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Soil Erodibility – Fitzroy Basin

Synthesis Report – Project RP112G

Soil and Land Resources, Science Division

Queensland Government

Prepared by

Peter Zund and Luke Finn
Soil and Land Resources
Science Delivery Division
Department of Science, Information Technology and Innovation
PO Box 5078
Brisbane QLD 4001

Disclaimer

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Executive summary

This project aims to produce a dataset that ranks soil erodibility across the Fitzroy Basin to better understand sources and processes of sediment run-off to the Great Barrier Reef. This project will build on a similar study undertaken in the Burdekin Basin during 2012-2014 to help prioritisation of investment for policy, extension, industry and scientific modelling under the Reef Water Quality science program (RWQ science program). This project supports the implementation of the Reef 2050 Plan.

Soil erodibility is defined for this project as the susceptibility of soil to erosion by water and wind. It is a composite expression of those soil properties that affect the behaviour of a soil.

The project plans to integrate and collaborate with other RWQ science program projects. The expected outputs from this integration are;

- Identifying research and information gaps related to soils and erosion
- Identifying areas with high soil erodibility at the sub-catchment level to improve prioritisation of investment in the basin
- An integrated understanding of soil erodibility
- Improved spatial information of soil erodibility
- Expanded online *Erodible Soils Report* (FORAGE Reports) that includes the Fitzroy basin
- Specific information available to Fitzroy land management programs
- Improved soil data available to the *Paddock to Reef* sediment load modelling program
- Improved soil data to other reef projects to assist with validation or support of their projects.

This report provides a summary of the land resource assessment work that has been undertaken in the Fitzroy. Approximately 80% of the Fitzroy basin is covered by three broad (1:500,000) land system surveys. These broad scale surveys do not have the necessary soil attributes per mapping unit to determine soil erodibility and the resolution of the mapping units is much coarser than required.

Soil erodibility will be predicted using the same model developed for the Burdekin basin. The model requires a set of spatial soil attribute data layers that cover the entire Fitzroy basin including the Boyne and other coastal catchments between Gladstone and St. Lawrence in a consistent 100 X 100m grid at six fixed depth intervals. The soil attribute layers will be created from existing and new soil samples to be collected. These soil attribute layers will be created using a digital soil mapping approach that uses soil profile physical and analytical data and environmental covariates. Covariates represent the terrain, soil parent material, geomorphology and climate of the Fitzroy.

The soil erodibility model predicts both surface soil stability and subsoil (B horizon) erodibility. The two predictions are combined into an inherent soil erodibility product. Products are planned to be freely available on Queensland Government web portals from 2017.

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Background information

The Reef Water Quality science program (RWQ science program) is designed to assist with the adoption of improved land management practices that will reduce the levels of sediment, nutrients and pesticides moving offsite from agricultural properties and impacting on the Great Barrier Reef (GBR).

Sediment has been identified as a major threat to the GBR lagoon water quality from the grazing areas within the Burdekin and Fitzroy basins (Kroon et. al. 2013). Sources of sediment have been found to be highly variable within and between these basins.

Mapping erodible soils in grazing lands is a project under the Queensland Department of Environment and Heritage Protection RWQ science programs supporting the implementation of Reef 2050 Plan. The objective of this project is to map soil erodibility in the Fitzroy basin in a similar way to the study completed in the Burdekin basin in 2014 (Zund and Payne 2014). This project was recognised as a priority under the RWQ Research Development and Innovation Strategy.

Soil erodibility is *a soils susceptibility to erosion by erosive agents (water and wind). It is a composite expression of those soil properties that affect the behaviour of a soil (mechanical, chemical and physical characteristics of the soil). Soil erodibility here is independent of the other factors influencing soil erosion such as topography, land use, rainfall intensity and plant cover, but may be changed by management.*

The most highly erodible soils are those that are most easily detached and transported by erosive forces. High soil dispersibility is a good indicator of high soil erodibility (Houghton and Charman, 1986).

Development of maps which indicate erodibility is a key step in identifying potential erosion sources within the landscape. This project will develop a dataset that identifies soils inherently vulnerable to erosion for use in prioritisation of investment and policy making, grazing land management extension and as a data source in other reef science projects in the Fitzroy basin.

Study area

The study area covers the Fitzroy basin which is located in the Central Queensland Highlands and the adjoining coastal catchments and islands between Gladstone and St. Lawrence (156,000 km^2). The Fitzroy basin is 142,665 km^2 and is the largest river basin flowing into the GBR, with the river mouth situated near Rockhampton. The Fitzroy basin is also the largest river system draining to the east coast of Australia with six major catchments; Fitzroy, Dawson, Isaac, Mackenzie, Comet and Nogoa (Figure 1).

Figure 1 - Catchments of the study area

The study area is within the subtropical climate zone as delineated by the Koppen climate classification (after BoM, 2005). Seasons are usually characterised by hot, humid summers where rainfall is usually dominant and warm to cool, moderately dry winters (particularly inland parts). The basin has a relatively steep rainfall gradient to the west (Figure 2).

The Fitzroy basin has a population of about 210,000 with approximately 80,000 based in Rockhampton (ABS, 2013). Agriculture is the dominant industry with 90% of all land used for food and fibre production (Figure 3). Grazing is the dominant agricultural land (85%). Cropping occupies five percent of the Fitzroy of which one-fifth is irrigated. Agriculture from the basin contributes $1.2 billion annually to the Queensland economy and 20% of the state’s Beef cattle herd is located within the Fitzroy. Mining is the other dominant industry in the region with 40 of Queensland's 55 coal mines located in the Fitzroy

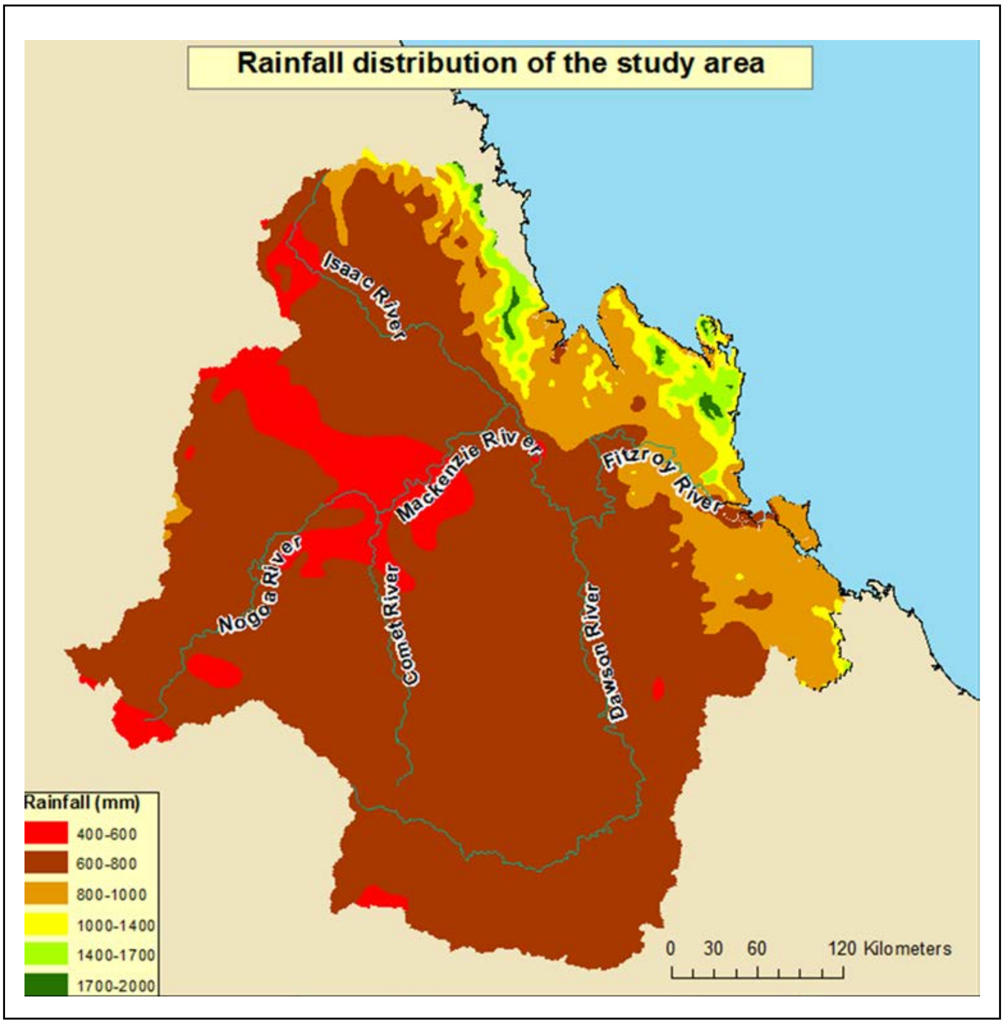

Figure 2 - Rainfall distribution of study area

Objectives

This project will complement a similar study completed in the Burdekin basin. The project will use existing data and new soils data collected specifically for this project. From the soil data a series of soil attribute maps across the study area will be created. These soil attribute maps will be used with a model of soil erodibility to produce surface, subsoil and overall soil erodibility dataset. This dataset ranks soil erodibility across the Fitzroy basin. Associated with this dataset will be a user guide and data for the FORAGE reporting system.

The products created by the project will be able to assist in identifying research and information gaps related to soils and erosion in the Fitzroy basin. The specific soil information will assist extension programs to reduce sediment runoff through land management initiatives.

This project will help prioritise investment for policy, extension, industry and Paddock to Reef modelling under RWQ science program and supports Reef 2050 Plan. This increased understanding of soil erodibility will assist with soil specific recommendations for cost effective management of erosion sources.

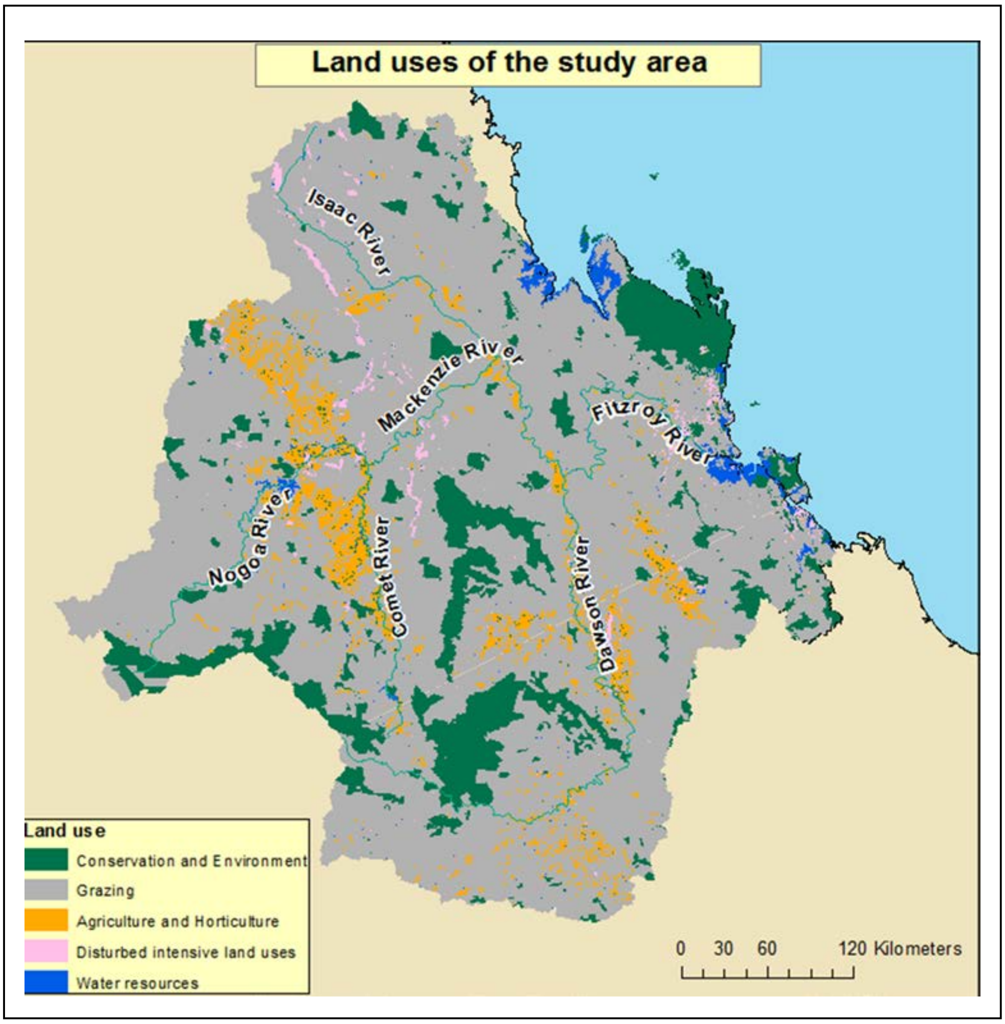

Figure 3 - Land uses of the study area

Soils and soil erosion in the Fitzroy Basin

The Fitzroy basin was the main focus of the Queensland Government Brigalow Land Development Scheme introduced in 1959 to develop the grazing industry in Central Queensland. Brigalow scrub generally grows on clay soils and these soils dominate the basin. In addition to these dominant clay soil plains, the basin also has a significant area of rocky shallow sandy soils in mountainous areas mainly in the south. Some of these mountains are capped with basalt flows. North of these mountains there are remnants of an elevated deeply weathered sedimentary plain with texture-contrast and gradational earthy soils. Where the elevated plain has been stripped away the extensive undulating plains of clay soils with Brigalow occur as previously mentioned. The eastern part of the basin is dominated by low granite ranges with a narrow flat coastal plain.

Soil and land system mapping

Some of the first soil surveys in the basin were undertaken in the 1950’s by Isbell (1954 and 1957) and Hubble (1961). These investigations and maps covered mainly the Brigalow lands in the Dawson, Don, Callide and Dee catchments. They involved limited investigations and were under taken to determine the development potential of public lands.

During the 1960's, CSIRO undertook the first comprehensive land inventory of the area, mapping the whole Fitzroy basin. They investigated the geomorphology, soil, vegetation and pasture potential of the area and produced land system maps at a scale of 1:500,000 (Gunn *et.al.* 1967, Story *et.al.* 1967 and Perry 1968).

Since these investigations there has been large scale land clearing under the Fitzroy Basin Land Development Scheme (Brigalow Scheme). Turner (1975) identified that the broad scale (1:500,000) land system surveys while useful for assessing development across large areas but were limited in on ground detail and impractical for property planning. Problems with a lack of detailed landscape and soils data meant land development in many areas was a case of trial and error, particularly in the early years. Attempts to monitor or model landscape change since development commenced in 1962 has been limited by an absence of data at a fine enough scale (Burgess, 2003).

Shields and Turner (1985) conducted a review of the availability of land resource data in Central Queensland and proposed a program of soil mapping at 1:100,000 scale to resolve land use issues. The program would provide a sound basis for land management decisions, development planning and soil conservation purposes. Due to the large area requiring mapping, a series of priority areas were chosen from which baseline data could be extrapolated. These priority surveys were;

- Nebo-Broadsound (Windeyers Hill 1:100,000 map sheet, Burgess 2003) which is typical of the Isaac-Connors and Mackenzie catchments.
- Central Highlands district (Kilcummin 1:100,000 map sheet, Shields and Williams 1991) which is in the Suttor and Isaac catchments.
- Dawson-Callide district (Banana 1:100,000 map sheet, Muller 2008) which is in the Callide, Dawson, Dee and Don catchments.
- Emerald district (Emerald 1:100,000 map sheet, Irvine SA and Tuck GA Unpublished) which is in the lower Nogoa catchment.

In addition to the priority areas mapped above, a number of irrigation development specific surveys have been undertaken along rivers, including; the Dawson (McCarroll and Forster 1999), Fitzroy (Forster and Sugars 2000), Nogoa - Emerald Irrigation Area (various studies) and the Calliope and Yeppoon Areas (Ross 1999) mainly covering the better agricultural soils. McCarroll (1998) completed transects for irrigation potential in select reached of the Comet and MacKenzie rivers.

Most of the soil data collected for the above surveys has been captured in the Soil and Land Information (SALI) database which has some 64 legacy land resource assessment projects covering the Fitzroy basin (Biggs *et.al.* 2000). However, approximately 90% of the information for the Fitzroy basin can be gained from 15 land resource assessment projects. These assessments are the main source of information and data for the modelling and subsequent mapping of the soil erodibility in the Fitzroy basin. Associated with these projects are nearly 12,000 soil observations with about 25% providing the necessary analytical data that can be used for the purpose of the soil erodibility modelling across the study area.

Inadequacies of existing soil and land system mapping

To map soil erodibility for current reef science questions in grazing areas land resource information at a scale of 1:250,000 (McKenzie et.al. 2008) or better is required in grazing areas. Unfortunately, the only consistent scale of mapping available of nearly the entire basin is 1:500,000 (land system mapping). Mapping at an adequate scale is available for only 21% of the study area which severely

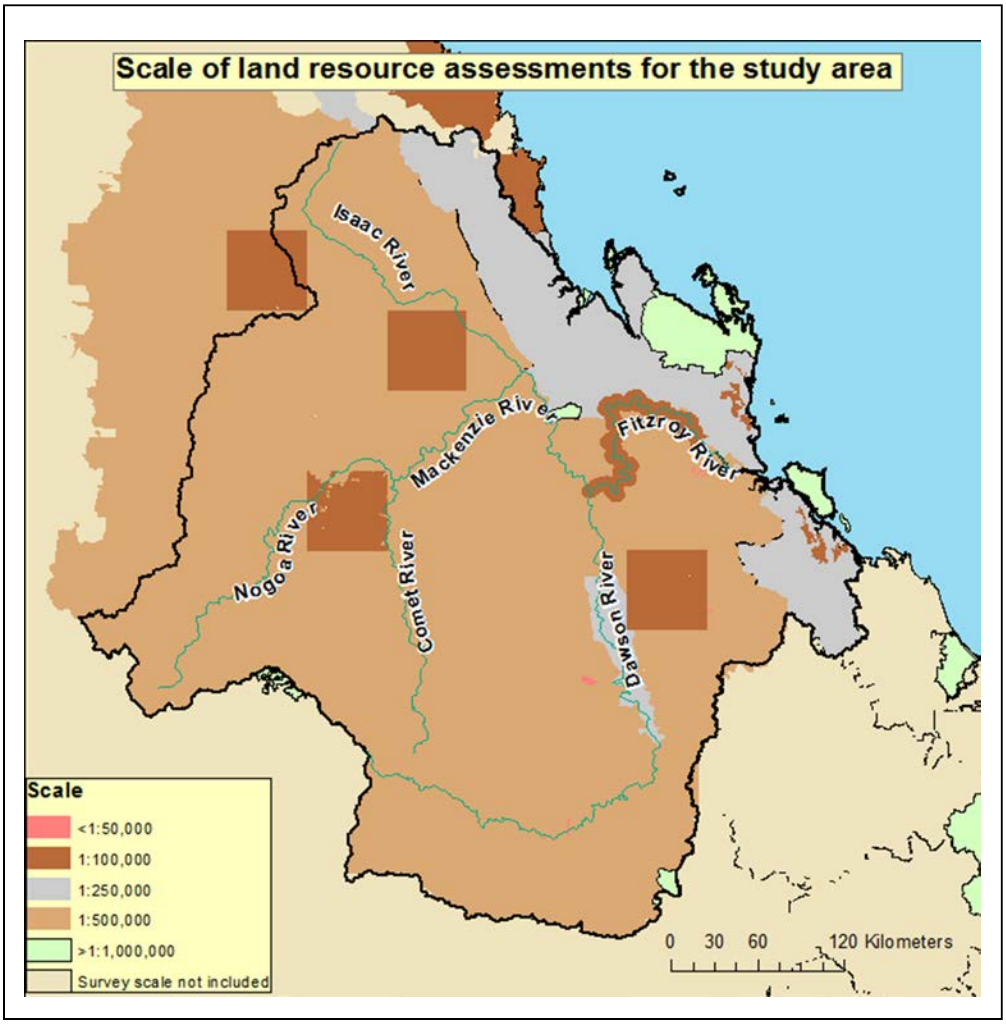

Figure 4 - Land resource assessments for the study area

degrades the ability to make accurate recommendations on erosion potential. Table 1 lists some of the past soil and land system surveys and Figure 4 shows their location.

The problem with existing soil survey information is two-fold; firstly, the mapping unit resolution varies widely between surveys (more detailed surveys have map units that cover a smaller area and hence maps are more detail, while broader surveys have map units that cover a large area and hence maps are less detail). Secondly, the soil information attributed to each mapping unit also varies between surveys, for example some surveys just have a map label (Land system) attributed to each map unit and soil information for that map unit is assumed to be that which is summarised in the accompanying report for the respective land system. While land suitability studies attribute each unique map unit with soil and land attribute information. Using current methodologies the second problem is more of a hindrance than the first problem. Map units can now be disaggregated or converted to a grid of cells, but the lack of soil attribute information is difficult to overcome. However most former soil surveys have described and analysed soil profiles at specific locations in a consistent manner and this project uses these site observations plus new site observations to produce soil attribute maps that can then be used to model soil erodibility.

Table 1- Soil and land system surveys in the Fitzroy basin

Soil Survey type	Scale	Survey name	Reference	Proportion of study area
Soil mapping of individual properties or small agricultural area	≤1:75,000	Soil survey of the Biloela Research Station, Central Qld. Soil Survey of the Brigalow Research Station, Central Qld. Soils and land suitability of the Gavial-Gracemere area, Central Qld Land suitability assessment and soils of the Calliope and Yeppoon areas.	Shields (1989) Webb (1971) McClurg (1999) Ross (1999)	<1%
Soil mapping of large agricultural areas	1:100,000	Soils of the Banana area, Central Qld. Land resource assessment of the Windeyers Hill area Land resource survey and evaluation of soils of the Kilcummin region Land Suitability for Irrigated Agriculture along the Fitzroy River Major soils of the Emerald 100,000 Map sheet	Muller (2008) Burgess (2003) Shield and Williams (1991) Forster and Sugars (2000) Irvine SA and Tuck GA (Unpub)	7%
Fine scale land system and land capability mapping	1:250,000	Soils of part of the Dawson River Valley, Central Qld. Land Systems of the Capricornia Coast Evaluation of Agricultural Land in the Taroom Shire Understanding and managing soils in the Nebo - Broadsound district,	Isbell (1957) Forster et al. (1995) Forster (1985) Burgess (1997)	13%
Broad scale land systems mapping	≥1:500,000	Land Systems of the Dawson Fitzroy area, Qld Land Systems of the Nogoa-Belyando area, Central Qld Land Systems of the Isaac-Comet area, Central Qld	Perry (1968) Gunn et al., (1967) Story et al., (1967)	79%

Soil erosion studies

In 2013 a multidisciplinary group of scientists reviewed and synthesised the scientific knowledge about water quality issues in the Great Barrier Reef (GBR) and concluded that the Fitzroy and Burdekin basins contribute 70% of the modelled total sediment load to the GBR lagoon and that three quarters of this load is from rangelands (Kroon *et.al.* 2013). Gully and stream bank erosion have been found to be the main forms of erosion suppling this sediment and the sediment is most likely to be clays (<16micron) (Kroon *et.al.* 2013).

Worldwide, gully erosion dominates grazing lands in the sub-humid / semi-arid (rainfall <750mm / year) climate zone such as Central Queensland (Ciesiolka, 1987).

There are several factors that influence erosion in the Fitzroy basin. The combination of these factors has led to the high erosion rates. These factors include;

- geology
- terrain
- rainfall variation and intensity
- land management practices affecting ground cover
- chemical and physical characteristics of the soils

In the Fitzroy, the Nogoa catchment has some of the worst soil erosion (Skinner *et al*. 1972) and is considered to be one of the worst eroded catchments in the 600-700mm rainfall belt of tropical Australia (Ciesiolka, 1987). The Nogoa was the first area in Queensland to be studied for soil erosion (Skinner *et al.* 1972). 11% of Nogoa catchment had severe gully erosion and 65% had sheet and rill erosion (Skinner et.al. 1972). The Nogoa catchment is highly susceptible to erosion due to the large area of shallow, dispersible, texture contrast soils, irregular and intense summer rainfall and grazing of native pastures (Skinner *et al.* 1972). Erosion is most prevalent in the north-western part of the catchment, on land characterised by the Drummond basin geological formation (Skinner *et al.* 1972) which consists of shallow marine and continental sediments (Olgers 1972).

The most susceptible land systems to erosion in the Nogoa catchment are the Craven, Hope, Portwine and Rutland Land Systems (Skinner *et al.* 1972 and Gunn *et al*. 1967). These land systems are predominantly shallow texture contrast soils on undulating relief. Gullying in these land systems is most severe in the large areas of folded sediments where large gullies have cut upwards along the vales or depressions between strike ridges (Skinner *et al.* 1972).

The main soils in these land systems are Southernwood and Medway families. These soils can have hard setting, massive, slowly permeable surface horizons with sparse ground cover (Gunn *et al.* 1967). In the Dawson and Fitzroy catchments Southernwood and Medway soils have also been identified as being highly susceptible to erosion (Gunn 1968). For the Nogoa Catchment, Skinner *et al*. (1972) developed a relationship between land systems and susceptibility to erosion. Land systems were ranked into five categories (in order of susceptibility to erosion).

Soil erosion is not strictly restricted to grazing lands. There is evidence of agriculture contributing to the erosion of some soils (although on a much smaller scale). Cracking clay soils (Vertosols) and dark grey brown soils (Dermosols) are liable to erode severely in areas of sloping relief where natural vegetation is disturbed (Gunn *et al.* 1967). This is particularly true within the Dawson and Fitzroy Catchments (Gunn 1968) where the erosion risk is prominent on arable clay soils rather than grazing lands. This erosion risk has been largely controlled with soil conservation practices (contour banks) on slopes greater than 5%.

Bank instability is another source of soil erosion that has been documented in past studies. Stephen (1982) found that most watercourses draining catchments larger than 700 ha are unstable and prone to erosion. Sallaway (1987) found many unstable waterways in cracking clay soils.

Soil Erodibility

Soil erodibility has been studied by many including Wischmeier (1976) who developed the Universal Soil Loss Equation (USLE), which is the most scientifically enduring empirical function. The USLE was developed from plot experiments on a range of cropping soils in the United States of America. The USLE is still used today and in some cases well beyond its original intent. It has been adapted to other purposes including the current reef catchments modelling. The weakness of the function for our purpose is that it is designed to model soil loss from sheet and rill erosion within the soil surface. However, within the reef catchments gully and stream bank erosion are the dominant forms of erosion supplying the greatest proportion of fine grained (<16µm) sediment to the GBR lagoon (Kroon *et.al.* 2013 and Lewis et.al. In Prep).

Past works in the Fitzroy basin have concluded that soils formed from sedimentary rocks are the most erodible, in particular soils derived from shales, mudstones and weaker sandstones (Skinner *et al.* 1972). Most erodible are texture-contrast or duplex soils, particularly shallow ones that have massive, hard-setting surfaces that are slowly permeable, have sparse vegetation cover and are in undulating landscapes with highly dispersive subsoils (Gunn *et al.* 1967 and Ciesiolka 1987). Cracking clay soils particularly with gilgai have also been found to be very erodible (Gunn *et al.* 1967). Soils with loose surfaces such as sands, self-mulching clays and weakly structured loams (low surface soil cohesion) were also important to soil erodibility (Burgess 2003).

The purpose of this project is to develop a soil erodibility dataset that assists with the identification of soils that are vulnerable to erosion. Gullies generally form when the protective surface soil is disturbed and erosive forces encounter dispersive subsoil. Hence, this project aims to produce a surface soil stability and subsoil (B horizon) erodibility product. The two predictions are combined into an inherent soil erodibility product.

In general soil stability and erodibility is influenced by the following soil attributes.

- Soil sodicity
- Soil salinity
- Soil cohesion
- Soil organic matter
- Clay mineralogy
- Soil calcium - magnesium cation balance
- Soil carbonates
- Soil texture
- Soil permeability/drainage
- Surface coarse fragments

Some of the above attributes do not occur in the Burdekin or Fitzroy in amounts significant enough to influence soil stability or erodibility. The model for the Burdekin (Zund in prep) uses soil texture, sodicity, mineralogy, salinity and dominance of magnesium ions on the clay colloid. The model is split into surface soil stability and subsoil erodibility. Different criteria apply to surface soil and subsoil erodibility models. The same models will be used for the Fitzroy.

The surface soil stability model categorises surface stability into moderately stable, non-cohesive, dispersive and highly erodible surface soils. The subsoil erodibility model categorises subsoil erodibility into non-dispersive, weakly dispersive, dispersive and highly dispersive subsoils. The combination of surface stability and subsoil erodibility models has created 17 soil erodibility categories (Zund and Payne 2014).

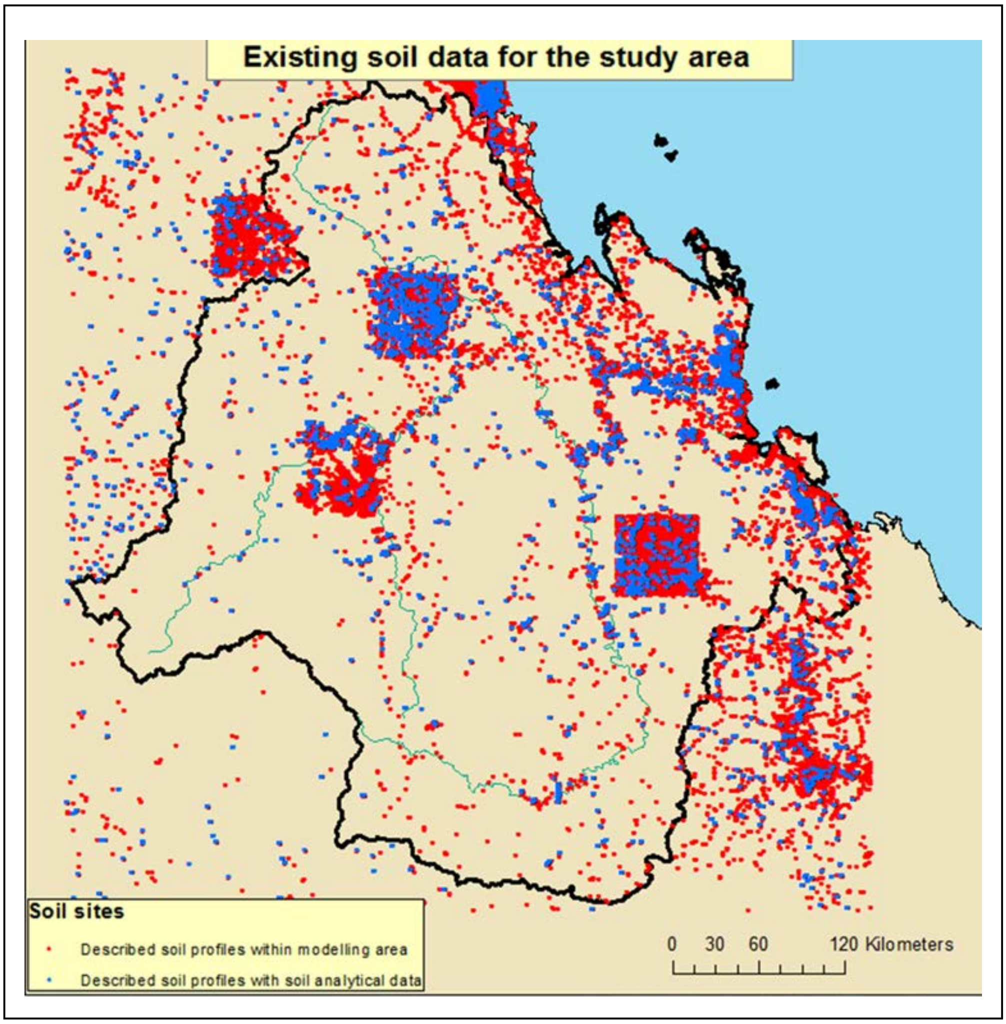

Figure 5 - Existing soil data for the study area

Methodology

The following section summarises the approach this project plans to take to produce a soil erodibility dataset for the Fitzroy that is similar to the dataset previously produced for the Burdekin.

Modelling process

Standards

It is planned that the project will use quantitative digital soil mapping (DSM) methods that were reviewed by McBratney *et al*. (2003) and are continuing to evolve. The resulting datasets will conform to Global Soil Map Specifications, release 2.3 (Science Committee 2012) and Soil and Landscape Grid (TERN 2014) specifications. The DSM approach described in the synthesis report for the project, *Mapping erodible soils in the Burdekin (RP63G)* (Payne and Zund 2014) will be used for this project.

Models and inputs

Soil erodibility will be predicted using the same soil erodibility model (Zund in prep) developed for the Burdekin basin. The model requires a set of spatial soil attribute data layers (rasters) that cover the entire Fitzroy basin in a consistent 100 X 100m grid.

Spatial soil attributes required for the soil erodibility model are,

- surface soil depth (A horizon depth)
- soil depth (depth to rock or strongly cemented horizons)
- clay mineralogy (clay activity in the 0.3 to 0.6m depth interval)

And for six fixed depth intervals (0.0 – 0.05m; 0.05 – 0.15m; 0.15 – 0.30m; 0.30 – 0.60m; 0.60 – 1.00m and 1.00 – 2.00m);

- soil texture (clay fraction (<0.002mm))
- soil sodicity (exchangeable sodium percent)
- soil salinity (electrical conductivity)
- soil calcium - magnesium cation balance (Ca / Mg ratio)

These soil attribute layers will be derived from soil profile physical and analytical sample data using DSM techniques (McBratney *et.al.* 2003). To augment the available data within the basin, data on similar landscapes adjacent but outside the basin will also be used to derive each soil attribute layer. The quality (reliability and spread) of existing soil physical and analytical data will be examined and where necessary extra sites will be sampled (Figure 5).

New and existing good quality soil data will be harmonised using a spline (Jacquier and Seaton 2012) to interpolate soil property values in-between the actual sample intervals. For duplex soils, the spline will be adjusted where necessary to account for the abrupt change in soil texture and hence the expected abrupt changes in soil property values.

In addition to sample point data, the DSM approach relies on environmental covariates that are correlated with soil-landscape forming factors or accurately delineate existing soil-landscape patterns. We propose to use environmental covariates derived from the following data sources,

- 1^{o} SRTM Derived 3^{o} Digital Elevation Model (DEM) version 1.0 (Gallant *et al*. 2009)
- The Ternary Radiometric Image of Australia (Nakamura and Milligan 2015)

- Climate data from the Australian Bureau of Meteorology
- Landsat TM imagery

Modelling

We plan to use a number of data mining models to fit quantitative relationships to the available sample data including Cubist and Random Forest models and then map the trend. Payne and Zund (2014) discuss the various approaches further.

Project products

Raster dataset of soil erodibility across the Fitzroy basin

This dataset includes the following rasters:

- surface soil stability raster
- subsoil erodibility raster
- overall soil erodibility raster

The dataset will have a nominal resolution of 1:250,000 with 100X100m pixels

A user guide will accompany the dataset to assist with interpretation.

Soil erodibility report in the FORAGE system

This project will provide data for the development of online Erodible Soils Report (FORAGE Reports) for properties in the Fitzroy, similar to reports currently available for the Burdekin catchment on the FORAGE system of information. These reports will be available by request for any Lot(s) on Plan within the Fitzroy basin from 2017 at a scale of 1:250,000 from the DSITI *Long Paddock* website. The data produced by the FORAGE system uses a simplified version of the overall soil erodibility raster along with the same surface soil stability and subsoil erodibility rasters.

Data and product availability

Products will be available via the Queensland Government web portals for data and publications. The base soil attribute data will be provided to the TERN Soil and Landscape Grid to improve the grid of attributes for the basin.

Integration with other reef science projects

Understanding sediment sources

This project will contribute to the integration of findings from other projects including those under the RWQ science program to develop an improved catchment-wide understanding of sediment sources and processes, specifically soil erodibility. The spatial context provided by this project combined with the understanding and datasets delivered from other projects will help to identify areas in the Fitzroy basin where sediments are coming from. The associated projects include

- mapping gully erosion (DNRM)
- identifying erosion processes and sources (RP65G)
- monitoring and mapping ground cover and fire in grazing lands of reef catchments (RP64G)
- spatial arrangement and seasonal dynamics of cover in grazing lands (RP105G)

- remote sensing ground cover and riparian vegetation (DSITI Remote Sensing Centre)
- sources of bio-available particulate nutrients (RP128G)

Changing land management practices

The Department of Agriculture and Forestry (DAF), the Fitzroy Basin Association and other organisations are running a program focused on achieving land management change in critical grazing areas. Extension initiatives include,

- implementation of a grazing best management practice (BMP) program
- establishment of a series of land management demonstration properties in the Fitzroy

This project will assist where possible with identifying areas vulnerable to soil erosion.

Monitoring progress

The Paddock to Reef program (P2R) is responsible for monitoring progress toward reef targets in grazing areas. The program includes, paddock, catchment, wetland and marine monitoring that involves both regular measurement of sediment and modelling of erosion processes. The outcomes from this project may help to inform the monitoring program.

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