

Cost effectiveness of gully remediation in the Burdekin catchment: preliminary insights based on measured data from monitoring sites

Rebecca Bartley, Scott Wilkinson, Anne Henderson and Aaron Hawdon



Cost effectiveness of gully remediation in the Burdekin catchment: preliminary insights based on measured data from monitoring sites

Rebecca Bartley¹, Scott Wilkinson¹, Anne Henderson¹, Aaron Hawdon¹

¹ CSIRO



Supported by the Australian Government's National Environmental Science Program
Project 2.1.4 Demonstration and evaluation of gully remediation on downstream water quality and agricultural production in GBR rangelands

© CSIRO, 2018



Creative Commons Attribution

Cost effectiveness of gully remediation in the Burdekin catchment: preliminary insights based on measured data from NESP monitoring sites and progress with new Lidar methodologies is licensed by the CSIRO for use under a Creative Commons Attribution 4.0 Australia licence. For licence conditions see: <https://creativecommons.org/licenses/by/4.0/>

This report should be cited as:

Bartley, R., Wilkinson, S., Henderson, A. Hawdon, A. (2018) *Cost effectiveness of gully remediation in the Burdekin catchment: preliminary insights based on measured data from NESP monitoring sites and progress with new Lidar methodologies*. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (28pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub.

The Tropical Water Quality Hub is part of the Australian Government's National Environmental Science Program and is administered by the Reef and Rainforest Research Centre Limited (RRRC). The NESP TWQ Hub addresses water quality and coastal management in the World Heritage listed Great Barrier Reef, its catchments and other tropical waters, through the generation and transfer of world-class research and shared knowledge.

This publication is copyright. The Copyright Act 1968 permits fair dealing for study, research, information or educational purposes subject to inclusion of a sufficient acknowledgement of the source.

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government.

While reasonable effort has been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

Cover photographs: Mt Wickham Station (front) and MinnieVale Station (back). Images by Rebecca Bartley.

This report is available for download from the NESP Tropical Water Quality Hub website: <http://www.nesptropical.edu.au>

CONTENTS

Contents.....	i
List of Tables.....	ii
List of Figures.....	iii
Acronyms	iv
Acknowledgements	v
Executive Summary	1
1.0 Introduction	3
2.0 Monitoring sites undergoing gully remediation	4
3.0 Calculating cost-effectiveness at field sites.....	7
3.1 Calculation of costs related to gully remediation.....	7
3.2 Calculation of sediment being delivered prior to intervention	8
3.3 Calculation of effectiveness of the treatment	9
3.4 Preliminary results.....	12
3.5 What did we learn from this analysis?	16
3.5.1 General findings.....	16
3.5.2 Field site specific findings.....	17
4.0 Insights and recommendations.....	20
References.....	22
Appendix 1: Comparison of Cost-effectiveness calculations	24

LIST OF TABLES

Table 1:	Description of the five study sites (Virginia Park, Meadowvale, Strathbogie, Minnievale and Mt Wickham).....	6
Table 2:	The general cost components included, generally included and excluded for gully remediation	8
Table 3:	The methods used to estimate the baseline rate of sediment yield, being that which would occur in the absence of treatment.....	9
Table 4:	Treatments and effectiveness values based on expert opinion (red) or measured estimates (blue)	11
Table 5:	Type of remediation, cost of project, effectiveness value, % fines and assigned delivery ratio for each site. Note that the Virginia Park treatment has been in place for 7 years and the Meadowvale and MinnieVale treatments for 2 years	12
Table 6:	Estimated fine sediment saving at the coast (t/y) using the different methods. Calculations can be found in Appendix 1	13
Table 7:	\$ per t/y at coast estimates of cost effectiveness using the 4 different approaches. Calculations can be found in Appendix 1.....	13
Table 8:	Comparison of long term erosion rates based on aerial photos and shorter term rates base on TLS. Methods and data describing the aerial photo analysis were presented in Bartley et al., 2017. Strathbogie is the only site where the current erosion rate is greater than the long term average, resulting in a ratio >1. Na = not available, due to instrument failure or no data yet collected. ^a note that Mt Wickham gully growth was measured in area (ha) and not linear increase. ...	14
Table 9:	Comparison of rainfall (mm) for the long term available record and the rainfall recorded at the sites for the measurement period	15
Table 10:	Comparison of cost-effectiveness calculations for Virginia Park	24
Table 11:	Comparison of cost-effectiveness calculations for Meadowvale	25
Table 12:	Comparison of cost-effectiveness calculations for Strathbogie	26
Table 13:	Comparison of cost-effectiveness calculations for MinnieVale	27
Table 14:	Comparison of cost-effectiveness calculations for Mt Wickham	28

LIST OF FIGURES

Figure 1:	Underlying soil type at each of the properties (Source: Atlas of Australian Soils)	5
Figure 2:	An example of the typical pattern of gully growth showing the early rapid growth phase compared to the slower more mature growth phase (after Rutherford et al., 1997).	17
Figure 3:	An example of mature gullies that have reached the ridgetop and are unlikely to extend further	19
Figure 4:	An example of a young gully with considerable potential to erode in the future.	19

ACRONYMS

CQU	Central Queensland University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DOEE	Department of the Environment and Energy
GBR	Great Barrier Reef
GU	Griffith University
LDC	Landholders Driving Change
Lidar	Light Detection and Ranging
NESP	National Environmental Science Program
NQDT	NQ Dry Tropics
NRM	Natural Resource Management
PCDs	Porous Check Dams
P2R	Paddock to Reef
QDAF	Queensland Department of Agriculture and Fisheries
RRRC	Reef and Rainforest Research Centre Limited
TWQ	Tropical Water Quality
TLS	Terrestrial laser scanner
TSS	Total suspended sediment

ACKNOWLEDGEMENTS

We would like to acknowledge the Australian Government's National Environmental Science Program (NESP), the Queensland Government and CSIRO for providing funding for this project. We would also like to acknowledge Glen Dale of Verterra for supplying the Mt Wickham historical air photo data and cost-effectiveness report, and to Jenet Austin (CSIRO) for reviewing a previous version of this report.

EXECUTIVE SUMMARY

This final technical report for NESP Tropical Water Quality Hub Project 2.1.4: Demonstration and evaluation of gully remediation on downstream water quality and agricultural production in GBR rangelands was to report on:

- (i) the effectiveness (in terms of cover, erosion and water quality) of various gully remediation approaches in the Burdekin Catchment; and
- (ii) The cost of various gully remediation approaches implemented.

The effectiveness of the remediation approaches were outlined in detail for the last two wet seasons in the following reports which are available on the NESP Tropical Water Quality (TWQ) Hub website:

- Bartley et al., (2017) for the 2016/17 wet season (<http://nesptropical.edu.au/wp-content/uploads/2017/10/NESP-TWQ-2.1.4-TECHNICAL-REPORT-1.pdf>) ;
- Bartley et al., (2018) for the 2016/17 and 2017/18 wet seasons (<http://nesptropical.edu.au/wp-content/uploads/2018/07/NESP-TWQ-2.1.4-TECHNICAL-REPORT-2.pdf>)

There have been no additional rain events since June 2018, therefore this report only presents component (ii) the cost-effectiveness of remediation at the NESP TWQ Hub sites. More specifically, this report provides a demonstration of the calculation of cost-effectiveness of gully remediation at five monitored sites in the Burdekin catchment, and the influence of different data analysis approaches for estimating sediment savings. Effectiveness data from the previous reports have been included in this report in a summarised form to support the cost-effectiveness calculations.

The key findings from this report include:

- Estimates of cost-effectiveness are sensitive to the gully metrics used to represent the baseline fine sediment supply (gully width, depth and length);
- Estimates of baseline sediment supply can be made by using terrestrial or airborne Lidar data to obtain more accurate gully dimensions, however, they need to be placed in the context of the longer term gully erosion trajectory (generally using historical air photos);
- The high variability in estimating sediment supply contributes to high variability in the estimates of cost-effectiveness. For this reason, cost-effectiveness is best calculated at the project or program scale (across numerous gullies) as this will help balance out the inherent spatial and temporal variability associated with gully dynamics at individual sites.
- Monitoring data collected at a site can greatly improve the estimate of cost-effectiveness for the remediation activity. Some of the data sets and their benefits include (i) the measured % of clay and silt of the soils at the site which can provide greater accuracy than interpolated estimates; (ii) measured changes in water quality leaving the sites that provide actual estimates of remediation effectiveness; and (iii) measured changes in the vegetation that provide early indicators of improved landscape health.
- Sites with the following attributes will be more cost-effective to treat (assuming the erosion rates and treatment costs are equal) when (i) more efficient sediment delivery to the coast; (ii) high proportion of silt and clay (%); (iii) higher nutrient content (although not yet formerly included in the calculations).

Focus of future work:

- Future studies should consider integrating cost discounting, production cost losses, maintenance costs and the influence of lag effects, however, these will need to be considered in the context of the high variability related to calculating the sediment savings and potential remediation effectiveness at a site.
- We need to better understand the spatial and temporal extent of the treatment effect for the various remediation techniques, as cost-effectiveness is sensitive to these estimates.
- This approach can be adapted to include potential savings and cost-effectiveness for particulate nutrients as well as for sediments.
- Continued monitoring of the water quality improvements of a range of gully remediation approaches.

1.0 INTRODUCTION

Benefit-cost or cost-effectiveness analysis is considered important for standardising approaches to evaluate outcomes in natural resource management (NRM) in many parts of the world (Yitbarek et al., 2012; Gooday et al., 2014; Posthumus et al., 2015) as well as in Australia (Rolfe and Windle, 2016). Cost-effectiveness is increasingly the tool of choice for identifying and prioritising projects for NRM funding (Pannell et al., 2012), however, there is still a major challenge in using these approaches to evaluate the success of programs in part due to a lack of “scientific research into landscape treatment-response relationships which link expenditure to outcomes” (Hajkowicz, 2009).

The Australian Government Reef Trust Phase II and IV Gully and Streambank erosion control Programs are using an approach which (i) identifies priority catchments for remediation, (ii) develops technical guidance for choosing sites and approaches for remediation and (iii) uses cost-effectiveness estimates at site scale as the key metric for prioritising and evaluating on-ground activities (Wilkinson et al., 2018a), based on methods described in the Gully and Stream Bank Toolbox (Wilkinson et al., 2016). The approach currently uses past changes in gully volume (width, depth and length) to estimate a baseline erosion rate. An assumed reduction in erosion rate is then used to estimate “effectiveness” following remediation. Knowledge of the clay and silt content in gully soil at the site (using soil data bases when measured data is not available), and the ratio of fine sediment delivered from the site through the river network to the coast, estimated by Paddock to Reef (P2R) catchment modelling, is then used to provide a potential sediment savings to the coast.

The aim of this report is to test the sensitivity of cost-effectiveness estimates to variations in input data. These methods are tested on the NESP field monitoring sites (Section 2). In particular, long and short term erosion rate estimates are tested (Section 3), and a number of recommendations are made based on this work so far (Section 4).

It is acknowledged that there is an active dialogue regarding the various methods for estimating cost effectiveness in the Great Barrier Reef (GBR) catchments (e.g. Mt Wickham cost-effectiveness report by Dale and Silverwood (2018), the Landholders Driving Change (LDC) meetings chaired by North Queensland Dry Tropics (NQDT), various projects being led by Central Queensland University (CQU) and Griffith University (GU), Queensland Department of Agriculture and Fisheries (QDAF) etc). This report provides some insights into the ‘effectiveness’ component of the cost-effectiveness calculations and will only touch on the ‘cost’ component of cost-effectiveness. It is also important to highlight that this report does not provide a rigorous review of the suite of cost-effectiveness approaches available (see Rolfe and Windle, 2016; Rust and Star, 2018). Rather, we aim to document some of the practical challenges of estimating cost-effectiveness in a diverse range of gully types, and identify the best data sets to use with this approach for the purpose of informing other projects and programs.

2.0 MONITORING SITES UNDERGOING GULLY REMEDIATION

Five properties in the Burdekin catchment were selected to undertake field investigations into the effectiveness of gully remediation on improving water quality. Two in the Upper Burdekin (Virginia Park and Meadowvale), one in the Bogie (Strathbogie), one in the Don catchment (Minnievale), and one in the Bowen (Mt Wickham) (Figure 1 and Table 1). The first four properties are NESP funded sites, and the Mt Wickham site is formerly a project under the NQDT LDC project. CSIRO has supported the water quality monitoring at all of these sites, and so the data are treated collectively as part of this project. The June 2018 technical report for this project (Bartley, et al., 2018) presented the ground cover, terrain and water quality data related to how the control and treatment sites are responding in terms of improved water quality on the five instrumented properties. These preliminary data were used to test the cost-effectiveness calculations in this report.

All sites are commercial grazing properties. The five sites represent a range of property sizes (3,000 to 39,000 ha), however, geologies, rainfall and dominant pasture species are relatively similar (Table 1). The soil types do vary, with Strathbogie residing on a mixture of granite and basalt lithologies (Figure 1B). Virginia Park and Meadowvale (Figure 1A) are dominated by Red Chromosols and Yellow to Brown Sodosols with dispersive B horizons (Rogers et al., 1999; Roth, 2004). Minnievale has been classified as a Red Dermosol.

Granite-derived soils such as granodiorites, and basalt-derived soils such as Vertosols, are known to contribute fine sediment at high rates to rivers in the Burdekin basin, based on sediment source tracing using geochemistry and clay mineralogy (Bainbridge et al., 2016; Furuichi et al., 2016). All properties lie within the 500-900 mm rainfall gradient (see Bartley et al., 2018 for maps of rainfall, vegetation and geology) and have similar vegetation cover. The gully types and erosional features do vary between the properties (Table 1).

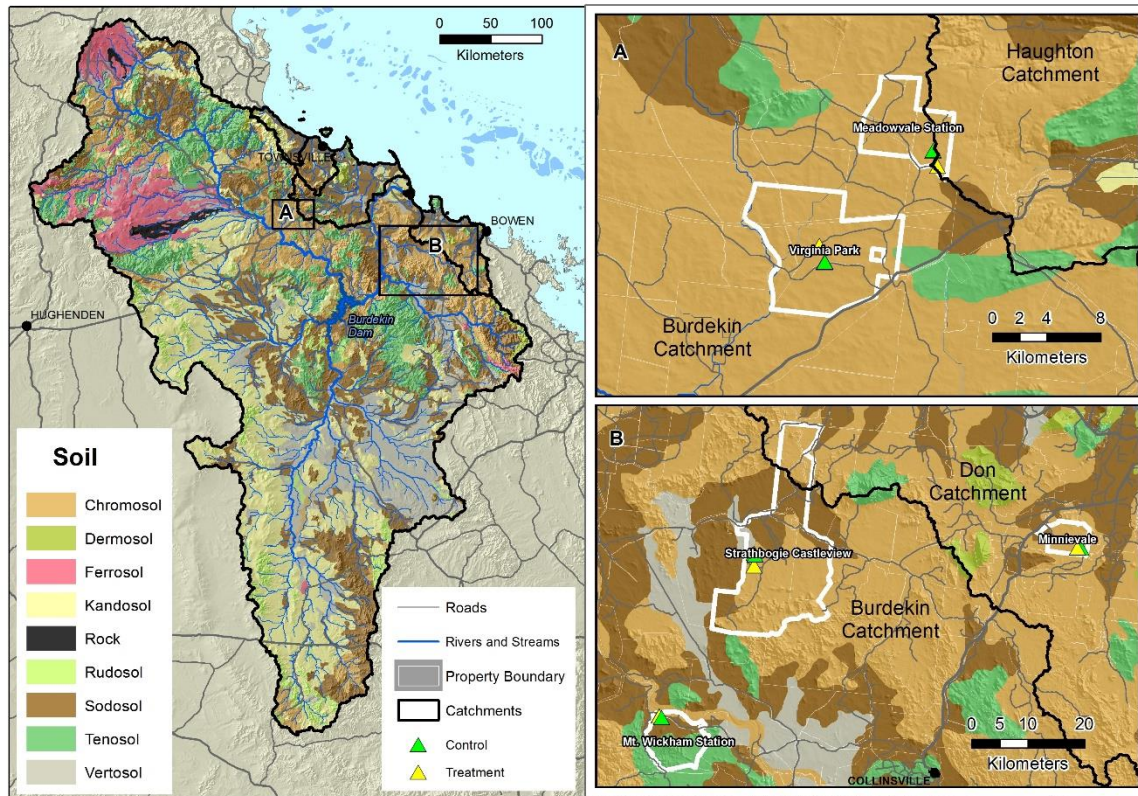


Figure 1: Underlying soil type at each of the properties (Source: Atlas of Australian Soils)

Table 1: Description of the five study sites (Virginia Park, Meadowvale, Strathbogie, Minnievale and Mt Wickham).

Property	Virginia Park	Meadowvale	Strathbogie	Minnievale	Mt Wickham
Management Unit (sub-catchment)	Upper Burdekin	Upper Burdekin (and Haughton)	Bogie	Don	Bowen
Local stream name and size	Treatment and Control both on Weany Creek (1400 ha)	Treatment in headwaters of Haughton river (1400 ha), Control on Wheel Creek (1000 ha)	Treatment and Control both on side arm (1300 ha) of Capsize Creek	Treatment site on Mary Creek (1500 ha) Control site on side arm of Four Mile Creek (1400 ha)	Treatment (3.03 ha) and Control 14.14 ha) sites both drain into Sandalwood Creek which connects with the Bowen river
Size of property (ha)	~7000 ha	~3000 ha	~39,000 ha	~3750 ha	~7790 ha
Soils	Red Chromosol	Red Chromosol	Black Vertosol	Sodic Hypocalcic Red Dermosol	Hypernatric Brown Sodosol
Geology	Granite and Granodiorite	Granodiorite	Granite, Basalt	Granodiorite	Granite and Granodiorite
Terrain (% slope property)	2-3%	2-3%	6-7% (due to high relief in south)	3-4%	10%
Average annual Rainfall (mm)	~ 660 mm	~ 680 mm	~ 750 mm	~ 880 mm	~ 600 mm
Vegetation over-story	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood + Poplar gum
Vegetation groundcover	Dominated by Indian Couch	Dominated by Indian Couch	Dominated by Indian Couch	Dominated by Indian Couch	Dominated by Indian Couch
Gully type	Linear hillslope gullies and scalds	Linear hillslope gullies and scalds	Linear hillslope gullies	Linear hillslope gullies and scalds	Linear hillslope gullies, scalds and major alluvial gullies (incl. tunnel erosion)
Lat Long Treatment Gully	-19.891629, 146.512731	-19.838936, 146.591086	-20.221489, 147.556607	-20.193492, 148.072038	-20.462457, 147.401984
Lat Long Control Gully	-19.902937, 146.51609	-19.828862, 146.588209	-20.20425, 147.558102	-20.194344, 148.077696	-20.465095, 147.407101

3.0 CALCULATING COST-EFFECTIVENESS AT FIELD SITES

3.1 Calculation of costs related to gully remediation

This report does not focus on the “cost” component of cost-effectiveness, however, there are some important baseline items to note.

- The cost calculations used in this document relate to the direct cost involved in designing and installing gully remediation;
- This includes the staff time required to undertake the works. However, staff time associated with planning, coordination and extension is not included;

The items (i) generally included, (ii) sometimes included and (iii) generally excluded in the cost component of the gully remediation works are summarised in Table 2. It is broadly acknowledged that, “there is high uncertainty in the cost estimate when cost-effectiveness is used for conservation or remediation planning, and they are most variable in the intermediate cost range” (Carwardine et al., 2010).

It is also important to highlight that this approach **does not include**:

- Discounting of future costs and effectiveness;
- Production costs to landholders, however, it is assumed that the land being remediated had little production benefit prior to remediation;
- Lag times for remediation to be effective – as the projects haven’t been running for long enough for such estimates to be made;
- Maintenance costs – as the focus so far has been on the selection, design and implementation of sites, however, the issue of site maintenance will be an important consideration into the future.

Rust and Star et al., (2018) estimate some of the indirect costs associated with gully remediation including an annual maintenance component and the opportunity costs of stock exclusion. Estimates of the annual maintenance cost are ~7 per cent per annum over a 10 year period and the stock exclusion costs were estimated to be ~3 half years assuming stock are excluded for 18 months after the remediation work was complete. The Rust and Star et al., (2018) approach currently assumes that:

- All sediment will reach the end of system, when in fact it is generally only the clay and silt component (~30%) of the sediment which is of interest, and of that only a proportion is delivered to the coast;
- Remediation is assumed to reduce gully sediment supply to zero (100% effectiveness), which is generally an over-estimate; and
- Average modelled estimates of sediment loss from gullies from P2R outputs represent the site specific erosion rates.

The focus of this report is to assess the variability in the sediment savings and effectiveness terms, so improvements in the cost modelling are not considered. These components could be included in the future.

Table 2: The general cost components included, generally included and excluded for gully remediation

Costs included	Costs generally included	Costs generally excluded
Materials (e.g. rocks, coir logs, geotextile etc)	Technical advice regarding design	Program management costs (overheads)
Machinery hire	Travel costs for staff to and from the site	Extension and property planning
Fencing		HSE requirements/costs including first aid training, safety gear etc (which may get charged to overheads?)
Labour for construction		Maintenance
Seed/seedlings		
Watering		

3.2 Calculation of sediment being delivered prior to intervention

The Reef Trust gully erosion control program cost-effectiveness calculator requires an estimate of the amount of sediment currently being delivered from a gully (in tonnes per year, t/y), which then allows an estimate of the potential sediment savings to be made at the site. However, there are several different methods available for measuring or estimating the amount of sediment generated from a gully. In this report we have used four different approaches for estimating the sediment loss at each of the monitoring sites that have Lidar, and three approaches for sites without Lidar. A summary of the methods is described in Table 3 and the calculations for these approaches are given in the Appendix A and available in spreadsheet form if needed. The cost (\$) remained the same for all scenarios. This comparison helps demonstrate the sensitivity of the approach but also helps compare the relative or likely differences or uncertainty associated with using the default calculations in the Toolbox.

Caveats for these approaches:

- In Method 3 (in Table 3), the terrestrial laser scanning (TLS) measured data was applied to the headcut proportion of the gully surveyed using the TLS. The remaining gully length was assumed to represent side wall erosion, where the rates were assumed to be ~20% of the headcut erosion rates (mm/yr) based on NESP terrestrial laser scanning (TLS) data and other gully erosion studies that have used erosion pins (Bartley et al., 2007; Wilkinson et al., 2018b).
- The effectiveness values were generally derived from the statistical difference in total suspended sediment (TSS) values measured at the monitoring sites (Table 4). At Meadowvale, there is not yet a statistically significant difference between treatment and control TSS data, so an effectiveness value of 0.1 was assigned. Where we don't yet have data for the Strathbogie and Mt Wickham sites, an effectiveness value of 0.7 was assumed.
- Where the treatments have been in place for two years or more (e.g. Virginia Park, Meadowvale and Minnie Vale), the control site TLS data was used to estimate the pre-treatment erosion rate because the erosion rates of the treated gullies are expected to

have been influenced by the treatments. At the sites that have not yet been treated (e.g. Strathbogie) the actual TLS values were used.

- Virginia Park and Meadowvale are physically based in the Upper Burdekin sub-catchment, which is not currently a priority area for Reef Trust. These sites were included as part of the NESP program due to the benefits derived from the long legacy of research data collected at these sites. For the purpose of evaluating the effectiveness of the treatments on \$/t, it was assumed that these sites had a delivery ratio of 0.96, which is the equivalent of being located in the Don catchment (i.e. downstream of Burdekin Falls Dam).
- In this report, the length of the gully is estimated as the distance from the top of the gully until a change in hydrological contribution which is generally at the junction with another gully.
- Estimates of historical erosion rates for Mt Wickham were undertaken by Verterra Ecological Engineering (Dale and Silverwood, 2018).
- The methods and data describing the aerial photo analysis were presented in Bartley et al., (2017) and the methods and results for the two years of TLS data were presented in Bartley et al., (2018). They will not be repeated here.

Table 3: The methods used to estimate the baseline rate of sediment yield, being that which would occur in the absence of treatment.

	Brief description	Method/Approach
1	Gully dimensions based on rapid field measurements	The long-term average rate since gully initiation based on gully length, width and depth derived from Google Earth or field inspection, adjusted to represent current rates by a decay factor of 50% (the default value given in the Gully Toolbox)
2	Gully dimensions obtained from Lidar (width, depth, length and area)	The long-term average rate since gully initiation based on gully metrics estimated by airborne Lidar, adjusted to represent current rates by a decay factor of 50% (where available, Virginia Park and Mt Wickham only).
3	Current rate based on repeat TLS measurements (scaled to whole gully)	The current rate was estimated based on the volume difference between repeated TLS scans of the gully headcut section (~20-90 m), scaled to the whole gully based on Lidar gully length. The TLS data is not available for Mt Wickham.
4	Current rate based on repeat air photos	The current rate was estimated based on changes in gully length between recent air photos (~1961 – 2006 where available) plus the Lidar derived terrain metrics for width and depth.

3.3 Calculation of effectiveness of the treatment

Where available, we have used the statistical difference (as a %) in TSS values measured at the NESP sites to represent the 'effectiveness' of that intervention (Table 4) (see Bartley et al., 2018 for a detailed description of how these data were calculated). We only have measured water quality (TSS control vs treatment) data on remediation effectiveness for three sites (Virginia Park, Meadowvale and MinnieVale). Remediation works for Mt Wickham have been undertaken, and the Strathbogie works have been designed and are planned for December 2018. Preliminary effectiveness data should be available for these sites in June 2019.

The NESP TWQ Hub project is working towards having a broader range of effectiveness metrics that include sediment loads, which are a product of sediment concentration and runoff at each site. However, obtaining reliable discharge estimates has so far been challenging, so the difference between sediment concentrations will continue to be used until reliable sediment load data are available.

Table 4: Treatments and effectiveness values based on expert opinion (red) or measured estimates (blue)

Remediation approach	Treatment Effectiveness estimate from Toolbox	Treatment Effectiveness estimate based on NESP measurements (2 wet seasons)	Site	Number of years of monitoring post treatment	Notes
Fencing only	0.2	0.1	Meadowvale	2 years	The fencing only data is showing some potential (e.g. increased grass cover in the bed of the channel allowing trapping), however, it is likely that this treatment will take longer to be effective compared with other treatments.
Fencing and 5 PCD's	0.5	0.7	Virginia Park	~7 years	The treatment was part of the P2R program and has been in place for ~7 years. As the PCD's are now filled with sediment, they have likely reached their maximum effectiveness. Tunnelling has started to occur under some PCD's. Note that this is higher than the value 0.5 generally attributed to these treatments, because of the complete livestock exclusion and total treatment of the gully length, and also because of the monitoring data.
Fencing and ~159 PCD's	0.5	0.5	Minnie Vale	2 years	This site appears to have had a relatively rapid and positive response in just two wet seasons. We anticipate that the effectiveness may improve to ~0.7 in coming years. Within gully PCD's are intended to trap eroded sediment, however, they do not necessarily reduce or prevent headcut erosion.
Ripping and stock raking, geofabric, fencing, grass seed	0.6	No measured treatment data yet, however, estimated to be 0.7	Strathbogie	First data will be available in 2019	Should have preliminary data after this coming wet season.
Earthworks, soil treatment, rock chutes, seed.	0.6	No measured treatment data yet, however, estimated to be 0.7	Mt Wickham	First data will be available in 2019	Should have preliminary data after this coming wet season.

3.4 Preliminary results

The type of remediation activity, cost, effectiveness value, % of fine sediment and delivery ratio used for each of the sites is given in Table 5. The estimated fine sediment savings using each of the approaches is presented in Table 6, and the cost-effectiveness in \$ per t/y is in Table 7. The long and short term measured erosion rates, and the ratio of these two metrics, are shown in Table 8, and the rainfall (mm) during each of the measurement periods is presented in Table 9.

It is acknowledged that it is not possible to have research grade data collected at all sites, however, the ratio of the current erosion rate (m/y) measured at each gully using a TLS and the long term erosion rate measured from historical air photos (m/y) can be useful to help identify gullies that are potentially younger, more active and likely to contribute more sediment into the future. The rainfall (mm) over the measurement period needs to be considered using this approach, and the rainfall data presented in Table 9 suggests that during the two wet seasons of data collection, the rainfall has been consistently under the long term average at all of the NESP sites, even with Cyclone Debbie moving across MinnieVale and Strathbogie in April 2017. So caution is required using this approach, however, the approach is still considered useful in a relative sense, and can potentially highlight relatively young and active gullies.

Table 5: Type of remediation, cost of project, effectiveness value, % fines and assigned delivery ratio for each site. Note that the Virginia Park treatment has been in place for 7 years and the Meadowvale and MinnieVale treatments for 2 years

Treatment site	Remediation activity	Estimated cost of project	Effectiveness value	% fines	Delivery ratio
Virginia Park	Fencing off headcut (~100 m) and 5 PCD's in gully (as well as cultivation and seeding of the catchment along contours)	\$3,440	0.7	0.33	0.96
Meadowvale	Fencing off only (~200 m)	\$3,759	0.1	0.32	0.96
Strathbogie*	Ripping and stock raking, geofabric, fencing, grass seed	\$21,500	0.7	0.74	0.87
MinnieVale	Stock management in gullied paddock and 159 PCD's installed around headcut and in gully channel	\$27,387	0.5	0.42	0.96
Mt Wickham	Earthworks, soil treatment, rock chutes, seed.	\$400,000	0.7	0.41	0.87

Table 6: Estimated fine sediment saving at the coast (t/y) using the different methods. Calculations can be found in Appendix 1

	Method	Virginia Park	Meadowvale	Strathbogie	MinnieVale	Mt Wickham
1	Gully dimensions based on rapid field measurements of gully dimensions	2.38	0.62	12.21	12.75	471
2	Gully dimensions obtained from Lidar gully metrics (width, depth, length and area)	1.98				116
3	Current rate based on repeat TLS measurements (scaled to whole gully)	1.24	0.64	76.88	6.83	
4	Current rate based on repeat air photos	5.37	1.74	14.85	4.49	1297

Table 7: \$ per t/y at coast estimates of cost effectiveness using the 4 different approaches. Calculations can be found in Appendix 1

	Method	Virginia Park	Meadowvale	Strathbogie	MinnieVale	Mt Wickham
1	Gully dimensions based on rapid field measurements of gully dimensions	1448	6035	1761	2147	850
2	Gully dimensions obtained from Lidar gully metrics (width, depth, length and area)	1786				3444
3	Current rate based on repeat TLS measurements (scaled to whole gully)	2765	5866	280	4007	
4	Current rate based on repeat air photos	641	2160	1448	5335	308

Table 8: Comparison of long term erosion rates based on aerial photos and shorter term rates base on TLS. Methods and data describing the aerial photo analysis were presented in Bartley et al., 2017. Strathbogie is the only site where the current erosion rate is greater than the long term average, resulting in a ratio >1. Na = not available, due to instrument failure or no data yet collected. ^anote that Mt Wickham gully growth was measured in area (ha) and not linear increase.

Field site	Gully type	Annual average rate of gully extension (m/y) $\pm$ SE (~1961-2016)	Gully headcut retreat using TLS (2016/17), m	Gully headcut retreat using TLS (2017/18), m	Average erosion rate (m/y) using the TLS (for 2 wet seasons (2016/17 and 2017/18))	Ratio of current to long term erosion
Virginia Park	Treatment	1.70 $\pm$ 4.14	0.46	0.34	0.40	0.24
	Control	0.38 $\pm$ 0.56	0.35	0.36	0.36	0.95
Meadowvale	Treatment	1.30 $\pm$ 1.36		Na	Na	-
	Control	1.64 $\pm$ 2.12		0.71	0.71	0.43
Strathbogie	Treatment	2.85 $\pm$ 4.37	18.10	7.80	12.95	3.55
	Control	3.65 $\pm$ 6.49	0.75	1.76	1.12	0.39
MinnieVale	Treatment	1.39 $\pm$ 2.54	0.50	0.10	0.30	0.21
	Control	1.59 $\pm$ 1.68	0.84	0.48	0.66	0.42
Mt Wickham	Treatment	0.06 (ha) ^a			Na	-
	Control				Na	-

Table 9: Comparison of rainfall (mm) for the long term available record and the rainfall recorded at the sites for the measurement period

Field site	Gully type	Long term mean annual rainfall (mm)	BOM Station and station number	Distance of BOM rain gauge from site (km)	Average Rainfall (mm) for aerial photo period	Rainfall (mm) at the site in 2016/17	Rainfall (mm) at the site in 2017/18	Average rainfall (mm) for 2 year monitoring period
Virginia Park	Treatment	650	Mingela Post office (33051)	~13 km	647	345	543	444
	Control	650	"	"	647	320	587	454
Meadowvale	Treatment	650	"	~8 km	647	402	722	562
	Control	650	"	"	647	342	763	553
Strathbogie*	Treatment	725	Strathmore (33082)	~32 km	669	577	474	526
	Control	725	"	"	669	608	493	551
MinnieVale	Treatment	841	Mt Dangar (33096)	~6 km	848	797	670	734
	Control	841	"	"	848	730	669	700
Mt Wickham	Treatment	626	Myuna (33292)	~20 km	626	Na	Full wet season not instrumented	
	Control	626	"	"	626	Na	"	

3.5 What did we learn from this analysis?

3.5.1 General findings

- The baseline erosion rate estimates using methods 1 and 2 are proportional to the length of the gully used.
- Current erosion rate estimates can be sensitive to the time period used to estimate erosion (Table 8 and Table 9). This is partly due to variations in erosion rate associated with rainfall variability, but also due to subtle variations in soil type and topography. Erosion rates can also vary depending on where the gully is in its growth lifecycle (see Figure 2). Several studies have shown that channel extension is initially rapid and then declines over time (Schumm et al., 1987). Graf (1977) proposed that gully growth was analogous to the exponential decay of radioactive material and a gully recedes at a rate proportional to the length of the valley material remaining up slope, with most of the erosion and growth occurring early in the phase of gully development. The erosion then declines proportional to the catchment area upslope of the gully (Rutherford et al., 1997).
- By using a combination of approaches to estimate gully growth rate, we will get a better understanding of where a gully is in its lifecycle and this will potentially influence the choice of gully for remediation and its relative cost-effectiveness. For example, Strathbogie has very high current erosion rates (measured using TLS) compared to historical rates (measured from historical air photos) (Table 8). This may, in part, be due to the contribution of Cyclone Debbie in 2016/2017 wet season. However, in 2017/18 the current erosion rates at the Strathbogie treatment site were still double the long term rates, and this was a below average rainfall year with no cyclones (Table 9). So it is likely that this gully is in its active 'growth' phase (e.g. Figure 2).
- This analysis emphasises that erosion rates, or potential sediment savings, are going to vary considerably from year to year for individual gullies and therefore it is important to have some estimate of the long term average gully growth over a longer (e.g. 20 year) time period to even-out the inter-annual variability.
- The length or area of the hillslope upslope of the gully, relative to the length of the current gully, should also be considered carefully when choosing the remediation approach. In some cases, shorter gullies that have considerable potential for extension into the future (e.g. Figure 4), are likely to benefit from control of headcut erosion even though the cost-effectiveness metrics may not be favourable. This would then need to be linked to the amount of sediment prevented into the future, and intervening at an early part of the growth phase.
- For the older more mature gullies (e.g. Figure 3), the headcut retreat rate may have declined, but they can continue to have higher wall erosion rates than the surrounding landscape (Wilkinson et al., 2018b). When extended over long distances, this can continue to be a considerable contribution of sediment. In these cases, reduced livestock access is a priority for treatment.
- PCDs trap sediment in the channel and do not reduce erosion of the headcut or walls. They are effectively reducing the delivery of sediment from the gully, but they are not targeting the actual sediment source. Other options should be considered for gullies with rapidly eroding headcuts.
- The time scale for remediation approaches to become effective is currently not considered. Different techniques will take different amounts of time to become effective.

For example, fencing may be cheaper, however, it is likely to take several years or maybe even decades to be effective. This should/could be considered in any further adaptations of this approach, and specifically the influence of the effectiveness lag time on the economic discounting term.

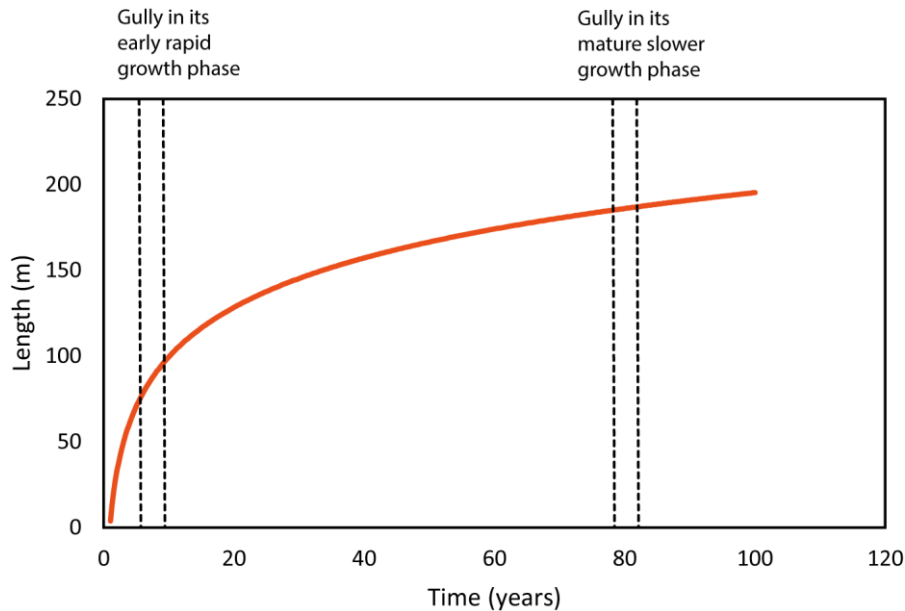


Figure 2: An example of the typical pattern of gully growth showing the early rapid growth phase compared to the slower more mature growth phase (after Rutherford et al., 1997).

3.5.2 Field site specific findings

Virginia Park

For most of the methods used in this analysis, the cost-effective values range between \$1448 - \$2765 per tonne (Table 7). Only when the long term erosion rates are used does the cost-effectiveness become <\$1000/t. The current TLS derived erosion rates are much lower (0.4 m/y) than the long term average (1.7 m/y) for the Virginia Park treatment site (Table 8). Interestingly, at the control site, the long term and current erosion rates are comparable within error (0.38 m/y vs 0.36 m/y; Table 8). This suggests that the erosion rate and potential sediment savings calculated based on the current TLS surveys for the treatment site are an underestimation (and thus an over-estimation of cost-effectiveness).

It is also possible that these gullies are at different points in their growth phase. Given the rainfall for the TLS measurement period is ~30% lower than the long term average for this site (Table 9), and that gully erosion is moderately correlated with rainfall ($r^2 \sim 0.3$; Wilkinson et al., 2018b), these two gullies may be in different phases of their growth trajectory, with the treatment site being more mature and the control site more active. However, additional data from above average rainfall years will be required to test this assumption.

Meadowvale

After two wet seasons with a “fencing only” treatment there is no (statistically significant) measurable effect of this treatment on TSS concentrations. This means that the overall cost-effectiveness for this site is above \$2000/t to date. Interestingly, using the historical erosion rates, the effectiveness of the fencing-only treatment would only need to increase to 0.3 to give this site a cost-effectiveness of <\$1000/t. The current TLS derived erosion rates (for the control site) are much lower in the recent two years (0.71 m/y) than they were in the past (1.64 m/r), noting that the average rainfall for the two year TLS measurement period is ~13% lower than the long term rainfall at this site. However, there is still several hundred metres before this gully will reach the ridge top, and therefore a low cost treatment option may be a suitable (and cost-effective) for this site in the long term.

Strathbogie

Using Methods 1 and 4, Strathbogie has cost-effectiveness estimates in the order of \$1450 to \$1760 per t. However, when the current erosion rates measured using the TLS over the last two wet seasons are used, the \$/t cost-effectiveness reduces to ~\$280/t. The rainfall over the last two wet seasons is ~20% below the long term average for this site, however, despite the reduced rainfall, the current erosion rates are ~2 to 6 times the long term average, suggesting that this site is in a rapid growth phase. This site has a very high proportion of silt and clay (~74%) and when this is combined with a high contemporary erosion rates, it makes this a suitable investment site in terms of cost-effectiveness.

MinnieVale

MinnieVale is the only site where the cost-effectiveness calculation is lowest using Method 1 (~\$2150/t/y). The long and short term gully erosion rates from the control (untreated) gully were used in this analysis (to avoid any direct influence of the treatments over the last 2 years), and again the current erosion rate is much lower (0.66 m/yr) than the long term average (1.59 m/yr). The rainfall for the last two years is ~17% lower than the long term average, however, at this site, many of the gullies are approaching the natural ridgeline, and it is likely that their erosion rate will decline in the future (if it hasn't already).

Mt Wickham

This is the only ‘alluvial’ style gully in this assessment and it has provided a useful test for these approaches. The cost-effectiveness of this site is ~\$308/t when the historical erosion rate data is used with the average depth data derived from the site Lidar. Interestingly, the cost-effectiveness is \$3444/t when the Lidar gully length and average width data are used with the default historical estimate of erosion rate. This suggests that for rapidly eroding sites, the default gully growth rate estimate may result in an overestimate of cost-effectiveness.

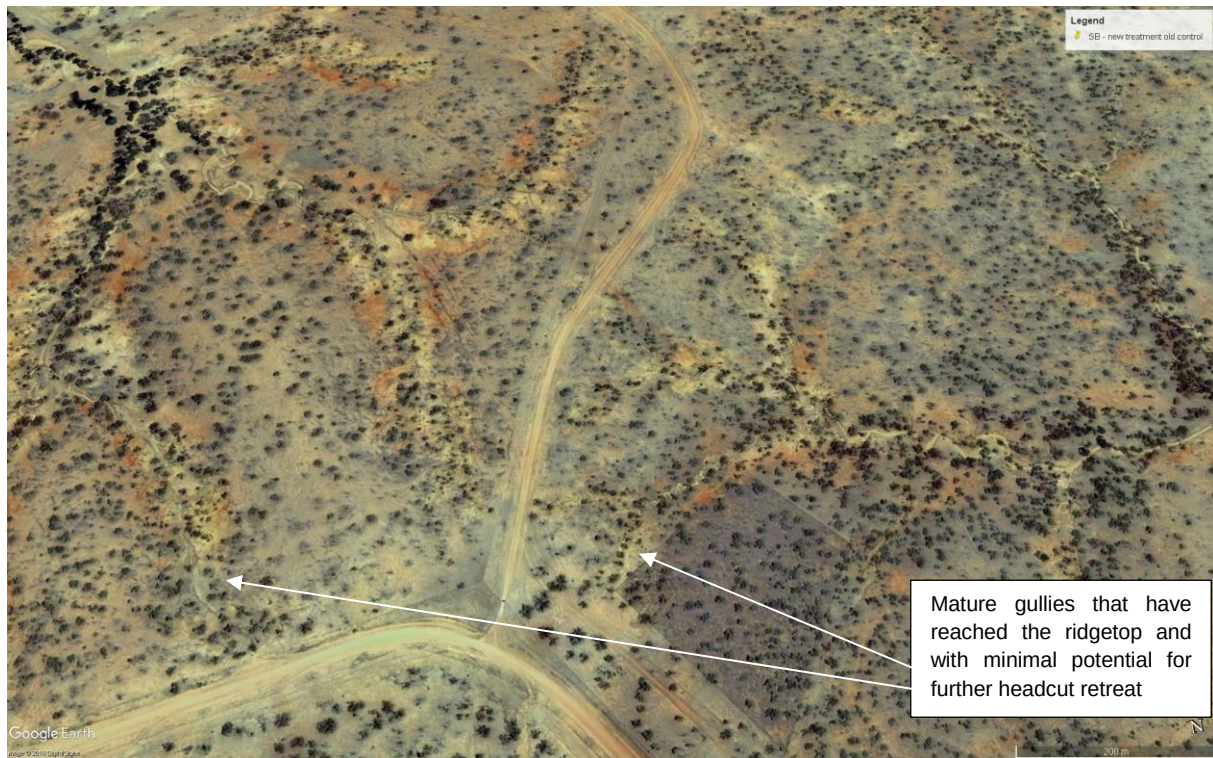


Figure 3: An example of mature gullies that have reached the ridgetop and are unlikely to extend further

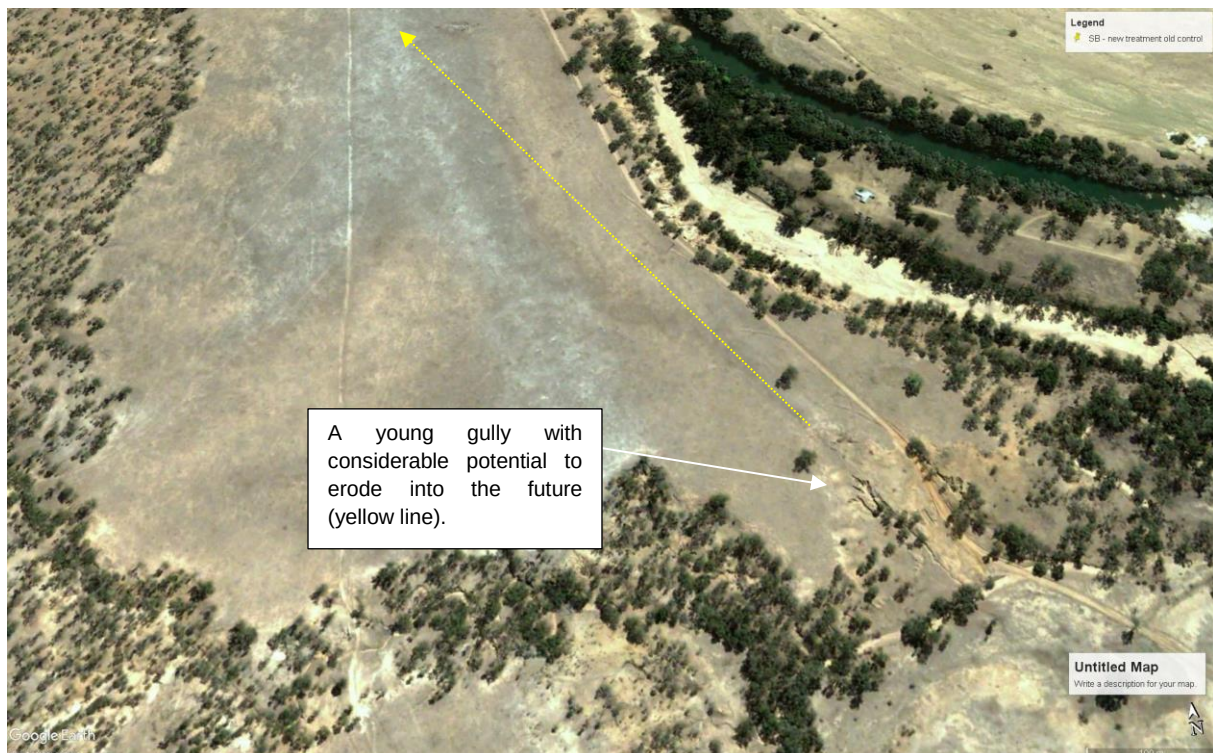


Figure 4: An example of a young gully with considerable potential to erode in the future.

4.0 INSIGHTS AND RECOMMENDATIONS

General comments:

- This report has highlighted that estimating the potential sediment savings at a gully remediation site has uncertainty attached, derived from the methods used to estimate the baseline erosion rate (e.g. Lidar data, TLS derived erosion rates etc).
- As a result, the difference between the highest and lowest \$/t/y cost-effectiveness estimates can vary from 2.8 and 11.2 fold for a given site depending on the metrics used. This is based on using a fixed cost for the remediation and assuming a fixed effectiveness. This highlights the value of using multiple measures to improve the estimate where feasible, and of devoting resources to undertake more comprehensive estimation methods.
- This study demonstrates that there can be high variability in the erosion rate and thus potential sediment savings and cost-effectiveness at a single site. Using the DEM's of difference of successive terrestrial and airborne Lidar captures will offer improved insights into the contemporary erosion rates, particularly when measured over time periods that represent the long term rainfall (>5-10 years). Accurate measurements over shorter periods are highly variable due to climate variations and longer-term measurements of baseline erosion rates based on historical air photos remain useful.
- At this stage of the NESP project (based on the results from two wet seasons) it is difficult to recommend a preferred approach to help reduce the variability in sediment savings and cost-effectiveness. Additional measured effectiveness data (to be collected in 2018/19 and 2019/20), as well as continued improvement of the terrain analysis techniques using Lidar, will hopefully yield a revised approach or recommendations in 2020.

Costing of projects

- Future studies could consider integrating cost discounting, production cost losses, maintenance costs and the influence of lag effects, however, these will need to be considered in the context of the high variability related to calculating the sediment savings and potential remediation effectiveness at individual sites.
- It may also be appropriate for costs to be calculated for a site (using only the costs associated with the direct remediation) as well as for an entire program (which would include the cost of extension and administration) which would allow the full cost of these programs to be evaluated.

Further work going forward

- We need to better understand the length of the treatment effect for the various techniques, as the cost-effectiveness method is highly sensitive to the length of the gully treated.
- We can partition the TLS derived erosion rates for the 'headcut' section vs the gully walls in the main trunk. This will provide a better estimate of the relative contribution of headcuts vs gully walls. This will then make it easier to estimate the relative sediment savings for each component of the gully. This could then be linked to the various gully units defined by the Lidar delineation.
- We can consider adapting this approach to include potential savings and cost-effectiveness for particulate nutrients as well as for sediments;

- Importantly, these activities need to be supported by continued monitoring of the water quality improvements from a range of gully remediation techniques in a field setting.

REFERENCES

- Bainbridge, Z., Lewis, S., Smithers, S., Wilkinson, S., Douglas, G., Hillier, S. and Brodie, J., 2016. Clay mineral source tracing and characterisation of Burdekin River (NE Australia) and flood plume fine sediment. *Journal of Soils and Sediments*, 16(2): 687-706, 10.1007/s11368-015-1282-4.
- Bartley, R., Hawdon, A., Henderson, A., Wilkinson, S., Goodwin, N., Abbott, B., Baker, B., Matthews, M., Boadle, D. and Jarihani, B., 2018. Quantifying the effectiveness of gully remediation on off-site water quality: preliminary results from demonstration sites in the Burdekin catchment. NESP Project 2.1.4. Milestone report, June 2018.
- Bartley, R., Hawdon, A., Henderson, A., Wilkinson, S., Goodwin, N., Abbott, B., Baker, B., Matthews, M., Boadle, D., Telfer, D., Smith, B., Jarihani, B. and Burkin, B., 2017. Quantifying the effectiveness of gully remediation on off-site water quality: preliminary results from demonstration sites in the Burdekin catchment. NESP Project 2.1.4. Milestone report, June 2017.
- Bartley, R., Hawdon, A., Post, D.A. and Roth, C.H., 2007. A sediment budget in a grazed semi-arid catchment in the Burdekin basin, Australia. *Geomorphology*, 87(4): 302-321.
- Carwardine, J., Wilson, K.A., Hajkowicz, S., Smith, R.J., Klein, C.J., Watts, M. and Possingham, H.P., 2010. Conservation Planning when Costs Are Uncertain. *Conservation Biology*, 24(6): 1529-1537, doi:10.1111/j.1523-1739.2010.01535.x.
- Dale, G. and Silverwood, B., 2018. Mt Wickham erosion approximation, Report prepared for NQ Dry Tropics.
- Furuichi, T., Olley, J., Wilkinson, S., Lewis, S., Bainbridge, Z. and Burton, J., 2016. Paired geochemical tracing and load monitoring analysis for identifying sediment sources in a large catchment draining into the Great Barrier Reef Lagoon. *Geomorphology*, 266: 41-52, <http://dx.doi.org/10.1016/j.geomorph.2016.05.008>.
- Gooday, R.D., Anthony, S.G., Chadwick, D.R., Newell-Price, P., Harris, D., Duethmann, D., Fish, R., Collins, A.L. and Winter, M., 2014. Modelling the cost-effectiveness of mitigation methods for multiple pollutants at farm scale. *Science of The Total Environment*, 468-469: 1198-1209, <https://doi.org/10.1016/j.scitotenv.2013.04.078>.
- Graf, W.L., 1977. The rate law in fluvial geomorphology. *American Journal of Science*, 277(2): 178-191.
- Hajkowicz, S., 2009. The evolution of Australia's natural resource management programs: Towards improved targeting and evaluation of investments. *Land Use Policy*, 26(2): 471-478, <http://dx.doi.org/10.1016/j.landusepol.2008.06.004>.
- Pannell, D.J., Roberts, A.M., Park, G., Alexander, J., Curatolo, A. and Marsh, S.P., 2012. Integrated assessment of public investment in land-use change to protect environmental assets in Australia. *Land Use Policy*, 29(2): 377-387, 10.1016/j.landusepol.2011.08.002.
- Posthumus, H., Deeks, L.K., Rickson, R.J. and Quinton, J.N., 2015. Costs and benefits of erosion control measures in the UK. *Soil Use and Management*, 31(S1): 16-33, doi:10.1111/sum.12057.
- Rogers, L., Cannon, M. and Barry, E., 1999. Land Resources of the Dalrymple Shire, Department of Natural Resources and CSIRO, Brisbane.
- Rolfe, J. and Windle, J., 2016. Benchmarking costs of improving agricultural water management in GBR catchments, National Environmental Science Programme - Final Report.

- Roth, C., 2004. A framework relating soil surface condition to infiltration and sediment and nutrient mobilisation in grazed rangelands of north-eastern Queensland. *Earth Surface Processes and Landforms*, 29: 1093-1104.
- Rust, S. and Star, M., 2018. The cost effectiveness of remediating erosion gullies: a case study in the Fitzroy. *Australasian Journal of Environmental Management*, 25(2): 233-247, 10.1080/14486563.2017.1393465.
- Rutherford, I.D., Prosser, I.P. and Davis, J., 1997. Simple Approaches to Predicting Rates and Extent of Gully Development. In: S.S.Y. Wang, E.J. Langendoen and F.D. Shields (Editors), *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*. The Centre for Computational Hydroscience and Engineering, The University of Mississippi, pp. 1124-1130.
- Schumm, S.A., Mosley, M.P. and Weaver, W.E., 1987. *Experimental fluvial geomorphology*. Wiley, Chichester.
- Wilkinson, S.N., Brooks, A., Hairsine, P.B., Crawford, D., Bartley, R. and Pietsch, T., 2016. Gully and Stream Bank Toolbox: A technical guide for the Reef Trust Phase IV Gully and Stream Bank Erosion Control Program, CSIRO, Report to the Department of the Environment (Reef Program).
- Wilkinson, S.N., Hairsine, P.B., Hawdon, A.A. and Austin, J., 2018a. Addressing gully erosion in the Great Barrier Reef catchments: priorities and progress. In: G. Vietch and I.D. Rutherford (Eds), *9th Australian Streams Management Conference 2018*; 12-15 August 2018; Hobart. River Basin Management Society, p575-582.
- Wilkinson, S.N., Kinsey-Henderson, A.E., Hawdon, A.A., Hairsine, P.B., Bartley, R. and Baker, B., 2018b. Grazing impacts on gully dynamics indicate approaches for gully erosion control in northeast Australia. *Earth Surface Processes and Landforms*, 43(8): 1711-1725, 10.1002/esp.4339.
- Yitbarek, T.W., Belliethathan, S. and Stringer, L.C., 2012. The onsite cost of gully erosion and cost-benefit of gully rehabilitation: A case study in Ethiopia. *Land Degradation & Development*, 23(2): 157-166, doi:10.1002/ldr.1065.

APPENDIX 1: COMPARISON OF COST-EFFECTIVENESS CALCULATIONS

Table 10: Comparison of cost-effectiveness calculations for Virginia Park

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Site Design Template (Table 4) Gully and Stream Bank Toolbox													
		Use RTK (if the stream gully and/or bank is not a road or driveway) or use a surveyor (if the stream gully and/or bank is a road or driveway)	Use LIDAR (if the stream gully and/or bank is not a road or driveway) or use a surveyor (if the stream gully and/or bank is a road or driveway)	Use LIDAR (if the stream gully and/or bank is not a road or driveway) or use a surveyor (if the stream gully and/or bank is a road or driveway)	Use LIDAR (if the stream gully and/or bank is not a road or driveway) or use a surveyor (if the stream gully and/or bank is a road or driveway)									
1	Property name	Virginia Park	Virginia Park	Virginia Park	Virginia Park	Comments or Source of Information			Greening Aust labour rate = \$45/hr	45 per hour				
2	Paddock name	Treatment	Treatment	Treatment	Treatment				Daily rate	360				
3									From DonRiver_PCD_Report_JAN2018/20180216.pdf					
4	Date	15/11/2018	15/11/2018	15/11/2018	15/11/2018				Labour (assuming Greening Australia rates)					
5	Person completing the report	R. Bartley	R. Bartley	R. Bartley	R. Bartley				Materials					
6	Latitude (decimal degrees)	-19.891629	-19.891629	-19.891629	-19.891629				Costs					
7	Longitude (decimal degrees)	146.512731	146.512731	146.512731	146.512731				Description					
8	Soil Australian soil order (e.g., Chromosol, Vertosol)	Chromosol	Chromosol	Chromosol	Chromosol									
9	Soil Subsoil stake test (Table/Slakes/Dispersive)													
10	Gully Length (m)	200	122	122	122	Based on Google Earth or Lidar								
11	Length (m) of potential sediment savings - distance to ridge	175	175	175	175	Approx. distance to ridge								
12	Gully Width (m)	6.4	5.2	5.2	5.2	Based on RTK surveys or Lidar								
13	Gully Area (ha)	0.1280	0.0634											
14	Gully Longitudinal slope within the gully (proportion)	2.90%	2.90%	2.90%	2.90%									
15	Gully Maximum depth (m)	1.6	1.6	1.6	1.6									
16	Gully Catchment area draining to the gully head (ha)	4.30%	4.30%	4.30%	4.30%									
17	Gully Ground surface slope above the gully head (proportion)													
18	Stream Banks Length of erosion control (km)													
19	Stream Banks Area of erosion control (ha)													
20	Erosion Control Activity numbers	5	5	5	5									
21	Historical erosion rate using aerial photos (m/y)	1.7	1.7	1.7	1.7	Based on aerial photos (Av. Linear retreat ~1970 - 2009)								
22	Current erosion rate using TLS (m/y)	0.14	0.14	0.14	0.14									
23	Gully Area growth rate if no action, averaged over >10y (m2/y)	6.40	3.17		8.84									
24	Gully or Streambank Depth of the active erosion (m)	1.1	1.8	1.8	1.8	Average depth of gully from RTK (1.1 m) or Lidar (1.8 m)								
25	Soil Estimated dry bulk density (t/m3)	1.54	1.54	1.54	1.54	Assuming bulk density reported in Wilkinson et al 2018								
26	Soil Estimated silt/clay content (proportion)	0.326	0.326	0.326	0.326	From P2R sites on Flumes								
27	Net soil loss based on TLS data (t/yr) at control site			5.68										
28	Gully Fine sediment supply from site if no action (t/y)	3.53	2.87	1.85	7.99									
29	Gully Erosion Control Effectiveness (proportion)	0.70	0.70	0.70	0.70	Based on NESP water quality data (statistical difference)								
30	Gully TSS saving at site (t/y)	2.47	2.01	1.30	5.59									
31	Stream Banks TSS saving at site (t/y)													
32	Hill Slopes TSS saving at site (t/y)													
33	TOTAL TSS saving at site (t/y)	2.47	2.01	1.30	5.59									
34	Fine sediment delivery efficiency to coast (proportion)	0.96	0.96	0.96	0.96	Assuming this site is location in Don River								
35	TOTAL TSS saving at coast (t/y)	2.38	1.93	1.24	5.37									
36	Cost (\$)	3440	3440	3440	3440									
37	Cost-effectiveness \$ per t/y at coast	1448	1786	2765	641									
38														
39														
40														
41														
42														
43														
44														
45														
46														
47														
48														
49														

Control 2016-18

Treatment 2016-18

Length	m	22	62
Erosion	m3	4.29	6.53
Erosion	m3/m	0.19	0.11
Deposition	m3	0.42	1.33
Net change	m3	3.86	5.20
Gully area	m2		
Bulk density	t/m3	1.54	1.54
Erosion	tonnes	6.60	10.06
Deposition	tonnes	-0.65	-2.05
Net change	tonnes	5.95	8.02
Net change (whole gully)	tonnes/y	8.50	11.45
Erosion	t/m	0.30	0.16
Deposition	t/m	-0.03	-0.03
Years of survey		2.00	2.00
Erosion	t/m/y	0.15	0.08
Deposition	t/m/y	-0.01	-0.02
Net change	t/m/y	0.14	0.06
Linear growth (m)	2015/16		0.95
Linear growth (m)	2016/17	0.35	0.46
Linear growth (m)	2017/18	0.36	0.34
Total linear growth	m	0.71	0.80
Av. Linear growth	m/y	0.36	0.40
Deposition as a proportion of erosion (%)		-10	-20

Length (m)

Erosion rate (t/m/y)

Erosion rate (t/y)

Comments

Length of gully influenced by treatment	122			
Length of Headcut	22.00	0.14	2.98	
Length of gully channel/walls	100.00	0.03	2.70	Assuming the erosion rate of the gully walls is ~20% of the headcut
Total			5.68	

Untitled Map

Map is responsive to your data

Legend

0 100 200m

Google Earth

Table 11: Comparison of cost-effectiveness calculations for Meadowvale

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Site Design Template (Table 4)	Gully and Stream Bank Toolbox	Use RTK (to the nearest cm) and Google Earth and do a bank growth rate (no treatment or not)	Use TSS derived with no sediment loss (or use a loss deduction)	Breaks on average 1 m from vegetation										
1	Property name	Meadowvale	Meadowvale	Meadowvale	Comments or Source of Information	Item	Cost	GST	Total	Comment					
2	Paddock name	Treatment	Treatment	Treatment		Labour	1500		150	1650	\\fsqld1-tsv.nexus.csiro.au\CLW-Share1\sg\ERMT_ResourceMangementSystem\Orders_Invoices_Purchasing_and_Suppliers\Orders\John_Ramsay\Labour_For_MV_Fence.pdf				
3	Date	15/11/2018	15/11/2018	15/11/2018		Electric Fence	918		92	1000					
4	Person completing the report	R. Bartley	R. Bartley	R. Bartley		Pickets	1000		100	1100	Est \$1000 worth of pickets (from enclosure order)				
5	Latitude (decimal degrees)	-19.838996	-19.838996	-19.838996		Fence hardware	1918		192	2109					
6	Longitude (decimal degrees)	148.591086	148.591086	148.591086		Total	3418		342	3759					
7	Soils Australian soil order (e.g., Chromosol, Vertosol)														
8	Soils Subsoil stake test (Table 5/Lakes/Dispersive)														
9	Gully Length (m)	190	190	190											
10	Length (m) of potential sediment savings - distance to ridge	190	190	190											
11	Gully Width (m)	7.7	7.7	7.7											
12	Gully Area (ha)	0.1483	0.1483												
13	Gully Longitudinal slope within the gully (proportion)	2.60%	2.60%	2.60%											
14	Gully Maximum depth (m)	2.6	2.6	2.6											
15	Gully Catchment area draining to the gully head (ha)	6	6	6	Based on Max from RTK survey										
16	Gully Ground surface slope above the gully head (proportion)	2.90%	2.90%	2.90%											
17	Stream Bank Length of erosion control (km)														
18	Stream Bank Area of erosion control (ha)														
19	Erosion Control Activity numbers														
20	Historical erosion rate using aerial photos (m/y)			1.3	Based on aerial photos (Av. Linear retreat ~1970 - 2009)										
21	Gully Area growth rate if no action, averaged over >10y (m2/y)	7.315		10.01											
22	Gully or Streambank Depth of the active erosion (m)	1.8	1.8	1.8											
23	Soils Estimated dry bulk density (t/m3)	1.54	1.54	1.54											
24	Soils Estimated silt/clay content (proportion)	0.32	0.32	0.32	Assume the same as VP										
25	Net soil loss based on TSS data (t/y) at control site		20.85												
26	Gully Fine sediment supply from site if no action (t/y)	6.49	6.68	8.88											
27	Gully Erosion Control Effectiveness (proportion)	0.10	0.10	0.10											
28	Gully TSS saving at site (t/y)	0.65	0.67	0.89											
29	Stream Bank TSS saving at site (t/y)														
30	TOTAL TSS saving at site (t/y)	0.65	0.67	0.89											
31	Fine sediment delivery efficiency to coast (proportion)	0.96	0.96	1.96											
32	TOTAL TSS saving at coast (t/y)	0.62	0.64	1.74											
33	Cost (\$)	3759	3759	3759											
34	Cost-effectiveness \$ per t/y at coast	6035	5866	2160											
35	Difference between min and max			2.793855649											
36															
37															
38															
39															
40															
41	Length of gully influenced by treatment	190													
42	Length of Headcut	34.30	0.32	10.93											
43	Length of gully channel/walls	155.70	0.06	9.93	Assuming the erosion rate of the gully walls is ~20% of the headcut										
44															
45	Total			20.86											
46															



Table 12: Comparison of cost-effectiveness calculations for Strathbogie

[illegible]

Table 13: Comparison of cost-effectiveness calculations for MinnieVale

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Site Design Template (Table 4)	Gully and Stream Bank Toolbox	Using RTK at the stream along gully and across from it at least 10m up bank	Using 12 dated aerial photos taken from 1970 to 2009	Ground truth verification of gully location and width to aerial photos	Comments or Source of Information	Materials	Labour (Daily rate = hourly rate \$45)	Number of hours for construction	Number of stick traps	Costs (with Description)						
1	Property name	MinnieVale	MinnieVale	MinnieVale													
2	Paddock name	Treatment	Treatment	Treatment													
3	Date	15/11/2018	15/11/2018	15/11/2018													
4	Person completing the report	R. Bartley	R. Bartley	R. Bartley													
5	Latitude (decimal degrees)	-20.193492	-20.193492	-20.193492													
6	Longitude (decimal degrees)	148.072038	148.072038	148.072038													
7	Soil: Australian soil order (e.g., Chromosol, Vertosol)																
8	Soil: Subsoil stake test (Table/Stakes/Dispersive)																
9	Total length of gully (m) to the stream line	150	150	150	From Google Earth												
10	Gully: Length (m)	790	790	790	Distance from top of gully to powerline												
11	Length (m) of potential sediment savings - distance to ridge	8	8	8	Used "wide" width from RTK surveys												
12	Gully: Width (m)	0.63	0.80	0.80													
13	Gully: Area (ha)	0.80%	0.80%	0.80%													
14	Gully: Longitudinal slope within the gully (proportion)	1.6	1.6	1.6	Using Wide RTK survey												
15	Gully: Maximum depth (m)	21.2	21.2	21.2													
16	Gully: Catchment area draining to the gully head (ha)	2.00%	2.00%	2.00%													
17	Gully: Ground surface slope above the gully head (proportion)																
18	Stream Bank: Length of erosion control (m)																
19	Stream Bank: Area of erosion control (ha)																
20	Erosion Control Activity numbers	159	159	159													
21	Historical erosion rate using aerial photos (m/y)	31.6	31.6	31.6	Based on aerial photos (Av. Linear retreat ~1970 - 2009)												
22	Gully: Area growth rate if no action, averaged over >10y (m ² /y)	1.3	1.3	1.3	Using Wide RTK survey												
23	Gully or Streambank: Depth of the active erosion (m)	1.54	1.54	1.54													
24	Soil: Estimated dry bulk density (t/m ³)	0.42	0.42	0.42													
25	Soil: Estimated silt/clay content (proportion)	33.90	33.90	33.90													
26	Net soil loss based on TSS data (t/yr) at control site	26.57	14.24	10.70													
27	Gully: Fine sediment supply from site if no action (t/y)	0.50	0.50	0.50	Assumed the same effectiveness at all sites												
28	Gully: Erosion Control Effectiveness (proportion)	13.29	7.12	5.35													
29	Gully: TSS saving at site (t/y)																
30	Stream Bank: TSS saving at site (t/y)																
31	Hillslope: TSS saving at site (t/y)																
32	TOTAL TSS saving at site (t/y)	13.29	7.12	5.35													
33	Final sediment delivery efficiency to coast (proportion)	0.96	0.96	0.96													
34	Final sediment delivery efficiency to coast (proportion)	12.75	6.83	5.13													
35	TOTAL TSS saving at coast (t/y)	27387	27387	27387													
36	Cost (\$)	2147	4007	5335													
37	Cost-effectiveness \$ per t/y at coast																
38	Difference between min and max			2.48427673													
39																	
40		Length (m)	Erosion rate (t/m/yr)	Erosion rate (t/yr)	Comments												
41	Based on control site metrics																
42	Length of gully influenced by treatment	790															
43	Length of Headcut	47.01	0.17	8.15													
44	Length of gully channel/walls	742.99	0.03	25.76	Assuming the erosion rate of the gully walls is ~20% of the headcut												
45																	
46		Total		33.90													
47																	
48																	

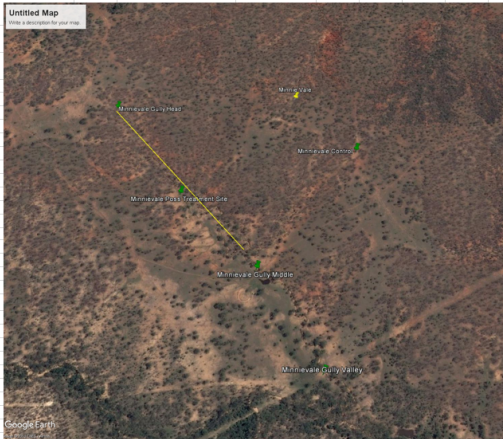


Table 14: Comparison of cost-effectiveness calculations for Mt Wickham

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
	Site Design Template (Table 4) Gully and Stream Bank Toolbox	Using Google earth estimate of length and width of the gully and the adjacent slope	Using Google earth estimate of length and width of the gully and the adjacent slope	Using Google earth estimate of length and width of the gully and the adjacent slope	Using Google earth estimate of length and width of the gully and the adjacent slope	Using Google earth estimate of length and width of the gully and the adjacent slope	Using Google earth estimate of length and width of the gully and the adjacent slope																	
1	Property name	Mt Wickham	Mt Wickham	Mt Wickham	Mt Wickham	Mt Wickham	Comments or Source of Information		Materials	Labour (Daily rate -hourly rate \$45)	Number of hours for construction	Costs	Comments											
2	Paddock name	Treatment	Treatment	Treatment	Treatment	Treatment	Earthworks - recontouring																	
3	Date	15/11/2018	43419	43419	43419	43419	Soil treatment																	
4	Person completing the report	R. Bartley	R. Bartley	R. Bartley	R. Bartley	R. Bartley	Rock chute grade control structures																	
5	Latitude (decimal degrees)	-20.462457	-20.462457	-20.462457	-20.462457	-20.462457	Seed																	
6	Longitude (decimal degrees)	147.401984	147.401984	147.401984	147.401984	147.401984	Watering																	
7	Soil: Australian soil order (e.g., Chromosol, Vertisol)	Chromosol	Chromosol	Chromosol	Chromosol	Chromosol																		
8	Soil: Subsoil stake test (Table/Slakes/Dispersive)																							
9	Total length of gully (m) to the stream line						From Verterra report																	
10	Length of headcut area (m)						Table 10. Cost of sediment abated using the gully toolbox approach compared with direct estimates																	
11	Gully Length (m)	550	100	1734			Gully toolbox calculations																	
12	Length (m) of potential sediment savings - distance to ridge (m2)						Gully: Growth rate average over >10y (m2/y)	1028		2007 - 2017 Low	2007 - 2017 High	2017 - 2027 Low	2017 - 2027 High											
13	Gully: Width (m)	150	125	9.8			Gully or Stream Bank: Depth of the active erosion	2.72																
14	Average gully headcut retreat (m/yr) based on TLS or lidar						Total erosion volume rate (m3)	2796		1157	2056	3634	1465											
15	Gully: Area (ha)	8.25	1.25	1.70			Soil: Estimated dry bulk density (t/m3)	1.61		1.61	1.61	1.61	1.61											
16	Gully: Longitudinal slope within the gully (proportion)						Total sediment loss rate (t/yr)	4502		1863	3310	5851	2359											
17	Gully: Maximum depth (m)	4.31	4.31	4.31	4.31	4.31	Soil: Estimated subsoil silt + clay (proportion)	0.4004		0.4004	0.4004	0.4004	0.4004											
18	Gully: Catchment area draining to the gully head (ha)	12.27	12.27	12.27	12.27	12.27	Fine sediment loss rate (t/yr)	1803		746	1325	2343	944											
19	Gully: Ground surface slope above the gully head (proportion)	0.40%	0.40%	2.60%	2.60%	2.60%	Erosion control effectiveness (proportion)	0.8		0.8	0.8	0.8	0.8											
20	Stream Bank: Length of erosion control (m)						Effective Fine sediment loss rate (t/yr)	1442		537	954	1874	680											
21	Gully: Area growth rate if no action, averaged over >10y (m2/y)	412.5	62.5	85.0	949	1028	Fine sediment delivery efficiency to the coast (p)	0.9		0.9	0.9	0.9	0.9											
22	Gully or Streambank: Depth of the active erosion (m)	2.72	2.72	3.4	3.4	2.72	Historical Fine sediment yield from site (t/y)	1298		671	1193	1687	850											
23	Soil: Estimated dry bulk density (t/m3)	1.68	1.68	1.61	1.61	1.61	Program cost of Gully Erosion control activities (\$)	\$400,000		\$400,000	\$400,000	\$400,000	\$400,000											
24	Soil: Estimated silt+clay content (proportion)	0.41	0.41	0.41	0.41	0.41	Cost-effectiveness (\$ per t/y)	\$308		\$745	\$419	\$237	\$588											
25	Net soil loss based on TLS data (t/y) at control site	772.83	117.10	190.69	2129.88	1845.75	Lidar metrics from Anne																	
26	Gully: Fine sediment supply from site if no action (t/y)	0.70	0.70	0.70	0.70	0.80	Mongully	Length	Area		MG_Avg_width	MG_Avg_Depth												
27	Gully: Erosion Control Effectiveness (proportion)	540.98	91.97	133.48	1490.92	1476.60	MW/C_trunk	718.4			8581	11.9	3.0											
28	Stream Bank: TSS saving at site (t/y)						MWT	1734.6			19067	11.0	3.3											
29	Hilltop TSS saving at site (t/y)						MWT_trunk	933.3			9105	9.8	3.4											
30	TOTAL TSS saving at site (t/y)	540.98	91.97	133.48	1490.92	1476.60																		
31	Fine sediment delivery efficiency to coast (proportion)	0.87	0.87	0.87	0.87	0.90																		
32	TOTAL TSS saving at coast (t/y)	471	71	116	1297	1329																		
33	Cost (\$)	400000	120000	400000	400000	400000																		
34	Cost-effectiveness \$ per t/y at coast	850	1683	3444	308	301																		
35	Difference between min and max			11.16917355																				
36																								
37																								
38																								
39																								
40																								
41																								
42																								
43																								
44																								
45																								
46																								
47																								

