Department of Science, Information Technology, Innovation and the Arts

Mapping erodible soils in grazing lands

Project RP63G – Synthesis report

Soil and Land Resources

2014

Great state. Great opportunity.

Queensland Government

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Executive summary

The Queensland Government, through the Department of Environment and Heritage Protection, Reef Water Quality program (RWQ program), aims through research, extension and education to reduce the discharge of sediment, nutrients and pesticides into the Great Barrier Reef (GBR) from cattle grazing properties over 2000ha in the Wet Tropics, Burdekin Dry Tropics and Mackay-Whitsunday catchments. Under this program, the Department of Science, Information Technology, Innovation and the Arts is undertaking an assessment to map erodible soils across the Burdekin Dry Tropics catchment to improve understanding of sediment source locations for reducing sediment loads.

Soils vulnerable to erosion are those which are prone to slaking and dispersion or are simply not aggregated (non-cohesive). When detached from soil aggregates soil particles, have the potential to be moved off site in run-off flowing onto the GBR. Identifying the location of these soils vulnerable to erosion will help inform extension and management activities that may reduce erosion.

The outcomes of this project are:

- improved spatial understanding of erodible soils in the Burdekin catchment
- improved spatial estimates of key soil attributes that influence erosion processes

This will assist in:

- identifying research and information gaps related to soils and erosion in the Burdekin catchment
- identifying vulnerable areas at the sub-catchment level to improve prioritisation of investment across the Burdekin catchment
- improving the information base for decision-making.

This report outlines:

- digital soil mapping framework and methodology to be undertaken.
- expected final products

This project has been funded by the RWQ program and is part of the ongoing science program that informs the Queensland Government’s implementation of Reef Water Quality Protection Plan (Reef Plan).

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Background

RWQ program is designed to assist the adoption of better management practices that will reduce the levels of sediment nutrients and pesticides moving offsite from agricultural properties and impacting on the waters of the GBR.

Sediment has been identified as the major threat to GBR water quality from the grazing area within the Burdekin Dry Tropics catchment (Brodie et al. 2008). The sources of sediment however, have been found to be highly variable within and between catchments.

This project is one of several RWQ science projects supporting the implementation of Reef Plan. The objective is to provide information on the location of erodible soils within the Burdekin Dry Tropics catchment (known here after as the Burdekin catchment).

This project is developing a soil erodibility framework where erodible soils are identified as those which are prone to slaking, dispersion or are simply massive or non-cohesive. These soil particles when detached have the potential to travel off site in run-off and enter waterways. The development of maps which indicate erodibility is a key step in identifying potential erosion sources within the landscape.

Soil attributes largely drive how vulnerable particular landscapes are to erosion. Understanding the interactions between soil attributes and how these impact on soil erosion is important in developing these maps. Whilst there are a number of soil attributes that influence soil erodibility, this project has concentrated on attributes that specifically drive slaking and dispersion of soil aggregates within the Burdekin catchment. The soil attributes that have been identified as the dominant drivers of soil erosion for the Burdekin catchment are:

- texture (Clay (%))
- sodicity (Exchangeable sodium % (ESP) and Calcium/magnesium ratio (Ca/Mg))
- Soil type – mineralogy (Clay activity (CEC/Clay%))
- Soil salinity (Electrical conductivity (dS/m))
- Soil organic carbon (%)

Scope and objectives

This project aims to improve the spatial understanding of erodible soils in the Burdekin catchment by mapping key attributes (as above) that influence different soil erosion processes. This will assist with soil specific recommendations for cost effective management of erosion sources and achieved by:

- developing raster surfaces of soil attributes related to erodible soils utilising digital soil mapping methodologies and maximising the value of 60 years of legacy soil data.
- improving and validating raster surfaces of soil attributes related to erodible soils using newly collected field observations and improved modelling techniques.
- producing a dataset of soil erodibility for the surface and subsoil as well as combined map summarising overall soil erodibility.

The resulting improvement in the spatial resolution of soil attributes relevant to erosion will improve the understanding of sediment sources. This information will be used to:

- identify research and information gaps related to soils and erosion in the Burdekin catchment
- identify vulnerable areas at the sub-catchment level to improve prioritisation of investment in the Burdekin catchment

Project linkages

This project is one of a suite of science projects funded through the RWQ program to develop an improved catchment wide understanding of erosion sources and process. This project provides the spatial understanding and context around soils that are inherently vulnerable to erosion. This spatial context combined with the understanding and datasets delivered from projects on the location of gullies, ground cover and sediment tracing/dating work, will help to identify areas in the Burdekin catchment most vulnerable to erosion.

Linkages with other RWQ projects include:

- RP26G *Collating current knowledge of sediment sources and grazing land management impacts in the Burdekin* highlights broad sub-catchments that represent important erosion source areas. This project will improve understanding and delineation of sediment sources within these broad areas.
- RP64G *Monitoring and mapping of ground cover and fire in grazing lands of the Reef catchments*.
- RP65G *Identifying erosion processes and sources* will inform on dominant erosion processes at sub-catchment scale. This project will improve understanding and delineation of sediment sources within these broad areas.
- RP66G *Gully mapping and drivers in grazing lands* will map locations of known gullies and use improved landscape data provided by the project to highlight further areas vulnerable to gully erosion. It will also identify the main drivers of gully formation and where these are operating in the landscape (e.g. areas of low ground cover upstream of active gully sites), to inform efforts to prevent gully formation.
- RP67G *PaddockGRASP redevelopment* will allow users (e.g. extension officers and graziers) to input and modify information about a property or paddock and run ‘what-if’ scenarios to assess the impact of various management options on key environmental variables, such as ground cover.
- RP68G Enhancing FORAGE. FORAGE, an online system will provide a suite of new reports on ground cover, land types and rainfall and pasture for land managers. Reports on areas of erodible soils from this project will be available through FORAGE.
- P2R modelling and monitoring programs rely on improved data collected under this project to improve pollutant load estimates.

Terrestrial Ecosystem Research Network (TERN) Soil Facility is producing a map of soil attributes across Australia. This project will provide improved estimates of particular soil attributes across the Burdekin Catchment.

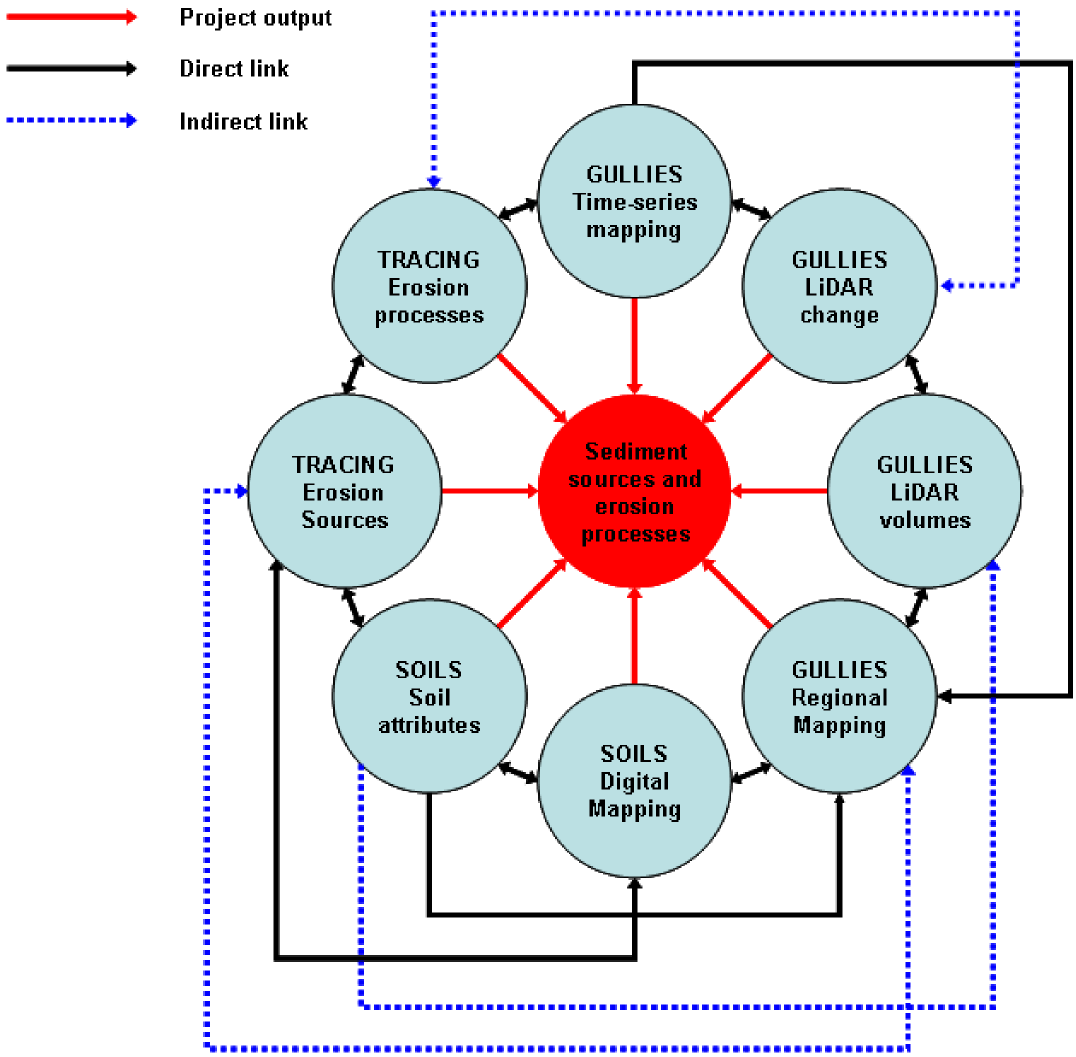

Figure 1 RWQ science program project linkages

Project area

The project area covers grazing lands in the Burdekin catchment. Grazing of natural vegetation is the dominant agricultural activity across the catchment from coastal environments, west of the coastal range, to the western boundary of the catchment. Climate classifications based on the Koeppen system (Stern *et al. 2000*) delineate the tropical, subtropical and grassland climatic zones across the project area with semi-arid grasslands dominating. The catchment suffers from a relatively steep rainfall gradient to the south west (Figure 2(a)). The catchment is dominated by 6 major sub-catchments, including Upper Burdekin, Lower Burdekin, Suttor, Cape-Campaspe (referred to as Cape), Bowen-Bogie and Belyando (Figure 22(b)).

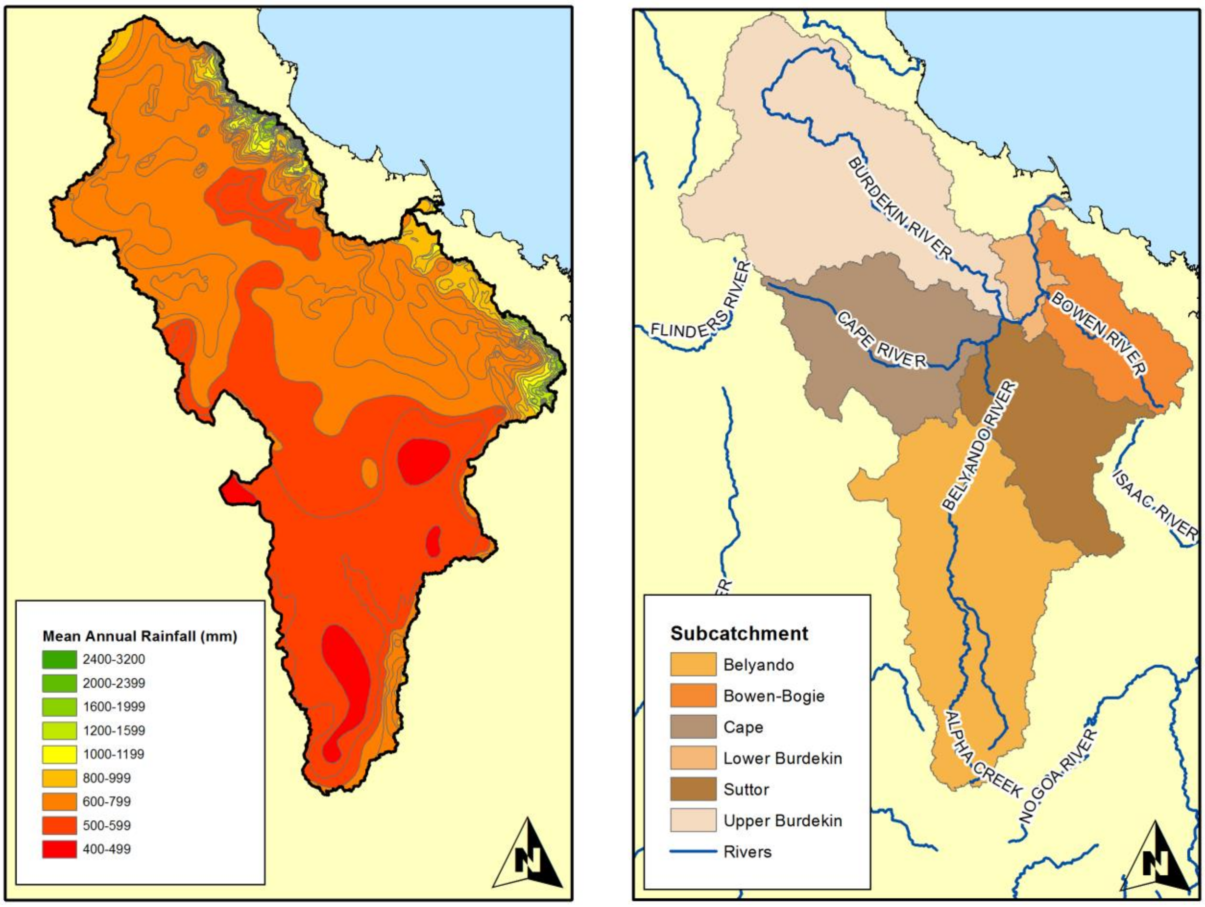

Figure 2 (a) Mean annual rainfall Burdekin catchment. (b) Sub-catchments of the Burdekin catchment.

Knowledge gaps

Existing spatial knowledge of erodible soils in grazing lands of the Burdekin catchment is limited as legacy spatial datasets are too coarse a scale and sampling points are insufficient in many regions to adequately prioritize investment.

An analysis, undertaken of the current soil site distribution across the Burdekin according to pedo-lithological classes[1] concluded that the Bogie, Bowen, Suttor and Belyando sub catchments are data poor due to very few soil sampling sites and coarse scale mapping. To identify the location of erodible soils, information needs to be consistent over the whole catchment at an appropriate scale. Soil and land resource mapping at a scale of 1:250,000 and finer is considered adequate to assist planning for extension in grazing regions (Gunn et al.,1988). Approximately one-third of the catchment has inadequate soils' information to broadly identify erodible soils for grazing extension and planning activities.

Past land resource assessment surveys provide various scales of soils' information focused upon different outcomes. Figure 3 shows the scale of the various soil surveys that have been done and the intensity of soil sampling in the Burdekin. For example, the Dalrymple Land Resource Survey (DLR) (Rogers, et al., 1999) had a focus on land degradation and hence collected data on existing

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[1] Pedo-lithological classes (pedolith) represent a uniform set of soil forming factors based on lithology, geomorphology and geological age of the underlying parent material. It is a concept developed by Brough, D.M *et al.* (2006).

erosion, salinity and dispersible soils. In comparison, the Kilcummin Survey (KCM) (Shields et al., 1993), had an emphasis on agricultural land suitability assessment and focused on information, such as soil fertility, soil wetness and workability (or properties which impact on agriculture).

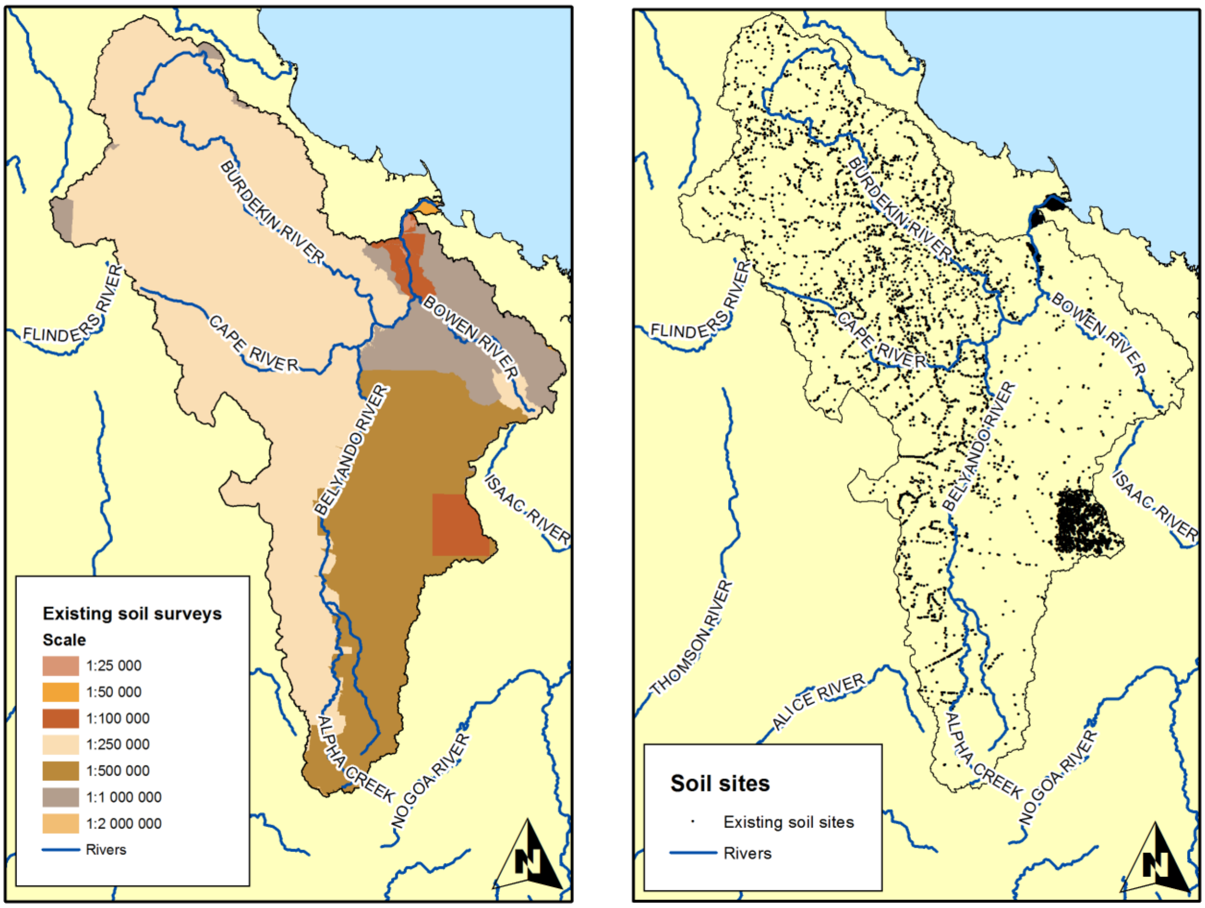


Figure 3 (a) Legacy soil surveys by mapping scale. (b) Legacy soil profile description sites.

Addressing knowledge gaps

To address the knowledge gaps in identified areas of the Burdekin catchment digital soil mapping (DSM) methods will be used to produce a series of uniform soil attribute layers (as described in methodology below) at a consistent resolution. New soil information will be collected from sampling points where existing soil information is inadequate. The DSM methodology has been tested on a wide range of soil mapping contexts throughout Australia and internationally and is the basis of the GlobalSoilMap.Net project (McBratney et al., 2003; Grunwald, 2006; Dobos et al., 2006).

Digital soil mapping methodology

The scientific foundation of soil mapping is based on Jenny's (1941) concept of factors of soil formation coupled with soil-landscape relationships (Hudson 1992). The spatial distribution of various soil types are a product of a unique set of soil forming factors. The soil forming factors that result in the spatial distribution of soils were identified by Jenny (1941) as a combination of climate, organisms, relief and parent material.

Digital soil mapping (DSM) has reframed characteristics of these soil forming factors into environmental variables that may be represented by environmental covariates. The methodology seeks to build quantitative relationships between these environmental covariates and field observations to spatially predict soil attributes across the study area. This technique has a number of advantages over traditional qualitative soil mapping techniques in that:

- relationships between soil properties and environmental variables are explicit
- validation of attribute surfaces is independent
- attribute surface predictions of uncertainty are spatially explicit
- an iterative process allows the attribute prediction model to be improved as new site observations are collected.

Various approaches to spatial prediction of soil attributes have been undertaken in the past but in recent years the hardware, software and knowledge tools required for large scale digital soil mapping have evolved from a research space to an implementation space. The efficiency improvements possible from digital soil mapping were analysed by Kempen et al. (2011). Within Australia, Bui et al. (2003) concluded that a quantitative mapping approach such as DSM delivered the most robust and efficient method for addressing knowledge gaps across a large catchment. As such a DSM approach was identified as the most robust approach for spatially predicting soil attributes to identify soil erodibility across the catchment.

The DSM method to be undertaken in this project is the soil spatial prediction function with spatially auto correlated errors (scorpan-SSPFe). This method was extensively reviewed in McBratney et al.(2003) and has been widely adopted internationally. The scorpan-SSPFe model uses a Jenny (1941) like formulation to build empirical quantitative relationships between soil and other spatially referenced factors with a view to using these as spatial prediction functions of soil attributes. This function is represented as:

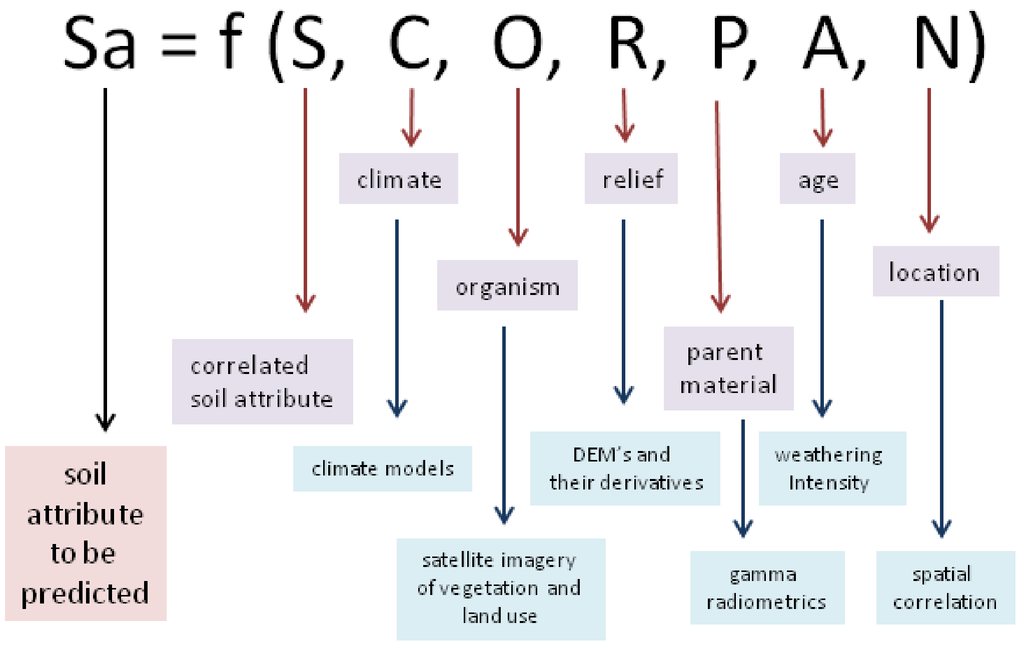


Figure 4 Digital soil mapping scorpan-SSPFe

The goal is to have each factor represented by one or more continuous or categorical variables known as environmental covariates. This achieves a more robust representation of the soil landscape continuum to build quantitative relationships between environmental covariates and field observations. This approach is largely empirical where evidence of a relationship exists it is used within the spatial prediction model. However, some expert interpretation and knowledge is utilized to remove spurious correlations of particular environmental covariates.

The DSM workflow that scorpan-SSPFe function is imbedded within is detailed as:

1. review existing soil mapping and site location distribution
2. compile available environmental covariates and generate derivatives
    - digital elevation models (DEM)
    - gamma radiometrics
    - satellite imagery
3. undertake statistically robust sampling program
4. fit quantitative relationships to analytical data and field observations
5. predict soil attribute surfaces.

Adapted from McBratney et al. (2003)

Existing soil mapping and site location distribution

The Burdekin catchment has a diverse and moderately coarse suite of legacy mapping products available to interrogate soil erodibility across the catchment. The available polygonal surveys were on the whole considered too coarse in a large proportion of the catchment to adequately estimate soil erodibility in a continuous manner across the entire catchment. In the case of existing described soil profiles, the coverage is equally variable. The current distribution of soil profile observations is heavily skewed towards the region covered by the 1:250, 000 Dalyrymple survey (Rogers et al., 1999) and the 1:100 000 Kilcummin survey (Shields et al., 1993). In turn the soil profile observations in the southern parts of the catchment are particularly sparse. As such a statistically robust sampling design was developed to address the disparity of sites in both the geographic and environmental space (Clifford et al., 2012).

Environmental covariates

Environmental covariates and their derivatives are the source from which quantitative information about landform, parent material and vegetation are derived. The use of continuous datasets such as these allow quantitative spatial relationships between covariate layers and observed site data to be derived. The three major environmental covariates to be used in this project are:

- digital elevation model (DEM)
- gamma radiometrics
- satellite imagery.

In addition to these raw environmental covariates a number of derivatives will be calculated off these datasets and included in the construction of quantitative spatial relationships to map erodible soils. These derivatives are described in more detail below.

Digital Elevation Model (DEM)

Terrain analysis is the processes by which elevation data is calculated into terrain derivatives that provide quantitative information about the topographic attributes that are a key driver in soil formation. Terrain analysis in the digital soil mapping context provides a quantitative link to soil formation processes within the landscape. The processes aim to elucidate spatial patterns through the use of statistical models.

The DEM to be used is the 1″Shuttle Radar Topographic Mission (SRTM) derived Digital Elevation Model (DEM-H Version 1.0 (Figure 5(a)). This is a one arc second (~30m) gridded DEM that represents ground surface topography with hydrological enforcement from 1:250 000 scale drainage data. The dataset was derived from the SRTM data acquired in February 2000, supported by the GEODATA 9″ DEM in void areas and the SRTM Water Body Data. Stripes and voids have been removed from the 1″ SRTM data to provide an enhanced and complete DEM.

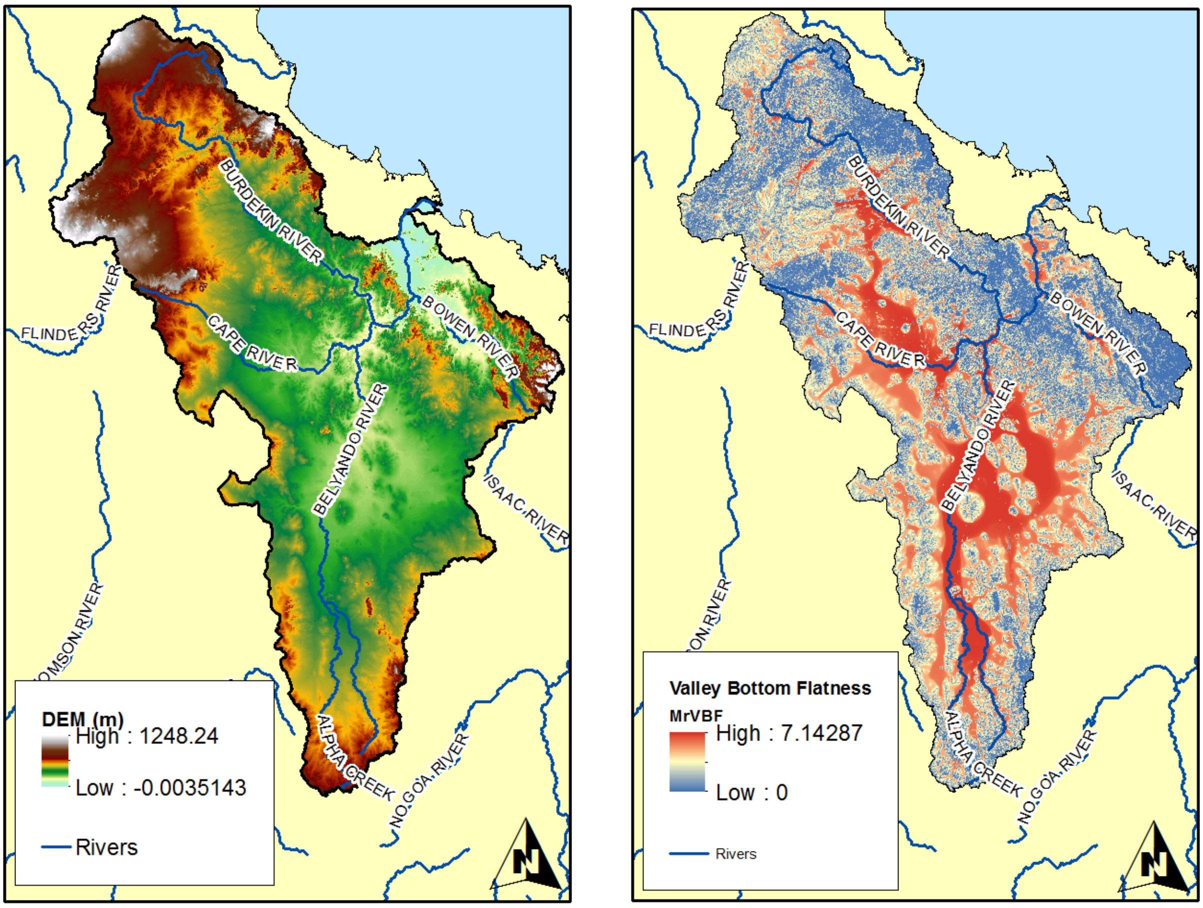


Figure 5 (a) 1” Hydrologically enforced digital elevation model. (b) Example of secondary terrain derivative of multi resolution valley bottom flatness (MrVBF)

Both primary and secondary terrain attributes were calculated using SAGA GIS. Examples of primary terrain attributes are slopes and curvatures. These attributes are simply calculated off the DEM elevation values. Secondary attributes are notably more complex being calculated off multiple primary terrain derivatives (Figure 5(b)). The goal of these more complex terrain derivatives is to characterize the spatial variability of landform processes such as colluvial processes. An example of these secondary terrain derivatives is multi resolution valley bottom flatness (MrVBF) shown in Figure 5(b).

Gamma Radiometrics

Airborne gamma-ray spectrometry is a critical environmental covariate in the digital soil mapping process. This dataset is a spatial representation of radioactive gamma-emitters, potassium (^{40}K), thorium (^{232}Th) and uranium (^{238}U), that emanate from the uppermost 30 to 40 centimetres of the land surface. Variations in concentrations of these radioelements relate principally to changes in the weathering, mineralogy and geochemistry of rock, regolith and soil material of the land surface (Figure 6(a)).

The gamma radiometrics to be used is extracted from Radiometric Map of Australia (Minty et. al. 2009). This Australia Wide Airborne Geophysical Survey (AWAGS) levelled and merged the patchwork of radiometric company surveys across the continent and in turn the Burdekin catchment. This dataset is the baseline to mosaic all current and future airborne gamma-ray spectrometric surveys in Australia.

Using the gamma radiometrics and DEM another covariate has been derived that relates to the weathering intensity of the landscape (Wilford et al., 2012) (Figure 6(b)).

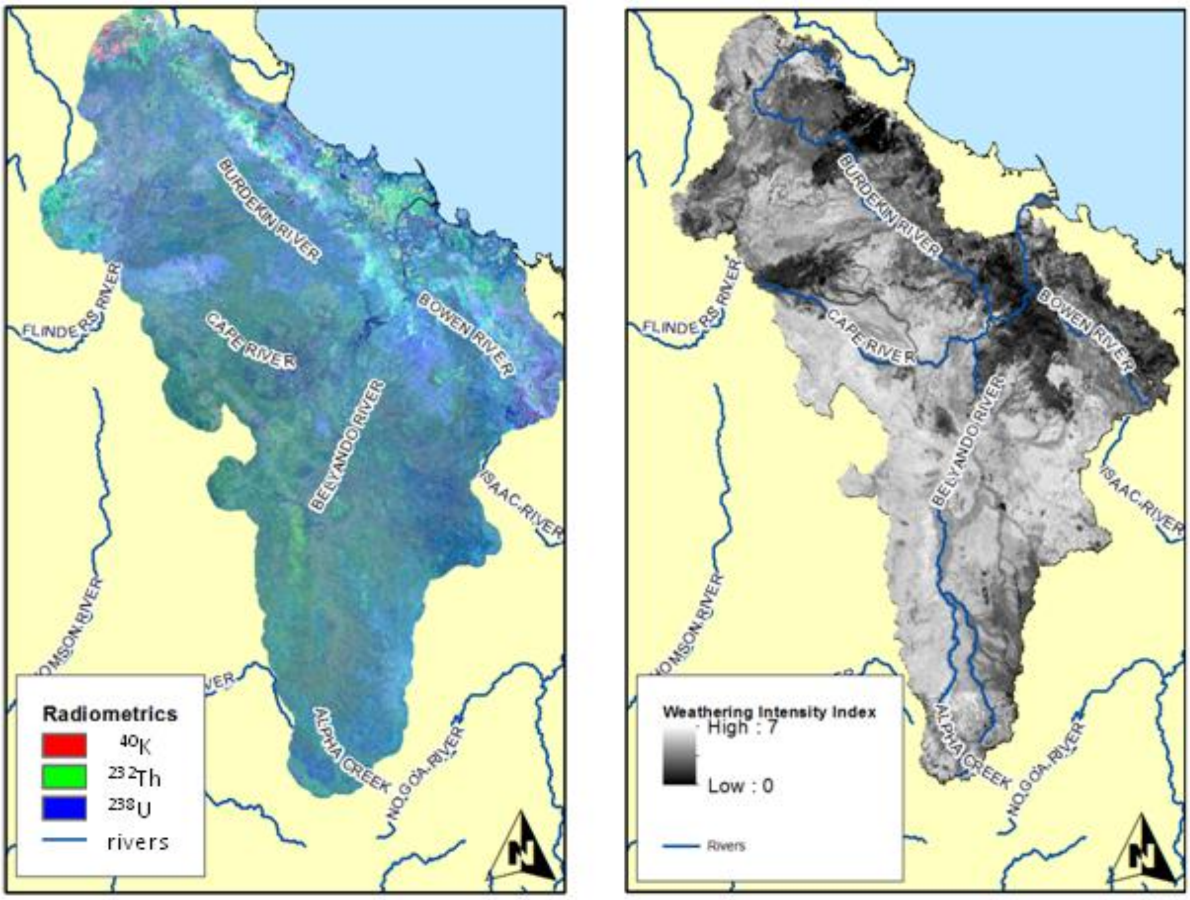


Figure 6 (a) Gamma radiometrics for the Burdekin catchment (b) Weathering intensity index for the Burdekin catchment

Satellite imagery

Landsat spectral data has been found to be useful in producing environmental covariates for DSM, particularly in arid and semi-arid regions like the Burdekin (Boettinger et al 2008). For example, Normalised Difference Vegetation Index (NDVI) has been used to represent vegetation and Fractional Vegetation Cover (FVC) and surficial environmental covariates for exposed soil and parent material. These datasets are currently being investigated for their effectiveness within our spatial prediction models.

Sampling design

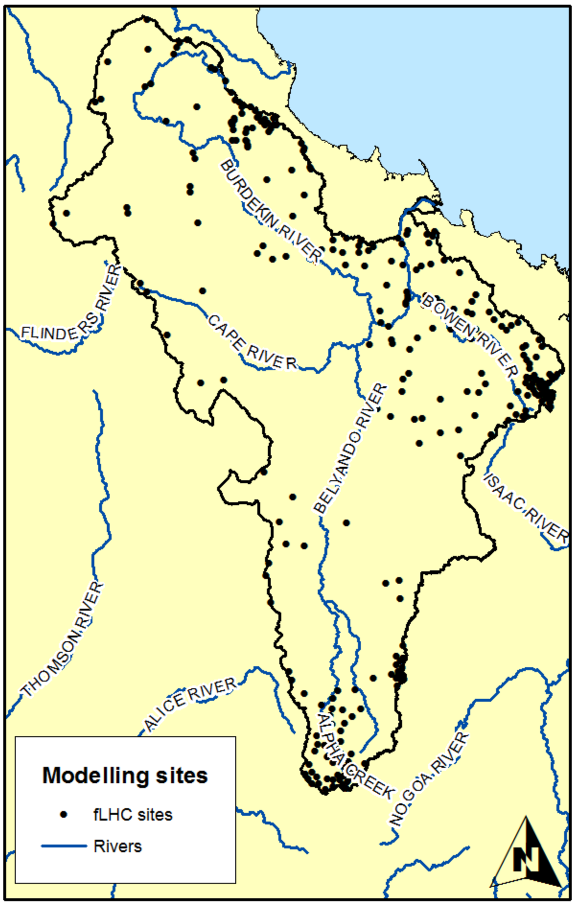
Traditional soil survey sampling design relies on the surveyors' intuition to create classes and locate soil boundaries on the assumption of strong relations between soil type and the environment. The traditional method implies that soil classes are discrete with abrupt boundaries. This project by comparison will undertake two statistically robust unbiased sampling approaches. The flexible latin hypercube sampling (fLHS) approach has been developed to identify sites to include in the spatial prediction models. Independent validation sites for these spatial prediction models were selected using Generalized random tessellation stratified sampling (GRTS).

Flexible latin hypercube sampling (fLHS)

The proposed sampling approach that has been developed and implemented is a fLHS method (Figure 7(a)), as detailed in Clifford et al. (2012). This method was developed as a modification to the statistically pure conditioned Latin Hypercube method to make fieldwork more efficient. The modification has allowed the incorporation of optimization criteria that fills the gaps in both the geographic and covariate (environmental) space relative to existing legacy soil observations. The optimization criteria also seeks to locate sites close to access points such as farm tracks to minimize disturbance and maximize efficiency.

Generalized random tessellation stratified sampling (GRTS)

The independent sampling approach implemented was GRTS (figure 7(b)). This method as detailed in Stevens et al (2004) is spatially balanced sampling approach that identifies existing sampling sites and implements a set of probability based hierarchical grid sites. This approach balances gap filling of the geographic space with geographic spread across the catchment.



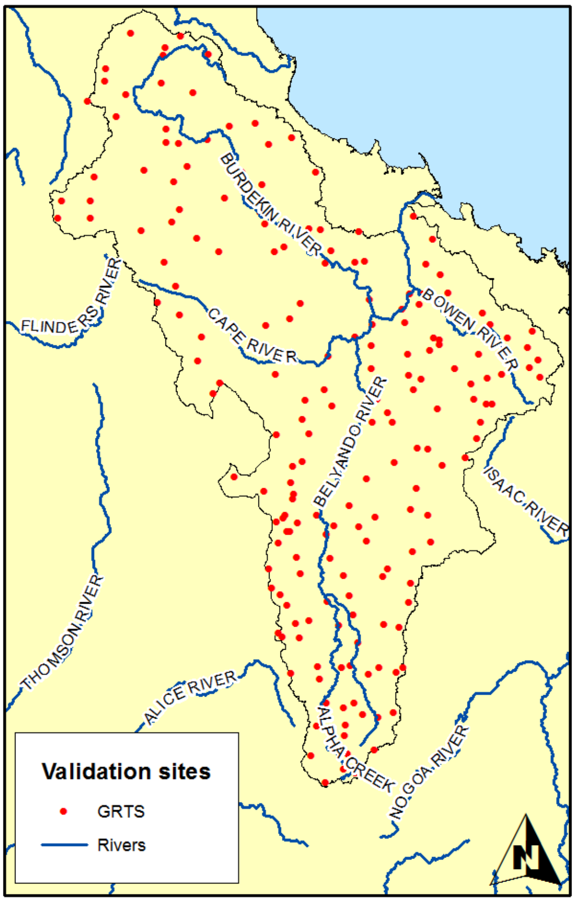


Figure 7 (a) New site observations to be collected to enhance modelling accuracy utilizing a novel flexible latin hypercube (fLHC) methodology. (b) New site observations to be collected as part of the validation exercise using a Generalized random tessellation stratified sampling (GRTS) methodology.

Soil sampling and analysis

At each sample site (Figure 7(a) & (b)), the soil profile will be described to 1.5m (or hard layer) according to the Australian Soil and Land Survey Handbook guidelines (McDonald et al., 1998). In addition, at standard depths down the profile, field pH, and the modified emerson dispersion test (Loveday and Pyle, 1973) will be conducted. Soil samples will be collected for standard soil survey analytical test suites. These tests will be comparable with existing soil analytical reference sites in the Burdekin catchment.

Fitting quantitative relationships

The process of fitting quantitative relationships seeks to match field observations and analytical results of a particular attribute to the environmental covariates. A model is then developed that can then predict the value of a particular attribute in areas that lack field observations. The modelling approach that has been undertaken is a pedo-geostatistical approach that utilizes several different kriging approaches.

The most effective approach that has been identified to date has been a co-kriging approach that maximizes the value of the large number of field observations against the more limited number of soil observations with analytical results. This approach weights the value of a particular result within the model. As such laboratory analysis results with their higher accuracy will be valued higher within the model where as a field observation will be valued lower. However whilst the model is fitted to the laboratory results the trend is fitted to the greater number of field observations. The advantage of this is that the uncertainty of the spatial prediction model can be substantially reduced. However a correlated field observation is not always available as such regression kriging approaches have been undertaken to develop the spatial prediction models for particular attributes.

In fitting quantitative relationships between soil observations and environmental covariates an analysis of the prediction uncertainty at each pixel is also produced. This uncertainty at each pixel is explained as the 5th and 95th percentile values. The range of these values provide an estimate of the spatial prediction models confidence at each location.

Prediction of soil erodibility

A soil erodibility index is being developed and refined through the validation component of the project. The design seeks to identify the major soil attributes that contribute to a soil being vulnerable to erosion and build them into a spatial classification framework to create groups of particular soil behaviours in the surface and the subsoil. Where the surface erodibility is related to sheet and rill erosion vulnerability and the subsoil erodibility is related to gully erosion vulnerability.

3. Outputs and final products

The final outputs from this project will include:

- a continuous raster dataset of soil erodibility for the Burdekin catchment for the surface soil, subsoil and summary combined soil erodibility**.** This dataset (90m pixels) will be available for download from the Queensland Government Information Service at www.data.qld.gov.au.
- a user guide to explain and interpret the dataset produced for extension officers, those delivering support services to landholders and land managers**.** This will be available from the Department of Environment and Heritage Protection Library service at http://www.qld.gov.au/environment/library/
- a technical report detailing specific methodologies and geostatistical techniques used. This will also be available from the Department of Environment and Heritage Protection Library service at http://www.qld.gov.au/environment/library/
- a FORAGE map report of the three erodible soil datasets centred around a property lot on plan at a scale of 1:250 000. These reports will be available from the Long Paddock website www.longpaddock.qld.gov.au/forage/
- continuous raster surfaces of soil attributes relevant to the catchment modelling activities of the Paddock to reef program (P2R)

Internal government clients will also be able to access information through the spatial information resource (SIR) to DNRM, EHP and DSITIA and DAFF Spatial database engine (SDE).

Ongoing value

These datasets detailing functional soil attributes and key landscape features in a continuous manner across the Burdekin will provide a valuable resource for the modelling community into the future. In the context of the GBR the soil attribute datasets underlying the interpreted surfaces will provide ongoing value to the P2R (paddock to reef) program as well as the agricultural and environmental modelling community as a whole.

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