Greening Australia and Department of Environment and Science

Innovative Gully Remediation Project

Forum Outcomes Report

March 2018

This initiative has been funded by the Queensland Government and Greening Australia to identify more innovative and cost-effective gully remediation techniques.

Greening Australia Queensland Government

Greening Australia gratefully acknowledges the contributions made by the participants of the Innovative Gully Remediation Project Forum. The quotes attributed to the various participants have been collated from various sources including notes and recordings of the Forum proceedings.

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Executive Summary

The Innovative Gully Remediation Project "*Forum Outcomes Report*" documents the key concepts, points of discussion, preliminary learnings and subsequent responses to an alluvial gully remediation forum held in May 2017 at Seagulls Resort in Townsville.

The forum was organised as a part of the Innovative Gully Remediation Project, funded jointly by the Queensland Government Reef Innovation Fund and Greening Australia's Reef Aid™ Program. This project's purpose is to identify more innovative and cost-effective gully remediation techniques applicable to the Great Barrier Reef (GBR) catchments.

The intent of the forum was to harness the collective knowledge of scientists and remediation experts to facilitate fresh thinking to tackle the challenges of large scale alluvial gully erosion in GBR catchments.

The forum used the joint Greening Australia/QLD government alluvial gully remediation trial site at Strathalbyn Station, in the lower Burdekin catchment, 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.

Eighteen (18) people attended the forum, representing a broad spectrum of remediation/rehabilitation practitioners, research scientists, project coordinators, and government stakeholders. The contributions of the forum attendees towards the information contained in this report are gratefully acknowledged.

Forum discussions

The forum discussions revolved around three main themes:

- preliminary site investigations as background to the Strathalbyn Project Site, and what those investigations reveal about future information needs to guide remediation/rehabilitation at that site and sites more generally
- potential treatment options and practitioner and researcher experiences of their implementation
- the purposes and design of monitoring programs to evaluate treatment effectiveness.

Key points from the forum

The key points from the forum discussions provide an useful overview of the range of questions that arise when attempting to define an approach to alluvial gully remediation in the GBR catchments. A summary of the key points by theme is provided below.

Preliminary site investigations

- Gullies should not be thought of as amorphous. Factors such as underlying soil characteristics, gully processes and form, and land use all contribute to gully evolution and rates of change.
- Comprehensive soil survey can greatly assist in defining appropriate remediation/rehabilitation strategies and treatments.
- Analyses of gully evolution over time can provide reasonably accurate estimates of sediment export which are useful for quantifying sediment reductions post-treatment and subsequently for comparing treatment efficacy and cost.

Potential treatment options

- Whilst diversion of catchment flows may be an appropriate strategy, such activities must be carefully designed to avoid unintended impacts.
- Optimal approaches to stabilising sodic soils are generally well understood, however on-site and resource availability constraints can make optimal approaches unviable.
- Similarly optimal earthworks design often involves a nuanced balance of competing factors, for example the slope of batters versus length of batters, and may involve compromise as a result of site constraints that impact the effectiveness of works, their cost, and potentially ongoing maintenance of remediation/rehabilitation sites.
- Although low-cost approaches based around changed grazing management and within gully sediment trapping structures have been successful in other areas of Australia, it is not yet clear if these strategies are appropriate, on their own, in alluvial gully remediation/rehabilitation sites in tropical north Queensland or in other GBR catchments.
- The significant constraints associated with soil chemistry, particularly very highly dispersive soils, are a key factor in the remediation/rehabilitation of alluvial gully sites in GBR catchments.
- Although native perennial ground cover over remediated/rehabilitated sites is the goal, many factors influence the longer-term revegetation of sites including site preparation, competition from exotic species, grazing regime, and climatic variables. However, specialist equipment may assist in the application of mulch and seed to remediation/rehabilitation sites.
- The role of shrubs and larger trees as pumps in the landscape should not be overlooked as a mechanism for dealing with sub-surface flows and drainage.

Monitoring and evaluation

- There are a wide variety of accessible monitoring tools and technologies available. The level of detail required to answer the questions being asked will dictate the monitoring equipment and methodologies required and also the cost.
- Technological advancements (eg. Drone-based LiDAR) have the potential to make high resolution land elevation measurements more affordable.

- Sediment reduction programs should focus on the sub 20 micron fraction of the suspended sediment loads in run-off waters, as this is the material that when suspended can be transported into the GBR lagoon.
- Intensive baseline investigations are required to accurately determine any sediment reductions resulting from treatment interventions.
- Aerial LiDAR data is valuable as a gully classification tool, as a design aid, and as a monitoring methodology if repeated and compared post-treatment.
- Terrestrial LiDAR has the capacity to record very detailed land surface measurements and therefore may be particularly useful for measuring changes from surface erosion.
- BACI (Before After Control Impact) design is important but can be difficult 'in the field", assumptions should be documented.
- A system of gully categorization and classification will allow the results of treatment trials to be more usefully transferred to future treatment sites.
- Detailed soil mapping can greatly assist gully classification and provide important information relevant to remediation/rehabilitation design, soil amelioration, and vegetation establishment.
- Vegetation surveys and biomass calculations can assist in determining the end-goal of remediation/rehabilitation as well as demonstrating a treatment's longer-term effectiveness.

Follow-up actions resulting from the forum

A number of the key points made during the discussions warrant further investigation and action. These actions are likely to improve the potential outcomes of the remediation trials proposed under the Innovative Gully Remediation Project, as well as broaden the collective understanding of alluvial gully research, remediation/rehabilitation, and evaluation.

A1. Soil mapping

An understanding of soils is critical to alluvial gully planning and remediation/rehabilitation. It was recommended that further soil sampling and analyses were required at Strathalbyn Station to improve the understanding of gully processes and also to assist remediation/rehabilitation planning and the evaluation of treatment effectiveness. Comprehensive soil sampling and mapping has now commenced under the Griffith University's NESP 3.1.7 project in conjunction with DES Science Division and DES Office of the Great Barrier Reef. The results of the soil sampling and the higher resolution soils map for the site will be released in April/May 2018.

A2. Ameliorants and soil conditioning

The type of ameliorants used, methods of application/incorporation into the soil, and subsequent capping of treated areas are all factors which should be further evaluated in the context of large scale alluvial gully remediation in the GBR catchments. The treatment trials at

Strathalbyn will therefore explore optimal approaches to the use of different ameliorants on reducing ongoing erosion at alluvial gully sites. These approaches may include the application of powdered and liquid gypsum, direct application of organic matter (mulch, mill mud), hydro-mulching, and other innovative methods such as high intensity low duration controlled stocking trials.

A3. Engineering design

Although there is extensive local experience in the design of stabilisation works in eroding agricultural and mining landscapes, there are still elements of alluvial gully remediation/rehabilitation design which could be better refined. These elements include design and construction specifications around the cost-effective treatment of tunnel erosion, the length and slope of regraded gully batters, the thickness of capping required on different batter slopes, the design of within channel check structures, and the potential for innovative low-cost soft engineering approaches. These elements will be investigated during the 2018 Strathalbyn remediation trials covering some 7 sites covering over 10Ha of direct interventions in 2018. The results of the trials will be used to develop rules of thumb and guidelines for consideration in future projects.

A4. Vegetation re-establishment

There is a great deal of expertise in pasture management in the local region, particularly related to grazing. In terms of optimal approaches to re-establishing vegetation within larger scale remediated alluvial gully systems (ie. 1-5 ha) the areas identified for further investigation include the role of stock management in improving groundcover and soil health (specifically soil carbon, organic matter, and fertility), the most appropriate species for seeding programs, the most appropriate types of ameliorants to improve revegetation success (eg. mulch types and application thickness) and the appropriateness of specialist equipment which may improve revegetation success or cost effectiveness (for example bale shredders, hydro-mulchers, seeders, etc). Trials involving the application of 225 tonnes of mulch over 5 ha using a Tomahawk 8500 bale shredder, hydro-mulching of a 2ha site, compost and mill mud application, and the use of various seeders will be undertaken in 2018.

A5. Monitoring and evaluation

Existing technologies for monitoring storm water run-off quality have been adopted to monitor the reductions in sediment loads coming from treated gully catchments (using a BACI design) and to evaluate the effectiveness of the various remediation/rehabilitation strategies implemented. In addition, a number of emerging or improving technologies such as drone-based and terrestrial-based LiDAR will be evaluated. To date there has been several data capture efforts covering the pre- and post-treatment gully forms at Strathalbyn using both high resolution aerial LiDAR (Griffith University) and terrestrial LiDAR (DES Science Division and Griffith University). It is hoped to further trial and evaluate these technologies at Strathalbyn Station under the Innovative Gully Remediation Project.

Introduction

The Innovative Gully Remediation Project

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 the collaboration is to develop cost-effective and scalable options for the remediation/rehabilitation[1] of alluvial gully systems that can be replicated in other areas of the Burdekin and within other Great Barrier Reef catchments.

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.

The Innovative Gully Remediation Project has a number of objectives including to:

1. 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.

Innovative Gully Remediation Forum

The Innovative Gully Remediation Forum is an activity of the overall project specifically targeting objectives 3-5 above.

[1] In this report, "rehabilitation" refers broadly to interventions to return a gully system to a more or less natural self-perpetuating state whereas "remediation" refers to interventions to stabilise gullies with less concern for the landform's previous natural state and a primary focus on limiting sediment export through controlling erosion processes

Gully remediation experts from a range of backgrounds, including organisations and individuals from the academic, government, and private consultancy fields (specifically landscape and mine site remediation and sodic soil treatment specialties), were invited to attend a one day forum in Townsville on 9th May 2017. The list of attendees is included in Table 1.

A comprehensive package of information was prepared before the forum and distributed to forum participants, including detailed descriptions of the site properties including: hydrography; soil types and constraints; land forms and topography; and descriptions of the gully locations, types, characteristics, and morphology.

The contributions of the forum attendees towards the information contained in this report are gratefully acknowledged.

Table 1 Innovative Gully Remediation Forum attendees.

Attendee	Organisation
Rohan Lucas	Alluvium Consulting Queensland
Will Higham	Cape York NRM
Peter Zund	DES – Science Division, Soil Scientist
Jean Erbacher	DES – OGBR, Program Manager
Lex Cogle	DES – OGBR, Project Contact
Damon Telfer	Greening Australia Program Manager
Delwyn Windridge	Greening Australia Botanist
Andrew Brooks	Griffith University
Tim Pietsch	Griffith University
Robin Thwaites	Griffith University
Thomas Baumgartl	University of QLD
Glenn Dale	Verterra
Peter Hairsine	Peter Hairsine Research Services
Jason Carter	TenchFisher
Jelenko Dragsic	Greening Australia
Lynise Wearne	Greening Australia
Scott Wilkinson	CSIRO
Jeff Shellberg	Gully Remediation expert - NQ
Sharon Cunial	Community member

Forum Outcomes Report

This report serves a number of purposes.

Firstly, it provides a summary of presentations and dialogue from the forum with the intention of providing information to those present at the forum and to other relevant individuals for further consideration and comment.

Secondly, it identifies the key points from the discussion which in turn have been used to prioritise areas of further investigation in the development of the Innovative Gully Remediation Project Site at Strathalbyn Station.

In line with the objectives of the forum, a number of follow-up actions taken post the forum discussions are documented in the final section of the Forum Outcomes Report.

Overview of Strathalbyn's Alluvial Gully Systems

The Griffith University Centre for Coastal Management was contracted by Greening Australia to conduct some preliminary site investigations and LiDAR data interpretation to assist in characterising the alluvial gully systems at Strathalbyn Station[2]. The assessment included investigating the evolution of the main gully complexes at the site and estimating the historical rates of sediment transport from mapped gully complexes. Preliminary soil analyses were also undertaken with the assistance of Peter Zund from DES Science Division.

Gully overview – Griffiths University

Andrew Brooks from Griffith University Centre for Coastal Management presented an overview of the gully systems at Strathalbyn Station. A summary of the presentation (obtained from a recording) along with a number of the figures used in the presentation are included below.

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.

A comparison of gully surface area increase using additional aerial images from 1956, 1972 and 1995 indicated that gully growth over the last 70 years has not been exponential and that the different gully sections in the North, Central and South gullies have different growth trajectories (see Figure 1 for an example from the northern gully systems).

Flooding events in the Burdekin River beyond ~20-25m heights would flood out and back up into the lower end of the gully systems. However it is believed that none of the recorded floods would have exceeded the gully levee.

Remnant surfaces were identified by comparing LiDAR data with 1945 aerial photos (see Figure 2). The sediment yield calculated in tons per hectare per year for the northern gullies shows that sediment yields from these systems range between 176 and 370 tonnes per hectare per year (Table 2).

2 A Brooks, J Spencer, J Daley, R Thwaites, and T Pietsch (2017) Final Report on Alluvial Gully Preliminary Characterisation – Strathalbyn Station. A Report for the QLD government Task Force Gully Innovation Programme with Greening Australia, May 4th 2017, Griffith University.

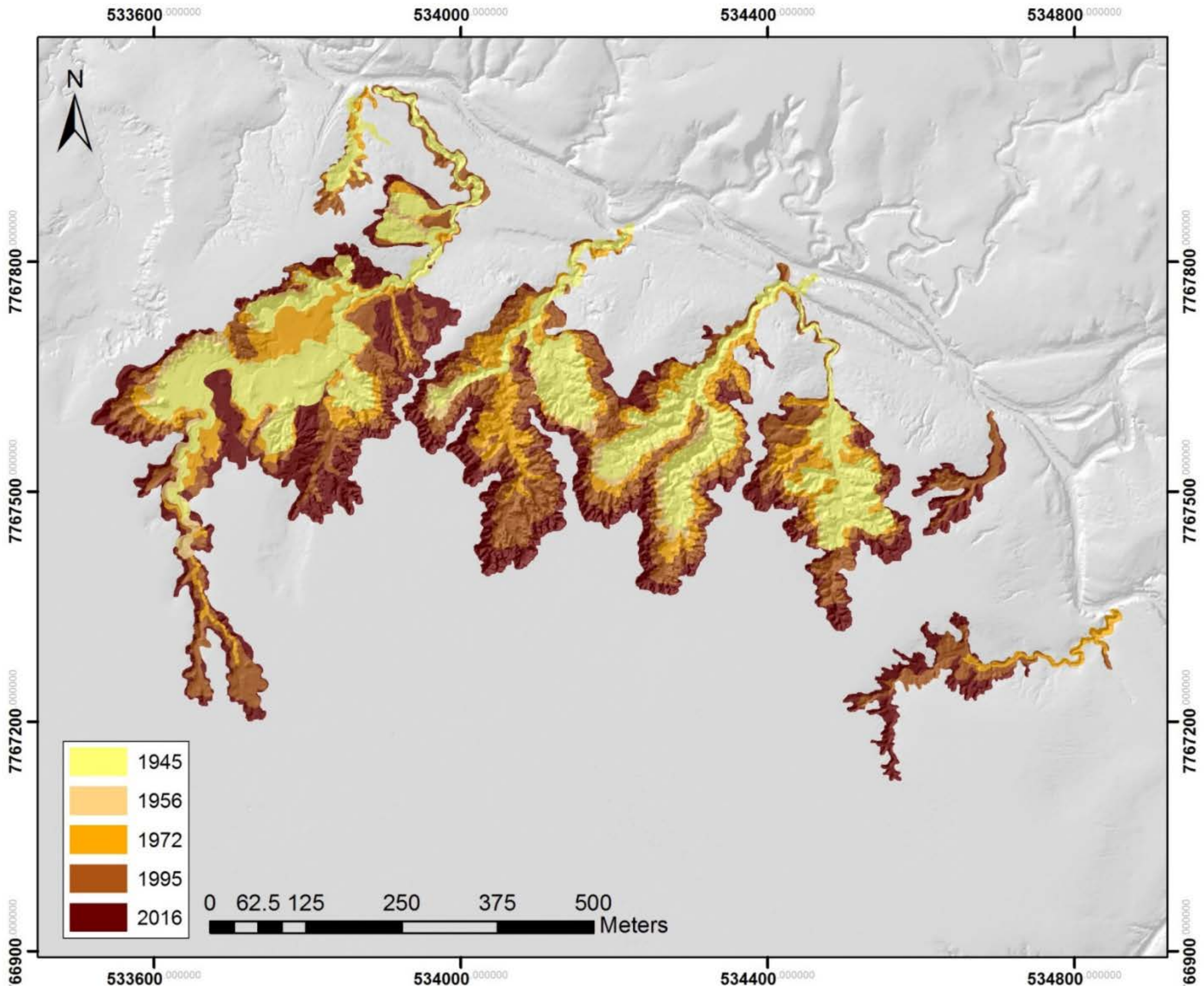


Figure 1 Growth of gully footprint in the Strathalbyn Northern Gully systems for years of available aerial imagery (*Source: Brookes et al., 2017*).

Increases and decreases in the rate of gully erosion over time are based on a range of variables e.g. gullies have a decreased rate where they have reached their catchment boundary. It was noted by Jeff Shellberg that an increase in gully area does not necessarily mean that the volume of sediment has directly increased as a result as erosion at the scarp may get shallower. Similarly, slowing of gully area may not be indicative of sediment export as there may be other internal processes e.g. gully floor erosion, contributing as much sediment or more than scarp retreat. More survey data is required in order to determine rates more accurately.

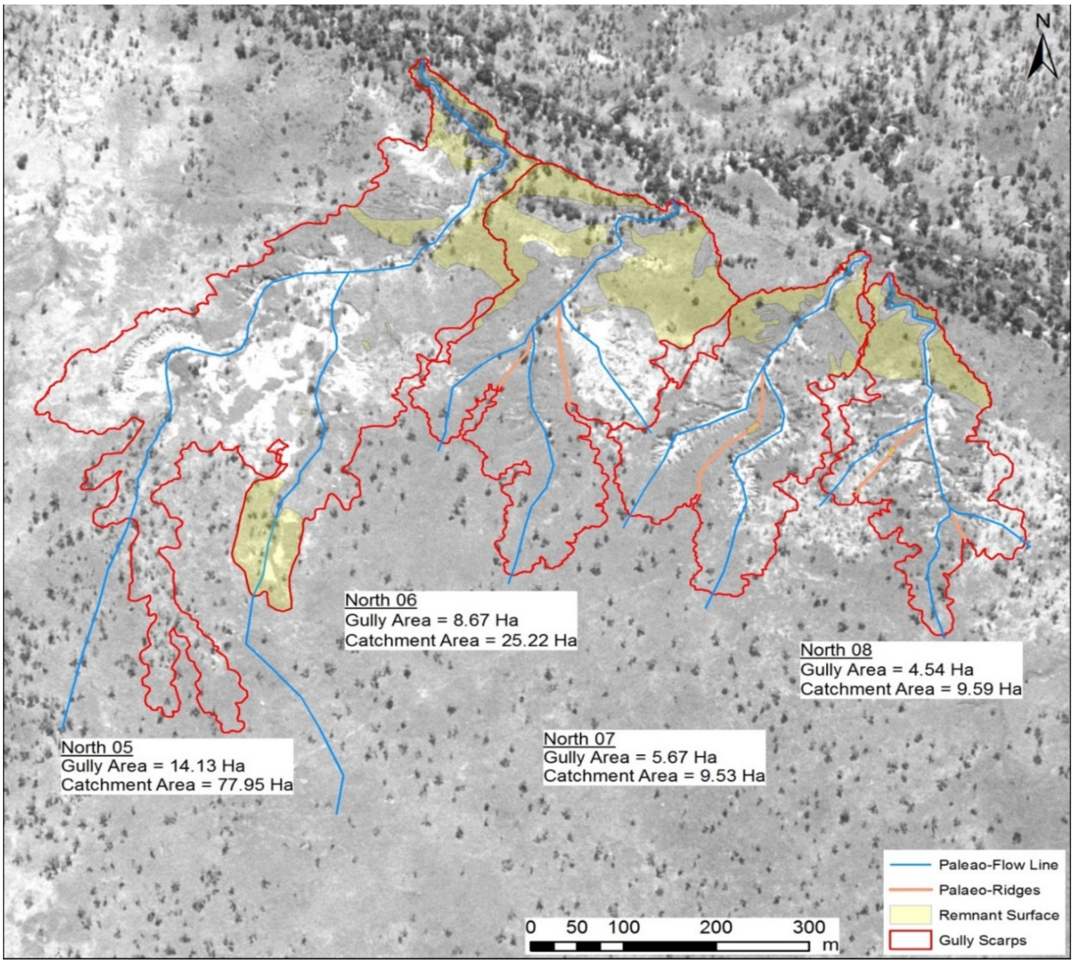


Figure 2 An overlay of 2016 northern gully scarp locations over the 1945 aerial imagery. Note the location of remnant surfaces that were used to calculate sediment yield over time through a comparison with the 2016 aerial LiDAR derived DEM (*Source: Brooks et al., 2017*)

Table 2 Gully sediment yield statistics for the northern gully systems, derived by the method described in *Figure 2* (*Source: Brooks et al., 2017*).

Gully Name	Volume Change (m3)	Change (t)	Sediment Yield (t/ha/yr)	Gully Catchment Area (ha)	Gully Scarp Area (ha)
North 05	126,529	215,099	211	78.0	14.13
North 06	73,079	124,234	199	25.2	8.67
North 07	88,750	150,875	370	9.5	5.67
North 08	33,891	57,615	176	9.6	4.54
TOTAL	**322,249**	**547,823**	**956**	**122.3**	**33.01**

A comparison of variation in rainfall data, recorded at nearby Dalberg Station, and variation in gully growth rates indicated that while rainfall was strong predictor for gully growth rate it was not the direct link. Other rainfall data such as rainfall intensity and periods of droughts may provide a clue. Other potential factors may relate to changes in land use and Andrew reflected that in his opinion 'the critical issue is when cattle were introduced, not when the land was cleared'.

Gully long profiles show variation throughout the system from steep scarp faces through to moderately graded profiles. Because of the variability in profile and soil type each gully should be approached individually with consideration given to its unique set of variable features and not as a blanket approach. Further different gullies have evolved at different rates and this should also be taken into consideration when deciding treatment options.

Soils overview – Peter Zund, DES Science Division

Peter Zund, as part of a broader team undertaking the preliminary site investigations, has contributed to the understanding of the Strathalbyn project site by providing soil survey, analysis, and interpretation expertise.

Peter gave a brief summary of the site based on the preliminary site visit and some early soil sampling results.

The gully sites within the project area occur on an ancient alluvial plain on the Burdekin River which is now essentially a relic terrace feature.

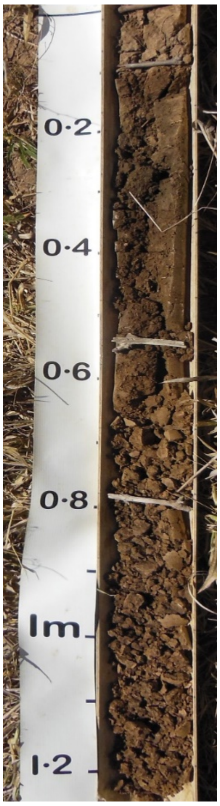
There are 2 main soil types present: a texture contrast duplex soil on elevated, freer draining areas of the levee (Plate 1A); and, cracking black/grey clay soils in distal floodplain back swamps and poorly drained areas of the terrace (Plate 1B). Both soil types are dispersive, the duplex soils being highly sodic having 30-40% ESP and the cracking clays having 16-18% ESP.

Salinity is not an issue in this system. Where salinity and sodicity are present together the soils don't erode as much, but this is a freshwater system and soils <1 dS/m salinity.

According to the existing soil mapping[3], 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. Peter's theory is that the cracking clays are less erodible. However, the "jury is out" on this and he's hoping through further work that gully erosion and soil type can be correlated and then applied to the Burdekin catchment generally and potentially to other Reef catchments.

[3] W P Thompson, M G Cannon, R E Reid, and D E Baker (1990) Soils of the Lower Burdekin Valley, North Queensland, Redbank Creek to Bob's Creek and south to Bowen River. Queensland Department of Primary Industries – Land Resources Bulletin.

Plate 1A
Texture contrast duplex soil, ESP 30-40%



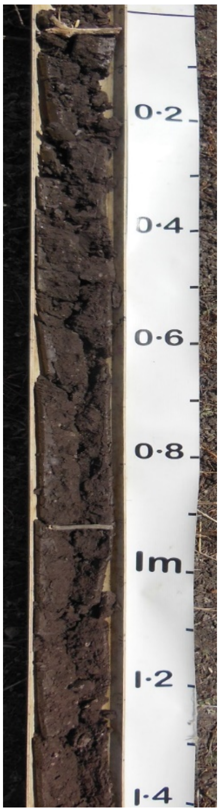


Plate 1B
Cracking black/grey clay soil, ESP 16-18%

Plates 1A & 1B **General soil types common to the Strathalbyn Gully Remediation site *(Source: Peter Zund, DES Science Division, 2017)*.**

Discussion of Potential Treatment Options

After the presentation of the background information, the forum then focused on potential treatment options for alluvial gullies. The discussion was initially intended to be framed according to discrete groups of treatment options that invariably are adopted as a part of a broader treatment "package". However, it was difficult to discuss the different options in such a way as most treatment options have multiple purposes and goals in terms of remediation. For instance, stabilising sodic soils through application of ameliorants has as its goal addressing structural/chemical issues within sodic soils but is also closely linked to the goal of re-establishing vegetative cover on the substrate.

Nevertheless, the discussion has been grouped into broad heading groups as a way of describing most accurately the comments that were recorded on the day. Some repetition is unavoidable.

Catchment flow diversion

The merits of diverting catchment flow through the use of diversion banks towards stable features or structures within the gullies was discussed. Rohan Lucas from Alluvium Consulting commented that 'Intercepting overland flow on minor tributary and flow diversion sites using a rock drop structure with some earth works has been successfully used for two decades in the mining industry".

The importance of using a thorough design process and considering topography, hydrology and soil types was emphasised. For instance, several participants noted that diversion banks can result in ponding or increased infiltration in duplex soils resulting in tunnel erosion. This phenomenon had been observed at some sites on the Cape at a distance of 20-30m from the gully head and was observed at Strathalbyn directly upslope of diversion banks and within 5m of the gully head.

- Robin Thwaites identified that "the LiDAR dataset for Strathalbyn was potentially not sufficient to identify subtleties and elevation details for designing drop structures". Damon Telfer commented that the LiDAR was useful as the basis of remediation/rehabilitation design and certainly an improvement on what it sometimes available.
- Andrew Brooks questioned "what proportion of gully erosion is arising from overland flow?". He thought that perhaps at this site it was a minor factor influencing the gully erosion rate with the major influence being direct rainfall impact onto highly dispersive soils.
- Glenn Dale acknowledged that 'It is useful to have some structures to slow overland flow, but there is a longer term potential for them to pond water". He thought that potentially they could be removed after a period (perhaps 2 years) commenting that such structures do need to be fixed in terms of installation period.

Plate 2 **The use of hay mulching on mid-batter faces may have value as a temporary flow retardant where batter lengths result in significant catchment areas *(Source: Glenn Dale, Verterra)***

Dispersive soil management

There was some discussion of the various techniques available for addressing the underlying limiting factors of sodic soils with very high dispersity. Essentially, the options discussed were:

- mechanical intervention whereby subsoil is regraded, compacted, and capped with non-erosive or less erosive material to a depth designed to prevent direct rainfall impact but also prevent rilling of the regraded batter slope.
- Direct amelioration of the subsoil through the application and incorporation to depth of gypsum at rates suitable to reduce the sodicity below a dispersivity threshold (eg. below ESP 6%: see Plate 3)
- The addition of various ameliorants to the finished surface including topsoil, compost, and organic matter such as mulch where available on-site or where affordable to import to site.
- Andrew Brooks and Jeff Shellberg noted that in the experience of projects on Cape York, the optimal approach was a combination of all three.
- Glen Dale commented that in a mining context, the issue of availability of materials (such as topsoil) often prevented the use of an optimal approach.

Plate 3 **Direct application of gypsum on this site at a rate of 18t/ha was sufficient to bring soil sodicity down to approximately 6% ESP** ***(Source: Damon Telfer, Fruition Environmental)***

Gully regrading, reshaping and earthworks and engineering design

Damon Telfer raised a number of questions around the design aspects of reshaping and regrading gullies. The points of discussion centred around the appropriate grade of batters versus batter length.

There were differing views around whether it was more appropriate to have shorter, steeper batters with less catchment area versus longer, lower slope batters which have less catchment area.

Comments generally reflected the fact that site design constraints may dictate what is possible in which case the question then becomes what type of capping material on batters is appropriate and at what thickness the capping should be applied.

The experimental trials on Cape York undertaken by Griffith University was noted to have some interesting data on the effectiveness of different batter treatments over time scales spanning a number of years.

There was some discussion of potential channel bed treatment options before the discussion moved onto the next topic.

Lower cost engineering solutions

The potential application of low-cost/lower technology/soft engineering options for alluvial gully stabilisation were discussed.

- Will Higham from Cape York NRM posed the question "Can we envision what the gully will look like if we just lock it up and do a series of less invasive treatments and let it evolve into its new shape?". In response to this question, Peter Hairsine reflected on the many sites he had visited throughout NSW and Victoria where low cost check dams had resulted in deposition and vegetation re-establishment over a long period. However, he believed soil chemistry was a crucial factor, as well as whether the deposited sediment was a good growth medium.
- Will thought that designs do not necessarily need to be low tech as such but careful consideration of grading or letting it erode to a stable point could potential achieve a result. The question was then asked whether such an approach could apply to alluvial gullies. One response from Rohan Lucas was that in his experience low level tinkering can have a big impact depending on what stage in the evolution of the channel you chose to intervene. Andrew Brooks thought that in the scenario described by Will we are already dealing with what's in place and we may get self-grading of the system but the real question is how long does it take and what are we losing in the meantime? Further, if multiple treatments were being proposed then the downside is in disturbing the site a number of times as opposed to one initial treatment. Andrew thought that it may be better to just deal with it in the first place and that there are cost benefits for larger upfront treatments.
- Generally, it was agreed that there is considered to be two conceptual continuums, either the approach can be high initial investment with theoretically low ongoing maintenance costs or a low initial investment which requires potentially higher ongoing maintenance costs.
- Robin Thwaites commented that these approaches rely on a long-term commitment and maintenance and questioned where the funding would come from.
- Scott Wilkinson commented that the good thing about spreading treatments over time is that you get to see the response of the system in different climatic conditions and also in some respects spread risk over time. He provided the example of where four different soft engineering treatments were applied to try to re-establish vegetation and in the end, after they had all suffered the same climate related effects over a number of years, the cheapest method was the most effective (which was mulch hay containing seed). The "take home message" for Scott was that you don't have to spend a lot of money, just do activities that help it along. There was general agreement that these approaches should be explored and tested for the efficacy.
- The issue of whether surface binding products were of use in a large-scale alluvial gully context was briefly raised before the discussion merged into the next topic (re-establishing vegetation), focusing primarily on the role of hydro-mulching (see below).

Re-establishing vegetation cover in treated gullies

The experiences of the group with regard to re-establishing vegetation cover within treated gully areas was discussed at length. There was general agreement that the major factor affecting long-term stability of sodic soil landscapes was a dense perennial ground cover. The role of trees and shrubs as effective groundwater pumps in these landscapes was noted, however the discussion focused on how best to establish ground cover and in particular perennial grass species.

1. The following comments were made in terms of preparing seed beds and improving germination:
    - Jeff Shellberg: 'Soil limitations will need to be addressed. Don't hydro-mulch as the seeds sit on surface and the newly germinated seeds will die too quickly, a prepared bed where seeds are cultivated into soil gives the best results. Harrow the seed in where possible, particularly where lower slope batters can be achieved'. Damon Telfer commented that 'hydromulching is effective on roadside batters where they carefully prepare the surface'.
    - Thomas Baumgartl: 'Compost is the least ideal material, it will mineralise quickly and attract weeds. Need a more stable organic compound. Successful in first two years but depletes quickly due to low C:N ratio. Low nitrogen organic matter is better e.g. straw, bark, mulch. With these options you get rainfall interception and moisture retention.
    - Will Higham: 'Dolichos (cow pea) hay mulching. A single round bale spreads over 12m length. On the Cape, 0.5ha have been treated with this method. Thicker stems last longer than grass hay. Still effective after 12 months. Have sowed seed through it but not a lot of vegetation has come through. The cow pea has germinated but died off.'
    - Rohan Lucas: 'One very successful example where round bales were rolled out and seed blown out (specialised equipment needed). Seeding and mulching at same time on black cracking clays (blue grass) with tree and shrub community can be successful but grazing must be excluded'. Jeff Shellberg commented that a similar method is used in the United States but with compost.
    - Rohan Lucas: 'A rougher surface is better for seed establishment". Robin Thwaites suggests the addition of a soil binder but Jeff Shellberg questions whether it is necessary as such binder set hard. Robin Thwaites commented that despite the soils being hard setting they still get wet and wash away readily'. A comment was made that sand is available from Bonnie Doone Creek and it's not sodic.
    - Tom Baumgartl: 'Question is what kind of vegetation do you want to establish? Then develop your soil and soil profile/type for it. Some species will require more preparation'.
    - Scott Wilkinson: 'Hand revegetation was effective with small pitting with a shovel on sites that he had had involvement with'.

2. On the issue of native vs exotic grass species:
    - Jeff Shellberg: 'Every native grass seedling I have planted was overtaken by exotic species within a few years'
    - Rohan Lucas commented that 'In general landholders don't care what grass you get as long as there is grass'.

3. On the issue of tussock vs stoloniferous grasses
    - Lex Cogle asked if there were "any comments on stiff grass hedges such as vetiver grasses'. Robin Thwaites commented that vetiver hedges were high maintenance and the less maintenance the better'
    - Robin Thwaites commented that 'you don't want tussocks' with Glenn Dale agreeing that 'any species that is stoloniferous is best'.
    - Scott Wilkinson though thought that 'you want the right species…even stoloniferous species such as Indian Couch are not good at erosion control, but native tussock species are better as their residue is more persistent. Native perennials are more effective but avoid all Buffell Grass'.
    - Damon Telfer raised the prospect of 'purpose grown native seed production to utilise in remediation/rehabilitation sites'.

4. Is irrigation useful or necessary?
    - Damon Telfer asked 'if irrigation to establish initial cover is advisable in a sodic soil context?'
    - Rohan Lucas: 'Cover crops might only need a water truck to get them going so generally no major irrigation infrastructure is needed. Also, the most effective species are those that get established early by themselves, therefore site preparation and seed selection are key'
    - Glenn Dale commented that he had used drip irrigation to establish bands of vegetation effectively. Irrigation is valuable to get the vegetation established and seeding before rain.
    - Scott Wilkinson 'Allan McManus from DAF (Department of Agriculture and Fisheries) is a contact for the Army, the road cuttings have Black Spear grass and other suite of grass species as a useful species guide.'
    - Jeff Shellberg: '*Themeda* or Kangaroo grass hangs in on sodic soils but is grazed by cattle as a priority'.

Pathways for natural stabilisation? Can the pathways be enhanced/ replicated/ mimicked?

The potential for alluvial gully systems to naturally recover over time was discussed. The following points were made:

- Peter Hairsine recalled that '50-70% of gullies in the middle Murrumbidgee have permanently established vegetation in the gully floor and are aggrading. This is after no intervention except for stock exclusion. To get this to occur you need a medium to grow vegetation, a moisture stable environment and nutrients. Porous check dams accumulate sand and coarse organic material and the system is then self-perpetuating. This may be something to aim for at a later stage in the recovery timeframe'.
- Rohan Lucas: 'Do works in parallel, that is do both grade control work to trap course material but also address the gullying process to treat fine sediments from scarp to be able to achieve sediment reduction targets. Bed control structures may be useful due

to the controlled nature of the outflow points into Bonnie Doon Creek. This also addresses secondary incision and creates an environment for vegetation establishment'.
- Robin Thwaites and Peter Hairsine: 'don't rule out check dams/ ponds to trap sediment within the gully' but these are not 'self-sustaining treatment options'.
- Rohan Lucas described the use of gully plug dams to achieve a sediment trapping effect 'They are like a leaky weir with a vertical pipe. Turbid waters sit for long enough for the fines to settle and vegetation establishes along the edge. They have about a 5m high wall'.
- Andrew Brooks: '25% of gully plugs used by, and maintained actively by farmers have failed. So it goes to show that they are not a reliable structure'.

Monitoring and evaluation of effectiveness

Current and previously used techniques for assessing effectiveness of remediation.

A quick presentation was provided on the current suite of techniques that are routinely proposed for monitoring effectiveness of gully remediation/rehabilitation works. The main techniques available were described in terms of those focused on sediment reduction efficacy assessment as a discrete category, and then other techniques that are utilised more generally in gully erosion remediation/rehabilitation programs.

The basic set of monitoring tools discussed were:

- Techniques previously used on projects
  - Digital camera time lapse photography
  - Site rainfall data using tipping gauges
  - Traditional survey techniques
  - Erosion pins and chains
  - Soil sampling and analyses
  - Vegetation response including vegetation surveys and land condition assessments
  - Water quality sampling systems included automated sampling units linked to either velocity sensors or sediment concentration sensors, water level loggers, rising stage samplers, and opportunistic grab samples
  - Aerial LiDAR capture and DEMs of difference
  - Terrestrial laser scanning to get high resolution landscape changes (sub 5cm)

- Current and emerging techniques
  - Drone photogrammetry and drone based aerial LiDAR
  - Lower cost water quality sampling systems

Designing a 'treatment effectiveness' monitoring program

There was some discussion for the remainder of the forum as to the need to tailor monitoring programs effectively to answer the questions that stem from the remediation trials. The main discussion points were centred around the following 6 themes.

1. There was general recognition that the main purpose of monitoring was to determine how much fine sediment transport was occurring from the post-remediation landscape? Several points were made:
   - Sediment reduction programs relevant to Reef protection should generally focus on the sub 20 micron fraction of sediment export as this is the material that when suspended can be transported into the GBR lagoon.
   - The level of data capture must be sufficient to answer the question of change post-remediation/rehabilitation. To achieve this it is important to understand the historical changes at a site and how this translates into sediment export over time. This allows calculation of the historical sediment export rate from a site which in turn allows a comparison to the post-remediation/rehabilitation export.
   - To determine export you need discharge as well as concentration of sediment. Both discharge and concentration change over the period of an event so the sampling program must account for this.
   - Peter Hairsine: 'Peer review of the data quality is important to allow data around cost per tonne saved to be determined'.
   - Damon Telfer: 'Before-After Control-Impact study is important but very hard to find control sites as in some cases it is difficult to apply treatments without interfering in control catchments, or control and treatment sites are not comparable on all variables'.

2. What type of monitoring program is both cost-effective and sufficiently informative given tight budgets?
   - Again, the level of detail required to answer the questions we are asking will dictate the monitoring required and also the cost.
   - Damon Telfer: 'The Strathalbyn project is keen to continue to develop the monitoring technologies used in recent projects to continue their evaluation and to add to the existing remediation success datasets. However, costs can be significant so we also need to determine what is the most efficient method of collecting adequate data to answer the questions'.
   - Jeff Shellberg summarised the discussion: 'If you want to show a reduction you need to measure it'.

3. Is aerial LiDAR capture sufficient or is terrestrial LiDAR at a higher resolution more appropriate? This question was not directly addressed but the following comments were made:
   - Peter Hairsine: 'This site has the advantage of LiDAR base data, in an ideal world the data would be repeated'.
   - Glenn Dale: What scale do you want to represent on maps. Drone based LiDAR should contribute in a greater way in time.
   - Jeff Shellberg referring to alluvial gully remediation on Cape York: ' LiDAR showed that 75% of fines was coming not from scarps but within gully'.

- Terrestrial LiDAR has the ability to produce a DEM at 5cm resolution however post-treatment effects can limit its ability to determine the landform surface accurately.

4. Are treatment trial outcomes at one site transferable to other sites?

- Peter Hairsine: 'It's horses for courses. Site needs to be categorised well enough to have some degree of confidence in transferability of information.
- Peter Zund: 'As it's an applied research project we really need to know what's going on so we can extrapolate from that'.

5. What level of information is required to understand site soil constraints?

- Lex Cogle asked 'What is the scale at which you need to map soils. When is 'enough' enough in terms of soil characterisation.
- Andrew Brooks: 'We won't know until we do it'.
- Robin Thwaites: 'The density of sampling spatially required depends on the scale. Relates to purpose again which in most cases is to identify the soil types for characterisation of the gully system. Hopefully this project will answer this question?'
- Thomas Baumgartl: 'The parameters that we need to describe the stability of the soil will help determine the sampling strategy. The question is what is the main driver of soil instability? Until we understand that we be operating a bit in the dark. A high-resolution soil map would be ideal'
- Robin Thwaites: 'We are not talking about a generic soil mapping approach. At Strathalbyn we still don't yet have a handle on the characteristics of the soil. A functional classification is required. 3D mapping with depth functions as well as lateral distribution is required'
- Lex Cogle: 'In terms of extension to other sites, is the characterisation of the site going to be thought of as a model?'. Andrew Brooks suggested that it would be a 'theoretical model useful for assisting classification'.
- Glenn Dale commented that 'it need not necessarily be a 'determining model' but may assist in the capture of monitoring data effectively' Jeff Shellberg added that modelling is not monitoring, but can be useful'.
- Glenn Dale: 'Good soils data leads into how well we can expect the different sites to respond to treatment'.

6. What are the most appropriate methods of vegetation assessment in these gullies?

- Peter Hairsine: 'Vegetation surveys need seasonal characterisation but also depend on whether the site is grazed or un-grazed'.
- Scott Wilkinson: 'Both vegetation cover and biomass are important. Getting the baseline on that is going to valuable'.
- Scott Wilkinson: 'Points of truth star pickets are worthwhile for demonstrating vegetative change'.

Key Points Arising from the Forum Discussion

Preliminary site investigations

Lessons from the preliminary investigations of the Strathalbyn gully sites

- Really important to target effort where it is needed.
- Gullies should not be thought of as amorphous, but rather they should be treated as individual gully lobes with the temporal component of gully evolution factored in.
- There has not yet been an extensive survey of bedrock or regolith in the gullies and adjacent creek and this needs to be done as a precursor to remediation planning.
- To understand the gully processes and development you need to hone into transition zone/interface between soil/material types, across the landscape.
- Scarp characteristics are good indicator of the level of gully activity.
- A more comprehensive soil survey would greatly assist in better determining appropriate remediation/rehabilitation treatments.
- Analyses of gully evolution over time can provide reasonably accurate estimates of sediment export which are useful for quantifying sediment reductions post-treatment and subsequently for comparing treatment efficacy and cost.

Strathalbyn soils landscape

- The Strathalbyn Project site currently has only general soils information from soil mapping undertaken in the 1990s.
- Preliminary soil sampling undertaken at the site reveals that soils in the northern gully complex area have high exchangeable sodium and low salinity, indicating that they are highly erodible.
- Further sampling and characterisation of the soils will better clarify the soil characteristics and distribution, which in turn will assist in developing a remediation plan for the site.

Potential alluvial gully treatment options

Catchment flow diversion

- Flow diversion structures may have an application where overland flow was contributing to alluvial gully erosion.
- Structures must be carefully designed to avoid ponding of water and to avoid erosion at the end point of the diversion.

- LiDAR datasets may be useful for design purposes in the absence of more detailed data but may be problematic in very flat landscapes.

Dispersive soil management

- The optimal approach to addressing sodic and dispersive soils was to regrade and compact subsoils, treat the batter surface to a depth of 15-20cm with gypsum, cap with a non-erosive material, and add topsoil, compost, and mulch.
- However, the relative availability of resources on site and/or for importing suitable materials to remote locations may mean treatments are not able to undertaken using an optimal approach.

Gully reshaping, regrading and engineering design

- Earthworks design must consider whether shorter, steeper batters are more appropriate than longer, shallower batters within the context of overall site design constraints, capping material availability, and likely effectiveness and costs of the proposed treatment method.

Lower cost engineering solutions

- Anecdotal evidence from other areas of Australia suggest that low-cost, soft engineering approaches based around changed grazing management and within gully sediment trapping structures have the potential to significantly reduce sediment export from eroding gullies.
- It is not clear if these strategies are appropriate, on their own, in alluvial gully remediation/rehabilitation sites in tropical north Queensland or in other GBR catchments.
- Soil chemistry is likely a key factor.

Re-establishing vegetative cover

- Initial irrigation to establish ground cover prior to the wet season has potential to improve vegetation establishment, particularly if used in conjunction with practices that assist seed germination on newly created batter surfaces.
- Hydro-mulching was thought to be ineffective in the long term, however this technique has been proven on road-side batters so further investigation is warranted.
- The most effective mulch materials are those that are longer lasting and which contribute to reducing runoff and direct rainfall impacts on the soil surface whilst allowing for ground cover species to establish.
- Specialist equipment may assist in the application of mulch and seed to remediation/rehabilitation sites.

- Although native perennial ground cover over remediated/rehabilitated sites is the goal, many factors influence the longer-term revegetation of sites including site preparation, competition from exotic species, grazing regime, and climatic variables.
- The role of shrubs and larger trees as pumps in the landscape should not be overlooked as a mechanism for dealing with sub-surface flows and drainage.

Natural recovery potential

- A combination of strategies including reducing factors contributing to scarp retreat, installing within gully sediment trapping structures, and managing land use is likely to increase the success of remediation projects in reducing sediment export.
- Maintenance of works will be required.

Monitoring and evaluation

- There are a wide variety of accessible monitoring tools and technologies available.
- The level of detail required to answer the questions being asked will dictate the monitoring equipment and methodologies required and also the cost.
- Technological advancements (eg. Drone-based LiDAR) have the potential to make high resolution land elevation measurements more affordable.
- Sediment reduction programs should focus on the sub 20 micron fraction of the suspended sediment loads in run-off waters.
- Intensive baseline investigations are required to accurately determine any sediment reductions resulting from treatment interventions.
- Aerial LiDAR data is valuable as a gully classification tool, as a design aid, and as a monitoring methodology if repeated and compared post-treatment.
- Terrestrial LiDAR has the capacity to record very detailed land surface measurements and therefore may be particularly useful for measuring changes from surface erosion.
- BACI design is important but can be difficult ‘in the field”, assumptions should be documented.
- A system of gully categorisation and classification will allow the results of treatment trials to be more usefully transferred to future treatment sites.
- Detailed soil mapping can greatly assist the gully classification process as well as provide important information relevant to remediation design, soil amelioration, and vegetation establishment.
- Vegetation surveys and biomass calculations can assist in determining the end-goal of remediation/rehabilitation as well as demonstrating a treatment’s longer-term effectiveness.

Follow-up Actions Resulting from the Forum

Actions going forward

Utilising the combined experience and knowledge of the forum participants to improve the remediation/rehabilitation outcomes in alluvial gully erosion projects was one of the objectives implicit in the purposes of the forum. With this in mind, a number of the key points made during the discussions warrant further investigation and action. These actions are likely to improve the potential outcomes of the remediation trials proposed under the Innovative Gully Remediation Project, as well as broaden the collective understanding of alluvial gully research, remediation/rehabilitation, and evaluation. Five actions have been identified.

A1. Soil mapping

The recommendation for further soil sampling to support the development of remediation options at the site has been subsequently adopted as a part of Griffith's NESP 3.1.7 project. Further soil sampling and analyses were commenced in conjunction with DES Science Division and DES Office of the Great Barrier Reef in July/August 2017. The results of the soil sampling including higher resolution soils mapping covering the site will be used to improve the understanding of gully processes and characterisation and also to assist remediation planning and the evaluation of treatment effectiveness. A report and refined soil map is due to be released in April/May 2018.

A2. Ameliorants and soil conditioning

The range of methods/techniques currently utilised in the mining and agricultural industries for the treatment of dispersive and in particular sodic soils have direct relevance to the treatment methodologies proposed for trial at the Strathalbyn Station Innovative Gully Remediation Sites. For instance, the type of ameliorants used, methods of application and incorporation into the soil, and subsequent capping of treated areas are all factors which should be further evaluated in the context of large scale alluvial gully remediation in the GBR catchments. The treatment trials at Strathalbyn will therefore explore optimal approaches to the use of different ameliorants on reducing ongoing erosion at alluvial gully sites. These approaches will include the application of powdered and liquid gypsum, direct application of organic matter (mulch, mill mud), hydro-mulching, and other innovative methods such as high intensity low duration controlled stocking trials.

A3. Engineering design

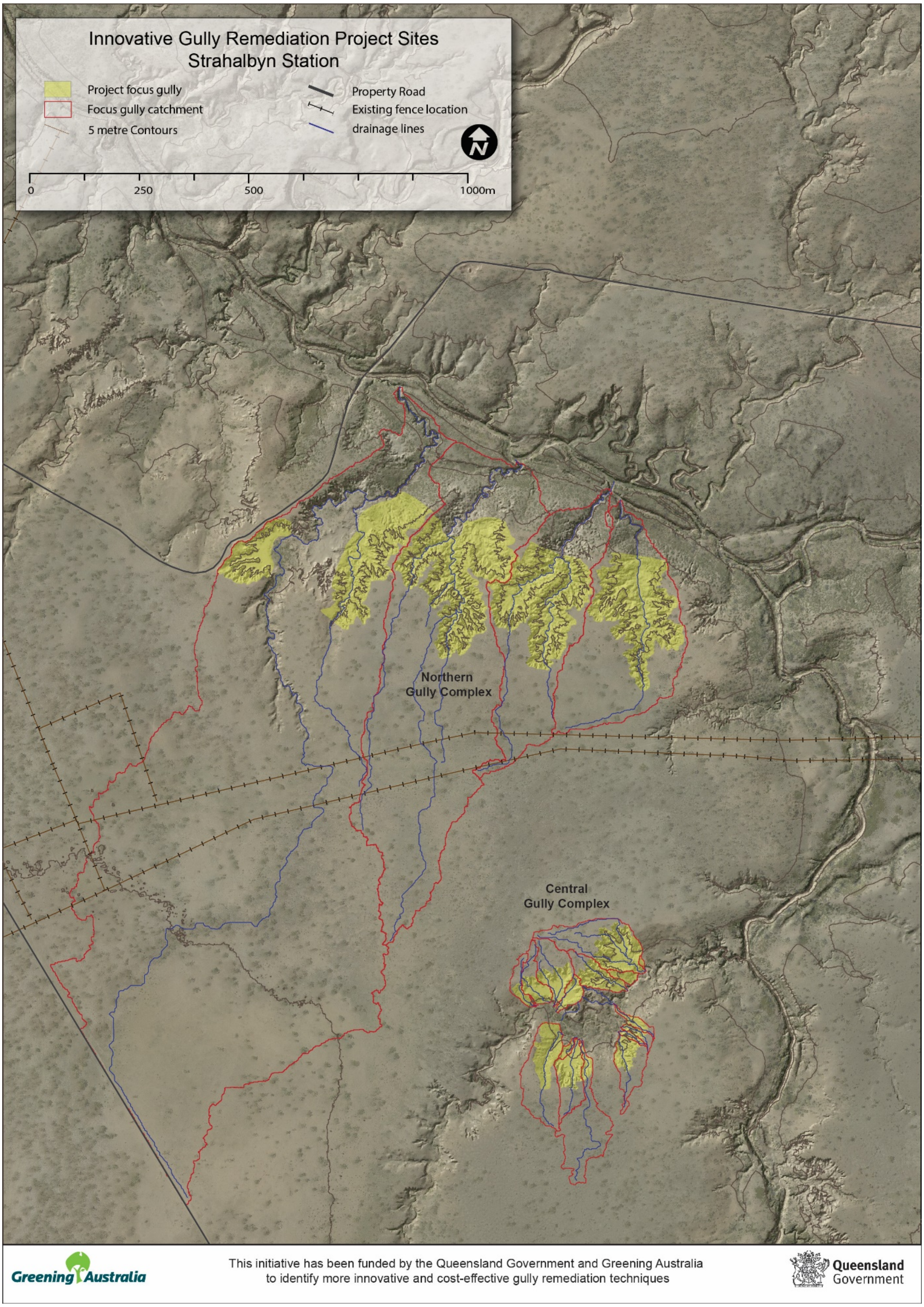
There is extensive experience available both locally (Central and North Queensland, and within Australia generally) of design principles relating to the stabilisation of eroding and mined landscapes and much of this experience is directly relevant to bulk earthworks design for alluvial gully remediation. Nevertheless, there are still elements of alluvial gully remediation design which could be better refined. These elements include design and construction specifications around the cost-effective treatment of tunnel erosion, the length and slope of regraded gully batters, the thickness of capping required on different batter slopes, the design of within channel check structures, and the potential for innovative low-cost soft engineering approaches. These elements will be investigated during the 2018 Strathalbyn remediation trials covering some 7 sites covering over 10Ha of direct interventions in 2018. The results of the trials will be used to develop rules of thumb and guidelines for consideration in future projects.

A4. Vegetation re-establishment

The desired end-state for remediated alluvial gully systems is generally agreed to be a stable landform with perennial (preferably native) ground cover (minimum 70% soil coverage at the end of the dry season), with adequate ground cover in the catchment to reduce overland flow during storm events and a diverse tree species cover to reduce sub-surface water flows. There is a great deal of expertise in pasture management in the local region, particularly grazing management. The areas identified for further investigation of optimal approaches to re-establish vegetation within larger scale remediated alluvial gully systems (ie. 1-5 ha) at Strathalbyn Station include the role of stock management in improving ground cover and soil health (specifically soil carbon, organic matter, and fertility), the most appropriate species for seeding programs, the most appropriate types of ameliorants to improve revegetation success (eg. Mulch types and application thickness) and the appropriateness of specialist equipment which may improve revegetation success or cost effectiveness (for example bale shredders, hydro-mulchers, seeders, etc). Trials involving the application of 225 tonnes of mulch over 5 ha using a Tomahawk 8500 bale shredder, hydro-mulching of a 2ha site, compost and mill mud application, and the use of various seeders will be undertaken in 2018.

A5. Monitoring and evaluation

There are a range of current technologies available to monitor the water quality of storm waters in agricultural/grazing landscapes. Many of these technologies have been adapted successfully by research institutions such as TropWater, Griffith University and CSIRO to monitor various water quality parameters within gullies and in the receiving waters of the Great Barrier Reef lagoon. These technologies have been adopted and will be used to monitor the reductions in sediment loads coming from treated gully catchments (using a BACI design) and to evaluate the effectiveness of the various remediation strategies implemented. Further, there are a number of emerging or improving technologies such as drone-based and terrestrial-based LiDAR which may prove valuable for refining our understanding of remediation responses and treatment effectiveness. To date there has been several data capture efforts covering the pre- and post-treatment gully forms at Strathalbyn using both high resolution aerial LiDAR (Griffith University) and terrestrial LiDAR (DES Science Division and Griffith University). It is hoped that these technologies can be trialled and evaluated at Strathalbyn Station under the Innovative Gully Remediation Project.


Innovative Gully Remediation Project Sites
Strahalbyn Station
Project focus gully
Focus gully catchment
5 metre Contours
Property Road
Existing fence location
drainage lines
N
0
250
500
1000m
Northern
Gully Complex
Central
Gully Complex
Greening Australia
This initiative has been funded by the Queensland Government and Greening Australia
to identify more innovative and cost-effective gully remediation techniques
Queensland
Government

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