Alluvial Gully Prevention and Rehabilitation Options for Reducing Sediment Loads in the Normanby Catchment and Northern Australia

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Executive Summary

Report Overview

This two-year project funded by the Australian Government's Caring for our Country Reef Rescue Initiative was undertaken by Griffith University to assess the options for preventing and rehabilitating alluvial gullies in the Normanby Catchment, with implications for alluvial gully management across northern Australia. Alluvial gullies eroding into terraces and elevated floodplains along river frontage with dispersive or sodic soils are a major sediment source in the Normanby catchment and northern Australia (Plate 1). Traditional Owners, cattle graziers and other local residents in the catchment and along Princess Charlotte Bay are concerned about economic, cultural and environmental impacts of local gully erosion and downstream sedimentation. Large alluvial gullies – and gullies in general – are often considered to be in the 'too hard basket' for basic land management action. However, large reductions in elevated sediment loads at the catchment scale will not be achieved unless gully erosion is addressed cumulatively through innovative proactive land management actions.

Plate 1 Examples of alluvial gullies in the Normanby catchment.

The aims of this report were to: 1) review the current scientific knowledge on alluvial gully erosion in northern Australia, 2) review scientific and grey literature on gully prevention, rehabilitation, and best management practice options applicable to alluvial gullies, 3) implement several field trials for preventing and rehabilitating alluvial gullies, and 4) provide information toward the future development of a comprehensive regional Best Management Practice (BMP) manual to address alluvial gully erosion based on scientific principles and proven field success. Social, economic, and political obstacles to cumulatively reducing gully erosion and sediment yield at the catchment scale are also reviewed.

While this report does not provide detailed BMP solutions for all gully erosion issues in the Normanby catchment or elsewhere, it does highlight in detail the nature of the problem and potential research and management actions for the future. Reducing sediment loads to river systems and coastal environments will not occur unless these cumulative and complex physical, chemical, biological processes together with social, economic, and political management issues are understood and addressed.

Background to Alluvial Gully Erosion

Alluvial gully erosion is both a natural and human land use accelerated erosion process. These alluvial gullies or 'breakaways' initiate on steep river and creek banks along river frontages and erode into river terraces and elevated floodplains with highly erodible soils (Plate 2; Plate 3). River incision over geologic time (base level), dispersive or sodic soils (high exchangeable sodium on clay particles), intense monsoon rainfall and flooding are natural factors priming the landscape for gully erosion. Since the margins of terraces and elevated floodplains are only infrequently inundated or backwatered by flood water, erosion from direct rainfall and overland water runoff from subtle terrace/floodplain slopes dominates gully scarp retreat.

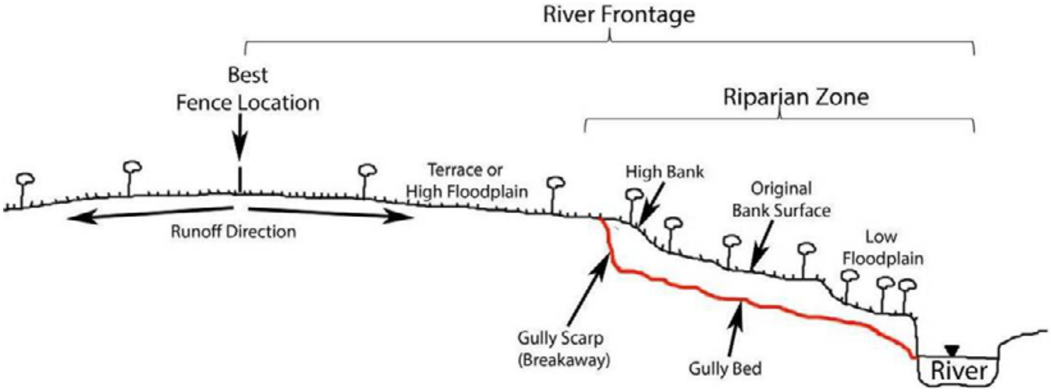

Plate 2 Cross-section drawing of an alluvial gully (bed and scarp) eroding into a terrace from a river bank.

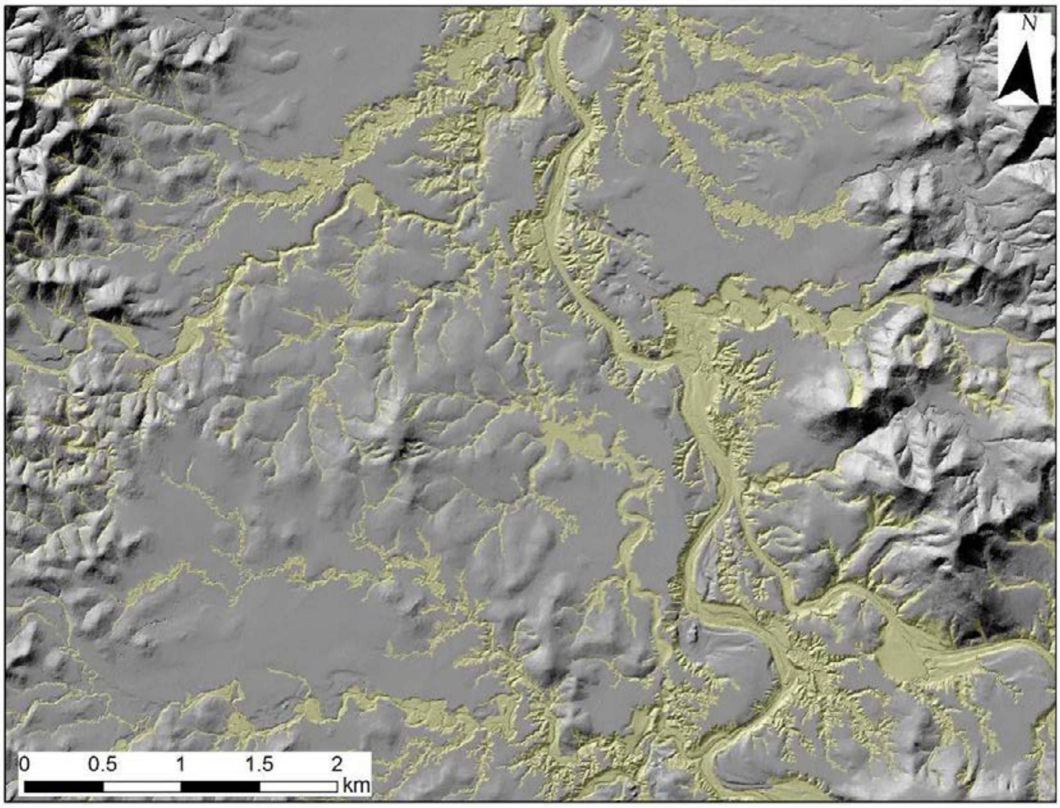

Plate 3 An airborne LiDAR hillshade map of alluvial & colluvial gullies and creek & river channels along the Granite Normanby River valley and frontage country showing the complexity of the channel network.

Sediment dating in alluvial gullies has shown that gully erosion rates have increased greater than 10 times since European settlement in some locations. Historic aerial photographs also document increased gully erosion after land use change. Modern gullies have eroded into older floodplain hollows and drainage channels that were earlier phases of gully erosion, as well as steep river banks. The recent accelerated phase of gullying can be linked to the introduction of cattle that congregate along river frontages, reduction of perennial grass cover, concentration of water along cattle tracks (pads), and an increase in water runoff into gullies (Plate 4), as well as intense late-dry season fires, roads, fence lines, agricultural clearing, and infrastructure development.

Plate 4 Examples of over-grazed riparian frontage with cattle tracks (pads) funnelling water down to gully heads, as well as cattle tracks cut into steep river bank hollows.

Sediment budget research in the Normanby catchment estimated that 37% (1,148,200 t/yr) of fine sediment (<63 µm) entering the river system comes from alluvial and colluvial gullies. Independent sediment tracing data suggests that >87% of fine sediment inputs (<10 µm) originate from sub-surface sediment sources (channel bank erosion, gully erosion, etc.), with hillslope surface sources only a minor contributor. The mapped area of active, bare-earth, alluvial gully erosion viewable by aerial photographs in the Normanby catchment is > 1000 ha. It has been estimated that >10,000 ha of gullies exist in the Normanby once the masking of trees is removed using Light Detection and Ranging (LiDAR) topographic data. These alluvial gullies are mostly concentrated on dispersive or sodic soils along terraces and elevated floodplains of river frontage areas, where cattle grazing is focused.

Principles of Gully Erosion Prevention and Control

There are three main approaches to prevent gully initiation and reduce gully erosion once started, which generally should be used in combination.

1. Reduce water runoff into and through gullies and drainage hollows.
2. Stabilise gully headcuts, sidewalls, and drainage hollows with vegetation and/or physical structure.
3. Reduce the gully channel slope and increase roughness using grade control structures and/or vegetation, which will trap sediment and promote revegetation.

Large-Scale Land Management to Prevent and Reduce Alluvial Gully Erosion

Mapped areas of concentrated alluvial gully erosion and soils with high erosion risk (i.e., dispersive or sodic soils along river frontage terraces, Plate 3; Plate 5; Plate 17) should be targeted for large-scale land management changes and localised intensive rehabilitation actions to cumulatively reduce sediment yields to downstream rivers, wetlands, estuaries, coasts, and off-shore reefs. Land management actions to directly or indirectly prevent or reduce alluvial gully erosion from high risk areas include:

- Increasing perennial grass cover on shallow slopes above gully prone areas such as steep river banks.
- Reducing water runoff toward gully prone areas by improving soil/vegetation hydrologic functions upslope.
- Reducing concentrated water runoff down cattle tracks (pads), roads, and fences.
- Increasing perennial grass cover within gully prone areas (river banks and hollows) to resist erosion and trap sediment.

A paradigm shift and a full suite of altered management actions (cattle, fire, weed, road, fencing) are needed on erosion-prone sodic soils along river frontage, in order to reduce the initiation of new alluvial gullies, slow gully erosion rates where already initiated, and aid in indirect/passive long-term rehabilitation efforts.

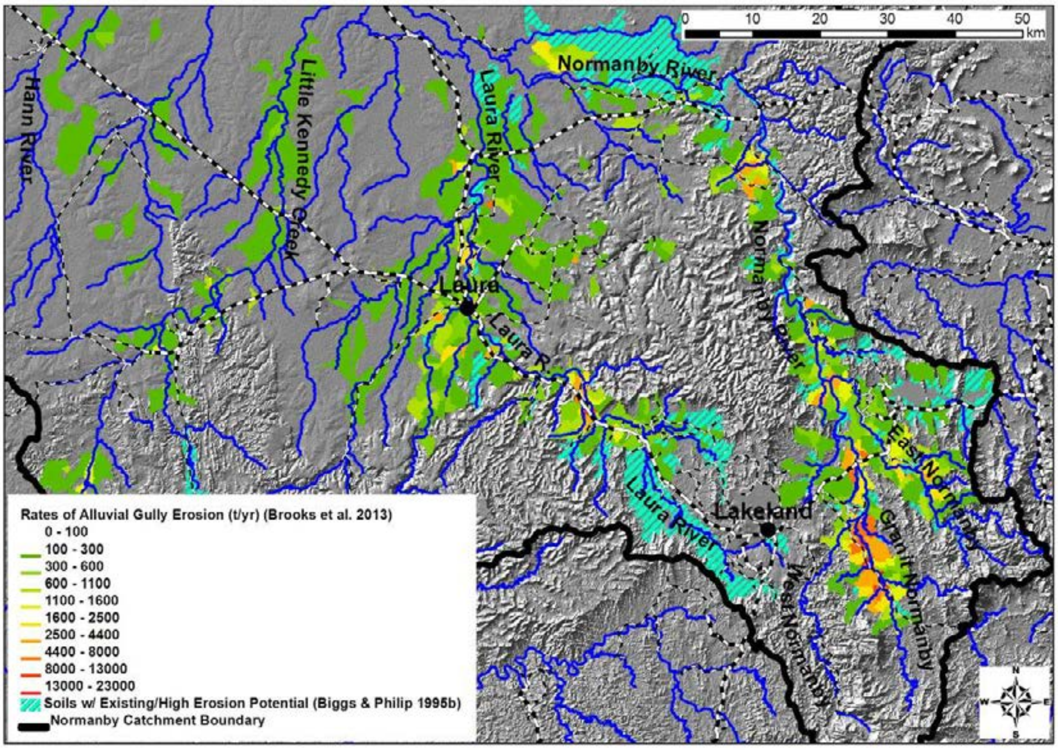

Plate 5 High risk areas of alluvial gully erosion in the upper Laura-Normanby catchment.

Cattle Management along River Frontage with Dispersive or Sodic Soils

Cattle grazing is a primary agent for accelerating gully erosion on highly-erodible sodic soils. Cattle grazing intensity and impacts are often concentrated along river frontage terraces and elevated floodplains. Ideally, permanently maintained cattle exclusion fencing is needed around large concentrated areas of gully erosion to create 'soil conservation areas' by fencing according to land type (i.e., sodic soils on river frontage). Several priority river frontage areas have been identified in the Normanby (e.g., the Granite Normanby River, Plate 5; Plate 17). Alternatively, seasonal spelling of cattle could be used if it can be demonstrated to reduce gully erosion. Government or market-based compensation is needed for the economic loss of graziers, such as payment for ecosystem services (carbon, biodiversity, soil retention) or promotion of 'improved pasture' management on stable and productive soils.

To document the effectiveness of cattle exclusion for vegetation recovery and soil erosion reduction, cattle exclusion experiments have been initiated around alluvial gullies in the upper Laura-Normanby catchment (Plate 6). Four (4) cattle exclusion areas (3-5 ha) were fenced in 2012 to start a long-term monitoring program (5 to 10+ years). A before-after, control-impact study design was used with vegetation and erosion plots and detailed repeat topographic surveys (LiDAR). Funding is needed for long-term monitoring.


Plate 6 An alluvial gully recently fenced off from cattle grazing, and changes in grass cover on a river terrace above a gully head inside and outside the fence after one wet season. Short-term vegetation improvements within the gully were minor after fencing.

- *Draft BMPs for Cattle Grazing on River Frontage with Dispersive or Sodic Soils*
  - Exclude cattle from mapped sodic soils on river frontage terraces and elevated floodplains.
    - Fence to land type.
    - For best management, fence completely around mapped erodible sodic soils, locating fences on more stable geology.
    - Otherwise, place fences well back from high banks when excluding cattle from immediate river frontage zones, when entire areas of sodic soils cannot be fenced. Include river terraces and flats upslope of gullies (breakaways) inside fence to increase grass cover and reduce water runoff from these catchment areas (Plate 2).
    - Use spear traps and rotated use of fire to move cattle off river frontage.
  - Wet season spelling (Dec-April) of cattle along erodible river frontage, when full cattle exclusion is not feasible.
  - Cattle exclusion or spelling will reduce cattle tracks (pads) over steep banks and across terrace/floodplain flats.

- Vegetation cover targets >75% at break-of-season (Nov), >1000 kg/ha perennial grass.
- Install off-stream water points for cattle on stable geology outside of mapped erodible sodic soils and well away from river banks.
- Reduce cattle numbers during drought. Use Bureau of Meteorology (BOM) climate forecasts and market forecasts to destock early for income benefits, soil protection, and prevention of land and pasture degradation.

Fire Management along River Frontage with Dispersive or Sodic Soils

Fire regimes on dispersive or sodic soils in river frontage terraces and elevated floodplains need to be tailored toward maximizing the health of perennial grass cover (for water runoff regulation and soil stability), minimizing weed dominance or spread, and regulating the amount of grass cover consumed by cattle each year to build up grass cover and fuel loads. In some highly eroded locations, fire should be excluded to maximise any potential vegetation cover. At the landscape scale, a return toward a mosaic (patchy) burn pattern and variable timing of fire regimes is needed, locally tailored to soil type and vegetation community (Plate 7). More scientific experimentation is needed to identify the most appropriate fires regimes for sodic soils on terraces and elevated floodplains in river frontage to promote perennial grass health, reduce water runoff and soil erosion, and minimise gully erosion, while also managing the balance between trees and grass. Some preliminary BMPs are included below.


Plate 7 Low intensity early-dry season burn in a colluvial hollow and perennial grass tussock and incompletely burnt organic mulch cover remaining after the low intensity burn.

- *Draft BMPs for Fire Management along River Frontage with Dispersive or Sodic Soils*
  - Cattle spelling during the wet season (Dec-April) or full cattle exclusion to improve perennial pasture health and build up fuel loads for appropriate fire regimes, if any.
  - In some highly erodible locations, fire could be excluded altogether to maximise any potential vegetation cover.
  - Reduce the occurrence of intense late-dry season fires through river frontage with sodic soil.
  - Create a mosaic (patchy) burn pattern at the landscape scale with variable timing.
  - Mange fire in a controlled fashion in discrete areas.
  - Locally tailor fire regimes to soil type and vegetation community for specific objectives (i.e. increase long-term perennial grass cover, weed control).
  - Use prescribed aerial and/or ground burning in the early-dry season to install fire breaks and take advantage of natural or made-made fire barriers.
  - Move the location of early-dry season fire breaks every year to burn in a mosaic pattern and not burn the same location repeatedly, especially along erodible river frontage.

- Avoid repeatedly using river frontage and riparian zones as fire breaks. Frequent fires can reduce the long-term health of perennial grass and increase gully erosion potential on terrace and floodplain margins.
- Do not repeatedly grade fence lines as fire breaks, as this will accelerate erosion.
- Early-wet season ‘storm-burns’ (1-3 days after first >25mm rain) should be used cautiously in strategic patches along highly-erodible river frontage with dispersive or sodic soils to avoid accelerated water runoff and soil erosion at the start of the wet season. Storm-burns should be used for specific localised purposes (rubber vine control; thickening of *Melaleuca viridiflora*, improving perennial grass germination/health) where long-term improvements of grass cover can be demonstrated to reduce gully erosion.
- Control cattle grazing of grass regrowth after both early-dry season and early-wet season fires to promote perennial grass health during critical growth periods, ensure good grass cover, and protect soil during early-wet season rainfall.

<u>Weed Management along River Frontage with Dispersive or Sodic Soils</u>

The invasion of exotic weeds into river frontage country and riparian zones has become ubiquitous in the Normanby catchment (Plate 8). Many annual weeds compete with preferred native perennial grasses, provide little ground cover at the beginning of the wet season, have low root density and soil cohesion, and change the infiltration potential of soils. Most weeds have been introduced or increased in river frontage from upstream land use, local disturbance such as over-grazing, altered competition dynamics between grass and weeds, intense late-dry season fires, roads and fences. More scientific experimentation is needed on how to control weeds (fire, chemical, mechanical, biological) along river frontage terraces and elevated floodplains with sodic soils to promote perennial grass health, reduce water runoff and minimise gully erosion.


Plate 8 Invasion of annual weeds onto terraces (Hyptis, Hairy Sida, Grader Grass) and river benches (Sicklepod) in Normanby river frontage.

- *Draft BMPs for Weed Management along River Frontage with Dispersive or Sodic Soils*
    - Spell cattle from river frontage to increase grass competition with weeds.
    - Use grass fuel loads after spelling to periodically use fire at appropriate times/locations for weed control (e.g., rubber vine) and breaking weed seed cycles (e.g., hyptis, grader grass).
    - Use herbicides and other control methods in strategic areas to reduce weed cover.
    - Prevent spreading weeds along roads and fences. Clean vehicles/machines regularly.
    - Prevent spreading weeds with imported hay.

- Prevent spreading weeds when moving cattle from weeded paddocks to less weeded areas, or between properties. Use holding paddocks with regular weed management to contain weed spread.

<u>Road and Fence Placement on River Frontage with Dispersive or Sodic Soils</u>

The best long-term solution to road and fence stability is to not locate this infrastructure on dispersive or sodic soils and river frontage areas (Plate 9; Plate 17). Once dispersive or sodic soils are disturbed, erosion is difficult to prevent. Roads and fences should be placed on stable soils and geology, such as on subtle ridge and spur crests between drainage catchments. Maps of soil/geology, topography (including LiDAR), erosion hazards, and aerial photographs (+Google Earth) can be useful for locating infrastructure during property planning and to minimise the number of crossings of existing gullies, unchannelled hollows, creeks, and rivers. This will reduce long-term road maintenance costs and rill and gully erosion. Where roads and fences must be located through erodible river frontage, frequent water diversion structures (whoa boys) should be installed and capped with locally imported soil/gravel, in addition to armouring the approaches to creek crossings to minimise gully erosion. Vegetation clearing should also be minimised, especially on steep banks.


Plate 9 Roads graded repetitively on river frontage with sodic soils can lead concentrated water flow and deep gully erosion.

- *Draft BMPs for Road & Fence Locations on River Frontage with Dispersive or Sodic Soils*
    - Avoid building roads and fences through river frontage with dispersive or sodic soils.
    - Locate roads and fences on stable soils and geology, such as on subtle ridge and spur crests between drainage catchments.
    - Minimise the number of road/fence crossings through unchannelled hollows, gullies, creeks, and rivers.
    - Scout and map the best routes for fences using motor bikes, GPS, topographic maps and Google Earth images. Adjust line accordingly to avoid erosion hazards.
    - Install frequent water diversion structures (whoa boys) capped with locally imported angular gravel, in addition to armouring the approaches to channel and hollow crossings.
    - Water diversion frequency depends on slope and soil type, but for highly erodible soils on slopes >5%, spacing should be every 10-25 metres.
    - Minimise vegetation clearing (grass and trees) especially on steep banks.

Vegetation Clearing along River Frontage with Dispersive or Sodic Soils
Tree clearing along river frontage can initiate or accelerate alluvial gully erosion by disturbing soil and vegetation from bulldozing, chaining, and stick raking vegetation, as well as changing the water balance by reducing water transpiration by trees, raising water tables, increasing sub-surface water seepage, and accelerate surface water runoff (Plate 10). Generally, clearing trees from dispersive soils on river terraces and floodplains of river frontage should be avoided. Where this has already occurred, mitigation measures can be instated to reduce the continuing or future erosion of alluvial gullies.

Plate 10 Clearing tree vegetation along river frontage can disturb dispersive soils and initiate or accelerate alluvial gully erosion.

- *Draft BMPs for Vegetation Clearing along River Frontage with Dispersive or Sodic Soils*
  - Avoid clearing trees and other vegetation along river frontage with dispersive or sodic soils.
  - Retain or install grass and tree vegetation buffers along with cattle exclusion along drainage lines, hollows, gullies, creeks and rivers, well back from breaks in slope of high banks
  - For small gullies and creeks, buffer widths should be > 50 m wide from the high banks where alluvial gullies often initiate.
  - For larger creeks and rivers, buffers should be > 100 m wide from the high banks to include the local catchment area of gullies and hollows.
  - In practise, uncleared buffers could be > 1 km from the centre of large creek or river channels (Plate 2).
  - Install contour banks on cleared paddocks to manage excess water runoff.
  - Install earthen banks around gully heads to divert water runoff into a safe disposal points.
  - Where tree regrowth after clearing is problematic, use cattle spelling, periodic fire, pasture competition, and chemical weed control to control regrowth, rather than repeated mechanical intervention that can disturb soils and accelerate erosion.

Direct Rehabilitation of Alluvial Gullies at the Local Scale

Direct gully rehabilitation of alluvial gullies on a site-by-site basis is applicable to strategic priority sites with significant human interest (roads, fences, dams, buildings, yards, key riparian paddocks, key waterholes, biodiversity hot spots, and/or cultural sites) where benefits to intervention outweigh the costs. Direct intervention is also applicable to young highly-active gullies in early development stages, where timely intervention is justified to prevent or slow future extreme erosion.

There are many bio-geo-engineering options available for direct intervention and rehabilitation of gullies, however most have not been well tested for alluvial gullies in northern Australia. Experimental trials in this report contribute to that research deficit, but ongoing research is needed to fully develop best management practices (BMPs). To reiterate, there are three main approaches to reduce the advance of existing gullies, which generally should be used in combination.

1. Reduce water runoff into and through gullies.
2. Stabilise gully headcuts and sidewalls with vegetation and physical structures.
3. Reduce the gully channel slope and increase roughness using structures and vegetation.

Water Diversion/Retention Banks above Gully Heads

Direct mechanical or engineering intervention to reduce water runoff patterns and volumes can be warranted in situations where the hillslope catchment is highly disturbed (e.g., agriculture fields) and where excess water runoff cannot be managed solely by increasing perennial vegetation cover (grass, trees, shrubs). Numerous types of water retention and diversion structures can be built, including contour banks for water retention, farm dams, and earthen water diversion banks immediately above gully headcuts, depending on the situation. Some structures such as contour banks are not appropriate for intact native grass woodlands. Others such as farm dams would be difficult to install and ineffective above lengthy fronts of alluvial gully head scarp. Water diversion banks above alluvial gully headcuts can reduce gully headcut erosion. However, they are also prone to failure by piping in dispersive sodic soils and can divert the erosion problem from one gully to another nearby making the erosion worse (Plate 11).

Plate 11 Water diversion banks above alluvial gullies can reduce erosion but also are prone to failure.

- *Draft BMPs for Diversion/Retention Banks above Gully Heads*
  - Construct contour berms in cleared paddocks only, or along roads and fences.
  - Divert excess runoff frequently and toward safe disposal areas armoured with rock. Avoid transferring the gully problem from one location to another.
  - For water diversion banks above gully heads in native grass woodlands, avoid disturbing native vegetation and dispersive or sodic soils where possible.
  - Use caution when using dispersive or sodic soils for diversion bank construction due to risk of soil piping and increased gully erosion.
  - Consider importing non-sodic soil or angular gravel from stable sites for diversion bank construction, rather than disturbing local dispersive or sodic soils.
  - Place banks far enough back from gully scarps to avoid damage by future gully retreat.

- Use field observations of water flow paths and detailed topographic data (LiDAR) for bank design.
- Use diversion banks in conjunction with gully revegetation, slope battering, gully grade control and cattle exclusion.

Increasing Perennial Grass Cover on Gully Slopes

Perennial grass cover is a key factor in stabilizing river banks, floodplain hollows and gullies. Reducing cattle grazing pressure along river frontage will help improve grass cover within and around potential and existing gully areas. However, once gully erosion has initiated and exposed nutrient poor sub-soils, natural revegetation can be slow. Experiments using native and exotic grasses to revegetate alluvial gully surfaces in the Normanby catchment have had mixed results. Grass seed sown directly on gully scarps, side walls, and excavated sub soils had poor germination success. Adding straw mulch and grass seed did not improve germination. Using a hydromulch mix (grass, gypsum, fertiliser, paper, bagasse, tackifier) on raw gully scarps in the wet season resulted in partial vegetation cover, concentrated in gully bottoms where moisture collected and sediment was trapped (Plate 12). More proactive revegetation efforts in association with soil amendments, slope battering, and grade control can be used to speed up vegetation recovery and promote gully stabilization.

Plate 12 Revegetation of gully scarps with hydromulch can result in modest but not complete cover improvements, while natural recolonisation can be successful with native grasses such as blady grass.

- *Draft BMPs for Increasing Perennial Grass Cover on Gully Slopes*
  - Fence cattle off from large areas of alluvial gullies and river frontage well back from high banks to allow perennial grass to grow, seed, recover, and compete with weeds.
  - Manage fire and weeds in river frontage to maximise perennial grass.
  - Hand or aerial seed grass vegetation in the wet season after initial heavy rains loosen the soils and provide prolonged soil moisture.
    - Focus grass revegetation efforts on gully toe-slopes and bottoms, in addition to areas immediately above gully scarps. Scarifying scalds and scarps may be needed for improved germination, but could temporarily increase erosion.
  - Revegetating gully scarps will have poor to moderate success unless intensive rehabilitation efforts are applied (e.g., slope battering, organic and chemical soil amendments, grass revegetation, cattle exclusion).

Intensive Rehabilitation of Gully Slopes

Both intact and battered alluvial gully slopes can be difficult to revegetate with perennial grass species due to the harsh nature of sodic, hard-setting soils with low nutrients and water availability. Importing non-sodic topsoil or capping sodic soils with rock and/or geotextile fabric – then revegetating with grass – can provide long-term stability. However, rock or good top-soil is not always available. Experimental results of intensive gully rehabilitation in the Normanby catchment indicate that physically regrading gullies, adding compost and gypsum, and revegetating with grass can reduce soil erosion compared to control sites with no soil amendments (Plate 13). In contrast, regrading gullies with machinery without soil amendments or where there is poor establishment of grass can actually increase gully erosion above previous levels. Using a full suite of treatments, erosion was reduced from >26.6 tonnes/year to 6.7 tonnes/year on a gully site that was battered and shaped into a hollow, amended with gypsum and hydromulch, and treated with wood grade control structures and a water diversion bank. This highlights that gully erosion can be reduced but not fully stopped even under intensive rehabilitation of a 0.2 ha gully for $6000.

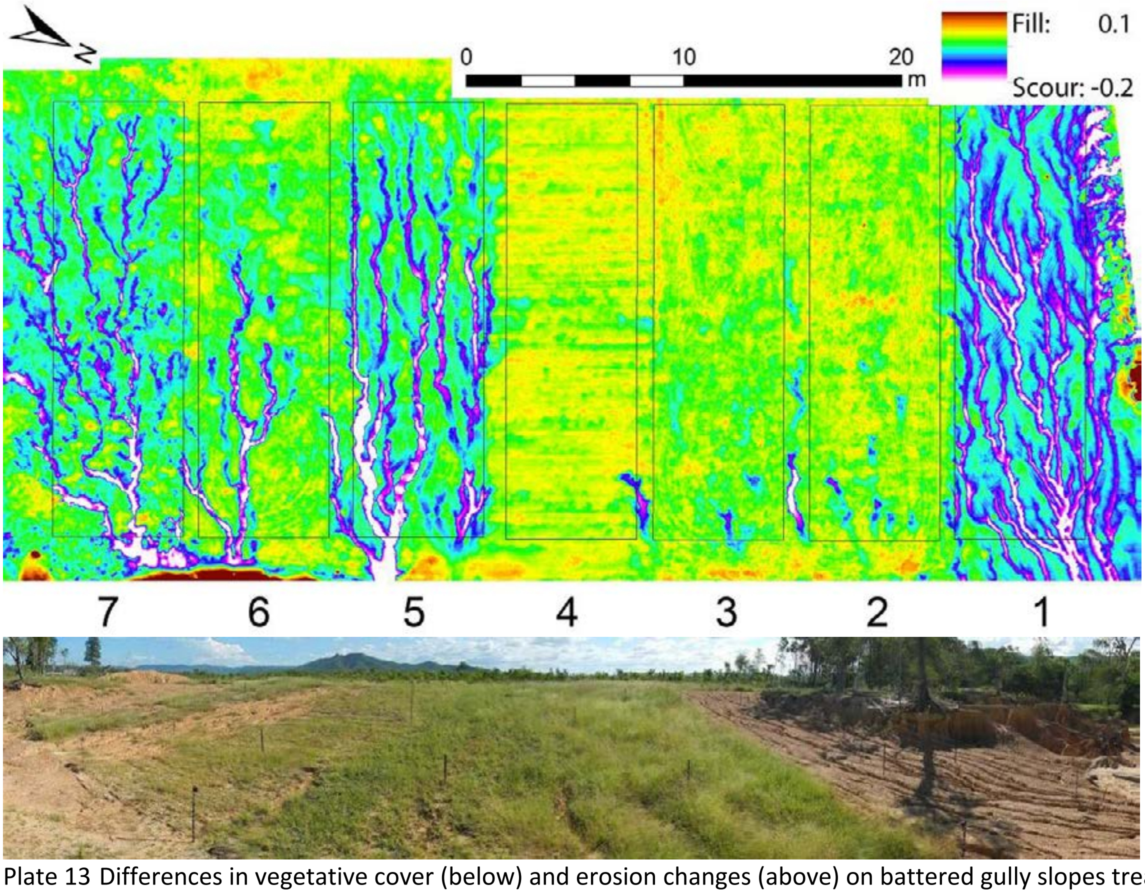

Plate 13 Differences in vegetative cover (below) and erosion changes (above) on battered gully slopes treated with different combinations of compost, straw, gypsum, and grass seed, and measured with terrestrial laser scanning (TLS) surveys in 2011 & 2013. Cattle were excluded via fencing. Control plot (1) is far right, full treatment plots (2-4) are centre, and partial treatment plots (5-7) are left.

- *Draft BMPs for Intensive Rehabilitation of Gully Slopes*
  - Do not batter (regrade) sodic gully slopes without revegetating and amending the soil, or capping with rock; they will re-erode into rills and gullies, accelerating erosion.
  - Where available, cap battered gullies with non-sodic topsoil or imported rock, then revegetate with perennial grass.
  - For rehabilitation of gully slopes in situ without imported soil or rock, batter (regrade) the gully into a stable shape and amend sodic soils with organic matter (compost or mulch), gypsum ($CaSO_4$), fertiliser, and perennial grass seed.
  - A combination of hydromulch for short-term erosion reduction and compost for long-term grass growth will provide the greatest erosion reduction benefit.
  - Install additional water diversion and grade control structures to reduce water runoff energy and local slopes.
  - Fence gullies to exclude cattle grazing from rehabilitation areas.

Grade Control and Headcut Drop Structures

Grade control and drop structures are applicable to narrow semi-confined gullies where overland flow dominates, but only some sections of unconfined alluvial gullies such as finger headcuts. Grade control structures (check dams) can prevent incision, reduce slope, dissipate energy, and trap sediment. Drop structures (weirs, chutes, flumes, etc.) installed at headcuts (scarps) can safely pass water runoff over the scarp edge and stop the gully headcut from advancing. These grade and drop structures can be made out of rock, gabion, concrete, sand bags, steel sheets or mesh, treated lumber, large woody debris (LWD), woven brush and/or live vegetation. Proper attention to engineering design, structure frequency, geomorphic processes, the stage or time of intervention, and long-term maintenance are essential for minimizing failure. Structures should be embedded into the underlying bed and adjacent banks to avoid undermining or outflanking, especially in dispersive soils. In the Normanby catchment, the placement of drop and grade structures is required at many young, very active headcuts advancing up floodplain hollows in river frontage areas in order to prevent major future erosion (Plate 14).

Plate 14 Young, rapidly advancing headcuts of alluvial gullies need to be stabilised with drop structures or rock grade control so that they do not develop into larger gullies and head scarps (Plate 1).

- *Draft BMPs for Grade Control and Headcut Drop Structures*
    - Grade control and drop structure are most applicable in young, linear gullies within semi-confined channels or valleys.
    - In large alluvial gully complexes, they are applicable to narrow finger headcuts and narrow outlets channels, but not wide gully bottoms or long scarp fronts.
    - Key (embed) grade control structures into bed and bank to prevent undermining and outflanking.
    - Use a size mixture of angular rock (or wood) to lock structures in place.
    - Avoid using loosely placed large boulders subject to piping through or around voids.
    - With drop structures at headcuts, use lateral and vertical cut-off walls to prevent water tunnelling around structures in dispersive soils. Install water seep holes through structures to prevent water pressure building up behind structures.
    - Monitor and maintain structures over time to ensure their longevity and functionality.
    - Minimise collateral damage from machine works on highly erodible soils.
    - Revegetate construction areas using perennial grass seed or hydromulch.
    - Do not use tyres or dump trash in gullies in an attempt at stabilization; this material will promote scour and accelerate erosion.

<u>Road Erosion: Prevention and Repair on Dispersive or Sodic Soils</u>

Improper road and fence location, construction and especially maintenance are major causes of gully initiation and acceleration on cattle station properties. They should be a major focus for intervention to reduce cumulative sediment yields. Avoiding highly erodible dispersive or sodic soils along river frontage and minimizing the number of crossings through hollows, creeks, and rivers where gullies initiate is key to prevention. For existing roads on dispersive or sodic soils, managing excess water runoff concentrating down roads and fences is key to erosion control. Large water diversion banks (whoa boys) installed frequently (every 10-25 m) down steep erodible slopes can reduce water concentration and gully erosion (Plate 15). However banks and road slopes must also be armoured with angular gravel or rock to prevent rilling and gullying of underlying sodic soils. Continuously regrading basic roads (Plate 9) or constructing large formed roads with mitre drains will accelerate gully erosion on fragile sodic soils. Rather, localised road erosion issues on sodic soils should be patched up each year following well-considered road maintenance plans and procedures.

Plate 15 Erosion on station roads over steep river banks in sodic soils can be reduced by installing frequent water diversion banks (whoa boys) and capping them with imported coarse rock.

- *Draft BMPs for Road Erosion Prevention and Repair on Dispersive or Sodic Soils*
    - Avoid and minimise road crossings though hollows, gullies, stream channels, and steep banks in dispersive or sodic soils.
    - Don't grade down roads year after year resulting in entrenched roads without drainage.
    - Don't regrade or fill in gullies on roads on steep banks each year just to gain immediate access. Address the actual cause of the gully erosion and manage water runoff.
    - Avoid continuously rerouting the road around erosion problem and ignoring them. Address the cause of the problem (excess water runoff).
    - When road abandonment is needed, address major water drainage issues with diversion banks and reseed with grass. Construct the new road to improved erosion control standards.
    - Bring past windrows from deep grading back onto the road surface, and use to crown the road surface and/or construct water diversion banks.
    - Reinstate the natural water flow direction (off the road) whenever possible.
    - On sodic soils, avoid constructing large formed roads with table and mitre drains, as disturbing fragile soils will accelerate gully erosion. Trying to overpower erosion problems with major machinery intervention can accelerate gully erosion on sodic soils.
    - Divert surface water runoff early along flow paths to prevent concentrated flow.
    - Install frequent, large water diversion banks (whoa boys) on top of the existing soil surface every 10 to 25m on highly erodible slopes >5%.
    - Construct high (>0.5m) and wide (5-10m) diversion banks to ensure long-term functionality and drivability.
    - Avoid diverting water into old gullies, toward creek/river banks and into hollows susceptible to gullying.
    - Where space is available on stable soils, dig a silt pond with sill outlet for diverting water into. Use the material to construct the bank (whoa boy).
    - Import angular gravel from stable local sources to armour steep road slopes and diversion banks at stream crossing approaches. Angular gravel/rock is preferred over river gravel, but both are better than native dispersive or sodic soils.
    - Seed disturbed areas with appropriate perennial grass species.
    - Develop annual road maintenance plans and procedures appropriate for dispersive or sodic soils. Annually patch up problem erosion areas and repair drainage structures. Allocate road maintenance budgets to proactively address problem areas, rather than let them develop into larger erosion problems that cost more in the long run.
    - Require grader/bulldozer drivers to attend workshops on erosion control.

<u>Fence Erosion: Prevention and Repair on Dispersive or Sodic Soils</u>

Fence lines can concentrate water and accelerate gully erosion when improperly placed, constructed, or maintained, in addition to when they are graded as fire breaks, used as roads, and cut by cattle tracks (pads). Proper fence placement around erodible soils can minimise future erosion and prolong the life of the fence. Best management practices to reduce gully erosion along fences include avoiding soil disturbance, using live trees as fence posts on steep banks, minimizing tree clearing and grass grading, installing water diversion banks armoured with gravel (Plate 16), and using prescribed fire, herbicides and/or slashers for fire breaks and vegetation management.

Plate 16 Installing frequent water diversion structures (whoa boys) along fences, and fencing tree-to-tree over steep banks with sodic soils, can reduce gully erosion along fences.

- *Draft BMPs for Fence Line Erosion Prevention and Repair on Dispersive or Sodic Soils*
    - Avoid and minimise fence line crossings though hollows, gullies, stream channels, and steep banks in dispersive or sodic soils.
    - Do not repeatedly grade fence lines as fire breaks and road access, as this will accelerate erosion.
    - Bring past windrows from deep grading back onto the fence line surface to avoid concentrating water, and use material to patch erosion areas and/or construct water diversion banks.
    - Install frequent, large water diversion banks (whoa boys) every 10 to 25 m depending on slope; manage surface water runoff to prevent concentrated flow.
    - Construct high (>0.5m) and wide (5-10m) diversion banks to ensure long-term functionality and prevent future machine operators from grading through them.
    - On steep slopes in erodible soil, armour water diversion banks with non-sodic soil/gravel to prevent cutting by rills and gullies. Use caution to not accelerate erosion during construction on steep erodible slopes.
    - Minimise the amount of tree and grass vegetation cleared and graded during fence installation and maintenance.
    - For fences down steep banks at crossings, use existing live trees as fence posts (tree-to-tree) to avoid the need for tree clearing and soil disturbance.
    - Use good fire management and variable early-dry season burning to control undesired fires.
    - If fencing must be used for fire breaks, use slashing and herbicides rather than grading fence lines and accelerating erosion. Maintain good grass cover in erosion sensitive areas.
    - Develop annual fence maintenance plans and procedures appropriate for dispersive or sodic soils. Annually patch up erosion hotspots, repair water diversion structures, and hand repair fences on steep banks and stream crossings. Require grader drivers to attend workshops on erosion control.

Social, Economic and Political Challenges to Alluvial Gully Rehabilitation

There are many social, economic, and political challenges to addressing alluvial gully erosion in the Normanby catchment on Cape York Peninsula. Motivational aspirations of graziers can range from strong 'economic & financial' to 'stewardship & lifestyle' motivations, which can influence conservation ethics and willingness to participate in and successfully complete government programs (e.g., Reef Rescue). Conservation funding programs need to be tailored to match and utilise these intrinsic motivations.

The grazing industry of the Normanby catchment and Cape York Peninsula is struggling economically and is in transition due to the long distance to markets, the extreme wet-dry climate, low soil productivity, land degradation from erosion and weed invasion, increased fixed and variable costs (e.g., rates, labour, fuel, material, feed), stagnant cattle prices, and increased debt levels associated with development and competition pressures. The result is little to no extra income or time to reinvest in long-term property management or soil conservation actions such as gully erosion control.

The total cost (commercial retail) of intensive gully treatments conducted in this study ranged from $3000 to $6000 for 0.2 ha, which included heavy equipment hire and labour, gypsum, hydromulch or compost, and fencing. Using local labour, machinery, and materials from individual properties might be able to reduce this to $2000 for 0.2 ha. This equates to $10,000 to $30,000 per hectare for intensive gully treatment, which is well above the average costs of grazing properties in the Normanby catchment (< $100 per ha). This direct intervention is most applicable where key infrastructure is threatened (e.g., roads, fences, yards, buildings, dams, key waterholes) or where young, incipient gullies can be stopped to prevent major future erosion and land loss. Direct intervention during this project was able to reduce gully erosion for $375 per tonne, which is less than the average sediment erosion abatement cost of $600/tonne paid by the Reef Rescue program. To reduce the estimated 736,400 tonnes per year eroded from alluvial gullies by 10%, it would cost $27,600,000 at $375 per tonne. Or alternatively, if 2000 ha of mapped gully in the catchment was treated with intensive intervention at $2000 per 0.2 ha, it would cost $20,000,000. Investing this level of government or market-based funding in the Normanby catchment might be better spent on purchasing large areas of degraded river frontage on specific cattle properties, and taking them out of cattle production as 'soil conservation areas' (Plate 5; Plate 17).

A fundamental paradigm shift in government policy and investment targets is needed to reduce gully erosion and sediment yields. Current cost-share programs are not achieving water quality improvements at the catchment scale in the Normanby catchment. Land management investments for erosion prevention and control should be driven by a holistic, long-term, process-based catchment-wide perspective, rather than relying on small, discrete, short-term projects with questionable benefits that treat symptoms rather than causes or only promote property development.

Targeted investment for gully erosion control at large mapped 'hot spots' (i.e., dispersive sodic soils on river terraces and adjacent floodplains) is needed using large-scale land management changes and localised intensive rehabilitation actions. Several priority river frontage areas for large-scale erosion management actions – such as cattle destocking to create soil conservation areas – have been identified in the Normanby catchment (e.g., the Granite Normanby River, Plate 5; Plate 17). Funding for large-scale actions could come from government investment for public benefit, market-based solutions (payment for ecosystem services of carbon, biodiversity, soil retention), and/or land utilization/tenure trading to destock cattle from highly erodible soils and develop more productive, less erosion prone soils for agricultural and economic benefit. However, government or market-based investments for combined carbon sequestration, biodiversity improvement, and soil conservation must pass the 'integrity' test by going beyond normal practice, be measurable and rigorously monitored, and be subject to peer review.

In addition to large targeted investments and incentives, a renewed emphasis should be placed on extension of knowledge, training, and certification programs that are founded within locally-based and long-term government funded programs [e.g., a reinstated Soil Conservation Service (SCS), Primary Industries, Landcare, Natural Resource Management (NRM) agencies]. These programs should focus on integrated property planning for erosion reduction and control and monitoring of results. Machine-operator certification programs (e.g., roads and fences) should be prerequisites for government funding for erosion control. The design, implementation, maintenance, and monitoring of more complicated gully erosion control projects might be best conducted by a team of qualified experts and practitioners (e.g., a reinstated Soil Conservation Service and geomorphologists).

For the Normanby catchment and Cape York Peninsula, a mixture of larger positive incentives and investments, extension and outreach, and long-term soil conservation programs will be needed to cumulatively reduce erosion at the catchment scale.

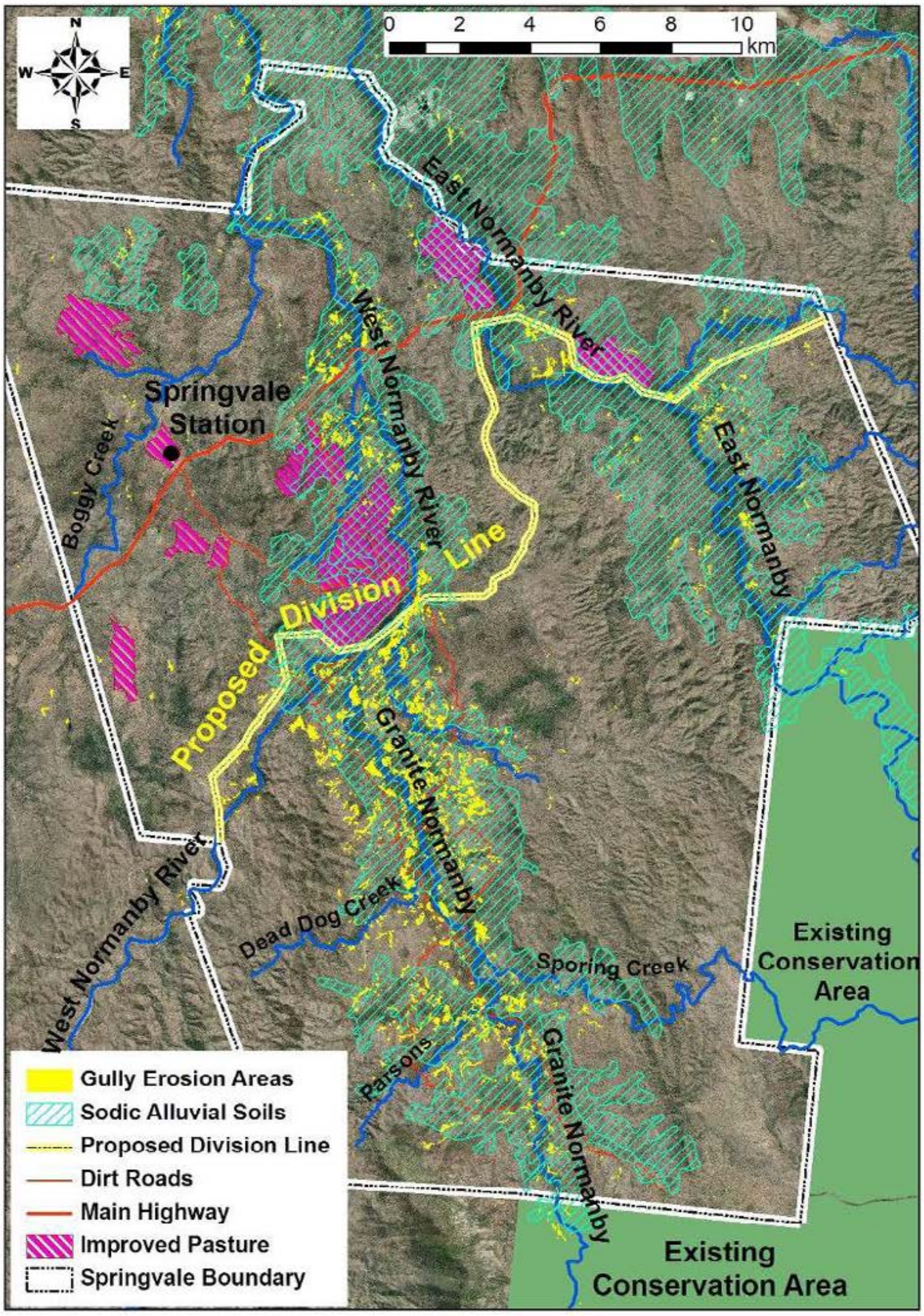

Plate 17 A DRAFT PROPOSED 'soil conservation area' - focused on the Granite Normanby River - where the highest concentration of alluvial gullies exists in the entire Normanby catchment. Note that existing 'improved paddocks' would stay under production and major monetary compensation would need to be provided to the lease holder for economic loss.

Future Research Priorities

Natural Vegetation Recovery Within and Above Alluvial Gullies

- The natural vegetation recovery potential within alluvial gullies and vegetation influences on reducing alluvial gully erosion are major topics for long-term research. Short-term cattle exclusion experiments cannot answer critical long-term recovery unknowns. The installation of small cattle exclusion experiments and direct revegetation conducted in this study are significant steps towards this research; however funding is needed for their continuation and expansion to larger land management units.
- 'Soil conservation areas' in high risk areas for alluvial gully erosion could be utilised as research stations to monitor large-scale, long-term experiments in savanna rangeland and gully erosion rehabilitation, using various gully, vegetation, fire, grazing and soil management regimes. These areas could also be conjunctively used for biodiversity improvements, carbon retention, and prevention of weed spread.

Proactive Revegetation Within and Above Alluvial Gullies

- Experimentation into large-scale aerial seeding grass vegetation into alluvial gullies during the wet season with a variety of plant species is needed before catchment-scale programs could be developed to cumulatively address gully erosion.
- The germination and growth success of a wider variety of native and exotic grass should be researched in sodic alluvial soils to determine the most appropriate species for seeding and stabilising gullies. The rooting depths and soil cohesion properties of native and exotic species also is poorly understood in sodic alluvial soils.
- The influence of annual weeds (herbs and grass) on the recovery of native perennial grasses, soil hydrological functions (infiltration, root cohesion, roughness), and accelerated water runoff from river frontage terraces need more research, in relation to downslope alluvial gully erosion.

Cattle Management and Alluvial Gullies

- Large-scale adaptive management research is needed on how to best balance the needs of cattle grazing, perennial grass health and cover, weed control, and fire management, while also reducing alluvial gully erosion on sodic soils and river frontage. Different cattle spelling and rotation regimes should be trailed to maximise vegetative cover in and around alluvial gullies while also supporting a viable cattle industry. Otherwise, cattle grazing pressure will need to be shifted away from large areas sensitive to gully erosion.
- The mechanisms of gully initiation and acceleration from cattle tracks (pads) needs more research. Studies should be conducted on animal migration routes and patterns via tracking, vegetation cover influenced by grazing along tracks, water runoff acceleration along tracks, subtle water flow paths across floodplain flats and hollows, cattle track concentration down pre-existing gully features, and the potential to revegetate and infill existing cattle tracks over time through cattle exclusion.

Fire Regimes and Alluvial Gullies

- Fire regimes research should be conducted to determine what specific fire regimes would be most appropriate to reduce water runoff, soil erosion, and the initiation or acceleration of alluvial gully erosion on river frontage woodlands and grasslands in northern Australia, especially on highly dispersive or sodic soils on alluvial terraces and floodplains. Research on the use of fire for weed control along river frontage terraces is also needed. Sediment erosion and yield should be measured in association with careful fire treatments and control sites.

Physical Control of Alluvial Gullies

- Headcut stabilisation field experiments are needed for controlling young very active headcuts of alluvial gullies using engineered chute and drop structures, especially in dispersive or sodic soils. Their physical- and cost-effectiveness, long-term stability, and geomorphic impacts are unknown for alluvial gullies.
- The use of water diversion berms above long alluvial scarp fronts should be researched and trialled in more detail. Careful consideration is warranted for disturbance of sodic soils, damage to native vegetation, flow paths on subtle topography, designing safe water disposal areas, future scarp retreat, and piping through berms in sodic soils.
- Road field experiments are needed on how to best install, manage and maintain simple dirt roads and tracks in highly dispersive or sodic soils and steep river banks on river frontage in northern Australia, in order to reduce alluvial gully erosion initiation and acceleration. Road research started in this study should be continued to understand longer-term declines in sediment yield from roads treated with preliminary BMP structures and surfacing.

Social-Economic Aspects of Alluvial Gully Control

- The costs and economic viability of alluvial gully erosion control measures needs more detailed research and guidance, with and without government or market-based assistance.
- The market potential for payments for ecosystem services (soil, carbon, biodiversity retention) to reduce alluvial gully erosion should be investigated in detail.
- The economic value of losses of sediment, riparian habitat, biodiversity, and carbon sequestration potential along river frontage needs to be quantified, as well as off-site impacts of alluvial gully erosion on downstream sedimentation, freshwater and marine habitat degradation, and cultural use and values across the landscape.
- The profitability of marginal and degraded grazing lands on Cape York Peninsula needs research attention, along with the economic and social costs of improving water quality by altering land use, and the economic benefits of soil retention to grazing and farm production.

Summary Key Issues

- Gully erosion is likely the dominant *accelerated* erosion process across the whole of northern Australia and the GBR catchments contributing to elevated river sediment loads.
- To date there have been few effective management strategies employed that are targeting and addressing this problem.
- Current models of delivering NRM funding are not effectively dealing with major concentrated areas of gully erosion, nor effectively reducing sediment yields.
- By default the management of gully erosion issues has been left almost entirely up to cattle graziers – with minimal effective assistance from government programs.
- Given the poor economic state of Cape York Peninsula cattle industry at present, cattle graziers have little capacity to properly address this problem. As such the problem persists unchecked or accelerated under current paradigms.
- With the predicted expansion of grazing intensity, mining and agriculture in northern Australia, the gully erosion problem will continue to increase if left unchecked (if nothing else through the expansion of the road network and growth of existing gullies).
- A completely new approach and scale are required to address gully erosion if any real progress is to be made towards reducing sediment yields from rangeland grazing country, which is the primary source for sediment pollution to local river systems in northern Australia and the GBR.

Summary Key Actions

- Large concentrated areas of mapped alluvial gully erosion with high erosion risk should be targeted for erosion reduction measures using large-scale land management changes (cattle, fire, weed, roads, fences) and localised intensive rehabilitation actions.
- Cattle grazing pressures need to be shifted away from river frontage areas with dispersive or sodic soils prone to alluvial gully erosion.
- A joint Federal/State/Territory partnership with key industries (cattle, mining, tourism and irrigated agriculture) is needed to re-establish a northern Australia or Queensland 'Soil Conservation Service'. The renewed SCS should have the specific purpose of developing the scientific, extension and application services required to address widespread soil and gully erosion with large-scale land management changes and localised intensive rehabilitation actions.
- Integrated, multidisciplinary property planning is needed to help shift grazing away from sensitive areas of high erosion risk, as well as help landowners (pastoral, agricultural, Indigenous) on Cape York Peninsula with improved land management, stock/pasture/crop management, and financial management.
- Once integrated property plans are developed, landowners assistance with action implementation and monitoring will be needed to adaptively manage perennial grass cover, weeds, fire, roads, fences, and erosion control measures.

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