



Erosion gully rehabilitation

Adaptations and learnings from sites in the Mary River Catchment



Erosion gully rehabilitation

Adaptations and learnings from sites
in the Mary River Catchment

By John Day, Becky Watson and Caitlin Mill
Mary River Catchment Coordinating Committee



Erosion gully rehabilitation:
Adaptations and learnings from sites in the Mary River Catchment

July 2023

Authors: John Day, Becky Watson and Caitlin Mill, Mary River Catchment Coordinating Committee (MRCCC)

Editing and design: Cindy Benjamin

Printing: Gympie Graphics

© Mary River Catchment Care Coordination Association, 2023

Copyright protects this publication. Except for purposes permitted by the Copyright Act, reproduction is prohibited without the prior written permission of the Mary River Catchment Coordination Association Inc.

Disclaimer: While every care has been taken to ensure the accuracy of the contents within this publication, the authors make no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and disclaims all responsibility and all liability for all expenses, losses, damages and costs which might be incurred as a result of the information being inaccurate or incomplete in any way and for any reason.

Acknowledgements

We wish to thank our construction team, Phil Lankowski, Noel and Marg Geritz, who were instrumental in all stages of on-ground project delivery. With their combined decades of experience, they consistently contributed to the ongoing learnings of the team throughout the construction process.

We would also like to acknowledge landholder contributions, particularly Owen Thompson's valuable experience in advising and mentoring landholders in gully rehabilitation.

Projects described in this publication were funded by the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation.

Foreword

Erosion is an ongoing process that all land managers must recognise and minimise where possible. From 2014 to 2019, members of the soil conservation and natural resource management community in the Burnett and Mary river catchments had the opportunity to study erosion processes and offer rehabilitation options on over 100 properties.

The publication *Gully Erosion: Options for prevention and rehabilitation; Experiences from the Burnett and Mary River catchments, Queensland* (Day and Shepherd, 2019) followed these experiences. Consulting this publication will provide readers with an overview of erosion control across many situations.

In the Mary River catchment, six years of on ground works to reduce fine sediment to the southern Great Barrier Reef lagoon resulted in new learnings about effective gully erosion rehabilitation. This extended period of focused work is the basis for the information provided in this guide.

The authors have worked as a team on the projects showcased in this guide. Through continuous learning, they have adapted and refined cost-effective erosion rehabilitation and stabilisation practices for the region's landholders to improve downstream water quality.

The erosion control work, and the learning will continue. This publication captures the team's combined 30+ years of experience, and their observations of each rehabilitation site, to guide others on their soil erosion management journey.



Rehabilitated gully in the Mary River catchment.

Table of contents

Foreword.....	3
Introduction to gully erosion.....	6
Prevention is better than cure.....	6
What is gully erosion.....	8
Gully catchment water flow estimations	10
Deciding what to do at an erosion site with gully potential	12
Gully erosion control using rock chutes.....	15
How to design a rock chute.....	16
Rock chute refinements and learnings	18
Background	18
The starting point: standard engineered rock chute design	19
Gully rehabilitation sites.....	20
Gully head rock fill chute.....	20
Rock chute combining two gully heads.....	28
Rock mattress.....	35
Gully filled and overland flow diverted.....	42
Rock chute with detention basin	52
Rehabilitated failed dam sites	60
Cut wall and rock mattress.....	60
Reinstate natural flow path and rehabilitate eroded areas.....	67
Geofabric drop structure sites.....	76
Drop structure using small earthmoving machinery, geofabric and some rock	76
Geofabric drop structure using hand tools only	81
Summary	87
Bibliography.....	87

■ Introduction to gully erosion

Erosion is the movement of soil and rock particles by wind or water. This natural process has shaped the topography of the landscape over millennia. The rate at which erosion occurs depends on the natural vegetation cover on the land, the intensity of wind and rain, the length of time the erosive forces are acting and the erodibility of the soils and rock at any one site. All activities carried out by humans, including our food production with domesticated animals and crops, have the potential to affect the rate at which erosion occurs and where it occurs. One of the most visual and destructive forms of erosion is gully erosion.

Maintaining good ground cover through sound pasture management, including forage budgeting, is the most resilient and cost-effective first step in reducing gully erosion risk, particularly in fragile landscapes.

Project participants agree ground cover should be the highest priority in fragile landscapes prone to gully erosion.

Prevention is better than cure – harnessing ground cover to combat gully erosion

It is crucial for grazing landholders to proactively address gully erosion on their land. By being proactive and focusing on maintaining good pasture and ground cover, landholders can significantly reduce runoff and soil erosion. There are practical techniques for maintaining good ground cover to safeguard a farm's sustainability and profitability.

The vital role of ground cover

Good pasture cover or ground cover plays a vital role in protecting the soil from runoff and erosion. Good ground cover intercepts raindrops, preventing them from impacting the soil surface and disrupting soil structure. Good ground cover will enhance water infiltration, minimise runoff, and retain soil, nutrients, and organic matter in place. Additionally, good ground cover contributes to soil health and assists in weed control. It includes living plants rooted in the soil, as well as mulch and litter on the soil surface.



Good ground cover is essential to protecting the soil from the erosive forces of raindrops and overland flow.

Importance of good ground cover

When ground cover exceeds 80% of the soil surface, runoff water causes little to no erosion. However, as ground cover decreases below this threshold, both runoff and erosion increases dramatically. This is due to the geometric patterns of bare ground and plants typically found in pastures. High levels of ground cover creates small isolated patches of bare ground surrounded by an extensive barrier of plants, effectively absorbing runoff and encouraging silt and organic matter deposition. As ground cover is lost, bare ground patches begin to connect, allowing runoff to flow more freely and concentrate into channels. Low ground cover (<50%) results in plants occurring as isolated 'islands' in a sea of bare ground, enabling unimpeded runoff and significant erosion potential.

Manipulating ground cover for erosion control

Carefully selecting pasture species can significantly reduce erosion and runoff risks. Choose pasture grasses that are well-adapted to your climate and soil type to ensure their persistence. Perennial pasture grasses are preferable to annuals due to their year-round cover and dry matter production. Grasses with deep, fibrous root systems are ideal as they enhance soil organic matter, improve soil structure, and maintain infiltration rates. These are known as '3P' grasses – perennial, productive, palatable, and importantly deep rooted.

Species with runners or stolons, such as Rhodes grass and Pangola, offer additional advantages, especially in drainage lines as they spread out covering the soil surface. Alongside species selection, effective pasture management that retains high levels of ground cover and pasture bulk are essential for erosion control.

Wet season spelling pastures during their peak growing periods (summer) allows the pasture to spread across the soil surface, set seed, drive roots deep into the soil and build energy reserves for climate extremes such as the next drought.

To combat gully erosion, grazing landholders must retain high levels of ground cover. Good ground cover acts as a shield, intercepting raindrops, reducing runoff, and safeguarding soil integrity. By understanding the critical role of ground cover and implementing strategies to maintain it, grazing landholders can protect their land's sustainability, profitability, and water quality.



When the soil surface is exposed it is prone to erosion.

What is gully erosion?

Gully erosion is a major environmental challenge that is widespread across Queensland landscapes. Gullies are considered the worst stage of soil erosion and are acknowledged as a significant contributor of sediment in water reservoirs and to the Great Barrier Reef lagoon.

Soil type and gully formation are closely linked. High-risk situations occur where the topsoil is bare and erosion-prone subsoils are exposed to direct contact with raindrop splash and flowing water. Erosion-prone soils tend to 'dissolve' (disperse) and slump (slake) very quickly when in contact with water. Highly dispersive soils are usually sodic and have a high level of exchangeable sodium. Soils that slake usually lack organic matter that helps bind the soil particles into stable aggregates. A field test for these characteristics involves placing a large, dry soil ped in a jar of water and observing any cloudiness in the water (dispersion) or disintegration of the soil ped (slaking).

All soils have varying proportions of minerals, sand, silt and clay, water, organic matter, microorganisms and gases. The arrangement of these elements creates the soil texture and affects how the soil responds to erosive forces. For example, sandy soils allow water to infiltrate through the profile to deep drainage, resulting in less runoff from the soil surface. In contrast, soils with clay at the surface will slow water infiltration and will have water running off the surface in heavy rainfall events.

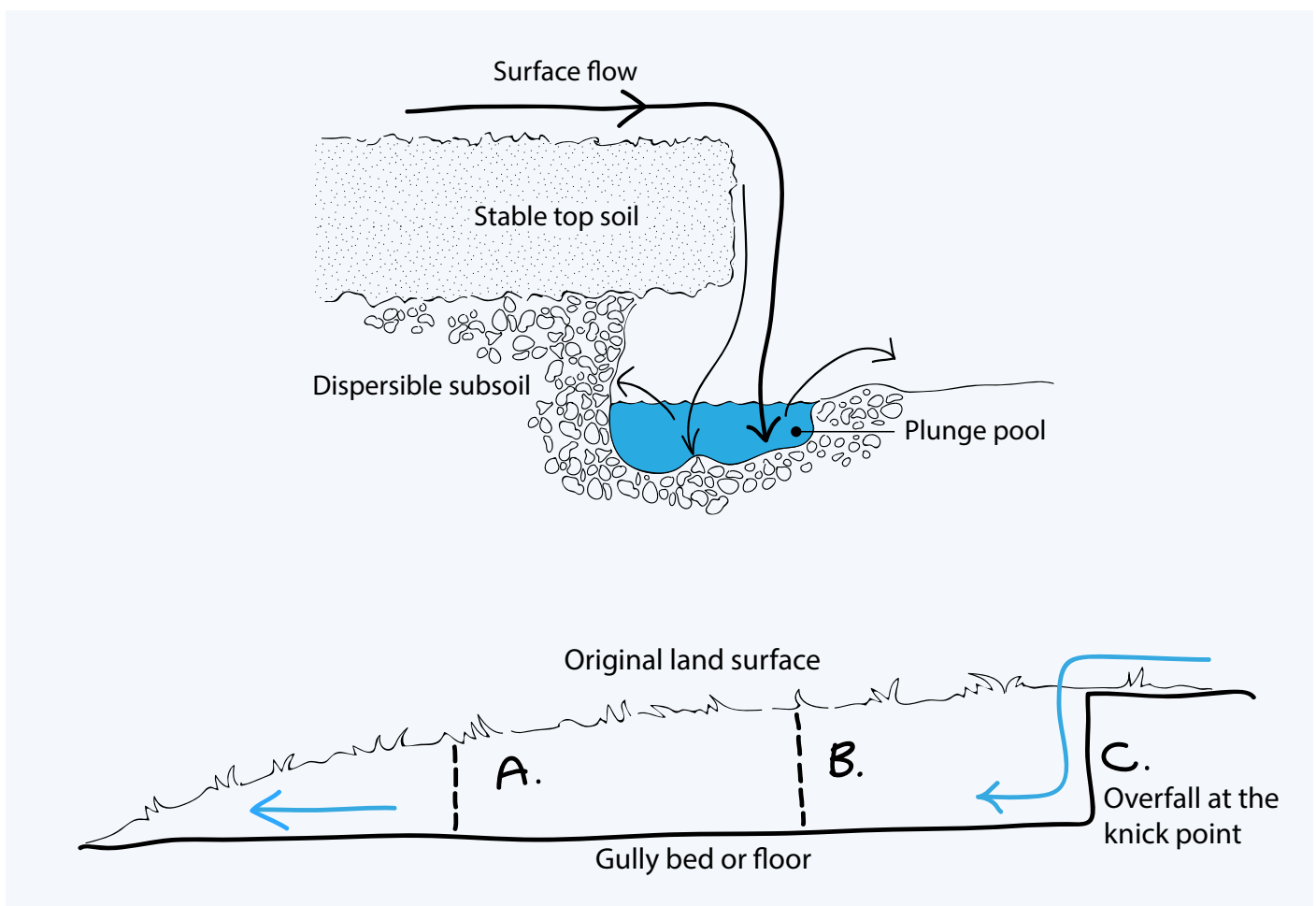


Figure 1 Gully advances – (top) gully head development; (bottom) changes in height and bed slope as the gully advances upslope. (From 'Soil conservation guidelines for Queensland', Ch. 13).

Some clay soils crack deeply, and runoff takes a long time to occur unless very heavy rain seals the cracks and causes rapid runoff. Soils with high silt content at the surface often set very hard and will result in extensive runoff during intense rainfall events. These soils tend to scald when vegetative cover is lost from the surface.

Generally, soils with a hard-setting surface and high sodium content in the subsoil, described as sodic soils or sodosols, are very prone to erosion. They will disperse and slake when in contact with water. Some heavy black and brown clay soils are also prone to slaking and dispersion, although they are often very productive soils. The soil texture, organic matter and chemical makeup will affect how erosion develops, so it is wise to test eroding soils to help define the best solution to stabilise the area and prevent more erosion. You can find detailed soil type descriptions on Queensland Government websites if you search 'common soil types in Queensland'.

Water will eventually run off most soils during extended or intense rainfall events. As water is concentrated in narrow pathways between grass tussocks, or along insect and animal trails, its velocity increases and magnifies the erosive force, washing away more soil.

If the subsoil is exposed and dispersive or slaking, then water turbulence tends to cause the subsoil to dissolve quicker than the topsoil. Topsoil with grass growing on it may collapse, causing small waterfalls to develop and increasing the water velocity and the rate of soil erosion (see Figure 1). This process continues, forming active gullies that grow deeper and wider in the landscape.

Soil formation rates are quite slow and can not compensate for soil loss due to gully erosion. Gullies are also a significant contributor of sediment to water courses, and they pose major threats to sustainability in cropping, horticulture and grazing production systems if left unchecked.

A gully is an erosion path with a depth exceeding 0.3 metres (m) and has active erosion at the head and walls.

What influences gully erosion?

Rainfall intensity and duration, wind, hail, ground cover, vegetation type, soil type, soil condition, land slope and land use all affect the initiation of gully erosion and the expansion of a gully.

Land managers can make decisions and implement actions that either increase or minimise erosion risk. Land managers can also undertake activities to rehabilitate gullies.

Gully catchment water flow estimations

When considering the rehabilitation of a gully erosion site, it is critical to estimate the amount of water that runs through the gully during rainfall events of differing durations and intensities. The size of the catchment, land slope, vegetation type, ground cover levels and soil permeability will directly influence the quantity and flow rate of water. Gullies are most prone to increased erosion following periods of extended drought when there is minimal ground cover. Water flow calculations are regularly based on this scenario.

Use the Rational Method, charts and descriptions provided in the *Soil Conservation Guidelines for Queensland*, Chapters 3 and 13 and the Appendix to calculate the peak water flows from any given catchment. A supporting spreadsheet '*RAMWADE tool*' is also available to help with calculations (see Bibliography). Seek the advice of an experienced technical officer to assist with calculating the peak flow for your catchment.

Once you have the estimated flows, you can design suitable structures to assist with the rehabilitation and stabilisation of the site. Ask an experienced technical officer to assist with designing structures to accommodate the peak flows from the catchment.

In some situations, getting professional technical advice on flow rates for an erosion site is not possible or economical. A fall-back position is to take notice of the largest flows you have witnessed through the gully. The depth of the highest flow through the gully, multiplied by the width of the flow, will give you a cross-sectional area of the amount of water flowing. For example, if the gully flow depth in a higher-than-normal rain event is 0.6 m across the gully width of 5 m, you will have a cross-section of 3 square metres (m²) of water. See Figure 2 below.

If the water flows at a certain velocity, we can work out the volume. Most gullies flow between 1 and 2 metres per second (m/s) depending on the gully floor's steepness, roughness and vegetative cover. To estimate the water velocity in m/s, measure the distance a floating object travels in 1 second (or 10 seconds, then divide the distance by 10). The water in the middle of the gully flows the fastest, so it is wise to measure an object floating in the middle of the gully.



Figure 2 Example of gully flow width and depth.

If the water in the gully at the highest point of the flow is travelling at 1.5 m/s, then a 1.5 m wall of water with a cross-section area of 3 m², is flowing past every second. Therefore, the volume of water flowing through the example gully at the approximate highest flow in a higher-than-average rain event is 4.5 cubic metres per second (m³/s).

If we want to manage this water, we must design a structure to cope with this water safely. The most destructive force causing erosion from runoff water is the velocity at which water moves. To reduce the water velocity in a stream or gully, we need to reduce the depth of flow.

Wide and shallow streams of water have less velocity and less erosive power. A rule of thumb is to keep the flow depth at around 0.3 m to keep the velocity within a normal range for most streams at about 1 m/s.

Many variables affect the velocity and flow depth including the vegetation on the gully floor. High levels of long grass will slow water down and increase depth without causing erosion. Increasing the design width of the structure will reduce the depth of flow to carry the 4.5 m³/s of water safely. A complex set of factors affect the outcome, but reducing the depth to 0.3 m and widening the path, reduces the chance of erosion.

Using calculations described in the *Soil Conservation Guidelines for Queensland*, a crest width between 17 m and 19 m can convey 4.5 m³/s of flow, at the safer velocity around 1 m/s.

The purpose of this exercise is to illustrate the complexity of the design process. To determine a suitable design width, it is necessary to trial multiple depth of flow and velocity combinations. As the depth reduces, the velocity reduces also, so we have two variables interacting that require complex maths or trial and error calculations. Having a technical officer to assist with the final design using the graphs and spreadsheets developed for this purpose will improve the accuracy of the outcome and reduce the chance of cost blowouts and structure failures.



The characteristics of the site, including catchment area, soil type and slope, will influence the decisions about gully remediation.

Deciding what to do at an erosion site with gully potential

The first step in managing an erosion site is to exclude livestock and allow vegetation to grow. Before undertaking further remediation, consider the size of the eroded gully, its position in the landscape and the size of the catchment delivering water to the site. Then think about what remediation methods may work best at the site. Table 1 provides some gully remediation options for consideration.

The inherent soil fertility and water-holding capacity of the soil at the site will strongly influence the rehabilitation speed. If the gully is on a cracking or uniform clay in 'Open downs', 'Brigalow' or 'Scrub' land types, the potential for quick revegetation will be higher than for gullies on duplex soils on 'Spotted gum' or 'Box' land types. Soil tests can show if soil modifiers, such as lime or gypsum, are needed to improve soil structure and chemical balance. Address these considerations at each site before making decisions about remediation options.

Table 1 Erosion remediation methodology decision process.

Remediation options Least cost, complexity & disturbance 	Erosion problem		
	Hill slope, rill and sheet erosion	Scalds – topsoil removed	Small gullies to 1 m, on smaller catchments < 10 ha
	Stock management to reduce grazing pressure, reduce numbers.	- Stock management to reduce grazing pressure, reduce numbers. - Mulch pasture to increase organic matter.	- Spell gully catchment AND fully exclude stock from the gully site. - Contour or graded stick rake lines to slow and divert water.
	As before, plus Contour stick rake lines.	As before, plus - Contour stick rake lines. - Fencing and spelling.	As before, plus Once-off high density grazing then seeding and wet season spelling.
	As before, plus Fence, rotational grazing, position cattle troughs to enable more uniform pasture utilisation.	As before, plus Contour deep ripping and seeding EXCEPT on steep slopes and highly sodic or dispersive soils.	Spelling and fencing, plus Designed diversion bank ONLY if suitable disposal area for water is available. Fill gully and seed.
	As before, plus Strategic contour sod seeding with wet season spell.	Spelling and fencing, plus If flat (below 1%) slope then pondage banks and seeding.	Spelling and fencing, plus - Gully head rock fill with designed crest width and rock size. - Consider using geofabric to construct a design-width drop structure.
Greatest cost, complexity & disturbance	Or If low sloping landscape (up to 2%) with suitable soil types then full cultivation and improved pasture grass and legume species planted.		Spelling and fencing, plus Fully designed rock chute with designed rock size.
			Spelling and fencing, plus Designed rock mattress with designed rock size. Suitable for a string of small gully heads down a short stream reach.

It is usually best to approach a gully erosion problem holistically, aiming to improve the whole property, not just halting the aggressive gully. Most erosion results from land management decisions, so it is important to address the causes; otherwise, the potential for further erosion is high. It is important to consider the rehabilitation options of smaller gullies before they become aggressive and costly to repair.

Soil erosion control is an iterative, continuous learning process. There is no 'one size fits all' solution to gully erosion. Cost, capacity, urgency, and logistics will likely influence the choice of rehabilitation method.

This guide provides several examples of gully remediation projects that have proven effective at serious erosion sites that resulted from the exceptional flood events through the Mary Valley in recent years.

Table 1 Erosion remediation methodology decision process (continued).

Remediation options Least cost, complexity & disturbance	Erosion problem		
	Larger deeper gullies with catchments > 10 ha	Dam by-wash erosion	Sheet, rill and gully erosion in cultivation land
	Spelling and fencing, plus Contour or graded stick rake lines to slow and divert water.	Spelling and fencing, plus Gully head rock fill with designed crest width and rock size.	Return the paddock to improved permanent pasture with legume inclusion and manage grazing for high vegetative cover.
	Spelling and fencing, plus If catchment peak flows below 3 m³/s for 1-in-50 year rainfall event AND suitable safe water disposal site available, then designed diversion bank, detention dam with stable outlet optional, fill gully and seed.	Spelling and fencing, plus Gully head rock fill with designed crest width and small rock enclosed in strong netting.	Minimum and zero tillage plus Suitable high stubble crop rotations to maximise ground cover at all times.
	Spelling and fencing, plus - Gully head rock fill with designed crest width and rock size. - Consider using geofabric to construct a design-width drop structure.	Spelling and fencing, plus Fully designed rock chute with designed rock size.	Minimum and zero tillage plus Design and survey a contour bank and waterway system with <u>double</u>-width bank spacings.
	Spelling and fencing, plus Gully head rock fill with designed crest width and small rock enclosed in strong netting.	Spelling and fencing, plus Rock chute designed using gabion rock baskets.	Minimum and zero tillage plus Design and survey a contour bank and waterway system with <u>single</u>-width bank spacings.
	Spelling and fencing, plus Fully designed rock chute with designed rock size.	Spelling and fencing, plus - Break dam wall and create rock mattress through wall at design width. - Fill by-wash gully and build bank so water flows through dam wall break.	
Greatest cost, complexity & disturbance	Spelling and fencing, plus Rock chute designed using gabion rock baskets.		

Successful project implementation is usually the result of:

- Outsourcing the required technical competency if the skills are not available within the business.
- Engaging reliable and experienced contractors who can visualise the intent and scope of the design.
- Seeking input from the landholder, civil contractors and designer to refine the details as the construction progresses.

There is no gully control structure or strategy that you can 'set and forget'. Regular monitoring and immediate action is imperative, especially after flow events.

The foundation of all erosion control and rehabilitation strategies is properly managing pasture, ground cover and water flow. Prevention is always much better than cure.

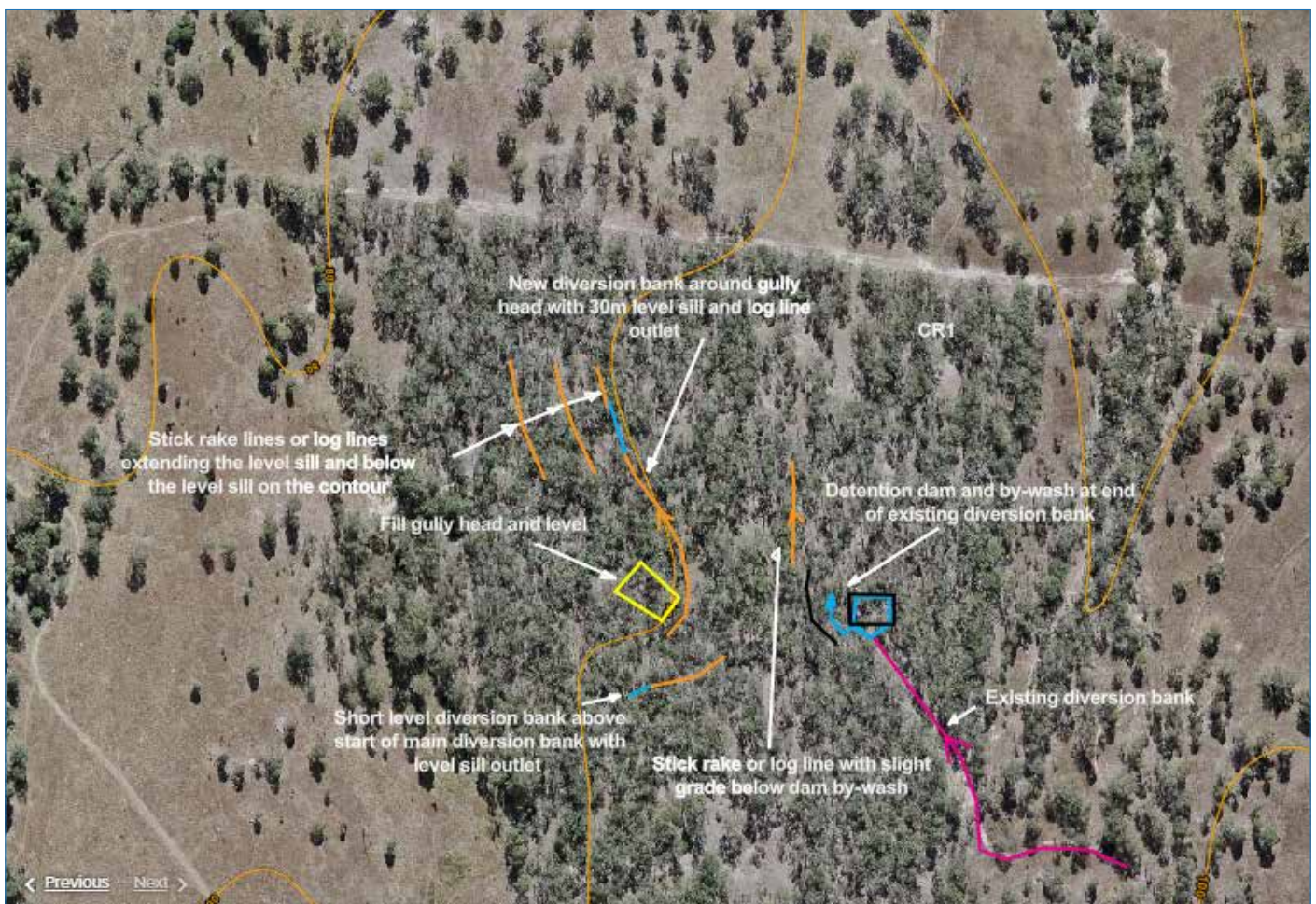


Figure 3 Gully rehabilitation often involves a suite of techniques that work together to slow and spread the flow of water.

Gully erosion control using rock chutes

Properly designed, installed and maintained rock chutes are often the best option for gully remediation in situations where low-cost options alone are insufficient. The low-cost options are outlined in Table 1 and discussed in detail in the publication: *Gully Erosion: Options for prevention and rehabilitation; Experiences from the Burnett and Mary river catchments, Queensland* (Day and Shepherd, 2019).

A rock chute can be a complete and permanent solution when an active gully head must be stopped to protect infrastructure or valuable resources. Vegetation will readily cover rock chutes, adding to the structure's strength and permanence.

Rock chutes are constructed using gravel, rocks of an appropriate size and geofabric on a shaped soil slope. Texcel and Bidim geofabrics were used in the construction of the rock chutes described in this publication. You can order these products in the strength required to suit the size of rock needed for the chute design. Gullies on less dispersive soil types and with lower peak flows may not require geofabric. For example, red soils and some brown clays can stabilise well with gravel and rock alone, provided there is a good mix of rock sizes and the area is compacted well.

All sites must be fenced to establish and maintain good ground cover for long-term site stability.



Rock chutes are an effective method to rehabilitate a wide variety of gully situations.

How to design a rock chute

Figure 4 shows the basic shape of rock chutes. The crest design should accommodate the natural landscape for minimal disturbance above the gully head. For example, the crest is not always symmetrical and will perform well as long as it meets the design width and is constructed level. On completion of the chute structure, exclude stock from the site, then sow pasture seed and apply fertiliser to promote rapid site recovery.

Rock chutes and similar engineering structures need to have a rigorous design process, including hydrological calculations that estimate the peak flows during rain events of a particular intensity. Once the peak water flow is estimated, design the structure to manage those flows. The main components of the rock chute design are a) crest width and flat section at the top leading to a batter to take the water to the gully floor and b) an apron or energy dissipater at the bottom designed to pool the water and dissipate its energy before it flows down the gully floor. See Figure 4.

The rock sizes required for stability in the chute at the given water velocity are an important design feature. Secure smaller rocks with strong netting stitched with plain wire if large rocks are hard to procure. Another option is to use gabion baskets.

The *Soil Conservation Guidelines for Queensland* (2015) includes a spreadsheet called *RAMWADE* to assist with calculations for peak flow, waterway width and diversion bank size. The *Rock Chute Design Data spreadsheet (CHUTE)* will specify the size of rock needed for a given peak flow, chute crest width and batter length. Both spreadsheets are available for free (see Bibliography) and, with some initial training, can provide invaluable assistance with rock chute design. The formula to calculate the width of a weir or rock chute crest for a given peak flow is available in the *Soil Conservation Guidelines* and can be converted into a spreadsheet if preferred.

Critical components of rock chute design, construction and maintenance

- Estimate the water volume and flow velocity entering the gully head and proposed chute.
- Use the water volume, velocity and gully head cut depth to calculate the desired crest width and chute length. Typical chute batters are 3:1 or 4:1 so, if the gully head is 1 m deep, the chute batter length will be 3 m or 4 m, respectively. The longer the batter, the better. Long batters reduce the water velocity without increasing the width. Small rocks become an option for chutes with wide crests and long batters (e.g. 10:1). However, the increase in total rock required will increase the cost.
- In high velocity and high flow situations, or where suitably large rock is unavailable, cover and secure the rock with heavy gauge wire netting tied down with heavy gauge plain wire and steel pegs. Gabions are also an option in this situation.
- Shape the gully head to the chute's design specifications for the crest width, batter and apron length. The design specifications are usually supplied in a diagram similar to Figure 4. Excavate the top bench of the chute crest deep enough for the required size and depth of rock.
- Construct cut-off trenches top and bottom as designed. If using wire netting, place this into the trenches at this stage to allow connection over the rock after placement (see photo series).
- Use gravel and geofabric according to soil type and condition to cover the batter soil before laying the rock.
- Have rock in the designed size range delivered and stockpiled close to the chute. If the specified large rock size is unavailable, use smaller-sized rocks secured with heavy gauge wire netting to hold the rocks in place during high-flow events. Without this netting over small rocks, the structure is likely to fail. It is useful to have additional rock delivered for future maintenance requirements.
- Place the rock in the cut-off trenches, on the top bench, the chute batter and on the apron in whatever order is practical given the site and machinery capability.

- Construct the energy dissipation apron using larger-sized rock and a rise of at least 0.3 m on the bottom lip (see Figure 4).
- Where possible, carefully compact rocks into place on the batter. Where geofabric is used, take great care to ensure the fabric is not damaged.
- Fence the site to exclude and manage livestock access.
- Establish suitable ground cover.
- Inspect the site after rain events and carry out timely maintenance to minimise repair costs and avoid structural failure.

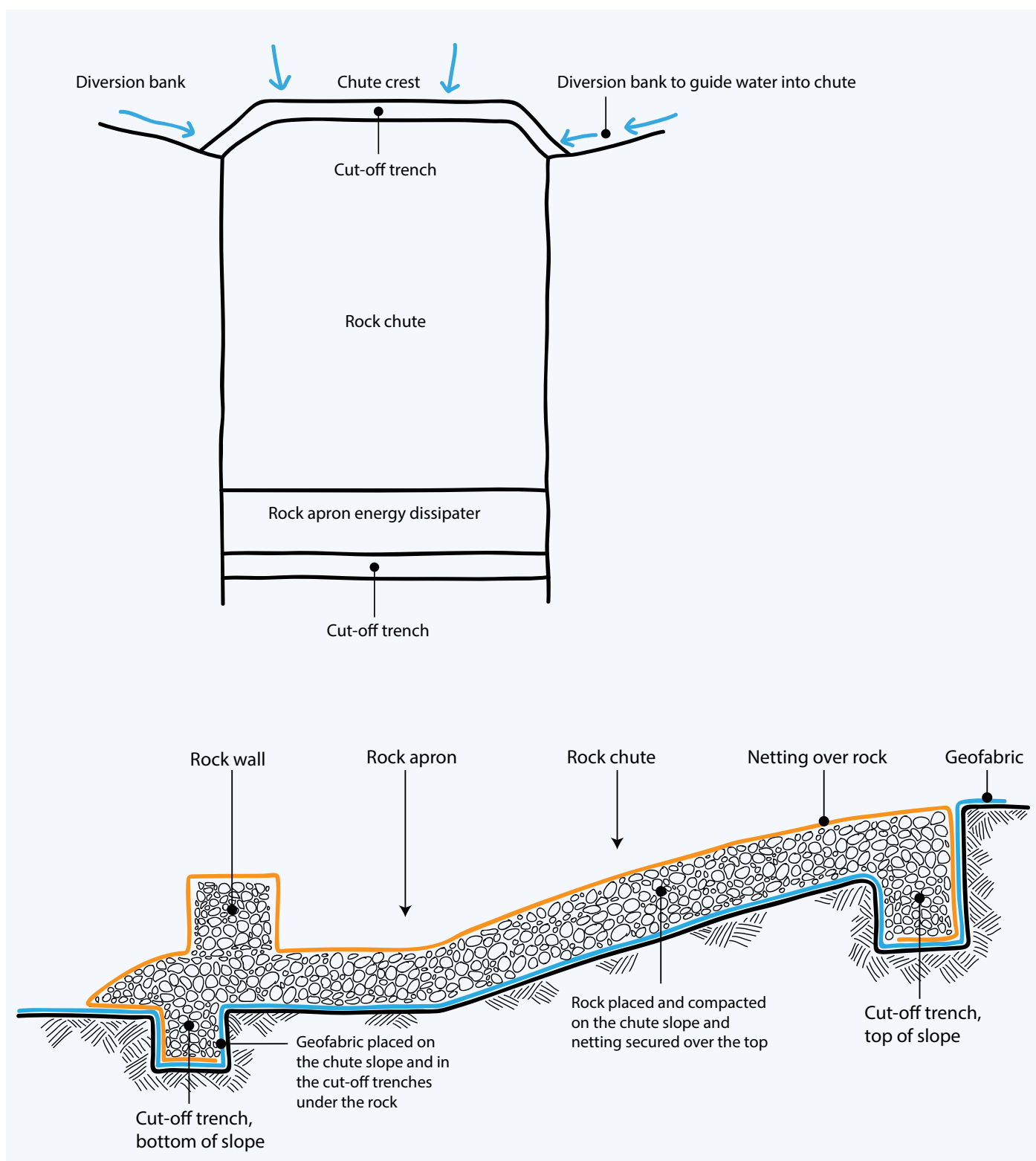


Figure 4 Example rock chute design – (top) aerial view; (lower) cross-section.

■ Rock chute refinements and learnings

Background

For three years, landholders with gully erosion issues in the Mary River catchment came forward seeking advice for rehabilitation options. With funding from the Great Barrier Reef Foundation, the Mary River Catchment Coordinating Committee (MRCCC) staff engaged with these landholders and provided detailed rehabilitation options for 24 gully erosion sites. After consultation and design refinement, the projects advanced to construction. The landholders and MRCCC team monitored the structures after the wet season and completed maintenance and small modifications as required.

During this period of activity, two local contractors with many years of experience, and machinery suited to the diversity and complexity of the projects, supported the design and construction team. The contractor with a skid steer, 5 t excavator and dump truck was allocated smaller projects and those with tight access issues. The contracting team with a 25 t excavator and dump truck was allocated the larger projects. Both contractors have a good reputation and are well-known to landholders in the region.

One landholder has also become skilled at constructing rock chutes and now quarries rock on his property for his own gully rehabilitation projects. This landholder is now part of the construction team and has mentored many other landholders in addressing their erosion issues and engaging with soil erosion mitigation works through the MRCCC.

Having a consistent team to design, project manage and construct all the projects has provided opportunities for extensive learning and refinements during the construction and monitoring period. The team has documented the learning journey and the practical refinements that arose due to the diverse project scenarios and the prevailing seasonal conditions.



Consider the type and size of equipment and machinery required to do the work efficiently and minimise damage to the surrounding area.

The starting point: standard engineered rock chute design

The basic design for a rock chute is outlined in the previous section. Conventional methods and procedures include use of geofabric, gravel, rock, cut-off trenches and energy dissipater aprons on rock chute structures.

A recent change to the conventional construction method seeks to avoid tunnelling that can occur under the geofabric placed on the batter. Due to its exceptional strength, geofabric can hold the rock in 'suspension' for a period, allowing water to erode the soil under the fabric during a significant rainfall event. The repair cost is often high when the rock and fabric later collapse into the holes.

Many engineers now suggest it is safer to use the geofabric over the top bench and cut-off trench only and not the entire batter. They recommend using gravel with high clay content to seal the exposed subsoil in the trenches and on the batter before any geofabric is used.

This modification allows the movement and settling of rock. Landholders can monitor the site and promptly rectify any subsidence they observe.

High clay-content gravel to seal dispersive subsoils reduces the exposure of subsoils to direct water flows and subsequent erosion. Protecting the surface this way mimics the natural slow moistening when the topsoil is in place, allowing moisture to seep into the subsoil.

With this adaptation in rock chute design in mind, the team trialled a double-security approach for the first sites in the Mary River catchment, which involved a 0.1 m layer of gravel across the whole structure and then laying geofabric before placing the rock. This approach has been the standard practice across the 24 recently completed projects. Through their work on the diverse sites, the team had significant learnings and developed modifications incorporated into the later projects. These learnings also influenced the maintenance activities on some of the early projects.

One size does not fit all. In the team's experience, each project required modification of the 'standard' rock chute design and construction to accommodate differences in the landscape, budget, availability of construction materials and site access.



Most projects will require a small team of experienced and knowledgeable practitioners, including the landholder.

GULLY REHABILITATION SITES

Gully head rock fill chute

Mary River flood plain gully site

Rehabilitation type	Gully head rock fill chute
Description of gully	Gully 2 m deep, 6 m wide 300 m to confluence with Mary River
Catchment size	104 ha
Flow rate	5.5 m ³ /sec (1-in-20 year rainfall event)
Landscape considerations/soil fertility	River flats with good ground cover of stoloniferous grasses
Other considerations	• Cost • Landholder preference to use smaller earthworks machinery to reduce impact on pasture • Inundation from river during medium to high flow events and associated 'draw down' • Aim to minimise removal of the well-established stoloniferous grass cover • High priority site given proximity to downstream Mary River and fine sediment to the southern Great Barrier Reef lagoon
Equipment	5 t excavator, skid steer and truck
Final cost (earthworks and materials only)	\$4000

Background

This gully had a 2 m deep head cut on a lateral runner from the main river. The head was narrow and deep, and the catchment delivering to the gully head was approximately 104 ha of river flats. The design team used the Rational Method to estimate peak flow as 5.5 m³/s for a 1-in-20 rainfall event. The gully head had retreated significantly, releasing 66 t/yr of fine sediment. If left unchecked, the gully would eventually isolate a section of productive grazing land.



Photo 1 Mary River flood plain gully head before works commenced.

Challenges

Overland flow and inundation occur regularly on the flats during medium to high flood events, making it difficult to manage construction works at the site. As with all sites described in this publication, a lack of capital for rehabilitation works was also a significant constraint. Several decisions and adaptations required a trade-off to achieve the most effective outcome for minimal capital investment.

As the head cut was 2 m deep, a batter of 3:1 plus 1 m bench at the top and 3 m apron at the bottom added up to a total rock chute length of 10 m. Enclosing the structure with wire netting would reduce the risk of rocks moving from the site during periods of inundation. The optimal design specifications of a 10 m chute and a 16 m crescent crest, all enclosed in wire netting, would be costly to implement. Any loss of pasture to accommodate the 10 m chute would add to the long-term cost of the structure.

Solution

Instead of the conventional rock chute construction method of excavating soil to create the 3:1 batter, the team filled the gully head with rock to form a 2:1 batter. Wire netting then encased the rock to stabilise the steep batter. The advantage of this approach was reduced batter and apron length and minimal grass disturbance. The project required 100–400 mm sized rock as designed from the freeware spreadsheet 'CHUTE'.

The other consideration during planning was the size of machinery needed and potential cost. The team chose the smaller machinery combination of skid steer and 5 t excavator to accommodate the tight crescent shape of this gully head and another gully which needed remediation nearby. This machinery can handle rock sizes up to 400 mm.

Design specifications

The aim was to construct a rock chute by filling the gully head with mixed rock and gravel from 100–400 mm or larger. To stabilise the rock batter 1.6 mm wire netting was laced together with 2.5 mm plain wire to encase the whole structure like a single large gabion. The wiring is labour-intensive and increases the cost, but it provides a high level of security to the integrity of the finished structure.

The team had observed the benefits of wire netting coverings while monitoring other rock chute structures constructed six years earlier, which had performed well through several large flow events.

The team integrated the landholder's wishes and observations of peak flow heights in the design approach.

Learnings and adaptations

- Adapt the site plan to accommodate the excellent grass cover and stability of the site at construction.
- Adapt the order of construction to suit the capability of the chosen machinery.
- Connecting the cut-off trenches from the crest and the bottom of the chute may provide a more robust and better-draining structure less prone to tunneling from the top cut off trench.
- Electing to fill to a steep batter and enclose with wire netting can reduce rock use and achieve a stable structure without needing a long batter and rock cover on a deep gully
- Using wire netting adds to the labour cost.
- Deliver the rock as close as practical to the work site to minimise inefficiencies.
- Leave a load of rock at the site above flood level for maintenance repairs.



Construction sequence

Photo 2 Survey the level crest.

The level 16m uneven crescent shaped crest was surveyed with a dumpy level and marked.



Photo 3 Dig bottom cut-off trench.



Photo 4 Prepare the crest and gully walls.

The gully head was tidied and shaped slightly to collapse overhangs and tunnels and pull back the topsoil for 1.5 m around the crest before constructing the 0.6 m x 0.6 m cut-off trenches. Due to access issues with the skid steer for placing the rock, the whole structure was built from the bottom up.



Photo 5 Bottom trench inlaid with netting and lined with clay gravel.

The bottom cut-off trench was built first. It extended across the gully floor approximately 4 m from the gully head and up the gully walls to intersect with the top cut-off trench, later constructed at the ends of the crescent crest. The bottom cut-off trench and the gully floor were lined with 10 cm of clay gravel and the heavy wire netting was placed in the bottom trench.



Photo 6 Trench and gully batter filled with rock.

The trench was half filled with fine rock (100–200 mm) and gravel, then topped up with 100–400 mm gravel mix, battered at approximately 2:1 so the bottom end of the fill sits on the gully floor approximately 5 m from the top cut-off trench.



Photo 7 Excavation of top cut-off trench.

The gully head was filled up to the edge of the 1.5 m bench where the topsoil was removed and then the top cut-off trench was constructed.



Photo 8 Wire netting and gravel placed in top cut-off trench.

The wire netting was placed in the top cut-off trench, similar to the bottom cut-off trench. The trench bottom and bench were covered with 10 cm of gravel.

This process left the wire netting secured and exposed right around the crest and across the bottom of the structure so more netting could be laced across the top to secure all of the rock



Photo 9 Geofabric Texcel R400 used to line around the full crest and over the bench only.



Photo 10 Gravel and rock placed over the fabric.

The fabric was covered with a 20 cm layer of gravel and rock ensuring loose ends of the geofabric facing downslope were covered.



Photo 11 Lengths of wire netting placed over the rock chute and attached to netting in cut-off trenches.

Wire netting strips connected to the netting in the bottom trench, stretched up and connected to the netting in the top trench ensuring the netting is tight and the strips are close enough together to lace with plain wire.



Photo 12 Wire netting laced together with 2.5 mm plain wire, to form one single large gabion.



Photo 13 Filling the gaps in the rock with gravel along the crest.

Once the wire lacing was complete, the lip of the chute crest was filled with gravel. This ensured the upstream edge of the cut-off trench was sealed so no water could flow directly into the trench and fill it quickly. It also provided an environment for grass to quickly grow over the lip.



Photo 14 Soil from excavation used for diversion wing bank construction.

The soil taken from the batter, the trenches and any widening or shaping of the gully floor and head was used to construct diversion wing banks on each side of the rock chute, approximately 15 m long and 0.6 m high constructed, to ensure the water from the catchment is concentrated on the stable rock fill chute structure. These banks were constructed at approximate right angles to the gully edge heading upslope either side and extended until the end was 0.6 m above the rock crest of the rock fill chute. The outlet ends of the banks were rock armoured for 3 m to a height of up to 0.6 m to ensure they do not erode.



Photo 15 Completed chute with stock exclusion fencing in place – looking upstream.

The site was fenced to exclude stock and allow revegetation of all the disturbed areas.



Photo 16 Looking downstream at completed chute.



Photo 17 Three months post-construction.
October 2020 at the beginning of first wet season.



Photo 18 Ten months post-construction.
May 2021 after the first wet season.

Rock chute combining two gully heads

Spotted Gum forest gully site

Rehabilitation type	Rock chute combining two gully heads
Description of gully	1.5 m deep, two heads approximately 5 m and 3 m wide
Catchment size	98 ha
Flow rate	19 m ³ /s (1-in-20 rainfall event)
Landscape considerations/soil fertility	Two active gully heads with two catchments on very poor sodic duplex soils
Other considerations	• Catchment used as a forestry plot with medium density tree cover and poor grass cover • Paddock lightly stocked • Remote location means increased delivery costs
Equipment	25 t excavator, body truck
Final cost (earthworks and materials only)	\$25,000

Background

The soil type at this site was strongly sodic, and the topography was undulating with a thick stand of spotted gum and ironbark used for a forestry reserve and some grazing. The catchment leading to the gully head is 98 ha, and the peak flow for a 1-in-20 rainfall event is 19 m³/s, estimated using the Rational Method. The gully head was 1.5 m deep and formed at the junction of the main stream and a smaller tributary coming in from the western side. The adaptation adopted at this site was combining the two gully heads into one design with an extended crest length. Due to the high peak flow, the rock size at this site was 700 mm.

Challenges

The biggest challenge at this site is the large catchment size, generating a large peak flow. The gully system is long and, several large lateral gullies have formed off the main gully over time. At the most upstream gully head, another lateral gully had recently developed. Another challenge at this site was the presence of tunnel erosion.



Photo 19 Main gully head, with side gully head coming from the right of picture.

Solution

The proximity of the two gully heads meant both could be arrested with a single rock chute design at the junction of the two catchments.

The team removed vegetation in and around the gully head to accommodate the works in line with best practice. The vegetation was later used to create part of the wing banks directing the water into the chute.

In the vicinity of the gully rehabilitation site, tunnels were either broken and compacted or cut off from overland flow by the extended wing walls channelling water over the rock chute.

Design specifications

The chute's design featured a 35 m long level crest around the top and a 3:1 gully head batter. The chute batter was approximately 8 m long, with an additional 2 m apron length constructed with large rocks to dissipate the energy.

The team applied gypsum to the battered stream banks and other disturbed areas at approximately 10 t/ha to counteract the soil sodicity. Then the site was seeded with a mix of Rhodes grass (Katambora and Reclaimer), Bissett creeping blue grass and some legumes to encourage quick revegetation.

Learnings and adaptations

- Adapt the site plan to accommodate the landform. In this case, one structure combined two gully heads that were physically close together.
- Adapt the construction order to suit the size and shape of the site. Introduce geofabric and rock from the bottom up, ensuring a sufficient overlap of geofabric strips.
- As the design rock size increases, it is essential to include a significant proportion of small rocks (100–200 mm) and gravel to fill the cavities between the large rocks so the chute surface is completely covered and protected from the high velocity flows.
- Ensure the stream bed is stable above the gully structure and repair it if necessary. Use rocks to fill any depressions that could initiate tunnels and compromise the structure.
- Survey the wing walls at a gradient of 0.5% or less to ensure the wing channels do not erode. Cover the wing walls and channels with topsoil to support grass establishment. Where possible and practical, extend the wing walls far enough to cut off flows that may cause erosion on the stream bank below the chute.
- Apply gypsum as required by a soil test to improve soil structure and assist with water infiltration and revegetation around the structure.
- Use low timber or mulch lines to reduce erosion below the wing walls on the bare banks on each side of the stream. If possible, place these structures to drain water away from the stream bank onto grassed areas. These bare areas are prone to significant erosion if high-intensity rainfall occurs before the grass establishes.
- Reseed if necessary to ensure the best chance of revegetation.



Construction sequence

Photo 20 Chute shaped to capture both gully heads.



Photo 21 Chute level crest constructed to design width.

The chute's level crest design length was 35 m around the top and the gully head was battered to 3:1. The chute batter is approximately 8 m long.



Photo 22 Top cut-off trench construction.

A cut-off trench approximately 0.8 m wide x 0.6 m deep was constructed around the top of the chute crest, 1 m upslope from the top of the batter. Another trench was constructed downstream of the rock apron.



Photo 23 Excavation of bottom cut-off trench and gravel placed on chute batter.

The batter of the chute and the bottom of the cut-off trenches were covered with approximately 10 cm of gravel with high clay content.



Photo 24 Cut-off trenches completed and gravel placed on batter and in trenches.

Site is ready for geofabric.



Photo 25 Geofabric laid over the chute. Rocks placed from the bottom cut-off trench to the top – due to size of chute.

Starting from the bottom and working towards the top, geofabric Texel 400R was laid over the clay gravel. Each strip of fabric was laid with a 0.5 m overlap of the previous strip. This ensures water flows over the sheet and not under (similar in principle to roof tiling).

The lower one-third of the cut-off trenches were filled with gravel and smaller rocks. A rock mix of 150–700 mm was placed and compacted on the geofabric covered batter. The same sized rocks were used to fill the top and bottom cut-off trenches.



Photo 26 Rock-fill on the chute close to finished.



Photo 27 The depressions in the gully above the crest were filled with small rock and compacted.



Photo 28 Completed rock chute. Fence constructed at the bottom end of the structure to stop rocks rolling away during rainfall events.

Galvanised wire mesh (1.6 mm gauge) was placed along the length of the bottom trench and up the gully walls. The mesh was fixed in place using rocks at the base and galvanised star pickets. This fence was designed to capture any 'rolling' rocks during events.



Photo 29 Some excess rock placed downstream of the apron and the fence.

Some of the larger rocks (700 mm) were placed at the end of the apron and at the base of the chute to assist with energy dissipation. Some surplus rocks were spread below the apron and fence to help stabilise the gully floor. A second short wire mesh fence was constructed below this to prevent the rocks from rolling away and to act as a silt trap.

The gully walls were battered at 1:1 for a distance of approximately 10 m downstream of the chute. During this process the topsoil and grass sod was scalped back and replaced over the batter to encourage quick revegetation.



Photo 30 Survey line for wing wall.



Photo 31 Wing walls with rock armour.

During construction, any excess soil from the battering and shaping process was retained. This soil was used to help construct diversion wing banks at each side of the chute to direct water over the rock chute. Using overburden avoided exposing any additional fragile subsoil. The wing banks were constructed to 1 m high and aligned at approximate right angles on a surveyed line at 0.4% slope on either side. The banks were turned up at the ends until the ends at ground level were at least 0.75 m above the chute's crest height.

The ends of the diversion banks were fortified with rock armour up to 0.8 m high for a distance of 3 m, using the smaller rock mix (150–700 mm) so the bank ends do not erode.



Photo 32 February 2022 after major floods in the area.
24-hour rain totals exceeded 600 mm in the area.

Rock mattress

Grey Box and Wattle gully site

Rehabilitation type	Rock mattress, whoa boys and silt trap weirs
Description of gully	Gully on two forks of a stream, one 30 m long with gullies to 0.75 m deep and the other 20 m long with gullies to 0.5 m deep
Catchment size	10 ha
Flow rate	3 m ³ /s (1-in-20 year rainfall event)
Landscape considerations/soil fertility	Very poor duplex soil on an 'Iron bark, wattle' land type with blue gums along the drainage lines and lower slopes
Other considerations	- Landholder has limited resources and no machinery for maintenance - Soil type is very susceptible to tunnelling
Equipment	5 t excavator, skid steer, body truck
Final cost (earthworks and materials only)	\$11,000

Background

This erosion site was on a minor ephemeral tributary of a creek that runs into the lower reaches of the Mary River. The stream forks at the site and both channels had gullied for a total length of 50 m. Several small gully heads were evident along the 3% bed slope. The gully erosion was between 0.5 m and 0.75 m deep. Incised gullies were approximately 1.5 m wide, and there were some small tunnels on the stream adjacent to the road where road water could enter over the bank. The catchment, although only 10 ha, is steep, and the peak flow for a 1-in-20 rainfall event is 3 m³/s, estimated using the Rational Method.

The landholder's previous efforts to remediate this gully site with battering and then porous check dams had failed due to inappropriate design and the contractor's unfamiliarity with gully remediation in fragile landscapes with highly dispersive subsoils.



Photo 33 Gully erosion with multiple head cuts and failed porous check dams. Inset: tunnel erosion in the catchment immediately upstream of the gullies.

Challenges

The texture contrast soil has a very dispersive and erodible subsoil. The driveway had effectively channelled water directly down the slope into the gully system, further accelerating the erosion. Tunnels along the eastern stream had also collected water from the driveway. A new approach was required.

Solution

The focus for rehabilitation at this site was to ensure overland flow was directed away from the gully streams as much as possible through the installation of whoa boys and long stick lines. The plan required the construction of whoa boys on the driveway, approximately 40 m apart, due to the steep slope of 7%.

A large forked rock mattress with strategically placed silt trap weirs stabilised the two eroding stream beds. On completion of the earthworks, gypsum was applied to all bare and exposed subsoil areas at a rate of 10 t/ha. Loam topsoil from another site was used to cover all bare areas. The site was then seeded and fertilised.

The landholder destocked the property during the construction of the gully stabilisation works and intends to keep it that way.

Design specifications

The team built a rock mattress to stabilise both channels and constructed whoa boys on the driveway upslope to redirect overland flow away from the eroding system.

The whoa boys were surveyed and constructed using the methodology described in *Gully Erosion: Options for prevention and rehabilitation; Experiences from the Burnett and Mary river catchments, Queensland* (Day and Shepherd 2019, pg. 12-14). In this fragile soil type, the team used imported gravel to reduce disturbance during the construction of the whoa boys. The grade used on the constructed whoa boys was 10 cm fall over the 4 m road width. The road slope was steep at 7%.

Fallen timber was used to construct mulch and stick rake lines to channel the water to a safe disposal area at least 20 m from the road, around the slope. The grade for the water diversion and spreading log lines was 10 cm every 25 m, or 0.4%.

Adaptations and learnings

The first adaptation was to choose a full rock mattress approach rather than using a rock chute for the top gully head.

The second adaptation was to treat both forks of the stream and the junction with a single structure.

Due to the shape of the structure and the low slopes involved, the team used high clay gravel to seal the shaped sodic subsoil rather than using geofabric or gravel and geofabric. This also reduced the overall construction cost.

Imported gravel to form whoa boys and stick rake lines to take water to a safe disposal point was considered safer than the usual excavation and bank construction using local soil. Previous experience with the fragile nature of these landscapes and their predisposition to tunnelling directed this choice.

Construction sequence



Photo 34 Exposing and compacting tunnels.

At the erosion site, all material from the failed porous check dams was removed.

All tunnel erosion on the eastern fork was exposed and compacted.



Photo 35 Filling, shaping and compacting the gully.



Photo 36 Another tunnel before it was collapsed.



Photo 37 Gully shaped ready for gravel and rock.

The beds were widened and shaped into a trapezoidal shape, 3 m wide for the short side, 4 m wide for the long side and 0.4 m deep. 3:1 batters were used on the sides of the channel for the full length of both sections. Once shaped and compacted, a 10 cm layer of high clay content road gravel was spread and compacted over the two gully floors and batters.



Photo 38 Finishing the rock mattress.

After the gravel a layer of 100–200 mm mixed rock was spread over both gullies and up the batters.



Photo 39 Fill gully head above tree.

A small gully head at the top of the short gully was also filled with a layer of gravel and rock then compacted, like the rest of the gully. Shaping was not necessary for this small feature due to the small catchment area.



Photo 40 Rock finished on both sides.

A silt trap weir installed prior to works had performed well during the rain event and was left in place. As the silt drops out, it provides a growing medium for grasses to colonise – an essential step in the landscape recovery process and for slowing the water moving across the landscape.



Photo 41 Log and gravel line along roadside to divert water away from the completed structure.

A diversion log line and gravel barrier was constructed parallel to the gully and road edge to divert run off from the road and the neighbour's paddock to a safe flat location downstream.



Photo 42 Gravel road base dumped in position on the driveway ready to be shaped into a whoa boy.

Dumping material in position saves machine time later on.

Whoa boys surveyed with 10 cm fall across the width of the road. The road slope was steep at 7%.



Photo 43 Whoa boys completed.

Lines of logs, fallen timber and mulch placed at the end of each whoa boy carry water at least 20m away from the driveway and out of the gully catchment. Log lines were surveyed with 10cm fall over 25 m, or a grade of 0.4%.



Photo 44 Ongoing maintenance of silt trap weirs below rock mattress.

A netting weir at the confluence of the fork worked perfectly and was full of silt. Another netting weir was constructed about 10m further downstream so the crest of the new weir was high enough to back water approximately 0.3 m up the wall of the existing netting weir. This was done to stop the undermining that was evident below the existing weir.



Photo 45 Looking downstream – completed project.

Rock mattress on either side and topsoil spread in the middle to provide favourable conditions for regeneration of ground cover.



Photo 46 February 2022 after major flooding in the area.

Gully filled and overland flow diverted

Where a rock chute would work but other options are more practical for the location
Iron Bark and Box ridge site

Rehabilitation type	Gully filled and detention basin and diversion banks constructed to take the flow away from the gully site
Description of gully	Gully 1.5 m deep, 5 m wide
Catchment size	16 ha
Flow rate	2.63 m ³ /s (1-in-20 year rainfall event)
Landscape considerations/soil fertility	Ridge top of iron bark on uniform clay soil grading downslope to granite duplex with sodic subsoil; soil fertility medium to low
Other considerations	• Getting rock to the site through the property would be logistically difficult and expensive – another method was needed to stabilise the gully • Valued timber in the rehabilitation area so careful planning required to reduce timber loss
Equipment	25 t excavator, body truck, tractor with front end loader, chain saw
Final cost (earthworks and materials only)	\$6000

Background

This gully erosion site is due to the diversion of water from a historic 15 ha contoured catchment onto an adjacent ridge top rather than into the eroded natural drainage line. Diverting water away from an erosion site is a common strategy, and the system worked quite well for many years. The contour system to the ridge design was suitable for normal rainfall conditions up to the 1-in-10 rainfall event. However, during the 2011 and 2013 flood events, the increased flow on the receiving catchment resulted in a new gully, which advanced rapidly up the slope.



Photo 47 Iron bark and Box ridge gully prior to rehabilitation.

The contoured area has quite good soil with productive pasture. The ridge top that receives the water from the contour system is a different land type with much poorer soil and a heavy timber cover that reduces the grass cover. The land type on the upper slope of the disposal ridge is 'Narrow leafed iron bark on clay' grading to 'Narrow leafed iron bark on granite' down the side slope where the gully has eroded.

The soil at the gully site is texture-contrast with a shallow 0.3 m loam topsoil over dispersive clay subsoil derived from decomposing granite bedrock. The total catchment is 16 ha with an estimated peak flow of 2.6 m³/s in a 1-in-20 year rainfall event.

Challenges

A rock chute on the new gully head could have stabilised this site; however, access for trucks carrying rock was problematic. The property is a commercial cattle operation, requiring the team to devise a compatible dual-purpose option for stabilising and rehabilitating the site in consultation with the landholder and the contractor.

The second main challenge was to minimise timber clearing in this Of Concern regional ecosystem.

Solution

The final strategy comprised detention water storage, water spreading, water diversion, gully fill and fencing. The soil on the slope is a granite loam topsoil with solid stands of blue couch grass – an effective grass for holding soil and reducing erosion. All bare areas were seeded with Rhodes grass, silk sorghum and Bissett creeping bluegrass. On completion of works, whoa boys were built on all tracks established during construction to ensure the tracks did not erode before they could grass up.

The construction of a fence around the site has created a small paddock, which the landholder can manage to maintain maximum ground cover at all times.



Photo 48 Iron bark and Box ridge gully prior to rehabilitation.

Learnings and adaptations

The adaptation at this site was to use the terrain to effectively assist with planning for overland flow. The team surveyed the area around the outlet of the existing diversion bank from the contour system to accurately determine where water had flowed and would flow if some structures were introduced. This survey informed the accurate siting and capacity of the detention dam and by-wash.

In conjunction with other measures, a detention structure enables better water management and utilisation, including providing water for livestock and wildlife.

The detention dam holds water very efficiently and will therefore require emptying before the next wet season to allow capture of initial flows from the first summer storms.

Using locally available resources, including spoil and felled timber, for filling the gully heads and installing log lines eliminated issues regarding truck access. It also resulted in considerable budget savings.

Landholder contributions during construction proved very effective and efficient. The small 50 hp tractor with a three-way bucket proved very useful for many tasks, including levelling and compacting the gully fill, placing the log lines and some clearing. The landholder also used his chain saw to cut timber for log lines from trees removed during the clearing. This assistance saved contractor time and reduced costs.

This site is a habitat and timber growth area on the property, so retaining the timber was important. Using an excavator to clear lines and construct diversion banks in heavily timbered sites enables more strategic clearing than other machinery options.

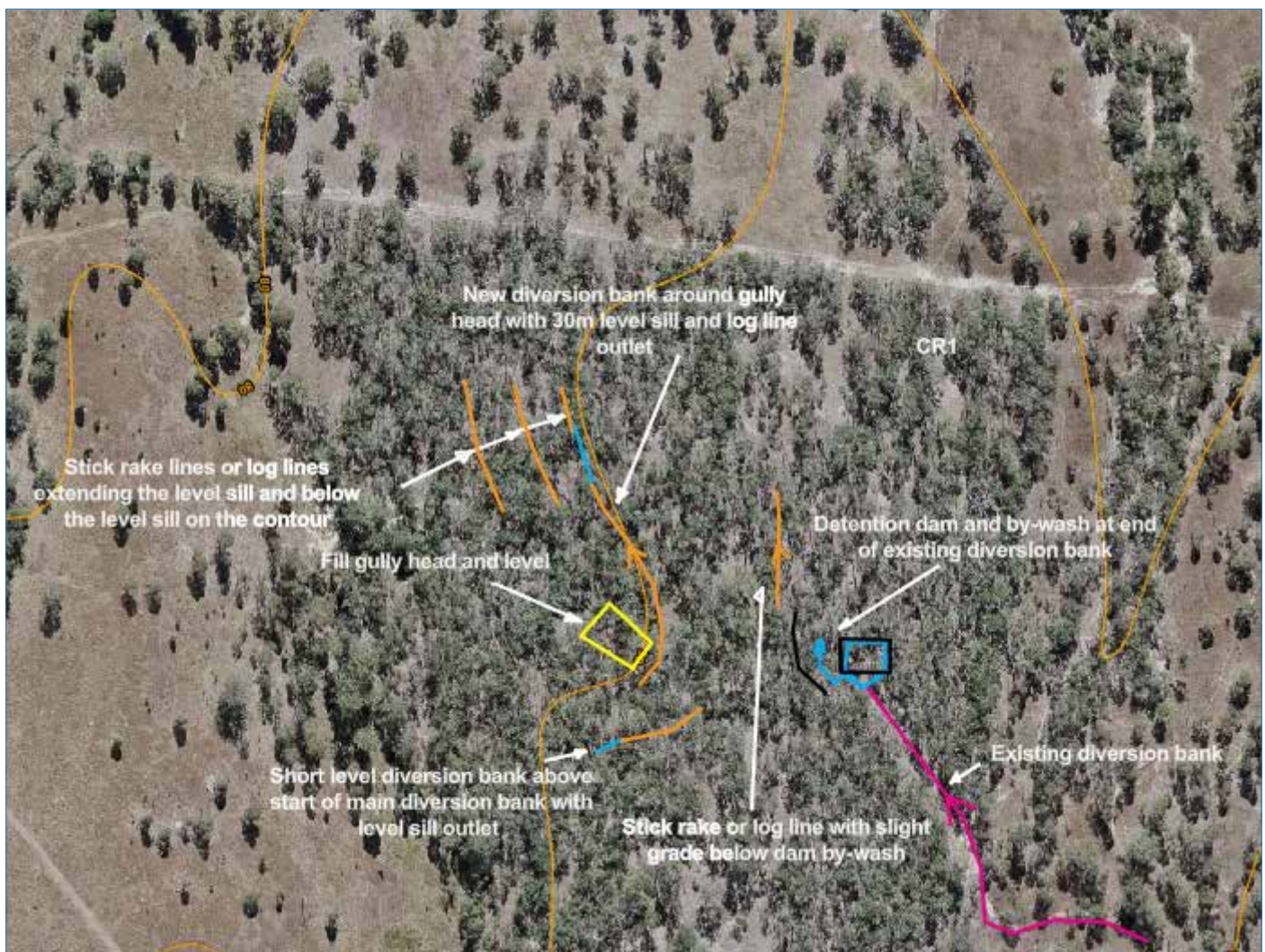


Figure 5 Suite of gully rehabilitation methods working to slow and spread the flow of water across the ridge at this site.



Construction sequence

Photo 49 Minimal trees cleared for detention basin.

The site of the detention dam at the end of the historic diversion bank outlet.



Photo 50 Detention basin taking shape.

To reduce the volume and speed of water reaching the slope above the gully head, a detention basin approximately 25 m long, 10 m wide and 1 m deep, was constructed at the end of the historical diversion bank delivering the water from the contour system on the adjoining slope.



Photo 51 Detention dam, complete with by-wash, surveyed along ridge line.



Photo 52 Detention dam by-wash surveyed almost level, with log lines in place.

The ridge top was quite flat at the site of the detention dam so the by-wash was surveyed almost level to retain more water and to take the water along the ridge line with the outlet approximately in the middle of the ridge. The by-wash placement and outlet was extensively surveyed and planned before work was started. Cascading stick rake or log lines approximately 25 m long were positioned about 2 m and 10 m below the dam by-wash outlet to slow and spread water. A slight grade of 0.2%, or 5 cm every 25 m, was surveyed in the log lines to lead and spread the water along the slope.



Photo 53 Excess clay soil was trucked from the detention basin site to the gully head downslope.



Photo 54 Spoil used to fill gully head.

Clay soil from the detention basin was used to fill the gully head.



Photo 55 Filled gully head.

The farm tractor was used to level and compact the fill.

Excess clay soil was placed along a by-wash bank and other small side gully heads below the main gully head cut.



Photo 56 Clearing survey line for the main diversion bank above the gully fill.

A diversion bank was surveyed so that it captured any water coming from the detention dam outlet and any other run-off from the slope.

The line was cleared with the excavator, which reduced the number of trees removed. The level sill and bank were constructed on the way back for time efficiency.



Photo 57 Main diversion bank level sill outlet.

A level sill outlet was constructed to spread the water at the outlet. The level sill excavation was 20 m long, 3 m wide and 0.3 m deep.

A series of three, 50 m long level log lines were surveyed and placed below the level sill approximately 10 m apart to further slow and spread the water from the outlet.



Photo 58 Levels were taken consistently along the channel floor during construction using a laser level.



Photo 59 Completed bank looking towards level sill outlet.

The bank was designed for a 1-in-20 year event and surveyed at 0.4% grade with a 3 m wide flat channel and a 1 m high bank at construction.

The bank took the water around the hillside to a well-grassed area with a much gentler slope.



Photo 60 Short top diversion bank above the start of the main diversion bank.

A short diversion bank was placed above the start of the main bank to take the top water from the natural drainage line out to a ridge line to further reduce the pressure on the depression that had gullied. This bank had a very small catchment size (<1 ha). A 25 m bank with 0.2% slope was constructed to 0.8 m with a 1 m wide channel.



Photo 61 Short top diversion bank level sill outlet showing the grassed slope where water spreads.

A level sill was constructed at the end of the short top diversion bank to spread water over the grassy slope below. The level sill outlet was constructed to 10 m long x 1 m wide x 0.3 m deep.



Photo 62 Background: Main diversion bank looking along the channel towards the outlet end.

Foreground: Short diversion bank above the main bank.



Photo 63 Whoa boys constructed on the way out to prevent erosion of tracks created during construction.



Photo 64 Completed July 2020.

Looking upslope towards diversion banks from what was the gully head.



Photo 65 Completed July 2020.

Looking downslope over diversion bank towards filled gully head.



Photo 66 February 2022 post-flood.

Detention basin full and ground cover has improved significantly.



Photo 67 February 2022 post-flood.
Level sill at outlet still holding some water following the flood.



Photo 68 February 2022 post-flood.
Fill in the gully head sank slightly. However, ground cover has established well in this slight depression.
The landholder has placed stick lines adjacent to the flow to trap soil and prevent further rilling.

Rock chute with detention basin

Black soil streambank gully site

*Deep narrow gullies challenge design

Rehabilitation type	Rock chute with detention basin
Description of gully	Gully head 2 m deep and 2.3 m wide, rapidly increasing in size to 15 m deep and 22 m wide. 100 m to confluence with Mary River.
Catchment size	8.9 ha, with an average slope of 2%.
Flow rate	1.8 m ³ /s (1-in-20 year rainfall event)
Landscape considerations/soil fertility	River flats with good ground cover of stoloniferous grasses. Good soil fertility.
Other considerations	• Cost • Inundation from river during medium to high flow events • Risk of erosion as flood waters recede due to saturation of the landscape • High priority site due to export of significant sediment loads to the Mary River and southern Great Barrier Reef lagoon • Very deep narrow gully with tunnelling along the edges
Equipment	25 t excavator
Final cost (earthworks and materials only)	\$9000

Background

This property is a small lifestyle block with approximately 110 m of Mary River frontage. A large gully that started on the downstream neighbour's property in the 1950s had crossed the boundary into this property. Historical imagery shows a small gully in 1952 and a slip circle failure on the riverbank immediately downstream by 1958. These erosion features continued to grow individually before the peninsular between them collapsed, and they joined around 1984–87. Flood imagery from 1999 shows the gully at bankfull height. Inundation from backwater was an important factor to consider for rehabilitation.



Photo 69 Aerial view of the gully before construction started, with the Mary River in the background.

Baseline monitoring of the gully occurred in December 2019 following stock exclusion. The gully was 2 m deep at the head cut and 2.3 m wide, with the depth increasing quite quickly and the width staying relatively narrow for at least 10 m. The gully where it meets the riverbank approximately 100 m away is approximately 22 m wide and 15 m deep. LiDAR comparison between 2009 and 2018 shows that the gully head had moved 25 m in a decade. The catchment above this gully is 8.9 ha, resulting in 1.8 m³/s flow during a 1-in-20 year rainfall event.

Challenges

The grazing land type is 'Blue gum flats,' which typically experience waterlogging in flood events. The subsoil is dispersive and prone to gully erosion. The soil is a deep Dermosol, with minimal texture contrast. The catchment is mainly pastured grazing land with little to no tree cover. The drainage area immediately above the gully is a wetland with good tall grass cover, including dense Para grass.

Flood water inundates the gully head during medium to major flood events in the river.

Solution

Stabilising the gully head involved a rock chute and a dam wall constructed approximately 20 m upstream from the rock chute crest. This storage acts as a detention basin to reduce the amount of water flowing directly through the rock chute at the gully head. It also acts as a silt trap and provides a water source for wildlife. Once the dam is full, the by-wash directs water to and through the rock chute. The dam size and design considered the cost and the storage area available without impeding access to the rest of the property. The detention capacity has helped the overall rehabilitation outcome.

All bare and disturbed areas, including tunnels and gully batters, received a gypsum treatment at 10 t/ha. They were then seeded and fertilised to encourage quick and vigorous revegetation. The seed mix included rhodes grass (Katambora and Reclaimer), Bissett creeping bluegrass and millet, with perennial ryegrass as a winter-active cover crop. The paddock had very good stands of pangola grass and para grass that quickly recolonised bare areas. Pangola sod laid on the battered gully walls below the chute at construction established well. The landholder removed all stock from the rehabilitation area.

Adaptations and learnings

With very deep narrow gullies, the cost of earthmoving can prohibit the construction of a conventional energy dissipator apron to the entire width of the chute. At this site, relatively small flows from a small catchment reduced the necessity for a conventional apron.

Using detention or silt trap dams, in conjunction with chutes or other structures, benefits water flow management and the landholder's farm management plans.

Tunnelling along gully edges or near gully heads must be addressed with appropriate management. Applying gypsum can reduce the risk of tunnel erosion in the future.

Use a soil test to determine the correct application rate for gypsum.

When there is a good cover of erosion control grass (e.g pangola) at a site, it is worth the effort to save sod and replant it on the bare batters and construction pads after completion. Saving the sods can avoid the need for mulching and re-seeding. Watering in after replacing the sods is worthwhile if water is available.

When addressing incised gullies leading to a major watercourse, it is essential to consider the impacts of inundation and the ~~likelihood of~~ remediation works when the water recedes. Receding water causes gullies to progress faster than the catchment size would suggest because the gully is the point of concentration for a vast volume of water released from the saturated floodplain.



Construction sequence

Photo 70 Beginning of the shaping.

The rock chute crest was skewed to the south to reduce the earthworks required to form the batter and apron.



Photo 71 Gully head chute shaping completed.

The chute level crest was 7 m across the top and the gully head was battered to 3:1 so the chute batter was approximately 6 m long.

A cut-off trench approximately 0.6 m wide x 0.6 m deep was excavated across the top of the chute crest 1 m up slope from the start of the batter. A second 0.6 m deep V-shaped cut-off trench was constructed across the bottom of the batter and up both sides of the shaped gully.

A 1 m wide x 0.3 m deep ledge on either side joined the top and bottom cut-off trenches, providing a flat surface where rock could hold the geofabric in place during construction.



Photo 72 Chute covered with high clay gravel.

The batter of the chute and the bottom of the cut-off trenches were covered with 10 cm of high clay gravel.



Photo 73 Geofabric placed to cover entire structure.

Geofabric (Texel 400R) was placed over the whole chute area and into the cut-off trenches top and bottom. Geofabric was held in place with small amounts of rock.



Photo 74 Geofabric completed and rock goes on.

The cut-off trenches were filled with a gravel and smaller rock mix to 200 mm over the geofabric first. A rock mix of 100–400 mm was carefully placed and compacted on the geofabric-covered batter and cut-off trenches top and bottom. The bottom of the batter had a higher component of the large 400 mm rock arranged to assist energy dissipation.



Photo 75 Netting fence constructed in bottom cut-off trench.

Heavy wire netting was secured in the bottom cut-off trench to be used later as a weir across the bottom of the structure to hold the last rocks on the batter in place during any large flow or flood events.



Photo 76 Batter gully walls to encourage grass growth.

Both edges of the gully below the structure were battered at 1:1 for approximately 15 m to improve revegetation efforts. Tunnels were excavated, back-filled and compacted before the battering and bank construction was completed.



Photo 77 Construct wing banks to direct flow over rock chute and to prevent creation of new tunnels.

Excess soil was retained and used to construct diversion wing banks at each side of the chute to direct flows over the rock chute. These banks were constructed to 1 m high.

The bank closest to the river continued upslope until the end at ground level was at least 0.6 m above the weir crest height.

The bank on the other side curved around the gully and captured water from the neighbour's paddock that was creating tunnels along that side of the gully wall. The end of the bank was again 0.6 m above the weir crest height.

To prevent banks eroding at the rock chute entry, banks were rock-armoured for a distance of 3 m and height of 0.5 m.



Photo 78 Place large rocks at the base of the chute for energy dissipation.

Due to the steep narrow gully, it was impossible to construct a conventional 2 m wide energy dissipater at the bottom. Larger rock was placed in the narrow gully bed below the netting fence for approximately 5 m to reduce the 'waterfall effect' below the netting and provide some more energy dissipation.



Photo 79 Rock chute complete July 2020.



Photo 80 Construct silt trap weirs in gully floor and plant pangola grass sods.

Two additional netting silt trap weirs were spaced at approximately 0.4 m vertical drops down the gully floor to assist with siltation and revegetation.



Photo 81 Detention dam construction.



Photo 82 Rock chute and dam wall looking upstream after rain. Ground cover is starting to establish.



Photo 83 Gully below chute after rain, showing netting weirs.



Photo 84 Detention dam after first rain event.



Photo 85 November 2020 at the beginning of the first wet season.



Photo 86 May 2021 following one wet season.



Photo 87 February 2022 floods.

Bankfull in the gully system from the Mary River.

Dam full and overflowing.

Ground cover at 100%.

REHABILITATED FAILED DAM SITES

Cut wall and rock mattress

Rehabilitating a dam wall gully site

Rehabilitation type	Rock mattress encased in strong netting.
Description of gully	The dam wall was breached and resulted in a gully.
Catchment size	31 ha.
Flow rate	9 m ³ /s for a 1-in-50 rainfall event.
Landscape considerations/soil fertility	The land type is 'Blue gum flats with deep alluvial, texture contrast soils'; topsoil fertility is good, and the subsoil is sodic with very poor structure
Other considerations	• A suitable disposal area was required for the large quantity of soil moved from the dam wall. • Subsoil was exposed on the creek banks, requiring amelioration to re-establish grass cover. • The creek bed below the structure is very narrow but reasonably stable.
Equipment	5 t excavator and skid steer
Final cost (earthworks and materials only)	\$14,000

Background

This dam wall on a small stream breached, and the repair efforts also later failed, leaving a deep gully downstream. The active gully head was moving upstream towards the dam excavation, which still held at least 2 m of water – a valuable resource for the landholder. The soil is texture-contrast with a loam A horizon and a deep dispersive sodic B horizon. The land type is 'Blue gum flats' at the dam, and most of the dam catchment area is 'Grey box' land type. The catchment delivering to the gully is approximately 31 ha.

The peak flow at the gully head is approximately 9 m³/s for a 1-in-50 rainfall event, estimated using the Rational Method and *Queensland Globe* topographic data.



Photo 88 Break in dam wall prior to work.

Challenges

The gully site is close to the Mary River and is inundated during flood events. The team considered the possible effects of 'draw down' following saturation.

Solution

The design team looked at two options for the rehabilitation of the site. The chosen method was a 25 m wide rock mattress covered with heavy wire netting at approximate natural ground level. This lower cost option provided a level, wide flow path with little or no resistance to spread and slow the flows. The second and more expensive option was a low rock weir 1 m high with a 25 m crest. This option would have increased dam capacity for the landholder.

The landholder's preferred contractor confirmed they could achieve the desired outcome with a 5 t excavator and skid steer.

The position of the rock stockpile and restricted machinery access necessitated that works begin at the upstream end and finish at the outlet end. The contractor spread excess soil over the creek bank, and gypsum applied at 10 t/ha improved soil structure and improved revegetation. Finally, the team seeded and fertilised the site and installed fencing to exclude stock.

Adaptations and learnings

The first adaptation was to modify the width of the cut through the dam wall to imitate the natural shape of the drainage line before the dam was constructed. At the full 25 m design width, the sudden change to a 10 m exit would concentrate the water energy and increase pressure on stream bed and banks below the structure. Narrowing the width to 20 m at the entry, lengthening the rock mattress and shaping it to the natural landscape significantly reduced the erosion potential.

Adding bentonite to the excavation before the gravel, geofabric and rock was a refinement to reduce the potential for seepage under and through the foundations of the structure. The previous failures of the dam wall, regardless of good repair techniques, prompted this addition.

There was a shortage of topsoil to cover the subsoil exposed during excavation. Gypsum applied to the exposed soil improved the soil structure around the site and promoted grass establishment.

Lacing the netting the length of the structure was very labour-intensive, so the team decided to lace the ends of the runs only and to clip the large central section. This saved hours in labour time and still produced a secure netting blanket.

Mixing the rock on site allowed a targeted rock mix coverage of the mattress with fewer gaps and less rock needed.



Construction sequence

Photo 89 Excavation of crest.

The first step was to fill and compact the gully while widening the gap in the broken wall to the design width of 25 m. During construction this width was reduced to 20 m to manage the costs and to complement the original shape and width of the stream bed. The rock chute was constructed longer and flatter to compensate for the width reduction.



Photo 90 Dam wall cut completed to design width.

The constructed gap was approximately 20 m at the upstream end and narrowed to 10 m at the downstream end of the gully cut. The remaining wall either side of the cut was battered back at 1:1. During this process the spoil was spread along the stream bank to above the normal flow height. This was done very efficiently with the skid steer.



Photo 91 Completed upstream cut-off trench with geofabric and inlaid with mesh – which secured the top mesh.

Cut-off trenches at least 0.5 m wide and 0.7 m deep (depth and width of bucket) were constructed on both ends of the levelled cut through the dam wall. Bentonite was broadcast at 10 kg/m² over the top of the whole levelled foundation to provide an impervious base layer to the structure.

Then a 10 cm layer of high clay gravel was spread over the full cut and trenches. Geofabric was laid into the trench allowing 2 m overlap and inlaid with 1.6 mm galvanised mesh. The trench was half-filled with small rock to ensure tight compaction and minimise running water contacting the subsoil.



Photo 92 Layering – first bentonite, gravel, Texcel 400R fabric then rock. Continuous surveying to ensure rock mattress was level across the width.

The layering work started with the upstream section and progressed downstream so the excavator did not travel over the geofabric.



Photo 93 Placement of materials.

The rock used was a mix of 100 mm to 400 mm that was mixed on-site as it was laid. The larger rock first with the gaps filled with the smaller rock.



Photo 94 Netting placed along the batter before adding rock to hold it in place.

Secured netting along the batters to provide the anchor point for attaching the final netting.



Photo 95 Looking upstream – shows the position of netting and rock mattress.

Netting and rock was laid so it extended 1.5 m up the walls of the battered sides to ensure the exposed soil was covered by rock to protect the wall in the event of a deep flow passing through the structure.



Photo 96 Covering the rock mattress with netting and stitching the overlapping lengths together starting at the upstream end.

A length of netting was secured in the bottom cut-off trench as an anchor point and back-filled with rock. Netting strips were placed starting at the upstream end and working downstream, with a half metre overlap. Soft 2.5 mm plain wire was used to lace each end for 6 m, tying off to netting secured in the trenches and along the batter. The remaining distance (10 m) in the middle of the structure was clipped to save time. Clipping alone has failed at other sites.



Photo 97 Gravel placed along the top cut-off trench was then shovelled by hand into the trench to fill cavities.

The laced netting provides robust and secure entry and exit points to the structure where the erosivity is greatest.



Photo 98 October 2020 – after the first rain event.

No damage observed to the structure and some organic deposition – a critical first step in rehabilitation.



Photo 99 Downstream end of the mattress after the first rain event.

Concrete sleepers were used to hold the fence in place. They remained in place following the rain event.

The deposition of some silt in the foreground was of note. Silt captured in the rock and netting will provide some growing medium for grasses to colonise the site.



Photo 100 February 2022 – after major flooding.

Ground cover is well established over the entire site. Livestock remain excluded from the site.



Photo 101 Aerial image illustrating the extent of ground cover over the site.

It is evident that the adjacent paddock has less ground cover due to grazing pressure.

Reinstate natural flow path and rehabilitate eroded areas

Dam by-wash gully site

Rehabilitation type	Dam wall break, gully fill, diversion bank, rock chutes, wide level sill with rock and netting weirs/gabions for stabilisation, siltation and revegetation of sill.
Description of gully	Gully 10 m deep, 20 m wide 75 m long to confluence with tributary of Mary River
Catchment size	134 ha
Flow rate	24.6 m ³ /s (1-in-20 year rainfall event).
Landscape considerations/soil fertility	Dermosol soils on grazing land type 'Blue gum flats on alluvium' with good topsoil fertility
Other considerations	• Cost. • Landholder preference to break wall to return channel to natural flow rather than stabilise gully • Inundation from river during medium to high flow events and associated 'draw down' • Landholder wanting dam filled to prevent cattle becoming bogged • High priority site due to export of significant sediment loads to the Mary River located 1 km downstream and to receiving southern Great Barrier Reef lagoon
Equipment	25 t excavator, 12 t body truck
Final cost (earthworks and materials only)	\$13,000

Background

The dam was constructed in the 1980s, and the by-wash started to erode badly with the first filling rains. The large floods of 2010, 2011 and 2013 completely emptied the dam except for a small excavation which became a bog hazard for stock. The site had deep and active erosion due to a poorly designed and constructed by-wash for the large dam.

This gully delivers sediment to the Mary River, approximately 1 km downstream. The catchment area is 134 ha and is described as a fast-flowing catchment. Medium river floods inundate the gully site. The soils are dermosols on land type 'Blue gum flats on alluvium'.



Photo 102 Aerial view of the site prior to start of works, eroded bywash on left.

The gully is 75 m long, 20 m wide and 10 m deep along the entire length. The peak flow for a 1-in-20 year rainfall event is approximately 24.6 m³/s, estimated using the Rational Method and *Queensland Globe* topographic data.

The landholder did not need to store water at this site, so stabilising the erosion was the principal aim. Two options appeared to have potential.

Challenges

The first and most obvious solution was to rehabilitate the by-wash by stabilising and revegetating the gully bed and banks in the existing alignment. This strategy could include rock groynes along the western edge of the gully, rock-fill at the mouth of the gully and some battering and topsoiling of the gully walls. Although relatively low cost, this option had a high risk of failure due to the inability to economically widen the channel enough to reduce the high velocity from high volume flows through the large catchment. The landholder was also reluctant to try this approach.

Another consideration was proximity to the Mary River. The landholder noted that the site is inundated during flood events higher than 13 m.

Solution

Rather than try to repair the dam by-wash, the team decided to restore the stream flow to its natural path. This option aimed to deal with the water volume and velocity by removing most of the old dam wall and creating a broad, level waterway with an original design width of up to 55 m. The shallow water would flow along the path of the original stream. The 55 m design specification was considered impractical and too expensive due to the very narrow and deep stream shape directly below the dam wall.

After careful consideration and recalculations, the team adopted a bottom-level sill width of 25 m. This option, although not ideal, more than doubled the existing flow width through the gully line and completely removed water flows through the actively eroding by-wash.

The small waterhole was filled with soil removed from the dam wall, pushing the water out the by-wash. More soil from the dam wall was used to seal off the current by-wash by extending



Photo 103 Looking upstream along the eroded by-wash.

the dam wall. The gully walls were battered and topsoiled for revegetation. This option required the movement of a large amount of soil (approximately 3000 m³). In consultation with the contractor, the team decided that a single 25 t excavator and a 12 t dump truck would be the most efficient way to move the soil around the site – a distance of 25 to 100 m.

Stabilising the freshly exposed level sill underneath the existing dam wall involved four wire netting-encased rock weirs (purpose-built gabions) evenly spaced apart using rip rap rock 100–200 mm. The cost of a full rock and geofabric mattress over the exposed soil was outside the budget potential of the project. These weirs reduced back water pressure and reduced water velocity through the structure.

The final level sill cut through the dam wall was 25 m by 25 m. The batters on the dam wall excavation at each side were approximately 1:1, similar to those used on many road cuttings. The base of the batters on the upstream end was rock-armoured up to 1.5 m above the level sill floor to reduce the chance of erosion of the inlet sides during high flows.

The site was fenced to exclude stock. Bare areas were seeded with Rhodes grass (Katambora and Reclaimer), Bissett creeping bluegrass, perennial ryegrass and pangola.

Adaptations and learnings

With this project, modifying the width of the designed dam wall break reduced the cost of construction and better matched the natural depth and width of the stable stream bed below the structure. Extended rock work addressed the risks associated with the increased depth of flow.

Eliminating the ponded water removed the bog potential for livestock.

Instead of a full rock mattress over the excavated level sill, four rock gabions encased in netting, rock armouring of the edges of the cut and the upstream end of the excavated opening in the dam wall secured the site. The rock work extended up the batters to above the expected design flow depth. Observations following significant rain events indicate no compromise on structure capacity to manage significant flow events.



Photo 104 Standing on the dam wall looking into the by-wash, for size perspective.



Construction sequence

Photo 105 Excavation through wall half completed.

Surveyed to ensure water will flow through the level sill and not pond upstream.



Photo 106 Draining the waterhole and backfilling with excavated material from the dam wall.

A small channel was excavated from the waterhole to the by-wash. Material from the dam wall excavation was used to fill the waterhole, pushing the water out through the excavated channel.



Photo 107 By-wash end sealed, creating an extension to the old dam wall. Diversion bank constructed to redirect overland flow.

Soil was transported to form a bund wall across the failed by-wash. All water is diverted back into the original drainage line through the constructed dam wall break.

A 0.6 m high diversion bank was constructed to run parallel with the by-wash on the western side. This aims to redirect overland flow from the flats to a small rock chute.



Photo 108 By-wash gully walls battered and topsoiled.

The vertical edges of the eroded by-wash were battered to 1:1 and then covered with the topsoil that was removed during battering.



Photo 109 Small gully on the end of the by-wash stabilised with rock-fill chute (using locally sourced larger rock and gravel).

A small gully on the north-western end of the gullied by-wash was also filled with rock and topsoiled so all eroded sites around the gullied area were stabilised during the construction.



Photo 110 Rock weirs evenly spaced along the excavated site.

Four rock weirs were positioned evenly along the excavated channel. They were 30 m in length, extended 1.5 m up the batter and were 1 m wide. Rip rap rock (100–200 mm) was used. Each weir was wrapped in galvanised wire netting to hold the small rock in place during flow events.



Photo 111 Completed: Looking downstream on the cut through the dam wall.

Batters at approximately 1:1. Cut through dam wall is dead level back to front and side to side. Rock armouring to 1.5 m on the batter inlet edges and extensions of the weir ends up the batter reduce the chance of erosion during high flow events.



Photo 112 Completed: Looking upstream through the cut in the dam wall that reinstates the original flow path.

Note retention of grass below the rock ~~groynes~~ to ensure as much stability as possible as the flow concentrates again to join the narrower stream below.



Photo 113 Completed: from the top rock chute captures water from overland flow.

- filled by-wash end
- filled and levelled waterhole
- surplus rock for any repairs
- reinstated flow path with rock weirs.



Photo 114 Completed: looking down the old by-wash.

Note the filled by-wash entry point on the right. The diversion bank in the foreground directs flows off the flats and down the rock chute.



Photo 115 Completed: looking from the rock chute constructed to take the water from the flat down to the stream bed.



Photo 116 Completed August 2020.

Note the position of the diversion bank along the by-wash top bank to divert water from the flats.

To ensure further gullying does not occur at the end of this bank, the landholder will need to be vigilant in sealing any signs of rilling.



Photo 117 May 2021 – post wet season.

Nine months since construction. Some rilling has occurred over the wet season. More grass seed was applied to the exposed areas.



Photo 118 February 2022 – mid wet season.

There was no significant damage to the structures following the 2022 floods. Most of the site has grass cover. The batters on the dam wall cut are still bare but stable.

Overland flow from the flats broke the diversion bank on the downstream side of the by-wash bund and caused some erosion. The landholder will extend the diversion bank to again take the flows down the rock chute on the upstream side of the bund wall.

GEOFABRIC DROP STRUCTURE SITES

Drop structures are rarely used but are an option for sites where machinery access is limited. The aim is to create a stable waterfall so the gully head cannot advance further up the depression floor. These structures can be fashioned most economically out of geofabric such as 'Texcel 400R' and 'Texcel 600R'.

It is necessary to calculate the peak flows at the site to design the length of the crest of the drop structure, reducing flow depth and velocity wherever possible. The design methodologies described earlier are applicable to drop structures.

As with rock chutes the crest of the drop structure needs to be constructed to design width and level (if achievable at the site). A top cut-off trench is essential and a bottom cut-off trench and wing walls are highly desirable.

Following construction of the cut-off trench to design width, the geofabric can be secured around the crest and draped over the face of the head and into the gully floor below. Fold the fabric ends back over the trench after it's filled, facing downstream, and peg it down with the pins to ensure the water travels over the fabric. A stilling pond, apron or energy dissipater is necessary to prevent undermining the gully headwall. When using geofabric, the stilling pond can be covered with the bottom of the fabric strips and secured in a narrow, deep cut-off trench at least 2 m downstream of the gully headwall.



Geofabric drop structures are a low cost-alternative to rock chutes but are not always a suitable option (refer to Table 1).

Drop structure using small earthmoving machinery, geofabric and some rock

Scrub gully site

Rehabilitation type	Geofabric drop structure with rock cut-off trenches
Description of gully	Gully 2.5 m deep, 4 m wide 30 m to confluence with Mary River
Catchment size	13 ha
Flow rate	3.3 m ³ /s (1-in-20 year rainfall event)
Landscape considerations/soil fertility	Dermosol soils on grazing land type 'Blue gum flats on alluvium' with good topsoil fertility
Other considerations	• Cost • Landholder preference to use smaller earthworks machinery to reduce impact on pasture • Inundation from river during medium to high flow events and associated 'draw down' • Minimise removal of the well-established, stoloniferous grass cover • High priority site given proximity to downstream Mary River. Need to reduce movement of fine sediment into the southern Great Barrier Reef lagoon
Equipment	5 t excavator, skid steer
Final cost (earthworks and materials only)	\$3000

Background

This site is a short steep gully leading away from the bed and banks of the Mary River and is close to a gully described in section 2.3, treated with a gully head rock-fill chute structure. The soils are alluvial texture contrast with approximately 0.3 m loam topsoil and a deep dispersive clay subsoil. The land type is 'Blue gum flats on alluvium'. At construction, a vigorous Bisset creeping bluegrass stand provided good ground cover. The gully head was 2 m deep and 4 m wide, grading to a depth of 4.5 m at the stream bank. The peak flow from the 12.5 ha catchment for a 1-in-20 year average recurrence interval (ARI) is 3.3 m³/s, estimated using the Rational Method and *Queensland Globe* topographic data.

Challenges

This site becomes inundated in medium to major flood events. The narrow, deep gully shape limits the crest length and restricts access to the gully floor. There was insufficient room to accommodate a rock chute and farm vehicle access.



Photo 119 Gully head March 2012.

Solution

A geofabric drop structure was the low-cost treatment chosen for this site. From the peak flow estimation, a crest length for the drop structure was designed at 16 m to reduce the flow depth significantly. The crest shape is a narrow crescent, and the natural landscape features helped form the wing walls.

The site was fenced to exclude stock and seeded to allow the maximum potential for revegetation of all disturbed areas.

Adaptations and learnings

Many small geofabric drop structures have been constructed in the Mary catchment using manual labour only. Using machinery at this site saved considerable time.

The team constructed the narrow cut-off trenches and pegged down the geofabric manually at other sites. Using machinery to place the rock and dig a wider cut-off trench was time efficient and resulted in a stronger, more resilient finish.

Placing rock in the bottom cut-off trench and below created a functional energy dissipation area in the structure.

Surveying the wing walls to convey the water over the structure ensures the flow doesn't outflank the structure.



Photo 120 Gully head prior to rehabilitation in 2020.



Construction sequence

Photo 121 Shaping the gully head and removing any overhangs and grass sods.

The 16 m crest was levelled to a width of 1.5 m while removing the topsoil, any overhangs and the grass from the gully head and walls below the crest.



Photo 122 Excavated top cut-off trench and geofabric shaped over the gully head.

A cut-off trench was constructed 0.5 m by 0.5 m, 1 m upstream from the lip of the gully head. A similar cut-off trench was constructed across the gully bottom and up the sides to meet with the ends of the top trench.

The top trench, the exposed subsoil lip around the level crest, the gully bed and bottom cut-off trench were lined with the geofabric (Texcel 400R). A single sheet of 6 m wide geofabric was stretched and arranged to create a smooth curtain over the gully head and walls.



Photo 123 Top cut-off trench filled with rock.



Photo 124 Top and bottom cut-off trenches and side wall trenches filled with rock.



Photo 125 Covering the cut-off trench rock-fill with topsoil to encourage revegetation.

At this site there was excess rock available, so it was spread over the gully floor and walls and below the bottom cut-off trench.



Photo 126 Drop structure completed – looking upstream.

The soil taken from the gully head shaping and cut-off trenches was used to cover the top cut-off trench rock-fill to encourage rapid grass growth.



Photo 127 Drop structure completed – looking downstream.



Photo 128 February 2022, after major flooding in the area.

The wing wall on the left of the gully was repaired with logs and small rock. The repairs remained intact following the 2022 floods.

Geofabric drop structure using hand tools only

Front gully site

Rehabilitation type	Geofabric drop structure (without machinery)
Description of gully	Gully 1.2 m deep, 6.2 m wide
Catchment size	6.05 ha
Flow rate	1.3 m ³ /s (1-in-20 year rainfall event)
Landscape considerations/soil fertility	Open blue gum with good stand of setaria and Rhodes grass ground cover; gently undulating topography
Other considerations	• Human resources and experience
Equipment	• surveyor's paint • brush cutter, chainsaw (to remove exposed roots / saplings), axe • spade, grubber, crow bar, post rammer, mallet • fabric scissors, wire cutters • ladder (for deep gullies >2 m)
Materials	• geofabric 2 m wide (400R as a minimum, 600R offers more strength) • star pickets (165 cm) and caps • heavy gauge galvanised wire chicken mesh • soft pliable plain wire • tent pegs and fabric pins • grass seed, gypsum, fertiliser
Final cost (earthworks and materials only)	\$700 + labour

Background

The gully is located on a property in the Wolvi district, east of Gympie. The property drains to Coondoo Creek in the easternmost sub-catchment of the Mary River. The catchment has a shallow, sandy topsoil over dispersive subsoil.



Photo 129 Gully head before rehabilitation. Note cattle tracks running parallel with the gully system.

Excluding livestock from the site allowed *Setaria* and *Rhodes* grass to establish and provide good ground cover. The gully was approximately 200 m long, averaging 2 to 4 m wide and 0.5 to 1 m deep at the gully heads. There are multiple gully heads along the gully system. The site chosen for the geofabric drop structure had a broad, shallow gully head. There were multiple cattle tracks on the sides and along the gully crest. The intention was to ensure the drop structure included the cattle tracks to protect the banks from the natural water flow. The peak flow from the 6 ha catchment for a 1-in-20 year ARI was 1.3 m³/s, estimated using the Rational Method and *Queensland Globe* topographic data.

Challenges

During prolonged periods of rainfall, paddocks become saturated, and pugging occurs. Further gully problems can occur if the pugging starts to disturb the subsoil. Previous management had allowed livestock to roam over and through the gully system, causing multiple cattle tracks and smaller gully heads. Despite excluding livestock and constructing some porous check dams, which assisted with ground cover recovery, gully heads were slower to repair.

Solution

A geofabric drop offers a quick and cost-effective solution for sites with a small catchment area and low flows. This technique protects the gully head from overland flow and seals the subsoil with geofabric. It is essential that the material remains in situ and that flow events do not undermine the structure.

The crest length depends on the characteristics of the gully and the topography surrounding the gully head. As a general rule, the structure should cover the actively-eroding gully head and margins and incorporate any areas that concentrate flows (e.g, cattle tracks). Geofabric drop structures are a low-impact method using hand tools only. It is a good idea to calculate the gully's ideal crest length. This gully would require a level crest length of at least 11 m to maintain the flow rate downstream of the structure at 1 m/s or less. This gully structure was offset slightly to accommodate the gully head, which was lower on one side and had increased flows coming from the adjacent paddock.

After completion, the site received significant rain, over 650 mm in five days in an already saturated catchment during 2022. The structure held in place and prevented any advancement of the gully head.

Adaptations and learnings

Choosing a site

- Smaller catchments (<10 ha) work best. It is worth trialling in larger catchments, but be prepared to undertake more maintenance activities.
- Geofabric drop structures may work on a river bank, but if the site is inundated, repairs will be required. Be prepared to lose materials and ensure pickets are installed along the bottom of the structure to prevent excessive movement of the fabric if inundation is likely.
- Constructing a series of porous check dams downstream can help slow water velocity, allowing sediment to settle and providing an environment suitable for establishing ground cover. For more information, refer to Section 5.1 of *Gully Erosion: Options for prevention and rehabilitation; Experiences from the Burnett and Mary River catchments, Queensland* (Day and Shepherd, 2019).
- Where a gully system has multiple gully heads, target the section with the most rapidly moving gully head. Measure gully head movement before and after a wet season. Exclude livestock from the area and consider trying the easiest gully head first.
- If possible and safe, observing water flow over the gully head during a decent rain event can help plan the structure's placement.

Materials

- Use soft, pliable wire for joining the fabric and high tensile wire between the pickets to tension the mesh.

- A thicker geofabric is ideal (e.g. 400R or 600R). Use only UV-rated fabrics; otherwise, exposure to the elements will reduce the structure's lifetime significantly. Narrower width geofabric (2 m) is best for these structures because the rolls are easy to handle without machine assistance.

Preparing the site

- Remove any trees in the base of the stream and poison them to avoid regrowth. Constructing around trees can work; however, floods can dislodge a tree and cause it to fall, lifting the structure.
- Use a chainsaw to cut any large roots projecting from the gully walls.
- Always include cattle tracks where possible.
- The crest length is always the most critical decision. Ensure the crest length includes all the most-eroded bank, and a bit more.
- Despite calculating the ideal crest length for the flow, since it is not a 'level' crest, water will concentrate at one or two locations. Ensure the trench is deep enough to hold the fabric at these locations, which are the weakest points of the structure.

The trench

- Place some off-cut material along the length of the trench and stockpile soil on these so it is not lost in the grass.
- Allow plenty of time to dig the trench. Four people might take two hours going steady to dig a 10 m crest if the ground is hard.
- Very highly dispersive soils will require extra gypsum along the gully bed and bentonite in the trench area to prevent tunnelling.
- Keep some soil for broadcasting with seed and fertiliser over the structure to fast-track grass establishment.

Placing and securing the fabric

- Never put a fabric join in a concentrated flow section.
- Ensure the centre fabric has plenty of overlap because this is where the water will concentrate.
- Stitch all joins in the fabric securely, ensuring the flap is facing downstream. Soft plain wire is easy to use, and is strong and durable. Use a sharp tool, such as small-pointed scissors or a scribe, to make holes in the fabric for the wire.

Star pickets

- When ramming the pickets, there will be uneven tension along the wire. Ram the pickets in small amounts, working from the centre outwards to the flanks to avoid breaking the wire.
- Where it is anticipated that large debris might come down in flood events, cut the star pickets to prevent excess material from accumulating behind the pickets and acting as a dam. When this happens, water outflanks the structure and can erode a bank further downstream.

Maintenance of structure

- Regular monitoring is essential, especially following flow events.
- Ensure early removal of woody vegetation growing on the structure to prevent large holes from forming in the fabric.
- Encourage stoloniferous grasses to grow over the structure. In the spring, broadcast some fertiliser over the structure to encourage grasses to reach in over the fabric.
- Clear any debris behind the pickets as soon as possible after a flow event to prevent water from diverting to an exposed bank downstream.
- Mend any holes in the fabric by 'stitching' a patch over the tear. Keep some fabric for this purpose.
- Rectify any further gullying downstream as soon as possible. In the early stages, a little spade work and log diversion lines can reduce or prevent further erosion.
- Exclude livestock.



Construction sequence

Photo 130 Dig cut-off trench, following the natural shape of gully head and including the cattle tracks.

Mark out the position of the structure, considering concentrated flow paths and including cattle tracks etc. Dig trench 1 m from the crest edge, to the depth of the spade (approx. 30 cm).

Place the fill on geofabric offcuts (this makes it easy to retrieve later).



Photo 131 Geofabric cut and placed over trench and into gully bed.

Cut the geofabric to length. The fabric should start almost at the centre of the gully floor and extend up the walls and into the trench. Cut the geofabric approximately 1 m past the trench to allow enough fabric to double back over the trench once it is filled.

Overlap the fabric starting with the outside layer first, working to the middle. The final middle section should cover the ends of side pieces and cover the length of the gully floor to create a continuous mat.



Photo 132 Backfill the trench with spoil and compact.

Back-fill the trench with spoil and compact as much as possible. Make sure to not overfill as this could divert water away from the structure.

Fold the fabric back over the filled trench, facing downstream.



Photo 133 Mesh secured along the crest and joins stitched.

Lay mesh along the crest, folding pleats to follow the shape with the gully. Peg down the mesh and fabric every ~0.5 m using tent pegs or fabric pins.

Drive star pickets through the edge of the mesh and fabric, into the trench, every 1–2 m.

Stich all the joins of the geofabric with soft wire, securing to the mesh at the top and a tent peg at the bottom of the structure.



Photo 134 Tension wire around the crest.

Spread soil and seed over the fabric and bare areas.

Thread a stronger gauge plain wire through the pickets and secure to the picket at each end. Carefully hammer in the star pickets to tension the wire. Without care, the wire can easily snap.

Lightly spread the remainder of the soil onto the fabric and seed with annual grass such as millet in summer or ryegrass in winter. Plant pangola runners in any areas of moisture-holding pools or low points in the gully bed.



Photo 135 Completed October 2019.



Photo 136 February 2021 monitoring, following two wet seasons.



Photo 137 February 2022 post floods.

Summary

This guide outlines several gully remediation works completed to repair serious erosion that occurred during the exceptional flood events through the Mary Valley in recent years.

Each site required careful assessment, design and construction. The examples in this guide illustrate the importance of a holistic approach to gully remediation that 1. seeks to halt the progress of an active gully head and 2. addresses land management practices that have contributed to the formation of the gully.

The project team have shared their considerable experience and demonstrated the value of continuous learning and problem-solving as each site posed its own set of challenges.

Rock chutes were commonly the most practical solution for both drainage line gullies and eroded dam walls and by-washes. At some sites, geofabric drop structures were the preferred solution.

Once construction was complete, on-going maintenance and repair after high flow events was critical for success. In most cases, the establishment of good ground cover and the exclusion of livestock was necessary to fully restore the site and maintain productivity.

Bibliography

Carey BW, Stone B, Norman PL, Shilton P (2015) *Soil conservation guidelines for Queensland*, Department of Science, Information Technology and Innovation, Brisbane.

Available online : <https://www.publications.qld.gov.au/dataset/soil-conservation-guidelines>

Day, John and Shepherd, Bob (2019) *Gully Erosion: Options for prevention and rehabilitation; Experiences from the Burnett and Mary River catchments, Queensland*.

Available online : https://bmrq.org.au/wp-content/uploads/2019/08/BMRG_Gully_Erosion_Manual.pdf

Queensland Globe. Available online : <https://qldglobe.information.qld.gov.au>

RAMWADE (RAtional Method WAterway DEsign) tool (version 7, April 2016), Queensland Government, Brisbane.

Available online : <https://www.publications.qld.gov.au/dataset/soil-conservation-guidelines/resource/e9316dcc-0c06-41a4-a7e9-deeb15345c70>

Rock Chute Design Data spreadsheet, USDA Agricultural Research Service (updated 2023).

Available online : <https://data.nal.usda.gov/dataset/rock-chute-design>

