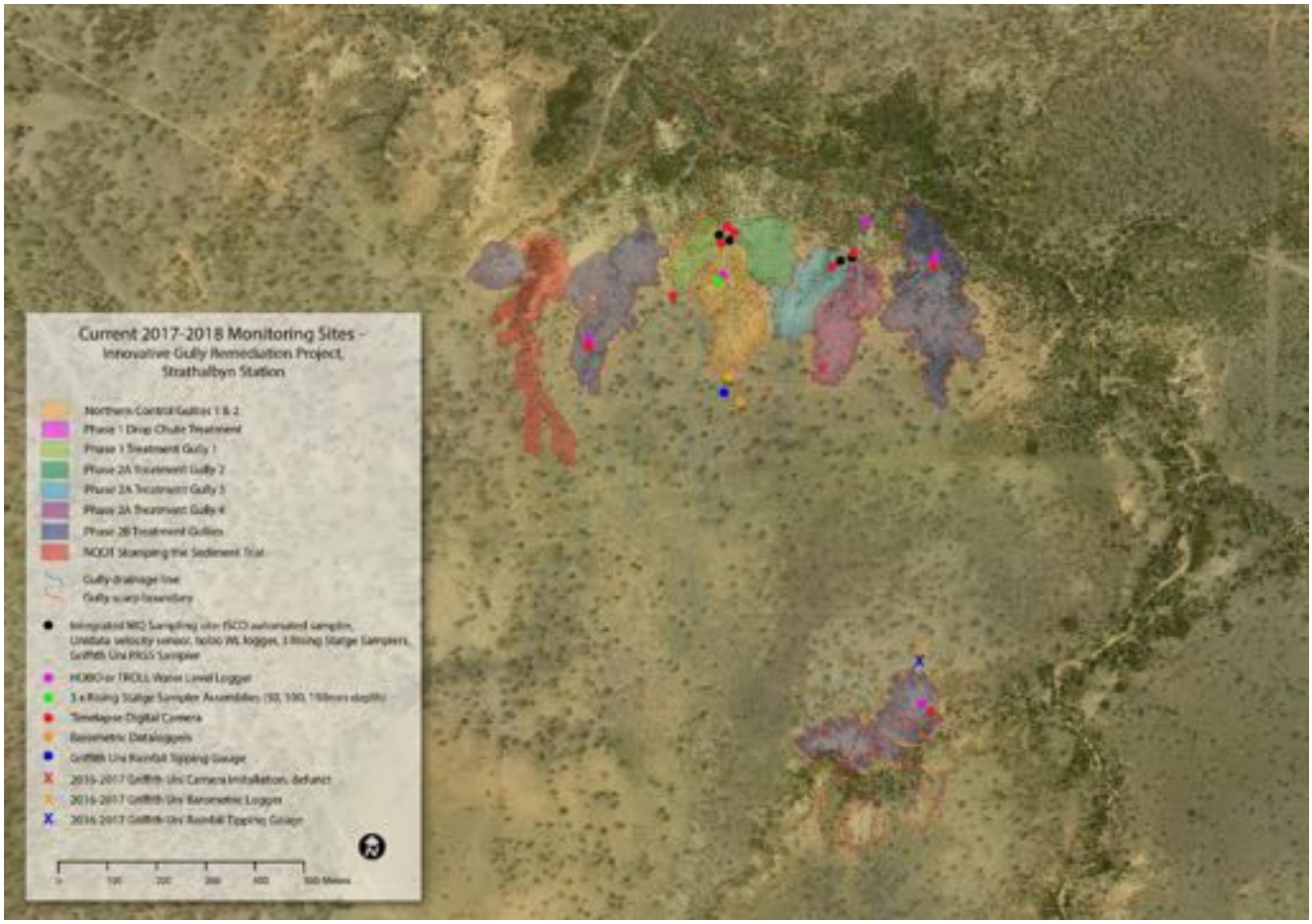
Monitoring

The water quality monitoring program incorporates a number of technologies for determining change in sediment export from treated gullies compared to untreated gullies. These include automated water quality sampling units triggered by flow, velocity sensors to assist determining discharge, rain gauges, rising stage samplers, water depth sensors, and innovative composite samplers known as PASS samplers (currently being trialed by Griffith University). Vegetation surveys, the use of time lapse digital cameras and drone photography, terrestrial laser scanning (Department of Environment and Science (DES) and Griffith University) and high resolution aerial LiDAR also assist interpreting the results of the remediation trials at the site (**Figure 4**). The following information below describes the setup of the water monitoring equipment to ensure comprehensive sampling between control and treated gully complexes, and before and after treatment monitoring (BACI design).

Treatment Gully 1 has a full suite of equipment installed (ie. velocity sensing ISCO automated unit, 3 x RSS, and water level logger, time lapse camera, and PASS sampler); Treatment Gully 5 (grade control) has a water level logger and a time-lapse camera, the control gully has one full suite plus an additional datalogger/RSS/camera site. Treatment Gullies 3, 4 and 8 have full suites to allow baseline information to be collected prior to works been implemented in 2018. The Central Gully complex also has a water level logger/RSS/camera site for base line data collection.

A permanent water quality monitoring point will be installed in Bonnie Doon Creek below the various gully remediation trials in July 2018 to help determine the long-term effects of the range of sediment reduction programs being implemented on Strathalbyn.

Figure 4 Current monitoring sites - Innovative Gully Remediation project



Phase 1 Gully Remediation Works

The Innovative Gully Remediation Project commenced on-ground works in late October 2017. The initial works involved three stages:

1. Development of an on-site quarry and processing of some 27,000t of quarry materials to use in the remediation works.
2. Completion of works within Treatment 1
3. Completion of works within Treatment 5

Quarry Development

Based on the site design and associated gully treatments, a significant quantity of soil and rock capping materials are required to implement the remediation actions identified in **Figure 3**. These materials are required over the life of the project and include soil/rock matrix sub 50mm for direct batter capping, graded rock between 50-150mm for check dam construction, and 150mm+ materials for grade control structures and drop chutes associated within diversion structures. Materials also required to repair any roads damaged as a result of project activities.

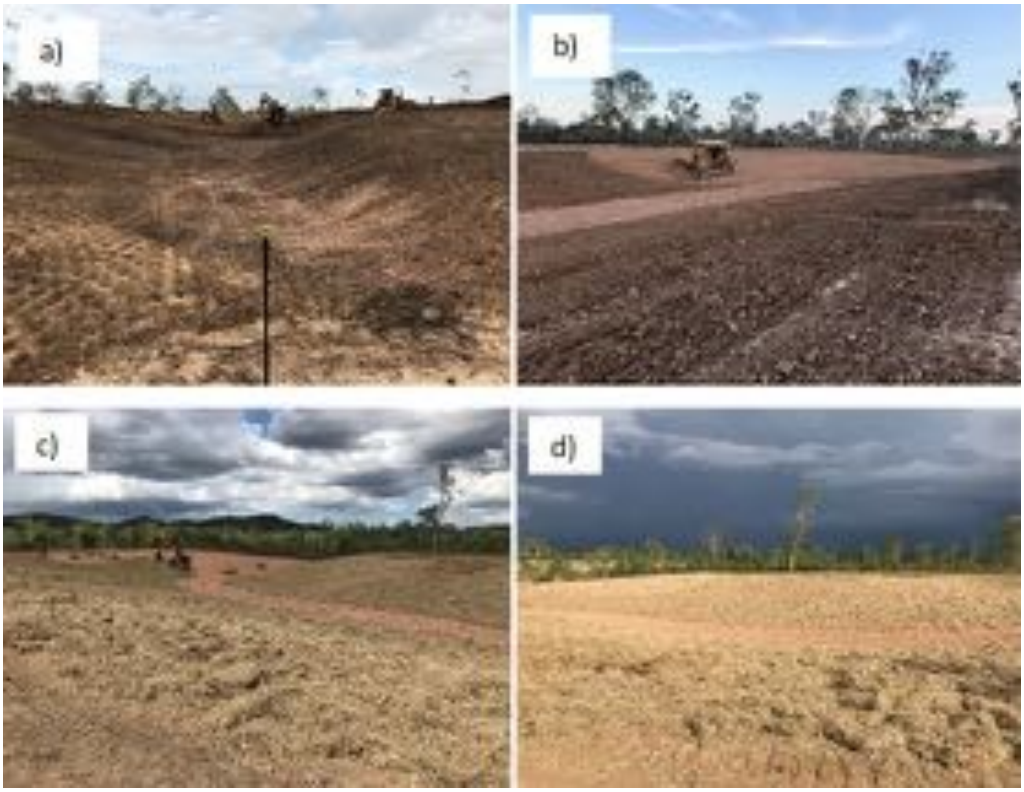
Three different options to access the required material were assessed as part of the project costings and logistics. This included trucking rock material to site from Collinsville at a cost of between $40-$42 per tonne including cartage. This would have required in excess of 1000 truck movements, and cost over one million dollars. Accessing rock material from the river, which again was cost prohibitive, and finally the development of a quarry onsite. The development of the quarry on site enabled the costs to be reduced to ~$15/tonne, but also significant savings in terms of road damage and time to get that quantity of materials to site

Completion of works within Treatment 1

Treatment 1 involved the extensive reshaping and regrading of a heavily incised alluvial gully of 1.2ha. **Plate 2** shows the gully prior to treatment, the following photo sequence in **Plate 3 (a-d)** outlines the approach used. In treatment 1, the heavily incised gully area was initially regraded to a pre-designed landform (**Plate 3a**). Supervision and monitoring during the works stage ensured a balanced cut and fill, therefore reducing costs and earthworks in these large alluvial gullies. The second stage involved capping with a 200mm thick layer of rock and soil from the quarry which occurred following the application of gypsum (18t per hectare) and ripped into the prepared surface (**Plate 3b**). All batters and disturbed areas were mulched (which was seeded with Rhodes grass) following construction works (**Plate 3c**). To ensure sufficient ground cover of the treated gully area, the entire site was re-seeded with Rhodes grass after rain in March 2018 (**Plate 3d**).

Plate 2 Alluvial gully prior to treatment 1 remediation works

Plate 3 Treatment 1 works through stages



Treatment 5 rock chute and diversion bank

The construction of a rock chute as part of Treatment 5 was designed to stabilize a rapidly retreating gully knickpoint and partial diversion of catchment flow from Treatment 1 down through the chute structure (**Plate 4**). Further work on the gullies below this point are planned for 2018 now the gully head has been stabilised. The rock chute was constructed by excavating material and keying rock into place such that the surface of the rock forms the design surface. All rock, except for rock forming the cut-off walls of rock chutes was underlain by granular filter material, to reduce the leaching of fines of the underlying material and to form a bedding surface into which the rock can settle. The cut-off wall located at the crest of rock chutes was encased with geotextile to provide resistance to flow through the rock beaching and to reduce the leaching of fines of the underlying material.

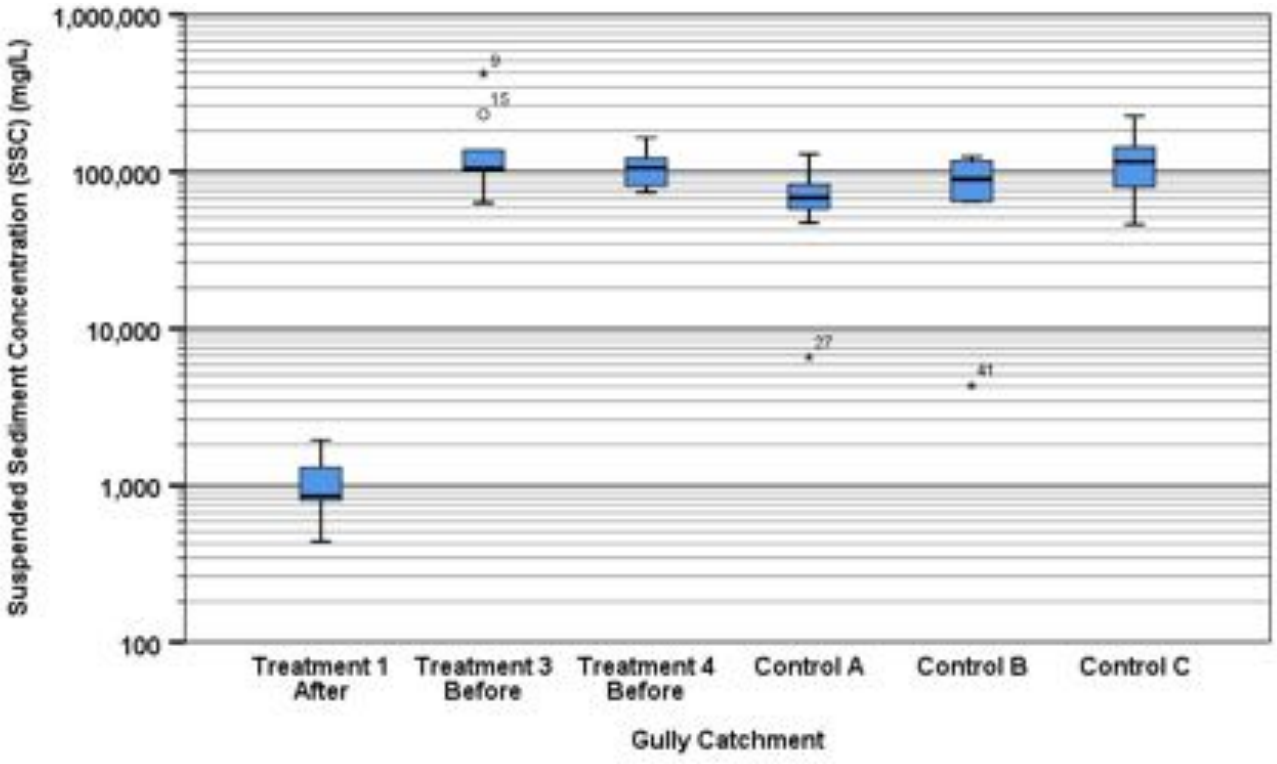
Plate 4 The rock chute at Treatment 5

Preliminary Results - 2017-2018 Water Quality Monitoring Phase 1 Gully Remediation Works

Water samples were collected between February – May 2018 from Strathalbyn Station gullies. Due to equipment failure of the ISCOs, samples were only collected from rising stage samplers (RSS) (50cm, 100cm and 150cm). In total 54 samples were collected across the gullies, and included Treatment 1 Gully (7 samples), Control Gully A (9 samples), Control Gully B (6 samples), Control Gully C (central Gully) (8) , Pre-treated Gully 3 (9 samples), and Pre-treated Gully 4 (9 samples). Analysis included Suspended sediment concentration (SCC), Total suspended solids (TSS), and particle size analysis (PSS). Only the average concentration from the TSS analysis is represented in **Figure 5**. Each of the five untreated gullies had substantially higher levels of TSS, ranging from 30,180- 422,529 mg/L when compared to the treated gully which had only between 306 - 1546 mg/L TSS (i.e. less than 2g) **(Figure 5)**.

An analysis of particle or grain size distribution of the sediment was also conducted to determine the amount of transportable suspended sediment likely to be exported from the gully. The transportable suspended particle sizes are considered to be those <20 µm diameter. In the samples from untreated gullies, approximately 75% of the sediment grain size was <20 µm in diameter. The treated gully sample had approximately 95% of sediment <20 µm, because the total exported sediment was only 306 -1546 mg/L, this equates to less than 2 gram/L of suspended sediment in the sample. Untreated gullies had total transportable sediment results of 6,600-162,000 gm/L. The has resulted in an average of greater than 97% decrease of total transportable suspended sediment samples in treated gullies in comparison to untreated gullies. Further analysis of the collected data will be undertaken over the next two months to calculate total sediment load from each gully.

Figure 5 Average Sediment Concentration (mg/L) from Treated and Untreated Gullies



Conclusions

Greening Australia are now currently implementing Phase 2 works as part of the Project. These works will target an additional 10.8ha of direct gully remediation using a variety of treatments including varying batter thicknesses and materials, different ameliorants for soil structure and chemistry improvements, modified forms of within channel check dams and other bed treatments, and different techniques for mulch application and seeding. A comprehensive water quality monitoring program focused on measuring treatment effectiveness in reducing sediment export will be initiated in late November in time for the 2018-2019 wet season. This program will build on the data already collected and also record change against baseline conditions determined in previous monitoring efforts.

Acknowledgments

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