QUEENSLAND WATER MODELLING NETWORK

Regional pilot application of MERGE gully erosion model

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For Queensland Water Modelling Network.
June 2022

Queensland Government

The Queensland Water Modelling Network (QWMN) is an initiative of the Queensland Government that aims to improve the state's capacity to model its surface water and groundwater resources and their quality. The QWMN is led by the Department of Environment and Science in partnership with the Department of Natural Resources, Mines and Energy and the Queensland Reconstruction Authority, with key links across industry, research and government.

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Citation

Roberts, M.E. (2022). *Regional pilot application of the MERGE gully erosion model*. Report to Queensland Water Modelling Network, Department of Environment and Science

Table of Contents

1. Executive Summary

The MERGE (Modelling Erosion Resistance for Gully Erosion) model was developed in response to the identified need for a process-based model of gully erosion to inform gully rehabilitation and management. MERGE was developed by the Queensland Water Modelling Network (QWMN) Senior Research Fellow, based in the Australian Rivers Institute (ARI), Griffith University, in collaboration with Queensland Government, researchers, scientists and end users in the QWMN, and academic partners.

Through this pilot, in collaboration with the Fitzroy Basin Association, the potential value of MERGE to explore and inform gully management to reduce total sediment export during rainfall-runoff events is demonstrated. A small gully in regional Queensland, located on the outskirts of Rockhampton on the banks of the Fitzroy River, was selected for this pilot. The selected gully is a candidate for on-ground actions to reduce erosion and prevent further expansion. The new owners of the property are keen to work with FBA to manage erosion on the property.

For this pilot eight different management combinations under wet season and dry season conditions are explored to understand the potential benefit of the different actions. This study found that erosion could be substantially reduced using a combination of rock capping, to prevent expansion of the head, and catchment works to divert runoff away from the gully. Roughening of the upper reach of the gully channel, which is unvegetated, was not found to be an effective management option. However, further research is advised to determine whether the method of representing this intervention is the cause of this result. These results should now be evaluated in comparison with other erosion management options, including direct stream bank control, to guide decision making.

2. Project Background

A key output of the Queensland Water Modelling Network Fellowship has been the MERGE model, which simulates erosion resistance for gully erosion through a process-based model of erosion from an idealised linear gully. The MERGE model has been applied in the field in Southeast Queensland through a collaboration with Healthy Land and Water and others. Linking the model to actual field data has helped demonstrate the practical value of a process-based model to help improve the design and location of on ground interventions. This study extends the application of MERGE to a pilot in Rockhampton in partnership with the Fitzroy Basin Association. The objectives of the pilot are to explore the on-ground implementation of MERGE, to develop workflows to support future applications, and to identify challenges in moving the model into on-ground practice.

The QWMN Senior Research Fellow carried out research between 2018 and 2021 to improve model functionality and capability between the catchment and its receiving water environments. Receiving water environments include the Great Barrier Reef lagoon and Moreton Bay as well as dams, lakes and rivers. Well-developed and relevant models can improve the design and monitoring of management interventions to reduce the flow of pollutants such as nutrients, pesticides and sediment to the downstream dam, river, bay or reef.

3. MERGE Gully Erosion Model

A brief description of MERGE is provided below. For a detailed description and model derivation see:

Roberts, M. E. 'MERGE: modelling erosion resistance for gully erosion – a process-based model of erosion from an idealised linear gully', *Soil Research*, 58(6): 576-591, 2020, doi: 10.1071/SR20027.

MERGE is a one-dimensional conservation of mass model for the concentration of sediment within the water column of a gully during a storm event. MERGE provides estimates of the mass of sediment (per unit time) exiting a gully during a rainfall-runoff event. The spatio-temporal variation of the sediment within the water column is due to advection, entrainment from the gully floor and walls as a sediment source, and deposition out of the water column.

The rate of erosion is determined by balancing the power available for erosion due to the rate of change of the potential energy of the flow, namely the change in height of the water multiplied by its weight, with the power required to erode a unit mass of sediment. MERGE divides the gully into two components, the gully head and the gully channel (Figure 1). The gully head is that region of the gully subject to water cascading over the head and walls as a waterfall. The size of the scour hole at the head can be a good indication of the length of the gully head. Within the gully head the power available for erosion is the sum of the power due to the waterfall (termed the waterfall power) and the stream power due to channel flow. Within the gully channel, no waterfall is present, and the power available for erosion is solely due to the channel flow. The power required for erosion is the sum of three factors: the power required to break the cohesion of the soil, that required to overcome static friction, and that required to lift the sediment into the flow, which is a function of the immersive weight of the sediment. Soil properties are therefore captured by two properties that impact the rate of entrainment, the soil cohesion term J, and the lifting term, which is itself a function of the sediment particle sizes and density. A higher soil cohesion term means results in less entrainment, while a lower term means more entrainment. Particles that are small and of lower density are easier to entrain, and therefore will result in more entrainment, while larger and higher density particles result in less entrainment.

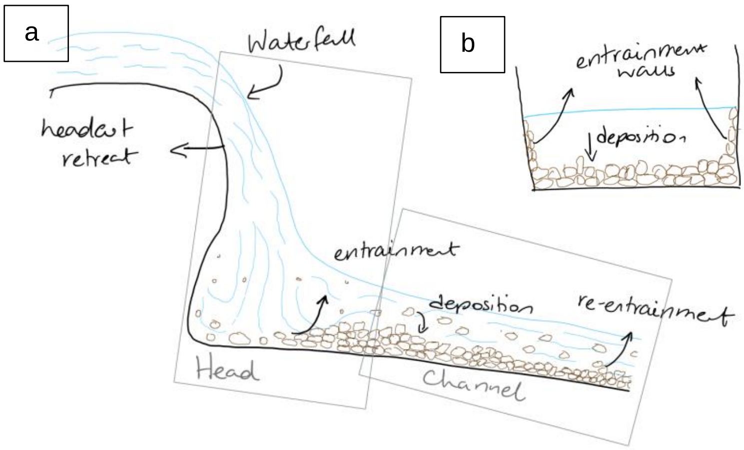

Figure 1: Schematic illustrating the key erosion and deposition processes in the gully. (a) Runoff cascades over the head of the gully driving headcut retreat. Sediment is entrained due to the power available from the waterfall and transported down the channel. Where the balance between the rate of entrainment and the rate of deposition shifts, a layer of sediment will be deposited on the gully floor, with re-entrainment of some of the deposited sediment (net deposition case). Otherwise, entrainment will dominate, and the gully floor and walls will continue to be eroded. (b) View up the gully channel illustrating entrainment from the walls and deposition onto the floor.

The rate of deposition is the product of the settling velocity of the sediment and the concentration of the sediment near to the base of the flow. While any form for the settling velocity may be used, it is convenient to use the widely applied Stokes Settling Velocity, which relates the settling velocity to the particle (or aggregate) density and the square of the radius under idealised flow conditions. Larger particles with higher density will have a higher settling velocity and therefore result in more deposition, while smaller particles with lower density will have a lower settling velocity and therefore result in less deposition. Deposition is not affected by the soil cohesion term.

The general concepts of entrainment and re-entrainment described by Hairsine and Rose (1992) are incorporated into the model. Deposited sediment is assumed to form a non-cohesive layer that uniformly covers the width of the gully floor, shielding the original soil matrix from erosion. This recently deposited sediment is termed the depositional layer, and the entrainment of sediment from this layer is re-entrainment. It is a requirement of the model that the depositional layer is fully re-entrained (removed) before the underlying soil matrix can be eroded. Where the rate of deposition exceeds the rate of entrainment net deposition will occur, which is termed the re-entrainment case as there will be no erosion of new soil from the gully floor. Over time, the thickness of this depositional layer will continue to grow, affecting the flow dynamics. MERGE is unable to capture any interactions between the depositional layer and the flow, that is, there are no automatic updates to how the flow is modelled (speed, depth) due to the growth of the depositional layer.

Where the rate of entrainment exceeds the rate of deposition, any recently deposited sediment is quickly re-entrained, and the gully floor will continue to be eroded. This is the entrainment case. The gully floor can be eroding under an entrainment case in one section, while experiencing net deposition (re-entrainment case) in another. Changes to the runoff conditions can also lead to changes in the balance between erosion and deposition and therefore the switching of states between entrainment and re-entrainment (and vice versa). As sediment is assumed to deposit only on the gully floor, and not gully walls, re-entrainment only applies to the gully floor.

An analytical solution is obtained by taking a quasi-steady state approximation. This approximation assumes that runoff is constant throughout the gully, that is, the flux is not a function of space, and that the concentration gradient in time can be neglected. Roberts (2020) demonstrates that the analytical solution is a good approximation to the full dynamic case. Three analytical solutions are

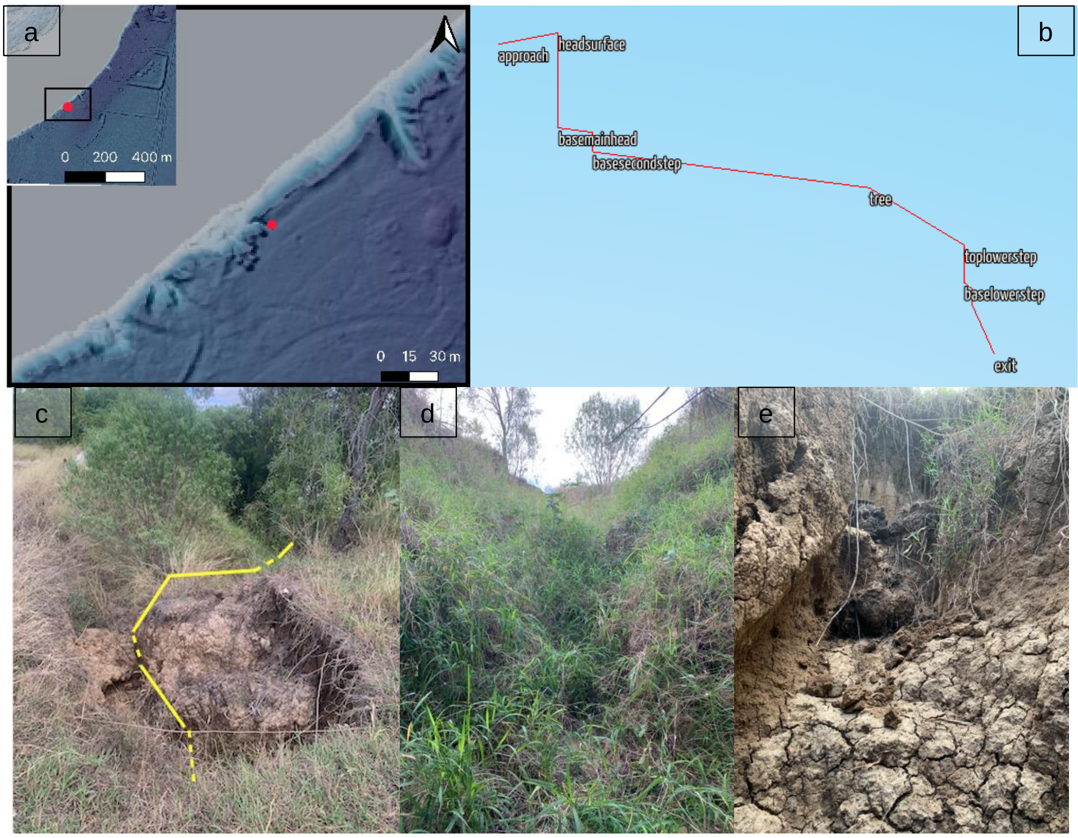

Figure 2: The gully is a small dog-leg gully that exits directly into the Fitzroy River. The upper section consists of an unvegetated head (with secondary internal step). The lower section has a well-defined channel well vegetated in the wet season . (a) Hillshaded DEM of the site illustrating the proximity to the Fitzroy River. (b) Schematic (line drawing)of the site illustrating the gully structure and key features, not to scale, (c) photograph of the gully viewed from above the head, with the channels and sections indicated by the yellow line (dashed line for head sections and a solid line for channel sections) (d) view up the gully from the toe, (e) view towards main head from in front of the tree located at the dog-leg. Photographs by Melanie Roberts, May 2022.

provided; one for erosion in the gully head, and one each for the entrainment and re-entrainment cases in the gully channel. An analytical criterion that determines whether entrainment or re-entrainment will dominate is also provided.

4. Site study description

The case study is a small classical gully located in the Fitzroy River basin approximately 2km west of Rockhampton, Queensland. The gully is situated on a cattle property that abuts the Fitzroy River. The property has recently come under new ownership; the property owners are keen to work with Fitzroy Basin Association to reduce erosion (streambank and gully) across the property.

The gully measures 21.8 m from its head to mouth, and consists of multiple steps (or internal heads) connected by steeply sloping channels. At the head, the gully is 2.4 m wide, and then narrows into a tighter channel of 0.8m as it drops down through a second step. The main channel measures 18.3 m and has two smaller (0.5 m and 0.2 m deep respectively) internal steps towards the lower reaches. At the toe, the gully is approximately 8 m wide and discharges directly into the Fitzroy River. A narrow incised channel is evident in the lower reaches. The lower steps are largely confined to this narrower channel. Refer to Figure 1 for a schematic of the gully, and Table 2 for the gully survey as applied in the simulations. Figure 1 also provides photographs of the gully viewed from the head and toe.

The gully is seasonally vegetated. In the wet season (see Figure 2), the lower reaches of the gully (below the tree in the schematic) is vegetated with long grass. Grass cover reduces in the dry season, however current information on dry-season coverage is not available. The age of the gully is unknown. The gully shows signs of recent expansion; recent erosion indicates that a second head, at right angles to the main head, is at risk of forming.

The proximity of the gully to the Fitzroy River prevented the extraction of the drainage area of the gully heads (present and newly forming) from the available digital elevation model[1]. This meant that it was not possible to directly link the modelled scenarios to specific rainfall events observed in the region. A road dissects the likely drainage area, potentially diverting runoff towards, or away, from the gully. Furthermore, a mound has been constructed parallel to the gully head (purpose not established for this study as pre-existing current landowners), which will also influence drainage within the area.

The site is situated near the intersection of two polygons in the 1:100000 scale soils map in Queensland Globe, being regions dominated by deep sandy soils (tenosols and rudosols) and cracking clay soils (vertosols). A sediment density of 1430 kg m^{-3} is assumed.

Climate

Rockhampton is situated on the Tropic of Capricorn and may be classified as having a subtropical climate with a distinct wet (December to March) and dry (June to September) season. The average annual rainfall is 800mm. Rockhampton is within the cyclone risk zone, is subject to summer thunderstorms, and has a well-documented history of flooding (BOM). The wet season is characterised by a greater rainfall depth and intensity in comparison with the dry season. Figure 3 shows the typical variation in rainfall patterns throughout the year, with an adjusted monthly rainy day normal illustrating the variation in rainfall intensity. The monthly rainy day normal is calculated for each month by dividing the average daily rainfall on days that it rains by the average number of days that it rains in that month, this metric is an adaption of the Rainy Day Normal of Vanmaercke *et al.* (2021).

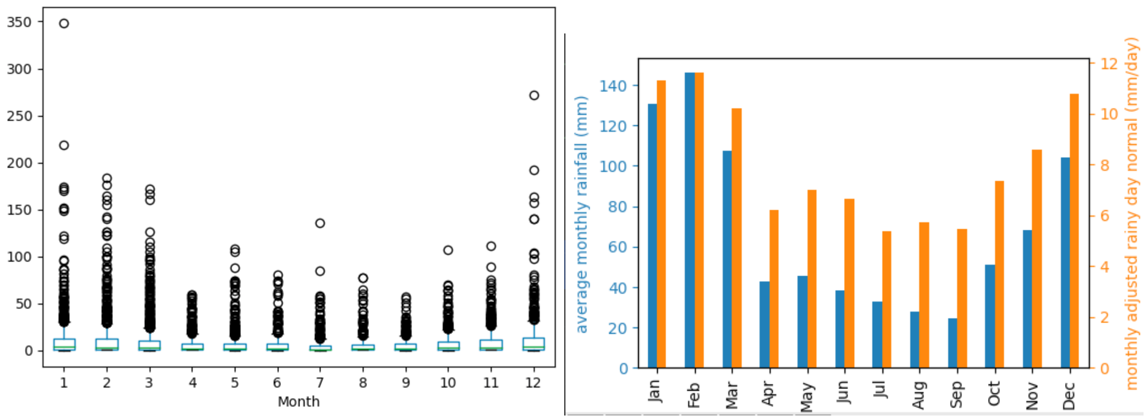

Figure 3: Rainfall intensity at Rockhampton Aerodrome 39083 BOM. a) Box and whisker plot of daily rainfall (mm) on days when rain was recorded, b) rainfall intensity plot showing the average monthly rainfall (1940 – 2021) and adjusted monthly rainy day normal.

5. Case studies

5.1. Baseline case (no interventions)

The role of vegetation in stabilising gullies and slowing the flow of runoff through a gully is well established. Four scenarios are considered, two corresponding to a wet season scenario with a vegetated gully in the lower section, and two corresponding to a dry-season scenario without vegetation. Vegetation is represented in the model through the Manning's roughness coefficient. A bare-soil Manning's roughness coefficient of 0.02 s $km^{-1/3}$ is assumed, increasing to 0.025 s $km^{-1/3}$

[1] Rockhampton-Livingstone 2015 Project, Airborne Laser Scanning (ALS) 1m Digital Elevation Model (DEM), obtained from ELVIS https://elevation.fsdf.org.au, May 2022.

under grass cover in the dry season and 0.045 s km$^{-1/3}$ in the wet season. The grass-cover in the lower reaches is further assumed to mitigate the effect of the shallow steps (0.5 and 0.2 m respectively) during high-flow events. In practice, increasing vegetation will increase the cohesion of the soil, and therefore should be coupled with an increase in the soil cohesion factor *J.* However, there is currently insufficient information to confidently set this parameter adjustment, and therefore a conservative approach was adopted. The benefits of vegetation are therefore under-represented in this model.

The wet-season scenarios model discharges of 8 and 16 m^3 s^{-1}, while the dry-season scenarios model discharges of 1.7 and 3.5 m^3 s^{-1}. Refer to Table 1 for a summary of the four scenarios. During low-flow events the flow concentrates in an incised channel in the lower reaches of the channel, spreading out through the full width during higher flow events. Dry-season low flow events are assumed to be concentrated into this channel (1 m wide), while the wet-season high-flow events spread across the full width of the gully. Although some overtopping of the narrow channel can be expected, this is not modelled explicitly. The steps in the lower channel are likely to be more influential on the flow during the dry season, due to the combination of minimal vegetation and concentrated flow. The contribution of the steps (intermediate head regions) is therefore modelled during low flow events, while a single channel in the lower section is modelled during high-flow events. During low-flow events the flow over the main head will not extend as far into the head, therefore a channel is introduced between the main head and upper step.

Table 1: Summary of Manning's Roughness and Discharge for the four modelling scenarios. Scenarios A and B are wet season scenarios with high intensity rainfall and well-established ground cover, scenarios C and D are dry season scenarios with low intensity rain events and low ground cover in vegetated sections

Scenario		Manning's Roughness n (s km$^{-1/3}$)		Discharge Q (m^3 s^{-1})
		Bare Soil	Vegetated	
Wet Season	A	0.02	0.045	8
	B	0.02	0.045	16
Dry Season	C	0.02	0.025	1.7
	D	0.02	0.025	3.5

MERGE is implemented within each section of the channel, taking the delivered sediment from the up-gully section as the boundary condition for each new section. Under the baseline case the discharge through each gully section is the same, and therefore the concentration exiting one section is the concentration entering the next section, providing continuity in both the concentration and the sediment flux. Interventions that work to slow the velocity of the discharge are modelled through the Manning's Roughness, which leads to a lower discharge for the same flow depth. Under these scenarios, continuity in the sediment flux is assumed, which introduces a discontinuity in the sediment concentration due to the discontinuity in the discharge. Within each section the depth of is calculated using Manning's Equation under an assumption of constant discharge through the gully in the absence of interventions. Interventions that affect the velocity of discharge are then applied assuming the depth of flow is maintained within each section. That is, the adjusted discharge due to e.g. roughening the channel is calculated by assuming the depth of flow is unchanged while the Manning's roughness coefficient is.

Tables 2 and 3 summarise the model parameter values under the four different scenarios for the various gully head and channel sections under the baseline case of no interventions. Model parameter values were selected based on field observations, or selected to provide reasonable rates of erosion, as judged by the author. Lower values for the carrying capacity, C^*, and power proportion, k, in comparison with Roberts (2020) and Prentice et al. (2021) were selected to provide rates that were more commensurate with the size of the gully. Further, a relatively high soil cohesion value was selected, despite the site being of highly erodible soil.

Table 2: Model parameter values that remain constant across all scenarios and gully sections

Parameter	Symbol	Value
Sediment density	σ	1470 kg m^{-3}
Particle radius	R	10 µm
Soil cohesion factor	J	1700 Ws kg^{-1}
Gravity	g	9.81 m s^{-2}
Friction term	F	0 Ws kg^{-1}
Initial concentration	C_0	0 kg m^{-3}
Carrying capacity	C^*	147 kg m^{-3}
Settling velocity	w_s	1.07×10^{-4} m s^{-1}
Fluid density	ρ	1000 kg m^{-3}
Power proportion	k	0.005
Concentration gradient	b	1

Table 3: Geometry of the gully in each section for the wet and dry season scenarios

Section	Width [m]	Slope	Length [m]	Waterfall depth [m]
Wet-season high flow scenarios (A and B)				
Initial head	2.4	0.02	3.1	2.0
Second step	0.8	0.05	0.4	0.4
Channel to tree	2.6	0.25	7.3	NA
Channel below tree	4.8	0.33	11	NA
Dry-season low flow scenarios (C and D)				
Initial head	2.4	0.02	0.3	2
Channel into second step	2.4	0.02	2.8	NA
Second step	0.8	0.5	0.4	0.4
Channel to tree	0.8	0.25	7.3	NA
Channel below tree	0.8	0.3	8.3	NA
Lower top step	1	0.17	0.5	0.5
Channel between lower steps	1	0.17	0.5	NA
Lower second step	1	0.33	0.2	0.2
Lower channel to exit	1	0.33	1.5	NA

5.2. Management actions and interventions

For this study three individual management/remediation actions for the site are considered, together with their combinations giving eight scenarios in total. These actions were selected based on discussions with FBA to understand typical approaches and options for remediation of the gully. Combinations of actions were considered to understand the additional benefits (or diminishing returns) that come from applying multiple actions at one site, as well as to reflect standard practice. The interventions explored are outlined below. Table 4 provides a summary of the interventions, and combinations, explored for this pilot.

Table 4: Management combinations explored in this study

Scenario		Interventions applied	Proportional sediment flux reduction (%) relative to baseline			
			Wet season		Dry season	
			A	B	C	D
o	Roughening of the upper channel	Roughening of the second step and channel	0.0	0.0	0.0	0.0
i	Rock upper	Rock cap the initial head and second step	41.7	41.6	34.2	34.1
io	Rock & roughen upper	Combination of (o) and (i)	41.7	41.6	34.2	34.1
ii	Rock upper and lower	Rock cap the initial head, second step, and first and second lower steps	41.7	41.6	43.2	43.3
iii	Diversion	Divert 50% of the runoff from entering the gully	49.7	50.7	49.5	49.4
iiio	Diversion & roughen	Combination of (o) and (iii)	49.7	50.7	49.5	49.4
iv	Diversion & rock upper	Combination of (i) and (iii)	70.6	71.4	66.8	67.4
ivo	Diversion & rock and roughen upper	Combination of (o) and (iv)	70.6	71.4	66.8	67.4

Other common interventions include re-sloping of the gully heads, porous check dams, and re-vegetation. These interventions were not explored as they were considered ill-suited to the location. Due to the steepness of the channel, porous check dams would require regular maintenance to ensure that their construction did not lead to new steps forming in the channel. Grass cover is well established in the lower reaches of the gully without direct management, suggesting that re-vegetation of the upper reaches would likely require ongoing management.

1.2.1. Rock capping of the gully head/s

Rock-capping refers to the application of rocks in the gully heads to reduce erosion. By rocking the gully head the effect of the waterfall over the head is significantly reduced (or removed entirely). The effect of rock-capping is modelled by assuming that there is no net-effect of the gully head on the concentration within the water column (Prentice *et al*. 2021). That is, the concentration exiting the head is assumed to be equal to the concentration entering the head.

1.2.2. Catchment works for water diversion

Management actions applied within the catchment are designed to reduce the volume and/or velocity of runoff entering the gully. Actions include construction of diversions, re-vegetation, and stock exclusion. Within this study, catchment works focussed on options that decrease the volume of runoff entering the head, however, is equivalent to any actions that achieve the same flux reduction. This case study considers actions sufficient to reduce runoff entering the head by 50%, which is consistent with works that reduce the effective drainage basin by 50%.

1.2.3. Roughening the gully channel to slow water discharge

The addition of obstructions into the gully acts to slow the flow, decreasing erosion and promoting localised deposition. Obstructions can include vegetation and porous check dams, however this case study considers natural debris such as logs and branches loosely woven to occupy at least 30% of the space. Following Arcement and Schneider (1989, Table 2), the obstructions are assumed to increase the Manning's roughness coefficient by 0.03 s $km^{-1/3}$. This intervention is focussed on the upper reaches of the gully where wet-season vegetation cover is low.

5.3. Results

Under baseline conditions, the rate of sediment discharge from the gully is modelled to be 5.5, 2.8, 0.8, and 0.4 $m^3\ s^{-1}$ for scenarios A to D respectively (refer to Tables 1 and 3 for a summary of these scenarios). The proportional reduction due to each combination of interventions is shown in Table 4.

6. Discussion

Simulation of the MERGE model indicates that significant reduction in the sediment delivery rate can be achieved at the case study site. The largest proportional reduction in sediment delivery (66.8 to 71.4%) is achieved through the combination of diverting 50% of the runoff from entering the gully and rock capping the main head and second step.

Stream and waterfall power, which together drive erosion, are proportional to the runoff flux travelling into and through the gully. Increasing discharge resulted in increasing sediment delivery (indicated by the colour of the bars in Figure 4) across all scenarios. Reducing the discharge is expected to lead to a roughly proportional reduction in sediment delivery. For this study, diverting 50% of the runoff from entering the gully resulted in sediment delivery reductions between 49.4% and 50.7%. Any action that significantly decreases the volume of water entering the gully, and hence reduces the discharge, will reduce the rate of erosion. Care must however be taken to ensure that runoff is not diverted to concentrate in new locations, driving new gully growth.

Head cut retreat is the primary mechanism of gully growth in younger gullies. The waterfall power available for erosion is typically much greater than the stream power during the initial rapid growth of the gully. Consequently, preventing head cut retreat through rock capping of the head is a valuable management action. Removing erosion at the main head and second step in the upper channel reduced sediment delivery by between 34.1% and 41.7%.

Combining diversion with rock capping in the upper section was shown to be highly effective. While the proportional benefits of both actions are not additive, they do collectively result in at least a two thirds reduction in sediment delivery, with reductions between 66.8% and 71.4% across the four scenarios.

Rocking of the lower channel steps provides a modest improvement (43.2% and 43.3% for scenarios C and D respectively) over that achieved in the upper section (34.3% and 34.1%). This is because of the relatively small drop of the lower steps, being 50cm and 20cm compared with 2m and 40cm in the upper section. No benefit is evident in the Wet Season scenarios (A and B) as the steps are not modelled in the wet season due to the greater fluxes and flow depth mitigating the impact of these steps. One limitation of the model is that flow depths greater than the head height will give spurious results and must be avoided.

Somewhat unexpectedly, roughening the gully channel by introducing logs and branches to slow the flow provided only a negligible improvement (reduction) in the sediment delivery rate. Analysis of the delivery through the gully system shows a substantial reduction in delivery in the roughened sections. However, this is not maintained in the down-gully sections, which raises questions about the appropriateness of the method by which this intervention is represented in the model. The analytical solution to MERGE, used in this analysis, assumes that the spatial gradient of the flux is negligible. While Roberts (2020) demonstrated the appropriateness of this approximation in the context of a uniform gully, further research is required to determine whether this approximation holds across sharp changes in the gully properties. The method by which the interventions are modelled may also contribute to this result. Further research is advised to explore how flow-controlling interventions (e.g. re-vegetation or roughening of the channel) are best represented within the model. In this study, the flow is assumed to maintain depth (d) with decreased discharge (Q) due to increased Manning's roughness. In practice, these interactions are more complex. Improved understanding of how flow is affected by obstructions is essential to improve how these and related interventions (porous check dams, weirs etc.) are best represented in the model.

The proportional reduction achieved by the various management approaches had limited variation under the different runoff scenarios. This provides confidence in the applicability of the results despite the limited range of runoff values investigated. Where possible, it is desirable to consider a range of design events, for example corresponding to 1 in 10 and 1 in 100 year events. This approach was limited by challenges extracting the drainage basin for the gully head, due to the proximity of the Fitzroy River.

Studies across multiple sites are required to constrain these parameters and provide further guidance to practitioners on their selection. The assumptions of a constant carrying capacity and power proportion across all sites also warrants further investigation.

7. Conclusion

MERGE was developed to provide low-cost desktop analysis of the potential benefit of different management approaches. This pilot has demonstrated that MERGE is suited to provide such an analysis, which can be undertaken with limited on-site information obtained using readily available tools (tape measure and camera) and public data sets.

The results of this study indicate that substantial reductions in the sediment delivery rate can be achieved. These results must be evaluated in line with the cost, both upfront and ongoing, of the actions, and the potential for greater reductions through investment at other sites on the property. Care must also be taken to ensure that new gullies would not result from diverting runoff away from the existing site, if that action were considered. In this instance, the proximity of the gully to the banks of the Fitzroy River also requires that consideration be given to the viability of interventions during extreme weather, as water may flow up the gully from the river, which is not captured in this analysis. Furthermore, the risks of stream bank erosion engulfing the gully must also be considered.

8. Related publications

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Related studies

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9. Acknowledgements

The author acknowledges the support of the Queensland Water Modelling Network and the collaborations within it. I thank Jenny Riches and Paul Bikaunieks for their many valuable contributions. This project would not have been possible in its current form without these contributions. I also thank those who provided feedback on this report and on the study.

The support of the Fitzroy Basin Association was instrumental to the success of this project, providing essential on-ground knowledge and relationships. I thank Daniel Boshoff for facilitating this pilot and providing invaluable insights. I also thank the land holders for inviting us to undertake this pilot on their land, and their cooperation with the project.

I thank Graeme Curwen, Griffith University, for assistance with GIS.

Glossary and Acronyms

Carrying capacity	Maximum concentration of sediment (mass per unit volume) that can be sustained within the water column. When the carrying capacity is reached, all available power is used maintaining the sediment in suspension within the water column. This means no erosion will occur.
Deposition	Removal of sediment from within the water column, the laying down of sediment on the gully floor.
Depositional layer	Layer formed by sediment being deposited out of the flow in the same (or very recent) runoff event.
Entrainment	Detachment and lifting of sediment into the water column.
GBR	Great Barrier Reef
Intervention	Management action to protect or rehabilitate gullied landscape with the intent of preventing erosion, encouraging deposition, or otherwise managing the land to meet environmental objectives.
MERGE	Modelling Erosion Resistance for Gully Erosion; a process-based mathematical model for gully erosion.
QWMN	Queensland Water Modelling Network
Re-entrainment	Entrainment from the depositional layer, that is, entrainment of recently deposited sediment
Runoff flux, Q	Volume of water (per unit time) entering (inflow) and flowing through the gully. Runoff flux is a product of the velocity and volume of the flow.
Soil cohesion coefficient, J	Term that represents the power (effort) required to break the cohesion of the soil and make the sediment available for entrainment.