Assessing the efficacy of a reach scale stability management program: the Mary River, Queensland

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Key Points

- Channel erosion represents a major source of fine sediment to the Great Barrier Reef (GBR) lagoon and is the target of government investment to reduce sediment loads.
- The banks of the Mary River near Kenilworth have been actively eroding for over five decades.
- A reach scale program (permeable groynes and revegetation over four full bends) led to approximately 85% less bank erosion during the 2022 floods than would be expected based on comparison with historical erosion rates and two nearby control sites.
- This study is the first known study to assess the performance of stream bank management programs within GBR catchments.

Abstract

Channel erosion represents a major source of fine sediment to the Great Barrier Reef (GBR) lagoon. Erosion is a natural and essential process in alluvial systems; however human activities such as land clearing, sand and gravel extraction, removal of riparian vegetation, and grazing pressure that limits reestablishment of vegetation, can result in accelerated rates of stream erosion. In the last decade the Australian and Queensland Governments have invested 10s of millions of dollars in programs to reduce sediment supply to the GBR, targeting agriculture, gullies and stream bank erosion. This paper analysis stream erosion within a heavily impacted reach of the Mary River across five decades and assesses the performance of a recent reach scale stream bank management program during the 2022 floods. The erosion was controlled with a combination of bank reprofiling, pile-field groynes and revegetation. The analysis highlights that the reach scale program (covering four bends) led to approximately 85% less erosion during the 2022 floods than would be expected based on comparison to historical erosion rates and two nearby control sites. This study is the first known study to assess the performance of stream bank management programs within GBR catchments.

Keywords

Great Barrier Reef, bank-erosion, revegetation, sediment, pile-field, groynes, evaluation

Introduction

Channel erosion represents a major source of fine sediment to the Great Barrier Reef (GBR) lagoon. Erosion is a natural and essential process in alluvial systems (Florsheim et. al. 2008); however human activities such as land clearing, sand and gravel extraction, removal of riparian vegetation or grazing pressure that limits reestablishment of vegetation can result in accelerated rates of stream erosion (Fryirs and Brierley 2001; Webb and Erskine 2003; Brooks, Brierley et al. 2003; Ivezich et. al. 2016). These erosion processes provide a pathway for sediments and nutrients, such as nitrogen and phosphorous, to enter waterways. Land use changes within the GBR catchments have resulted in significant increases in sediment and nutrient loads to the GBR lagoon (Waterhouse et al., 2012). Streambank erosion is estimated to contribute ~30- 40% to end of catchment sediment yields (Bartely et. al, 2015). As a result, stream bank erosion has been identified as a major sediment and particulate nutrient delivery process impacting on the GBR.

In the last decade the Australian and Queensland Governments have invested 10s of millions of dollars in programs to reduce sediment supply to the GBR, targeting agriculture, gullies and stream bank erosion. Several studies have investigated the effectiveness of agriculture and gully programs (Khan et. al. 2023; Stokes et. al. 2023). The benefits of remnant riparian vegetation on sediment loads has also been documented in some GBR catchments (Connolly et al., 2015; Leonard and Nott, 2015, Bartley et al., 2008).

However, there are no known published studies in GBR catchments that have measured the effectiveness of stream bank management programs (Wilkinson et. al. 2022).

In this paper we examine the performance of a reach scale streambank stabilisation project in the Mary River near Kenilworth following major flooding in 2022.

Background

Overview

The Australian Government's Reef Trust program has developed the *Gully and Stream Bank Toolbox. A technical guide for gully and stream bank erosion control programs in Great Barrier Reef catchments. 3rd Edition* (Wilkinson et. al. 2022) to guide the planning and implementation of streambank projects. The Toolbox recommends reach scale revegetation as the primary tool for reducing rates of channel erosion. However, where rapid erosion is clearly ongoing and cannot be otherwise managed, engineered stream bank erosion control is recommended.

A common engineered stream bank erosion control technique used in the GBR catchments in conjunction with revegetation works is pile-field groynes. A primary function of pile-field groynes is to mitigate bank erosion by reducing near bank flow velocity and shear stress, increasing fine and coarse sediment deposition, and promoting vegetation establishment (Alauddin, et. al, 2011, and Carling, et. al, 1996). Timber piles have a finite design life (10-15 years). The goal of the groynes is to establish vegetation along the lower bank to help provide long term stability beyond the design life of the piles themselves.

A key component of the Toolbox is to describe a process to determine the ratio of the investment cost relative to the total reduction in fine sediment loads delivered to the GBR lagoon. This requires the following information:

- A baseline erosion rate based on multi-temporal aerial imagery and LiDAR analysis
- An estimated effectiveness of erosion control works
- An estimated cost for the erosion control works

The average effectiveness (i.e. reduction in erosion rates) of stream bank engineered protection works (including pile-fields) over 30 years is estimated at 60% , or 70% with ongoing riparian maintenance (Wilkinson et. al. 2022). There are no known published studies evaluating the effectiveness of engineered stream bank protection combined with revegetation in the GBR catchments.

Study area

The Mary River rises in the Conondale Range near Maleny and flows in a northerly direction, through Gympie, and discharges into the Great Sandy Strait near Fraser Island. The catchment area is approximately 9,595 km^2, with an approximate stream length of 300 km. The study area is a 4 km reach located in the upper reaches of the Mary River, inland from the Sunshine Coast adjacent to the township of Kenilworth.

The Mary River through Kenilworth is a sand and gravel bed river with a sinuous planform. Within the river valley there are older terrace units and more contemporary inset floodplains. The channel largely abuts the inset floodplain units within this reach. The reach has a long history of erosional channel change associated with clearing of catchment and riparian vegetation, and with sand and gravel extraction.

Alluvium (2014) identified that there has also been considerable widening (approx. 100-200%) and channel straightening since the 1950s which has resulted in an estimated 1,900,000 m^3 (9 m^3 /m/year) of sediment export from this reach. In 2014-15, stakeholders worked together to develop a rehabilitation plan. The plan made costed, prioritised recommendations for the management of riparian, instream and floodplain zones.

Since the development of the plan each of the key stakeholders have implemented significant works in the 4 km study reach including:

- The implementation of four streambank stabilisation projects including bank reprofiling, pile-field groynes and revegetation between 2015 and 2021
- Revegetation, weed control and stock exclusion across 5 kilometres of river frontage

The program of works and interventions consisted of:

- Bank reprofiling at actively eroding steep outside meander banks to a gradient of 1V:3H to allow for native riparian vegetation establishment.
- Pile-field groynes along the toe of reprofiled banks to reduce the near bank velocity, promote deposition and protect establishing vegetation.
- Reach scale revegetation and stock management.

In early 2022 the reach experienced a major flood with an 5% AEP, the largest since the 1990s which allowed the performance of the works to be assessed.

Figure 1. Images before (left) and after (right) of the works within the Mary River adjacent to Kenilworth

Method

The erosion rates pre and post works have been estimated using the methodology outlined in the *Reef Trust Gully and Stream Bank Toolbox 3rd Edition* (Wilkinson et. al, 2022) and supporting guidelines provided in the *Stream bank Erosion Control Assessment Tool (SECAT) Survey User Guide, Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Humphreys and Wilkinson, 2021). The key steps involved in the methodology, a summary of the data used, as well as sources of data and key assumptions, are summarised below:

- Historical channel erosion was assessed with aerial imagery for seven temporal periods between 1971 to 2003.
- Four LiDAR datasets of the study reach were available from 2008, 2014, 2018 and 2022. Digital Elevation Models (DEMs) of difference (DoD) were developed between each two successive LiDAR datasets (i.e. 2008-2014, 2014-2018, 2018 -2022). As-constructed surveys were available for each of the four streambank stabilisation projects immediately after construction. These datasets were merged with either the 2014 (one site) or 2018 LiDAR data (three sites) depending on the year of construction. This ensured that change in the DoDs was due to erosion and not the engineering earthworks. The DEMs were co-registered to minimise any systematic errors in the DoD, and a limit of detection (LOD) of 0.3 m applied to account for uncertainty. The DoDs and volume estimates were developed using the Prof. Joe Wheaton's geomorphic change detection software (https://gcd.riverscapes.net/).
- The same erosion assessments as the treatment sites were also undertaken at two control sites, one upstream and one downstream, but only for the three periods when LiDAR data was available. The control sites selected have similar characteristics and erosion mechanisms to the sites assessed in the study reach.
- The flood history of the Mary River was also assessed to provide context for the erosion trajectory assessment using the downstream Moy Pocket gauge. To analyse the hydrologic data, 10 flow periods ranging from 3 – 7 years were specified which aligned with the multi-temporal imagery and LiDAR analysis. For each flow period the peak flow, total flow and climate correction factors were calculated.

Results

Pre-works period

The cumulative sediment production along with annual flow volume in the 48 years between 1971 and 2018 (Period 1 to Period 9) are shown in Figure 2. Rates of bank erosion (and hence sediment production) are typically larger during the wetter periods and less in drier periods. Despite the variation in erosion in wet and dry periods, over the 48 year period rates of bank erosion, and hence sediment production, is remarkably consistent over time (R^2=0.98) with an average annual sediment loss of 18,500 m^3/year.

The bank condition prior to the works throughout the reach consisted of steep, near vertical outside meander banks with exposed sandy-loams to sandy-clay alluvial sediments (see Figure 1). Banks retreated as a result of toe scour and subsequent gravitational mass failure. Hydraulic modelling indicates the shear stresses required to mobilise the exposed alluvial sediments along the toe are frequently exceeded in even small to moderate flow events (Alluvium, 2014). As a result, it was predicted that bank retreat would continue unless managed.

Post works period

The sediment production volumes post works were estimated using the DoDs as shown in Figure 2 and Figure 4. A summary of the sediment loss estimates is provided in Table 1. Compared to the baseline erosion rate the efficacy of the works across the assessment period at the four major stabilisation sites is between 95.4 – 99.6 %. Across the reach the efficacy of the works across the assessment period is 81.8 %. Note the reach scale estimates included areas where no stabilisation works were undertaken and areas where there was revegetation only.

The peak discharge and annualized erosion volume for each of the ten periods is shown in Figure 3. A line of best fit was developed for period 1-9 showing a very high correlation between peak discharge and annualized sediment loss (i.e. $R^2 = 0.82$). Note that this relationship would predict sediment production of around 27,000 m^3 for the discharge associated with Period 10 (post works), but instead that period recorded the second lowest erosion volume (around 3,000 m^3/yr).

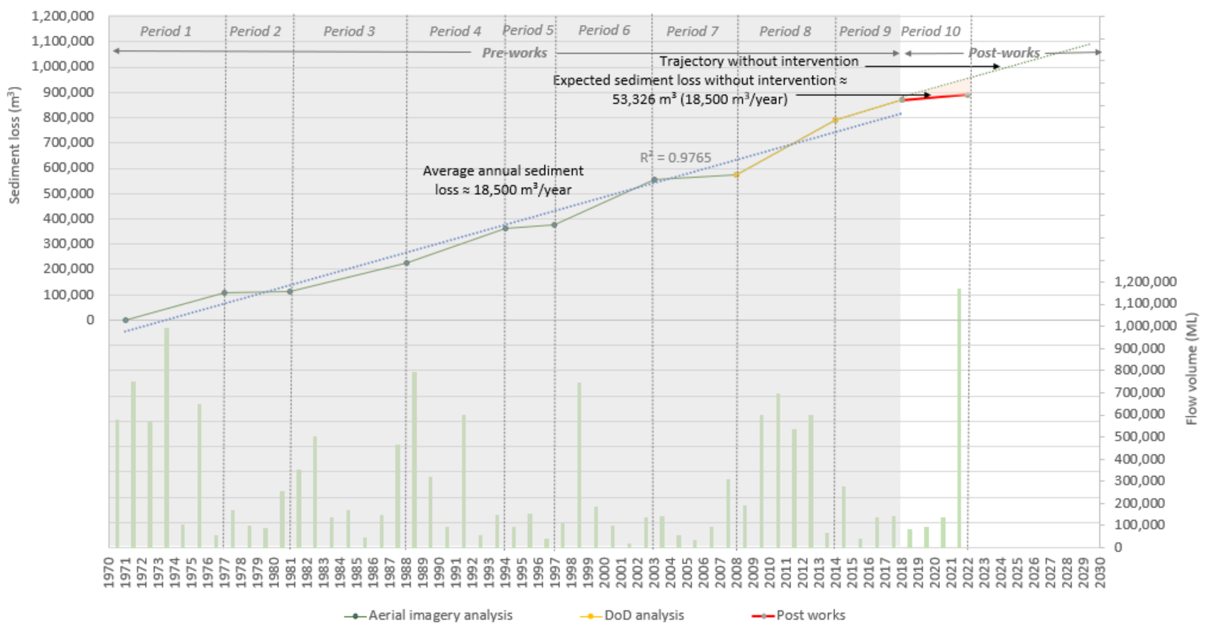

Figure 2. Cumulative sediment production from the Mary River Kenilworth reach, and annual flow volume since 1971. The pre-works periods (1-9) is shown in the grey shaded box along with the linear line of best fit. The post works period (10) is also shown. The colour of the erosion line shows the erosion rate assessment method (i.e. aerial imagery or DoD analysis) for each period.

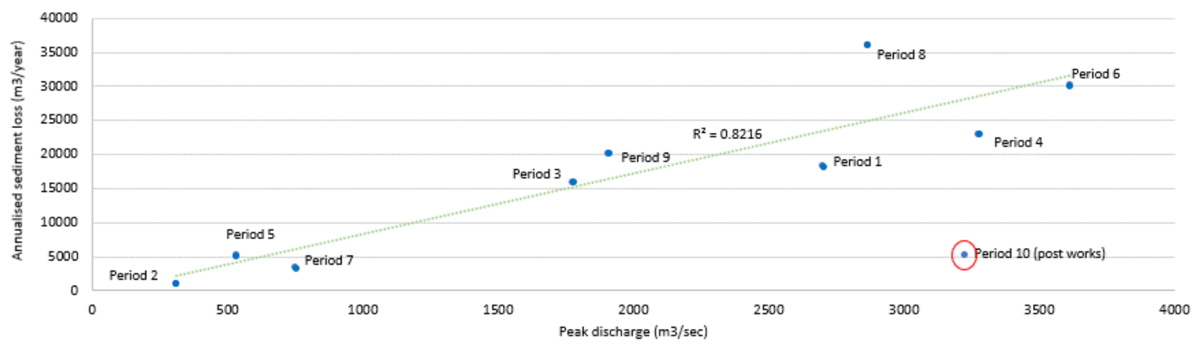

Figure 3. Plot of peak discharge and sediment loss for each period in the study reach. Note the line of best fit relates to the pre works period data (period 1 – 9). A red circle shows the outlier Period 10.

Control site assessments

The sediment loss at the two control sites have been estimated for erosion periods 8,9 and 10 (when LiDAR data was available). At the downstream site LiDAR data was available for each year and sediment estimates were derived using DoD analysis. At the upstream site LiDAR was available for 2008, 2014 and 2022 so a combination of DoD, and LiDAR and aerial imagery analysis was used to calculate erosion rate.

Erosion from the study reach (i.e. the treatment reach) was compared to both control sites (Table 1). The results demonstrate that erosion rates in the control sites are highly variable, and usually much less than for the treatment reach due to their smaller spatial scale. However, at upstream and downstream control sites the sediment loss in period 10 was 78% and 112% of the annualised sediment loss within Period 8 respectively. However, within the study reach the Period 10 sediment loss was only 14% of annualised sediment loss during Period 8. The comparison with the control sites suggests that the performance of the works within the study reach is approximately 86% as without management the sediment production would be approximately equal to the Period 8 sediment production volume (similar to the control sites).

Table 1. Summary of sediment loss estimates for study reach and control sites for period 8, 9 and 10

		Sediment loss (m^3)					
Period	**Years**	**Downstream control site**		**Upstream control site**		**Study reach**	
		Total (m^3)	**Annualised (m^3/year)**	**Total (m^3)**	**Annualised (m^3/year)**	**Total (m^3)**	**Annualised (m^3/year)**
8	2008-2014	36,872	6,145	11,515	1,919	215,752	35,959
9	2014-2018	9,229	2,307	1,503	376	80,272	20,068
10	2018-2022	19,257	4,814	8,564	2,141	20,674	5,169
Period 10 sediment loss/Period 8 sediment loss			78%		112%		14%

Conclusions

Sediment from river bank erosion is one of the major threats to the GBR. Five decades of multi-temporal analysis shows that erosion rates are close to linear over time despite a highly variable flow regime. This is an important result as it allows us to make good estimates of future sediment delivery from the river over decades. This study also demonstrates that 'soft' engineering techniques to bank stabilisation (bank reprofiling, pile-fields, riparian revegetation, and stock management) can dramatically reduce erosion rates. This is shown by the 2022 flow year (part of Period 10) which had the largest flow volume on record and would have been expected to cause substantial bank erosion based on past rates. However, the works, which occurred between 2015 and 2021, substantially increased bank resistance and reduced near bank velocity and shear stress. The works led to approximately 85% less erosion during the 2022 floods than would be expected based on the following analysis:

- Comparison to the baseline erosion rates within the study reach based on five decades of multi-temporal analysis
- Comparison to the nearest upstream and downstream control sites which had the following characteristics:
    - Outside meander which abuts a floodplain unit
    - Unvegetated lower bank (overbank vegetation was acceptable)
    - No bedrock controls along the bank
    - Was not managed in any way during 2008-2022

This project is the first to demonstrate that soft engineering approaches can be highly effective at reducing rates of channel erosion and reducing sediment loads to the GBR. Over time as the vegetation further establishes within the channel, along the bank and across the overbank zone increased erosion resistance would be expected. The findings of this study are consistent with Hardie et.al. (2016) who found revegetation programs can be used to create a suite of high quality, structurally diverse riparian vegetation that can reduce the occurrence, extent and scale of flood related channel change in alluvial stream systems.

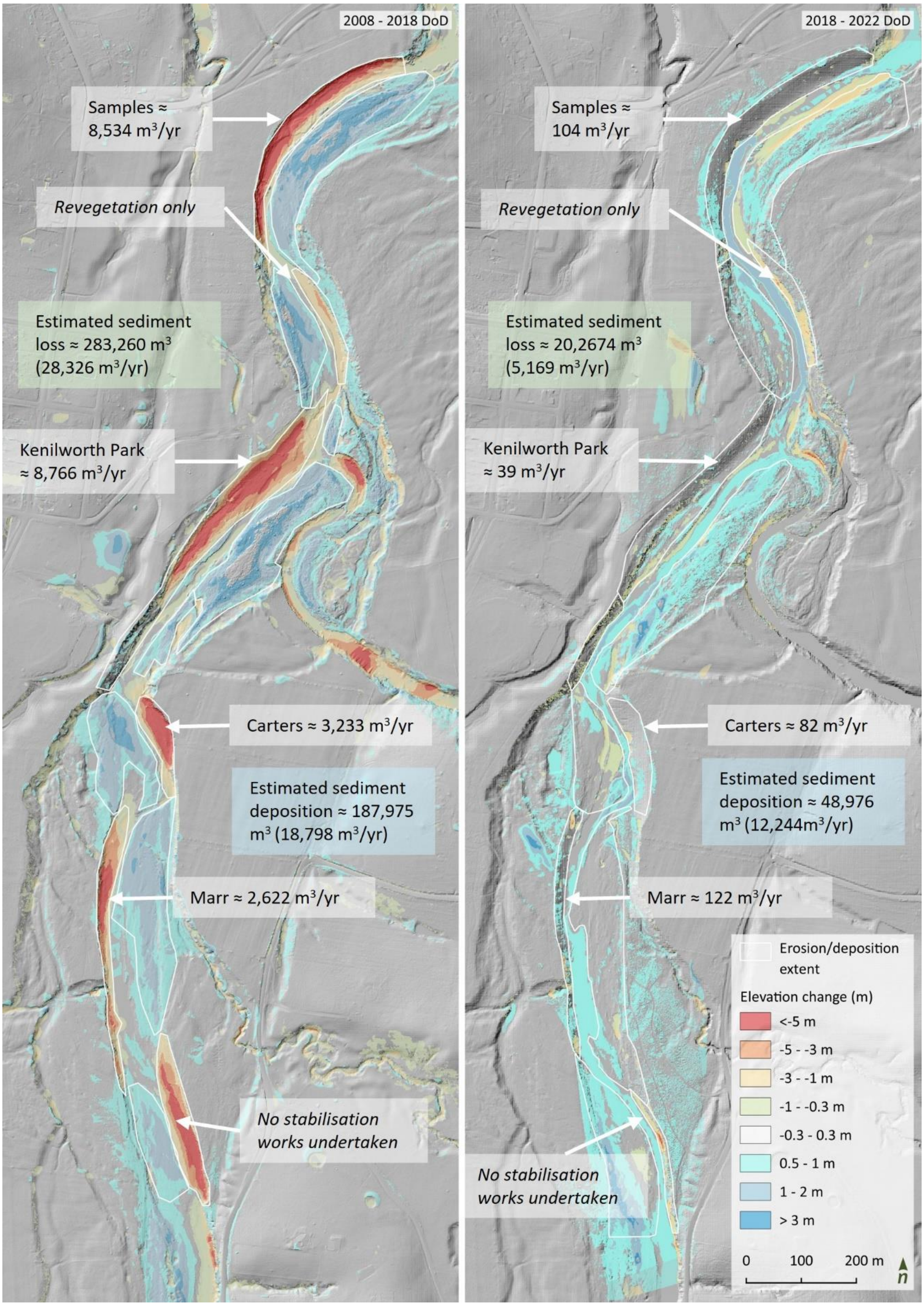

Figure 4. Erosion and deposition estimates pre (left panel) and post (right panel) works across the study reach. Note the DoD on the left is showing surface change between 2018 and 2008 however the Kenilworth Park works were completed prior to 2018 and the pre works erosion estimates used the 2014-2008 DoD.

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