

Quantifying the effectiveness of gully remediation on off-site water quality: Preliminary results from demonstration sites in the Burdekin catchment (second wet season)

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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

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This report should be cited as:

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 (second wet season)*. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (75pp.).

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.

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Cover photographs: Rebecca Bartley

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ACRONYMS

CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEHP	Department of Environment and Heritage Protection
DEMs	Digital Elevation Models
DoDs	Digital Elevation Models of Difference
DSITI	Department of Science, Information Technology and Innovation
GBR	Great Barrier Reef
LDC	Landholders Driving Change
NESP	National Environmental Science Program
P2R	Paddock to Reef
PCD	Porous check dams
QDES	Queensland Department of Environment and Science
RTK	Real time kinematic
TLS	Terrestrial Laser Scanner
TWQ	Tropical Water Quality

ABBREVIATIONS

BACI	before, after, control, impact
DON	dissolved organic nitrogen
ML	mega litres
PN	particulate nitrogen
SD	standard deviation
SE	standard error
TN	total nitrogen
TSS	total suspended sediment

ACKNOWLEDGEMENTS

We would like to thank the Australian Government's National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland State Government Department of Environment and Heritage Protection (DEHP) and the Department of Science, Information Technology and Innovation (DSITI) for funding this research. I would also like to thank Peter Zund, Queensland Department of Environment and Science (QDES) and Seonaid Philip (CSIRO) for supporting the soil sampling at three of the properties in 2018, so we now have consistent soil descriptions for all of the sites. We would also like to thank the Property owners for allowing access to their properties and involvement in the projects. Thank you to Rob, Sue and Matt Bennetto, John Ramsay and Family, Darren Watts and Family, and Barney and Juanita Gordon. Thankyou also to Dr Elisabeth Bui (CSIRO) for reviewing an earlier version of this report.

Team member contributions to the project:

Rebecca Bartley designed the project, managed the contracts and project milestones, analysed the water quality and particle size data and wrote the report.

Aaron Hawdon lead the design of the water quality instrumentation set-up and installation at all sites, instrument trouble-shooting and maintenance and prepared the hydrograph data.

Anne Henderson processed the velocity and flow data, calculated spatial data analysis metrics and prepared the maps and figures for the report.

Scott Wilkinson co-designed the project (including experimental design) and facilitated the collaborative links with the Reef Trust projects and previous Paddock to Reef (P2R) work at Virginia Park.

Nick Goodwin was responsible for the terrestrial laser scanning at all of the gully sites and developed the DEMs of difference and volumetric erosion change data.

Brett Abbott was responsible for the design, collection, analysis and presentation of the land condition and hillslope vegetation data.

Brett Baker supported the collection and submission of the water quality data, assisted with field installation and maintenance, and collected the RTK surveys. He also prepared the field sampling manual for our delivery partners.

Mel Matthews was responsible for the collection, submission and maintenance of the water quality data, and assisted with field installation and maintenance.

David Boadle assisted with the water quality instrumentation set up and testing.

Ben Jarihani ran the Index of Connectivity analysis.

REPORT OVERVIEW

This document represents the 2017/18 annual research report for NESP TWQ Hub Project 2.1.4 (Demonstration and evaluation of gully remediation on downstream water quality and agricultural production in GBR rangelands). The results from the first wet season (2016/17) for four grazing properties were presented in Bartley et al., (2017). This current report presents the results for the 2017/18 wet season for the four original sites, and it now includes a fifth property, Mt Wickham, which is part of the Burdekin Landholders Driving Change network. This report is written as a stand-alone report, and therefore there is considerable repetition from the previous 2017 report. Table 1 outlines the differences between the 2017 and 2018 reports. To reduce the size of the report, some information has been removed (e.g. air photo interpretation). This document presents the technical information from the field sites only.

Table 1: Comparison of removed and new information included in this report (2018) compared with Bartley et al., 2017

Data/information in Year 1 only (2017)	New data information in Year 2 (2018)
Historical Air photo interpretation	Inclusion of the new Landholders Driving Change Mt Wickham site
Review of remediation effectiveness from across the world	New velocity sensors installed and initial data analysed in anticipation of measuring flow discharge for constituent load estimation
Zebedee terrain scanning results	More detailed analysis of the nitrogen speciation at the various sites
	Comparison of hillslope vs gully TSS concentration and particle size data
	Options for identifying high risk gullies at the catchment/property scale

EXECUTIVE SUMMARY

Gully erosion contributes ~40% of the excess soil erosion to the Great Barrier Reef (GBR) from just ~0.1% of the catchment area, however, methods and approaches for reducing this erosion source are not well tested in this environment. Gully erosion is a complex process influenced by soil properties, terrain, surface and sub-surface runoff and vegetation. There is significant Government investment in GBR water quality improvement focused on reducing gully erosion, and there is an urgent need to evaluate the most cost-effective methods for reducing the sediment and particulate nutrients generated and delivered from this erosion source.

This study was designed to evaluate the effectiveness of a range of remediation options for the smaller more ubiquitous hillslope gullies found within rangeland systems of the Burdekin basin, however, in 2018, an additional property (Mt Wickham), containing alluvial gullies, was added to the analysis.

A total of five properties are being evaluated in this report. Two properties located in the Upper Burdekin, one in the Bogie, one in the Don River catchment and one in the Bowen. Paired gully sites (treatment and control) were identified at each property. The remediation options implemented on the treatment gullies include a mixture of fencing, stock exclusion, sediment trapping structures (within the gullies) and hillslope vegetation management. Remediation at the Mt Wickham property will be more intensive (and expensive) commensurate with the contribution of sediment from this source. Of the five properties being monitored, only three had active treatments installed prior to the 2017/18 wet season, however, one of the sites with active remediation now has eight years of treatment data.

To quantify the effectiveness of the various treatment options a suite of monitoring equipment and sites have been set up on both the treatment and control gully at each location. These metrics include (i) estimates of land condition, vegetation cover, biomass and species diversity on the hillslopes above each gully as well as within the gullies, (ii) repeated 3D laser scanning of terrain to estimate changes in erosion and deposition, and (iii) water quality and quantity monitoring equipment that allows the measurement of water stage, runoff volume, turbidity, sediment and nutrient concentration and particle size. Water quality samples from these sites have also been shared with other projects looking at the bio-availability of nutrients, geochemical tracing and nutrient isotope analysis.

The hydrological reporting period presented in this report is primarily from the November 1st 2017 until April 30th 2018, however, where appropriate data from both wet seasons is presented. The key results so far suggest that:

- Gully catchment land condition at all sites remains in C or D class, and the pasture species are dominated by the exotic perennial grass Indian couch, forbs, and/or exotic legumes. Indian couch is known to indicate relatively poor infiltration compared to that associated with native perennial species.
- Porous check dams (or PCDs) constructed from sticks and logs, in combination with stock exclusion fencing, appear to have a statistically significant impact on the amount of vegetation (% cover and/or biomass) that stabilises gullies floors and walls. This, in turn, appears to have significantly reduced the total suspended sediment (TSS) concentrations

within the gullies treated with PCDs, although several more years of average to above average rainfall is required to validate this finding. There is also a commensurate reduction in the total nitrogen following remediation with PCDs.

- Erosion of the gully headcuts during the 2017/18 wet season, as measured using the RIEGL Terrestrial Laser Scanner (TLS), ranged from 0.10 m at Minnievale Treatment site, to 7.8 m at Strathbogie. The maximum rate in 2017/18 was much lower than the 18.1 m headcut retreat measured at Strathbogie in 2016/17. However, the Strathbogie site, which is located on Vertosol soils continues to have much higher erosion and headcut retreat rates than gullies on other soil types, despite the reduced rainfall in 2017/18.
- Sediment yield from the gullies ranges from 0.06 tonnes per metres (t/m/yr) at the Virginia Park treatment gully to 1.08 t/m/y at Strathbogie which has no treatment. The linear extent or change was not measured at Mt Wickham, as this is part of the Landholders Driving Change (LDC) Project, however, the erosion mechanism is likely to be very different at that site as sub-surface tunnel erosion is present.
- After the second wet season, there is still a strong relationship between the catchment area above the gully and average sediment yield (t/m/yr) for untreated gully sites ($r^2 = \sim 0.86$). Catchment area is a surrogate for runoff volume or energy and is the strongest predictor of sediment yield found in this study so far.
- The total suspended sediment (TSS) concentrations vary considerably between sites with the highest mean concentrations being measured at Mt Wickham at $\sim 57,000$ mg/l. This gully has very highly sodic sub-surface soils. The other gullies had peak concentrations between ~ 5000 and $\sim 11,000$ mg/l. The total nitrogen (TN) concentrations follow a similar pattern to TSS when comparing the control and treatment sites. Interestingly, although Mt Wickham has much higher TSS concentrations than the other sites, the TN values are not statistically different.
- At the long running treatment site (Virginia Park) the amount of nitrogen coming off the untreated control site is ~ 5080 $\mu\text{g/l}$ which is more than three times the nitrogen concentration from the treatment site (~ 1550 $\mu\text{g/l}$). In addition, the form of nitrogen varies between the treatments. That is, at the control site, $\sim 92\%$ of the total nitrogen (TN) is in particulate form (PN), whereas at the treatment site, only $\sim 60\%$ of the TN is in particulate form, the remainder is largely dissolved organic nitrogen (DON). This most likely reflects the increased vegetation cover at the treatment site reducing the amount of particulate nitrogen (PN), but also contributing some nitrogen via the breakdown of vegetative matter.
- The proportion of particulate nitrogen (PN) in the total nitrogen (TN) concentrations varies between $\sim 60\text{-}90\%$ for different sites.
- The high sediment concentrations measured at Mt Wickham help justify this site as part of the LDC program. These types of remediation projects will potentially have high effectiveness, but they will also come at a high cost and are confined to certain locations. Therefore, understanding the effect of improved land management and gully remediation is still a priority for more ubiquitous smaller gullies. In addition, it is important to understand how we can improve the eco-hydrological function of these landscapes as a whole, so that we can potentially reduce the runoff and sediment loss from all erosion sources, including hillslopes and streambanks.

The next 6 months of this project will be focusing on:

- Maintaining and servicing the monitoring equipment to collect a third wet season of data to estimate the effectiveness of treatments across four, hopefully five sites;
- Using a range of data metrics collected in this study to calculate estimates of the cost-effectiveness for treatments at all of the sites. These estimates will be used to help inform the future investments in gully erosion control; and
- Developing methods for identifying 'hot-spot' gullies within catchments to prioritise sites for remediation. The data from the instrumented sites can then be used to run what-if scenarios for the properties under a range of remediation options.

1.0 INTRODUCTION

There is considerable evidence demonstrating that excess sediment and associated nutrients from catchments adjacent to the Great Barrier Reef (GBR) are having a deleterious influence on seagrass beds (Waycott et al., 2005) and inshore coral reef ecosystems (De'ath et al., 2012). Gully erosion covers just 0.1% of the catchment area draining to the GBR, however, sediment source tracing, erosion mapping and load monitoring indicates that gully erosion supplies ~40% of the fine sediment (silt and clay, <63 μm particle size) exported from river basins to the GBR lagoon (Olley et al., 2013; Wilkinson et al., 2015a). The area occupied by gullies is estimated to have increased ~ 10 fold since European settlement in parts of Northern Australia (Shellberg et al., 2010), and the length of gullies in GBR catchments is now estimated to be in excess of 87,000 km (Wilkinson et al., 2015a).

In tropical Australia, gullies can be broadly differentiated into two types: large alluvial gullies (McCloskey et al., 2016; Shellberg et al., 2016) and the smaller, more ubiquitous linear or hillslope gullies (Wilkinson et al., 2018). Both gully forms are likely to be a major anthropogenic sediment source in GBR catchments. Gully erosion is known to be related to soil properties (Wilkinson et al., 2015a; Castillo and Gómez, 2016), surface and sub-surface runoff (Vanmaercke et al., 2016), terrain attributes (Chaplot, 2013) and vegetation above and below the ground (Prosser and Slade, 1994; Gyssels et al., 2005; De Baets et al., 2009). Although the specific location, causes and timing of gully erosion in tropical Australia are not fully understood, emphasis has now turned to understanding the cost-effectiveness of gully remediation options, with the longer term goal of reducing sediment and particulate nutrient delivery to the GBR.

As part of the Reef Trust 2 and 4 programs, the Australian Government is investing in gully remediation projects in focused gully prone areas of the GBR catchments (Wilkinson et al., 2016). Gully erosion has been a problem across many parts of the world since 750 AD (Doolittle, 1985) and gully remediation, using structures like check dams, have been used for centuries in some areas (Quinonero-Rubio et al., 2016; Wei et al., 2016). There is evidence from other parts of the world that gully remediation can be effective on smaller linear gullies (Polyakov et al., 2014; Nichols et al., 2016; Guyassa et al., 2017) and on larger alluvial or badland systems (Hevia et al., 2014; Ranga et al., 2016). There is, however, very limited data on the effectiveness of various gully remediation approaches in the tropical catchments draining to the GBR.

Hundreds of millions of dollars are spent each year on catchment and stream remediation across the globe in an effort to reduce the amount of sediment and nutrients delivered to ecologically sensitive receiving waters (Bernhardt et al., 2005; Kondolf et al., 2008; Kurth and Schirmer, 2014; Wohl et al., 2015). However, measuring the effectiveness of these investments is challenging due to the variability in erosion processes and long lag times between remediation implementation and water quality (Zhang et al., 2017) or ecological response (Kroon et al., 2014). In 90% of stream restoration projects in the USA, there was no monitoring of project effectiveness and limited data were collected to determine which activities were successful and those that were not (Bernhardt et al., 2005). This greatly limits the transferability of approaches between locations and makes calculating the cost-effectiveness of such programs very challenging.

The overarching aims of this project are to (i) provide new knowledge about the links between gully remediation, ground cover, erosion rates and water quality and (ii) to help quantify the cost-effectiveness of remediation strategies used in the Reef Trust 2 investments. The type of remediation approaches used in this program are outlined in Wilkinson et al., (2015c) and are primarily based on using vegetation and targeted low cost engineering structures. These structures are used to reduce flow velocities, facilitate sediment and seed trapping, and reduce sediment yield from gully systems. This program is focused on using a combination of vegetation management and structural control approaches because vegetation (grass) management, on its own, is unlikely to meet the current water quality goals within the time frames required (Bartley et al., 2014), and engineered gully structures are known to have a limited lifespan (Gellis et al., 1995) or high failure rate (Nyssen et al., 2004). Long term studies have shown that downstream water quality can be improved using a combination of engineering and vegetation management (Guyassa et al., 2017; Zhang et al., 2017).

This project aims to provide evidence of the relative effectiveness of these gully remediation approaches to stakeholders and the public. This report represents the primary deliverable for the second wet season of analysis for NESP TWQ Hub Project 2.1.4 June 2018 milestone. This study is located in the Upper Burdekin, Bowen, Bogie and Don sub-catchments of the larger Burdekin basin. These areas are known to be contributing higher anthropogenic sediment yields than other areas (Bainbridge et al., 2014; Bartley et al., 2015) and the Burdekin is the largest source of sediment to the GBR lagoon (Kroon et al., 2012). The Upper Burdekin sites (Virginia Park and Meadowvale) were chosen as they will capitalize on previous research investments looking at rangeland management and water quality response (Hawdon et al., 2008; Wilkinson et al., 2013; Bartley et al., 2014; Wilkinson et al., 2014). The Bogie (Strathbogie) and Don (Minnievale) sites are Reef Trust 2 partnership projects. Mt Wickham is a new site that is part of the Burdekin Landholders Driving Change (LDC) project. The project includes partners from Queensland Government, NQ Dry Tropics Regional Body and Greening Australia.

2.0 EXPERIMENTAL DESIGN

2.1 General approach

In this study, we use an adaptive monitoring framework similar to that outlined in Figure 1. The key question that we are asking is, 'is there a measurable improvement in the erosion and water quality leaving remediated gully sites compared to sites left un-treated?' The monitoring approach used is a modified BACI (before, after, control, impact) design (Green, 1979). It is a modified design as we do not have the luxury of measuring before conditions at all of the sites within a three year funding period. Without the before condition data we will have less statistical power to measure the effect of a change that can be directly attributed to the 'treatment'. However, the use of a control site will provide an estimate of the variability that would likely occur at the site prior to remediation. In this case, the standard error or deviation (SE or SD) of the variability of the control site will need to be exceeded before we can attribute any of the change to the treatment. It is acknowledged that BACI designs with multiple control sites and temporal replication are more robust (Underwood, 1994), however, as with most monitoring studies, there is a need to balance the monitoring design, and the funding available for the project. In this study, each site had one treatment and one control site.

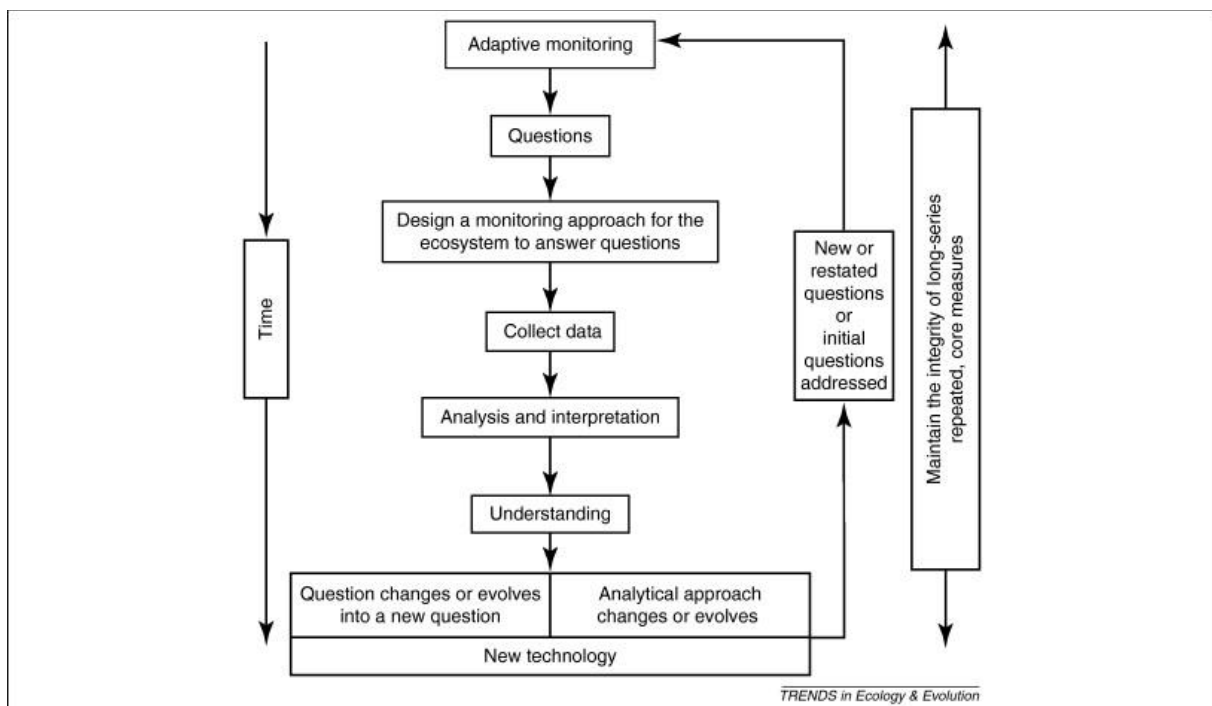


Figure 1: The adaptive monitoring framework implemented in this study (Lindenmayer and Likens, 2009)

2.2 Gully remediation options

The Gully Erosion Toolbox, a document prepared for the Reef Trust gully remediation program (Wilkinson et al., 2015c), outlines a range of treatment options suitable for gully remediation. The treatment options are based on evidence of the effectiveness of studies elsewhere in the world (see review undertaken in Bartley et al., 2017 NESP report). The evidence from these published studies highlight that although gully remediation can be effective, there is also significant risk associated with gully remediation, with many studies highlighting the high failure

rate of within gully structures (e.g. Nyssen et al., 2004). Therefore, the treatment options in this study are primarily based on using vegetation, fencing and low cost engineering structures. The logic also being that if these options are effective, then it should be possible to treat a larger area for a given cost. A conceptual diagram of the relative role of these options on runoff and sediment/nutrient losses are described in Figure 2 and Table 2.

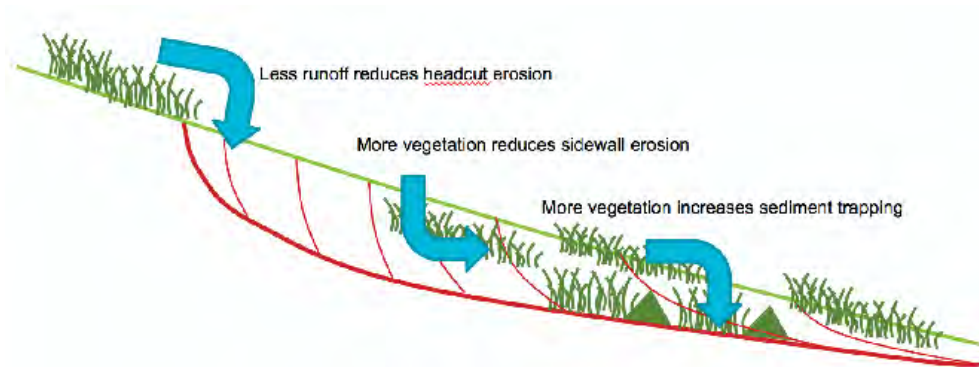


Figure 2: Conceptual model of the outcome of various treatment options within a gully (Wilkinson et al., 2015a). The green triangles represent within gully trapping structures such as porous check dams (PCDs).

Table 2 outlines the conceptual framework used to capture the various 'effectiveness' measures used in this study. As we are not sure exactly which variable will be the most suitable for quantifying the effectiveness of gully response following remediation, we are following a multiple lines of evidence approach. Table 2 describes the range of treatments being trialled along with our hypothesised response or outcome. We then outline the primary, secondary and tertiary response variables and the associated technique used to measure this response. Following gully remediation we anticipate that improvement in vegetation, both on the hillslope, and within the gully, will be a primary or initial response (Wilkinson et al., 2013). If the vegetation improves, then we expect to see an improvement in the rate of erosion and the concentration of the sediments (and particulate nutrients) leaving the site. Finally, in the longer term, we expect to see a change in runoff on both the treated hillslopes above the gully and also within the gully. However, because of the long time frames associated with a reduction in runoff following improvements in ground cover (Bartley et al., 2014), and the high variability in rainfall within and between years, we don't necessarily expect to see a statistically significant difference in the runoff related variables within the time frame of this study.

Table 2: The range of gully remediation treatment options, expected outcomes and measurement metrics. The number of √'s represents the relative magnitude of expected response. The text in blue highlights legacy or ancillary data not currently covered within the NESP project and green is not reported this year

Treatment				Stock management, controlled grazing on hillslopes	Ripping, seeding and re-vegetation of hillslope	Fencing off gullies and stock removal	Porous within gully structures	Solid within gully structures
Expected Outcome or Objective				Improved vegetation (cover/biomass) on hillslopes above the gully	Improved vegetation (cover/biomass) + infiltration on hillslopes above the gully	Improved vegetation (cover/biomass) on gully walls and floor	Slows down runoff and facilitates deposition of sediment (and attached nutrients and seeds)	Slows down runoff and facilitates deposition of sediment (and attached nutrients and seeds). Creates backwater.
Indicator response variable or	Metric	Specific Attribute	Measurement technique					
Primary	Vegetation cover and biomass	Hillslope cover and biomass	Surveys of cover and biomass on the hillslopes above the gully	√√	√			
		Gully wall and floor cover and biomass	Surveys of cover and biomass within the gully	√		√√	√√	√√
	Within gully erosion (t)	- Headcut erosion - Wall erosion or deposition	DEMs of Difference using the TLS (erosion) * bulk density	√	√	√		
Secondary		- Floor erosion or deposition				√√	√√√	√√√
	Improved water quality	- Sediment conc. (mg/l) - Nutrient conc. (mg/l) - Particle size	Samples collected during events across the hydrograph	√	√	√√	√√√	√√√
Tertiary	Reduced runoff (mm) or rainfall –runoff coefficient (%)	Hillslope runoff	Hillslope Flumes and runoff troughs at Virginia Park and Meadowvale	√	√√			

		Within gully runoff	Discharge based on depth and velocity in gullies			√	√√	√√√
<i>Evidence</i>				Evidence suggests increasing cover on hillslopes will result in progressively lower runoff coefficients for early wet season events, but annual runoff will not change significantly. Sediment concentrations should improve but evidence is weak to date (Bartley et al., 2014)	See review in Table 1 in Bartley et al., 2017, although very little data on pasture, with the main focus on trees	See review in Table 1 in Bartley et al., 2017	See review in Table 1 in Bartley et al., 2017	See review in Table 1 in Bartley et al., 2017

3.0 STUDY LOCATION

3.1 The Burdekin catchment

The Burdekin basin is ~130,000 km² and drains into the Great Barrier Reef (GBR) Lagoon south of Townsville on the east coast of Australia. It has the largest mean annual runoff of any of the GBR catchments at 10.29×10^6 ML and is the largest contributor of anthropogenic derived fine sediment to the GBR lagoon (Kroon et al., 2012). The Burdekin river directly influences ~47,000 km² of marine area which includes ~246 coral reefs and 73 seagrass beds (Devlin et al., 2012), however, the flood plume from the Burdekin catchment can extend as far north as Cairns in high runoff years (Brinkman et al., 2014; Waterhouse et al., 2015).

3.2 Trial sites

Four properties were chosen in the Burdekin catchment: two in the Upper Burdekin (Virginia Park and Meadowvale), one in the Bogie (Strathbogie) and one in the Don catchment (Minnievale). An additional property, Mt Wickham, has been instrumented under the Landholders Driving Change (LDC) project, and an analysis of the water quality collected in 2017/18 is included in this report. Importantly, however, the NESP funding does not cover additional data analysis and interpretation from this site in outward years.

All sites are commercial grazing properties. The five sites represent a range of property sizes (3000 to 39,000 ha), however, geologies, rainfall and dominant pasture species are relatively similar (Table 3). The soil types do vary, with Strathbogie residing on a mixture of granite and basalt lithologies (Figure 3 and Figure 4). Virginia Park and Meadowvale 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 (Figure 5) and thus they should have similar vegetation cover (Figure 6). Chromosol soils are known to have a relatively high density of gully erosion (Wilkinson et al., 2013). The gully types and erosional features do vary between the properties (Table 3). The gully treatment options used at each of the sites are described in Section 3.3.

Table 3: 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-leafed Ironbark and Bloodwood	Widely spaced Narrow-leafed Ironbark and Bloodwood	Widely spaced Narrow-leafed Ironbark and Bloodwood	Widely spaced Narrow-leafed Ironbark and Bloodwood	Widely spaced Narrow-leafed Ironbark and Bloodwood + Popular 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

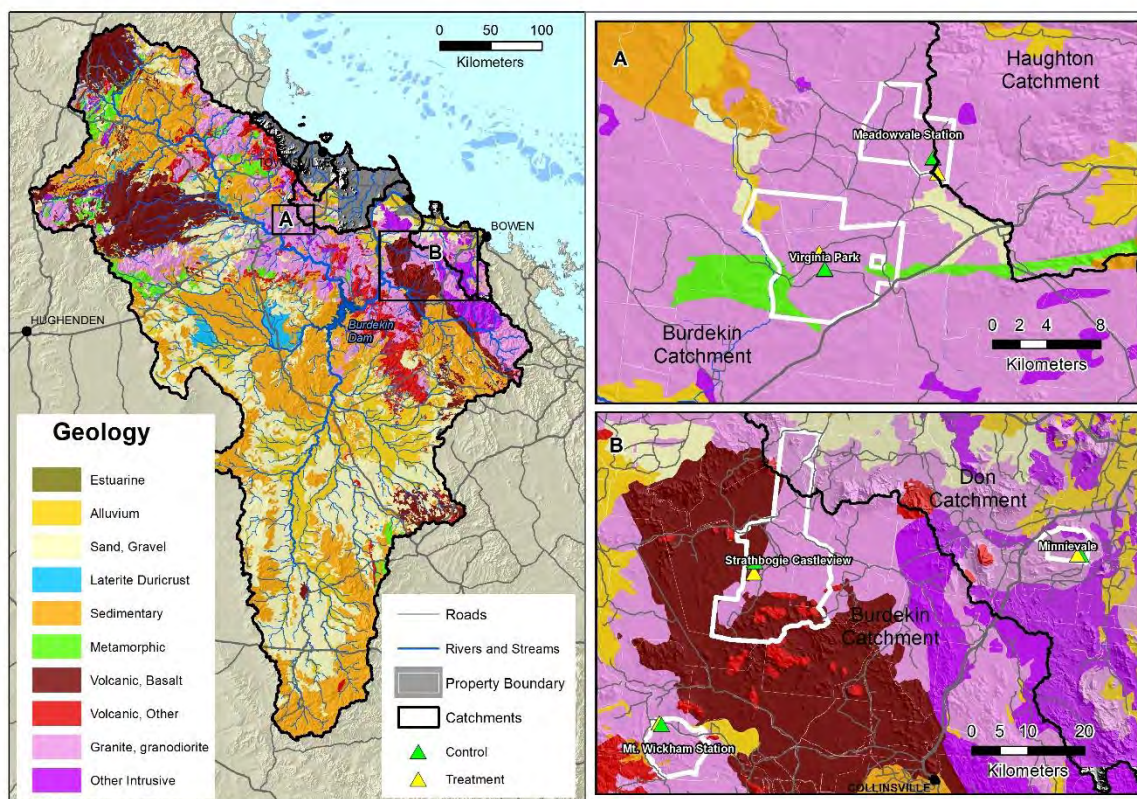


Figure 3: Underlying geology at each of the trial properties (Source: GeoScience Australia)

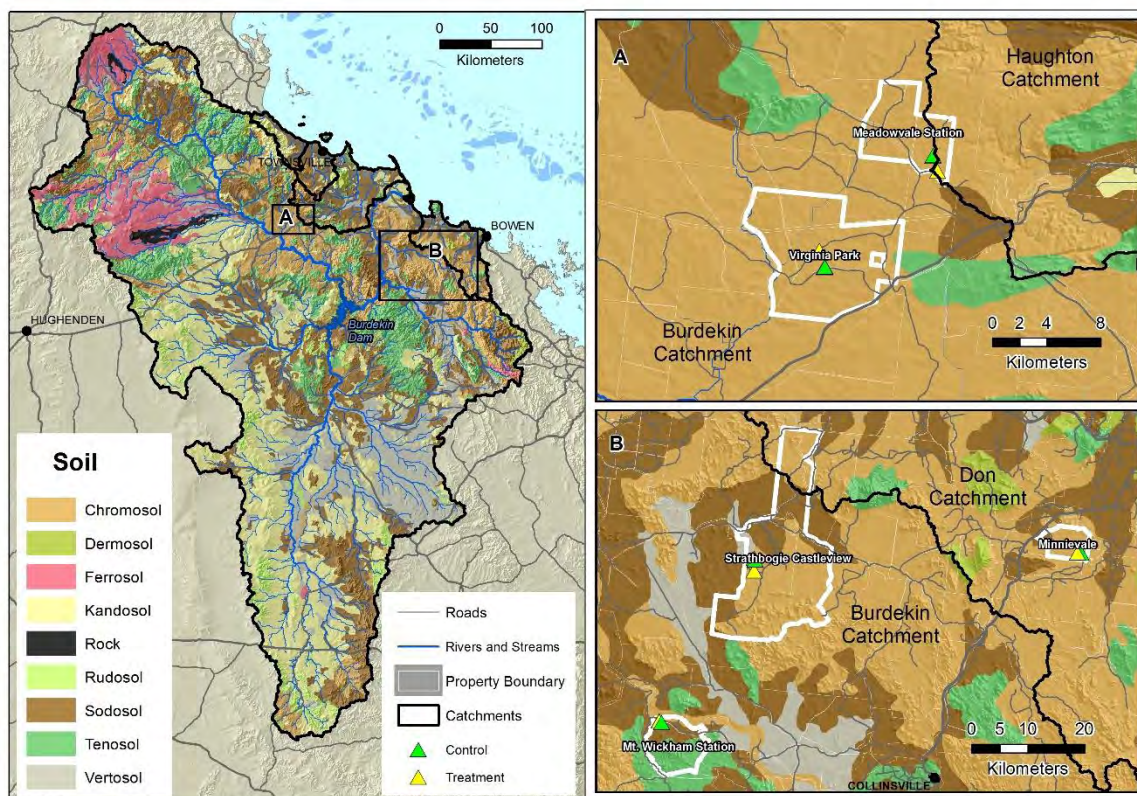


Figure 4: Underlying soil type at each of the properties (Source: Atlas of Australian Soils)

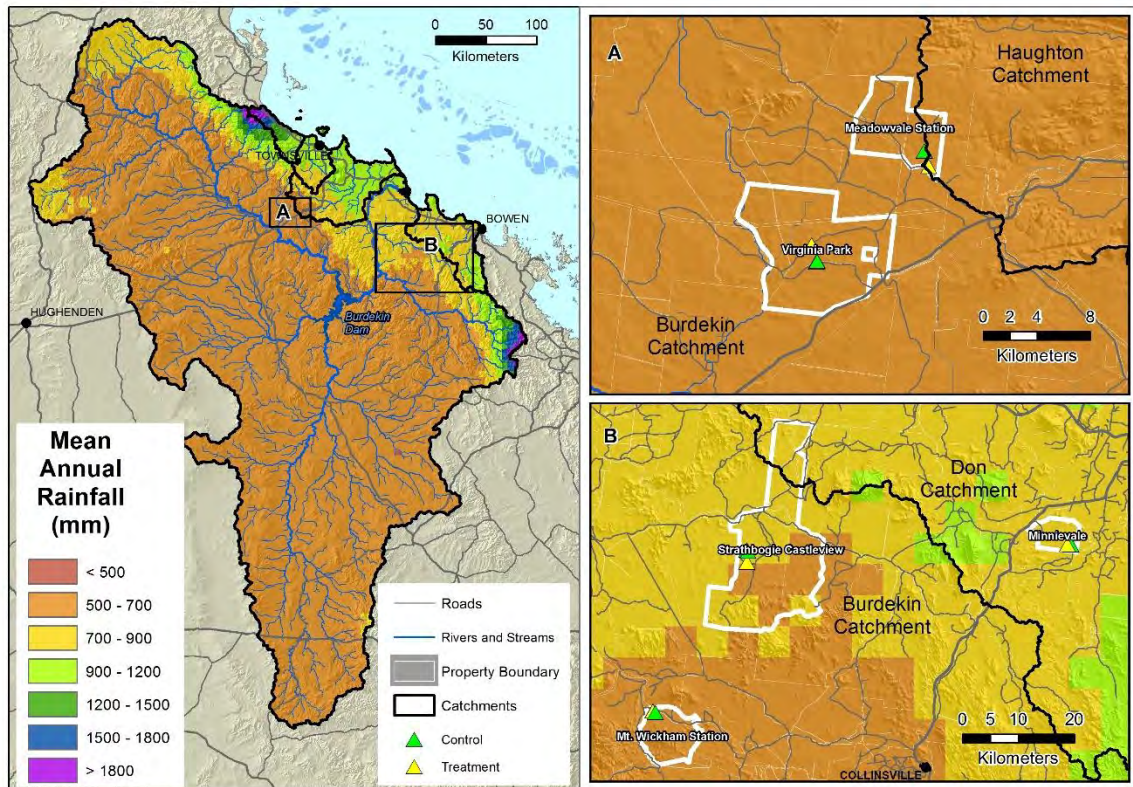


Figure 5: Rainfall distribution for each of the properties (Source: SILO 5 km grid)

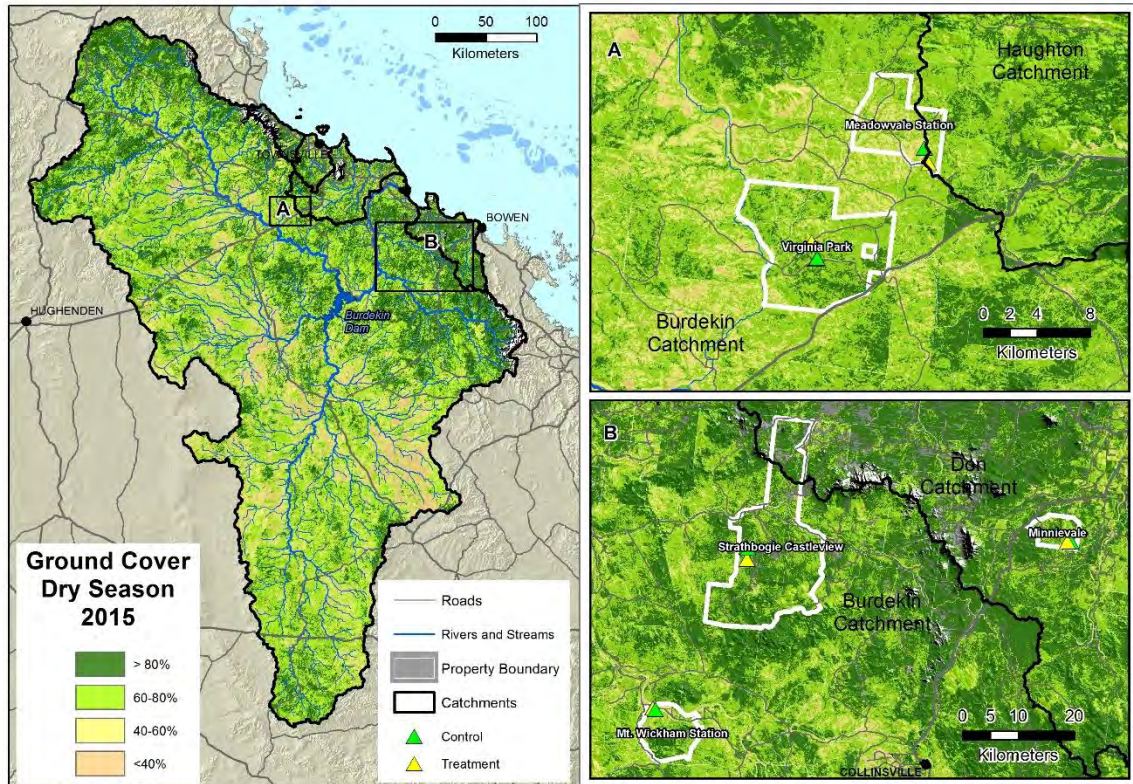


Figure 6: Total ground cover (2015) for each of the properties (Source: Queensland Government fractional ground cover product)

3.3 Treatments applied at each site

The main treatment options for each of the gully sites were selected from the Gully Toolbox (Wilkinson et al., 2015c), as well as through consultation with the delivery partners and landholders. The final choice and installation of the remediation at each site was the responsibility of a third party, being NQ Dry Tropics in the case of Strathbogie, and Greening Australia at Minnievale. CSIRO organised the treatments at Meadowvale which was paid for by the NESP program, and at Virginia Park which was paid for by the Paddock to Reef Program (in 2010). The treatments across the five properties represent a spectrum of remediation options, and a summary of the approaches used are outlined in Table 4. There are currently no remediation plans for Strathbogie, although opportunities for this site to be reengaged via the LDC program are being explored. Diagrams showing the locations of the treatments and associated measurement infrastructure are presented in Section 5.

Table 4: Description of treatment history at each site. LDC = Burdekin Landholders Driving Change (Major Investment Project)

Activity	Virginia Park	Meadowvale	Strathbogie	Minnievale	Mt Wickham
Managing organisation	CSIRO	CSIRO	NQDT	Greening Aust.	NQDT (MIPs, LDC)
Date control site monitoring began	2000	2000	2016	2016	2018
Date treatment was initiated	2010	2017	NA	2016	NA
Date treatment site monitoring began	2010	2016	2016	2016	NA
Fencing – electric fence	√ Two strand	√ Four Strand	NA	√	NA
Fencing – permanent fence			NA		
Wet season resting from stock in paddock upslope	√			√	
Stock exclusion	√	√	√		Yes
Retention structures on gully bed	√ n = 5 stick traps		TBA	Total n = 200 porous check dams	Yes, proposed
Hillslope treatment	√ Disc plough above the treatment gully		TBA	Ripped (with narrow boot, sprayed and seeded)	Yes, significant earth works, soil treatment and chute structures
Hillslope flow diversion			TBA		Yes, significant re-contouring
Active revegetation with seed				e.g. Creeping blue grass, R.Rhodes, V8 stylo	Yes, significant re-vegetation

Alternative stock watering points				√	
Source of funding for the treatment	Paddock to Reef	NESP	Potentially LDC (formerly Reef Trust)	Reef Trust	LDC

4.0 METHODS

4.1 Vegetation and pasture metrics

Vegetation metrics were measured above each of the NESP gullies at the end of the dry season (October–November) and then again at the end of the wet season (April). Landscape and vegetation condition transects were installed upslope of the uppermost head section on both the treated and control gullies at all sites. Transects were run along slope contours and varied in length and spacing for each site depending on gully-head catchment size. Four to five transects were used at each treatment and control location. Each transect has a permanent marker at the beginning and end to facilitate repeat measures. Pasture metrics were recorded along each transect using a 1m² quadrat based on the methods of Tothill et al., (1992), with placement of quadrats dependent on transect length at each site (30 quadrats were sampled for each treatment/control area). Metrics included the main pasture species and/or functional group composition and frequency, above-ground pasture biomass (DMY), total cover, litter cover, basal-area %, defoliation level and key soil surface condition metrics (Tongway and Hindley, 1995). In addition landscape condition was calculated along each transect using PATCHKEY (Abbott and Corfield, 2012). The condition assessments were aggregated to reflect ABCD landscape condition as used across grazed landscapes in the GBR catchments (Aisthorp and Paton, 2004; Chilcott et al., 2005; Bartley et al., 2014). Cover and biomass estimates were calibrated against standard quadrats taken at each site using classified quadrat photographs. Biomass standards were oven dried to attain dry matter yield, removing vegetation water retention error between treatments. A real time kinematic (RTK) survey ran from upslope of the vegetation survey to the valley section for each gully system.

Gully vegetation cover and biomass were also measured within each gully, on the gully walls and gully floor. The sampling methodology was very similar to the hillslope survey. A minimum of three transects were measured across each gully, representative of the head, middle and valley sections. At each transect, % cover, biomass and dominant cover type was assessed using 0.25m² (0.5 x 0.5m) quadrats. Three quadrats were assessed on each wall (six in total) and six quadrats assessed in the deepest part of the channel in the gully floor. Analysis of the statistical differences between control and treatment sites were undertaken using Microsoft Excel 2013 and Sigmaplot Version 13. In most cases a t-test for means and non-parametric Mann-Whitney rank sum test were conducted. The within gully vegetation surveys were all recorded post-wet season for 2016/17. The hillslope surveys were both pre and post wet season.

4.2 Gully erosion

4.2.1 Current rates of gully erosion: terrain analysis

Terrain mapping of the NESP gullies was used to (i) provide metrics on the gully width, gully slope and shape for the purpose of flow modelling, and (ii) estimate the amount of erosion or soil loss (and deposition) between years. Soil erosion can generate both fine (<63 µm) and coarse (>63 µm) sediment. Terrain analysis, expressed as digital elevation models (DEMs) of difference (DODs) will capture erosion of the entire soil profile, including fine and coarse material. The water quality monitoring (Section 4.4) will focus on the fine sediment only.

Airborne Lidar was flown at Mt Wickham, although analysis of that data was not part of this project.

To estimate upslope catchment areas for the treatment and control gullies, Lidar data (0.5-1.0 m) was used for Virginia Park and Meadowvale, and the Shuttle Radar Terrain Model (1 Arc Second, SRTM) (Gallant et al., 2011) derived DEM was used at Strathbogie and Minnievale. Three surveying techniques were used to capture terrain data in this study.

RTK surveys

The slope of gully beds, hillslope above the gully, and locations of reference markers were surveyed using an RTK (Real time kinematic) GPS system (Ashtech, ProMark 200) with a tolerance of +/- 12mm in the horizontal plane and 15mm in the vertical. The slope of the gully bed was surveyed by traversing the entire gully channel, collecting survey points along the deepest part of the channel, representative of each reach.

RIEGL Terrestrial laser scanner

The TLS instrument used in this study was the RIEGL VZ400. The TLS was registered using five ground control points at each site. The control points consisted of a 50cm star picket driven flush into the ground with a concrete collar. Survey bipods with reflectors were then placed over these marks to establish consistent xyz locations between scanners and for repeat surveys. To link RIEGL scans collected on the same day, additional 'mobile' reflectors were placed strategically around the sites. Registration was then performed by matching distances between reflector pairs (see Goodwin et al., 2016 for details). The RIEGL has an inbuilt fine-scan option to accurately locate reflector locations and is used to register separate scans into the same coordinate system with errors typically < 1cm. These datasets are then projected into real world coordinates using the internal GPS and digital compass. The number of scans captured between sites varies due to differing morphological complexity and area to be mapped. Note that TLS scanning has not occurred at Mt Wickham. Aerial Lidar surveys will be used to detect change at this site, and only the baseline data has been collected. Note that Zebedee data has also been collected for all of the sites, however, at the time of report preparation, the data had not been fully evaluated. The RIEGL is considered the more accurate approach for estimating changes in erosion rates, and it is the approach used in this report.

Change detection

Digital elevation models (DEMs) were developed for all surveys from the RIEGL scanner by selecting the minimum (ground) elevation from all the points in a 5cm x 5cm XY interval. A 3 x 3 median filter was then applied to the resulting grid to remove spurious values. Common extents were required for comparison of the DoDs. For the gully, a modified region grow approach was applied to an unclipped RIEGL DEM. This approach utilises a difference from mean elevation (DFME) (Evans and Lindsay, 2010) and a slope layer to detect the gully edges. A 50 cm buffer was then applied to ensure full capture of the gully edges.

To statistically separate 'true' from 'false' geomorphic change, a ± 0.1 m threshold was set in the DEMs of difference (DODs) to account for propagated error. This is considered conservative based on the previous work carried out at Virginia Park (Bartley et al., 2016), however, it is appropriate given the diversity of gully morphologies across the eight sites (Goodwin et al., 2017). A sediment bulk density of 1.5 t/m^3 is assumed to convert erosion volumes into tonnes of sediment. This is considered an average for granodiorite soils under

different grazing management practices, where the values range from 1.35 to 1.85 t/m³ (Bartley et al., 2010).

4.3 Runoff

An automatic monitoring station was installed at each of the treatment gullies (Figure 7A). The monitoring station recorded rainfall, stage height, turbidity and water temperature at 1-min intervals during runoff events. The station also housed an ISCO auto-sampler that collected 1-L water samples at programmed intervals across the hydrograph. These samples were processed according to the methods in Section 4.4. A camera was installed at the treatment sites to capture photos during runoff events.

Each of the control sites were fitted with a simpler tripod monitoring station that measured rainfall, stage height and turbidity. Bulk water quality samples were collected manually after each (accessible) event using poly-pipe rocket structures (Figure 7B). Data from both the treatment and control sites had telemetered communications to allow remote access of data.

Unidata Starflow QSD ultrasonic doppler was installed above the turbidity sensor at each site in 2017. The sensor measures the velocity of particles or bubbles in the water (presumed to be the same velocity as the water) using the doppler shift between transmitted and received ultrasonic signals. The sensors are mounted facing downstream to reduce the impact of particles damaging the sensor face and debris build up on measurement. The sensors require reconfiguration from factory default settings to capture data in gully systems.



(A)



(B)

Figure 7: (A) Example of a treatment gully set up and (B) and example of a control gully set up including two rising stage samplers

4.4 Water quality and particle size

A description of the water quality sampling procedures for this project is outlined in Baker et al., (2016). In brief, following significant runoff events that triggered the samplers, the ISCO

bottles were collected and the samples were filtered and frozen if collected within 24 hours of the event. These samples were analysed for TSS and the full suite of nutrients (total nitrogen, total dissolved nitrogen, NH_3 , NO_x , total phosphorus, total dissolved phosphorus, FRP) at the JCU TropWater Laboratory, Townsville. Samples that were not collected within 24 hours were analysed for TSS only. A sub-set of the samples collected were also sent for particle size analysis. The samples were processed on a Malvern Mastersizer which is a laser diffraction analyser with a lens range of 0.02 – 2000 μm .

To test for a difference between water quality sample results between control and treatment sites, three techniques were used. Firstly, Student's t-test were applied when the data were normally distributed and when the data was not normally distributed, non-parametric Mann-Whitney rank sum test were undertaken. Secondly, Cohen's d score for effect size was calculated (McGough and Faraone, 2009), and finally the % difference between the mean values.

4.5 Soil characterisation and condition metrics

Soil characterisation using the Australian Standard Yellow Book soil description (McDonald et al., 2009) was undertaken at Minnievale, Strathbogie and Mt Wickham during April 2018. Soils at Virginia Park and Meadowvale had been previously characterised and described under the Paddock to Reef program. There will now be consistent soil attribute data for all of the sites. The data is currently being analysed by the Queensland Government Chemistry Centre and the results will be submitted to the SALI data base on completion. The results will not be presented in this report but will be made available via SALI in the December reporting.



(A)



(B)



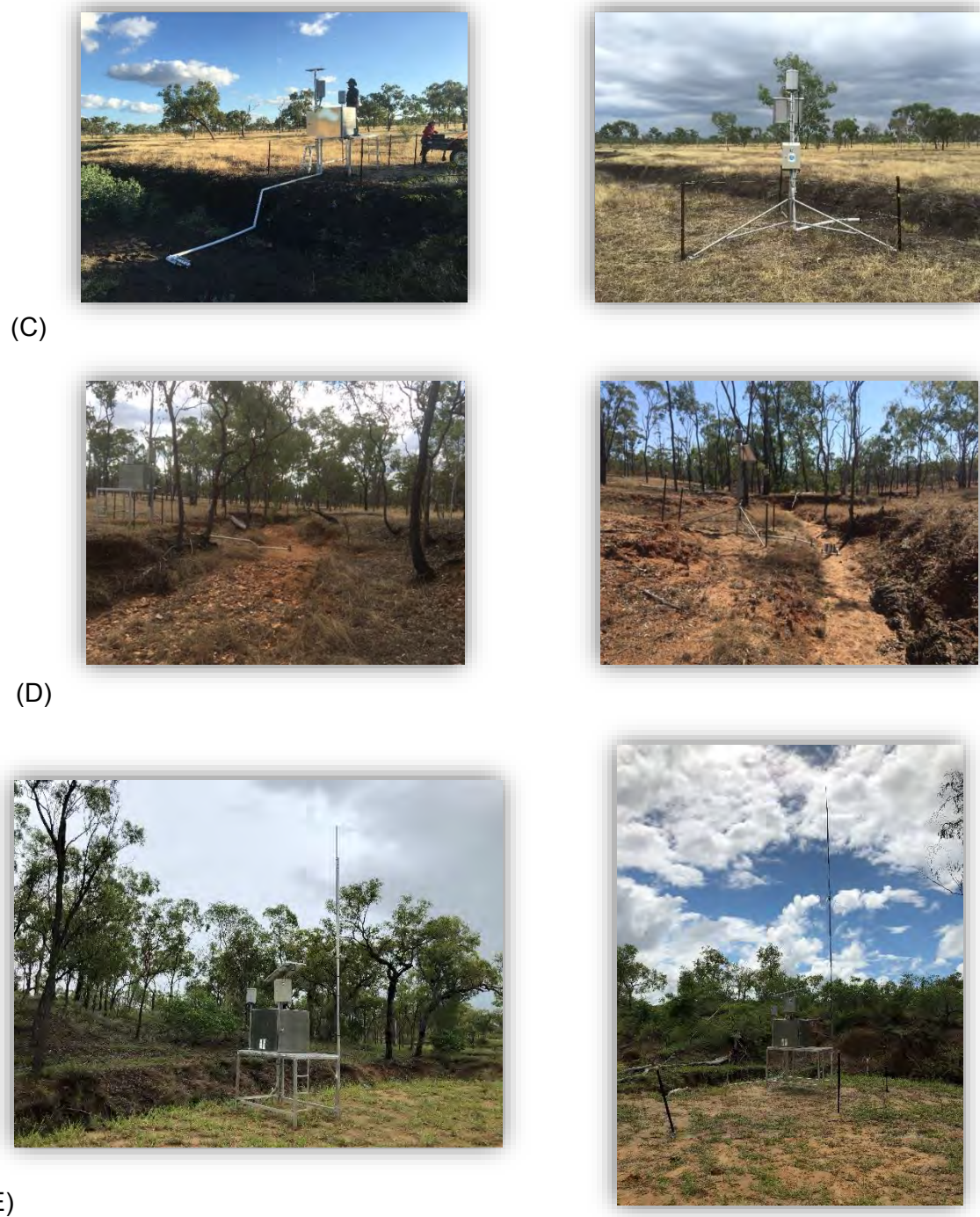


Figure 8: The treatment (left) and control (right) instrumented gullies at each property. (A) Virginia Park (B) Meadowvale (C) Strathbogie, (D) Minnie Vale and (E) Mt Wickham

5.0 RESULTS

The results presented in this section represent a combination of data measured in the 2016/17 and 2017/18 wet seasons.

5.1 Treatment location and survival

5.1.1 Virginia Park

The Virginia Park Treatment site represents the longest running of all of the treatment sites. This is the 8th wet season of water quality monitoring at this site, and the results build on previous work funded in the Paddock to Reef (P2R) program (Wilkinson et al., 2013; Wilkinson et al., 2014; Wilkinson et al., 2015b; Wilkinson et al., 2018). A fence around this treatment gully, and instream structures, were installed in 2010 (Figure 9). Some treatment of the hillslope above the gully with a disc plough was also undertaken in 2010. There are six porous check dams (PCDs) or stick traps installed within the gully; three are above the water sampling site, and three are below. The PCDs have required no maintenance over the seven year period, however, with increased organic matter now being trapped in the channel, it is possible that that structures may start to break-down over the coming years. Figure 10 demonstrates how one of the PCDs in the treatment gully has evolved over time. The backwater area upstream of each PCD has now filled with sediment, and therefore they may have reached their maximum effectiveness in terms of sediment trapping. They will hopefully continue to be effective by slowing the water down enough so that sediment and associated seeds are trapped. It is the vegetation that will grow from these seeds that are the long term mechanism for stabilising these smaller gullies.

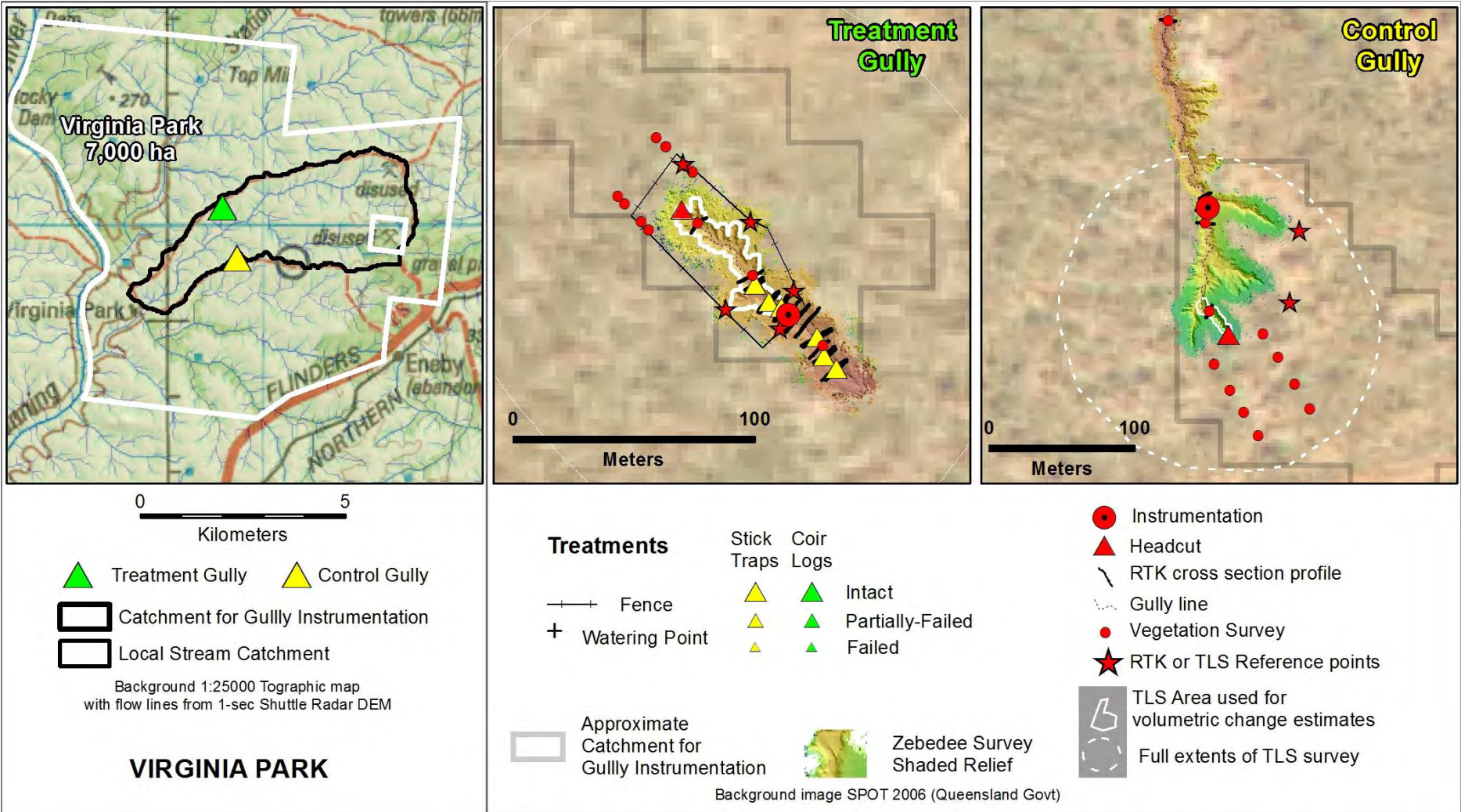


Figure 9: Location of the Virginia Park site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

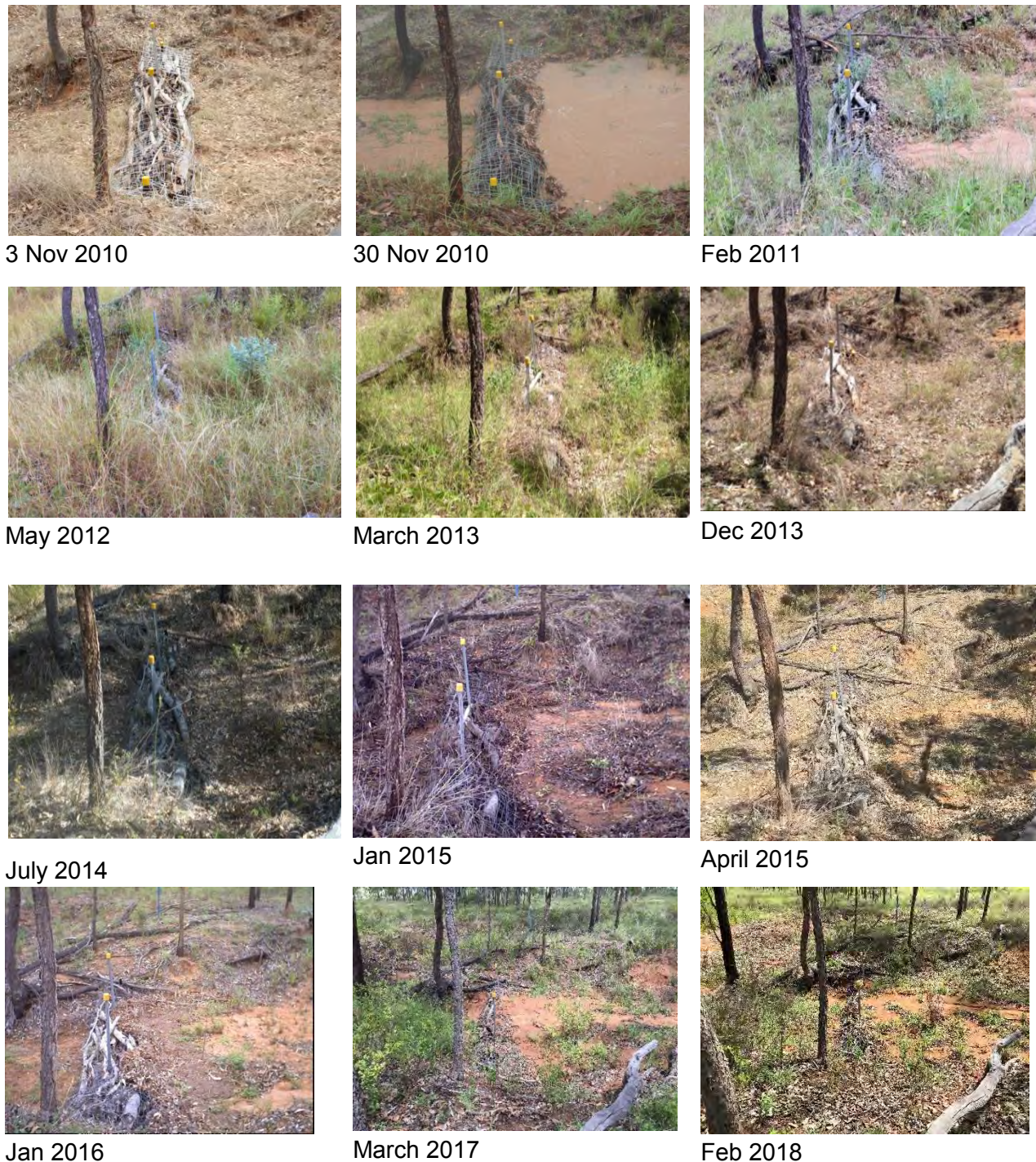


Figure 10: Changes in the vegetation adjacent to a check-dam structure (#1) in the Treatment gully (upstream is to the right) at Virginia Park from 2010 to 2018 (adapted from Wilkinson et al., 2015b).

5.1.2 Meadowvale

The Meadowvale site has the simplest of all of the treatments being cattle exclusion fencing only. The gully exclusion fence was completed in 2017 and therefore the water quality data collected in 2016/17 represented a base line year to compare the treatment and control sites. The 2017/18 wet season was the first to evaluate the gully treatment. The cattle exclusion fence is constructed using a combination of four strands of heavy duty barbed wire and electric fencing, encompassing the gully head and water quality monitoring system (Figure 11).

This site also builds on previous research by CSIRO (Hawdon et al., 2008). The treatment gully is adjacent to a re-instated long term runoff trough, initially installed by DPI in the 1980's. The hillslope treatment includes a 4 Ha area that has had light or no cattle grazing since 1986, and cattle exclusion since 2002. So approximately half of the hillslope above the treatment gully has had cattle exclusion for more than 15 years. The control gully at Meadowvale has been monitored for 16 years (1999 – 2016) using erosion pins, topographic survey techniques and vegetation transects.

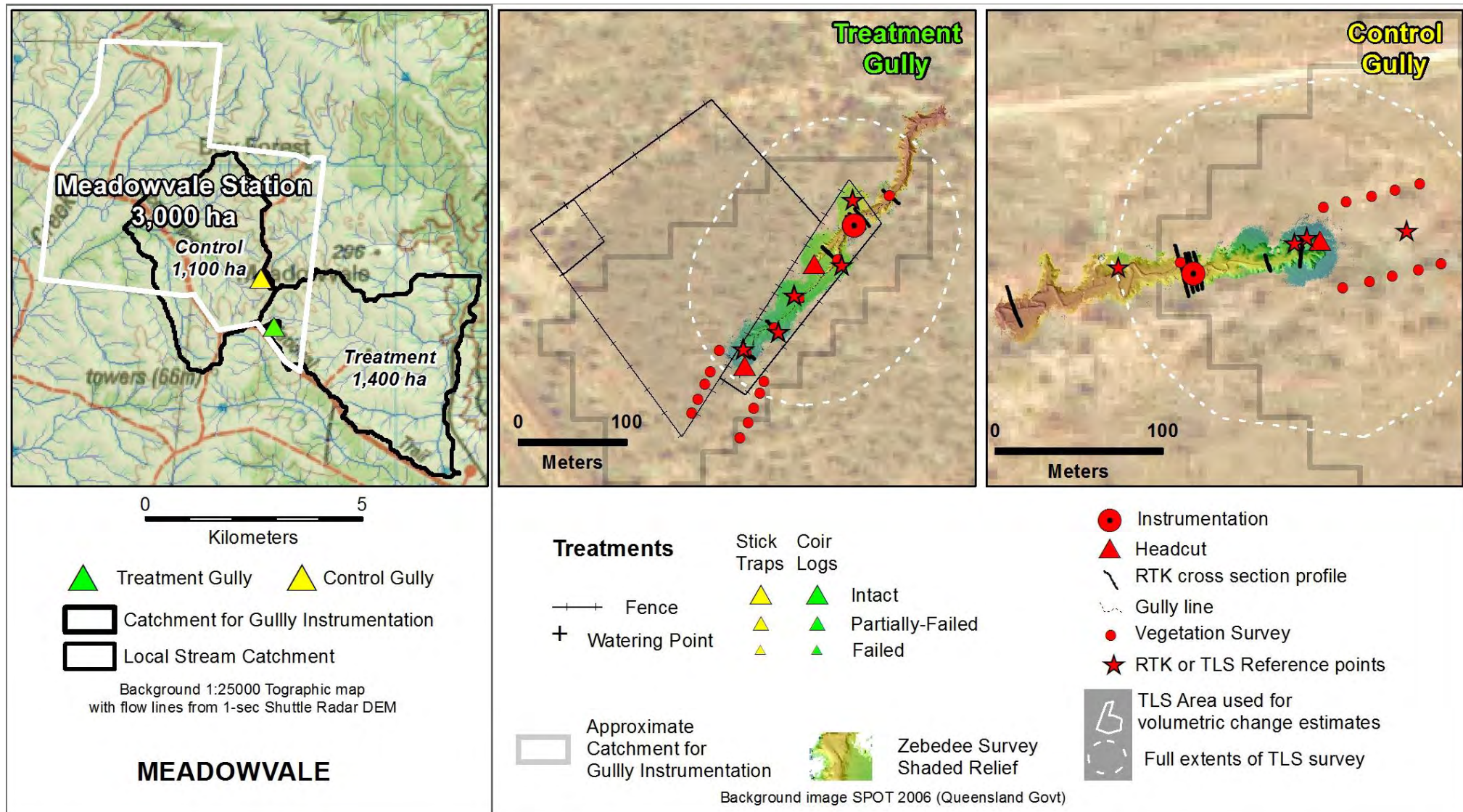


Figure 11: Location of Meadowvale site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

5.1.3 Strathbogie

The Strathbogie site is a Reef Trust 2 gully remediation site being managed by NQ Dry Tropics. This site has not undergone treatment (Figure 12). There was a remediation plan in progress in 2016/17 that was delayed, and then after Cyclone Debbie, the landholder withdrew from the project. Therefore, the water quality data collected at this site represents a second base line year to compare to any future treatment effects. There are discussions with the Landholders Driving Change program as to whether this project will be included in their mix of remediation projects.

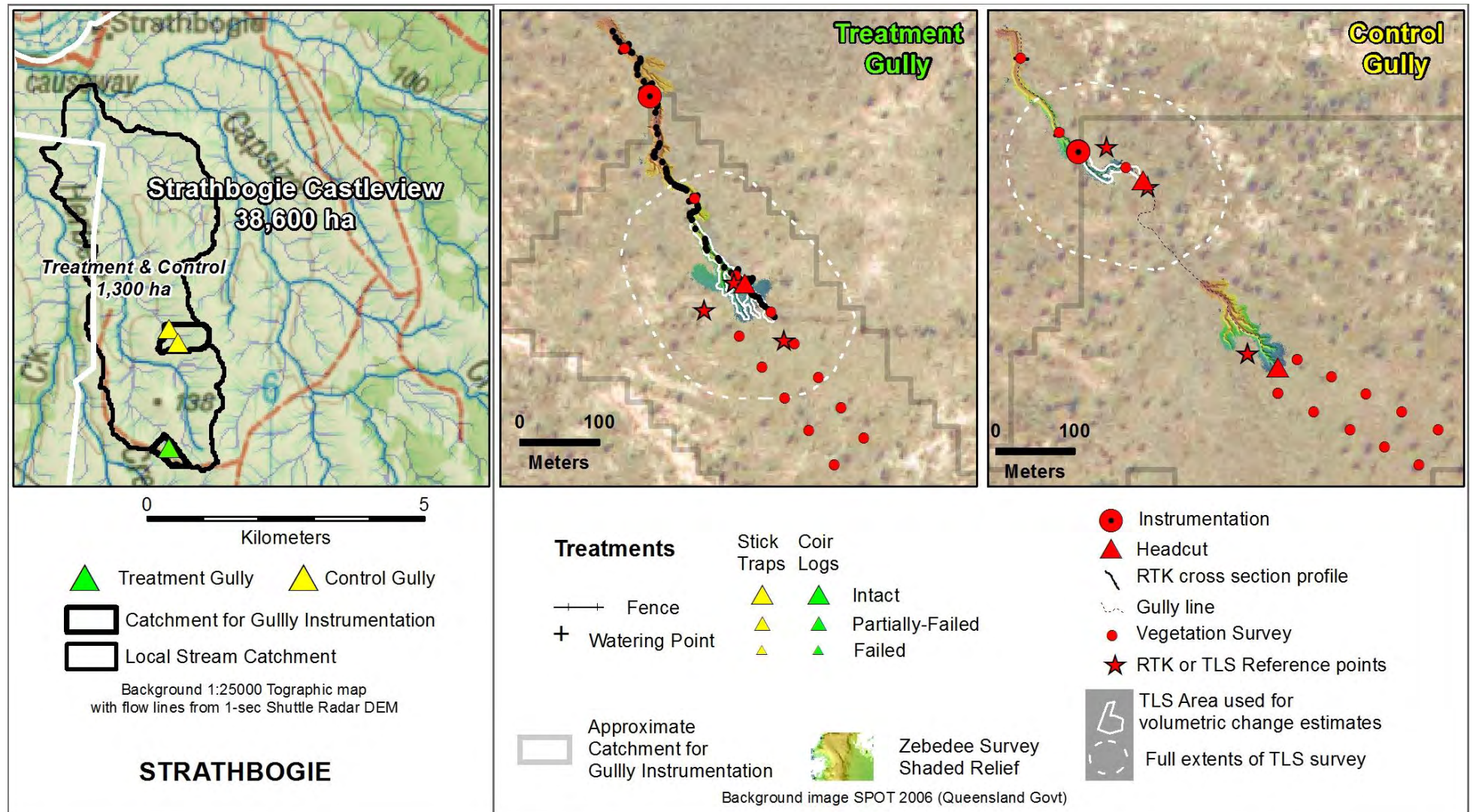


Figure 12: Location of Strathbogie site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

5.1.4 Minnievale

The Minnievale site is a Reef Trust 2 gully remediation site being managed by Greening Australia. This site has had the most significant number of remediation works undertaken. The main treatment gully has been fenced off (~4 km of fencing). A total of 135 within gully structures installed in 2016. There were two types of structures (coir logs and stick traps or PCDs); they were installed in the main gully and the side arms of the main gully (Figure 14). Many of the coir logs failed during the 2016/17 wet season (95% failure rate), and subsequently they were replaced with ~147 stick trap dams (Figure 13) in 2017 (Figure 15).

Ripping and seeding of the catchment directly upslope of the treatment gully was undertaken using exotic pasture species in 2016/17. A pasture restoration site was also implemented in association with the Don River Trust and DAFF, however, this is just outside of the drainage boundary of the treatment gully. Monitoring points, baseline vegetation surveys and land condition assessment were also undertaken by Greening Australia, however, they are not presented in this report and are instead part of their Reef Trust reporting. The landholder has also undertaken a Grazing Management Plan (GMP) and has adapted his grazing numbers and rotations in the treatment paddock.



Figure 13: Example of the stick traps installed at Minnievale station

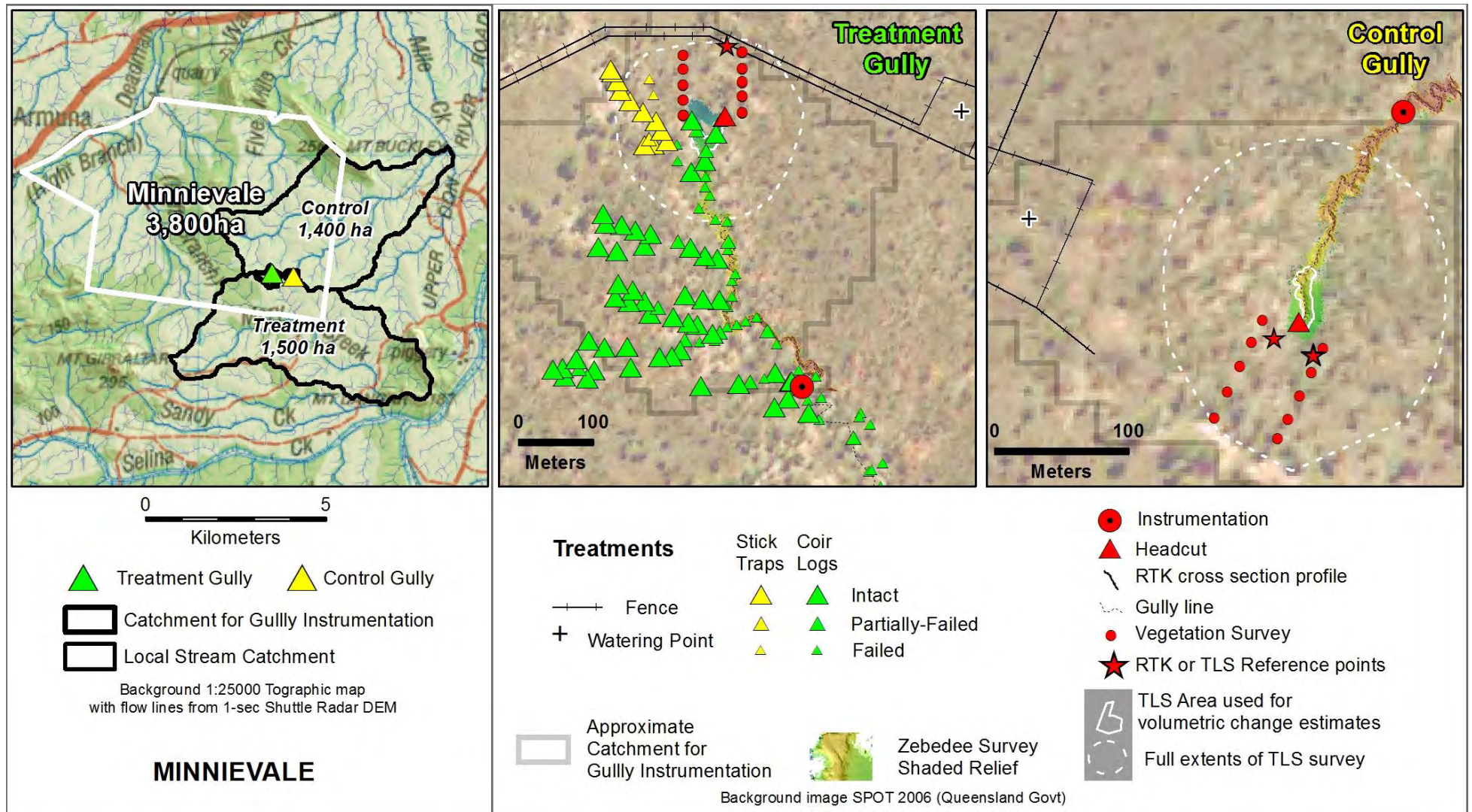


Figure 14: Location of Minnievale site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations for the 2016/17 wet season are shown.

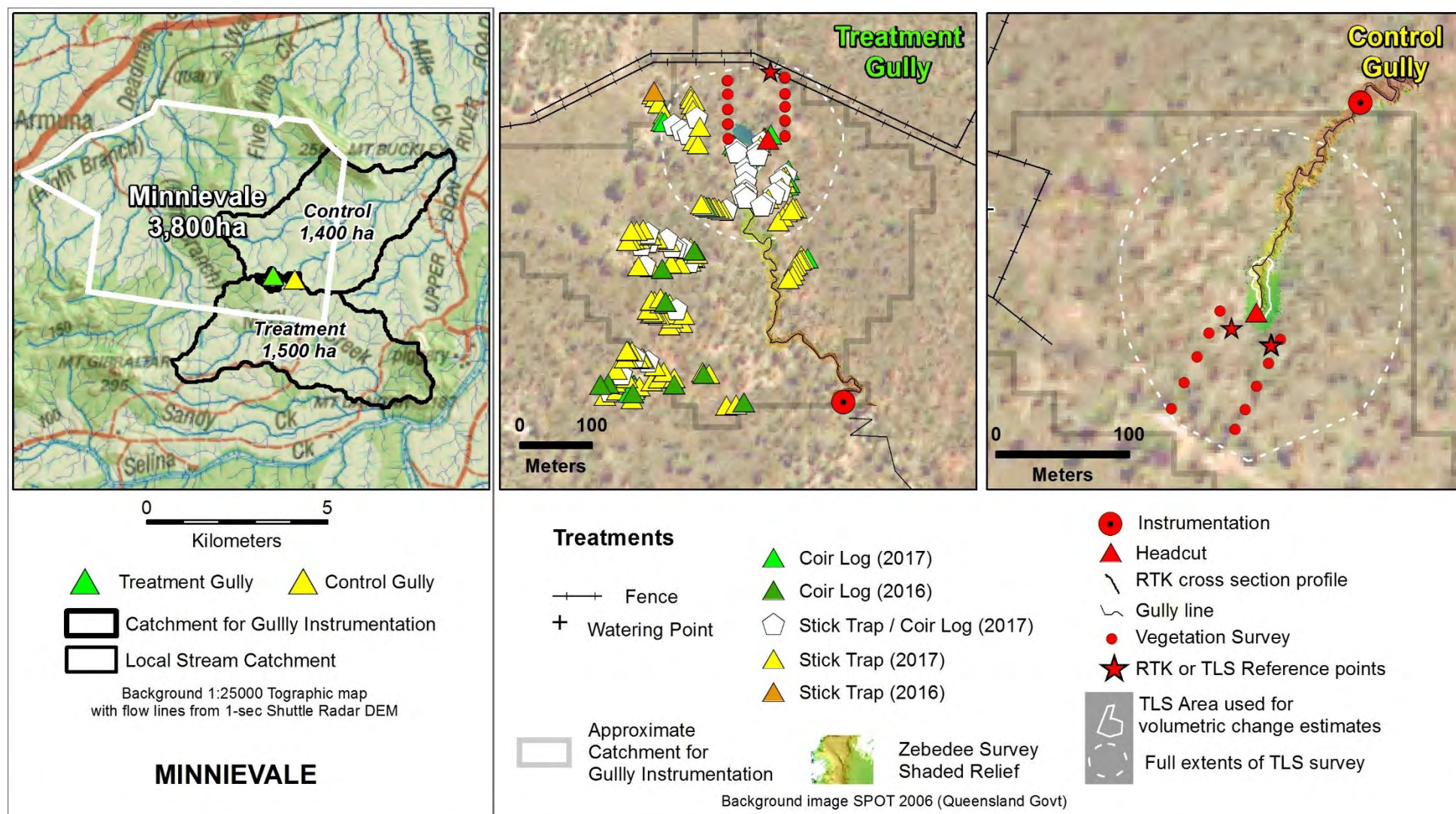


Figure 15: Location of Minnievale site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations for the 2017/18 wet season are shown. Note the changes to the location and type of structures at this site from the previous wet season.

5.1.5 Mt Wickham

The Mt Wickham site is a new site added in 2017/18. The Mt Wickham site is a combination of linear and alluvial gully formations on highly sodic soils that drain into Sandalwood Creek and then into the Bowen River. It is important to note that this site is not formally funded by NESP, however, CSIRO was commissioned to install the water quality instrumentation at a treatment and control gully, using a similar approach to the other NESP sites. Some preliminary water quality data was collected by CSIRO at the time of installation and analysed along with the other NESP samples in this study. Future water quality data collection and analysis will, however, be the responsibility of NQ Dry Tropics (NQDT) as part of their LDC project.

The remediation of the treatment site has not yet occurred, but the site plan has been completed by Verterra and Alluvium consulting services. The remediation plan involves a combination of grade control rock chutes, re-contouring of the badland area (see Figure 16B), soil amelioration using a range of chemical treatments and revegetation using a range of pasture and legume species. The draft remediation plan is being reviewed by the NQDT technical panel.



Figure 16: (left) Single channel gully and (right) highly sodic soil resulting in Badlands or alluvial gully formation. Both gully types are found on Mt Wickham Station

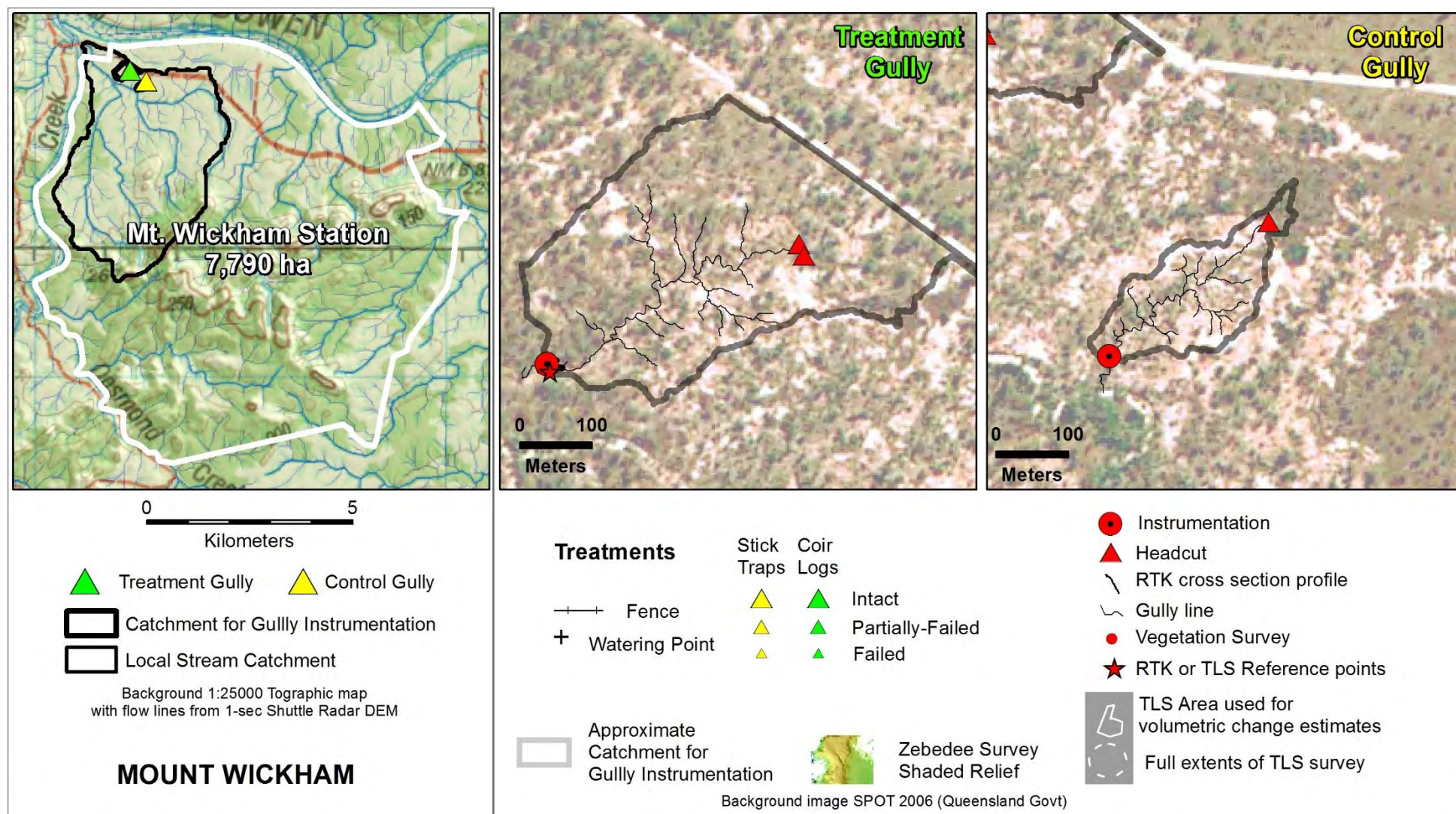


Figure 17: Location of the Mt Wickham (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

5.2 Landscape condition

Table 5 presents the land condition classification results based on data collected on the hillslopes above each gully on each of the four properties. Land condition is dominated by C (poor) and D (very poor) class states for all sites, and there has been no major shift in land condition from 2016/17 (see Bartley et al., 2017). Treatment and control conditions at each site are similarly poor to very poor or C-D condition. At all properties, land condition improved across the wet season, with the most notable change in 2017/18 at Strathbogie which shifted from 20% of land in C condition pre-wet season to 80% of land in C condition (with the remaining land all in D condition in both pre and post wet season). However, this is considered to be due primarily to a rapid recruitment of *Bothriochloa pertusa* following very heavy grazing (removing most *B.pertusa* plants) in the previous dry season. No land condition data was formerly collected at Mt Wickham, however, it is likely that this landscape would be in D condition both pre and post wet season.

Table 5: A, B, C, D Land condition classification for each of the properties in this study. Note no data has yet been collected for Mt Wickham

	Landscape condition (%)			
	A	B	C	D
Virginia Park				
Treatment: pre-wet (Nov 2017)		1	31	68
Treatment: post wet (April 2018)			47	53
Control: pre-wet (Nov 2017)			55	45
Control: post wet (April 2018)			61	39
Meadowvale				
Treatment: pre-wet (Nov 2017)		2	37	61
Treatment: post wet (April 2018)		3	52	45
Control: pre-wet (Nov 2017)		3	43	54
Control: post wet (April 2018)			70	30
Strathbogie				
Treatment: pre-wet (Nov 2017)			-	-
Treatment: post wet (April 2018)			86	14
Control: pre-wet (Nov 2017)			20	80
Control: post wet (April 2018)			88	12
Minnievale				
Treatment: pre-wet (Nov 2017)			19	81

Treatment: post wet (April 2018)			40	60
Control: pre-wet (Nov 2017)			34	66
Control: post wet (April 2018)			61	39
Mt Wickham				
Treatment: pre-wet (Nov 2017)				
Treatment: post wet (April 2018)				
Control: pre-wet (Nov 2017)				
Control: post wet (April 2018)				

5.3 Vegetation and pasture metrics

5.3.1 Hillslope

The vegetation and pasture metrics for the hillslope above each of the treatment and control gullies for 2017/18 is presented in Table 6. A summary of these metrics is also presented with the water quality data in Table 10. There were no differences in pre or post wet season ground cover at any of the sites. There were significant differences in end of dry season pasture biomass at Virginia Park and Meadowvale, and for end of wet season at Meadowvale and Minnievale. There were differences in pre and post wet season litter at both Virginia Park and Meadowvale. There were no differences in any of the cover metrics at Strathbogie, which is logical as there is no treatment in place at that site.

5.3.2 Gullies

The vegetation metrics for the gully floor and walls for 2017/18 are presented in Table 7. The gully vegetation data followed a similar pattern to the hillslope data above. There was a significant difference between the treatment and control sites for % cover on the gully walls and Virginia Park and biomass on gully walls and Minnievale. The gully floor or channel data was significantly different at Virginia Park for both cover and biomass, and for % cover at Meadowvale and biomass at Minnievale. Again there were no differences recorded at Strathbogie, where no fencing or treatments have been installed.

Table 6: Amount of cover on the hillslope at the end of the dry season (2017) and end of the wet season (2018). Standard deviation shown in parentheses. Where the text is highlighted in **blue/bold, there is a significant difference between the hillslopes above the Treatment and Control gullies**

	Virginia Park			Meadowvale			Strathbogie			Minnievale		
	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff
End of Dry (Nov) Cover (%)	73(20)	61 (27)	P=0.140	66(30)	50 (28)	P=0.087	-	-	-	64 (26)	60 (25)	P =0.528
End of wet (April) Cover (%)	74 (17)	76 (19)	P = 0.5	93 (116)	69 (25)	P = 0.145	87(18)	93(10)	P=0.09	73 (22)	70 (25)	P = 0.613
End of Dry (Nov) Biomass (kg/ha/yr)	1291 (787)	501 (505)	P<0.001	252 (311)	71 (43)	P=0.003	-	-	-	456 (328)	307 (315)	P = 0.077
End of wet (April) Biomass (kg/ha/yr)	1155 (676)	1549 (662)	P = 0.217	1127 (528)	551 (414)	P = 0.00	847 (320)	864 (446)	P=0.854	1319 (986)	607 (994)	P =0.004
End of Dry (Nov) grass basal area (%)	0.73 (0.5)	0.66 (0.53)	P=0.696	0.38 (0.42)	0.25 (0.23)	P=0.205	-	-		0.42 (0.36)	0.32 (0.39)	0.284
End of Wet (April) grass basal area (%)	0.46 (0.46)	0.60 (0.37)	P=0.263	0.64 (0.40)	0.63 (0.51)	P=0.969	0.49 (0.25)	0.50 (0.31)	P=0.926	0.42 (0.38)	0.51 (0.37)	P=0.363
End of Dry (Nov) Litter (%)	38.13 (29.55)	12.84 (24.54)	P=0.003	32.93 (36)	9.30 (22.08)	P=0.01	-	-	-	9.3 (21.64)	9.66 (18.95)	P =0.985
End of Wet (April) Litter (%)	52.06 (27.17)	3.34 (6.20)	P<0.001	21.67 (28.86)	4.47 (11.11)	P=0.004	8.51 (10.25)	5.31 (7.00)	P=0.132	9.14 (16.98)	8.59 (19.55)	P=0.900

Table 7: Average amount of cover on the gully walls and floor at the end of the wet season (April 2018). Standard deviation shown in parentheses. Where the text is highlighted in **blue/bold, there is a significant difference between the Treatment and Control gullies.**

	Virginia Park			Meadowvale			Strathbogie			Minnievale			Mt Wickham		
	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff	Treatment	Control	Sig. Diff
Gully walls															
% cover	37.5 (23.6)	25.0 (24.15)	P=0.013	30.36 (25.60)	34.31 (26.97)	P=0.662	42.12 (35.01)	30.41 (27.25)	P=0.142	23.33 (20.60)	26.74 (26.61)	P=0.919	34.69 (23.94)	28.92 (23.68)	P=0.231
Biomass (kg/ha/yr)	0.69 (0.55)	0.59 (0.68)	P=0.164	0.58 (0.60)	0.44 (0.22)	P=0.941	1.46 (1.56)	1.13 (1.05)	P=0.861	0.91 (0.86)	0.60 (0.0)	P=0.009	0.75 (0.27)	0.83 (0.52)	P=0.708
Gully floor															
% cover	55.65 (29.49)	10.83 (10.76)	P<0.001	18.83 (15.69)	16.33 (28.11)	P=0.003	42.12 (35.01)	30.41 (27.25)	P=0.142	23.33 (20.60)	26.74 (26.61)	P=0.919	34.69 (23.92)	28.92 (23.68)	P=0.231
Biomass (kg/ha/yr)	0.91 (0.77)	0.22 (0.06)	P<0.001	0.41 (0.24)	0.38 (0.26)	P=0.670	1.46 (1.56)	1.13 (1.05)	P=0.861	0.91 (0.86)	0.60 (0.0)	P=0.009	0.75 (0.27)	0.83 (0.53)	P=0.708

5.3.3 Current rates of gully erosion: terrain analysis

The total erosion, deposition and net change in the volume of sediment for each gully in 2017/18 are presented in Table 8, and the gully head retreat rates in Table 9. The DODs are presented in Figure 20 to Figure 23. Due to issues with site set up at Meadowvale, there is less data available at that site, and terrestrial laser scanning was not undertaken at Mt Wickham. The scanning length is slightly different at each gully, therefore a normalised erosion metric in tonnes per linear metre (t/m) of gully surveyed is provided. Estimates of the net soil loss (erosion minus deposition) is shown for each site in Figure 19.

The results suggest that the headcut erosion (m) and rate (t and t/m) is highest at the Strathbogie site. At the Strathbogie property, there is no treatment in place, therefore this result highlights the natural variability in erosion rates that can occur between gullies in the same landscape. Similar to the data from last year, there is a strong ($\sim r^2 = 0.83$) relationship between the average erosion rate (t/m/yr) and the drainage area above the gully headcuts, for all sites.

Table 8: Gully volumetric change results for 2017/18 using the RIEGL Terrestrial laser scanner. The U_{crit} threshold for defining erosion/deposition was set as 0.1 m at all sites. Bulk density of sediment is set as 1.5 t/m³. Meadowvale treatment gully scanning had errors and no data is available for this wet season.

Property	Gully	Catchment area (ha) upslope of instruments	Length of gully surveyed with the TLS (m)	Normalised sediment <i>eroded</i> per gully length surveyed (t/m/yr)	Normalised sediment <i>deposited</i> per gully length surveyed (t/m/yr)	Net change (t/m/yr)	Deposition as a proportion of erosion (%)
Virginia Park	Control	3.8	22	0.15	0.01	0.13	10
	Treatment	1.6	62	0.08	0.02	0.06	20
Meadowvale	Control	7.4	34	0.37	0.06	0.31	17
	Treatment	6.0	na	na	na	na	na
Strathbogie	Control	38.1	82	1.1	0.01	1.08	1
	Treatment	17.4	88	0.26	0.04	0.22	16
Minnievale	Control	9.7	47	0.24	0.07	0.17	29
	Treatment	21.2	77	0.21	0.11	0.11	50

Table 9: Gully headcut retreat rates in 2016/17 and 2017/18 using the RIEGL Terrestrial laser scanner. Meadowvale treatment gully scanning had errors and no data is available for this wet season.

Property	Gully	Gully headcut retreat (2016/17), m	Gully headcut retreat (2017/18), m	Total gully headcut movement over two wet seasons (m)
Virginia Park	Control	0.35	0.36	0.71
	Treatment	0.46	0.34	0.80
Meadowvale	Control	na	0.71	0.71
	Treatment	na	na	na
Strathbogie	Control	18.10	7.80	25.90
	Treatment	0.75	1.76	2.24
Minnievale [#]	Control	0.84	0.48	1.32
	Treatment	0.50	0.10	0.60

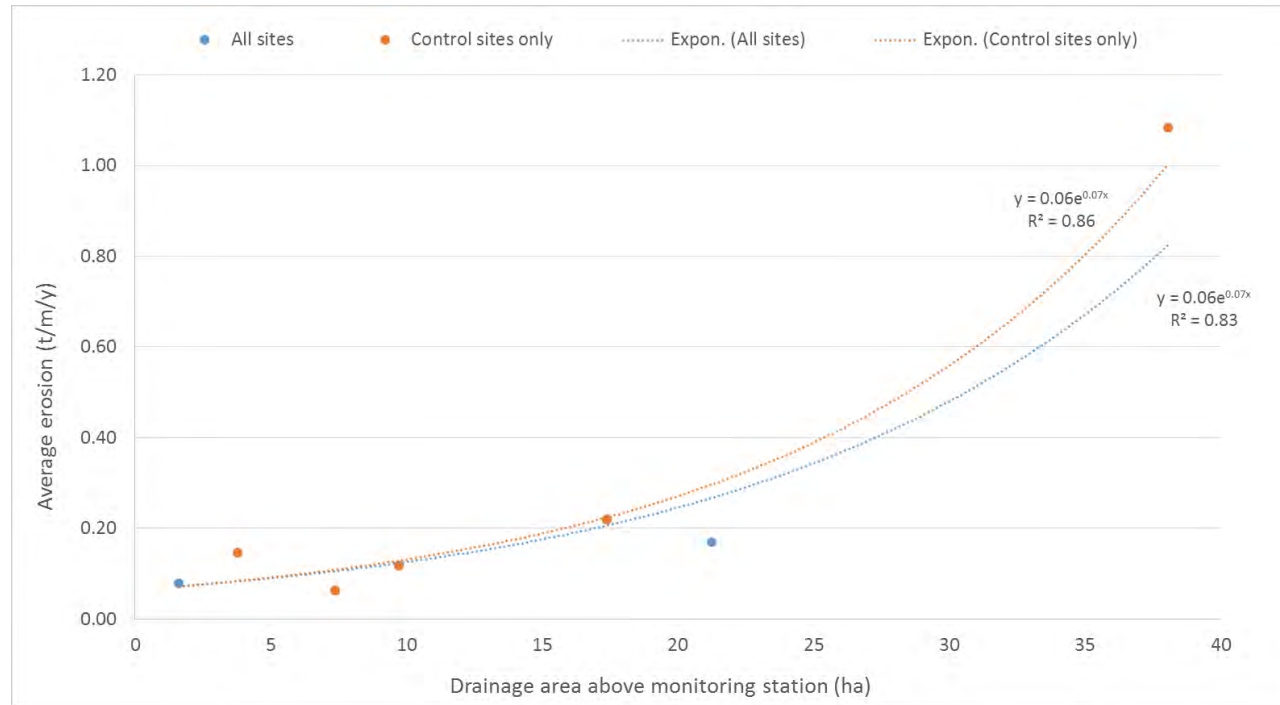
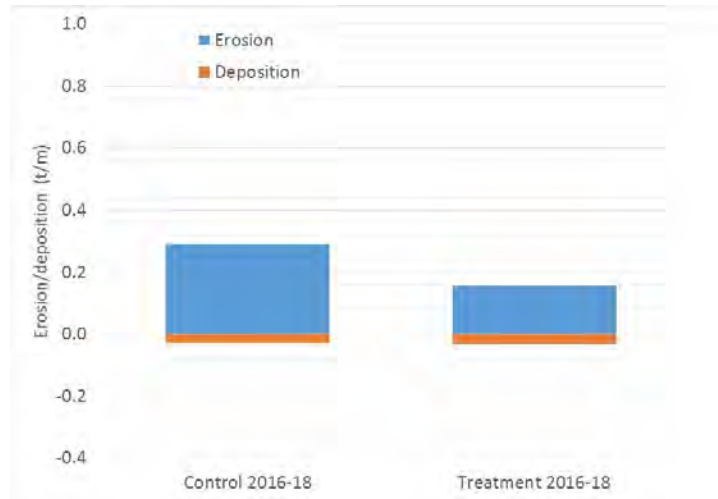
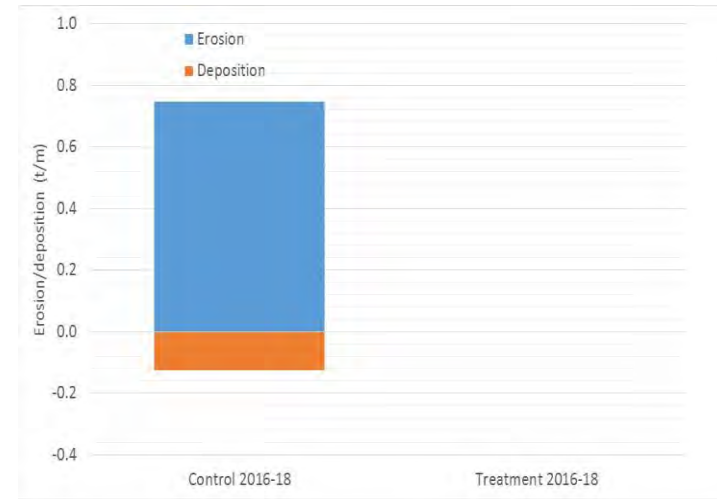


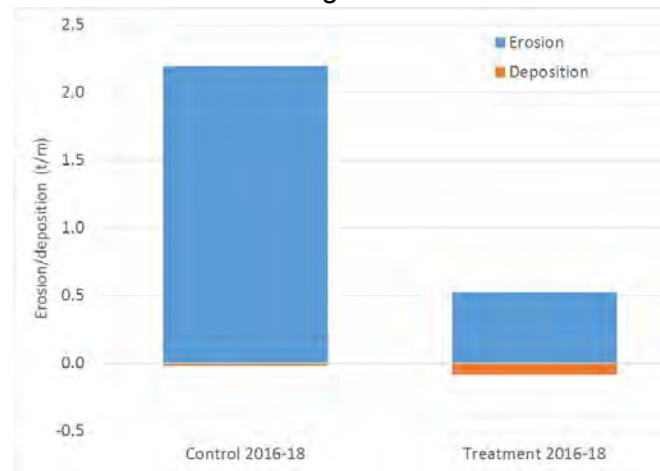
Figure 18: Relationship between upslope gully catchment area (ha) and the average TLS measured erosion rate (t/m/y) from the combined wet season periods for all gully sites (treatment and control) and control sites separately.



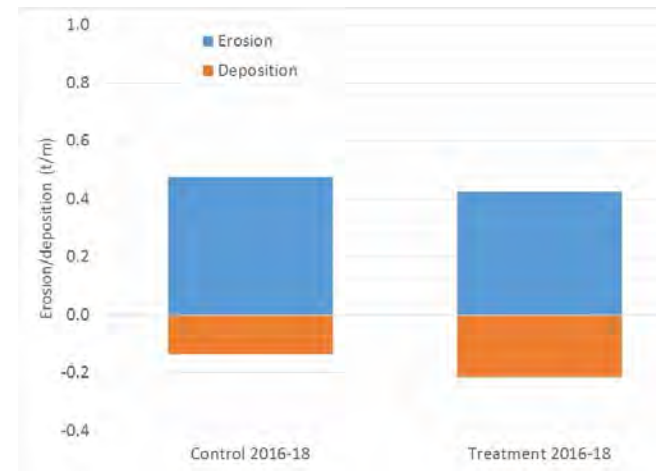
Virginia Park



Meadowvale



Strathbogie



Minnie Vale

Figure 19: Net sediment movement (tonnes per metre surveyed, t/m) for each of the gully sites (assuming a soil bulk density of 1.5 t/m³) for the 2016-18 period. Erosion is represented by positive (+ve) values and deposition negative (-ve) values.

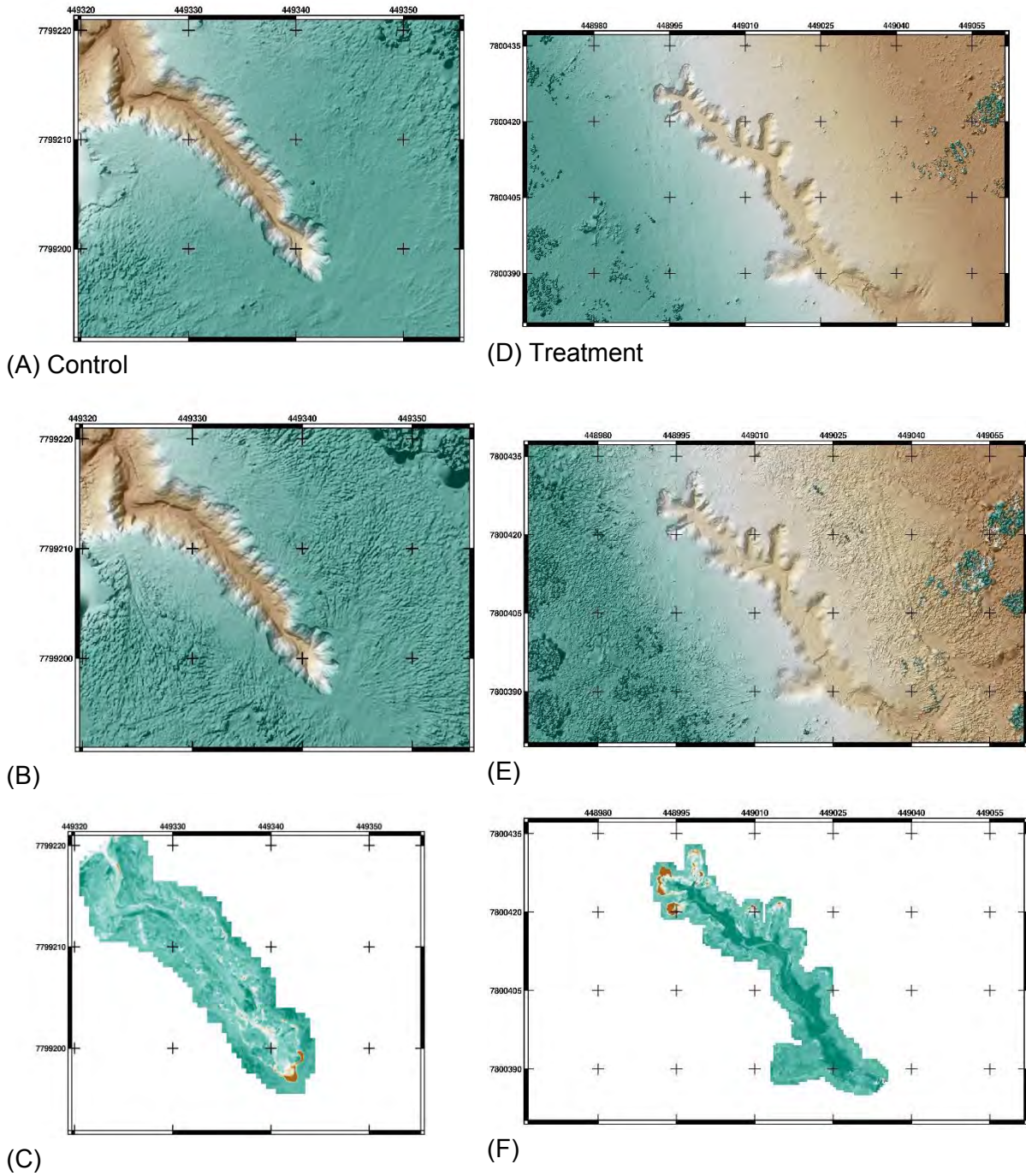


Figure 20: Virginia Park (A) control gully in 2016 (B) control gully in 2018 and (C) DEM of Difference; (D) treatment gully in 2015, (E) treatment gully in 2018 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is deposition and brown is erosion.

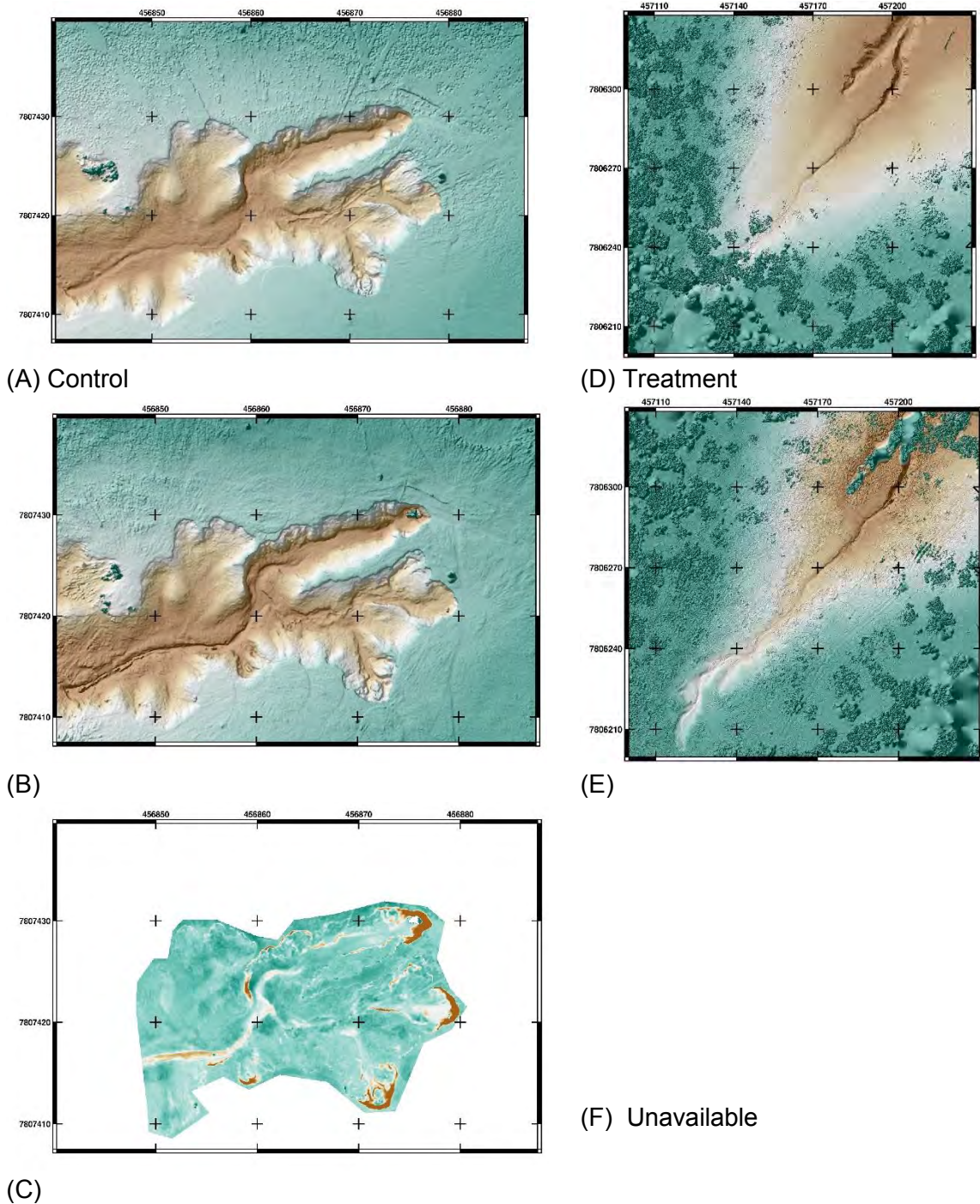


Figure 21: Meadowvale (A) control gully in 2017 (B) control gully in 2018 and (C) DEM of Difference; (D) treatment gully in 2017, (E) treatment gully in 2018 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is deposition and brown is erosion. Treatment site unavailable due to scanning alignment.

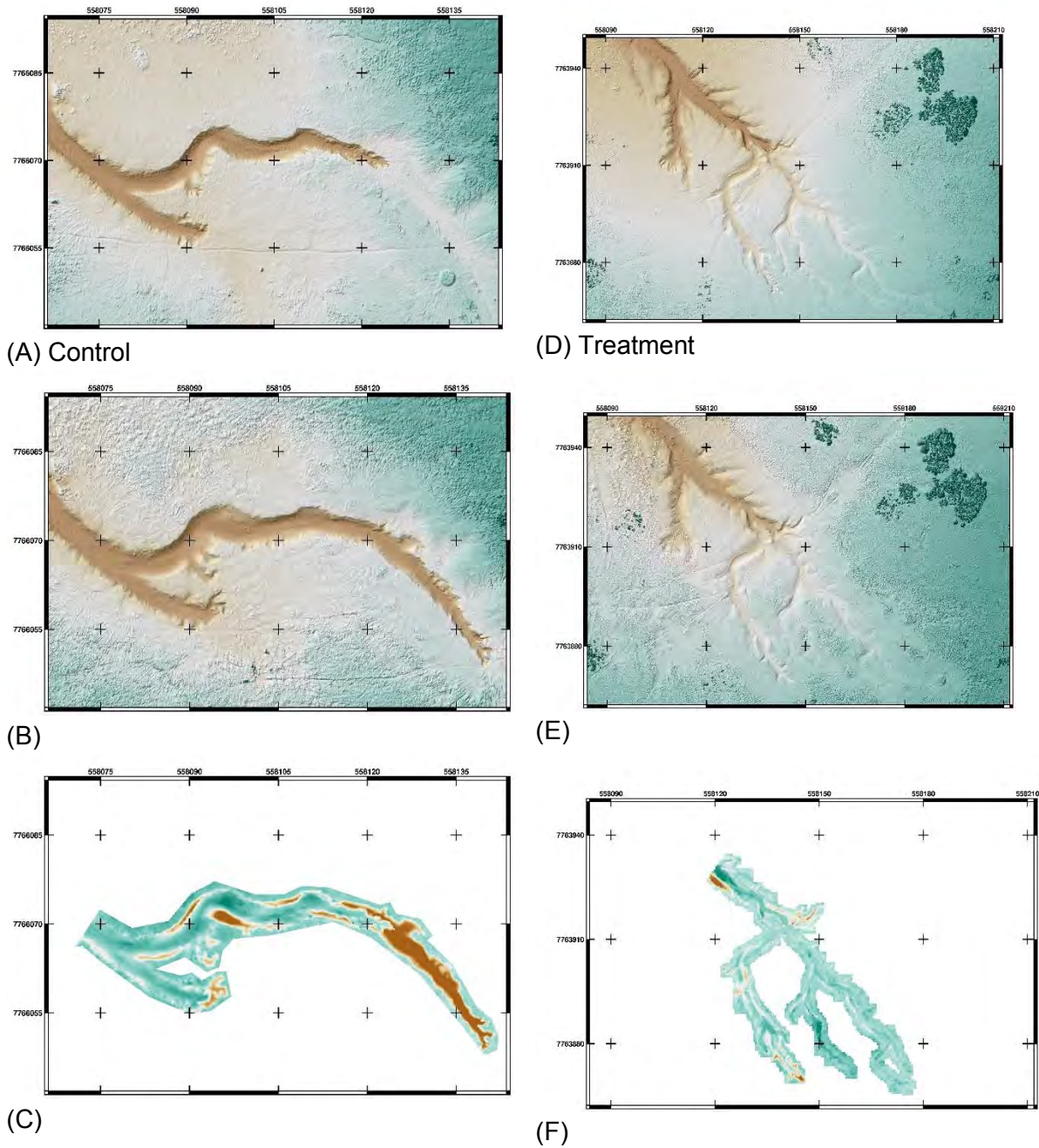


Figure 22: Strathbogie (A) control gully in 2016 (B) control gully in 2018 and (C) DEM of Difference; (D) treatment gully in 2016, (E) treatment gully in 2018 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is deposition and brown is erosion.

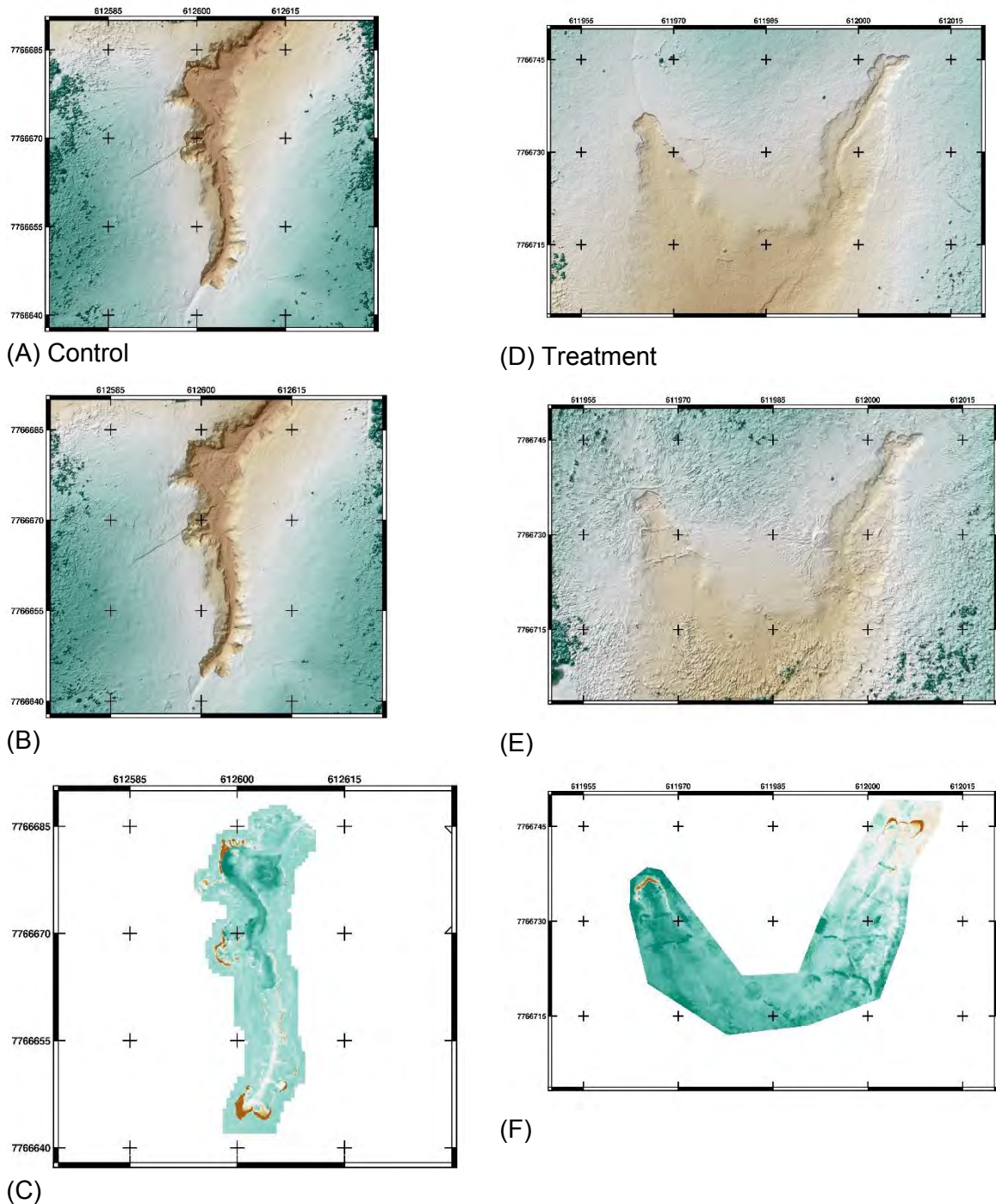


Figure 23: Minnievale (A) control gully in 2016 (B) control gully in 2018 and (C) DEM of Difference; (D) treatment gully in 2016, (E) treatment gully in 2018 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is deposition and brown is erosion.

5.4 Rainfall, runoff, water quality and particle size

A summary of the rainfall, runoff and water quality data collected during the 2017/18 wet season (November 1, 2017 to April 30, 2018) for each of the sites is presented in Table 10. The rainfall and hydrographs for the wet season for each site are presented in Appendix A. Images of each of the four treatment gullies before, during and after an event are presented in Figure 24: Figure 24 to Figure 28.

The Upper Burdekin sites had near average rainfall (Virginia Park and Meadowvale), however, Strathbogie and Minnievale had considerably less rainfall than the long term average for the area. Water depths were recorded in each gully, and were used to generate stage hydrographs from which the samples for water quality analysis were chosen (Appendix A). Velocity sensors were installed in 2017 to help support the estimate of discharge, however, the initial measurement data highlighted that the manufacturer supplied settings were not appropriate for gully systems and an effort was required to investigate appropriate configurations after an investigation subsequent flow events. After this investigation there were too few events to enable to reliable development of rating curves (Table 11). Therefore, no discharge calculations are presented for any of the sites. Assuming sufficient flow events in the next wet season, any subsequent rating curves can be used to back calculate runoff depth values from previous wet seasons.

A comparison in the Total Suspended Sediment (TSS) and Total Nitrogen (TN) concentrations between control and treatment gullies for all sites are presented in Figure 29 to Figure 33 and the mean $\pm$ standard error (SE) estimates are presented in Table 10. The highest TSS concentrations in 2017/18 wet season were measured at Mt Wickham, Virginia Park and Strathbogie, and the highest TN concentrations were recorded at Minnievale and Meadowvale (Table 10).

At Virginia Park and Minnievale, the two sites that had active treatments, the TSS concentrations were lower in the treatment gully than on the control gully (Table 12). This provides some confidence that the treatments are working to reduce TSS concentrations. Given there is a similar difference in the hillslope and within gully cover metrics (Table 6 and Table 7), this suggests that the differences in cover and biomass are influencing water quality by reducing sediment detachment as well as increasing sediment trapping.

A more detailed comparison of the form of nitrogen measured in the gullies was possible this year (for some, but not all, sites). Figure 35A shows that the ratio of dissolved organic nitrogen (DON), dissolved inorganic nitrogen (DIN) and particulate nitrogen (PN) varies between Virginia Park, Meadowvale and Mt Wickham. The proportion of PN makes up ~60%, ~80% and ~92% of the total nitrogen (TN) at each site, respectively. The proportion of DON, DIN and PN also varies between control and treatment gullies at Virginia Park (Figure 35B), which may reflect the higher pasture cover and biomass at the treatment gully.

To understand how particle size of the eroded material varies between the various erosional units (hillslopes, scalds and gullies) a comparison of TSS concentration and particle size data (where available) was undertaken for Virginia Park, for data collected in similar rainfall years (Table 13). This suggests that the TSS concentrations can vary between erosional units, with sediment concentrations from scalds (Flume 3) being higher than from gullies, which are higher than for grassed hillslopes (Flume 1), however, the particle size of this material is largely the same (Table 13).

Table 10: Summary of rainfall, runoff, water quality concentration and loads for each of the sites for the 2017/18 wet season. * Note that Mt Wickham was only installed on 21/2/18 and CSIRO is not contracted for land condition monitoring at this site.

		Virginia Park		Meadowvale		Strathbogie		Minnievale		Mt Wickham *	
		Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
Site Rainfall (mm)	2017-2018 (Jul-Mar)	543 mm	587 mm	722 mm	763 mm	474 mm	493 mm	669 mm	670 mm	132 mm	154 mm
Long term rainfall (mm)	BOM, long term data	650 mm (record length 1899-2016)		650 mm (record length 1899-2016)		725 mm (record length 1886-2016)		841 mm (record length 1961-2016)		626 mm (record length 2000 -2018)	
Catchment area (km ²)		0.016	0.038	0.06	0.074	0.174	0.038	0.021	0.097	0.03	0.14
Catchment area (ha) above monitoring station		1.6	3.8	6	7.4	17.4	38.1	21.2	9.7		
Slope – hillslope above gully (%)		4.3	3.9	2.9	3.0	2.1	2.2	2.0	2.9	2.2	2.1
Hillslope Cover (%)	Post-wet	74	76	93	69	87	93	73	70	na	na
Gully walls (% cover)	Post-wet	38	25	30	34	42	30	23	27	35	29
Gully floor (% cover)	Post-wet	56	11	19	16	42	30	23	27	35	29
TSS concentration (mg L ⁻¹)	Mean ± SE	451 ± 75 (n =30)	5667 ± 1525 (n =6)	1853 ± 306 (n =38)	2637 ± 776 (n =8)	3835 ± 794 (n =11)	2800 (n =1)	1946 ± 256 (n =11)	4150 ± 850 (n =2)		57000 ± 8215 (n =4)
	Range	97 to 1600	1200 to 11000	190 to 7900	620 to 6600	490 to 8400		950 to 3600	3300 to 5000		41000 to 74000
TN (mg L ⁻¹)	Mean ± SE	1445 ± 97	5813 ± 558	2163 ± 380	8733 ± 2573	-	-	1959 ± 204	14704		7601 ± 1262
	Range	1185 to 2006	4658 to 7339	825 to 5892	5784 to 13861			1551 to 2177	-		4406 to 9947
Median particle size (µm) measured	Mean ± SE	7.34 ± 1.5		22.5 ± 1.7		5.7 ± 0.5		10.4 ± 1.9			24.5 ± 2.4

Table 11: Summary of progress with velocity data for the 2017/18 wet season

Site	Event Threshold	No. of events exceeding threshold	No. of events with velocity data	No. of events with usable velocity data	Depth vs Discharge relationship available after one wet season
Virginia Park - Control	300	0	0	0	
Virginia Park – Treatment	210	8	7	4	<i>Preliminary relationship developed</i>
Meadowvale - Control	120	14	6	6	<i>Preliminary relationship developed</i>
Meadowvale - Treatment	120	9	4	1	
Strathbogie – Control	300	0	0	0	
Strathbogie -Treatment	120	2	0	0	
Minnie Vale –Control	100	14	3	2	<i>Preliminary relationship developed</i>
Minnie Vale – Treatment	100	6	4	4	<i>Preliminary relationship developed</i>
Mt Wickham – Control	200	2	0	0	
Mt Wickham - Treatment	200	1	0	0	

Table 12: Treatment differences (treatment vs control) emerging in TSS concentrations after 2 wet seasons

Site	Remediation in place	Statistical Significance (Student t-test or Mann-Whitney Rank** sum test when not normally distributed). Bold = significantly different.	Cohen's d score for effect size (% of the treatment group with a TSS conc. below the average of control group)	% difference in mean TSS concentration between treatment and control (reduction)
Virginia Park				
2016/17	Yes	P = 0.013**	-2.29, 99%	76%
2017/18	Yes	P <0.001	-2.13, 98%	92%
Meadowvale				
2016/17	No	P = 0.994	0, 50%	0%
2017/18	Yes	P=0.182**	-0.32, 62%	30%
Strathbogie				
2016/17	No	P= 0.801	-0.20, 58%	14%
2017/18	No	NA (too few samples)		
Minnie Vale				
2016/17	Yes	P= 0.001	-1.24, 88%	48%
2017/18	Yes	P= 0.0079	-1.86, 96%	53%
Mt Wickham				
2016/17	No	NA		
2017/18	No	NA		

Table 13: Partition of TSS concentration and particle size of sediments moving in the water column between the hillslope and gully system at Virginia Park

	Rainfall (mm)	Median/Mean TSS conc. (mg/l)	Particle size (µm) – D50	Data source
Hillslope (Flume 1, 2004/05)	345	288/299 (n = 28)	6.99	MLA
Hillslope (Flume 3, 2004/05)	360	1000/1920 (n= 3)		MLA
Gully (Treatment, 2017/18)	382	625/876 (n = 32)	7.30	NESP 2016/17



(A)



(B)



(C)



(D)

Figure 24: Treatment gully at Virginia Park in (A) 2016 (B) during an event in 2017 and (C) at the end of reporting period in April 2017 and (D) at the end of reporting period in April 2018



(A)



(B)



(C)



(D)

Figure 25: Treatment gully at Meadowvale in (A) 2016 (B) during an event in 2017 and (C) at the end of reporting period in April 2017 and (D) at the end of reporting period in April 2018



(A)



(B)



(C)



(D)

Figure 26: Treatment gully at Strathbogie in (A) 2016 (B) during an event in 2017 and (C) at the end of reporting period in April 2017 and (D) at the end of reporting period in April 2018

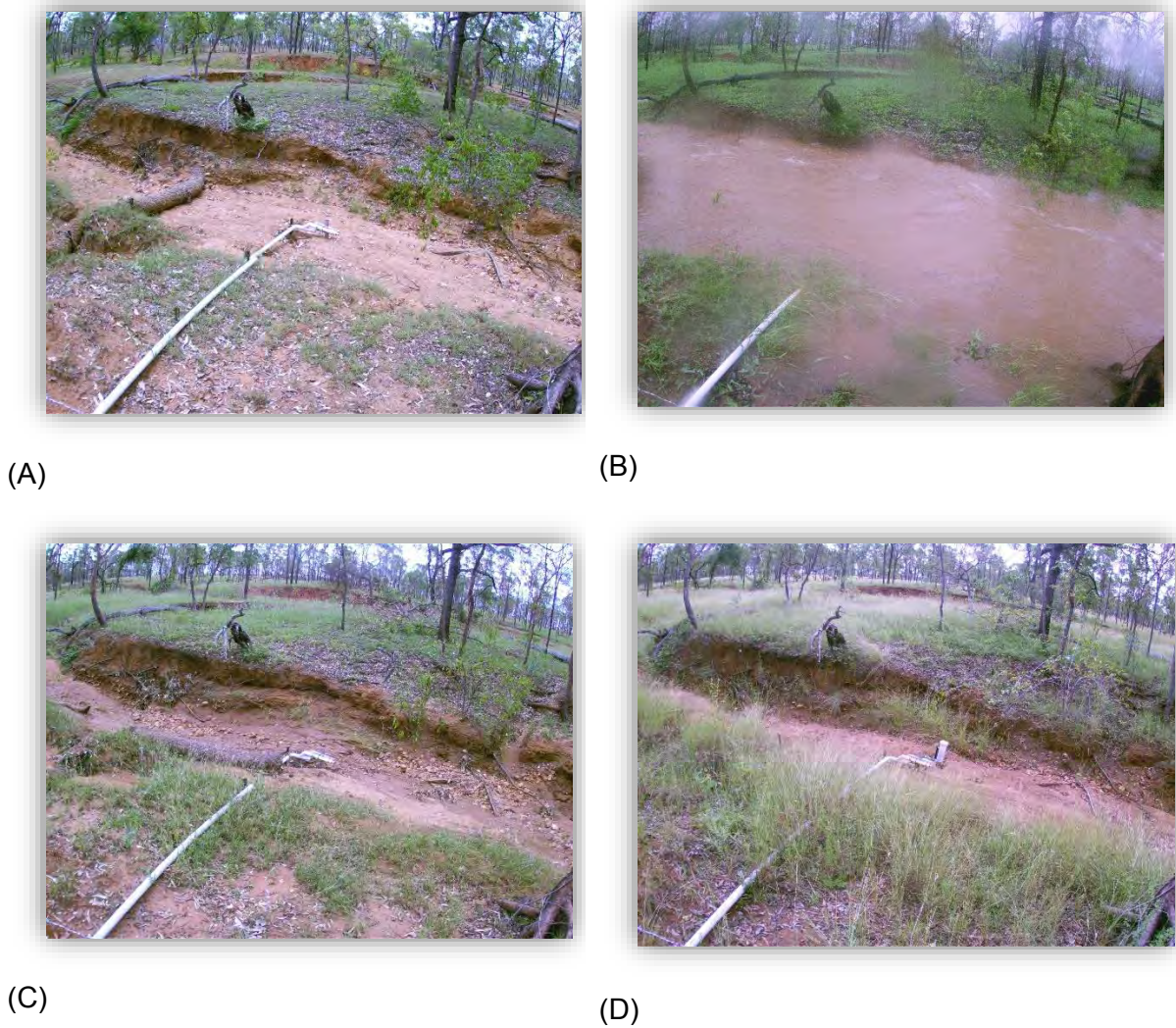


Figure 27: Treatment gully at MinnieVale in (A) 2016 (B) during an event in 2017 and (C) at the end of reporting period in April 2017 and (D) at the end of reporting period in April 2018



Figure 28: Control gully at Mt Wickham before (left) and during (middle) an event and at the end of reporting period (April 2018)

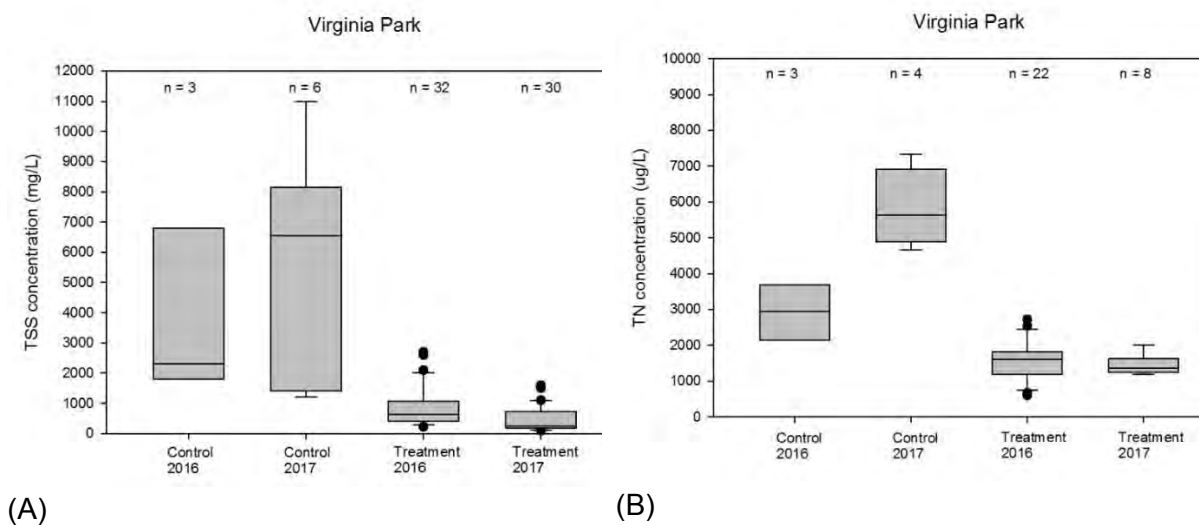


Figure 29: (A) TSS concentration and (B) TN concentrations at Virginia Park for two wet seasons

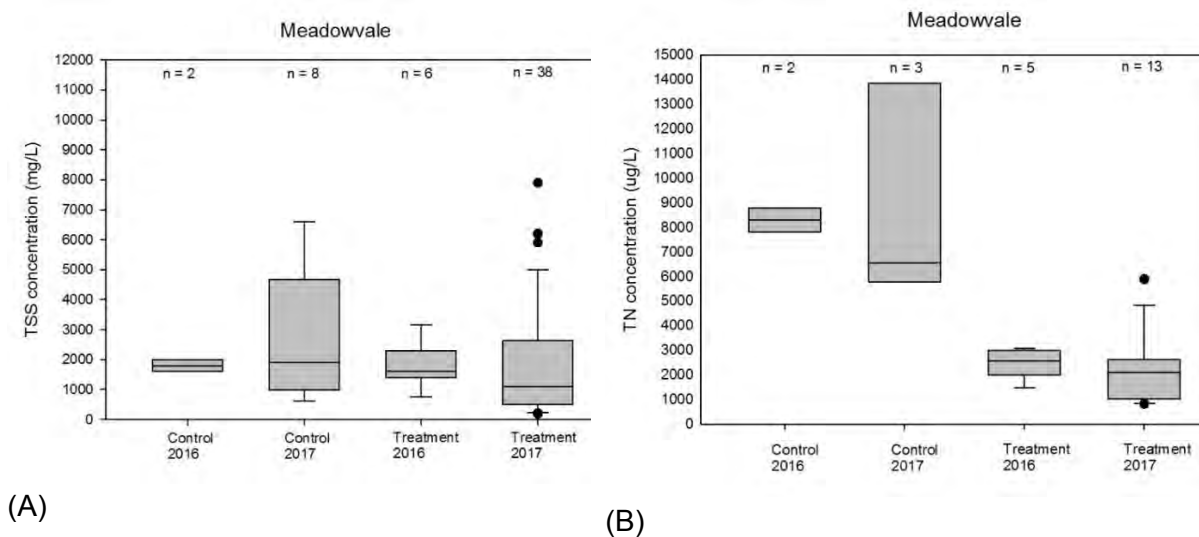


Figure 30: (A) TSS concentration and (B) TN concentrations at Meadowvale for two wet seasons

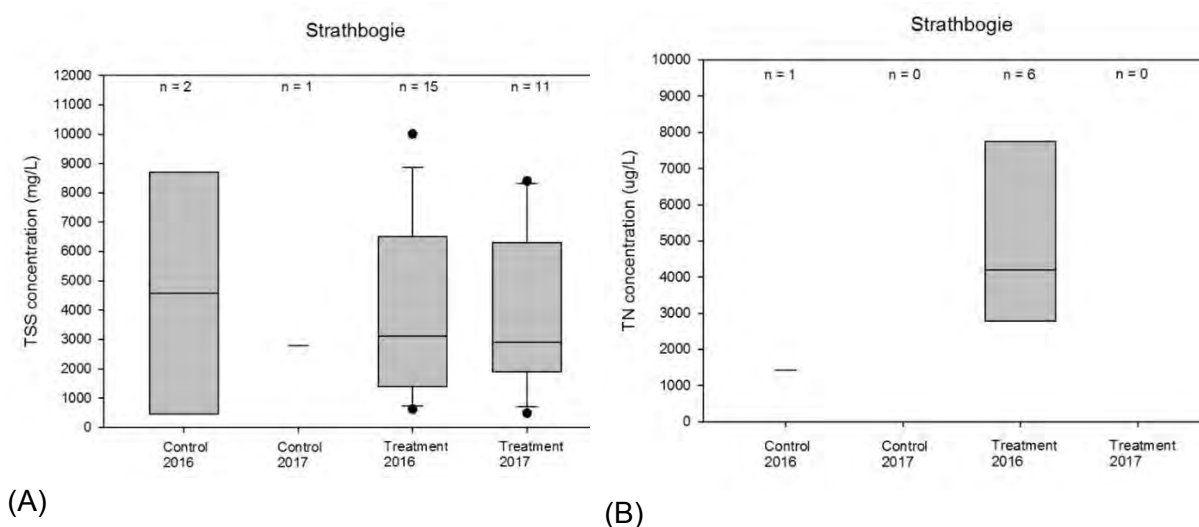


Figure 31: (A) TSS concentration and (B) TN concentrations at Strathbogie for two wet seasons

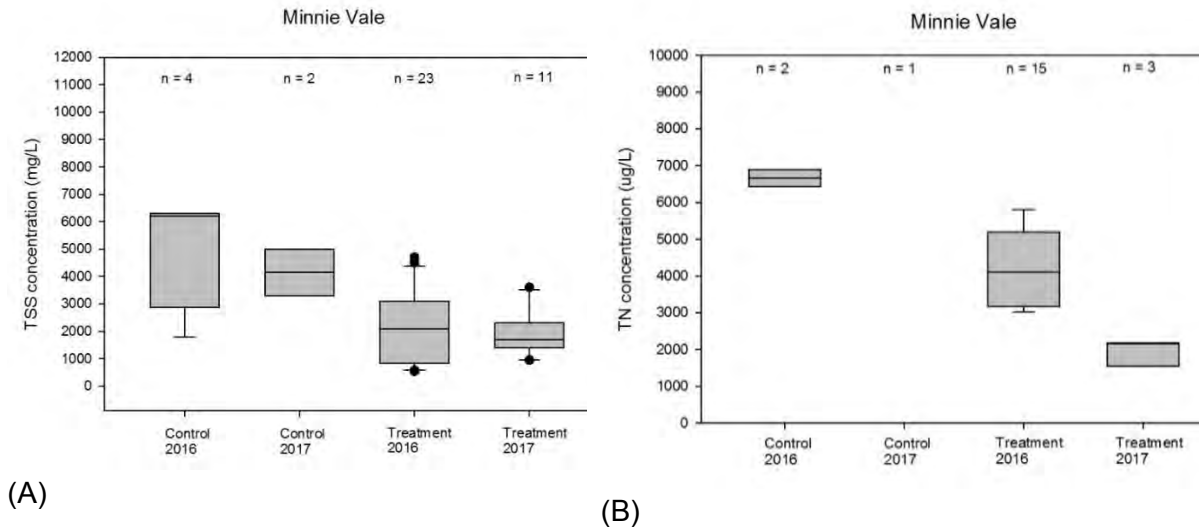


Figure 32: (A) TSS concentration and (B) TN concentrations at Minnievale for two wet seasons

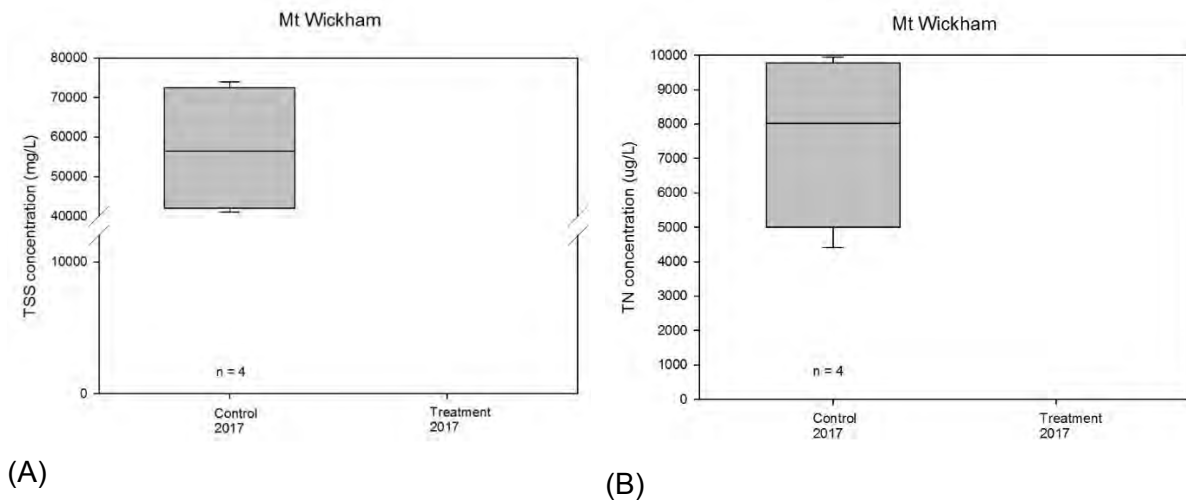


Figure 33: (A) TSS concentration and (B) TN concentrations at Mt Wickham in 2017/18 wet seasons

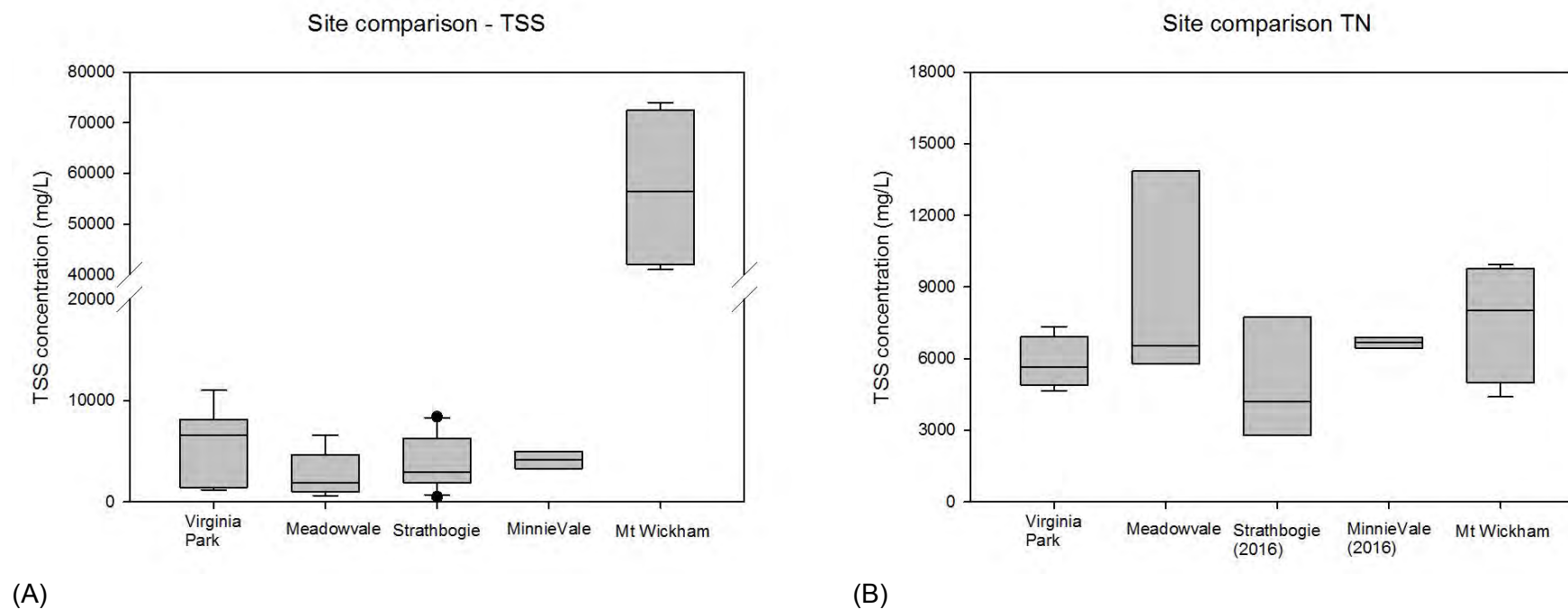


Figure 34: (A) comparison of TSS data from un-treated gullies in 2017/18 (B) a comparison of TN data treatment sites as there was insufficient data from control sites alone for TN (using a range of 2016/17 and 2017/18 data)

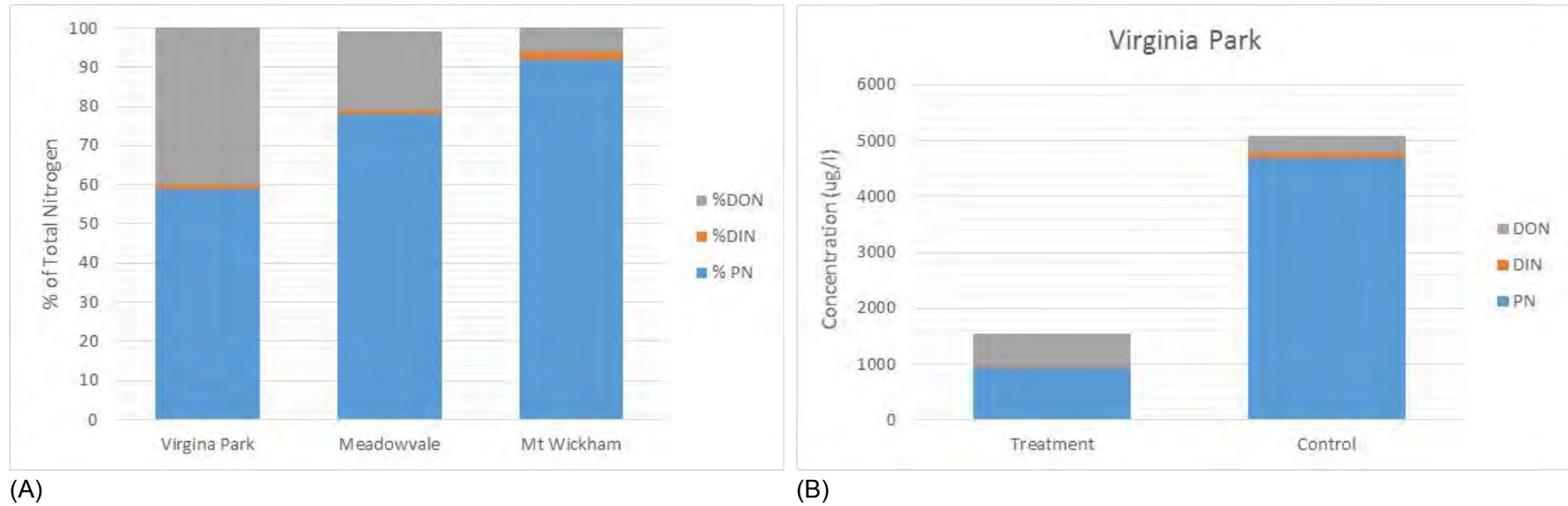


Figure 35: (A) Ratio of nutrient speciation contributing to total N loads at three sites (Virginia Park, Meadowvale and Mt Wickham) and (B) the difference in nitrogen forms between a long term treatment and control gully at Virginia Park

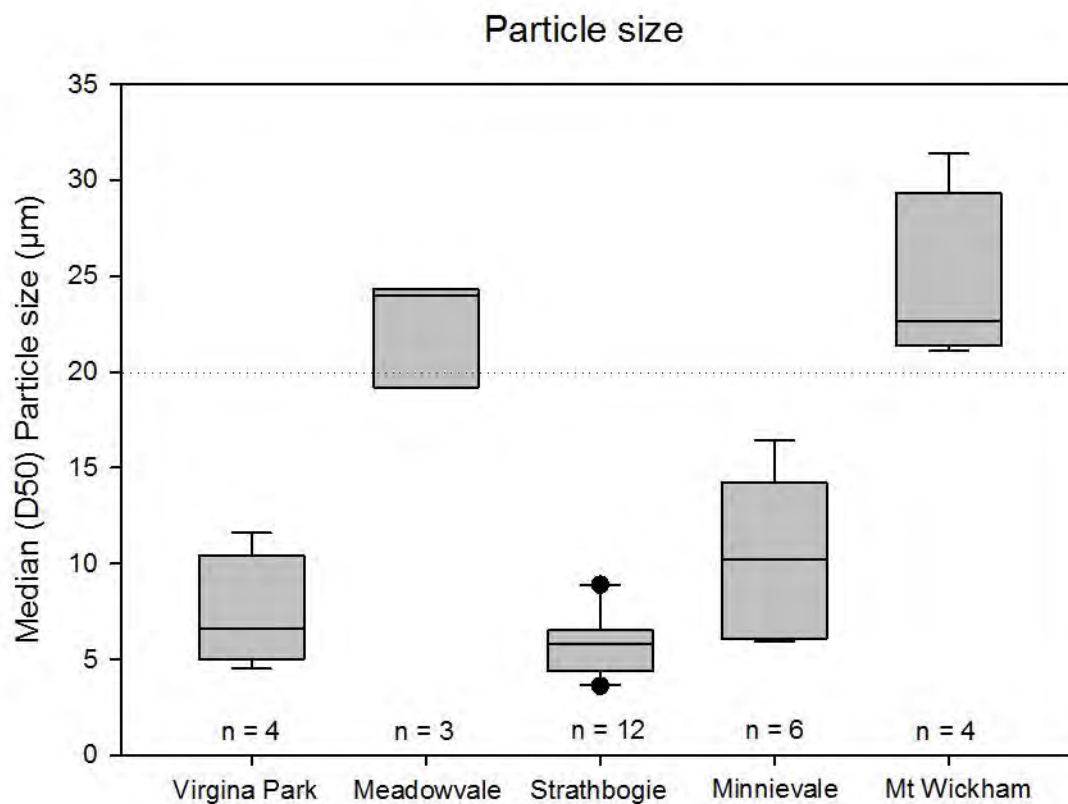


Figure 36: Particle size of suspended sediment collected at each of the five properties over the two wet seasons. Note that sediment <20 µm (dotted line) is considered to be the most ecologically detrimental for the GBR (Bainbridge et al., In Review).

6.0 IDENTIFYING PRIORITY HOT-SPOT GULLIES FOR REMEDIATION AT THE PROPERTY SCALE

One of the challenges on properties with numerous active gullies, has been the ability to identify and prioritise the gullies that should be selected for remediation. In this project, we have trialled and tested two approaches for potentially helping identify which areas of a catchment or property would be the most appropriate for gully remediation: (1) catchment area upslope of the gully headcut; and (2) the Index of Connectivity (Borselli et al., 2008). We have used one of the NESP research sites, Virginia Park, to demonstrate the application of these approaches, however, it is anticipated that these approaches could be applied to any property or catchment that has reasonable terrain data (preferably Lidar) to represent the channel network.

6.1 Using gully upslope catchment area

As identified in Figure 18, there is a strong relationship between the gully erosion rate (t/m/yr) and the area of the catchment upslope of the gully head. Using the available Lidar and ArcGIS, catchment areas for all gullies in the Weany Creek catchment on Virginia Park Station have been delineated into those with upslope catchment areas (UCA) of >10 ha, >5 ha and > 1ha (Figure 37). Based on this analysis there are six gullies that have UCA of >10 ha and are therefore likely to have higher gully erosion rates than other gullies in the catchment all things being equal. It is also expected that soil type and ground cover would influence gully erosion rate, however, the soil type is relatively uniform on this property, and ground cover metrics have been included in the Index of Connectivity approach below. Therefore, this relatively quick method could be used for rapid assessment of 'hot-spots' within highly gullied properties.

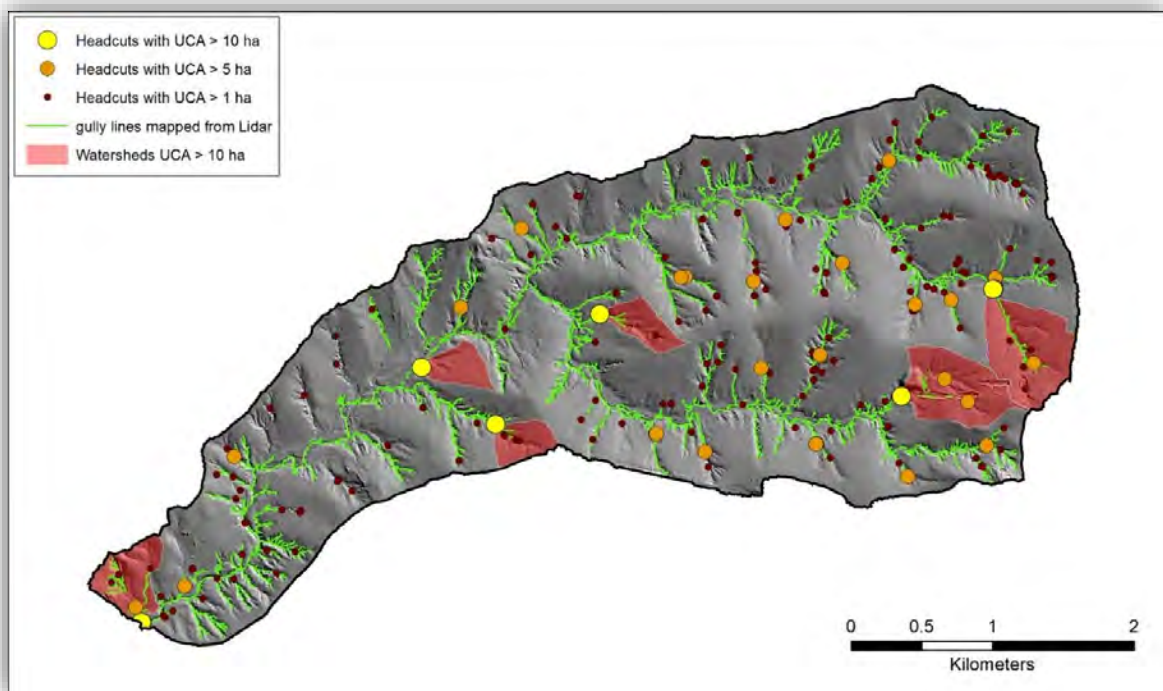


Figure 37: Identification of gullies with catchment areas >10 ha, >5 ha and >1 ha at Virginia Park.

6.2 The Index of connectivity

The index calculates the relative connectivity of sub-catchments to both (i) the channel network and (ii) the catchment outlet. It is a relative risk approach that estimates the connectivity of catchment area based on the upslope area, average slope and a weighting factor that can incorporate estimates of ground cover or soil type. The connectivity is primarily about the potential 'connectivity' of water or runoff, but it can also represent sediment or nutrients or any constituent that moves in runoff. The methods for this approach are described in more detail in Borselli et al., (2008) and Sidle et al., (2017). In brief, the Index of Connectivity (IC) is defined by Equation 1 and described in Figure 38. The strength of the IC approach is that it explicitly represents the distributed flow path that water would take moving through a landscape, as opposed to the lumped representation of hydrology within other approaches such as the Universal Soil Loss Equation (USLE). The IC approach also considers the potential for deposition (or dis-connectivity) within each segment.

We applied the Index of Connectivity to the Virginia Park NESP study site to highlight which sub-catchments would have the highest relative connectivity to (i) the main stream channel network (Figure 39), (ii) to the entire channel network including mapped gullies (Figure 40) and (iii) to the catchment outlet (Figure 41). For each of these scenarios, the ground cover was represented as a consistent 50%, however, in future scenarios, spatially explicit ground cover can be used via the weighting factor.

The results suggest that there are specific parts of the catchment that have higher connectivity (red and orange areas) and therefore higher potential or relative risk of delivery of water and sediment/nutrients to the stream network. Having a gullied landscape increases the connectivity of many areas of a catchment (Figure 40). In terms of the delivery of water and sediment to the end of a catchment, the areas closest to the catchment outlet will generally be the highest risk, all other things (such as soil type and ground cover) being equal (Figure 41).

$$IC = \log_{10} \left(\frac{D_{up}}{D_{dn}} \right)$$

Equation 1

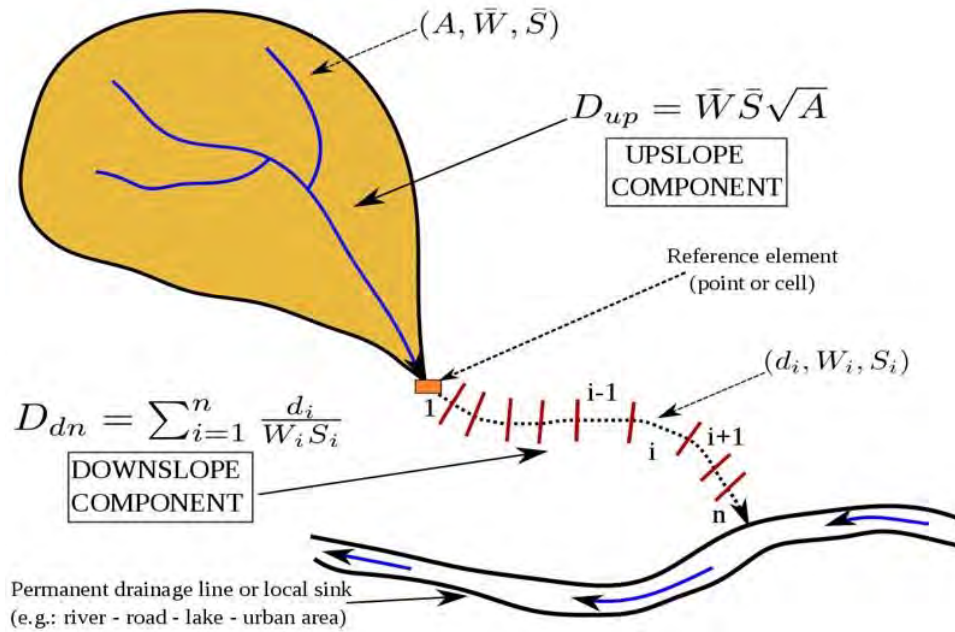


Figure 38: Input components to the Index of Connectivity (IC), where A = upslope area, W is a weighting factor, S is the average slope gradient (after Borselli et al., 2008)

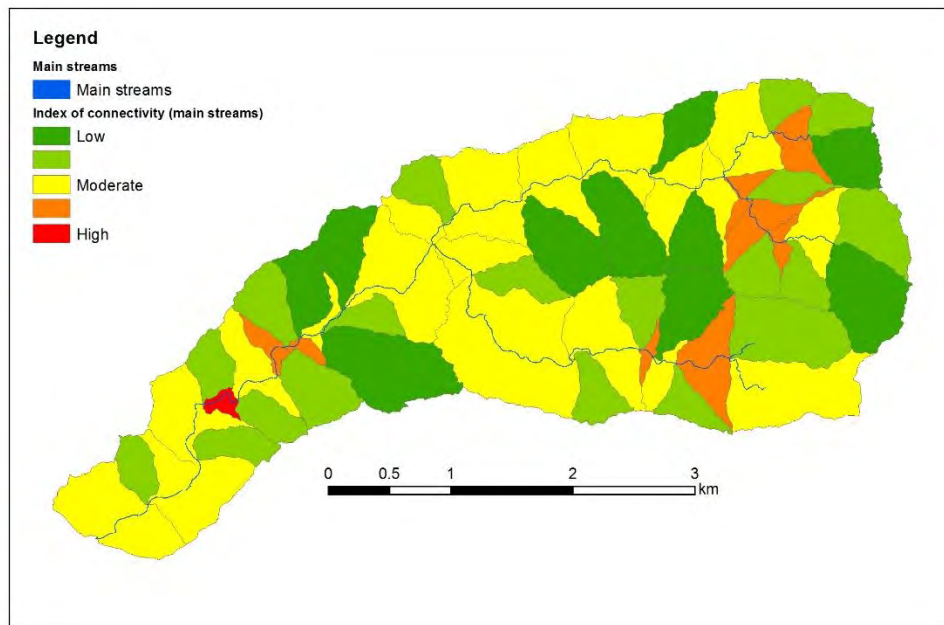


Figure 39: Application of the Index of Connectivity to the Weany Creek catchment using a basic stream network. The gully network is not explicitly mapped, and therefore this primarily represents hillslope connectivity.

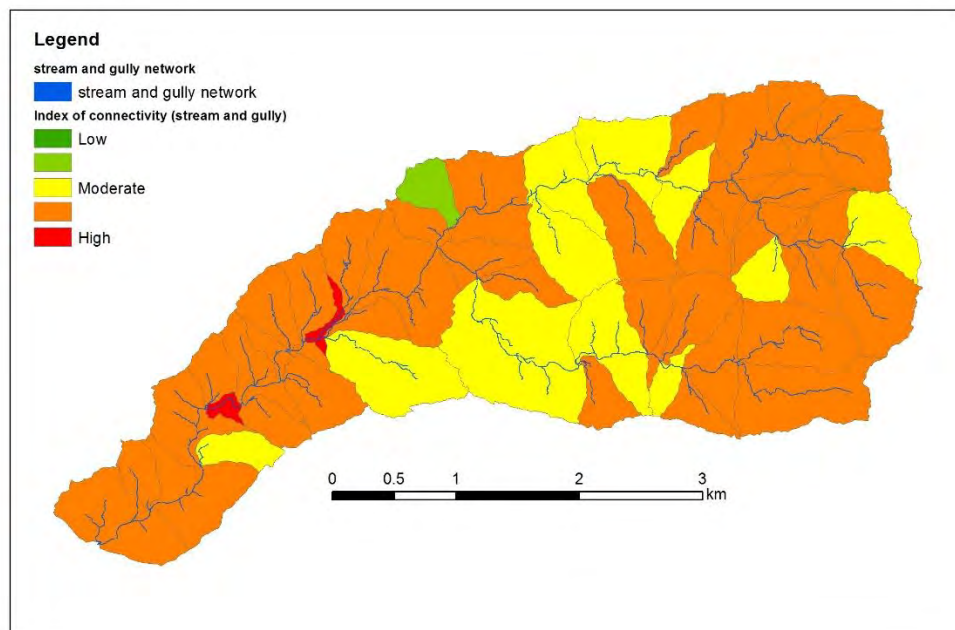


Figure 40: Application of the Index of Connectivity to the Weany Creek catchment using the full channel network (based on Lidar mapping) which includes the stream and gully network.

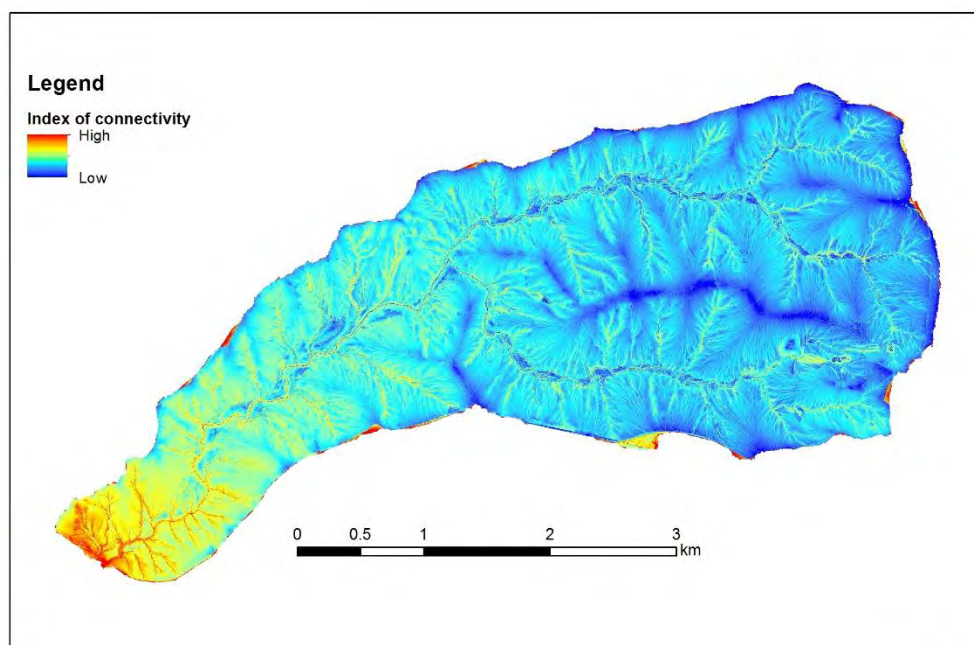


Figure 41: The connectivity of each area in the catchment to the catchment outlet.

6.3 Identifying hot-spots areas for remediation

These approaches together help identify areas with high erosive potential (upslope catchment areas) and then the potential of those areas to have high delivery or connectivity to the stream network and beyond. Using these approaches could be a more efficient way to identify high risk areas within a property that are worthy of remediation investment. Given that significant (often >\$1m) is being spent on remediation at some sites, these approaches could improve the identification of high risk areas worthy of investment.

The Universal Soil Loss Equation (USLE) approaches within the SedNet (or SourceCatchments) framework have traditionally been used to estimate the relative contribution from sub-catchments within a property (e.g. Kinsey-Henderson et al., 2005), and future NESP work will be undertaken to evaluate how these approaches vary at a range of catchment scales. Where appropriate, the specific gully data collected as part of the NESP project will be used to help calibrate and validate the modelling approaches.

7.0 DISCUSSION

The main aim of this project is to quantify the effectiveness of gully erosion control activities (gully remediation) on erosion processes and water quality. Achieving this within a diverse biophysical landscape is challenging because erosion is dependent on many variables including climate variations. We are accounting for and monitoring as many of the landscape attributes which affect gully erosion (e.g. soil type, geology, rainfall, vegetation, terrain) to increase our ability to identify the effects of erosion remediation activities separate from other factors.

The initial aim of this project was to monitor sites that were part of the Reef Trust Gully Erosion Control Programme. However, due to the timing of activities at those sites, and our requirement for well-matched control gullies at each site, only two out of the four sites are in the Reef Trust Programme. We have consequently also included additional sites used in previous CSIRO research funded by Meat and Livestock Australia and the Paddock to Reef Program. In 2018, we also included the Mt Wickham Landholders Driving Change site, although it is not formerly funded by the NESP program.

Cover metrics

The ground based landscape condition analysis determined that all of these sites are in C or D condition, with a small proportion (<5%) of the Upper Burdekin properties transitioning to B condition. The pasture metrics measured on the hillslopes suggest that these sites are all very similar as they are dominated by the exotic, but naturalised pasture species Indian couch, forbs, and/or exotic legumes. This is characteristic of areas where heavy grazing has occurred over long periods, and is typical of State 3 and 4 grazing systems as specified within pasture state and transition models (McIvor and Scanlan, 1994; Ash et al., 2011). In these cases, exotic species have become dominant and replaced native species, the soil has become degraded through an increase in erosion, topsoil compaction and reduction in infiltration. A return to a higher condition from this level requires long time periods (>10 years) of wet season rest and reduced forage utilisation, with pasture composition returning only gradually towards native perennial tussock grasses (Bartley et al., 2014). Mechanical intervention such as ploughing and reseeding may accelerate the process but is not proven. The initial wet season monitoring of forage has indicated that while the % cover and biomass (kg/ha) may be higher at Virginia Park, which has undergone grazing land management over the last decade, the plant basal area is still low. This highlights that a combination of pasture metrics is required to quantify the functional vegetation attributes at these sites, and that reinstating eco-hydrological function in these degraded landscapes is challenging. The cover results from within the gullies suggests that those sites that have been fenced off and cattle excluded are showing a measurable increase in pasture cover and biomass. This provides greater support to the need for cattle to be removed from gullied areas to allow pasture to recover.

Terrain analysis

The results from the terrain analysis have been very useful for highlighting how variable gully erosion and deposition can be between gullies in the same soil type, and between the same gully in different years. For the second year in a row, the most reliable predictor of gully erosion rate is the upslope catchment area draining to the gully headcut. There was no significant relationship with rainfall or ground cover. The main limitation to the terrain analysis is that it

captures all of the sediment fractions (fine and coarse) and so it is best used in conjunction with the water quality data which represents the fractions of sediment/nutrients that are mobilised in the runoff and moved downstream.

Water Quality

The results from the second wet season suggest that there is a statistically significant difference in the TSS concentrations measured between the treatment and control sites at both Virginia Park and Minnievale. This is a good sign given that the 2016/17 and 2017/18 wet seasons were quite different. This suggests that a combination of gully fencing, stock exclusion and porous check dam instream structures are potentially effective at improving downstream water quality. The significant difference in the cover and/or biomass between the treatment and control gullies at these sites supports these results. A third wet season of results will help to confirm this trend.

The water quality results also highlight that Mt Wickham has much higher sediment concentrations than any of the other sites. It is therefore justified as a high priority remediation site for the LDC program. It is well established that the Bowen catchment has much larger sediment yields ($t/km^2/yr$) compared to any other catchment in the GBR catchments, and these results help provide another line of evidence for that investment. Importantly, however, there will be a limited number of willing landholders prepared to undertake remediation on the scale of Mt Wickham (and Strathalbyn). These types of remediation projects will potentially have high effectiveness, but they will also come at a high cost. Hence understanding the effect of improved land management and gully remediation is still a priority for the smaller gullies. In addition, it is important to understand how we can improve the eco-hydrological function of these landscapes as a whole, so that we can potentially reduce the runoff and sediment loss from other erosion sources including hillslopes and streambanks.

Identifying hotspot gully areas at the property scale

In response to the need for relatively rapid approaches for identifying hot-spot areas with highly gullied properties, two approaches were trialled at one of the NESP properties (Virginia Park) to demonstrate the potential of (i) gully upslope catchment area and (ii) the index of connectivity, for differentiating high risk gully sites. Further work will be undertaken to further integrate these approaches with the specific data collected at each of the NESP research sites.

8.0 AREAS OF FURTHER WORK

In the remainder of this project we will:

- Estimate the cost-effectiveness of the gully treatments at the three treatment sites. These results will be compared with the approach used in the Reef Trust sediment savings calculator;
- Continue to monitor the control and treatment sites for a third wet season;
- Work with our research partners to provide insights into how the results from this study link with the studies on nutrient geochemical tracing, nutrient bio-availability and marine impact.
- Continue exploring options for scaling up the results from the individual gullies to demonstrate effectiveness at larger scales. This will also involve improved approaches for rapidly assessing high priority gully sites for remediation.

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APPENDIX 1: WATER DEPTH, TURBIDITY AND SAMPLE HISTORY FOR EACH SITE

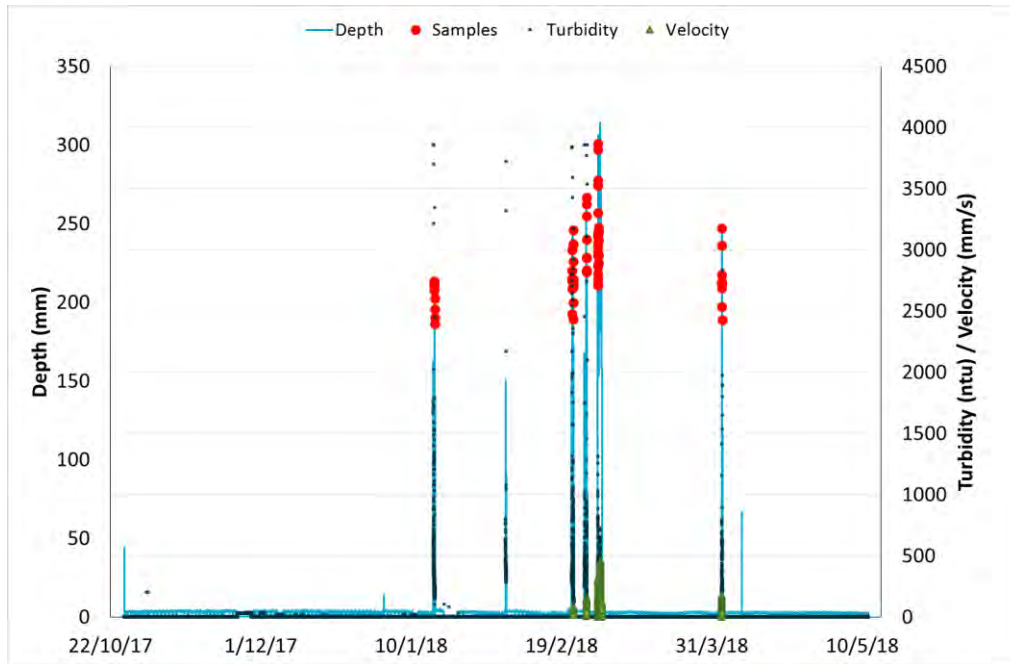


Figure 42: Virginia Park Treatment gully runoff, turbidity, velocity and sample points on the hydrograph.

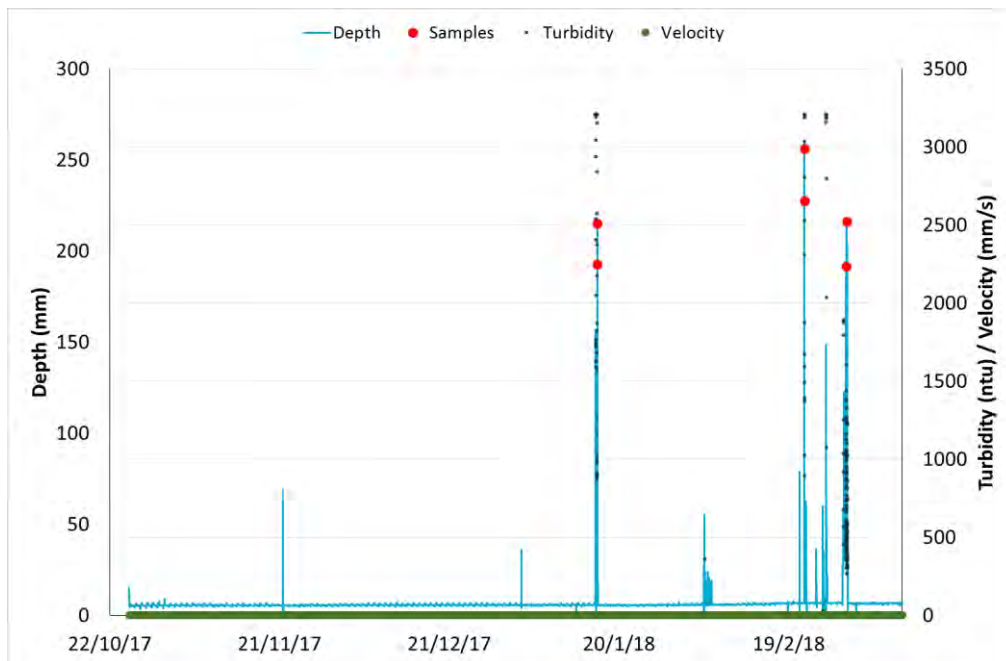


Figure 43: Virginia Park Control gully runoff, turbidity, velocity and sample points on the hydrograph.

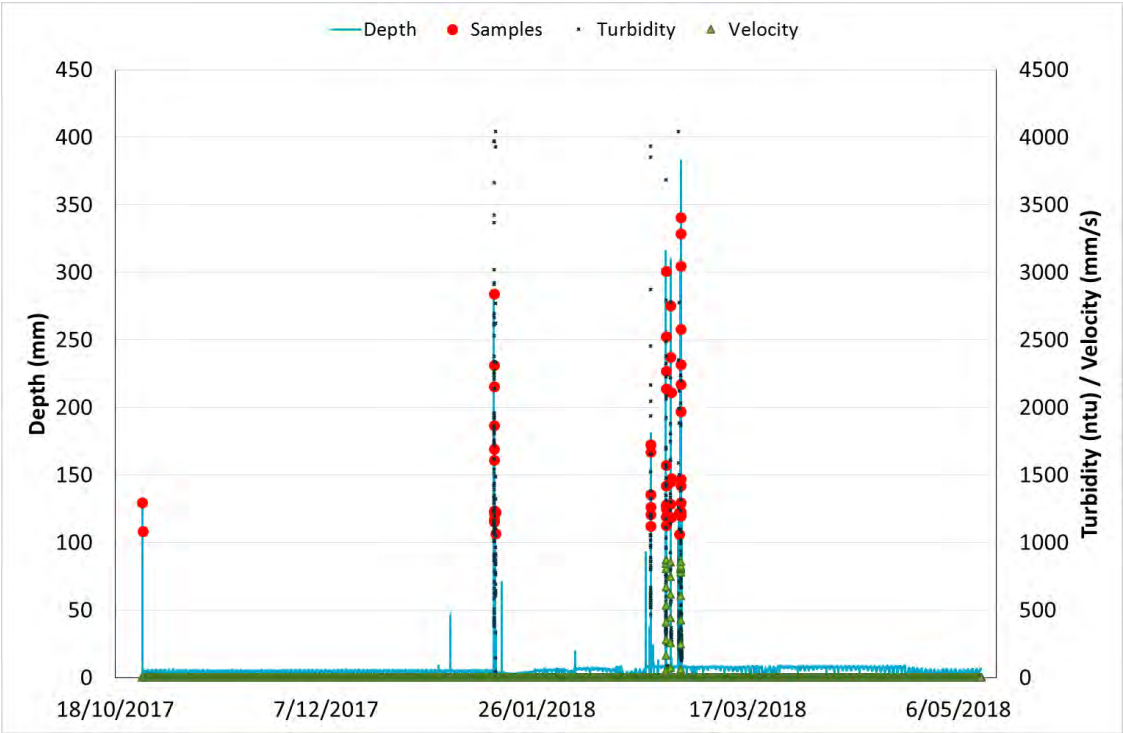


Figure 44: Meadowvale Treatment gully runoff, turbidity, velocity and sample points on the hydrograph

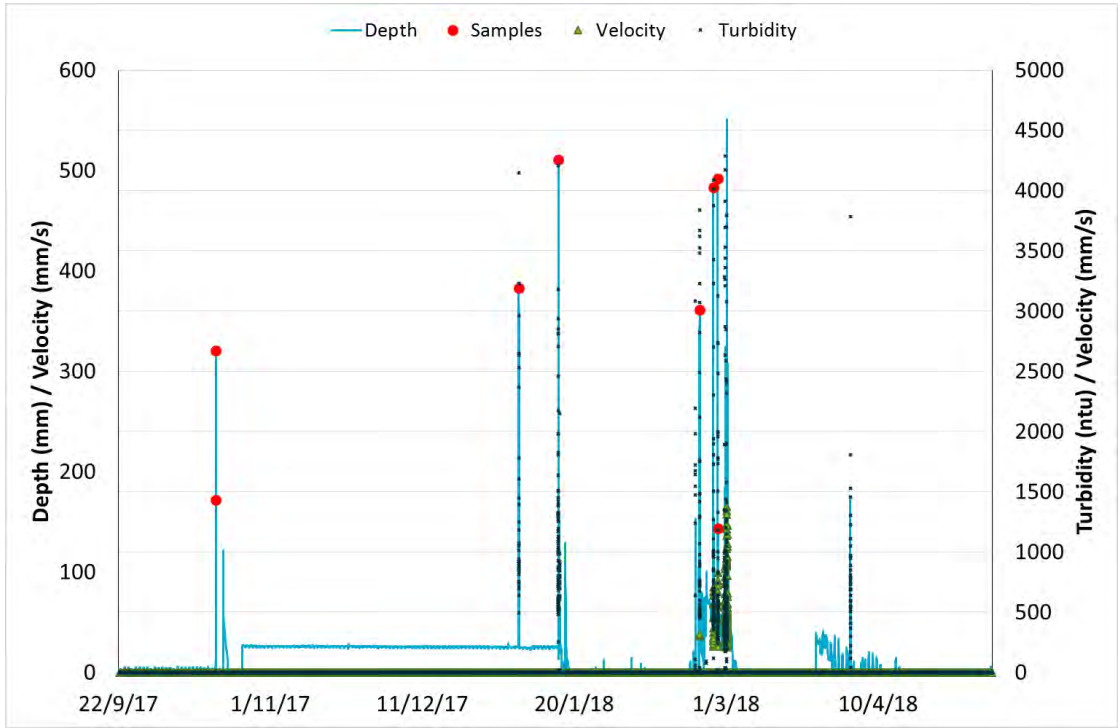


Figure 45: Meadowvale Control gully runoff, turbidity, velocity and sample points on the hydrograph.

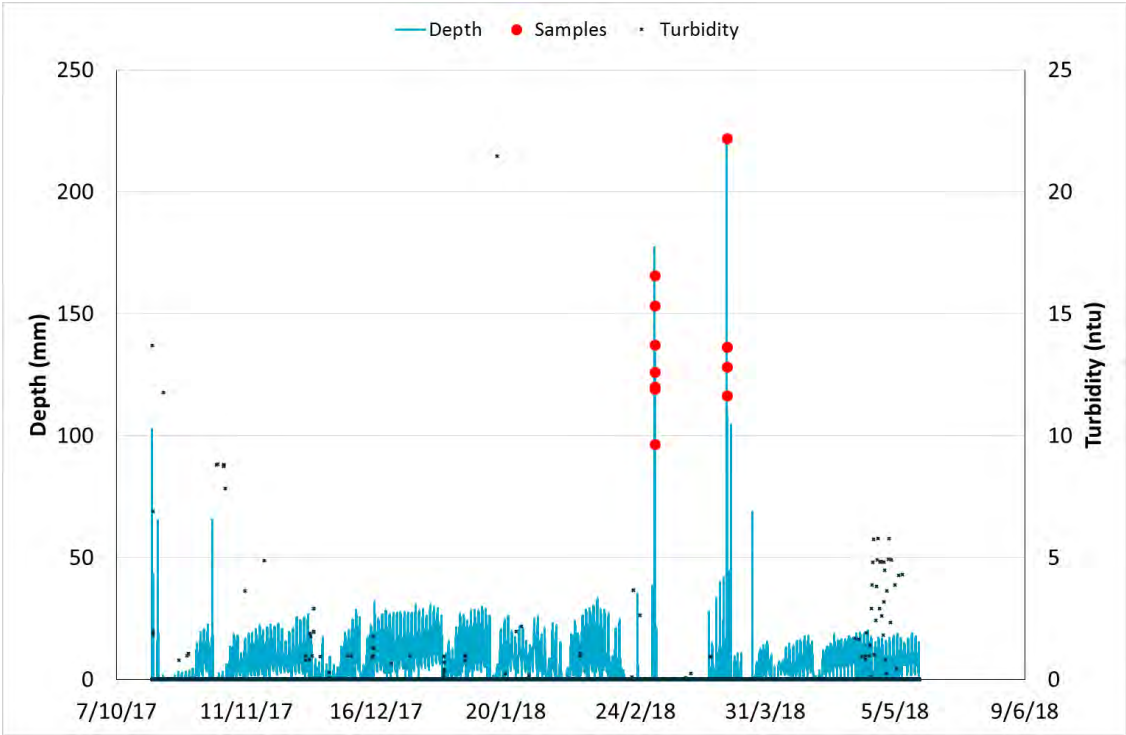


Figure 46: Strathbogie Treatment gully runoff, turbidity and sample points on the hydrograph.

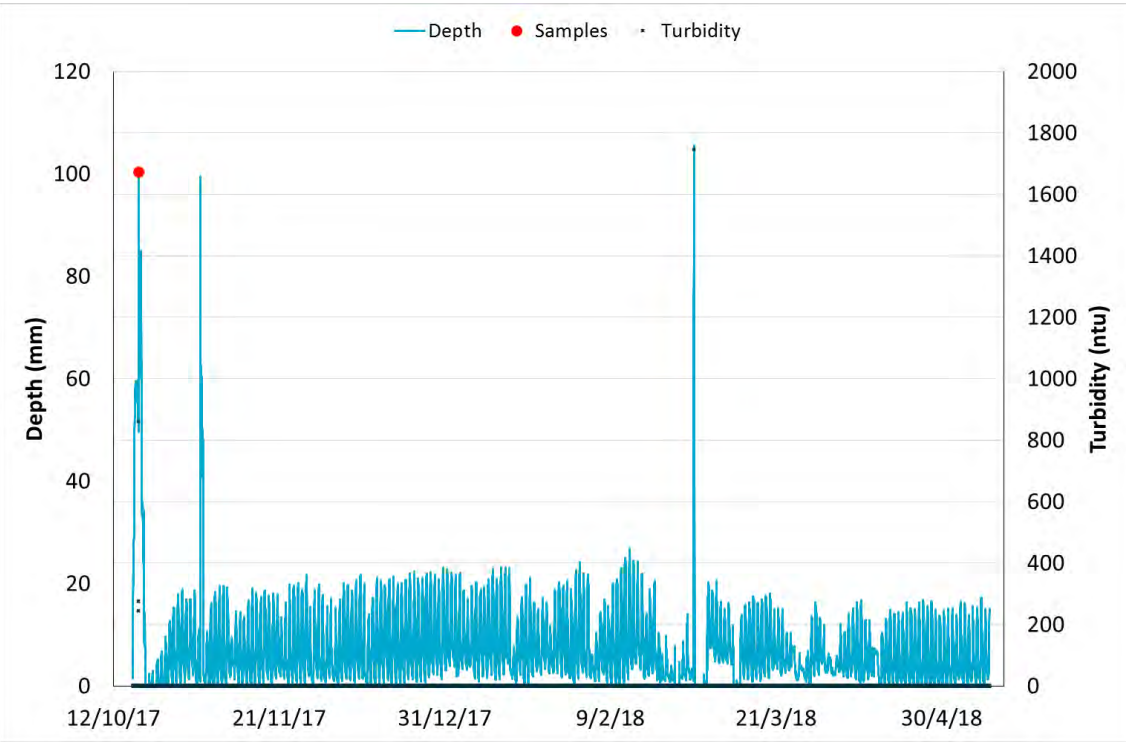


Figure 47: Strathbogie Control gully runoff, turbidity and sample points on the hydrograph.

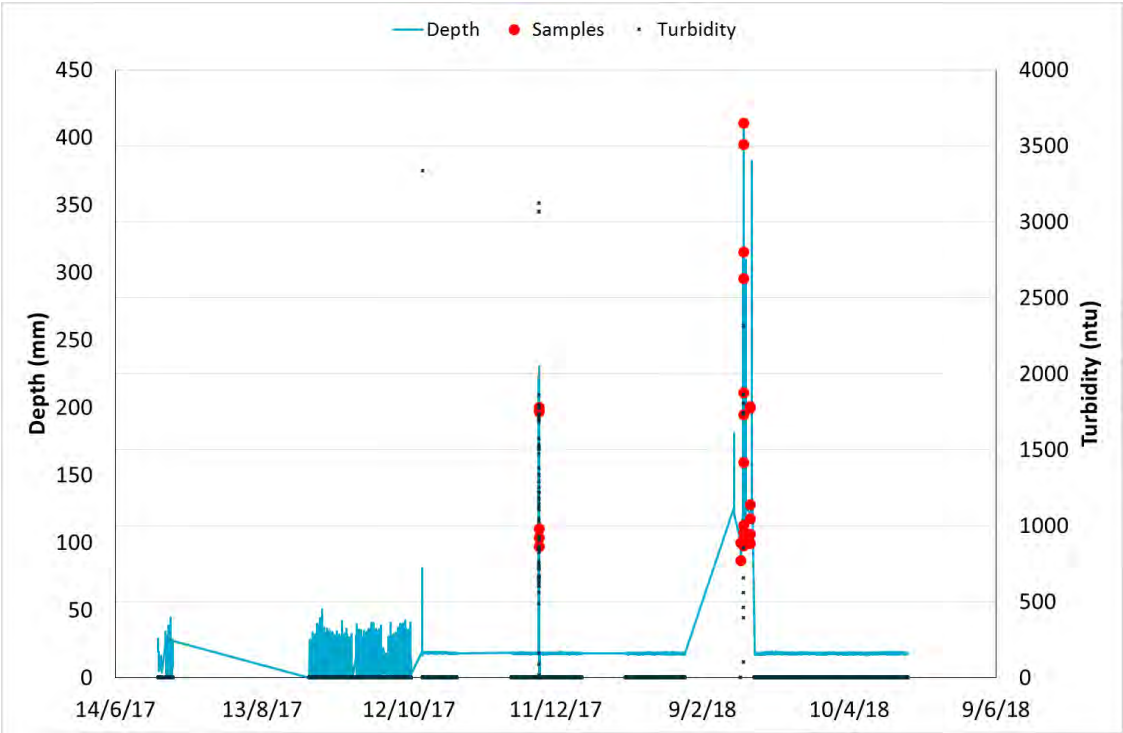


Figure 48: Minnievale Treatment gully runoff, turbidity and sample points on the hydrograph.

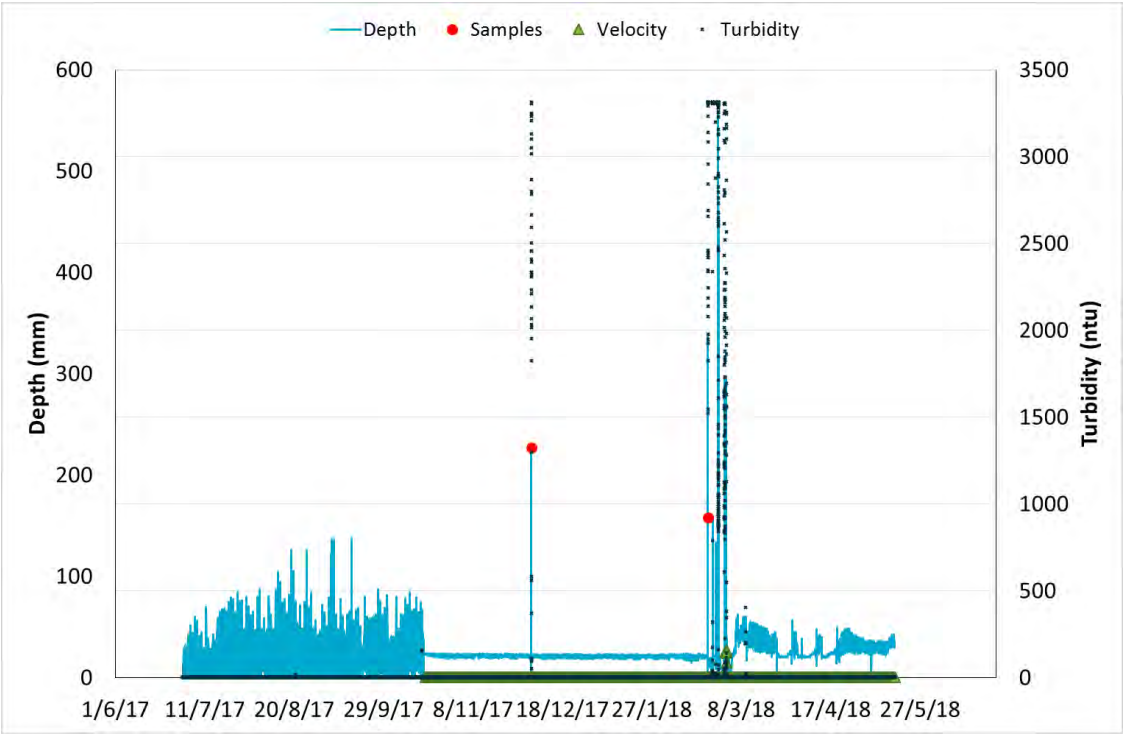


Figure 49: Minnievale Control gully runoff, turbidity, velocity and sample points on the hydrograph.

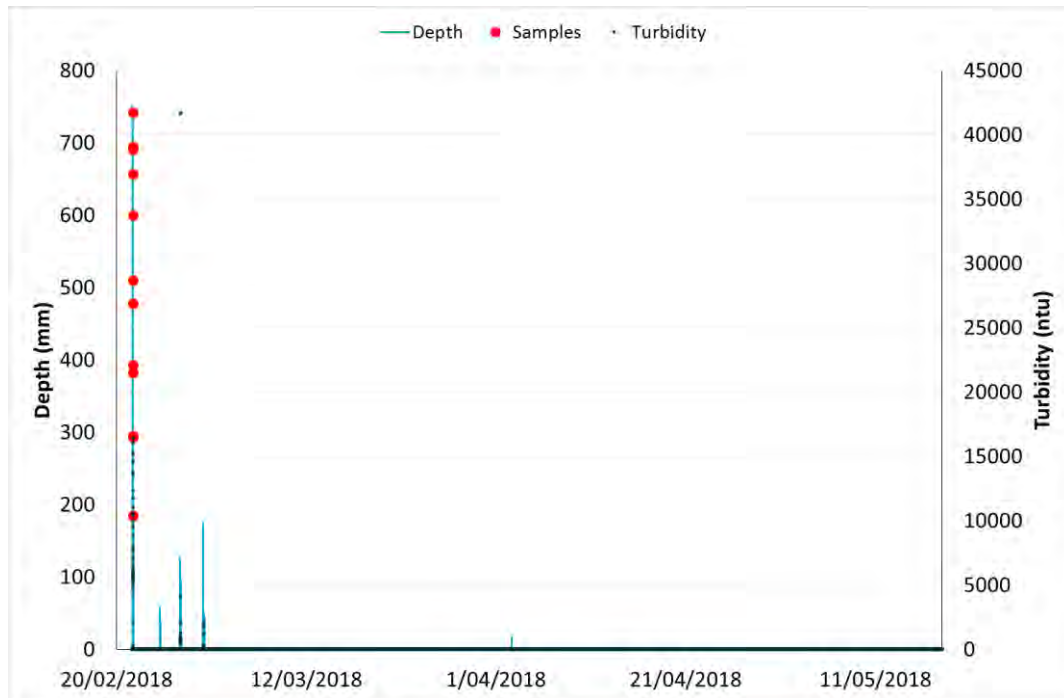


Figure 50: Mt Wickham Treatment gully runoff, turbidity and sample points on the hydrograph. Electronic issue prevented sample collection at this site for the first event. Sample marker where the sampler would have sampled.

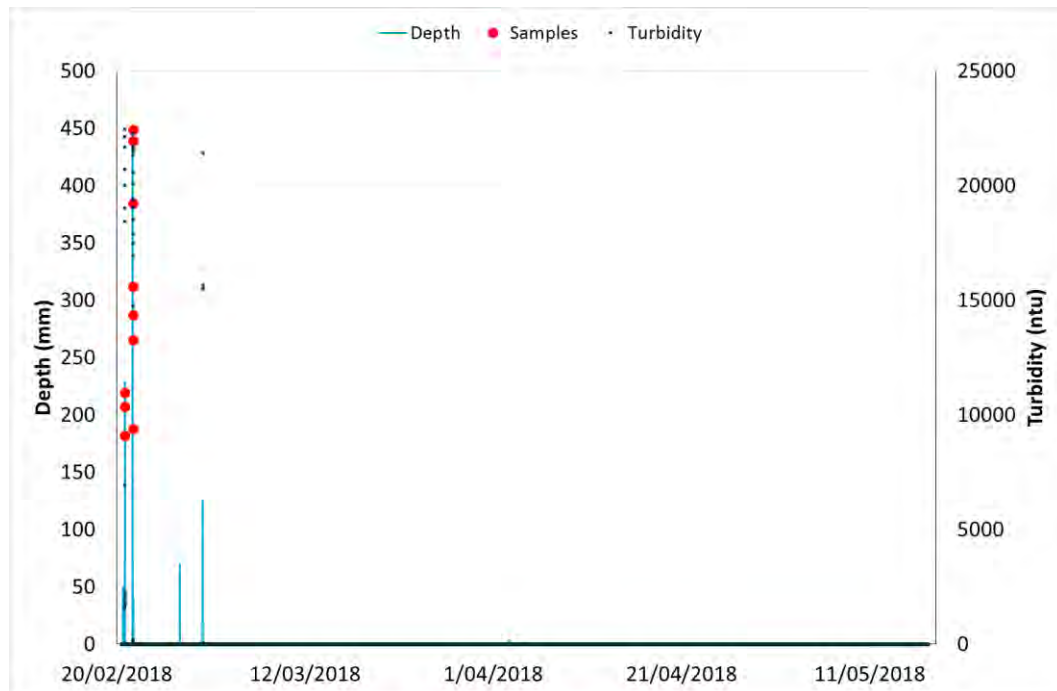


Figure 51: Mt Wickham control gully runoff, turbidity and sample points on the hydrograph.

