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Wilkinson et.al. – Addressing gully erosion in the Great Barrier Reef catchments

Addressing gully erosion in the Great Barrier Reef catchments: priorities and progress

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Key Points

- Current Australian Government gully erosion control programs are targeted to catchments which make the largest contributions to fine sediment export from gully erosion
- Cost-effectiveness is the guiding principle for designing works that are suitable for each gully site
- One Program has so far implemented erosion control on >170 gullies, treating >500 ha of gully area
- A much larger investment will be required to achieve a targeted 25% reduction in sediment load
- Targeted gully erosion control remains a key approach to manage the ecological condition of the Great Barrier Reef.

Abstract

Gully erosion control is a priority approach for reducing fine sediment exports to the Great Barrier Reef lagoon, because it is the largest source of fine sediment across the 423,000 km^2 of contributing catchment area. This paper describes the development and implementation of a recent Australian Government program. We interpreted prior modelling of catchment sediment budgets to identify 10 priority catchments that contribute larger amounts of fine sediment from gully erosion. Site scale designs considered the ratio of project cost to the mass of fine sediment prevented from entering coastal waters. More intensive and costly activities such as engineered rock chute structures were targeted to sites with rapid erosion, where they are required and can be cost-effective. Projects have so far implemented erosion control works on more than 170 gullies. The average cost-effectiveness has been of the order of $700 per t/y reduction in fine sediment export at the coast, generally being better for gullies with larger areas. The total gully area treated to date is 500 ha area, relative to 20,000 ha of total gully area in priority catchments. Learnings have accrued from implementing and monitoring a range of gully erosion control activities in a variety of settings, which will refine program design and implementation into the future.

Keywords

Gully erosion, soil erosion, sediment, particulate nutrients, rehabilitation, remediation.

Introduction

The Great Barrier Reef (GBR) ecosystem is being impacted by multiple stressors including global warming and associated ocean acidification, and also poor water quality which deteriorated following the European settlement of the GBR catchments. Investment in managing the terrestrial causes of impaired water quality in the GBR lagoon is an important pathway towards GBR protection because water quality influences recovery from all stressor events including coral bleaching and physical damage from cyclones, and because Australia can unilaterally address it (Hairsine, 2017). Fine sediment and nutrient exports from river basins to the GBR lagoon are the largest drivers of GBR water quality, and reduction targets have been set for them (The State of Queensland, 2017). Fine sediment impairs coral recruitment and growth, while nutrients also reduce coral reproduction and water clarity (Fabricius, 2005), and enhance outbreaks of Crown of Thorns Starfish (Fabricius et al., 2010). Particulate nutrients comprise 60–80% of the total terrestrial nutrient load to the lagoon (Kroon et al., 2012; McCloskey et al., 2017). In marine waters, 55–80% of particulate nitrogen is bioavailable within months (McCulloch et al., 2003; Burdige, 2005; Radke et al., 2006), and this material can be delivered at least 100 km from river mouths (Bainbridge et al., 2012). Controlling upstream erosion to reduce fine sediment and nutrient impacts requires careful targeting to be efficient (Lu et al., 2004). The erosion control approaches which are most appropriate also depend on local climate, erosion processes, land uses and governance.

Gully erosion control has been identified as the priority approach to managing fine sediment and particulate exports from GBR catchments (Wilkinson et al., 2015c). Sediment tracing studies have identified subsoil as the main source of river TSS in the Burdekin (Wilkinson et al., 2013b; Wilkinson et al., 2015b), Fitzroy (Hughes et al., 2009), and Normanby basins (Olley et al., 2013); together these basins deliver half of the total GBR TSS load (Kroon et al., 2012; McCloskey et al., 2017). These results are supported by field measurements showing that hillslope erosion rates are modest apart from on bare ground (Bartley et al., 2010; Silburn et al., 2011), and also that gully erosion is extensive; approximately 87,000 km of gullies have been mapped in GBR catchments (Thorburn and Wilkinson, 2013). While GBR stream channels are large, with some notable exceptions (e.g., Mary River) they have not undergone rapid historical expansion (Bainbridge, 2004; Hughes et al., 2010) such as has occurred in southeast Australia (Rutherfurd, 2000). Catchment modelling based on these datasets indicates that 50% of all TSS eroded in the GBR lagoon derives from gully erosion (McCloskey et al., 2017), although gullies occupy <0.5 per cent of all grazing land (Wilkinson et al., 2015c).

As well as addressing the largest TSS source, gully erosion control can potentially be implemented without requiring broad-scale changes in the land use surrounding gullies. This arguably makes it a more tractable approach to securing long-term reductions in TSS loads in grazing land than approaches which rely on reducing livestock grazing pressure. Stocking rates in Northern Australia have more than doubled since the 1970s (McIvor, 2010), including in some GBR catchments where extensive land degradation has occurred as a result of over-grazing in past droughts (McKeon et al., 1990). Many studies indicate that grazing within sustainable stocking rates that maintain vegetation condition is more profitable in the long term (Wilkinson et al., 2014), but under some conditions heavy stocking is regarded as being more profitable over decadal timelines, even accounting for declines in productivity caused by land degradation (Bowen and Chudleigh, 2018). In addition to economic drivers, the climate of tropical Australia is highly variable in world terms, making it particularly difficult to match stocking rates to annual forage availability.

This paper describes the development of the Gully Erosion Control Program, within the Australian Government Reef Trust Phase II investments (http://www.environment.gov.au/marine/gbr/reef-trust/investments), current progress on implementation, and learnings to date. We describe an approach to identifying priority catchments, development of technical guides, and frameworks for designing and implementing cost-effective erosion control projects and for monitoring and evaluating initial works.

Priority catchments

For erosion control to be cost-effective it needs to be spatial targeted (Lu et al., 2004), and well-designed and implemented. This is particularly the case given how extensive gully erosion is within GBR catchments, the substantial targets for reducing fine sediment exports, and the relatively limited resources available. The GBR gully erosion control programs have been targeted spatially at two scales; choosing priority catchments, and then selecting sites within those catchments. Firstly they were constrained to operate within priority catchments in which gully erosion makes high contributions to fine sediment export to the GBR lagoon ($t/km^2/yr$). These catchments contain many gullies, and they efficiently deliver sediment to the coast because they do not have large downstream sinks such as reservoirs or large floodplains. Catchments with high river sediment delivery efficiency were also favoured because by definition a higher proportion of site sediment savings would be effective at the river mouth. Gully contribution for the 47 catchment units draining to the

GBR lagoon (Figure 1a) was obtained from the latest available catchment modelling in the Paddock to Reef Program (e.g., McCloskey et al., 2017). The gully contribution rates were also estimated relative to gully area within each catchment (t/ha/yr); differences in gully mapping methods between catchments contributed uncertainty to those estimates.

Building local capacity was an additional objective which resulted in priority catchments being identified in multiple NRM regions. There was little publicly-funded gully erosion control occurring in GBR catchments prior to these programs.

Ten priority catchments were thus identified across multiple NRM regions (Figure 1), which together contained a total of approximately 20,000 km of gullies (approximately 20,000 ha in area). The second stage of spatial prioritisation was selecting sites within priority catchments, as described later.

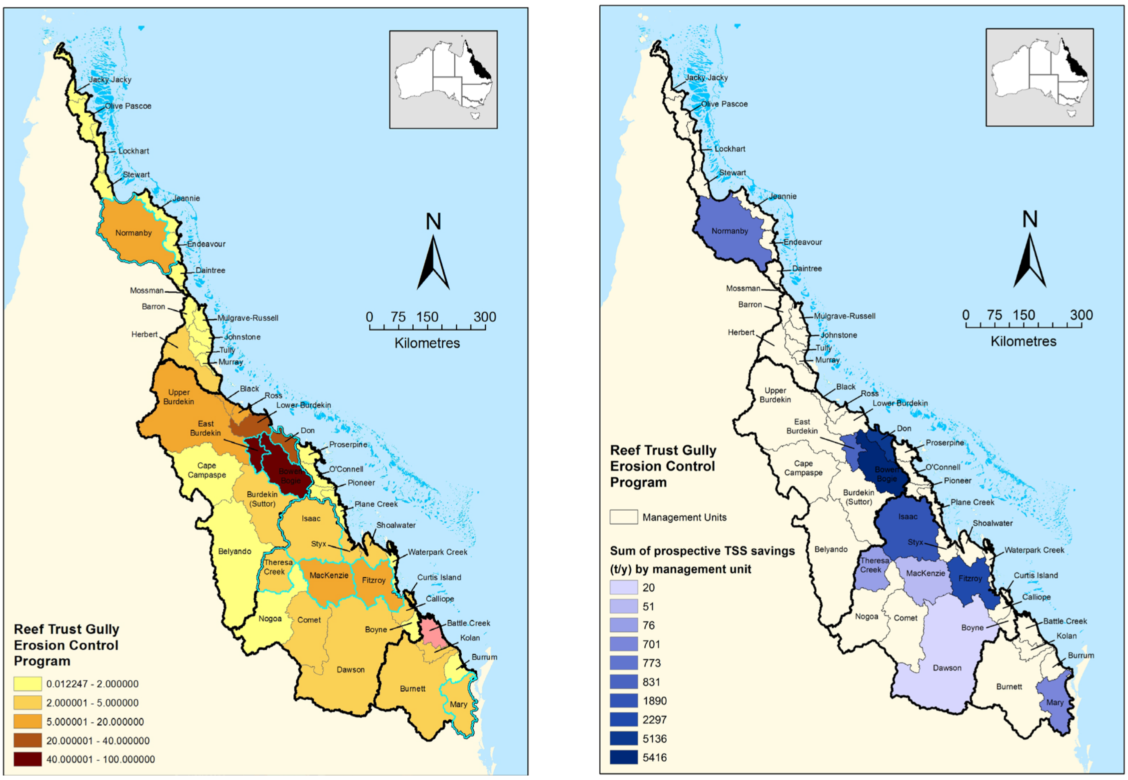

Figure 1. (Left) Gully and stream bank erosion contributions to fine sediment export from GBR catchments (McCloskey et al., 2017). Priority catchments are shown with blue borders. (Right) Prospective sediment reductions based on Reef Trust Phase II gully erosion control planned in each catchment up to May 2018.

Toolbox for erosion control planning

As technical partners for the Reef Trust erosion control program, we assembled a "toolbox" of technical guidelines for gully erosion control (Wilkinson et al., 2015a), which was updated for a subsequent investment phase which included stream bank erosion (Wilkinson et al., 2016). These guides were designed for use by local agencies to inform their bids for program funding and subsequent on-ground activities. These guides defined:

- Objectives of gully erosion control as (i) assisting sediment retention within the gully floor by reducing the runoff gradient and increasing ground cover, (ii) increasing the resistance of gully walls to erosion by revegetation or otherwise, and (iii) reducing headcut erosion by structural means or by managing surface runoff. Higher levels of vegetation cover, and more diverse vegetation composition within and around gullies is known to be associated with lower gully erosion rates (Wilkinson et al., 2018).

- A range of recommended erosion control activities, which drew on limited gully remediation studies in GBR catchments (Shellberg and Brooks, 2013; Wilkinson et al., 2013a; Wilkinson et al., 2017)), studies elsewhere (summarised in Thorburn and Wilkinson, 2013; Wilkinson et al., 2015c).

- A site-specific approach to designing erosion control was defined. Some activities are applicable at all sites; such as to control livestock access (fencing, and water points where required), weeds and pest animals. Where required and warranted to control more active gully erosion, higher-cost activities were recommended in addition; such as active revegetation, porous check dams, managing upslope drainage, grade control structures and gully reshaping.

- Monitoring and reporting frameworks for the design and implementation of erosion control to enable adaptive management. These are described in more detail below.

Framework for designing and monitoring cost-effective gully erosion control

Even within priority catchments gully sediment yield is highly variable due to differences in gully catchment area, runoff volume, depth and soil erodibility. Selecting gully sites with sufficiently active erosion is essential to achieving reductions in river sediment loads, and there is a risk of over-investment in relatively stable sites. The following framework was established to assess potential sites and to identify suitable and cost-effective approaches to gully erosion control:

1. Estimate recent average sediment yield from the gully to the GBR lagoon, accounting for wet and dry periods, and catchment model estimates of the efficiency of sediment delivery to the coast

2. Estimate potential sediment savings by identifying suitable erosion control activities, and estimating their effectiveness as a proportional reduction of historical sediment yield

3. From the above, determine an appropriate ceiling for public investment at the site, by assuming a target cost-effectiveness (typically $500–1,000 per t/y fine sediment reduction at the coast)

4. Cost the suitable activities in more detail and determine if they can be delivered within the budget, including any in-kind contributions. If not, then revise the proposed activities to improve the cost-effectiveness, or seek other sites.

To enable adaptive management within the programs, these steps are recorded in a site report, supported by the site history and erosion issues, the objectives and details of erosion management, and project budget. Each site is also monitored before and after installation, including grazing management, works integrity vegetation condition and cover at several points within the gully, and photo points. Un-treated 'control' gullies are established where available, to enable comparison of changes due to treatment and climate.

Preliminary results and learnings

An important objective of this program has been to develop learnings which can guide future activities. Identifying candidate gullies has been greatly assisted by pre-existing gully mapping (Brooks et al., 2013; Darr and Pringle, 2017). However in heavily-gullied areas, information on which gullies are eroding rapidly has also greatly benefited prioritisation. A historical air photo archive (https://qimagery.information.qld.gov.au/) has been useful in estimating rates of gully expansion to assess the cost-effectiveness of planned works.

Almost all sites include fencing to control livestock access and allow revegetation, consistent with the program strategy. Where permanent exclusion is not planned, the intended grazing regime has been documented with land holders to reduce the risk that grazing will jeopardize the erosion control outcomes. Decision support for when to use more active erosion control techniques, such as porous check dams or rock chutes, is emerging in certain settings. Use of porous check dams has been found to be best suited to gullies with small catchment areas (<2 ha in undulating terrain) where vegetation is not too degraded and where natural regeneration is likely. Applying them to sites which are highly degraded with little vegetation and soil A-horizon remaining has been found to give a lower probability of successful revegetation. Accounting for degraded conditions is challenging for any landscape restoration, particularly in gullies where runoff is concentrated. Alternative options which rely less on revegetation include constructed sediment traps, or gully plug dams (Carey et al., 2015b).

To date the average cost-effectiveness has been \$700 per t/y reduction at the coast. This includes all expenses related to on-ground works including technical design, but not administration or communication activities. At the scale of individual gullies, the cost-effectiveness tends to be better when treating gullies with area >0.1–1 ha (Figure 2). The pre-treatment gully specific sediment yield (t/ha/yr erosion rate) has a weaker influence on cost-effectiveness (data not shown), which suggests that more expensive treatments are being generally applied only where required to address more rapid erosion.

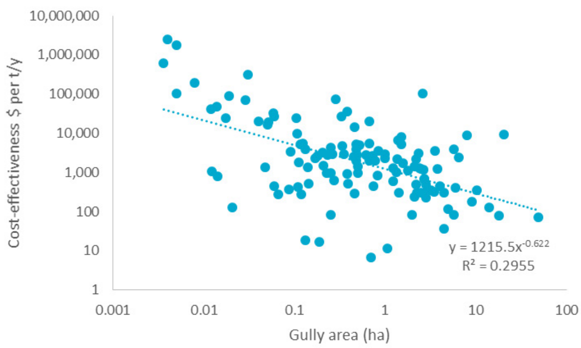

Figure 2. The cost of reductions in sediment load (t/y) estimated at the coast, relative to individual gully area (note the log scales on both axes). Gullies smaller than 0.1 ha are typically more expensive to treat than larger gullies.

In some areas engaging land holders to host gully erosion control projects has taken longer than expected. Targeting gully remediation to fewer sites with larger gullies, or emphasising only cheaper treatments for less active gullies, are ways to improve efficiency in this operating context.

Monitoring and evaluation

Post-implementation monitoring has been successful in prompting land holders and project leaders to revisit sites, to check for failures in grazing management and structures. Ideally monitoring would continue into the future to identify maintenance needs. Livestock exclusion has resulted in impressive vegetation responses around gullies at some sites, particularly when past grazing pressure has been heavy, and if significant rainfall occurs. Poor germination of native grass species has hampered revegetation within some gullies. At many sites vegetation responses have only just commenced. Intensive gully reshaping and rock chute treatments have been rapidly effective relative to their respective control sites which continue to show substantial headcut retreat. Due to shortcomings in design or installation, some rock chutes and porous check dams have required repairs. These have been completed within the projects. It is clear that hydraulic structures require a robust design process, including:

- Estimating catchment area and associated peak runoff rates of specified recurrence interval using methods such as the rational method (Carey et al., 2015a)
- Calculating the minimum stable rock size for rock chutes based on the slope and flow width of the structure (e.g., Keller, 2003)
- Ensuring the correct rock chute configuration including abutments to prevent bypass flow, apron or stilling basin at the downstream end, and geotextile and soil amelioration as required
- Scheduling sufficient time for the design and to source the correct materials and equipment.

Perhaps the most important outcome to date has been development in the local capacity to implement erosion control in GBR catchments, which will underpin ongoing progress in the years ahead.

Conclusions

The Reef Trust Phase 2 projects have so far implemented gully erosion on more than 170 sites, treating more than 500 ha of gully area (100 km in length) in a wide range of land use, soil type, topography and climate. Information on spatial patterns in gully sediment supply and delivery from catchment modelling in the Paddock to Reef program (McCloskey et al., 2017), supported by sediment source tracing and field measurements, has been very useful for defining priority areas. Information on gully erosion rates allows further improvement of prioritisation at site scale where it is available. We continue to recommend a site-specific approach to selecting and designing either fencing / revegetation or engineering style gully rehabilitation depending on site conditions and erosion rates. Site monitoring has enabled learnings to be identified for common treatments and soil types. The sites completed and skills developed are valuable resources to guide future implementation of gully rehabilitation.

We conclude that targeted erosion control can deliver reductions in sediment loads to the GBR lagoon. The average cost of the erosion control activities has been $700 per t/yr reduction in fine sediment load delivered to the GBR lagoon. Based on this cost, the two Reef Trust programs funded to date will reduce fine sediment loads to the GBR by ~1%. This is a small proportion of the 25% sediment reduction target required to meet water quality guidelines (The State of Queensland, 2017), making the scale of the challenge clear. However, there are many gullies remaining to be treated in the priority catchments, and the resulting aggregate cost of meeting GBR sediment and nutrient reduction targets is likely to represent an attractive payback in terms of retaining the ~$6 billion annual economic value of the reef. Efficiency can be increased by focusing on sites with large and active gullies. Local capability to implement gully erosion control has increased, and continued targeting of activities will help to ensure efficiency and effectiveness at site scale.

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