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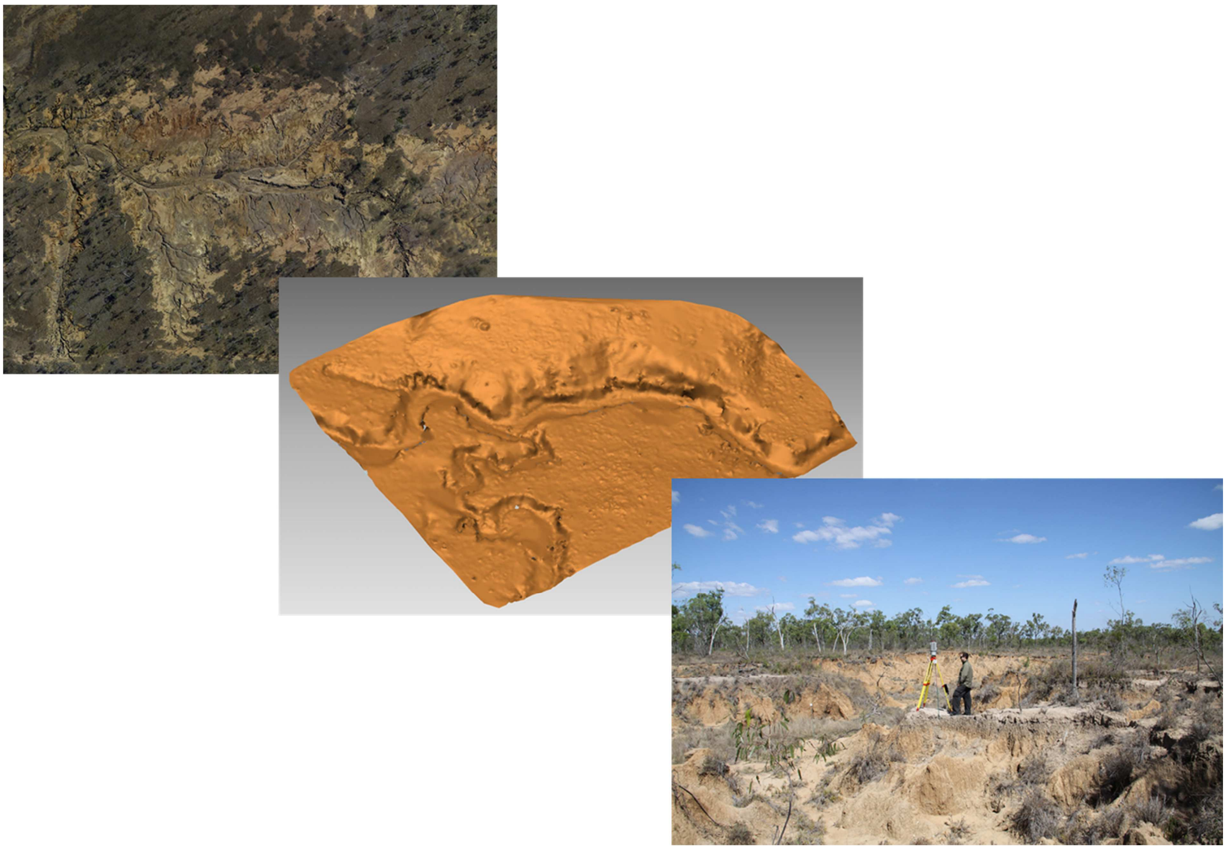

RP66G Summary Report

Gully mapping and drivers in the grazing lands of the Burdekin catchment

Remote Sensing Centre

November 2014

Great state. Great opportunity.

Queensland
Government

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On behalf of
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Executive summary

Recent studies of sediment sources in the Great Barrier Reef (GBR) lagoon have shown that gully erosion is a dominant contributor of sediment, particularly in the Burdekin and Fitzroy catchments. Gully erosion also presents a significant challenge to the grazing industry, impacting land condition and reducing productivity. There has been limited work undertaken to comprehensively map gully locations, and to quantify and monitor gully erosion processes in GBR catchments at scales or resolutions appropriate for land management decision-making. Where mapping studies have been conducted, the information has been of limited use due to low accuracy, scale limitations or the maps being of limited geographic extent. This project aimed to provide spatially-comprehensive mapping and monitoring of gully erosion in the Burdekin catchment to improve knowledge of where gullies occur and to attempt to better understand the processes and drivers of gully erosion, particularly in the grazing lands of the catchment. The outcomes are intended to serve multiple needs including: providing improved information for targeting erosion prevention and remediation efforts; to support grazing extension programs aimed at improving grazing land management to improve sustainability of the grazing industry in GBR catchments; and, to help improve water quality models.

Improved mapping of gully locations in the Burdekin was achieved by visual observation of satellite and aerial imagery and predictive modelling. Mapping was produced at two resolutions, 5km and 1km. The 5km resolution mapping combined high resolution mapping, a predictive model of gully presence and visual observations of gully prevalence across the entire catchment. Gully presence was mapped in 7 classes relating to the amount of gullying present, where gullying was observed. The 1km resolution mapping was achieved entirely through visual interpretation of a 1km grid, each grid divided into one hundred, 100m x 100m cells to provide a count or percentage of gullying evident in each 1km grid cell. Mapping was targeted at key areas identified in the 5km map as having high gully presence. A mapping guideline has also been developed to support ongoing application of this mapping approach in other parts of the GBR grazing lands and potentially other locations around the world which are affected by gullying.

Changes in gully extent and volume were mapped and quantified over multiple time scales and at different resolutions in an effort to improve knowledge on rates of change and volumes of sediment loss when changes occur. Very high resolution LiDAR data was captured for a number of transects over at least two dates and digital elevation models developed. Differences in elevation between the dates were compared by first classifying where gullies occur, and then determining the depth and volume of gullies to provide quantitative estimates of change. Elevation thresholds were required to account for potential errors in the LiDAR data due to different sensor configuration and acquisition specifications for different capture dates, pre-processing artefacts and issues of classifying complex terrain, where vegetation and other land cover features are present. Long-term gully change was mapped at ten sites for dominant land types using historical imagery. The mapping was limited by available historical imagery and difficulty in image rectification and identifying features in imagery of varying resolution and quality. Gully extents were mapped over time (up to nearly 60 years at some sites) using a grid cell-based approach, at 30m resolution. Extents were compared over the time-series to quantify the two-dimensional expansion of gullies and proportional rates of change.

The 5km and 1km resolution gully maps showed that nearly 60% of the Burdekin catchment has very low to low gullying present. This means there are very few or no gullies apparent in the imagery used for the mapping. Sub-catchments with the highest prevalence of gullying were the

Upper Burdekin, Bowen-Broken and the northern part of the Suttor where sedimentary and granitic geologies dominate. The predictive modelling showed a strong relationship between gully presence and elevation above drainage lines with most gullies occurring within the first 1.5m. The model also found that where there was a high probability of gullies occurring, there was still only around 5% chance of actually finding a gully, suggesting that gullies are rare features in a whole-of-landscape context.

The gully change monitoring approaches showed that where sampling was undertaken, some active gullying was detected. There is some uncertainty in the change estimates from the LiDAR data due to thresholds used and differences between sites and issues with the data. The LiDAR analysis showed that gullying could be up to about 10% of a site and the change analysis indicated that large changes of over 10,000m^3 has taken place in some areas in a three year period. The LiDAR data also showed a high correlation between gully area and gully volume, suggesting that mapping of gully area may provide a proxy for volume, where volume data is not available. The results of the LiDAR change analysis and the long-term change analysis also suggested that larger gully changes may be episodic or event-based, driven by intense, localised rainfall events and possibly exacerbated by low cover. This could highlight the need for land management approaches that protect at risk areas when they are most vulnerable such as at the end of a drought or the break of dry season.

Future mapping and monitoring efforts should focus on continuing catchment-scale mapping of gully locations using simple and consistent mapping approaches. Developing appropriate management strategies for gullies relies on first knowing where gullies are in the landscape, and then understanding the erosion processes which have led to their formation and ongoing activity. This project has developed multiple lines of evidence to help improve understanding of where gullies are and how they are changing. However, large knowledge gaps remain including understanding the fate and timing of sediment delivered from gullies, and developing the most appropriate technologies and approaches for managing and monitoring gullied areas. Research issues still remain about how to best use airborne LiDAR for determining gully volumes and changes over time. Emerging technologies such as ground-based laser scanning, imagery and LiDAR capture from Unmanned Aerial Vehicles (UAVs), sediment tracing and digital soils mapping all present opportunities to help improve our understanding of gully processes to enable effective management strategies for improving land condition and water quality in the grazing lands of the GBR.

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1. Overview

This summary report is a synopsis of a larger report prepared to document the tasks and outcomes of the Reef Water Quality Science Program project: ***RP66G Gully mapping and drivers in the grazing lands***. The project aimed to map and quantify gully extent and rates of change at a range of scales in the Burdekin catchment, Queensland. The work is part of a larger program which aimed to improve understanding of sediment sources and erosion processes within grazing lands of the Burdekin catchment.

The project focussed on the method development and delivery of a range of gully mapping products to:

- improve understanding of gully locations, activity, and longer-term processes that influence gully formation and evolution
- highlight areas that are more likely to have gullies or be at risk of gully formation
- help government, industry and natural resource management groups to focus grazing extension and land management investment efforts to vulnerable areas
- assist the Paddock to Reef monitoring, modelling and reporting program (under Reef Water Quality Protection Plan) to improve model parameterisation for gullies in select areas

2. Introduction

Present knowledge of gully locations, processes and contribution to the sediment budget in the Burdekin catchment is limited. In a review of sediment sources in the Burdekin catchment, Bartley (2011) highlighted that there is a large disparity between studies (e.g. Prosser et al. 2001; Kinsey-Henderson et al. 2005) about the scale of gully erosion in the catchment. This is mainly attributed to the poor quality gully data used in models and uncertainty in predictive methods. Further, a range of findings have been reported in the literature regarding where sediment is originating within the catchment, which sediment fractions pose the greatest risk to the Great Barrier Reef (GBR), and which erosion processes and land management types can be attributed to the source of the sediment (e.g. Lewis et al., 2006; Bartley et al., 2007; Bainbridge et al., 2008).

In a summary of the scientific evidence, the 2013 Scientific Consensus Statement (Brodie et al., 2013) has identified gullies as a dominant contributor to the sediment load in the GBR receiving waters. This is particularly relevant in the Burdekin and Fitzroy catchments, the largest contributor of sediment to the GBR of all reef catchments. There is a clear need for consistent mapping of landscapes susceptible to gully erosion and mapping of past and present gully extent and volume. These data should be at a range of scales and in formats that are suitable for prioritisation of prevention, rehabilitation, and investment and extension activities and for use in catchment-scale water quality models.

This project aimed to produce information at a range of scales to improve knowledge of sediment sources and erosion processes in the Burdekin catchment by using remote sensing, statistical modelling, manual digitising and field survey methods. The specific objectives of the project were to:

I. Map gully locations in the Burdekin catchment at a range of scales to provide multiple sources of information about gully presence, gully absence, and risk of gully formation.
II. Identify and map active and dormant gully systems using historical aerial photography and satellite imagery to improve understanding of gully processes and help identify areas where the greatest current activity is occurring in the catchment.
III. Quantify changes in gully extent and volume using multi-date airborne LiDAR. This provides measures of volumetric changes to actively eroding gullies in a range of landscapes.
IV. Develop a suite of simple, repeatable methods that can be used to map and quantify gully erosion activity in other GBR catchments, and more generally, in Queensland and elsewhere.
V. Where possible, link these data and information to other lines of evidence obtained from sediment tracing (RP65G) and soil attribute mapping (RP63G) Reef Water Quality R&D projects to enhance landscape understanding in the Burdekin for improved decision-making and policy implementation.

3. Methods

3.1 5km gully presence map

A gully presence map at 5km grid cell resolution was compiled for the Burdekin catchment by dividing the catchment into 5521 cells of 5x5 km. Each grid cell was assigned with one of seven gully presence values (Very high, High, Medium-high, Medium, Low-medium, Low and Very Low). Gully presence values were determined by a number of methods that are based on a range of information sources and have varying levels of confidence:

- 1595 cells (28.9%) were visually inspected with high resolution (<1m) imagery (very high level of confidence),
- 579 cells (10.5%) were visually inspected with medium resolution (<10m) imagery (high level of confidence),
- 1120 cells (20.3%) were assessed for extent of gully presence based on the output of a model that identified areas at low risk of gully erosion (medium level of confidence),
- 922 cells (16.7%) were assessed based on erosion trends within particular subregions (medium level of confidence), and
- 1399 cells (25.3%) were assigned values based on the output of a predictive model of gully presence. The predictive model variables were aspect, flow accumulation, slope length, curvature and catchment area (medium to low level of confidence).

The 5km gully presence map was converted to a gully density map by assigning each cell in the map with a density value based on high resolution mapping of gully presence and extent at selected locations. The relationship between mapping at known locations and the classified gully presence cells was used to extrapolate gully density to cells which did not have high resolution mapping.

3.2 1km gully presence map

The 5km gully presence map was used as a base to refine areas to 1km resolution. Cells classified ‘Very high’ and ‘High’ within the 5km Gully Presence Map was divided into 1km x 1km cells. Each 1km^2 cell was further divided into a grid of 100 cells, each measuring 100m x 100m. Gully presence in each of the 100 cells was visually interpreted and a count of the number of 100m x

100m cells with gullying present was assigned to the 1km x 1km cell. This provided a percentage of gullying present at the 1km resolution.

3.3 LiDAR data analysis for gully change monitoring

Light detection and ranging (LiDAR) data provides a detailed measurement of the three-dimensional surface of the earth. When captured across multiple dates, changes in the earth's surface (e.g. gully erosion) can be measured and monitored.

A multi-date LiDAR dataset was captured for 15 gullied sites in the Burdekin and 4 sites in the Fitzroy catchment (Figure 1 and Table 1). The Burdekin sites were captured on two dates in 2010 and 2013 using a similar capture configuration between dates and were targeted at know gully locations and were some land management efforts had been made to address gully formation and erosion. The Fitzroy sites were captured on 3 dates in 2007, 2010 and 2013 with the 2007 capture using a different sensor and capture configuration.

Digital Elevation Models (DEMs) were generated from the LiDAR data for each site and for each date at a 50cm resolution. Gullies were classified using the 'difference from mean elevation'. This method classifies depressions in the landscape where the difference in elevation between a particular location and the surrounding area is greater than a specified threshold. The same approach was used by Evans and Lindsay (2010) to classify gullies using LiDAR.

Gully depth was calculated by re-interpolating the non-gully ground return, i.e. putting a 'lid' across the top of the classified gullies, and differencing this layer with the original DEM. Gully volume was calculated by summing the gully depth pixel values and converting these values into volumetric units (cubic meters). Gully change (both lateral and volumetric) was then determined by comparing mapped extents and gully volume estimates between LiDAR dates (2010 and 2013) using a change threshold of 45cm. Changes less than this chosen threshold were found to be contaminated by erroneous measurements due to processing issues with the LiDAR and difficulty in deriving DEMs in complex erosional landscape features.

3.4 Gully chronosequence mapping

Gully chronosequence mapping refers to mapping the long term change in the extent of gullies using historical imagery. Ten sites were selected from a range of land types in the Burdekin catchment and historical and recent aerial and satellite imagery was used to map gully presence and expansion between image dates.

For each site, historical aerial imagery dating as far back as the 1940's was acquired. For each site, an average of six images with approximately ten year intervals between images, were ortho-rectified to enable comparison in gullied extent over time.

A of 30m x 30m was generated for site and, beginning with the earliest available image date, the number of cells that showed gulling was counted and the areas (in m^2) was calculated. The counts were then compared to assess rates of change over time and to compare these rates between land types.

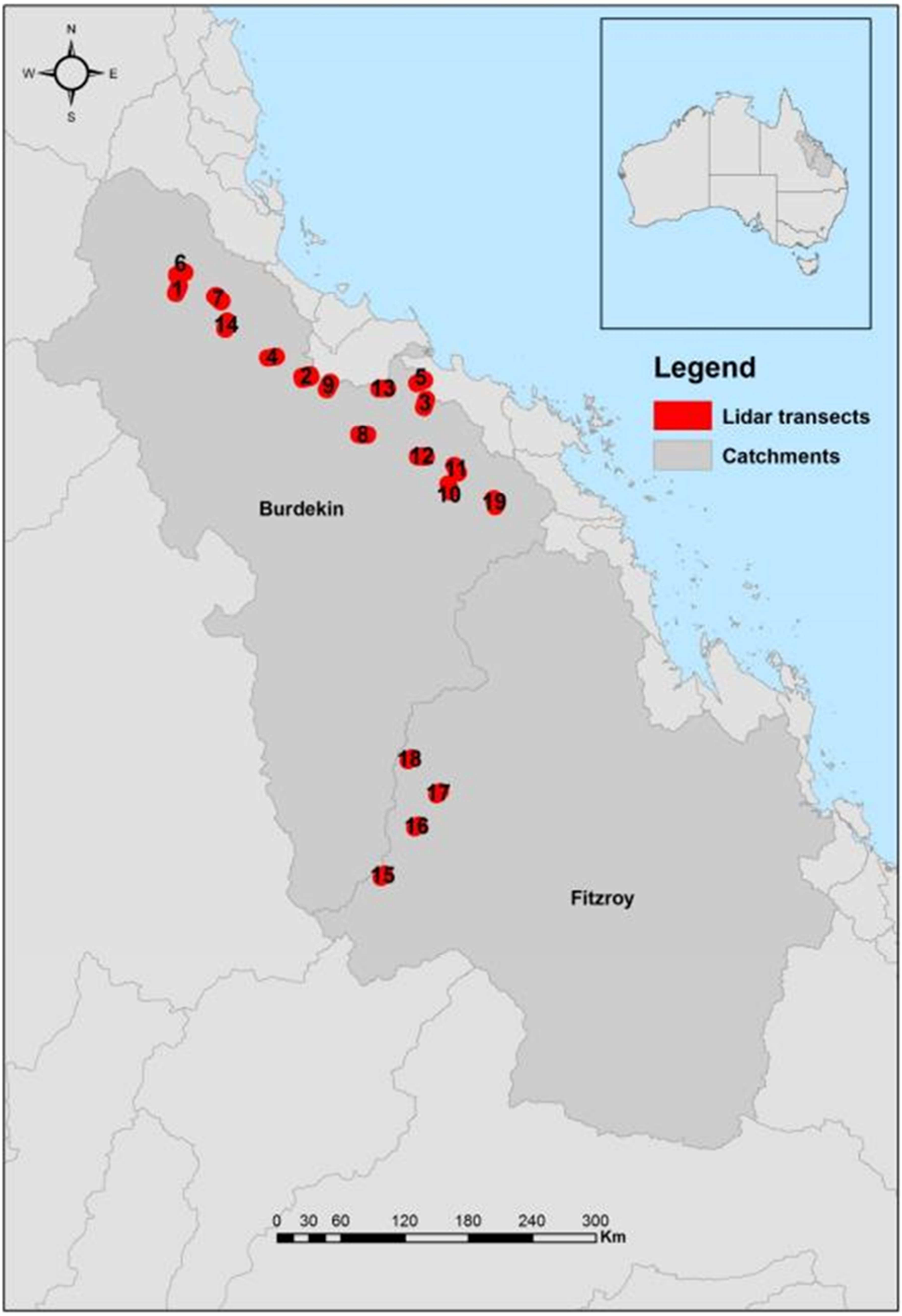

Figure 1 Location of LiDAR transects in the Burdekin and Fitzroy catchments. Site numbers correspond with site names in. Sites 1 (Blue Range) and 8 (Mount Ravenswood) were excluded from reporting due to processing errors.

Table 1 LiDAR data capture site and details (refer to Figure 1for locations of sites in the Burdekin). Sites 1 (Blue Range) and 8 (Mount Ravenswood) were excluded from reporting due to processing errors.

Site No.	Site	Region	Year	QA issue
1	Blue Range	Burdekin	2010, 2013	Horizontal errors
2	Fanning	Burdekin	2010, 2013	Pass
3	Fish Creek	Burdekin	2010, 2013	Pass
4	Keelbottom Creek	Burdekin	2010, 2013	Pass
5	Kirknie Creek	Burdekin	2010, 2013	Pass
6	Lyall Creek	Burdekin	2010, 2013	Pass
7	Marshes Creek	Burdekin	2010, 2013	Pass
8	Mount Ravenswood	Burdekin	2010, 2013	Horizontal errors
9	Oaky Creek	Burdekin	2010, 2013	Pass
10	Parrot Creek	Burdekin	2010, 2013	Pass
11	Pelican Creek	Burdekin	2010, 2013	Pass
12	Red Hill Creek	Burdekin	2010, 2013	Pass
13	Spring Creek	Burdekin	2010, 2013	Pass
14	Starbright	Burdekin	2010, 2013	Pass
15	T1-T2	Fitzroy	2007, 2010	Pass
16	T3-T4	Fitzroy	2007, 2010, 2013	Pass
17	T5-T6	Fitzroy	2007, 2010, 2013	Pass
18	T7-T8	Fitzroy	2007, 2010, 2013	Pass
19	Turrawulla	Burdekin	2010, 2013	Pass

4. Results

4.1 5km gully presence map

Five thousand five hundred and twenty one 5km x 5km cells were classified into seven classes of gully presence. Of these cells, 24 cells were classified ‘Very high’, 109 were ‘High’, 276 were ‘Medium-high’, 716 were ‘Medium’, 979 were ‘Low-medium’, 2741 were ‘Low’ and 676 were Very low’ (Figure 2). This map was simplified to four classes of gully density to generate a gully density map for the Burdekin at 5km grid cell resolution (Figure 3).

Gully presence was found to be greatest in the Upper and Lower Burdekin and Bowen-Broken sub catchments.

4.2 1 km gully presence map

There are approximately 99957 1km x 1km grid cells in the entire Burdekin catchment. At the time of writing, 7603 or 7.6% of the1km x1km grid cells in the Burdekin had been assessed for gully presence. This includes grid cells in all classes of the 5km gully presence map with high and very high classes being almost entirely sampled and assessed. This product highlights sections of the Burdekin where high rates of gullying were observed in the 5km Gully Presence Map. Only 0.24 per cent of the 1km gully presence mapping featured ‘gully count’ values greater than 79 and less than two per cent of the map featured ‘gully count’ values greater than 59. This suggests that where gullies are present, they are still a relatively small proportion of the landscape. Mapping continues in the Burdekin through a collaborative effort involving DSITIA and DNRM.

4.3 LiDAR data analysis

Figure 4 and Figure 5 shows an example of a classified gully extent. The results generally show good visual agreement between the LiDAR classification and orthophotography suggesting that LiDAR data, classified using an objective DEM differencing approach, can accurately map the extent of gullies.

Noise in data is inherent to all LiDAR captures and models. The selection of a noise threshold has a large impact on the estimate of gully change between 2010 and 2013 because a high proportion of gully change occurs at lower magnitudes of change. For this study, a 45cm threshold was selected based on a range of tests to determine at which threshold errors in the LiDAR were minimised. The selection of this threshold corresponded with other studies in the literature. At this threshold, the Marshes Creek site had the greatest change between LiDAR capture dates, almost 30,000m^3, followed by the Turrawulla site (15,000m^3). Analysis of the LiDAR-derived gully area and volumes, a strong relationship was found between gully area and volume, suggesting that a two-dimensional area estimate such as that derived from the gully presence mapping, may provide a suitable surrogate for gully volume where three-dimensional data is not available.

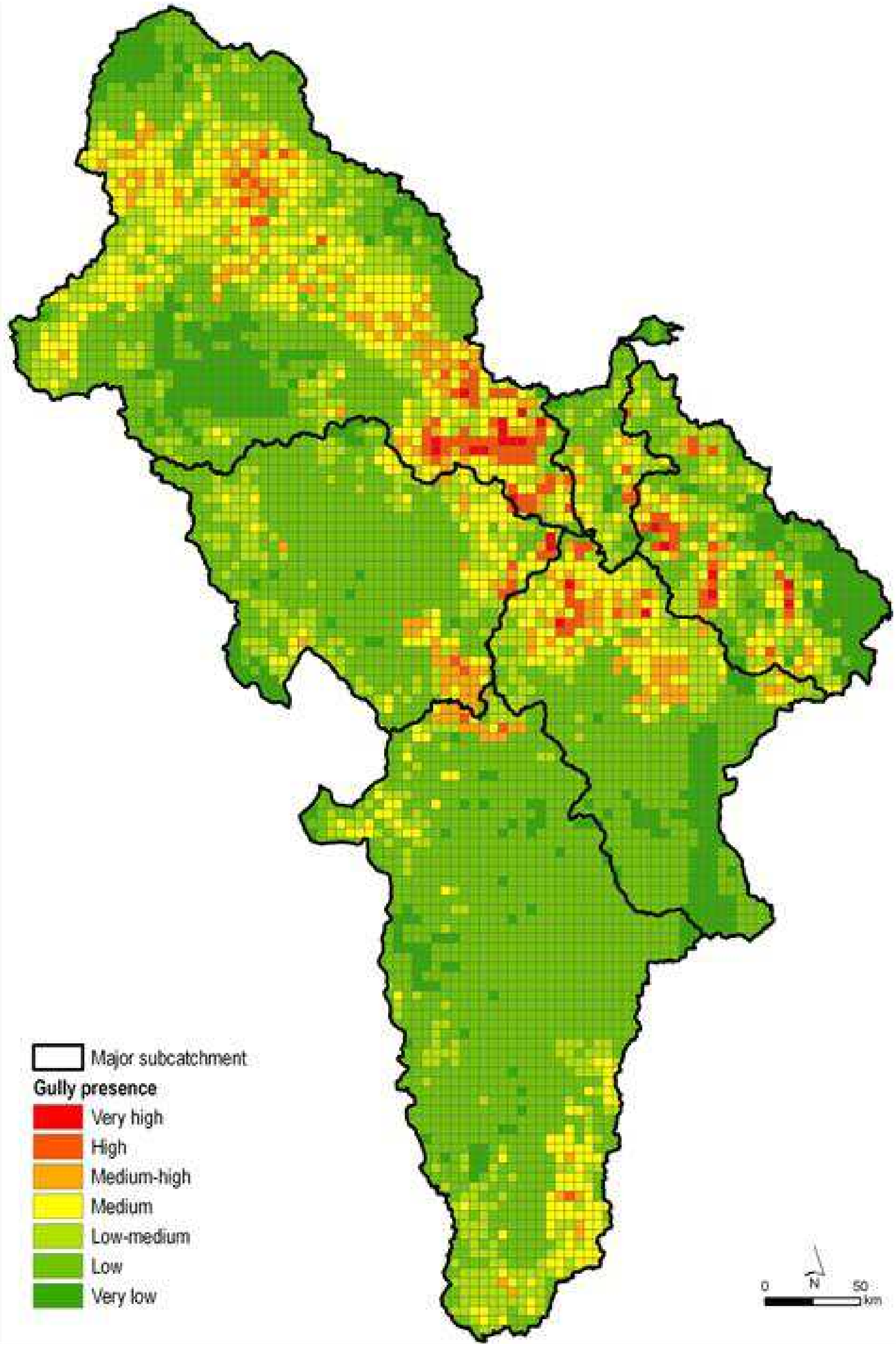

Figure 2 5km resolution gully presence map.

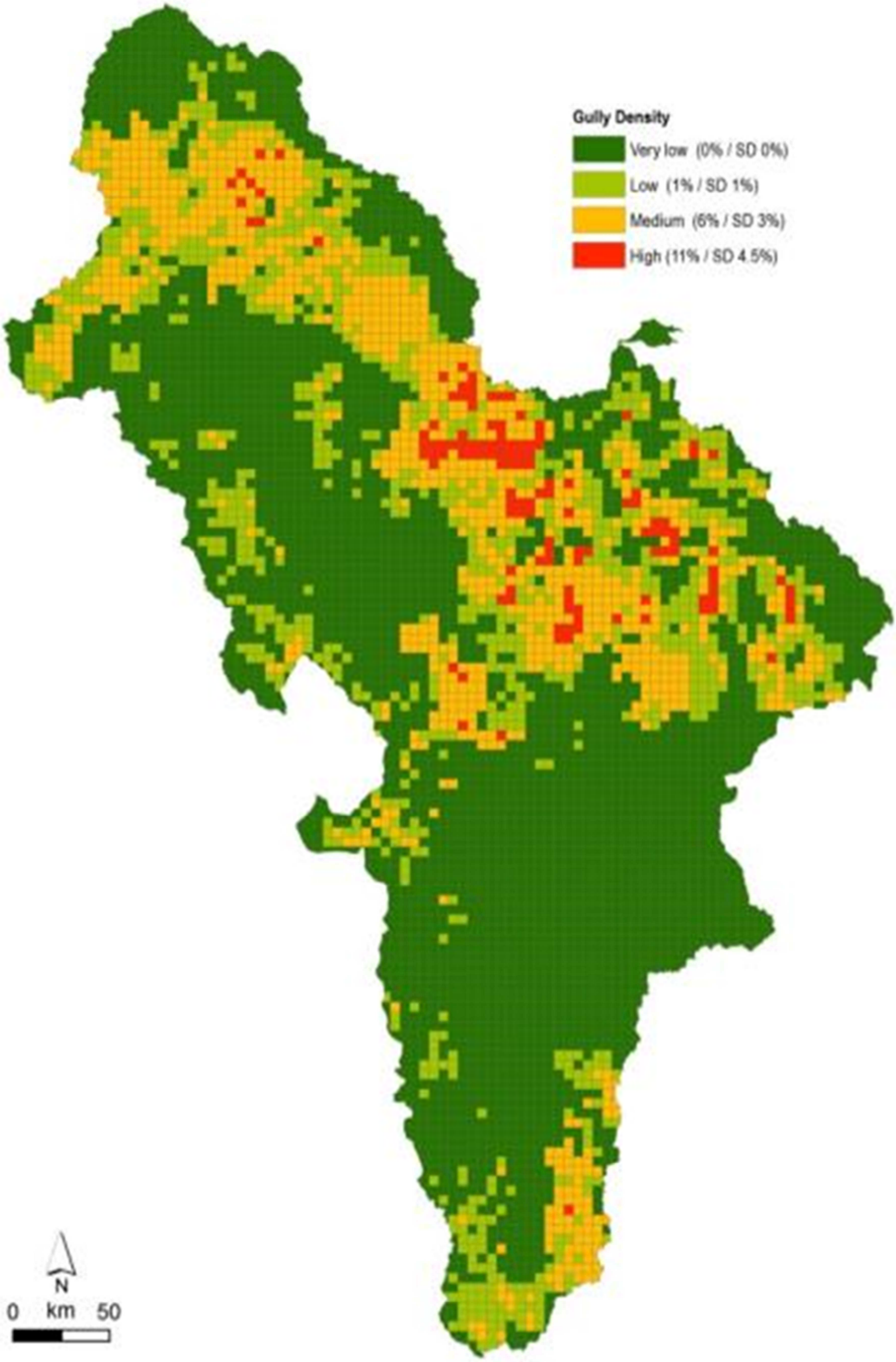

Figure 3 5km resolution gully density map.

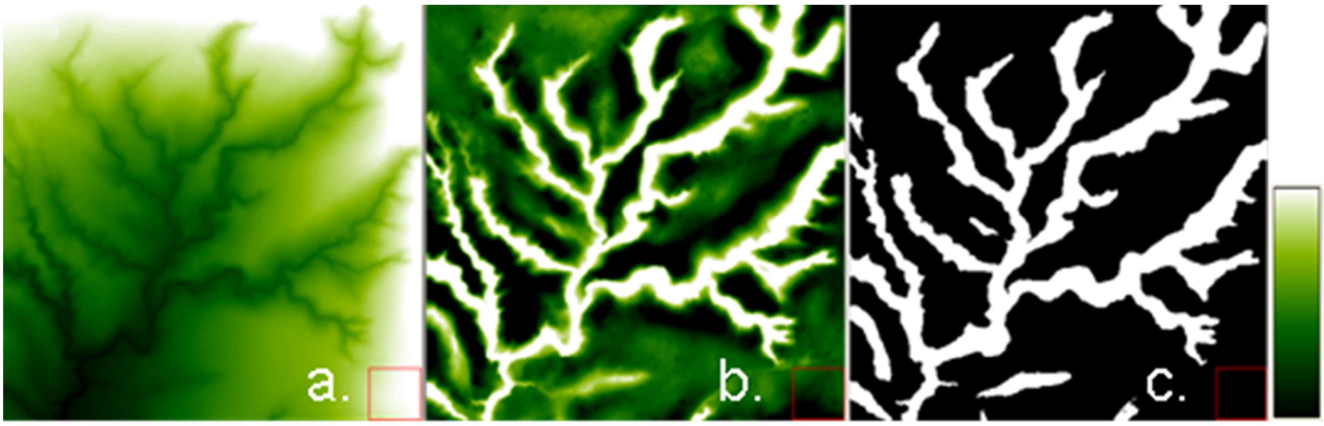

Figure 4 Example of a LiDAR derived DEM (a), the difference from mean elevation (b) and the classified gully extent (c) for a subset at one of the LiDAR sites (Blue Range). In the difference from mean elevation image (b), lighter shades indicate greater difference from mean elevation. This information is used to automatically classify the gully extent. Subset extent 200 x 200 m; DEM elevation range 360 to 375m; Difference layer elevation range = -59cm to 76cm.

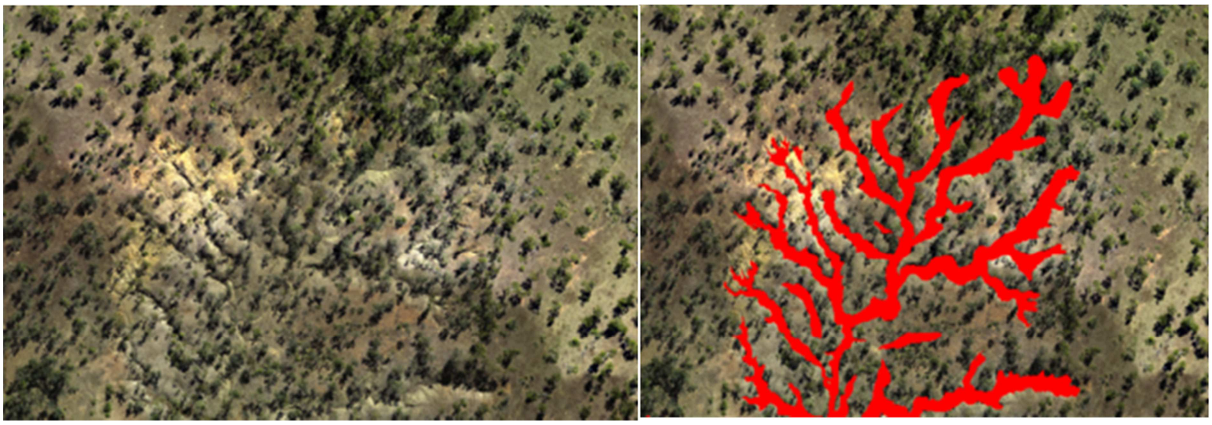

Figure 5 Orthophoto of the gullied area (left image) shown in Figure 4and classified gully extent based on LiDAR data (right image).

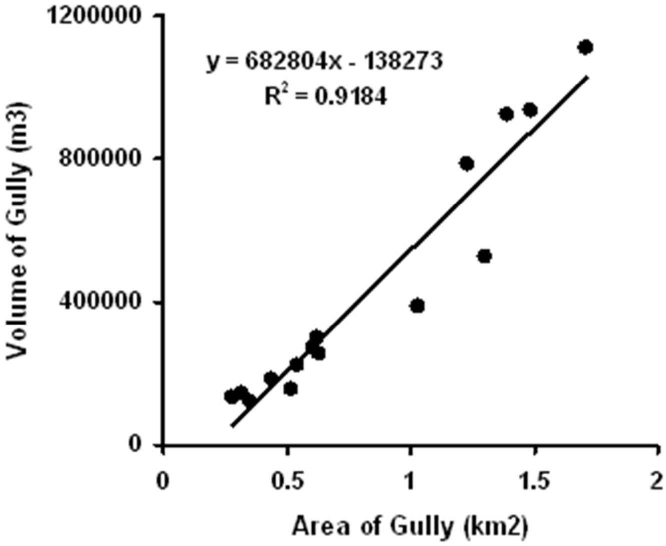

Figure 6 Relationship between gully area and volume. As gully area increases, the gully volume increases.

4.4 Gully chronosequence mapping

The gully chronosequence mapping was limited to only ten sites due to issues of comparing older imagery with more recent imagery and the difficulty of accurately mapping gullies in different imagery sources. However, despite this relatively small sample, a range of different location and dominant land types in the Burdekin were observed and some trends were evident. Figure 7shows an example of the mapping for three dates at two of the locations sampled. The most notable trend observed related to gully activity; nine gullies were found to be active. Excluding two outliers, the gullies sampled had an average yearly rate of expansion of 50.4m^2/year (Figure 8). One site (Site 10) was not able to be reliably assessed due to difficulty in defining the gully extent in the available imagery. Erosion rates were not constant over the observation period and large expansions appear to have occurred during short periods, possibly driven by particular rainfall events.

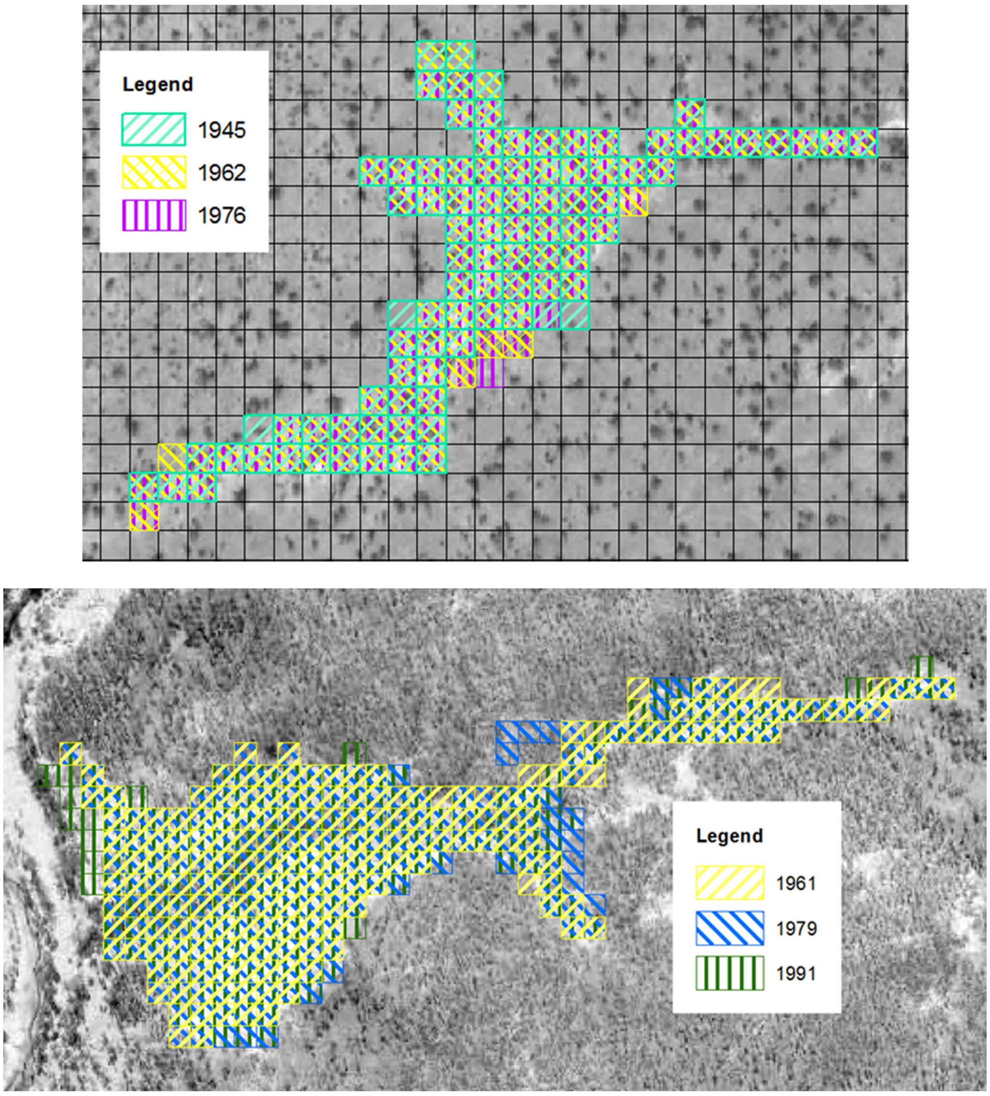

Figure 7 Example of gullied cells observed over three different dates with the earliest available date shown.

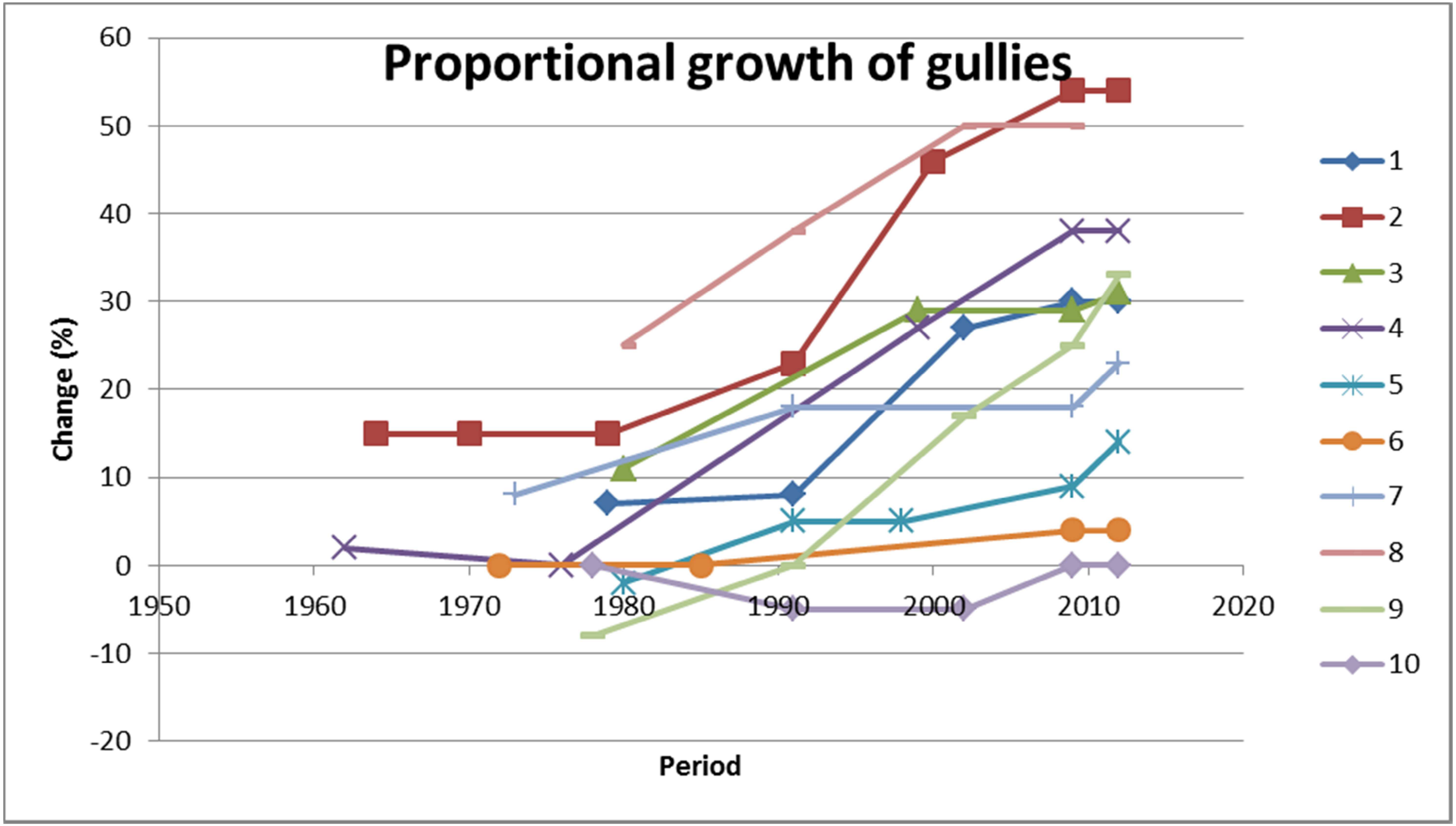

Figure 8 Proportional gully growth for the ten gully chronosequence sites, measured relative to original gully size as mapped in the first available date of imagery. Nine of the sites showed clear expansion over the time period. The gully activity at the remaining site (site 10) was not able to be reliably determined due to difficulty in defining the gully extent in the different imagery sources.

5. Key findings

The multiple scales of information, data and methods developed by this project have led to a number of key findings. Some of these relate to methodological issues and some relate to the location and dynamics of gullies, particularly in the Burdekin. These key findings are summarised as follows:

i. Gully mapping across large areas using remotely sensed imagery is challenging. It relies on having a consistent, repeatable and mappable definition of gullies which can be applied at multiple scales and across multiple image capture platforms. Simple, pragmatic and efficient methods are required to ensure consistency in the application of any mapping approach. Outputs must balance available resources for mapping against end-user requirements. A key outcome of this project has been the development of a guideline for catchment-scale gully mapping in Queensland. The guideline provides clear definition, guiding principles and efficient methods for manual and semi-automated mapping of gullies.

ii. Approximately 60% of the Burdekin catchment has low to very low presence and prevalence of gullies. This means there are very few or no gullies present in those areas. A large proportion of this area is in the Cape-Campaspe and Belyando sub-catchments and the southern half of the Suttor sub-catchment.

iii. Approximately 3% of the Burdekin catchment has high to very high presence and prevalence of gullies. This means that there is severe or highly prevalent gullying in these areas. Gullies can be either linear or extensive systems. The majority of these are in the Upper Burdekin and Bowen-Broken-Bogie catchments. A further 19% of the Burdekin catchment has medium or medium-high gullying present - gullies are frequent but are more likely to be relatively small and linear.

iv. Based on a predictive model of gully presence, there is a strong relationship between elevation above drainage lines and gully presence. Ninety-six per cent of gullies occur within 1m of elevation above a drainage line. However, the probability of finding a gully in these areas is only about 4-5%. This suggests that although the model is useful for identify areas where gully probability is higher, the absolute prevalence of gullies in the landscape is still low.

v. Mapping and monitoring gullies with LiDAR data requires accurate and consistent capture specifications, data processing and quality checking by LiDAR data providers. Thresholds are required when comparing differences in digital elevation models between multiple dates to account for noise and misclassification in the data. Based on the literature and testing as part of this project, these thresholds are nominally around 40-45cm, although this may vary depending on the quality of the data and the complexity of the terrain and land cover in the area of interest.

vi. Automated mapping of gullies from LiDAR imagery requires an algorithm which is capable of detecting elevation differences over varying ranges. This is due to the differences in the morphology of individual gullies and gully systems. Any approach must balance errors of omission and commission.

vii. Very high resolution mapping and change analysis of gullies using LiDAR data showed that of the 16 sites in the Burdekin and Fitzroy that were able to be analysed, all had at least some change in gully extent and volume between the two capture dates (2010 and

2013/14). The largest changes mapped were in excess of 10,000m^3 at Marshes, Parrot Creek, Starbright and Turrawulla sites. The exact timing and the fate of the sediment from these changes is unknown.

viii. Very high resolution mapping and change analysis of gullies using LiDAR data also showed that there is a strong correlation between gully volume and gully area. This relationship could be used to extrapolate gully volume for areas where only gully area mapping was available. Further analysis should focus on relationships to soil erosion vulnerability to best approximate expected gully volume for different soil structural characteristics. Assumptions would need to be made about management history but this could improve gully volume estimates for water quality model parameterisation and regional prioritisation.

ix. Mapping changes in gully extents using historical imagery is challenging and resource intensive, particularly for large areas. Locating historical imagery for a particular location requires extensive investigation of air photo archives to find suitable imagery that can be geo-located accurately to be able to reliably compare change over time. Identifying gullies in older imagery, and also in some new imagery, can be extremely difficult resulting in a large degree of subjectivity in mapping outputs. It is suggested that gully chronosequence mapping should only be undertaken where the study area is restricted to a local site and where reliable imagery is available.

x. Ten gullies sites were mapped over a 40-60 year period for some of the dominant land types of the Burdekin, using historical and recent aerial photography and satellite imagery. All but one of the sites demonstrated active gullying. Extension of gullies appeared to occur at different rates through time. From this limited sample, few relationships could be established between active gullying and soil erosion vulnerability or land type. A greater sample would be required to test these relationships.

xi. Results of multi-temporal monitoring of gullies using LiDAR data and historical imagery suggest that significant gully change is largely event driven. Any one location could change rapidly where erosion causing factors combine under favourable conditions such as low cover and high intensity localised rainfall.

6. Recommendations for future work

This project has developed and tested a number of approaches for mapping and monitoring gullies. Based on experiences in this project, including resourcing levels and issues with third party data acquisition, the following six recommendations are made for future work. These are listed in a general order of priority however prioritisation of these future projects would be dependent on end user requirements and investment strategies.

i. Continue development of the Catchment-scale Gully Mapping Guidelines and provide support for ongoing efforts by DNRM and DSITIA to continue mapping gully presence at 1km resolution (or higher) in the Burdekin, Fitzroy and Burnett-Mary catchments.

ii. Provide support for the establishment of a yearly gully monitoring program based mainly around field-based terrestrial laser scanning, with the possibility for periodic (~5 year) acquisitions of airborne LiDAR for established sites, subject to available resources. This program would require approximately 6-12 months of development to design a sampling program and establish appropriate survey and processing specifications for the use of terrestrial laser scanning for monitoring gully changes. This program has the potential to include stream banks. The program should also include gully (and stream bank) prevention/remediation sites in order to help monitor and evaluate the cost-benefit of any intervention strategies.

iii. Investigate and develop an appropriate mechanism for the integration of key landscape indicators of land condition. This includes gully mapping, soil erosion vulnerability, ground cover and management practice data. The catchment-scale water quality modelling may be the most appropriate mechanism for this work. With respect to the multiple scales of gully mapping produced by this project, some methods based on machine learning approaches have been suggested by Griffith University. These approaches integrate data at multiple scales to predict gully presence and volume change. These approaches may warrant a small-scale, sub-catchment study to test the model outputs.

iv. New technologies are emerging such as Unmanned Aerial Vehicles (UAVs) and space-borne stereo imagery. DAFF has previously demonstrated the application of UAVs for capturing imagery and generating digital surface models over a gully remediation trial on Spyglass Research Station in the Burdekin. Outputs still require testing and validation but the results did show some promise. It is suggested that further investigation of UAV technology for mapping and monitoring gullied areas be considered. With regards to space-borne stereo imagery, RSC have an agreement with the Chinese Satellite Applications Centre for Surveying and Mapping (SASMAC) who operate the ZY-3 satellite. This satellite has high resolution stereo-imagery capable of producing 4m digital surface models. Although still relatively coarse resolution for monitoring specific gullies, it is recommended that an assessment of these data be undertaken to determine the applicability of the imagery for catchment-scale mapping in three dimensions. Trial imagery will be provided free-of-charge as part of the collaboration with SASMAC.

v. Mapping and monitoring of gullies can only provide part of the story when it comes to understanding gully contributions to sediment loads and impacts on the GBR. Improved understanding of transport pathways, residence times, and dominant processes is still required. It is recommended that future geomorphological studies be focussed on these key issues.

vi. There is very limited information about the cost-benefit of gully prevention and remediation approaches. The gully mapping provides improved targeting of management, however, without adequate understanding of cost-benefit of different management approaches, this targeting may be misguided. It is recommended that where possible, science and monitoring efforts be combined with on-ground efforts and economic modelling to improve knowledge of where and when to expend resources for gully management.

7. Data publication

A number of products and data have been developed as part of this project. These will be made available through Open Data portals in late 2014 or early 2015. Further releases of data and mapping will be undertaken as mapping is progressed by DNRM and LiDAR data is resupplied from the LiDAR data provider.

Table 2 lists those data sets to be released under Creative Commons (BY attribution) licencing in the near future. The data will be made available through approved Open Data portals, including, where possible, the Queensland Globe. These data will be of use to government agencies, regional NRM groups, academic researchers and Paddock to Reef modelling staff.

Table 2 List of data sources to be released as Open Data from this project

Data set name	Resolution	Format	Delivery mechanism
Burdekin catchment 5km gully presence map	5km grid	TIFF	SIR, QGIS
Burdekin catchment 1km gully presence mapping	1km grid	TIFF	SIR
2010 LiDAR data and derived DEMs	As per LiDAR specifications	LAS, TIFF	TERN Auscover
2013/14 LiDAR data and derived DEMs	As per LiDAR specifications	LAS, TIFF	TERN Auscover

8. References

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