Reducing sediment delivery to the Great Barrier Reef using spatial data

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Key Points

- Existing low-resolution spatial data was analysed to determine the relative extent of erosion potential between sub-catchments within large sub-catchments draining into the Great Barrier Reef
- Priority sub-catchments were identified using a multi-criteria analyses based on stakeholder values
- High-resolution data was captured within these sub-catchments and detailed analysis undertaken
- This allowed for targeted stream management recommendations within the priority sub-catchments that provided cost effective sediment reductions.

Abstract

Channel erosion within Fitzroy Region waterways has been identified as a significant source of sediment and nutrient loads to the Great Barrier Reef (GBR). With a vast size (more than twice the area of Tasmania) and limited funding for analysis or on-ground works Alluvium were engaged by Fitzroy Basin Association (FBA) to determine the best value for money catchment management responses in priority sub-catchments to protect the GBR and improve river health. Using a combination of existing low-resolution spatial data and targeted field visits we developed an understanding of the catchment physiography, fluvial geomorphology, stream physical form and riparian condition within each sub-catchment. A prioritisation process using a Multi-Criteria Analysis was developed and used to compare the relative priorities for management between each sub-catchment. We developed high-level stream restoration plans in the priority sub-catchments and subsequently collected high resolution spatial data. The high-resolution data was analysed to improve system understanding and supplement the findings and subsequent management recommendations from the previously developed stream restoration plans. The high-resolution data allowed us to assess recent erosion and channel changes within the sub-catchments to determine how active the streams were. This allowed for targeted stream management recommendations that provided cost effective sediment reductions. Streambank stabilisation works have subsequently been designed and constructed resulting in an annual fine sediment erosion reduction of over 30,000 tonnes.

Keywords

Sediment, erosion, Great Barrier Reef, spatial data, prioritization, multi-criteria analysis, stream stabilsiation

Introduction

The Fitzroy Region (the Region) is located in central Queensland and drains into the Great Barrier Reef (GBR) near Rockhampton. The Region is approximately 156,000 km² in size, more than twice the area of Tasmania. Channel erosion within the waterways of the Region has been identified as a significant source of sediment and nutrient loads to the GBR. For example, Major flooding in 2013 and 2017 resulting from Cyclone Oswald and Cyclone Debbie respectively

Figure 1. Sediment plume from the Fitzroy River following flooding resulting from Cyclone Oswald in 2013

resulted in significant erosion of riverbanks and gullies and delivery of sediment to the GBR.

An understanding of the fluvial geomorphology, stream physical form and riparian condition can help inform broader catchment management responses to protect the GBR and improve river health. FBA initially sought flood recovery assessments and subsequently reach scale waterway management plans for priority regions to address the issues identified and increase the resilience of the streams to future flooding. With a vast area and limited funding for analysis or on-ground works Alluvium were engaged to determine the best value for money catchment management responses in priority sub-catchments to protect the GBR and improve river health. The Region is comprised of six major sub catchments, for this study we assessed three sub-catchments in the north east of the Region, The Isaac, The Mackenzie and The Fitzroy River catchments (**Figure 2**). The investigations were undertaken in a number of studies over a number of years (Alluvium 2017, Alluvium 2019a, Alluvium 2019b and Alluvium 2019c).
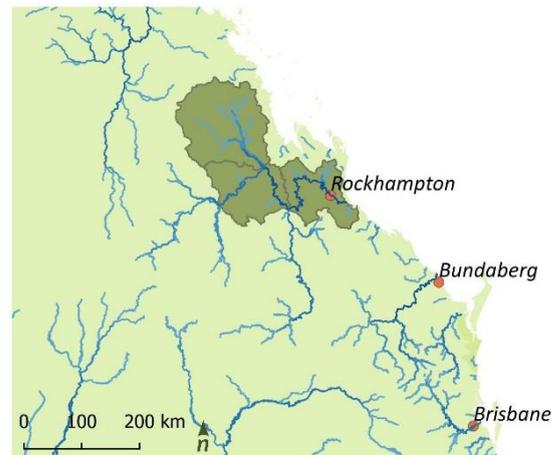

Figure 2. Project Study area – major management catchments highlighted in dark green

Study objectives

FBA sought geomorphic assessments of waterways across the Isaac, Mackenzie and Fitzroy River catchments to determine priority areas for management intervention to reduce sediment delivery to the GBR. Several interrelated assessments were carried out following Cyclone Debbie, each aiming to identify stream reaches that can play a critical role in reducing sediment and nutrient delivery to the coast. The assessment sought to provide sufficient overview of geomorphic condition to inform catchment and waterway management programs which will need to consider broader catchment processes (i.e. agricultural runoff, urban runoff, hillslope and gully erosion etc.) and ecological condition.

Project context

Stream channels are the primary conduits for the delivery of catchment derived sediments and nutrients to the coast. Sediments can be derived from hillslopes, gullies and channel erosion. These sediments are periodically (short to long term) stored in geomorphic units including floodplains, benches, bars and islands. These geomorphic units can exert significant control on waterway processes and impact on how sediments are transported and stored within the fluvial system.

Adjustments to channel form occur as a result of relationships that exist between channel form, flow and sediment supply and transport. At the reach-scale, the type of adjustment that can take place is constrained by the valley setting, the nature of bed and bank materials, and riparian vegetation. This gives rise to a wide diversity of different channel forms (or stream types). Understanding the stream types across a region can greatly assist in understanding waterway condition and sediment transport and storage processes.

Vegetation plays an important role in these processes. Erosion is a natural and essential process in alluvial systems; however human activities such as land clearing, removal of riparian vegetation or grazing pressure that limits reestablishment of vegetation can result in accelerated rates of channel erosion and sediment delivery. In addition, vegetation within channels and floodplains can play a critical role in capturing and stabilising sediments transported through channel networks. The condition of riparian vegetation is an important factor in sediment generation, transport and delivery.

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Study area attributes

Within the Isaac, Mackenzie and Fitzroy River catchments elevations range from 1000 m AHD in the headwaters of the Isaac River tributaries to sea level in the lower Fitzroy River. The catchment areas and lengths of stream per stream order are outlined in **Table 1**.

Table 1. Study region catchment areas and lengths of stream

Catchment	Area (km²)	Total length of stream (>SO3) (km)
Isaac River	22,459	6,737
Mackenzie River	13,027	2,339
Fitzroy River	11,445	4,072

The study region experiences a sub-tropical climate with summer dominated rainfall and high inter and intra annual variability. Annual average rainfall is spatially variable and ranges from 550 mm in the western catchment to 2000 mm in the coastal ranges. Extremely intense rainfall events have been recorded in the region, generally associated with cyclonic activity and southerly excursions of the monsoon trough (Hacker, 1988).

Land use within the region is dominated by agricultural enterprises. Approximately 80 – 90 % of the region is used for grazing, with isolated pockets of nature conservation or forestry/vegetation as well as irrigated cropping throughout each sub catchment. Mining is taking place in scattered areas along the western extent of the study region in both the Isaac and Mackenzie River catchments.

Modelled fine sediment connectivity to receiving waters (developed as part of the Fitzroy Catchment Reef Water Quality Protection Plan 2013 modelling) were used to inform the project (Dougall et al, 2014). The ratios determine the proportion of fine sediment generated within a sub-catchment that will reach the GBR, with the <20 µm fraction identified as most likely to reach the GBR. The ratio takes into account trapping of sediment and particulate nutrients in storages including floodplain storage. Within the study area, the fine sediment connectivity displays a strong gradient moving upstream, with sub-catchments in the Fitzroy catchment having the highest connectivity and the upper sub-catchments within the Isaac catchment having the lowest.

Assessment method

High level geomorphic assessment

A high-level geomorphic assessment of the waterways was undertaken for each 3rd order and above stream within the study area. The assessment involved spatial analysis of existing LiDAR data and aerial imagery (including historic aerial imagery) supported by targeted on-ground and aerial (helicopter) assessments. The process was iterative, as a desktop study informed the on-ground and aerial assessments, and the results from the on-ground and aerial assessments were used to update the desktop assessment.

The resolution and date of available LiDAR data and aerial imagery was variable across the catchment. The LiDAR resolution was predominantly 30 m, which was not sufficient to make detailed assessments at the stream scale but was adequate for an assessment of stream confinement. The date and resolution of the aerial imagery ranged from 25 cm resolution 2014 imagery within the Fitzroy catchment to 70 cm resolution 2012 imagery within the Mackenzie and Isaac catchments. Therefore, assessments within the Isaac and Mackenzie catchments may contain a higher level of uncertainty than in the Fitzroy catchment. Additionally, due to the date of the imagery, the impacts of more recent flood events such as Cyclone Debbie could not be assessed by desktop studies only.

The assessment further delineated the Isaac, Mackenzie and Fitzroy catchments into 58 sub-catchments, with 22, 15 and 21 sub-catchments located within each of the catchments respectively. The assessment included:

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- Classification of lateral confinement - A higher-level assessment of the degree of lateral confinement was undertaken. Alluvial channels can be confined to varying degrees by bedrock valley margins. The degree of confinement is an important boundary condition that controls the form of a channel. It can help determine the width of the zone in which the alluvial channel can migrate as well as the patterns and rates of migration. This could help inform riparian management practices and the degree of lateral erosion.
- Lateral stream stability - Each stream (3rd order and above) was assessed based on stream bank degradation using aerial imagery from 2012 for the Mackenzie and Isaac catchments, and 2014 for the Lower Fitzroy catchment. Where available, information from a field assessment and helicopter assessments was also used. Zones of degradation were identified for each stream, and a proxy length degradation for each sub-catchment was calculated to be able to identify the comparable extent of streambank degradation between sub-catchments.
- Riparian vegetation condition - canopy cover was used as a surrogate for root reinforcement and hydraulic resistance along channel banks. The assessment utilised aerial imagery from 2012 for the Mackenzie and Isaac catchments, and 2014 for the Lower Fitzroy catchment. Where available, information from the road field crossing assessment and helicopter assessments was also used.
- Gullying - Gully density mapping developed by the Department of Natural Resources, Mines and Energy (DNMRE) was provided by the FBA for use in this project. The mapping was used to identify the spatial distribution of gullies within each sub-catchment and to compare gully densities between sub-catchment.
- Connectivity to downstream receiving waters (i.e. the GBR).

Field and aerial helicopter assessments

Reconnaissance by helicopter were undertaken on two occasions by Alluvium and FBA personnel to assess landscape domains, stream processes and erosion sites. The aerial assessment allowed for rapid identification of landscape domains (such as the footslopes of the Clarke-Connor Range) and reaches of stream (such as the alluvial reaches of the lower Fitzroy River) vulnerable to erosion, and erosion sites and the associated site condition, i.e.:

- presence of bedrock and its impact on limiting future erosion potential

- vegetation condition, including whether vegetation condition indicates recent or previous erosion

- scale of erosion

Figure 3. Field locations and helicopter photo locations visited by Alluvium and FBA staff within the study area

On-ground rapid geomorphic assessments were also undertaken by Alluvium personnel. The location of the field sites were determined through a combination of accessibility from adjacent public land, which were predominantly road crossings, and ensuring maximum coverage of the study area. A total of 84 sites within 29 sub-catchments were visited across the three catchments. During the field assessment, observations relating to bed and bank material/morphology/condition, riparian vegetation condition and instream habitat were recorded. The locations of field sites and helicopter assessments undertaken as part of this study, as well as the Fitzroy Basin Flood Recovery Assessment are shown in **Figure 3**.
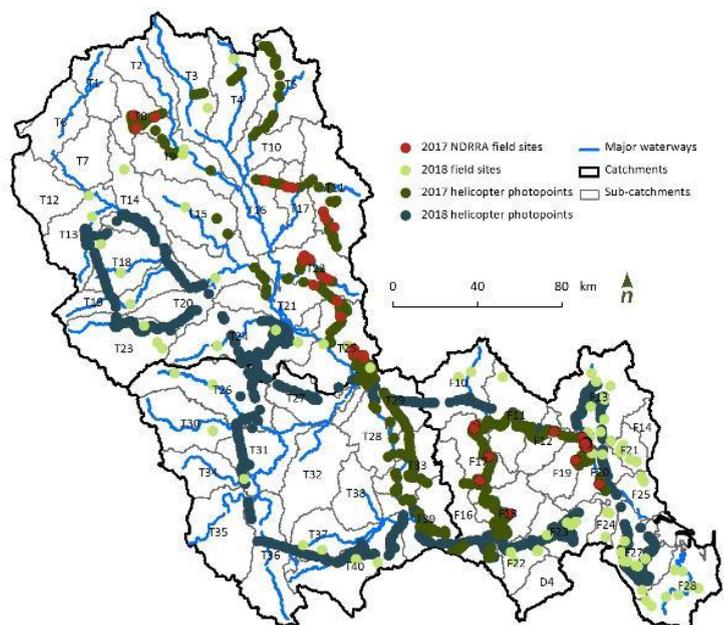
Prioritisation

A prioritisation process was developed to determine priority sub-catchments for management intervention within the study area. To compare the relative priorities for management between each sub-catchment, a simple two stage Multi-Criteria Analysis (MCA) was developed and used. Objectives for sub-catchment management and subsequent criteria were developed during a workshop with representatives from the FBA and Alluvium. A scoring system for each of the criteria was then developed using the assessments undertaken in the sub-catchment summaries. The objectives were not rated as equal, for example, reflecting government funding priorities sediment mobilisation and delivery to downstream receiving waters was considered a higher concern than improving river health. As such, each objective was given a weighting compared to other objectives.

High-level findings

Extensive streambank degradation and gullying across each of the three catchments was identified. Streambank erosion and gullying was generally more prevalent in the Fitzroy River main channel and the Isaac catchment (particularly the western Isaac catchment) compared to the remainder of the Fitzroy catchment and Mackenzie catchment. The impacts upon downstream receiving waters, including the GBR, is likely to be greater from erosion processes in the Fitzroy catchment as fine sediment connectivity displays a strong gradient moving up the study area, with sub-catchments in the Fitzroy catchment having the highest connectivity and the upper sub-catchments within the Isaac catchment having the lowest.

Figure 4. Priority ranking for management intervention across the study area

The prioritisation ranking for management intervention within the study area is shown in **Figure 4**. The majority of high-ranking sub-catchments are located within the Fitzroy catchment. Higher ranking sub-catchments are also located in the north-west of the Isaac catchment and the along the western boundary of the Mackenzie and Isaac catchments. The priority for management intervention may change as objectives for management interventions change or if the sediment connectivity ratios are updated during future water quality modelling.

Detailed assessment

More detailed stream condition assessments were undertaken in the Fitzroy River main branch (split into three reaches) and the seven highest priority sub-catchments. The assessments included a more detailed desktop analysis, collection and analysis of high-resolution data (LiDAR and aerial imagery) and a targeted field program to identify the geomorphic processes and likely trajectory of each of the waterways.
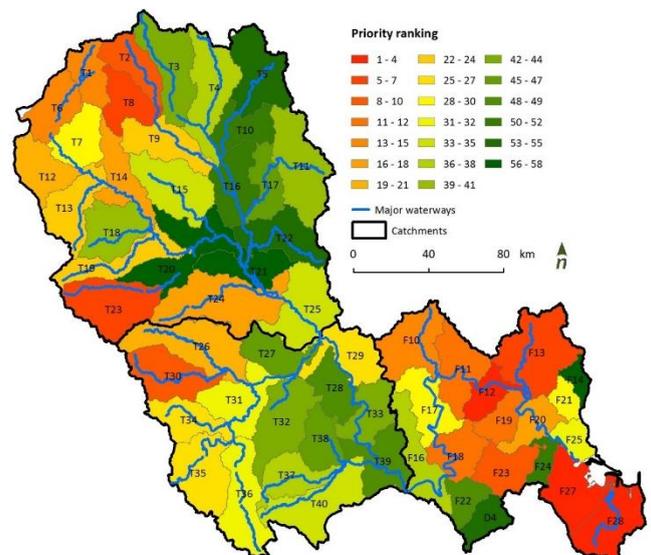
Terrain analysis

The analysis of high-resolution data included the development of Digital Elevation Models of Difference (DEMoD), which identify changes in ground surface elevation from two LiDAR datasets captured at various temporal scales to determine the volume of sediment eroded from the banks and the dominant erosional process (**Figure 5**).

To provide a higher level of certainty and understanding of sediment loss within each of the priority areas, an assessment of major erosion sites was undertaken. The volume of sediment released from individual sites where there had been significant change in the elevation of the terrain was quantified. Additionally, for each erosion site, the erosion mechanism (e.g. meander migration, wet flow failure, floodplain scour) and geomorphic unit (e.g. floodplain or inset channel feature) was identified.

Figure 5. Example of a DEMoD in the Fitzroy River – Red showing erosion and blue showing deposition

Aerial imagery assessment through time

Aerial imagery from various years between 1952 and 2019 were available to assess the historical channel change (**Figure 6**). The analysis of historical aerial photos enabled changes in vegetation condition, channel width and planform to be assessed. Understanding historical rates of channel change can assist in predicting the future trajectory of the system. Additionally, in areas beyond the extent of the DEMoDs, estimations of sediment mobilisation volume due to bank erosion were made using historical aerial imagery and LiDAR data.

Figure 6 - Comparison of historical aerial imagery – red line indicates 2019 streambank alignment

Results

Within the Fitzroy River study reach, significant erosion has occurred since the 1950s. Between 2009 and 2019, over 4.5M m^3 of sediment was mobilised from the study reach (**Table 2**). The majority of major erosion sites are concentrated around two areas, a meander cutoff and the confluence of a tributary (where historic meander cutoffs have occurred). The majority of sediment mobilisation has been caused by meander migration within the floodplain in these zones caused by meander development following cutoffs. The volume of sediment mobilised from these areas is likely elevated due to the loss of bank and floodplain resistance following land clearing and grazing. Sediment erosion volumes are highest in the downstream reach (reach 1), which has the highest connectivity to the GBR and the lowest in the upstream reach (reach 3), which has the lowest connectivity to the GBR.

Within the sub-catchments, major erosion and sediment mobilisation between the early 1950s and 2019 was identified, however the extent to which it occurred varied greatly between sub-catchments. The temporal analysis of aerial imagery indicates that active meander migration, channel widening, gullying and channel straightening processes have occurred since the early 1950s at several locations throughout the study areas.
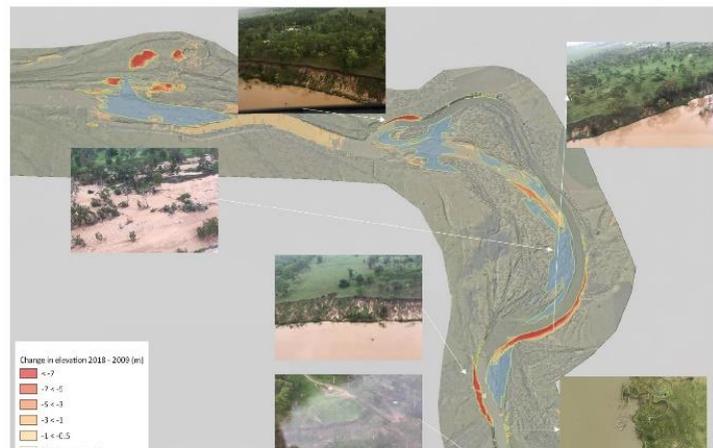
Major changes were more prevalent in the sub-catchments F23 (Neerkol Creek) and F28 (Raglan Creek) (**Table 2**). The volumes of sediment mobilised were significantly less than in the Fitzroy River, in part due to the difference in height of streambanks.

The stream network degradation is still in an active phase of declining condition trajectory and is unlikely to recover in many reaches in the short or medium term, even if pressures such as cattle grazing and vegetation clearing were removed. Without management intervention, significant sediment mobilisation is likely to occur and impact upon river health and that of the receiving waters, including the GBR.

Table 2. Volumes of sediment mobilised from each priority sub-catchment and reach

Reach or sub-catchment	Volume of sediment mobilised (m³)	Volume of sediment mobilised per stream length (m³/km)
Fitzroy River reach 1	1,654,074	40,541
Fitzroy River reach 2	2,444,773	29,209
Fitzroy River reach 3	592,096	7,476
F12	24,200	323
F13	4,500	60
F23	113,700	1,995
F27	70,800	1,106
F28	159,850	1,665

Outcomes

Sub-catchment summaries

High level, one-page sub-catchment summaries were developed for each of the 58 sub-catchments. These detail sub-catchment assets, streambank stability and degradation zones, riparian vegetation extent, gully erosion and connectivity to downstream waterways.

Stream-restoration plans

Stream restoration plans were developed for each priority sub-catchment and for the Fitzroy River main branch. These plans recommend a framework that assists in identifying a program of works that aims to increase the natural resilience of the system through the establishment of high quality, structurally diverse riparian vegetation. Revegetating historically cleared stream systems can significantly reduce the economic costs of flood events and provide environmental benefits. However, due to the current condition of some of the streambanks, associated management interventions including structural works and stock control will be required to aid vegetation establishment in some areas.

Figure 7. Example of recommended level of intervention in a priority sub-catchment

To assist in determining the most appropriate erosion treatments throughout the study area, the erosion potential for each section of bank throughout each reach was identified (**Figure 7**). Additionally, stakeholder assets/values and desired outcomes were identified through a stakeholder consultation as part of the Lower Fitzroy River Assessment (Alluvium, 2019b). Subsequently, a level of management intervention was recommended for each section of bank through each of the reaches. The findings could be used to develop a prioritised program of works. The program of works would include structural intervention at major streambank erosion sites with a high erosion potential, and protecting and enhancing riparian vegetation in areas of moderate and high erosion potential throughout the remainder of the reach.
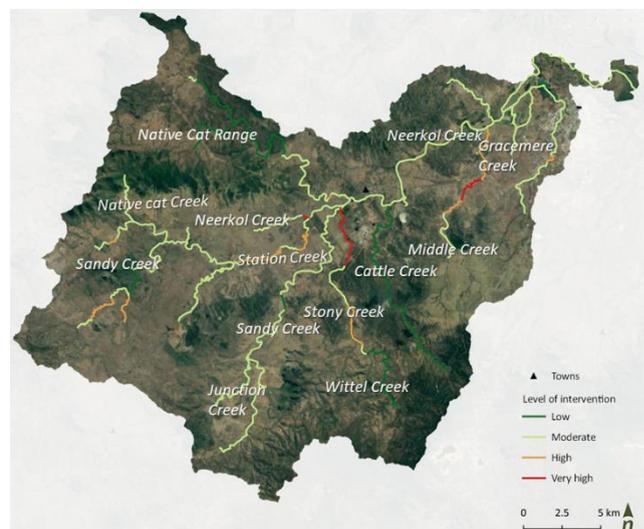
On-ground works

Stream restoration works have been designed and implemented at several of the major erosion sites identified on the Lower Fitzroy River (**Figure 8** and **Figure 9**). The works include both soft and hard engineering solutions, including bank battering, installation of pile fields and revegetation. These works included one of the largest stream bank stabilisation project in Australia and represented over $2M worth of investment. Detailed bank erosion modelling at two of the sites estimates that the stabilisation result in sediment mobilisation reductions of over 90 %, which equates to over 50,000 m³ of sediment per annum.

Figure 8. Streambank stabilsiation works implemented along the Fitzroy River

Conclusions

This study has developed an understanding of geomorphic condition for each sub-catchment in the Fitzroy, Isaac and Mackenzie catchments. Channel erosion and degraded riparian vegetation within these catchments are factors that contribute to significant sediment and nutrient load exports to downstream receiving environments, including the GBR. Undertaking a high-level analysis of existing datasets combined with a prioritisation process provided a cost-effective method to identify sub-catchments with the potential for significant sediment delivery to the GBR. Subsequent investment in data collection and analysis in these sub-catchments allowed for targeted stream management recommendations within the Fitzroy Region that provided the potential for cost effective sediment reduction programs. The management plans have already been used to guide investment within the region, with bank stabilisation works resulting in an average annual reduction in sediment of over 30,000 m³.

Figure 9. example of a major erosion site on the Fitzroy River before (top) and after (below) stream stabilisation works

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