

Quantifying the effectiveness of gully remediation on water quality: preliminary results from demonstration sites in the Burdekin catchment (third wet season)

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Supported by the Australian Government's National Environmental Science Program
Project 5.9 Demonstration and evaluation of gully remediation on downstream water quality and agricultural production in GBR rangelands

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National Library of Australia Cataloguing-in-Publication entry:
978-1-925514-41-4

This report should be cited as:

Bartley, R., Hawdon, A., Henderson, A., Wilkinson, S., Goodwin, N., Abbott, B., Bake, B., Boadle, D., and Ahwang, K. (2019) *Quantifying the effectiveness of gully remediation on off-site water quality: preliminary results from demonstration sites in the Burdekin catchment (third wet season)*. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (111pp.).

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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ACRONYMS

BACI	Before, After, Compare, Impact
DEM	Digital Elevation Model
DOEE	Department of the Environment and Energy
EOD	End of the dry season
EOW	End of the wet season
GBR	Great Barrier Reef
Lidar	Light Detection and Ranging
LDC	Landholders Driving Change
NESP	National Environmental Science Program
NQDT	NQ Dry Tropics
P2R	Paddock to Reef
PCDs	Porous Check Dams
RRRC	Reef and Rainforest Research Centre Limited
RTK	Real Time Kinematic
TWQ	Tropical Water Quality
TLS	Terrestrial Laser Scanner
TSS	Total suspended sediment

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 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.

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

Kahlytah Ahwang assisted with the water quality sample collection and site maintenance.

Damon Telfer coordinated water quality sample collection for Mt Wickham, Strathbogie and Minnievale sites.

Barbara Colls managed the water quality sample collection project for Mt Wickham, Strathbogie and Minnievale sites.

Delwyn Windridge coordinated the remediation works at the Minnievale sites.

Matt Miles (previously Andrew Yates) coordinated the remediation works at Mt Wickham.

ACKNOWLEDGEMENTS

We would like to acknowledge the National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub, CSIRO and the Queensland Government for providing funding for this report. We would also like to acknowledge Glenn Dale of Verterra for supplying the Mt Wickham remediation report, and the numerous helpers at Fruition Environmental who assisted with water quality sample collection.

We would also like to thank the property owners for allowing access to their properties and involvement in the projects. Thankyou to Rob, Sue and Matt Bennetto, John Ramsay and Family, Darren Watts and Family, Barney and Juanita Gordon and Warren Woodhouse. Thankyou also to Dr Ben Jarihani (University of the Sunshine Coast) for reviewing an earlier version of this report.

REPORT OVERVIEW

This document represents the 2018/19 annual research report for NESP TWQ Hub Project 5.9 (Gully remediation effectiveness). The results from the first (2016/17) and second (2017/18) wet seasons were presented in Bartley et al., (2017) and Bartley et al., (2018). This report presents the cumulative results up to the 2018/19 wet season for control/treatment remediation projects on five different properties in the Burdekin catchment. This report is written as a stand-alone report, and therefore there is considerable repetition from previous reports.

A summary of the differences between the three NESP TWQ Hub monitoring reports are described in Table 1. This document presents the technical information from the field sites only. Information regarding other research collaborations, paper outputs, communication and indigenous engagement is described in a separate NESP TWQ Hub milestone administration report.

Table 1: Comparison information included in annual wet season reports for this NESP TWQ Hub project

	Data and information presented
First wet season (2016/17)	Historical Air photo interpretation of control and treatment gullies
	Review of remediation effectiveness from across the world
	Zebedee terrain scanning results
Second wet season (2017/18)	Inclusion of the new Landholders Driving Change Mt Wickham site
	New velocity sensors installed, and initial data analysed in anticipation of measuring flow discharge for constituent load estimation
	More detailed analysis of the nitrogen speciation at the various sites
	Comparison of hillslope vs gully TSS concentration and particle size data
	New site-specific soil data collected (and presented) for Strathbogrie, Minnievale and Mt Wickham
	Options for identifying high risk gullies at the catchment/property scale
Third wet season (2018/19)	First preliminary velocity data obtained for most sites
	First preliminary estimates of runoff, % runoff, sediment and total nitrogen loads at 10 sites.
	Preliminary 'report card' for each property to summarise the results

EXECUTIVE SUMMARY

Gully erosion contributes ~40% of the excess soil erosion to the Great Barrier Reef 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 catchment, however, in 2018, an additional property (Mt Wickham), containing alluvial gullies, was added to the analysis.

Gully erosion control on 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 was more intensive (and expensive) commensurate with the contribution of sediment from this source. Of the five properties being monitored, only four had active treatments installed prior to the 2018/19 wet season, however, one of the sites with active remediation now has nine 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 a treatment and control gully at each location. These monitoring 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 from the November 1st 2018 until April 30th, 2019, however, where appropriate data from all sampled wet seasons is presented.

Summary of monitoring results (for 2018/19)

- Most sites have shown some improvement in % cover or biomass following treatment implementation, however, gully catchment land condition at all sites remains in C or D class.
- The pasture species (at most sites) are primarily dominated by the exotic perennial grass Indian couch, forbs, and/or exotic legumes. Indian couch gives relatively poor infiltration compared to native perennial species, so measurable changes in runoff are not expected within five years.

- The 'fencing off only' remediation site (Meadowvale) has shown improved gully floor/channel vegetation biomass, which is increasing the sediment trapping potential of the site. In the 2018/19 wet season, sediment deposition in the treatment gully was 16%, compared to just 8% for the gully with no treatment.
- The sites that have had fencing and porous check dams installed (Virginia Park and Minnievale) are showing improvements in the vegetation metrics in the gully floor/channel and gully walls. This increased cover, in conjunction with the sediment check dam structures, resulted in 99% trapping of eroded material at Virginia Park in the 2018/19 wet season, and >100% trapping at Minnievale (more fine sediment was trapped than was estimated to be eroded from the gully). This suggests that the structures are also trapping some hillslope material.
- At the sites where the head-cuts have been fenced off for between 3-9 years, the annual gully head-cut retreat rates have declined.
- The larger scale remediation works (e.g. Mt Wickham) have resulted in improved vegetation metrics in the first full wet season of monitoring. There are also early indicators of improvements in total suspended sediment (TSS) concentrations following the major earth works at the treatment site. It is expected that at least one to two more wet seasons will be required to statistically quantify water quality improvements, and considerably longer to quantify load reductions.
- The Strathbogie site, which has basalt derived Vertosol soils, continues to have much higher head-cut retreat rates than gullies on other soil types. Two un-treated gullies at this site extended ~10 m and 28 m during the 2018/19 wet season.
- Net sediment yield from the gullies range from (a net deposition of) -0.07 tonnes per metres (t/m/yr) at the Minnievale treatment gully, to 2.58 t/m/y at Strathbogie which has no treatment.
- Like previous years, there is a strong ($r^2 = 0.87$) relationship between the average soil loss (t/m/y) and the drainage area above the gully head-cuts for non-treated sites. This relationship highlights that the catchment area above the gully head is a primary driver of erosion rate for these gullies. 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 ~41,800 mg/L. This gully has very highly sodic sub-surface soils. The other gullies had peak concentrations between ~3000 and ~9,000 mg/L.
- The total nitrogen (TN) values are highly variable between sites, and between events within sites, and not as responsive as sediment to remediation treatment. The total nitrogen (TN) concentrations follow a similar pattern to TSS when comparing the control and treatment sites. Although Mt Wickham has much higher TSS concentrations than the other sites, the TN values are generally not statistically different between 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, so that we can potentially reduce the runoff and sediment loss from all erosion sources, including hillslopes and streambanks.

Key management messages

- It is possible to improve gully floor vegetation biomass (and in some cases % vegetation cover) if a series of porous check dams (PCDs) are installed, and livestock is managed (but largely excluded) for >3 years.
- Gully head-cut erosion rates are much faster in basalt (vertisol) soil types. These sites also have relatively high sediment concentrations and fine particle sizes that can move long distances in the GBR Lagoon.
- Total suspended sediment (TSS) concentrations are very high in large alluvial gullies, but TN concentrations are similar to those in hillslope gullies.
- Early results suggest that alluvial gullies can be re-vegetated in relatively short (~12 month) time frames (given sufficient rainfall), and re-shaping appears to have reduced TSS concentrations. Structural treatments are likely to be important for stabilising these sites.

Key policy messages

- There is a lot of interest from landholders, Regional Bodies and all levels of Government to demonstrate that the investment in on-ground remediation in the GBR is making a difference. There is an assumption is that we have been doing this 'remediation' work for some time, and we should be able to see a result within one to two wet seasons. We have been modelling possible/potential responses for more than a decade, however, these are some of the first control/treatment field trials that are measuring multiple response indicators, including water quality. The key message is that this type of research will take time, at least 4 years for a well-designed experiment, and a lot of luck with respect to rainfall and instrumentation behaviour.
- This project has collected a range of indicators, including vegetation and terrain metrics, which are likely to show earlier changes to treatment than runoff, water quality and loads. These early indicator results can be used to help communicate the findings while we wait for the water quality results to become clearer. An example of the site response report card that has been developed for each site is shown in Table 2.

Recommendations for other remediation projects undertaking monitoring

- Due to the high variability in rainfall and site characteristics in these landscapes, whenever possible, measurements should be collected from both control and treatment sites for at least two wet seasons prior to remediation works being undertaken. This provides much greater statistical power to detect changes in shorter time frames.
- We need to be careful to balance the expectations related to wanting to measure a change in water quality and loads when choosing sites with landholders. Sites need to be as comparable as possible (e.g. the same soil, vegetation, rainfall, terrain, morphology,

instrumentation) otherwise it introduces additional bias into the statistical analysis that reduces the ability to detect a change.

- Where funding permits, use the same instrumentation at both control and treatment sites. Using cheaper cut down monitoring equipment reduces the number of samples collected and subsequently the statistical power to detect changes between the control and treatment sites is reduced.
- Measuring particle size of the sediment is very useful for determining the size of the sediment leaving a site. This is important, because finer sediment has a greater potential of reaching the GBR Lagoon. However, changes in particle size are unlikely to be a cost-effective measure of remediation effectiveness. The proportion of sediment that is trapped (stored) with the gully system is likely to be a better metric.

Over the next 12 months, this project will:

- Continue to monitor the control and treatment sites for a 4th (and final NESP funded) wet season.
- Update the runoff and TSS and TN loads estimates for all the sites by improving velocity estimates and rating curves.
- 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.
- Draft peer reviewed journal publications describing these results.

Table 2: An example of the site summary report card that was developed for each site. This represents a summary of the treatment effects at the Mt Wickham site (1 year of treatment data). **Green** suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. A **red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. Na means data not yet available.

TREATMENT: Major earth works, rock chutes and revegetation.		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %			There are some pre-treatment data for the treatment and control sites, however, there was insufficient pre-treatment flow data to complete all analysis.
	Hillslope biomass (kg/ha)			
	Gully floor/channel – cover %			
	Gully floor/channel – biomass (kg/ha)			
	Gully walls – cover (%)			
	Gully walls – biomass (kg/ha)			
Terrain/erosion	Erosion (t/m/y)	na	na	
	Deposition (t/m/y)	na	na	
	Net change (t/m/y)	na	na	
Runoff, water quality and loads	TSS conc. from samples (mg/L)			
	TN conc. from samples (ug/L)			
	TSS Loads (t/ha)			
	TN Loads (kg/ha)			
	TSS - Flow adjusted annual mean conc. (FAAMC) (mg/L)			
	TN Flow adjusted annual mean conc. (FAAMC) (ug/L)			
	Runoff (mm)	na		
	% Runoff	na		

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., (2019) 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 third wet season of analysis for NESP TWQ Hub Project 5.9 June 2019 milestone. The study sites are 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 and Fruition Environmental.

2.0 EXPERIMENTAL DESIGN

2.1 General approach

In this study, we use an adaptive monitoring framework like 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.

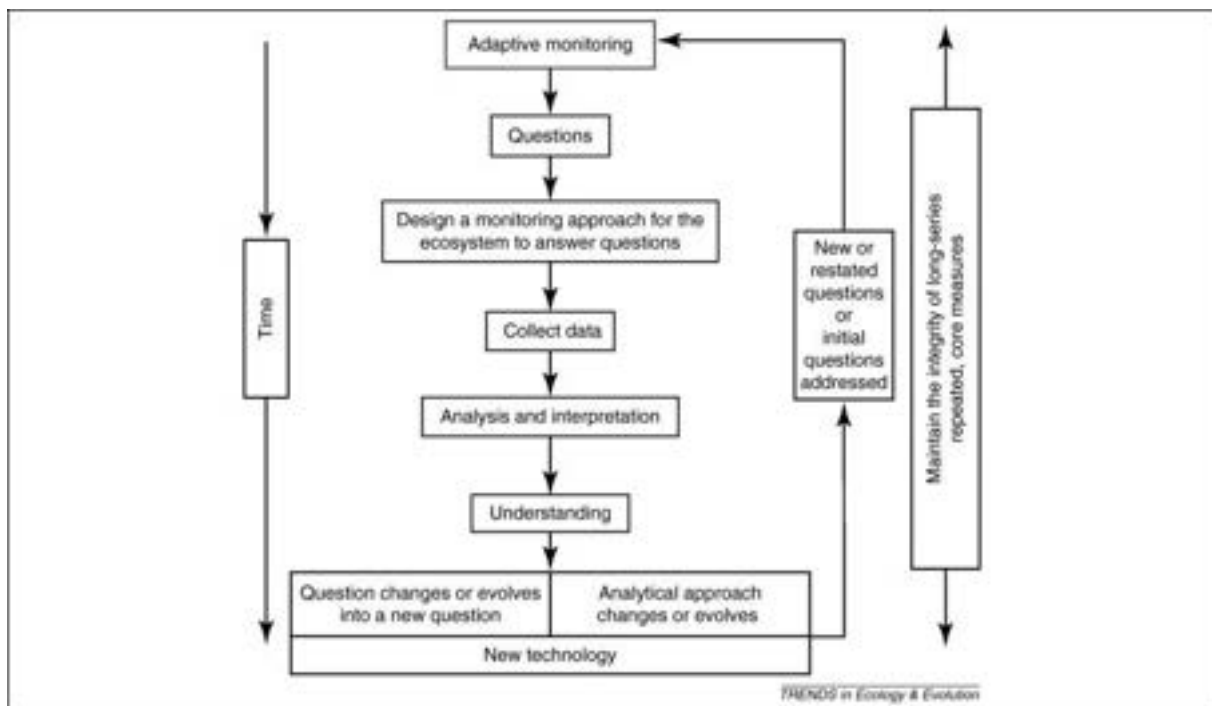


Figure 1: The adaptive monitoring framework implemented in this study (Lindenmayer and Likens, 2009)

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 TWQ Hub report). The evidence from these published studies highlights that although gully remediation can be effective, there is also significant risk associated with gully remediation, with many studies having a 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 some of these options on runoff and sediment/nutrient losses are described in Figure 2 and Table 3.



Figure 2: Conceptual model of the outcome of various treatment options within a gully (Wilkinson et al., 2019).

Table 3 outlines the conceptual framework used to capture the various ‘effectiveness’ measures used in this study. As erosion control techniques affect gully sediment yield through a range of processes, and the project objective is to advance the understanding those processes as well as the effect on sediment yield, we are following a multiple lines of evidence approach. Table 3 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. Noting that contextual variables are also monitored, including rainfall, vegetation composition and soil properties.

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 a reduction in the rate of erosion and the concentration of the sediments (and particulate nutrients) leaving the site. Finally, in the longer term, if catchment vegetation condition improves considerably, we expect to see a change in % runoff. 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 3: The range of gully remediation treatment options, expected outcomes and measurement metrics. The number of √'s represents the relative magnitude of expected response.

<i>Treatment</i>					Stock management, controlled grazing on hillslopes	Ripping, seeding and re-vegetation of hillslope	Fencing off gullies and stock removal	Porous structures within gully	Solid within gully structures
<i>Expected Outcome or Objective</i>				Likely time frames of response	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.
<i>Indicator or response variable</i>	<i>Metric</i>	<i>Specific Attribute</i>	<i>Measurement technique</i>						
<i>Primary</i>	Vegetation cover and biomass	Hillslope cover and biomass	Surveys of cover and biomass on the hillslopes above the gully	Between 3-10 years [linked to rainfall/climate cycle and pre-existing land condition]	√√	√			
		Gully wall and floor cover and biomass	Surveys of cover and biomass within the gully		√		√√	√√	√√
<i>Secondary</i>	Within gully erosion (t)	- Head-cut erosion - Wall erosion or deposition	DEMs of Difference using the TLS (erosion) * bulk density	Could be relatively rapid (e.g. 1-2 years) for engineering works. Longer time frames (e.g. >5 years) for more passive treatments	√	√	√		
		- Floor erosion or deposition					√√	√√√	√√√

	Improved water quality	- Sediment conc. (mg/L) - Nutrient conc. (mg/L) - Particle size	Samples collected during events across the hydrograph	From 4 to 20 years to confidently detect the effects (Melland et al., 2018)	√	√	√√	√√√	√√√
Tertiary	Reduced runoff (mm) or rainfall – runoff coefficient (%)	Hillslope runoff	Hillslope Flumes and runoff troughs e.g. Virginia Park and Meadowvale	Likely similar to above	√	√√			
		Within gully runoff	Discharge based on depth and velocity in gullies				√	√√	√√√
Evidence					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 also (McIvor et al., 1995; Silburn et al., 2011)	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 catchment 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.

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 4). The soil types do vary, with Strathbogie residing on granite lithology with a valley fill of basalt-derived soils (Figure 3 and Figure 4). Virginia Park and Meadowvale are on granodiorite lithology with soils dominated by Red Chromosols and Yellow to Brown Sodosols with dispersive B horizons (Rogers et al., 1999; Roth, 2004). Minnievale is also on granodiorite lithology with soil 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 mean annual 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 4). The gully treatment options used at each of the sites are described in Section 3.3.

Table 4: Description of the five study sites (Virginia Park, Meadowvale, Strathbogrie, Minnievale and Mt Wickham).

Property	Virginia Park	Meadowvale	Strathbogrie	Minnievale	Mt Wickham
Management Unit (sub-catchment)	Upper Burdekin	Upper Burdekin (and Haughton)	Bogie	Don	Bowen
Local stream name and size	Treatment and Control both on Weany Creek (1400 ha)	Treatment in headwaters of Haughton river (1400 ha), Control on Wheel Creek (1000 ha)	Treatment and Control both on side arm (1300 ha) of Capsize Creek	Treatment site on Mary Creek (1500 ha) Control site on Side arm of Four Mile Creek (1400 ha)	Treatment (3.03 ha) and Control 14.14 ha) sites both drain into Sandalwood Creek which connects with the Bowen river
Size of property (ha)	~7000 ha	~3000 ha	~39,000 ha	~3750 ha	~7790 ha
Soils	Red Chromosol	Red Chromosol	Black Vertosol	Sodic Hypocalcic Red Dermosol	Hypernatric Brown Sodosol
Geology	Granite and Granodiorite	Granodiorite	Granite, Basalt	Granodiorite	Granite and Granodiorite
Terrain (% slope property)	2-3%	2-3%	6-7% (due to high relief in south)	3-4%	10%
Average annual Rainfall (mm)	~ 660 mm	~ 680 mm	~ 750 mm	~ 880 mm	~ ~600 mm
Vegetation over-story	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood	Widely spaced Narrow-leaved Ironbark and Bloodwood + 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	-19.8916, 146.5127	-19.8389, 146.5910	-20.2214, 147.5566	-20.1934, 148.0720	-20.4624, 147.4019
Lat Long Control Gully	-19.9029, 146.516	-19.8288, 146.5882	-20.204, 147.5581	-20.1943, 148.0776	-20.4650, 147.4071

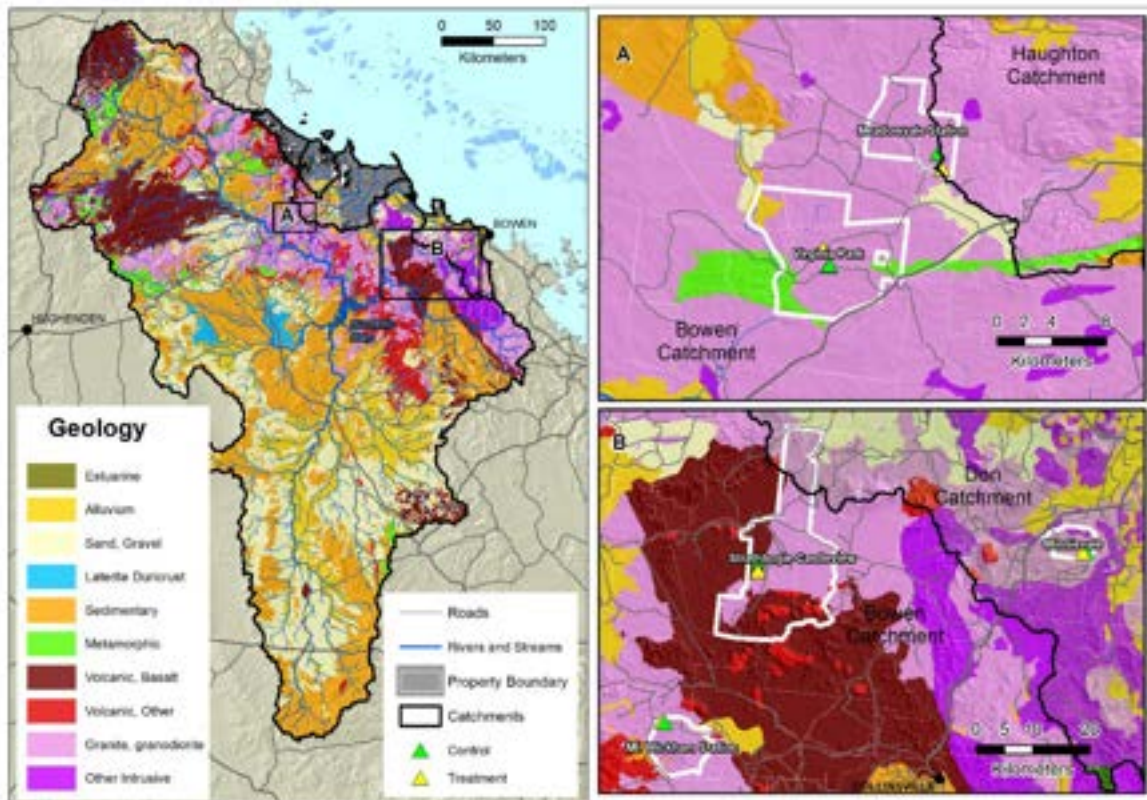


Figure 3: Underlying geology at each of the trial properties (Source: GeoScience Australia)

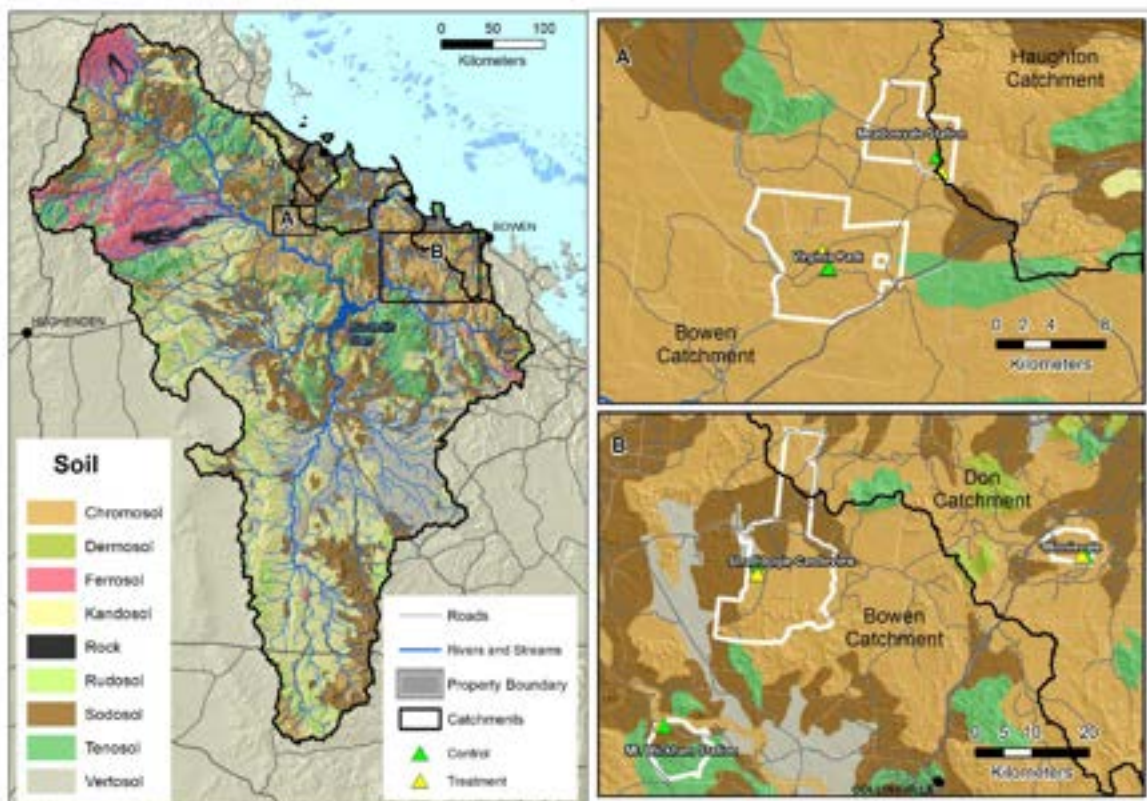


Figure 4: Underlying soil type at each of the properties (Source: Atlas of Australian Soils)

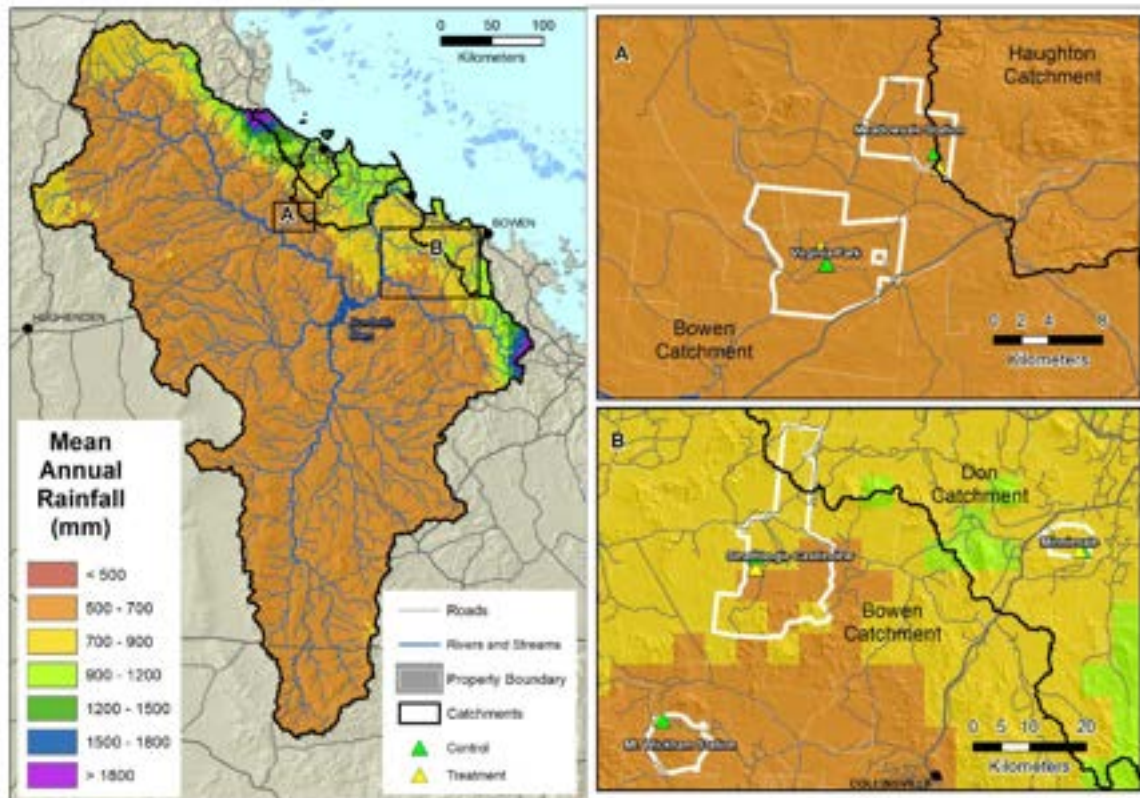


Figure 5: Rainfall distribution for each of the properties. Mean annual rainfall from ~100 years of daily records (Source: SILO 5 km grid)

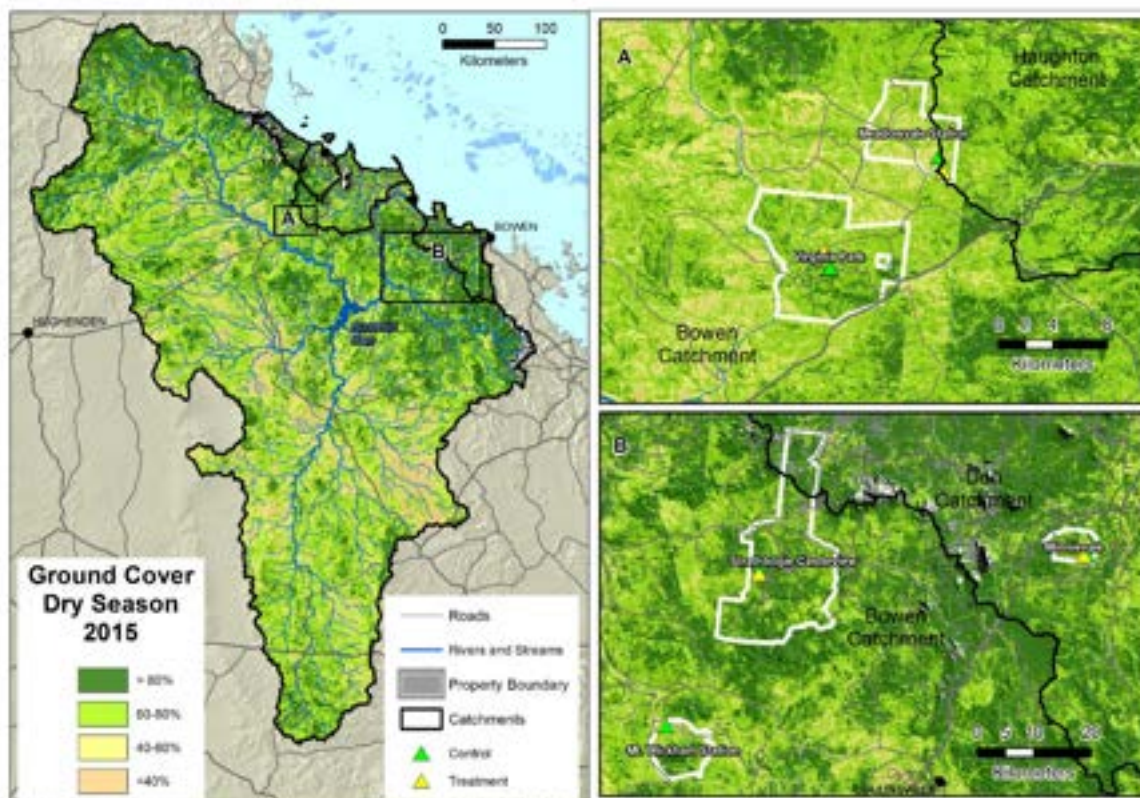


Figure 6: Total ground cover for each of the properties (Source: Queensland Government fractional ground cover product from 2015)

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 Mt Wickham, 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 5 and Figure 7. Remediation plans have been prepared for Strathbogie and are planned for installation during the dry season in 2019. Diagrams showing the locations of the treatments and associated measurement infrastructure are presented in Section 5.0.

Table 5: 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
Wet season resting from stock in paddock upslope	√	NA	NA	√	NA
Stock exclusion/reduction	√	√	√	√	√
Retention structures on gully bed	√ n = 5 stick traps	NA	TBA	Total n = 200 porous check dams	Yes, proposed
Hillslope treatment	Yes, disc plough above the treatment gully	Yes, ~30% of catchment has long term exclusion	TBA	Ripped (with narrow boot, sprayed and seeded)	Yes, significant earth works, soil treatment and chute structures
Hillslope flow diversion	NA	NA	TBA	NA	Yes, significant re-contouring
Active revegetation with seed	NA	NA	?	e.g. Creeping blue grass, R.Rhodes, V8 stylo	Yes, significant re-vegetation
Alternative stock watering points	NA	NA	√	√	
Source of funding for the treatment	Paddock to Reef	NESP TWQ Hub	Potentially LDC (formerly Reef Trust)	Reef Trust	LDC

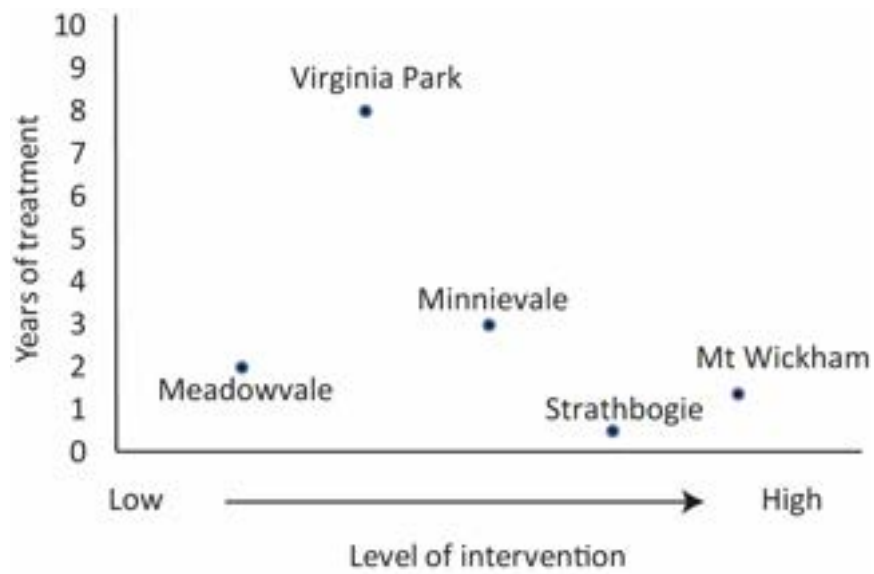


Figure 7: The length of treatment (years) relative to the intensity of intervention. Low level of treatment at Meadowvale represents fencing off only. The high level of treatment at Mt Wickham is mine site scale rehabilitation. Note that the Strathbogie remediation works will be installed during the dry season in 2019.

4.0 METHODS

4.1 Vegetation and pasture metrics

Vegetation metrics were measured on the hillslope above each of the NESP TWQ Hub gullies at the end of the dry season ('EOD', October–November) and then again at the end of the wet season ('EOW', April). Measurements were initiated in November 2016 at all sites except Mt Wickham which started in August 2018. Landscape and vegetation condition transects were installed upslope of the uppermost head section on both the treated and control gullies at all sites (Figure 8). 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. Sampling was initiated at the end of the first wet season (April 2017) for all sites except Mt Wickham which started in August 2018. 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 0.25 m² (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. Box plots of the % cover and biomass data at the end of each wet season for control and treatment sites were analysed using Sigmaplot Version 14. In most cases a t-test for means and non-parametric Mann-Whitney rank sum test were conducted to evaluate differences between treatment and control sites.



(A)

(B)

Figure 8: Example of vegetation sampling for % cover and biomass on (A) the hillslopes above the gullies and (B) on the gully floor/channel.

4.2 Gully erosion – terrain analysis

Terrain mapping of the NESP TWQ Hub 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 ($<63\ \mu\text{m}$) and coarse ($>63\ \mu\text{m}$) 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, Meadowvale and Mt Wickham, and the Shuttle Radar Topography Mission (1 Arc Second, SRTM) (Gallant et al., 2011) derived DEM was used at Strathbogie and Minnievale. A number of surveying techniques were used to capture terrain data in this study.

(i) 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 $\pm 12\text{mm}$ in the horizontal plane and 15mm in the vertical. The slope of the gully bed was surveyed by traversing the entire length of the gully collecting survey points along the deepest part of the channel and identifying key locations such as head-cuts and instrumentation. Cross sectional profiles were also surveyed at representative sites within each reach, and at 5 m intervals adjacent to the instrumentation.

(ii) 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 (drone based?) 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.

(iii) 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 5 cm 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). Bulk density data was collected at each field site and was used to convert erosion volumes into tonnes of sediment. Values ranged from 1.35 to 1.85 t/m³.

(iv) Hand held terrestrial laser scanning trial - Zebedee

Additional survey data was acquired on a trial basis during site visits using a hand-held laser scanner (Zeb-REVO). However, converting zeb-REVO data into quantitative terrain data is outside the scope of this project. We include crudely georeferenced Zeb-REVO terrain data in the site location maps only as it provides additional context.

4.3 Velocity and runoff

An automatic monitoring station was installed at each of the treatment gullies (Figure 9A). 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 9B). Data from both the treatment and control sites had telemetered communications to allow remote access of data.

Obtaining discharge and velocity measurements were one of the most challenging aspects of this project so far. During the NESP study we have undertaken the following approaches to estimate discharge:

- **Wet season 1 (2016/17):** Hec-RAS modelling was applied at all sites, but it was considered not suitable without measured velocity data to constrain modelled estimates;
- **Wet season 2 (2017/18):** given the modelling didn't work, low cost (~\$2k each) Unidata Starflow QSD ultrasonic doppler sensors were 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. Unfortunately, the manufacturer supplied settings didn't provide measured water velocity in natural environments and no data were collected that season. The sensors require reconfiguration from factory default settings to capture data in gully systems.
- **Wet season 3 (2018/19):** the settings in the velocity sensors were corrected and velocity data was collected from 9 out of 10 NESP TWQ Hub sites (the only site without velocity data didn't flow). However, the quality of the data is highly variable between sites and currently our load estimates have high uncertainty.
- **Wet season 4 – next year (2019/20):** The same Starflow ultrasonic Doppler velocity sensors will be installed at the LDC sites, however, two (\$7k, research grade acoustic Doppler IQ) sensors have been purchased, through CSIRO funds, to calibrate and test the Starflow sensors. These will be installed beside the Starflow sensor at a site to obtain robust rating curves (most likely Mt Wickham and Strathbogie). Once obtained, the IQ will be moved to another site. This may take several wet seasons. Ideally, we would have the more expensive instruments at all sites but is generally cost prohibitive.



(A)



(B)

Figure 9: (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 including total nitrogen (TN), total dissolved nitrogen, NH_3 , NO_x , total phosphorus (TP), total dissolved phosphorus and filterable reactive phosphorus (FRP) at the JCU TropWater Laboratory, Townsville. Samples that were not collected within 24 hours were analysed for TSS, and in some cases TN and TP. 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 .

Samples collected were checked for quality control and some samples were removed when scrutinised due to equipment malfunction or damage. To test for a difference between water quality sample results between control and treatment sites, Student's t-test were applied when the data were normally distributed. When the data was not normally distributed, non-parametric Mann-Whitney rank sum test was applied.

4.5 Loads estimates

To estimate loads of suspended sediment (TSS) and total nitrogen (TN) the following steps were undertaken:

- (1) Depth, velocity and RTK surveyed cross-sectional area data were used to generate a stage-discharge rating curve for each site;
- (2) Linear relationships between TSS and TN sample concentrations and coincident turbidity data were derived for all sites (Table 6). Turbidity data was not used when (i) the instrument exceeded the instrument calibration threshold; (ii) turbidity sensor readings were erroneous due to damage or sensor malfunction, or when the sensors were buried. These relationships allowed for estimation of TSS and N from turbidity.

When there was no turbidity data (due to sensor issues or instrument burial), TSS and TN concentrations were infilled using sample interpolation.

- (3) Total suspended sediment (TSS) and total nitrogen (TN) loads were then generated for each event and each water year (generally Nov to April) by multiplying discharge by concentration.
- (4) For all sites flow weighted annual average mean concentrations (FWAAC) were generated by dividing the annual load by annual runoff. This provided a quick visual assessment of the relative change in concentration between sites.
- (5) For some sites (i.e. Mt Wickham) event mean concentrations (EMCs) were generated for individual events by dividing the event load by event runoff. This provided a flow weighted mean concentration for each event. The event mean concentration (EMC) value for each event and year was calculated using mass of the sediment (in tonnes) divided by the runoff volume (in ML) during the time interval (T) (after Kim et al., 2004).

Noting that we have not yet dealt with sampling error or uncertainty in the discharge and load calculations which can be high in semi-arid systems (Kuhnert et al., 2012).

Table 6: Turbidity-TSS and Turbidity- TN relationships for each site.

Property	Gully	Years of data	Turbidity -TSS	Turbidity- TN
Virginia Park	Control	3	$y = 3.3665x - 920.38$, $R^2 = 0.7978$ (n=11)	$y = 1.9008x + 960.55$, $R^2 = 0.6381$ (n=4)
	Treatment	3	$y = 0.8793x + 23.719$, $R^2 = 0.9084$ (n=69)	$y = 0.5507x + 1093.8$, $R^2 = 0.5539$ (n=30)
Meadowvale	Control	3	$y = 1.0946x + 180.78$, $R^2 = 0.836$ (n=7)	$y = 6.4349x - 888.73$, $R^2 = 0.9433$ (n=5)
	Treatment	3	$y = 1.8895x - 243.41$, $R^2 = 0.8656$ (n=70)	$y = 1.2516x + 684.63$, $R^2 = 0.7718$ (n=30)
Strathbogie	Control (SBT)	3	$y = 0.8852x + 279.62$, $R^2 = 0.8347$ (n=7)	$y = 0.8276x + 23.057$, $R^2 = 0.9998$ (n=3)
	Treatment (SBT2)	3	$y = 1.2037x + 271.4$, $R^2 = 0.6298$ (n=11)	$y = 1.5332x + 368.44$, $R^2 = 0.9999$ (n=3)
Minnievale	Control	3	$y = 2.5555x - 2738.6$, $R^2 = 0.7498$ (n=7)	$y = 7.1229x - 9263.8$, $R^2 = 0.4119$ (n=4)
	Treatment	3	$y = 1.0997x + 129.92$, $R^2 = 0.7781$ (n=30)	$y = 2.9022x - 523.96$, $R^2 = 0.7125$ (n=12)
Mt Wickham	Control	2	$y = 3.3193x - 8900.7$, $R^2 = 0.9073$ (n=15)	$y = 0.5546x + 3.2406$, $R^2 = 0.7694$ (n=15)
	Treatment	1	$y = 3.0879x - 1175.3$, $R^2 = 0.8911$ (n=45)	$y = 0.6862x + 2310.3$, $R^2 = 0.685$ (n=26)

4.6 Development of a remediation site report card

In a review by Melland et al., (2018) positive water quality effects were measured in 17 out of 25 reviewed studies of agricultural management improvement, with positive effects occurring from 1 to 10 years after the measures were implemented, however, it took from 4 to 20 years to confidently detect the effects for catchments between 1 and 100 km². The response time broadly increases with catchment size. It is also particularly challenging in areas of GBR catchments that have very high rainfall variability as “the change required to identify a statistically significant change in the mean is directly proportional to the interannual variability, and less dependent on the length of data available. The interannual variability of Australian streams is twice that of Northern Hemisphere streams, therefore, a greater change is required

in Australian flow volumes before a statistically significant change can be identified” (Chiew and McMahon, 1993).

Due to the challenges and long time frames involved in measuring improvements in water quality following gully remediation, several studies use other alternative measurements such as the proportion of sediment stored behind check dam structures (Heede, 1979; Hevia et al., 2014; Borja et al., 2018), however, the time frames to quantify improvement using these approaches can be just as long (generally decades). Of the studies that have demonstrated an improvement in water quality, they generally had the following attributes:

- **Control sites paired with treatment sites.** We have that at the NESP and LDC sites.
- **Before data or baseline data (often at least 2 years of baseline data) at both control and treatment sites** (Bishop et al., 2005; Ali et al., 2017; Carvin et al., 2018; Singh et al., 2018). We rarely have that due to funding timelines and the urgency to demonstrate an effect; but ironically, without baseline (before treatment) data it is very difficult (or takes longer) to quantify a treatment effect. We have some baseline data at a few sites (e.g. Strathbogie and a small amount at Mt Wickham), but not at other sites.
- **Constituent loads data which requires robust measurements of discharge (Q) estimates and water quality concentrations.** Obtaining reliable discharge data has been challenging at many sites. Often long (> 10 year) trends of runoff data are required to reliably detect statistical changes in loads (e.g. Rustomji et al., 2008).
- **In many of the studies, they only compared coincident events between control and treatment sites** and removed non-paired events (e.g. Bishop et al., 2005). This means that treatment and control sites should be located as close to each other as possible so that rainfall (and hopefully) runoff conditions are similar.

It is very difficult to obtain control and treatment sites in natural or agricultural settings that are going to have exactly the same physical characteristics. Where-ever possible, treatment and control sites should have the same soil type and vegetation. However, when selecting sites, issues such as landholder input and the suitability of sites for monitoring equipment installation and access often take precedence over choosing areas with equal drainage area and topography (slope). There are always subtle differences in the amount of rainfall received between control and treatment sites, hence runoff volumes will vary even in the absence of treatment.

Acknowledging some of the challenges associated with detecting a statistically significant change in water quality from remediation, a preliminary remediation response ‘report card’ has been developed to help demonstrate if there have been improvements in the ‘early’ indicators (e.g. vegetation response) (see Table 7). The report card also highlights the different data analysis approaches that can be used, acknowledging that the most robust design includes a baseline measurement period at both the control and treatment sites prior to remediation (BACI, two way ANOVA). In some cases, this approach will not be possible, so less robust, but still valid comparisons of control and treatment data (using t-tests) are also provided.

In this 2018/19 wet season report, a summary report card has been developed for each of the five properties in this trial. This is considered a useful tool for summarising and communicating the large amounts of data that has been collected at each site.

Table 7: Summary of the treatment effects (Fencing and PCD's) at the XX site (3 years of treatment data).

Green suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. **na** means data not yet available.

TREATMENT: XX		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover			
	Hillslope biomass			
	Gully floor/channel – cover			
	Gully floor/channel – biomass			
	Gully walls - cover			
	Gully walls - biomass			
Terrain/erosion	Erosion			
	Deposition			
	Net change (m ³)			
Runoff, water quality and loads	TSS conc.			
	TN conc.			
	TSS Loads			
	TN Loads			
	TSS EMC			
	TN EMC			
	Runoff (mm)			
	% Runoff			

5.0 RESULTS – COMBINED FOR ALL FIVE SITES

5.1 Landscape condition and vegetation metrics

Table 8 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 in three years of monitoring (see Bartley et al., 2017). At all properties, land condition improved across the wet season, with the most notable change in 2018/19 at Mt Wickham (treatment) which shifted from 100% of land in D condition pre-wet season to 78% of land in C condition at the end of 2018/19 wet season.

A summary of the vegetation and pasture metrics for the hillslope above each of the treatment and control gullies for 2018/19 is Table 12. Details of the measured changes in hillslope % cover and biomass are given in the results section for each property (see Section 6).

Table 8: A, B, C, D Land condition classification for each of the properties in this study (pre and post 2018/19 wet season)

	Landscape condition (%)			
	A	B	C	D
Virginia Park				
Treatment: pre-wet (Nov 2018)			43	57
Treatment: post wet (April 2019)			24	76
Control: pre-wet (Nov 2018)			23	77
Control: post wet (April 2019)			47	53
Meadowvale				
Treatment: pre-wet (Nov 2018)		1	35	64
Treatment: post wet (April 2019)		1	44	55
Control: pre-wet (Nov 2018)				100
Control: post wet (April 2019)			32	68
Strathbogie				
Treatment: pre-wet (Nov 2018)			6	94
Treatment: post wet (April 2019)			50	50
Control: pre-wet (Nov 2018)			9	91
Control: post wet (April 2019)			17	83
Minnievale				
Treatment: pre-wet (Nov 2018)			20	80

Treatment: post wet (April 2019)			43	57
Control: pre-wet (Nov 2018)			36	64
Control: post wet (April 2019)			32	68
Mt Wickham				
Treatment: pre-wet (Nov 2018)				100
Treatment: post wet (April 2019)			78	22
Control: pre-wet (Nov 2018)				100
Control: post wet (April 2019)			9	91

5.3 Current rates of gully erosion: terrain analysis

The gully head retreat rates for the last three wet seasons are presented in Table 9, and the average erosion, deposition and net change in the volume of sediment for each gully for the study period are presented in Table 10. The terrain analysis imagery is presented separately for each site in Section 0. 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 terrain analysis for the Mt Wickham site is not part of the NESP TWQ Hub project.

Note that the length of gully scanned using the TLS is slightly different at each gully (Table 10). Therefore, the average TLS measured erosion rate has been normalised to tonnes of soil lost per metre of gully length scanned using the TLS (t/m/y) (Figure 11 and Table 10). This makes it more appropriate to compare the relative amounts of soil lost between treatment and control sites, however, caution is needed when extrapolating these results to other gullies as they represent a combination of head-cut and sidewall erosion which will be the most active part of the gully.

The results demonstrate that the head-cut retreat (m) and erosion rate (t/m/y) is highest at the Strathbogie site with ~28 m of head-cut movement and 2.58 t/m/y sediment loss. At the Strathbogie property, there is currently no treatment in place, therefore this result highlights the natural variability in erosion rates that can occur between gullies in the same landscape (9.65 m – 28.06 m; Table 9).

Like previous years, there is a strong relationship between the average erosion rate and the drainage area above the gully head-cuts for non-treated sites ($r^2 = 0.97$ for t/y or $r^2 = 0.87$ for t/m/y; Figure 10 and Figure 11). This relationship highlights that the catchment area above the gully head is a primary driver of erosion rate for these gullies.

Table 9: Gully head-cut retreat rates over the three wet seasons using the RIEGL Terrestrial laser scanner.

Property	Gully	Gully head-cut retreat (m)			Average annual movement over measurement period (m)
		2016/17	2017/18	2018/19	
Virginia Park	Control	0.35	0.36	0.2	0.30
	Treatment	0.46	0.34	0.19	0.33
Meadowvale	Control	na	0.71	0.90	0.81
	Treatment	na	na	0.73	0.73
Strathbogie	Control (new)	0.75	1.76	9.65	4.05
	Treatment (new)	18.10	7.80	28.06	18.00
Minnievale [#]	Control	0.84	0.48	1.16	0.83
	Treatment	0.50	0.10	0.11	0.24

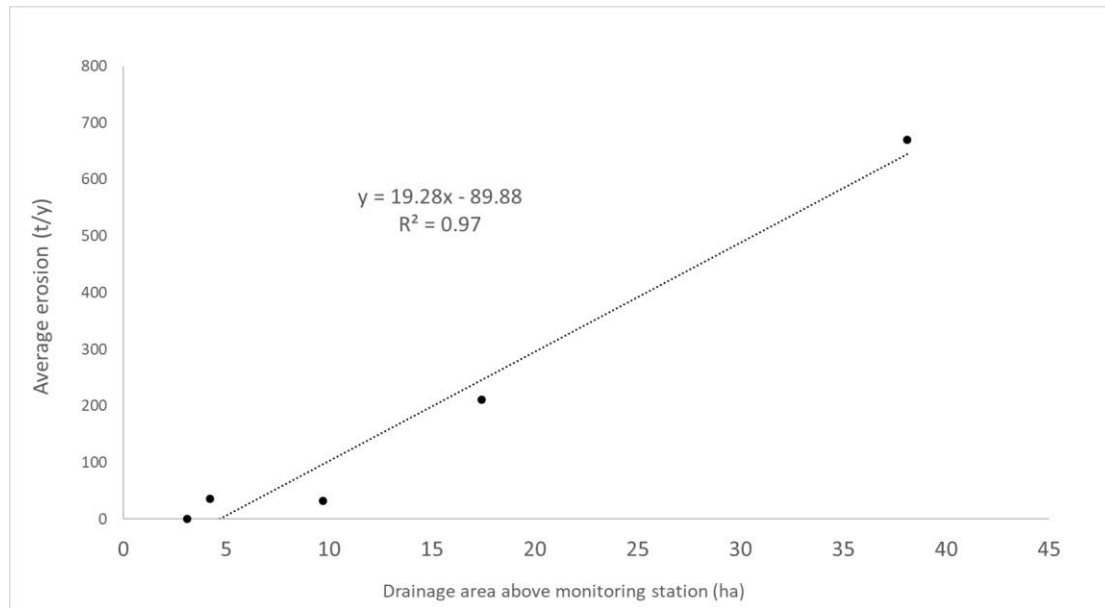


Figure 10: Relationship between upslope gully catchment area (ha) and the annual average TLS measured erosion rate in tonnes per year (t/y). The results are based on the combined wet season periods (2016 - 2019) for all control (un-treated) gully sites. Note that the scanned areas differ slightly between sites, and the t/yr represents the erosion from the head-cut and some gully walls (depending on the length of the scan). These data represent the absolute amount of erosion from each site.

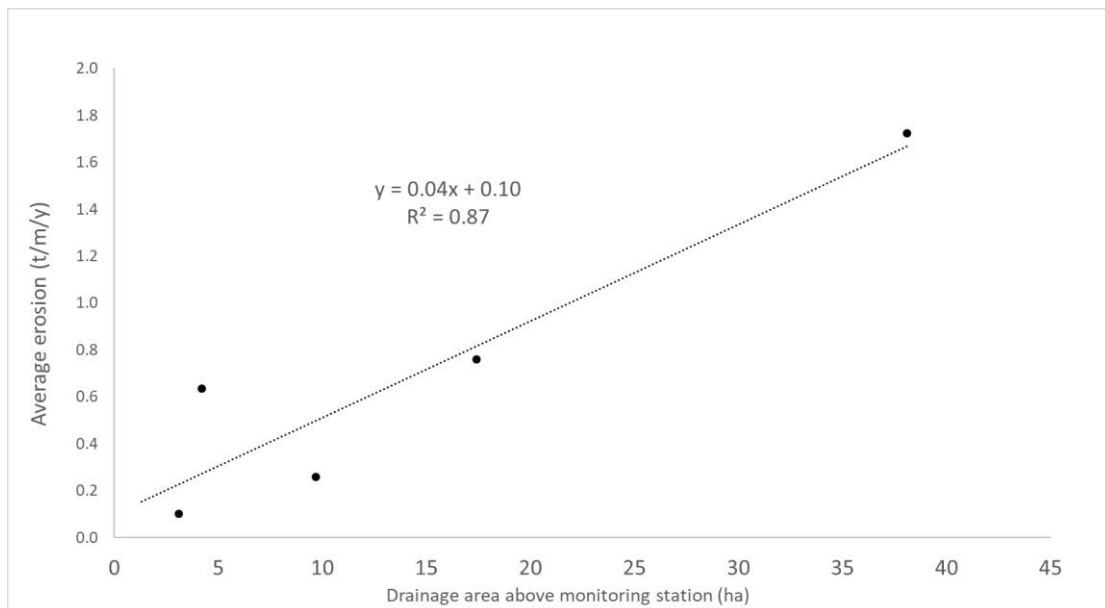


Figure 11: Relationship between upslope gully catchment area (ha) and the annual average TLS measured erosion rate in tonnes per metre scanned per year (t/m/y). The results are based on the combined wet season periods (2016 - 2019) for all control (un-treated) gully sites. Different gullies had different scanning lengths (see Table 10), so this metric (t/m/y) normalises the data and makes the results comparable between sites.

Table 10: Annual average gully volumetric change results using the RIEGL Terrestrial laser scanner. The U_{crit} threshold for defining erosion/deposition was set as 0.1 m at all sites (except Meadowvale where it was 0.15-0.3). Note instrument malfunction reduced the years of survey at Meadowvale. Catchments are estimated from best available regional terrain data: a = 0.5-1 m Lidar DEM, b = 30 m Shuttle Radar Topographic Mission DEM.

Property	Gully	Bulk density (t/m ³) derived from measurements above the control gully	Catchment area (ha) upslope of instruments	Years of data represented at each site	Length of gully surveyed with the TLS in 2019 (m)	Normalised sediment eroded per gully length surveyed (t/m/yr)	Normalised sediment deposited per gully length surveyed (t/m/yr)	Net change of sediment (t/m/yr). Negative numbers = deposition	Deposition as a proportion of erosion (%)
Virginia Park	Control	1.66	3.1 ^a	3	27.46	0.10	0.01	0.09	7%
	Treatment		1.3 ^a	4	58.52	0.12	0.12	0.00	99%
Meadowvale	Control	1.5	4.2 ^a	2	28.2	1.27	0.10	0.59	8%
	Treatment		5.0 ^a	1	138.00	0.13	0.02	0.11	16%
Strathbogie	Control (SBT)	1.27	17.4 ^b	3	92.20	1.14	0.10	1.04	9
	Treatment (SBT2)		38.1 ^b	3	129.50	2.59	0.01	2.58	<1%
Minnievale	Control ^b	1.5	9.7	3	41.20	0.26	0.09	0.17	35%
	Treatment ^b		21.2	3	27.20	0.15	0.22	-0.07	>100%

5.2 Rainfall, velocity and runoff

The 2018/19 wet season was an above average rainfall year at most sites which exacerbated some of the challenges in obtaining reliable depth, velocity and water quality data at a site. During this study, the project had challenges with (i) sensor malfunctions (ii) sensor burial and re-scour (iii) sensors being damaged by moving objects (iv) green ant nests in sensors and (v) wires chewed by livestock. Despite these challenges, this was the first year we had usable velocity data at most of the sites (Table 11). The rainfall and hydrographs for the wet season for each site are presented in Appendix A. We were able to obtain preliminary discharge and sediment and total nitrogen loads for all sites (except Virginia Park control site). The rating curves derived from the 2018/19 data were then used to back calculate discharge and loads for previous years, however, some years have very poor data (see Appendix B). We anticipate that the 2019/20 wet season data will improve these estimates.

A summary of the rainfall, runoff, water quality and loads data for the 2018/19 wet season (November 1, 2018 to April 30, 2019) for each of the sites is presented in Table 12. **All runoff and loads data presented in this report is considered preliminary and it will likely change in subsequent reporting years.**

Table 11: Summary of progress with velocity data for the 2018/19 wet season

Site	Event Threshold	% of event records with Velocity data	% of event records with usable Velocity data	Full depth profile represented in Velocity data	Depth vs Discharge relationship available after one wet season
Virginia Park - Control	300	0%	0%	No	Data un-reliable
Virginia Park – Treatment	210	33%	33%	Yes	<i>Good</i>
Meadowvale - Control	120	19%	11%	Yes	Discharge is a rough estimate
Meadowvale - Treatment	120	88%	56%	No	Ok, but not the full range of depths
Strathbogie – Control (SBT)	300	53%	24%	No	Discharge calculated, but low
Strathbogie - Treatment (SBT2)	120	92%	90%	No	Discharge calculated, but low
Minnie Vale – Control	100	100%	100%	No	Low discharge, only one event.
Minnie Vale – Treatment	100	57%	38%	Yes	Low discharge
Mt Wickham – Control	200	33%	17%	Yes	Backwatering complications
Mt Wickham - Treatment	200	54%	50%	No	Discharge calculated, but low

5.4.2 Water quality and particle size

A comparison in the Total Suspended Sediment (TSS) and Total Nitrogen (TN) concentrations between the control gullies for all sites are presented in Figure 12 and for control and treatment sites in Table 12. The highest TSS concentrations in 2018/19 wet season were measured at Mt Wickham which were many times higher than all other sites. The TN values were much more similar between the sites, although Mt Wickham still had the highest median TN concentrations.

Due to the initial budget constraints when installing the water quality monitoring equipment at each site, it was decided that the treatment site would receive the more expensive fully automated (ISCO) sampler set-up, and the control site would receive a cheaper rising stage sampler (RSS) that collected two samples in any given event. To test that the RSS samplers were sampling the water (and thus constituents) in a similar way to the ISCO samplers, coincident RSS samplers were also located with ISCO samplers at three treatment sites. Coincident RSS samples from the RSS and ISCO sampler at Meadowvale (n = 5 samples), Strathbogie (n = 1) and Minnievale (n = 5) were compared (Figure 13).

The results demonstrate that there is a reasonable comparison between measurement approaches for lower TSS concentrations, however, the agreement is generally poor at higher TSS concentrations. In response to this result, and the challenge of only being able to measure two water samples in any event at the RSS samplers, it is now recommended that all sites have paired instrumentation using ISCO samplers. Paired ISCO systems are now installed at Strathbogie and Mt Wickham.

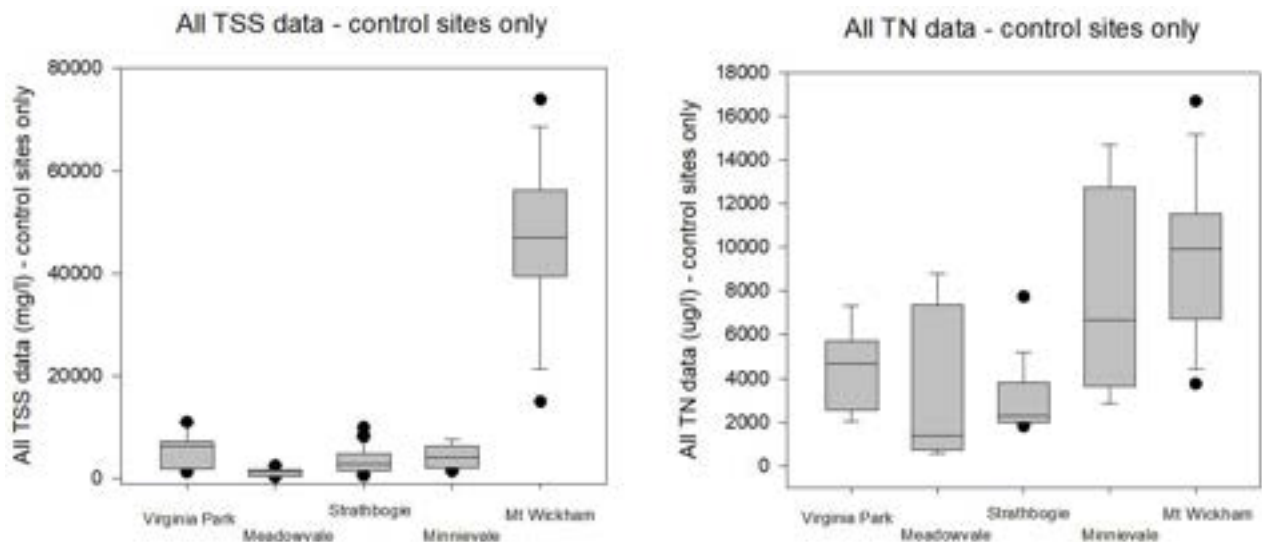


Figure 12: (Left) comparison of TSS data from all un-treated gullies for all TSS data at each site (right) comparison of TSS data from all un-treated gullies for all TN data at each site (2016- 2019).

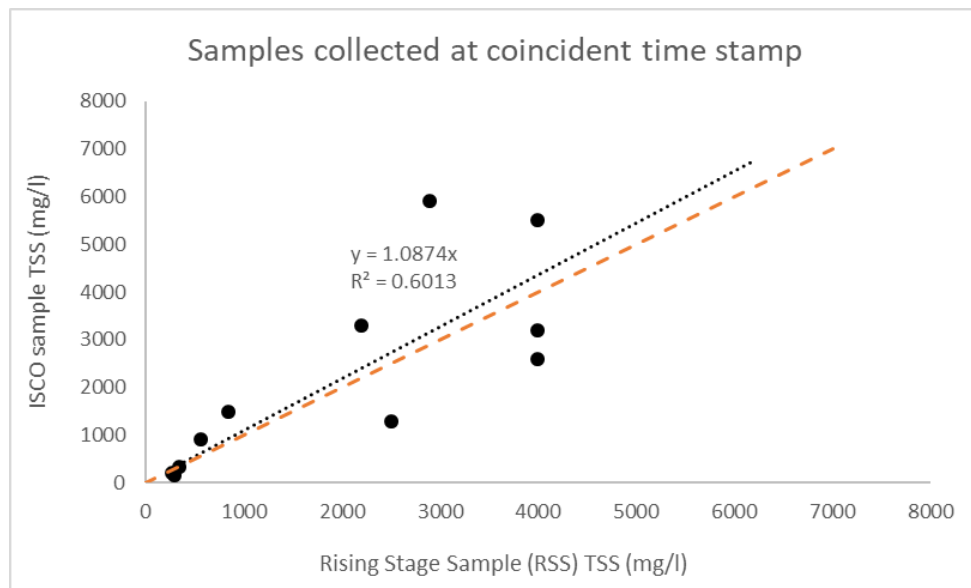


Figure 13: Comparison of water samples collected at the same stream location at the same time using (i) a rising stage sampler and (ii) an ISCO water sampler. Orange dashed line is the 1:1 line.

5.4.4 Comparison of particle size data

The results of the particle size analysis (PSA) data from each of the five sites from the first two wet seasons are shown in Figure 14A and the sample results from the three wet seasons in Figure 14B. The results demonstrate that you do need at least 10 samples at a site, over a range of seasons, to adequately characterise the particle size at a site.

There is a weak relationship with TSS concentration and particle size for four of the sites (Figure 15A) suggesting that as TSS concentration increases, particle size decreases, however, this relationship doesn't hold when the Mt Wickham PSA data is included (Figure 15B).

Figure 16 suggests that PSA is not particularly useful for discriminating between control and treatment sites (acknowledging that the number of samples is very low), given that the treatments at this site (Virginia Park) have been in place for ~8 years. There is relatively high scatter in the PSA values within a site between years, meaning that it is not going to be particularly useful for identifying treatment effects in the early years of monitoring. It may be more appropriate to measure PSA before treatment, in the first year or two of treatment and then at the end of monitoring (say in Year 5). Given the relatively high cost of PSA analysis (\$180/sample), PSA probably does not need to be collected routinely as part of the treatment analysis. PSA is primarily for identifying soil and land types that typically have very fine-grained material that are likely to travel into the GBR Lagoon. In saying that, knowledge of the PSA can be used to interpret landscape processes. For example, Meadowvale has the coarsest PSA of any site suggesting that this region may have already lost (eroded) a lot of its finer grained top soil.

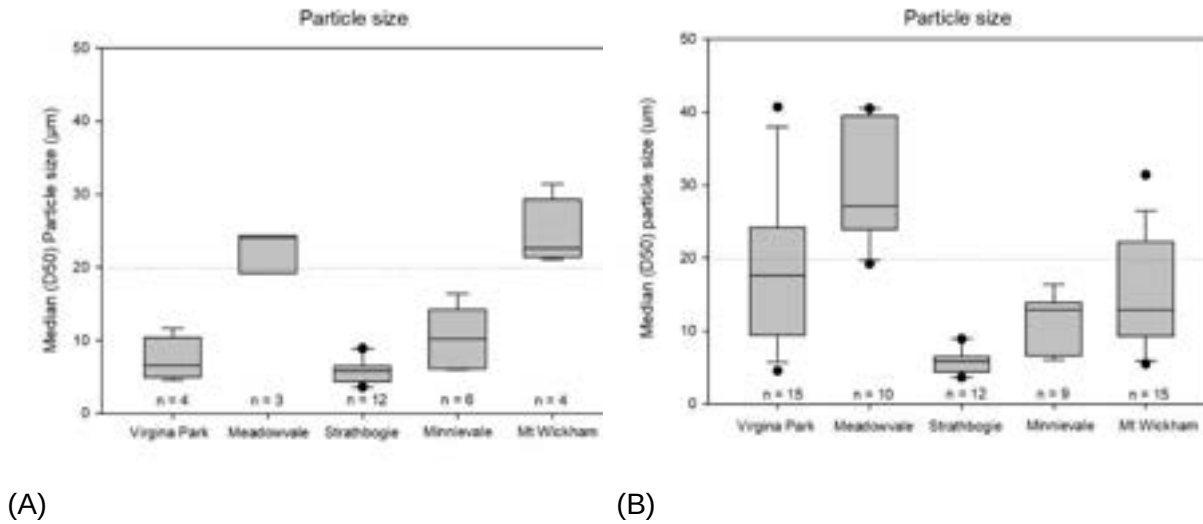
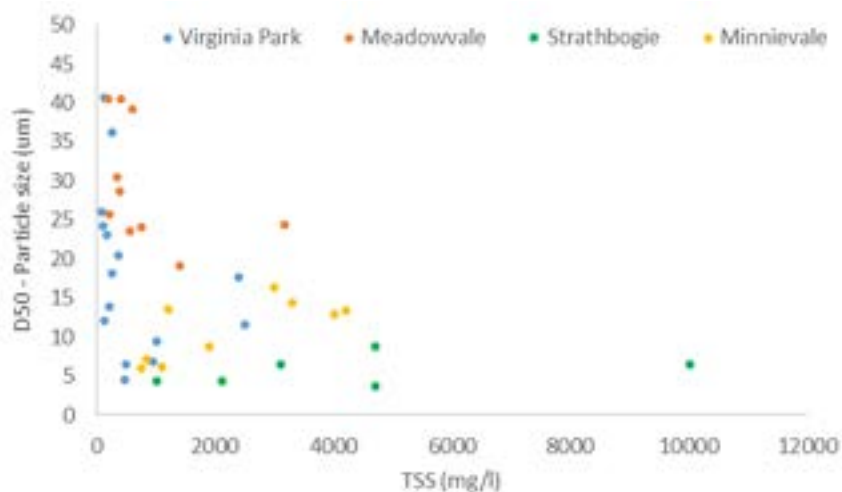
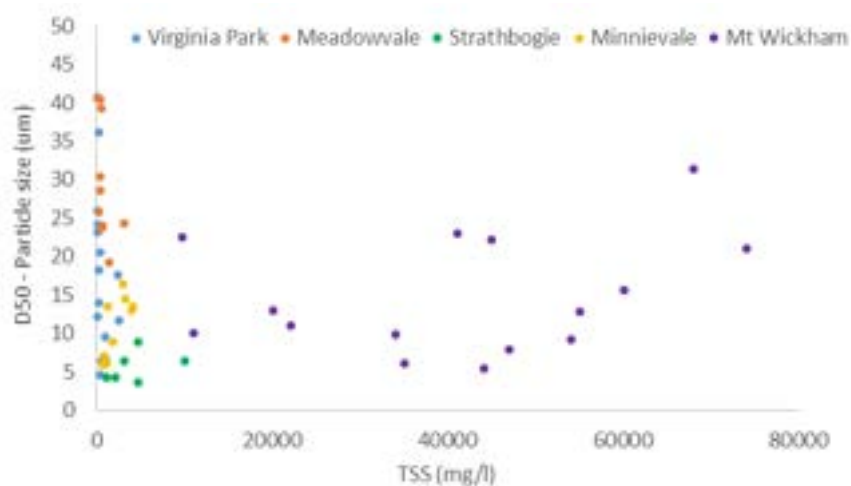


Figure 14: Particle size of suspended sediment collected at each of the five properties over (A) the first two wet seasons and (B) all data from three wet seasons. Note that sediment $<20 \mu\text{m}$ (dotted line) is considered to be the most ecologically detrimental for the GBR (Bainbridge et al., 2018).



(A)



(B)

Figure 15: Relationship between TSS (mg/L) and particle size (D50) – data from all field sites

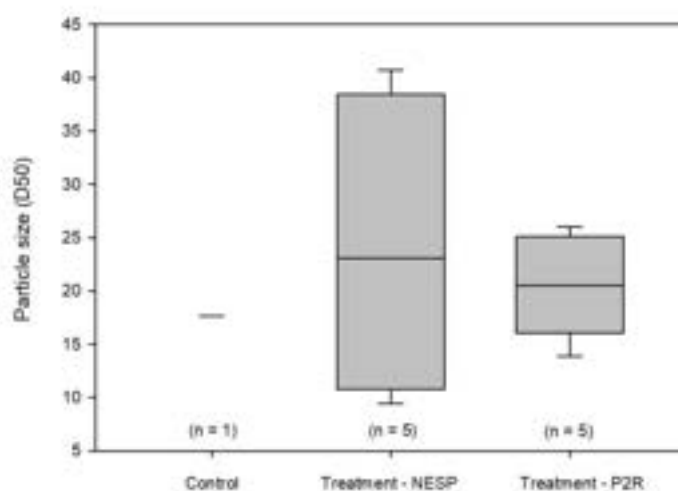


Figure 16: Comparison of particle size from the control and two treatment sites at the Virginia Park site showing that particle size is, at this stage, providing less discrimination between treatments (compared to TSS – see Figure 22).

**Table 12: Summary of rainfall, runoff, water quality concentration and loads for each of the sites for the 2018/19 wet season (July 2018 to March 31st 2019).
Catchments are estimated from best available regional terrain data: a = 0.5-1 m Lidar DEM, b = 30 m Shuttle Radar Topographic Mission DEM**

		Virginia Park		Meadowvale		Strathbogie		Minnievale		Mt Wickham *	
		Treatment	Control	Treatment	Control	SBT2 - Treatment	SBT - control	Treatment	Control	Treatment	Control
Site Rainfall (mm)	2018-2019 (Jul-Mar)	788	858	1403	1135	1352	1384	1072	1077	1117	1175
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 (ha) above monitoring station		1.3 ^a	3.1 ^a	5.0 ^a	4.2 ^a	38.1 ^b	17.4 ^b	21.2 ^b	9.7 ^b	14.1 ^a	3.0 ^a
Slope – hillslope above gully (%)		4.3	3.9	2.9	3.0	2.2	2.1	2.0	2.9	2.2	2.1
Hillslope Cover (%)	Post-wet	75	65	84	68	9	90	83	73	83	73
Gully walls (% cover)	Post-wet	38	25	30	34	30	42	23	27	35	29
Gully floor (% cover)	Post-wet	56	11	19	16	30	42	23	27	35	29
Runoff (mm)		367	Na	144	280	98	78	82	23	76	161
% runoff		47%	Na	10%	25%	7%	6%	8%	2%	7%	14%
TSS concentration (mg L ⁻¹)	Mean ± SE	449±118	2400	695±209	753±207	2631±855	3108±532	1271±266	4433±1107	23590±2195	41812±3547
	Range	47-3300	-	120-4900	300-1700	580-6900	770-8500	120-3300	1400-7600	9300-60000	13000-68000
Sediment yield (t)		5.9	2.1	1.8	7.0	63.9	28.3	10.7	5.8	174.0	159.6
Sediment yield (t/ha)		4.5	0.7	0.4	1.7	1.7	1.6	0.5	0.6	12.3	52.7
TSS Flow adjusted annual mean conc. (mg/L)		1230	2930	299	496	1704	2089	612	2608	16158	32573

TN (ug L ⁻¹)	Mean ± SE	1594±349	2019	1892±423	1957±1008	2583±1155	2665±255	4109±955	6632±2139	7986±716	10048±976
	Range	381-5681	-	335-6521	548-6945	884-5944	1811-4937	982-9296	2839-14074	2190-14736	3752-16702
Total Nitrogen yield (t)		8.8	1.5	6.3	18.4	82.2	23.2	13.1	13.9	66.3	26.4
Total Nitrogen yield (t/ha)		6.8	0.5	1.3	4.4	2.2	1.3	0.6	1.4	4.7	8.7
TN Flow adjusted annual mean conc. (ug/L)		1847	2036	1042	1313	2193	1715	751	6250	6162	5384
Median particle size (µm) measured	Mean ± SE		18.0 ± 2.8		29.6 ± 2.5		5.8 ± 0.5		10.9 ± 1.3		14.8 ± 2.0

6.0 RESULTS – BY PROPERTY

6.1 Virginia Park

6.1.1 *Treatment progress*

The Virginia Park treatment site represents the longest running of all the treatment sites. This is the 9th 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 17). 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 nine year period, however, with increased organic matter now being trapped in the channel, it is possible that structures may start to break-down over the coming years. 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 (Figure 18). 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 considered the long-term mechanism for stabilising these smaller gullies.

It is important to note that the electric fence that was surrounding the treatment site was knocked down in a storm sometime during 2018 and cattle had access to the Treatment site for ~6 months leading up to the wet season in 2018/19. The fence has now been fixed, however, the results for 2018/19 may have been influenced by the cattle accessing the treatment site. Figure 18 shows the field sites at Virginia Park under different flow event and non-event conditions over the last three wet seasons.

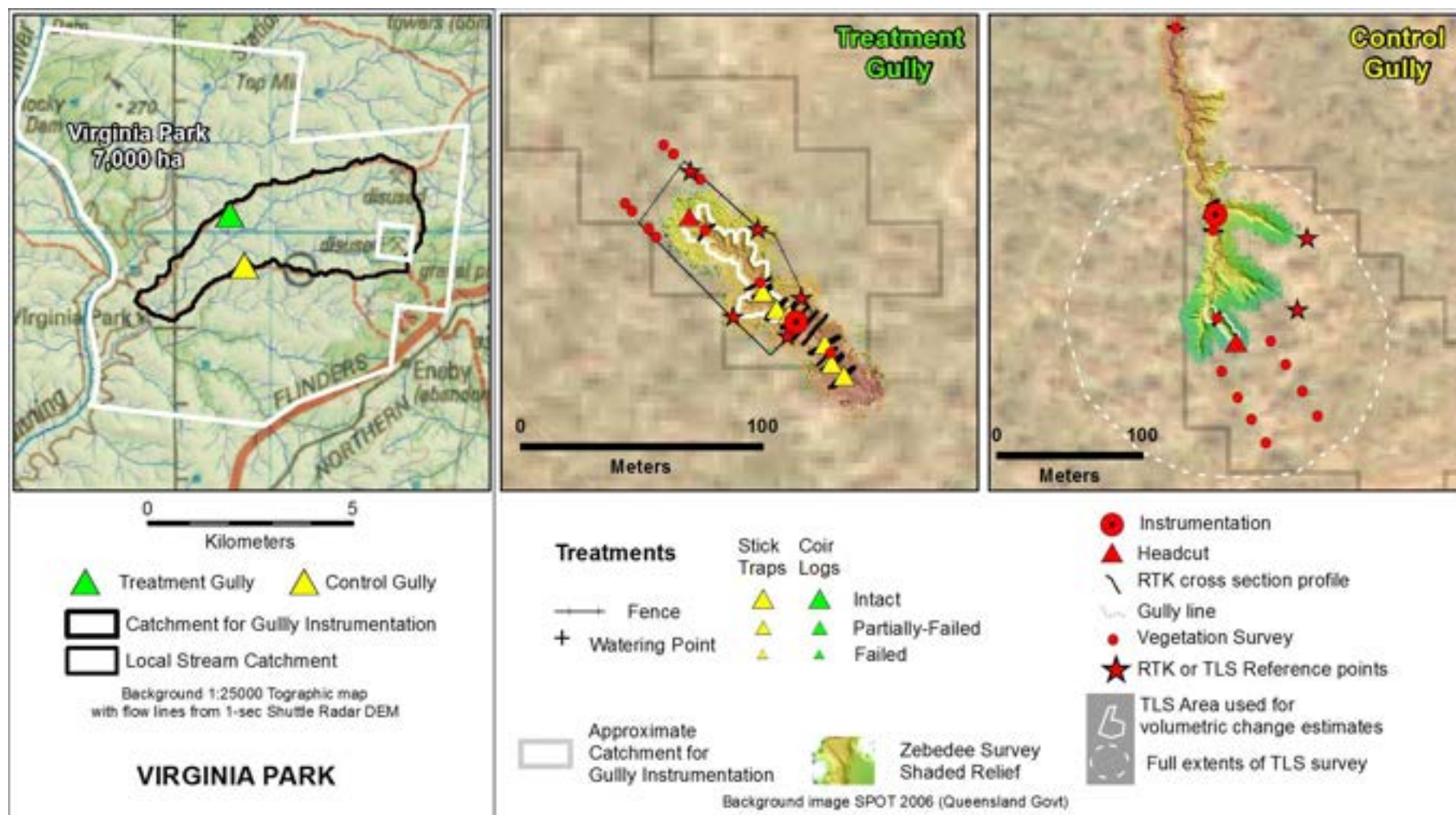


Figure 17: Location of the Virginia Park site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

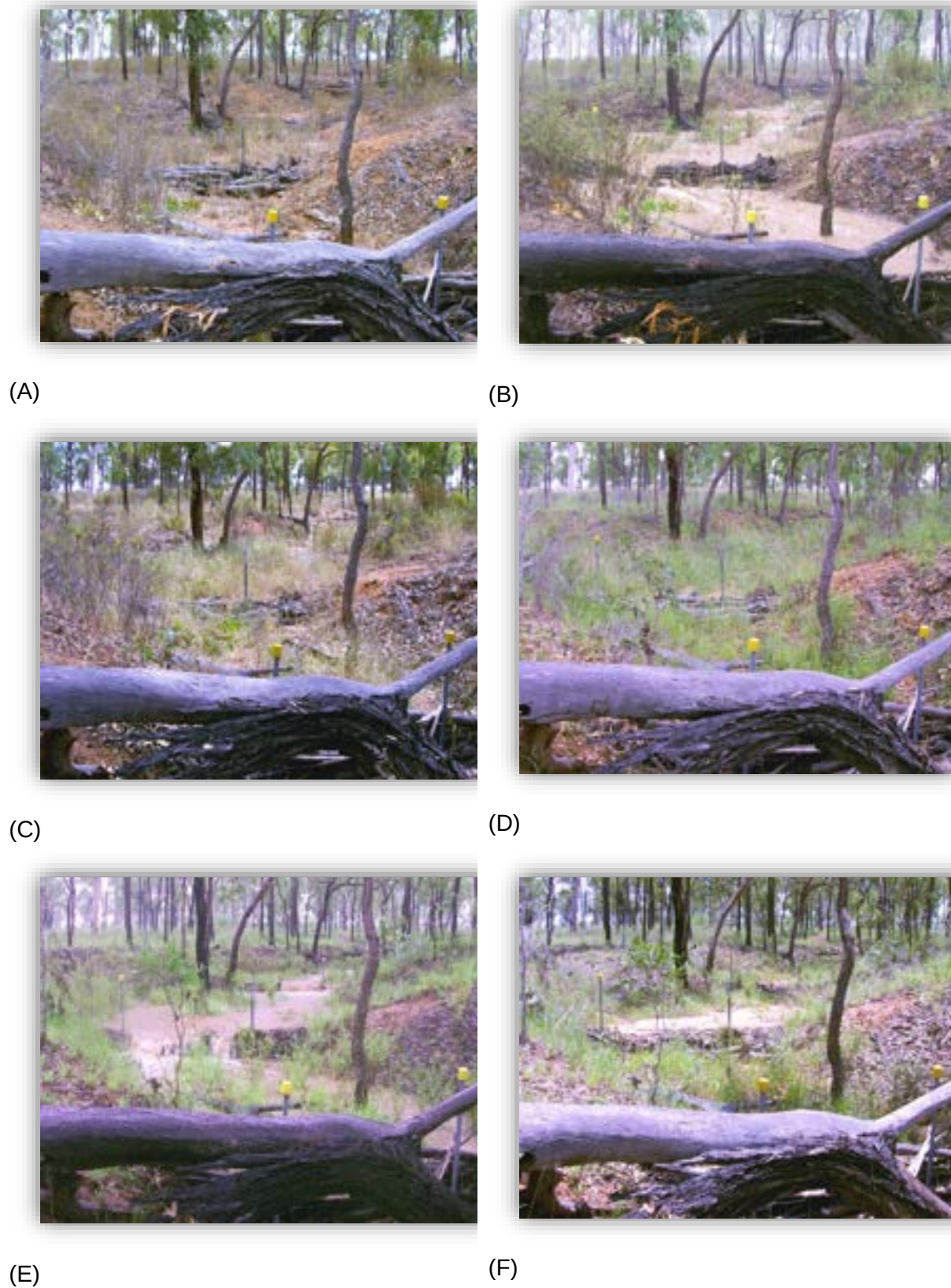


Figure 18: Treatment gully at Virginia Park in (A) 2016 (B) during an event in 2017 (C) at the end of reporting period in April 2017 (D) in April 2018 (E) during an event in 2019 and (F) at the end of April 2019

6.1.2 Vegetation response

Figure 19 presents the end of wet season % cover and biomass data for the hillslope above the control and treatment gully at Virginia Park as well as the gully walls and gully floor. The results demonstrate that there has been little change in the hillslope % cover over the study period. There has been a slight increase in hillslope biomass at the treatment site, however, this is not significantly different to the control site ($p=0.699$). There is a significant difference in the end of wet (EOW) % cover and biomass on the gully floor ($p<0.001$, 2018/19) which is likely to be a direct consequence of the location of the PCD structures. There has not been a coincident response in gully wall vegetation with no difference between control and treatment sites.

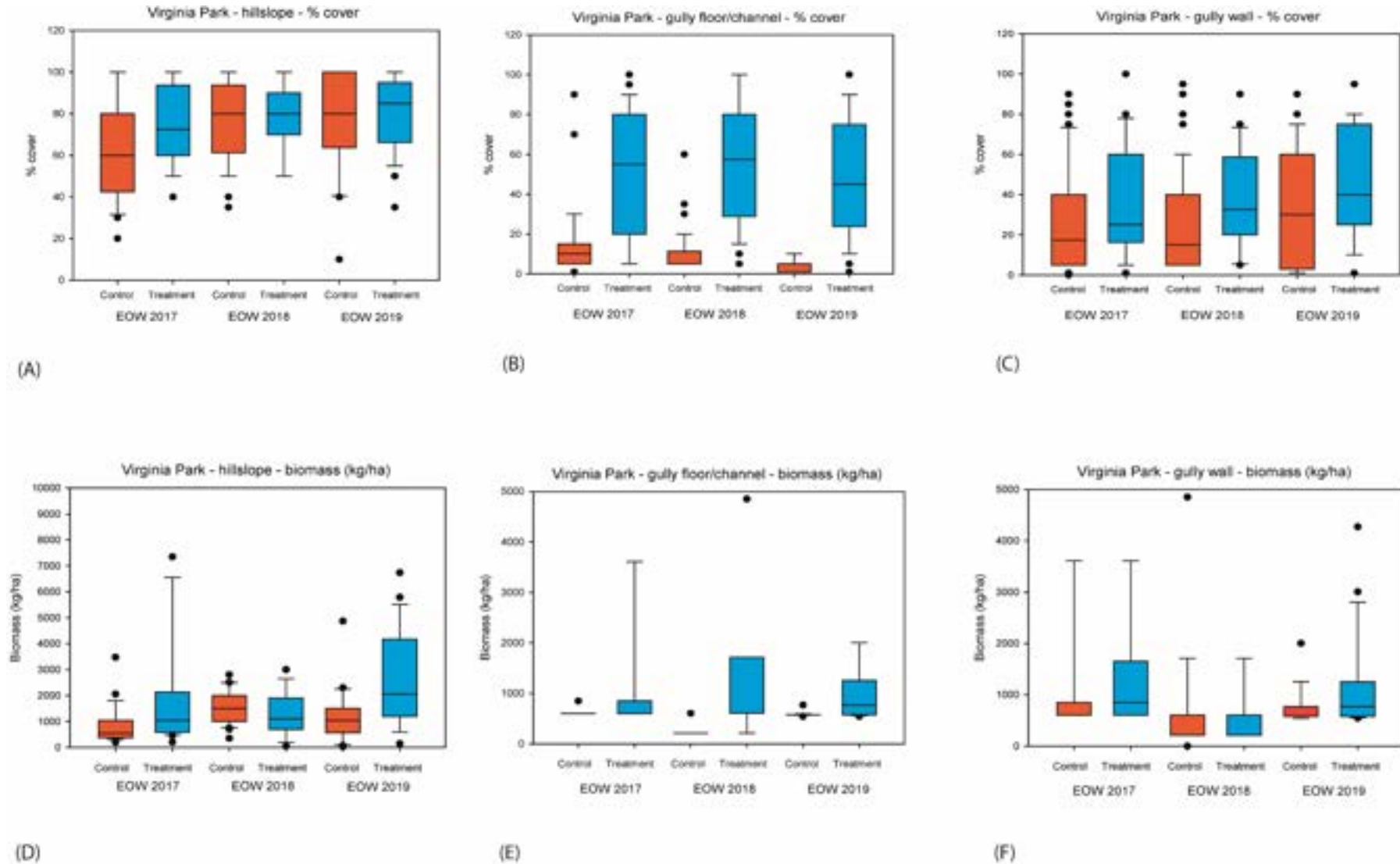


Figure 19: Virginia Park control and treatment sites showing the changes in % cover on the (A) hillslope, (B) gully floor/channel and (C) gully walls, and change in pasture biomass (kg/ha) on the (D) hillslope, (E) gully floor/channel and (F) gully walls over the three year NESP TWQ Hub study period. Note extreme outlier data were excluded at some sites for plotting purposes.

6.1.3 Terrain changes

The terrain analysis results obtained using the terrestrial laser scanner (TLS) were presented in Table 9 and Table 10. The volumetric change in sediment erosion and deposition between the treatment and control site at Virginia Park is presented in Figure 20.

The results demonstrate that the amount of sediment lost from the head-cut area is similar between the control and treatment sites, but the amount of sediment deposited (or trapped) in the gully as a % of erosion varies between 7% for the control, and 99% for the treatment site. The treatment site terrain scan includes ~ 3 of the PCD's installed at this site, suggesting that most of the sediment that was eroding was being trapped or deposited by the structures. The fact that there is still fine sediment being measured downstream suggests that the hillslope above the gully is a continued source of sediments and nutrients into the gully.

Figure 21 presents the TLS results including the DEMs of Difference which show the dominant locations of the erosion (mainly the head-cuts) and the deposition areas. The linear head-cut growth of the treatment site is on average 0.33 m/y (Table 9) which is similar to the control site of 0.3 m/y. Both the control and treatment sites have had a slight decline in head-cut retreat rate over the three year study period (Table 9) which, somewhat counter-intuitively, is inversely related to the amount of rainfall received at the site over the last 3 years (Figure 23). Given that the PCD's are now full of sediment, they may not be able to continue to capture as much sediment in future years.



Figure 20: Net sediment movement (tonnes per metre surveyed per year, t/m/y) for Virginia Park (using a measured soil bulk density of 1.66 t/m³) for the 2016-19 period. Erosion is represented by positive (+ve) values and deposition negative (-ve) values.

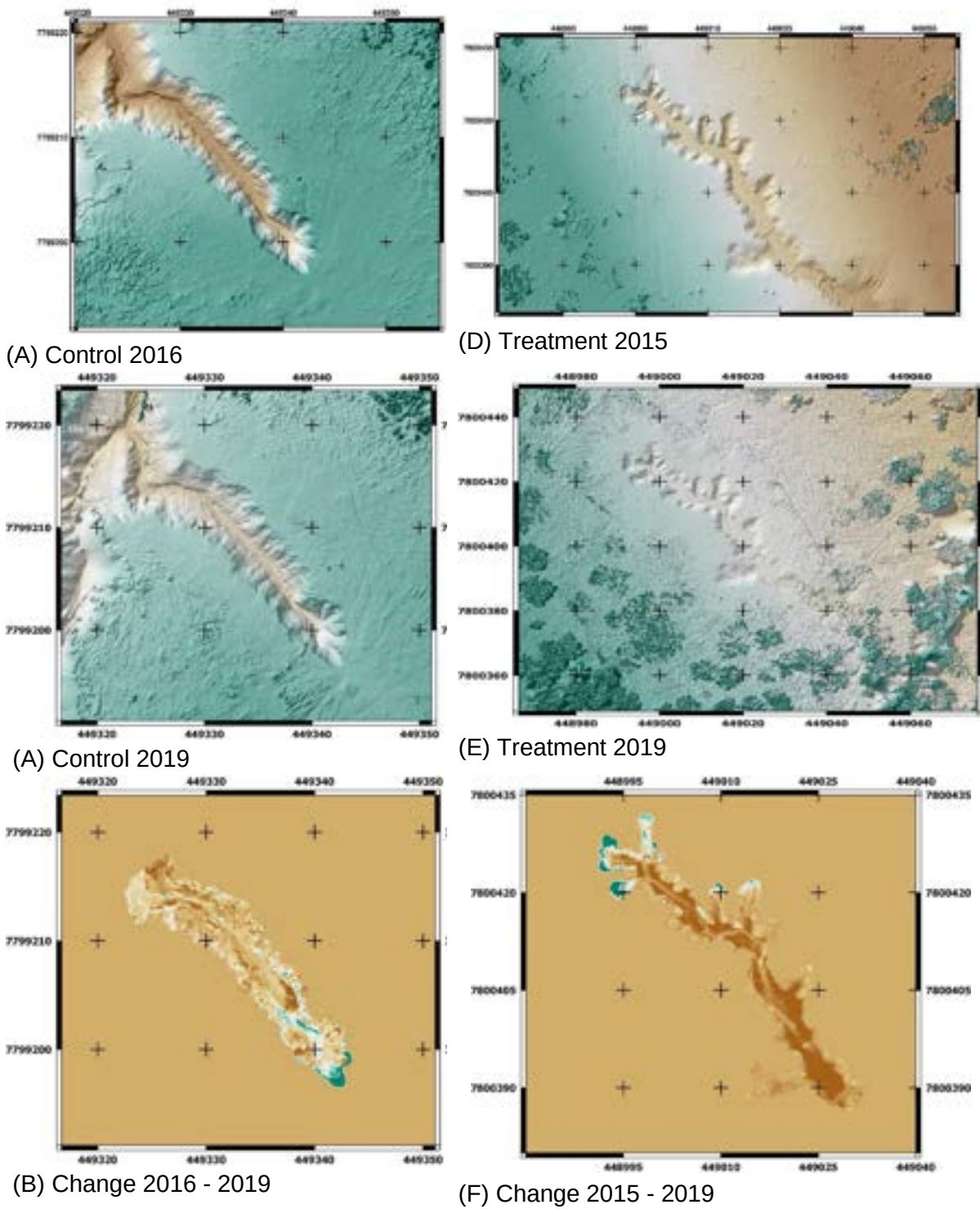


Figure 21: Virginia Park (A) control gully in 2016 (B) control gully in 2019 and (C) DEM of Difference; (D) treatment gully in 2015, (E) treatment gully in 2019 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is erosion and brown is deposition.

6.1.4 Water quality, runoff and loads

As discussed in Section 4.6, being able to evaluate trend changes over time generally requires pre-treatment data to confidently determine whether a treatment has had an effect independent of any natural or climatic variability between sites. We have water quality and loads data prior to the installation of the PCD's at the Treatment site, but not at the control site. This reduces the statistical approaches that can be applied.

The TSS and TN concentration data suggests that samples from the treatment site are statistically lower than at the control sites during 2017/18 wet season ($p < 0.001$) (Figure 22A). The low number of samples make this comparison difficult in other years, however, the general trend in the median values suggests that the concentrations of TSS and TN are less at the treatment site.

This was the first year that we have been able to present runoff, TSS and TN loads data for these sites (Figure 23). In addition to not having pre-treatment control site water quality and loads monitoring, we had many challenges with the monitoring instrumentation at the control site. This has mainly been related to bed level changes as coarse sediment has moved through the gully system (smothering and un-covering equipment). Consequently, no data was presented for the control site.

The TSS and TN loads at the treatment site generally follow the rainfall trend with an increase in loads in 2018/19 compared to other years. The TSS loads presented for 2017/18 are lower than expected given the rainfall amount, however, this may reflect the pattern of rainfall distribution over the wet season and/or possibly sensitivities in the rating curve to changes in channel profile.

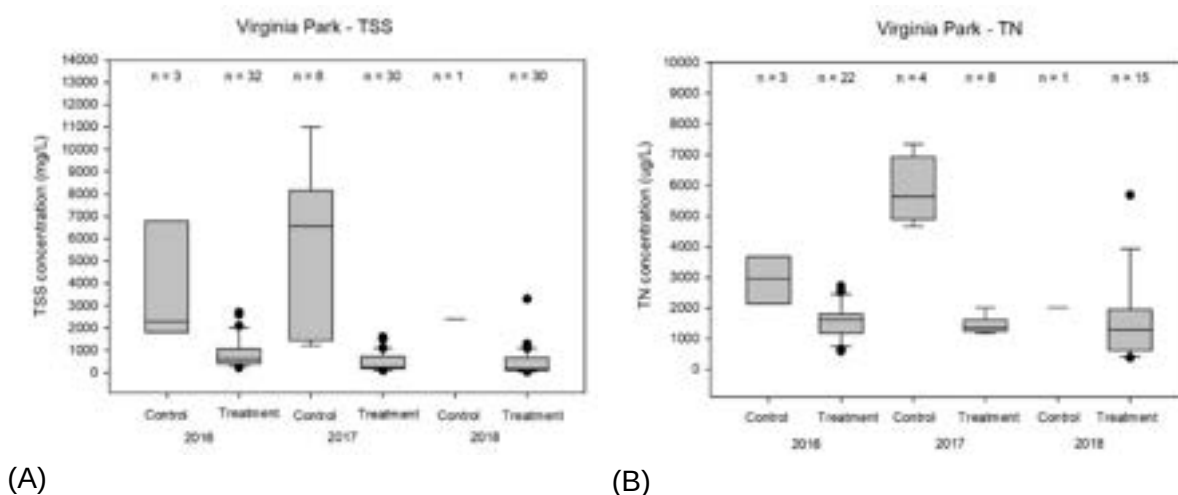


Figure 22: (A) TSS concentration and (B) TN concentrations at Virginia Park for three wet seasons. Year is start of wet season (2016/17, 2017/18, 2018/19)

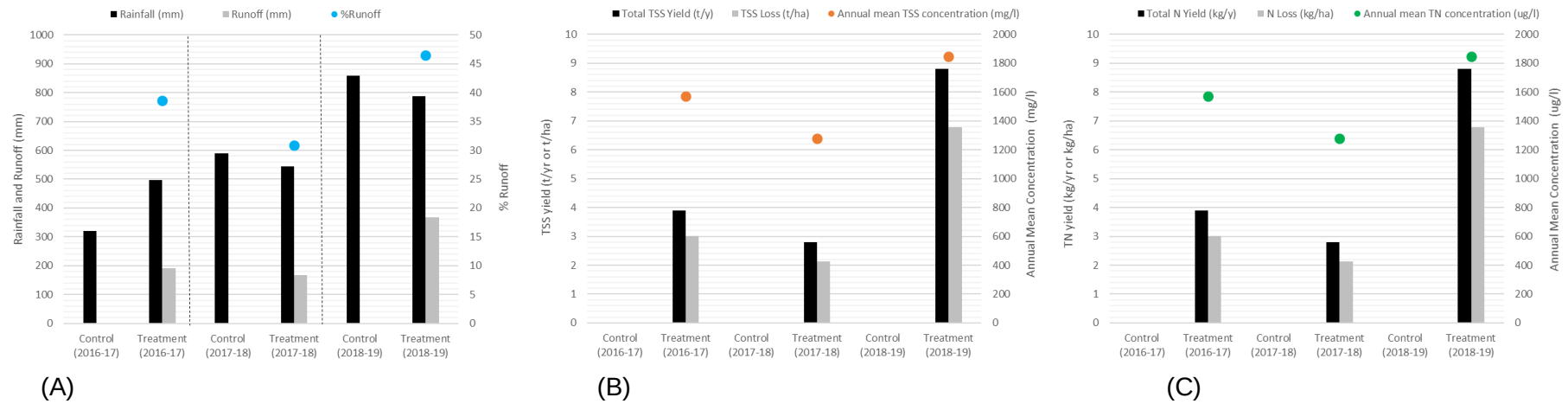


Figure 23: Virginia Park Control and Treatment results for (A) Rainfall, runoff and % runoff (B) Total Suspended Sediment (TSS) loads (t/y and t/ha) and flow weighted annual average TSS concentration (mg/L) and (C) Total Nitrogen (TN) loads (kg/y and kg/ha) and flow weighted annual average TN concentration (ug/L).
NOTE: these data are considered preliminary and will be updated with additional data next year (see data quality caveats in Appendix B). Runoff and loads data were not presented for the control site due to low confidence in the estimates.

6.1.5 Summary: Virginia Park

Table 13 is an attempt to synthesise all the data sets that have been collected at the site into a summary report card. The most accurate method for evaluating change is using a BACI design which requires pre-treatment data at both a control and treatment sites. Because no runoff data was collected at the control site prior to the implementation of the treatment, a BACI design will not be possible for most of the data at this site.

Overall, the fencing and PCD treatment is having a measurable effect on gully floor and wall vegetation cover and biomass, but not on hillslope vegetation; although there are early signs of improved biomass on the treated hillslope (compared to the control). There has been a reduction in head-cut erosion at the treatment site over the three years (but also at the control). The PCD treatment appears to have been effective at inducing deposition behind the structures. This appears to have had some initial success at reducing the TSS and TN concentrations in some years.

Table 13: Summary of the treatment effects (Fencing and PCD's) at the Virginia Park site (3- 9 years of treatment data). **Green** suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. **Na** means data not yet available.

TREATMENT: Fencing and PCD's		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %		na	Some pre NESP TWQ Hub cover and biomass data is available. Data has not yet been analysed.
	Hillslope biomass (kg/ha)		na	
	Gully floor/channel – cover %		na	
	Gully floor/channel – biomass (kg/ha)		na	
	Gully walls – cover (%)		na	
	Gully walls – biomass (kg/ha)		na	
Terrain/erosion	Erosion (t/m/y)			There is no pre-terrain (TLS) data for both treatment and control sites
	Deposition (t/m/y)			
	Net change (t/m/y)			
Runoff, water quality and loads	TSS conc. (mg/L)			
	TN conc. (ug/L)			
	TSS Loads (t/ha)	X		
	TN Loads (kg/ha)	X		
	TSS EMC (mg/L)	X		
	TN EMC (ug/L)	X		
	Runoff (mm)	X		
	% Runoff	X		

6.2 Meadowvale

6.2.1 Treatment progress

The Meadowvale site has the simplest of all 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 24).

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 25 shows the field sites at Meadowvale under different flow event and dry conditions over the last three wet seasons. The improved grass cover in the channel or floor on the treatment gully is visible over the three-year monitoring period.

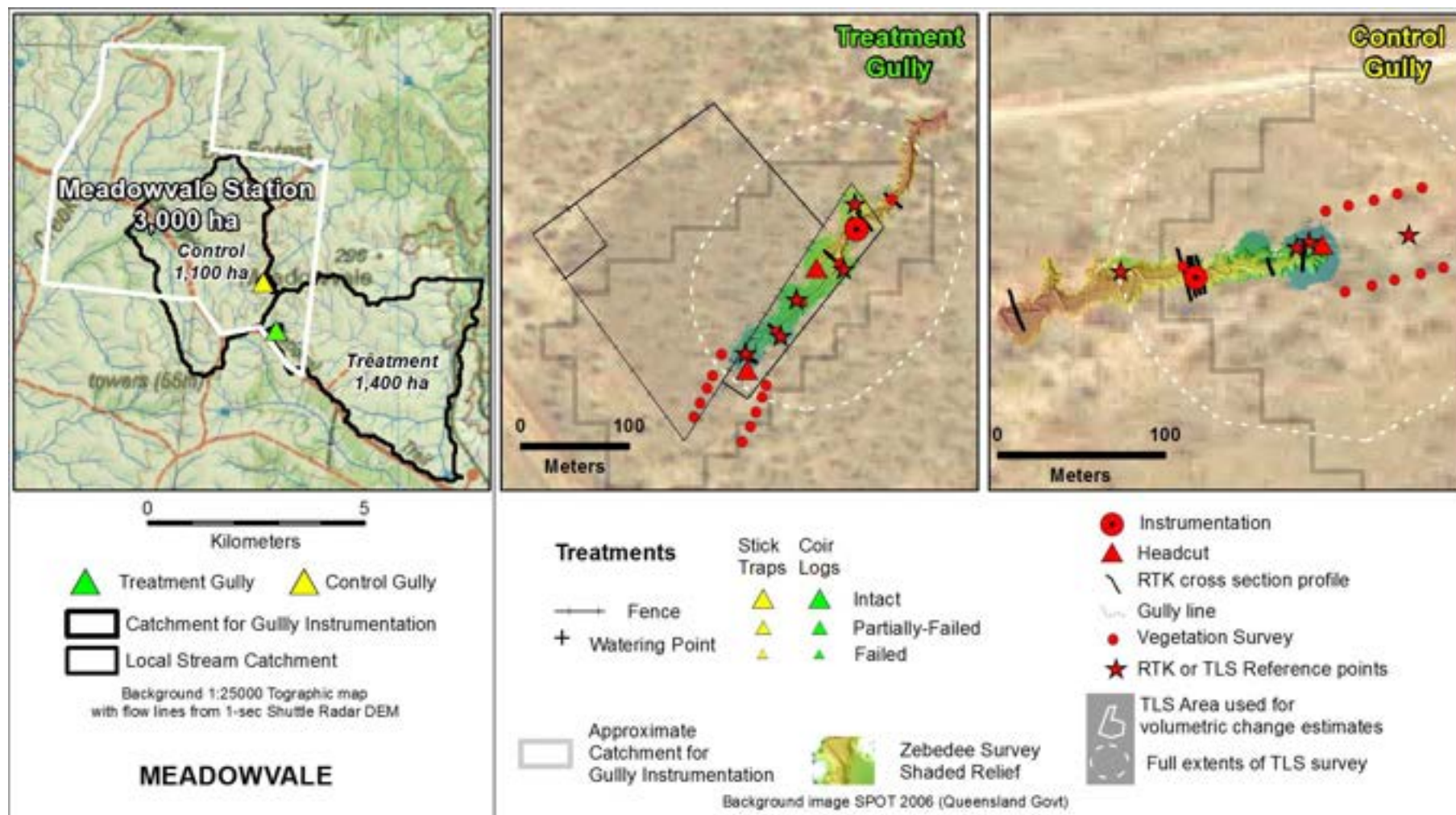


Figure 24: Location of Meadowvale site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.



Figure 25: Treatment gully at Meadowvale in (A) 2016 (B) during an event in 2017 (C) at the end of reporting period in April 2017 (D) at the end of reporting period in April 2018 (E) an event in 2019 and (F) at the end of wet season in 2019

6.2.2 Vegetation response

Figure 26 presents the end of wet season % cover and biomass data for the hillslope above the control and treatment gully at Meadowvale as well as the gully walls and gully floor. The results demonstrate that there has been little change in the hillslope % cover over the study period, but there has been a significant increase in hillslope biomass at the treatment site in 2017/18 and 2018/19 ($p < 0.001$). There is a significant difference in the end of wet (EOW) % cover on the gully floor ($p < 0.001$, 2017/18) but this pattern reduced in significant in 2018/19 ($p = 0.101$). Despite visual improvements and anecdotal evidence that vegetation in the gully has improved (Figure 25E), there has not been a coincident response in gully floor biomass or wall vegetation measurements, with no statistical differences between control and treatment sites.

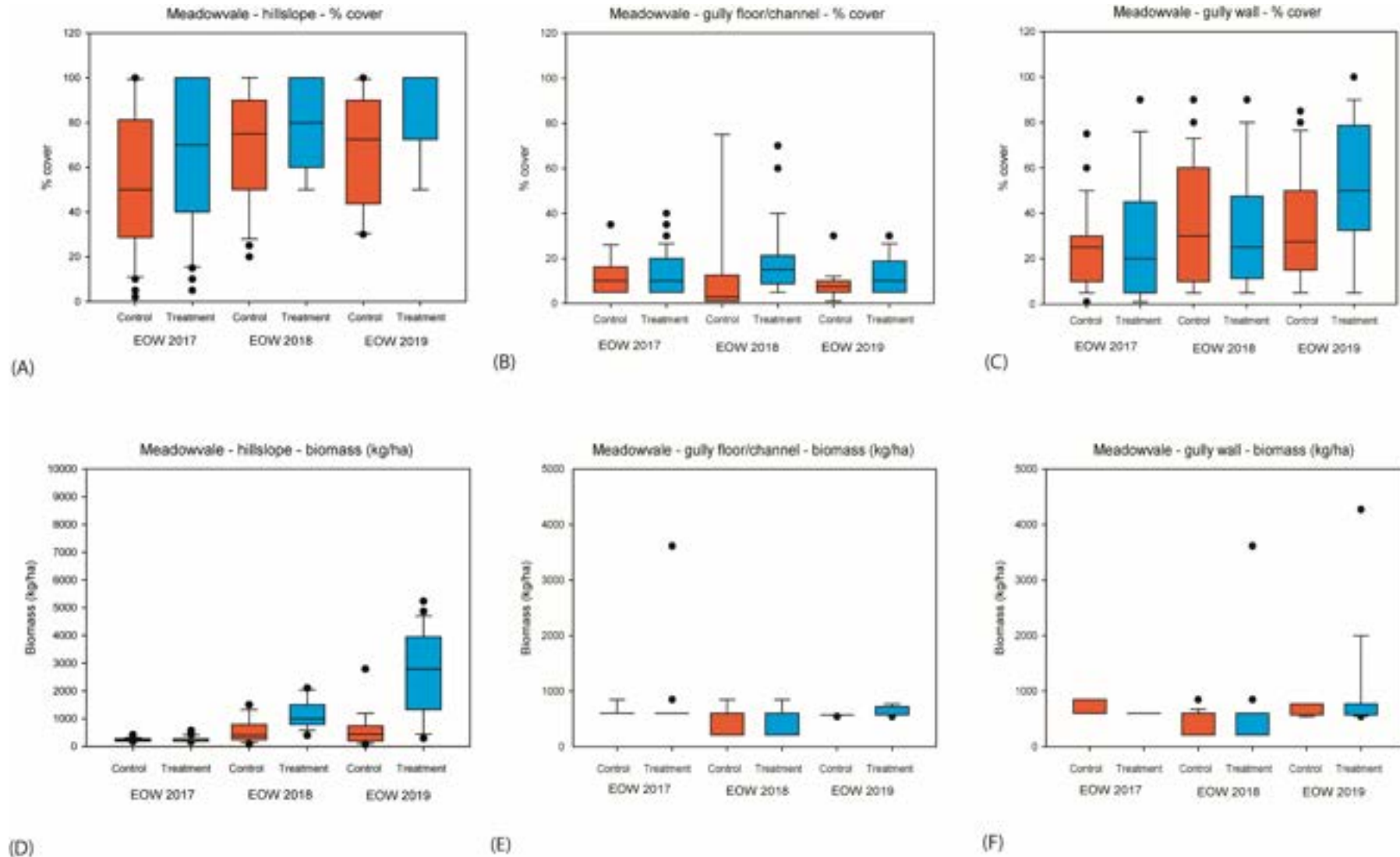


Figure 26: Meadowvale control and treatment sites showing the changes in % cover on the (A) hillslope, (B) gully floor/channel and (C) gully walls, and change in pasture biomass (kg/ha) on the (D) hillslope, (E) gully floor/channel and (F) gully walls over the three year NESP TWQ Hub study period. Note extreme outlier data were excluded at some sites for plotting purposes.

6.2.3 Terrain changes

The terrain analysis results obtained using the terrestrial laser scanner (TLS) were presented in Table 9 and Table 10. The volumetric change in sediment erosion and deposition between the treatment and control site is presented in Figure 27.

Due to scanning challenges at this site in 2017/18, we have limited change data for the treatment site outside of 2018/19. The results demonstrate that the head-cut retreat rate is similar between the control (0.81 m) and treatment (0.73 m) sites, but the amount of sediment deposited (or trapped) in the gully as a % of erosion varies between 8% for the control gully, and 16% for the treatment site (see Figure 27; Table 9). Figure 28 presents the TLS results including the DEMs of difference which show the dominant locations of the erosion (mainly the head-cuts for the control site) and the deposition areas.

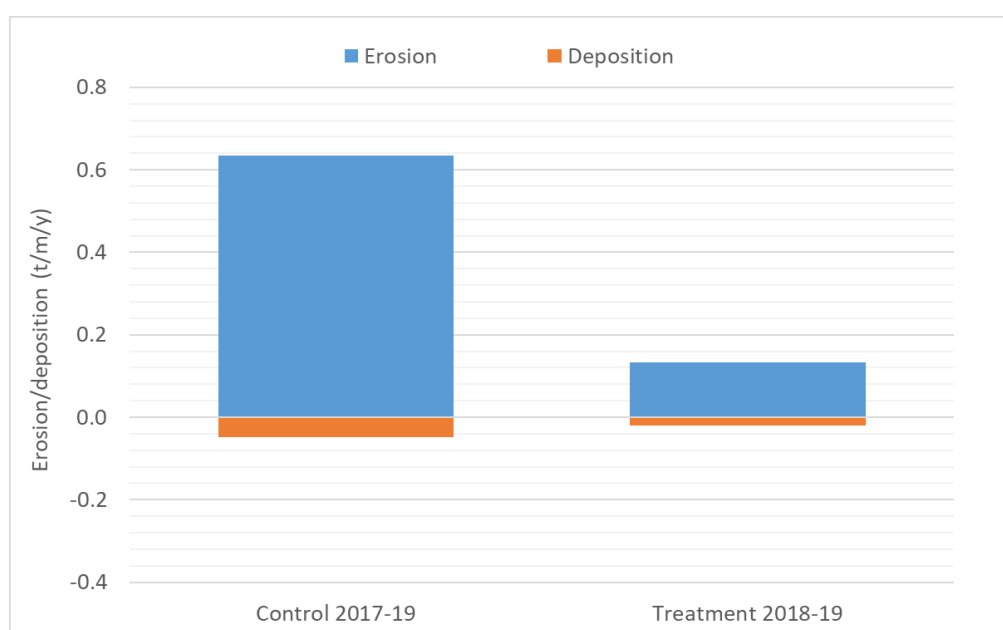


Figure 27: Net sediment movement (tonnes per metre surveyed per year, t/m/y) for Meadowvale (using a measured soil bulk density of 1.5 t/m³) for the 2017-19 period for the control and 2018-19 for the treatment. Erosion is represented by positive (+ve) values and deposition negative (-ve) values.

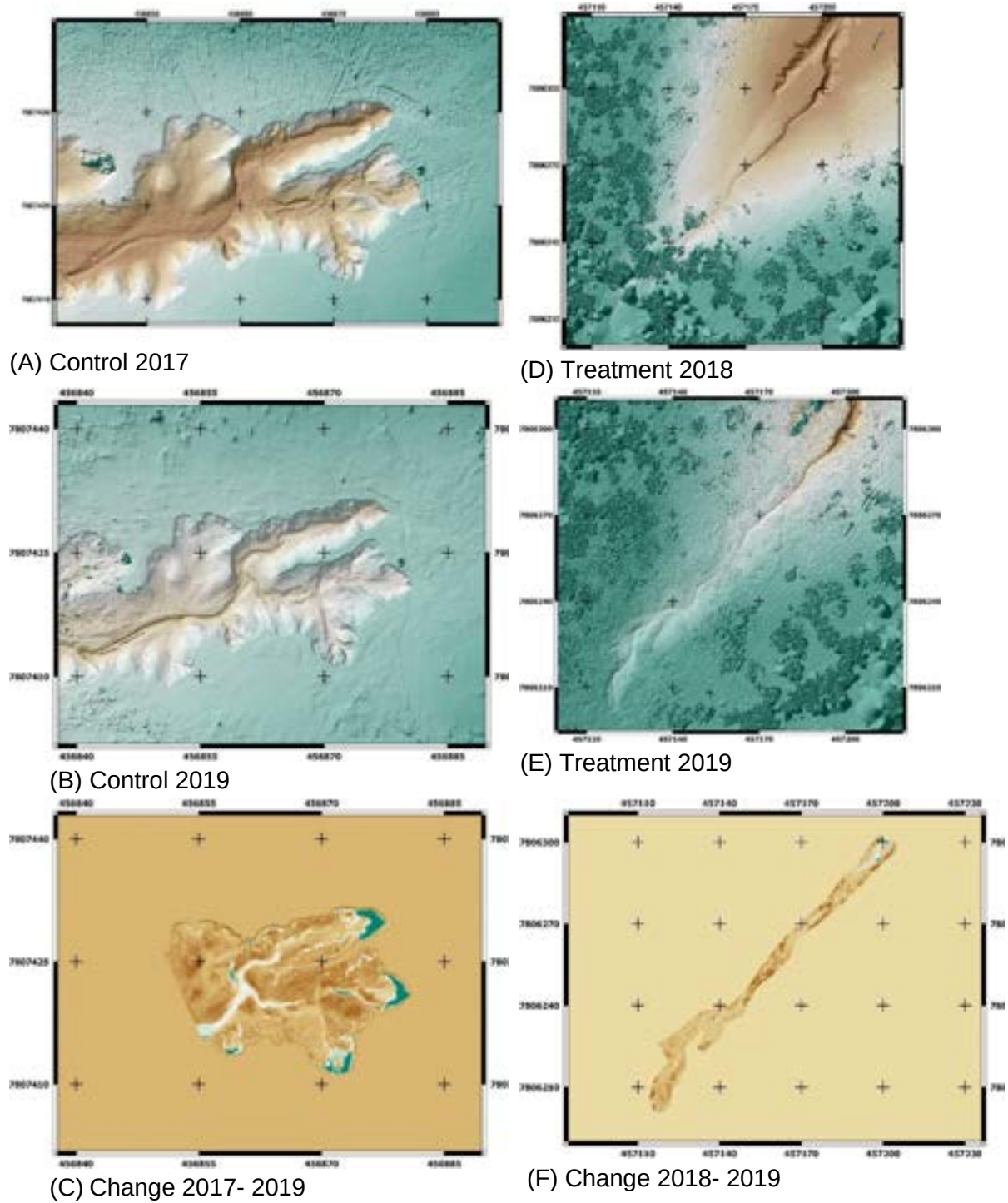


Figure 28: Meadowvale (A) control gully in 2017 (B) control gully in 2019 and (C) DEM of Difference; (D) treatment gully in 2017, (E) treatment gully in 2019 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is erosion and brown is deposition.

6.2.4 Water quality, runoff and loads

As discussed in Section 4.6, being able to evaluate trend changes over time generally requires pre-treatment data to confidently determine whether a treatment has had an effect independent of any natural or climatic variability between sites. We have water quality and loads data prior to the installation of the PCD's at the Treatment site, but very few ($n=2$) samples at the control site. This reduces the statistical approaches that can be applied at this site primarily to t-tests between control and treatment each year.

The TSS data at the treatment site are statistically lower than at the control sites during 2018/19 wet season ($p<0.001$) (Figure 29A). Although there were differences in the TN values between treatment and control sites in the first two years of treatment, low sample numbers and problems with green ants nesting in the sensors, make these early data un-reliable. There is no statistical difference in TN concentration values in 2018/19.

This was the first year that we have been able to present runoff and TSS and TN load data (Figure 30). Although the hydrology data is considered preliminary (awaiting another year of velocity data), the treatment gully has had consistently lower rainfall-runoff ratios (% runoff) than the control site in all years of this study. A large section of the hillslope above the treatment gully has had a cattle and kangaroo enclosure since 2002 (17 years) which may partly explain this result. Interestingly, although the rainfall was the highest at the treatment site during the 2018/19 wet season, it had the lowest TSS loads (and TN loads) in the last two wet seasons. This may be due to the treatment effect; however, it may also be because the treatment gully is mature and not as active as the control gully.

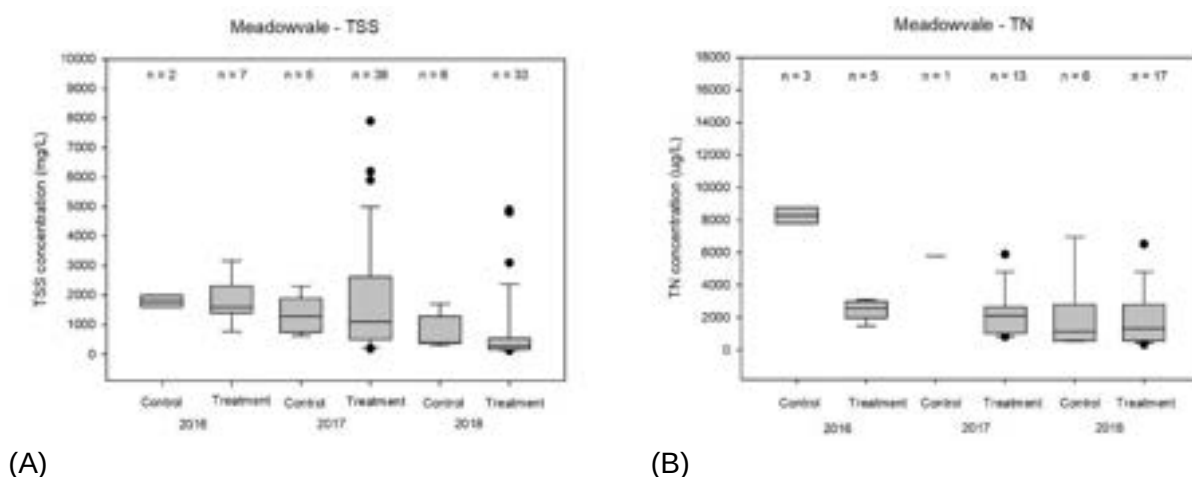


Figure 29: (A) TSS concentration and (B) TN concentrations at Meadowvale for two wet season

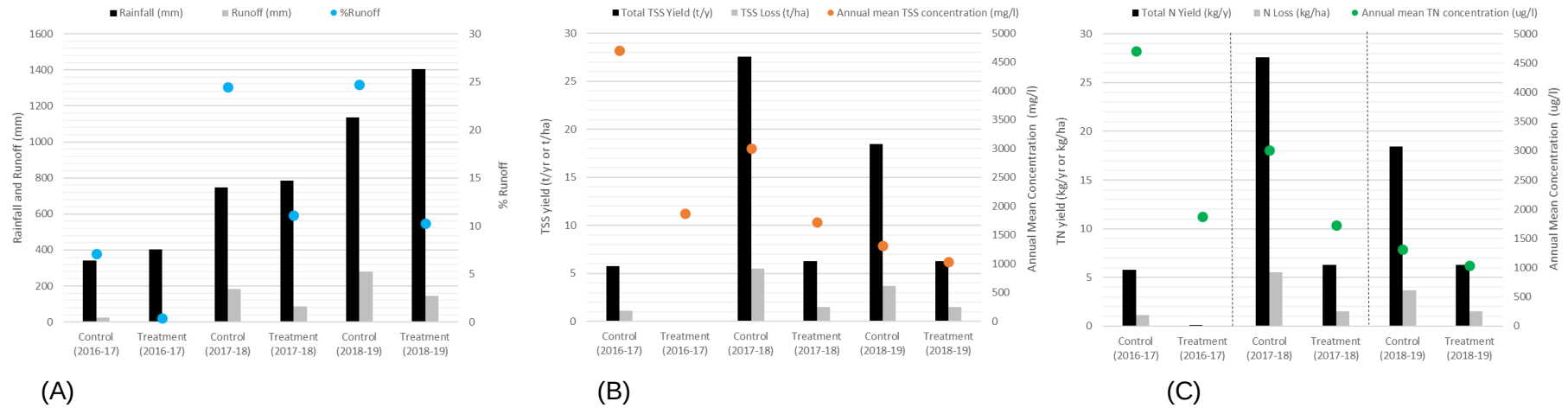


Figure 30: Meadowvale Control and Treatment results for (A) Rainfall, runoff and % runoff (B) Total Suspended Sediment (TSS) loads (t/y and t/ha) and annual average TSS concentration (mg/L) and (C) Total Nitrogen (TN) loads (kg/y and kg/ha) and annual average TN concentration (ug/L). NOTE: these data are considered preliminary and will be updated with additional data next year (see data quality caveats in Appendix B).

6.2.5 Summary: Meadowvale

Table 14 synthesises all the data sets that have been collected at the site into a summary report card. The most accurate method for evaluating change is using a BACI design which requires pre-treatment data at both a control and treatment sites. Because minimal runoff and sample data were collected at the control site prior to the implementation of the treatment, a BACI design will not be possible for most of the data at this site.

The initial early indicator variables suggest that although there are some improvements in hillslope biomass and gully channel cover, there has been no change in gully wall cover or biomass. There does, however, appear to be consistent differences between the control and treatment for the other metrics such as erosion, runoff and water quality. This was not necessarily expected for this site. There are a number of potential factors leading to this result: (i) there could be a number of instrument or measurement errors that we hope to improve next wet season (ii) that the treatment gully is actually much older and more mature than the control gully (which can be supported by the fact that the treatment gully has almost reached the ridge top) and therefore it would naturally have lower data even in the absence of treatment; or (iii) that the long term grazing exclosure has actually had a positive effect on the hydrology of this hillslope, which is being expressed in the different data.

Table 14: Summary of the treatment effects (Fencing and PCD's) at the Meadowvale site (3 years of treatment data). **Green** suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. **Na** means data not yet available.

TREATMENT: Fencing only (with long term cattle enclosure above the treatment)		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %		?	Some pre NESP TWQ Hub cover and biomass data is available. Data has not yet been analysed.
	Hillslope biomass (kg/ha)		?	
	Gully floor/channel – cover %		?	
	Gully floor/channel – biomass (kg/ha)		?	
	Gully walls – cover (%)		?	
	Gully walls – biomass (kg/ha)		?	
Terrain/erosion	Erosion (t/m/y)			There is no pre-terrain (TLS) data for both treatment and control sites, and although there was a single pre-treatment flow year, there was insufficient data to draw conclusions using a BACI design.
	Deposition (t/m/y)			
	Net change (t/m/y)			
Runoff, water quality and loads	TSS conc. (mg/L)			
	TN conc. (ug/L)			
	TSS Loads (t/ha)			
	TN Loads (kg/ha)			
	TSS EMC (mg/L)			
	TN EMC (ug/L)			
	Runoff (mm)			
	% Runoff			

6.3 Strathbogie

6.3.1 Treatment progress

The Strathbogie site was a Reef Trust 2 gully remediation site, that is now being managed by NQ Dry Tropics under their LDC program. This site has not yet undergone remediation treatment (Figure 31). There was a remediation plan in progress in 2016/17 that was delayed, and then after Cyclone Debbie, the landholder withdrew from the project. Given the baseline data collected at this site, and the significant erosion at the control site, we switched the control and treatment sites over and installed matching water quality instrumentation so that both the treatment and control sites have ISCO samplers. The new treatment site instrumentation was installed during the dry season in 2018. At the same time, NQ Dry Tropics reengaged the landholder and a remediation treatment plan were prepared by contracted consultants. The treatment works were to be installed in January 2019, however, the site received over 400 mm in two days in early January, and the works were not completed. The remediation is expected to be completed during the dry season in 2019.

Fortuitously, we now have three years of pre-treatment data at both the treatment and control sites. All data presented below is from two non-treated sites. For those readers familiar with these data and sites, it is important to note that the control and treatment sites have been swapped. The new control is named (SBT) and the new treatment is named (SBT2). Figure 32 shows the field sites at Strathbogie during different event and dry conditions over the last three wet seasons.

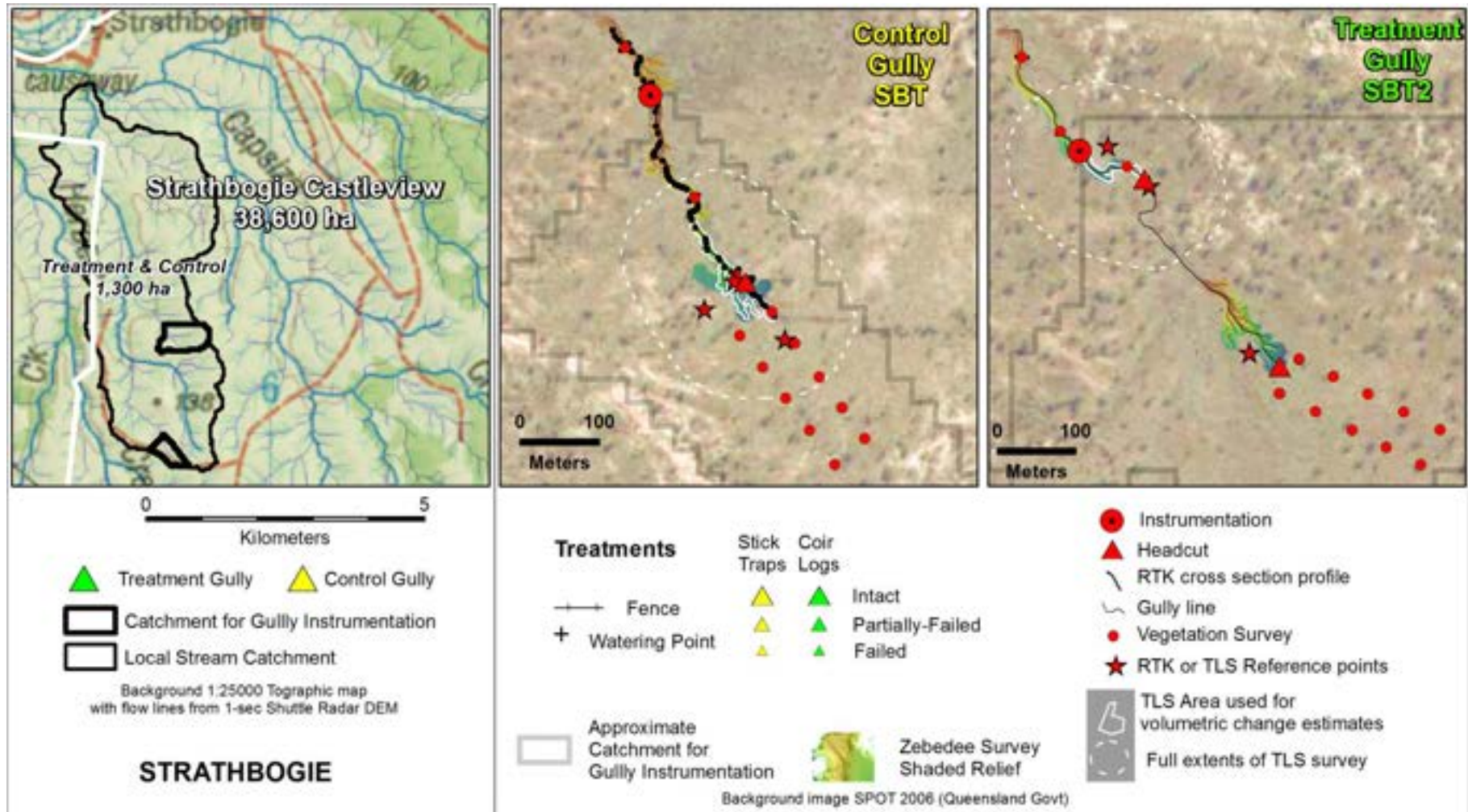


Figure 31: Location of Strathbogie site (left) and the Control and Treatment gullies. The location of the treatment structures and monitoring equipment/locations are shown.



(A)



(B)



(C)



(D)



(E)



(F)

Figure 32: Old Treatment (now control) gully at Strathbogie in (A) 2016 (B) during an event in 2017 (C) in April 2017 and (D) at the end of reporting period in April 2018 (E) during an event in 2019 and (F) at the end of January 2019

6.3.2 Vegetation response

Figure 33 presents the end of wet season % cover and biomass data for the hillslope above the control and treatment gully at Strathbogie as well as the gully walls and gully floor. There has been no treatment at this site, therefore we were not expecting any differences in the data between control and treatment site. Interestingly, there was a significant difference ($p=0.043$) in the hillslope biomass data between the control and treatment sites in 2018/19 (Figure 33D). This demonstrates how variable these sites can be even in the absence of a treatment, which again highlights the critical need of pre-treatment data where-ever possible.

There is considerable variability within and between the treatment and control values for the gully wall and channel data particularly for early years, again highlighting how different these sites can be in the absence of a treatment. Overall, for the 2018/19 wet season there is no significant difference in the cover or biomass metrics within the gully (channel or walls).

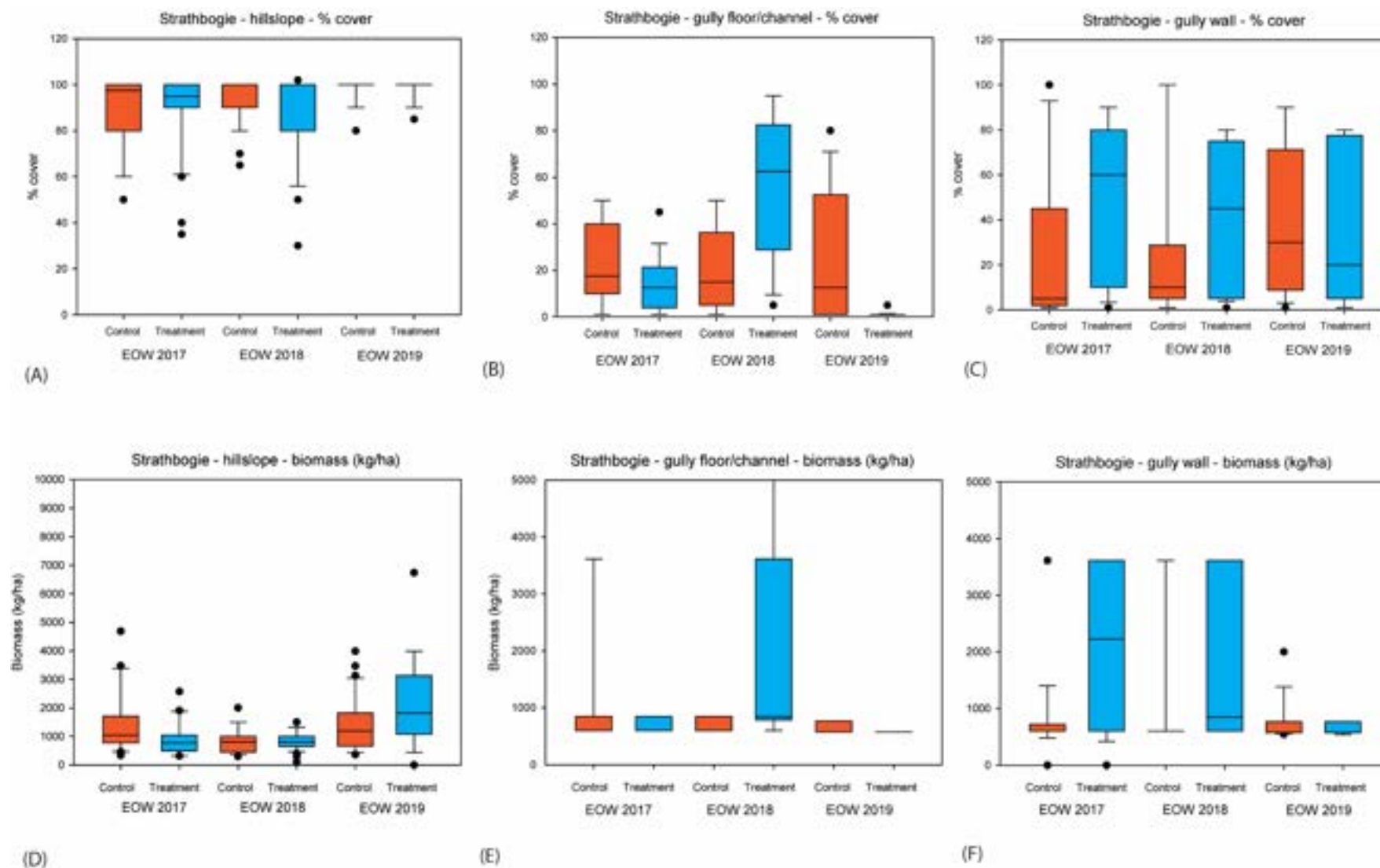


Figure 33: Strathbogie control and treatment sites showing the changes in % cover on the (A) hillslope, (B) gully floor/channel and (C) gully walls, and change in pasture biomass (kg/ha) on the (D) hillslope, (E) gully floor/channel and (F) gully walls over the three year NESP TWQ Hub study period. Extreme outlier data were excluded at some sites for plotting purposes. Noting that no treatment have yet been applied at this site, no changes were expected.

6.3.3 Terrain changes

The terrain analysis results obtained using the terrestrial laser scanner (TLS) were presented in Table 9 and Table 10. The volumetric change in sediment erosion and deposition between the treatment and control site is presented in Figure 34.

The results demonstrate that the amount of sediment lost from the head-cut area is much higher at the treatment site compared to the control. The treatment gully has a net loss of sediment (erosion minus deposition) of 2.58 t/m/y compared to 1.04 t/m/y for the control. This again highlights how variable the erosion rates can be for different gullies in the same landscape. Interestingly, the proportion of the eroded sediment being deposited or trapped at this site is very low being ~ 9% at the control site and <1% at the treatment site. This suggests that without active treatment, these gullies undergo very little natural trapping or deposition of the relatively fine (<4 μm) sediment.

Figure 35 presents the TLS results including the DEMs of Difference which show the dominant locations of the erosion. Unlike some of the other sites that were dominated by erosion only in the head-cut section, these sites had erosion in the head-cut, but also on the walls of the gully. The linear head-cut growth of the treatment site is on average 18.00 m/y (Table 9) with a massive 28 m of erosion in the 2018/19 wet season alone. Both sites have had their largest head-cut retreat in 2018/19 which coincides with the some of the largest 2-3 day rainfall totals in the region for many decades.

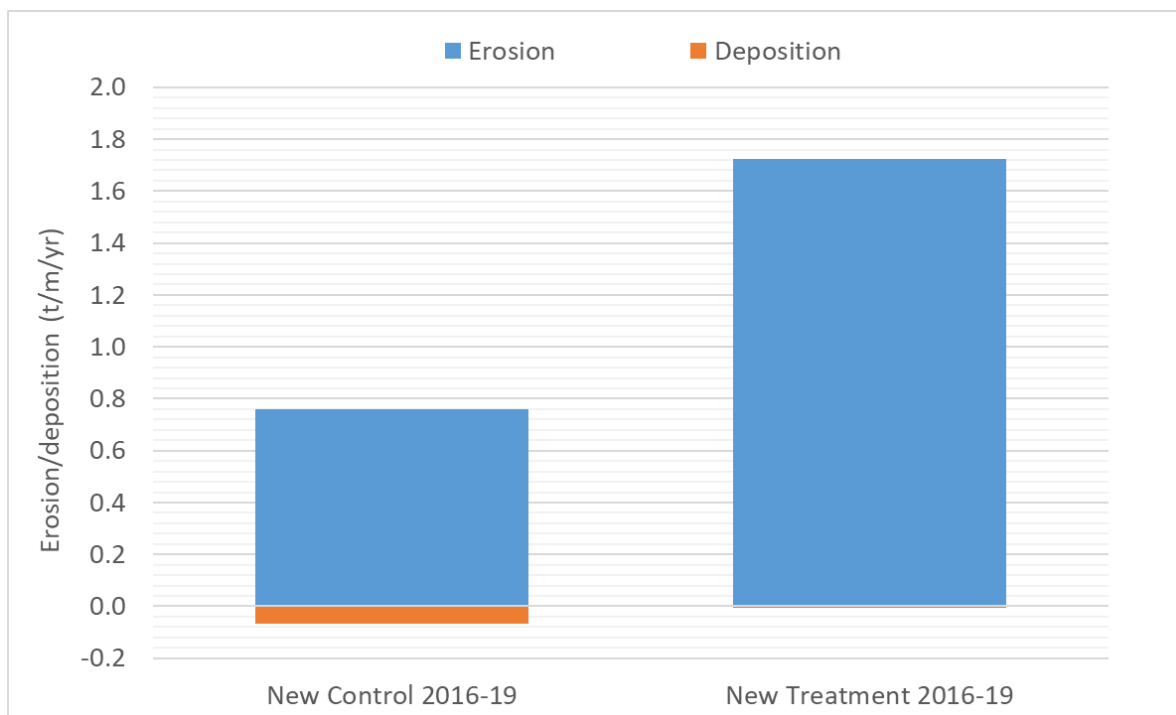


Figure 34: Net sediment movement (tonnes per metre surveyed per year, t/m/y) for Strathbogie (using a measured soil bulk density of 1.27 t/m³) for the 2016-19 period. Erosion is represented by positive (+ve) values and deposition negative (-ve) values.

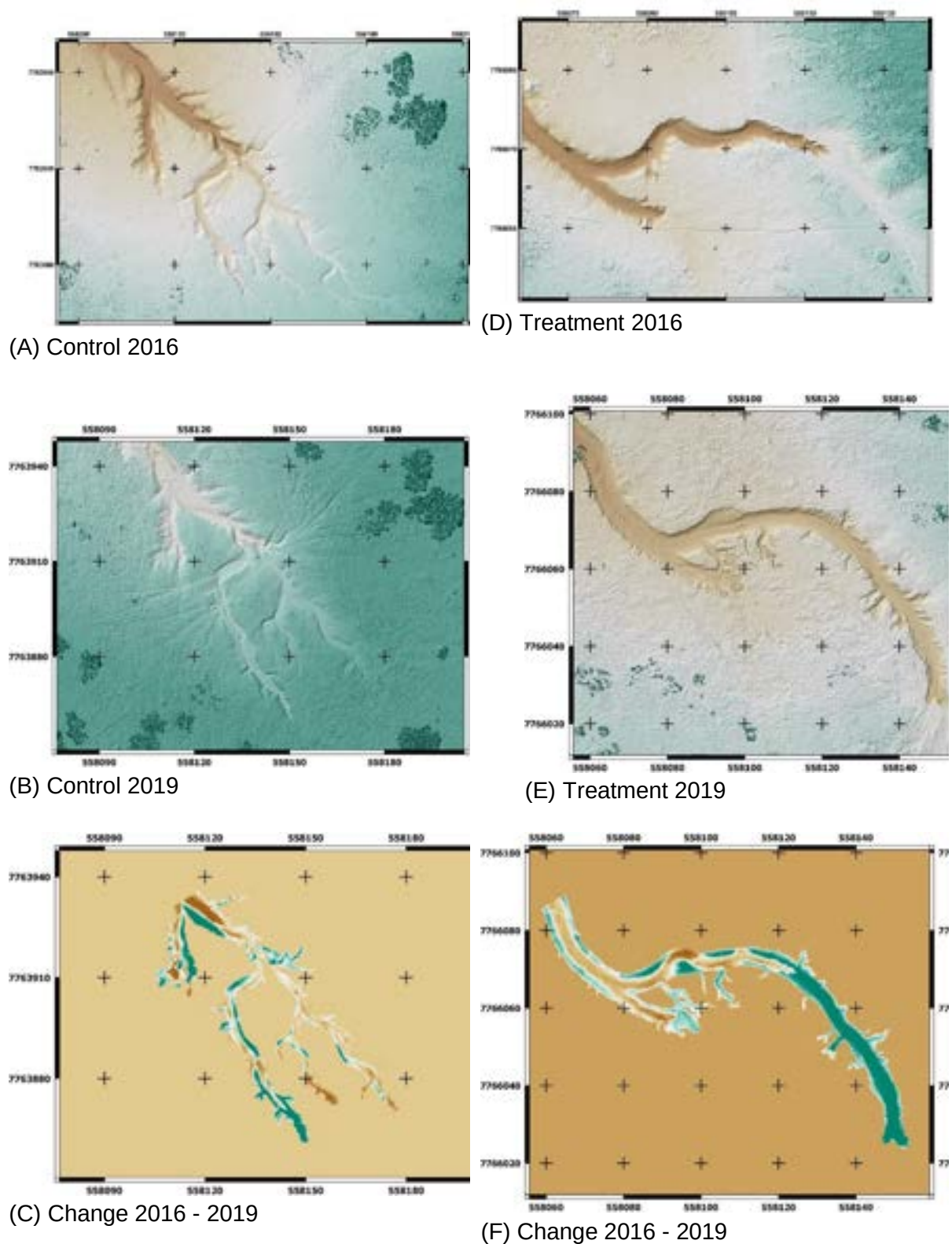


Figure 35: Strathbogie (A) control gully in 2016 (B) control gully in 2019 and (C) DEM of Difference; (D) treatment gully in 2016, (E) treatment gully in 2019 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is erosion and brown is deposition.

6.3.4 Water quality, runoff and loads

As discussed in Section 4.6, being able to evaluate trend changes over time generally requires pre-treatment data to confidently determine whether a treatment has had an effect independent of any natural or climatic variability between sites. We have water quality and loads data prior to the installation of the PCD's at both the treatment and control sites at Strathbogie. This means that a complete BACI analysis will be possible at this site following treatment.

The TSS and TN concentration data from 2018/19 is the most robust as this is when the second ISCO system was installed at the new treatment site. During 2018/19 there is no statistically significant difference in the TSS or TN concentrations measured at this site (Figure 36).

This was the first year that we have been able to present runoff, TSS and TN data for these sites (Figure 37). Noteworthy is the extreme rainfall variability in annual totals at this site with ~1320 mm of rainfall in 2018/19 compared to ~475 mm the previous year. Because of this rainfall and runoff variability, we have had several challenges with the monitoring instrumentation at this site, particularly in 2017/18 and 2018/19 when there was repeated burial (and re-excavation) of the monitoring equipment (see Figure 32C and F). Consequently, no data was presented for either site in 2017/18 and the 2018/19 is considered preliminary and we hope to improve this estimate with additional velocity data in 2019/20.

Despite the instrument challenges, the TSS and TN loads at the treatment site generally follow the rainfall trend with an increase in loads in 2018/19 compared to other years, and the TSS and TN loads being higher at the very active treatment gully, compared to the control gully.

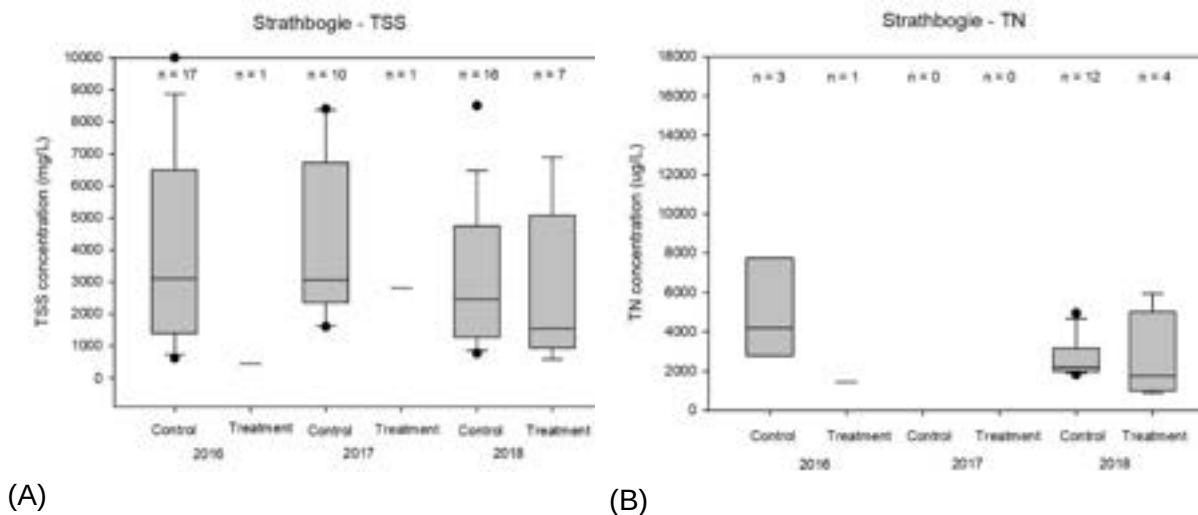


Figure 36: (A) TSS concentration and (B) TN concentrations at Strathbogie for two wet season.

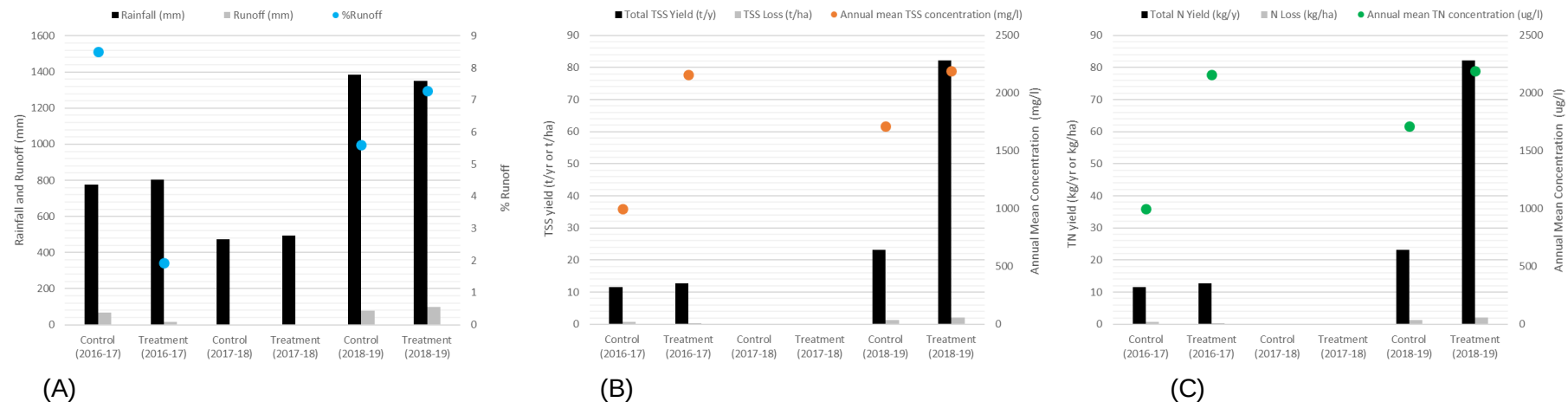


Figure 37: Strathbogie Control and Treatment results for (A) Rainfall, runoff and % runoff (B) Total Suspended Sediment (TSS) loads (t/y and t/ha) and annual average TSS concentration (mg/L) and (C) Total Nitrogen (TN) loads (kg/y and kg/ha) and annual average TN concentration (ug/L). No loads data is presented in 2017/18 due to instrument issues. **NOTE: these data are considered preliminary and will be updated with additional data next year (see data quality caveats in Appendix B).**

6.3.5 Summary: Strathbogie

Figure 15 is an attempt to synthesise all the data sets that have been collected at the site into a summary report card. As there is yet no treatment at this site, the report card will be completed in 2019/20.

Table 15: Summary of the (potential) treatment effects at the Strathbogie site (3 years of treatment data).

Green suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. **Na** means data not yet available.

PROPOSED TREATMENT: Fencing, rock chute and PCD's + water diversion.		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %		√	There is pre-treatment data for both sites and so a BACI design will be possible at this site (assuming adequate velocity and water quality data is collected)
	Hillslope biomass (kg/ha)		√	
	Gully floor/channel – cover %		√	
	Gully floor/channel – biomass (kg/ha)		√	
	Gully walls – cover (%)		√	
	Gully walls – biomass (kg/ha)		√	
Terrain/erosion	Erosion (t/m/y)		√	
	Deposition (t/m/y)		√	
	Net change (t/m/y)		√	
Runoff, water quality and loads	TSS conc. (mg/L)		√	
	TN conc. (ug/L)		√	
	TSS Loads (t/ha)		√	
	TN Loads (kg/ha)		√	
	TSS EMC (mg/L)		√	
	TN EMC (ug/L)		√	
	Runoff (mm)		√	
	% Runoff		√	

6.4 Minnievale

6.4.1 Treatment progress

The Minnievale site is a Reef Trust 2 gully remediation site being managed by Greening Australia. The main treatment gully has been fenced off (~4 km of fencing). A total of 135 within gully structures were 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 38). 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 in 2017 (Figure 38 and Figure 39).

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 (exact numbers are pending).



Figure 38: (A) Example of the stick traps installed at MinnieVale station and (B) measurements of the vegetation cover and biomass behind the stick straps at this site in April 2019.

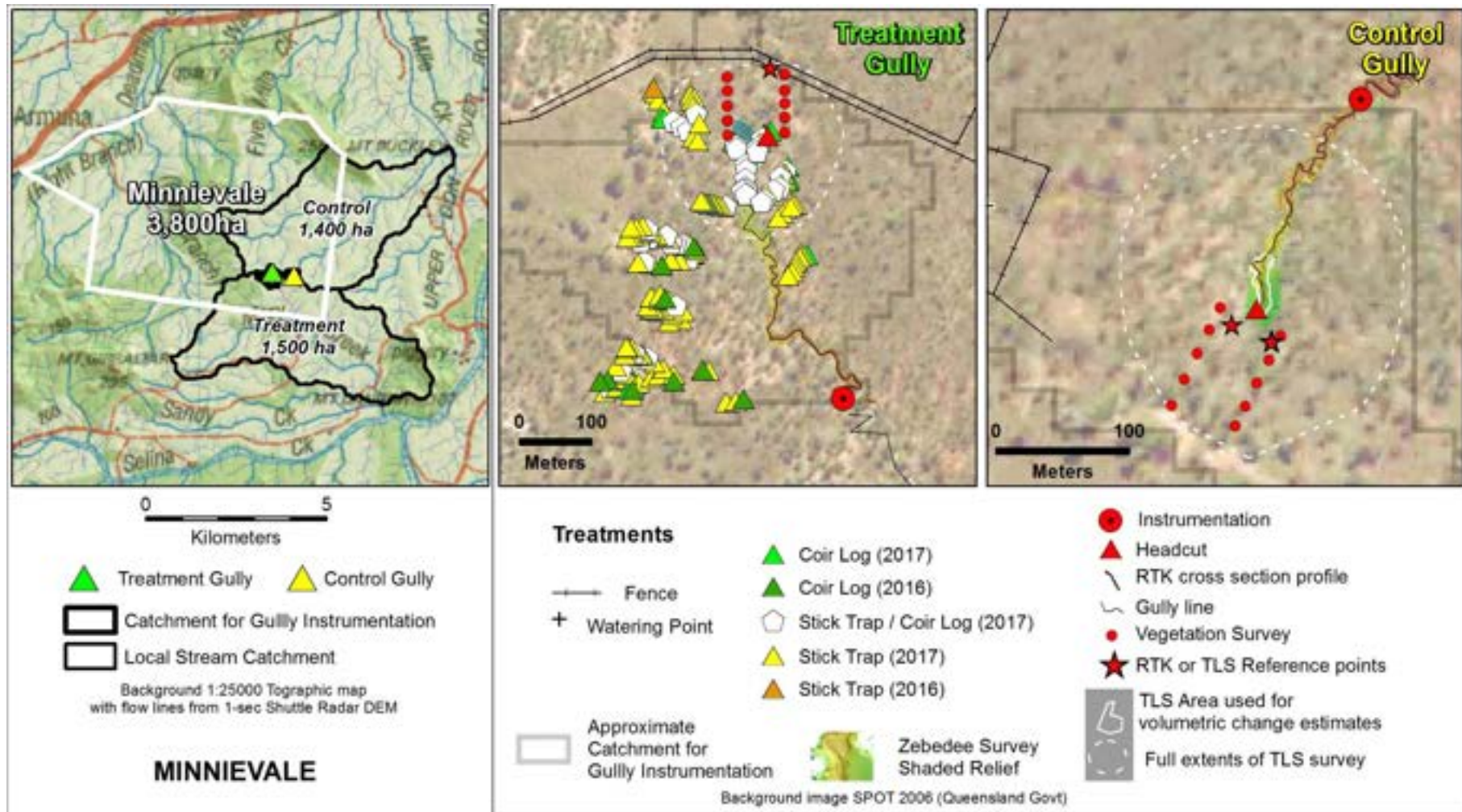


Figure 39: Location of Minnievale site (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations for the 2017/18 wet season are shown. Note the changes to the location and type of structures at this site from the previous wet season.



(A)



(B)



(C)



(D)



(E)



(F)

Figure 40: Treatment gully at MinnieVale in (A) 2016 (B) during an event in 2017 (C) in April 2017 and (D) at the end of reporting period in April 2018 (E) during an event in Dec 2018 and (F) after the event in December 2018.

6.4.2 Vegetation response

Figure 42 presents the end of wet season % cover and biomass data for the hillslope above the control and treatment gully at Minnievale, as well as for the gully walls and gully floor. The results show that there has been a general upward trend of the % ground cover on the hillslope and on the gully walls, however, this change has been at both the treatment and control sites. Therefore, this change is likely to be strongly related to rainfall patterns, unless the landholder has been reducing stock access in the control paddock as well as treatment paddock (we don't currently have that information). The biomass data continues to follow the significant differences between the control and treatment site observed in 2017/19 with significantly more biomass (kg/ha) on the treatment hillslope ($p < 0.001$), on the gully floor ($p = 0.04$) and gully walls ($p < 0.001$) compared to the control (Figure 41).



Figure 41: Increased biomass at the Minnievale treatment site in 2018/19

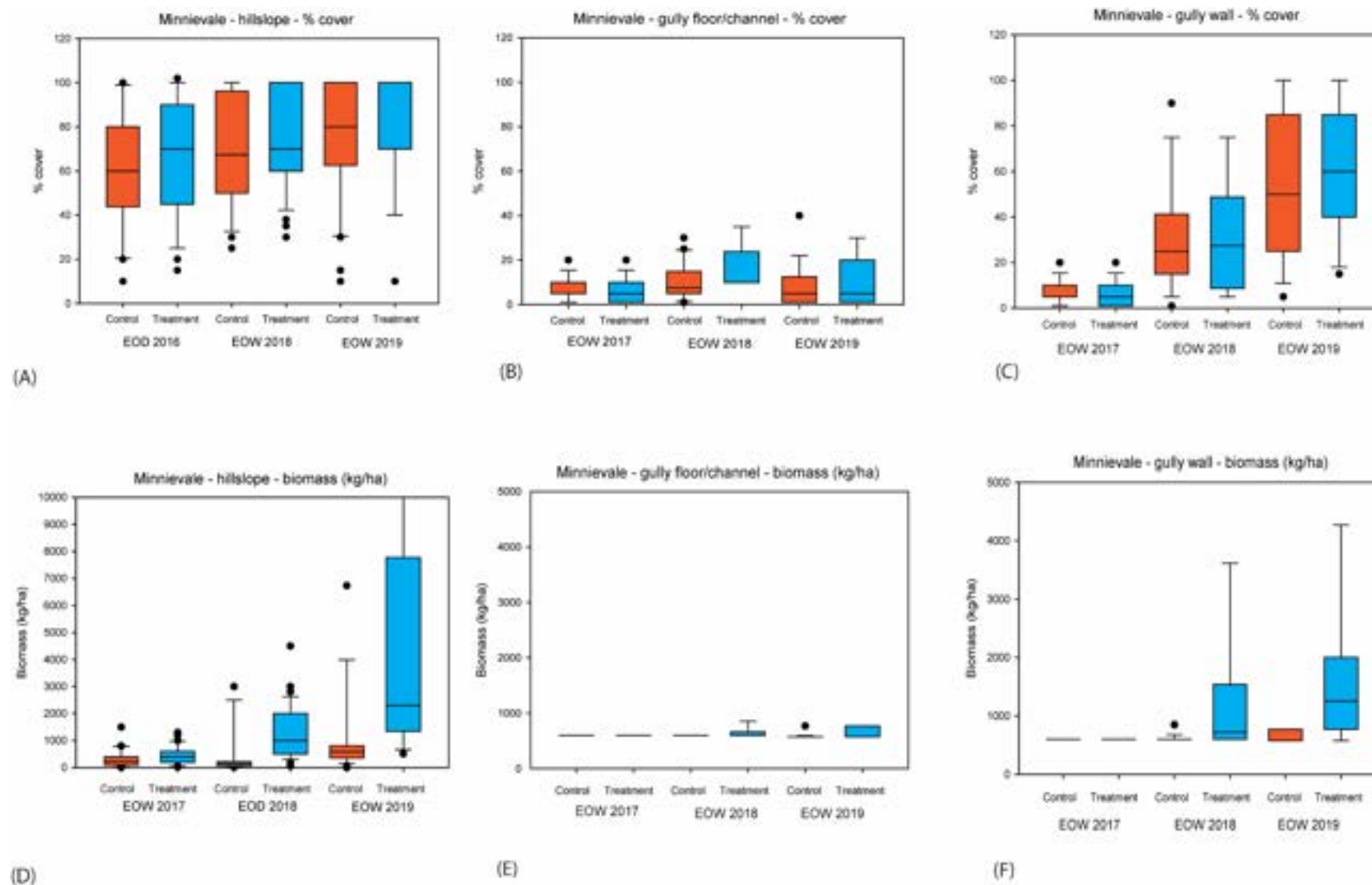


Figure 42: Minnievale control and treatment sites showing the changes in % cover on the (A) hillslope, (B) gully floor/channel and (C) gully walls, and change in pasture biomass (kg/ha) on the (D) hillslope, (E) gully floor/channel and (F) gully walls over the three year NESP study period. Note extreme outlier data were excluded at some sites for plotting purposes.

6.4.3 Terrain changes

The terrain analysis results obtained using the terrestrial laser scanner (TLS) were presented in Table 9 and Table 10. The volumetric change in sediment erosion and deposition between the treatment and control site is presented in Figure 43.

The results demonstrate that the amount of sediment lost from the head-cut area of the treated gully (0.15 t/m/y) is almost half that of the control gully (0.26 t/m/y). At the control site, ~35% of the sediment is being trapped or stored in the gully. Interestingly, in the treatment gully more than 100% of that sediment is being trapped by the check dam structures. The fact that more sediment is being trapped than was eroded from the gully, suggests these structures are also trapping sediment that has come in off the hillslope.

Figure 44 presents the TLS results including the DEMs of difference which show the dominant locations of the erosion (mainly the head-cuts) and the deposition areas. The 3-year linear head-cut growth of the treatment site is on average 0.24 m/y (Table 9) which is ~25% of the control site rate of 0.83 m/y. The treatment site has consistently had lower head-cut retreat rates over the study period, but in 2018/19 the retreat rate of the treatment gully (0.11 m/y) was ~10% of the control site (1.16 m/yr) (Table 9). The large amount of deposition behind the check dams can be observed in the left arm of the treatment site (Figure 44F).

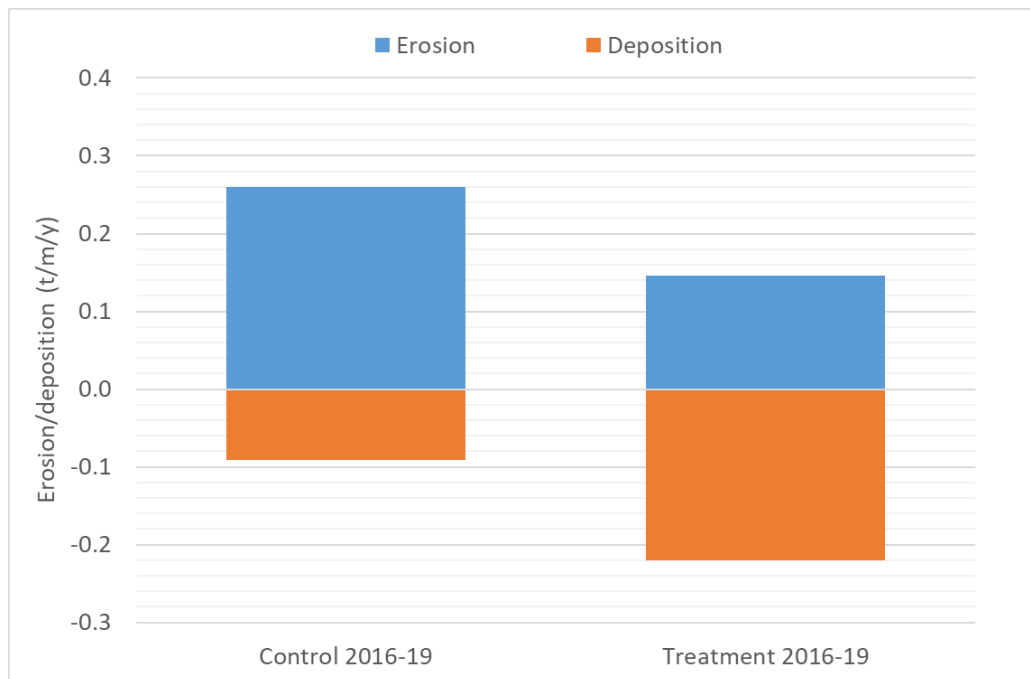


Figure 43: Net sediment movement (tonnes per metre surveyed per year, t/m/y) for Minnievale (using a measured soil bulk density of 1.5 t/m³) for the 2016-19 period. Erosion is represented by positive (+ve) values and deposition negative (-ve) values.

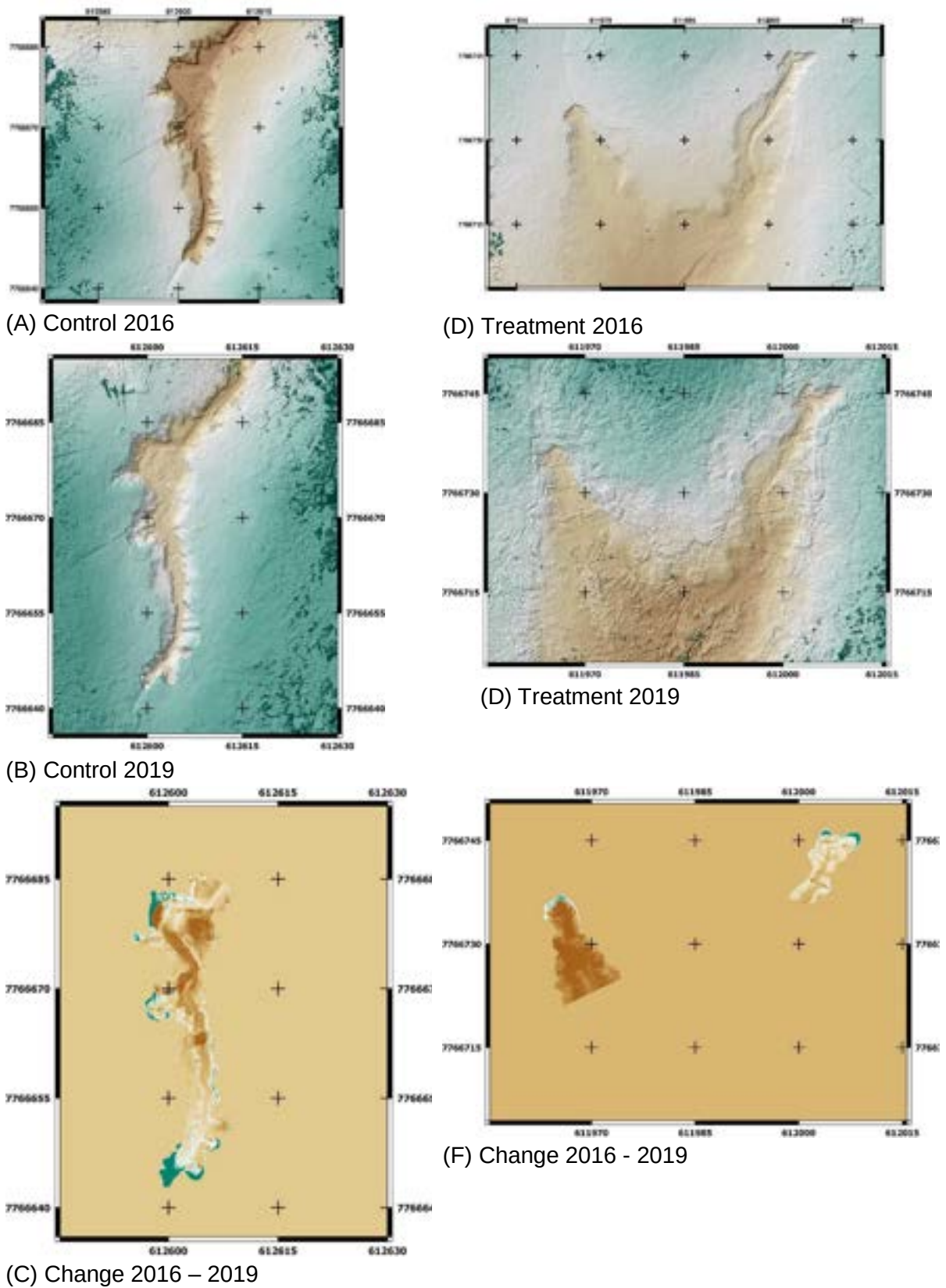


Figure 44: Minnievale (A) control gully in 2016 (B) control gully in 2019 and (C) DEM of Difference; (D) treatment gully in 2016, (E) treatment gully in 2019 and (C) DEM of Difference as measured by the RIEGL terrestrial laser scanner, where dark green is erosion and brown is deposition.

6.4.4 Water quality, runoff and loads

As discussed in Section 4.6, being able to evaluate trend changes over time generally requires pre-treatment data to confidently determine whether a treatment has had an effect independent of any natural or climatic variability between sites. We don't have any water quality and loads data prior to the installation of the PCD's at the Treatment site as there was considerable pressure to install the remediation projects at the Reef Trust 2 sites as quickly as possible. Hence no before treatment period is available. This reduces the statistical approaches that can be applied at the Minnievale site.

Despite the TSS concentrations between the treatment and control sites at Minnievale being statistically significant in 2016/17 and 2017/18 wet seasons, this year this effect was not significant ($p = 0.066$), although the median concentrations for TSS were much lower at the treatment site (~1270 mg/L) compared to the control site (4430 mg/L) (Table 12). The rainfall at the treatment and control sites was similar between in 2018/19, however, preliminary estimates suggest that the amount of runoff was much greater at the treatment site (Figure 46A). The flow adjusted annual mean TSS and TN concentrations (which is the total load divided by runoff) at the treatment site was lower in all years compared to the control site (Figure 46 B and C).

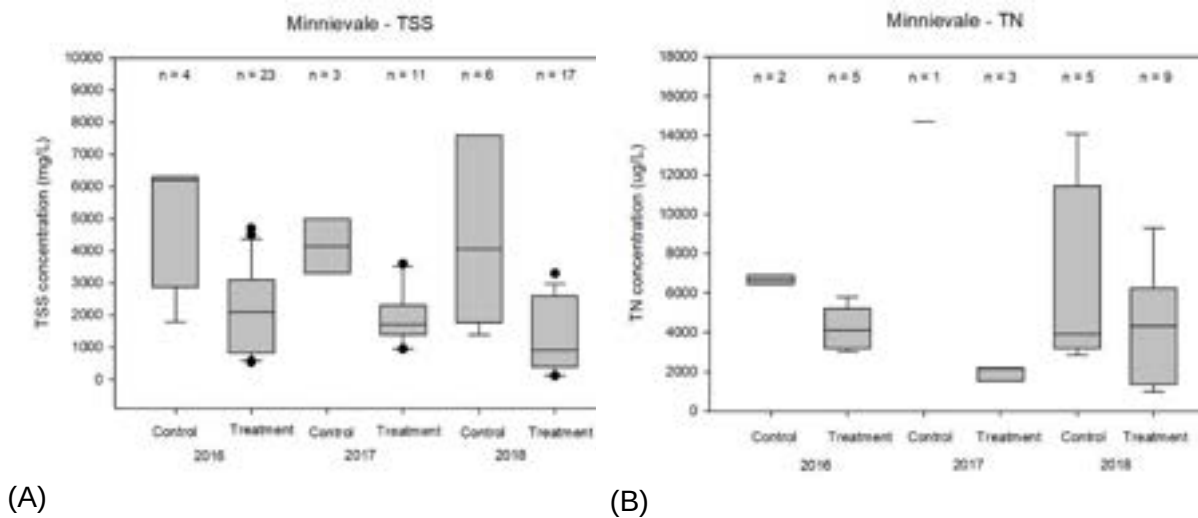


Figure 45: (A) TSS concentration and (B) TN concentrations at Minnievale for two wet seasons

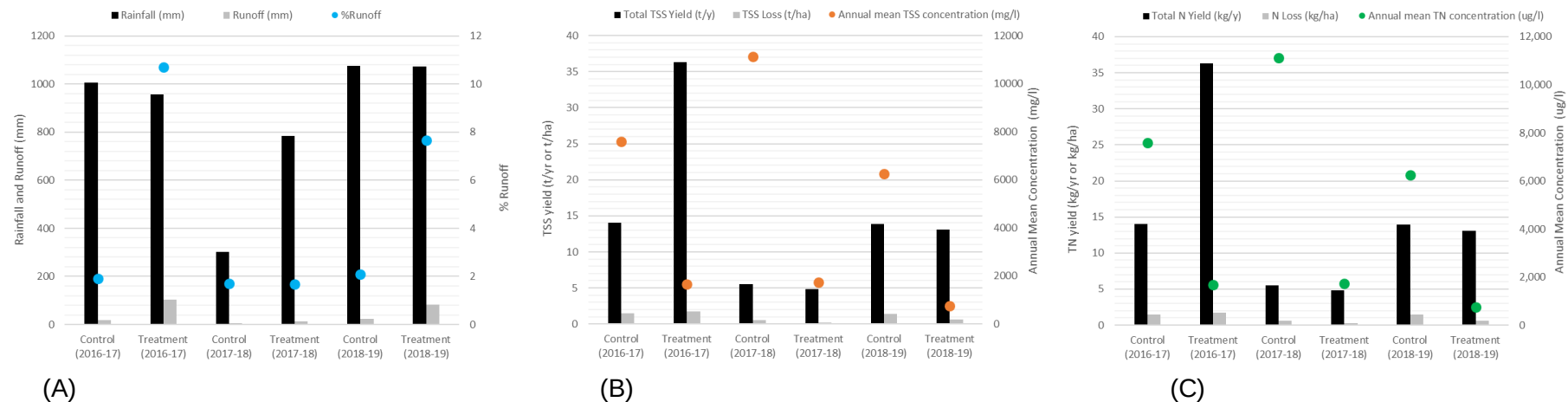


Figure 46: Minnievale Control and Treatment results for (A) Rainfall, runoff and % runoff (B) Total Suspended Sediment (TSS) loads (t/y and t/ha) and annual average TSS concentration (mg/L) and (C) Total Nitrogen (TN) loads (kg/y and kg/ha) and annual average TN concentration (ug/L). NOTE: these data are considered preliminary and will be updated with additional data next year (see data quality caveats in Appendix B).

6.4.5 Summary: Minnievale

Table 16 is an attempt to synthesise all the data sets that have been collected at the site into a summary report card. The most accurate method for evaluating change is using a BACI design which requires pre-treatment data at both a control and treatment sites. Because no data was collected at either site prior to the implementation of the treatment, a BACI design will not be possible for this site.

Overall, despite not having pre-treatment data at, most of the indicators suggest that the remediation is having a positive effect on the treatment gully. The % of ground cover has improved at both the control and treatment sites over the study period, and the increase in biomass (on the hillslope and within the gully channel and walls) at the treatment site is significantly greater than the control. The amount of head-cut erosion has declined at the treatment gully over time, whereas the control site had its highest retreat rate in 2018/19. The proportion of sediment being trapped or stored in the treatment gully was >100% in 2018/19 compared to ~35% at the control site. The increase in biomass, in conjunction with the stick trap structures, has significantly improved the TSS and TN flow adjusted annual mean concentration (FAAMC) at the treatment site compared to the control.

Table 16: Summary of the treatment effects (Fencing and PCD's) at the Minnievale site (3 years of treatment data). **Green** suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. **Na** means data not yet available.

TREATMENT: Fencing only (with long term cattle enclosure above the treatment)		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %	Orange	Grey	There is no pre-treatment data for either the treatment and control sites
	Hillslope biomass (kg/ha)	Green	Grey	
	Gully floor/channel – cover %	Orange	Grey	
	Gully floor/channel – biomass (kg/ha)	Green	Grey	
	Gully walls – cover (%)	Orange	Grey	
	Gully walls – biomass (kg/ha)	Green	Grey	
Terrain/erosion	Erosion (t/m/y)	Orange	Grey	
	Deposition (t/m/y)	Green	Grey	
	Net change (t/m/y)	Orange	Grey	
Runoff, water quality and loads	TSS conc. from samples (mg/L)	Orange	Grey	
	TN conc. from samples (ug/L)	Orange	Grey	
	TSS Loads (t/ha)	Orange	Grey	
	TN Loads (kg/ha)	Green	Grey	
	TSS - Flow adjusted annual mean conc. (FAAMC) (mg/L)	Green	Grey	
	TN Flow adjusted annual mean conc. (FAAMC) (ug/L)	Green	Grey	
	Runoff (mm)	Orange	Grey	
	% Runoff	Orange	Grey	

6.5 Mt Wickham

6.5.1 Treatment progress

Mt Wickham was a new site added in 2017/18. The water quality monitoring equipment was installed on 21st February 2018, and pasture and biomass surveys were initiated in August 2018. 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 (Figure 47). 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 TWQ Hub sites. For consistency, the results of that project are presented alongside the other NESP TWQ Hub sites.

The remediation of the treatment site commenced on the 22nd of October 2018 following the site plan completed by Verterra and Alluvium consulting services (Figure 48). The remediation plan involves a combination of grade control rock chutes, re-contouring of the badland area, soil amelioration using a range of chemical treatments and revegetation using a range of pasture and legume species (Figure 50). Phase II of the on-ground works is planned for the beginning of the dry season in 2019. Further works will include remediation of the untreated gullies on the western side of the main gully channel. Involving excavating, reshaping, ameliorating and construction of rock chutes. Images of the control and treatment water quality monitoring equipment before, during and after events in the 2018/19 wet season are shown in Figure 52.



Figure 47: (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.

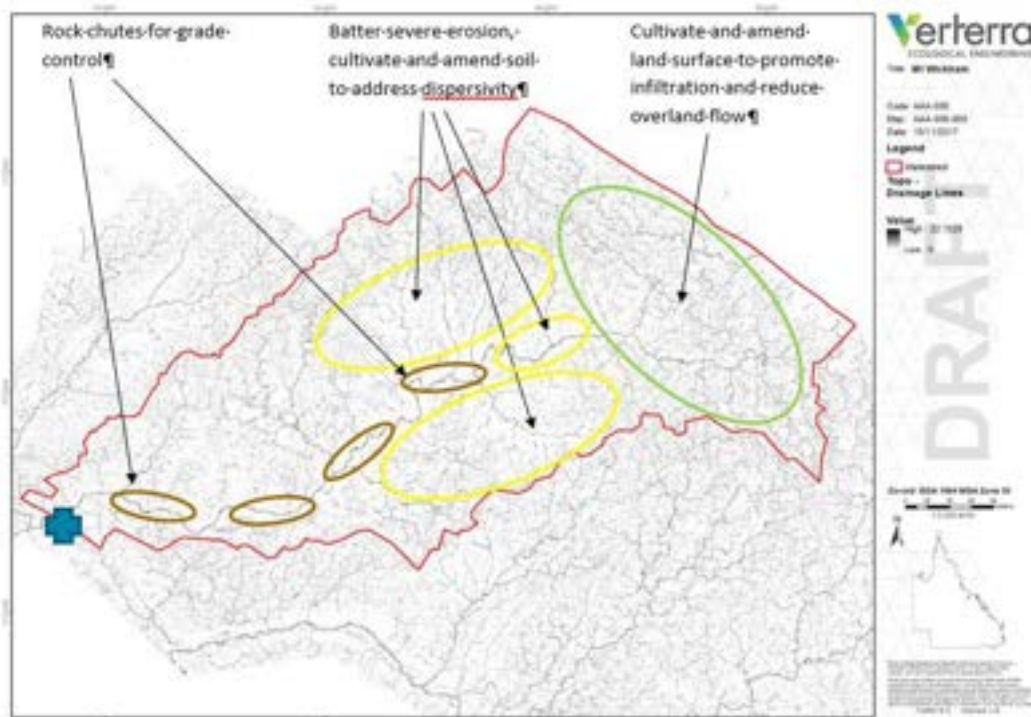


Figure 48: Mt Wickham planned erosion control activity (Source: Verterra, 2018)



Figure 49: Image taken during sample collection for the January/February rainfall event (Photo credit: Damon Telfer). Note the area under the gully 1A text with little vegetation as a result of works to repair holes and tunnel erosion following the heavy rainfall in July (Source: NQ Dry Tropics)



(A)



(B)



(C)

Figure 50: (A) Gully 1A during excavation, looking across the gully towards Blue Valley Road (B) Rock chute 5 looking upstream in the main gully; (C) Gully 1A being ripped with harrows. Looking towards the outlet (Source: NQ Dry Tropics).

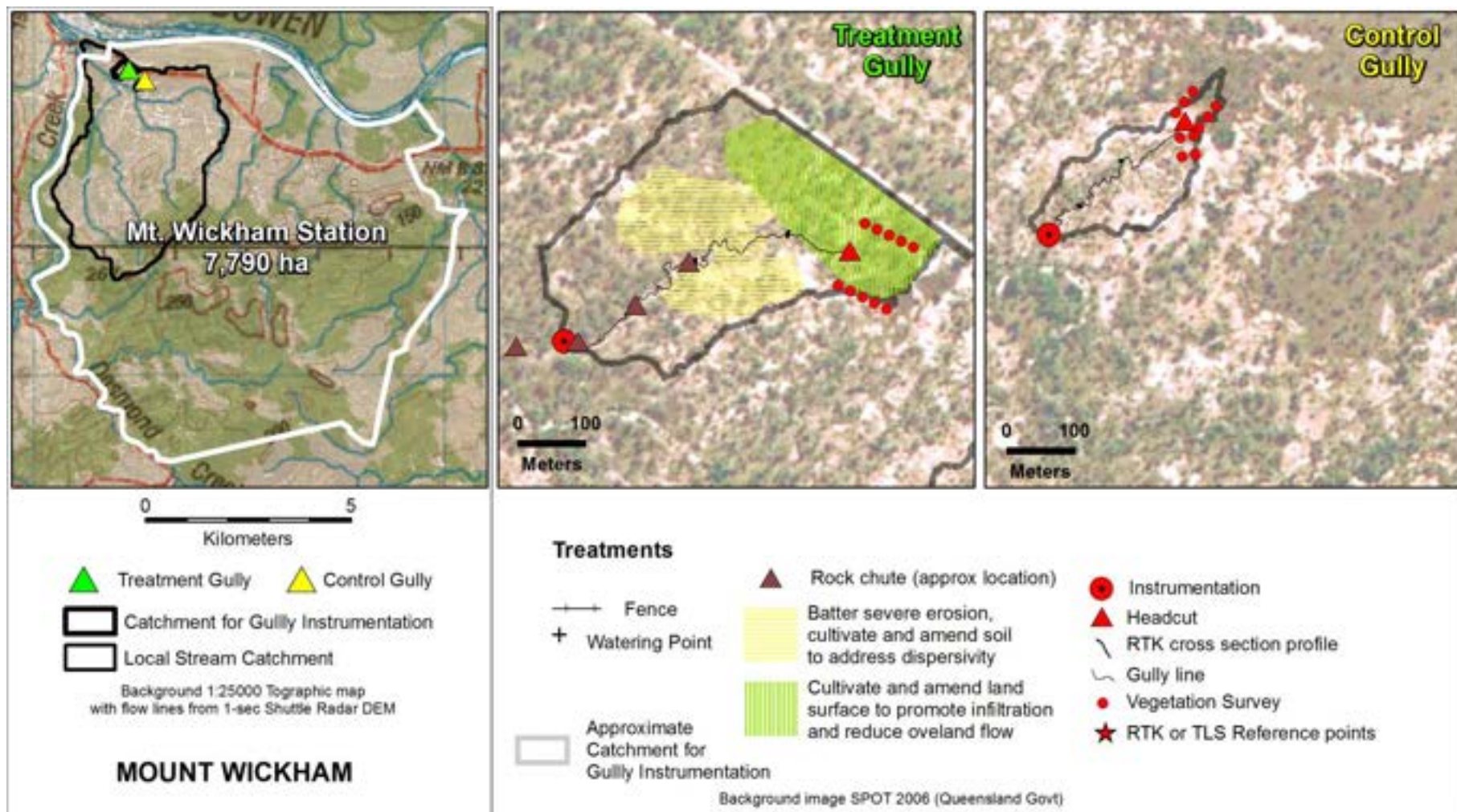


Figure 51: Location of the Mt Wickham (left) and the Treatment and Control gullies. The location of the treatment structures and monitoring equipment/locations are shown.

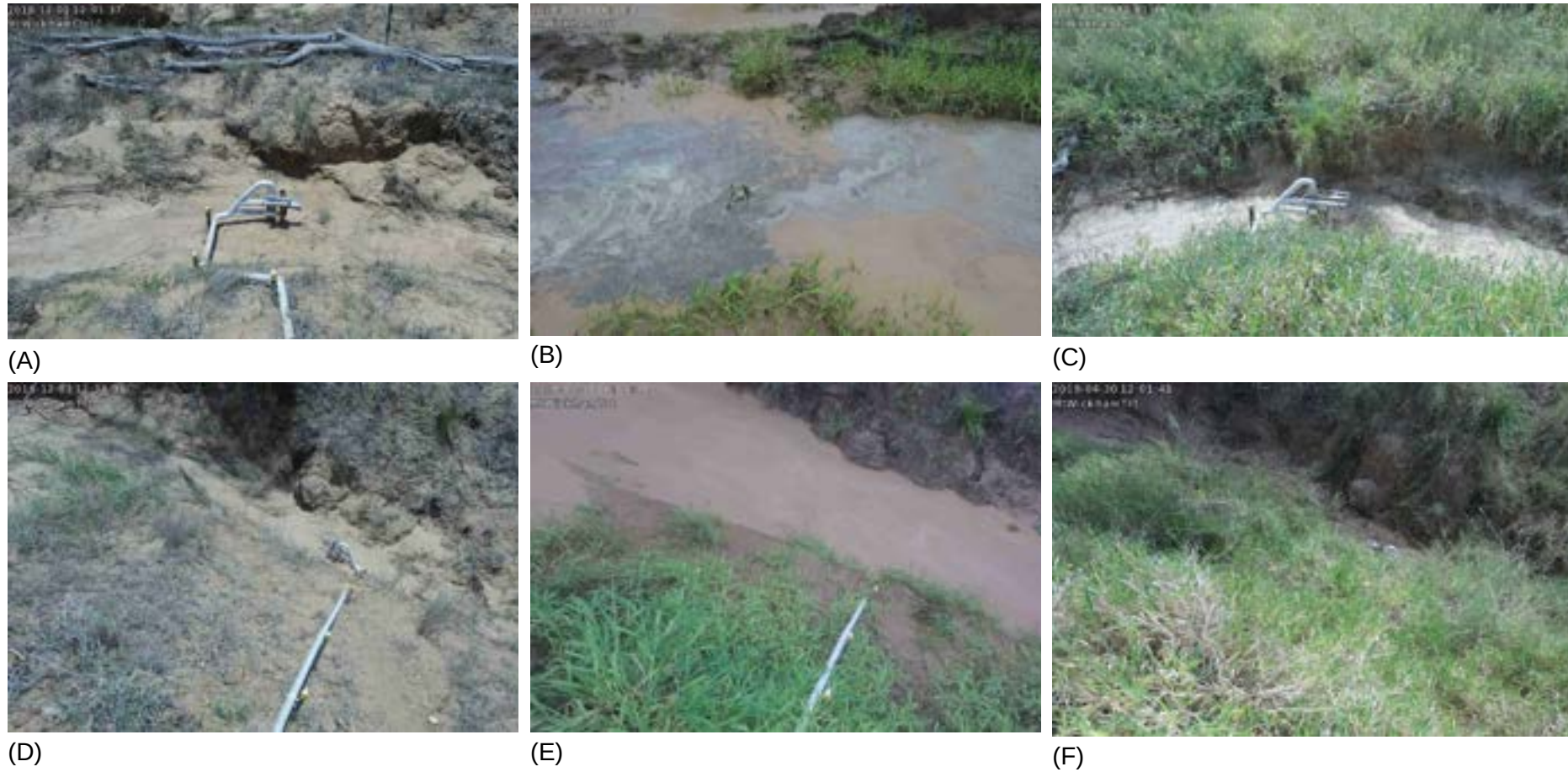


Figure 52: Mt Wickham Control gully (A) before (B) during and event in Dec 2018 and (C) April 2019. Mt Wickham Treatment gully (A) before (B) during and event in Dec 2018 and (C) April 2019.

6.5.2 Vegetation response

The data have been presented in the same format as the other NESP TWQ Hub sites, acknowledging that the vegetation data collection did not commence at this site until August 2018. Figure 53 presents the end of wet season % cover and biomass data for the hillslope above the control and treatment gully at Mt Wickham as well as the gully walls and gully floor.

At the end of the 2017/18 wet season, there was a significant difference in the hillslope % cover, with cover being significantly less on the treatment than the control site ($p < 0.001$). There was also higher % cover on the gully walls at the treatment site than the control site ($p = 0.019$). In 2018/19, following treatment, the treatment hillslope now has significantly greater % cover ($p < 0.001$) and biomass ($p < 0.001$) than the control hillslope (Figure 53A and D).

There are also significant increases in gully wall cover ($p < 0.004$) and biomass ($p < 0.007$). There is no difference the gully floor/channel cover ($p < 0.860$) and biomass ($p < 0.163$), which is not unexpected as the sediment trapping treatment structures have yet to be installed in the lower section of the gully near the instrumentation. The channel also underwent significant scour during the 2018/19 wet season.

The more robust Two-way ANOVA was performed on the hillslope and gully wall cover and biomass data. These data were not normally distributed, and transformation did not normalise the data. There was a statistically significant interaction between the pre and post treatment data (time) between the control and treatment sites (location) for the hillslope biomass ($p < 0.001$) and both gully wall % cover ($p = 0.014$) and biomass ($p = 0.004$) data, but not for hillslope % cover.

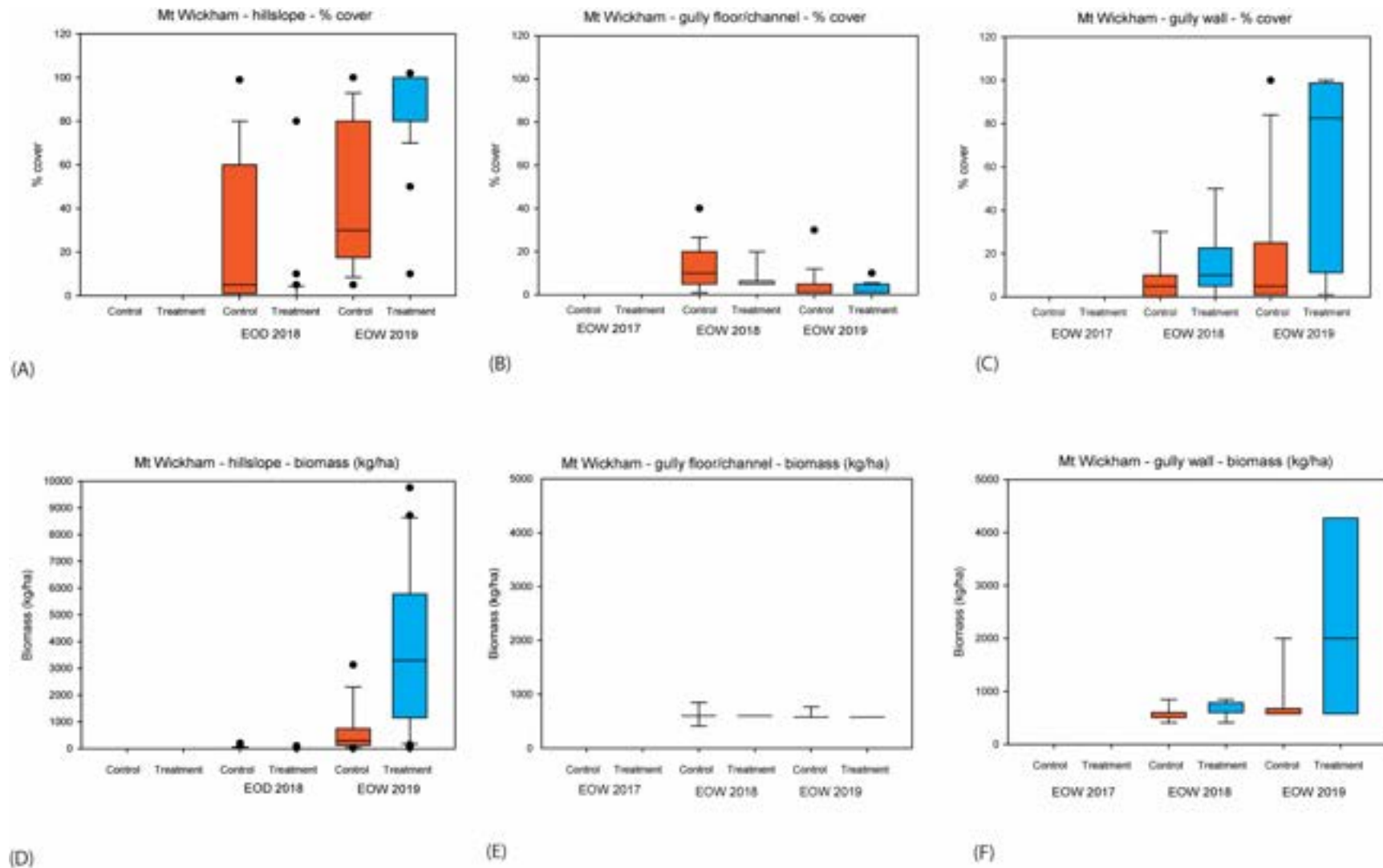


Figure 53: Mt Wickham control and treatment sites showing the changes in % cover on the (A) hillslope, (B) gully floor/channel and (C) gully walls, and change in pasture biomass (kg/ha) on the (D) hillslope, (E) gully floor/channel and (F) gully walls over the three year NESP TWQ Hub study period. Note extreme outlier data were excluded at some sites for plotting purposes.

6.5.3 Terrain changes

CSIRO and the NESP TWQ Hub project have not been responsible for the terrain analysis comparisons at this site, so there are no terrain data to report on for the Mt Wickham site. It is understood that repeat lidar imagery will be collected in 2019 or 2020 which could be used to assess the changes in erosion, deposition and net sediment loss from this site.

6.5.4 Water quality, runoff and loads

In the 2018/19 wet season there was >1100 mm of rainfall at the site, which is considerably higher than the long-term average for this area (Figure 54). There was some slight backwatering at the flow sensors due one event at the control site. These data were removed from the flow analysis, however, the discharge estimates for this year are considered preliminary (see Appendix B). The sediment loads from Wickham are in the range of 160-180 t/y for the control and treatment sites, however, the unit area sediment yields are much lower at the treatment site (~12 t/ha/y) compared to the control (~53 t/ha/y). The unit area TN loads were lower on the treatment site, but the flow adjusted annual mean concentration of TN is still higher on the treatment site (Figure 54C).

Figure 55 shows the range of TSS and TN samples measured at Mt Wickham during a single small event at the control site in 2017/18 and a ~16 events in 2018/19 (see Appendix C). There was at least one event at both the treatment and control site prior to remediation works on the 22nd of October. In the single pre-treatment event there were 4 water quality samples collected at the control site and 16 samples at the treatment site (Figure 56A). These pre-treatment samples allowed for a BACI Two-way ANOVA to be conducted on the data. The results show that there is a significant difference between the control and treatment sites ($P < 0.001$), however, this effect is not significant at the 95% confidence level when sample time (pre and post treatment) is included ($P = 0.09$). This is because there has also been a reduction in TSS concentration at the control site, between 2017/18 and 2018/19, despite no active treatment. The data shows that the reduction in TSS concentration has been greater at the treatment site, however, additional data will be required from next wet season to assess whether this reduces further, independently of the control site.

Using the TSS samples on their own is less accurate (Figure 56A), however, a correlation of the TSS samples from direct lab measurement with the event mean concentrations (EMC, event load divided by runoff) values has an r^2 of 0.97 (data not shown). This analysis needs further testing, but it is hoped that in future years, lab results will be a good early indicator of remediation response. Loads analysis will still be needed, but results will take longer, and the correlation is not as strong as for nitrogen.

Using flow weighted event mean concentration (EMC) data for each event (Figure 56B) is the more robust method for comparing between treatments as it balances out differences in rainfall and runoff between the sites. However, there is an insufficient number of pre-treatment (before) events to undertake any statistical analysis using the EMC approach.

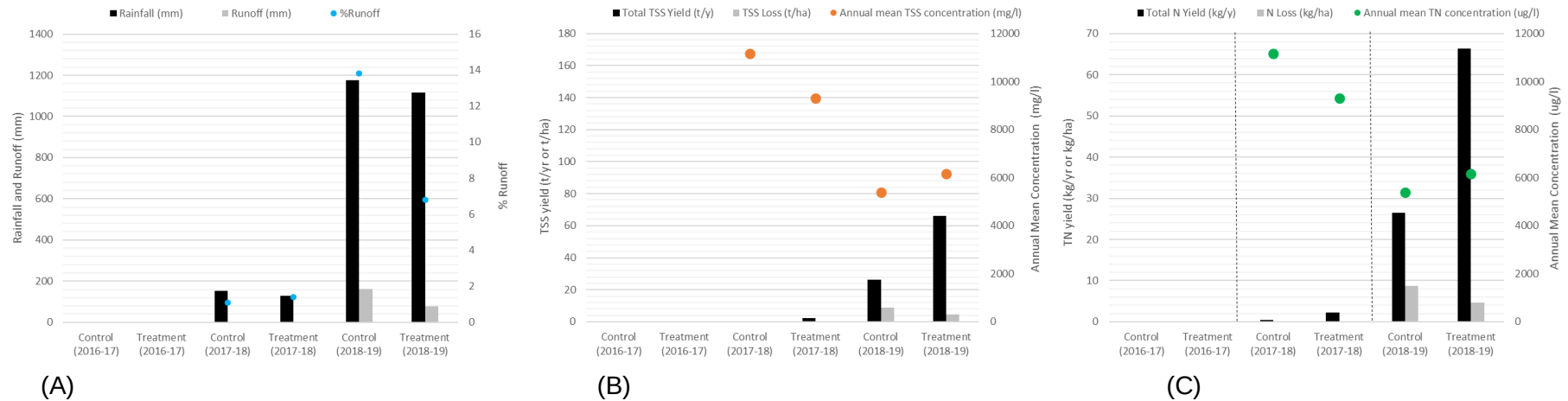
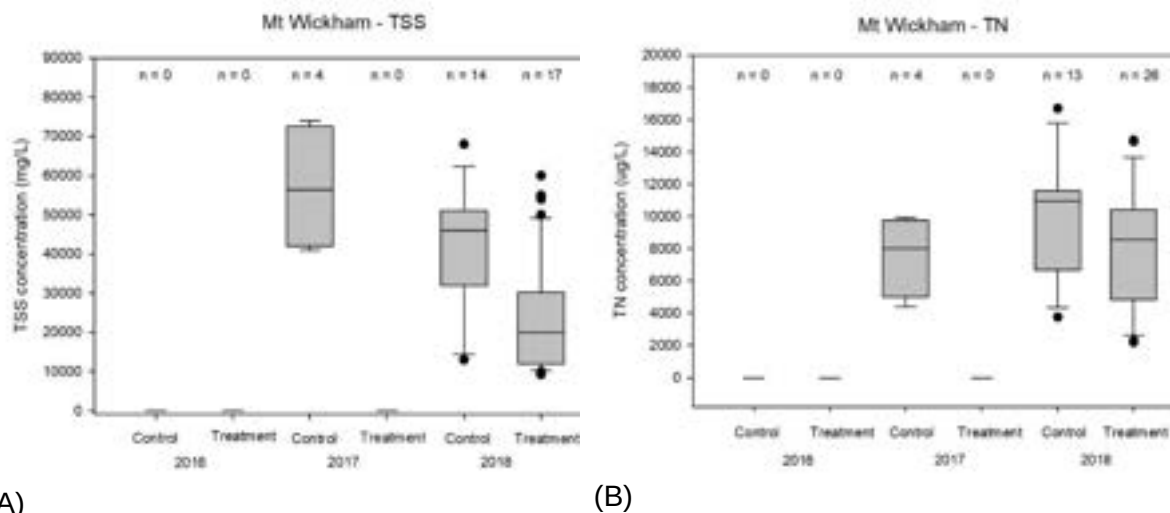
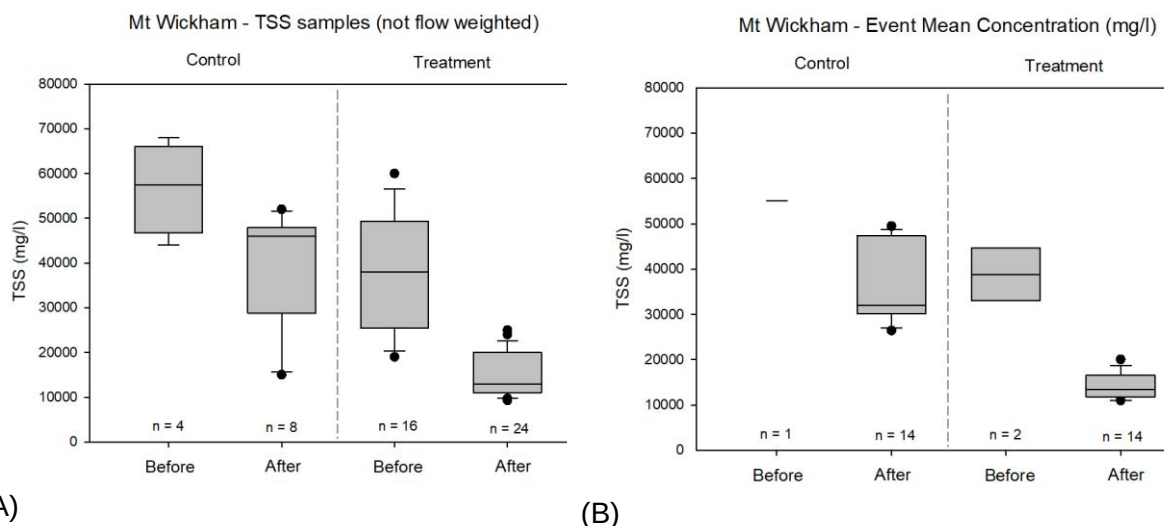


Figure 54: Mt Wickham Control and Treatment results for (A) Rainfall, runoff and % runoff (B) Total Suspended Sediment (TSS) loads (t/y and t/ha) and annual average TSS concentration (mg/L) and (C) Total Nitrogen (TN) loads (kg/y and kg/ha) and annual average TN concentration (ug/L). The 2017/18 data was for a single event only and not the entire wet season as instruments were installed in February 2018. **NOTE: these data are considered preliminary and will be updated with additional data next year (see data quality caveats in Appendix B).**



(A) (B)
Figure 55: (A) TSS concentration and (B) TN concentrations at Mt Wickham for two wet seasons (noting 2017/18 was for single late wet season event). No samples were collected in 2016/17 or at the treatment site in 2017/18.



(A) (B)
Figure 56: Mt Wickham TSS data from the 2018/19 wet wet season before and after remediation works (treatment). Graph (A) is the TSS concentration lab data for all events before and after treatment was implemented on the 22nd of October 2018, and Graph (B) is the flow weighted Event Mean Concentration (EMC) for the events before and after treatment.

6.5.5 Summary: Mt Wickham

Table 17 is an attempt to synthesise all the data sets that have been collected at the site into a summary report card. The most accurate method for evaluating change is using a BACI design which requires pre-treatment data at both a control and treatment sites. Fortuitously, some before treatment data was collected at the Mt Wickham site. This includes % cover and biomass data, and water quality samples from one flow event.

Only one wet season has passed since the treatment works were undertaken at Mt Wickham, however, because of the large scale of the remediation works, there are some early positive response indicators. The amount of biomass on the hillslope and gully walls has significantly improved using the most robust statistical indicators. The water quality data, particularly TSS concentrations, also show early very positive signs of improvement. Because there was only a single event sampled prior to the treatments being implemented, it will be difficult to use the more robust (BACI) design to assess changes in TSS and TN loads.

Table 17: Summary of the treatment effects (Fencing and PCD's) at the Mt Wickham site (showing 1 year of treatment data). **Green suggests that a change has been observed between treatment and control in all years. **Orange** suggests a change has occurred between treatment and control in some years, but it may not be strongly significant. **Red** means no change has been detected in any years. **A red X** means that there is no effect yet due to problematic data streams. **Grey** means that the approach will not be applicable at this site. Na means data not yet available.**

TREATMENT: Major earth works, rock chutes and revegetation.		Treatment response compared to control		Comments
		Basic assessment of control vs treatment effects (e.g. t tests)	BACI design (Two-way ANOVA)	
Early/leading indicators	Hillslope cover %			There are some pre-treatment data for the treatment and control sites, however, there was insufficient pre-treatment flow data to complete all analysis.
	Hillslope biomass (kg/ha)			
	Gully floor/channel – cover %			
	Gully floor/channel – biomass (kg/ha)			
	Gully walls – cover (%)			
	Gully walls – biomass (kg/ha)			
Terrain/erosion	Erosion (t/m/y)	na		
	Deposition (t/m/y)	na		
	Net change (t/m/y)	na		
Runoff, water quality and loads	TSS conc. from samples (mg/L)			
	TN conc. from samples (ug/L)			
	TSS Loads (t/ha)			
	TN Loads (kg/ha)			
	TSS - Flow adjusted annual mean conc. (FAAMC) (mg/L)			
	TN Flow adjusted annual mean conc. (FAAMC) (ug/L)			
	Runoff (mm)	na		
	% Runoff	na		

DISCUSSION AND RECOMMENDATIONS

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. Quantifying the improvement in water quality following remediation is extremely challenging, particularly in natural systems with highly variable climates (Walling and Kleo, 1979). Issues such as uncooperative weather, instrument failure and time lags between treatment and response, all contribute to numerous projects not demonstrating improvements in water quality (Meals et al., 2010).

Acknowledging some of the challenges associated with detecting a statistically significant change in water quality following remediation, a preliminary remediation response 'report card' was presented to help demonstrate if there have been improvements in the 'early' indicator (e.g. vegetation response) data. The report card also highlights that different statistical approaches can be used to detect a change, acknowledging that the most robust design includes having a baseline measurement period for both the control and treatment sites prior to remediation (BACI, two-way ANOVA). In some cases, this approach will not be possible, so less robust, but still valid comparison of control and treatment (t-tests) were also provided.

7.1 Summary of monitoring results (2018/19)

- Most sites have shown some improvement in % cover or biomass following treatment implementation, however, gully catchment land condition at all sites remains in C or D class.
- The pasture species (at most sites) are primarily dominated by the exotic perennial grass Indian couch, forbs, and/or exotic legumes. Indian couch gives relatively poor infiltration compared to native perennial species, so measurable changes in runoff are not expected within five years.
- The 'fencing off only' remediation site (Meadowvale) has shown improved gully floor/channel vegetation biomass, which is increasing the sediment trapping potential of the site. In the 2018/19 wet season, sediment deposition in the treatment gully was 16%, compared to just 8% for the gully with no treatment.
- The sites that have had fencing and porous check dams installed (Virginia Park and Minnievale) are showing improvements in the vegetation metrics in the gully floor/channel, and to a lesser degree on the gully walls. This increased cover, in conjunction with the sediment check dam structures, resulted in 99% trapping of eroded material at Virginia Park in the 2018/19 wet season, and >100% trapping at Minnievale (more fine sediment was trapped than was estimated to be eroded from the gully). This suggests that the structures are also trapping some hillslope material.
- At the sites where the head-cuts have been fenced off for between 3-9 years, the annual gully head-cut retreat rates have declined.
- The larger scale remediation works (Mt Wickham) have resulted in improved vegetation metrics in the first full wet season of monitoring. There are also early indicators of improvements in total suspended sediment (TSS) concentrations following the major earth works at the treatment site. It is expected that at least one to two more wet seasons will

be required to statistically quantify water quality improvements, and up to 10 years to quantify load reductions

- Hillslope gullies in basalt soils erode rapidly, particularly where they have undulating granite catchments. Two un-treated gullies at this site extended ~10 m and 28 m, respectively, during the 2018/19 wet season.
- Sediment yield from the gullies range from (a net deposition of) -0.07 tonnes per metres (t/m/yr) at the Minnievale treatment gully, to 2.58 t/m/y at Strathbogie which has no treatment. Terrain analysis at Mt Wickham was not part of this project, so no terrain data is available for that site.
- Like previous years, there is a strong ($r^2 = 0.87$) relationship between the average erosion rate (t/m/y) and the drainage area above the gully head-cuts for non-treated sites. This relationship highlights that the catchment area above the gully head is a primary driver of erosion rate for these gullies. 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 ~41,800 mg/L (is slightly lower than in the mean of 57,000 mg/L recorded in 2017/18). This gully has very highly sodic sub-surface soils. The other gullies had peak concentrations between ~3000 and ~9,000 mg/L.
- The total nitrogen (TN) values are highly variable between sites, and between events within sites, and not as responsive as sediment to remediation treatment. The total nitrogen (TN) concentrations follow a similar pattern to TSS when comparing the control and treatment sites. Although Mt Wickham has much higher TSS concentrations than the other sites, the TN values are generally not statistically different between 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, so that we can potentially reduce the runoff and sediment loss from all erosion sources, including hillslopes and streambanks.

7.2 Key management messages

- It is possible to improve gully floor vegetation biomass (and in some cases % vegetation cover) if a series of porous check dams (PCDs) are installed, and livestock is managed (but largely excluded) for >3 years.
- Gully head-cut erosion rates are much faster in basalt (vertisol) soil types. These sites also have relatively high sediment concentrations and fine particle sizes that are capable of moving long distances in the GBR Lagoon.
- Total suspended sediment (TSS) concentrations are very high in large alluvial gullies, but TN concentrations are similar to those from hillslope gullies.

- Early results suggest that alluvial gullies can be re-vegetated in relatively short (~12 month) time frames (given sufficient rainfall), and re-shaping appears to have reduced TSS concentrations. Structural treatments are likely to be important for stabilising these sites.

7.3 Key policy messages

- There is a lot of interest from landholders, Regional Bodies and all levels of Government to demonstrate that the investment in on-ground remediation in the GBR is making a difference. There is an assumption is that we have been doing this 'remediation' work for some time, and we should be able to see a result within one to two wet seasons. We have been modelling possible/potential responses for more than a decade, however, these are some of the first control/treatment field trials that are measuring multiple response indicators, including water quality. The key message is that this type of research will take time, at least 4 years for a well-designed experiment, and a dose of luck with respect to rainfall and instrumentation behaviour.
- This project has collected a range of indicators, including vegetation and terrain metrics, which are likely to show earlier changes to treatment than runoff, water quality and loads. These early indicator results can be used to help communicate the findings while we wait for the water quality results to become clearer.

7.4 Recommendations for other remediation projects

- Due to the high variability in rainfall and site characteristics in these landscapes, whenever possible, measurements should be collected from both control and treatment sites for at least two wet seasons prior to remediation works being undertaken. This provides much greater statistical power to detect changes in shorter time frames.
- We need to be careful to balance the expectations related to wanting to measure a change in water quality and loads when choosing sites with landholders. Sites need to be as comparable as possible (e.g. the same soil, vegetation, rainfall, terrain, morphology, instrumentation) otherwise it introduces additional bias into the statistical analysis that reduces the ability to detect a change.
- Where funding permits, use the same instrumentation at both control and treatment sites. Using cheaper cut down monitoring equipment reduces the number of samples collected and subsequently the statistical power to detect changes between the control and treatment sites is reduced. The new set-ups at Strathbogrie and Mt Wickham have the same monitoring systems for both control and treatment sites. This is the more expensive ISCO samplers, but this is a more robust approach and will hopefully provide statistically significant results in a shorter time frame (fewer wet seasons).
- Measuring particle size of the sediment is very useful for determining the size of the sediment leaving a site. This is important, because finer sediment has a greater potential of reaching the GBR Lagoon. However, changes in particle size are unlikely to be a cost-effective measure of remediation effectiveness. The proportion of sediment that is trapped (stored) with the gully system is likely to be a better metric.

7.5 The next 12 months of this project

- We will continue to monitor the control and treatment sites for a 4th (and final NESP TWQ Hub funded) wet season.
- Update the runoff and TSS and TN loads estimates for all of the sites by improving velocity estimates and rating curves.
- 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.
- Draft peer reviewed journal publications describing these results.

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APPENDIX A: WATER DEPTH, TURBIDITY AND SAMPLE COLLECTION FOR 2018/19 AT EACH SITE

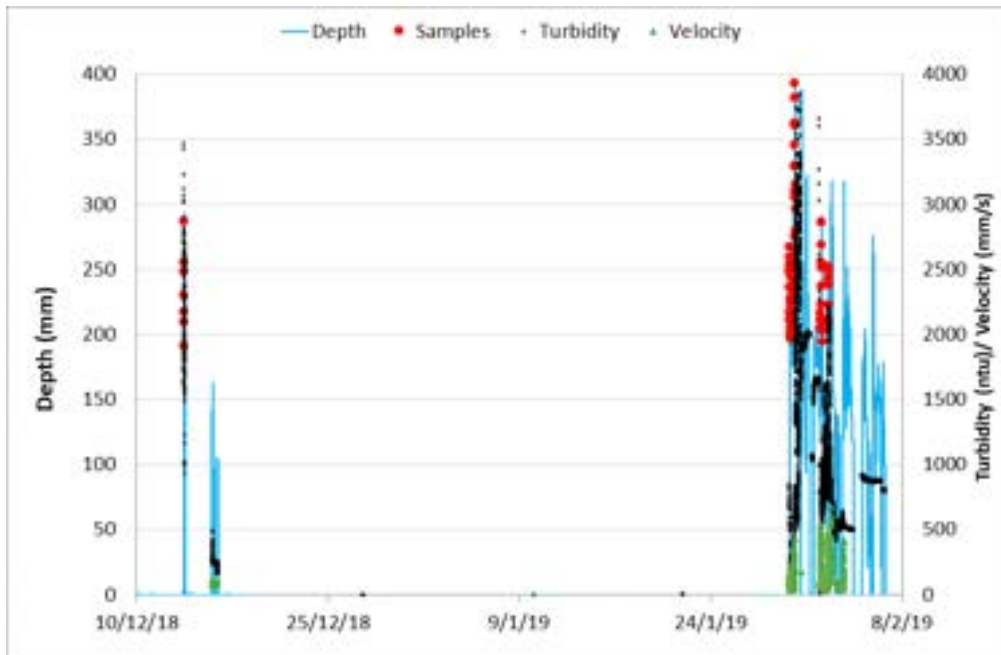


Figure 57: Virginia Park Treatment gully runoff, turbidity, velocity and sample points on the hydrograph.

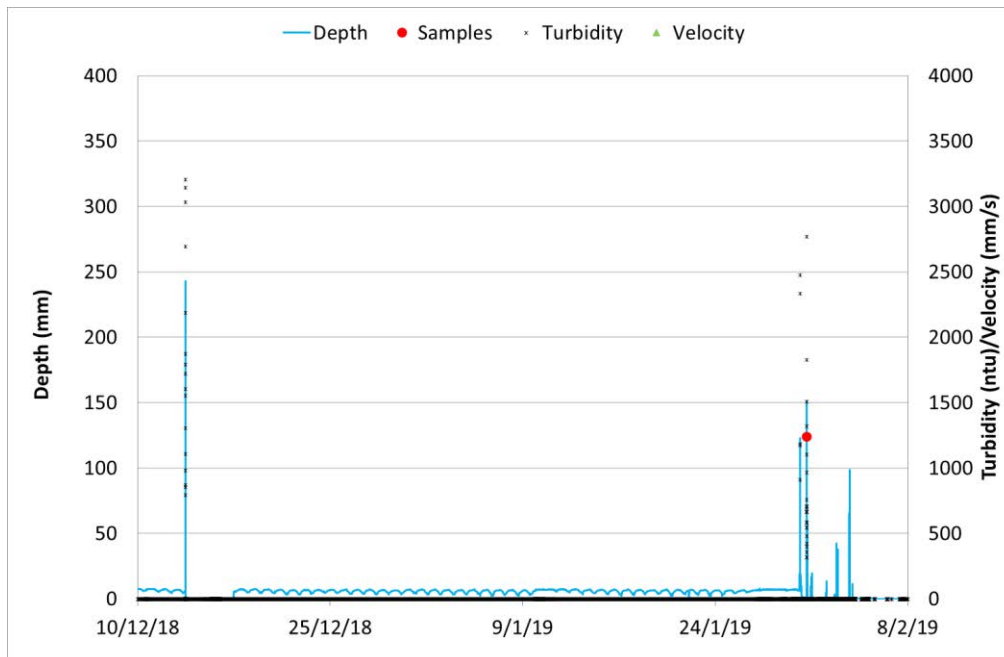


Figure 58: Virginia Park Control gully runoff, turbidity, velocity and sample points on the hydrograph.

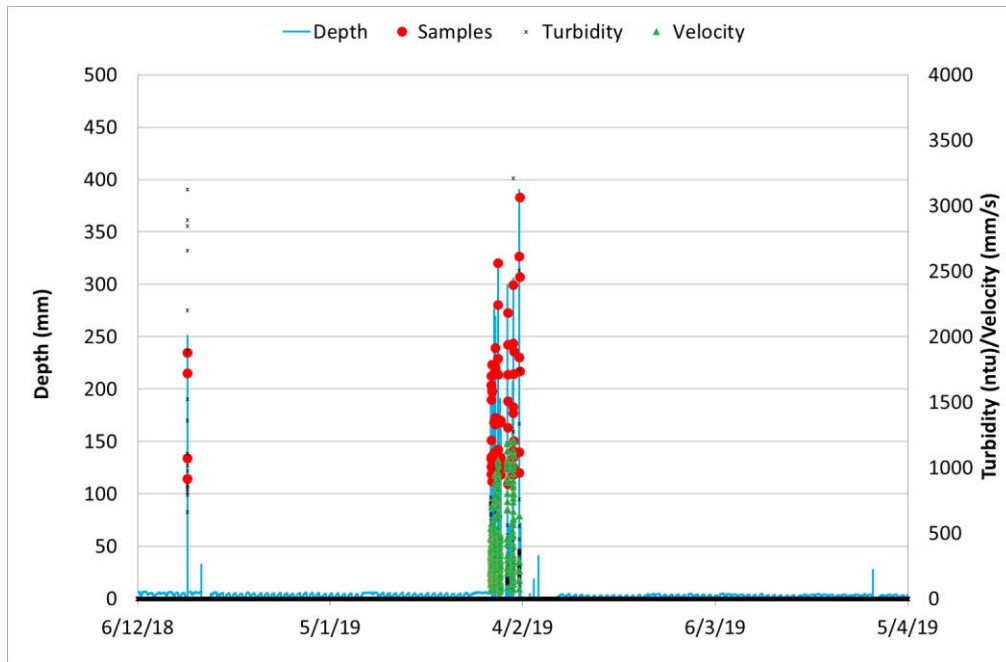


Figure 59: Meadowvale Treatment gully runoff, turbidity, velocity and sample points on the hydrograph

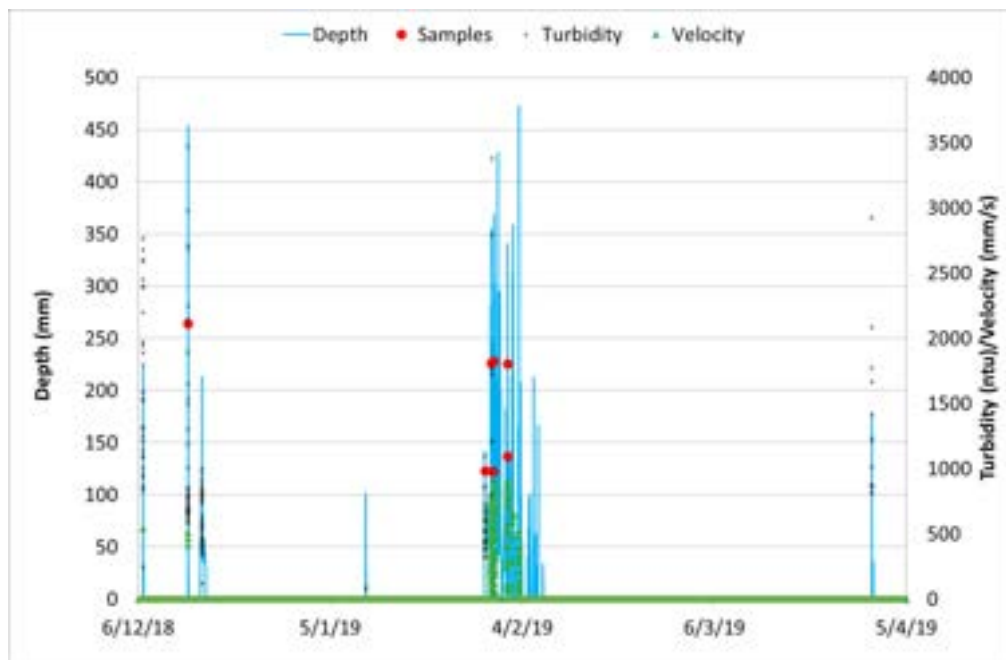


Figure 60: Meadowvale Control gully runoff, turbidity, velocity and sample points on the hydrograph.

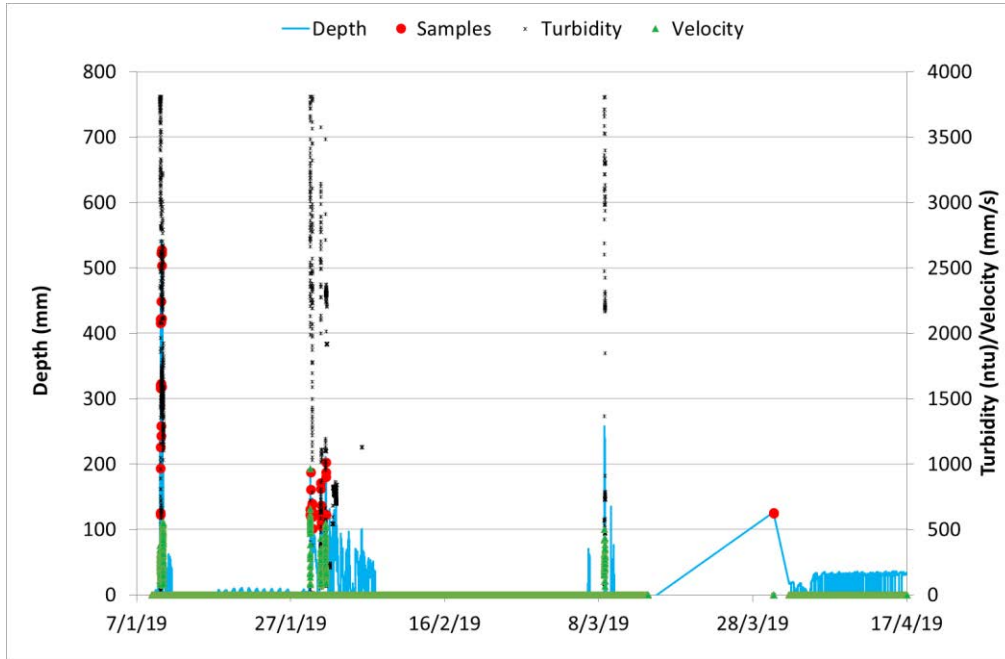


Figure 61: Strathbogie Treatment gully runoff, turbidity and sample points on the hydrograph.

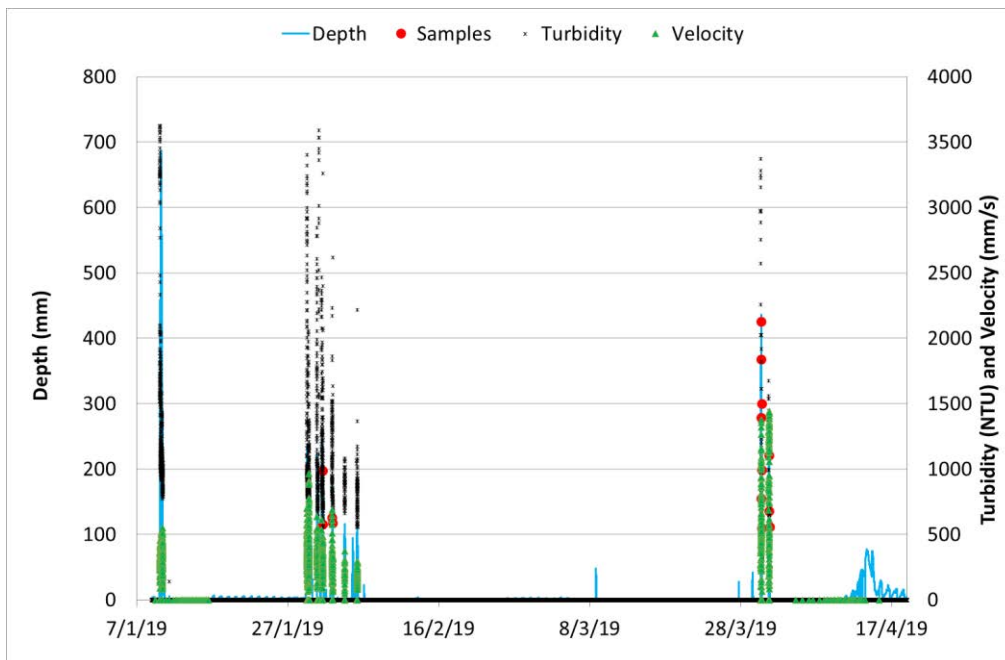


Figure 62: Strathbogie Treatment2 gully runoff, turbidity and sample points on the hydrograph.

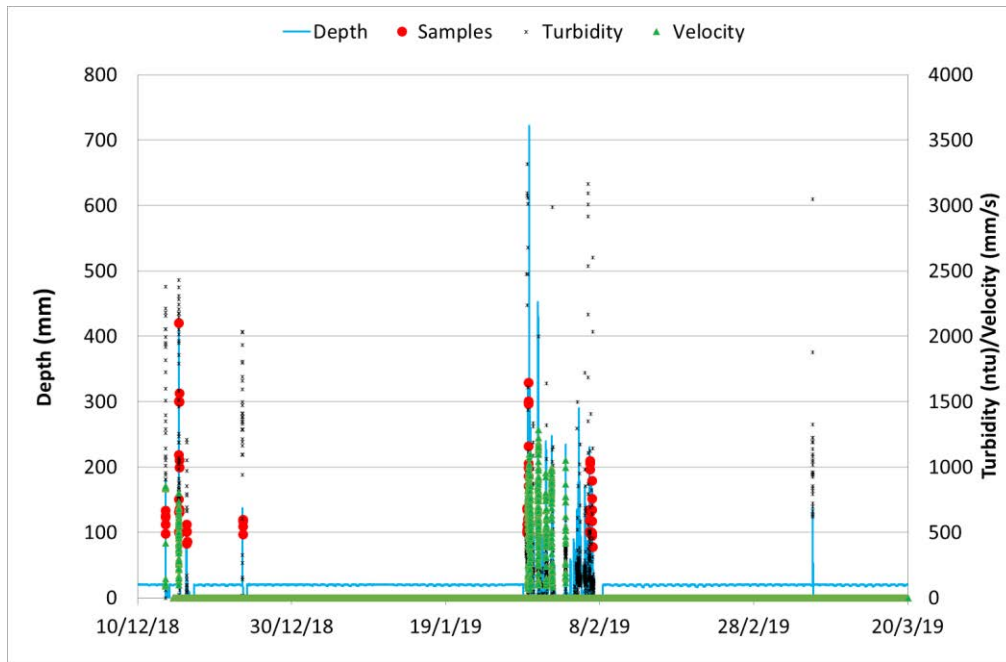


Figure 63: Minnievale Treatment gully runoff, turbidity and sample points on the hydrograph.

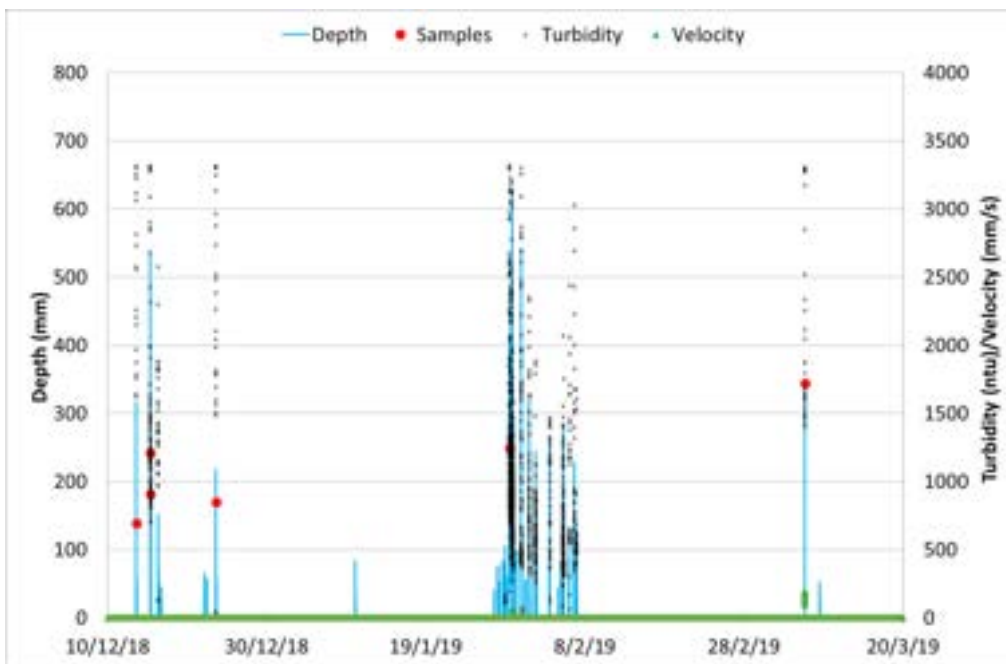


Figure 64: Minnievale Control gully runoff, turbidity, velocity and sample points on the hydrograph.

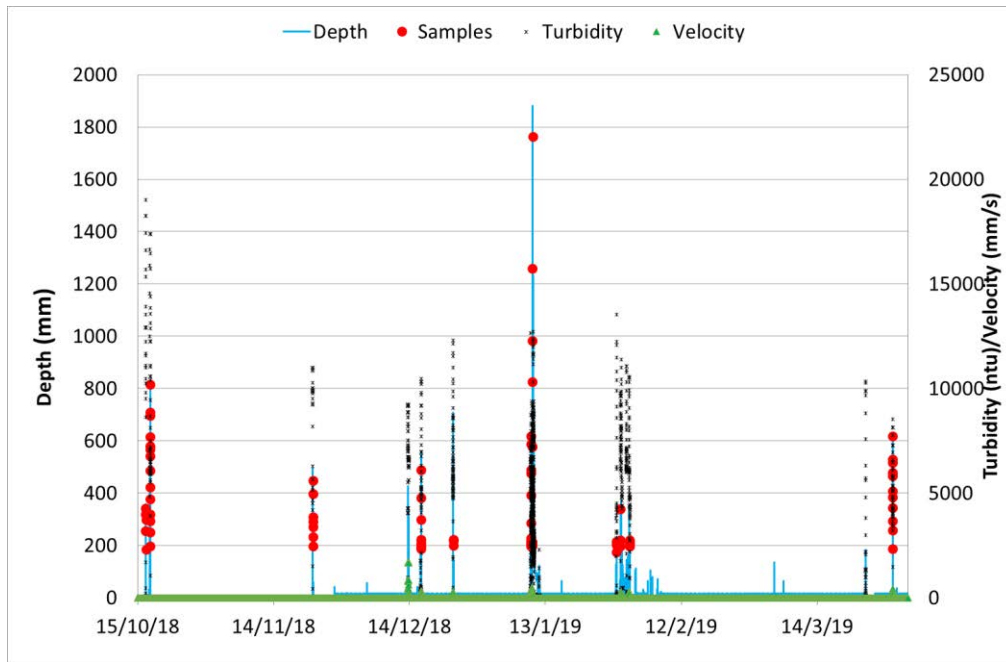


Figure 65: Mt Wickham Treatment gully runoff, turbidity and sample points on the hydrograph.

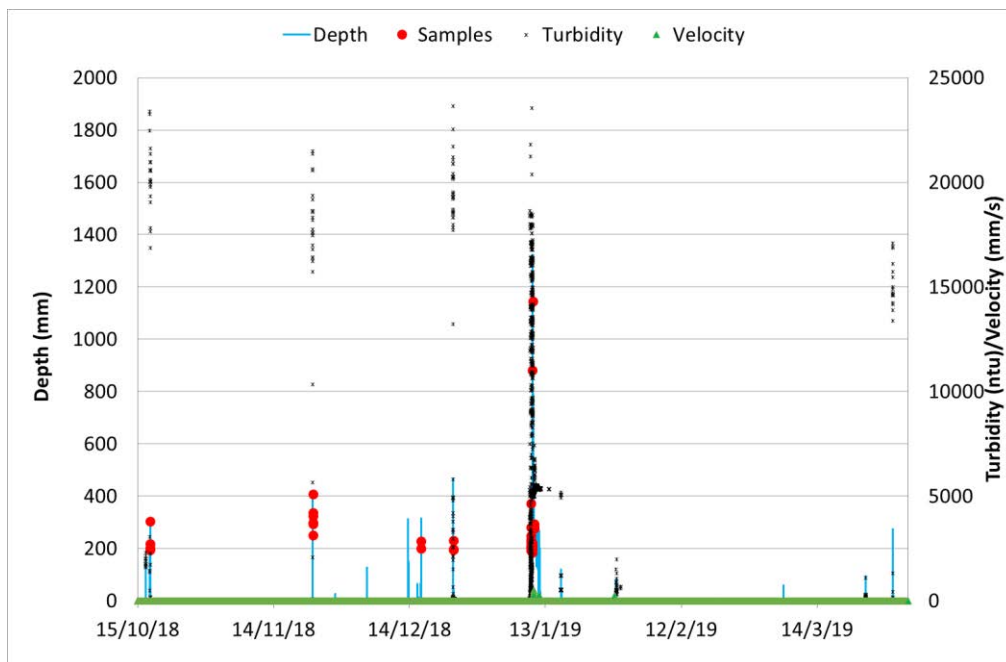


Figure 66: Mt Wickham control gully runoff, turbidity and sample points on the hydrograph.

APPENDIX B: RAINFALL, RUNOFF AND LOADS DATA AT ALL SITES FOR ALL YEARS

Table 18: Rainfall and preliminary runoff and TSS and TN loads estimates for all sites for the years of measurement

Confidence colour	Discharge Issues	Loads Issues
Excellent	a - few or no velocity data	a - Very few samples
Good	b - Incomplete or noisy vel data	b - Turbidity data missing or wrong
Questionable	c - Depth data for year has issues	c - Marginal to Poor turbidity relationship
Poor	d - backwatering	d - Species of constituent not well predicted by turbidity

Water Year (ending June)	Site	Catchment area (sq km)	Rainfall (mm)	Runoff (mm)	%Runoff	Total TSS Yield (t/y)	Total N Yield (kg/y)	N Loss (kg/ha)	Discharge confidence	Loads Confidence	% of discharge with loads estimated
2019	Virginia Park Control Gully	0.031	858.0	23.3	3	2.1	1.5	0.50	a,c		100%
2018	Virginia Park Control Gully	0.031	590.0	7.3	1	0.8	0.8	0.30	a,c		100%
2017	Virginia Park Control Gully	0.031	319.8	8.5	3	0.8	0.9	0.28	a,c	b	15%
2019	Virginia Park Treatment Gully	0.013	788.0	366.6	47	5.9	8.8	6.77		b	100%
2018	Virginia Park Treatment Gully	0.013	543.0	167.7	31	0.7	2.8	2.14			100%
2017	Virginia Park Treatment Gully	0.013	496.0	191.6	39	2.0	3.9	3.01			100%
2019	Meadowvale Control Gully	0.050	1135	280.3	25	7.0	18.4	3.7	b	b,c	33%
2018	Meadowvale Control Gully	0.050	749	183.2	24	10.8	27.6	5.5	b	b,c	69%
2017	Meadowvale Control Gully	0.050	342.400	24.413	7.130	1.384	5.8	1.2	b	c	100%
2019	Meadowvale Treatment Gully	0.042	1403	144.1	10	1.8	6.3	1.5	b		92%
2018	Meadowvale Treatment Gully	0.042	784	87.3	11	4.9	6.3	1.5	b		100%
2017	Meadowvale Treatment Gully	0.042	402	1.7	0	0.1	0.1	0.0	b		
2019	Minnie Vale Control Gully	0.097	1077	22.8	2	5.8	13.9	1.4	b	b	77%
2018	Minnie Vale Control Gully	0.097	301	5.1	2	2.3	5.5	0.6	b		98%

2017	Minnie Vale Control Gully	0.097	1006	19.0	2	5.6	14.0	1.4	b		91%
2019	Minnie Vale Treatment Gully	0.212	1072	82.1	8	10.7	13.1	0.6	b		
2018	Minnie Vale Treatment Gully	0.212	784	13.2	2	5.1	4.9	0.2	b		
2017	Minnie Vale Treatment Gully	0.212	956	102.4	11	22.1	36.3	1.7	b,c	b	
2019	SBT (Control) Gully	0.174	1384	77.9	6	28.3	23.2	1.3		b	
2018	SBT (Control) Gully	0.174	474	2.6	1	1.4				b	
2017	SBT (Control) Gully	0.174	777	65.9	9	15.2	11.5	0.7			
2019	SBC-SBT2 (Treatment) Gully	0.381	1352	98.4	7	63.9	82.2	2.2			
2018	SBC-SBT2 (Treatment) Gully	0.381	493	0.0	0	0.0	0.0	0.0			
2017	SBC-SBT2 (Treatment) Gully	0.381	804	15.5	2	9.9	12.8	0.3			
2019	Mount Wickham Control Gully	0.030	1175	161.7	14	159.6	26.4	8.7	d	b	19%
2018	Mount Wickham Control Gully	0.030	152	1.6	1	2.8	0.5	0.2		d	100%
2017	Mount Wickham Control Gully										
2019	Mount Wickham Treatment Gully	0.141	1117	76.1	7	174.0	66.3	4.7			100%
2018	Mount Wickham Treatment Gully	0.141	127	1.7	1	7.4	2.3	0.2			100%

APPENDIX C: MT WICKHAM EVENT ANALYSIS

Table 19: Mt Wickham Control site showing the events prior to remediation in orange. The Treatment works started on the 22nd October

Runoff Event	Start time	End Time	Duration hrs	Runoff (m3)	Loads (kg)	Samples	Avg from samples	Avg TSS from Timeseries (Turb-TSS relationship)
1	17/10/2018 17:34	17/10/2018 17:52	0.3	40	2,179	4	56750	55148
2	22/11/2018 16:04	22/11/2018 16:24	0.3	61	3,034	2	48500	49504
3	13/12/2018 17:38	13/12/2018 17:49	0.2	24	1,144	0		46765
4	16/12/2018 12:56	16/12/2018 13:07	0.2	24	1,122	2	47500	47095
5	23/12/2018 15:17	23/12/2018 15:48	0.5	85	4,100	0		48000
6	23/12/2018 15:56	23/12/2018 16:01	0.1	10	468	1	48000	48000
7	9/01/2019 19:07	9/01/2019 19:13	0.1	11	511	0		47001
8	9/01/2019 19:30	9/01/2019 20:56	1.4	213	7,017	4	29750	32889
9	10/01/2019 1:10	10/01/2019 1:16	0.1	11	292	0		26434
10	10/01/2019 1:32	10/01/2019 1:40	0.1	14	398	0		27454
11	10/01/2019 1:42	#N/A	0.0	1	39	0		27720
12	10/01/2019 1:54	11/01/2019 0:07	22.2	3,426	105,871	1	31000	30902
13	11/01/2019 2:35	11/01/2019 8:10	5.6	598	18,523	0		31000
14	11/01/2019 13:18	11/01/2019 16:49	3.5	354	10,988	0		31000
15	30/03/2019 15:25	30/03/2019 15:38	0.2	27	835	0		31000

Table 20: Mt Wickham Treatment site showing the events prior to remediation in orange. The Treatment works started on the 22nd October.

Runoff Event	Start time	End Time	Duration hrs	Runoff (m3)	Loads (kg)	Samples	Avg from samples	Avg TSS from Timeseries (Turb-TSS relationship)
1	16/10/2018 18:38	16/10/2018 18:55	0.3	88	3,909	5	41800	44592
2	17/10/2018 17:32	17/10/2018 18:15	0.7	370	12,207	11	35727	33027
3	22/11/2018 16:10	22/11/2018 16:32	0.4	129	2,237	6	17833	17339
4	13/12/2018 17:43	13/12/2018 18:14	0.5	165	2,208	0		13383
5	13/12/2018 17:43	13/12/2018 18:14	0.5	165	2,208	1	12000	13383
6	16/12/2018 12:53	16/12/2018 13:30	0.6	207	4,150	3	19000	20069
7	23/12/2018 15:22	23/12/2018 16:29	1.1	480	6,715	1	14000	13989
8	9/01/2019 18:45	9/01/2019 18:53	0.1	30	333	0		11002
9	9/01/2019 19:07	9/01/2019 20:50	1.7	572	8,243	6	14217	14399
10	10/01/2019 1:09	10/01/2019 11:43	10.6	7,897	99,008	4	12875	12537
11	28/01/2019 16:04	28/01/2019 16:05	0.0	6	76	1	12000	12000
12	29/01/2019 14:05	29/01/2019 14:26	0.4	99	1,689	1	17000	16987
13	29/01/2019 19:31	29/01/2019 19:54	0.4	113	1,856	0		16426
14	31/01/2019 13:15	31/01/2019 13:44	0.5	137	1,645	1	12000	12032
15	31/01/2019 14:08	31/01/2019 14:12	0.1	16	178	1	11000	11281
16	30/03/2019 15:18	30/03/2019 15:56	0.6	292	3,214	0		11000

