Developing guidelines for agriculture development in northern Australia to avoid and reduce accelerated erosion

The case of the Gilbert/Etheridge River Integrated Agriculture Project

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Cover photographs

Front cover - Andrew Brooks inspecting the erosion hazard potential of the soils within the Gilbert development area. Photo - John Spencer

Back cover - Exposed tree roots within an alluvial gully in the Gilbert catchment, highlighting the susceptibility of this landscape to erosion. Photo – Andrew Brooks© Charles Darwin University 2015

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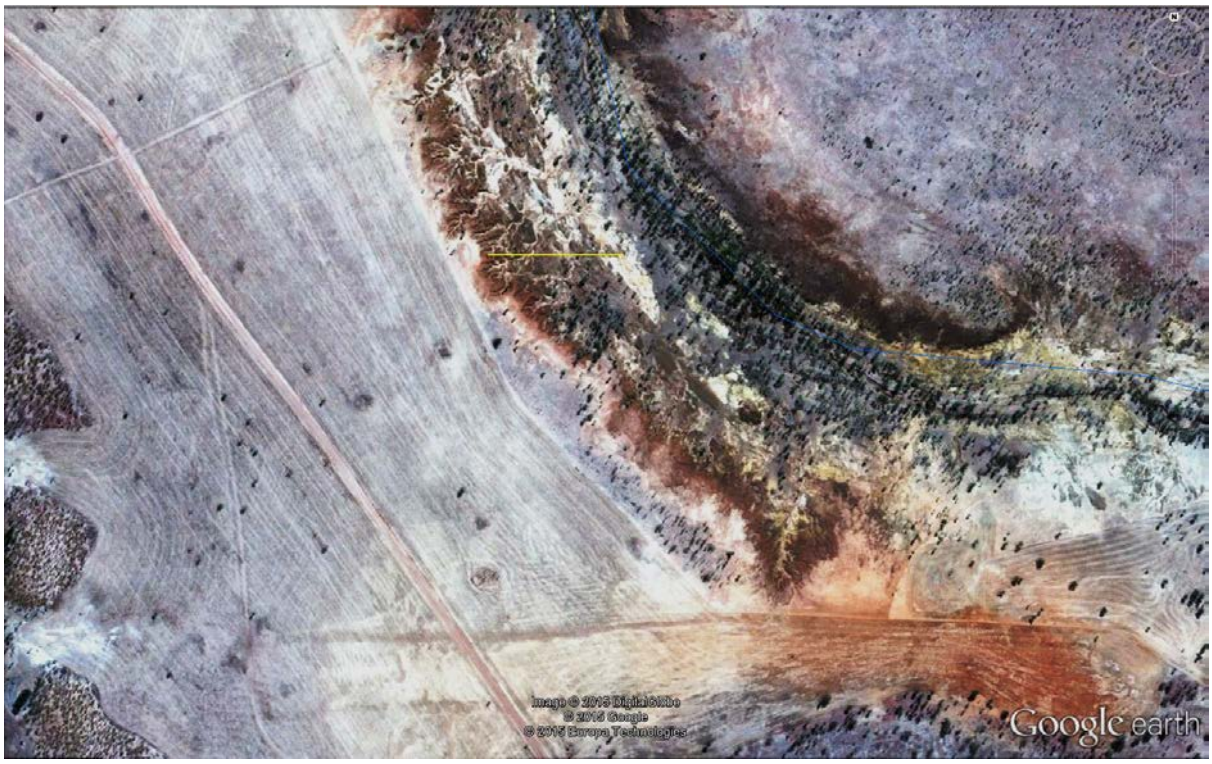


Figure 1 Example of recent clearing for agriculture in the Gilbert catchment adjacent to highly gullied land (yellow scale bar is 200m in length)

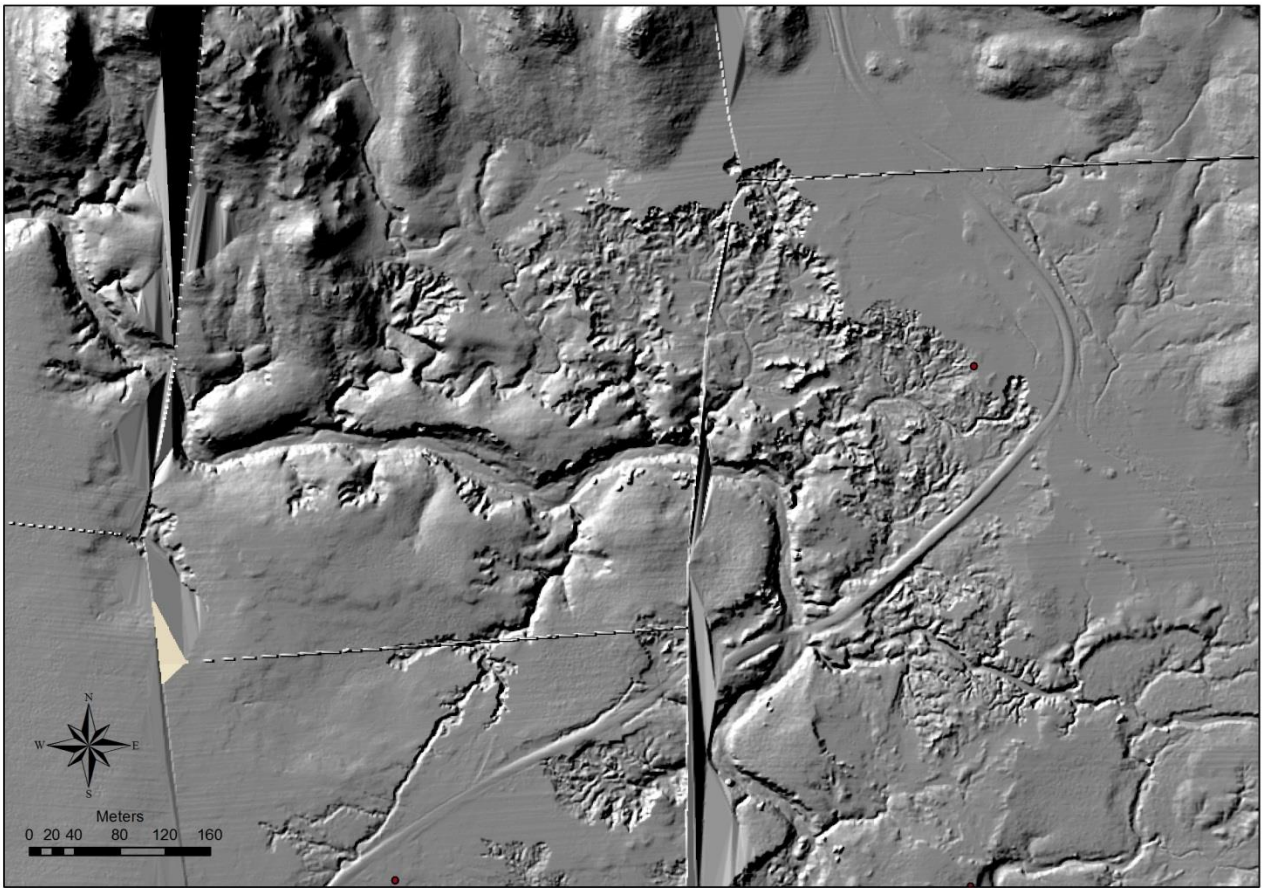


Figure 2 Alluvial gully complex in the Greenhils area adjacent to the Gilbert River. Specific sediment yields more than 3000t/ha/yr have been measured from wihin this gully complex

1 Executive summary

1.1 Context

There has been considerable interest in recent years as to the potential for irrigated agriculture development within the Gilbert River region. To date two proposals for establishing irrigated agriculture in the Gilbert catchment have been proposed; the Gulf Savannah Development proposal focused around the pockets of good quality alluvial soils along the Gilbert River between Greenhills and Chadshunt Stations; and a second larger proposal known as the Integrated Food and Energy Development proposal focused on Kutchera and Chadshunt Stations, in the Dismal Creek catchment bounded by the Gilbert, Etheridge and Einasleigh Rivers. To date more attention has been directed at IFED due to the scale of the proposal and the high profile nature of its proponents. The IFED project has also attracted more criticism from the local community because of its scale and its radical departure from accepted practice by focusing on areas of low quality soils supplemented by large scale fertigation (i.e. irrigation with all plant nutrients provided within the supplied irrigation water). For this reason we have chosen to focus on the IFED case study to explore some of the land management challenges faced through implementing such a project in this landscape. The study focal area, bounded by the Einasleigh, Gilbert and Etheridge Rivers was also the focal area for previous synoptic scale erosion hazard mapping undertaken by Griffith University in 2006.

The Flinders and Gilbert River Agricultural Resource Assessment (FGARA) published by CSIRO in 2013 assessed a broad range of issues around the suitability of the soils, climate and access to water and markets in the Gilbert region for a broad range of potential crops. Despite the comprehensive analysis undertaken by CSIRO in the FGARA, one issue not canvassed was the potential risks of initiating major sub-surface erosion in the form of gully and channel erosion in the area. In the adjacent Flinders and Mitchell River catchments, sub-surface erosion has been found to contribute between 97% -100% of the sediment load to these rivers, hence it is critical that any development in this landscape be assessed for its potential to accelerate sub-surface erosion processes. To address this gap, the Federal Government commissioned this report as an emerging priority through the National Environmental Research Programme (NERP).

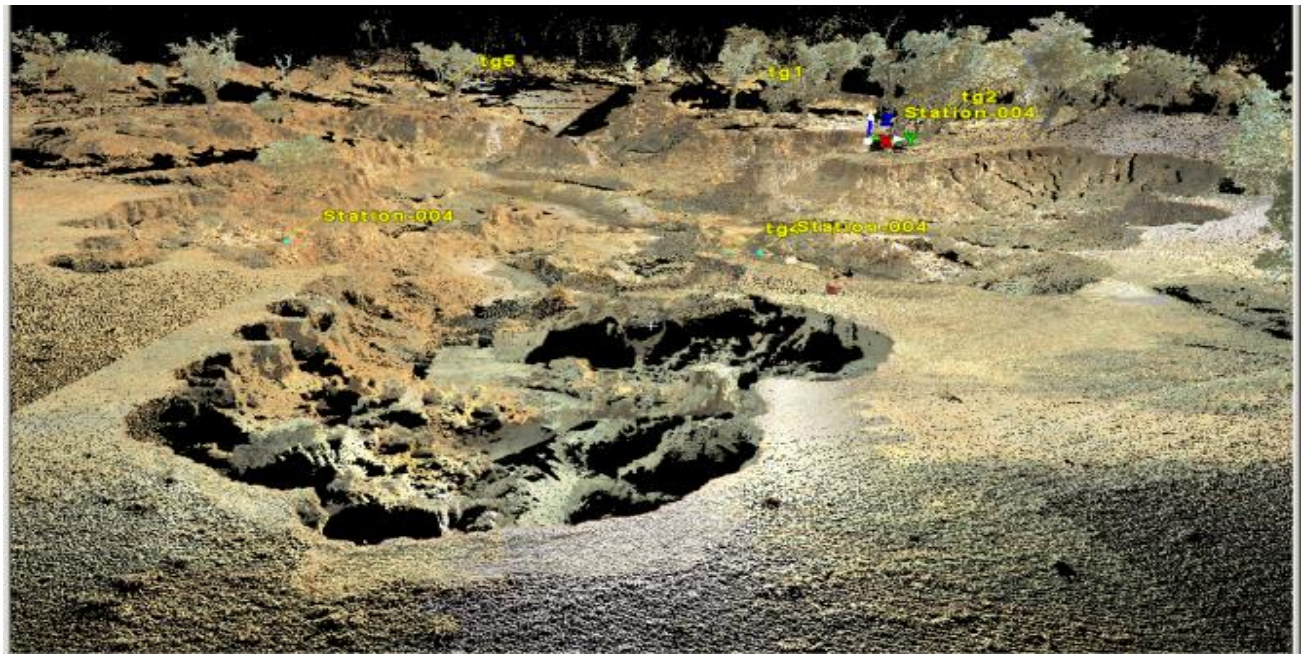


Figure 3 Terrestrial LiDAR scanner image of a highly active alluvial gully in the Gilbert catchment

1.2 Key findings

1.2.1 Gully extent

A remote sensing mapping programme undertaken by Griffith University in 2006 in conjunction with the Northern Gulf Natural Resource Management Group (NGNRMG), found that gully erosion was widespread through the region, both in the form of hillslope gullies on the Georgetown granite soils and alluvial gullies on the areas of Quaternary alluvium along the main rivers in the region. A total of around 10,000 ha of active gullies were mapped using ASTER satellite imagery in the initial synoptic scale mapping exercise. As part of this study we revisited the earlier mapping both on the ground and through manually digitising gullies using the much higher resolution imagery that is now available in Google Earth compared to what was available when the original mapping was undertaken. This analysis found that the original mapping over-estimated the extent of highly active gullies, probably by a factor of around two (giving a total area of active gullies of around 5000 ha).

The over-estimation was, however, not uniform. Areas with relatively low gully density per unit area (the large majority of the landscape) tended to significantly under-estimate the total extent of gullies, by as much as a factor of 10; while areas with high gully densities (smaller areas with extensive gullying) tended to over-estimate by a factor of about 4.

Given the inherent error that clearly exists in the remote sensing mapping approach, we can conclude that, providing satellite imagery of sufficiently high resolution is available (2.5m pan sharpened Spot 5 data as a minimum), manual digitisation based on visual observation is the only satisfactory method for mapping gullies in this landscape at a level that is sufficient for management and sediment budget quantification. This assumes that LiDAR data is not available, which would be the preferred data source if it was widely available.

1.2.2 Gully erosion rates

As part of this study we re-surveyed several gullies using differential GPS of gully scarp boundaries and Terrestrial LiDAR scanning of gully sections at sites for which we had airborne LiDAR data captured in 2006. The results from these surveys indicate that fairly typical alluvial gullies are delivering sediment yields of 260 - 450 t/ha/yr of sediment to the stream network (from the active gully area). More active gullies, such as the site G9GC1 at Greenhills are producing specific yields of 2160 t/ha/yr.

1.2.3 Gully erosion sediment yields

Assuming the sediment yields from the moderately active gullies are representative of the yields more generally, mean annual sediment contribution from gullies within the upper Gilbert fan would fall within the range 1.3 – 2.3 Mt/year, most of which can be regarded as land-use accelerated erosion. If the observed specific yields in the order of 2000 t/ha/yr are representative of a significant proportion of the mapped gullies, the mean annual sediment yields from gullies could be several times more than this conservative range.

1.2.4 The IFED proposal

Proposal Overview: The proposed IFED irrigated agriculture area is located in the Dismal Creek catchment (encompassing two properties currently used as grazing leases - Chadshunt and Kutchera), which have a combined area of around 103,500 hectares. The area of the proposed development within these two properties is 65,000 ha., consisting of around 1600 x 40 ha plots, which would be leased in a share-farming type arrangement. Under this model lessees are responsible for clearing and laser levelling the land in preparation for irrigated agriculture and are contracted to provide the agricultural products to the processing plants on site. The IFED developers would provide the water infrastructure, the sugar mill for processing the sugar cane that is proposed as the primary crop, and a guar gum processing plant, to process the guar beans that are proposed as the other major crop to be grown on the site. The water supply infrastructure will consist of two major off-river water storages, on Dagworth and Huonfels Stations, that will receive 550,000 Ml/yr (around 1 Sydharb) in flow diverted from the Einasleigh and Etheridge Rivers each year, plus an unspecified volume from local runoff in the dam catchments. In total the two storages have a capacity of 2,100,000 Ml (or around 4 Sydharbs). The high flow diversion from the Einasleigh River equates to around 40% of the mean annual flow at Dagworth, which means that in low flow years that it will be a much higher proportion. Soil fertility was not regarded as an important criteria for site selection given that most nutrients required by the crops will be supplied in the water supply via sub-surface trickle irrigation in the process known as fertigation. While soil fertility may not be regarded as important, soil structure, stability and drainage capacity are critical if irrigation is to be sustainable in the long term and land degradation is not to ensue in the short to medium term.

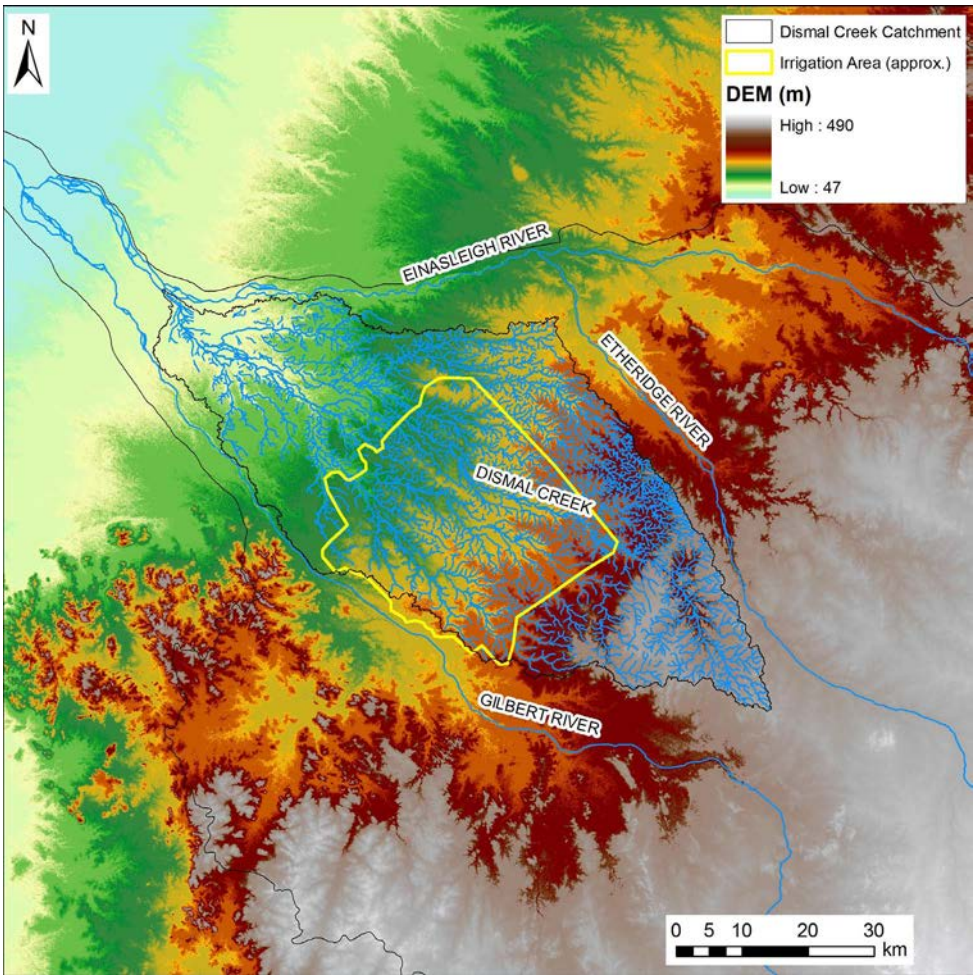


Figure 4 DEM map showing the location of the proposed IFED agricultural area (outlined in yellow) within the Dismal Creek catchment above the apex of the Gilbert megafan. Note that the area is far from flat, located as it is on the tertiary age deposits of the upper Gilbert megafan, which is largely disconnected from upstream sources of "new" alluvium

1.2.5 The FGARA soil suitability analysis

The CSIRO FGARA soil suitability analysis assessed a wide range of derived parameters using a Digital Soils Mapping (DSM) approach to assess the suitability of 74 different crop/irrigation scenarios in this region. The DSM approach relied heavily on remotely sensed radiometric data, coupled with 30m topographic data and limited ground survey data. Hence, systematic error in the radiometric data could introduce substantive error into the mapping.

A major caveat in the CSIRO FGARA report was that much of the area falling within the Karumba geologic formation (also known as the Holroyd Plain and the Wyaaba Beds in other geologic maps) is known to have poor predictive power with regard to surface soil characteristics. The Karumba formation, which consists of the Tertiary age remnants of the upper part of the Gilbert alluvial megafan deposited between 2.6 and 23 Ma, was acknowledged to contain extensive areas of well-developed fericrete and other lateritic deposits, which are known to interfere with the radiometric signatures, potentially leading to spurious results in the Digital Soils Mapping approach. As shown in Figure 4, virtually the entire area of the proposed IFED agricultural precinct falls within the area flagged by CSIRO as being 'known to predict poorly'.

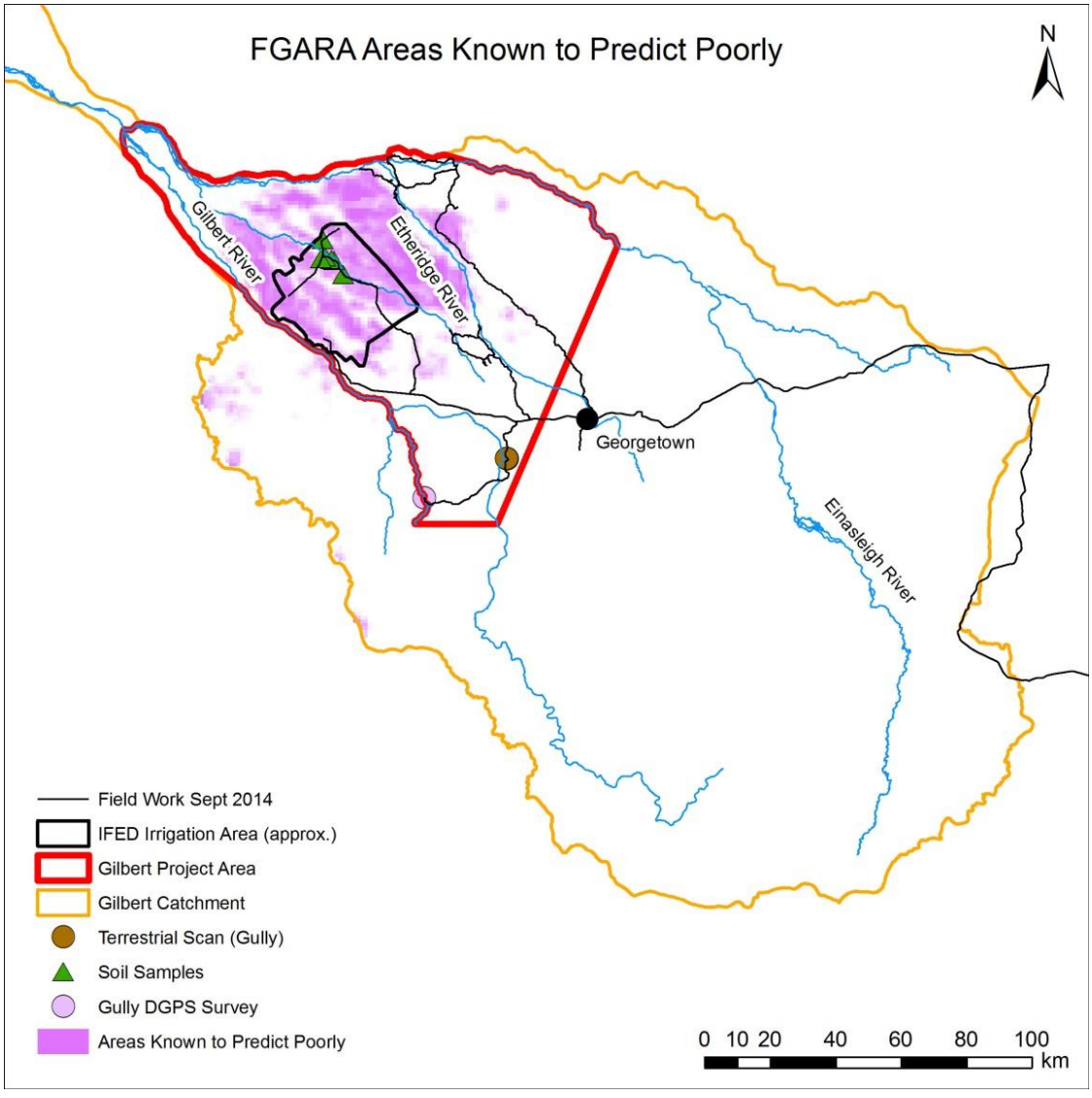


Figure 5 Map of the study area and the Proposed IFED area which shows that almost the entire area encompassed by the IFED agricultural area falls within the bounds of the area "known to predict poorly"

With a 90m pixel resolution the analysis is also blind to complex spatial heterogeneity, and so variability at finer resolution was necessarily averaged to the minimum resolution of the analysis. Our initial assessment is that there is considerable spatial variability in the soils within this area at a much finer resolution than is likely to have been captured by the 90m resolution radiometrics (irrespective of the issue outlined above associated with lateritic soils).

The CSIRO FGARA soil suitability analysis classified most of the soils in the IFED area as class 3 or 4 soils for spray, trickle and furrow irrigation. However, as highlighted above, these results must be viewed with considerable scepticism given the known limitations of the survey techniques in this area. This is acknowledged in the FGARA documentation, which states: "The Assessment is designed to inform consideration of development, not to enable particular development activities. As such, the Assessment informs – but does not seek to replace – existing planning processes." (Bartley 2013, Preface).

In many areas it appears likely that the assessment over-estimated the suitability of the soils for irrigated agriculture, and it is likely that a much greater proportion of the soils in this area are class 5 soils. In particular the fact that sub-surface dispersibility was not systematically assessed, may render the assessment of the area as predominantly class 3 soils for trickle irrigation as overly optimistic. If the majority of the soils are indeed class 4 or class 5, and irrespective of whether fertigation is used, as a first order site selection criterion, this would typically preclude such an area being selected as the focus of a major irrigated agriculture development.

While the soil suitability analysis considers the susceptibility of surface erosion as a function of surface soil K factor and slope, and concludes that there is little erosion risk in this area, such an assessment does not assess the risk posed by sub-surface erosion – which is likely the source of >97% of all sediment delivered to streams in the region (based on evidence from the adjacent Mitchell catchment). Our preliminary assessment would suggest that sodic dispersible sub-soils are widespread within this area, and that much of the landscape is susceptible to sub-surface erosion, should these sub-soils be exposed.

1.2.6 Landscape analysis of the IFED area

The defining characteristic of the IFED area is that it is situated on an extremely old landscape surface, which was deposited as part of the Gilbert megafan between 2.6 – 23 million years ago. As the Etheridge and Gilbert Rivers have incised into the upper megafan the Dismal Creek catchment has effectively become isolated from the upper Gilbert catchment, starving it from any 'new alluvium' from the upper catchment. Consequently, the soils in this area have been weathering in-situ since they were deposited, giving rise to extremely poor, low nutrient soils.

A topographic analysis of the IFED area highlights the fact that this area is highly dissected by the well-developed Dismal Creek catchment stream network (Figure 6). The landscape is relatively steep for irrigated agriculture with a typical cross-valley gradients in the range of 0.3-0.6% and a typical long-valley gradient of 0.14-0.18%. These slopes are around three times the down-valley gradients, and up to 10 times the cross valley gradients found within the Burdekin irrigation area.

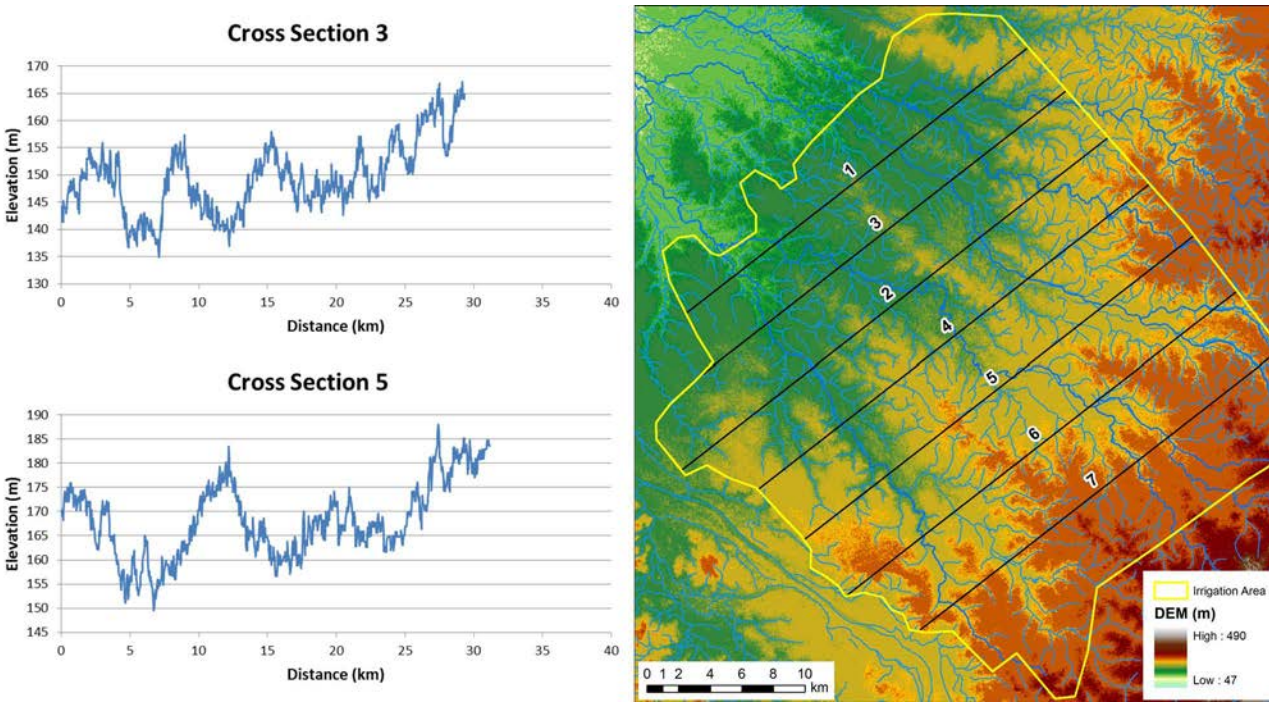


Figure 6 DEM and cross valley sections through the Dismal Creek catchment area encompassed by the proposed IFED area showing the highly developed stream network within this area and the cross-valley topographic variability

1.2.7 Soil erosion hazard in the IFED area

Our mapping indicated that there are 106ha of active gullies within the IFED agricultural precinct, which are fairly evenly distributed across the whole site, but particularly associated with drainage lines (i.e. they are predominantly alluvial gullying). There are also numerous examples of small gullies which have been initiated by road drainage lines. This suggests that much of the landscape is prone to gully erosion if disturbed.

Random field samples indicate that highly dispersible sodic sub-soils are common.

The soil chemistry data indicates a complex relationship between gully erosion and soil chemistry, and the traditional assumptions about soil stability (e.g. high Ca/Mg ratios = stable soils) may not necessarily apply in these soils. It is likely that there is a multi-variate, non-linear relationship between soil chemistry and erodibility. It is recommended that much more work needs to be done to understand this relationship.

Given that most gullies are initiated in, or adjacent to, drainage lines, the density of the drainage network in this area highlights the need to be extremely cautious and endeavour to exceed best management practices in the design and layout of the road network and areas that will be cleared and laser levelled.

Given the micro topography of the area, the development of paddocks for irrigation, particularly sub-surface trickle irrigation, will inevitably mean that sodic soils are exposed, which will need to be stabilised with large quantities of gypsum. The costs of gypsum required to stabilise the soils will need to be factored into the economic analysis of the overall development strategy.

Given the apparent susceptibility of this landscape to gully erosion, none the least due to the antiquity of the landscape, the presence of sodic soils, the gradient of the landscape and the high drainage density, generous buffers will be required around all drainage lines/depressions; and around all existing gullied areas to ensure that gully erosion is not exacerbated in this area.

1.2.8 Buffer design to reduce the threat of gully erosion

Given the constraints identified within this landscape, and the high risk of initiating gully erosion under an intensified land-use regime, we recommend that generous buffers are left around all drainage lines and existing gullies that vary in width according to the stream order.

We modelled a range of buffer widths as a function of stream order according to the equation:

Where $S_0 > 1$: Bw (m) = n x S_0,

Where $S_0 = 1$: Bw (m) = $2n$ x S_0

Bw = buffer width (each side of stream), n = buffer multiplier (10 – 45m); and S_0 = stream order (Strahler)

All mapped gullies also include a buffer of the same extent as the 1st and 2nd order streams.

Based on the modelling, a buffer multiplier of 45m is achievable and would leave around 75,000 ha of land that could potentially be developed, while minimising the threat of gully erosion initiation in and around the drainage network.

Further work would need to be done to refine the stream network given that this analysis was based on the available 1:100,000 scale stream network, and there are some drainage lines not captured in this analysis. However, the total area would not differ significantly from that represented here.

If it did transpire that there was a significant length of stream network missed in this analysis it may be necessary to reduce the buffer multiplier, but we would not recommend that it be reduced to less the 30m.

The aim with these buffers would be to completely eliminate all land use pressure from these zones, including clearing, roads and tracks and disturbances associated with water infrastructure.

These buffers should be the bare minimum area within the agricultural precinct left uncleared. Additional wildlife corridors should be superimposed on this network to provide wildlife movement across the drainage network (i.e. in a NW/SE direction).

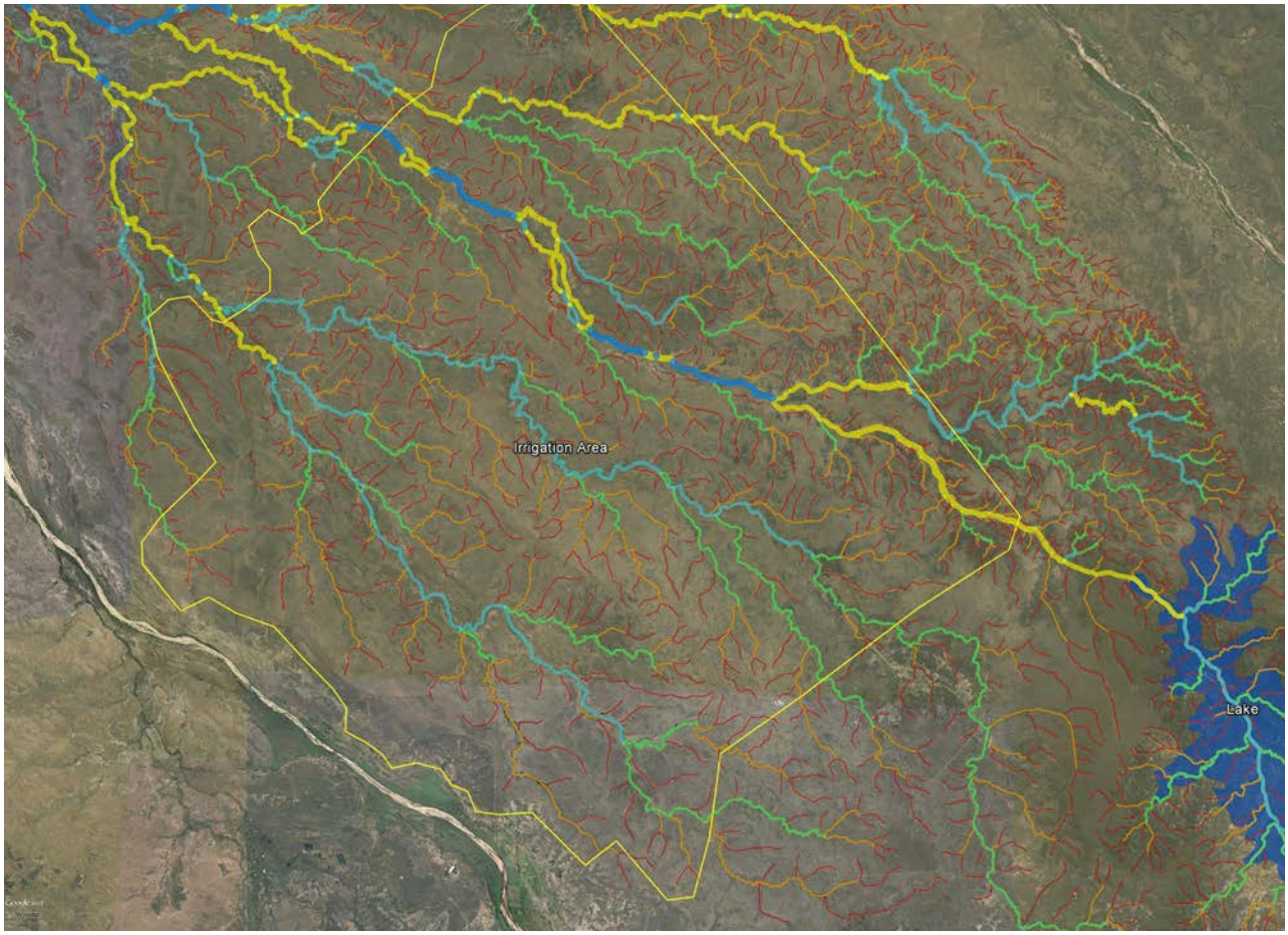


Figure 7 Proposed stream network buffers for the Dismal Creek catchments area

1.2.9 Offset opportunities

Despite the limitations of the earlier remote sensing gully mapping it is clear that there are some areas of intensive gully activity which should be the focus of remedial activities irrespective of whether further developments proceed within the Gilbert region. In the event that large scale developments do proceed, significant contributions towards the rehabilitation of these areas should be built into the development process. Costs of intensive gully rehabilitation have been shown to be in the order of $30,000 per hectare of active gully (Shellberg and Brooks, 2013).

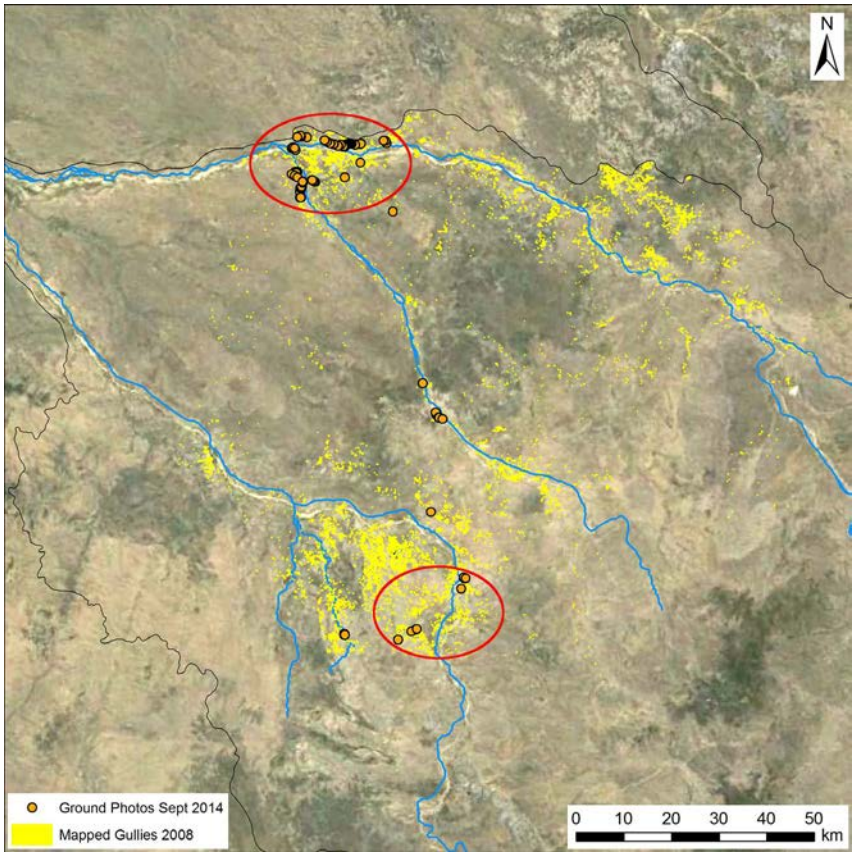


Figure 8 Map showing the aggregation of alluvial gullies in the area around the confluence of the Einasleigh and Etheridge Rivers and on the Gilbert River in the Greenhills areas. Note the gully mapping shown here is the earlier remote sensing-based mapping which has been shown to over represent the extent of gullies in the areas of high gully concentration. Hence the actual extent of gullies is less than represented here, but we do know that there are some major gully complexes here that could be managed with appropriate investment

2 Background

With the current focus on developing the agricultural potential of northern Australia, it is critical to evaluate potential risks that characteristics of this landscape pose to the viability of these new developments, as well as to the existing natural assets. A major investigation undertaken by CSIRO in the Gilbert catchment (Petheram *et al.*, 2013), assessed the suitability of the catchments for irrigated agriculture from a broad range of perspectives, including, climate, soils, crop agronomic suitability, the potential for the location of dams, access to markets and broader macro-economic factors, amongst other factors. The one factor that was not considered in the CSIRO analysis, however, was the suitability of the soils from the perspective of their potential susceptibility to alluvial gully erosion, or the likely threats of the initiation of off-site erosion in areas immediately adjacent to areas likely to be developed. Alluvial gully erosion has been shown to be widespread across northern Australia, and is prevalent in some of the areas that are currently under active consideration for intensive agricultural development (Shellberg and Brooks, 2012). Research undertaken through the Tropical River and Coastal Knowledge Programme (TRaCK) has highlighted the extent of current alluvial gully erosion across large areas of the northern Australia (Table 1, Figure 9), which by definition occurs on the alluvial land that is potentially most prospective for agricultural development. Whilst only a small proportion of the total land area, the extremely high erosion rates that occur within alluvial gullies, which can often have erosion rates that exceed 500 t/ha/year from individual gully complexes (Brooks., *et al.*, 2008; Shellberg, *et al.*, 2012), with sediment concentrations at gully outlets that exceed 100,000 mg/l. (Shellberg *et al.*, 2013). The catchments draining to the Gulf of Carpentaria and indeed most large floodplain rivers in northern Australia, including the larger ones draining to the Great Barrier Reef, are highly prone to this type of alluvial gully erosion (Brooks *et al.*, 2009; Shellberg & Brooks, 2012, 2013), and hence this is a critical issue in any development scenario.

Research has shown that not only does this erosion process represent the dominant sediment source to most large rivers in northern Australia (Rustomji *et al.*, 2010; Shellberg and Brooks, 2012), but it also represents a key threat to infrastructure such as roads, dams, irrigation paddocks and other infrastructure across large areas of the north.

Table 1 Areas of mapped (minimum) active gully erosion across key northern Australian catchments

Catchment	Basin Number (Code) Figure 3	Bare Ground Minimum Area of Alluvial Gullies (ha)	% Catchment Area
Normanby (QLD)[5]	105	2,031	0.08%
Mitchell (QLD) [1,2,3,4,12]	919	16,700	0.23%
Gilbert (QLD) [1]	917	10,100	0.22%
Leichhardt (QLD) [1]	913	29,100	0.87%
Gregory/Nicholson (QLD) [1]	912	12,300	0.24%
Victoria (NT)[7]	811	10,400	0.22%
Fitzroy (WA)[15]	802	36,300	0.39%

This form of erosion represents a dominant source of accelerated erosion in many tropical rivers and as such is disproportionately responsible (compared with the area of land involved) for the elevated sediment load in many rivers in Northern Australia (Shellberg and Brooks, 2012).

Alluvial gully erosion can be very difficult and expensive to manage and so once initiated it represents a threat to the viability of the some of the most valuable alluvial land assets as well as to infrastructure and to downstream river reaches and receiving waterbodies. Consequently, avoiding the initiation of new alluvial gully erosion should be given the highest priority in natural resources management planning, even ahead of any actions to address existing gully erosion problem areas.

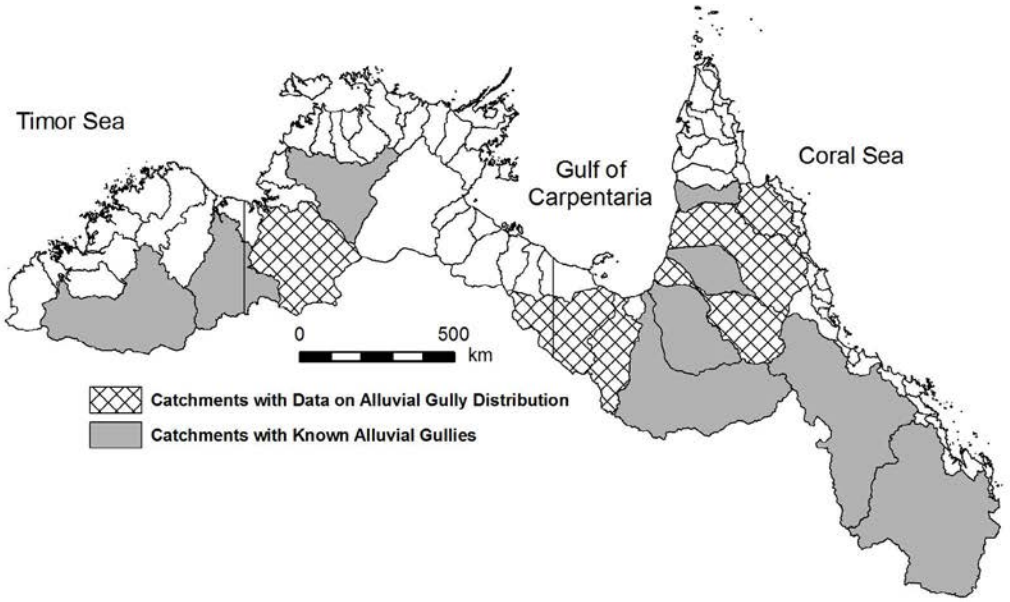


Figure 9 Map showing the catchments in northern Australia which either have mapped distributions of the extent of alluvial gully erosion or where alluvial gullies are known to exist but have yet to be mapped. Catchments shown in light grey

3 Project overview

Given the high degree of interest in agricultural development across northern Australia and the known threat posed by alluvial gully erosion, there is a pressing need to look closely at the extent to which this inherent characteristic of the northern Australian landscape poses a risk to investment in the north. In this project we use the Gilbert/Einasleigh area as a case study to assess how an irrigation development might be planned and implemented in such a way as it minimises the risk of initiating new alluvial gully erosion or exacerbating existing erosion problem areas (both alluvial gullies and stream bank erosion). To date two proposals for establishing irrigated agriculture in the Gilbert catchment have been put forward; the Gulf Savannah Development proposal (2009), and the Integrated Food and Energy Development proposal (IFED, 2012). To date most attention has been directed at IFED due to the scale of the proposal and the high profile nature of its proponents. It is also fair to say that the IFED project has attracted more criticism from the local community because of its scale, its radical departure from accepted practice, and the greater potential impact/benefit of the development on the local economy, infrastructure and environment. For this reason we have chosen to focus on the IFED case study to explore some of the land management challenges faced through implementing such a project in this landscape. We have chosen an area bounded by the Einasleigh and Gilbert Rivers as the focus for this study (Figure 10, Figure 11), as this encompasses the areas in which irrigated agriculture development is proposed, and includes the focal areas for previous synoptic scale erosion hazard remote sensing mapping undertaken by Griffith University (Brooks *et al.*, 2006)

Gully mapping work undertaken as part of this previous remote sensing mapping programme was not ground truthed to the extent that would have been preferred at the time, and so one of the first tasks of this project was to revisit the areas previously mapped and undertake further ground truthing of the mapping beyond that undertaken in the original synoptic scale mapping exercise.

4 Project objectives

1. This project will improve the knowledge base for planning and assessing potential erosion risks associated with new agriculture developments in northern Australia, particularly off site gully and stream bank erosion that may be inadvertently initiated as part of the development process.
2. The project will raise awareness of issues associated with gully and streambank erosion (and elevated sediment loads in rivers) within the community so that unintended consequences associated with agricultural development might be avoided.
3. Within the pilot study area, the project will also identify the areas that are currently highly degraded under broad-scale grazing and the data developed within the project should inform land-use planning processes.

5 Structure of this report

This report has been broken into three parts:

1. Review of relevant background data, including:
    a. the 2006-07 gully mapping project undertaken by Griffith for the Northern Gulf NRM Group and Federal Govt;
    b. the CSIRO FGARA report;
    c. other research undertaken through the Tropical Rivers and Coastal Knowledge (TRaCK) Programme.
2. Undertake a preliminary soil erosion risk assessment of the area proposed for development within the Integrated Food and Energy Development (IFED) in the Gilbert catchment, which includes analysis of the landscape setting and susceptibility of the soils to erosion during the development process and over the longer term operation of the agricultural area.
3. Provide management recommendations regarding:
    a. approaches for minimising the impacts of development within the development area – should development's such as the IFED proceed
    b. How to avoid development in inappropriate (high risk) areas
    c. The identification of hotspots of gully activity for potential remedial actions as offsets to land-use intensification in low risk, high value land.

6 Review of 2006 Griffith University gully mapping

6.1 Regional scale remote sensing gully mapping

In 2006 alluvial gully erosion was identified as a key threat to water quality across large areas of the northern and southern Gulf regions, and a collaborative project between the Northern Gulf NRM Group, Land and Water Australia and Griffith University (Brooks *et al.*, 2006) was set up to undertake synoptic scale mapping across the region to gauge the scale of the issue. This mapping exercise, which was the first of its kind in Queensland, put the issue of gullies in alluvium firmly on the agenda for land and water managers across northern Australia. While extensive gully erosion mapping had previously been undertaken in the Victoria River District in the Northern Territory, it had not been articulated that this erosion process differs fundamentally from the standard hillslope erosion model that was widely recognised in southern Australia, and was assumed to be similar across northern Australia (e.g. Prosser *et al.*, 2001). While hillslope gully erosion does occur in northern Australia, alluvial gully erosion is far more widespread and represents a greater threat to water quality, aquatic ecosystems and to infrastructure than does hillslope gullying.

In this part of the project, we revisit a number of sites that were originally surveyed in 2006 and undertake follow-up surveys to gauge the rates of alluvial gully activity over the intervening 8 year period since the last surveys. We also revisit a sample (0.63%) of the gullies mapped in the Gilbert catchment in 2006 from ASTER satellite imagery. We drew upon a range of datasets that were collected during the previous research as outline in Table 2. Key datasets that are being used as base data for assessing change since the original work was undertaken in 2006/07 include the LiDAR data, ground GPS surveys of selected gullies; gully distribution derived from ASTER imagery, aerial imagery.

Table 2 Datasets that have been reviewed during this project and which have formed the basis for subsequent analyses of erosion potential undertaken during this study

Dataset	Comments
Aerial video 2004	Video covering major channels flowing to the Gulf of Carpentaria (film using digital video camera, with incorporated GPS system, fixed to underside of single engine fix wing plane).
Airborne data 2006 (Airborne Research Australia, small fixed wing plane with underwing instrumentation pods)	Lidar (1m resolution) blocks covering ~128km^2 within the Gilbert catchment.
	Trispectral laser scanner (NDVI) covering LIDAR blocks.
	High resolution aerial photos approximately positioned from aircraft GPS.
On-ground field work 2006	Tracklog record of all investigated sites and routes in between.
	Extensive ground photo catalogue (co-ordinates extracted from tracklog).
	GPS survey of selected gullies
Aster	Mosaic of one year of the Northern and Southern Gulf regions
	Selection of individual scenes
Landsat	Library of SLATS yearly mosaic and individual scenes.
Selection of historic aerial photos	Various resolutions
Final Gully Mapping Data polygons	15m pixel resolution & 1km grid showing proportion of grid square occupied by gully pixels

The focal area for this study is shown in Figure 10, along with the GPS track logs showing the ground survey undertaken in this study. This builds on the pre-existing field and aerial surveys completed in, 2004, 2006 and 2008. The study focal area encompasses the areas of greatest gully erosion density as well as the areas that are proposed for irrigated agriculture development (Figure 11).

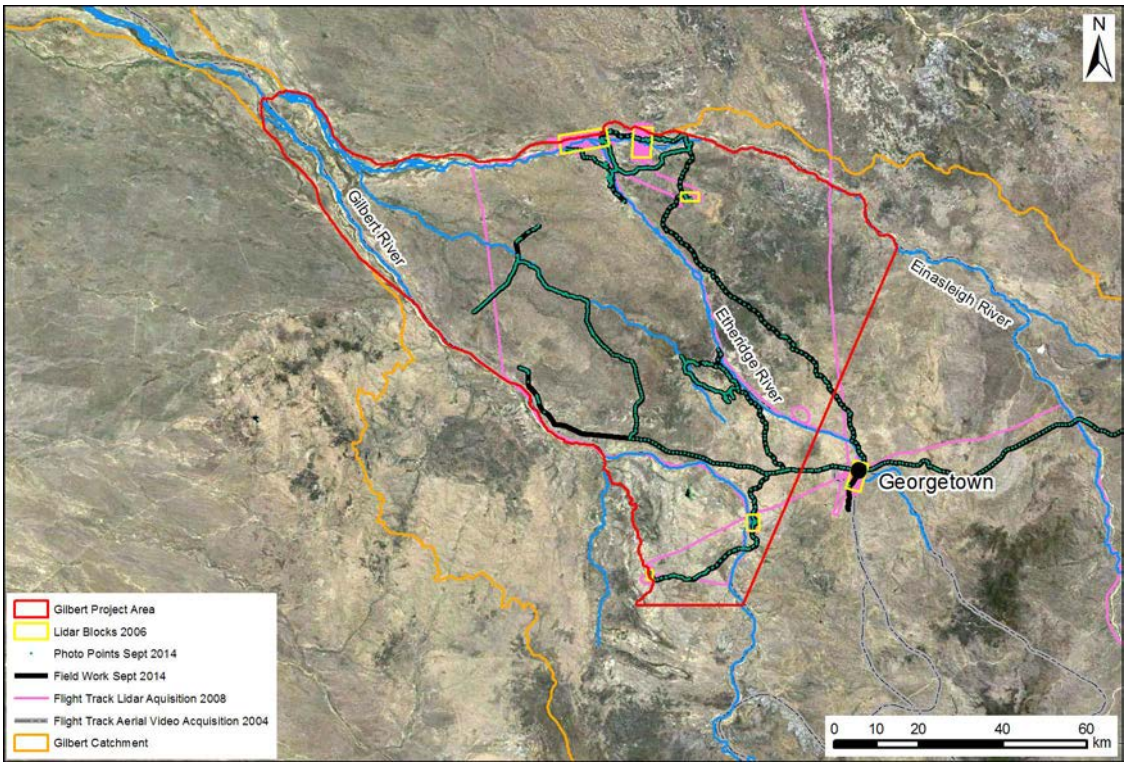


Figure 10 Map of the Gilbert River Project area (outlined in red), which encompasses the area likely to be developed for irrigated agriculture, and within which erosion studies have been conducted. Also shown is the coverage of the various datasets that have been used in this study

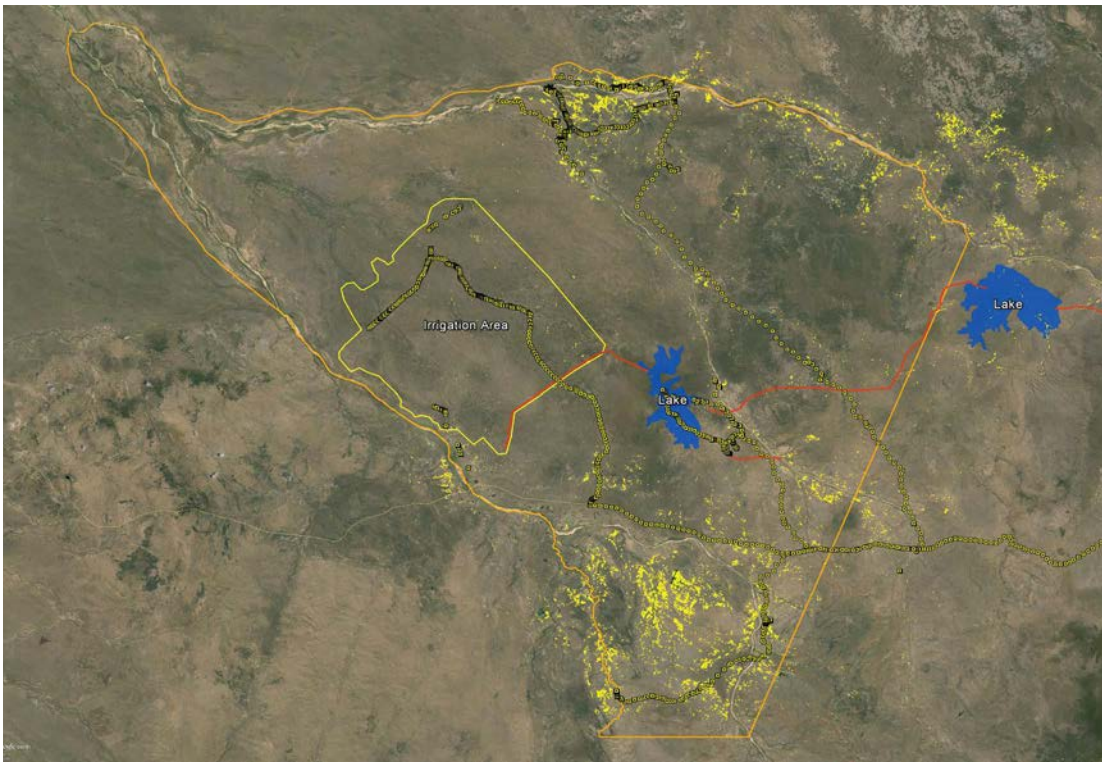


Figure 11 Image showing the focal study area (orange outline) with the location of the major infrastructure for the IFED project indicated (i.e. 2 off-stream water storage lakes; diversion channels (red); and the proposed irrigation area (yellow outline). The yellow polygons scattered across the image are the gully areas as mapped from Aster imagery in 2006. Also shown are the centre pts of ground photos collected in 2014 as part of the ground validation exercise for the gully mapping

6.2 Reassessment of 2006 alluvial gully erosion hazard mapping

Initial ground-truthing was undertaken by visiting a sample of 55 (or a sample of 0.63 %) of the mapped gully polygons on the ground (Figure 12) and ascertaining whether the mapped features were accurately mapped. Results from this exercise (Table 3) indicated a high proportion of false positives from the ASTER gully mapping exercise. The most common features that were misrepresented were light coloured rocky outcrops or patches of annual grasses located on floodplains in approximately the locations that alluvial gullies would be expected. Based on these results we then carried out another test using Google Earth imagery, in which we digitised all visible gullies. Such an analysis was not possible when the original mapping was done due to the limited availability of high resolution imagery covering the majority of the area within Google Earth back in 2006, where the best available imagery was the ~30m Landsat imagery. In part, the misrepresentation of gully polygons in the original mapping is a data resolution issue, given that the ASTER analysis was largely detecting areas of "bare ground", which are generally closely associated with gully distribution, but are not an exclusive indicator. Often the actual gullies are a smaller proportion of the total area that is mapped as bare ground using the ASTER remote sensing technique. There were also some registration issues with the original mapping that explain some of the difference between mapped and observed gullies, given that there are often gullies in close proximity to the mapped gully pixels, but not at the exact location.

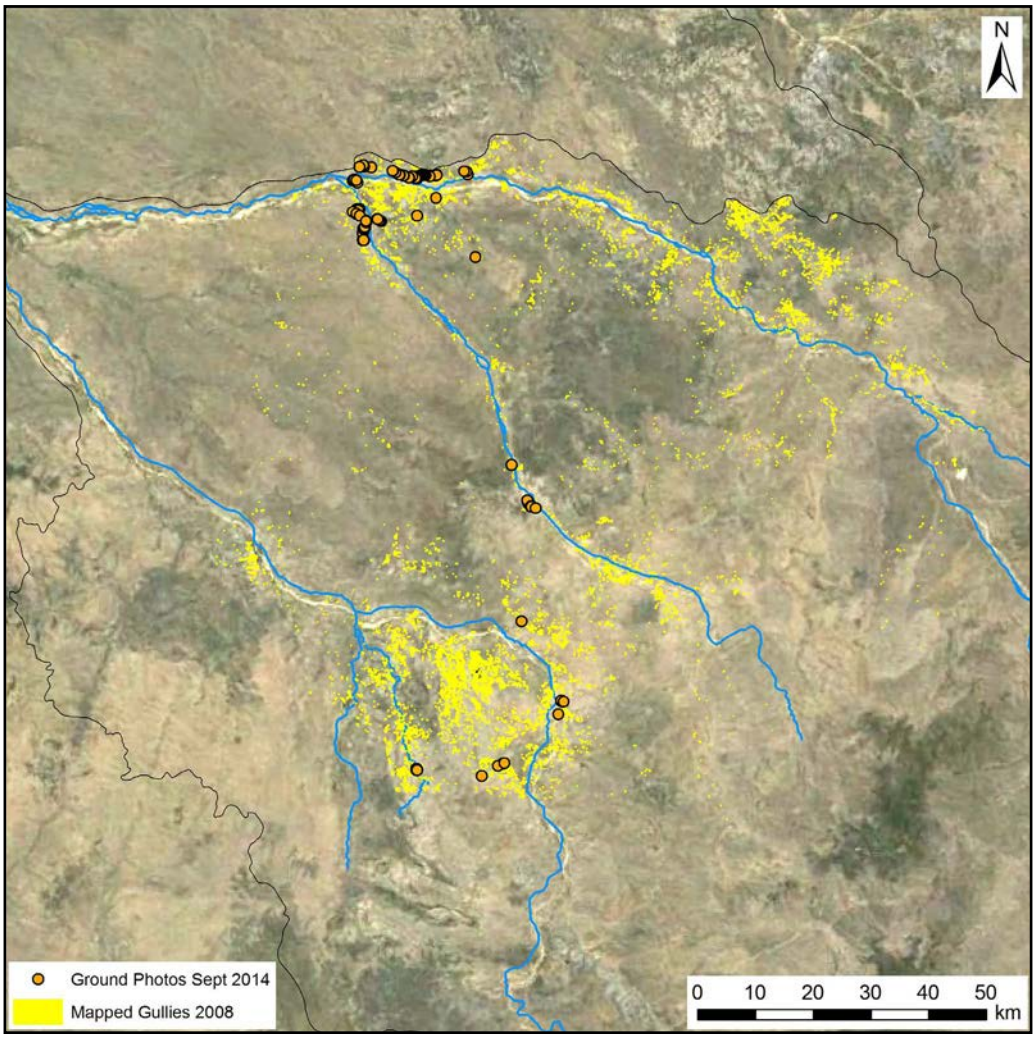


Figure 12 Locations of gully polygons with on ground field visits (316 photos were taken amongst 55 gully polygons)

Table 3 Summary statistics of the "ground-truthed" gully polygons

Number of Mapped Gullies (2006)	8671
Number of 2008 mapped Gully Polygons Visited (2014)	55 (0.63%)
True Positives for the 55 Gully Polygons	16 (29%)
False Positives for the 55 Gully Polygons	39 (71%)

6.2.1 Google Earth gully mapping

The existing ASTER derived gully mapping has been reassessed both on the ground and using the higher resolution imagery now available across the entire catchment. At the time that the mapping was undertaken in 2006/07 the 15m resolution ASTER imagery was the highest resolution imagery available across the region. As a minimum, there is now 5m pan-sharpened Spot imagery available across the whole region, with selected areas having <1m Quickbird and other image sources. With these data we have sampled a portion of the area originally mapped and re-mapped it via manual digitisation of visible gully and scald areas. A grid of 1/10th of a degree squares was overlain on the gully mapping undertaken in 2006 using Aster satellite imagery. Thirteen grid squares were selected wherein gullies that are discernible in Google Earth imagery were manually mapped. Additional gullies were manually mapped to complete the coverage within the IFED irrigation area. A total of 473 gully polygons were manually digitised. As shown in Table 4 there were was a similarly high number of false positives indicated using the manual digitisation method from Google Earth as the field checking.

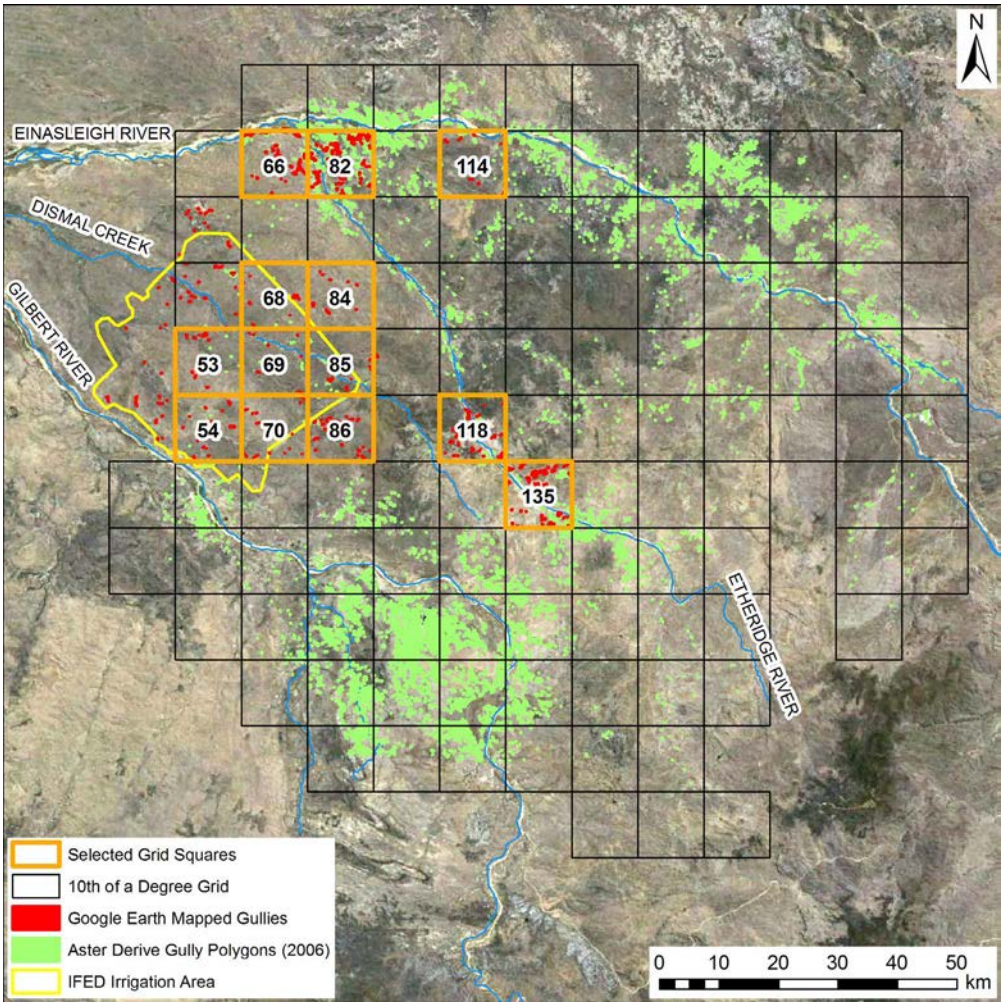


Figure 13 Map showing the distribution of the 0.1 degree grid with the sample grids highlighted in orange

Table 4 Summary statistics for the Google earth gully mapping test data

Total area of Google Earth mapped gullies.	5.6 km^2
Area of Google Earth mapped gullies with Aster mapping Area	5.2 km^2
Total area of overlap between Google Earth mapped gullies and Aster derived gully polygons (2006).	0.87 km^2
Percentage of Google Earth mapped gully area captured in Aster derived gully polygons (2006) area.	16.8%
Ratio of the number of Google Earth mapped gullies intersecting and not intersecting Aster derived gully polygons (2006).	143/420 (34%)

Table 5 Table showing the extent of gullies in the test blocks represented in both the ASTER derived gully layer and the Google Earth mapped gully layer

Grid Square	Google Earth Mapped Gully Area (km^2)	Area of Aster Derived Gully Polygons Intersecting Google Earth Mapped Gullies (km^2)	Percentage of Google Earth Mapped Gullies Captured in Aster Derived Gully Polygons
53	0.0971	0.0034	3.5%
54	0.1627	0.0019	1.2%
66	0.9259	0.1822	19.7%
68	0.1029	0.0090	8.7%
69	0.0753	0.0051	6.8%
70	0.0640	0.0000	0.0%
82	1.3882	0.5629	40.5%
84	0.1178	0.0173	14.7%
85	0.1223	0.0074	6.1%
86	0.2725	0.0044	1.6%
114	0.0863	0.0089	10.3%
118	0.4328	0.0018	0.4%
135	0.9391	0.0472	5.0%
Total	**4.7869**	**0.8516**	

Table 6 Table showing extent of over/under representation of gully area ASTER derived gully layer and the Google Earth mapped gully layer

Grid Square	Google Earth Mapped Gully Area (km^2)	Aster Derived Gully Polygons Area (km^2)	Ratio of Google Earth Mapped Gully Area and Aster Derived Gully Polygon Area Within Grid Square
53	0.0971	0.0702	138%
54	0.1627	0.0227	716%
66	0.9259	0.7694	120%
68	0.1029	0.0347	297%
69	0.0753	0.0718	105%
70	0.0640	0.0115	558%
82	1.3882	5.4733	25%
84	0.1178	0.0367	321%
85	0.1223	0.0995	123%
86	0.2725	0.1305	209%
114	0.0863	0.2980	29%
118	0.4328	0.3496	124%
135	0.9391	1.1583	81%
Total	**4.7869**	**8.5260**	

6.2.1.1 Summary of gully mapping Ground-Truthing

The analysis above (Table 5, Table 6) shows a poor relationship between Google Earth mapped gullies and the Aster derived gully polygons. Figure 14 shows that the number of false positive gullies (from ASTER) increases exponentially as the number of Google Earth mapped gullies per grid square increases. This suggests that the ASTER-based method is fairly good at low gully densities, picking out isolated gullies from the surrounding landscape, providing it is of a sufficient scale to be detected. In areas of low gully density, however, the ASTER imagery tends to under predict gully area, whereas in areas with high gully density the ASTER mapping tends to both overestimate the total area of gullies, and have a poor ability to predict the actual location of gullies.

The general conclusion we can draw from this exercise is that while the ASTER based mapping can give a general idea of the relative distribution of alluvial gullies within these savannah environments (i.e. it can distinguish areas of high and low gully density) the technique is not sufficiently accurate for quantitative predictions of gully area or potential sediment loads derived from gully erosion. Manual digitisation of gullies is a far superior method, providing image resolution equivalent to 2.5m pan-sharpened Spot data (or better) is available within Google Earth. The ASTER derived mapping from the 2006 study does give a reasonable idea of the hotspots of gully activity, but the mapping requires further detailed work if it is to be used as a basis for property-scale rehabilitation planning. It should also be noted that, where available, high resolution (1m) lidar data is far superior for gully mapping than any remotely sensed imagery.

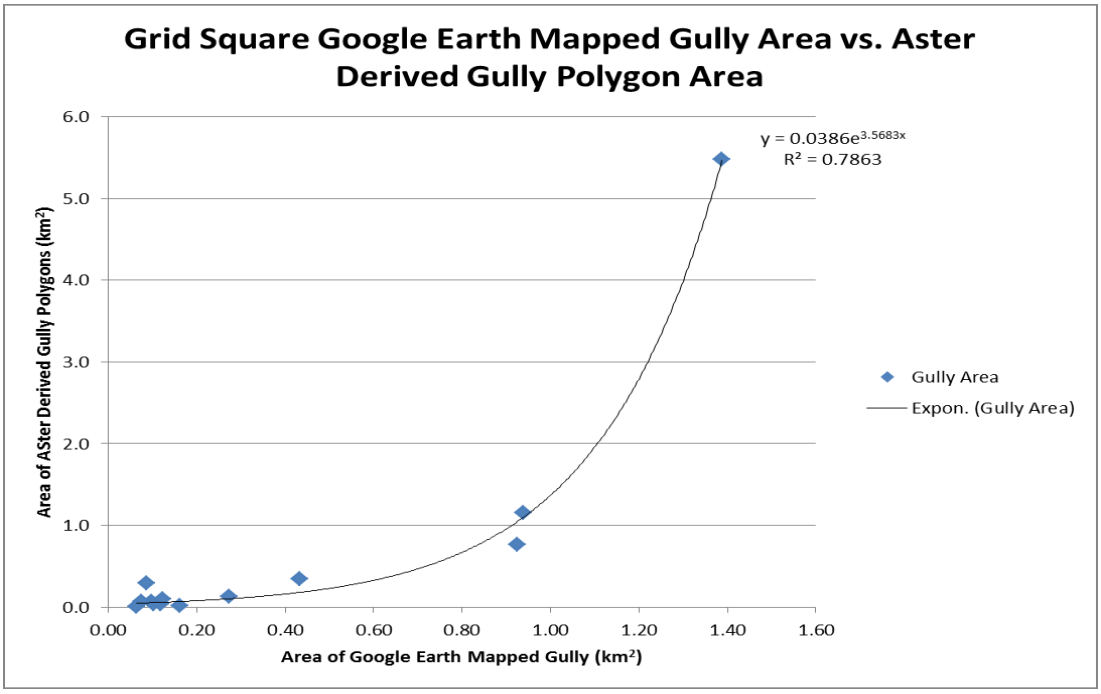


Figure 14 Graph showing the relationship between Google Earth mapped gully area (per grid square) compared with ASTER derived gully area (per 1/10th degree grid square)

6.3 Resurvey of previously surveyed gullies using Differential GPS and Terrestrial LiDAR

To ascertain the rates of sediment production associated with gully erosion in the Gilbert area we undertook resurveys of a number of gullies that had originally been surveyed in 2006. One gully complex was resurveyed using terrestrial LiDAR and two using differential GPS (Figure 16, Figure 19). The results from these resurveys indicate that the gullies have typically been expanding at a rate of 1 – 2% of their 2006 area per annum over the last 8 years. Together, the two gullies surveyed have contributed a minimum of around 15,000 tons of sediment over the 8 year period (2000 t/yr) between surveys from headscarp retreat alone. From similar analysis elsewhere (Shellberg., *et al.*, 2013) , we know that the contribution from new gully headscarp retreat to the total sediment yield from the gully complex is only a minor proportion of the total sediment yield at the gully outlet – perhaps only 25% (Shellberg *et al.*, 2013) – and hence the total yield from the gullies is likely to be much greater than this figure.

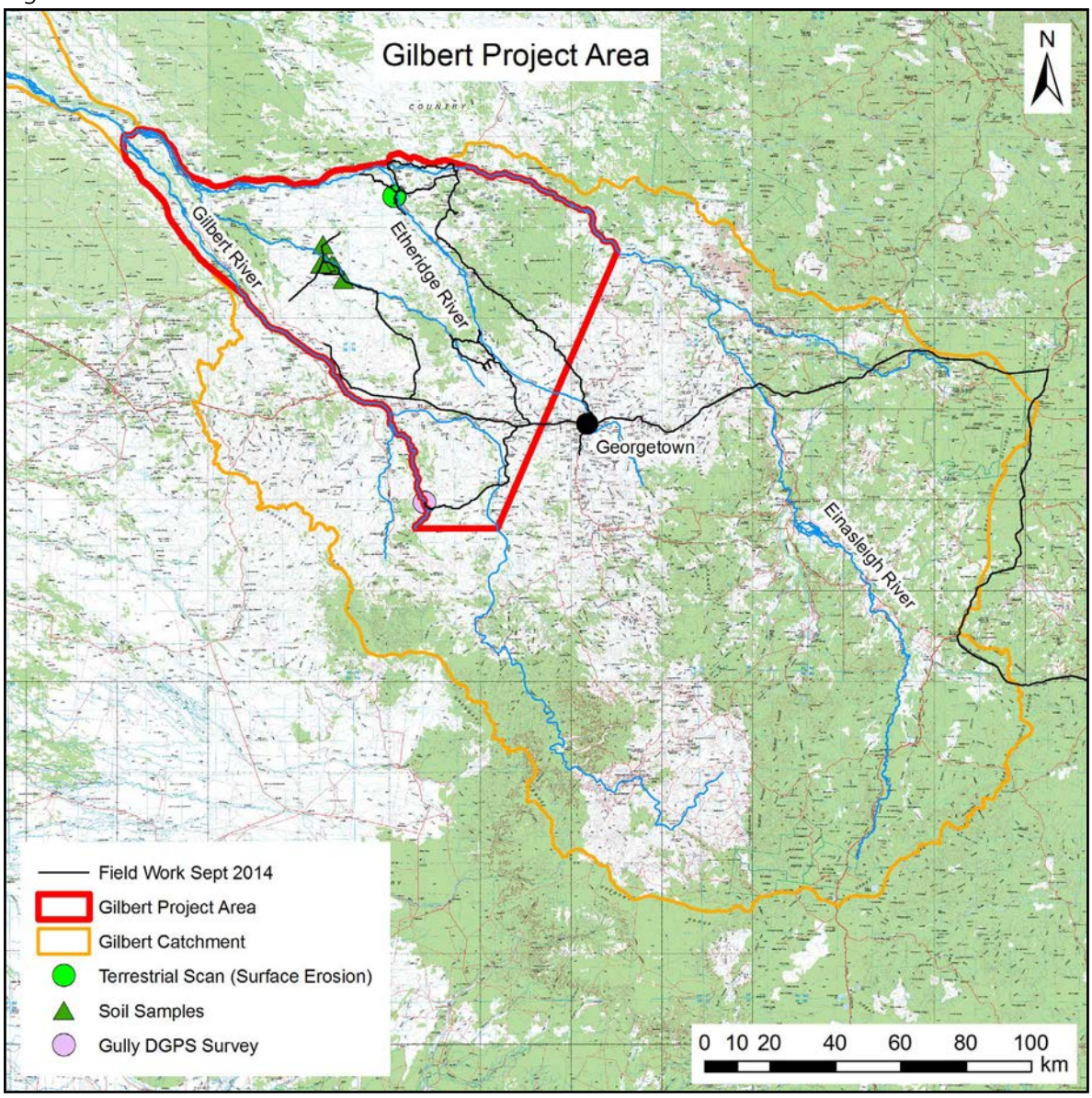


Figure 15 Map showing the location of sites at which detailed gully resurveys were carried out.

6.3.1 Gully Erosion rate Analysis - 2006 – 2014 – Abingdon gully complex 1 (ABGC1) – Bel Bel Crossing

6.3.1.1 Erosion Volume Estimate

The area of erosion for the surveyed gullies was determined from the areal difference between the 2006 and 2014 ground survey, and the volume of change estimated by extrapolation from the LiDAR DEM acquired in 2006. A representative area of gully present in the 2006 LiDAR was selected and was then broken into relatively homogenous sections (Erosion Polygons) (Figure 17). An area proximal to each erosion polygon was then digitised and the pixels values of the DEM within the Estimate Polygons (Figure 17) extracted and an average elevation calculated. The average elevation of an Estimate Polygon was the subtracted from each pixel elevation of the corresponding Erosion Polygon. The total volume of erosion was then determined from the sum of the differences between all erosion polygon pixel elevations and the average polygon elevation for the adjacent polygon. The total volume of erosion for the gully complex (ABGC1) was determined to be 6450.99 m^3 (+/- 1612 m^3), or 224 t/ha/yr +/- 56 t).

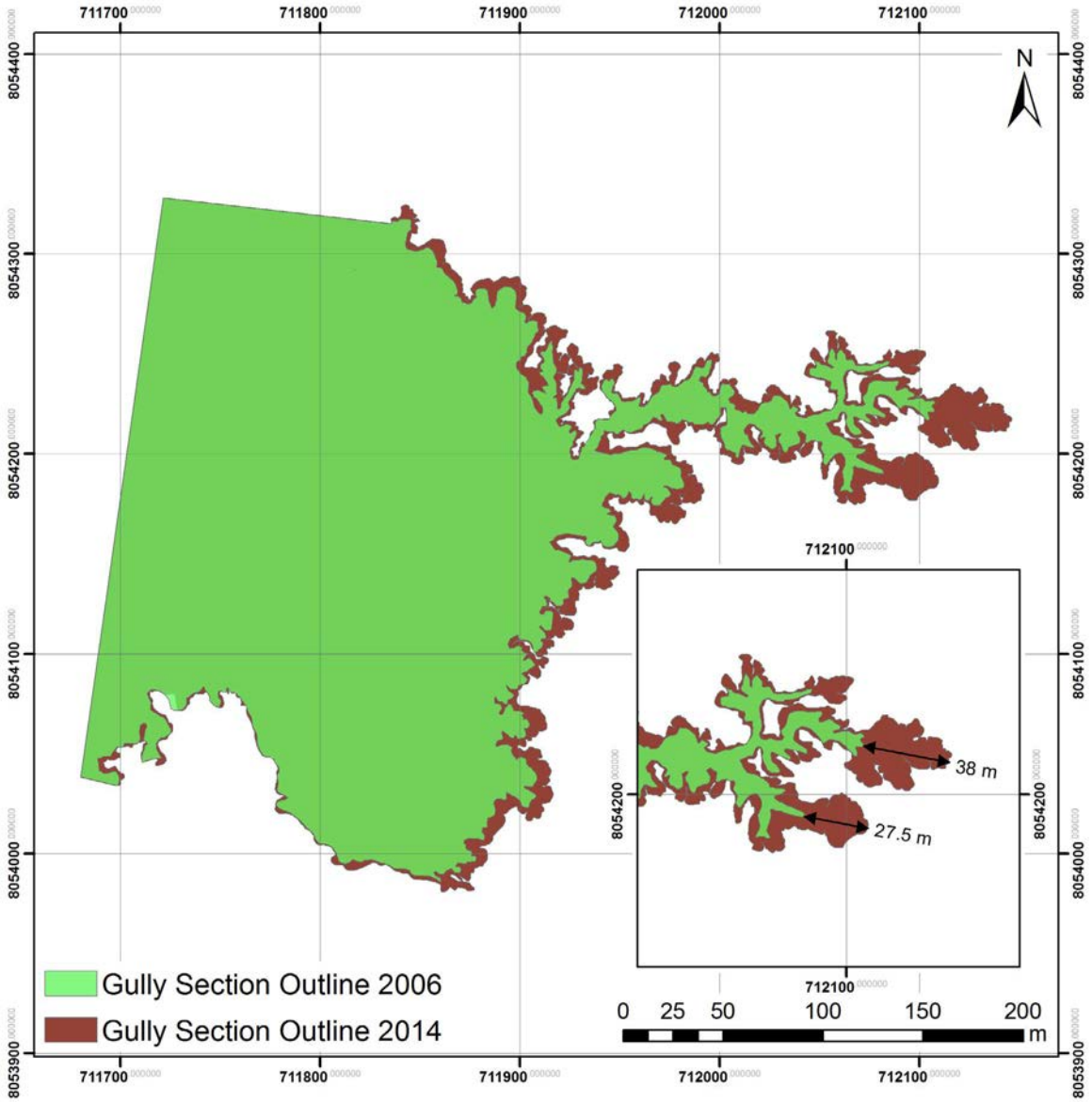


Figure 16 Comparison between differential GPS gully scarp surveys completed in 2006 and 2014

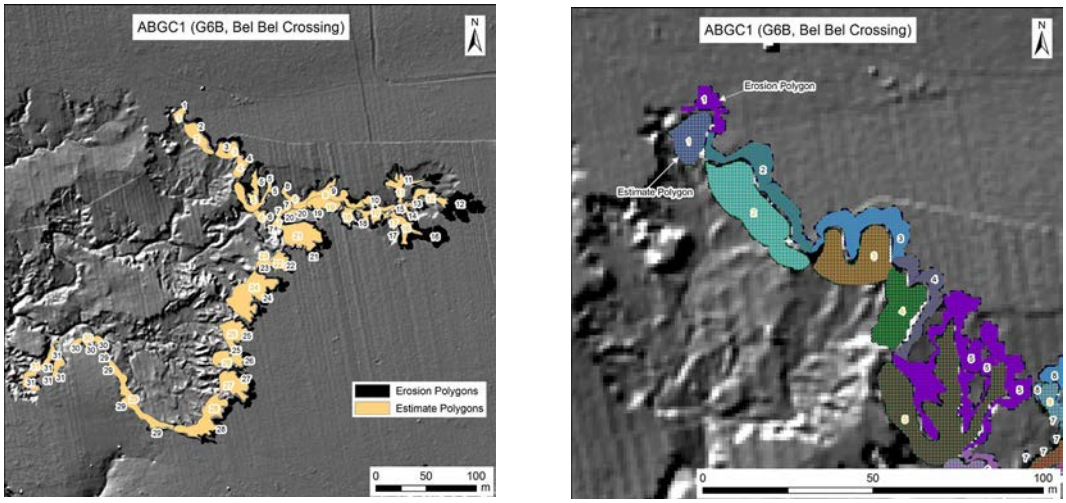


Figure 17 Change detection procedure based on 2008 LiDAR data from the BelBel crossing site

Table 7 Change in total are of the gully at BelBel Crossing on the Einasleigh River 2006-2014

ABGC1 Headscarp retreat rate and sediment yield	
Gully Area 2014	72110.05 m^2
Gully Area 2006	64686.91 m^2
Area Increase	7471.87 m^2 (11.6%)
Volume Estimate	6450.99 m^3
Sediment yield (BD 1.8)	224 t/ha/yr (head scarp only) (+/- 56)

6.3.2 Gully Erosion rate Analysis - 2006 – 2014 Gully complex 1 G9A GC2 –

6.3.2.1 Erosion volume estimate

A similar process to that described above for ABGC1 was also undertaken for G9AGC2 and the total sediment yield from this gully complex determined to be 1746 m^3 (+/- 436 m^3) or 137 t/ha/yr. As with the other site, this figure is from the headscarp retreat only, and as such the total sediment yield from the gully is likely to be 2 – 3 times higher than this.

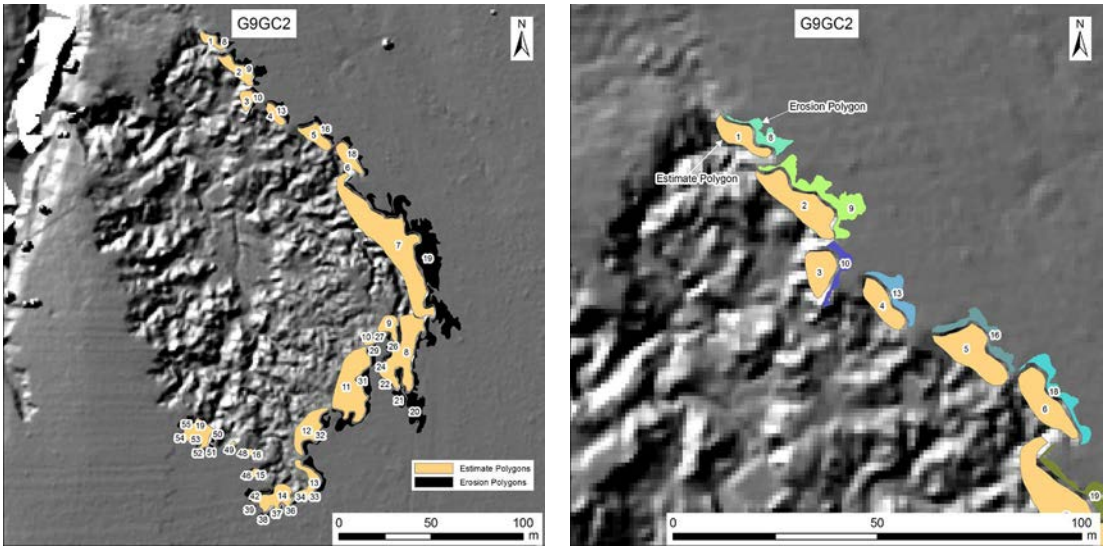


Figure 18 Change detection procedure based on 2008 LiDAR data from the G9A GC2 site near Greenhills

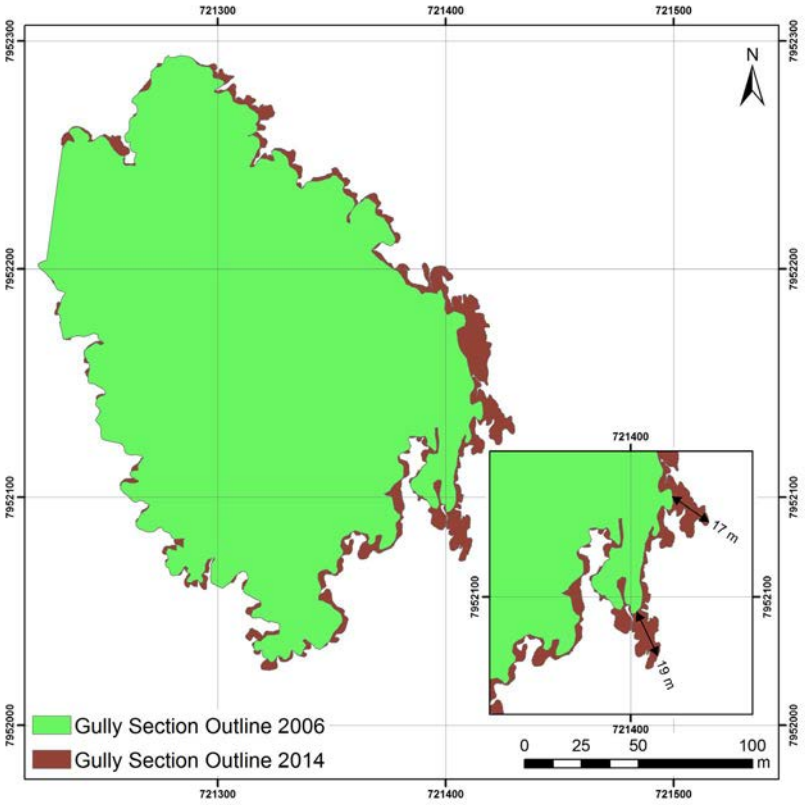


Figure 19 DGPS gully surveys 2006 & 2014 from site G9A on the upper Gilbert River (indicated in pink on Figure 15)

Table 8 Change in total area of the gully at site G9A 2006-2014

ABGC1 Headscarp retreat rate and sediment yield	
Gully Area 2014	72110.05 m^2
Gully Area 2006	64686.91 m^2
Area Increase	7471.87 m^2 (11.6%)
Volume Estimate	6450.99 m^3
Sediment yield (BD 1.8)	224 t/ha/yr (head scarp only) (+/- 56)

6.3.3 Terrestrial LiDAR scanning of gully systems

High resolution scans of alluvial gullies were undertaken at selected sites previously surveyed, in order to both quantify the extent of erosion, but also to better understand the relative contributions from different parts of the gully complex. The following example from the Greenhills area on the Gilbert River (see Figure 15) highlights the extent of sediment production from a large alluvial gully complex, and enables us to differentiate the relative contribution from the gully head and from within the gully complex. The average specific yield from this section of the much larger gully complex (Figure 20) is 2164 t/ha/yr, with 44.8% of the sediment yield from the past 8 years derived from head-scarp extension, and 55.2% derived from the internal portion of the pre-existing gully. The data indicates (Table 9) that in this highly active system the gully is expanding at a rate of around 5% per annum. While the sampled gully is only around 0.2ha in size, it is a part of a larger gully complex with a total area of around 15 ha. Hence, even accounting for the fact that the sampled section of this gully may be the most active part of the gully, and hence the overall average sediment yield might only be around 1000 t/ha (which is in line with similar gullies in the Mitchell catchment – see Shellberg *et al.*, 2013) it is likely that this gully complex is delivering, on average, more than 15,000 t/ year to the channel network.

Figure 20 Image of the surrounding broader alluvial gully complex at Greenhills showing the gully segment for which a high resolution 5cm DEM was derived from a Leica C10 terrestrial LiDAR. The yellow box highlights the scanned section of the gully complex

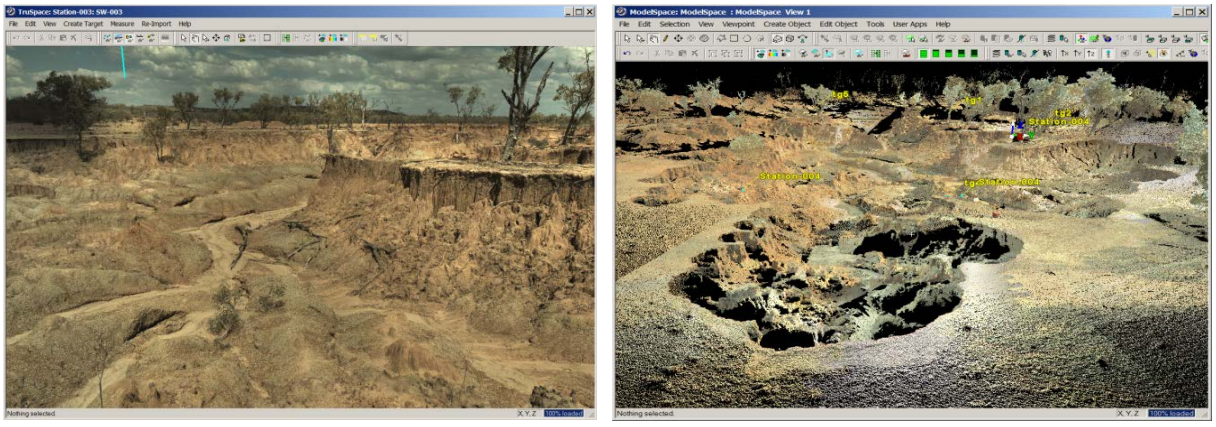


Figure 21 Gully G9BGC1 showing some of the scanned images derived from the scans of the area highlighted in Figure 20

Table 9 Summary statistics showing the volume of erosion

Gully Extension Area		
Volume Eroded	1027 m^3	(44.8%)
area	597 m^2	(28.2%)
Specific yield	***3,440 t/ha/yr (BD = 1.6)***	
Gully Internal Area		
Volume Eroded	1267 m^3 (55.2%)	(55.2%)
area	1523 m^2	(71.8%)
Specific yield	***1,664 t/ha/yr (BD = 1.6)***	
Total area of gully change (sum of two above)		
Volume Eroded	2294 m^3	(100%)
area	2120 m^2	(100%)
Specific yield	***2164 t/ha/yr (BD = 1.6)***	

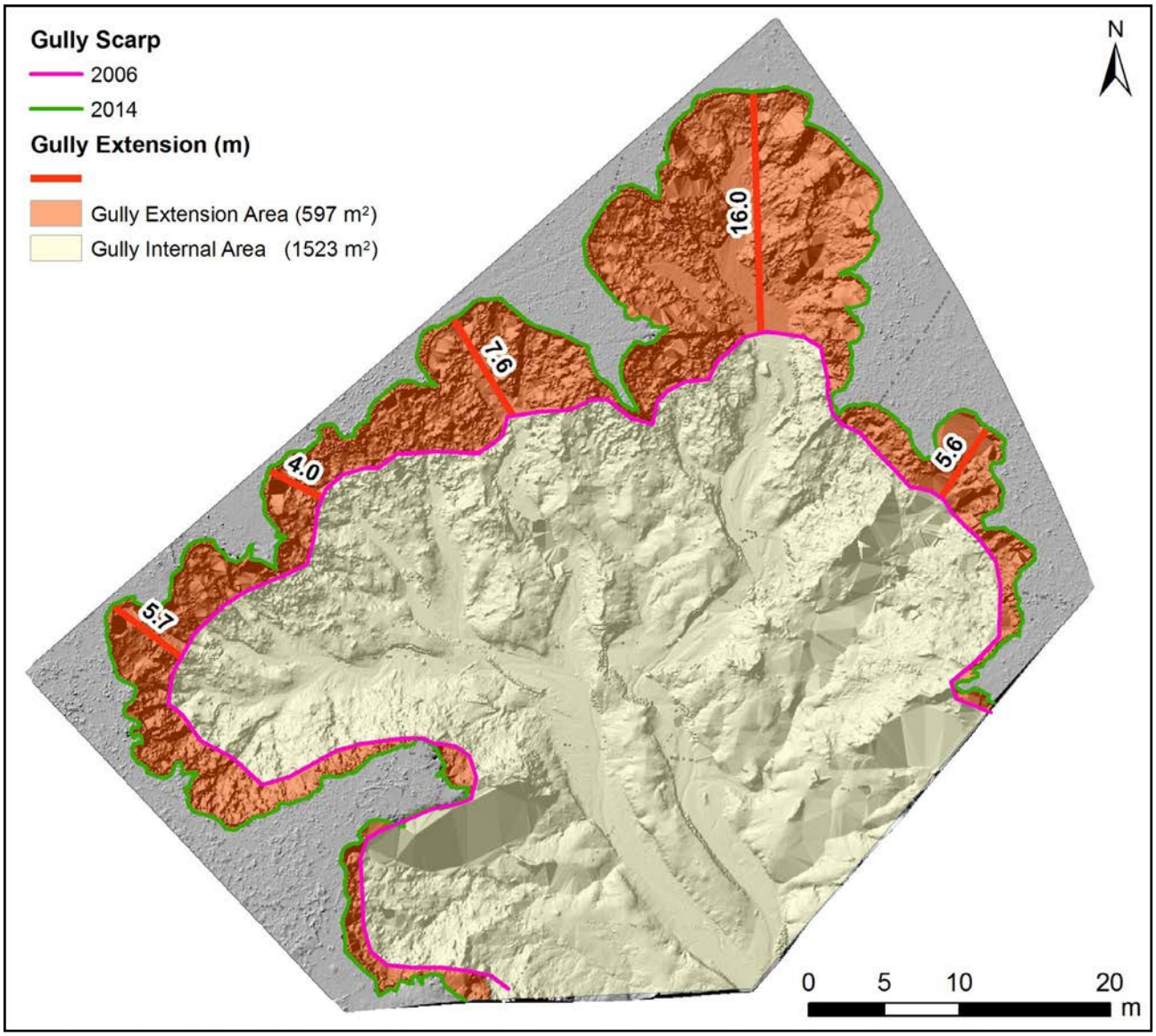


Figure 22 5cm pixel resolution DEM of the scanned gully at Greenhills showing the area of gully extension in the 8 year period from October 2006 to October 2014. Of the total sediment exported from this gully over this period, 44.8% was derived from headscarp extension and the remaining 55.2% from erosion of internal gully surfaces

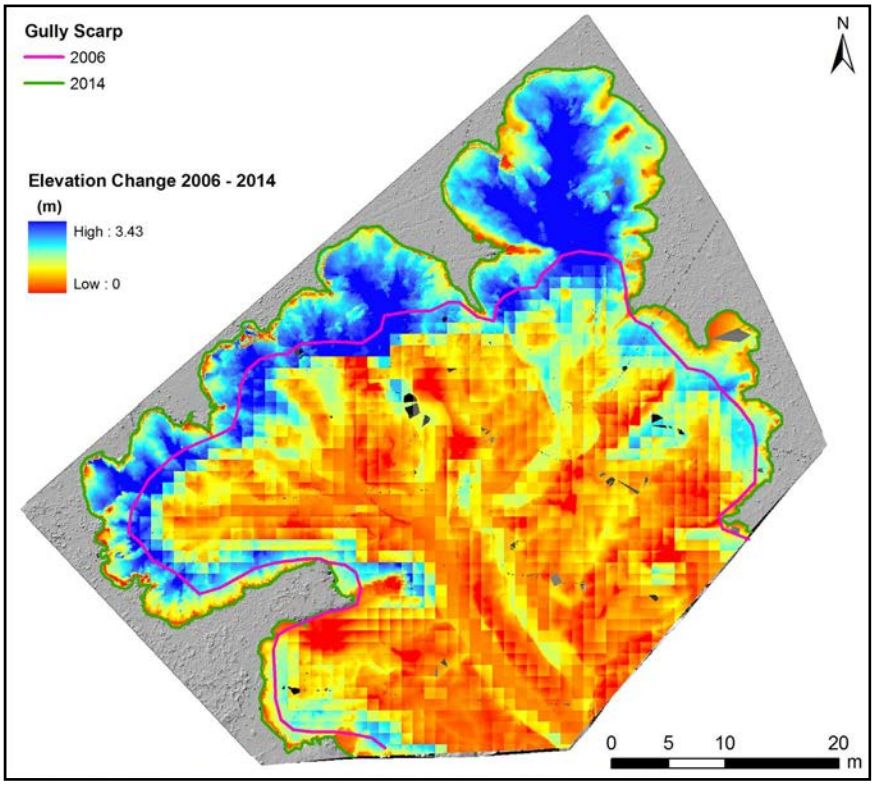


Figure 23 Elevation change image which shows the distribution of erosion from both gully headscarp retreat and erosion of internal gully slopes. Note that there is little net change from the gully floor during this period, which reflects the transport limited nature of alluvial gullies (sensu Rose et al., 2015).

6.3.4 Summary of rates data

From these data it is apparent that alluvial gully systems within the central Gilbert are consistently producing significant volumes of sediment. Minimum estimates of the sediment yield from these gully complexes puts the rates at between 130 and 225 t/ha/yr, largely based on estimates from the headscarp retreat alone. As demonstrated elsewhere (Shellberg et al, 2013) the total yield from a large alluvial gully complex such as this is likely to be as much as 2 – 3 times higher than that from headscarp retreat alone, so if we take the lower estimate to account for the fact that some of the internal erosion has already been accounted for, the typical rates should fall somewhere between 260 - 450 t/ha/yr of sediment to the stream network (from the active gully area). Rates at the upper end of the range, as demonstrated by the data from G9GC1 at Greenhills, are producing specific yields of 2160 t/ha/yr. As yet it is unclear how representative these rates are of the broader region, but as indicated in Figure 20, there are much greater areas in this general area of which these rates would appear to be typical.

Based on the gully mapping and these updated erosion rate data, it is possible to estimate the total sediment yield from gullies in the mid Gilbert region. From the 2006 gully mapping (Brooks., *et al.*, 2006) a total of 9980 ha of gullies were mapped from the areas covered by the ASTER imagery – an area extending from the Gilbert fan apex to around Forsyth in the upper catchment. If we assume that the mapping on average may be over estimating the total area of active gullies by a factor of two (i.e. where the over-estimation (4 fold) in some areas with many gullies is offset by under-estimation in others (10 fold)), giving a conservative estimate of around 5000 ha of active gully area within the catchment. Based on these figures, mean annual sediment contribution from gullies would fall within the range 1.3 – 2.3 Mt/year, most of which can be regarded as land-use accelerated erosion. If the observed specific yields in the order of 2000 t/ha/yr are representative of a significant proportion of the mapped gullies, the mean annual sediment yields from gullies could be several times more than this conservative range.

6.4 Soil suitability and the CSIRO FGARA Report

The major series of studies and associated reports completed by CSIRO (Petheram *et al.*, 2013) into the agricultural potential of the Flinders and Gilbert River systems (The Flinders and Gilbert Agricultural Resource Assessment - or FGARA) was tasked with assessing the capacity of this landscape to support economically and environmentally sustainable intensive agricultural development. The assessment focused primarily on the four key attributes of the region and the potential constraints on, or issues around, irrigated agriculture:

- The suitability of soils to support a range of intensive agricultural activities
- The availability and reliability of water resources to support the development, and the potential viability of various irrigation development schemes
- The economic viability of any development given the constraints on market access and associated constraints
- Potential negative impacts on the environment and on existing industry (e.g. the commercial fisheries in the Gulf of Carpentaria).

Given that this report is focused on avoiding potential risks associated with development on unsuitable soils, for the purposes of this report we will focus on summarising just those aspects of the FGARA study that dealt with soils in the Gilbert catchment. This will form a useful background for further analysis of the suitability of soils in the proposed IFED area. The reader is referred to the FGARA reports for further information on the other three aspects of agricultural development in the region. The key focus in this review will centre on the area outlined for prospective development under the IFED scheme in the area bounded by the Einasleigh, Etheridge and Gilbert Rivers.

6.4.1 Soil suitability assessment

Given the vast area of the Gilbert catchment and the limited time available for undertaking the soils suitability analysis within the FGARA, the analysis by necessity was required to adopt what is referred to as a digital soil mapping approach (Petheram, 2013). This approach uses a spatial statistical modelling approach and relies heavily on remotely sensed data, particularly aerial radiometric survey (Figure 24), coupled with the 1 arcsec Dem (~30m) and limited field survey (Figure 25). Within the context of a simplified regional geology (Figure 26, Figure 27), a picture of the region's soils and their appropriateness or otherwise for various cropping scenarios is derived using a spatial geo-statistical modelling approach. The final product comes in the form of a 90m resolution raster map which assesses the suitability of a vast array of potential crops under different irrigation scenarios (e.g. furrow, trickle, spray) (Figure 28). The derived maps are classified into 5 suitability classes, as outlined in Table 10.

The suitability framework makes the following assumptions for irrigated crops: (i) unlimited irrigation water is available to the cropping location; (ii) spray irrigation systems can deliver irrigation rates of up to 16-17 mm/day during periods of peak demand; (iii) spray irrigation systems can deliver irrigation rates of 24-25 mm/day for sugarcane crops during periods of peak demand; (iv) the applied irrigation water infiltrates sufficiently well to maintain soil water in the rooting profile sufficient for crop growth (crops not stressed); (v) spray irrigation scheduling allows sufficient time for regular maintenance; (vi) the amount of water applied does not drain below the rooting depth (CSIRO, 2012).

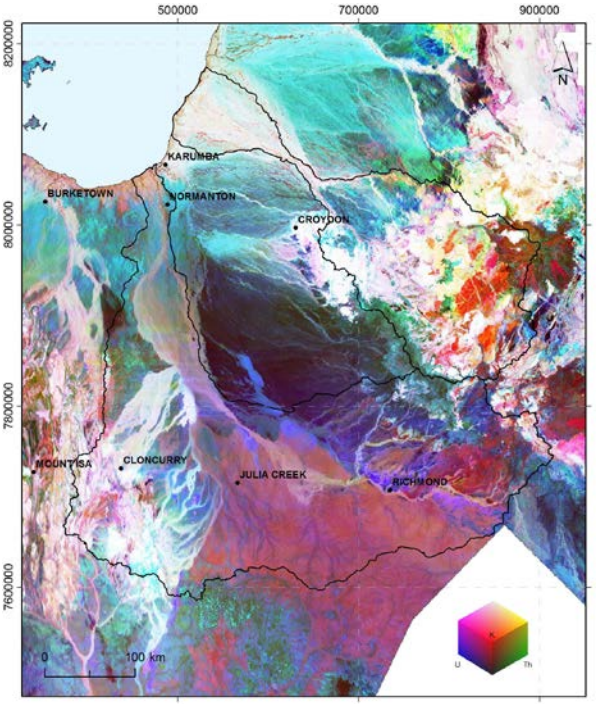


Figure 24 Ternary image of merged regional radiometrics datasets for the Flinders and Gilbert catchments (outlined as black polygons) and their surroundings. The merged radiometric datasets are presented as a ternary (red, green, blue) image, with potassium specified in the red channel, thorium in the green channel and uranium in the blue channel. This image indicates significant variability in the alluvial cover across the two catchments, reflecting a varied source for the materials present (source CSIRO 2012 fig 3.4).

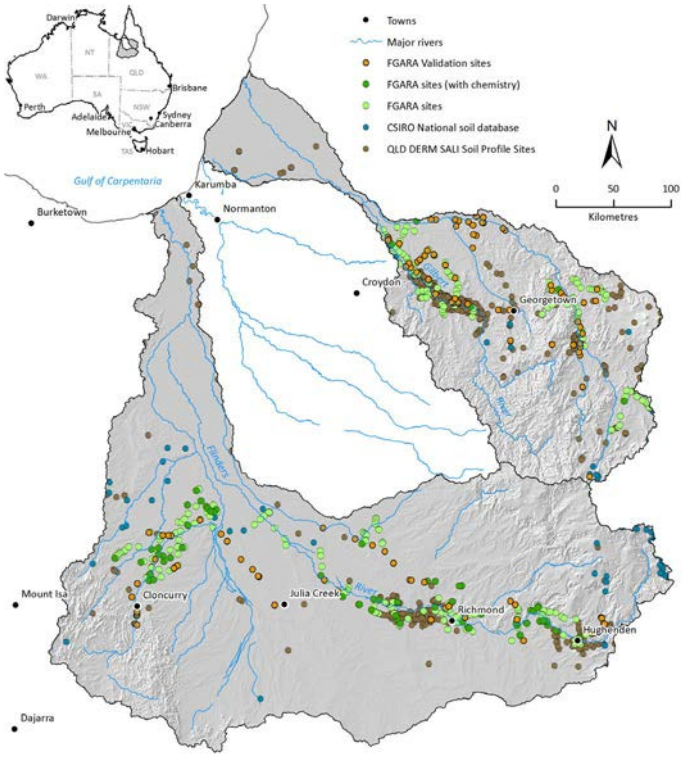


Figure 25 Map showing the distribution of field soil samples used in the digital soils mapping exercise for the FGARA digital soils mapping exercise

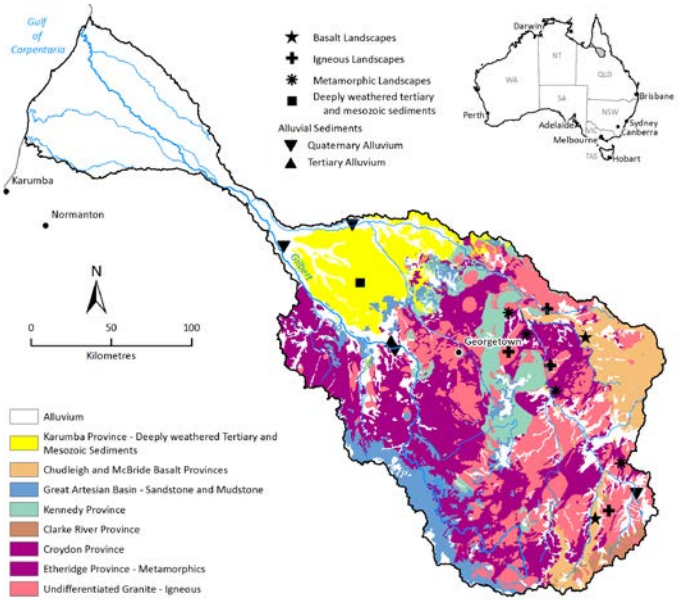


Figure 26 Broad geological units described in the CSIRO FGARA reporting. Note the Karumba formation depicted in yellow, which coincides with the Holroyd Plain unit mapped in the original Qld Govt geological mapping of the region (Grimes and Douch, 1978) , which is the original depositional surface of the palaeo Gilbert magefan

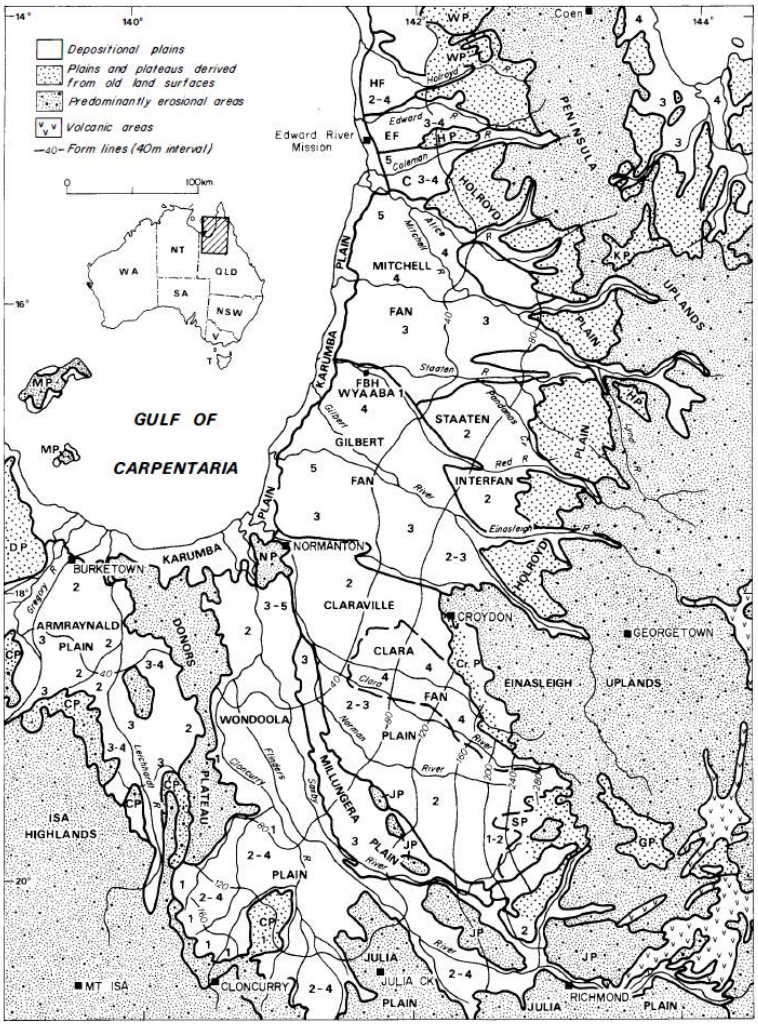


Figure 27 Physiographic map of the Gulf plains from Grimes and Doutch (1978) showing the location of the Holroyd Plain which is the unit that is synonymous with the Karumba Formation as represented by the CSIRO mapping (Figure 26)

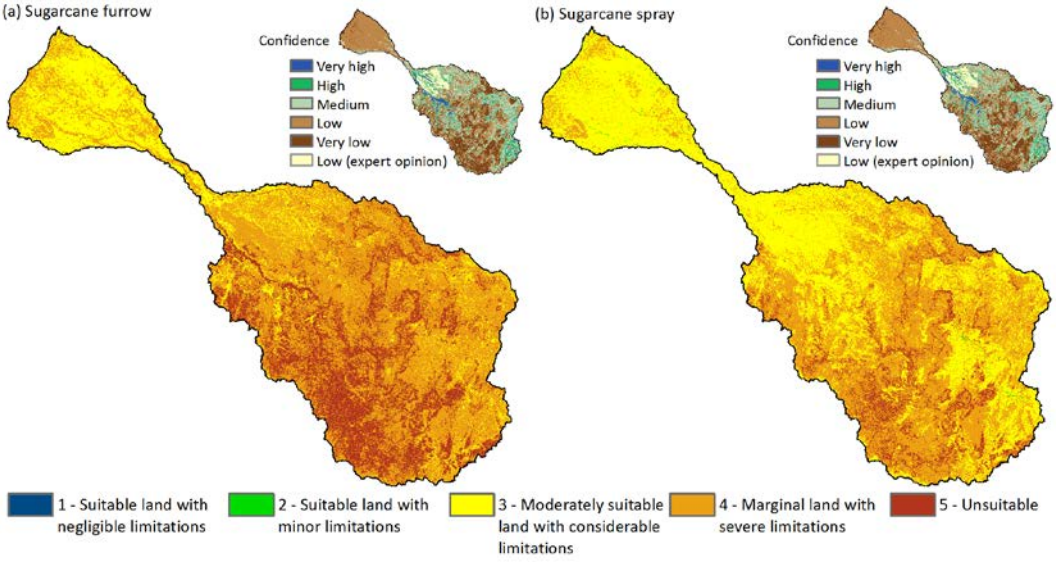


Figure 28 Example of the digital soils suitability mapping produced for the FGARA

Table 10 Suitability classification applied in the FGARA

Class	Description
Class 1	**(Highly) Suitable land with negligible limitations.** This is highly productive land requiring only simple management practices to maintain economic production.
Class 2	**Suitable land with minor limitations** which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.
Class 3	**Moderately suitable land with considerable limitations** which either further lower production or require more than those management practices of class 2 land to maintain economic production.
Class 4	**Marginal land which is presently considered unsuitable due to severe limitations.** The long term significance of these limitations on the proposed land use is unknown. The use of this land is dependent upon undertaking additional studies to determine whether the effects of the limitation(s) can be reduced to achieve sustained economic production.
Class 5	**Unsuitable land with extreme limitations that preclude its use.** Class 5 is considered unsuitable having limitations that in aggregate are so severe that the benefits would not justify the inputs required to initiate and maintain production in the long term. It would require a major change in economics, technology or management expertise before the land could be considered suitable for that land use. Some class 5 lands however, such as escarpments, will always remain unsuitable for agriculture.

6.4.1.1 Soil Suitability Analysis - Overview

A broad range of parameters were considered in the soil suitability analysis, including:

- furrow irrigation efficiency (which is a proxy for soil infiltration characteristics),
- microrelief, which is primarily intended to represent the presence of gilgai which can lead to ponding and poor paddock drainage, as well as being an indicator for the potential presence of sodic soils. A threshold of 30cm of micro-relief was adopted as a threshold for consideration, although it is not clear how this was observed from the 1 sec DEM, given that this is well below the resolution of topographic variability that can be detected from such data. There would appear to be a contradiction between being able to detect the presence of gilgai but not to be able to measure landscape complexity (below).
- Nutrient balance - pH
- Rockiness (e.g. the presence of gravels, stones and boulders)
- Soil depth
- Soil physical condition
- Soil moisture availability
- Surface soil erodibility (as represented by the USLE K factor; Wischmeir and Smith, 1975; Rosewell and Loch, 2002) (Table 11)
- Wind erosion.

Factors **not assessed** include, flooding, salinity, secondary salinization and landscape complexity.

Table 11 The four soil stability categories based on K-factor used in this study (Rosewell and Loch, 2002)

K-FACTOR	SOIL ERODIBILITY CLASS
<0.02	Very low (very stable soils
0.02-0.04	Low to moderate (stable soils)
0.04-0.06	High (unstable soils)
>0.06	Very high (very unstable soils)

Most of these soil characteristics upon which the analysis is based can only be reliably determined from field survey, and hence the region-wide extrapolation of these parameters is highly dependent on the statistical representation between the soil survey data and the remote sensing data. Hence, even with a perfect relationship between the site data and the remotely sensed data at a site (which is extremely unlikely), any misrepresentation or inaccuracies in the way that the remotely sensed data represents the ground conditions will lead to compounding errors in the final representation of the soil suitability predictions.

Within the IFED focal area it would appear that there is potential for significant misrepresentation of the soil suitability classification due to some of the inherent characteristics of this part of the landscape, in large part due to the geological province upon which the site is located. As shown in Figure 29 and Figure 30 it is apparent that due to the presence of fericrete and other laterites within these Plio-Miocene age (2.58 – 23.03 Ma) fan depositional units (variously described as the Karumba Province, the Holroyd Plain or the Wyaaba Beds), that the radiometric data and hence the soil suitability mapping, are likely to give spurious results in this area. Hence, without considerable investment in extensive field mapping of the soils within the Karumba province (i.e. outside of the areas that have had detailed field sampling - Figure 26), considerable caution should be taken in assuming that the digital soils mapping predictions provide a useful guide for planning irrigated agricultural development. Even within these constraints (which have a tendency to paint this particular area in the most positive light possible), it is apparent (e.g. Figure 28) that for traditional furrow irrigation of crops like sugar cane, there are virtually no soils which fall into suitability classes 1 – 3.

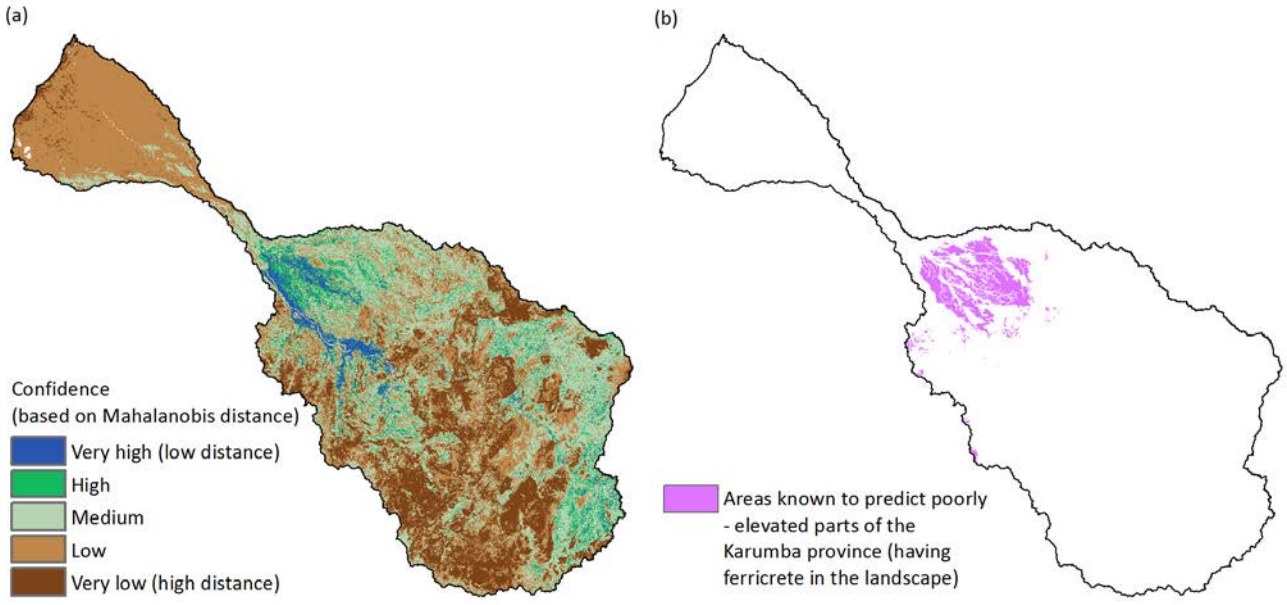


Figure 29 Maps from the FGARA digital soils mapping which provide estimates of the confidence in the mapping outputs. Note the apparent contradiction between the two maps, where map (a) indicates high to very high confidence in the map predictions in the area immediately above the fan apex, whereas map (b) indicates that because of the nature of the geological province (Karumba province or Holroyd Plain – depending on which geologic map you use) that it is likely that the radiometric data will give spurious results in this area hence leading to inaccurate soil suitability predictions

It is also worth pointing out that the way in which soil erodibility is assessed within the soil suitability assessment only considers the role of surface erosion, as a function of the USLE K factor and the land slope. The K factors assessed only represents the erodibility of the surface soils, not the sub-surface soils, which are the primary determinant of whether the landscape is susceptible to gully erosion. As highlighted above, and explored further below, gully erosion is the dominant erosion process in this landscape, particularly erosion into alluvial surfaces deposited within Quaternary age floodplains, or into the old fan unit depositional surfaces. Sediment tracing within the adjacent Mitchell and Flinders catchments (Caitcheon *et al.*, 2012) demonstrated that sub-surface sediment sources (gully and stream bank erosion) represented 97% and 100% respectively of the sediment load entrained within the main channels of these two catchments. While the equivalent tracing study has not been undertaken in the Gilbert, there are many similarities between the Gilbert megafan and the Mitchell megafan (see Brooks *et al.*, 2009), and hence it is highly likely that a similar ratio of surface/sub-surface erosion as observed in the Mitchell occurs in the Gilbert. Hence, to understand the susceptibility of this landscape to erosion, one has to understand the primary drivers of gully and channel erosion, which can only be done by placing the contemporary landscape within the context of the long term evolution of the entire alluvial megafan, as further detailed in Section 7.1.2.

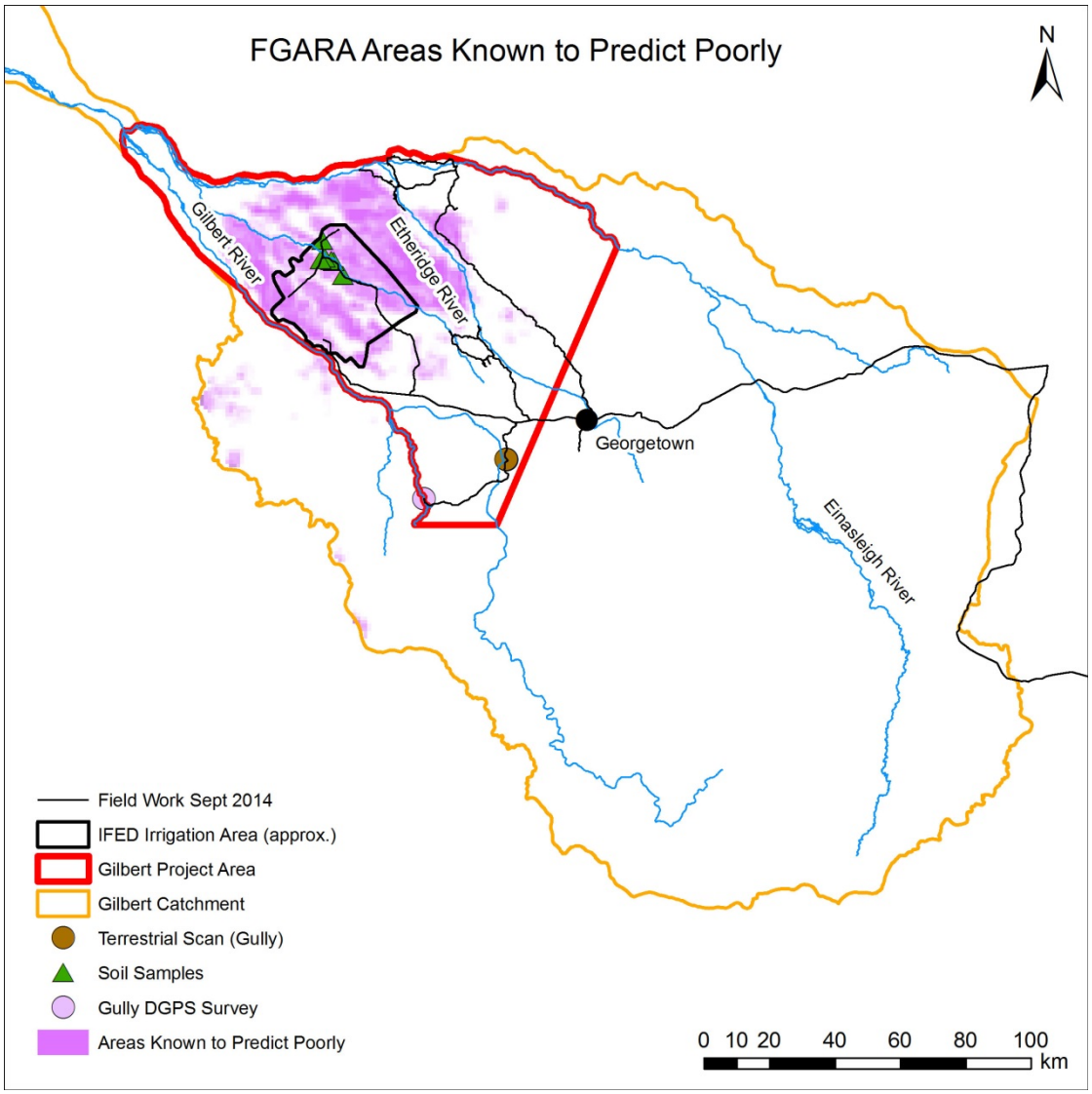


Figure 30 Blow up of the Gilbert Fan area depicted in Figure 29 which shows that the IFED agricultural precinct is located within the area that is depicted as having low predictive power using the digital soils mapping approach.

7 The IFED proposal

7.1 Overview of proposal

The IFED proposal is an integrated food and energy production development which has as its centre a major water resource infrastructure development coupled to a proposed 65,000 ha irrigated agricultural precinct. The irrigation area is proposed to supported extensive areas of sugar and guar beans (for guar gum). The precinct will include a sugar mill and an electricity co-generation plant which will be fuelled with the waste products from the sugar mill. The proposal is a fairly radical departure from usual practice in major irrigated agriculture developments, which normally identify areas of highly suitable soils and design the infrastructure around the supply of water to these areas of productive soils. In this case the primary focus was on the design of the water harvesting and storage infrastructure such that it would be able to gravity feed the water to the agricultural precinct. The proposal incorporates a practice called fertigation, a process where all plant nutrients will be delivered to the crops within the water supply, delivered to the crops via sub-surface trickle irrigation. The location of the agricultural area was thus dictated by the location of the water infrastructure, with soil fertility and productivity a low order consideration. In essence this is a process similar to large scale hydroponics, where it is assumed that the only purpose of the soil is to provide the physical substrate to support the plants. Such an approach, however, requires soils that have uniform slopes (i.e. requiring laser levelling) and that will not wash away under intense monsoonal rains. In the following section we will assess whether a sufficient extent of such soils exist within this area, and what some of the management concerns may be within this area.

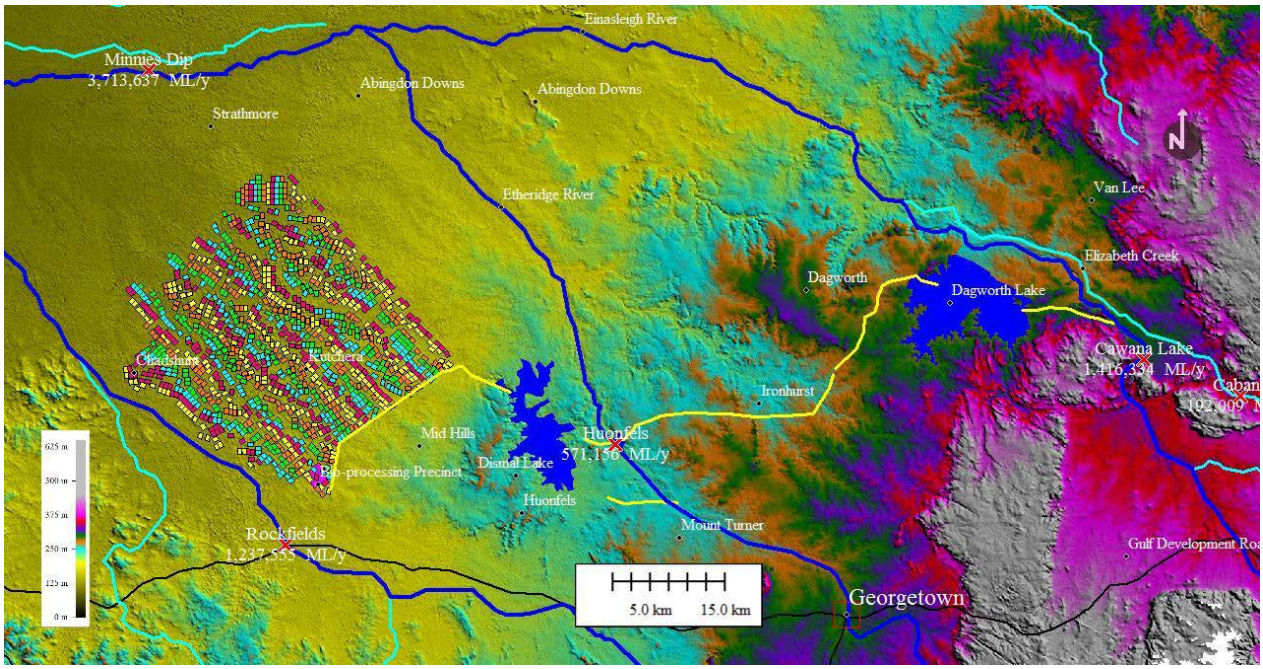


Figure 31 Map of the proposed IFED development showing the water infrastructure and the location of the agricultural precinct. Shown here are the proposed off-stream dams which will extract around 40% of the mean annual high flows from the Einasleigh River at Dagworth (550,000 Ml per annum), where it will be stored in Dagworth dam and transferred to Dismal lake on Huonfles Station via an open channel. The Dismal lake storage is also fed by the local Dismal Creek catchment, which is a significant catchment in its own right. Also shown are the ~1600 x 40 ha plots that will be the focus for the agricultural precinct on Kutchera & Chadshunt Stations. Source http://www.agriculture.gov.au/abares/outlook-2014/Documents/presentation-slides/keith-deLacy-presentation.pdf

7.2 Geological and topographic context for the IFED site

In order to assess the suitability of the soils within the IFED area, we firstly need to understand the landscape evolutionary history of the site. Placing the site within its landscape evolutionary context can provide understanding of whether the site is comprised of recently deposited alluvium (the typical location of irrigated agriculture, other than volcanic soils), and if not what the dominant geology is and what it's weathering and erosional history has been.

Perhaps the defining characteristic of the Gulf Rivers between the Holroyd and the Norman Rivers is that this entire landscape consists of a sequence of merged alluvial megafans (***sensu*** Leier *et al.*, 2005), dominated by the Mitchell and the Gilbert megafans. As can be seen in Figure 32 the IFED agricultural precinct is located on the upper (and oldest) depositional units of the Gilbert megafan.

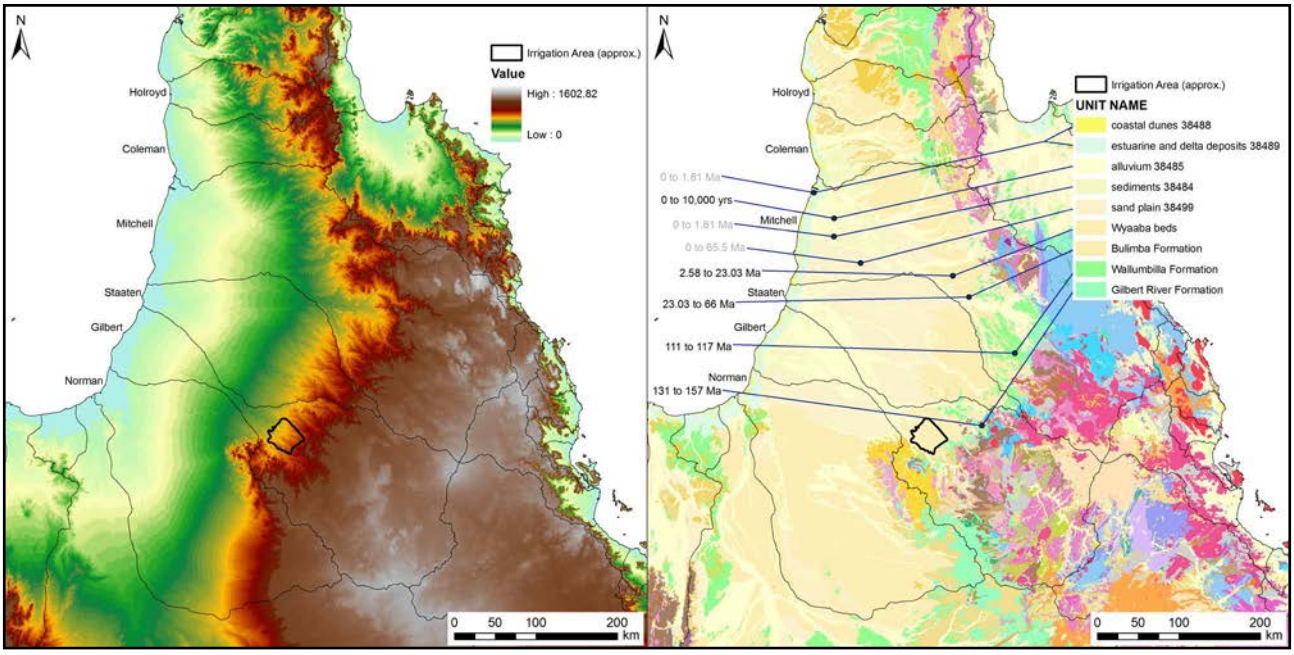


Figure 32 Digital elevation model (DEM) of Cape York and the Southern Gulf (LHS) showing the IFED irrigation area (black rectangle) within the upper reaches of the Gilbert megafan, and within the Plio/Miocene age Wyaaba beds (RHS) - which are some of the oldest alluvial sedimentary deposits within the Gilbert megafan. These units are actively incising and have been weathered in-situ for more than 2.6 million years

Looking more closely at this region of the Gilbert megafan (Figure 33) it is evident that the three major river systems in the Gilbert megafan (the Gilbert, Etheridge and Einasleigh Rivers) have incised into this upper portion of the megafan since it was deposited in the Miocene, isolating the Dismal Creek catchment into what is now a completely separate sub-catchment within the broader megafan. This has had the effect of separating this area from the upper source areas of the broader Gilbert megafan catchment starving it of "fresh" alluvium from the major volcanic and igneous source zones of the upper catchment. Hence, the Dismal Creek catchment has largely been eroding, weathering, and redistributing the old alluvial fan sediments that were deposited several millions of years ago. It is for this reason that this landscape unit is characterised by extremely weathered lateritic soils which have been leached and weathered in the monsoonal savannah environment for millions of years, leaving extremely low nutrient, and potentially unstable sodic soils (discussed further below).

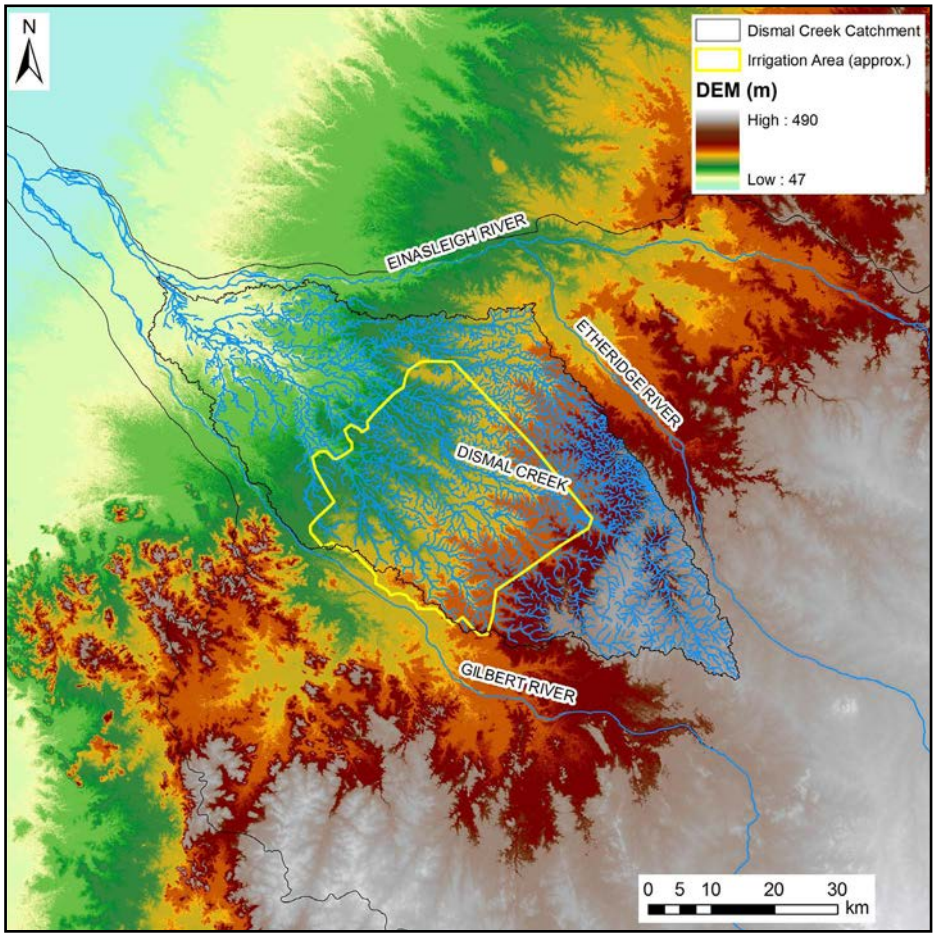


Figure 33 A DEM of a section of the upper Gilbert Fan showing the highly dissected topography encompassed within the IFED irrigation area. Also shown is the highly dissected nature of the drainage network with the irrigation area. The Irrigation area falls within the Dismal Creek catchments, which is a relatively steep, well developed catchment in its own right, set within the broader context of the Gilbert Fan. As can be ascertained from this image, this area is not a flat alluvial plain that one might expect in the typical irrigation areas found on the lower Burdekin or the Murray Darling.

Also evident from this blow up image of the megafan topography, is that far from being a relatively flat floodplain system, as most irrigated agricultural areas tend to be whether they are in the tropics (eg. the Burdekin) or the temperate zone (Murray-Darling), this area is highly dissected, forming a complex dendritic stream network in its own right. As can be seen from Figure 34, which shows a series of topographic cross sections through the proposed IFED agricultural precinct with the Dismal Creek catchment, there is considerable relief, both across the fan (dissecting the channels) and longitudinally down the major tributary systems within the zone (Figure 35). Cross valley slopes (i.e. between the interfluves of the adjacent creeks and the creek line) are typically in the order of 0.3 - 0.6%, while longitudinal (down valley) slopes are in the order of 0.14-0.18 %. This is around three times the down-valley slope on the Burdekin irrigation area and around 10 times the typical cross floodplain slopes in the Burdekin.

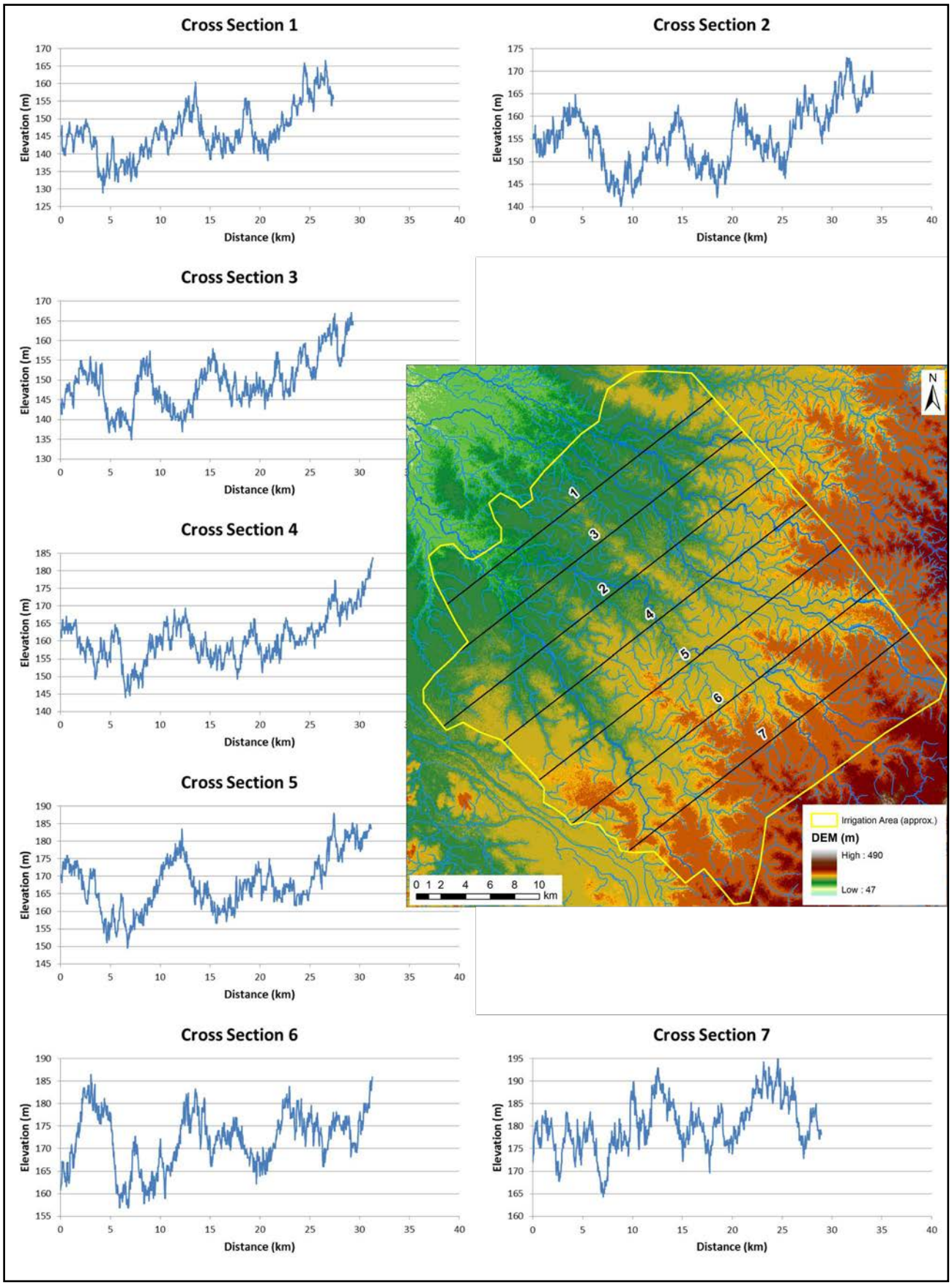
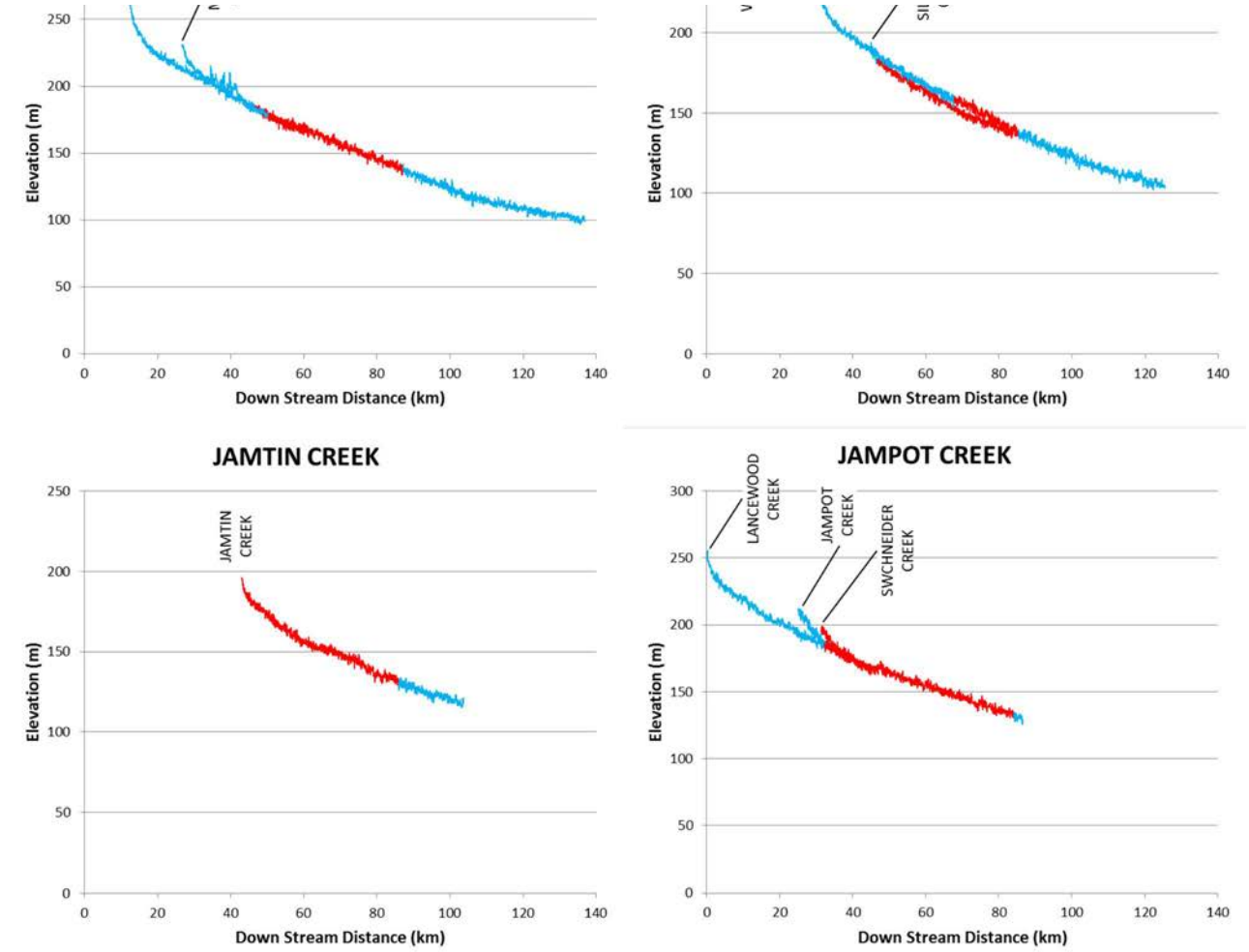


Figure 34 Cross sections of the Dismal Ck catchment showing the considerable relief (> 20m) between the ridges separating consecutive creek lines. Cross section locations are shown on the 30m DEM



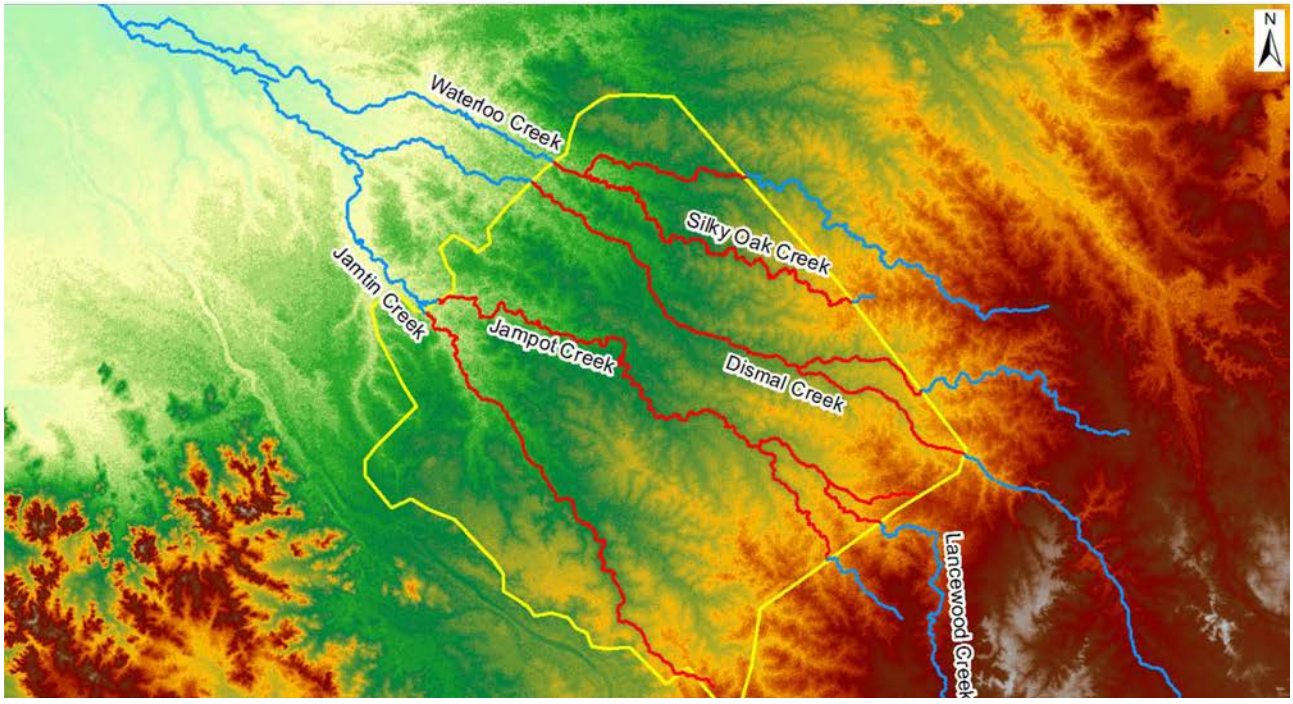


Figure 35 Longitudinal profiles of the major creek lines running through the Dismal Ck catchment showing the relief encompassed within the irrigation area (indicated in red), and the relatively steep gradient of the streams within the irrigation area (~ 0.14 – 0.18%)

8 Field reconnaissance of the IFED agricultural precinct

While it was not within the scope of this project to undertake detailed soils mapping within the agricultural precinct, and hence to comprehensively assess the suitability of the landscape for irrigated agriculture, we have been able to undertake a preliminary field reconnaissance which enables us to highlight some of the inherent land degradation risks associated with the intensive development in this area. As part of this analysis we undertook some initial soil chemistry analyses in areas of know erosion hazard (i.e. existing gully erosion sites) (Figure 36). While it is acknowledged that a much more comprehensive analysis of soil chemistry would be required to fully assess the erosion risks of this landscape, even this preliminary data enables us to highlight some of the inherent risks, particularly when we place this in the context of the regional landscape evolutionary history, the topographic constraints, and the distribution of existing gully erosion. It should be stressed that the current landuse is relatively low intensity grazing, and so the extant gullies would represent the starting point from which we could expect considerable expansion under a land-use intensification scenario, unless careful measures are put in place to minimise the threat.

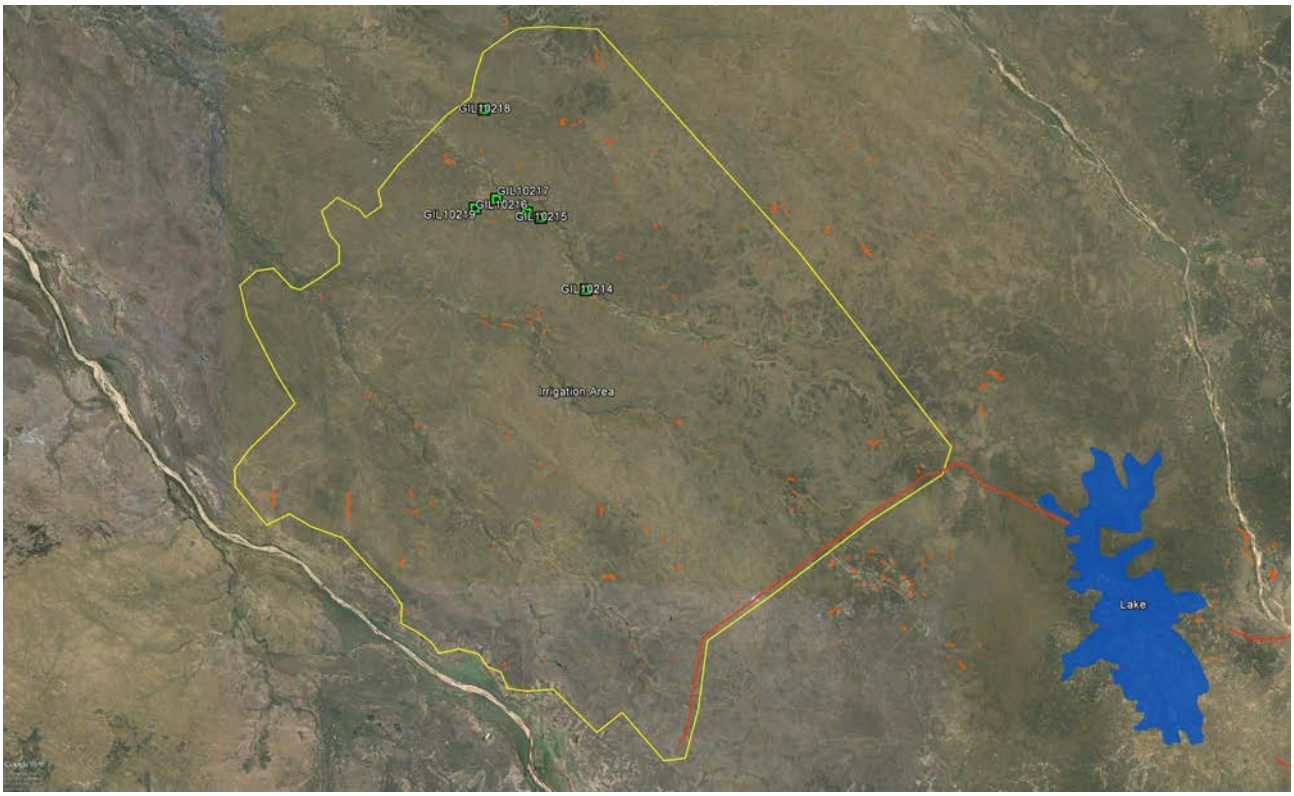


Figure 36 Map showing the distribution of existing gullies (red polygons) within the Dismal Creek catchment. Most of these existing gullies are alluvial gullies that are located within or near to drainage lines in the area

8.1 Current gully extent

A total of 106 ha of gullies were mapped within IFED agricultural precinct, which represents around 0.16% of the total land area. Whilst this is below the average for the broader Gilbert study area, as can be seen in Figure 36, the gullies are distributed throughout the site, and are prevalent in areas in and around drainage lines and water courses. There are also many examples of gullies initiated by road drains, which is one of the common initiation mechanisms for gullies in this landscape, along with cattle pads through riparian areas (see Shellberg & Brooks., 2012, 2013). While the extent of gullies in this area is currently at moderate levels, the fact that they are distributed fairly evenly across this landscape, highlights the fact that there are plenty of susceptible soils in the area. Hence there is substantial risk of the extent and severity of gullies increasing if the proposed scale of intensive development proceeds. In particular, this development is based on the intensive cultivation of around 1600 small plots and therefore necessitates a very extensive network of roads and tracks through this landscape. Such a high density network of roads and tracks represents a significant threat to the initiation of gully erosion, given that it would be impossible to design a road network in addition to that 65,000 ha of irrigation, that doesn't intersect numerous times with the relatively dense stream network in this area.

8.2 Soil chemistry and gully hazard

Soil chemistry data was collected in a pilot study focusing on gully erosion sites within the IFED Irrigation area. Initial soil chemistry analysis was undertaken at nine sites, with the results indicating considerable complexity in the soil chemistry. These preliminary results indicate that a much greater sampling density is required to understand the suitability of the soils within the area for agriculture, and their relative susceptibility to erosion. The variability of the soil chemistry between sites that are relatively close together, and all of which are eroding, indicates there is a complex interaction of factors driving the erodibility of these soils. The base saturation data associated with sub-surface soils at each of the sampled gully sites, shown in Figure 39 and Figure 40, indicate that no one soil chemistry indicator can be used as a predictor of soil erodibility. High exchangeable sodium percentage (ESP) is generally thought to represent erodible soils, whereas a high Ca/Mg ratio is thought to indicate a low susceptibility to erosion. These results raise questions about the validity of these assumptions in this landscape given that all of these samples come from sites that are experiencing active gully erosion. This is further demonstrated in the dispersion data also presented below (Figure 41) which indicates that dispersibility alone is not the sole arbiter of whether the soil is susceptible to gully erosion, and that there is not always a clear relationship between high ESP and erodibility. Less dispersive soils are also subject to gully erosion where there is sufficient flow concentration to drive gully incision and expansion. Some of these samples, however, are so dispersive that the Emmerson Aggregate Tests, which are usually run for 22 hours, were complete within 30 seconds. The most erodible samples (GIL10216) came from a gully that has no outlet connected to a stream network, and yet is evidently highly active, indicating that the material eroded within the gully is transported out of the gully in suspension via overland flow that passes through and over the gully. Such behaviour represents an extreme level of erosion hazard, which if more widespread would be a considerable cause for concern. Interestingly this sample had Ca/Mg ratio greater than 1.0 and a relatively low ESP, which ordinarily would place this soil in a fairly stable soil category. Hence, there is clearly much still to be learnt about the behaviour of soils in this landscape.

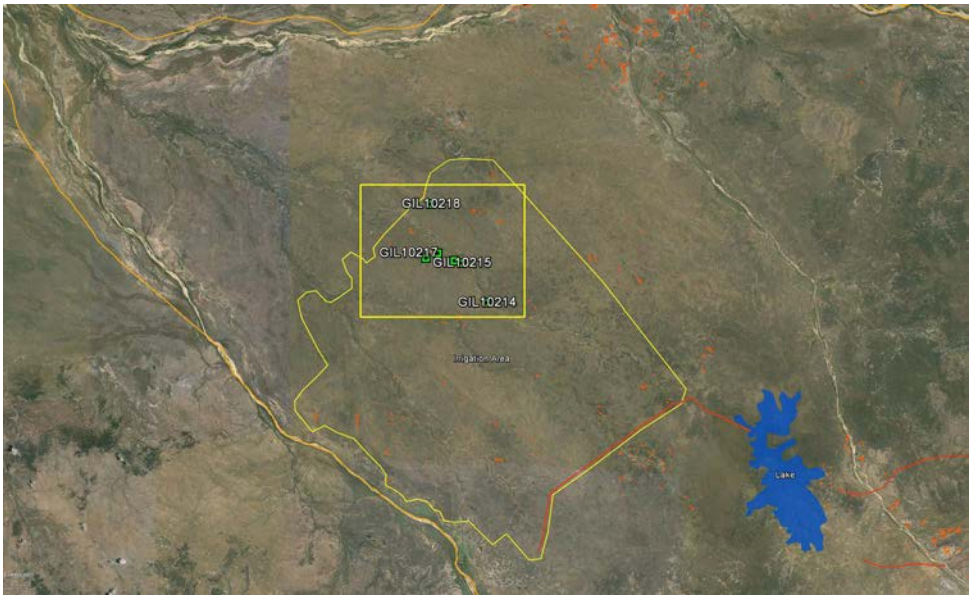


Figure 37 Location of the sampled gully sites within the study area

Figure 38 Gully soil sample sites within the IFED irrigation area

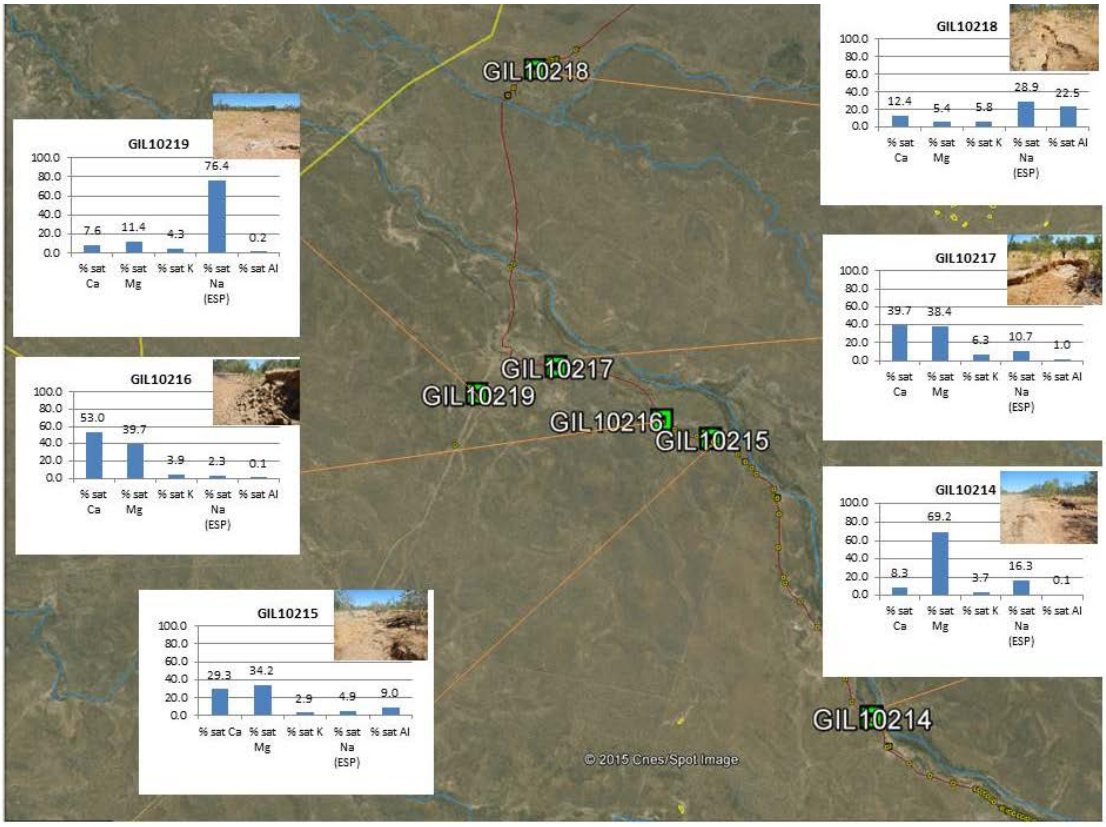


Figure 39 Base saturation associated with sub-surface soils at each of the sampled gully sites. These data indicate that no one soil chemistry indicator can be used as a predictor of soil erodibility. High ESP is generally thought to represent erodible soils, whereas a high Ca/Mg ratio is thought to indicate a low susceptibility to erosion. These results raise questions about the validity of these assumptions in this landscape

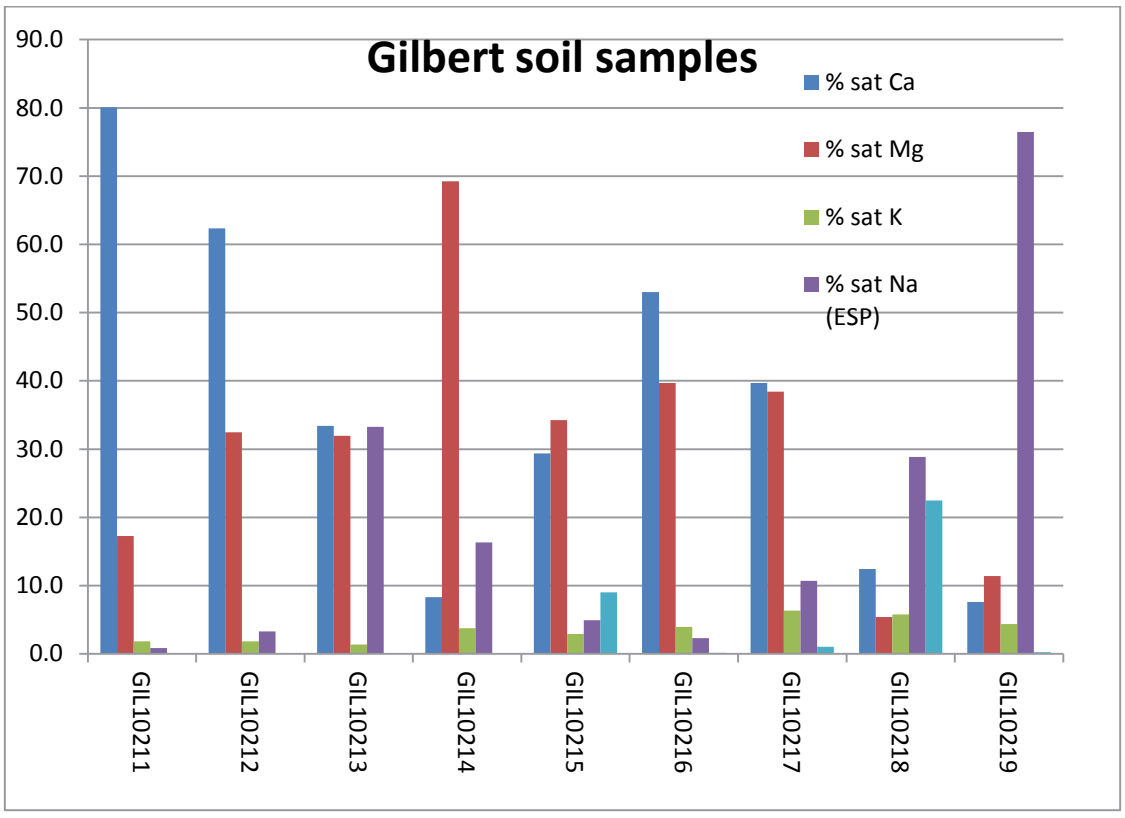
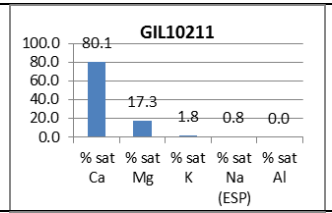
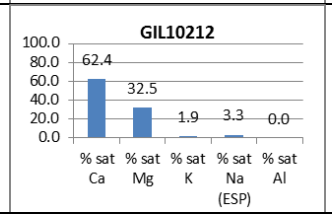
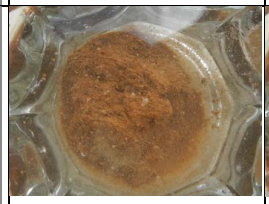
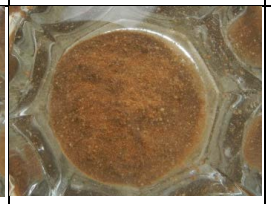
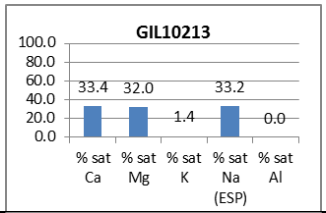
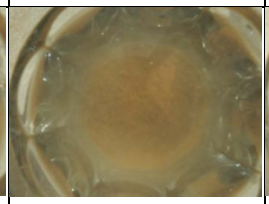
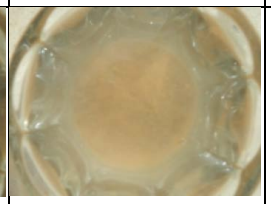
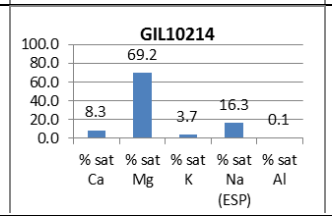
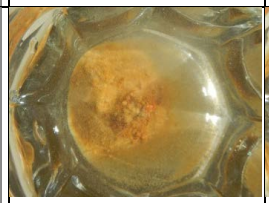
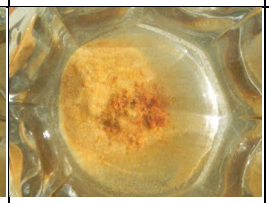
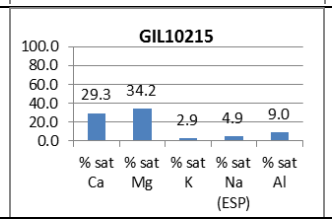
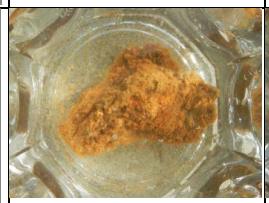
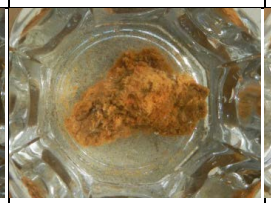


Figure 40 Base saturation % values for sample sites

Sample #		Dispersion @30 secs	Dispersion @ 60 secs	Dispersion @ 90 secs	Dispersion @ 120 secs	Comment
GIL10211 Abingdon Gully 'A' Horizon soil						Little evidence if slaking or dispersion after 2 mins
GIL10212 Abingdon Gully 'B' Horizon soil; ~0.5m below orig soil sfce						Fully slaked after 60 secs
GIL10213 Abingdon Gully 'C' Horizon soil; - Gully floor ~1m below orig soil sfce						Fully slaked and dispersed after 60 secs
GIL10214 Kutchera Rd Gully sub-sfce material						Fully slaked after 30 secs
GIL10215 Kutchera Rd Gully						Partially slaked after 2 mins

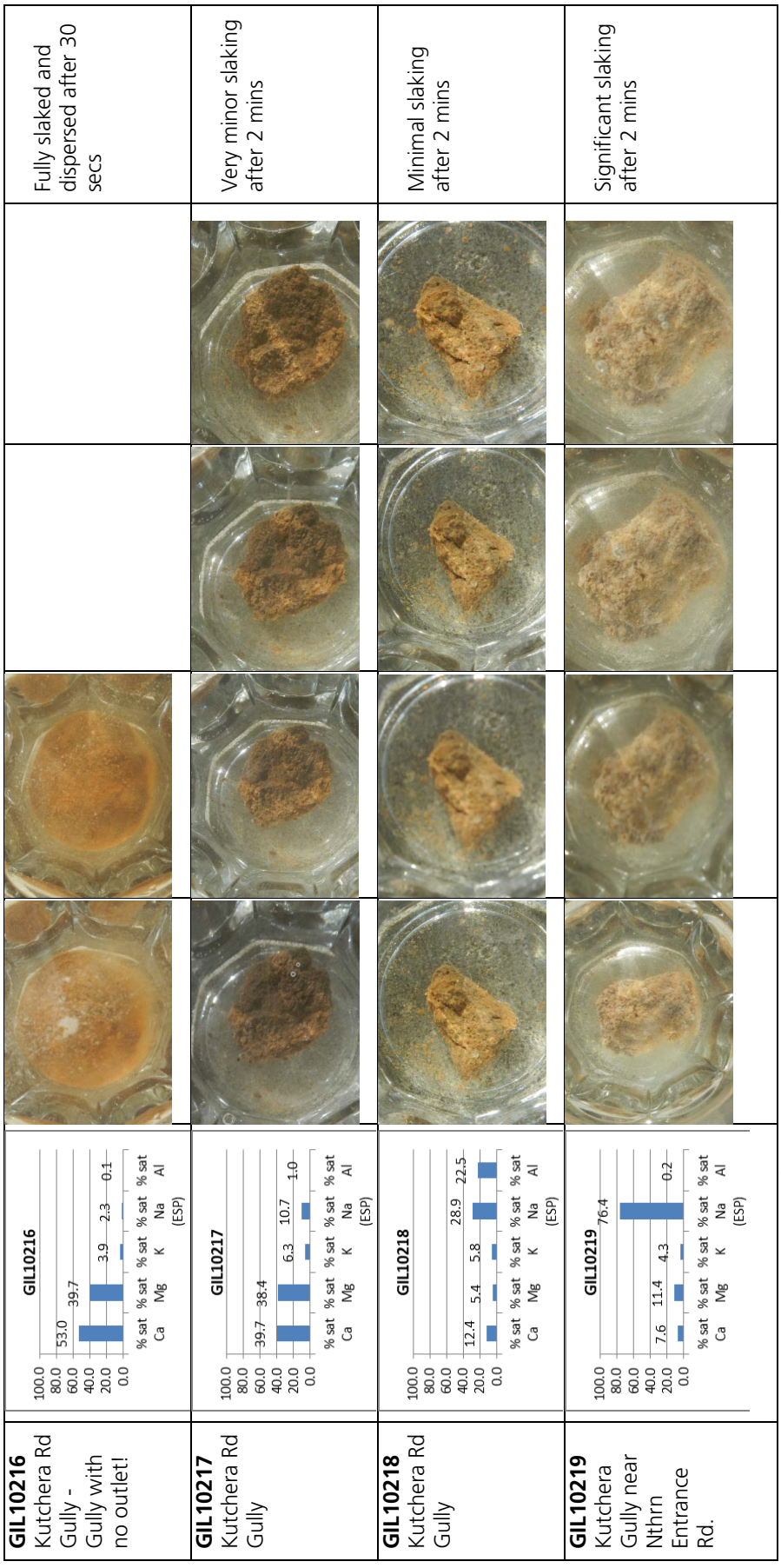


Figure 41 Pictorial representation of the soil dispersion tests carried out at selected sites within the IFED irrigation area. Some of these samples are so dispersive that the tests, which are usually run for 22 hours, were complete within 30 secs. The most erodible samples (GIL10216) come from a gully that has no outlet connected to a stream network, and yet is evidently highly active. Suspended sediment must be being removed via overland flow that passes through and over the gully.

8.3 Identify the alluvial stream and river channel network at highest available resolution and identifying appropriate buffers

Ephemeral stream channels like the one shown in Figure 42 are a common feature of the study area and collectively may well be a more dominant source of sediment to the channel network than gully erosion. Hence any development activity that might accelerate the erosion of channels like this needs to be carefully controlled. It is also clear that gully erosion is generally very closely linked to the stream network, with many gullies initiating from disturbances in the riparian areas adjacent to stream lines. To this end we have proposed a network of buffers be left retained under any development scenario which has the effect of minimising new disturbances anywhere close to drainage lines, and provides for maximum dissipation of energy for flows generated off cleared paddocks or the extensive road network that will be required in the proposed development.

Figure 42 Ephemeral stream channels like this one in the Gilbert catchment can contribute significant volumes of sediment to the channel network, and further disturbance to such channels from clearing, road crossings etc., could significantly increase this sediment input.

In order to minimise the risk of initiating sub-surface erosion around the stream network, buffers around all stream lines and existing gully areas need to be maximised. To test the viability of different buffers we modelled a range of buffer widths that are a function of stream order, according to the equation:

Where S0 > 1: Bw (m) = n x S0,

Where S0 = 1: Bw (m) = 2n x S0

Bw = buffer width (each side of stream), n = buffer multiplier (10 – 45m); and S0 = stream order (Strahler)

All mapped gullies also include a buffer of the same extent as the 1st and 2nd order streams.

We initially modelled the scenario where all stream orders where treated equally (i.e. no additional factor added to first order stream lines), and these results are presented as well (Table 12 and Figure 43), but given the large number of first order streams and the propensity for gullies to initiate in these first order stream we believe that the additional buffer around first order streams is necessary, and achievable. Examples of some of the buffer scenarios are shown in Figure 44 - Figure 46, which also provide an example of the 40 ha development plots for scale.

Based on the modelling, a buffer multiplier of 45m would appear to be achievable and would still leave around 75,000 ha of land that could potentially be developed, while minimising the threat of gully erosion initiation in and around the drainage network (Figure 47). Anything less than 30m is insufficient to provide an adequate buffer between the developed farm land and the associated infrastructure and the stream lines. Further work is required to refine the stream network given that this analysis was based on the available 1:100,000 scale stream network, and there are some drainage lines not captured in this analysis. However, the total area would not differ significantly from that represented here.

If it did transpire that there was a significant length of stream not represented in the 1:100K stream network it may be necessary to reduce the buffer multiplier, but we would not recommend that it be reduced to less the 30m.

The aim with these buffers would be to completely eliminate all land use pressure from these zones, including clearing, roads and tracks and disturbances associated with water infrastructure.

These buffers should be the minimum area left uncleared within the agricultural precinct. Additional wildlife corridors should be superimposed on this network to provide wildlife movement across the drainage network (i.e. in a NW/SE direction).

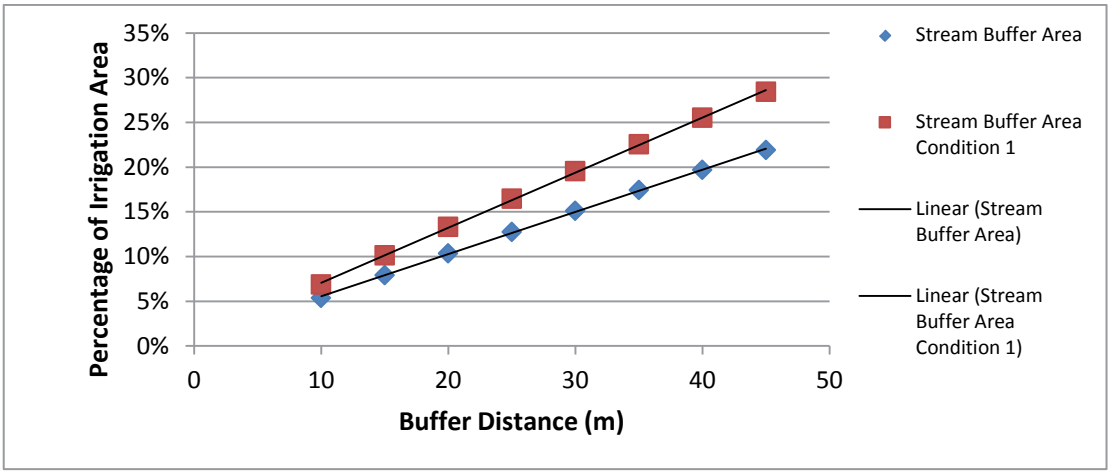


Figure 43 Plot showing the proportion of the IFED area that would need to be left out of production to provide adequate buffers

Table 12 Effect of different buffer widths on the proportion of land taken out of production.

	Approximate IFED Irrigation Area				Total exclusion
	(ha)	(km²)			
	103,539	1,035			
	Stream Buffers Area		Gully Buffer Area		
	(ha)	(km²)	(ha)	(km²)	
Stream Buffer (m) = X * S_0 Gully Buffer (m) = X where X is the buffer multiplier					
30	15,325	153.25	324	3.24	15%
35	17,671	176.71	366	3.66	17%
40	19,963	199.63	408	4.08	20%
45	22,210	222.10	453	4.53	22%
Where S_0 = 1; Buffer (m) = X * 2 * S_0, Where S_0 > 2; Buffer (m) = X * S_0 Gully Buffer (m) = X * 2 where X is the buffer multiplier					
30	19,628	196.28	594	5.94	20%
35	22,647	226.55	695	6.95	23%
40	25,618	256.18	802	8.02	26%
45	28,522	285.22	914	9.14	28%

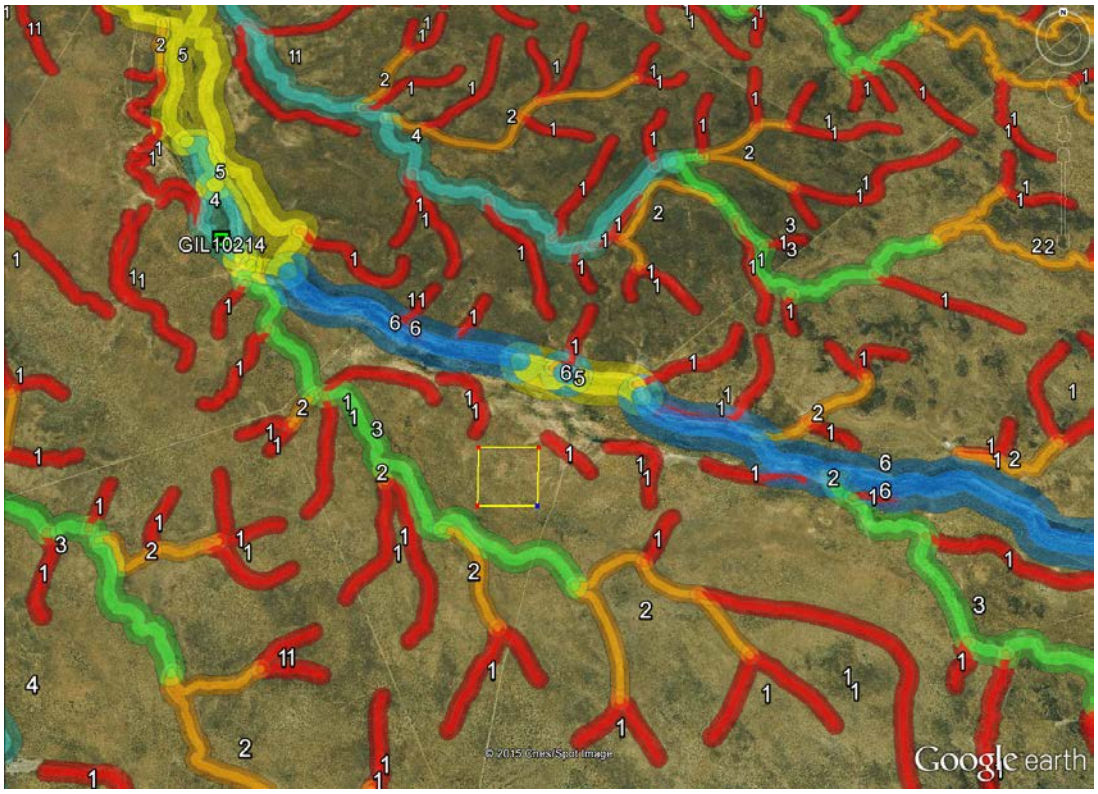


Figure 44 Example of two buffering options within the IFED area (20x stream order (darker colour) & 45 x stream order). Yellow box is a 40 ha plot for scale

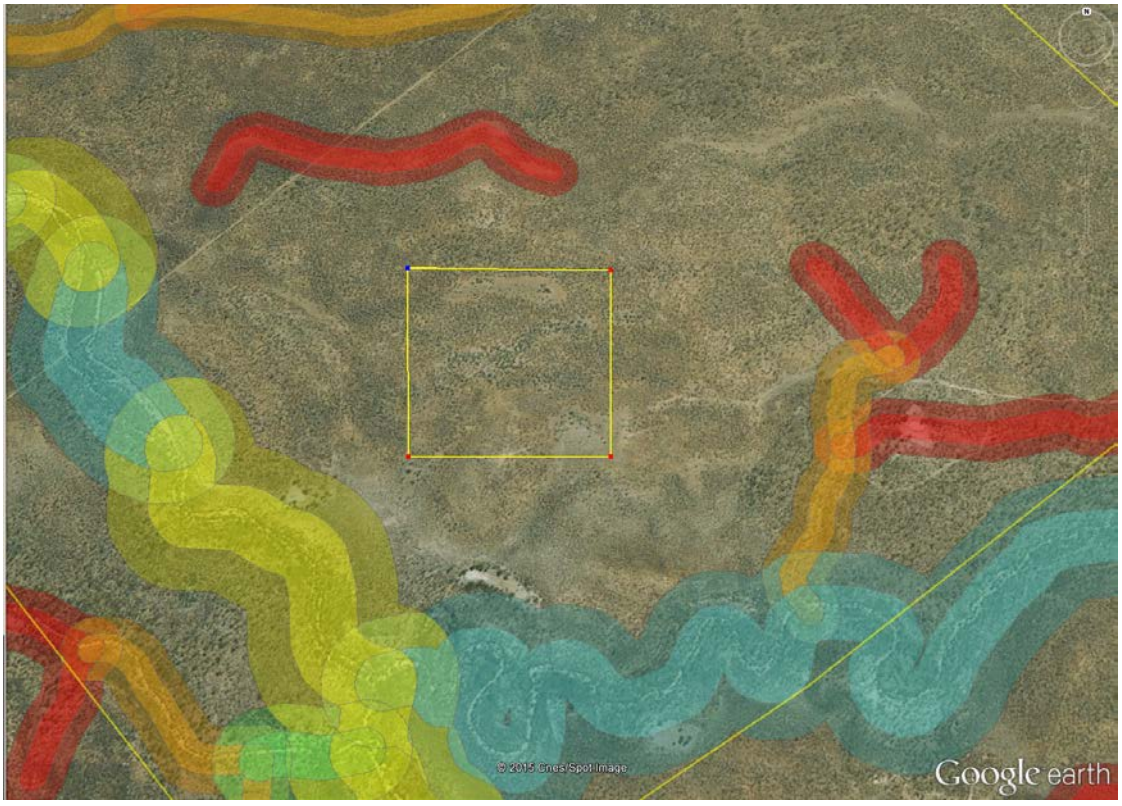


Figure 45 Blow up showing the 20m buffer and the 45m buffer. The yellow box represents a 40 ha plot

Figure 46 Blow up of a section of the Kutchera ag area showing the proposed 45m buffer (i.e. 90m for 1st and 2nd order stream lines). The box here represents the size of the 30m pixels used in the FGARA soil suitability analysis.

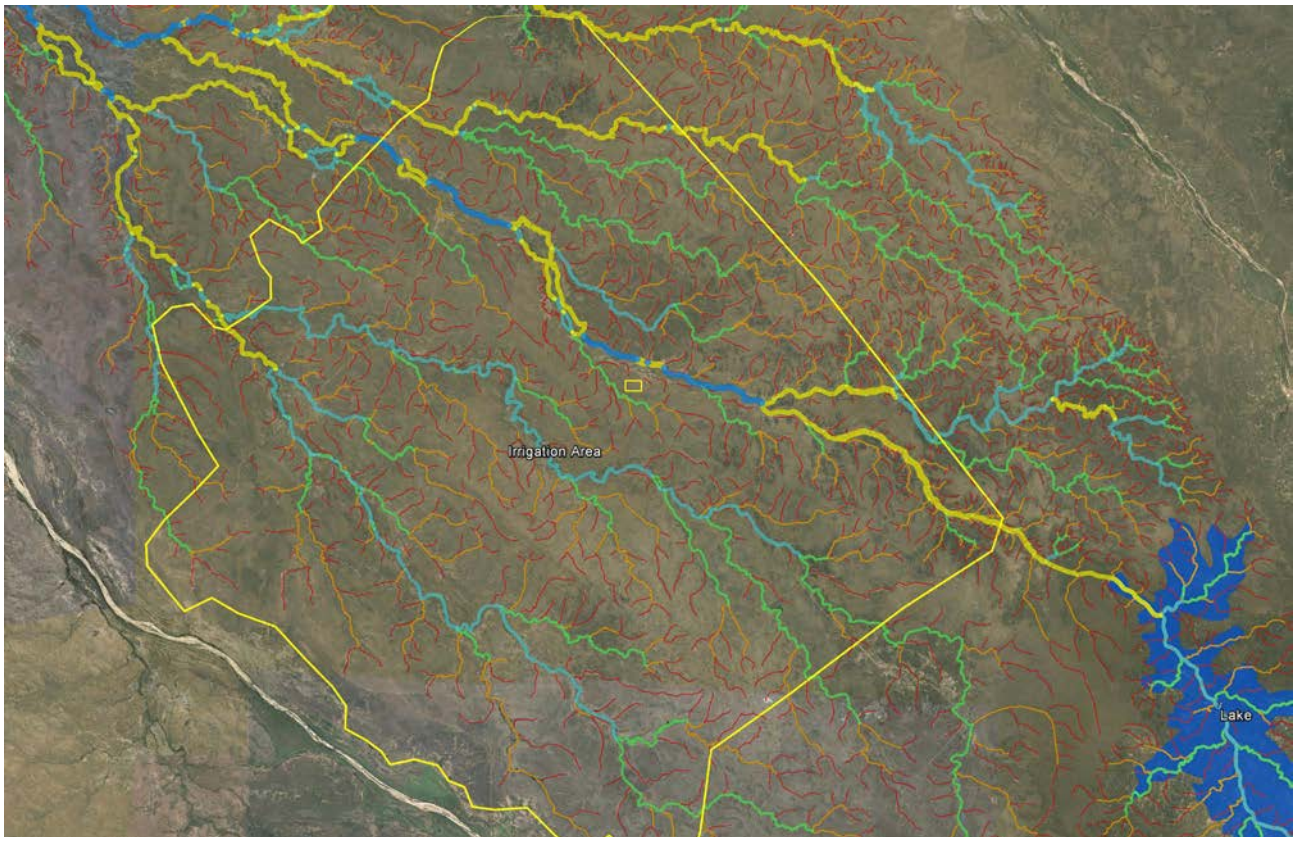


Figure 47 Map of the whole IFED showing the proposed minimum buffer (45m x stream order; with 1st order streams = 2nd streams). For scale a 40 ha plot is shown in the centre of the image

8.4 Potential offset areas

One of the aims of this research was to identify potential areas that could be rehabilitated as a means of offsetting some of the inevitable impacts that will flow from a major development such as that proposed in the IFED. Alluvial gully erosion represents the largest source of accelerated erosion in the Gilbert and many other catchments in northern Australia (Shellberg & Brooks, 2012), and it has been demonstrated that many gullies will continue to supply sediment at equivalent rates to those observed over recent years and decades for many hundreds if not thousands of years. (e.g. Shellberg, 2011). By comparison, sediment supply rates from hillslope gullies, such as those observed in the Georgetown granites, are likely to be starting to decline, in the same way that the hillslope gullies in the Burdekin have been shown to be well into the non-linear phase of negative exponential decay (Wilkinson *et al.*, 2013). For this reason, major reductions in sediment yield are most likely to be achieved through active management of active alluvial gullies, which if left unchecked will continue to contribute excessive sediment to the stream network for the foreseeable future (on management timelines). Investment in managing the majority of hillslope gullies, will not be cost effective given that most are declining anyway.

Based on the reasoning outlined above, the largest aggregation of alluvial gullies that could be managed with appropriate investment, are those along the Einasleigh River in the vicinity of the Confluence with the Etheridge River (Figure 48). A variety of approaches are appropriate here, although experience from elsewhere (Shellberg and Brooks, 2013), indicates that active remediation will be required if significant reductions in erosion rates are to be achieved.

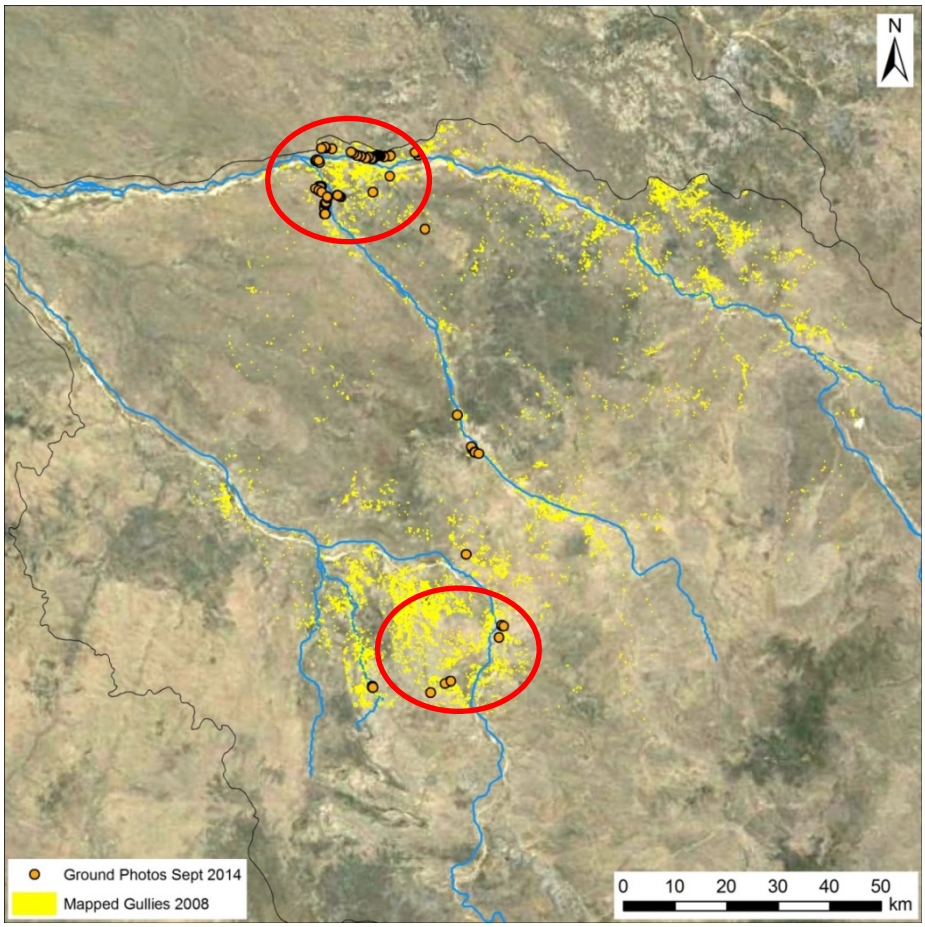


Figure 48 Map showing the aggregation of alluvial gullies in the area around the confluence of the Einasleigh and Etheridge Rivers and on the Gilbert River in the Greenhills areas. Note the gully mapping shown here is the earlier remote sensing-based mapping which has been shown to over represent the extent of gullies in the areas of high gully concentration. Hence the actual extent of gullies is less than represented here, but we do know that there are some major gully complexes here that could be managed with appropriate investment.

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