Reef Trust Phase IV
GULLY AND STREAM BANK TOOLBOX
2ND EDITION, JUNE 2019
A technical guide for the Reef Trust Phase IV Gully and Stream Bank Erosion Control Program

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Cover image: A diversion bank and exclusion fence just completed around a large gully in the Fitzroy River basin. A rock chute (not shown) was also installed to convey the diverted runoff into the bed of the creek. A second stage will fence along the riparian zone. Photograph by Neilly Group Engineering, supported by Fitzroy Basin Association and Reef Trust.

Back cover: The Bowen River after a large flow event, February 2019. Photograph by Matt Curnock, supported by TropWATER JCU, GBRMPA, the Queensland Government, the Landholders Driving Change project, CSIRO and the NESP Tropical Water Quality Hub.
Reef Trust Phase IV

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EXECUTIVE SUMMARY

This is a guide to targeting, designing and implementing gully and stream bank erosion control activities in Great Barrier Reef (GBR) catchments. It is intended to guide implementation of the Reef Trust Gully and Stream Bank Erosion Control Program (the Program), and similar programs to improve water quality and riparian vegetation. The primary goal of this Program is to reduce the amount of fine sediments and associated nutrients delivered to the lagoon of the GBR. Erosion of subsoil contributes ~90% of the fine sediment load delivered to the GBR (Olley et al., 2013; Wilkinson et al., 2013). The majority of this is derived from erosion along gully and stream channels, with gully erosion contributing at least 40% and stream bank erosion approximately 30%. Some subsoil is also derived from rilling on hillslopes. The GBR catchments are large and erosion is extensive, so the Program targets ten of the 47 GBR catchment management units which deliver fine sediment to the coast from gullies and eroded stream banks at large rates per hectare. Work at other sites may also be demonstrated to have similar cost-effectiveness.

After the introduction of livestock grazing and other catchment disturbances in the period 1850–1900, and particularly following land-use intensification in the mid twentieth century, gully erosion became extensive along drainage lines and in floodplain adjacent to some large river channels. It has been estimated that the GBR catchments contain more than 87,000 km of gully length (Wilkinson et al., 2015a). Stream banks exposed to grazing and degradation of vegetation have also been eroding at accelerated rates. Current land managers have largely inherited these problems, although ongoing degradation or removal of vegetation greatly increases the risk of further gullies forming and streambanks becoming unstable.

The most common approaches to controlling gully erosion are to reinstate a mix of vegetation to stabilise these landscape incisions, and in some cases to install engineered structures and earthworks. Managing drainage of roads and tracks (including cattle tracks) can also be used to reduce the concentration of runoff into gullies. Application of gypsum and mulch is required to protect exposed sodic soils. Stream bank erosion control involves initial exclusion of livestock followed by strict control on livestock access, and re-establishing woody vegetation on the banks and within channels along extended stream reaches. Cumulative erosion control benefits are achieved by having large proportions of the gully and stream channel network well-vegetated, by slowing the velocity of runoff throughout the stream network. A more connected network of vegetation also enhances the condition of terrestrial and freshwater ecosystems. Some stream bank sites may also require engineered structures to protect the bank toe, although this is only in exceptions, since stabilising a few stream bends has limited effect at catchment scale and such works can simply divert flow energy to nearby areas.

To ensure cost-effective reduction of sediment loads to the GBR lagoon, planning erosion control in this Program involves assessment of site sediment load reductions and costs before sites are selected and works designs are finalised. Having the appropriate skills is essential before undertaking works, to ensure that erosion is safely and correctly controlled.
Whether the user is an experienced practitioner in erosion control or new to erosion control in the GBR catchments, here is the process for using this document:

**Step 1:** Read Section 1 to get an understanding of what the program is trying to achieve.

**Step 2:** Before stepping into a vehicle to look at sites and engage landholders, collate preliminary desk-top data about sites that would be suitable. See Section 2 for a list of tools and data.

**Step 3:** Once some basic data on erosion at candidate sites is compiled, estimate likely cost-effectiveness using the calculator presented in Section 4. This is a useful framework for thinking about how active the erosion is, and therefore the relative investment that should be applied to a site in terms of the direct costs of rehabilitation works. It should also be useful when you need to choose between multiple sites. To achieve the sediment and nutrient reductions required for the GBR within the next few decades, funding must be well targeted. There is no shortage of sites to choose from, however, sites that have high historical and current erosion rates, are closer to the coast (with high sediment and nutrient delivery ratios) and are on fine-grained soil are generally going to be more cost-effective for any given treatment.

**Step 4:** Once you have a range of sites and activities that you think may be cost-effective, generally less than $1,000 per tonne per year (t/y) reduction in fine sediment loads, it is time to engage landholders and assess their willingness to be involved, and the different types of remediation suitable for each site. At this stage, Section 3 summarises considerations for selecting and designing erosion control activities in GBR catchments. More detailed design resources and case studies are referenced here also. Iteration is commonly required between Steps 3 and 4.

**Step 5:** Document your expected outcomes and design so that they can be reviewed by landholders and the Program technical partner, and the sediment saving estimate and budget can be refined. Section 4 lists the key parameters to define.

**Step 6:** As part of the design phase, consider how to monitor and evaluate the works. Monitoring allows the Australian Government to determine whether grant funding is achieving value for money, and demonstrates the positive change from all the hard work being implemented under the program. You are best placed to collect data on the success of implementing erosion control to help inform adaptive management of the approach, maintenance requirements, and future investments. This involves well-designed before and after photo monitoring, including comparison with nearby un-treated control sites, which can underpin a powerful story about the changes achieved. The recommended quantitative monitoring focuses on leading indicators of erosion control such as improved vegetation that are relatively quick to measure. Consider adding erosion and water quality monitoring at large demonstration sites, either directly or through focused research projects. Methods for monitoring can be found in Section 4.

We acknowledge that application of erosion control activities will continue to evolve as new data and insights come to light, based on experience from the Reef Trust and other gully rehabilitation programs. We hope this document is useful and we look forward to working with you to reduce the amount of sediment and particulate nutrients leaving our catchments and reaching the Great Barrier Reef lagoon.
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1 INTRODUCTION

1.1 Gully and stream bank erosion defined

Gullies and stream banks have steep slopes and are exposed to runoff, making them vulnerable to erosion, and requiring of greater protection against erosion than elsewhere.

**Gully erosion** can be defined as the recent incision of the land surface to a depth of more than 0.3 m. Gullies are widespread in semi-arid climates globally, caused by a combination of drought and flood cycles, geomorphic and hydraulic controls and land use change (e.g., Ciesiolka, 1987).

Initiation of gully erosion is often triggered by vegetation degradation such as that caused by excessive grazing pressure and drought-flood cycles. An individual gully starts when a small near-vertical wall is created at a stock track or other vegetation or soil disturbance, in a drainage line or where seepage reduces the strength and erosion resistance of soil during and after rainfall. The new gully expands upslope due to the instability of the wall and grows deeper and wider.

While some gully features were noted by early European explorers, the vast majority of active gullies in Great Barrier Reef (GBR) catchments today developed following the introduction of cattle and sheep grazing post-1850 (Wilkinson *et al.*, 2013; Shellberg *et al.*, 2016). Before that time, active gully erosion is understood to have been much less common than what we see today, because intact native vegetation and undisturbed soils are more resistant to gully incision (Prosser and Slade, 1994). Most gullies in the catchments of the GBR formed in an era when the focus was on expanding or intensifying land uses, and in that sense gully erosion is a problem which current land managers have mostly inherited. However, in some instances new gullies continue to form where vegetation is cleared and/or land is over grazed.

Today, it is estimated that the length of gullies in GBR catchments totals >87,000 km (Wilkinson *et al.*, 2015a), or approximately 87,000 ha assuming a mean width of 10 m (noting that gullies are not all linear features). While this represents just 0.3% of grazing land, analysis of sediment source tracing, erosion mapping and load monitoring indicates that gully erosion supplies ~40% of the fine sediment (silt and clay, <63 µm particle size) exported from river basins to the GBR lagoon (Wilkinson *et al.*, 2015a). There is large variation in erosion rate and fine sediment yield between individual gullies.

![Figure 1. Two forms of gully erosion which occur in reef catchments. Left: hillslope gully erosion. Right: alluvial gully erosion. Photographs from the Burdekin River basin by Scott Wilkinson and Rebecca Bartley.](image)
Gully erosion occurs in two general forms within GBR catchments. Hillslope gully erosion is a linear or branching feature along what was a surface flow path or drainage line. Alluvial gully erosion involves incision of floodplain and river frontage country in deeper alluvial sediment deposits adjacent to large streams and is characterised by irregular gullies deviating away from the predominant alignment of the pre-existing stream bank. Alluvial gullies may or may not follow subtle drainage depressions in the floodplain. Examples of both gully forms are shown in Figure 1. In addition to extending the drainage network upstream, gully erosion can also involve enlargement of natural minor stream channels, in some instances up to several times their prior depth and width. The resulting large channels may also initiate the extension of many gully branches along contributing drainage lines. More detailed definitions of hillslope and alluvial gully erosion are given by Brooks et al., (2009).

Gully erosion can be driven by a combination of surface runoff or seepage from upslope, by direct rainfall on the gully area, and by scour from flow moving through the gully. Gully sediment yield is influenced by land management in two ways; (i) by surface runoff from upslope, and (ii) by impaired vegetation cover on gully walls and floor which exposes them to rainfall and increases runoff generation within the gully. Some gullies, particularly larger gullies, can become self-perpetuating once they get to a certain size. This growth may be independent of the immediately adjacent land-use. By contrast, some hillslope gullies remain discontinuous, with incised sections separated by indistinct sections.

Stream bank erosion is the removal of soil or sediment from steeply sloping banks along the sides of a major or minor stream channel. Some larger streams have smaller channels inset within a larger “macro” channel; erosion of the banks of either channel is included in this Program. Stream bank erosion is a natural process that occurs through channel migration and through channel cross-sectional adjustment in response to changes in water and sediment discharge and vegetation status.

Stream bank erosion occurs through various processes including: (i) by rain splash or local runoff on the bank face, (ii) by the scouring action of water flowing in the stream, and (iii) by mass failure of the bank profile. Many stream banks will be affected by a combination of these processes. The extent to which these processes operate to erode the bank is a function of the balance between the erodibility of the bank material (including the protective effects of stream bank vegetation) and the power of the stream. Changes to land use and catchment and channel vegetation have resulted in bank erosion rates that are considerably higher than natural background levels in many parts of the world including northeast Australia.
Figure 2. Clockwise from top left (1) A major dry-tropics stream with stream banks exposed to rain splash and scour (Bowen River). (2) A minor dry-tropics stream eroding through scour and mass failure of the bank profile (in the Upper Burdekin catchment). Note the absence of a distinct riparian vegetation community, which is common in this stream type. The gravel bedload accumulation is causing local channel widening. (3) Meander migration and slumping of poorly vegetated stream banks on the Mary River, in a more humid climate (Google Earth). (4) A large stream in the humid tropics where the stream bank is eroding through scour and mass failure (Photographs by Rebecca Bartley and Andrew Brooks).
Where are gully and stream bank erosion most severe?

At landscape scale gully erosion is more extensive (and more rapid) in areas with:

- deeper and less-stable soil (e.g., Sodosols),
- terrain of low to moderate slopes and around river channels, and
- where runoff is concentrated in drainage lines and valley bottoms.

Stream bank erosion rates vary spatially, but are larger in the following areas:

- Where stream bank vegetation (trees, shrubs, grasses) is poor either through clearing or livestock grazing;
- Where stream bank soil is more erodible, and not in reaches confined by rock outcrops;
- Where the stream channel has recently widened (e.g., through bed sediment deposition) or has deepened;
- On the outside of stream channel bends (meander migration);
- Where disturbances such as sand and gravel extraction quarries, alluvial mining or channel diversions occur;
- Stream bank erosion at any point is affected by the size and velocity of flow peaks, which are regulated by the amount of vegetation on the banks and in the stream, both locally and for many kilometres upstream and downstream.

Within each river catchment, gully and stream channels typically form one connected drainage network. The classic spatial configuration is that gullies are higher in a catchment and drain into streams. However, it can be difficult to define where a gully transitions to a minor stream. Alluvial gully erosion can occur adjacent to the bank of large stream (river) channels in the dry tropics; in this case the high banks can be dominated by alluvial gully erosion, while the lower inset stream banks and benches may display more typical stream bank erosion driven by scour and mass failure. Therefore, gully and stream bank erosion often occur together and can reinforce each other (see box below).

This Program addresses both gully and stream bank erosion, and it targets priority areas. This approach enables large proportions of the gully and stream channel network to be treated in those areas to capture the cumulative benefits from reducing both processes.

Gully and stream bank erosion act together

The gully and stream channel network work together to efficiently deliver water and fine sediment to the catchment outlet, increasing fine sediment loads.

- Degraded riparian vegetation can initiate and accelerate gully and streambank erosion.
- Stream channel incision (deepening) can trigger gully erosion upstream.
- Surface runoff is delivered more rapidly and efficiently from gullied landscapes, increasing the variability of flood peaks – with flood waters rising faster and higher, and falling more rapidly (increasing mass failure)
- Reduced vegetative roughness in stream channels provides less opportunity for trapping sediment from gully erosion upstream.
- The coarse fraction of sediment from gully erosion deposits on stream channel beds and bars in lower gradient reaches, increasing stream bank erosion adjacent to these deposits.
1.2 Objectives of erosion control

1.2.1 Program objectives

The Program objectives are detailed in the Australian Government Reef Trust Program Guidelines. In summary, they are to:

- Reduce sediment entering the GBR lagoon from agricultural land-uses
- Test the use of remediation approaches across a range of Gully and Stream Bank environments to guide investment in sediment reduction Programs across Reef catchments
- Increase protection of riparian habitat
- Seek continual improvement of understanding and capacity to manage sediment losses
- Build a legacy of capacity to address erosion from these landscapes into the future.

Project Activities should therefore focus on strategies which deliver the greatest reduction in sediment yield for the lowest cost per tonne of sediment and nutrient export avoided or reduced. They should also address both the causes and the ongoing effects of gully and stream bank erosion.

1.2.2 Gully erosion control

The objectives of gully erosion control are well-established from numerous examples around the world (e.g., Geyik, 1986). They are:

(i) To stabilise and to increase sediment trapping on the base of the gully by increasing the amount of vegetation to slow the flow (Figure 3). Porous check dams may assist this process. Stabilising gully depth is an essential part of reducing further expansions.

(ii) To reduce sidewall erosion by increasing vegetation cover and biomass within and around the gully, which protects against rain splash and provides root reinforcement; this requires fencing to control livestock access and enable vegetation to grow (passive revegetation). Active revegetation activities (e.g., seeding, planting, slope stabilisation, and soil amelioration) may be necessary also.

(iii) To stabilise the headcut either by structural control or by reducing runoff and seepage into gullies. Runoff can be physically diverted away from the gully head, although it can be difficult to discharge diverted runoff safely without triggering or accelerating gully erosion where the runoff re-enters the drainage channel network.

Improving soil health is another way to reduce runoff into the gully, although it can require large changes in grazing pressure and take a long time to achieve substantial impacts on runoff where vegetation has become degraded.

The relative importance of these three objectives will be site dependent based on where erosion rates are highest. Engineering activities should be used only if (i) relevant activities of lower cost are also applied, (ii) if they are required and (iii) are cost-effective.
Figure 3. The objectives of gully erosion control for reducing gully sediment yield (Wilkinson et al., 2015). Each site has a unique combination of erosion processes including rain splash, sheet wash, rilling, sapping, tunnelling, fluvial scour and mass failure. To reduce the rate of these processes by addressing the three objectives shown here, a site-specific combination of the erosion control activities described in Section 3 is required.

To prevent new gullies, managing runoff is secondary to managing vegetation in and around drainage lines, because exposed soils require little runoff to initiate gullies (Prosser and Slade, 1994).

The success or failure of gully erosion control activities based on these objectives depends on how well activities are selected and designed appropriately to suit the terrain, soil and climate of each site. It is also important that activities are implemented consistently within established guidelines. Selecting activities is discussed in Sections 1.3 and 3. For example, achieving full re-vegetation of gully floors, sidewalls and headwall of large gullies in very unstable soil can require multiple interventions to establish a stable surface, including reconfiguring slopes and changing land management (e.g., Brooks et al., 2016a; 2016b).

In specific situations, gully revegetation combined with some deposition structures can result in large reductions in sediment yield, for example:

- Livestock exclusion, increased vegetation and check dams reduced sediment yields by between 78% and 90% in a study in a semi-arid climate in the USA (Heede, 1979).
- Check dams and vegetation restoration reduced runoff volumes by ~80% in a study in Ethiopia (Nyssen et al., 2004).
- Gullies under long term livestock exclusion in the upper Burdekin catchment had sediment yields 77% lower than gullies under moderate or heavy grazing pressure (Wilkinson et al., 2018).

The details and risks of common erosion control activities are described in Section 3. The Program also allows for innovation, including trials of new erosion control activities.
1.2.3 Stream bank erosion control

Stream bank erosion control can be a challenging endeavour. While gullies can be controlled reasonably independently, historical changes to the stream channel structure and function in one reach affect other reaches. In a similar way, future stream management at one site can also affect erosion elsewhere. Many landholders, with different perspectives, are adjacent to each stream. Consequently, we cannot completely rebuild ‘natural’ streams. At the same time, large floods will sweep away poorly considered works.

A process-based approach to stream management involves the following questions:

• What are my objectives and those of other stakeholders?
• How has the stream changed since Europeans arrived?
• What are the stream’s main natural assets and problems?
• Which reaches should you work on first?
• Is intervention necessary?
• What are the best strategies and actions to meet the objectives?

The rehabilitation manual for Australian streams (Rutherfurd et al., 2000a; Rutherfurd et al., 2000b), and the Queensland Soil Conservation Guidelines Chapter 11 (Carey et al., 2015b) are recommended reading for those considering substantial stream management projects. We also strongly suggest that you seek professional advice on approaches to stream management issues if you are not confident that you have a strong background in this field.

This Toolbox does not describe the details of planning and implementing comprehensive stream management, but outlines the relevant considerations for common activities. Appendix C illustrates some stream bank erosion scenarios in GBR catchments with suggested approaches to erosion control.

Revegetation and engineering

The most common and lowest risk approach to managing stream bank erosion is to improve riparian vegetation by passive (e.g., livestock exclusion and weed control) or active means (e.g., planting). Stream bank revegetation protects against bank erosion by:

• Protecting the soil surface from rain splash and scour by stream flow, and from direct disturbance by livestock
• Increasing the soil cohesive strength by root reinforcement, protecting against mass failure
• At reach scale in-channel and stream bank vegetation roughens the channel, and slows the velocity of flow down the channel thus reducing the available energy available to erode the channel.

The value of riparian vegetation improvement increases with the area and length treated. Research has shown that riparian vegetation is most effective when buffer width is 5—30 m and buffer length > 1 km (Feld et al., 2011). Revegetating one isolated (e.g., 500 m long) stretch of stream bank can shift the focus of erosive stream energy downstream, reducing the overall net benefit.

Many studies have demonstrated stream bank revegetation to be effective. For example:

• The mean erosion rate of banks with riparian vegetation on the Daintree River was 85% lower than that of banks without riparian vegetation (Bartley et al., 2008).
• Stream bank erosion during a large flood event was much less at revegetated sites than at comparable sites without intact vegetation (Hardie et al., 2012).
• Riparian fencing on its own, without active revegetation, reduced stream suspended sediment (SS) loads by ~60% (Owens et al., 1996).
• Fencing off and actively revegetating streams can reduce sediment yields by 33—80% (Line et al., 2000).
• Cattle exclusion from riparian areas resulted in a rapid transition from a wide, shallow stream with an unstable bed and heavily grazed and trampled banks, to a stream with more stable, vegetated banks (Howard-Williams and Pickmere, 2010).
• Studies by Robertson and Rowling (2000) demonstrated that seedlings and saplings of dominant Eucalyptus tree species were more abundant in areas with no stock access, and the biomass of groundcover plants was an order of magnitude greater in areas with no stock access. See also Jansen & Robertson (2001).
In contrast, Miller and Kochel (2013) found that 50% of engineered structures (e.g., grade control structures and Bendaway weirs) showed signs of impairment after 5 years. Only consider engineered bank erosion control if there is evidence of very active erosion, if a costly stabilisation strategy can be justified on a cost per tonne of sediment avoided, and if stream bank vegetation is already extensive in the catchment. Consult the Technical Partner at site concept stage. Fine resolution information about bank properties and hydraulic conditions at the site is required to ensure that the engineering modifications will last (Frothingham, 2008; Simon et al., 2014). Anything that specifically addresses infrastructure protection will require co-investment.

A typical layout of stream bank vegetation management for erosion control in a grazing setting includes fencing a suitable distance back from the stream (Figure 4). Setbacks should also be extended where the channel is likely to undergo some normal lateral movement.

**Figure 4.** The width of stream bank vegetation and the set back of stream bank fencing from the bank top is determined considering the bank height (see Section 3.3.2).

Like other areas in the landscape, vegetation in riparian zones often requires ongoing management to control weeds or pest animals.

Appendix B contains photos that illustrate some considerations when assessing stream bank erosion problems, and the multiple approaches available to addressing stream bank erosion, including revegetation, engineering and also upstream management of gullies and stream banks.

Where gully and streambank erosion occur at the same site or on different levels of stream banks on a large river, erosion control activities should be designed to address both types of erosion.

**Benefits other than erosion control**

Good management of gully and stream bank vegetation can have benefits beyond improving downstream water quality (Lovett et al., 1999; Volume 1). These include:

- Supporting sustainable land use:
  - Shade and shelter for livestock in neighbouring paddocks
  - Facilitates mustering by removing livestock from difficult to muster areas
- Reduced loss of productive land through erosion
- Improves water quality for consumptive use, for example cleaner water pumped from streams has been shown to improve animal growth

- Improving ecosystem condition:
  - Regulation of water temperature and light conditions for fish habitat
  - Supplies woody debris and seeds directly into the channel (which can support erosion control and fish habitat)
  - Near-stream habitat for wildlife.

1.3 Planning and implementing erosion control

1.3.1 A spatially-integrated approach to identifying cost-effective erosion control sites

This Program is focused on ten priority Management Units that contribute large amounts of fine sediment to the GBR coast from gully and stream bank erosion (see Section 2). Within a priority Management Unit, one or several priority areas should be identified by referencing to the priorities for gully and stream bank erosion control defined in regional Water Quality Improvement Plans and other datasets and field assessments (as described in Section 2). Priority areas should be large enough to provide sufficient opportunities for erosion control relative to the resources available in the project.

Once priority areas have been identified, a critical aspect to achieving cost effective gully and stream bank control for protecting the GBR is to identify individual sites within the priority areas where large sediment reductions can be achieved, using data analysis and field assessment. By concentrating efforts at sites with large sediment savings, fewer sites are required in a project, which reduces the fixed costs of establishing each site including monitoring and landholder engagement. The project has a budgeted expenditure and the number of landholders the project team can engage with each year is limited. The total sediment savings required to make the whole project cost-effective should also be known, giving an estimate of the target average sediment savings for sites in the project. Sites with small sediment savings must be offset by those with larger sediment savings.

If sites with small sediment savings are also included they should typically be nearby to or upstream of large sites. This can help support the legacy of sediment savings at larger sites, and to facilitate the necessary landholder engagement to enable engineering type works. Activities at these sites may include simpler fencing and revegetation type activities, or landholder training and advice.

The relative split of investment between gully and stream bank erosion control in the priority areas should consider the relative significance of gully and stream bank erosion as sediment sources, according to catchment modelling or regional WQIPs. However, the existing knowledge of sediment sources should be verified through field visits.

Sediment reductions will often be larger at sites with larger gully areas, and / or with rapid erosion, which warrant more intensive erosion control activities such as gully head rock chutes. The experience on many projects to date is that all activities including fencing and revegetation are more cost-effective when targeted to sites with rapid erosion. So pre-screening sites using the method in Section 4.3 is essential. For example, fencing and revegetation can be extremely cost-effective if livestock can be excluded from multiple large erosion features with a single fence, but are less efficient at project scale if implemented at sites with smaller sediment reductions.

Cost-effectiveness is defined in terms of the Reef Trust funds required for designing and implementing the activities ($), as a ratio to the long-term estimated reduction in mean-annual fine sediment load delivered to the GBR lagoon (t/yr) – see the box below.
Estimating cost-effectiveness

In this Program the long-term effect of erosion control on mean-annual fine sediment loads to the GBR lagoon is estimated for each site by the Delivery Partner to help inform the design process; if the cost is excessive then lower-cost activities or other sites should be considered. These estimates will later help to inform the Great Barrier Reef Report Card and program evaluation.

The effect of erosion control is estimated as:

\[
\text{Sediment saving (t/y)} = \text{Baseline yield} \times \text{Effectiveness} \times \text{Delivery to coast}
\]

Baseline fine sediment yield can be calculated using:

1. The current rate method, in which the mean annual gully or stream bank erosion rate is estimated from the difference in gully volume or stream bank position between two recent dates for which historical data is available such as air photos (the period must be >10 years and the estimate may need adjusting to represent average climatic conditions).

2. The whole-of-life method, in which the current gully erosion volume is divided by gully age, and then typically scaled down to account for decay in erosion rate over time. This is used where insufficient historical data are available.

The effectiveness of erosion control is estimated as a proportion of the baseline yield (Table 1). Delivery to coast is defined for each Management Unit by Paddock to Reef Catchment modelling, and sub-catchment values are available on request.

Cost is the Program funds required for designing and implementing the activities including site design, labour and materials (excluding site identification, communication, monitoring and administration).

Sites outside of priority areas or priority catchments may potentially be included, if they will deliver cost-effective sediment savings. However, these sites should be discussed with the technical partner and Department before design work is contemplated.

Identifying sites for cost-effective erosion control within priority areas requires addressing the following questions:

1. Does the baseline sediment yield and hence the projected sediment reductions, warrant the capital expenditure?
   - A site sediment reduction calculator is provided to facilitate estimating the sediment reductions which can be achieved (see Section 4.3). The site sediment reduction is estimated relative to a baseline untreated case and is typically informed by the sediment yield over recent decades. This calculator should be used prospectively to identify cost-effective sites, and then refined during design. A site visit is essential to refine and confirm the baseline sediment yield. But it also raises landholder expectations of some action, so do some desktop analysis first if possible, based on air photos or LiDAR. Then you will know approximate sediment savings, and the budget and treatment options which are potentially cost-effective.

2. Does the landholder the project proceeding and are they prepared to exclude stock from the project area for sufficient time to allow revegetation, often several years?
   - Landholder consultation is essential in site identification and works design but project teams should lead the engagement rather than expecting landholders to propose activities.
   - Rather than seeking to constrain individual points of stream adjustment, stream bank erosion control should aim for a well vegetated zone within which the channel has room to move. This vision can contrast individual landholder objectives. The delivery partner may need to divide expenditure between what individual landholders want (e.g. hard engineering at a particular stream bank site), and what is most cost-effective at catchment scale for the medium to long term health of the river and reef.
1.3.2 Designing and implementing suitable and cost-effective erosion control activities

The common erosion control activities for hillslope and alluvial gullies and for stream banks are listed in Table 1. There are three parameters included in Table 1 which help to select suitable and cost-effective activities for a site:

- Recommended complementary activities are listed for each activity (Table 1, forth column). Activities with darker shading (e.g., 1 and 2) are foundational activities which can be used on their own and are necessary to support more expensive activities (e.g., 3 and 6).

- Relative unit area costs and the requirement for specialist technical expertise (typically these are related). A feasibility study and a detailed technical design by a soil scientist, geomorphologist or engineer are necessary for planning more intensive activities. The Program technical partner can also help to guide the erosion control approach.

- Erosion control effectiveness (Table 1, second column from right), which is defined as the proportional reduction in fine sediment yield which can be expected if the activity is fully implemented across the eroding area. The effectiveness estimates given in Table 1 can be applied in the sediment reduction calculator, but may be adjusted to suit each site if that can be justified. The effectiveness estimates are deliberately conservative considering several factors;
  - The degree of local evidence.
  - The risk of failure at a proportion of sites,
  - The longer time that non-structural activities take to reach full effectiveness.
  - The effectiveness of engineered stream bank erosion control recognises that halting erosion on one bend (and hence halting the ongoing lengthening of that bend and associated reduction in river slope and flow velocity), will increase the erosive force on adjacent bends downstream, relative to the non-treated baseline case.
Table 1. Guidance on the order of implementation of erosion control activities for different gully and stream erosion types, and the circumstances when to invest in more intensive erosion control activities. Section 1.1 contains photos of each erosion type. Each activity is detailed in Section 3. Note: the estimates of erosion control effectiveness are based on expert opinion and are a guide only. Refer to footnotes.

<table>
<thead>
<tr>
<th>Channel erosion type [see definitions in Section 1.1]</th>
<th>Erosion control activity [darker colours denote foundational activities, which should also support more intensive activities shown in lighter colours]</th>
<th>When to consider applying activity (criteria for when to consider stepping to the next / higher cost option)</th>
<th>Recommended complementary activities [those in brackets apply in some cases]</th>
<th>Relative unit area cost / technical complexity assuming recommended complementary activities are undertaken if required</th>
<th>Estimated erosion control effectiveness assuming recommended complementary activities are undertaken if required</th>
<th>Activity detail see section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope gully [dry tropics and/or wet tropics if present]</td>
<td>1. Improving grazing management in gully catchments</td>
<td>On properties with land in poor condition, and on which other erosion control activities are also implemented.</td>
<td>2</td>
<td>$</td>
<td>0.1</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>2. Fence to control livestock access to erosion control sites</td>
<td>Essential pre-requisite for all activities where livestock are present (may result in additional watering point being required)</td>
<td>1</td>
<td>$$</td>
<td>0.2</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>3. Actively revegetate gully [including brush matting or compost &amp; contour debris placement on lopes, where required]</td>
<td>After fencing &amp; any other works have been undertaken Soil EAT class &gt;2</td>
<td>1, 2 [4, 5, 6]</td>
<td>$$$</td>
<td>0.3</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>4. Porous check dams</td>
<td>Small catchment areas and non-dispersive soils [see detail]</td>
<td>1, 2, [3]</td>
<td>$$$</td>
<td>0.4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>5. Road and catchment runoff management including diversion banks</td>
<td>Where overland flow or road runoff is contributing to erosion and diversion can be safely implemented. Use of ripping only under certain circumstances.</td>
<td>1, 2, 3, [4]</td>
<td>$$$</td>
<td>0.2</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>6. Gully head rock chutes</td>
<td>At rapidly moving gully headcuts e.g., &gt;1m/yr over last 10+ yrs</td>
<td>1, 2, 3, 4, 5</td>
<td>$$$</td>
<td>0.6</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>7. Gully reshaping + gypsum</td>
<td>Rapidly eroding gullies with dispersive/slaking soils EAT class 1 &amp; 2</td>
<td>1, 2, 3, 4, 5, 6</td>
<td>$$$</td>
<td>0.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>
### Table 1. Guidance on the order of implementation of erosion control activities for different gully and stream erosion types, and the circumstances when to invest in more intensive erosion control activities. Section 1.1 contains photos of each erosion type. Each activity is

<table>
<thead>
<tr>
<th>Channel type</th>
<th>Erosion control activity</th>
<th>Estimated erosion control effectiveness</th>
<th>Relative unit area cost / technical complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Small active gullies/scalds (dispersive/slaking soils)</strong></td>
<td>1. Improving grazing</td>
<td>$$$</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2. Fence to control livestock</td>
<td>$$$</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>3. Actively revegetate gully (including brush matting or compost &amp; contour debris placement on lopes, where required)</td>
<td>$$$</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>4. Porous check dams (dry non-dispersive soils (see detail))</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>5. Road and catchment runoff management including diversion banks (B)</td>
<td>$$$</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>6. Gully head rock chutes (1 m/yr over last 10+ yrs)</td>
<td>$$$</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>7. Gully reshaping + gypsum (C class)</td>
<td>$$$</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>8. Gypsum/lime + composting or mulching to support reveg</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>9. Soil capping with stable soil/rock as alternative to 8</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>10. Rest shaping</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Small catchment areas and at rapidly moving gully headcuts</strong></td>
<td>11. Fence, and weed and/or land management agreement ensures no grazing for at least 5 years</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Medium active gullies (dispersive/slaking soils – high gully indicator)</strong></td>
<td>12. Actively revegetate streambank and mid-level in-channel benches and bars</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>13. Bank toe protection by debris or silt traps to facilitate deposition and revegetation</td>
<td>$$$</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Highly active gullies with dispersive/slaking soils – EAT</strong></td>
<td>14. Engineered streambank toe protection or bed protection using rock or timber structures (+/- battering &amp; revegetation)</td>
<td>$$$</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Notes:**
- Larger numbers indicate higher cost.
- Darker colours denote foundational activities, which should also support more intensive activities shown in lighter colours.
- The effect can be added to that of within-gully activities.
- The drainage work reduces runoff into the gully by a large proportion (50%)
## Skills needs

It is important to secure the right skills and expertise for erosion control. Locating, designing and constructing activities correctly is essential for works to give good value water quality improvement, and for them to be effective through droughts and floods. Poorly located or designed structures will fail. The use of machinery in the hands of an unskilled and uninformed operator can be disastrous for erosion.

The expertise to identify erosion control sites includes:

- Grazing land management extension and landholder engagement
- Spatial analysis (GIS) working with historical air photos and / or LiDAR digital elevation model differencing
- Calculating sediment reductions using the calculator provided and field surveys

The technical expertise to manage, design and implement erosion control will depend on the on-ground activities but can include:

- Site surveying to locate structures (e.g., Porous Check Dams)
- Hydraulic structure design including design peak runoff estimation (for rock chutes, gully reshaping and engineered bank erosion control); designing large structures requires RPEQ registration as described in Section 3.1.
- Soil sampling and chemical analysis (exchangeable sodium, pH, Cation Exchange Capacity), and designing chemical amelioration (gypsum or lime), particularly for dispersive and sodic soils where engineered structures or earthworks are contemplated
- Revegetation of grasses, shrubs and trees as suits the site including weed control
- Repeatable site monitoring of vegetation cover and land condition at controlled locations
- Planning, purchase, delivery and installation of inputs such as fencing, rock, mulch, gypsum, seed and technical consultants

*All on-ground works should be supervised by skilled and experienced personnel.*

Other erosion control activities not described in this document can be proposed, however should be reviewed by the appropriate technical experts for their cost effectiveness and long term viability.

A process for documenting and reviewing the erosion control design before commencing implementation is described in Section 4.3. This enables Program evaluation, and adaptive management of activities in the Program.

The integrity of erosion control activities should be maintained at all sites until at least the conclusion of the Program. This is ensured by undertaking annual monitoring and preventative maintenance as described in Section 4.4.
Recent analyses of catchment model outputs and related datasets identified priority catchment management units in the GBR catchments in which gully and stream bank erosion contributes high levels of fine sediment to the GBR (Wilkinson et al., 2015a; Bartley et al., 2015). The ten Management Units for this Program (Figure 5) were selected considering the latest catchment modelling undertaken by the Paddock to Reef Program (RC7; McCloskey et al., 2017). That modelling also underpinned the Scientific Consensus Statement (Waterhouse et al., 2017), the 2015 Fitzroy Water Quality Improvement Plan (WQIP), and the 2016 Burdekin WQIP. Gully and streambank erosion in these 10 units contributes more than half of the fine sediment export contributed from gully and stream bank erosion across all 47 GBR catchment management units. The priority units are primarily closer to the coast where rainfall and erosion rates are higher. They are also well-connected through the river network to the coast, so that the effect of erosion control on sediment export to the GBR lagoon will not be attenuated by deposition processes occurring in large dams or floodplains downstream of project sites.

The delivery partner should target project activities in each of their management units within priority areas (see Section 1.3.1). Identification of the priority areas should consider their contributions to fine sediment export as assessed by the relevant regional WQIP (Table 2). The boundaries of sub-catchments defined in the regional WQIPs are shown in Appendix A maps and are available as shapefiles on request to the authors.
Table 2. Reference to priority sub-catchments within Regional Water Quality Improvement Plans

<table>
<thead>
<tr>
<th>Management Unit</th>
<th>Link to Water Quality Improvement Plan documents</th>
<th>Items within the Water Quality Improvement Plan identifying priority sub-catchments (other items may exist)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normanby</td>
<td>Cape York Natural Resources Management, Eastern Cape York Water Quality Improvement Plan 2016: <a href="http://waterquality.capeyorknrm.com.au">http://waterquality.capeyorknrm.com.au</a></td>
<td>Figure 21, areas A and B, Page 58</td>
</tr>
<tr>
<td>Bowen Bogie, East Burdekin, Lower Burdekin, Don</td>
<td>NQ Dry Tropics, Burdekin Region Water Quality Improvement Plan 2016: <a href="http://www.nqdrytropics.com.au/wqip2016">www.nqdrytropics.com.au/wqip2016</a></td>
<td>Table 5.7 Figure 5.2.</td>
</tr>
<tr>
<td>Pioneer-O’Connell⁶</td>
<td>Mackay Whitsunday Water Quality Improvement Plan 2014-2021: <a href="http://reefcatchments.com.au/water/wqip/">http://reefcatchments.com.au/water/wqip/</a></td>
<td>Figure 15 Figure 13.</td>
</tr>
<tr>
<td>Mary</td>
<td>Water Quality Improvement Plan For the Burnett Mary Region, 2015: <a href="http://www.bmrg.org.au/our-Programs/planning-evaluation-technology/water-quality-improvement-plan/">http://www.bmrg.org.au/our-Programs/planning-evaluation-technology/water-quality-improvement-plan/</a></td>
<td>Figure 22</td>
</tr>
</tbody>
</table>

A The Pioneer and O’Connell are managed together in this Program
Figure 5. Management units draining to the GBR lagoon. Priority management units for this Program are outlined in blue. The Pioneer and O’Connell are treated together as one management unit in this program.
Within priority areas, candidate properties should be identified. This process may be assisted by the following datasets:

- Priority areas for stream bank erosion control and riparian revegetation are defined in the WQIPs at sub-catchment scale.
- Mapping of gully extent in the priority management units (see maps in Appendix A; gully density data are available on request to the authors). There are differences in the gully mapping methods used between management units, however, this mapping is not used to allocate funds between management units.
- Historical air photos help to identify sites and estimate historical erosion rates; portals include:
  - QImagery [https://qimagery.information.qld.gov.au/]
  - Google Earth Pro (View: Historical Imagery)
  - Queensland Globe Website (also useful for accessing information on soils, water courses, roads and infrastructures) [https://qldglobe.information.qld.gov.au/]
- LiDAR digital elevation models (DEMs) can help to identify gully and stream channel extent in treed areas, and also indicates gully depth and volume. Multiple LiDAR DEMs can indicate recent erosion rates where the change in elevation is larger than the limit of detection (~0.5 m). LiDAR DEMs are also useful for designing erosion control activities, by defining erosion depth and slope angles and gully catchment area.
- Geomorphic assessments and walking the landscape to assist identifying gully erosion that is just starting, active and mature or stable.
- Ground cover imagery from VegMachine [https://vegmachine.net/] or other portals.
- Soil properties, which in some areas differs strongly in erodibility and nutrient content [http://www.asris.csiro.au/]. For larger erosion control sites it is worth collecting and analysing local soil samples to improve estimates of soil properties. This is particularly important for stream banks which are often poorly represented in soil mapping.
- Landholder discussions.

Prevention of gullies in non-gullied parts of priority areas is also important, especially areas with duplex (texture-contrast) soil types, such as Chromosols (red goldfields) and Sodosols (“spewy” soils with yellow/brown subsurface clay). These soils have high clay content in the subsoil which limits infiltration, leading to more frequent saturation of the soil surface, and more surface runoff. They are also likely to be dispersive or slaking. Reducing further gully growth in areas with sodic subsoils is particularly important because once these subsoils are exposed they are very difficult to stabilise.

This Toolbox can also apply to areas of significant gullying outside of the priority catchments, particularly those which are shown to be cost-effective to treat, and which deliver sediment efficiently to the GBR lagoon.
3 GULLY AND STREAM BANK EROSION CONTROL ACTIVITIES

3.1 Introduction

This section describes in detail the gully and stream bank erosion control activities listed in Table 1. Activities should be implemented following the strategy described in Section 1.3, including implementing the complementary activities listed in Table 1. Delivery Partners should familiarise themselves with relevant activities using the Objectives, Location, Design and Implementation detail in each subsection below.

3.1.1 Seek relevant information

This document is not exhaustive. Applicants and Delivery Partners (and other land managers interested in addressing erosion and sediment losses) are encouraged to also consult other recent references.

The context of gully and stream bank erosion control alongside grazing practices to reduce the water quality risk of grazing is outlined in:


References on gully erosion control in Queensland include:

• Gully Erosion: options for prevention and rehabilitation [Day and Shepherd, 2019]
• Queensland Soil Conservation Guidelines, Chapter 13 [Carey et al. 2015c]
• Alluvial gully prevention and rehabilitation options for reducing sediment loads in the Normanby catchment and northern Australia [Shellberg and Brooks 2013]
• Managing alluvial gully erosion; and Alluvial Gully Systems Erosion Control & Rehabilitation Workshop [Brooks et al. 2016a; 2016b]

References for stream bank erosion control include:

• Queensland Soil Conservation Guidelines, Chapter 11. Stream Stability [Carey et al. 2015b]
Erosion control activities other than the ones described may be utilised provided they address the objectives and strategy described in Section 1, and their suitability can be justified and they are demonstrated to be cost-effective.

3.1.2 Administrative responsibilities

All activities should be undertaken with Work Health and Safety obligations in mind.

Regulatory requirements such as securing relevant permits to undertake activities including vegetation management are the responsibility of Delivery Partners [see Table 3].

Table 3: A list of the key Federal, State and Local Government legislation that may be relevant to gully and streambank remediation works.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Legislation</th>
<th>Agency</th>
<th>Contact details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation clearing or removal</td>
<td>Vegetation Management Act 1999</td>
<td>Department of Natural Resources, Mines and Energy (Queensland Government)</td>
<td>Ph: 13 QGOV (13 74 68) <a href="http://www.dnrme.qld.gov.au">www.dnrme.qld.gov.au</a></td>
</tr>
<tr>
<td>Heritage issues</td>
<td>Aboriginal Cultural Heritage Act 2003 Torres Strait Islander Cultural Heritage Act 2003</td>
<td>Department of Agriculture and Fisheries (Queensland Government)</td>
<td>Ph: 13 QGOV (13 74 68) <a href="http://www.daf.qld.gov.au">www.daf.qld.gov.au</a></td>
</tr>
<tr>
<td>Protected plants and protected areas</td>
<td>Fisheries Act 1994 Forestry Act 1959</td>
<td>Department of Agriculture and Fisheries (Queensland Government)</td>
<td>Ph: 13 QGOV (13 74 68) <a href="http://www.daf.qld.gov.au">www.daf.qld.gov.au</a></td>
</tr>
</tbody>
</table>
### 3.1.3 Engineering design and review

Design and construction of large erosion control structures requires the use of licenced design engineers and specific review procedures to manage safety and financial risks:

- Use of CHUTE or equivalent procedures for rock chute rock size selection, reviewed by Technical Partner for compliance with use of required method. Engineers require relevant prior experience required including oversight of installation.

- Structural gully or stream bank works costing more than approximately $100,000: Specific design method(s) required by professional with RPEQ registration (https://www.bpeq.qld.gov.au/) which is ensured by the delivery partner, with designs reviewed by Technical Partner. Engineers require relevant prior experience required including oversight of installation.

Delivery Partners should monitor and maintain the integrity of activities until the end of the Program, making refinements as required to ensure the longevity of the erosion control.

### 3.2 Improving grazing management in gully catchments

#### 3.2.1 Objectives

Gully and stream bank erosion is a symptom of excessive grazing pressure in the past (or ongoing). Good vegetation cover and condition within gullies is associated with much lower gully wall erosion rates than at low cover levels (Wilkinson et al., 2018). Therefore, improving grazing land management is a supporting activity to gully and stream bank erosion control. This can include property planning. Improving grazing management also protects the legacy of more intensive erosion control activities by reducing pressure on fencing around gullies and stream banks. Extension and infrastructure to improve grazing management may also be regarded by landholders as a benefit to offset in-kind costs of engagement associated with implementing gully and stream bank erosion control actions.
Figure 6. Vegetation cover and biomass increased markedly as a result of livestock exclusion around this gully in the Normanby catchment, from June 2016 (left) and March 2018 (right; Photos by Cape York NRM).

Figure 7. Hillslope gully erosion on granodiorite soils in the Don River catchment, resulting from removal of tree cover and heavy grazing pressure. Gullies such as this will require stock exclusion for a period and major changes in ongoing livestock access to enable revegetation of the gully channel and banks. Significant changes to grazing land management in the gully catchment and cattle pad drainage management will reduce surface runoff into the gully heads in the very long term (Andrew Brooks). Porous check dams can also help to revegetate the gully floor.
On its own this activity is unlikely to substantially reduce gully or streambank erosion in the short term. However, more conservative forage management and wet season spelling have been shown to reduce runoff volumes over 5–10 year time frames in areas of high fertility and times of average or above rainfall (Owens et al., 2003; Connolly et al., 1997; Sitburn et al., 2011), particularly if deep-rooted perennial grasses are restored. Response times can be much longer if vegetation is degraded, rainfall is below average and soil is less fertile (Hawdon et al., 2008; Bartley et al., 2014).

Improving grazing management can also help to prevent initiation of additional gullies in the future. Many gullies formed during the expansion of the grazing and cropping industries between 1850 and 1900, and much later in some areas. There remains a significant risk of new gullies forming associated with tree clearing and the intensification of grazing and cropping enterprises. An ongoing risk with improving grazing management alone is that it does not provide control on livestock access to gullies and streambanks and is very prone to continued changes after the project monitoring is complete.

There are three main approaches to improving grazing management described below; improving forage management, fencing and water points:

### 3.2.2 Improving forage management

Improving forage management involves engaging the landholder in extension programs or discussions to support gully and stream bank erosion control activities, either within the fenced area including gullies or stream banks, or in paddocks draining into gullies or adjacent to fenced stream banks, or elsewhere on properties requiring gully and stream bank erosion control.

- **This is an essential accompaniment to other erosion control activities at sites where gully fencing does not cover the entire gully catchment.**

- **Stocking rates should ensure that forage use is within levels that sustain vegetation composition and condition, which ranges from 10 to 35% of the annual herbage growth (10% in low fertility land types common in degraded areas), to sustain the perennial composition of forage (Hunt et al., 2014).**
  - A forage budget is typically constructed based on standing forage near the end of the wet season (April), planning until the next grass production date (when grass growth exceeds consumption). The budget should be updated with another measurement of standing forage 1–2 months later, and stocking rates adjusted at that time accordingly. Updating early in the dry season means smaller stocking adjustments are required to maintain the forage budget within sustainable levels than leaving adjustments to later in the dry season.

- **There are considerable resources available to support training and grazing management:**
  - Grazing BMP modules for Grazing Land Management and Soil Health [www.bmpgrazing.com.au](https://www.bmpgrazing.com.au);
  - Forage [https://www.longpaddock.qld.gov.au/forage/](https://www.longpaddock.qld.gov.au/forage/) FORAGE incorporates a number of products such as SILO climate data, satellite imagery and AUSSIEGRASS modelled pasture growth, delivering them by email as easy to understand PDF property-scale reports, to help decision-making in grazing land and environmental management
  - Consider commercial training and service providers also.

- **Spatial information can greatly assist property planning processes related to improved forage management, including:**
  - Available soil mapping and distribution
  - Land type and regional ecosystem mapping
  - Current and historic ground cover (that can be supported by soil and vegetation distribution)
  - Fencing infrastructure supporting grazing management.
• Training may also involve graziers beyond those hosting erosion control projects where that helps to achieve Program objectives. However, this Program does not fund one-on-one extension programs outside of properties where other gully and stream bank erosion control activities are being implemented.

• It is recommended to include forage management in agreements with landholders

• The site report [see Section 4.3] should specify:
  – Which landholder training is used
  – The form and duration of landholder agreement (written, verbal)
  – The agreed approach to setting stocking rates and desired outcomes such as forage utilisation rates, minimum forage levels, spelling timetables.

• Site monitoring should include ground cover and composition, and ideally forage biomass, as described in Section 4.4.

3.2.3 Fencing to improve grazing management

As a part of planning erosion control, additional fencing and water points to improve grazing management may be required (Section 3.3 describes fencing gullies and stream banks). Considerations include:

• Where linear branching gullies are extensive across entire paddocks (e.g., gully spacing of <500m, such as occurs on red goldfields soils with many drainage lines or in plains country with dispersive soils) it may not be feasible to fence around all gullies. In this scenario paddock subdivision fencing may improve forage management within the gullied paddocks (e.g., enable wet season spelling and lower forage utilisation rates).

• Paddock subdivision to improve forage management such as to enable pasture spelling in areas draining to gullies [where they have been fenced separately] typically has a private benefit and should have landholder co-investment.

3.2.4 Managing water points

Water points are high stock traffic areas where soil is typically bare and compacted and large quantities of excrement accumulate. Generally, water points are connected to a network of stock tracks that convey overland flow rapidly across the land surface, which can accelerate gully and stream bank erosion if tracks converge on those features. Manage water points by:

• Locate new livestock watering points in higher parts of the landscape far from gullies and stream banks, and at a minimum distance of 50 meters from gullies and streambanks.

• Moving watering points to more favourable locations is a relatively expensive measure. In this Program, a typical reason to fund a water point will be where new gully fencing prevents access to what was previously the only perennial water in the paddock. Otherwise, caution must be exercised in funding this activity even on a co-investment basis, as simply adding watering points can result in an increase in grazing pressure, exacerbating land degradation and gully erosion. Additional water points can also attract more native grazing animals and require ongoing maintenance.
3.3 Fencing to control livestock access to erosion control sites

3.3.1 Objective

Degraded areas like gullies and stream banks can be preferentially grazed if not fenced. Gullies and riparian areas also require higher levels of vegetation biomass than other areas of the landscape because:

- Gullies and stream banks generally have steeper slopes than hillslope surfaces, reducing soil stability and increasing runoff energy;
- Soil around gullies and stream banks may be weakened by being saturated more frequently and for longer than higher in the landscape;
- Gullies and stream banks are exposed to much higher runoff volumes and shear stresses due to concentration of surface runoff from the hillslope area above.
- Many gullies have exposed dispersive or slaking sub-soils which are less stable when exposed to rainfall.

The main objectives of fencing are to:

- Control livestock access to erosion prone areas
- Enable the area in and around gullies, streambanks and riparian areas to be managed with higher biomass levels than surrounding paddocks so it does not revert to its previously eroded state
- Provide the land, soil and native vegetation ‘a rest’ from livestock grazing, particularly during the wet season when gullies and stream banks are more vulnerable to erosion.

If gullies are contained within larger paddocks the grazing pressure in gullies is frequently observed to be above sustainable levels. In contrast, once gullies are fenced, and provided fences are maintained, conscious decisions...
are required to graze these areas and higher biomass levels can be maintained. Revegetation without fencing or livestock management is an ineffective investment as livestock will eat new seedlings and new vegetation growth. In areas of permanent cropping, fencing around an erosion control site may be unnecessary.

Note: This technique is a prerequisite supporting activity at all gully and stream bank erosion control sites, where livestock is present, or likely to be present in the future.

Gully and stream bank fencing can have co-benefits for grazing land management by:

- Excluding cattle from rough areas to reduce animal injuries and because they complicate mustering;
- Assisting paddock subdivision enabling better management of grazing pressure to improve land condition.
- If these areas are small relative to the surrounding paddocks they can be largely excluded with little impact on property grazing management.

### 3.3.2 Location

When locating the fencing, there are several issues to consider:

- It should not include unnecessarily large areas that may increase the need to graze within that extended fenced area more frequently.
- Integrating gully fencing with streambank/riparian fencing is strongly recommended where gullies are connected to streams.
- Incorporate as many gullies as possible, and as many extensive areas of eroded stream bank and riparian areas as possible in relation to the length of the fence to be installed.
- Fencing location needs to be planned with the support of the landholder because they will be responsible for its maintenance in the long term.
- Where possible, avoid fencing in flood-prone areas, or use alternate fencing designs.
- Existing fences and associated gates need consideration in the design of new fencing associated with this Program.
- The grazing regime within the fenced area needs to be agreed with the landholder and specified in the site report (see Section 3.2.2).
- Clearly state the intended life of all new fences installed (whether project duration or permanent).
- If fencing will remove livestock access to existing water points then a new off-stream water point may be provided. Refer to the considerations listed in Section 3.2.4.

### Streambanks

Stream bank fencing must be located where it will rarely flood, particularly if streamflow velocities are significant. This is typically close to the high bank of the watercourse with a sufficient setback. Based on the work of Abernethy and Rutherfurd (1999) the fence line setbacks are established by taking into account a minimum of 5 meters (or the minimum width under the Vegetation Management Act [1999]) plus the bank height in meters and adding an estimate of the erosion rate to continue over a 20 year period of tree growth (in meters). The calculation should follow Equation 1 below:

\[
\text{Stream bank erosion control width (m)} = 5 \text{ m (or the minimum width under the Vegetation Management Act [1999])} + \text{bank height (m)} + \text{allowance for continued erosion over 20 year period of tree growth} \quad \text{(Equation 1)}
\]

Riparian zones of insufficient width lead to poor plant cover, erosion and/or weeds (Paul et al., 2018).
Gullies

- Use at least a 20 m set-back around the active gully head and side branches (more if required) to allow for ongoing erosion and to encompass erosion-prone areas such as scalds. Ensure that the fence encloses all areas where other gully erosion control activities are undertaken.

- Where linear branching gullies are extensive across entire paddocks (e.g., gully spacing of <500m, such as occurs on red goldfields soils with many drainage lines or in plains country with dispersive soils) it may not be feasible to fence around all gullies. In this scenario Paddock subdivision fencing may improve forage management within the gullied paddocks (e.g., enable wet season spelling and lower forage utilisation rates). In these circumstances fencing should have landholder co-investment.

- Where possible, separate gullied or frontage country from areas less vulnerable to gully and stream bank erosion.

3.3.3 Implementation

Factors to consider in implementation:

- The first and foremost consideration for fences around erosion control sites is that they are stock-proof. These fences should be of robust construction i.e. effective at excluding livestock when forage biomass in and around the gully is much higher than in the paddock (i.e., small dropper spacing and additional strands will be needed beyond a standard subdivision fence).

- Prevent livestock access at the downstream end with a secure flood gate if the fence crosses the gully channel.

- Felling trees or disturbing ground vegetation to erect the fence should be kept to the absolute minimum required to access the site by vehicle and erect the fence. Where possible low impact tree to tree fencing can be used to minimise disturbance. Do not undertake earthworks or disturb the ground vegetation cover other than as required to access the site.

- Fencing should be completed before revegetation (either active or passive) around gullies or physically disturbed and deteriorated riparian areas.

- For sites where some grazing continues within the erosion control area (after an initial no-graze period and modified from historical patterns and by the new fencing), a documented agreement with the landholder should include specification of the grazing regime planned for the erosion control area. This grazing management should ensure vegetation condition is sufficient for erosion control, and is ideally specified as
  - Stocking rates should be kept very low, e.g., consumption of ~10% of standing biomass; a substantial forage biomass should always be maintained.
  - The timing of grazing (dry season only).

- Where the fenced area will not have a water point consider including a spear gate to allow cattle to escape.

- If temporary electric fencing is proposed (not recommended except in the special circumstances):
  - It must be combined with reduced forage utilisation grazing management in the surrounding paddock (see Section 3.2), since temporary electric fences do not provide as much control of livestock
  - Electric fencing units that provide back-to-base notification of fence breaches are available, which may reduce the surveillance burden to land holders.

- Where existing fencing and gates have resulted in stock tracks or cattle pads that lead to overland flow into gullies or streams, those stock tracks should be remediated by installing small diversion banks or otherwise as appropriate.

- Ensure that any clearing related to fenceline construction complies with State Government vegetation management regulations (see Table 3)

- Achieving the objectives requires that grazing in the fenced area is carefully controlled, and that should be ensured through ongoing site monitoring (see Section 4.4).

- Virtual fencing may become a viable alternative to constructed fencing in future, but would require considerable co-investment from the landholder.
3.3.4 Monitoring, reporting and maintenance

Monitoring should include land condition assessment and ground cover and composition inside and outside of the fence as described in Section 4.4.

Fencing requires considerable maintenance with respect to fires, floods, feral and native animals. Where possible:

- The integrity of the fence should be maintained at least for the duration of the Program and preferably permanently.
- Depending on the location and grazing pressure, stock will often need to be completely excluded from areas being treated for active gully erosion for several (>5) years until revegetation and recovery is complete. After the revegetation period is complete, short periods of dry-season grazing may occur within the fenced area to manage fire risk or vegetation composition where appropriate.
- Where block fences are required to prevent stock movement up and down a river, such as at property and paddock boundaries or the downstream end of large gullies, annual (post-wet season) fence maintenance is required as part of the ongoing project activities. Responsibility for fence maintenance during and after the Program should be agreed in writing with the land holder. There is a benefit to landholder involvement in fence construction and maintenance if it helps to ensure livestock exclusion and fence maintenance.

3.4 Revegetation of gullies and stream banks

3.4.1 Objectives

The main objective of revegetation is to improve land and soil condition by increasing (native) vegetation cover and biomass and root reinforcement. Facilitating rainfall to penetrate deep into the soil, reducing the runoff that causes erosion, is important around gullies and on steep areas. A diverse mixture of grass, shrub and tree components of vegetation in the native regional ecosystem of the area is ideal for erosion control and soil health in the long term.

- For streambanks, the primary objective of revegetation is to maintain a mix of grasses, trees and shrubs on the banks, and within the channel area that is subject to flow inundation. This will reduce but not eliminate bank erosion.
- For gullies, the objective is to establish a self-maintaining vegetated area that protects the soil surface from rain splash, slows down runoff (by obstructing flow and roughening the soil surface), and increases gully wall strength by reinforcing the soil with roots. Ground cover is particularly important in areas with dispersive and slaking soils.
• Particularly at dry tropic sites, woody stem densities when planting should ideally be low enough to allow grass growth between tree plantings, but clearing existing native tree cover is actively discouraged, even if it is thicker than ideal.

Revegetation can be achieved through assisted natural regeneration (passive revegetation) or by direct planting (active revegetation).

3.4.2 Location

One of the major components of revegetation is determining the size of the area or buffer to be restored. Typically the area will focus within the fence that controls livestock access to an erosion control site (see Section 3.3.2). Revegetation should also include rehabilitated legacy stock tracks and disturbed areas such as livestock camps.

Vegetation is not the answer to all stream bank erosion problems and has limitations. Some level of erosion is natural, and creates fish habitat. Extensive tree clearing in some stream systems has deepened and widened some streams (particularly in more coastal GBR catchments) so that they carry much more stream power today. Situations where vegetation may be insufficient include (Rutherfurd et al., 2000b; p337):

• In highly energetic rivers where flow velocities are too high or the rate of toe scour is too rapid, stabilisation of the bank toe with engineered approaches may be a pre-requisite to enable vegetation to grow (see Section 3.9).
• Stream salinity can kill revegetation, sometimes many years after it is completed.
• Where a high stream bank face (>3 m) has no trees revegetating the bank top will be insufficient.
• Sites dominated by weeds. Weeds can often be controlled but may require a strategic whole of stream approach to prevent re-infestation (e.g., Lantana spp.), and if that is not possible they can preclude revegetating some sites.

3.4.3 Revegetation design

Active or passive

There are two revegetation approaches; passive regeneration by controlling livestock access and managing competition from weeds and feral animals, and active revegetation such as mulching, seeding and planting.

• Passive revegetation is more cost-effective where native trees, shrubs and grasses occur nearby and upstream to provide seeds.
• The likelihood of passive regeneration being sufficient will depend on the soil type, current soil structure and land condition. For example, surface treatment may be required for highly compacted and low-fertility soils, and will generally be required where dispersive sub-soils are exposed.
• Natural regeneration is very slow in degraded landscapes, especially in areas of low rainfall and low-fertility soils, or where natural vegetation has been completely removed historically. The presence of box, sandalwood or ironbark species are indicators that the soil type may be of poor quality, and that additional treatment is required to support vegetation growth. Active revegetation is required in these areas, and also where vegetation has been disturbed by project works. Re-vegetation in these areas can be very challenging and specialist expertise should be sought.
• Active revegetation involving tree planting can require irrigation during establishment, which can limit its applicability in drier areas.
Considerations generic to gully and stream bank revegetation

- Perennial tussock grasses with large basal area and root mass are preferred where available, because they assist rainfall penetration and provide litter. Creeping stoloniferous grasses can be used to provide total cover within gully channels.
- Woody shrubs and trees are important for maintaining soil water and nutrient balance and generating litter, which provides protection against rain splash and creates micro dams to slow runoff.
- Local professional advice should be sought for active revegetation techniques and species.
- Soil testing by a trained specialist is recommended when dealing with sodic soils to determine the exact nature of the soil and the requirements for chemical treatment. Soil sodicity varies from slight to strong and different approaches may work in different situations. Not all slaking and dispersive soils are sodic.
- Revegetating exposed sodic soils, within and around gullies, which are strongly dispersive on contact with water is assisted by providing a cover of organic mulch, compost and/or non-dispersive topsoil, after chemically treating with gypsum to support initial vegetation establishment (Shellberg and Brooks, 2013; Carey, 2014; Brooks et al., 2016a; 2016b).
  - Keep mulch out of annual flood areas where it will be washed away.
  - Weed control, such as by mulching or weed mats can be important to allow planted vegetation to establish.
- Controlled fire may be a suitable site preparation tool in some cases, e.g., for dense rubber vine or bellyache bush.
- Procedures for re-establishing vegetation cover on large gullies in slaking or dispersive soils and in degraded landscapes (such as drier inland areas on soils of low fertility) are not well-tested. Developing and trialling appropriate techniques in those settings is important to improve outcomes.
- In the humid tropics revegetation is typically more rapid but more frequent weed control is also required

Revegetation approaches that are specific to gullies, include:

- Surface ploughing near gullies should be avoided because of the exposure of erodible soils to further erosion
- It is very expensive to rip entire paddocks for pasture renovation and that should be funded by the land holder rather than this program (ripping is also mentioned in Section 3.6).
- Seeding directly with rapid-growing grasses is a cheaper alternative than planting which can be more suitable for revegetating large areas of sodic soils.
- Mobbing of cattle in a gully to bring nutrients and organic matter and churn the soil surface has been demonstrated to be successful in a small gully on black cracking clay soil. However, it remains an experimental technique and any trials should be closely monitored. It is unlikely to be effective in sodic soil or in deep gullies.

Revegetation approaches that are specific to streambanks, include:

- When the riparian zone has poor tree cover, additional trees should be planted to accelerate vegetation establishment.
- When riparian zones have higher vegetation cover, assisted natural regeneration will be more likely.
- Where the stream bank erosion is too rapid, revegetation can be combined with structural measures to stabilise the bank toe (see Section 3.9).
- Careful consideration needs to be given to the vertical zonation of riparian trees and shrubs when planting on stream banks. Some riparian vegetation such as reeds (e.g. Lomandra spp.) and rushes (e.g. Phragmites spp.) require continually access to sub-surface moisture to survive and thrive and are effective at the bank toe, while deeper rooted woody species and grasses are planted further up the bank face.
- Off-stream watering points. This program supports these only if proposed fencing excludes livestock from existing water points.
- Species native to the local area should be used wherever feasible. In some cases, local seed collection for endemic species may be required.
• All revegetation should avoid species which may become weeds in the area.
• In situations where local native grasses are not available, exotic grasses can be used effectively as erosion control provided they are already established in the local area.
• Vegetation that is likely to attract grazing animals or to require livestock grazing to prevent it out-competing other functional groups should not be used for revegetation. In particular, revegetation should avoid using Buffel grass (Cenchrus ciliaris) and exotic legumes (e.g., Stylosanthes spp.). These species are likely to enhance the risk of fire under low grazing pressure and attract grazing pressure.
• The Salinity Management Handbook (The State of Queensland, 2011) should be used as a reference to identify appropriate species with salt tolerance when it is considered that the salinity problem has not reached extreme levels. Revegetation of areas prone to salinity has a high risk of failure which should be assessed before proceeding.

3.4.4 Implementation

• Revegetation may be implemented in strategic phases (e.g., establishing grasses followed by shrubs and trees).
• Careful timing of seeding and planting with weather patterns is required to reduce the risk of revegetation failing.
• Monitor the vegetation cover and composition at representative locations within the site as described in Section 4.4.
• Replacement of unsuccessful seeding or replanting may be required if initial plantings die.
• Maintenance will include preventing livestock access until revegetation is mature, and ongoing weed control.

3.5 Porous Check Dams (PCDs)

3.5.1 Objectives

Typically gully floor sediment deposits have a very small proportion by weight of silt and clay particles (Bartley et al., 2007), leaving them too dry, unstable and nutrient poor to sustain much vegetation apart from weeds which die off during droughts (Wilkinson et al., 2013). The main purpose of installing porous check dams (PCDs, sometimes called leaky weirs or silt trap weirs) is to slow the flow and enhance the deposition of sediment, nutrients and seeds on the upstream side. This should improve soil condition in the base of gullies, to allow and assist the germination of available seeds. Once established, vegetation enhances sediment deposition to reduce gully sediment yield, leading to gradual gully infilling in the very long term. If PCDs do not trigger revegetation then they can only store a finite volume of sediment. An introductory video is: Introduction to Check Dams: An Erosion Control Practice - RUVIVAL Toolbox - YouTube.

PCDs have been widely used in gully management both worldwide and in Australia and have been trialled in the GBR catchments (Wilkinson et al., 2013; Day and Shepherd, 2019). PCDs are relevant for hillslope gullies, however, trials have also been undertaken in alluvial gullies, alongside other activities. PCDs should be used in combination with fencing to allow vegetation to become established in the gully.

A practical guide to designing and installing porous check dams is given in Day and Shepherd (2019).
3.5.2 Location

PCDs can be located by following these general principles:

- On their own, PCDs will have a larger relative effect on gully sediment yield in gullies of modest depth and erosion rate (<1 m/yr), or where they are accompanied with improved grazing management in the gully catchment.

- The catchment area above a porous check dam should be no more than 2 hectares for shallow soils (e.g., red goldfields granite-derived soils), and no more than 10 hectares in low relief landscapes with deep permeable soils (e.g., dark cracking clay). Siting PCDs in larger catchment areas is likely to lead to failure to trap fine sediment, and also structural failure.

- PCDs are more effective in soils with Emerson Aggregate Test (EAT) > class 2. They are less effective in fine-textured soils, particularly dispersive soils (e.g., Sodosol alluvium and basaltic Vertosol), because very fine sediment tends not to settle out. More solidly constructed check dams are required in these settings.

- Revegetating highly sodic soil (Exchangeable Sodium >30%, or EAT4 < 2) is very difficult and typically requires chemical treatment in addition to physical works.

- PCD’s should be located in flatter depositional areas with <2% slope. Typically PCDs are located in the downstream half of a gully.
  - Avoid locating PCDs in the steep section of gully immediately below gully headcuts where they will trap little sediment, unless they are for grade control protection of structures.
  - Avoid placing PCDs in narrow sections where runoff is deeper and faster
  - Avoid placing PCDs in sections with steep gully walls, which are an indicator of ongoing gully widening that will result in flow going around the structure (out-flanking)
  - Porous check dams are best located on straight segments of gullies where flows are not likely to impact the sidewalls of the gullies and out-flanking can be minimised.

- PCDs are not effective at stabilising headcut erosion because the energy of runoff over a headcut will typically overcome the resistance of gully floor vegetation which PCDs aim to enhance.

- PCDs placed upstream of the gully head do not significantly slow headcut advance and will have an insignificant effect on the volume of runoff into the gully.

- PCDs are not required when gully floors are already vegetated.

- When multiple porous check dams are normally used in each gully (which is recommended), ensure that PCDs are spaced so that the crest of each PCD is at least as high as the base (toe) of the next PCD downstream to prevent scour downstream of each check dam. Use a survey level to determine the correct spacing. For example in a gully with bed slope of 0.02 (2 percent), check-dams of 0.5 m height will be spaced closer than 25 m (slope = check-dam height / max spacing; Figure 10).

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**Figure 10. Porous check dam arrangement in longitudinal section. Runoff is slowed such that some fine sediment and seeds are deposited upstream (to the right) of each check-dam, improving the moisture and nutrient status. To prevent scour downstream of check-dams ensure they are spaced so the crest of each check-dam is at least as high as the base (toe) of the next one upstream.**

3.5.3 Design

- PCD height should be kept to <0.6 m to reduce the risk of failure.
  - In sodic soil consider reducing the check-dam height and spacing to avoid outflanking (and combine with soil treatments and revegetation).
- For large gully catchment areas and runoff volumes (assuming the gully slope is flat enough that check-dams will enable fine sediment deposition), consider
  - keying check-dams into the gully sidewalls, and
  - include energy dissipating aprons on the gully floor downstream of each check-dam.
- The crest of the PCDs should be higher on the sides of the Gully (to divert higher flow velocities away from the Gully walls).

3.5.4 Implementation

PCD construction requires specialist skills including experience with locating, designing and constructing PCDs. In general:

- Soil tests are a highly recommended before building PCDs, which assist identifying whether soils are slaking, dispersive or sodic. The Emmerson Aggregate Test (EAT) can identify soil dispersion and slaking levels.
- In some cases where the gully floor has a shallow inset drainage channel, wads of brush can be oriented along the drainage channel to improve contact between the PCD and the irregular cross-section.
- The Delivery Partners or specialists should set out and mark the PCD locations using levels.
- Avoid heavy machinery use as the risk of soil disturbance and further gully erosion increases as well as the introduction of weed seeds.

Options for construction materials can include:

- Use durable materials which will not have large gaps
- Fallen timber or rock wrapped into bundles using wire mesh. Construction starts with laying the mesh across the base of the gully. The ends of the mesh are positioned so that the completed structure will be firmly against the gully wall with either end well above flow level. The fallen timber or rock is then piled in a sausage-like shape along the mesh. The mesh is then closed over the timber or rocks and secured with fencing wire. Finally, star pickets are driven through the centre of the barrier at approximately 2 metre intervals, to anchor the check dam to the base of the gully.
- Wire netting
- Rocks large enough to not be washed away. The rocks should be of mixed sizes with minimal rocks smaller than 5cm in diameter.
- Log structures tied to vertical posts inset and anchored into the base of the gully.
- Weed mat can be used as a scour apron on the downstream site but should be keyed into the bed sediment. Scour matting may also be used. It lasts 15 years and encourages vegetation to grow through.
- Note that the materials suggested above are preferable to the geotextile (weed mat) barriers (or sand bags) used for temporary erosion control on construction sites because those are less porous.

Other examples are described in:

- Soil Conservation Guidelines for Queensland Chapter 13 (Carey et al., 2015c)
- Gully erosion Part 2 (Catchments and Creeks Ltd, 2010)

The significant manual labour component in constructing timber and wire PCDs in-situ makes them less popular with many landholders than structures constructed with machinery such as rock structures. Timber structures can also be damaged by wildfire.
3.5.5 Examples of porous check dams

Figure 11. Left: A rapidly eroding gully in the Mary River catchment in August 2017, with an exposed gully bed and banks and degraded vegetation adjacent to the gully as a result of grazing (looking upstream). Right: The same view in June 2018, 10 months after the installation of fencing, excluding grazing from the site and a porous check dam, constructed of steel mesh and posts with cuttings of local timber. Silt has deposited and Setaria (clumping grass, exotic) is growing upstream of the PCD, while African Stargrass (stoloniferous grass, exotic) is in the foreground. The gully has a 6 ha catchment (larger than the maximum recommended for PCDs), and small scour holes occurred around the structure. A further 9 PCDs were installed upstream of the one shown (photos Mary River Catchment Coordinating Committee).

Figure 12. Common failure mechanisms for porous check dams. In these cases the failures were attributed to the catchment areas being too large given the high rainfall and shallow soil. In addition, the coir log check dam was not adequately secured and the material has poor durability (left), and the ends of the timber and wire check dam were either not keyed into the bank or wrapped up the bank to above the flow level (right). (Photographs by Greening Australia)
3.5.6 Monitoring and maintenance

Given that the purpose of PCDs is to increase vegetation in the gully, long-term livestock exclusion, or large reductions in grazing pressure for the foreseeable future, are essential for PCDs to be effective. Weed control may also be required.

The vegetation cover and composition immediately upstream of PCDs is a measure of success and monitoring locations should be established at PCD locations.

The integrity of the PCD should be maintained at least for the duration of the Program. Repairing small breaches in these structures is important after large runoff events.

In the instance where the depth of accumulated sediment approaches the depth of the PCD wall, a further PCD can be built on top of the existing structure if required.

3.6 Runoff diversion banks and drainage management

3.6.1 Background and objectives

The aim of runoff diversion banks is to divert run-off water away from gully heads and into natural waterways or stable areas which are not susceptible to erosion (Geyik, 1986). Roads, tracks and other compacted areas of soil are known to produce high levels of runoff. Carefully designed drainage of these surfaces can help reduce concentrated flow reaching existing gullies and minimise the chance of new gullies forming. However, there is a risk of starting a new gully where the water is diverted, so the placement and construction of these features needs expert support. Road drainage is relatively expensive and should be considered only where runoff into active gullies is dominated by road drainage. Where maintenance of road drainage provides a private benefit a co-investment from the landholder should be required.

Typically road drainage causes gully erosion due to poor land condition, and reducing grazing pressure is an important complementary activity to reduce erosion risk.

3.6.2 Location

- Diversion banks should only be considered if there is somewhere for the flow to be diverted that will have a low risk of initiating a new gully elsewhere or accelerating an existing gully.
- The main limitations on the area from which runoff diversion can occur is finding a suitable location for safe water disposal, and the cost of constructing large diversion banks. As a guide, 20 ha catchment area is about the practical limit.
- Road drainage takes several forms including culvert pipes (not common in grazing areas), cross drains (also locally called speed bumps or “whoa boys”) and road crowning.

3.6.3 Design and construction

- Soil testing by a trained specialist is recommended prior to undertaking any earthworks.
- There is a risk that the use of heavy machinery may damage catchment vegetation.
- Water diversion structures require long-term maintenance including cleaning drains and water spreading structures, otherwise they can cause gully erosion (Nichols et al., 2018), and several GBR projects have been working to repair such erosion from old dams, ponded pastures and contour banks.

Other comprehensive and practical references on building these structures should be consulted, including the Soil Conservation Guidelines for Queensland (https://publications.qld.gov.au/dataset/soil-conservation-guidelines) and Day and Shepherd (2019).
Diversion banks:
• As the potential damage from failed diversion banks is high, calculate the peak runoff expected and design diversion banks for a 1 in 50 year runoff event.
• Diversion banks should be located using survey techniques and they should not be installed with gradients greater than 1/10th of the land slope on which the bank is located (and do not exceed a 0.5% gradient).
• Water-spreading pond with a level sill at diversion bank outlets are essential to reduce the energy of diverted runoff water.
• Diversion banks are designed as grass channels, therefore establishing and maintaining a vigorous grass cover is essential. Stockpiling and replacing topsoil over the channel will increase the chances of grass establishment, and is critical to avoid new erosion problems especially if dispersive erodible soils are exposed.
• Diversion banks or detention structures, together with their runoff discharge areas, should be included inside the gully fencing or otherwise managed at high biomass to maximise water infiltration.

Road drainage
• Road drainage takes several forms including culvert pipes (not common in grazing areas), cross drains (also locally called speed bumps or "whoa boys").
• The use of drainage along a road reduces the risk of erosion by overland runoff from roads. Local councils may have locally applicable guidelines. The specific spacing will depend on local factors. A rule of thumb measure is every 50 m for slopes < 3% and 25m for slopes > 3%.
• Flat drains (rather than v drains) are more likely to reduce the velocity of water flow, carry a greater body of water at lower risk of erosion, and are easier to install and maintain.
• Drain slopes should be <0.03%. Drains with slopes >0.05% will have greater potential to erode.

Contour ripping
• Ripping along the contours can reduce the volume of runoff generated from a catchment, and can be part of a comprehensive revegetation effort (Section 3.4). However, this activity is costly and has environmental risks and is not generally encouraged in this Program. Conditions on its use in this Program include:
  - It should not be undertaken near gullies.
  - It should not be undertaken in areas with slaking or dispersive sub-soils.
  - It should not be undertaken where it involves tree removal.
  - Ripping should be confined to small degraded areas of catchment draining into a gully treated with other erosion control measures.
3.6.4 Examples:

Figure 13. Diversion bank built to divert an 8 ha catchment away from a large gully which was reshaped and revegetated in the Upper Burdekin catchment. Left: Newly constructed diversion bank with topsoil (light brown soil) replaced across the channel area in May 2016. Right: Same location in April 2019. Livestock were excluded from the area for three years to assist revegetation. Photos by Bob Shepherd.

Figure 14. Water spreading structure on a ridge, at the outlet end of the diversion bank shown in the previous figure. Left: May 2016 after construction. Right: March 2017 [photos by Bob Shepherd]. Topsoil was spread over the structure after construction to assist revegetation.
3.7 Gully head rock chutes

3.7.1 Objective

A rock chute is a rock ramp designed by an engineer or qualified specialist used to prevent the continued upslope movement of a gully headcut, or a secondary deeper incision within a channel (Figure 16). Rock chutes are preferred over solid concrete drop structures which are more expensive and are more likely to fail by scour from downstream or tunnelling upslope.

Figure 15: Example of road drainage delivering into an alluvial gully (right circle; although road drainage was not the primary cause of the gully). Road drains further from the gully have to date not resulted in a connecting channel (left circle).

Figure 16: A secondary incisional phase progressing up along the floor of an existing alluvial gully, at rates of metres per year. This is the sort of site where a rock chute is cost-effective. The primary gully headwall can be seen in the background (photo by Andrew Brooks).
3.7.2 Location

Due to the cost of construction, rock chutes are more cost-effective when used to stabilise gully heads that are very active (e.g., at least tens of centimetres and often metres of headcut erosion per year). The larger the contributing catchment area above active gully heads, the larger will be the future benefit from halting gully headcut erosion with a rock chute. In some areas of deeper soil gully heads may represent a secondary incisional phase into the floor of an existing gully feature, which generates high rates of runoff (Figure 16).

Rock chutes are used where cheaper options such as porous check dams are ineffective due to the gully size and rate of expansion. They are also used where reshapin g and revegetating a gully headcut into a grass chute will be insufficient to stabilise erosion due to the large runoff volume, or a variable climate reducing vegetation erosion resistance, and/or where dispersive and low fertility soils are exposed that make revegetation difficult. In mature gullies where the headcut is near the gully catchment boundary, it is likely that the runoff volume is smaller and the headcut erosion rate is slower. In such situations rock chutes typically have poor cost-effectiveness.

3.7.3 Design

It is critical that rock chutes are designed using a standard and recognised design procedure. It is cheaper to build it right the first time than to repair it (based on experience from many failed structures). Common causes of rock chute failure include out-flanking or scouring around rock chutes by surface runoff or tunnelling, and scouring of under-sized rock from the face of the structure in large events.

Rock chute design involves determining the design rock size which must be large enough to be stable during a design peak runoff, and this can be an iterative process adjusting the rock chute width and length. The design peak runoff is preferably of a 50 year Annual Return Interval (ARI). Sometimes a 20 years ARI may be deemed as sufficient. Please note the requirement for RPEQ registration for large engineering projects as described in Section 3.1. The following are some of the procedures which have been used to design rock chutes in Queensland (refer to the Reference list):

Design peak runoff estimation:

- Australian Rainfall and Runoff: A guide to flood estimation (Ball et al., 2016).
- The Rational Method; Queensland Soil Conservation Guidelines Chapter 4 (Carey et al., 2015a). This method is typically only used for small structures.
- RORB rainfall-runoff model https://www.monash.edu/engineering/departments/civil/research/themes/water/ rorb
- Grid-based 2 dimensional hydrologic models, in the case of complex catchments such as those containing large embankments or storages. When calculating design peak runoff, dams within a catchment will generally be assumed to be full prior to the event, unless dam storage volume is large relative to the design event volume.

Design rock size:

- CHUTE manual and tool [https://toolkit.ewater.org.au/Tools/CHUTE; Keller et al., 2003]
- Queensland Soil Conservation Guidelines Chapter 13 (Carey et al., 2015c).
- Gully Erosion Parts 1, 2 and 3 [Catchments and Creeks Ltd., 2010].

Assessing the need for soil amelioration and geotextile under the rock is required by a trained specialist, because gullies are frequently associated with slaking and dispersive soils. This should typically include laboratory analysis of soil chemistry, which requires careful sampling design and can cost approximately $1,000.

Gabion baskets or rock-filled wire mattresses can enable use of rock of smaller sizes. However they should not be used in situations where high sediment loads are expected from upstream, which can remove the wire protective coating resulting in rusting and failure of the structure. Concrete mats are another possible solution; which are concrete blocks wired together, although the use of these in dispersive soil should be regarded as experimental, with more intensive monitoring and accounting for higher risk of failure when estimating effectiveness.
The use of heavy machinery in construction will result in disturbance of the gully and its immediate surrounds thus introducing new erosion risks. Therefore, a revegetation plan for the surrounding area is required as part of the design and should be included in the site report. This should include fencing to control livestock access and active revegetation, and a variety of grasses and woody vegetation.

In rare circumstances, an alternative to a rock chute is a gully head dam. They are not standard practice because they are less stable than a rock chute and are more expensive since an engineered dam bywash is usually required, which resembles a rock chute. There are substantial risks that the gully head will continue to erode upstream of the dam, or that the dam bywash will breach the dam or widen the gully downstream, especially in erodible soil (Carey et al., 2015c). Failure of the dam wall is a risk in erodible soil. Therefore, gully head dams must be very well engineered and constructed on the basis of quantitative estimates of peak runoff volume for a design event of 50 year ARI or greater. Gully head dams should be fenced and the water pumped to water point(s) higher in the landscape. Only consider a gully head dam if landholder co-investment makes that a much more cost-effective alternative than a gully head rock chute.

Figure 17. A rock chute installation in the Mary Catchment. Left: before construction in April 2016. The gully had an extensive catchment area, and the gully head was advancing across a small flood plain with highly dispersive subsoil. Right: after the first major rainfall event in March 2019 (note the same clump of trees on the left of both images). The first runoff event had a 2 year flow recurrence interval, following 126 millimetres of rain over 3 days including 83 millimetres within a few hours. Total cost of the rock chute was $55,000, plus the land manager provided ~$100,000 in kind contribution primarily in the cartage of rock material from a quarry on the property. The estimated direct cost per tonne of sediment saved was $340 per tonne per year fine sediment reduction at the river mouth, or $1,153 per tonne per year including the in-kind costs. Photos by Scott Wilkinson [left] and Owen Thompson [right].
3.7.4 Construction

Checklist for rock chute construction:

1. Engineered grade control structures take considerable time (many months) to design, plan and implement.
2. The requirement for State and Local Government approvals must be established (as summarised in Table 3).
3. The rock material should be inspected to ensure its suitability ahead of committing to construction.
4. Technical specialists who designed the structure should oversee construction to ensure any site constraints are adequately addressed.
5. The skill and experience of contractors building rock chutes also influences the work quality and cost.
6. Minimise the area disturbed by heavy machinery and thoroughly revegetate the disturbed area.
7. Designing engineer should provide an inspection/maintenance schedule which describes minor upkeep/repair that can be achieved by the delivery partner or landholder, as well as indicators of potential major failure that require immediate investigation by an engineer. A small stockpile of rock should be left on site to facilitate minor fixups. A fund equivalent to 10% of construction costs should be established to support these ongoing activities.

3.7.5 Monitoring and reporting

Rock chutes are expensive and prone to failure by scour, outflanking and tunnel erosion. To help ensure that rock chutes are well designed, the site report for a rock chute design should include the following elements (template is available):

1. Design peak runoff
   - State the design reference documents and method.
   - Catchment area; where LiDAR is available this should be used; consult Geoscience Australia via http://elevation.fsdf.org.au/, and/or Qld remote sensing centre.
   - Peak runoff recurrence interval selected (years).
   - Associated design peak rainfall intensity including time of concentration and source.
   - Associated runoff coefficient.
   - Resulting peak runoff volume rate estimate,

2. Rock material design
   - State the method used to calculate D50 (middle axis length of the median rock size).
   - Factor of safety applied when specifying rock size.
   - Required specific gravity of rock.
   - Required rock gradation (degree of sorting) as D100 and D20 (m) (B-axis). Or quote D90/D50=1.8 etc.
   - Required angularity of rock.
   - Required rock quality (strength).

3. Description and justification of the configuration, including:
   - Soil sodicity.
   - Use of geofabric or not, and why.
   - Use of soil amelioration or not, and why.
   - Use or not of abutments to direct flow over the chute crest, and why.

4. Dimensions and diagrams of the rock chute including Plan view, Long section elevation, and Cross section elevations including the upstream crest and the downstream apron.

5. Estimated rock quantity.
3.7.6 Maintenance

Ongoing maintenance and the establishment of vegetation around structures is essential to mitigate the effects of large events.

Monitoring points should include the flow path downstream of the rock chute to assess any scour impacts.

3.8 Gully reshaping

3.8.1 Objectives

Gully reshaping involves the use of heavy machinery to reform the gully into evenly sloping areas (batters) that are then capped with a variety of surface materials and/or revegetated to prevent ongoing erosion of the slopes from direct rainfall and/or upslope runoff. Reshaping of gullies can provide a more stable surface to enable revegetation, but is also dependent on successful control of surface runoff. Because of the cost of reshaping and the associated comprehensive rehabilitation strategy, it is more likely to be cost-effective for large highly active alluvial gullies in erodible soil.

Reshaping must be implemented only in combination with other gully erosion control activities: "In regions with heavy rains, filling, shaping and diversions alone will not suffice to control gullies. Additional Gully control and slope stabilization measures, such as capping, check dams and revegetation should be undertaken" (Geyik, 1986). Treating this kind of gully requires design and construction to be undertaken by skilled and experienced professionals.

3.8.2 Location

Reshaping is typically required for alluvial gullies in highly dispersive or slaking soil materials of poor fertility, which will typically not recover through natural regeneration even when cattle and other disturbance factors are permanently removed. Some hillslope gullies can also be reshaped to enable more complete revegetation, but this would generally require in-kind contributions to be cost-effective for water quality improvement.

Gully reshaping is typically a relatively high cost activity on a per unit area basis (typically >$30,000 per ha), so this approach is only applicable in areas of highly active gully erosion which are generating high sediment yields (typically with site sediment yields > 100 t/ha/yr), and which cannot be treated using more passive approaches.

3.8.3 Design

Where there is evidence of pipe or tunnel erosion, the tunnels will need to be excavated to their maximum depth, and back upslope until all evidence of the tunnel erosion is removed. Otherwise tunnelling will continue, and will destabilise the rehabilitated area.

Depending on the sodicity and associated dispersibility of the sub-surface soil materials, the resultant slopes of most reshaped gullies will require chemical treatment with either gypsum or lime (depending on pH) to neutralise soil sodicity, and so develop a stable surface capable of supporting revegetation. Reshaping sodic soils without neutralising sodicity and reestablishing a stable surface soil and vegetation cover has been shown to increase erosion rates above the rates of untreated gullies (Shellberg and Brooks 2013; Brooks et al., 2016a; 2016b).

Depending on the scale of the gully, and the resultant slope lengths and gradients, there are a wide variety of surficial treatment options once reshaping earthworks are completed. Gully reshaping has a risk of failure in the period immediately following construction in the event of severe rainfall. To reduce this risk, consideration should be given to using mulch and irrigation to support revegetation ahead of the first wet season rains. Rock capping is difficult to revegetate and may require more maintenance in the long term.
Tunnel erosion occurs through excessive subsurface water movement, especially where there is landscape relief (sloping surfaces). In soils prone to tunnelling, the risk of future tunnelling may be reduced by planting trees within and around the reshaped area as part of the revegetation, possibly following the initial establishment of grasses. In the long term this will tend to increase soil strength and stability.

The reshaped area will be more steeply sloping than the residual surface upslope of the gully, and hence more vulnerable to erosion. In order to maintain the integrity of the reshaped area, it should not be used for routine grazing. Secure fencing for ongoing control of livestock access is required, and grazing should be managed very conservatively, as described in Section 3.3.

Often, reshaping is only required on only part of a large gully, with other techniques more cost-effective in most parts such as further away from the gully head or where the gully is less deep, or the soil is more stable.

### 3.8.4 Implementation

Planning a gully reshaping project should address the following considerations, in addition to those listed in Section 1.3:

- Undertake an analysis of the soil materials within the gully to determine:
  - Average particle size distribution (sand, silt and clay content) of the source sediment being eroded from the gully; this will improve the estimation of sediment reduction.
  - Soil chemistry – particularly ESP, pH, CEC. The soil analysis and setting the application rates for gypsum or lime should be undertaken by a professional soil scientist or geomorphologist. Treatment design should be undertaken by a suitably qualified professional.

- Key considerations for the design:
  - Access to suitable materials to the site (rock, mulch, gypsum, grass seed etc.)
  - Access to suitably qualified machine operators and machinery
  - Ensure all approvals are acquired (e.g. vegetation clearance regulations, working on waterways etc.)
  - Does the gully experience back-watering from the adjacent creek or river? If so can you employ a strategy that appropriately addresses this?
  - Do you know what the catchment area is above the active gully scarp and the flow pathways?
  - Can upslope flow be safely diverted so that it doesn’t initiate a new gully?
  - Does the site exhibit tunnel erosion? If so, has a design been developed that adequately addresses this process?
  - What level of monitoring is required for the scale of the project?
3.8.5 Case studies

Figure 18 Example of a large alluvial gully in the Lower Burdekin River catchment which was reshaped. Note the large stack of hay bales is sitting on a peninsular between two gully lobes. (Photo by Damon Telfer)

Figure 19 Same site as the above Figure after construction. Left: initial excavation and reshaping of the right hand gully lobe. Right: After both reshaping and capping of both lobes, and following the first rains on the site. Both gully lobes were reshaped to battered slopes, treated with gypsum, were capped with graded rock, and were then covered with straw mulch and seeded with pasture grasses. The lobe on the left included a series of porous check dams on the gully floor while the one on the right had a complete rock capping over the entire gully floor (Photos by Damon Telfer).
Figure 20: Same location as in Figure 18, in March 2019 following 500mm of rain over two weeks.

Figure 21. An alluvial gully that was reshaped without additional soil stabilisation or revegetation activities. As demonstrated by Shellberg and Brooks, 2013 and Brooks et al., 2016a; 2016b, this will have increased erosion rates above the pretreatment levels. Note that a berm was built around the Gully in the belief that overland flow was driving the erosion process, when in fact the rain falling directly on the Gully surface was the primary driver of ongoing erosion in these highly unstable soils. Note that the berm is being undercut by rainfall dispersing the exposed subsoils.

[Photograph: Andrew Brooks]
3.9 Engineered stream bank erosion control

3.9.1 Objectives

While engineered stream bank protection can be cost-effective where infrastructure assets are threatened, it can very rarely be justified as a cost-effective way to improve water quality at the scale of the whole GBR – compared with more passive vegetation regeneration approaches. This section outlines some of the considerations for engineered stream bank protection, as the most expensive type of erosion control activity which needs much more careful planning than livestock exclusion fencing or passive revegetation activities.

3.9.2 Location

Engineered stream bank erosion control should only be done as part of a broader (valley) planning process, as described in Section 1.2.3. A frequent scenario is that stream bank erosion control planning is initiated in response to erosion in a recent large flow event. Often there is a landholder expectation that sites of large erosion will be controlled. However, sites of the most recent erosion or of apparent erosion may not be the highest priority for engineered stream bank erosion control. Hard engineering works may simply divert the problem to banks further downstream, setting up a cascade of bank erosion problems, each in itself presenting as a local crisis to the landholder impacted. The total money spent on bank protection can very quickly exceed the value of the land that would have been lost, if bank hardening is implemented in a piecemeal way.

When prioritising for water quality improvement (total erosion across the stream network), the solution is to move away from treating isolated symptoms and towards managing the river as a whole. This is in contrast to a local asset protection approach (e.g., a single river bend migrating into area used for agriculture or grazing). Whole of river management requires considering the stream channel behaviour and setting objectives at valley scale. The resultant approach can involve revegetating the channel and banks over extended reaches and giving the river room to move where necessary. Transitioning to this strategic approach presents its own difficulties, as inevitably the impacts of a living, minimally constrained river channel will fall disproportionately on some, while the benefits accrue to others. Also, it can be more difficult to evaluate the long term benefits of broad scale interventions within current knowledge and program timetables.

Appendix B contains a series of photos illustrating considerations regarding stream bank erosion control in GBR streams, including when revegetation or engineering or other approaches should be considered.

3.9.3 Design

It is important to develop a ‘template’ for the desired condition of the stream early in the design process. For example, a process for “Natural Channel Design” is available in Rutherfurd et al., (2000b).

The most common options for engineered stream bank stabilisation are timber pile retards or pile fields, and rock beaching or revetment. Rock groynes are also sometimes used in high-energy situations [see detailed descriptions in Rutherfurd et al., 2000b]. Timber pile retards are designed to slow the flow velocities adjacent to the bank and to enhance deposition so that woody vegetation can re-establish and help to protect the bank. An alternative to driving straight piles into the stream bed is to use clumps of large logs cabled together, termed engineered log jams. There are detailed design procedures for each of these structure types.

Full-width structures across the bed of a stream channel and reduce the severity of deepening upstream [Rutherfurd et al., 2000b]. Examples include rock riffles and timber pile or ‘pin ramps’.

Design of engineered structures for stream bank erosion control should be done by an experienced engineer with RPEQ registration.
3.9.4 Implementation

Proposals for stream bank engineering works require a site visit from the technical partner during concept planning stage, before a detailed site design is developed. Detailed site design must involve an experienced professional. Options and considerations for engineered stream bank protection are described in Rutherfurd et al. (2000b), and in the Queensland Stream Management Guidelines. Maintaining vegetation during the life of the project is essential. Monitoring vegetation outcomes is important.
4 MONITORING AND REPORTING

4.1 Objectives

With an urgent need to continue to improve water quality entering the Great Barrier Reef, and the investment of public funds, it is important that the implementation of the project activities and their impacts is measured and documented. Therefore, an essential part of the Project Activities is to report the erosion problems being targeted, the objectives and details of planned work, and the response to activities at project sites. This can help to identify requirements for site maintenance. Collating data and experiences across sites can enable trends in behaviour, and improvements in the approach to be identified.

Monitoring and Reporting in the Program has several objectives:

1. To define the expected outcomes against which monitoring results will be compared.
2. To document the site design process to enable review within the project team and by the technical partner, and to keep the landholder informed.
3. To enable learning and adaptive management of the selection and design of erosion control activities within projects and across the Program, by considering the cost-effectiveness of activities, and by incorporating partner and landholder perspectives of those activities.
4. Site Monitoring aims to confirm the completion and integrity of on-ground activities within each project and identify any maintenance needs;
5. To assist the technical partner and the Paddock to Reef Monitoring, Modelling and Reporting Program to estimate erosion reductions from activities funded by the Program;
6. To facilitate communications by projects to stakeholders; e.g., through factsheets or field days.
7. To ensure any ongoing maintenance issues are identified and rectified to ensure that the Program activities achieve their maximum potential.
8. To provide a baseline for subsequent monitoring of longer-term outcomes on vegetation, erosion, land management and grazing-related outcomes.
9. To provide a credible record of our activities funding through the Reef Trust Gully and Streambank program against the objective of Improving water quality entering the Great Barrier Reef.

The monitoring focuses on leading indicator variables (e.g. vegetation, integrity of the works etc.). The monitoring does not need to accurately measure the reduction in sediment yield at each site, which is expensive and beyond the scope of the Program. But it will give a good indicator whether the remediation is trending in the right direction (e.g. is vegetation growing, are the engineering works holding) which are a good indicator of potential long term success. We are after ‘a signpost, not the second decimal place’. Monitoring should be relatively more detailed at sites with larger works.

The technical partner will aggregate monitoring results to assess GBR-wide outcomes. Complementary research will be undertaken through NESP (the National Environmental Science Programme) and similar research programs to provide more detailed measurement at selected sites to determine whether estimated sediment load reductions are achieved.
4.2 Progress reporting

Delivery Partners are required to report a summary of progress implementing activities every six months. This will be undertaken through the Australian Government’s Monitoring, Evaluation, Reporting and Improvement Tool (MERIT - https://fieldcapture.ala.org.au/). The following content needs to be included with the six monthly reporting:

Progress of activity implementation and outputs achieved. This is a brief description supported by quantities. Include summary findings of successes and challenges across all the sites and any learnings or recommendations.

List the site reports completed in the period, or updated for activities completed in the prior period, as described in Section 4.3, as supported by site design data including cost-effectiveness. In the early stages of the project this may also occur separately to regular reporting dates. Also list sites where before treatment and after treatment site monitoring is complete as described in Section 4.4.

The Queensland Government Paddock to Reef Program also has specific reporting requirements which projects in GBR catchments are required to fulfil.

4.3 Site reports on activities and monitoring

The site conditions, erosion control objectives and activities at each planned site should be described in a site report provided to the Department and Technical Partner as well as the landholder. A summary of site monitoring results is added to the site report when available. As well as justifying the investment during planning phase, the site reporting also facilitates subsequent communication activities to parties external to the project; it is a ‘case study’ from which summary information can be drawn. A site can be a gully network or stream bank area, or a property containing a combination of these.
The Site Report documents the following elements (suggested headings are given in bold):

<table>
<thead>
<tr>
<th>Heading</th>
<th>Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Background.</strong> A brief description of the site prior to project activities, including:</td>
<td></td>
</tr>
<tr>
<td>a. <strong>Site description</strong> including the soil, land type and land condition around the gully and stream banks, and the relative dominance of ground vegetation functional groups (exotic or native, annual or perennial, legumes or grasses)</td>
<td></td>
</tr>
<tr>
<td>b. <strong>Recent grazing</strong> practices including estimated stocking rates where available</td>
<td></td>
</tr>
<tr>
<td>c. Significant <strong>historical events</strong> impacting the erosion control site or property</td>
<td></td>
</tr>
<tr>
<td>2. <strong>Erosion issues:</strong> Briefly describe the cause and nature of the erosion and objectives of the erosion control strategy</td>
<td></td>
</tr>
<tr>
<td>a. <strong>Context of the erosion control site(s)</strong> relative to property infrastructure, property size and land type composition</td>
<td></td>
</tr>
<tr>
<td>b. The <strong>extent and nature</strong> of the gully and stream bank erosion, including lengths or areas, depth, wall and bed slopes, catchment area draining to gully heads.</td>
<td></td>
</tr>
<tr>
<td>c. <strong>History</strong> of the erosion issues</td>
<td></td>
</tr>
<tr>
<td>3. <strong>Erosion management:</strong></td>
<td></td>
</tr>
<tr>
<td>a. <strong>Describe and justify</strong> the design details of erosion control activities (where multiple gullies or stream banks are treated differently at a site then tabulate the activities by feature):</td>
<td></td>
</tr>
<tr>
<td>i. Improving <strong>grazing management:</strong> List training to be implemented. Quantify the improvements in terms of forage utilisation levels and spelling regimes, and describe how they have been agreed and will be monitored. Describe any fencing or water points included.</td>
<td></td>
</tr>
<tr>
<td>ii. <strong>Fencing:</strong> Describe the total length, planned location of the fence including setback from gully and/or stream bank, fence design and intended duration.</td>
<td></td>
</tr>
<tr>
<td>iii. <strong>Revegetation:</strong> List the planned mix of species and functional groups and implementation timeline.</td>
<td></td>
</tr>
<tr>
<td>iv. <strong>Porous Check Dams:</strong> Describe the number, dimensions and materials of check dams, who will construct, revegetation methods, hydraulic or other technical designs, soil treatment, planned approach to forage management.</td>
<td></td>
</tr>
<tr>
<td>v. <strong>Diversion banks and drainage management:</strong> Describe and illustrate the structure design.</td>
<td></td>
</tr>
<tr>
<td>vi. <strong>Gully head rock chutes:</strong> Include all elements listed in Section 3.7.5, and design diagrams</td>
<td></td>
</tr>
<tr>
<td>vii. <strong>Gully reshaping:</strong> Describe the planned works and design process including all relevant quantities such as completed slopes and areas, soil amelioration rates, capping rock size, revegetation; illustrate by available drawings</td>
<td></td>
</tr>
<tr>
<td>viii. <strong>Engineered stream bank erosion control:</strong> Describe the works and design process including all relevant quantities.</td>
<td></td>
</tr>
</tbody>
</table>
b. **GIS map** of the site, preferably over aerial imagery (e.g. Google Earth™). It may help to first prepare a ‘mud map’ during the field visit as described in Section 4.4.5. The final GIS map should include:

- i. Extent of gully and stream bank erosion features to be treated, and **erosion features** which will be used as controls for monitoring,
- ii. Extent and current condition of stream bank and channel vegetation
- iii. Existing **infrastructure** including fencing, road and tracks, stock watering points,
- iv. Planned **project activities** including fencing, check-dams, revegetation, etc.
- v. **Monitoring and photo-point locations**, as described in Section 4.4. These can be finalised on the ‘as-built’ map once the design of activities is confirmed. Monitoring should include at least one representative erosion feature at each site,
- vi. **Broader scale mapping** of the multiple sites and the connecting stream network, with indications of connectivity issues and management

c. **Cost-effectiveness calculator.** In the planning phase Table 4 (in xlsx format) should be used to evaluate and revise the proposed activities to ensure the costs of activities is not excessive considering the estimated sediment savings. Provide Table 4 with the report in **xlsx format**. Sediment savings estimates should be realistic and account for uncertainty by being conservative. Planned activities should be typically below $1,000 per t/yr sediment reduction. Note: the estimates of erosion control effectiveness in Table 1 are based on expert opinion which may be modified where justified.

d. Upload to MERIT before construction paperwork demonstrating **compliance** with State Government regulations such as those related to the Water Act, Vegetation Management and Fishways

4. **Project Budget** Itemise each of the above activities in the budget including design costs, onsite labour and materials, and any landholder co-investments

5. **The property perspective:** Describe the scope, duration, status and form of the agreement with the landholder (or cite as an attachment). Also describe the degree of and reasons for landholder support, including how the project integrates with, adds to, benefits or changes land management and grazing on the property (update this at the end of the project), why the landholder is willing to support and maintain this project. The purpose of documenting this is to identify the win-wins that assist landholder engagement

   *This concludes the report for planned works to be reviewed and endorsed by the Technical Partner before commencing implementation*

Once site activities are endorsed (if not already complete):

6. **Measuring the outcomes:**

   a. ‘Before-treatment’ monitoring table (Table 5) as described in Section 4.4.

   b. Photos of gully catchment, head, middle and downstream end

   *In periods after the site works have been completed, add to the Site Report:*

   c. The ‘After-treatment’ monitoring table (Table 5)

   d. Representative photos at same monitoring locations as Before-treatment monitoring

   e. A narrative summary of the vegetation responses and structural integrity, and a brief description of the effectiveness of each activity in contributing to the intended erosion control outcomes, including what worked well and learnings.

   f. The Erosion Management, Project Budget or other sections of the Site Report should be updated to reflect ‘as-built’ modifications.
Table 4. Site cost-effectiveness calculator. A completed example is shown. For details refer to the notes in the spreadsheet available from the authors. White fields provide site context. Blue fields are inputs to the cost-effectiveness calculation. Green fields are calculated in the spreadsheet, or can be provided directly if a different method is followed (describe and justify the method and inputs).

<table>
<thead>
<tr>
<th>Site Design Template (Table 4)</th>
<th>Gully and Stream Bank Toolbox</th>
<th>Site 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddock name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Person completing the report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude (decimal degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitude (decimal degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil: Australian soil order (e.g., Chromosol, Vertosol)*</td>
<td>Chromosol</td>
<td></td>
</tr>
<tr>
<td>Soil: Subsoil slake test (STable/SLakes/DIspersive)*</td>
<td>SL</td>
<td></td>
</tr>
<tr>
<td>Gully: Longitudinal slope within the gully (proportion)</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Gully: Maximum depth [m]</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Gully: Catchment area draining to the gully head (ha)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Gully: Ground surface slope above the gully head [proportion]</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Gully: Length (m)</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Gully: Width (m)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Gully: Area (ha)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Gully: Estimated gully age</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Stream Bank: Length of erosion control (km)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stream Bank: Area of erosion control (ha)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Erosion Control Activity numbers</td>
<td>1, 2, 3</td>
<td></td>
</tr>
<tr>
<td>Gully or Streambank: Historical area growth rate (m²/y)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Gully or Streambank: Depth of the active erosion [m]</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Gully: Baseline rate decay from historical rate (proportion)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Gully or Streambank: Baseline volumetric growth rate (m³/y)</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Soil: Estimated dry bulk density (t/m³)*</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Soil: Estimated silt+clay content [proportion]*</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Gully: Baseline Fine sediment supply from site (t/y)</td>
<td>56.25</td>
<td></td>
</tr>
<tr>
<td>Gully: Erosion Control Effectiveness [proportion]</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Gully: Fine sediment saving at site (t/y)</td>
<td>28.125</td>
<td></td>
</tr>
<tr>
<td>Stream Bank: Fine sediment saving at site (t/y)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Hillslope: Fine sediment saving at site (t/y)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TOTAL fine saving at site (t/y)</td>
<td>28.125</td>
<td></td>
</tr>
<tr>
<td>Fine sediment delivery efficiency to coast [proportion]</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>TOTAL fine saving at coast (t/y)</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Cost ($)</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>Cost-effectiveness $ per t/y at coast</td>
<td>817</td>
<td></td>
</tr>
</tbody>
</table>
A. Estimate from historical air photos and Google Earth, or LiDAR. Gully Length is the longest overall dimension of the gully, and Width is the average gully top width measured at right angles to the length, such that Area (ha) = Length (m) × Width (m) / 10,000. Gully area can be overwritten if calculated independently from average gully width.

B. Can be estimated from aerial imagery if clearly defined, or by mapping the upstream contributing area in GIS using the 1° Hydrologically Enforced Digital Elevation Model [DEM-H; ANZCW0703014615] (Gallant et al., 2011), available from http://www.ga.gov.au/scientific-topics/national-location-information/digital-elevation-data.

C. For linear gullies Growth rate = average extension (m/y) × Gully width (m). If no data on historical changes in extent can be obtained then assume Growth rate = Gully area / 100 × 0.5 (assumes gully age = 100 years and current erosion rate = 50% of the average rate since gully initiation). If repeat LiDAR elevation models are available the growth rate can be entered directly here.

D. From site inspection, instructions are given in spreadsheet calculator.

* Soil properties can be obtained from the map viewer in ASRIS (http://www.asris.csiro.au/) [“Maps” menu button]:

1. Add data by expanding the “Layers” list on the RHS using the folder button. The “Levels” describe different resolutions of data; Level 4 is the best available in most grazing areas.

2. Add soil Bulk density (or other data) by clicking the checkbox in the Level 4 list, then click “Refresh Map” in the bottom right.

3. Identify the data values for each soil layer by clicking on the “i” button on the toolbar then clicking on the coordinates of interest, the data display at the bottom of the screen. Layer 3 or 4 (0.5-1m depth) will generally best represent the properties of gully walls. ASRIS doesn’t display silt content, only clay content. The total fine proportion of soil (clay+silt) will be ~10% higher than the clay content. If the data resolution does not accurately map soil types seen in the field then use data values from a nearby area of the same soil type (soil order) present at the gully.

E. Baseline fine sediment yield to the coast (t/y) = Area Growth rate (m²/y) × Depth of the active erosion (m) × Soil dry bulk density (t m⁻³) × Soil proportion of silt + clay × Baseline rate decay from historical rate × Fine sediment delivery efficiency to coast.

F. From Table 1, or estimated based on the monitoring results from comparable field trials in the area. If a combination of techniques are used then list them, and note that the total effectiveness may be the sum of that for in-gully and gully-catchment activities. For projects which will make additional sediment savings by improving ground cover over significant areas of hillslope erosion, those sediment savings should be added to the gully sediment saving when calculating cost-effectiveness. Describe the method details and variations in the site report.

G. Total Fine Sediment saving = Historical fine sediment yield to the coast × Erosion control effectiveness × Delivery efficiency to the coast (technical partner can assist with delivery efficiency).

H. This is the cost to Reef Trust not including in-kind contributions. It includes the on-ground costs and other site-specific costs such as technical consultants and staff time (they can be apportioned across the project).

The site sediment savings spreadsheet (Table 4) calculates the baseline sediment yield by approximating erosion volume as a box. The colour coding in the spreadsheet denotes information (white cells), input to calculations (blue cells), and calculated results (green cells) – do not enter data into green cells unless you wish to change or overwrite a formula to suit a particular site configuration, in which case please provide a written justification as a comment inserted into that cell, or a note on the side.

Width is the average top width, often this is the width half way along a linear gully. We need the average depth over the whole area of the eroding area to represent that feature as a box. It is easy to overestimate average depth because one’s eyes tend to jump to the deeper drainage lines and hollows. If a gully has a triangular cross section with a narrow channel at the bottom of planar/straight side slopes then the average depth is half the depth of the channel at that point. For gullies with substantial channels that are surrounded by a large scalled area, it can be worth calculating the total volume in two parts; the channel(s) and the surrounding scalled area, since each has very different width and depth. If we combine the channel depth with the scald width or area we end up with an unrealistically large hole.

The box volume is then distributed over the gully age (often estimated at 100 years if no local information is available) to estimate erosion rate (cubic metres per year). This is the whole-of-life method for calculating the baseline [no-treatment] sediment yield, and it includes a 0.5 multiplier to account for the gully activity slowing down over the gully life.

The current rate method is an alternative, which is based on the change in gully area between two dates multiplied by the depth of active (current) erosion. Alternatively, enter the mean-annual change in volume directly.
if you have calculated it from two LiDAR DEMs. It is important that the two dates are at least 10 years and ideally 20 years apart to represent the long term average climate. The current rate method doesn’t use a 0.5 multiplier if the calculation period is short relative to the whole gully life (eg 20 years relative to 100 years), because it can be assumed that untreated erosion over the next 20 years will be similar to the last 20 years. A decay multiplier of 0.7 should typically be applied if the historical period used to estimate baseline is around half or more of the whole gully life (eg 20 years relative to 50 years). If erosion over a short period (eg 8 years) is known accurately then it should be used in preference to air photo estimates, but that rate should be adjusted so that it better reflects the long-term average climate; adjust up if the 8 years was drier than average or down if it was wetter than average; the relative difference in rainfall can guide what adjustment is required in that case.

**Figure 22. Process for site reporting in the Program**

**Process:** The site reporting process is described in Figure 22. If some aspects of the design remain preliminary, a general approach including its estimated cost-effectiveness can be discussed with the technical partner. Queensland Government Paddock to Reef monitoring and State planning and reporting obligations should also be considered and planned to reduce duplication where possible.
4.4 Site monitoring methods

4.4.1 Principles

Monitoring isolates the effect of treatment from external factors like variability in the weather and stocking rates. For this reason monitoring should use a Before After Control Impact (BACI) design in which some gullies or stream banks on each property are left untreated for comparison over time, and both the treated and untreated erosion sites are monitored before and after the erosion control activities are completed. The monitoring is designed to be reasonably rapid to undertake in the field (~30 minutes for 2 people), and to require limited experience. Comparisons between sites and over time should be undertaken by those doing the monitoring, and reviewed by a separate person not involved in the monitoring.

4.4.2 Timing of monitoring

Each site should ideally be monitored at least three times during the project:

1. Before site activities commence, generally after the technical partner has reviewed the design. Ideally this is early in the dry season between March and May so that results are comparable with later years.

2. Shortly after treatment: For essential activities undertaken at all sites [e.g., controlling stock access] this will mostly be photo point measurements, provided treatment occurred within the same dry season as the before-treatment monitoring. If the activities involved physical revegetation or earthworks, the effects of this disturbance should be monitored as described in the following subsection.

3. At the end of each subsequent wet season (between March and May) following completion of erosion control activities. Seasonal rainfall predominantly drives gully erosion and the responses to revegetation activities. Measurement at the end of the wet season is also ideal to indicate the effectiveness and integrity of remediation activities.

4. Where possible, also repeating the Landscape Condition Assessments upslope of the gully late in the dry season (between September and November) will capture the lowest functional state for the season to provide context for measuring recovery, helping to guide forage management.

4.4.3 Monitoring design

In each paddock or property that gully erosion control works are planned and undertaken, at least one gully should be monitored, which is/are typical of all the gullies treated. At least one comparable gully feature, or part of the gully if there is only one feature, should be left untreated and also monitored using the same protocol as for the treated gullies. The monitoring protocols described here were adapted from those in the Gully Toolbox [Wilkinson et al., 2015b].

The standard monitoring design includes:

1. Land Condition Assessments (LCAs) immediately upslope of the gully head, and in the paddock outside the planned fence location. The method is described in the monitoring template tool available from the authors.

2. Gully head location relative to a permanent reference marker, to enable the erosion rate between monitoring dates to be estimated. For gullies of irregular planform (e.g., in alluvial soil) a number of markers around the gully may be more appropriate.

3. Vegetation cover and composition, and photo points at 3–5 marked sampling locations within or around the site, coinciding with erosion control activities such as check-dams and contour banks. The furthest upslope and downslope of structural activities must be included. This sampling approach is used instead of monitoring every individual structure, to reduce field collection time where multiple treatments (such as revegetation and check dams) are installed. The same monitoring locations are used at each date of monitoring.

a. Ideally, and at the discretion of the delivery partner additional measures such as vegetation functional groups [exotic or native, annual or perennial, legumes or grasses], or repeat DEMs to monitor stability of a reshaped gully, can be monitored each time to better define the response to treatment, by adding to the monitoring spreadsheet.
4. Rainfall in the last 12 months from a farm record or nearest Bureau of Meteorology station.

5. Landholder perspectives of the project activities, including the Water Quality Risk Benchmarking questions (with the landholder).

6. Additional monitoring is recommended at sites with large investments (e.g., >$200,000), or where other techniques are more effective. This may include erosion pins, repeat LiDAR DEMs, runoff water quality monitoring, drone photography and time-lapse fixed cameras. For stream bank sites the Tropical Rapid Assessment of River Condition (Dixon et al., 2006) is recommended for monitoring riparian condition.

Partnering with technical specialists or research providers may be considered.

Monitoring should be recorded, and subsequently reported, using the template and instructions below [Table 5]. The table can be used for recording comments at the site by cross-referencing from each comment field (using A, B, C, etc) to comments written on a separate sheet. The table can be adapted to the site to make best use of legacy data, or to add additional data collected. Refer to the footnotes at the bottom for instructions on how to fill in each row. Don’t forget to include in the last row of Table 5 all those comments the landholder has made about why the project works for them. EG: new fence will keep the cattle out of the creek, that country isn’t growing anything anyway, keen to fix up an eyesore...

Table 5. Monitoring report template (for details refer to the footnotes which continue over the page).

<table>
<thead>
<tr>
<th>Monitoring Report Template</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddock name</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Date of monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of Observer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment (T) or Control (C) gully</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA (Land Cond. Ass.) outside the erosion control fence: Ground cover (%)</td>
<td>^</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA outside the erosion control fence: Pasture condition (1-4)</td>
<td>^</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA outside the erosion control fence: Soil condition [1-5]</td>
<td>^</td>
<td></td>
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</tr>
<tr>
<td>Length of grazing period outside the erosion control fence [days per year]</td>
<td>^</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocking rate outside erosion control fence during grazing [animal equiv. /km²]</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LCA inside the erosion control fence: Ground cover (%)</td>
<td>^</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA inside the erosion control fence: Pasture condition (1-4)</td>
<td>^</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA inside the erosion control fence: Soil condition [1-5]</td>
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<tr>
<td>Length of grazing period inside the erosion control fence [days per year]</td>
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<td></td>
</tr>
<tr>
<td>Stocking rate inside the erosion control fence during grazing [animal equiv. /km²]</td>
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<tr>
<td>Gully head distance to reference marker [m]</td>
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<td></td>
<td></td>
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<tr>
<td>Active erosion depth [m]</td>
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<td></td>
<td></td>
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<tr>
<td>Erosion control fence: Integrity [1-3]</td>
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<td></td>
</tr>
<tr>
<td>Monitoring location #1 feature</td>
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<td></td>
<td></td>
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<tr>
<td>Monitoring location #1 integrity [1-3]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #1 cover upstream [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #1 comment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring Report Template</td>
<td>Site 1</td>
<td>Site 2</td>
<td>Site 3</td>
</tr>
<tr>
<td>----------------------------------------------------------------</td>
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<td>--------</td>
</tr>
<tr>
<td>Monitoring location #2 feature</td>
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<tr>
<td>Monitoring location #2 integrity (1-3)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #2 cover upstream (%)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #2 comment</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #3 feature</td>
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<td></td>
<td></td>
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<tr>
<td>Monitoring location #3 integrity (1-3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #3 cover upstream (%)</td>
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<td></td>
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<tr>
<td>Monitoring location #3 comment</td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #4 feature</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #4 integrity (1-3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #4 cover upstream (%)</td>
<td></td>
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<td></td>
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<tr>
<td>Monitoring location #4 comment</td>
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<td></td>
<td></td>
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<tr>
<td>Monitoring location #5 feature</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #5 integrity (1-3)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #5 cover upstream (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring location #5 comment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall in last wet season (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landholder perception of activities (1-5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landholder comments about the project activities</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A Estimate the average percent of total ground cover including grass, litter, or other ground vegetation.
- “Outside the fence” means the area which is used for routine grazing.
- “Inside the fence” means the area where livestock access is controlled by the fence for erosion control.

B 1 = >80% 3P, 2 = 60–80% 3P, 3 = 10–60% 3P, 4 = <10% 3P (refer to monitoring template tool)

C 1 = Stable, 2 = Slight disturbance, 3 = Moderate disturbance, 4 = Severe disturbance, 5 = Very Severe disturbance

D Measure the distance from the nearest part of the gully head to a permanent marker (stake) installed ~20 m upslope.

E Measure the vertical distance between the natural land surface to the floor of the gully channel 10 m downstream of the gully head.

F 1 = Fully intact, 2 = Signs of potential failure, 3 = Total failure. Measure integrity of activity relative to its objective (eg for a fence this is excluding livestock, for a check dam this is slowing runoff to deposit fine sediment and seeds)

G In a treated site the feature is an activity type (See Table 1).
- Location #1 should be the most upstream physical erosion control activity (e.g., diversion bank, porous check dam), whether it is within or upslope of the gully or stream bank, but inside the fence if installed. Location #5 should be at the most downstream project activity inside the fence (e.g. porous check-dam). Locations #2 – #4 (at least one location) should be inside the fence spaced evenly between #1 and #5.
- In a control site, Location #1 should be 10 m below the gully head or upstream end of the stream bank area, Location #5 should be at a location comparable to treated Locations #5 in terms of the distance below a gully head, and Locations #2 – #4 should be at equivalent locations to the treated sites.

H Estimate the percent ground cover of vegetation within 2m × 2m area upslope or upstream from that point, at or in line with the centre of the gully channel.
I.e.g., Comment on the vegetation composition and structure at the location by noting presence within 2m × 2m area upslope or upstream of tree (T), shrub (S) and ground cover species (G), e.g., “TSG.” Add other notes e.g., “this location has recently had runoff”, “grass showing the effects of fire”, “Indian Couch only”, “lots of cowpats”, “soil is more compacted here than at the planned fenceline.”

J Use the nearest Bureau of Meteorology gauge or reliable property records

K 1 = Completely supportive, 2 = Somewhat supportive, 3 = Neither supportive or unsupportive, 4 = Somewhat unsupportive, 5 = Completely unsupportive.

L Describe how the project activities have impacted on grazing land management by the landholder, any ‘win-wins’ for grazing management such as paddock subdivision enabling pasture spelling, or infrastructure or environmental benefits that are valued by the landholder, or problems created by the project.

4.4.4 Photography to support monitoring

Photography is an important monitoring technique, provided the photo point locations and camera heights are consistent between dates. Key points:

1. For each monitoring location the photo point should be on one (north) side of the gully
2. A metal star picket (stake) should be driven in at each photo point, to provide a permanent marker of sufficient height.
3. The camera can be placed on the top of the photo point stake to achieve a consistent field of view.
4. The entire feature being monitored (e.g. gully head, check dam) should be contained within the frame of the photo.
5. The photo file formats should be *.jpg.
6. Resolution should be high so that a typical photo file is >3 Megabytes.

The locations for site monitoring photographs are listed in Table 6. This table can be used at the site as a checklist to tick off photo locations completed. Subsequently, it should be used to index photo filenames for reporting.
Table 6. Site monitoring photograph index.

<table>
<thead>
<tr>
<th>Photopoint field checklist, and filename index</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddock name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of Photographer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gully (G) or Stream bank (SB)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fence line: into paddock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fence line: along fence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fence line: ground inside fence</td>
<td></td>
<td></td>
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<tr>
<td>Gully head or stream bank top: upslope</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gully head or stream bank top: downslope</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gully head or stream bank top: ground</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gully head or stream bank top: from side</td>
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<tr>
<td>Monitoring location #1: across feature</td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #1: oblique upstream 45 degrees</td>
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<tr>
<td>Monitoring location #2: across feature</td>
<td></td>
<td></td>
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<tr>
<td>Monitoring location #2: oblique upstream 45 degrees</td>
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<td>Monitoring location #2: oblique downstream 45 degrees</td>
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<td>Monitoring location #3: across feature</td>
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<td>Monitoring location #3: oblique upstream 45 degrees</td>
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<td>Monitoring location #3: oblique downstream 45 degrees</td>
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<tr>
<td>Monitoring location #4: across feature</td>
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<tr>
<td>Monitoring location #4: oblique upstream 45 degrees</td>
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<td>Monitoring location #4: oblique downstream 45 degrees</td>
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<tr>
<td>Monitoring location #5: across feature</td>
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<tr>
<td>Monitoring location #5: oblique upstream 45 degrees</td>
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<tr>
<td>Monitoring location #5: oblique downstream 45 degrees</td>
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<td></td>
</tr>
<tr>
<td>General photos (add description and comments)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.4.5 Mapping out erosion control activities and monitoring at the site

Monitoring locations listed in Table 5 should be included and labelled on the GIS map of site activities. Recording GPS co-ordinates of each location may assist this process.

Drawing a ‘mud map’ while at the site drafting the activity design and undertaking the before treatment monitoring [e.g., Figure 23] will assist in the later preparation of a GIS map of monitoring locations relative to other project activities. Follow the check list of items below to include:

- Shape and steepness of gullies and stream banks shown
- Overall dimensions of gully shown (length/width/depth)
- Height of head cut shown
- Locations of existing infrastructure (fencing, roads, tracks, stock watering points)
- Location of check dams and other planned activities
- Other features located e.g. erosion features
- Monitoring locations as per Table 5.
- Location and direction of photo points marked
- Annotated comments; e.g., “The walls are near vertical for about 30m below the gully head with active erosion. Below this point the walls start to slope away and do not show any signs of slumping.”

Figure 23. Example ‘Mud map’ for a property, including on-ground activities, and monitoring locations (MS#, LCA) including an untreated control gully (middle left).
4.4.6 Reporting site monitoring results

The monitoring table and photo record should be accompanied by a short narrative report summarising the overall outcome of monitoring for each gully during the reporting period. This report should be supported by the GIS map and >5 example photos (preferably side by side with photos from previous monitoring dates), and included in the site report as described in Section 4.3. The report should also include an update on the land holder perspectives of the project, and the grazing practices in and around the project area. Table 5 should be attached in .xlsx format [template available on request]. The photo index Table 6 should be attached for reference and the photo files archived by the delivery partner.
This report was funded by the Australian Government through the Reef Trust. Amy Warnick and Antonia Gamboa Rocha assisted with revising Section 3. Draft versions were reviewed by John Gallant, Christian Roth (CSIRO), Jennifer Mackenzie (Terrain), Mary River Catchment Coordinating Committee, and Reef Trust team members. Advice on gully remediation activities was provided by John Day. Case studies and photographs were kindly contributed by Mary River Catchment Coordinating Committee and Greening Australia. We would also like to thank members of many of the Regional bodies and Delivery Partners for their advice and feedback on improvements for this edition.
6 references


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Gully density data are available by request from the authors as Geotiff grids (1 km² resolution). The original gully density data were of varying resolution. Where it was of finer resolution than presented here it can be sourced from the data custodians if required: In the Normanby Griffith University (Brooks et al., 2013) mapped a subset of gullies as high-resolution polygons. In all other catchments, Darr et al., (©Copyright DNRM, unpublished data) mapped gully presence or absence in 100 m pixels, which is here aggregated to 1 km² as a percentage of 100 m pixels containing gullies.

Site selection, and design of erosion control activities, should also be informed by the spatial priorities identified in regional Water Quality Improvement Plans, by other fine resolution data sources such as aerial photography or Google Earth, and/or by site visits.
Figure 24. Density of gully erosion in the Normanby management unit, derived from mapping and sediment budget modelling sourced from Griffith University [Brooks et al., 2013]. Gully density as shown here aggregates mapping of colluvial and alluvial forms of gully erosion, and also eroding secondary streams, which are included in gully erosion mapping in other management units. The density of eroding secondary streams relative to gullies was estimated based on the relative contributions of gully erosion and secondary streams to basin suspended sediment inputs estimated by Brooks et al. (2013). Density is shown at 1 km² resolution.
Figure 25. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Herbert River catchment, as mapped by Shawn Darr et al., (©Copyright DNRM). Sub-catchment boundaries are as defined for the Wet Tropics WQIP.
Figure 26. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Lower Burdekin management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchments shown are as defined in the Burdekin WQIP.
Figure 27. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the East Burdekin management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchments shown are as defined in the Burdekin WQIP.
Figure 28. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Bowen Bogie management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchment boundaries are as defined in the Burdekin WQIP.
Figure 29. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Don management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchment boundaries are as defined in the Burdekin WQIP.
Figure 30. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Don management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchment boundaries are as defined in the Mackay-Whitsunday WQIP.
Figure 31. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Fitzroy management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data). Sub-catchments shown are as defined in the Fitzroy WQIP.
Figure 32. Percentage of 100 m areas containing gully erosion, in each 1 km² pixel in the Mary River management unit, as mapped by Shawn Darr et al. (©Copyright DNRM, unpublished data).
8 APPENDIX B: STREAM BANK EROSION CONTROL SCENARIOS

This Appendix comprises photos of stream bank erosion scenarios from GBR catchments, with captions describing the erosion processes and some suitable erosion control strategies and activities. The photos are grouped by erosion type; dry tropics minor and major streams, and humid tropics major streams.

Dry tropics minor streams

Figure B1 Small ephemeral channel in dry savannah country. The sandy bedload delivered from gully and streambank erosion in the catchment upstream is enhancing local channel aggradation and driving channel expansion. As is typical of small dry tropics streams, there is very little by way of a distinct riparian vegetation community along this creek, with the major vegetation type being grasses, shrubs and scattered trees. A channel such as this would best respond to reduced bed material load input (i.e. treating upstream gullies) and stock exclusion from the channel zone, to improve grass and shrub cover (Andrew Brooks).
Figure B2 Small ephemeral channel in the Laura River catchment showing bank erosion of old terrace material. Note that the bank toe is comprised of indurated (hardened old sediment) that is not erodible. The fact that the bank toe is stable suggests that this bank will not erode a great deal more than it has thus far. (Andrew Brooks).

Figure B3 Small ephemeral channel in the Normanby River catchment indicating moderate outer bank erosion (by the exposed tree roots) largely driven by flow scour and point bar accretion. Management strategy as for Figure B8 (Sol Brich).
Figure B4 Highly active ephemeral channel in the Bowen River catchment within a riparian area subject to very active alluvial and hillslope gully erosion. The high sandy bedload in the channel here is being delivered from the upstream gully erosion. Note also the lack of a distinct riparian vegetation community as is characteristic of ephemeral channels in savannah landscapes. The recommended approach here is to addresses the gully and stream bank erosion across as much of the upstream sub-catchment as possible and exclude livestock from this highly degraded riparian zone. Exposed dispersive soils may need to be treated (Andrew Brooks).
Dry Tropics Major Rivers

Figure B5 Main channel of the lower Burdekin River. The banks and bars are reasonably well vegetated and there is little evidence of livestock tracks or grazing pressure (livestock are already excluded). The key management issue in this section of river is weed invasion of the riparian zone – notably rubber vine and bellyache bush. Without weed management the extant vegetation will be compromised in the medium to long term, potentially leading to future increased erosion rates (Andrew Brooks).

Figure B6 The Bowen River channel. An inset channel is fringed with vegetation (primarily Melaleucas). Note how the zone between this fringing vegetation and the high bank is heavily grazed and lined with stock tracks. Exclusion of stock to the top of the high bank would encourage vegetation colonisation within this area, improving stability of the toe of the high bank. It is common to see this scenario, where the low bank is stable, but with erosion occurring immediately behind this well vegetated zone (Andrew Brooks).
Figure B7 Example of erosion of the high terrace behind a vegetated inset bench. In this case the high bank is fairly erosion resistant, but the lack of suitable substrate at the toe is preventing the establishment of vegetation at the bank toe. It would be difficult to justify expenditure of engineering works or active revegetation to stabilise this bank surface, given that it would likely disturb the existing vegetation and potentially increase bank shear stress. Excluding livestock, and in some locations encouraging deposition on the bank face with silt fences or timber will encourage regeneration. (Jeff Shellberg).

Figure B8 Example of a large dry channel showing extensive stands of in-channel woody vegetation, which helps to reduce stream energy and facilitates the deposition of finer sediment fractions. The key issue in this image is over clearing well into the riparian zone. A fence set back to the top of the high bank would significantly improve this situation (Andrew Brooks).
Figure B9 Localised bank slump within the inset floodplain of a dry tropics river. Because of the localised nature of the erosion an engineering approach could not be justified here. Facilitating localised deposition through debris placement or silt traps to encourage the establishment of trees at the bank toe would be an appropriate management strategy here (Andrew Brooks).

Figure B10 Major bank slumps within alluvial terrace material on the outside of a meander bend on a tributary of the Bowen River. In this situation the bank toe consists of silts and clays which erode by dispersion as well by fluvial scour from stream flow. Sites such as this can deliver large volumes of sediment. Livestock exclusion will encourage tree growth within the channel. Treating the gullies and streambanks throughout the catchment will help to reduce the peakiness of runoff in the long term. Due to the scale, engineered toe protection may be considered. Stabilising slumped material on the bank face may assist revegetation (Andrew Brooks).
Figure B11 Tributary of the Bowen River which has a stable bedrock bed. The key erosion issues are the steep upper edge of the inset channel bank, alluvial gully erosion on the upper bank, and the livestock tracks and grazing pressure. Livestock exclusion would enable the remnant vegetation to respond well and also encourage more vegetation establishment in the channel (Andrew Brooks).

Figure B12 Riparian zone on the Bowen River with a large area of alluvial gully erosion draining to a large pool. There is evidence of grazing pressure on the river frontage country. The ideal scenario here would be to exclude livestock from the area between the road and the river and a comprehensive rehabilitation plan for the gully area. (Andrew Brooks).
Humid Tropics major streams

Figure B13 Apparently active bank erosion on a coastal river in a humid climate. This bank is somewhat protected by a stable bedrock toe. The management strategy here would be to establish vegetation (tree cover) on the bank top and the bank toe and bank face upstream of the eroding bend. The riparian width should be larger considering the bank height (Andrew Brooks).

Figure B14 Not all banks that appear to be eroding are active sediment sources. These 10m + high banks on the O’Connell River are relatively stable because they are in indurated deposits (hardened old sediment). These banks require no active management. The low banks of the inset floodplain (left of image) are active sediment sources and should be the focus of stream bank management (Andrew Brooks).
Figure B15 Bench erosion of a well vegetated tropical river. Provided stock are excluded and weed invasion is managed from a site such as this, natural regeneration will stabilise this site fairly readily [Andrew Brooks].

Figure B16 High energy humid tropical stream with insufficient riparian zone at the downstream end of the bend, where the cane paddock extends to the bank top [Andrew Brooks]. Tree roots in the riparian zone would help to stabilise the stream bank.