Rehabilitation of Erosion Gullies

Adaptations and Learnings from the Mary River Catchment

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Mary River Catchment Coordinating Committee

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Foreword

Erosion is an ongoing process which all land managers need to 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. Readers are advised to consult this publication to gain an overview of erosion control across many situations.

In the Mary River catchment, there has been six years of works to reduce fine sediment to the southern Great Barrier Reef, resulting in new learnings on how to effectively rehabilitate gully erosion. This extended and focused period of work has formed the basis for the information provided in this guide. The authors have worked as a team on all of the projects showcased in this guide and through a process of continuous learning have adapted and refined erosion control practices to try and create the best possible, cost-effective rehabilitation and stabilisation outcomes for the region's landholders and downstream water quality.

The work on erosion control will continue and the learning will continue. The team hope that their combined 30+ years' experience and observations provided in this guide can give others a good head start on their soil erosion management journey.

1 Introduction

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 groundcover through sound pasture management including forage budgeting is the most resilient and cost effective first step in reducing the potential for gully erosion to occur particularly in fragile landscapes.

Project participants agree groundcover should be the highest priority in fragile gully landscapes. Groundcover can be difficult to manage given the light nature of the country but is super essential or the place just falls apart.

1.1 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.

Gully formation can be closely linked to soil types and situations where the topsoil is denuded and the erosion prone subsoils are exposed to direct contact with rain drop splash and water flows. Erosion prone soils have a tendency to “dissolve” or disperse and slump very quickly when in contact with water. This is referred to as dispersion and slaking. A dispersion test (placing a large ped of soil in a jar of water) provides some indication of the degree of sodicity or propensity to slake.

All soils are made up of minerals, sand, silt and clay, water, organic matter, microorganisms and gas. All these elements are arranged in various amounts and textures which affects the way the soil responds to erosive forces. Very sandy soils allow the water to infiltrate down through the profile to deep drainage and don’t result in runoff from the soil surface. The soils with clay at the surface will not allow water to infiltrate as quickly and will have water running off the surface in heavy rainfall events. Some clay soils crack deeply and it will take a long time for runoff to occur unless there is very heavy rain which will seal the cracks and cause quick runoff. Soils with high silt content at the surface often set very hard and will result in extensive runoff during intense rains. These soils tend to scald when vegetative cover is lost from the surface. As a general rule, soils with a hard setting surface and a high sodium content in the sub soils, described as sodic soils or sodosols, are very prone to erosion. They will disperse and slake on contact with water. The heavy black and brown clay soils are prone to slaking and dispersion as well, although they are often very productive soils. The soil texture, organic matter and chemical makeup will affect the way erosion develops, so it is wise to get a soil test on eroding soils to help define the best solution to stabilise and prevent more erosion. Detailed soil type descriptions can be found on Queensland Government WEB sites if you search “common soil types in Queensland”.

Most soil will eventually have water running off during extended or intense rainfall events and as water is concentrated in a narrow pathway between grass tussocks or insect and animal trails, the velocity increases which in turn increases the erosive force which cuts deeper and deeper into the soil.

If the subsoil is exposed and it is dispersive or slaking, then the turbulence tends to cause the sub soil to dissolve quicker than the topsoil. The topsoil may still have grass growing in it on the edges of the initial bare soil patch. Often small waterfalls develop which again increases the speed and size of the erosion event (see Figure 1 below). This process continues, deeper and wider, forming the gullies we see in our landscapes.

Soil formation rates are quite slow and gully erosion dramatically accelerates the rate of soil loss from a landscape. 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.

If an erosion path has developed to a depth exceeding 0.3 metres (m) and has active erosion at the head and walls, it can be classed as a gully.

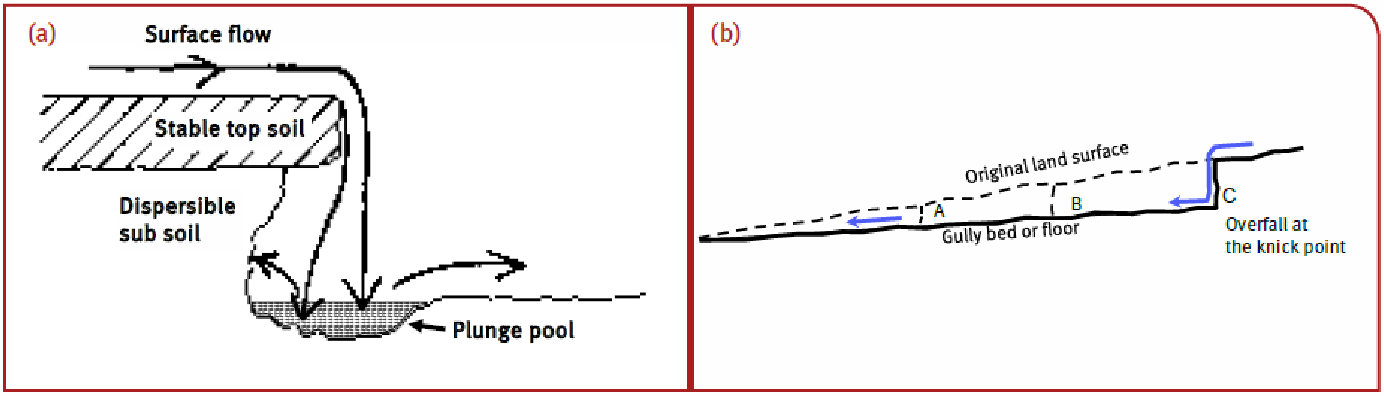

Figure 1 Gully advances – (a) gully head development; (b) changes in height and bed slope as the gully advances upslope. (From the Queensland Soil Conservation Guidelines, Ch. 13).

1.2 What influences gully erosion?

As mentioned earlier, gully erosion is influenced by rainfall intensity and duration, wind, hail, ground cover, vegetation type, soil type, soil condition and land slope. All these factors can affect the initiation of gully erosion and the rate and extent to which the gully erosion expands in a natural, unchanged situation. Human activities associated with modern civilisations also affect all soil erosion processes, including gully erosion.

1.3 Gully catchment water flow estimations

When considering a gully erosion site, of critical importance is the amount of water which is running through the gully during rainfall events of differing durations and intensities. This is directly influenced by the size of the catchment, land slope, vegetation type and vegetation cover levels on the catchment and the rate at which the soil naturally allows water infiltration. For example, gully sites are most prone to erosion following periods of extended drought when there is minimal groundcover. Calculations are therefore regularly based on this scenario.

Calculations can be done to estimate the peak flows from any given catchment by using the Rational Method, charts and descriptions provided in the Soil Conservation Guidelines for Queensland, Chapters 3 and 13 and the Appendix. A supporting spreadsheet 'RAMWADE Flow Tool Calculator' is also available to help with calculations (https://www.publications.qld.gov.au/dataset/soil-conservation-guidelines/resource/e9316dcc-0c06-41a4-a7e9-deeb15345c70). It is important to 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 then design suitable structures to assist with the rehabilitation and stabilisation of the site. Once again, it is important to have an experienced technical officer to assist with the design of structures which need to accommodate the peak flows from the catchment.

If it is not possible or economic to get professional technical advice on the peak flows and design widths of rehabilitation options for erosion sites, a fall-back position is to take notice of the largest flows you have witnessed through any of the gullies on your property. The depth of the highest flow through a 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 0.6m across the gully width of 5m, you will have a cross section of 3 square meters of water (m^2). See Figure 2 below.

Figure 2 Example of gully flow width and depth

If we consider that the water is flowing at a certain velocity, then we can work out volume. Most gullies will flow between 1 and 2 meters per second (m/s) depending on the steepness of the gully floor and other factors like roughness or vegetation in the gully floor. The velocity can be estimated by measuring the distance a floating object travels in 1 second (or 10 seconds, then dividing the distance by 10) to get the velocity in m/s. The water in the middle of the gully will be flowing the fastest so it is wise to measure an object floating in the middle of the gully. If the water in the gully at approximately the highest point of the flow is travelling at 1.5m/s, then for every second a wall of water 1.5m multiplied by the cross section area of $3m^2$, is flowing past. The result of this multiplication is 4.5 cubic meters per second (m^3/s), which is the volume of water which is flowing through our example gully at the approximate highest flow in a higher than average rain event.

If we want to manage this water, we need to 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 velocity in a stream or gully, we need to reduce the depth of flow.

The wider and shallower the water flow, the less velocity and less likely to erode. A rule of thumb is to keep the flow depth at around 0.3m and this will generally keep the velocity within a range that is normal for most streams at around 1m/s.

There are a lot of variables which 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. By increasing the design width of our structure, the depth of flow will be reduced to safely carry our $4.5m^3/s$ of water. A complex set of factors affect the outcome, but reducing the depth to 0.3m and widening the path, reduces the chance of erosion. Using calculations described in the Soil Conservation Guidelines for Queensland for waterways in cropping, and weirs for gully chutes, the crest width needed to convey $4.5m^3/s$ of flow, at the safer velocity around 1m/s, is between 17m and 19m.

This exercise is to provide an idea of the complexity of the design process. To get a suitable width, both the depth of flow and velocity change, so it is not just a simple exercise of putting in a new depth of flow and multiplying the sum out. As the depth reduces, the velocity reduces also, so we have two variables interacting which requires complex maths or trial and error calculations. Having someone to assist with the final design using the graphs and spreadsheets which have been developed for this purpose, will improve the accuracy of the outcome and reduce the chance of costly blowouts and structure failures.

1.4 How to decide what to do with an erosion site with gully potential

An erosion site can always be initially managed through stock exclusion fencing to achieve optimal groundcover. Before undertaking further remediation the following is considered: size of the eroded gully, position in the landscape and the catchment delivering water to the site. The next step is theorising what remediation methods may work best at the site. The decision process described in Table 1 may provide some options for those with limited experience at developing remediation strategies for erosion sites.

Soil type should be considered, however if you have erosion problems it is highly likely that the soils are either slaking or dispersive. The most important distinction is the inherent fertility and water holding capacity of the soil. If the soil is a cracking or uniform clay in open downs, Brigalow or Scrub land types, the potential for quick revegetation will be higher than duplex soils on a spotted gum or Box land type. Soil tests can show if soil modifiers, such as Lime or Gypsum, are needed to improve soil structure and chemical balance. These considerations can be addressed at each site before decisions on remediation options are investigated.

Table 1 Erosion remediation methodology decision process

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

Larger deeper gullies with catchments above 10ha		Include fencing and spelling	Include fencing and spelling	Include fencing and spelling	Include fencing and spelling	Include fencing and spelling
	Contour or graded stick rake lines to slow and divert water. Fencing and spelling.	If catchment peak flows below 3m^3/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, seed, fence and spell.	Gully head rock fill with designed crest width and rock size. Could consider using geofabric to construct a design width drop structure.	Gully head rock fill with designed crest width and small rock enclosed in strong netting.	Fully designed rock chute with designed rock size.	Rock chute designed using gabion rock baskets.
Dam by-wash erosion	Include fencing and spelling	Include fencing and spelling	Include fencing and spelling	Include fencing and spelling	Include fencing and spelling	
	Gully head rock fill with designed crest width and rock size.	Gully head rock fill with designed crest width and small rock enclosed in strong netting.	Fully designed rock chute with designed rock size.	Rock chute designed using gabion rock baskets.	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.	
Sheet, rill and gully erosion in cultivation land			Include minimum and zero tillages	Include minimum and zero tillages		
	Return the paddock to improved permanent pasture with legume inclusion and manage grazing for high cover.	Use minimum and zero tillage and suitable high stubble crop rotations to maximise ground cover at all times.	Design and survey a contour bank and waterway system with double width bank spacings.	Design and survey a contour bank and waterway system with single width bank spacings.		

2 Gully Erosion Control using Rock Chutes

Rock chutes properly designed, installed and maintained may be the best option to provide more permanent gully remediation in situations where the erosion site cannot be recovered using the low cost options alone. These options have been identified 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). When it is critical that a gully head is stopped to protect infrastructure or valuable resources, a rock chute can be a complete and permanent solution. Rock chutes are very versatile as vegetation will readily cover the structures which adds to their strength and permanence.

Rock chutes can be constructed using gravel, rock of an appropriate size and some geofabric on a shaped soil slope. Geofabrics which have been used in the construction of rock chutes are Texcel and Bidim. These can be ordered in the strength required to suit the size of rock you need to use on the chute. In soil types that are less dispersive and when the peak flows are lower, the geofabric can be an option rather than a necessity every time. Red soils and some brown clays are examples of soil types which can perform with gravel and rock alone when the rock is a good mix of sizes and compacted well.

It is essential all sites are fenced to ensure good groundcover establishment and regeneration providing long term site stability.

2.1 How do we go about designing a rock chute?

The basic shape for rock chutes is shown below. The crest can be positioned to accommodate the natural landscape for minimal disturbance above the gully head. For example, they don't have to be symmetrical, as long as the crest meets the design width and is constructed level. On completion of the chute structure, it is essential sites are excluded from stock, seeded and fertilised to promote rapid site recovery.

Rock chutes and similar engineering structures need to have a rigorous design process taking into account the hydrological calculations which estimate the peak flows during rain events of a particular intensity. Once the water flows are estimated, the structure can be designed to manage those flows. The main components of the rock chute 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 which is kicked up to pool and take the energy out of the water before it flows on down the gully floor. See Figure 3.

Another consideration is the size of rock required for stability in the chute given the velocity of the water expected through the chute. To overcome the necessity for very large rock, the rock can be secured by covering the chute with strong netting stitched with plain wire or by using gabion baskets.

One methodology for the calculations and designs can be obtained from the Soil Conservation Guidelines for Queensland (2015). The spreadsheet called RAMWADE found in the Guidelines can assist with peak flow calculations, waterway width calculations and diversion bank size calculations. Another spread sheet available as freeware from the internet is CHUTE. This spreadsheet will assist with specifying the size of rock needed for a given peak flow, chute crest width and batter length. Both spreadsheets are free 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 given a peak flow, is available in the Guidelines and can be converted to a spreadsheet as well.

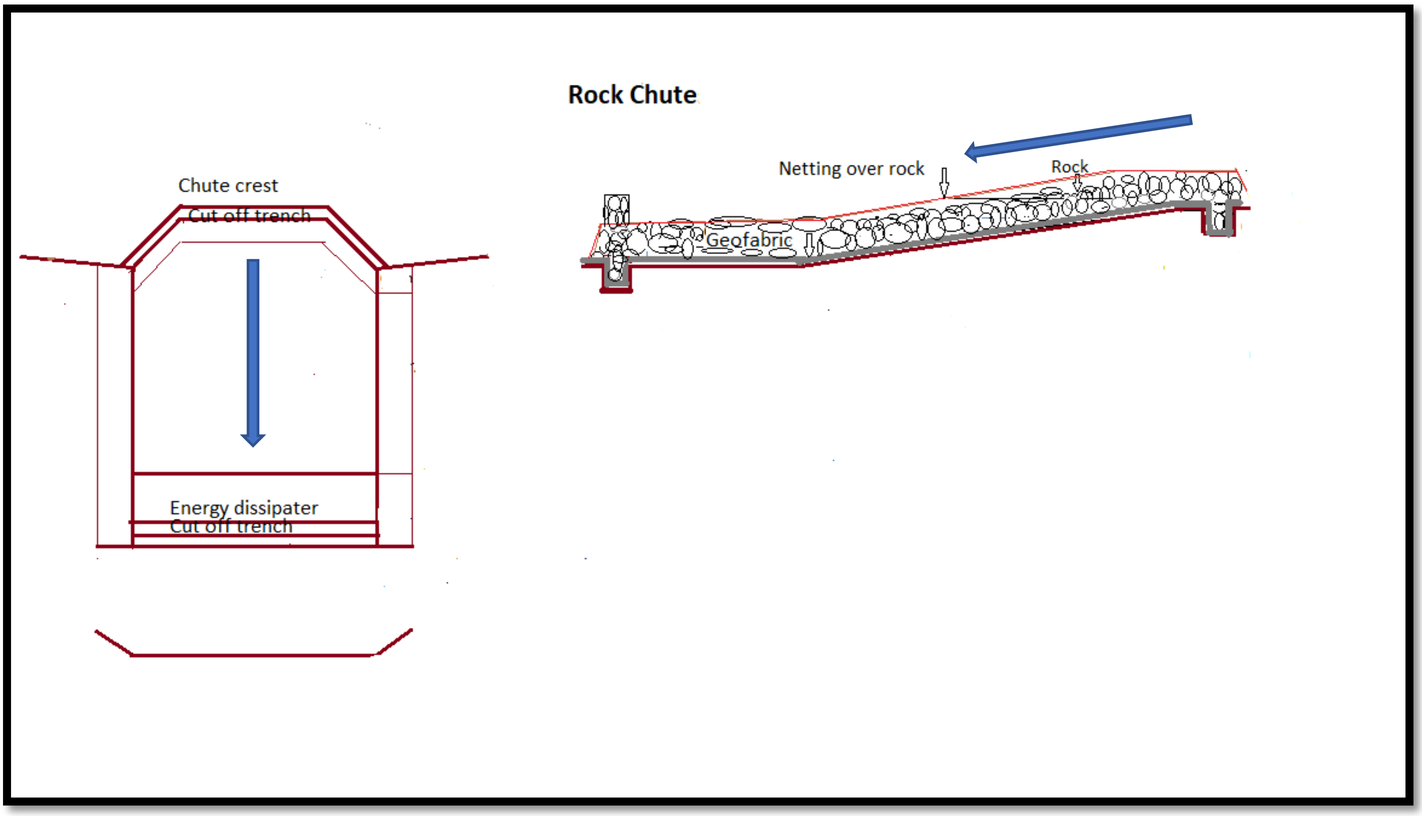

Figure 3 Example rock chute design – (left) aerial view; (right) cross section.

2.2 Critical components of rock chute design, construction and maintenance

- Estimate the water volume and water flow velocity entering the gully head and proposed chute.
- With the water volume, velocity and gully head cut depth, calculate the desired crest width and length of the chute. The batter often used is 3:1 or 4:1 i.e. if the gully head is 1m deep, the chute batter length will be 3m or 4m as required. The longer the batter the better, as this reduces the water velocity in conjunction with the width. Up to 10:1 can be used if resources allow i.e. for wide crests and long batters, smaller rock can be used. Note however that the total rock required will increase along with 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 tightened with heavy gauge plain wire and steel pegs. Gabions are also an option in this situation.
- Shape the gully head to the specifications of the structure needed i.e. construct the crest width, batter and apron length as per the calculated design specifications. This data is usually supplied in a Diagram (see Figure 1 above). Ensure the top bench of the chute crest is excavated deep enough to allow the size and depth of rock needed.
- 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 prior to laying the rock.
- Have rock supplied in the designed size and stockpiled close to the chute. Where specific large rock size is unavailable, smaller rock can be used with installation of heavy gauge wire netting over the structure which serves to hold rock in place during high flow events. Without this netting, the structure is likely to fail. It is also useful to have additional rock delivered for further 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.
- Ensure the energy dissipation apron is constructed correctly with larger rock and a rise of at least 0.3m on the bottom lip (see Figure 3 above).
- Carefully compact rocks into place on the batter if possible and where geofabric is used, great care must be taken to ensure fabric is not damaged.
- Fencing and stock management
- Ongoing site inspection following rain events is critical to ensure timely maintenance is undertaken to prevent costly repairs.

3 Variations on a theme: Rock chute refinements and learnings

3.1 Background

In the Mary River catchment over a three-year period, landholders with gully erosion issues 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 a total of twenty-four gully erosion sites. After a period of consultation and design refinement, the projects advanced to construction. The structures were monitored following the wet season, then maintenance and small modifications were completed as required.

During this extended period of activity, the design and construction team was supported by two local contractors with many years of experience and machinery suited to the diversity and complexity of the projects involved. Smaller projects and those with tight access issues were allocated to the contractor with a skid steer, 5-tonne excavator and dump truck. Larger projects were allocated to the contracting team with a 25-tonne excavator and dump truck. Both contractors were widely known by landholders and welcomed due to their good reputation in the region.

One landholder has also become very skilled at constructing rock chutes and has expanded his property operation to quarrying his own rock. This landholder has become one of the construction team and has mentored many other landholders in addressing their erosion issues and engaging with soil erosion mitigation works through the Mary River Catchment Coordinating Committee.

Having a set team to design, project manage and construct across all of the projects has provided the platform for extensive learnings and refinements during the extended period of construction and monitoring. This situation provided a perfect opportunity for the team to document the learning journey and the evolution of practical refinements necessitated by the diverse suite of project scenarios and the prevailing seasonal conditions.

3.2 The starting point: standard engineered rock chute design

The basic design for a rock chute has been outlined in Section 2. Conventional procedures have provided the recipe which includes the use of geofabric, gravel, rock, cut off trenches and energy dissipater aprons on rock chute structures. More recently, many engineers have refined the use of geofabrics to a cut off trench only and not the full batter. The exposed subsoil in the trenches and on the batter is sealed using gravel with high clay content. The geofabric can be used on top of this in the top cut of trench. The changed practice appears to be a response to instances when some tunnelling has occurred under the geofabric. Due to its exceptional strength, the fabric is able to hold the rock in 'suspension' for a period, then collapsing following a significant event with the ensuing high cost of repair.

The modification to high clay gravel only in preference to geofabric on the structure, allows movement and settling of rock. In this way, early observations of subsidence can be noted and timely maintenance action undertaken.

High clay content gravel is preferred in order to seal the dispersive subsoils. This reduces the exposure of subsoils to direct water flows and subsequent erosion. This mimics the slow moistening which occurs naturally when the topsoil is in place and moisture infiltrates through the profile to the subsoil.

Given the evolution of this adaptation in rock chute design, the approach taken for the first sites in the Mary River catchment was to try to double the security in the structure by using gravel across the whole structure to 0.1m and then also laying geofabric before the rock is placed. This has been the standard practice across the twenty-four projects most recently completed. Due to the diversity of sites there have been some significant modifications and learnings incorporated in the later projects. These learnings have been incorporated in the maintenance completed on some of the early projects. One size does not fit all and modifications to accommodate site differences swiftly become the norm in a design and construct work program.

In the team's experience, each project required modification of the 'standard' rock chute design to accommodate the landscape, budget, availability of construction materials and site access.

4 Rock chutes refined

4.1 Mary River flood plain gully – gully head rock fill chute

Rehabilitation type	Gully head rock fill chute
Description of gully	Gully 2m deep, 6m wide 300m to confluence with Mary River
Catchment size	104ha catchment
Flow rate	5.5m^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 very good, established, stoloniferous grass cover • High priority site given proximity to downstream Mary river and fine sediment to the southern Barrier Reef
Equipment	• 5T excavator, skid steer and truck
Final cost (earthworks and materials only)	$4,000

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

4.1.1 Background

The first gully was 2m deep at the head cut on a lateral runner coming from the main river. The head was narrow and deep and the catchment delivering to the gully head was approximately 104ha of river flats. The peak flow was estimated at 5.5m^3/sec for a 1 in 20 rainfall event using the rational method. The gully head had retreated significantly, releasing 66t/yr of fine sediment. If left unchecked, the gully would have retreated across the flat isolating a section of productive grazing land.

4.1.2 Challenges

The site was complicated due to the need to manage overland flow and inundation. The flat is regularly inundated by medium to high flood events. The second challenge, as with all sites in this publication, relates to lack of capital for rehabilitation works. Decisions and the resulting adaptations taken are always a trade-off between achieving the most effective outcome for minimal capital investment.

As the head cut was deep at 2m, a batter of 3:1 plus 1m bench at the top and 3m apron at the bottom, added up to a rock chute total length of 10m. Due to the inundation potential, it was felt that the structure would need to be enclosed with wire netting to ensure the rock did not move from the site. A chute of this length with the design crest of a crescent 16m was becoming very costly with rock and wire inputs. Furthermore, any pasture lost as a result of this length of chute would have added to further loss of stability on the flat.

4.1.3 Solution

Instead of using a conventional rock chute design where soil would be excavated to a 3:1 batter, rock was used to fill the gully head and form a 2:1 batter. The rock was encased in netting to stabilise the steep batter. The advantage of this approach was reduced batter and apron length and minimised grass disturbance. Rock size used was 100mm to 400mm as designed from the freeware spreadsheet 'CHUTE'.

The other consideration during planning was the size of machinery needed and potential cost. Due to the tight crescent shape of this gully head, and another nearby, the smaller machinery combination of skid steer and 5-tonne excavator was chosen. This size machinery can also handle the rock size up to 400mm. For bigger rock sizes, the larger machines are needed.

4.1.4 Design specifications and construction sequence

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

The benefits of a wire netting covering have been observed over a 6-year period while monitoring other rock chute structures constructed much earlier, which have performed through a number of large flow events.

The landholders' wishes and observations of peak flow heights have been considered in the design approach.

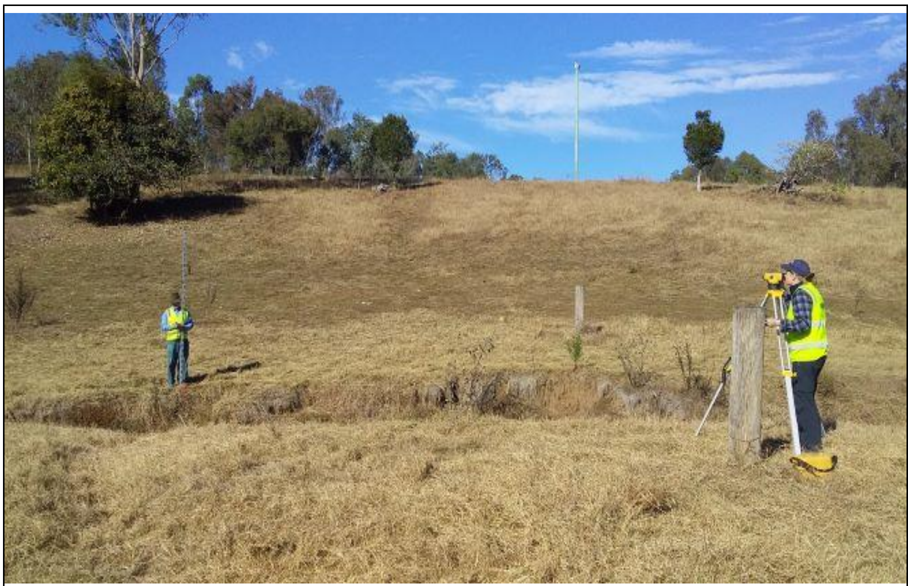	*Photo 2* **Surveying the level crest** The level 16m uneven crescent shaped crest was surveyed with a dumpy level and marked as the first step.
	*Photo 3* **Dig bottom cut off trench**
	*Photo 4* **Preparing the crest and gully walls** The gully head was tidied and shaped slightly with overhangs and tunnels collapsed and the topsoil pulled back for 1.5m around the crest before the 0.6m x 0.6m cut off trenches were constructed. Due to access issues with the skid steer for placing the rock, the whole structure was built from the bottom up.

Photo 5

Completed bottom trench inlaid with netting and lined with clay gravel

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

Photo 6

Trench and gully filled with rock 2:1

The trench was then filled with fine rock (100mm to 200mm and gravel), up to half then topped up with the 100mm to 400mm gravel mix, battered at approximately 2:1 so the bottom end of the fill sits on the gully floor approximately 5m 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 1.5m 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. The trench bottom and bench were covered with 10cm of gravel.

Photo 9

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

Photo 10

Gravel and rock placed over the fabric

More gravel and rock filled the same as the bottom trench. With lose ends of the geofabric facing down slope, more rock was added to finish the rock cover.

	*Photo* 11 **Lengths of wire netting placed over the rock chute and attached to netting in cut off trenches** 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 securing all of the rock.
	*Photo 12* **Wire netting laced togther with 2.5mm 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 the grass to quickly grow over the lip.

	*Photo 14* **Soil from excavation used for diversion 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 15m long and 0.6m high constructed, to ensure the water from the catchment is concentrated on the stable rock fill structure. These banks were constructed at approximate right angles to the gully edge heading upslope either side and extended until the end was 0.6m above the rock crest of the rock fill chute. The outlet ends of the banks were rock armoured for 3m up to 0.5m high 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 the maximum potential for revegetation of all disturbed areas.

Photo 16

Looking downstream at completed chute

Photo 17

3 months post-construction

October 2020 at beginning of first wet-season

Photo 18

10 months post-construction, post first wet season

May 2021

4.1.5 Learnings and adaptations

- Adapt site plan to accommodate the grass cover and stability of the site at construction.
- Adapt order of construction to suit the capability of the machinery being used.
- Connecting the cut off trenches from the crest and the bottom of the chute may provide a stronger and better draining structure.
- Electing to fill to a steep batter and enclose with wire netting can reduce rock use and retain stabilisation potential compared to a standard long batter and rock cover on a deep gully.
- Wire netting use requires extra labour costs.
- To minimise inefficiencies, rock should be delivered as close as practical to the work site.
- Leave a load of rock at the site above flood level for maintenance repairs.

4.2 Spotted Gum forest gully – rock chute combining two gully heads

Rehabilitation type	Rock chute combining two gully heads
Description of gully	1.5m deep, two heads approximately 5m and 3m wide
Catchment size	98ha
Flow rate	19m^3/sec (1 in 20 rainfall event)
Landscape considerations/ soil fertility	Two active gully heads with two catchments. 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	• 25T excavator, body truck
Final cost (earthworks and materials only)	$25,000

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

4.2.1 Background

This site could not have been more different from the first site described. The soil type was strongly sodic, the topography was undulating with a thick stand of spotted gum and iron bark used for a forestry reserve and some grazing. The catchment leading to the gully head is 98ha and the peak flow for a 1 in 20 rainfall event is 19m^3/sec, estimated using the Rational Method. The gully head was 1.5m deep and was 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 and extended crest length. Due to the high peak flow, the rock size at this site was 700mm.

4.2.2 Challenges

The biggest challenge at this site is the large catchment size, leading to large peak flow. The gully system is long and over time has resulted in the formation of several large lateral gullies, breaking off the main gully. At the most upstream gully head, another lateral gully had recently formed.

Another challenge at this site was the presence of tunnel erosion. In the vicinity of the gully rehabilitation site, tunnels were either broken and compacted or cut off from overland flow with the extended wing walls channelling water over the rock chute.

4.2.3 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.

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

4.2.4 Design specifications and construction sequence

The chute level crest was designed at 35m around the top and the gully head was battered to 3:1. This meant the chute batter was approximately 8m long, with an additional 2m apron length constructed with large rock to dissipate the energy.

Gypsum was applied to the battered stream banks and the whole disturbed area, at a rate of approximately 10t/ha. Following this, the same area was seeded to encourage quick revegetation. The seed mix used included: rhodes grass (Katambora and Reclaimer), bissett creeping blue grass and some legumes.

Photo 20

Chute shaped to capture both gully heads.

Photo 21

Chute level crest constructed to design width

The chute level crest was designed at 35m around the top and the gully head was battered to 3:1 so the chute batter is approximately 8m long.

Photo 22

Top cut off trench going in

A cut off trench approximately 0.8m wide x 0.6m deep was constructed around the top of the chute crest 1m up slope from the start of the batter at the top. Another trench was constructed at the bottom at the end 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 was covered with approximately 10cm of high clay content gravel.

Photo 24

Cut off trenches completed and gravel placed batter and trenches with site ready for geofabric

Photo 25

Geofabric laid over the chute, rock placed from the bottom cut off trench to the top - due to size of chute

Geofabric Texel 400R was laid with an 0.5m overlap over the clay gravel starting from the bottom working towards the top. This ensures water flows over the sheet and not under (similar to roof tiling principle).

The cut off trenches were filled with gravel and smaller rock mix up to a third of the trench depth.

A rock mix of 150mm to 700mm was placed and compacted on the geofabric covered batter and top and bottom cut off trenches.

	*Photo 26* **Rock fill on the chute close to finished**
	*Photo 27* **The depressions in gully above the crest filled with small rock and compacted**
	*Photo 28* **Rock on chute finished and fence in at the bottom** 1.6mm galvanised netting mesh was placed in the length of the bottom trench and up each adjacent gully wall. This was fixed in place using the rock and galvanised star pickets. This fence was designed to capture any 'rolling' rock during events.

	*Photo 29* **Some excess rock placed downstream of the apron and the fence.** Some of the larger rock (700mm) was concentrated for the apron end and at the base of the chute to assist energy dissipation. There was some surplus rock which was spread below the apron and fence to help stabilise the gully floor. A second short netting fence was constructed below this rock to hold it in place and act as a silt trap. The edges of the gully below the structure were battered at 1:1 for approximately 10m to allow quicker revegetation. During this process the topsoil and grass sod was scalped back and when the subsoil was battered at 1:1, the topsoil and sod was spread over the batter to encourage quick revegetation.
	*Photo 30* **Survey line for wing wall**

Photo 31

Wing walls completed with rock armouring

During construction, any excess soil from the battering and shaping process was retained and used to help construct diversion wing banks at each side of the chute to direct flows over the rock chute. Using over burden avoided exposing the fragile subsoil. The wing banks were constructed to 1m 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 0.75m above the weir crest height.

The ends of the diversion banks were also rock armoured up to 0.6m high for a distance of 3m, using the smaller rock from the 150 – 700mm rock mix, to ensure the ends do not erode.

Photo 32

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

4.2.5 Learnings and adaptations

- Adapt site plan to accommodate the landform, in this case combining the two gully heads which were physically close together.
- Adapt order of construction to suit the size and shape of site, introduce geofabric and rock from the bottom up ensuring good overlap of geofabric.
- As the design rock size increases it is important to include a significant proportion of small rock 100mm to 200mm and gravel to fill the gaps and cavities amongst the large rock so the chute surface is completely covered and protected from the flow velocities.
- Ensure the stream bead is stable above the gully structure and repair if necessary, i.e. rock fill any depressions which could predispose to tunnelling into the structure.
- Survey the wing walls at no steeper than 0.5% to ensure they do not erode in the channels and cover with topsoil to ensure grass has a good chance of germination. Extend the wing walls far enough to cut of flows which may cause erosion on the stream bank below the chute, where possible and practical.
- Apply gypsum as required by soil test to improve soil structure and assist with infiltration and revegetation.
- Use low timber lines and mulch lines to reduce erosion below the wing walls on the bare banks on each side of the stream below the construction. If possible, place these structures to drain water away from the stream bank into grassed areas. These bare areas can cause significant erosion if there is a high intensity rainfall event before grass is established.
- Reseed if necessary to ensure the best chance of revegetation.

4.3 Grey Box and Wattle gully – rock mattress

Rehabilitation type	Rock mattress, whoa boys and silt trap weirs.
Description of gully	Gully -two forks of a stream, one 30m long with gullies to 0.75m deep and the other 20m long with gullies to 0.5m deep.
Catchment size	10ha catchment
Flow rate	$3m^3$/sec (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	• 5T excavator, skid steer, body truck
Final cost (earthworks and materials only)	$11,000

Photo 33 Gully erosion with multiple head cuts. Inset: tunnel erosion in the catchment immediately upstream of the gullies.

4.3.1 Background

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

The landholder's previous efforts to remediate this gully site had failed due to lack of appropriate design and contractor's unfamiliarity with gully remediation in fragile landscapes with highly dispersive subsoils.

4.3.2 Challenges

The soil type is a texture contrast soil with a very dispersive and erodible sub soil. The driveway had been effectively channelling water directly down the slope into the gully system, further accelerating the erosion. Tunnels along the eastern stream had also directed water from the driveway. A new approach was required.

4.3.3 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 installation of whoa boys and long stick lines. Whoa boys were constructed on the driveway approximately 40m apart due to the steep slope of 7%.

The two eroding stream beds were stabilised with a large forked rock mattress with strategically placed silt trap weirs. On completion of the earth works all bare and exposed subsoil areas were spread with a good layer of gypsum (10,000kg/ha). Additional loam was sourced to cover all bare areas. The site was then seeded and fertilised.

The property has remained destocked since construction and the landholder intends to keep it that way.

4.3.4 Design specifications and construction sequence

A rock mattress was used to stabilise both channels, and whoa boys constructed on the driveway upslope to redirect overland flow away from the eroding system.

The whoa boys were surveyed and constructed similar to the methodology described in the Gully Erosion book (Day and Shepherd 2019, pg. 12-14). In this fragile soil type, an option to reduce disturbance during construction of the whoa boys was to use imported gravel. Dead timber was then used to construct mulch and stick rake lines to channel the water away to a safe disposal at least 20m from the road, around the slope. The grade used on the constructed whoa boys was 10cm fall over the 4m width of the road. The road slope was steep at 7%. The grade for the water diversion and spreading log lines was 10cm every 25m or 0.4%.

Photo 34

Exposing tunnels and compacting

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

Photo 38

Finishing the rock mattress

After the gravel a layer of 100mm to 200mm 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, as with the rest of the gully. Shaping was not necessary for this small feature due to small catchment.

	*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 to continue trapping silt. 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 neighbours 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** If possible, dumping material in position will save machine time later on. Whoa boys surveyed with 10cm fall across the width of the road. The slope was steep at 7%.

Photo 43

Whoa boys completed

Lines of logs, dead timber and mulch at the end of each whoa boy were used to carry water at least 20m away from the driveway and out of the gully catchment. Log lines were surveyed with 10cm fall over 25m, or 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 downstream from that one so the crest of the new weir was high enough to back water approximately 0.3m up the wall of the existing netting weir. This was done to stop some potential undermining which was starting 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

4.3.5 Learnings and adaptations

- The first adaptation was to use a full rock mattress approach rather than using a rock chute for the top gully head.
- The second adaptation was to deal with both forks of the stream and the junction as the one structure.
- Due to the shape of the structure and the low slopes involved, high clay gravel was used to seal the shaped sodic subsoil rather than geofabric or both gravel and geofabric. This was also partly for cost efficiencies.
- Imported gravel and stick rake lines were used to form whoa boys and take water to a safe disposal point rather than the usual process of excavation and bank construction using local soil. Previous experience of the fragile nature of the landscape and predisposition to tunnelling directed this choice.

4.4 Iron Bark and Box ridge – gully filled and overland flow diverted

***When a rock chute would work but other options were more practical for the location**

Rehabilitation type	Gully filled; detention basin and diversion banks constructed to take the flow away from the gully site
Description of gully	Gully 1.5m deep, 5m wide
Catchment size	16ha catchment
Flow rate	2.63m^3/sec (1 in 20 year rainfall event)
Landscape considerations/ soil fertility	Ridge top of Iron bark on uniform clay grading downslope to a 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 • Heavy timber in the rehabilitation area so careful planning required to reduce timber loss.
Equipment	• 25T excavator, body truck, tractor with front end loader, chain saw.
Final cost (earthworks and materials only)	$6,000

Photo 47 and Photo 48 Iron bark and Box ridge gully prior to rehabilitation

4.4.1 Background

This gully erosion site is a result of water from a historic 15ha contoured catchment being diverted for disposal onto an adjacent ridge top rather than into the eroded natural drainage line. This is quite a common strategy when diverting water away from an erosion site. The contoured area is quite good soil with productive pasture. The ridge top where the water from the contour system was placed is a different land type with a much poorer soil and a heavy cover of timber reducing the grass cover. The land type on the disposal ridge is Narrow leafed iron bark on clay at the ridge top grading to narrow leafed Iron bark on granite down the side slope where the gully has eroded.

The delivery of water from the contour system to the ridge was suitable under normal rainfall conditions up to the 1 in 10 rainfall event which the contour system was designed for. The system worked quite well for many years. However the increased flow on the receiving catchment resulted in the formation of a new gully which advanced rapidly up the slope during the 2011 and 2013 flood events. The soil at the gully site is texture contrast with a shallow 0.3m loam topsoil over dispersive clay subsoil derived from decomposing granite bedrock. The total catchment is 16ha with a peak flow estimated of 2.6m^3/sec in a 1 in 20 year rainfall event.

4.4.2 Challenges

The site could have been stabilised with a rock chute on the new gully head. This option was considered however access for trucks carrying rock was problematic. The property is a commercial cattle operation so a compatible and dual purpose option for stabilising and rehabilitating the site was devised through consultation with the landholder and the contractor.

The second main challenge was to ensure all clearing was kept to a minimum as the regional ecosystem was identified as Of Concern.

4.4.3 Solution

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

A fence was constructed around the whole ridge and slope area which created a small paddock which can be managed to maintain maximum cover at all times.

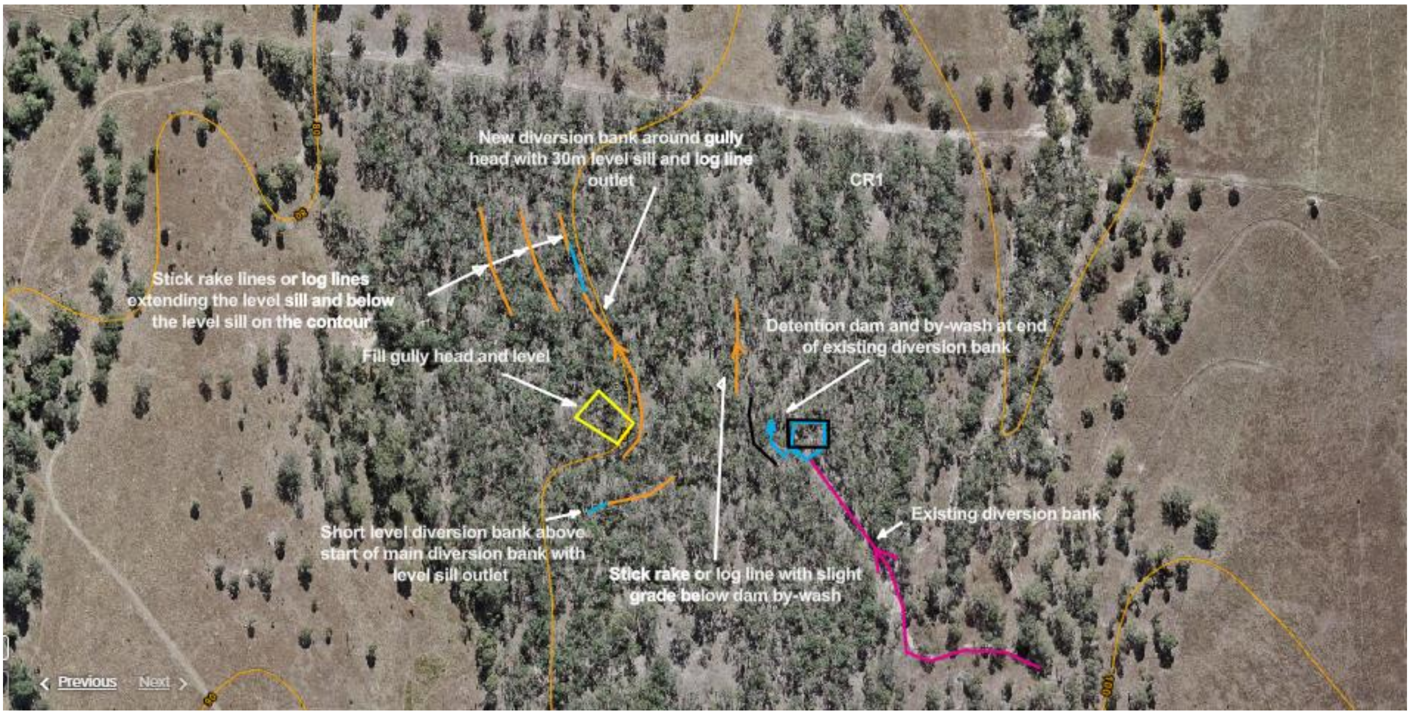

Figure 4 Suite of gully rehabilitation methods working to slow and spread the flow of water across the ridge

4.4.4 Design specifications and 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 slow water reaching the slope above the gully head, a detention basin approximately 25m long and 10m wide and 1m 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 25m long were positioned about 2m and 10m below the dam by-wash outlet to slow and spread water. A slight grade of 0.2%, or 5cm every 25m, 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 20m long, 3m wide and 0.3m deep.

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

Photo 58

Levels 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 3m wide flat channel and a 1m 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 which had gullied. This bank had a very small catchment size (<1ha). The 25m bank with 0.2% slope was constructed to 0.8m with a 1m 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 10m long x 1m wide x 0.3m 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 the track exposed 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* **Feb 2022 post flood** Detention basin full and ground cover has improved significantly.
	*Photo 67* **Feb 2022 post flood** Level sill at outlet still holding some water following the flood.
	*Photo 68* **Feb 2022 post flood** Fill in the gully head has sunk 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.

4.4.5 Learnings and adaptations

- The adaptation at this site was to use the terrain to effectively assist with planning for overland flow. The area around the outlet of the existing diversion bank from the contour system was surveyed to check accurately where water had flowed and would flow if some structures were introduced. This information informed the accurate siting and capacity of the detention dam and by-wash.
- A detention structure in conjunction with other measures enables better water management and utilisation including provision of water for livestock and wildlife.
- The detention dam holds water very efficiently and will therefore require emptying before the next wet season which allows capture of initial flows from the first summer storms.
- Use of locally available resources, including spoil and felled timber, for filling the gully heads and installing log lines eliminated issues raised regarding access for trucks. It also resulted in considerable budget savings.
- Landholder contributions during construction proved very effective and efficient. The small 50hp tractor with the three way bucket proved very useful for a number of tasks, including levelling and compacting the gully fill, placing the log lines and some clearing. The landholder also used his chain saw to cut useful timber for log lines from trees removed during the clearing. This assistance saved contractor time and ultimately cost.
- Using an excavator to clear lines and construct diversion banks in heavily timbered sites enables more strategic clearing versus other machinery options. This site was a habitat and timber growth area on the property and keeping the timber was important.

4.5 Black soil streambank gully – rock chute with detention basin

Deep narrow gullies challenge design

Rehabilitation type	Rock chute with detention basin
Description of gully	Gully head 2m deep and 2.3m wide, rapidly increasing in size to 15m deep and 22m wide. 100m to confluence with Mary River.
Catchment size	The catchment area flowing to the gully is 8.9ha, with an average slope of 2%.
Flow rate	1.8m^3/sec (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 from inundation • High priority site due to export of significant sediment loads to the Mary River and Great Sandy Strait • Very deep narrow gully with tunnelling along the edges
Equipment	• 25T excavator
Final cost (earthworks and materials only)	$9,000

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

4.5.1 Background

This property is a small lifestyle block with approximately 110m of Mary River frontage. A large gully that started on the downstream neighbouring property in the 1950s had crossed the property 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 bank-full height. This inundation from back water was an important factor to consider for rehabilitation.

Baseline monitoring of the gully occurred in December 2019, following stock exclusion. The gully was 2m deep at the head cut and 2.3m wide with the depth increasing quite quickly and the width staying relatively narrow for at least 10m. The gully where it meets the riverbank approximately 100m away is ~22m wide and ~15m deep. LiDAR comparison between 2009 and 2018 shows that the gully head had moved 25m in a decade. The catchment above this gully is 8.9ha and results in 1.8m^3/sec flow during a 1 in 20 year rainfall event.

4.5.2 Challenges

The grazing land type is Blue gum flats which describes that waterlogging might be a problem in flood events. Subsoil on the property is dispersive and prone to gully erosion. The soil is a deep Dermosol. The catchment is largely pastured grazing land with very 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 from the river inundates the gully head during medium to major flood events.

4.5.3 Solution

A rock chute was constructed to stabilise the gully head at this site. A dam wall was also constructed approximately 20m upstream from the rock chute crest. This storage acts as a detention basin reducing the amount of water flowing directly through the rock chute at the gully head. It also acts as a silt trap and provides a source of water for wildlife. The by-wash was constructed to direct water to and through the rock chute once the dam is full. The size of the dam was determined at construction by taking into account the cost and the area available to hold water without impacting on 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 10,000kg/ha. They were then seeded and fertilised to encourage quick and vigorous revegetation. The seed mix included: rhodes grass (Katambora and Reclaimer), bissett creeping blue grass, millet and perennial rye grass as a winter active cover crop. The paddock had very good stands of pangola grass and para grass which quickly recolonised bare areas as well. Pangola sod was spread on the battered gully walls below the chute at construction with great establishment success. All stock were removed from the rehabilitation area.

4.5.4 Design specifications and construction sequence

Photo 70

Beginning of the shaping

The rock chute crest was skewed to the south to reduce the amount of earthworks in forming the batter and apron.

Photo 71

Gully head chute shaping completed

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

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

A 1m wide x 0.3m 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 10cm 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 200mm over the geofabric first. A rock mix of 100mm to 400mm 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 400mm 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 15m to allow grass regeneration. The topsoil and grass sod was scalped back and reserved then replaced following shaping. All tunnels were excavated, back filled and compacted before the battering and bank construction was completed.

<table>
<tr>
<td></td>
<td>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 1m high.
The bank closest to the river continued upslope until the end at ground level was at least 0.6m above the weir crest height.
The bank on the other side curved around the gully and captured water from the neighbour’s paddock which was creating tunnels along that side of the gully wall. The end of the bank was again 0.6m above the weir crest height.
To prevent banks eroding at the rock chute entry, banks were rock armoured for a distance of 3m and height of 0.5m.</td>
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<td>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 2m wide energy dissipater at the bottom. Larger rock was placed in the narrow gully bed below the netting fence for approximately 5m to reduce the ‘waterfall effect’ below the netting and provide some more energy dissipation.</td>
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Photo 79

Rock chute complete July 2020

Photo 80

Construct silt trap weirs in gully floor and plant para grass sods

Two additional netting silt trap weirs were spaced at approximately 0.4m 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** Bank full in the gully system from the Mary River, dam full and overflowing. Groundcover at 100%.

4.5.5 Adaptations and learnings

- With very deep narrow gullies, the cost of earth moving can prohibit the construction of a conventional energy dissipator apron to the full width of the chute. At this site, relatively small flows from a small catchment reduced the necessity for a conventional apron.
- The use of detention or silt trap dams in conjunction with chutes or other structures can be beneficial to the water flow management and also the landholders farm management plans.
- Tunnelling along gully edges or near gully heads need to be addressed with appropriate management. Application of Gypsum can reduce risk of tunnel erosion in the future.
- Use a soil test to assess the correct application rates 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. This can replace mulching and seeding. Watering in afterwards is also an option if water is available.
- When addressing incised gullies leading to a major watercourse, it is essential to consider the impacts of inundation and likely remediation works that follow when the water recedes. In many cases it is this process which causes the gullies to progress faster than the catchment size would suggest. This is because the gully is the point of concentration for huge amounts of water to be released from the saturated floodplain.

5 Rehabilitating failed dams

5.1 Dam Gully – cut wall and rock mattress

Rehabilitation type	Rock mattress encased in strong netting.
Description of gully	The gully was the breach in the dam wall.
Catchment size	The catchment delivering to the gully head is approximately 31ha.
Flow rate	The peak flow at the gully head is approximately 9m^3/sec 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 subsoil is sodic with very poor structure.
Other considerations	• A lot of soil had to be moved from the dam wall so a disposal area for this close by was needed • Subsoil was left covering the creek banks so amelioration needed to allow grasses to re-establish • Creek bed below the structure is very narrow but reasonably stable
Equipment	• 5 tonne excavator and skid steer
Final cost (earthworks and materials only)	$14,000

Photo 88 Break in dam wall prior to work

5.1.1 Background

This small dam is located on a small stream. It had failed in the past and repair efforts also later failed. Following the last failure, a deep gully formed which was cutting its way back through the stream bed towards the dam excavation which was still holding at least 2m of water – a valuable resource for the landholder. Soils are 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 grey box in the majority of the dam catchment. The catchment delivering to the gully is approximately 31ha. The peak flow at the gully head is approximately 9m^3/sec for a 1 in 50 rainfall event, estimated using the Rational Method and Qld Globe topographic data.

5.1.2 Challenges

A confounding factor to consider is the proximity to the Mary River. The site is inundated during flood events and therefore the possible effects of 'draw down' following saturation had to be considered.

5.1.3 Solution

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

The landholder had contractor preference who then confirmed the desired outcome could be achieved with 5 tonne excavator and skid steer.

Due to the position of the rock stockpile and limitations for machinery access, construction commenced at the upstream end first, back to the outlet end. Excess soil was spread over the creek bank. Gypsum was the applied at 10,000kg/ha to the area to improve soil structure and provide the best chance for revegetation. Finally the site was seeded, fertilised and fenced to exclude stock.

5.1.4 Design specifications and 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 25m. During construction this width was reduced to 20m 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 20m at the upstream end narrowing to 10m 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 there was a lot of soil which had to spread along the stream bank up out of normal flow depth. This was done with the skid steer very efficiently.
	*Photo 91* **Completed upstream cut off trench with geofabric and inlaid with mesh – which will secure the top mesh** Cut off trenches at least 0.5m wide and 0.7m (depth and width of bucket) were constructed on both ends of the levelled cut through the dam wall. Bentonite was broadcast at 10kg/m^2 over the top of the whole levelled foundation to provide an impervious base layer to the structure. Geofabric was laid into the trench allowing 2m overlap and inlaid with 1.6mm galvanised mesh. Trench was half filled with smaller rock to ensure good tight compaction and reduced space for running water.

Photo 92

Illustrates the layering – first bentonite, gravel, Texcel 400R fabric then rock. Continuous surveying done to ensure rock mattress was level across the width.

The layering was done starting with the upstream section working downstream so preventing excavator travelling over the geofabric.

Photo 93

Work site illustrating placement of materials

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

Photo 94

Netting placed along batter before rock added to hold it in place

Secured netting along batters provides the anchor point for attaching the final netting.

Photo 95

Looking upstream illustrating position of netting and rock mattress

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

Photo 96

Covering the rock mattress with netting and stitching overlapping lengths together from upstream to downstream

Once the rock was laid in and a length of netting placed in the bottom cut off trench the whole structure was covered with netting strips. The strips were placed from up to downstream with a half meter overlap. Soft 2.5mm plain wire was used to lace each end for 6m tying off the wire to netting secured in the trenches and along the batter. The remaining distance (10m) 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 secured laced netting provides a 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 mattress after first rain event** Concrete sleepers observed were used to hold the fence in place. They remained in-tact following the rain event. Of note is some deposition of silt in the foreground captured in the rock and netting. This will provide some growing medium for grasses to colonise.
	*Photo 100* **February 2022 after major flooding** Ground cover is well established over the entire site. It remains excluded to livestock.

	*Photo 101* **Aerial image illustrating extent of ground cover over the site** It is evident the paddock adjacent is taking longer to rehabilitate given stock access.

5.1.5 Adaptations and learnings

- The first adaptation was modifying the width of the cut through the dam wall to imitate the natural shape of the drainage line prior to the dam construction. At the full 25m design width, there would have been a dramatic change in water energy as the flow concentrated through a 10m exit. By reducing the width to 19m at the entry, lengthening the mattress and shaping it to the natural landscape, the erosion potential was thereby reduced significantly.
- The addition of bentonite to the excavation before the gravel, geofabric and rock were introduced, 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 technique, prompted this addition.
- The shortage of topsoil to cover the spoil from the excavation led to the addition of gypsum to improve the soil structure around the site so revegetation could be achieved.
- During lacing the netting the length of the structure was causing slow progress so the decision was made to only lace the ends of the runs and 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 less gaps and less rock needed.

5.2 Dam by-wash gully – reinstate natural flow path and rehabilitate eroded areas

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 10m deep, 20m wide 75m long to confluence with tributary of Mary River.
Catchment size	134ha catchment
Flow rate	24.6m^3/sec (1 in 20 year rainfall event)
Landscape considerations/ soil fertility	Soil is dermosols Mm7 and Mm8 grazing land type “Blue gum flats on alluvium” with good topsoil fertility.
Other considerations	• Cost • Landholder preference to break wall not 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 1 km to Mary river and fine sediment to the Southern Barrier Reef
Equipment	• 25t excavator, 12t body truck
Final cost (earthworks and materials only)	$13,000

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

Photo 103 Looking upstream along the eroded by-wash

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

5.2.1 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 very deep and active erosion as a result of a poorly designed and constructed by-wash for the large dam.

This gully delivers sediment to the Mary River, approximately 1km downstream. The catchment is 134ha and is described as a fast flowing catchment. Medium river floods inundate the gully site. The soils are described as dermosols on land type "Blue gum flats on alluvium". The gully is 75m long, 20m wide and 10m deep along the full length. The peak flow for a 1 in 20 year rainfall event is approximately 24.6m^3/sec estimated using the Rational Method and Qld Globe topographic data.

The landholder did not need the water from the storage, so stabilising the erosion was the principle aim. There were two options which appeared to have potential.

5.2.2 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 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. This strategy was lower cost however 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, where the landholder noted that the site would be inundated during flood events greater than 13m.

5.2.3 Solution

So rather than try to repair the dam by-wash, the decision was made to restore the stream flow to its natural path. This option aimed to deal with the water volume and velocity by removing the majority of the old dam wall and creating a wide level waterway with an original design width up to 55m. The shallow water would flow along the path of the original stream. The 55m design specification was recalculated as it was impossible due to the very narrow and deep stream shape directly below the dam wall. The time to excavate and move the extra soil was also outside the budget for the project.

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

Soil removed from the dam wall was first used to fill the small waterhole, in a way that pushed the water out the by-wash. The remaining soil was then used to seal off the current by-wash, by extending the dam wall. The gully walls were battered and topsoiled for revegetation. This option required movement of a large amount of soil (approximately 3,000m^3). After consultation with the contractor it was decided that a single 25tonne excavator and a 12tonne dump truck would be the most efficient way to move the soil around the site – a distance of 25 to 100m.

The freshly exposed level sill underneath the current dam wall was stabilised with a series of 4 wire netting encased rock weirs (groynes) evenly spaced apart using rip rap rock 100mm – 200mm. The cost of a full rock and geofabric mattress over the exposed soil where the dam wall was removed was outside the budget potential of the project. These groynes reduced back water pressure and reduced water velocity through the structure.

The final level sill cut through the dam wall was 25m x 25m. The batters on the dam wall excavation at each side were at approximately 1:1, similar to those used on many road cuttings. The base of the batters on the upstream end were rock armoured up to 1.5m 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 blue grass and perennial rye grass and pangola.

5.2.4 Design specifications and 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 then transported to form a bund wall across the failed by-wash. All water is diverted back into original drainage line through the constructed dam wall break. A diversion bank was also constructed to 0.6m high which runs 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, top soiled.

The vertical edges of the gullied by-wash were battered to 1:1 and then spread with the topsoil which 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 top soiled so all erosion sites around the gullied area were stabilised during the construction.

Photo 110

Rock groynes evenly spaced along the excavated site

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

Photo 111

Completed: Looking downstream on 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 1.5m on the batter inlet edges and extensions of the groyne ends up the batter, to reduce the chance of erosion during high flow events.

Photo 112

Completed: Looking upstream through the cut in the dam wall, which 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 which captures water from overland flow
- filled by-wash end
- filled and levelled water hole
- surplus rock for any repairs
- Reinstated flow path with rock groynes

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 to direct flows off the flats 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 applied to exposed areas.
	*Photo 118* **February 2022 – mid wet season** The main channel and groynes remain intact after inundation from the 2022 floods. Most of the site has grass cover. The batters on the dam wall cut are still bare but stable. Water from the flats has concentrated its flow 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.

5.2.5 Adaptations and learnings

- With this project the width of the designed dam wall break was modified to accommodate the cost of construction and the natural depth and width of the stable stream bed below the structure. The increased depth of flow was acknowledged with extended rock work.
- The dam which still held water was drained and filled so there was no potential for water ponding causing any bog potential for stock.
- A full rock mattress over the excavated level sill was modified to 4 rock weirs encased in netting, rock armouring of the edges of the cut and the upstream end of the excavated opening in the dam wall. The rock work was extended up the batters to above the expected design flow depth. Observations following significant rain events, would indicate there was no compromise on structure capacity to manage large flow events.

6 Geofabric low cost options

Drop structures are used in very few instances and are an option for sites where machinery access is limited. Structures can be fashioned most economically out of geofabric. The geofabric "Texcel 400R and 600R" have been used. The aim of these structures is to create a stable waterfall so that the gully head cannot advance further up the depression floor. Once again, it is important to know the size of the peak flows at the site so that the length of the crest of the drop structure can be designed to reduce flow depth and velocity wherever possible. The design methodologies as described earlier are used here again.

Once the cut off trench has been constructed 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. To ensure the water travels over the fabric, the fabric ends can be folded back over the trench after it's filled, facing downstream, and pegged down with the pins. Once again, a stilling pond, apron or energy dissipater is necessary to ensure the face of the gully head is not undermined. When using geofabric, the stilling pond can be covered with the bottom of the fabric strips, again secured in a narrow deep cut off trench at least 2m downstream of the gully head wall.

6.1 Scrub gully – geofabric drop structure using small earth moving machinery and some rock

Rehabilitation type	Geofabric drop structure with rock cut-off trenches
Description of gully	Gully 2.5m deep, 4m wide 30m to confluence with Mary River
Catchment size	13ha catchment
Flow rate	3.3m^3/sec (1 in 20 year rainfall event)
Landscape considerations/ soil fertility	Soil is dermosols Mm7 and Mm8 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 very good, established, stoloniferous grass cover • High priority site given proximity to downstream Mary river and fine sediment to the Southern Barrier Reef.
Equipment	• 5t excavator, Skid steer.
Final cost (earthworks and materials only)	$3,000

Photo 119 March 2012

Photo 120 Gully head prior to rehabilitation in 2020

6.1.1 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 which was treated with a gully head rock fill chute structure described is section 2.3. The soils are alluvial texture contrast with approximately 0.3m loam topsoil and a deep dispersive clay subsoil. The land type is "Blue gum flats on alluvium". There was good ground cover at the time of construction with a vigorous stand of bisset creeping blue grass. The gully head was 2m deep and 4m wide grading to a depth of 4.5m at the stream bank. The peak flow from the 12.5ha catchment for a 1 in 20 year ARI is 3.3m3/sec estimated using the rational method and Qld Globe topographic data.

6.1.2 Challenges

This site becomes inundated by flood water in medium to major flood events. The narrow deep gully shape provides limitations to crest length and access to the gully floor. There was minimal room to accommodate a gully rock chute and farm vehicle access.

6.1.3 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 16m to significantly reduce the flow depth. Crest was shaped as a narrow crescent and the natural landscape features dictated the wing walls.

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

6.1.4 Design specification and construction sequence

Photo 121

Shaping the gully head and cleaning any overhangs and removing grass

The crest was levelled to a width of 1.5m 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 0.5m x 0.5m, 1m 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 and the gully floor and bottom cut of trench were lined with the geofabric Texcel 400R. A single sheet of 6m 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

The trenches were then filled with fine rock 100mm to 200mm and compacted to secure the geofabric in place.

	*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 this was spread over the gully floor and walls over and below the bottom cut off trench.
	*Photo 126* **Drop structure completed looking upstream** The soil taken from the gully head shaping and cut of trenches was used to cover the top cut off trench rock fill to create an environment to grow grass quickly if rain falls and there are no large flows in the gully.

	*Photo 127* **Drop structure completed looking downstream**
	*Photo 128* **February 2022 after major flooding in the area** Note the wing wall on the left of gully image. This was repaired using logs and worked well following observations taken following significant flooding in 2022.

6.1.5 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 site constructed by hand used narrow cut off trenches and the geofabric was pegged down. Using machinery, rock and a wider cut off trench provided time efficiency and a stronger, more resilient finish.
- Having rock in the bottom cut of trench and below created a useful energy dissipation area in the structure.
- To ensure the flow doesn't outflank the structure, wing walls need to be surveyed to convey the water over the structure.

6.2 Front gully – Geofabric drop structure using hand tools only

Rehabilitation type	Geofabric drop structure (without machinery)
Description of gully	Gully 1.2m deep, 6.2m wide
Catchment size	6.05ha catchment
Flow rate	1.3m^3/sec (1 in 20 year rainfall event)
Landscape considerations/ soil fertility	Open blue gum with good setaria and Rhodes grass. Gently undulating
Other considerations	• Human resources and experience
Equipment / Materials	Equipment / tools • Surveyors paint • Brush cutter • Spade • Grubber • Crow bar • Fabric scissors • Post rammer • Wire cutters • Mallet • Axe • Chainsaw (to remove exposed roots / saplings) • Ladder (for deep gullies >2m) Materials • Geofabric 2m wide (400R as a minimum, 600R offers more strength) • Star pickets (165cm) 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

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

6.2.1 Background

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

The site has been fenced allowing good groundcover to establish. Setaria and rhodes grass dominate the pasture mix. The gully was approximately 200m, averaging 2 – 4m wide and 0.5 – 1m deep at the gully heads. There are multiple gully heads along the gully system. The site chosen for the geofabric drop featured a wide shallow gully head where multiple cattle tracks were sighted both sides and along the crest. The intention was to ensure the drop structure included the cattle tracks which served to protect banks from the natural water flow. The peak flow from the 6ha catchment for a 1 in 20 year ARI was 1.3m^3/sec estimated using the Rational Method and Qld Globe topographic data.

6.2.2 Challenges

During prolonged periods of rainfall, paddocks become saturated and pugging occurs. This initial grazing issue can lead to further gully problems if the pugging starts to disturb the subsoil. Previous management had allowed stock to track over and through the gully system causing multiple cattle tracks and smaller gully heads. Despite fencing and constructing some porous check dams which assisted with ground cover recovery, gully heads were slower to repair.

6.2.3 Solution

A geofabric drop offers a quick and cost effective solution for sites with a small catchment area and flows. It is a technique which seals the head from overland flow erosion by protecting the subsoil with geofabric. The technique described below ensures the material remains in situ and is not undermined from flow events.

The crest length is dependent on the characteristics of the gully and the lay of the land at the periphery of the gully head. As a general rule, the structure should cover the actively eroding gully head and margins and incorporate any areas which concentrate the flows (for example cattle tracks), as practicable. Geofabric drop structures are a low impact method using hand tools only, meaning the lay of the land will determine placement and extent of the structure. Regardless, it is a good idea to calculate the ideal crest length of the gully. This gully would require a level crest length of at least 11m to maintain the flow rate downstream of the structure at 1m/sec 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.

As a note of confidence, this example received significant rain in excess of 650mm over five days in an already saturated catchment during 2022. The structure held in place and prevented advancement of the gully head.

6.2.4 Design specification and construction sequence

Photo 130

Dig cut-off trench; follow the natural shape of gully head and include the cattle tracks

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

Place the fill on geofabric offcuts – this makes for easy retrieval 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 1m past the trench. This is to allow enough fabric to double back over the trench section once 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 tie it all together.

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 create a diversion.

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

Photo 133

Mesh secured along the crest and joins stitched

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

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

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

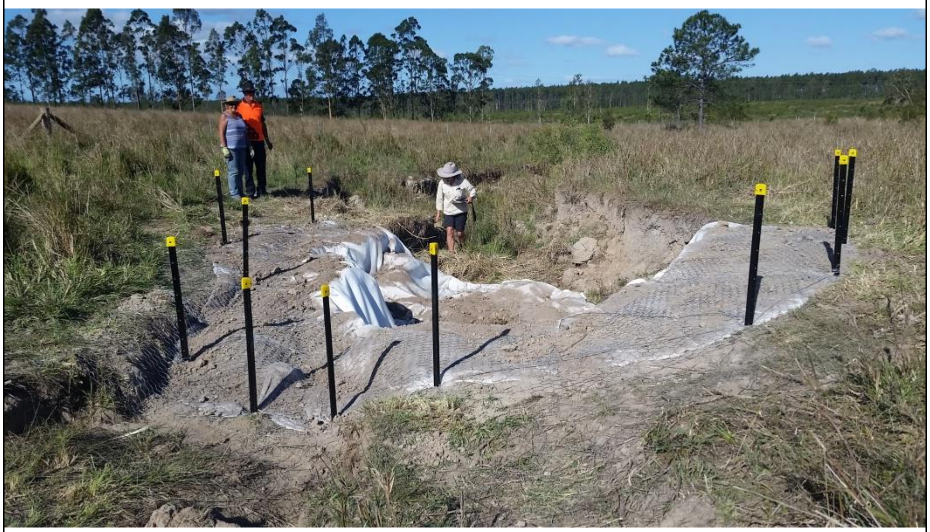

Photo 134

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 snap easily.

Lightly spread the remainder of the soil onto the fabric and seed with annual grass – millet in summer, rye in winter. Plant pangola runners in any areas of moisture holding pools / low points in the gully bed.

Photo 135

Completed October 2019

Photo 136

February 2021 monitoring, following 2 wet seasons

Photo 137

Feb 2022 post floods

6.2.5 Adaptations and learnings

Choosing a site

- Smaller catchments (<10ha) work best, however it is worth trying in larger catchments but be prepared to take on more maintenance activities.
- Constructing on a river bank is worth trying but be prepared to lose materials if site becomes inundated – ensure pickets are installed along the bottom of the structure to prevent excessive movement of fabric if site is likely to be inundated from the river flooding.
- Constructing a series of porous check dams downstream can help with water velocity by slowing the system, allowing sediment to settle and providing an environment suitable for groundcover establishment. 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 there are multiple gully heads within a single stream (as in this example), target a site most likely to benefit. This can be assessed by measuring gully head movement after a wet season. Try the easiest one to start with, always ensuring cattle remain out of the area.
- If possible and safe to do so, observing flow over the gully head during a decent rain event can be helpful for planning placement of the structure.

Materials

- Use soft, pliable wire for joining the fabric and high tensile wire between the pickets to tension the mesh.
- A thicker geofabric is more ideal (400R or 600R was used in the Mary catchment). Make sure to source only UV rated fabrics otherwise exposure to the elements will reduce the lifetime of the structure significantly. Smaller width geofabric (2m) is best for these structures as the rolls can be easily handled without machine assistance.

Preparing the site

- Remove any trees in the base and poison to avoid regrowth. Constructing around trees can work, however floods can also dislodge a tree and cause it to fall, lifting the structure.
- Use a chainsaw to cut any large roots projecting out from the gully walls.

The crest length is always the most critical decision

- Best to always include cattle tracks where possible.
- Ensure crest length includes all the most-eroded bank and a bit more.
- Despite calculating the ideal crest length for the flow, the fact is 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 as this will be the weakest point of the structure.

The trench

- Have some sections of cut off material placed along the length of the trench where soil can be stockpiled – this avoids losing soil material in the grass.
- Allow plenty of time to dig the trench – 4 people might take 2 hours going steady to dig a 10m crest if the ground is particularly hard at the time.
- 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 all the structure to fast track the recovery process.

Placing and securing the fabric

- Never put a fabric join in a concentrated flow section.
- Ensure the centre fabric has plenty of overlap as this is where the water will concentrate.
- All joins in the fabric must be stitched securely, ensuring the flap is facing downstream. Soft plain wire has been used here – although timely to use, it is strong and durable. A sharp tool such as small pointed scissors or a scribe can be used to make holes for the wire.

Star pickets

- When ramming the pickets, there will be uneven tension along the wire – best to do small amount working from the centre outwards to the flanks to avoid breaking the wire.
- Where it is anticipated large debris might come down in flood events, it is advisable to cut the star pickets to more suitable length otherwise material can accumulate behind the pickets and act as a dam. When this happens water outflanks the structure and can erode a bank further downstream.

Maintenance of structure

- Regular monitoring is important, especially following flow events.
- Ensure early removal of woody vegetation growing on the structure to prevent large holes in the fabric.
- Stoloniferous grasses growing over the structure should be encouraged. In the spring, broadcast some fertiliser over the structure to encourage grasses to reach in over the fabric.
- Ensure area remains stock free.
- Clear any debris behind the pickets as soon as possible after a flow event to prevent water diverting to exposed bank downstream.
- Any holes in the fabric can be mended by 'stitching' a patch over the torn fabric – best to keep some fabric for this purpose.
- Any further gullying downstream should be rectified as soon as possible. In the early stages, sometimes a little spade work and / or log diversion lines can reduce / prevent further erosion.

7 Summary

Soil erosion control is an iterative, continuous learning process. There is no 'one size fits all' in gully erosion control. The rehabilitation method is dependent on many factors including cost, capacity, urgency, and logistics.

It is worthwhile having a suite of options to offer a landholder with an interest in improving the property as a whole rather than just an interest in targeting an aggressive gully. Most erosion is a result of land management. If this is not addressed then the potential of further erosion is high. It is important to consider the rehabilitation options of smaller gullies before they become aggressive and costly to repair.

This guide has been focused on rock chutes due to the proliferation of serious erosion sites from the exceptional flood events through the Mary Valley in recent years. Rock chutes are an effective but costly remediation method and it is critical to have a good design. If the technical competency is not available then the skills should be outsourced.

Confidence in the project delivery is optimised with reliable and experienced contractors who are able to visualise the intent and scope of the design. Details are refined as the construction progresses, and input from the landholder, civil contractors and designer will increase the long-term viability of a project.

In summary, there is no structure or strategy which you can set and forget. Regular monitoring is imperative, especially after flow events. Maintenance requirements must be identified and carried out in a timely manner to prevent further degradation to the structure and potential failure.

The key to erosion control is managing pasture, groundcover and water. This is the foundation of all rehabilitation strategies. Prevention is always much better than cure – *a stitch in time saves nine*.