



A disturbance index approach for assessing water quality threats in Eastern Cape York

**Final DRAFT -
for Comment**

**Appendix 1: A report to South Cape York Catchments
and Cape York NRM for the Cape York
Water Quality Improvement Plan (Report
No ARI16AB002)**

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Olive Vale Station Development for Intensive agriculture 2013 image (top) and 2015 (bottom)

Acknowledgements: The development of this report has been significantly enhanced by discussions with Jeff Shellberg, Christina Howley and Will Higham. ...

In memory of Kuku Yalanji/ Kuku Yimithirr Elder Ronnie Harrigan whose leadership, generosity of spirit, hospitality and sheer decency have been an inspiration to all of our team over the last 7 years while undertaking research on his traditional lands throughout the Normanby Catchment.

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1 Executive Summary

1.1 Background

- 1.1. Current datasets that underpin GBR catchment water quality models do not include many of the key disturbances that are actually driving declining catchment water quality.
- 1.2. For management efforts to cost-effectively target the sources of sediment and nutrients being delivered to the northern GBR (nGBR) lagoon it is critical that we have high resolution data on the locations and nature of all disturbances.
- 1.3. Previous research in the Normanby catchment (which represents about half of the total catchment area to the nGBR) highlighted the role of gully erosion as a primary source of accelerated erosion (Brooks et al., 2013)– which is primarily a function of a century of cattle grazing pressure in the landscape.
- 1.4. Channel erosion, particularly from small ephemeral channels has also been highlighted as a major sediment source, although it is extremely difficult to quantify the extent to which the erosion of these channels represents an anthropogenically accelerated source. It is reasonable to assume that such sources may have doubled since European settlement, but it is difficult to identify any particular site that is accelerated. For this reason we have not included this source in this analysis – but it should be assumed that channel erosion is a key sediment (and nutrient) source and should be addressed wherever possible.
- 1.5. While cattle were the primary factor triggering new gullies and accelerating existing gully erosion, other key triggers for initiating and accelerating gully erosion are the myriad linear disturbance features across the eastern Cape in the form of roads, tracks, fencelines and associated disturbances (such as quarries). All of these features have the capacity for increasing and concentrating runoff, and thereby accelerating surface erosion of the road surfaces themselves and from the gullies they initiate or accelerate. Of particular interest are the sensitive areas where these features cross streamlines. These are the most sensitive sites for gully initiation, but they also represent pathways for directly delivering elevated suspended sediment and nutrient loads directly into the stream network.
- 1.6. In this report we present new data that highlights some of the distribution of these disturbances across the Eastern Cape.
- 1.7. Due to time and resource limitations, we have focused efforts in the Normanby and Stewart catchments, to demonstrate the extent of these linear disturbances and their relationship to other disturbances - such as the existing gully distribution data.
- 1.8. Due to problems with comparing different types of disturbances, we have not combined all disturbances into a single index, rather we present each disturbance type as a separate layer. To better understand how these myriad disturbance features potentially influence the stream network, we have calculated the number of each disturbance feature upstream of each of the AHGF (Australian Hydrologic Geospatial Fabric, <http://www.bom.gov.au/water/geofabric/index.shtml>) sub-catchments of which there are ~ 9600 in the Normanby catchment alone and ~ 19,300 in the whole Eastern Cape.
- 1.9. In addition to gully and channel erosion, erosion associated with **linear disturbance features** (roads, tracks and fencelines) are likely to be a key source of anthropogenically accelerated erosion, and are probably the one that we can potentially have the most influence over as part of ongoing management practice. These features also serve as a useful **proxy** for most other landuse pressures. For example, the most intensively farmed area in the Normanby around Lakeland - has the highest density of roads, tracks and fence lines. Indeed it is possible that these features themselves are the key sources of elevated sediment and nutrient loads in this area, over and above the farmed land itself.
- 1.10. It is likely that these linear disturbance sources and pressures from new agricultural developments may take over from cattle grazing as being the primary driver of new and accelerated gully erosion into the future.

1.2 Results

- 1.11. 13 categories of linear disturbance features were mapped across Normanby and Stewart catchments.
- 1.12. There is a total of 10,800km of linear disturbance features in these two catchments, which equates to a total area of 7990 ha of highly disturbed land.
- 1.13. This is around double the combined total area of all other high intensity land uses combined on Eastern Cape York (i.e. all intensive agriculture, residential and rural residential land – based on QLUMP 2013).
- 1.14. Of the 13 classes of linear disturbance feature mapped within the Normanby and Stewart catchment, by far the largest category by area are fencelines (30%), followed by main dirt roads (14.3%) and minor farm tracks (11.4%).
- 1.15. Of the total extent of linear disturbance features by length, 75.9% (Table 6) are characterised by fencelines and farm tracks of various sizes on public and private land.
- 1.16. Associated with these roads, tracks and fencelines are around 8950 stream intersection points.
- 1.17. Comparison with the new mapped linear disturbance feature mapping and existing road network mapping indicates that these readily available published road network datasets only capture around 27% of the full extent of linear disturbance network, and completely miss the most extensive of these – fencelines and most of the small farm tracks.
- 1.18. Only around 32% of the stream intersection points are captured within the Geodata3 (GEODATA TOPO 250K Series 3 <http://www.ga.gov.au/metadata-gateway/metadata/record/64058/>) representation of linear disturbance features across the whole Eastern Cape.
- 1.19. With this in mind, the linear disturbance maps for the whole Eastern Cape should only be considered to be an initial indication of the relative extent of catchment disturbance (Figure 1). From this mapping there are a total of around 5300km of roads and tracks with 75% being unsealed tracks. Associated with these roads are around 4800 stream intersection points. If the same degree of under representation of linear disturbance applies across the whole region it is likely that there are around 20,000km of linear disturbance features, and 15,000 stream line intersection points, all of which are likely to be delivering sediment and nutrient loads to the stream network that are above “natural” levels to varying degrees.
- 1.20. While intensive agriculture and urban and rural residential landuses still comprise a relatively small proportion of the total area in the Eastern Cape, these are the landuses that are likely to see the greatest growth in the near future and as such they need to be closely monitored and mitigated to ensure that water quality impacts are minimised.

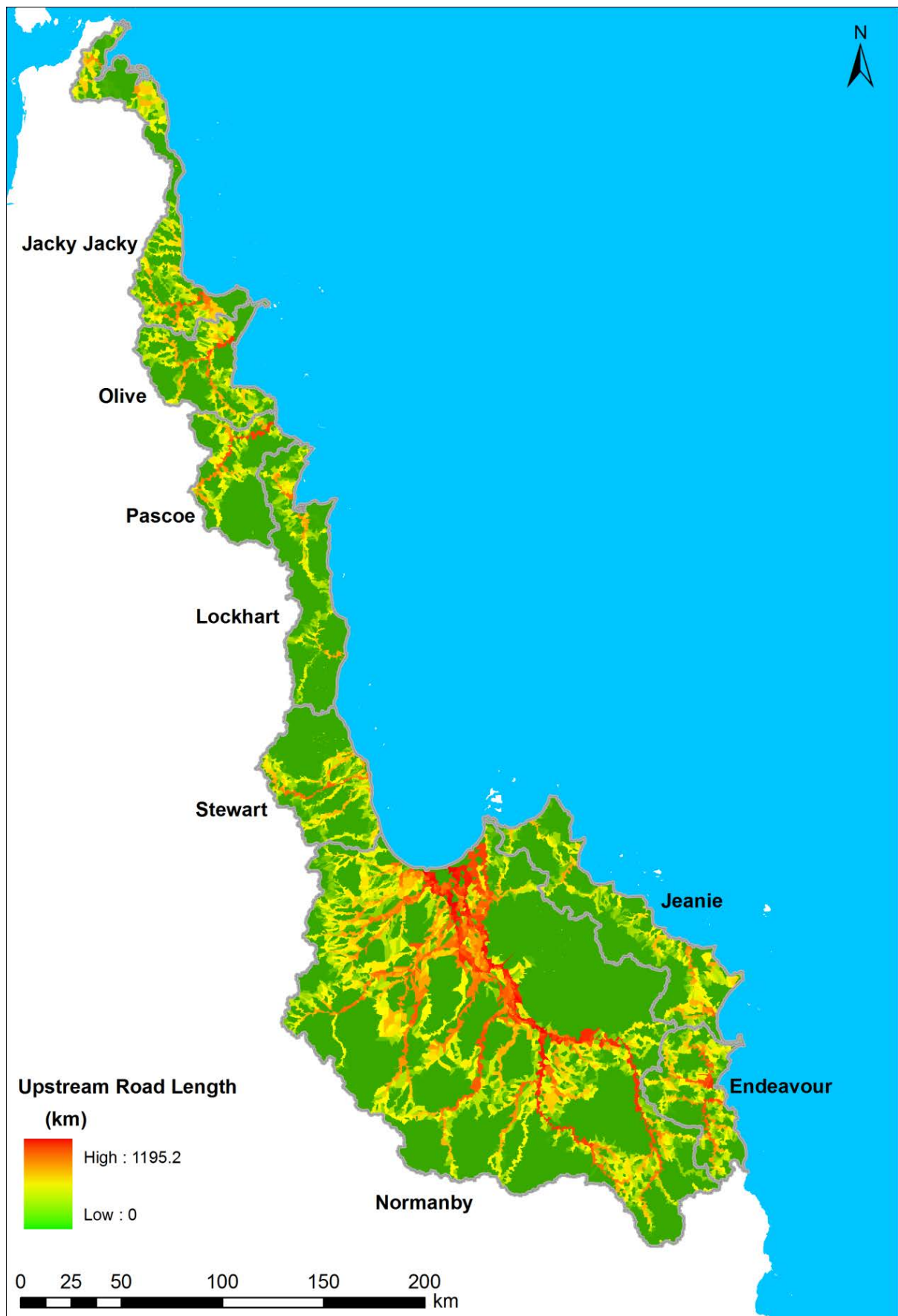
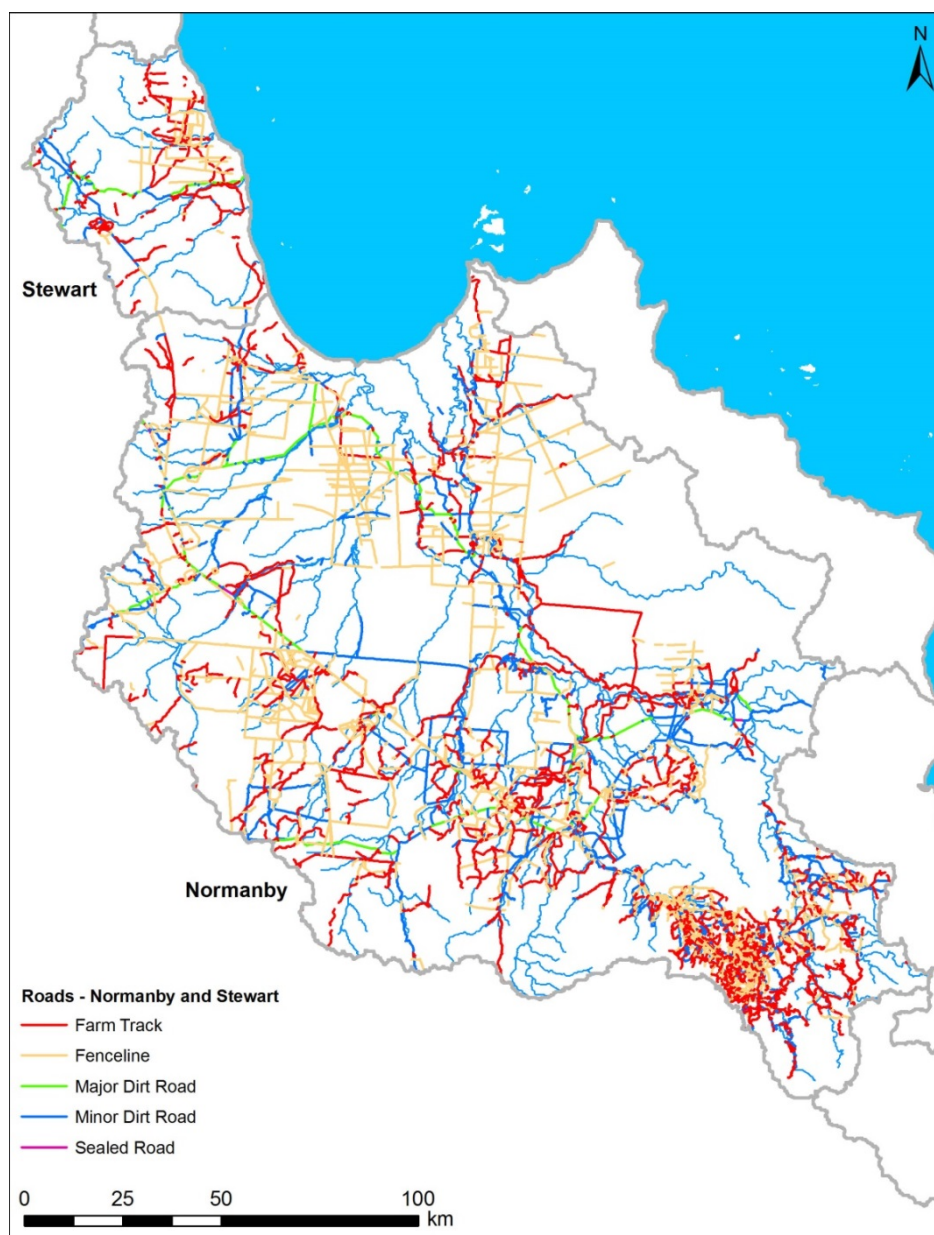


Figure 1 An index of potential road disturbances on the stream network of the eastern Cape. These data represent the absolute minimum extent of the linear disturbance network given that they are derived from the existing Geodata3 road network. Detailed mapping in the Normanby and Stewart catchments shows that this existing data represents only about 26% of the total linear disturbance network.

1.3 Recommendations

1. Gully erosion mapping similar to that carried out in the Normanby catchment should be completed for the whole Eastern Cape. This will enable the full extent of sediment sourced from gullies to be quantified for the whole northern GBR
2. Given that existing road network mapping only captures around a quarter of all linear disturbance features in the Cape, Intensive mapping of these features, similar to that completed for the Normanby and Stewart catchments, should be completed for the remainder of the eastern Cape catchments.
3. QLUMP landuse classes should be expanded to include roads, tracks and fencelines as a separate category, given that in Cape York they are the single largest intensive landuse.
4. Higher resolution mapping and analysis of disturbances should be undertaken around urban areas to better understand the water quality threats at sufficiently high resolution that individual threats can be targeted.
5. Cape York NRM and South Cape York Catchments (as the primary guardians of Reef water quality in the nGBR) should take up the responsibility for maintaining a database of disturbance features throughout the eastern Cape and updating the database on an annual basis to ensure that an up to date register of disturbance features is maintained across the region. This will form the basis for ongoing water quality management prioritisation across the region.
6. Accompanying the maintenance of a disturbance register, both organisations should undertake systematic ground truthing of the mapped disturbance features as part of their everyday activities. This can include things like:
 - 6.1. Running GPS tracklogs whenever new roads are traversed and comparing these with the mapped database;
 - 6.2. Logging the locations of road and track crossings of the stream network encountered during day to day operations to compare with the mapped stream intersection point dataset;
 - 6.3. Mapping of gullies encountered as part of daily activities;
 - 6.4. Systematic mapping of tracks and fencelines as part of property management planning activities;
 - 6.5. The location of any new point source disturbances.
7. To better differentiate the relative impacts of the disparate disturbance features, empirical data on their respective water quality impacts needs to be collected on each class of disturbance feature in different parts of the landscape, so that the comparative effort between different management activities can be assessed (for example undertaking gully repair compared with road improvement works).
8. The maintenance of a disturbance database, coupled with improved data on relative impacts of different disturbances, should form the basis for the prioritisation of management effort within the region.
9. While the management of gully erosion is likely to continue to be the highest priority for improving *current* water quality in the nGBR, future declines in water quality are most likely to come from the intensification of landuse, be it associated with agricultural developments, such as that proposed for Olive Vale Station, or from urban and peri-urban development around Cooktown and other settlements in the eastern Cape. This being the case, the highest priority should be given to ensuring, before approvals are granted, that any landuse intensification only occurs in such a manner to minimise the impacts on water quality. It should be noted that while the catchments east of the Normanby are relatively small, they are relatively short and steep and thus well connected to the reefs immediately adjacent to these catchments. Consequently development pressures in these catchments collectively could have a disproportionately high impact on the inshore reefs of the nGBR, and potentially on the Crown of Thorns Starfish Initiation Zone off Lizard Island.
10. These water quality management imperatives need to be effectively communicated to planners at both state and local government level.

11. The highest priority for planners is to avoid developments of any kind in sensitive environments (e.g. sodic soils subject to gully erosion). More detailed mapping is required in order to identify areas in which all development should be avoided.
12. Where approvals are granted for larger developments, world best management practice (WBMP) erosion and water quality mitigation measures must be enforced to ensure that the water quality declines are kept to an absolute minimum. Such standards will need to be higher than those typically considered to be industry BMPs.
13. For the myriad small land management activities that don't require state government or even council approval (e.g. building new fences or putting in farm tracks) there needs to be a major public education campaign about the potential for these activities to degrade local water quality.
14. A series of BMP guidelines and associated education campaigns also need to be developed so that landholders are aware as to how these activities can be undertaken in such a way that water quality impacts are minimised.
15. Strong relationships need to be built with local government engineers and those responsible for Reef water quality management to ensure that WBMP practices are being used for the construction and maintenance of roads within the region.



2 Background

It is becoming apparent that the relatively intact northern Great Barrier Reef (nGBR) represents a fundamentally important stronghold of resilient coral reefs that might hold the key to the survival of the entire GBR in a warming global ocean. With multiple stressors such as the warming of global oceans, ocean acidification, increasing cyclone magnitude and frequency and declining catchment water quality all impacting the coral reefs of the GBR, it is only catchment water quality that we can directly influence on short (<10 year) timescales (De'ath et al. 2010). Given the severe declines in the coral reef cover documented in the central and southern parts of the GBR (De'ath et al. 2012), the northern GBR is the last stronghold of healthy reefs and could hold the key to the long term survival of the reefs to the south as the oceans warm to become more like the conditions currently found in the northern GBR. Hence the maintenance and improvement of the water quality to the Northern GBR is one of the highest priorities for the overall management of the GBR.

In a somewhat ironic twist, at the same time that Cape York is now becoming appreciated as the highest priority region for the long term survival of the GBR, Cape York is also the target for a major development push as part of the broader northern Australia development agenda. There is no doubt that both agendas are at odds, which serves to highlight the need to quantify existing pressures on water quality in Cape York, and to closely monitor and quantify the cumulative effect of the myriad new development activities that will be undertaken as part of this broader development push. While the high-profile developments such as those occurring on Olive Vale Station will inevitably attract attention, there is potential for the myriad small developments and their associated impacts on the landscape to have a greater cumulative impact on water quality than the few large developments. Hence, there is a pressing need to very closely monitor, quantify and mitigate the impacts associated with things like: new housing developments, new secondary roads, new farm tracks, new fence lines, road widening, new power line easements and all of the other myriad small development activities that will inevitably occur in the Cape in years to come. It goes without saying that a very high bar should be set for major new agricultural developments given their scale and the potential for major water quality impacts if such developments are not adequately planned and implemented according to the highest standards. Consideration should also be given to the secondary pressures associated with greater tourist visitation on road and track usage in the area, all of which have the potential to accelerate erosion, and reduce water quality. Not only do we need to systematically quantify all of these development pressures but we need to educate all stakeholders, from landholders, tourist operators and local government (amongst others) as to what can be done to minimise water quality threats from all these sorts of developments.

To ensure that water quality in the Cape doesn't decline further than it already has, we need to both mitigate the existing water quality threats, and at the same time minimise the impacts of any new developments. Achieving this dual strategy firstly requires high quality data on where the threats are, which can then provide the basis for targeting resources to the areas of greatest need of rehabilitation and mitigation. However, as always, prevention is better and cheaper than attempting to cure a problem once initiated, so the highest priorities for water quality management are education; avoidance of development in highly sensitive areas; and the implementation of Best Management Practices (BMPs) for all sorts of development activities to ensure water quality decline is minimised from the outset.

In this report we set out an approach for quantifying some of the key major threats to water quality, focusing in detail on the Normanby and Stewart catchments due to time and resource constraints. We would strongly recommend the mapping exercise undertaken in these two catchments should be extended to the rest of the Cape.

2.1 Existing Water Quality Threats

As outlined in Brooks et al., (2013) the major accelerated sediment source that is delivering sediment to the Northern GBR is associated with gully erosion and particularly alluvial gully erosion in the Normanby catchment (and many other catchments). A detailed review of the processes driving gully erosion in the Normanby catchment and approaches to gully management is contained within a report by Shellberg and Brooks (2013) <http://www.capeyorkwaterquality.info/references/cywq-223>. A strategy for prioritising gully management has been further developed for the Cape York Water Quality Improvement Plan (see Brooks et al., 2016).

While a concatenation of factors has led to the distribution of accelerated gully erosion across the region, the key underlying ingredient is the location of susceptible sodic soils within the appropriate landscape setting (*sensu* Brooks et al., 2007, 2008, 2009). However, the widespread acceleration of gully erosion can be attributed to a number of disturbance pressures that both trigger and perpetuate gully erosion. As proposed by Shellberg et al (2010; subm.) the dominant trigger for accelerated gully erosion in Cape York and many parts of northern Australia is disturbance associated with cattle, and most notably cattle pads through the most sensitive part of the riparian zone; the transition between the channel banks and the associated floodplain or terraces. Cattle regularly ply this sensitive zone on their daily transit between the pastures on the floodplain and associated frontage country to the water points within the river network. Under a broad scale grazing regime this initiation mechanism is the dominant factor contributing to accelerated gully erosion.

Cattle pads and associated grazing pressure however, are not the only drivers of accelerated gully erosion. There are a number of other linear disturbance features within this landscape that have the capacity to both initiate gully erosion (with the attendant water quality impacts associated with the massively accelerated volumes of sediment and nutrients contributed to waterways from gullies) but also to contribute elevated sediment and nutrient yields in their own right. Unsealed roads and fencelines are a major feature of this landscape whose extent and density has not previously been well quantified. Results presented in this study show that the road and fenceline extent and density tends to significantly increase as a function of landuse and population intensification, both spatially and temporally. So while cattle might have been the dominant initiator of gullies in the past, roads tracks and fencelines could become more significant initiators of gullies in the future, particularly if landuse intensification continues to increase at the rates seen in recent years around areas such as Lakeland. More significantly, as landuse intensification (such as that proposed on Olive Vale and Springvale Stations) pushes into more marginal and potentially erodible soils, the role of these gully erosion trigger mechanisms will only increase in importance.

2.2 Roads as Sediment Sources

Sediment pollution from unsealed roads has been documented throughout the world as a significant driver of declining water quality and ecological degradation of the stream network (Reid et al., 1981, Dunne and Dietrich, 1982; Reid and Dunne, 1984, Grayson et al., 1993, Ziegler and Giambelluca, 1997; Giambelluca et al., 2000; Wemple et al., 2001; Croke and Mockler, 2001, Russell et al., 2001; Deckers et al., 2002; Collins, 2002, Bubb et al., 2006). To date very little consideration has been given to the role of roads as sediment sources in the management of water quality to the Great Barrier Reef, largely due to the fact that to date it has not been incorporated into catchment models, and indeed is not even included as a separate category in the statewide land use mapping. Yet in relatively undeveloped regions such as Cape York with its tropical monsoonal climate, where a large proportion of the roads are unsealed and typically reggraded, and sometimes resurfaced, after each wet season, the cumulative effect of unsealed roads is potentially the single most significant land-use impact that is resulting from current management practices. This is likely to be more significant when the secondary effect that roads play in initiating gully erosion is also taken into account.

2.2.1 Review of Gleeson 2012

A study undertaken in the Normanby catchment (Gleeson, 2012) represents a first attempt to begin to quantify the water quality impacts associated with roads in the Normanby basin. The study provided an initial estimate of the extent of the road network in the Normanby catchment, in which the existing mapped road network encapsulated within the standard topographic mapping layers, was updated and extended through digitisation of all visible roads and farm tracks on the best available imagery at the time available through Google Earth. Roads and tracks were classified within the Normanby catchment into four classes, as per Table 1, and their overall extent and distribution quantified. It is important to note that due to the resolution of the imagery available at that time, many small farm tracks were not mapped, nor were fencelines.

Based on these data alone, which we now know to be a significant under-estimate of the total extent of roads (see new data below), a total of 3113 km of roads or around 5165 ha of road surface area was mapped throughout the Normanby catchment alone. Even this underestimated road area represents the single largest intensive landuse in

the catchment; more than double the area of the other main intensive landuse (cropping/horticulture) which at the time was around 2185 ha (ABS 2010 data). The mapped road network was also shown to intersect the 1:100k stream network 1190 times, providing direct pathways for sediment and nutrient enriched runoff to enter the stream network.

These data were then coupled with empirical data on the length and area of different categories of roads and tracks directly contributing runoff into the stream network (Table 2). Based on a limited data set it was estimated that the mean contributing road surface area for each road crossing was 2344 m², which equates to a total effective contributing road surface area of 279 ha feeding directly into the stream network at the catchment scale from the data derived in Gleeson's study.

When coupled with empirical sediment concentration data from the surface runoff component of road erosion (i.e. excluding drain gully erosion), collected over a single wet season, initial minimum estimates of road runoff were derived. The suspended sediment concentration of the runoff generated from three main unsealed road segments, from late November 2011 to early February 2012 ranged from 113mg L⁻¹ to 13,509 mg L⁻¹, with a mean production of 1779 mg L⁻¹. The concentrations measured in this study are likely to be an underestimate of the real mean supply of suspended sediment from the surface of the roads as a result of all experimental sub-catchments receiving well below the long term mean rainfall per month (**Error! Reference source not found.**).

Table 1 Summary statistics of the Normanby catchment roads from Gleeson (2012). Note the imagery from which these data were derived is generally 2006 and 2009 data

	classification basis	av width (m)	total length (km)	total surface area (ha)
farm tracks	minor tracks < 7m wide	5.1	552.3	293.8
2ndry dirt rds	dirt roads 7 - 15m wide	12.7	1925.9	3587.6
major dirt rds	main dirt roads > 15m wide	20.5	588.2	1177.0
total dirt rds			3066.5	5058.5
sealed rds	tar sealed roads	21.2	47.4	107.2
total all roads			3113.9	5165.7

Table 2 Unsealed road dimensions and event mean SSC values for road runoff in the Normanby catchment and a minimum estimate of road runoff excluding drain gully sediment contributions (Gleeson, 2012)

	average	1 stdev
average contributing length (m)	182.8	180.2
average width (m)	12.8	
total stream crossings	1,190	
Average contributing area per crossing(m ²)	2,344	
total contributing area (m ²)	2,789,830	
total area (ha)	279.0	
average conc. (mg/l)	1,029	1961
av events >11mm/yr	35	
av RF/event (mm)	29.7	
av RF/event/crossing (l)	69,629	
av sed/event/Xing (kg)	71.6	
Mean annual rd surface erosion	2,984	5687

The delivery of road surface runoff and suspended sediment was also observed to occur via gully pathways originating from road drainage outlets. It was estimated that a mean volume per drain of 132 m³ of soil has been

displaced due to the formation of gullies at the outlet of 42% of the all V-Drains analysed in the study (Figure 2). This represents an additional contribution to sediment yield over and above the sediment sourced from the road prism (Table 2). Average V-Drain spacing for the study area is 144m (on both sides of the roads), hence there is potentially around 1800 m³ of road induced gully erosion per km of main unsealed road (MUSR) that could be contributing to elevated sediment loads within the stream network. It is not known however, over what time span these V drain induced gullies have formed. The presence of exposed roots and active headcuts suggest that these gullies are fresh and active - and it would be safe to assume that at the most we are likely to be talking a decade as the upper limit.



Figure 2 Examples of gullies emanating from road drains within the study area. 42% of road drains in the study area were found to have gullies like this associated within them

It was found that the average suspended sediment concentration measured over the sampling period from the surface runoff of all the experimental roads (Battle Camp Road; the Palmerville Road and the Peninsula Development Road), was between 2 – 4 orders of magnitude greater than the suspended sediment generated from hillslope erosion within the catchment's major land use, open range cattle grazing.

In summary, the study highlights the significant threat that unsealed road networks potentially pose to the water quality of wet-dry tropical catchments, such as the Normanby Catchment. However, the study is limited in the degree to which it has captured all minor roads within the catchment and it did not include fence lines, which often become de-facto farm tracks and locations for fire breaks, both in the form of control burn zones or graded lines. Given the potential threat to nGBR water quality indicated by Gleeson's study, further detailed work is required to fully quantify the effect of all linear disturbance features and associated disturbances (e.g. quarries etc.) within this landscape. The following report begins the process of quantifying the cumulative impact of all anthropogenic disturbances in this landscape.

3 Threats to Water Quality in the Northern GBR: Building a “Disturbance Index” approach to identify priority management areas.

In addition to the water quality threats posed by gully and road erosion, there are a raft of additional disturbance features in the landscape that need to be quantified in order to build a complete picture of the full suite of disturbance threats. Other threats include: new intensive agricultural areas, urban areas, homesteads, mines and quarries. Late season fires are another disturbance that potentially threatens water quality, but the mapping of late seasons burns are dealt with separately within the Cape York WQIP and so is not included here. In the following we present some data in a form which is intended to provide a visual representation of the minimum extent of some existing disturbance across the Eastern Cape. We also present some more detailed data for the Normanby and Stewart catchments which highlights the sorts of data needed across the region to fully appreciate the extent and location of various water quality threats. While these data are not a sediment budget, and at this stage cannot be directly compared with one another due to the lack of sufficient empirical evidence for their relative contributions to elevated sediment and nutrient loads, we argue that these data provide a much more meaningful representation of the immediate threats to water quality than do current sediment budget models, such as Source Catchments.

The data we present here are by no means complete, nor is the approach the last word on how these data should be represented and quantified. In particular at this stage we have not attempted to integrate all disturbances into a single index. This would require having empirical evidence as to their relative sediment and nutrient contributions, but more importantly, insights into the delivery pathways to the stream network, and the extent of attenuation of the respective contributions through the catchment and out to the reef. This is a much more complex task than can be completed in this exercise, but these datasets can potentially be the building blocks for further analysis.

An argument can be made that the building of a new model is not a priority; rather we should instead focus all effort on just identifying the disturbances and ensuring that the contribution of each threat is kept to an absolute minimum (given that there is no way that any of the disturbances will have zero impact on water quality). Hence, rather than continuing to plough resources into producing yet more meaningless model predictions, these resources should be redirected to the detailed mapping and characterisation of existing of water quality threats and efforts focused on the minimisation or rehabilitation of these identified threats. Then, as the Qld Audit Office recommends (<https://www.qao.qld.gov.au/report-20:-2014-15>), much greater effort should be directed towards the monitoring (at multiple scales) to determine ongoing trajectories of water quality change resulting from rehabilitation efforts and future catchment disturbance.

3.1 Key Disturbances

The following disturbance maps are presented at two scales; the first at high resolution based on detailed mapping in the Normanby and Stewart catchments (roads/linear disturbance features and gullies), while the remainder of the data are presented at coarse resolution derived from existing published data, notably the GEODATA TOPO 250K Series 3, the 1:100K stream line data as well as the Qld Land Use Mapping (QLUMP, 2013) data.

3.1.1 Detailed mapping of Roads, tracks and fencelines in the Normanby and Stewart catchments

The roads tracks, fence lines and other disturbance features were mapped from Google Earth imagery and classified initially into one of the 13 classes shown in Table 3. These were subsequently amalgamated into the 5 classes shown on the right of Table 3 to enable comparison with the Geodata 3 roads dataset. As part of the mapping process four additional disturbance features were also mapped where they were encountered; dams, contour berms, quarries and airstrips. These additional features are not included in the roads and fencelines dataset.

Table 3 Summary characteristics of the 13 classes of linear disturbance features digitised from Google Earth showing the key features used to delineate each class. An additional 4 categories of disturbance features were also mapped but not included in the linear disturbance feature mapping. See Appendix 1 for examples of each class.

Classes		Description	width (m)	Amalgamated Classes
1	Farm tracks major	Unsealed, evidence of well used surface often joining roads to buildings, or main access to strategic farm assets. Grass strip between wheel tracks absent.	3-8 m	Farm Track
2	Farm tracks minor	Surface alternates from solid graded to 2 wheel tracks - vegetation cover may be present. Provide access to water points, distant parts of country.	2-3m	Farm Track
3	Fence lines	Obvious cleared fenceline that does not have compelling evidence for a road alongside.	4-10m	Fenceline
4	Fence lines overgrown	Seen as a discernible line through vegetation, may go for several kilometres. Bare ground along fence not often visible.	2 to 4m	Fenceline
5	Fence lines with road	Obvious bulldozed clearance that includes a road alongside.	10 to 14m	Fenceline
6	Main dirt roads	Unsealed, named developmental roads, dual carriageway, >15m wide	>10m wide	Major Dirt Road
7	2 wheel tracks	Track seen as 2 wheel lines, indicating occasional use. Often very remote.	Approx. 2m	Minor Dirt Road
8	Minor dirt roads	Unsealed, single carriageway, solid appearance, includes driveways to farms	5-10m	Minor Dirt Road
9	Railway Line	Embankment, Overgrown by now.	20 to 30m	Minor Dirt Road
10	Secondary dirt roads	Unsealed, table and V drains to divert roadside drainage, single lane or dual carriageway	10-20m	Minor Dirt Road
11	Track	Wide clearance of vegetation, often without evidence of active road. Possible powerline easement or seismic line, width variable.	>15m	Minor Dirt Road
12	Highway	Tarsealed, white line, dual carrigeway, bridges	20-25m	Sealed Road
13	Tar sealed roads	Tarsealed, white line optional, in towns or rural zone.	8-10m	Sealed Road
14	Quarry	Obvious working pad for extraction or storage of material.	30-200m	na
15	Airstrip	Landing strip	30-120m	na
16	Contour berm	Soil conservation berms across contours of paddocks	2-3m	na
17	Dam	A dam across a watercourse	30-40m	na

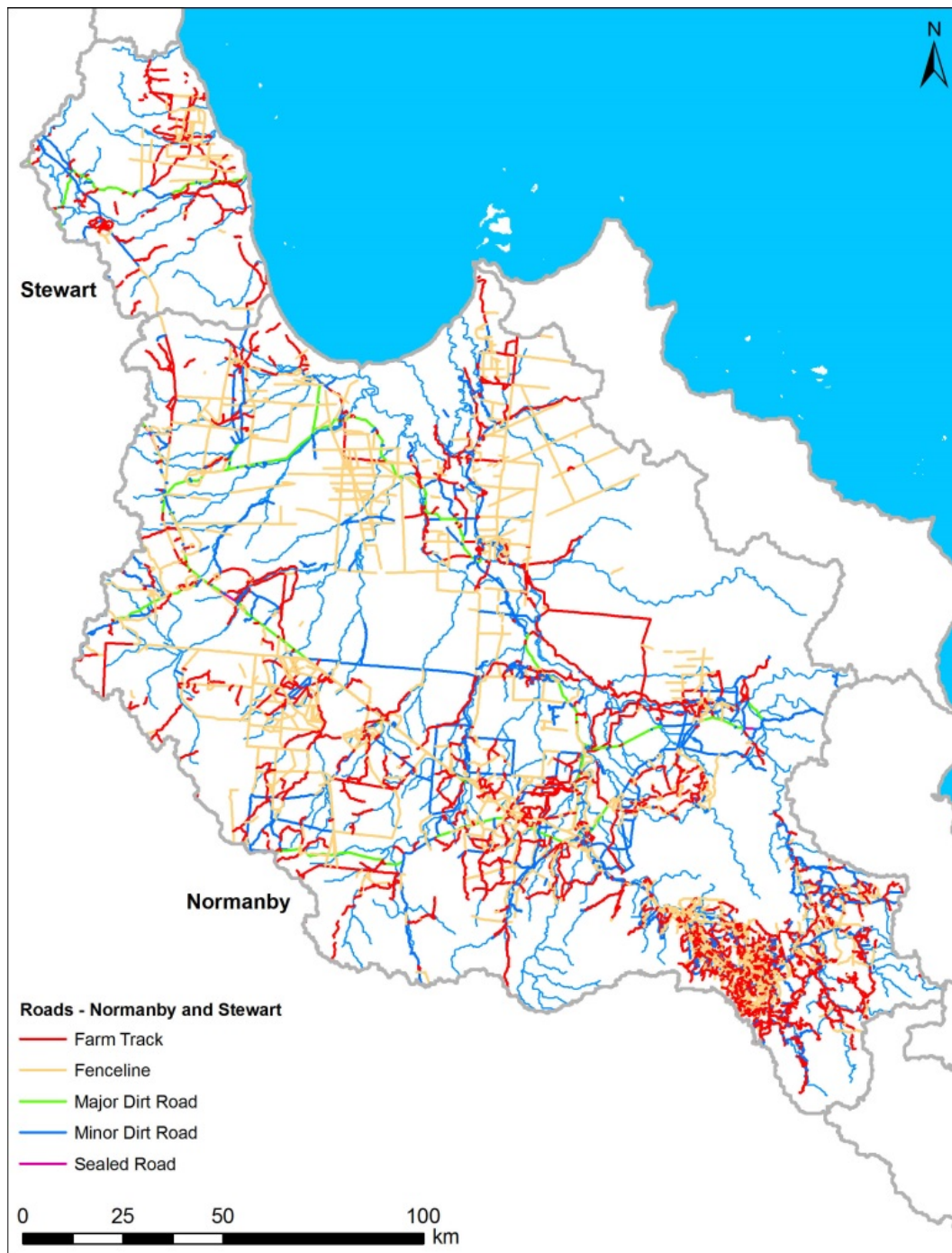


Figure 3 Map of the Normanby and Stewart River catchment with the 5 amalgamated classes (as per Table 3), showing the distribution of roads, tracks and fencelines.

3.1.2 Summary of Linear Disturbances in the Normanby and Stewart Catchments

As shown in Table 4 there was a total of 10,800km of linear disturbance features within the Normanby and Stewart catchments, which equates to a total area of 7990 ha of highly disturbed land. This is more than double the extent of roads and tracks mapped by Gleeson in her initial assessment of linear disturbance features (Gleeson, 2012), and is around double the combined total area of all other high intensity land uses combined on Eastern Cape York (e.g. all intensive agriculture, residential and rural residential land). Once the detailed distribution of these sorts of disturbances in all eastern Cape York catchments is undertaken, this “land use” will dwarf all other land-uses by a considerable margin. Of the 13 classes of linear disturbance feature mapped within the Normanby and Stewart catchment, by far the largest category by area are fencelines (30%), followed by main dirt roads (14.3%) and minor farm tracks (11.4%). Of the total extent of linear disturbance features by length, 75.9% (Table 6) are characterised by

fencelines and farm tracks of various sizes on public and private land, few of which are captured on any existing land use or spatial data sets. Hence, if we are to properly represent these sorts of disturbances in our planning for GBR water quality management, it must be a priority to map and quantify these sorts of disturbances.

Table 4 Summary statistics of linear disturbance features in the Normanby and Stewart catchments

Normanby - Stewart			
	Feature Type	Road Length (km)	Road Area (km ²)
1	2 wheel tracks	380.28	0.94
2	Farm tracks major	1329.25	6.87
3	Farm tracks minor	2408.60	9.07
4	Fence lines	2795.38	23.98
5	Fence lines overgrown	1092.68	3.32
6	Fence lines with road	571.51	7.34
7	Highway	134.69	1.44
8	Main dirt roads	535.61	11.38
9	Minor dirt roads	897.34	6.41
10	Railway Line	13.55	0.19
11	Secondary dirt roads	522.21	5.84
12	Tar sealed roads	12.81	0.15
13	Track	101.33	2.94
total		10795.25	79.88

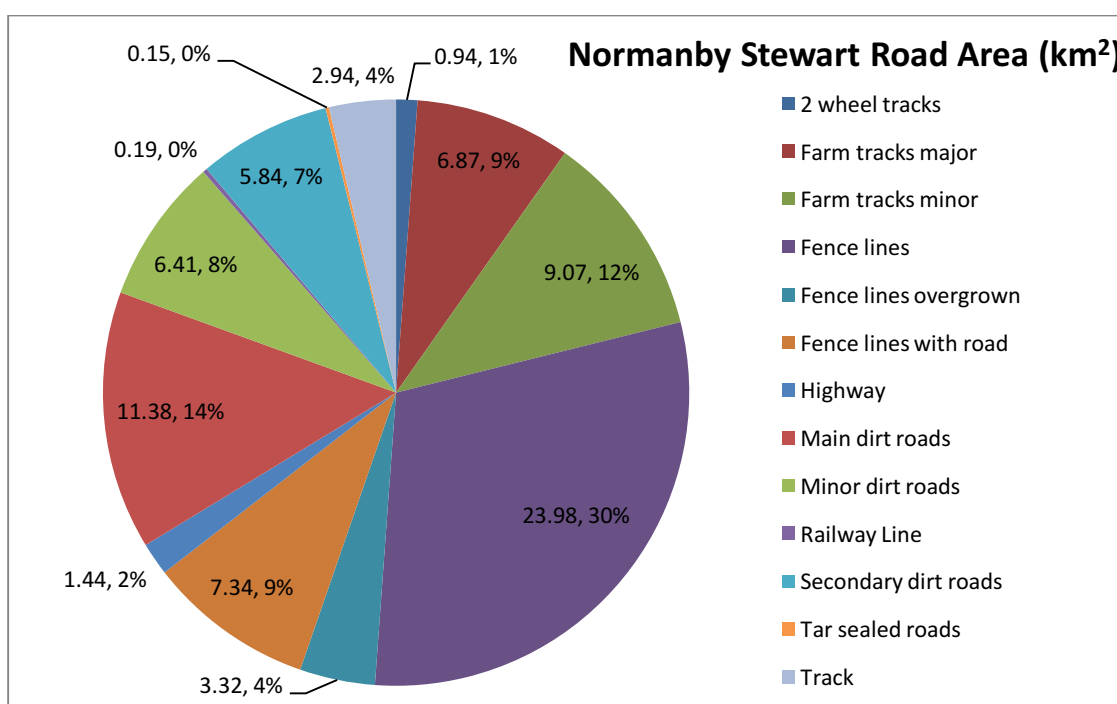


Figure 4 Proportional breakdown by area of the various categories of linear disturbance feature within the Normanby and Stewart catchments.

3.1.3 Impacts of Linear Disturbance features on the Stream Network

To gauge the potential impact of these linear disturbances on water quality we have mapped the location of all points in the landscape where the various features intersect the 1:100K representation of the stream network. The

rationale for mapping these points is that it is at these locations where there is a direct connection between the road or fenceline network and the water course, and hence the potential for the direct delivery of sediment and particulate nutrients directly into streams. The 1:100k stream network should be regarded as being an absolute minimum representation of the true stream network, and hence the actual number of intersection points could be much higher than that represented here.

From the data shown in Table 5 and Table 5, there are a total of 8956 points of intersection between the road/fence network, with the largest contributor being minor farm tracks (26.7%), followed by fence lines (23.9%) and major farm tracks (10.5%). Of all the intersection points, 74.6% are associated with minor farm tracks and fencelines. Hence, while there is no doubt that the major road network can have a disproportionate impact of sediment and nutrient runoff to the stream network, the sheer extent of the small tracks and fencelines means that these disturbances certainly cannot afford to be overlooked.

In Figure 5 we have also attempted to visually represent in a fairly simplistic manner (i.e. by treating all intersection points equally), the cumulative impact of all road/fence/stream intersections on the different tributaries throughout the whole basin. To do this we have used the AHGF 1:250K sub-catchment polygons as a basis for aggregating the number of intersection points upstream of each sub-catchment within the stream network. From this analysis it is evident that the Laura and Normanby tributaries experience by far the greatest potential cumulative impacts from road/fence/stream intersections upstream.

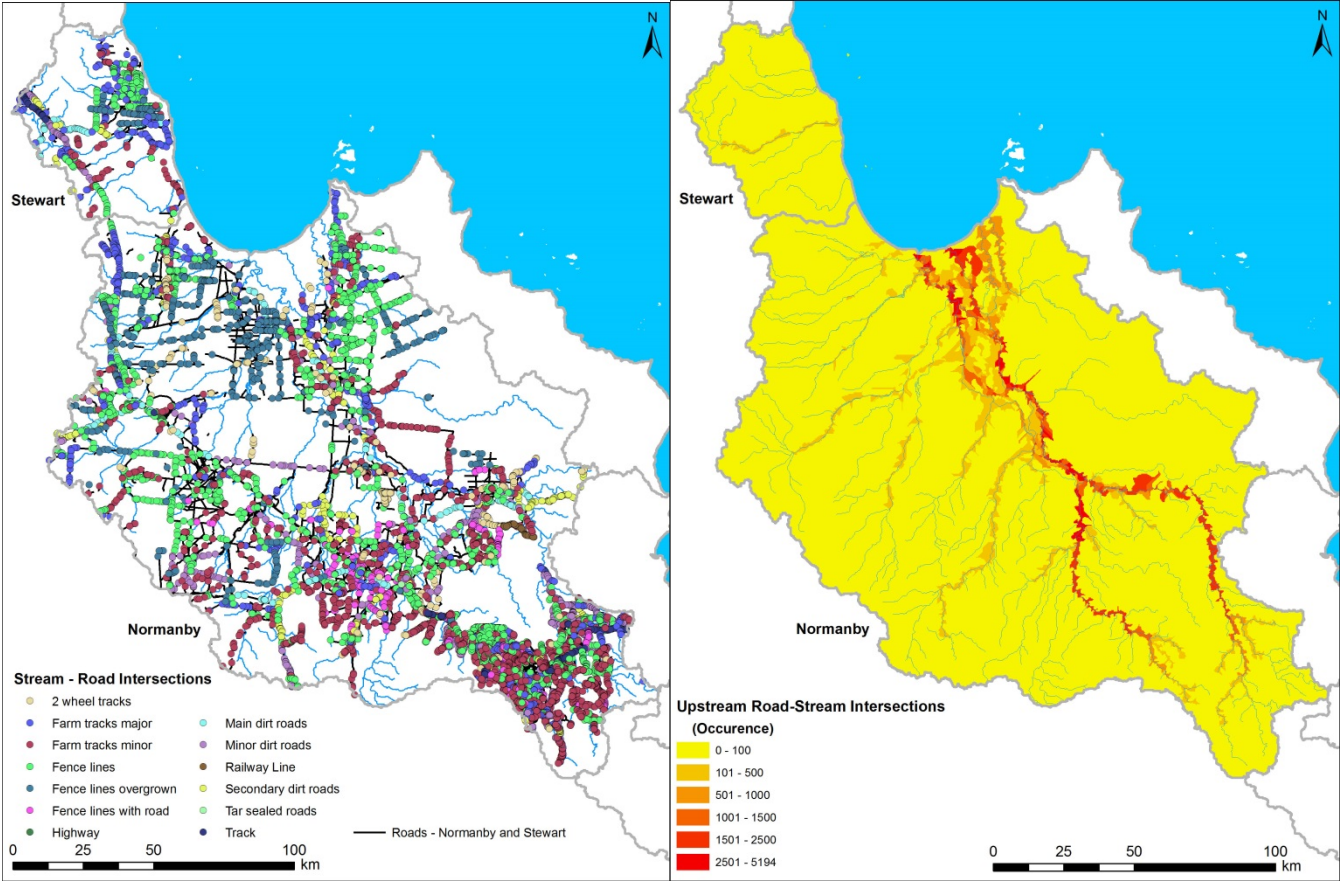


Figure 5 Map of the Normanby and Stewart catchments showing the points of intersection between the 1:100K stream network and the mapped linear disturbance network (left), and (right) showing a graphical representation of the upstream cumulative number of stream network intersection points for each of the sub-catchments within the Normanby/Stewart basins.

Table 5 Breakdown of the number of intersection points between the stream network (1:100K) and various linear disturbance categories.

Normanby - Stewart stream intersection pts		
Feature Type	Count	Percent

1	2 wheel tracks	300	3.3%
2	Farm tracks major	943	10.5%
3	Farm tracks minor	2390	26.7%
4	Fence lines	2141	23.9%
5	Fence lines overgrown	711	7.9%
6	Fence lines with road	498	5.6%
7	Highway	187	2.1%
8	Main dirt roads	321	3.6%
9	Minor dirt roads	874	9.8%
10	Railway Line	36	0.4%
11	Secondary dirt roads	395	4.4%
12	Tar sealed roads	6	0.1%
13	Track	154	1.7%
total		8956	100%

Table 6 Amalgamated linear disturbance classes showing the breakdown of the stream intersection points (1:100K stream network) by disturbance category

Normanby - Stewart			
Feature Type		Count	Percent
1	Farm Track	3333	37.2%
2	Fenceline	3350	37.4%
3	Major Dirt Road	321	3.6%
4	Minor Dirt Road	1759	19.6%
5	Sealed Road	193	2.2%
		8956	100%

3.1.4 Comparison Between Digitised Linear Disturbance Network and I:250K Geodata V3

Given the limited time and resources available for this project, it was not possible to undertake the same intensity of mapping across the whole of the Eastern Cape as was undertaken within the Normanby and Stewart catchments. To enable an initial assessment of the relative degree of some key disturbance factors to be characterised across the whole region, a similar type of analysis to that undertaken in the Normanby was carried across the eastern Cape catchments using an existing, nationally consistent data set – the GEODATA TOPO 250K Series 3. There is no doubt that this dataset significantly under-estimates the extent of linear and other disturbance features within this landscape, but it has been assumed that the under-representation is spatially consistent. Hence, to test the extent to which this dataset is missing disturbance features, a comparison between the two datasets in the Normanby and Stewart catchments was undertaken to quantify the degree of underestimation. To enable the most appropriate comparison to be made, we have amalgamated the 13 classes in the detailed classification into classes that best represent those contained within the Geodata3 dataset.

A cursory visual inspection of the two maps represented in Figure 6 shows that there are vastly less linear disturbance features contained with the Geodata3 road network than represented in the digitised maps. Data presented in Table 7 shows that the total length of roads and tracks (2,908 km) is less than a third of that measured from the digitised data (10,800 km). Similarly the number of stream intersection points is around a third (2631 cf 8956). Most significantly, however, the features that are missing are the myriad small tracks, fencelines and minor roads that are ubiquitous throughout the landscape. Clearly the implication from this comparison is that a similar exercise of systematically digitising all disturbance features throughout the remainder of the eastern Cape must be undertaken as a matter of priority. However, there is a reasonable spatial relationship between the two datasets, which suggest that the Geodata3 dataset can be used to provide an overview of the relative extent of roads and tracks across the entire eastern Cape.

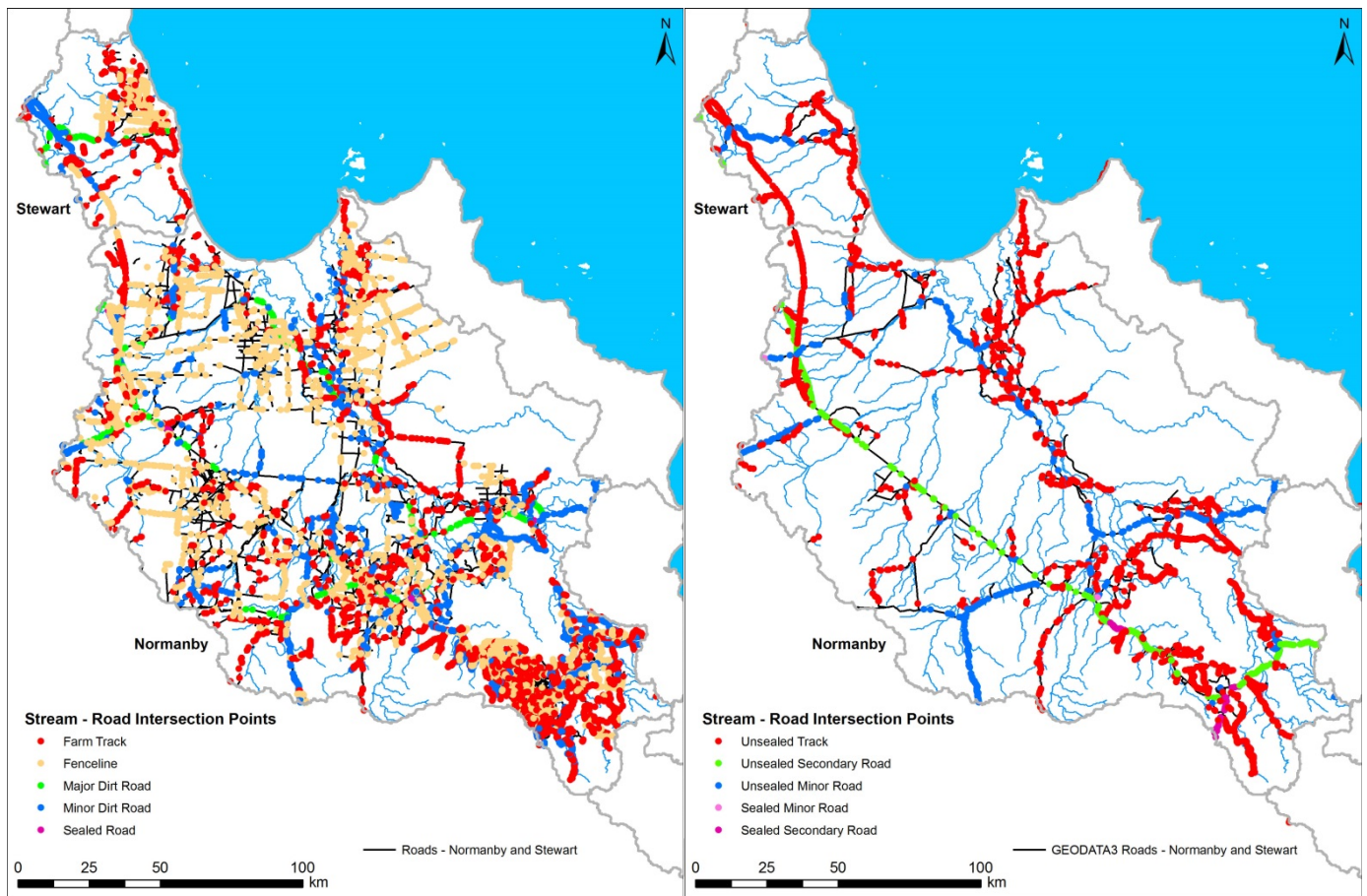


Figure 6 Comparison between the amalgamated road/linear disturbance network intersecting the 1:100K stream network as digitised in this study (left) and the available published road network from the nationally standardised 1:250K Geodata 3 topodata (right).

Table 7 Road and tracks lengths as represented by the Geodata 3 topodata

Normanby Stewart GEODATA 3			
	Feature Type	RoadLen (km)	RoadLen (%)
1	Unsealed Track	2035.15	70.0%
2	Unsealed Secondary Road	246.94	8.5%
3	Unsealed Minor Road	578.77	19.9%
4	Sealed Secondary Road	42.31	1.5%
5	Sealed Minor Road	4.77	0.2%
	Total	2,908	100%

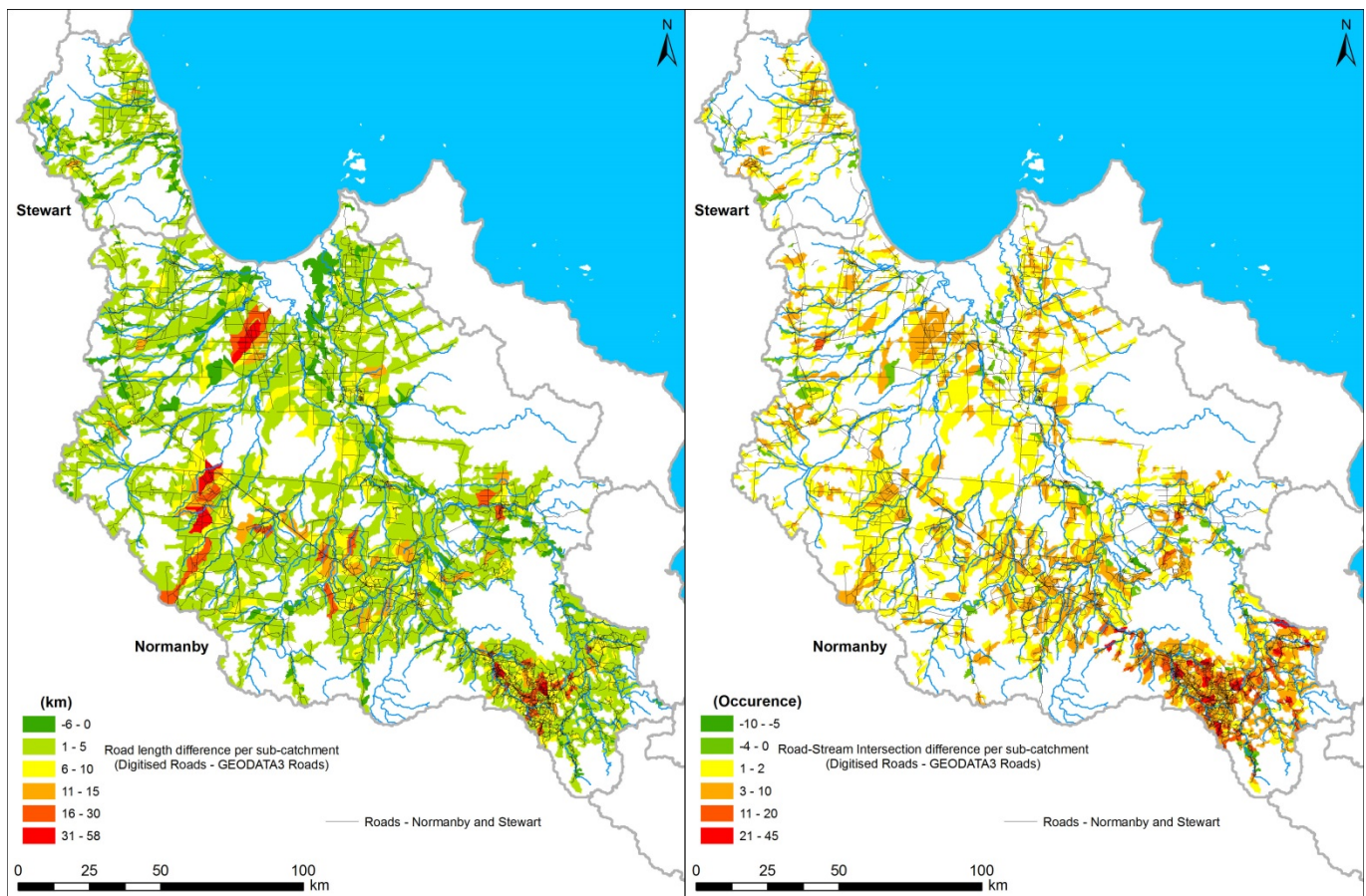


Figure 7 Difference maps showing the extent to which the Geodata 3 topodata under represents a more realistic representation of the extent of linear disturbances within the Normanby and Stewart catchments digitised from Google Earth imagery. The AHGF sub-catchment polygons were used as the basis for measuring the difference in linear extent of roads/tracks/fences (Left) and the total number of stream intersection points (right).

3.1.5 Gullies

The degree to which gullies dominate the sediment budget in the Normanby catchment has been well described in Brooks et al., (2013) and Shellberg and Brooks (2013), as have the methods by which gully distribution was mapped and sediment yields quantified. A management prioritisation for gullies within the Normanby catchment has been outlined in Brooks et al., (2016). In this section we have included gully disturbances for completeness, in the Normanby, given that they are the dominant anthropogenic sediment source, in concert with ephemeral channels, but these other documents should be referred to for management planning associated with gully erosion. In this exercise we have reanalysed the gully data presented in Brooks et al., (2013) into a similar format to that used for the road/stream intersections in Figure 5. More data on the relative contributions of sediment and nutrients from different linear disturbance classes is needed before we can directly compare these various disturbances.

Having mapped the distribution of linear disturbance features in the Normanby catchment, it is interesting to note that there is not a strong relationship between the linear disturbance network and the mapped locations of active gullies. This would tend to confirm that the highest order controls on the location and distribution of gullies are the nature of the soils and the landscape setting, and that their reactivation post-European settlement is likely to be predominantly driven by cattle grazing pressure. This is not to say that these linear disturbance features are not themselves contributing to the initiation and acceleration of gully erosion, but that these other factors are higher order controls in this process.

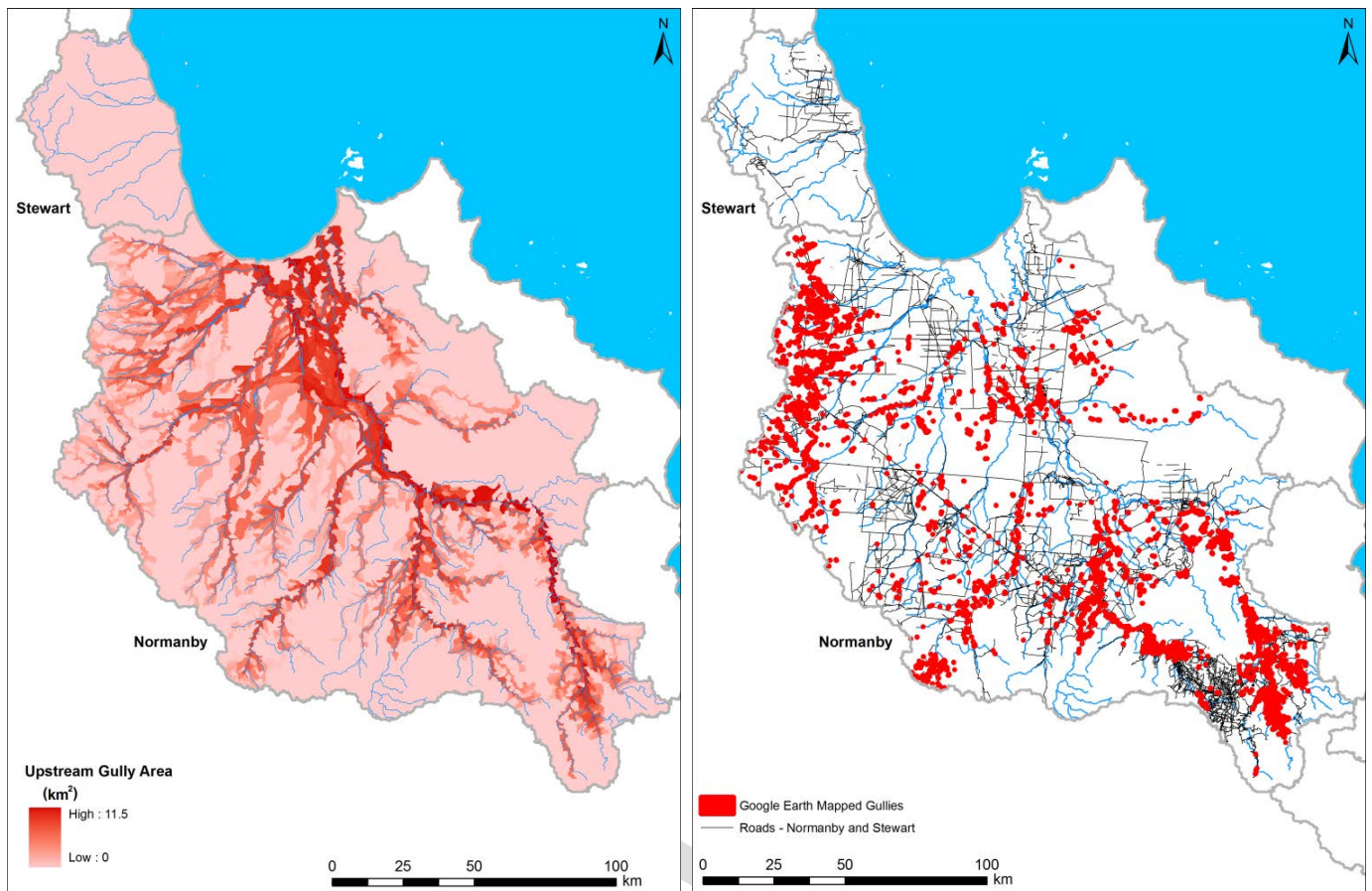


Figure 8 (left) Map of the upstream cumulative gully area for each sub-catchment. This indicates the relative impact of gully erosion on different tributaries within the Normanby Basin, highlighting the West Normanby River as the key hotspot for gully erosion (as outlined in Brooks et al., 2013). The map on the right shows the relationship between mapped gully locations and the road/track/fenceline network – showing a relatively poor relationship between the two. This is not to say that roads, tracks and other linear disturbances don’t trigger gullies, but rather that there are some higher order controls that dictate the location of large mapped gullies (e.g. soils, topographic location).

3.2 Whole of Eastern Cape Disturbances

Despite the limitations of the common datasets that we have for the full extent of the Eastern Cape catchments, the following summarises the relative landuse disturbances within the region using a similar approach to that used at higher resolution in the Normanby and Stewart catchments. These data should be considered as a bare minimum indication of potential relative impact of different landuse categories between the various catchments.

As can be seen in Table 8 the dominant landuse type is grazing on unimproved native pasture, with National Park and traditional Indigenous land comprising the vast bulk of the landuse categories. Given that many National Parks are old pastoral leases as is much of the traditional land, cattle (and other feral animal) impacts have been experienced across virtually the entire landscape, and for the most part, these impacts continue to this day to varying degrees - even within National Parks.

Of the other landuse categories, we have amalgamated the plethora of classes of intensive agriculture and horticulture into a single category of “intensive agriculture” and isolated the two other key landuse categories of urban and rural residential (Figure 9). By focusing on these three categories, we believe this represents the key landuse types that are likely to be having an impact on GBR water quality (Figure 11), over and above the other grazing sediment sources, associated with gully and channel erosion. These categories are the ones that need to be watched and closely monitored if water quality decline is to be minimised into the future.

Table 8 Summary of the major land use classes across the Eastern Cape catchments.

	Category	km ²	Percent
1	Grazing native vegetation	15557.69	36.2%
2	National park	12694.83	29.5%
3	Traditional indigenous uses	9270.52	21.5%
4	Other conserved area	2803.03	6.5%
5	Managed resource protection	1369.04	3.2%
6	Marsh and wetland	980.92	2.3%
7	Intensive Agriculture	33.25	0.08%
8	Urban and Rural Residential	5.60	0.01%
9	Other	311.24	0.72%
Total		43026.12	

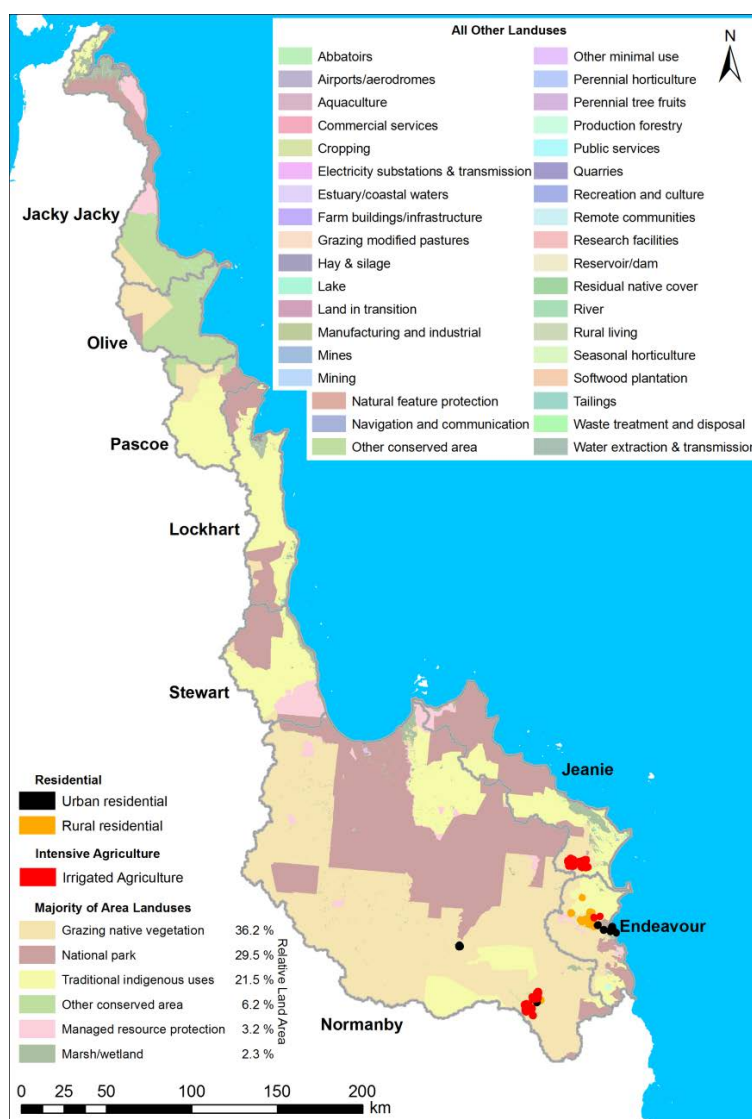


Figure 9 Land use map of the Eastern Cape York (QLUMP 2013) highlighting the key landuses that are likely to be having an impact on GBR water quality; intensive agriculture (red); urban residential (black); rural residential (gold). Note that not all settlements are represented in the residential class

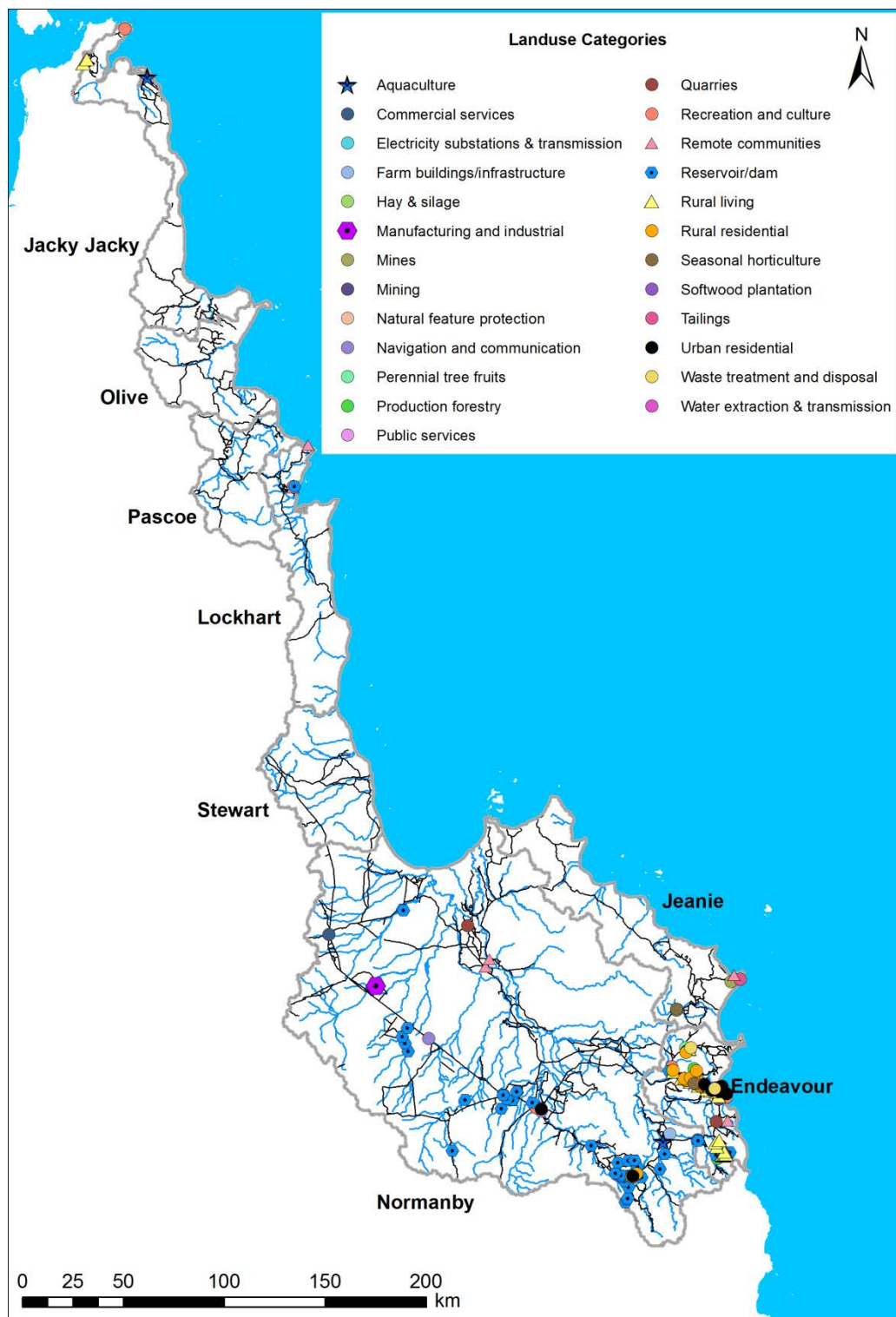


Figure 10 Location of land use categories (QLUMP 2013) covering relatively small areas. Shown here to complement figure 9 where the small areas are not visible.

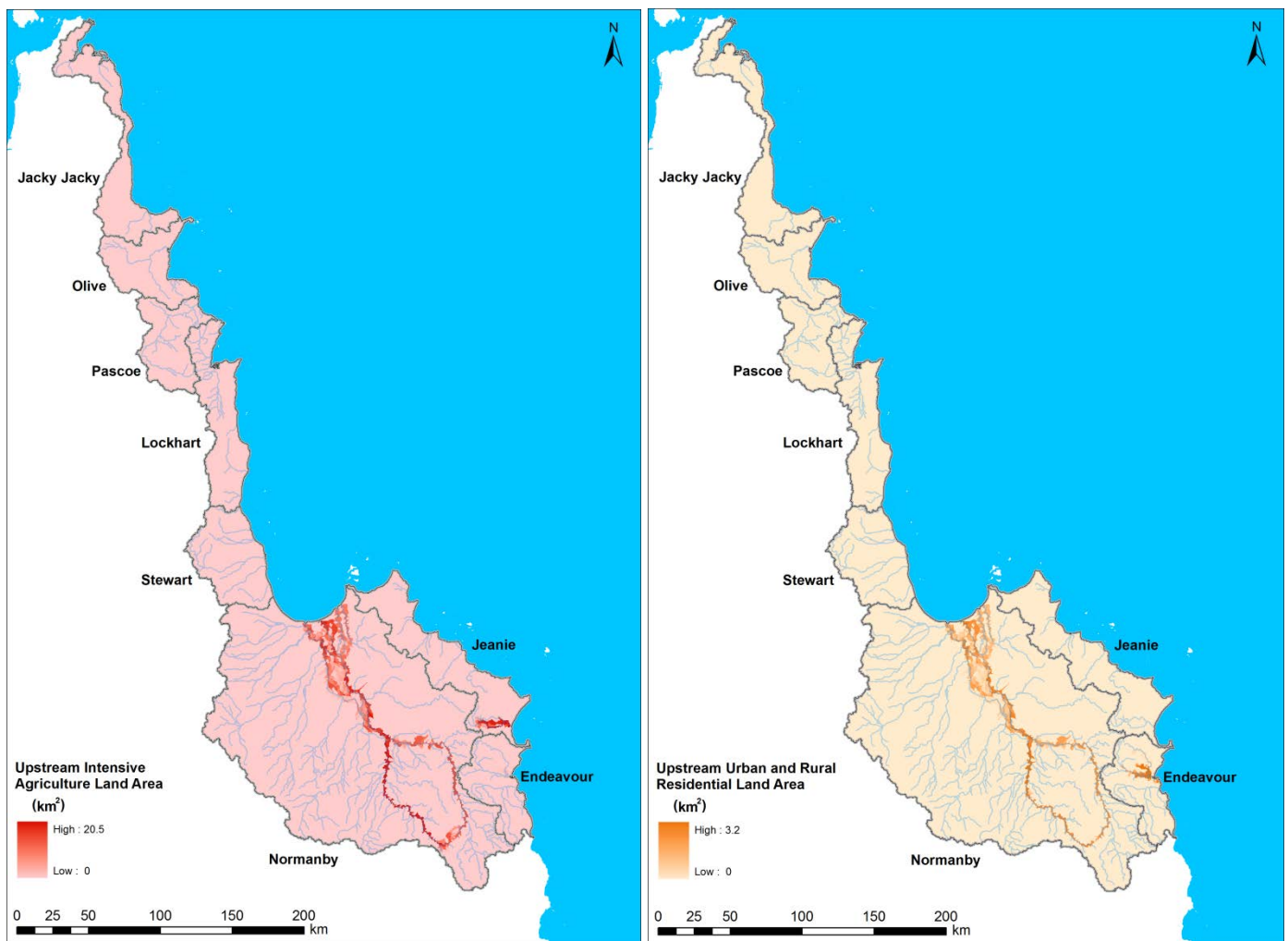


Figure 11 Potential upstream influence on water quality associated with Intensive agriculture (left) and urban/rural residential (right).

3.2.1 Roads as a Proxy Disturbance Index for the Eastern Cape

Given the limited availability of high resolution datasets on various disturbances across the whole region, and taking into account all caveats outlined above regarding the accuracy and completeness of the available road data set for the Eastern Cape, the road data is probably the best available indicator of the relative degree of disturbance for the whole region, particularly when coupled with the intensive landuse data shown in Figure 11. The map shown in Figure 12 shows the various stream intersection points across the region, while the two maps in Figure 13 show the potential influence on the stream network associated with the road network, in terms of the total length of road upstream of each AHGF sub-catchment and the total number of stream intersection points. Whilst these maps are a minimum representation of the linear disturbance network, they serve to highlight that there are few locations where some degree of human impact has not occurred.

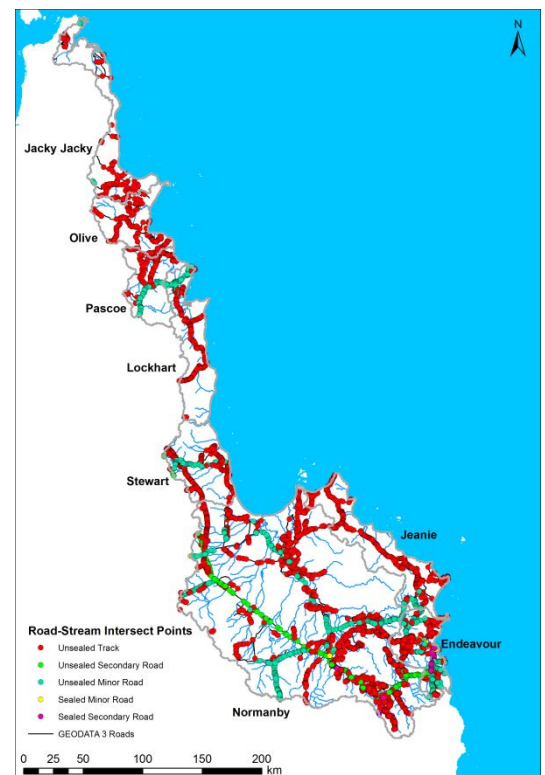


Figure 12 Map of the Eastern cape showing the road stream intersection points for the 5 main road classes within the Geodata3 dataset.

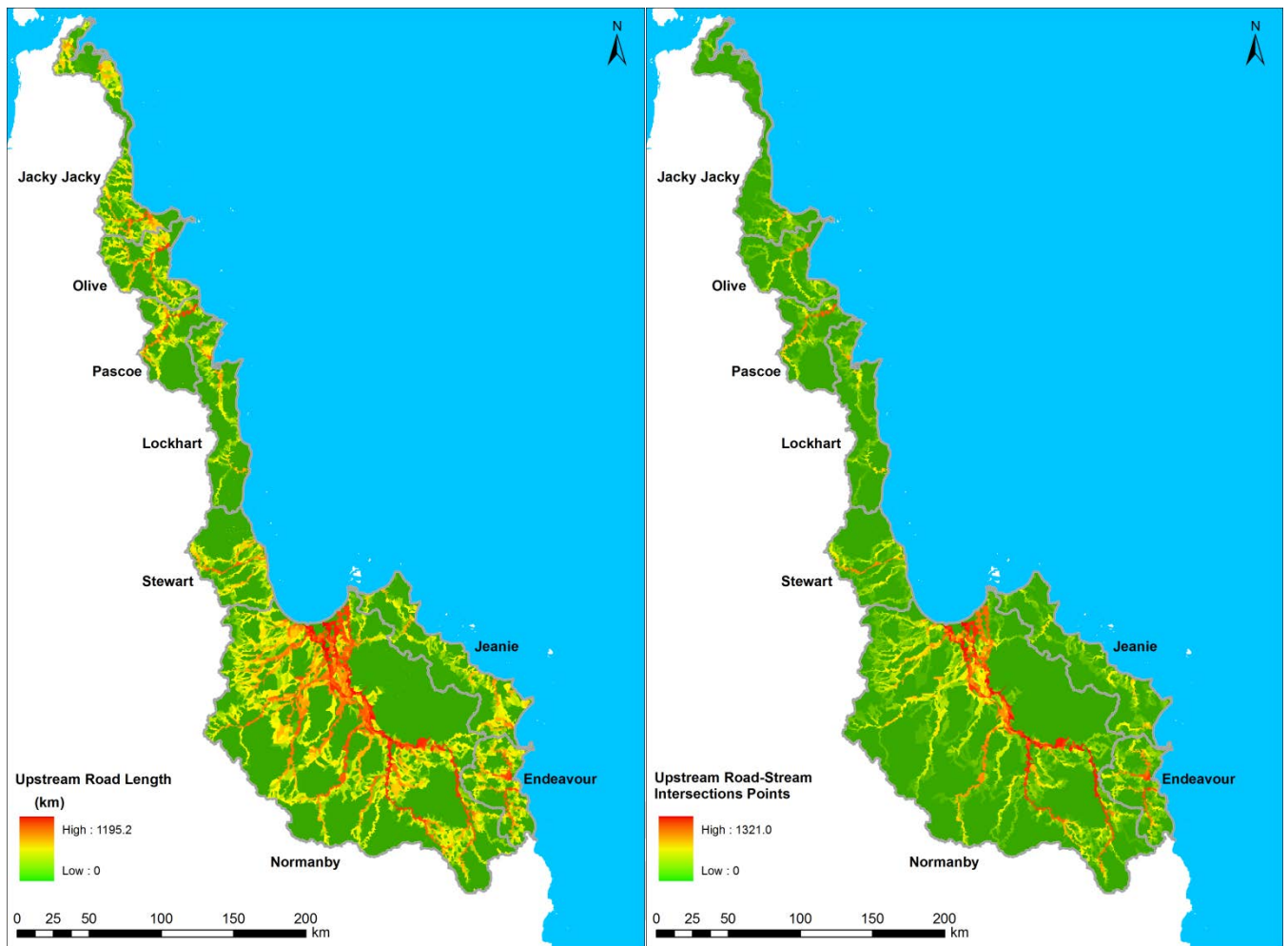


Figure 13 Maps of the upstream extent of roads for each of the ~19,000 AHGF sub-catchments in the eastern Cape. The map of the left shows the upstream extent of road length, while the map on the right shows the number of road/stream intersection points. These maps serve as a proxy for relative landuse pressure on the different catchments draining to the Northern GBR.

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4 Appendices

4.1 Appendix 1

Quantifying roads, farm tracks, fences and other disturbances in the Stewart and Normanby Catchments

This document outlines the methods used for digitising and classifying a range of linear disturbance features within the Normanby and Stewart basins all of which are potential threats to water quality in the northern GBR. This mapping and associated analysis on its own doesn't quantify the precise degree of threat posed by any one disturbance feature, rather it forms a base dataset which serves to highlight the relative degree of disturbance across landscape, and forms the basis for future on ground quantification of the relative impact of each of these features. Time and resources didn't allow for the completion of this exercise across the entire eastern Cape York region, so we have focused the detailed analysis on two key catchments (the Normanby and Stewart Basins) and compare this with a similar type of analysis for the remainder using the readily available published datasets contained within the GEODATA TOPO 250K Series 3. This exercise serves to demonstrate that the existing published datasets (of which there are a number of others) significantly under represent the true degree of disturbance in the landscape from linear and other disturbance features. We investigated all freely available road datasets and found all to be deficient, albeit not in a consistent fashion. This being the case, we would strongly recommend that similarly intensive mapping is conducted across the remainder of the Cape in due course. Such an exercise needs to be updated every few years as new imagery becomes available.

The beauty of the approach undertaken in the Stewart and Normanby Basins is that it simply utilises free publically available high resolution Google Earth imagery as the basis for systematically mapping a range of disturbance features. Having established a basis for classifying the different linear (and non linear) disturbance feature, such an exercise could be readily undertaken across the remainder of the Cape. It is recognised that the spatial distribution of the imagery is not always consistent (i.e. the image resolution varies across the catchments) and that the image dates are not always consistent either. Figure 14 shows the distribution of high resolution Astrium data (~50cm) against a background of 5m Spot data. For this reason, coupled with the fact that Google Earth is being constantly updated as new imagery becomes available, we would recommend that mapping of this sort should be updated every few years. Not only will this capture information contained within updated image layers, but it will enable temporal trends in disturbance to be identified and tracked.

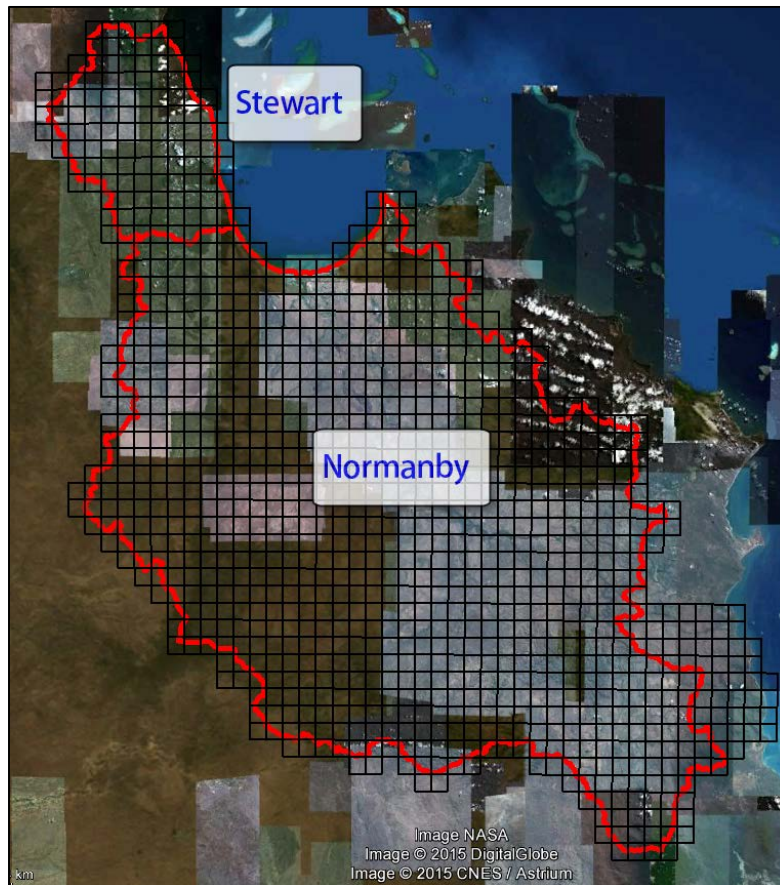


Figure 14 A 5km by 5km grid was overlaid on the Stewart and Normanby catchments to assist locating roads, fence lines and other features.

Google Earth provided high resolution imagery over the majority of the study area, allowing scanning with an apparent eye altitude of 1000m or less to easily detect isolated vehicle tracks with distinctive parallel wheel tracks. Where imagery was not of such high resolution an eye altitude of around 2km was used. Reflective watercourse bottoms and animal tracks did sometimes appear similar to vehicle tracks, but close inspection would reveal the more orderly nature of man-made tracks compared to the more meandering nature of water sculpted paths or animal tracks.

Potential pitfalls

Given the rapid pace of development beginning to occur in some parts of the Cape, care needed to be taken to ensure that the most recent image layer was being used within Google Earth when the mapping was undertaken. In some instances the default imagery wasn't necessary the most up-to-date, but more recent imagery was available within the historical image tool. This can provide very useful information as to recent development activities in parts of the landscape. Examples of recent developments are shown in Figure 15 and Figure 16. As a trap for the unwary, Google Earth Pro – always shows the most recent imagery on the default layer whereas standard Google Earth does not necessarily.



Figure 15 Default imagery shows a paddock with a variety of minor farm tracks in imagery dated 8/1/2013 (Cook paddock Springvale Station on the East Normanby River). Compared with more recent imagery from 10/23/2015 which shows a large farm dam has been built between the two time steps.

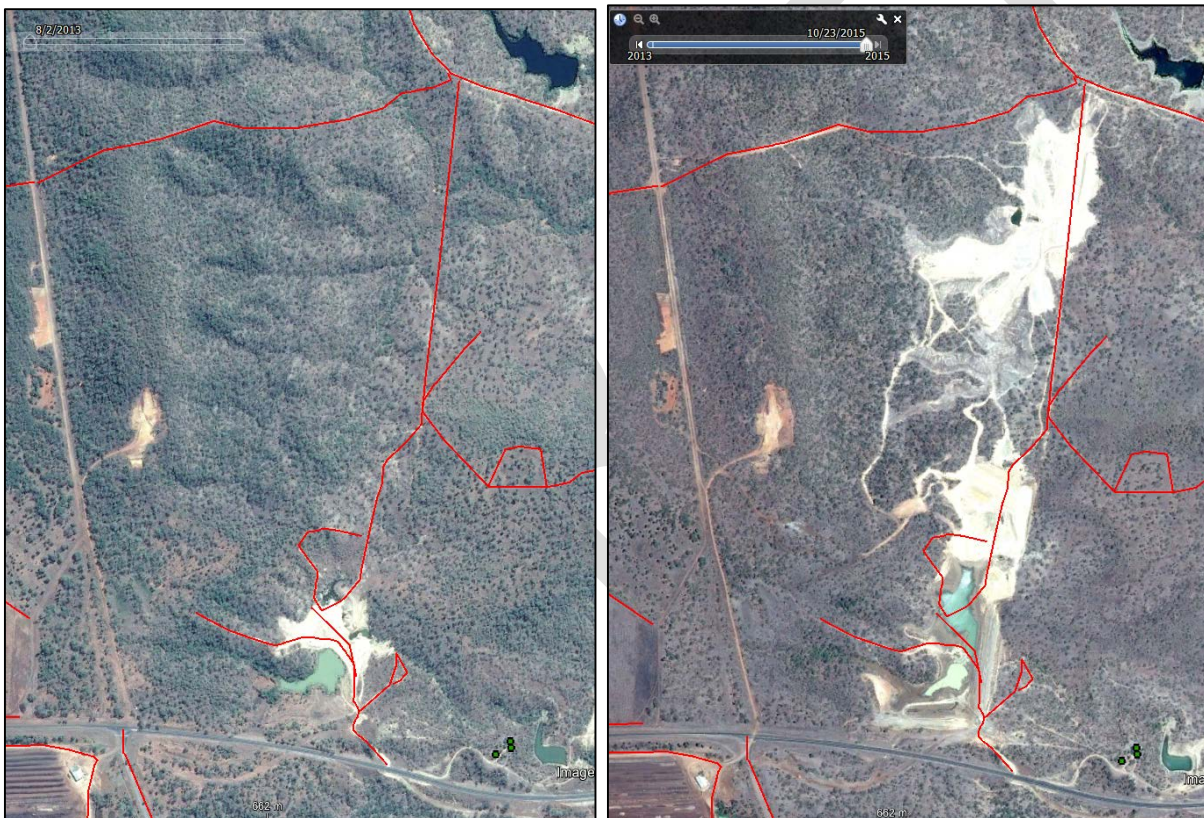


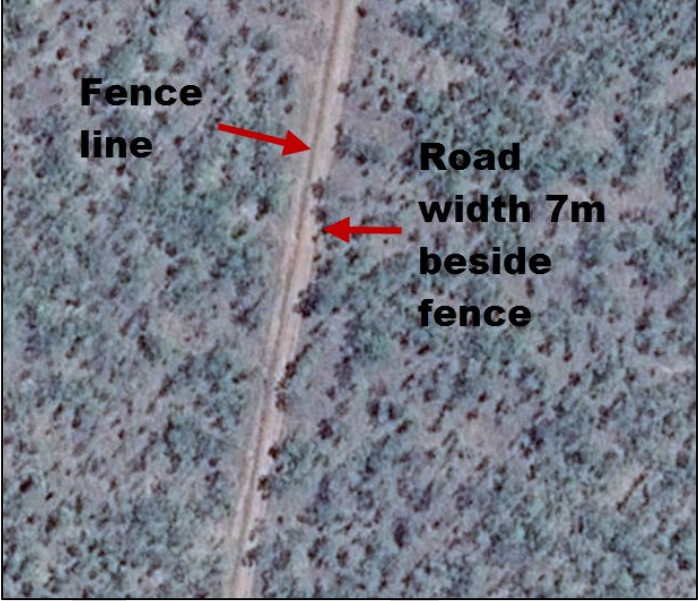
Figure 16 On left a fence and minor farm track travelling cross country to a small dam is visible in standard Google Earth imagery dated 8/2/2013, and was digitised and classified as such. Imagery dated 10/23/2015 shows a major dam construction site and associated disturbance 4km north east of Lakeland.

- Table 9 Summary characteristics of the 13 classes of linear disturbance features digitised from Google Earth. An additional 4 categories of disturbance features were also mapped but not included in the linear disturbance feature mapping.

Classes		Description	width (m)	Amalgamated Classes
1	Farm tracks major	Unsealed, evidence of well used surface often joining roads to buildings, or main access to strategic farm assets. Grass strip between wheel tracks absent.	3-8 m	Farm Track
2	Farm tracks minor	Surface alternates from solid graded to 2 wheel tracks - vegetation cover may be present. Provide access to water points, distant parts of country.	2-3m	Farm Track
3	Fence lines	Obvious cleared fenceline that does not have compelling evidence for a road alongside.	4-10m	Fenceline
4	Fence lines overgrown	Seen as a discernible line through vegetation, may go for several kilometres. Bare ground along fence not often visible.	2 to 4m	Fenceline
5	Fence lines with road	Obvious bulldozed clearance that includes a road alongside.	10 to 14m	Fenceline
6	Main dirt roads	Unsealed, named developmental roads, dual carriageway, >15m wide	>10m wide	Major Dirt Road
7	2 wheel tracks	Track seen as 2 wheel lines, indicating occasional use. Often very remote.	Approx. 2m	Minor Dirt Road
8	Minor dirt roads	Unsealed, single carriageway, solid appearance, includes driveways to farms	5-10m	Minor Dirt Road
9	Railway Line	Embankment, Overgrown by now.	20 to 30m	Minor Dirt Road
10	Secondary dirt roads	Unsealed, table and V drains to divert roadside drainage, single lane or dual carriageway	10-20m	Minor Dirt Road
11	Track	Wide clearance of vegetation, often without evidence of active road. Possible powerline easement or seismic line, width variable.	>15m	Minor Dirt Road
12	Highway	Tarsealed, white line, dual carrigeway, bridges	20-25m	Sealed Road
13	Tar sealed roads	Tarsealed, white line optional, in towns or rural zone.	8-10m	Sealed Road
14	Quarry	Obvious working pad for extraction or storage of material.	30-200m	na
15	Airstrip	Landing strip	30-120m	na
16	Contour berm	Soil conservation berms across contours of paddocks		na
17	Dam	A dam across a watercourse	30-40m	na

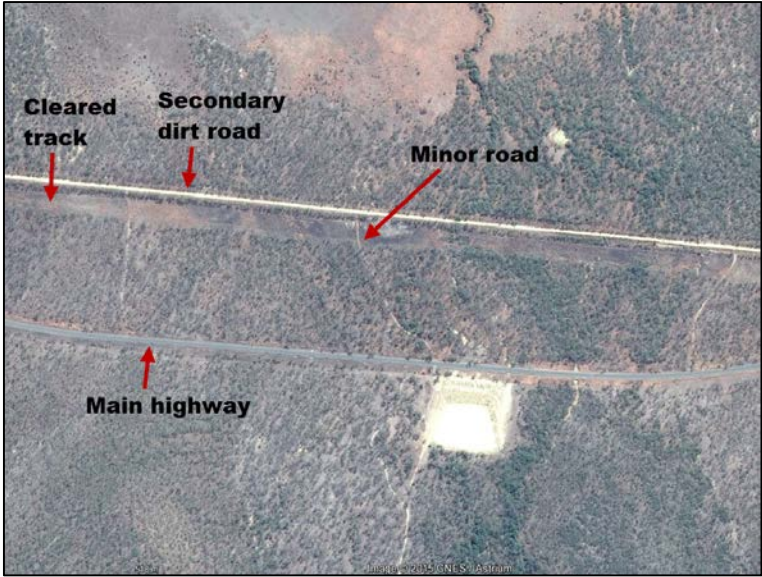
• Table 10 Examples of features for each class

Classification	Description	Criteria	Width in m
1	Farm tracks major	Unsealed, evidence of well used surface often joining roads to buildings, or main access to strategic farm assets.	3-8m
			
2	Farm tracks minor	Surface may alternate from solid graded to 2 wheel tracks - vegetation may be present up center of track. Provides access to water points, distant parts of country. Width variable as multiple tracks may skirt bogs, gullies, but mainly one and a bit vehicle width wide.	2-3m
			

5	Fence lines with roads beside	Obvious bulldozed clearance that includes a road alongside. Has characteristic linear features.	10 to 14m
 			
6	Main dirt roads	Unsealed, named developmental roads, dual carriageway, bridges	>10m wide
Peninsula Developmental Road beyond the tarseal 			

7	2 wheel tracks	Track seen as 2 wheel lines, indicating occasional use. Often very remote.	Approx. 2m
			
8	Minor dirt roads	Unsealed, less than full dual carriageway, solid appearance, well-travelled, includes driveways to farms	5-10m
			

9	Railway Line	Abandoned Cooktown-Laura railway embankment, overgrown. Sinuous path.	20 to 30m
			
10	Secondary dirt roads	Unsealed, cutouts to divert water, single lane or dual carriageway, bridges	10-20m
WELCOME ROAD  BATTLE CAMP ROAD 			

11	Track	Wide clearance of vege without evidence of active road. Possible powerline clearance? Old road alignment. Width variable.	>15m
 Cleared track Secondary dirt road Minor road Main highway  40m wide clearance between fence and trees			
12	Highways	Tarsealed, white line, dual carriageway, bridges, formed shoulder	20-25m
Peninsula Developmental road near Lakeland   Image © 2013 CNES / Astrum			

13	Tar sealed roads	Tarsealed, white line optional, in towns or rural zone.	8-10m
Residential streets in Lakeland 			
14	Quarry	Obvious working pad for extraction or storage of material.	Width variable, 30-200m
			

15	Airstrip	Cleared land for landing planes on - long and wide	Width variable. 30-120m
			
16	Contours	Soil conservation berms across fall line of paddocks	
			

17	Dam across water course	A dam across a watercourse	30-40m
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4.2 Appendix 2

Cumulative upstream summation of sub-catchment variables

The spatial distribution of disturbance factors within the landscape describes where something occurs but does not provide information as to the downstream accumulative effect on water quality. In this study we used the hydrologic sub-catchments within the AHGF (Australian Hydrologic Geospatial Fabric, <http://www.bom.gov.au/water/geofabric/index.shtml>) dataset as the framework to sum up each disturbance factors upstream of every sub-catchment. The maps shown in the body of the report above that describe an “upstream” disturbance factor have been calculated in this way. Table A21 shows the number of sub-catchments among the catchments of the whole Eastern Cape.

Table A2.1 Number of sub-catchments across the Eastern Cape catchments.

	Catchment	AHGF Sub-Catchments
1	Endeavour	1005
2	Jacky Jacky	1373
3	Jeanie	1739
4	Lockhart	1889
5	Olive	979
6	Pascoe	855
7	Normanby	9626
8	Stewart	1889
	Total	19355

All upstream summations of this type show a general pattern of low values in the headwater streams and large values in the lower sections of the main channels. The more specific patterns that might be seen in a map of the upstream accumulation of a particular disturbance is the relative burden it may have on different main tributaries. That is, how the spatial distribution of a disturbance interacts with the stream network.

A further step, not in the scope of this project, would be to evaluate the attenuation of the effect of each disturbance factor as a function of the distance downstream from the point or area of the disturbance. With downstream attenuation data the calculation of cumulative effect could include, not only the sum of upstream occurrences, but also the subtraction of a particular disturbance as its effect diminishes with increasing downstream distance.

In the lower part of the rivers of eastern Cape York, most particularly in the Normanby, there are bifurcations (diffluences) of the river system. In these instances the algorithms used here divide the upstream summed values equally among the downstream branches. An equal division is a somewhat simplistic, but any other approach would require evaluation or estimation of flow characteristics at diffluence junctions during a range of flows.