A cost effective method for targeting gully rehabilitation effort in high priority GBR sub-catchments

Brooks, A.P.[1], Spencer, J.[1,] Curwen, G. [2]

[1]Centre for Coastal Management, Griffith University, [2]Australian Rivers Institute, Griffith University

Key Points

- To meet the ambitious Reef 2050 targets for sediment and nutrient load reductions to the GBR, thousands of gullies will need to be rehabilitated over the next decade.
- Efficiently targeting rehabilitation of gullies in GBR catchments is critical to cost-effectively reducing sediment and nutrient yields to the GBR in a timely fashion.
- The key metric for measuring the effectiveness of gully rehabilitation is the unit cost per tonne of sediment reduction (from recent annual trend) or per tonne of avoided sediment.
- Catchment managers need a high resolution gully prioritisation strategy to enable them to know which gullies to target, according to how much sediment can be reduced and at what cost.
- A strategy used for the Cape York Water Quality Improvement plan is proposed as an exemplar of how this can be done very cost effectively ($0.3 - $0.5/ha).

Abstract

Concentrations of gully erosion have been identified in the Normanby, Bowen and upper Burdekin catchments, amongst others, where we know that a large proportion of the fine sediment delivered to the Great Barrier Reef (GBR) is sourced from gully and channel erosion (typically 80-90%). Achieving the ambitious targets for improving GBR water quality over the next decade requires thousands of these gullies to be rehabilitated. In order to prioritise the most cost-effective strategy for maximizing sediment reduction from gullies in the shortest amount of time, mangers need to know the location of individual gullies, their current erosion rates, their spatial distribution and their connectivity to the stream network. The gully prioritization approach developed for the Cape York Water Quality Improvement Plan is proposed as a data driven prioritization strategy that can be cost-effectively employed (@~$0.3-$0.5/ha) within hotspot sub-catchments like the Bowen River. However, at present sufficiently high resolution data does not exist in areas other than the Normanby catchment, to enable us to prioritise specific management effort for individual gullies. This can only be achieved if there is an appropriate investment in high resolution LiDAR data to underpin a gully classification and prioritisation strategy that enables us to target individual gullies for rehabilitation. This data not only provides the basis for the gully classification and prioritization, but it forms the baseline for the monitoring strategy to test the effectiveness of the rehabilitation effort.

Keywords

Alluvial gully erosion, prioritisation strategy, sediment reduction, nutrient reduction, Great Barrier Reef

Introduction

The threats to the Great Barrier Reef (GBR) from climate change induced coral bleaching, ocean acidification, cyclones, and crown of thorns starfish outbreaks driven by nutrient laden flood plumes, and reduced light availability associated with sediment runoff, are now well known. Of all these stressors, it is only the management of catchment water quality and direct disturbances to the reef (such as dredging and shipping) that we can realistically influence at appropriate timeframes, and at an appropriate scale, to potentially buy the GBR time to adapt to the inevitable impacts of global climate change. This places huge pressure on governments and those involved with the implementation of on-ground system repair works to focus efforts on addressing the dominant threats to water quality so that significant and measurable improvements in water quality can be made on a sufficiently short timeframe (e.g. 10 years) to take some of the pressure off the reef.

The recent purchase by the Queensland government of Springvale Station in Cape York represents a new policy direction by government which is now recognizing that resources need to be much better targeted at key erosion hotspots. A key impetus in the decision making process to purchase this property was the knowledge that 40% of all sediment delivered to the Normanby River system from gully erosion was sourced from this one property. This is not to suggest, however, that properties with aggregations of gullies need to be purchased to be managed, none the least because it is unlikely that such a concentration of gully erosion exists in any other catchment. In most circumstances targeted gully rehabilitation should have no material impact on the normal operation of a grazing property, given that the small areas of intense alluvial gully erosion are currently completely unproductive. The important thing is that rehabilitation needs to be focused on the very small proportion of the landscape that is disproportionately contributing sediment and nutrients to the rivers. However the only way the high density aggregation of gullies on Springvale could be identified was due to the Federal Government's foresight in funding detailed research across the Normanby catchment, which provided data at a sufficiently high resolution (e.g. extensive repeat aerial LiDAR, sediment tracing etc.), enabling the precise locations of gullies to be mapped across the catchment, along with their relative sediment contributions.

Recent monitoring data (Bainbridge et al., 2014) shows the Bowen-Bogie Rivers contribute on average 70% of the total sediment load at the Burdekin River mouth and around 60% of the silt/clay fraction, representing around 30% of the total silt-clay input to the entire GBR lagoon (GBRL). Preliminary mapping indicates that there are >2000 ha of alluvial gullies within the lower 100 km of the Bowen floodplain/terrace system (Brooks et al., 2016), which likely deliver a significant proportion of fine sediment load to the GBRL. Sediment tracing data (Wilkinson et al 2013) indicates that 86–96% of sub 10 micron sediment sourced from the Bowen is derived from sub-surface sources and it is likely that the majority, and most spatially confined proportion, of this sediment is sourced from large alluvial gullies along the Bowen River (Figure 1). Similar proportions of sub-surface source dominance have been found in most of the large catchments draining to the GBR (Hughes et al., 2009; Tims et al., 2010; Olley et al., 2013), with extensive gullies being responsible for a significant proportion of fine sediment load in all of the large dry-tropics catchments. Large alluvial gullies are also one of the most connected sources of fine sediment, delivering sediment in many cases directly into the mainstem channels of the largest rivers draining to the reef. A recent pilot study has also demonstrated that alluvial gullies are major sources of particulate nutrients to the GBR (Garzon-Garcia et al., 2016). Hence, significantly reducing the loads derived from these alluvial gullies is critical if Reef 2050 targets are to be met (Anon 2015).

Field reconnaissance in the Bowen catchment indicates that there is considerable diversity of gully form, process and rates of activity, on highly variable soils, and hence there is a similar diversity of management responses that need to be carefully matched to the nature of the gully erosion process and location. Recent reports by Shellberg and Brooks (2013) and Carey (2015) have canvassed a range of management strategies that can be employed to reduce sediment yields from gullies, but what is missing in most catchments is the knowledge about which approach is appropriate for each gully type given the wide diversity of forms (Figure 1). Applying the wrong management strategy can increase erosion rates (Shellberg et al., 2013; Brooks et al., 2016). Previous research (e.g. Brooks., et al., 2009, Shellberg et al., 2013, Rose et al., 2015) has identified a suite of geomorphic and hydrological controls and drivers of alluvial gully erosion, however understanding the relative importance of these drivers requires classifying gully types using high resolution aerial LiDAR data and other remotely sensed data coupled with field data.

Management Prioritisation and the Cost-Effectiveness Conundrum

Given the growing body of evidence that gully erosion is a key threat to GBR water quality, and hence reef resilience, catchment managers are now confronted with the task of directing scarce resources to rehabilitate the sites that will have the greatest impact on reducing sediment and nutrient loads from gully sources. A prevalent view amongst policy makers and managers, is that because we only have scarce resources, these are best directed at numerous small scale low cost projects which can be undertaken by private land holders with limited resources. It is argued that these types of projects are cost effective because they are cheap, whereas larger scale interventions on large highly active gullies are not cost-effective due to the fact that they require substantial external inputs and have a high cost per unit area. (i.e. they are expensive) Some go so far as suggesting that the only option is to direct the scarce available management resources towards a strategy that minimizes the formation of new gullies (e.g. through Best Management Practice grazing), implying that we will have to live with the existing population of gullies and the associated sediment and nutrients they deliver until they exhaust themselves. In some circumstances, if a gully is in the later stages of its evolutionary cycle such a strategy might be appropriate. However, if a gully is in the early or mid-stages of its evolutionary cycle and it has the potential to grow into a gully that will produce thousands of tonnes of sediment and associated nutrients per year, or continue producing such sediment and nutrient loads, then leaving such a gully to exhaust itself would be irresponsible. In some locations large alluvial gully systems will continue to erode for anywhere between several hundred to a 1000 years or more (Shellberg et al., 2016).

Figure 1 A selection of gullies found within a relatively confined area of the lower Bowen River floodplain/terrace systems demonstrating some of the diversity of gully morphology and soil characteristics within the broader category of alluvial soils in this region. Effective erosion mitigation is contingent upon the appropriate management approach being tailored to the gully/soil type. (All photos Andrew Brooks except top right John Spencer)

Undoubtedly, the most appropriate approach does not require choosing one or other of these strategies, but instead looks to design an integrated strategy which strikes the appropriate balance between all approaches in a holistic manner, and seeks to reduce sediment and nutrient loads in the shortest time at the lowest unit cost. If for example, 90% of the sediment and nutrients is coming from 10% of the largest and most active gullies, then the most cost-effective strategy will have to include major investment in the rehabilitation of the large active gully sources – irrespective of how challenging the task appears.

Cost Effectiveness of Gully Treatments

When it comes to prioritising gully management activities the only metric that counts is the cost to prevent a tonne of sediment being delivered to the stream network, and how long it will take to achieve that reduction, taking account of the proportion of that tonne of sediment that is less than 16µm which is likely to be delivered to the reef lagoon. The best estimate available at present for the cost to undertake complete gully regrading and stabilization from trials sites in the Normanby catchment is around $30,000 per hectare (Shellberg & Brooks., 2013), from a gully that was contributing on average 360 t/ha/yr. Assuming a 75% reduction in annual yield post-treatment (as per Shellberg & Brooks., 2013, Brooks et al., 2016), this puts the cost at $111 per tonne of sediment avoided. The close proximity of a site like this to the main channel of the Laura River, means that it has a relatively high sediment delivery ratio (SDR), and hence high cost-effectiveness. By comparison, a Zunni Bowl treatment like that shown in Figure 2 costs around $1500 to build, including materials, labour and vehicle costs, in a gully that was producing an estimated 2.8 t/yr prior to construction (Jared Sunderland pers. comm). Hence the unit cost for this treatment was around $540/ tonne, assuming the treatment is 100% effective. It is also likely that a small gully like this has a much lower sediment delivery ratio than a large alluvial gully, pushing the cost of effective sediment reduction to the reef somewhat higher. The other factor that needs to be accounted for when weighing up different treatment options is the time required to replicate such an approach as well as the economies of scale of focusing effort in a very confined area. An average sized alluvial gully might contribute 1000 t/yr; from 2-3 ha of gully, and hence might cost $60K-$90K to treat and take two weeks to complete. However, achieving the equivalent water quality improvement via the treatment of multiple small gullies using low cost measures, (e.g. Figure 2), would require the treatment of several hundred individual gullies (to account for the lower SDR and less than 100% effectiveness), and would end up costing at least 5 times more, and take as much as 30 times longer to achieve an equivalent outcome (assuming 3 people could treat one gully per day).

Figure 2 Left – An example of intensive gully regrading in the Normanby catchment (Jeff Shellberg) and (right) small scale gully control works in the Burdekin catchment (courtesy Nth Qld Dry Tropics)..

Requirements for Benefit-cost analysis and High Resolution Gully Prioritisation

In order to fully assess the cost comparison between various treatments and hence to prioritise the appropriate mix of rehabilitation measures undertaken, high resolution spatial and temporal data is required to underpin the decision making process. In particular, data is required on:

1) The relative distribution of each type and scale of gully (at the resolution of an individual gully)
2) The sediment and nutrient yield from each type of gully (based on time series gully volume data or a reconstructed gully evolution history - e.g. from historical aerial photography)
3) The relative connectedness of the gullies to the stream network, as an indication of their SDR.
4) The effectiveness and cost of the rehabilitation strategy employed to reduce the sediment and nutrient yield from each gully type
5) Information about constraints on accessing sites and/or accessing material and services required to treat the gullies (i.e. logistical constraints).

The only way this can be done at an appropriate resolution that is applicable for on-ground management prioritisation, is if we have high resolution aerial LiDAR data in the key sub-catchments we know to have major aggregations of gullies, to underpin a prioritisation framework that enables us to compare the sediment contributions from individual gullies. The approach undertaken in the Normanby catchment (Brooks et al., 2015) has enabled the development of a detailed gully rehabilitation strategy to be derived to underpin the Cape York Water Quality Improvement Plan (CYWQIP), and is summarized in the following section. The cost of completing this mapping work and developing the prioritisation strategy across the 2,450,000 ha Normanby catchment was around $0.30 per hectare. Not only does this data set provide the basis for the prioritisation of system repair works in the catchment but it provides high resolution baseline data against which treatment effectiveness can be measured. Alternative on-ground qualitative methods have also been proposed as a prioritisation method, but applying such an approach across the entire landscape would require visiting every gully on the ground, a process that would be extremely time consuming, and ultimately more expensive than the airborne LiDAR approach.

Normanby River Gully Prioritisation Approach

The following is an outline of the approach adopted in the Normanby catchment for prioritizing gully management effort.

1) Development of catchment wide gully distribution mapping (Brooks et al., 2013; 2015)
    a. Bare ground gullies are mapped across the entire catchment in Google Earth (GE)
    b. All gullies are also mapped within selected LiDAR blocks across the catchment (in this case a sample of 41 blocks with a total area of 782.5 km^2 (or 3.2% of the total catchment area).
    c. Compare GE gullies with LiDAR derived gullies in the areas of data overlap and derive underestimation ratio (bare ground gullies mapped in GE will always be an underestimate due to the presence of varying degrees of vegetation that obscure some portion of large alluvial gully complexes).
    d. Derive minimum sediment yields from gullies using repeat LiDAR (of the original 41 blocks (or 78,250 ha) of LiDAR data captured across the Normanby in 2009, around 22% (or 16,310 ha) was reflown in 2011, representing 0.7% of the total catchment area. Sufficient resources were not available to refly all of this again in 2015, so the refly focused on 7 of the LiDAR blocks in the upper Normanby and Laura Rivers, with a total area of 5536 ha, or 0.23% of the total catchment and 7% of the original 2009 data.
    e. These data (a-d) then form the basis for deriving catchment scale (minimum) sediment contributions from gullies at the scale of the 9621 sub-catchments derived for the Australian

Hydrological Geospatial Fabric (AHGF) catchment dataset in the Normanby Basin. Sediment yields are interpolated at the AHGF sub-catchment scale using the combined GE and LiDAR derived gully datasets.

f. The output from this is used to derive the catchment scale gully distribution as shown in Figure 3.

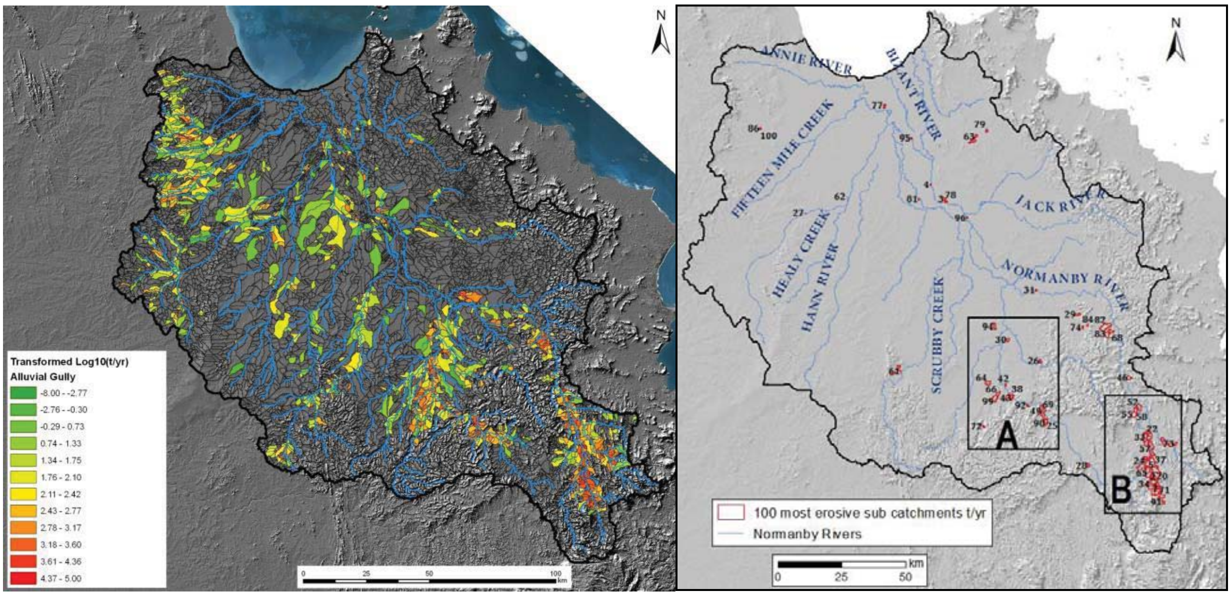

Figure 3 Alluvial gully erosion distribution within the Normanby catchment from Brooks et al (2013) (left), and the prioritised hottest 100 gullies (right). Note that Box B is Springvale Station within which 43 of the top 100 gully sub-catchments are located. The top 100 gully sub-catchments contribute 56% of the total gully sediment yield to the Normanby

g. The output from the catchment mapping at the AHGF sub-catchment scale is then used to rank the top 100 sub-catchments contributing both alluvial and colluvial gully erosion (Figure 3).

h. Additional filters are then added to include such things as:
    i. Connectivity of the site (likely Sediment Delivery Ratio)
    ii. The location of LiDAR data (which improves confidence in the analysis and provides baseline data against which the quantum of erosion mitigation can then be measured)
    iii. Location of road access
    iv. Landholder participation

i. Having ranked the top 100 sub-catchments, individual gully complexes are then identified within the top 100 sub-catchments and clusters of gullies are then identified within each block. The top 100 gully sub catchments produce 56% of the gully sediment yield to the Normanby basin from less than 1% of the total land area

j. Tables are then produced showing the relative sediment contributions from specific gully management units.

k. The most tractable gullies are then selected. This equates to the ones that can be most effectively managed to produce the greatest sediment reductions with a high degree of certainty (lowest risk) over management timeframes for the lowest cost per tonne of sediment reduction, bearing in mind gully type and stage of evolution.

l. Coupled with on-ground information, decisions can then be made as to the most appropriate strategies to be employed in different areas. It should be pointed out that there is NO ONE SIZE FITS ALL SOLUTUION for gully rehabilitation. There are a wide diversity of gullies which are a function of their soil type, landscape position, landscape evolutionary history, land-use history, vegetation community composition, rainfall and flood regime. Ensuring that the right strategy is applied to the right gully is a major challenge requiring an ongoing adaptive management approach.

Conclusions

Cost effective gully management requires a high resolution gully prioritisation strategy to be developed so that available resources can be most efficiently targeted, such that the maximum sediment and nutrient reductions to the GBR are achieved in the shortest time possible. The approach developed for the Normanby WQIP is an extremely cost-effective strategy for prioritising on-ground management (~ $0.30 /ha), and could be readily applied in key sub-catchments within the Burdekin, upper Herbert and Fitzroy catchments, where presence/absence mapping has provided a first order estimate of gully density. The most cost effective approach for treating gullies will not necessarily be the one that appears the cheapest at first blush. The only metric of cost effectiveness which counts is the cost of reducing a tonne of sediment and associated nutrients from being delivered to the reef lagoon. The time taken to achieve the outcome must also be considered. This can only be assessed once the relative distribution of gullies of different types, scales and sediment yields has been established from a high resolution mapping and priorisation strategy.

Acknowledgments

The research upon which this paper is based was funded through the Federal Govt’s Reef Rescue programme in conjunction with CYSF and RRRC, the National Environment Science Programme (NESP), and Cape York WQIP process, through CYNRM and South Cape York Catchments. Special thanks to Kevin Gale, Sheriden Morris, Trish Butler, Julie Carmody, Will Higham, Jason Carroll, Jared Sunderland and Jeff Shellberg.

References

Anon (2015) https://www.environment.gov.au/marine/gbr/publications/highlights-long-term-sustainability-plan

Bainbridge, Z. T., Lewis, S. E., Smithers, S. G., Kuhnert, P. M., Henderson, B. L., & Brodie, J. E. (2014). Fine-suspended sediment and water budgets for a large, seasonally dry tropical catchment: Burdekin River catchment, Queensland, Australia. Water Resources Research, 50(11), 9067-9087.

Brooks, A.P., Shellberg, J.G., Knight, J., Spencer, J. (2009) Alluvial gully erosion across the Mitchell fluvial megafan, Queensland Australia. Earth Surface Processes and Landforms, 34, pp. 1951 – 1969.

Brooks, A.P., Spencer, J., Olley, J., Pietsch, T., Borombovits, D., Curwen, G., Shellberg, J., Howley, C., Gleeson, A., Simon, A., Bankhead, N., Klimetz, D., Eslami-Endargoli, L., Bourgeault, A., (2013) An Empirically-based Sediment Budget for the Normanby Basin: Sediment Sources, Sinks, and Drivers on the Cape York Savannah. Griffith University, 506pp. https://www.researchgate.net/publication/258337838

Brooks, A.P., Curwen, G., Spencer, J., 2015. A Framework for Prioritising Gully Management in the Normanby Basin Cape York. A report to South Cape York Catchments for the Cape York Water Quality Improvement Plan by the Australian Rivers Institute, Griffith University, 28 pp. http://maps.capeyorknrm.com.au/sites/default/files/downloads/Appendix%202%20Gully%20Prioritisation.pdf

Brooks, A., Spencer, J., Curwen, G, Shellberg, J., Garzon-Garcia, A, Burton, J. & Iwashita, F. (2016) Reducing sediment sources to the Reef: Managing alluvial gully erosion. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns (375pp.).

Carey, B. (2015) Soil Conservation Guidelines for Queensland – 3rd Edition.

Garzon-Garcia A, Burton J, Brooks AP. (2016). Bioavailable nutrients and organics in alluvial gully sediment. Department of Science, Information Technology and Innovation, Dutton Park. pp59.

Hughes, A., Olley J.M, Croke, J., and Webster, I., (2009) Determining floodplain sedimentation rates using 137Cs in a low fallout environment dominated by channel- and cultivation-derived sediment inputs, central Queensland, Australia Journal of Environmental Radioactivity 100/10, 858–86

Rose, C.W., Shellberg, J.G., and Brooks, A.P., (2015) Modelling Suspended Sediment Transport in a Sand-bed Alluvial Gully in northern Queensland, Australia. : Earth Surface Processes and Landforms. IF 2.5. subm. April 2014

Shellberg, J.G., Brooks, A.P. (2013) Alluvial Gully Prevention and Rehabilitation Options for Reducing Sediment Loads in the Normanby Catchment and Northern Australia. Prepared by Griffith University, Australian Rivers Institute for the Australian Government Caring for Our Country Reef Rescue Program, Cooktown, Qld.

Shellberg, J.G., Brooks, A.P., Rose, C.W., 2013a. Sediment production and yield from an alluvial gully in northern Queensland, Australia. Earth Surface Processes and Landforms, 38, 1765-1778. DOI: 1710.1002/esp.3414

Shellberg, J.G., Spencer, J., Brooks, A.P., Pietsch, T., (2016). Degradation of the Mitchell River Fluvial Megafan by Alluvial Gully Erosion Increased by Post-European Land Use Change, Queensland, Australia. Geomorphology, V 266 pp105-120. http://dx.doi.org/10.1016/j.geomorph.2016.04.021 -

Tims, S.G., Everett, S.E., Fifield, L., Hancock, G., Bartley, R., 2010. Plutonium as a tracer of soil and sediment movement in the Herbert River, Australia. Nuclear Instruments and Methods in Physics Research 268, 1150–1154.

Wilkinson, S. N., Hancock, G. J., Bartley, R., Hawdon, A. A., & Keen, R. J. (2013). Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Australia. Agriculture, *Ecosystems & Environment*, *180*, 90-102.