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A remote sensing approach for mapping and classifying riparian gully erosion in Tropical Australia

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Final Report

Project No – GRU37

A remote sensing approach for mapping and classifying riparian gully erosion in Tropical Australia

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Initial Project Overview

Recent aerial and ground reconnaissance through the Gulf of Carpentaria has identified riparian gully erosion as one of the dominant contemporary sediment sources to many of the large rivers draining into the Gulf of Carpentaria. Similar processes have also been identified in the Savannah regions of the NT and WA, particularly the Victoria and Ord Rivers. It has also been suggested that broad scale gully erosion of this type and associated local scale denudation is a fundamental control on vegetation community dynamics in these regions (Pringle and Tinley, 2003), and yet existing ecological models do not take this into account. Fundamental questions persist concerning this widespread phenomenon. Particularly, is widespread gully erosion an inherent characteristic of this landscape associated with base level adjustments and long term landscape evolution, and has it been accelerated by land-use impacts (e.g. cattle grazing and altered fire regimes) or other external drivers such as climate change? A crucial step in unravelling the causal mechanisms underpinning this process is the mapping of its distribution and severity and placing this within a broad landscape context. Understanding and managing this erosion process has been identified as a high priority in all regional plans by the groups consulted for this proposal. This project will develop a procedure for mapping riparian gully erosion within Australia's tropical rivers; it will develop a classification scheme for prioritising the threats posed by gullying in different parts of the landscape; it will validate the approach in five focal river systems in Queensland and the Northern Territory (the Coleman River on Cape York; the Mitchell River in the North/Eastern Gulf; the Leichhardt, Gregory and Nicholson Rivers in the Southern Gulf; and the Victoria River in the NT); and it will produce gully erosion hazard maps for these five rivers.

Project objectives as identified in the proposal

1. Review International literature of remote sensing approaches to mapping similar features in other parts of the world.
2. Undertake baseline evaluation of gully erosion in each of the five focus river catchments

3. Develop a conceptual model of riparian gully erosion processes for tropical river catchments across northern Australia.
4. Develop a remote sensing method for mapping gully erosion hazards in tropical river catchments
5. Validate the gully erosion mapping procedure in five river systems.
6. Develop a gully erosion severity index based on the observed types and the severity of gully erosion in the five Focus Rivers.
7. Produce initial maps of gully erosion based on severity index classes in the five focal catchments.
8. Provide an estimate of the accuracy of the mapping method developed.

Summary of methods and modifications.

1. Methods as Originally Proposed

A hierarchical, iterative procedure will be adopted, using data of various spatial resolutions within an existing hierarchical geomorphic classification of riverine landscapes in the region (see Brooks et al., 2005).

By drawing on the 1st order basin level classification morphometrics in Brooks et al (2005) (such as basin structure and broad drainage pattern) an initial image classification procedure will be developed to enable targeting of probable gullying areas for closer attention. The refinement in stage two will focus on developing reliable methods for classification of stream reach based on Brooks et al (2005) 2nd and 3rd order classification where valley confinement and reach homogeneity will be used to target increasingly higher resolution gullying potential.

The third level of processing will be to develop a schematic defining gullying extent and degree. Using this classification an image classification methodology can be developed to provide thematic maps showing gullying extent and degree. Development and validation of remote sensing methods will be undertaken using both existing video data and filed based surveys.

2. Modifications

The methods as outlined above were followed in broad terms, however, all stages were modified to reflect new knowledge derived from the 2006 field campaign, as well as limitations associated with the data and the nature of the problem as one becomes more familiar with the problem (as might be expected). As a result of our extensive field campaign in 2006 a new conceptual model was developed to describe a completely new type of gully morphology and process that was based in the alluvial sections of the catchments rather than the structure described in Brooks et al 2005. The third level of the methodology involved the development of a remote sensing method. Initial testing suggested that an object oriented approach would by the most suitable, as it has an inherent hierarchical structure. However, the inability of commercial software to process large images necessitated a change to a more traditional pixel based methodology. Furthermore, because of inherent problems with the satellite data we were working with, we were required to undertake processing of individual Aster scenes rather than the mosaics of whole catchment extents ((as originally proposed). This involved fine tuning the processing algorithms at each iteration – a significantly more time consuming processing approach than was originally anticipated. The main reason for the variation between scenes was that unclear descriptions were provided by the original requestor of the Aster data (NGRMG) regarding the need for either dry season or wet season imagery but not a mixture of both.

The exclusion of the Victoria River catchment (located in the Northern Territory) resulted partly from a need to respect the intellectual property of Gillian McCloskey who was undertaking a PhD looking at gully erosion processes in the Victoria River, NT, but also because of the unavailability of appropriate satellite imagery in the NT. It was considered to be more appropriate that Gillian's work remains as a separate study to this work.

Summary of Results

Objective 1: Review international literature of remote sensing approaches to mapping similar features in other parts of the world

Annotated bibliography

In an effort to gauge the extent of the international literature relating to gully erosion and remote sensing a search of the citation index Web of Science was undertaken along with specific journal searches, where incomplete coverage in Web of Science was observed, using the search terms "remote sensing" and "gully erosion" resulted in eleven articles identified. One was about suspended sediment source fingerprinting (Collins and Walling 2004), another about water erosion mapping in Iraq (Hussein 1998) others were concerned with modelling and mapping gully erosion, two in South Africa (Flugel, Marker *et al.* 2003; Sidorchuk, Marker *et al.* 2003) and two Spain (Martinez-Casasnovas 2003; Ries and Marzolff 2003). A number of less specific searches were required to identify the range of published research on mapping gully erosion using remote sensing. The terms "remote sensing" and "erosion" identified 274 articles; "remote sensing" and "mapping" identified 348 articles; and "mapping" and "erosion" found 538 articles. The three-way combination of the terms "erosion" and "mapping" and "remote sensing" resulted in identification of 71 articles. An assessment of these references was undertaken from which an annotated bibliography was produced. The annotated bibliography has been reported in the 1st Progress report (Brooks et al., 2006), see Appendix 1.

An analysis of the literature failed to identify methods for mapping of gully erosion over very large areas (as required for this project). In particular, the use of high resolution Aster imagery at the regional scale involving large mosaics for the purpose of gully erosion mapping had not been undertaken. However, a number of approaches for mapping rangelands and mapping erosion gullies (such as Hessel and van Asch 2003; Martinez-Casasnovas 2003; Vrieling, Rodrigues *et al.* 2007) have been published.

The review informed the development of a remote sensing method with two foci:
1) an overarching data centric management strategy (to cater to a large number of images (>30), very large files sizes (>10 Gb) and data storage (>2Tb)); and
2) a scene specific target detection and delineation strategy.

Objective 2: Undertake baseline evaluation of gully erosion in each of the five focus river catchments

A baseline evaluation of gully erosion has been completed for the Queensland catchments with both gully distribution and gully density maps produced from Aster satellite imagery. All NRM groups have been provided with copies of these products and have been involved in interpreting the maps via a user group workshop held in Mareeba in November 2007. A summary of baseline metrics describing the results of gully erosion mapping in each of the mapped catchments is provided in Table 1. Other aspects of the baseline mapping are reported with Objectives 6 and 7 below.

In addition to the baseline estimation of gully erosion from Aster satellite imagery, an important part of the baseline assessment was the acquisition of baseline field, airborne and satellite data including repeated GPS field surveys of selected gullies, acquisition of airborne Lidar, photos, tri-spectral scanner data and high resolution forward-looking video. A summary of data acquired for this project has been reported in the 1st Progress report (Brooks et al., 2006), see Appendix 1.

Further to the acquisition of new data, Aster satellite imagery were acquired via Geoimage Pty Ltd who provided a compilation of Aster images acquired over the period 2000 to 2005. In total 114 Aster scenes covering the Northern Gulf and 119 Aster scenes covering the Southern Gulf were acquired and processed before being made available for use by this project. Also, elevation data in the form of 30m

SRTM DTED 2 digital elevation data covering the study area were acquired from the Australian Dept of Defence through Geoscience Australia. These two datasets provided the highest resolution baseline data available over northern Australia.

Table 1: Summary of gully erosion baseline survey derived from Aster satellite imagery.

Catchment	Total Catchment Area (km^2)	Catchment Area Analysed (km^2)	Gully Area (km^2)#
Gilbert	46,324	11,365 (24.5%)*	99.8 (0.22%)*
Gregory/Nicholson	51,696	17,372 (33.6%)	123 (0.24%)
Leichhardt	33,287	17,430 (52.4%)	291 (0.9%)
Mitchell	71,630	37,438 (52.3%)	191 (0.3%)
* ( ) percentage of total catchment area			
# derived from Aster imagery			

Objective 3: Conceptual models of Riparian Gully Erosion processes and typology

Gully Morphology

Based on extensive field survey and air photo interpretation, we have identified four primary gully morphological variants, which we hypothesise can be attributed to different formative processes. As with many natural systems, a complex continuum of gully forms exists, and invariably most gullies will have elements of more than one of the primary variants. For the purposes of this project, however, it was important to keep the typology as simple as possible as the basis for the remote sensing mapping, whilst at the same time capturing key elements of the variability that will allow us to begin to unravel the underlying processes driving riparian gully erosion in tropical rivers. Appendix 1 provides a description of the four key gully types identified as reported in the 1st Progress report (Brooks et al., 2006). More recently the development of gully erosion conceptual models has been published in Brooks et al. 2007a; Brooks, et al. 2007b; Brooks et al. (in review); Shellberg, et al. 2008a; Shellberg, et al. 2008b.

Objective 4: Develop a remote sensing method for mapping gully erosion hazards in tropical river catchments

In order to assess the extent of alluvial gully erosion in the focal catchments a large volume of satellite, airborne and ground data were required due to the large area of the study. Because of the large number of files their large size it was necessary to define a data handling strategy as a precursor to image processing. This was achieved by developing a data centric process within an adaptive framework responding to Aster data coverage and quality scene by scene. A major unforseen limitation of the Aster data was the provision of image scenes acquired over a wide range of conditions, both season (wet and dry) and across years (from 200 – 2005). The consequence was that Aster processing had to proceed on a scene by scene basis with each scene exhibiting significant differences due to variations in vegetation coverage and quality across seasons affecting the expression of bare ground compared with eroded gully areas.

The second phase of the remote sensing method was a gully identification and delineation strategy undertaken on a scene by scene basis. The resultant gully mapped areas were then mosaiced to create catchment extents prior to validation and analysis of gully patterns.

The remote sensing methods were revised after the first iteration due to unforseen limitations with both computing resources and computer software due to the very large data volumes involved. As a result the remote sensing method for detecting and delineating gullies had two phases 1) using an object orient approach using Definiens software; 2) using a pixel based decision tree classification using ENVI software. The object oriented approach was published in Knight et al (2007), and involved image segmentation at different scales, but in a production environment was found to be unable to process large datasets efficiently (if at all). The revised approach used a decision tree classification was scalable to any sized image scene. The decision tree approach was found to be efficient because it allowed for reduction in the number of pixels being processed as the tree became more refined. The decision tree approach was described in Brooks et al. (in review).

A significant part of the remote sensing process involved calibration of features in the aster data against field data and airborne imagery (Lidar, aerial photos and tri-spectral scanner data) acquired for the project.

Objective 5: Validate the gully erosion mapping procedure in five river systems

A gully validation strategy utilising both data acquired during the project and using Quickbird imagery publicly available via Google Earth online was developed. The approach has been described in Brooks et al. (in review). Two phases of validation were undertaken. The first followed the initial phase of gully mapping where validation of both gully erosion detection and the spatial extent of gullies detected were assessed. The second phase of validation followed the second iteration of gully mapping during which additional data were used to refine the extent of gullying to areas of alluvium with in catchments. Also, erroneously mapped features such as roads features and in-channel sediment were manually removed from the extent of gullying.

The validation approach developed was novel in that it utilised the KML digitizing capacity of Google earth to construct a very high resolution validation dataset based on 1 km grid cells overlayed onto both the Aster and Google earth data. Google earth KML vectors were converted to ArcGIS shape files and then evaluated against the Aster derived gully extent maps. Areal corrections were applied to the Aster derived gully maps based on the output of the Quickbird validation process. The Google/Quickbird mapped gullies were also calibrated against field surveys of gully scarp fronts (totalling ~ 50km).

Objective 6: Develop a gully erosion severity index based on the observed types and the severity of gully erosion in the five focus rivers.

A severity index concept was developed whereby an artificial grid of 250m 500m and 1km cells covering the extent of the catchments were used to interrogate the Aster gully maps to estimate the proportion of each cell mapped more as a description of gully density than severity. This approach was described in Knight et al (2007).

To derive a concept of severity we used the density of gullies in a grid cell as an indicator of severity where a maximum coverage of gully in a grid was designated as the most severe. A consequence of this approach was that severity was found to be grid cell size dependent, but provided similar patterns at all scales. The main problem faced when using the term severity compared with density is that severity requires an understanding of the process dynamic for which we have little data; where as density only requires delineation of spatial patterns within an arbitrary spatial framework. The benefit of the 3 grid cell sizes (250m, 500m and 1km) was in the potential to provide a range of detail depending on the end use. For example at a farm scale the 250m cells provided sufficient detail but was not to large (file size wise) where as a 250m cell across the entire catchment produced a map that was unnecessarily large (files size wise) given the end use, where as the 1km cell size provided adequate resolution at the catchment scale but as a much smaller file size. Examples of density grid maps at the three density grid scales for the Mitchell catchment have been reproduced in Appendix 2.

Objective 7: Produce initial maps of gully erosion based on severity index classes in the five focal catchments

The initial mapping of gullies in the Mitchell catchment identified that the particular form of gully erosion evident was in the alluvial sections of catchment. Giving rise to the use of the term alluvial gullies to distinguish this form from the predominant form described in the literature, hillslope gullies. The extent of gully mapping in each of the focal areas was confined to areas of alluvium, which were delineated at a broad scale by the intersection of geology and soils data. Maps of both gully extent (as mapped polygons) and as a density grid have been reproduced in Appendix 3. Maps of both extent and density have been provided to collaborators as described below.

Objective 8: Provide an estimate of the accuracy of the mapping method developed

As a result of the validation process three estimates of the accuracy of the mapping method were derived: 1) inter-operator comparisons; 2) gully detection accuracy assessment; and 3) gully delineation accuracy assessment.
Accuracy assessment for inter-operator comparison provided a means of evaluating how individual operators performed against each other and the result was used to scale each persons digitizing effort to a standard for validation of the gully detection and gully delineation assessments. Table 2 summarise the interoperability comparison where both gully area and gully perimeter as digitized by each of three operators were compared with the Aster derived area and perimeter for the relevant validation areas.

Table 2: Summary of inter-operator accuracy assessment for the three operators.

	Operator 1	**Operator 2**	**Operator 3**	**Aster**
Area (ha)	7.68	8.98	3.57	6.84
Comparison (O/A)	112%	1.31%	52.1%	
Perimeter (km)	11.74	8.92	4.96	7.18
Comparison (O/A)	163.5%	124.3%	69.1%	

The gully detection validation involved comparing the detection rate from the Aster processing against high resolution Quickbird Google earth 1km grid evaluation process with an overall detection accuracy of 75%.

Table 3 summarises the results of the gully detection validation process.

TruePositive	**TrueNegative**	**FalsePositive**	**FalseNegative**	
52	135	45	18	250
21%	54%	18%	7%	100%

The accuracy of the Aster based delineation of gully areas and perimeters was validated by manual digitization of gullies as seen in Quickbird Google earth high resolution imagery. The results of the gully delineation accuracy assessment are summarised in Table 4 and have been summarised in Knight et al (2007) and Brooks et al. (in review).

Table 4: Summary of gully mapping validation.

Catchment	Gully Area Validation			Gully Perimeter Validation		
	Aster (a) (ha)	Quickbird (q) (ha)	Comparison q/a (%)	Aster (a) (km)	Quickbird (q) (km)	Comparison q/a (%)
Gilbert	202.9	150.8	74%	na	na	na
Gregory/Nicholson	181.8	214.7	118%	104.18	62.5	60%
Leichhardt	376.8	434.7	115.4%	289.3	189.1	65.4%
Mitchell	460.1	384.1	83%	327.8	250	76.3%

Outline of how outputs can be adopted and summary of communication

The outcomes of this research have already been incorporated into the new Resource Investment Strategy document for the Northern Gulf Resource Management Group (NGRMG). This has come about through our close collaboration with the regional bodies throughout the life of the project, and culminated in the PIs involvement in a strategic planning workshop with the NGRMG in late 2007, and a review of their RIS in early 2008. Several new projects building on this project have been included into the new *Caring For Country* RIS document. At the time of writing we have been advised by NGRMG that two of the projects have been short listed for funding. This includes a project that is beginning to look at methods for remediating gully erosion in Northern Australia.

The outcomes of this research will also form a major input to the sediment budget project being undertaken within TRaCK.

The outcomes of the work have been presented at numerous community fora over the last two years, including:

- Brooks, A., Knight, J., Shellberg. J., and Spencer, J (2008). Sediment dynamics in the Mitchell Catchment" Presentation to the Palmer River Forum – a one day stakeholder workshop on mining issues in the Mitchell Catchment organised by the Mitchell River Watershed management Group – Mareeba May 16th 2008.
- Brooks A. Burrows, D. Knight, J., Shellberg, J., Spencer, J & Lymburner, L. (2008) Seminar entitled "Mining impacts on sediment budgets in the Mitchell River catchment" presented at the Nth Qld AUSIMM meeting – Cairns 21 st & 22nd Feb, 2008.
- Brooks, A., Knight, J., Spencer, J. and Shellberg. J (2007) "A remote sensing approach to mapping alluvial gully erosion in the Northern and Southern Gulf regions." Presentation to the Northern Gulf NRM Group Annual General Meeting, Mt Surprise, Nov 23 2007.
- Brooks, A., Knight, J., Spencer, J. and Shellberg. J (2008) Presented 2 day workshop for ~ 30 Stakeholders within the Mitchell River catchment on gully erosion and bedload transport in the Mitchell and Gilbert River catchments. Mareeba, Nov. 2007.
- Brooks, A., Knight, J., Spencer, J. and Shellberg. J (2006) "A remote sensing approach to mapping alluvial gully erosion in the Northern and Southern Gulf regions." Presentation to the Northern Gulf NRM Group Annual General Meeting, Undarra, Oct, 2006.

Assessment of commercial potential

The outcomes of this research have significant implications for our understanding of the development potential of Northern Australia (or the limits to development). Hence, given the interest in developing northern Australia, most recently espoused at the 2020 Summit in Canberra, policy makers and business interests would be strongly advised to consider the implications of any development activities on erosion potential, or indeed whether areas flagged for development are subject to gully (or other) erosion processes.

Publications

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Brooks AP, Knight JM, Spencer J (2006). "A remote sensing approach for mapping and classifying riparian gully erosion in Tropical Australia. Milestone 2, Report 1 to Land Water Australia for project GRU 37." Australian Rivers Institute, Griffith University, Nathan, Qld, Australia

Conference Presentations/Seminars

Brooks, A., Knight, J., Shellberg. J., and Spencer, J (2008). Sediment dynamics in the Mitchell Catchment" Presentation to the Palmer River Forum – a one day stakeholder workshop on mining issues in the Mitchell Catchment organised by the Mitchell River Watershed management Group – Mareeba May 16th 2008.

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Brooks, A., Knight, J., Shellberg. J., and Spencer, J. (2008) Seminar presented to Australian Rivers Institute (ARI) Gold Coast node entitled "Developing sediment budgets for large rivers in northern Australia: a remote sensing and field-based approach". March 21, 2008.

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