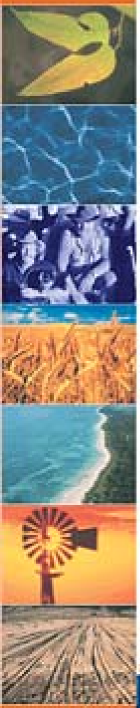
National Land & Water Resources Audit
An Initiative of the Natural Heritage Trust



CONDAMINE CATCHMENT WATER EROSION MONITORING

Geoff Titmarsh and Lucy Larkin

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

This report has been produced in partnership with:

Published by: National Land & Water Resources Audit

Postal address: GPO Box 2182
Canberra ACT 2601

Office Location: 86 Northbourne Ave
Braddon ACT 2612

Telephone: 02 6263 6035
Facsimile: 02 6257 9518
Email: info@nlwra.gov.au
Internet: http://www.nlwra.gov.au

The National Land & Water Resources Audit provides data, information and nationwide assessments of Australia's land, water and biological resources to support sustainable development.

Publication data: Geoff Titmarsh[1] and Lucy Larkin[2] (2007) *Condamine Catchment Water Erosion Monitoring*, prepared for the National Land & Water Resources Audit, Canberra.

[1] Queensland Department of Natural Resources and Water

[2] Condamine Alliance

geoff.titmarsh@nrw.qld.gov.au

This project was managed by the National Land & Water Resources Audit.

National Land & Water Resources Audit

An Initiative of the Natural Heritage Trust

Condamine Catchment Water Erosion Monitoring

Geoff Titmarsh[1] and Lucy Larkin[2]
[1] Queensland Department of Natural Resources and Water
[2] Condamine Alliance

geoff.titmarsh@nrw.qld.gov.au September 2007

Contents

1. Introduction

In 2005 the National Land & Water Resources Audit (NLWRA), through the National Committee on Soil and Terrain (NCST), convened four expert panels to advise on the monitoring and reporting of soil condition using indicators of four soil processes - soil acidification, soil carbon changes, water erosion and wind erosion (McKenzie & Dixon 2006). The NLWRA then commissioned a series of tests of the four expert panels' recommended approaches to monitoring those processes.

For water erosion, the ideal way to test those approaches is to measure actual soil loss and relate that to the indicators recommended, but over large areas this is impractical and enormously demanding of resources. It is easier to establish a risk (or hazard) of erosion and monitor that risk plus the uptake of management options that minimise the risk. This does not give a direct measure of soil loss but provides an assessment of water erosion potential. The expert panel recommendations were a combination of these tactics:

- for sheet erosion, monitor groundcover and land management practices
- for gully erosion, monitor gully length and land management practices
- for streambank erosion, monitor erosion incidence and land management practices.

This document reports on an assessment of those recommendations applied at catchment scale and provides information on procedures that others may follow and improve upon. For convenience, sections related specifically to sheet erosion have a background colour of pale blue; gully erosion sections are pale green; and streambank erosion is yellow.

Tasks involved were:

- Comparing methods for estimating groundcover
- Report on use of land management practices for water erosion control
  - Undertake air photograph interpretation and ground observations of gully erosion
  - Report on use of land management practices for gully erosion control
  - Undertake air photograph interpretation and ground observations of streambank erosion
  - Report on use of land management practices for streambank erosion control.

This assessment was conducted in and around the Condamine River Catchment in Queensland (see Figure 1) from its source near Killarney to its confluence with the Dogwood Creek near Miles, after which it becomes the Balonne River. The catchment includes mixed farming upland areas and an extensive floodplain which is predominantly used for grain growing. The assessment involved officers from the Condamine Alliance and Queensland Murray-Darling Committee Natural Resource Management Regions and the Queensland Department of Natural Resources and Water. Cash funding was provided by the NLWRA and 'in-kind' by other participating bodies. The assessment was conducted during 2007.

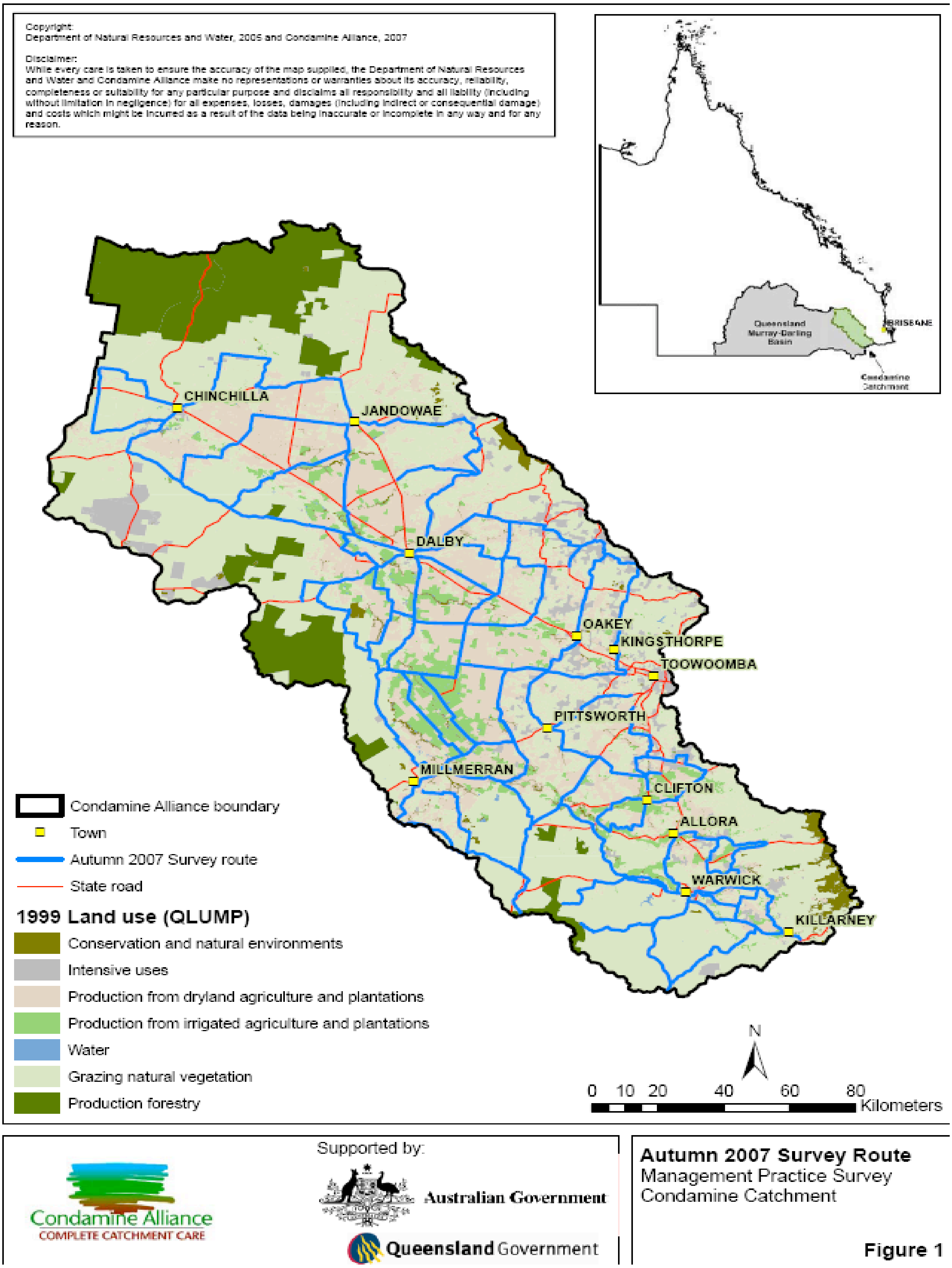


Figure 1. Condamine Catchment showing survey routes

1.1 Definition

Soil erosion by water is the detachment and entrainment of soil particles by water. This occurs naturally (at geological time scales) but can be accelerated by changes in cover and soil conditions as a result of human activities.

Soil erosion by water occurs in four ways:

- raindrop impact on the surface and soil particles moved by the forces of that impact (splash)
- surface flow either as spread (sheet or inter-rill erosion) or channelised (e.g. rill, gully and streambank erosion) flows where soil is moved either by saltation or in suspension
- tunnelling (mostly associated with soils that have dispersible layers where soil is moved as a fine suspension and often associated with gully erosion)
- mass movement (landslides, streambank slips).

Spread (sheet) and rill erosion is often referred to as *hillslope erosion*. It refers to the detachment and transport of soil material by raindrop impact and overland flow. Erosion-induced features such as rills and silt deposits are often removed by tillage.

Gully erosion is the loss of soil material from the head, walls or floor of a ‘permanent’ erosion feature, typically more than 30 cm deep. The gully consists of a head-cut scarp, as well as eroded walls and floor. The gully head advances by headwall retreat due to the waterfall effect and subsurface flow at the base. Material discharges either directly into a stream network or onto a depositional fan when slopes are reduced or flows are spread.

Streambank erosion is the incision by a stream into its bed and banks which often comprise floodplain sediments. Undercutting and saturation slumping are common mechanisms of streambank erosion, especially on the outside of bends of meanders.

Groundcover is taken to mean any attached or loose vegetable material on the soil surface. The quantity of groundcover (as a percentage) can be determined by comparison with photo standards (Carter 2002, McCord 2005). While gravels and stones, crusts and cryptogams are also forms of groundcover and influence erosion rates, these are less dynamic than vegetation and can be dealt with as part of soil surface characteristics. As a further refinement, groundcover can be measured at the time of maximum exposure to erosive forces (i.e. least cover), or as an integrated value of ‘duration of exposure’.

Hazard is taken here to mean the exposure or vulnerability of the soil to erosion due to its inherent (natural) properties.

Risk is taken to mean hazard as modified by human intervention.

1.2 Rationale

Soil erosion has on-site and off-site consequences (White 1986) with ecological and edaphological implications (Hadley *et al.* 1985). Ecological considerations are related to off-site damages in terms of sedimentation and eutrophication of water bodies plus loss of soil productivity due to nutrient removal. The edaphological considerations relate to deterioration in soil structure and impact on capacities such as soil infiltration and plant-available water.

These on-site and off-site impacts have an economic cost.

Various measures can reduce erosion. Considerable public and private resources are invested in these measures. As such, there is need to ascertain if value for money is achieved (cost/benefit). As well, there may be a case for preparation for possible future erosion events by influencing management responses and policy direction.

In both cases it is necessary to estimate erosion levels or risk and whether changes in land management affect them. Thus, the purpose of monitoring is to determine water erosion level and/or risk, how they are changing over time and opportunities to reduce them.

The risk and level of soil erosion by water along with amount of alternate land management practices can be monitored at a variety of spatial scales e.g. a particular point, management unit, district or region or even nationally, with each scale requiring a different technique. This report examines several methods of estimating that risk and level of land management practices at a regional scale.

2. Monitoring methodology

There are at least two objectives to monitoring soil erosion by water:

1) to estimate the actual amount of soil erosion (during or post-event) and/or
2) to estimate the risk of soil erosion, and the trend over time (pre-event) as modified by changes in land management practices.

Fulfilling both objectives would require different methodologies. The first may be satisfied by physical measurement of soil movement with some models and extrapolation to fill in any gaps (over time or space). Measurements would occur during events - typically by determining the runoff hydrograph (using gauging stations or some other flow measuring device) and sediment concentrations (by subsampling) during that hydrograph and then calculating a total soil movement figure – or post-event using some ground survey and/or sediment budgeting technique(s) such as use of fallout radionuclides. This would be impractical on a large scale but could be possible using representative areas and extrapolation across the entire area, although this would introduce further errors.

In the second situation, emphasis is placed on measuring attributes and management practices that impact on soil erosion. Erosion levels can then be inferred using models which utilise information such as the level of soil conservation practices in place, their efficacy and the likelihood of erosive rainfall events (often inferred using statistics gleaned from past rainfall records). This report is based on the latter.

In the Condamine River Catchment the main erosion forms are hillslope, gully and streambank with mass movement restricted in extent and location (principally in the steeper headwaters). This report is restricted to the first three forms.

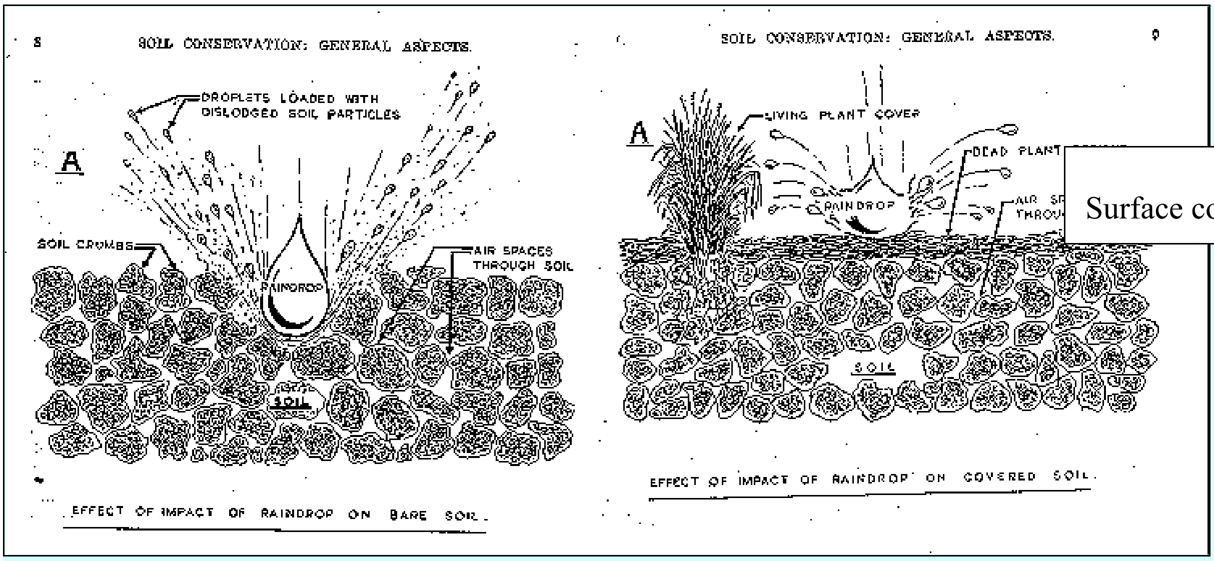
Hillslope erosion

Fundamental erosion processes include detachment, transport and deposition of soil particles by raindrops and surface flow (Foster *et al.* 1985).

Starting at the top of a catchment, soil erosion is a result of raindrop impact which dislodges particles making them available for transport in shallow inter-rill (sheet) flows or as direct downslope splash. Anything that reduces the kinetic energy of raindrops striking the soil surface is therefore beneficial in reducing this erosion. These include surface cover (the canopy intercepts raindrops), ponding of water (so raindrops strike water rather than soil) and modifying raindrop size (really only practical for irrigation systems). Managing cover is the main way to influence erosion due to this mechanism and cover in direct contact with the soil is even more effective against inter-rill erosion than cover alone (Foster 1982).

Other factors influencing inter-rill erosion are soil erodibility properties (particle size distribution, organic matter, moisture etc.) and effective land slope.

Hillslope erosion comprises both rill and inter-rill forms. As inter-rill flows increase downslope they usually concentrate into well defined channels or rills. Flows detach and move soil when their shear forces are greater than the soil’s cohesive strength. As well, undercutting and sloughing of side walls can occur. Rill erosion, the most identifiable indicator, is affected by the rate and velocity of runoff, soil properties and any incorporated or attached plant material.



Surface cover and

Raindrop impact (from Ladewig & Skinner 'Soil Conservation in Queensland' Queensland Agricultural Journal, January 1950

The USLE (Universal Soil Loss Equation) devised by Wischmeier & Smith (1978) is accepted worldwide as a legitimate means of estimating average annual hillslope erosion levels. The base USLE equation is:

A computed soil loss per unit area **= RKLSCP** where

R is the rainfall and runoff factor

K is a soil erodibility factor

L is the slope length factor

S is the slope steepness factor

C is cover and management factor

P is the support practice factor.

Numerical values for these factors have been derived from a variety of sources and can be obtained from the literature.

For a given location/catchment, factors easily manipulated are **L** (e.g. by constructing contour banks), **C** (e.g. by maintaining vegetative cover) and **P** (e.g. by carrying out operations on the contour). The influence of any support practices (**P**) on erosion is limited to short slope lengths only. Once contour banks have been installed (and maintained) then only the cover factor (**C**) can be readily altered.

Wischmeier & Smith (1978) provided tables and graphs as a starting point for allocating values for local use when calculating average annual soil loss for a hillslope. That publication also contains information on deriving local values for these factors some of which are available in the literature e.g. Rosenthal & White (1980) contains rainfall erosion index information for Queensland (**R**), Loch *et al.* (1998) have some **K** values and Littleboy *et al.* (1989) have a formula for calculating the **C** factor developed for the inter-contour bank area

(5-7% slope, 60 m slope length) for clay soils:

$$C = 16.52 - 0.46COVER + 0.0031\,COVER^2$$ for COVER <50%

$$C = 2.54 - 0.0254\,COVER$$ for COVER ≥50%

where *COVER* is combined crop and surface residue cover (%).

These equations can be represented graphically by Figure 2.

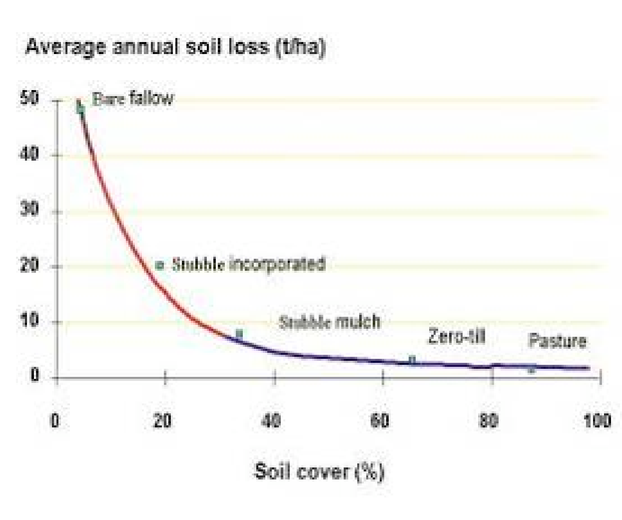


Figure 2. Average annual soil loss vs. cover for contour catchments on the eastern Darling Downs (7% slope, 60 m slope length), Freebairn & Wockner (1986) data

Other models range from point models e.g. PERFECT (Littleboy *et al.* 1992), hillslope and small catchments e.g. WEPP (Flanagan & Nearing 1995), to large catchments e.g. SWAT (Neitsch *et al.* 2002) and E2 (eWater CRC). The level of expertise, skill and computer hardware required to run these models and analyse outputs is often above that of a layperson.

The amount of erosion during any one event depends on many things such as rainfall factors (intensity, duration, raindrop size, etc.), soil features (strength, cover levels and type, etc.), landscape attributes (land slope), flow characteristics (stream power) and so on. As these are not consistent across a catchment, spatially or temporally, erosion will vary in size and timing.

Monitoring of erosion can be carried out directly using bounded plots or sub-catchments (Ciesiolka *et al*. 1995, Ciesiolka and Rose 1998, and many other publications) but given the variability of events across time and space this would be an extremely resource hungry exercise and logistically impossible.

The only practical way to estimate soil erosion level or risk across a catchment the size of the Condamine River is to use some easily measurable surrogate(s). From discussion above, the USLE factors fit the bill. For a catchment, the **R, K, L,** and **S** factors are nominally fixed (once contour banks have been constructed and maintained) leaving **C** and **P** as the only transient factors. The support practice factor, **P,** has little influence thus leaving cover **(C)** as the main aspect to monitor.

A robust relationship exists between soil cover and erosion levels (Figure 2) making soil cover a reasonable indicator of erosion risk. Soil cover is easily measurable with good accuracy at paddock level, requires no specialist equipment other than an informed eye with further development in remote sensing possibly being practical in providing soil cover estimates at the farm, catchment and regional scales (Freebairn & King 2003).

One consideration is that a measure of cover on a particular day will give a snapshot of soil erosion potential on that day only. One option to overcome this is continuous monitoring of cover levels but this may be time consuming and costly.

Land management practices often have direct impact on soil cover levels, e.g. overstocking, cultivation and fire all reduce cover while conservation tillage seeks to retain vegetative cover for as long as possible after crop harvest. Table 1 illustrates soil cover levels resulting from a range of crop/soil management practices.

Table 1. Expected soil cover during the critical summer period (October–March) for crop and tillage management options (from Freebairn & King 2003)

Predominant crop-tillage management	**Typical soil cover (%)**
Grazed oats	<5
Wheat – fallow, stubble burnt or incorporated (disc plough)	<5
Wheat – fallow, stubble retained (sweep plough)	30-50
Wheat – fallow, no-till (herbicide weed control)	>60
Sorghum, stubble retained	>60
Sunflower	<30
Pasture, well managed	>80

Thus, an indicator of erosion level or risk would be the level of appropriate land management practices in place. The usefulness of such an approach has some qualifications, e.g. many relationships involved are qualitative in nature only and some practices have immediate or transient effects on cover levels (e.g. wildfire) while others are more stable (e.g. zero tillage). Contour banks also provide a level of protection but depend on their spacing and capacity – and maintenance. So while management practice implementation as a measure of soil erosion level or risk has promise, careful choice of practice and interpretation of data are required for it to be useful.

Hillslope erosion between contour banks

Gully erosion

Gullies are easily identifiable and definable features resulting from concentrated flows. Development is generally recognised as commencing with channel erosion by downward scour of topsoil, upward movement of the gully head and enlargement of the depth and width then some healing or stabilisation with vegetation growing in the channel (NRW 2007). Secondary gullying may develop from over-steepening of silt deposits in the gully bed or overfalls as runoff enters from the gully sides.

Hillslope

The erosion process is dictated by soil strength and stream power of the flow. Soil strength is affected by its inherent properties such as aggregate stability along with any disturbance, e.g. by tillage. In an undisturbed state some soils are more susceptible to gully erosion particularly those with dispersible B horizons (often termed 'sodic' soils) and which are susceptible to tunnelling, often a preliminary to gullying. Stream power is influenced by discharge, slope and channel roughness. So if the stream power is greater than soil strength then erosion occurs until detachment produces a load greater than the flow can transport and causes deposition.

In the Condamine River Catchment there are two broad areas of gully erosion: in the high clay soils which are cultivated or heavily disturbed e.g. by tillage, rills can develop into gullies (unless controlled by conservation measures); and in grazing lands on 'sodic' soils tunnelling and gullying can occur even with minimal disturbance.

Stewart (1968, referenced in State of the Environment Advisory Council 1996) claimed gully networks reach their maximum extent about 50 years after clearing. This argument is reinforced by Beavis *et al*. (1999), who found that, at catchment scale, gully networks in part of the area Stewart surveyed appear to have retracted in response to management change. Prosser & Winchester (1996) and Hughes & Prosser (2003) concur. Thus, it seems gullies have a 'natural' life after which they stabilise, but the damage has been done.

Monitoring could take two paths:

- 'direct' measurement or analysis of soil and landscape attributes that predispose the area to gullying (including physical survey and scrutiny of aerial photography and remotely-sensed images which provides a length or density of gullies which then has to be multiplied by some cross-sectional area to give volume). These procedures would have to be carried out at regular intervals to determine a trend on erosion levels.
- analysis of combinations of control management practices and land resource/land use/land/management/flow attributes within a GIS to develop a 'risk' map which would require ground-truthing. This 'risk' map could be used to estimate levels of gully erosion by applying a volume (ascertained by field survey) to the different levels of 'risk' and summing those. It would be necessary to monitor the relevant land management practice over time and periodically update the 'risk' map to assess trends.

Gully erosion example

Further information on gully erosion at www.nrw.qld.gov.au/factsheets/pdf/land/l81.pdf

Streambank erosion

Stream geomorphology is dynamic on a geologic scale but the rate of change can be altered by human activities. Both sedimentary and erosion processes are at play. Streambanks erode by runoff flowing over the sides or by scouring and undercutting. Some bed erosion may occur by flow as well and any sediment is then transported by suspension, saltation and bed load movement (Frevert *et al.* 1955). Overbank flow can also erode banks and associated floodplain, and in extreme cases result in channel avulsion where the 'existing' channel is abandoned in favour of a new one.

Sediment yields of streams could be used as an indicator of sediment movement and erosion levels within that catchment. This could be measured in several ways, e.g. reservoir accumulation rates coupled with surcharge sampling, but deciphering the sources of that sediment and relative amounts is not easy. As well, developing a picture of erosion within a catchment is complicated by the need for use of a delivery ratio(s) and knowledge of the source(s) of that sediment. As such, not only is it expensive and uncertain it is useful as a gross measure only.

Another way of estimating streambank erosion is direct measurement using survey techniques. This would be relatively easy where the erosion is highly visible and of reasonable size, e.g. slumps, but more difficult where sheet erosion only occurs. As well, the level of implementation of control practices could be used.

An alternative involves analysis of combinations of control management practices and land resource/land use/land/management/flow attributes within a GIS to come up with a 'risk' map which would require ground-truthing. This 'risk' map could be used to estimate levels of streambank erosion by applying a volume (ascertained by field survey) to the different levels of 'risk' and summing those. It would be necessary to monitor the relevant land management practice over time and periodically update the 'risk' map to get a grasp on trend of erosion levels.

Streambank erosion example

Streambank erosion

2.1 *Sampling location and scale*

Hillslope erosion

When establishing a monitoring program, it is important whether it is erosion risk or actual level of erosion that is to be determined. Different monitoring strategies and parameters to be measured are required. To get actual levels of erosion requires direct measurements for all runoff events across the entire catchment and preparation of a soil erosion/movement budget. This is usually impractical and monitoring of risk is normal.

Drive-by surveys can cover large areas with minimum effort. Surveys can be along ‘permanent’ or temporary traverses and ‘runs’ made at key periods within the annual groundcover cycle. The number required each year depends on resources available and how rapidly groundcover levels change, e.g. cover in cultivated areas could change much more rapidly than grazed areas.

An example is the annual survey by Condamine Alliance which undertakes a roadside survey of groundcover and other erosion-related parameters for the catchment to just downstream of Chinchilla (Figure 3). Land uses are mixed and generally it is the interaction of cultivation on self-mulching high clay soils and intense thunderstorms which predisposes this region to water erosion.

The Condamine Alliance survey involves a snapshot of soil cover conditions and management practices across the catchment and, using Figure 2, the risk associated with these conditions can be converted into expected average annual soil loss. There is no need for sites to be fixed but to have sufficient sites spread across the catchment to allow an estimate of cover on a subregion basis. It is prudent to record the location of sites such that subsequent observations can be made at the same points if required.

An initial sampling run (autumn 2006) involved 980 sites with the intention of using these to confirm assumptions made on ‘homogeneity’ of subregions using knowledge of the landscape and land systems and allow a reduction in the number of sites in subsequent surveys. This proved to be so and site numbers have been reduced to about 300 (advice from Peter Dunn, University of Southern Queensland).

Timing of such surveys is important as soil surface condition and vegetative cover along with rainfall (amount and intensity) vary with time of year. It is generally accepted that surveys should be carried out at the time of maximum risk (i.e. least cover and highest rainfall intensity). This could be seen as predisposing interpretations to a doom and gloom scenario rather than average conditions.

The Condamine Alliance survey is road-based and ‘transects’ are selected using roads aligned roughly north-south with sites about 10 km apart ensuring a coverage of all land uses and land systems (Figure 3). Observations recorded on field sheets (see Appendix 1), are made over a 100 m x 100 m square (starting 10 m from fencelines) on both sides of the road keeping each side as a separate record. The location is recorded using a GPS and panoramic photos taken to allow follow up observations and for reference.

The survey takes about three weeks (two people, one vehicle) with about five minutes at each site filling in the field sheet plus travel. Groundcover levels are estimated using photographic standards such as Molloy (1986) and Berry (2007). Berry (pers comm.) and Larkin (pers comm.) have other photo and diagrammatic standards. The Fitzroy Basin Association (www.fba.org.au/) is developing photo standards for grazing land.

Remote sensing

Direct estimate of cover can be obtained from satellite imagery e.g. the Queensland Department of Natural Resources and Water (NRW) monitors woody vegetation levels at about 0.5 km^2 resolution as part of its State Landcover and Trees Study (SLATS) – see website www.nrw.qld.gov.au/slats/index.html.

Within the newer QScape program of NRW, a Bare Ground Index (BGI, Percentage of Bare Ground) - at 25 m^2 resolution - is generated from Landsat imagery (Scarth *et al*. 2006). Annual (from 1988) images in early spring are used to generate products including a time series of BGIs, minimum and maximum bare ground levels. This information is available internally or as part of a joint project between NRW and external bodies and for Queensland and NSW only. With time, this policy of restricted release could alter.

Up-to-date regional modelled pasture biomass (using AussieGrass) can be obtained via the Longpaddock website (www.longpaddock.qld.gov.au) on a regional basis. Similar information can be obtained from the National Agricultural Monitoring System (www.nams.gov.au/index.cfm?fa=nams.home). This is at 5 km^2 resolution and biomass needs to be converted into groundcover levels.

There are some problems with the usefulness of remotely-sensed images e.g. imagery provides a snapshot in time only; Landsat orbits occur about monthly and any cloud cover present reduces the image quality; groundcover is directly influenced by climate (NRW is working on removing climate influences from the signal); BGI includes bare soil, rocks and stones; tree cover (if <20%) can skew results; reflectance from sloping lands may result in incorrect indices; and local calibration is required. Longevity of the Landsat7 satellite may also be a factor. There is possibility of using MODIS imagery in future – its orbits are daily, imagery is free but it has a lower resolution (250 m^2). At present there is no freely available method of assessing groundcover relevant to soil erosion using remote sensing.

Uptake of management practices and what works

Another indicator of erosion risk is the level of appropriate land management practices, e.g. those that maintain high levels of surface cover. Trends in the use of no-till and reduced tillage practices in part of the cropping region of Queensland from 1995 to 2010 have been derived using Australian Bureau of Agricultural and Resource Economics (ABARE 1999) and Australian Bureau of Statistics (ABS 2001) data and reported in Thomas *et al*. (2007).

Mail-out surveys have been used, e.g. by the Eastern and Western Farming Systems Projects of GRDC (Christodoulou & Lawrence, pers comm.) to gauge the level of uptake of improved management practices. These are not trivial exercises and response can vary – anything above 50% return of survey forms would be regarded as good.

Roadside surveys can also be used with the Condamine Alliance methodology described above. A survey across the Darling Downs in the 1980s as part of the GRDC and Queensland Government-funded Viable Farming Systems Group Project (Knowles-Jackson, pers comm.) recorded information as shown in Appendix 2.

This survey was seen as a good method to:

- assess erosion potential in a district
- assess trends in surface management across the region
- direct extension support to high priority areas.

Initially, 100 sites were surveyed four times per year but this became nearly 1,000 sites by twice a year. It was difficult to maintain commitment and the survey lapsed after several years and data were not stored centrally.

Another indicator of adoption of conservation farming practices is the relative change in farm implement sales, which show a decline in disc ploughs and increase in sales of chisel ploughs and no-till planters since the 1960s in southern Queensland (Freebairn & King 2003). At best, this information is of regional value only.

Another indicator would be the land protected by contour banks. In Queensland, a record of the area on which contour banks were constructed on a shire basis (annual, cumulative) was maintained by the Soil Conservation Branch of the (then) Department of Primary Industries in its annual report. Those records are still available (Carey, pers comm). However, with branch and departmental restructures (1992) records have been updated only spasmodically. Most recent work (contour bank construction) has been carried out by Landcare groups. Records of new works are kept within reporting arrangements of these groups.

Gully erosion

Local experience and knowledge are probably the most reliable means of defining gullies in a landscape. This knowledge often resides with district soil conservation officers and landholders – they could easily draw on a map where gullies exist, their nature, rate of change and status. In Queensland, the numbers of such officers have declined in recent years as demand for their services declines. Alternative methods for determining gully location and rate of change need to be determined.

Visual inspection

Estimates of gully erosion presence can be carried out by visual inspection. Pearce & Gray (2000) surveyed Glengallan Creek, a tributary of the Condamine River, by walking its length. Positive aspects include assurance of gully identification and extent. Negative aspects are that it is time consuming, labour intensive - two people average about 15 km per day using two vehicles – and some personal interpretation is required (possibly introducing bias). This is not practical over large areas and more suited to validating data from other methods.

Aerial photo interpretation

Aerial photo interpretation was used to develop maps of gullies in parts of NSW and Victoria in the 1960s (Hughes *et al.* 2001, Hughes & Prosser 2003). The identification of gullies on high altitude aerial photographs can be problematical (Ries & Marzolff 1997). Emery (1972) acknowledged the usefulness of the technique but recognised difficulties in application such as photograph tonal quality, soil colour, ground litter and presence of trees.

A trial to test the methodology for identifying gullies was carried out in the Millmerran district (Figure 3) using aerial photos from 1945, 1978 and 2001.

Cultivation is predominantly on heavy cracking clay soils in this locality. These soils are prone to gullying and local conservationists identified areas known to have gullied in the past. While it could be seen from the aerial photos that erosion had occurred, discrete gullies could not be identified. Most likely tillage operations had masked them. In grazing areas on all soil types, gullies and their lineal extent could be more readily identified provided there was limited tree cover. Even with gullies in open (non-timbered) grazing areas, it was difficult to determine dimensions using stereoscopes – perhaps lower altitude photos are required, as suggested by Ries & Marzolff (2003), with field verification.

This method could be used to define the linear extent of gullies where suitable photography exists and gullies are easily identified but even for these, ground-truthing of depth/width dimensions – using surveying techniques - is required to provide a measure of gully erosion in weight/area units.

Computer programs (GIS, Cubist software)

Hughes *et al.* (2001) and Hughes & Prosser (2003) built upon mapping data from NSW and Victoria using environmental attributes in conjunction with Cubist regression tree software (Rulequest 2001). The methodology used was:

- for selected areas, gully densities were mapped from aerial photographs – as length of gully per unit area and converted into discrete gully density polygons
- environmental attribute data relevant to gully development (e.g. land use, relief, climate indices, geology, soil characteristics and groundcover – 15 in total) were collated and averaged for each polygon
- both datasets were entered into the Cubist model where rule-based gully densities (in terms of the attributes) were generated for each polygon
- predicted gully densities were compared with measured gully densities for calibration purposes.

Dougall *et al.* (in press) improved upon the work of Hughes *et al.* (2001) for the Fitzroy River Basin, Queensland, where the modelled and test data were not well correlated. Rather than aerial photography to delineate gullies they used Quickbird satellite imagery (0.6 m^2 resolution) with detected gullies digitised linearly on-screen. They also used a different environmental attribute set (Table 2) and tested a range of grid resolutions for suitability.

Table 2. Environmental attributes used by Dougall *et al.* (in press)

Data name	Scale	Source
Land system	1:500,000	CSIRO
Land type	1:100,000	EPA Herbarium
Landuse	1:100,000	NRW
Geology	1:250,000	Geosciences Aust.
Non-remnant vegetation	1:100,000	EPA Herbarium
Sodic soils	1:500,000	CSIRO
Rainfall	5*5 km grid	BOM
Bare ground index	25 m	SLATS Landsat TM
Slope	25 m DEM	NRW
Flow accumulation	25 m DEM	NRW
Soil A horizon clay%	1:500,000	CSIRO
Soil B horizon clay%	1:500,000	CSIRO
Soil A horizon thickness	1:500,000	CSIRO
Hillslope length	25 m DEM	NRW

They found an attribute layer grid resolution of 2.5 km to be statistically best for modelling the type and scale of their chosen environmental attributes. They also found Soil A horizon thickness and clay%, Soil B clay% with land type and system attributes to be of most predictive importance and no advantage in using more than these variables.

They compared the Cubist approach with support vector machines (SVM, which take nonlinearity and interaction into account) and multiple linear regression. All three approaches produced similar results using slightly different environmental attributes.

This methodology does not directly measure the stability of the gully network - examination of model runs using aerial photographs or satellite imagery of different dates is required. As well, extra work is required to measure of gully erosion levels in weight/area units.

As an alternative to surveying depth/width dimensions for this, Eustace (pers comm. 2007) evaluated the use of aeroplane-mounted Light Detection and Ranging (LIDAR) technology. The LIDAR data used have a spatial resolution of 0.3 m and provided vertical accuracy to within 0.09 m. This proved sufficiently accurate to be useful in deriving gully volume changes over time. The drawback is expense. Work in the Fitzroy Basin cost about $70,000 to cover 10 km^2.

Denham (2006) investigated the use of Spot 5 imagery (using the 2.5 m panchromatic band to resample the 10 m multi-spectral bands) to delineate gullied areas in the Condamine Catchment. He found the imagery to have the necessary resolution to detect gullies visually. Using a simple logistic regression model involving bands 1, 2 and 3 to automate detection proved to be problematical with a few false predictions. He suggested that use of feature recognition software may be useful with quite a deal of field validation. He also said the approach is unlikely to be adequate for measuring gully dimensions.

The use of this technology requires moderate computing power, relevant skills and expertise.

Other means of monitoring gully movement/growth include use of ground surveys - ensuring benchmarks are put in place to allow resurvey comparisons - and time lapse photography - again ensuring photos over time are taken from the same spot (e.g. use a steel picket). Ground surveys can provide direct volumes of soil lost but are time consuming, while photos provide evidence of growth only, no volume.

Use of landscape and soil attributes for prediction

Waters (pers comm.) and others investigated the possibility of defining gully-prone areas in the Condamine River Catchment reversing the work of Dougall *et al.* (in press). They overlaid a number of spatial layers of variables/attributes relevant to gully initiation in a GIS to predict gully-prone (or risk) areas. This risk map was then compared (on a spot basis) with aerial photographs and local knowledge to assess its usefulness.

Landscape attributes with potential as predictors were selected based on Dougall *et al.* (in press) in Table 4 and catchment coverage of these sourced electronically (shape files).

Table 4. Landscape attributes to predict gully erosion risk (from Dougall *et al.*)

Attribute	Map scale	Data source
Land system[1]	1:250,000	NRW
Land type	1:250,000	NRW
Land use	1:250,000	SLATS[2]
Non-remnant vegetation[1]	1:250,000	SLATS[2]
Sodic soils	1:250,000	SALI[3]
Bare ground index	1:250,000	Scarth, pers comm
Soil A horizon clay%	1:250,000	SALI[3]
Soil B horizon clay%	1:250,000	SALI[3]
Soil A horizon thickness	1:250,000	SALI[3]
Slope	1:25,000	NRW DEM
Hillslope length	1:25,000	NRW DEM
Flow accumulation	1:25,000	NRW DEM

1 Attributes consequently omitted from Condamine mapping exercise

2 SLATS - Department of Natural Resources (2000)

3 SALI – Soil and Land Information database, Queensland Department of Natural Resources and Water

Land system and non-remnant vegetation layers were subsequently omitted as they are accounted for in other attributes (land system in land type and non-remnant vegetation in land use). Using an ‘expert opinion’ approach, each spatial layer was then rescaled so that all values within each layer were assigned a number between 1 and 10 (Table 5).

Using a GIS platform, the attribute layers were then gridded (at 25 m resolution) and added vertically (simple addition with equal weighting to each attribute layer) to give an overall score for each cell.

Figures 3 and 4 show that this approach has potential for defining gully-prone areas (or a risk map). The maps show risk in roughly the right places but location of, and boundaries between, different ratings require further work. In order to refine the procedure, there is need for a sensitivity analysis of the attributes selected (both attribute and weighting applied) with an examination of whether other attributes are better predictors. In addition, this method needs to be evaluated against the Cubist software to determine which produces a better result.

Millmerran

Table 5. Attributes and ratings used for Condamine Catchment gully risk prediction

Attribute	**Rating (1-10)**	**Comment**		**Attribute**	**Rating (1-10)**	**Comment**
Land type	Alluvium = 1 Brigalow clay sheets = 1 Volcanics = 6 Traprock = 8 Walloon coal measures = 8 Granites = 8 Basaltic uplands = 10 Kumbarilla sandstone = 10 Marburg sandstones = 10	Assigned rating using experience of regional soil conservationists and pedologists – spatial data from SALI.		Bare ground index	50-100% = 1 30-50% = 5 1-30% = 10	Rating for bare ground index classes based on cover and soil loss where below 30% cover soil loss increases exponentially – Figure 2
Land use	Water = 1 Intensive animal = 1 Intensive use = 1 Irrigated crop = 2 Irrigated horticulture = 2 Grazing = 7 Forestry = 7 Cropping = 10	Assigned rating using experience of regional soil conservationists and pedologists - spatial data from QLUMP (2004).		Soil A horizon clay%	0-17.5% = 2 17.5-27.5%= 4 27.5-37.5%= 6 37.5-47.5%= 8 >47.5% = 10	Rating based on statistical clumping of base data (Jenkes technique) and assumption that the higher the clay content, the greater the ability to gully.
Sodic soils	Absent = 1 Present = 10	Rating assigned by conservationists and pedologists based on propensity of sodic layers to tunnel - spatial data from SALI.		Soil B horizon clay%	0-38% = 2 38-46.5% = 4 46.5-54.2%= 6 54.2-65.5%= 8 >65.5% = 10	Rating based on statistical clumping of base data (Jenkes technique) and assumption that the higher the clay content, the greater the ability to gully.
Soil A horizon thickness	0-8.5 cm = 1 8.5-12.5 cm = 2 12.5-16.5 cm = 3 16.5-22.5 cm = 4 22.5-30.5 cm = 5 30.5-38.5 cm = 6 38.5-47.5 cm = 7 47.5-65 cm = 8 65-130 cm = 9 >130 cm = 10	Rating based on statistical clumping of base data (Jenkes technique) and assumption that the deeper the soil, the deeper the gully.		Hillslope length	0-30 m = 1 30-60 m = 2 60-90 m = 3 90-120 m = 4 120-150 m = 5 150-180 m = 6 180-210 m = 7 210-240 m = 8 240-270 m = 9 >270 m = 10	Rating based on statistical clumping of base data (Jenkes technique) within GIS layer developed from DEM and the rule that the longer the hillslope length, the higher the rating.
Slope	<1% = 1 1-3% = 3 3-5% = 5 5-8% = 7 >8% = 10	Ratings for slopes based on factor for the USLE (Wischmeier & Smith 1978).		Flow accumulation	1-10	Rating based on statistical clumping of base data (Jenkes technique) of cumulative contributing area (cell number) upstream of cell within GIS layer developed from DEM and the larger the contributing area, the higher the rating.

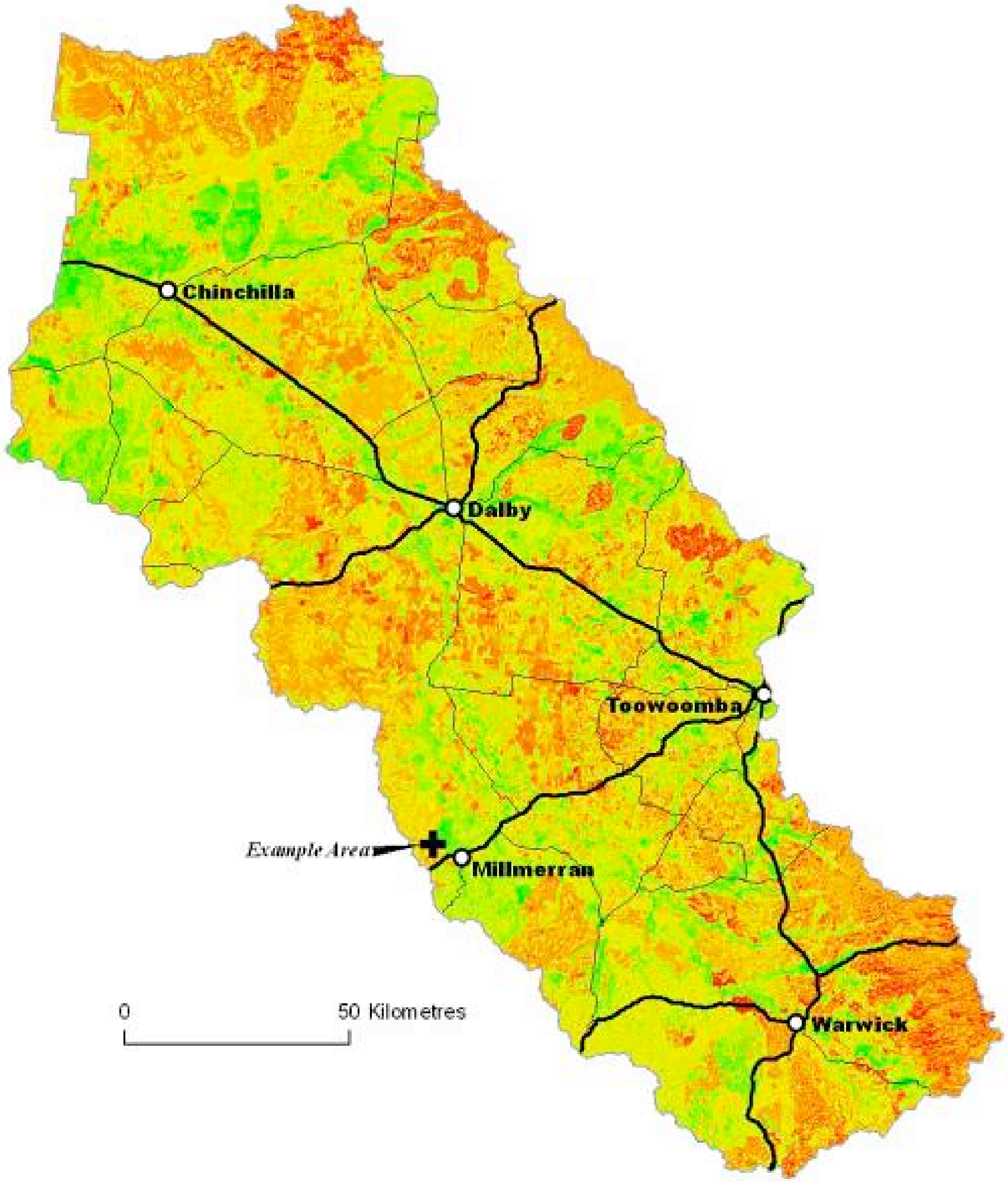


Figure 3. Draft predicted gully erosion risk for Condamine River Catchment

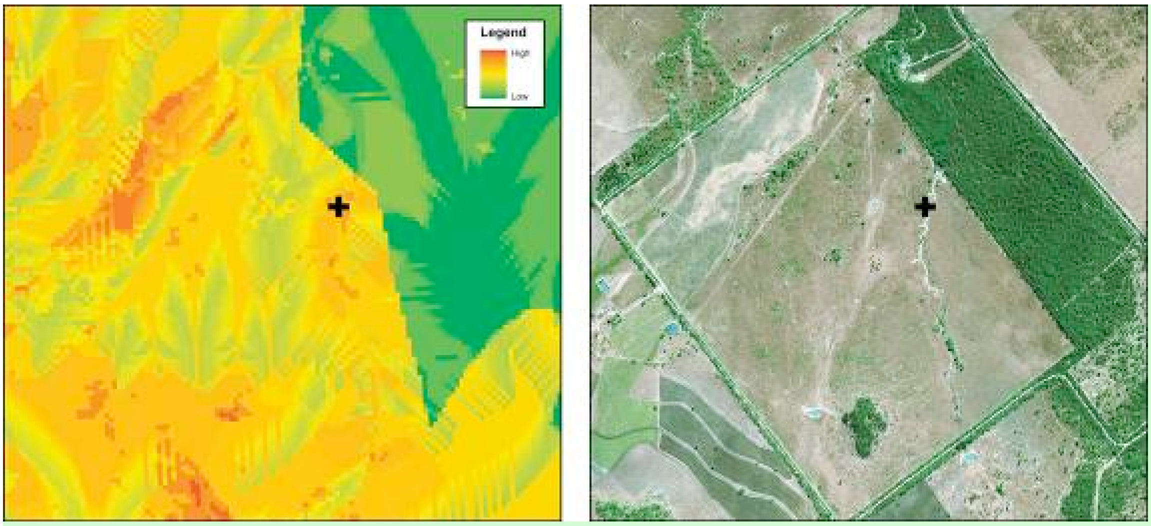


Figure 4. Comparison of draft gully erosion risk prediction output and aerial photograph

Output is a gully risk map only – useful in its own right especially for determining where higher levels of management are required. With field verification and measurement this could be converted into a gully density map (length of gullies per unit area – by multiplying lengths by some cross-sectional area).

Gully erosion rates (in weight per area units) can be derived by comparison of gully dimensions over time. The most accurate way would be to survey gully dimensions at two points in time (using LIDAR or ground survey techniques) but this would be impractical across the entire catchment. Another way would be to multiply the differences in gully densities established using the above technique or equivalent at two points in time by some 'average' gully size. This introduces several sources of error but offers a reasonable solution.

Uptake of management practices and what works

For gullies, prevention is usually much easier than cure with the control method largely dependent on size. Preventative measures include maintenance of groundcover, spreading water away from stock and vehicle tracks, installing contour banks and strip-cropping in flood-prone cultivation areas. Beavis *et al.* (1999) found that regeneration of timbered areas, construction and maintenance of contour banks, and stock and pasture management to increase groundcover levels are associated with stabilisation of networks.

Most gullied areas in cultivation in upland areas in the Condamine Catchment have been repaired using a combination of diversion and contour banks, land levelling/filling and reduced tillage practices. Some major gullies in floodplains and waterways have proven difficult and expensive to control – often left until major infrastructure e.g. a road, is threatened.

Where run-on water is a factor in upland areas, diversion to a safe disposal area is wise, and on floodplains then spreading the flow is effective. It is a matter of economics where gullies are deep as to whether it is worthwhile filling them or altering the use of that land. In grazing or forestry areas, unless something of value (infrastructure) is threatened, it is often not worthwhile using engineering works to control gully heads. Engineering methods include reshaping and revegetating, chutes of various materials, drop structures, dams - see website www.nrw.qld.gov.au/factsheets/pdf/land/l81.pdf and similar for more details.

In practice, it has proven difficult to control gullies once they have developed, especially in soils with dispersible horizons. Flexible structures e.g. gabions or vegetated areas (using vetiver, African star, kikuyu grasses etc) are necessary in swelling soils.

Streambank erosion

Field inspection

As for gully erosion, several techniques have been trialled in the past to ascertain the incidence of streambank erosion – from visual sighting and recording to use of video recordings, LIDAR and remote sensing imagery.

The work of Pearce & Gray (2000) along Glengallan Creek outlines one way of identifying and locating every erosion incidence along a creek. They walked the entire length of the creek noting and taking information about each streambank erosion point. Table 3 lists the type of information they gathered at each location. To be more useful for streams, other information could be collected, e.g. location on stream (inside/outside of a bend), sediment deposition areas, bed stability etc.

Table 3. Information for Glengallan Creek (Pearce & Gray 2000)

Inspection day	Site ID	Date	GPS coord.	Recent rain	Soil type	Depth at side gully head	Width at side gully head
Side gully length	Currently active?	Active head?	Active sides?	Secondary Gully?	Seepage flows?	% cover above	Grass cover
% cover in gully	Grass type	Other veg.	Drainage line type	Land use	Weeds	Obvious contributing factors	Comments

This methodology is relatively simple and gives a complete picture of streambank erosion incidence, requires minimal equipment, but is highly labour intensive.

Results could be extrapolated to some extent but only to streams with similar attributes. To cover larger regions (or longer lengths of stream) some sub-sampling procedure becomes necessary. Examples are the Rapid Appraisal methodology (Jansen *et al*. 2005, Dixon *et al.* 2006), State of the Rivers methodology (Phillips & Moller 1995, Van Manen 2001) and Victorian Department of Sustainability and Environment's Index of Stream Condition (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/stream_cond_index.

All provide a 'snapshot' of stream condition and a time series is required to determine any trends.

Dixon *et al.* (2006) used two indicators (proportion of exposed tree roots and extent of slumping, gullying and undercutting within transects) in assessing riparian condition methodology. Scores assigned to these indicators in conjunction with scores for another 22 indicators are manipulated to give an overall stream reach condition. The Victorian ISC approach is similar.

The State of the Rivers (SOR) provides a more comprehensive method for classifying the physical and ecological condition of streams. Copies of relevant reports (Phillips & Moller 1995, Van Manen 2001) are at www.nrw.qld.gov.au/science/state_of_rivers/index.html. Here, streambed, bar and bank stability and dominant erosion processes are assessed for a length of stream at each site. The final condition rating represents the average percentage of bank which is unstable at the site. Each survey point takes two to three people about one hour (plus travel).

To provide meaningful results representative sampling points need careful selection. The SOR methodology uses 'homogeneous stream sections' so that the sections have similar natural features and condition ratings. This delineation involves progressive division into smaller and smaller units until the required result is achieved, usually using a reconnoitre survey. This subdivision can be assisted by use of soil type, geology, vegetation, stream gradients and natural and artificial barriers.

For the Upper Condamine Catchment (Dalby upstream) Phillips & Moller (1995) found 71% of streambanks were stable or very stable, 11% were unstable or very unstable, but 94% were undergoing some erosion. They also found 50% of the streambed was unstable; the bed and banks in the Dalby to Chinchilla section to be more stable, with 1% only of banks unstable and 1% of the bed to be very unstable and 5% unstable. Their report identifies sections of streams of different stability but further on-site inspection would be required to clearly identify sites if any remedial works on unstable sites were envisaged.

There is subjectivity involved in these types of assessment thus providing a source of variability in results due to operator difference.

Video/aerial photo/remote sensing

Video footage has been trialled as a means of obtaining information for assessing streambank stability and erosion points (plus other attributes) in the Border Rivers Catchment by the Queensland Murray-Darling Committee Inc. (Prentice pers comm.) - area of coverage shown in Appendix 3 - and in the Mt Lofty Ranges (Jones 2004). This can be used to identify larger erosion incidences but is time consuming as someone has to watch the video noting the location of those erosion sites. For the QMDC video, a geo-referenced photographic frame is produced about every 20 m. Identifying erosion under thick tree cover is difficult if not impossible. QMDC is investigating recognition software but that will probably not overcome this problem.

A similar procedure was trialled in the Brisbane River Valley (Witte *et al.* 2001) where they captured laser (LIDAR) and digital video data for 180 km of river. They determined the erosion potential (low, medium or high) of riparian areas using foliage projected cover (FPC) from the video data and slope (from a Digital Terrain Model generated from the LIDAR data).

The main limitation with this approach is cost. Although the video footage capture is reasonable - about $70/km for the Border Rivers work - automating the generation of erosion potential is much more expensive, somewhere between $500 and $1,000 per kilometre to capture the data, produce DTMs and vegetation mapping for the Brisbane Valley work. This is because attributing the vegetation type is a manual task and takes time.

The Millmerran Shire River Improvement Trust in 2002 had low level aerial photos (fixed wing aircraft) taken along the Condamine River within shire boundaries, over 100 km, for a cost of about $1,700, i.e.<$20/km. These photos were suitable for easily identifying the presence of erosion but manual assessment is required to pinpoint erosion zones.

No methods give actual levels of erosion – that requires much more work.

Uptake of management practices and what works

A few publications outline streambank stabilisation works, e.g. Land and Water Australia website (www.rivers.gov.au/publicat/riprap/index.htm) is an excellent source of material but, as for gully erosion, prevention is much better than cure.

Engineering measures are mostly required to control active mass movement erosion (slumps), e.g. bank battering and rock breaching, brushing and groynes, whereas scouring can often be controlled by managing riparian vegetation. Breakouts, where natural levees are breached, usually require engineering work supported by vegetation to stabilise them. In the Condamine River Catchment, larger undertakings have been carried out by River Improvement Trusts (RITs) – Clifton Jondaryan, Millmerran, Wambo and Warwick - and records are available from individual trusts or the Department of Natural Resources and Water which compiles an annual report covering all Queensland RITs.

Fencing of riparian land and installation of off-stream watering points to allow different management to the rest of a paddock is a good step in this direction. In 2005-06 in the Condamine Catchment about 15 km of streambank were fenced and 200 off-stream watering points installed for this purpose – see www.condaminealliance.com.au/images/stories/downloads_2006/11nov16CondamineAnnualReport2006_Final.pdf.

The Natural Heritage Trust project NHT97-2974 ‘Implementing sustainable riverine management in the Queensland Murray-Darling Basin’ combined several smaller projects involving Landcare groups in the Condamine Catchment in 1998-2002, including fencing sections of the riparian zone, rock protection of a meander bend and revegetation of the riparian zone, with varying success.

2.2 Sampling frequency

The longer monitoring continues, the more useful the data will be. This is because trends may emerge which could be attributed to changing land management practices and/or climatic conditions if data relevant to those causes are gathered.

Hillslope erosion

For the Condamine Catchment, runs are made along each traverse in autumn - chosen to fit with cropping cycles as autumn has been the time of least groundcover (prior to seeding). However this winter crop-dominant rotation is changing to summer crop-dominant and stubble retention practices are increasing. It is planned to carry out autumn and spring surveys to allow for these changes when resources allow. This roadside survey is not particularly useful for detection of gully or streambank erosion given the low probability of those erosion types occurring at field sites. Remote sensing or low level aerial photography holds greater promise for detection of those erosion types.

Gully erosion

The frequency or need of monitoring erosion levels depends on whether any control practices have been in place, the type of control mechanisms, weather and level of risk to infrastructure.

If engineering control structures are used there is a need to check structures after each runoff event until their stability is assured, after which these need infrequent/intermittent monitoring only (every 10 years or longer).

If changes have been made in management, e.g. grazing pressure reduced, then gullies should be examined after each major runoff event to determine if those practices have a beneficial impact. If there is a positive impact, reducing the frequency of monitoring would be justified.

Streambank erosion

Incidence is often the same frequency as gully erosion (both forms being erosive flood-dependent), so monitoring of incidence and level would need to be carried out only once every 10 years or longer. As for gully control structures, checking on any engineering measures would have to be carried out after each flood until their stability is assured.

2.3 Data measurement

Hillslope erosion

Field methods

Condamine Alliance transects were planned and the first observations made on a 'suck and see' approach, effectively developing the method by practical experience. Field sheets have been modified over time to reflect this with the most recent version attached (Appendix 1).

Observations of groundcover and other attributes are made at fencelines by visually comparing the paddock condition with reference material. Once calibrated, two staff in one vehicle can cover about 30 sites per day.

Equipment

Vehicle, field photo standards, field data recording sheets (back up to electronic forms on GPS), GPS with built-in form capability, plots of traverses, roads and soil landscape zones on SPOT5 imagery (aerial photographs would suffice as well), camera, slope measuring device (clinometer or abney level – an abney level takes longer to use than the clinometer).

Manpower

Initial planning took two weeks (one person), field survey three weeks (two people), data entry two weeks (one person) and analysis reporting two weeks (one person).

No field sampling or laboratory analyses are involved.

Gully erosion

Field and office method

It proved impractical to delineate most gullies using aerial photographs so the work of Hughes *et al.* (2001), Hughes & Prosser (2003) and, more recently, Dougall *et al.* (in press) was tested in relation to using GIS to develop a gully risk map. The risk map was examined with soil conservationists familiar with some gully-prone areas. They identified localities of gullies and then scrutinised the aerial photographs and risk map for agreement (example in Figure 3).

Equipment

Vehicle, aerial photos, satellite imagery, computer with GIS or required software, attribute layers (or access to).

Manpower

Collation of attribute layers, use of GIS etc – one week (two people with substantial GIS skills), scrutiny of aerial photos, risk map etc, two days (four people), familiarity with technique, analysis, reporting one week (one person).

Streambank erosion

No direct measurements were taken. Use of high altitude aerial photography proved inconclusive and time did not allow an inspection of the entire stream network, only isolated spots. An assessment of methodologies available for estimating streambank erosion levels points towards using broad survey techniques such as State of the Rivers.

2.4 Data collation

Hillslope erosion

Data were collected using electronic forms (GPS) with back-up paper field recording sheets (after GPS form facility failed) – template available from Condamine Alliance.

Gully erosion

Spatial data layers - as polygons - were collated from relevant database by Searle (pers comm). These were then converted to grid format in ArcGIS and attribute ratings (as for Table 5) assigned to each cell using expert opinion. Cell values were then added arithmetically within the GIS to give a risk map i.e. all equally weighted – weighting could be altered based on sound reasoning if required. Predicted gully locations were compared with those identified using a sequence of aerial photographs from mid-1940s to current (collated from NRW archives) and local knowledge.

Streambank erosion

Previous study reports were collated from websites and personal contacts. Aerial photographs (1:40,000) were examined to identify erosion in the Condamine River Catchment. It was difficult to identify incidences unless they were particularly large and clear-cut using that scale. The low altitude photos of the Millmerran River Improvement Trust and aerial video of

QMDC were more useful. Reliance on broadscale surveys such as *State of the Rivers* seems the only way to get an overall picture of streambank erosion in a catchment of this size.

2.5 Data storage and management

Hillslope erosion

Original paper records (field sheets) are filed in a metal cabinet. These sheets are scanned and stored electronically along with the hand-entered database files and GPS field forms on a local computer with back-up on a CD.

Field sheet data are transposed manually into a database from which they are entered into a GIS and shape files produced for analysis, reporting and display.

Normal precautions for the storage and management of digital data are applied including the appointment of a data custodian.

Gully erosion

The spatial data layers, GIS files etc are stored electronically on a local computer and backed up on tape. Normal precautions for the storage and management of digital data are applied including the appointment of a data custodian. GIS output files were used for analysis, reporting and display purposes.

Historic aerial photographs are stored in a metal filing cabinet while current photographs are stored electronically on an NRW database as well as being publicly available as hard copy.

Streambank erosion

Reports cited are stored in libraries (hard copy) or in electronic format on the NRW computer network, original datasheets filed in a metal filing cabinet or archive boxes. Normal precautions for storage and management of digital data are applied including the appointment of a data custodian.

2.6 Data analysis and interpretation

Hillslope erosion

The survey technique used is appropriate to produce regional information such as uptake of alternative management practices. Figures 5 and 6 are examples of this type of product and were extracted from summary and full reports on the Condamine Alliance website.

Care has to be used when developing information products from data of this type. For example, presentation of aggregated numbers (as in Figure 6) to compare district uptake of practices and the like is relatively straight forward and safe but the data have limited value if trying to determine cause and effects. Field knowledge and expertise are also necessary to minimise the danger of drawing erroneous conclusions.

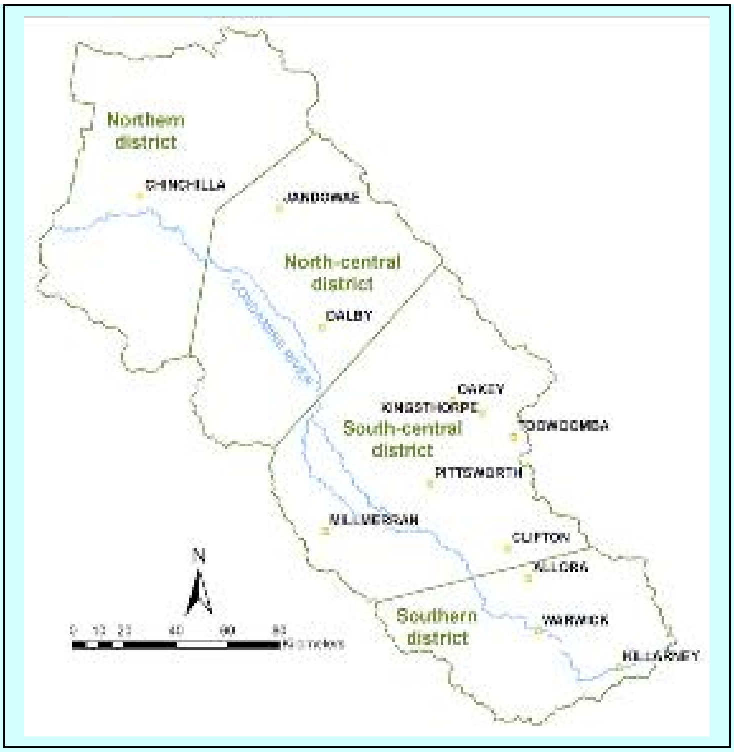


Figure 5. District map (courtesy Condamine Alliance)

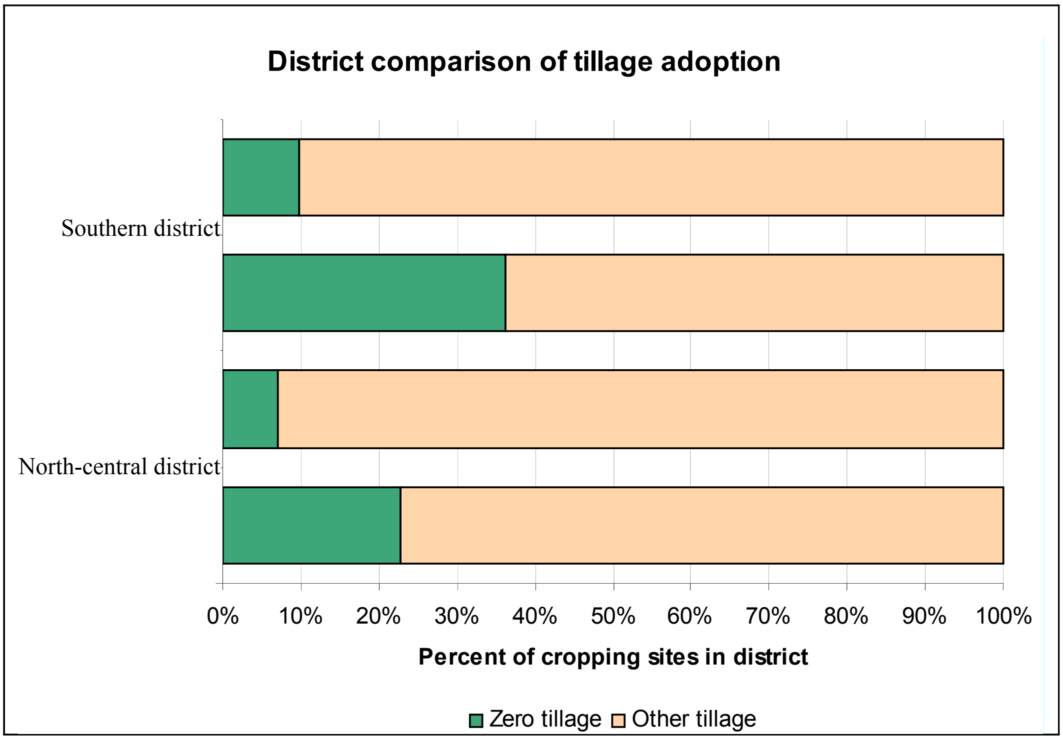


Figure 6. Tillage practice adoption by district (courtesy Condamine Alliance)

Time series data (as shown in the Condamine Alliance 2007 performance report) are useful in showing trends in implementation of various management practices.

Gully erosion

Perusal of a time series of aerial photographs showed that most of the gullies historically evident in upland cultivation have been eliminated as cultural practices have altered, demonstrating the value of time series imagery or aerial photographs. A few too large to repair by cultural practices alone remain on cultivated floodplains and in grazing areas – these would require major uneconomical engineering works.

Streambank erosion

No data analyses were carried out.

2.7 Quality assurance

Hillslope erosion

Accuracy of data entry was confirmed by having field staff check each other’s notes and one staff member intermittently read from the database while a second checked this against the original field data sheet and photographs. Logical consistency tests (e.g. grazing sites should not have tillage practices listed etc) were also applied.

Gully erosion

Accuracy of data entry was confirmed by having staff check each other’s input. The GIS output is largely unvalidated and the attributes used and assigned ratings require a sensitivity analysis. As such, the reliability of output is low at this stage.

Streambank erosion

Not applicable.

2.8 Metadata

Hillslope erosion

The metadata statement for the primary data is contained in the Condamine Alliance report and is consistent with ANZLIC standards.

Gully erosion

The metadata statement for the primary data is consistent with ANZLIC standards and available from Departmental sources.

Streambank erosion

The metadata statement for the primary data is consistent with ANZLIC standards and available from Departmental sources.

3. Reporting

Full and summary reports are available plus fact sheets containing parts of the information.

3.1 Audiences

There are several audiences for water erosion monitoring information, each requiring different outputs/products of different spatial and temporal scales. NRM regional bodies and Landcare groups require aggregations of paddock information to provide a regional overview. These groups need to know the soil erosion risk of all types at a point in time to allocate funding. They also need to know the trends in erosion risk, why those trends exist and whether their programmes are having an impact. Verification of this would most likely require additional information from landholders as to the impetus for change in practices.

State agencies and industry bodies need to know the general on-ground situation, and which regions are improving and which are declining.

National policy and funding bodies including State of the Environment (SoE) require a similar level of detail to the states.

3.2 Products

Products available include the reports referenced and the GIS layers, some data mentioned in this report. These layers and other data can be manipulated into a range of formats e.g. pie diagrams, bar charts, graphs, tables etc. Development of any products requires adequate resourcing (often under-estimated) so that inferior products are not produced.

3.4 Confidentiality

There could be privacy issues with primary data - particularly with easily identifiable locations. Often, once the data have progressed from raw or primary data to information products of a general nature there are often no issues of confidentiality.

Hillslope erosion

As the primary data were collected ‘from the roadside’ there are theoretically no issues with regard to farmer approval for its collection or subsequent use. Condamine Alliance has a policy of not releasing primary data which can be easily geographically located, rather they release lumped or non-site specific data.

Gully erosion

Some primary electronic data are not publicly available, e.g. Bare Ground Indices. The GIS output is available but, due to the low confidence level attached to it, its use would have caveats attached. Aerial photographs are available.

Streambank erosion

Some primary electronic data and internal reports are not publicly available. Released reports are available as are aerial photographs.

4. Discussion

The objective was to establish a baseline condition for water erosion risk within the Condamine River Catchment of Queensland, and, with ongoing monitoring, to show whether that risk increases or diminishes over time.

Hillslope erosion

Using the 2006 Condamine Alliance survey as reference, a baseline condition has been established. This hazard has increased due to drought and loss of groundcover.

The roadside survey monitoring technique appears to be a rapid and viable means of assessing hillslope erosion from local through to the regional level, although possibly not to the national level due to resourcing requirements.

Technical skills are required for field work, GIS skills for presentation and data handling and scientific interpretative skills for analysis. Budget required would be in the order of 12 weeks salary total plus vehicle hire and operating per survey of 300 points or so. The area covered would depend on the distance between survey points. On-site electronic data entry using drop-down menus (on GPS) saves time and reduces the chance of error (no double handling).

Given the privacy and confidentiality policy of Condamine Alliance the utility of information collected is limited to lumped, summary or regional information only, not site specific. As well, specific sites are not revisited. If at least a percentage of the sites had continuous monitoring i.e. had a mix of fixed plus roving sites, better use could be made of the data.

Gully erosion

Perusal of historical aerial photographs shows that gully erosion has decreased throughout the catchment due to altered land management practices and reduced erosive rainfall events.

The GIS-based technique using soil and landscape attributes with an associated gully erosion rating appears to be technically feasible and shows promise for assessing gully erosion hazard and consequent risk given alternative land uses. This is limited by the level and detail of the land resource information available. Determination of actual erosion levels requires either extensive field surveys or some remotely-sensed survey technique such as LIDAR to create accurate DEMs over time – both technically feasible but expensive.

On-going monitoring of both management practices and gully density would provide evidence of the efficacy of alternative land use and management practices in controlling gully erosion but only over a long period of time (covering major erosive events).

Streambank erosion

On-going monitoring of both management practices and incidences of erosion would provide evidence of the efficacy of alternative land use and management practices in controlling erosion but only over a long period (covering major erosive events). The State of the Rivers survey type methodology would be better.

4.1 Current national activities

Hillslope erosion

Quite probably none exists.

Gully erosion

The work of Dougall *et al.* (in press) and continuing in the Fitzroy River Basin is building on the work of Hughes *et al.* (2001) and Hughes & Prosser (2003) in developing a computer-based means of establishing gully erosion within a catchment.

Streambank erosion

This aligns with Victorian Department of Sustainability and Environment Index of Stream Condition work.

4.2 Future developments

Hillslope erosion

The ability to use remote sensing to estimate groundcover levels is continuing.

Gully erosion

There is a need to develop relationships between gully volume and gully risk derived using soil and landscape attributes.

Streambank erosion

The State of the Rivers reports of Phillips & Moller (1995) and Van Manen (2001) provide baseline information for the level of streambank erosion. These show that most streambanks and beds are unstable to some degree.

Both video and imagery/LIDAR approaches to identifying streambank erosion risk and level appear to hold promise at all spatial scales but to extend this to monitoring actual streambank erosion levels would be extremely resource hungry at any but the local level. The State of the Rivers survey type methodology would be better and could be applied at all spatial scales.

A roadside monitoring technique to ascertain erosion risk or level is not feasible as in many areas there is often no public access along streams. The GIS-based technique using imagery and LIDAR as trialled by Witte *et al.* (2001) holds promise for identifying erosion risk as it technically feasible but expensive. The use of video only, as trialled by QMDC, can be used to identify major erosion sites under limited tree cover but is labour intensive at this stage.

Determination of actual soil erosion levels requires either extensive field surveys or utilising some remotely sensed survey technique such as LIDAR to create accurate DEMs over time – both technically feasible but expensive.

To fully test and utilise the imagery/LIDAR approach would require someone familiar with GIS and other relevant software plus fieldwork for ground-truthing output. This would take several months of dedicated staff plus some operating resources.

To fully test and use the GIS/Cubist approach would require someone familiar with the software plus fieldwork to verify predictions. One procedure would be to carry out a sensitivity analysis of attributes used (and others) and ratings and then identify areas that cover a range of gully erosion risks (from GIS output and local knowledge) using a time series of aerial photographs and ground-truthing to determine gully densities (km/km^2) and dimensions of selected gullies (using survey techniques) for these areas over time. Then multiply these densities by some gully dimensions to give a volume (convert to weight using density) and so, an erosion rate. This would take several months of dedicated staff with requisite skills plus operating resources.

5. Further information

Australian Bureau of Agricultural and Resource Economics (1999) AgAccess (©1999), Available at **www.abare.gov.au**.

Australian Bureau of Statistics 2000, Agricultural Census - Selected Shire Results 2000/01, Canberra.

State of the Environment Advisory Council (1996) Australia State of the Environment 1996, Report to Commonwealth of Australia. CSIRO Publication 150, Collingwood.

Beavis SG, Zhang L, Jakeman AJ, Gray SD (1999) Erosional history of the Warrah Catchment in the Liverpool Plains, NSW. *Hydrological Processes* 13, 753-761.

Berry V (2007) Assessing stubble cover – Photo standards for sorghum crops, QLD DPI&F Brisbane.

Ciesiolka CA, Coughlan KJ, Rose CW, Escalante MC, Mohd. Hashin G, Panningbatan EP, Sombatpanit S (1995) Methodology for a multi-country study of soil erosion management. *Soil Technology* 8, 3, 179-192.

Ciesiolka CAA, Rose CW (1998) The measurement of soil erosion. *In*: Soil Erosion at Multiple Scales: Principles and methods for assessing causes and impacts. (Eds FWT Penning de Vries, F Argus, J Kerr) CABI Publishing with International Board for Soil Research and Management.

Denham R (2006) Notes on preliminary classification of gully erosion using Spot 5 Image. Queensland Department of Natural Resources and Water, Indooroopilly.

Department of Natural Resources (2003) Land Cover Change in Queensland 2001-2003. A Statewide Landcover and Trees Study (SLATS) report.

Dixon I, Douglas I, Dowe J, Burrows D (2006) Tropical appraisal of riparian condition version 1 for use in tropical savannas. Land and Water Australia, River and Riparian Land Management Technical Guideline No. 7.

Dougall *et al.* (In press) Fitzroy SedNet Improvement Project.

Emery KA (1975) Identification of soil erosion from aerial photographs. *Soil Conservation Journal* October 1975, 219-240.

eWater CRC see www.ewatercrc.com.au and follow links to **www.toolkit.net.au**.

Flanagan D, Nearing M (1995) USDA Water Erosion Prediction Project (WEPP). Technical documentation. NSERL Report 10, USDA_ARS- MWA West Lafayette, IN.

Foster GA (1982) Modelling the erosion process. In: Hydrologic Modelling of Small Watersheds. (Eds CT Haan, HP Johnson, DL Brakensiek) ASAE Monograph No. 5, American Society of Agricultural Engineers, St Joseph, Michigan.

Foster GR, Young RA, Romkens MJ, Onstad CA (1985) Process of soil erosion by water. In: Soil Erosion and Crop Productivity (Eds RF Follett, BA Stewart). American Society of Agronomy Inc, Crop Science Society of America Inc. and Soil Science Society of America Inc., Madison, Wisconsin, USA.

Freebairn DM, Wockner GH (1986) A study of soil erosion on vertisols of the eastern Darling Downs, Queensland. I. Effect of surface conditions on soil movement within contour bay catchments. *Aust. J. Soil Res*. **24**: 135-158.

Freebairn DM, King CA (2003) Reflections on collectively working toward sustainability: indicators for indicators! *Australian Journal of Experimental Agriculture* **43**, 223-238.

Frevert RK, Schwab GO, Edminster TW, Barnes KK (1955) Soil and Water Engineering. John Wiley & Sons, New York.

Hadley R, Lal R, Onstad C, Walling D, Yair A (1985) Recent developments in Erosion and Sediment Yield Studies. Technical Documents in Hydrology, UNESCO, Paris.

Houghton PD, Charman PEV (1986) *Glossary of terms used in soil conservation.* Soil Conservation Service of NSW.

Hughes AO, Prosser IP, Stevenson J, Scott A, Lu H, Gallant J, Moran JM (2001) Gully Mapping for the National Land and Water resource Audit. CSIRO Technical Report 26/01.

Hughes AO, Prosser IP (2003) Gully and Riverbank Erosion Mapping for the Murray-Darling Basin. CSIRO technical report 3/03.

Jansen A, Robertson A, Thompson L, Wilson A (2005) Rapid Appraisal of Riparian Condition, Version Two. Land and Water Australia, River and Riparian Land Management Technical Guideline No 4A.

Jones L (2004) Videography of the Mt Lofty Ranges watercourses. South Australian Department of Water, Land and Biodiversity Conservation, Report DWLBC 2004/22.

Ladewig JE, Skinner AF (1950) Soil Conservation in Queensland – General Aspects. Queensland Agricultural Journal **70**, 14-24.

Littleboy M, Freebairn DM, Hammer GL, Silburn DM (1992) Impact of soil erosion on production in cropping systems. II. Simulation of production and erosion risks for a wheat cropping system. *Australian Journal of Soil Research* **30**, 775-788.

Loch RJ, Slater BL, Devoil C (1990) Soil erodibility (K(m)) values for some Australian soils. *Australian Journal of Soil Research* **36,** 6, 1045-1055.

McCord A (2005) State Survey Monitoring Manual - Cropping Districts Information Management DWLBC.

McKenzie NJ, Dixon JC (2006) Monitoring soil condition across Australia. Recommendations from the expert panels prepared on behalf of the National Committee on Soil and Terrain for the National Land & Water Resources Audit.

McKenzie NJ, Henderson B, McDonald WS (2002) Monitoring soil change: principles and practices for Australian conditions. CSIRO Land and Water Technical Report 18/02, Canberra.

Molloy J (1988) Field manual for measuring stubble cover. Queensland Department Primary Industries and Fisheries, Brisbane.

NRW (2007) Queensland Soil Conservation Handbook. Department of Natural Resources and Water. **www.nrw.qld.gov.au/land/management/erosion/index.html#design**.

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR (2002) Soil and Water Assessment Tool User’s Manual, Version 2000. Texas Water Resources Institute, College Station, Texas.

Pearce P, Gray J (2000) Report on the stream erosion survey of Glengallan Creek. Department of Natural Resources & Mines internal report.

Phillips N, Moller G (1995) An ecological and physical assessment of the condition of streams in the Upper Condamine River and major tributaries. State of the Rivers Report, Department of Primary Industries.

Prosser IP, Winchester SJ, (1996) History and development of gully initiation and development in eastern Australia. *Zeitschrift fur Geomorphologie, Supplementband* 105, 91-109.

QLUMP - Queensland Land-Use Mapping Program (2004) Land-use mapping-methodology. Department of Natural Resources & Mines. **http://nrm/science/lump/methodology.html**

Ries JB, Marzolff I (1997) Identification of sediment sources by large-scale aerial photography taken from a monitoring blimp. *Physics and Chemistry of the Earth* 22, 3-4, 295-302.

Rosenthal KM, White BJ (1980) Distribution of a rainfall erosion index in Queensland. Division of Land Utililisation Report 80/8, Department of Primary Industries, Brisbane.

Rulequest (2001) Data mining with Cubist. **www.rulequest.com/cubist-info.html**.

Scarth P, Byrne M, Danaher T, Henry B, Hassett R, Carter J, Timmers P (2006) State of the paddock: monitoring condition and trend in groundcover across Queensland. Proc. 13th Australasian Remote Sensing and Photogrammetry Conference, Canberra.

Stewart J (1968) Erosion survey of New South Wales Eastern and Central Divisions, reassessment 1967. *Journal of Soil Conservation Service of NSW* **24**, 3, 139-54.

Thomas GA, Titmarsh GW, Freebairn DM, Radford BJ (2007) No-tillage and conservation farming practices in grain growing areas of Queensland – a review of 40 years of development. Accepted for publication *Australian Journal of Experimental Agriculture.*

Van Manen N (2001) An ecological and physical assessment of the condition of streams in the Maranoa, Balonne and Lower Condamine River Catchments. State of the Rivers Report, Department of Natural Resources and Mines QNRM01026.

Waters D (2007) Department of Natural Resources and Water, Toowoomba, Queensland.

White PJ (1986) A review of soil erosion and agricultural productivity with particular reference to grain crop production in Queensland. *Journal of the Institute of Agricultural Science* 52, 1 12-23.

Witte C, Dowling R, Weller D, Denham R, Rowland T (undated) Quantifying riparian vegetation and streambank form through the use of airborne laser scanning and digital video data. Department of Natural Resources & Mines internal report.

Witte C, Dowling R, Denham R (2001) Quantifying riparian vegetation and streambank form along sections of the Brisbane River and Lockyer Creeks, Stage 1 QNRM01041.

Wischmeier WH, Smith, DD (1978) Predicting rainfall erosion losses – a guide to conservation planning. US Department of Agriculture, Agriculture Handbook No. 537.

6. Acknowledgements:

The authors wish to thank Ross Searle, Dave Burton, Dave Waters, Shawn Darr, Mark Genrich, John Gray and Doug Muller of the Queensland Department of Natural Resources and Water and Jim Dixon, Department of Agriculture and Food, Western Australia.

7. Appendices

Appendix 1. Data and definitions – Condamine Alliance Field Record Sheet

Attribute	**Definition**	**Units/acceptable values in database**
Date	Date of field observation	dd/mm/yyyy
Time	Time of field observation	Army time XX:XX hours
Recorder	Observation team leader	Text, First name initial, full surname.
Site number	Unique value, note that for monitoring purposes the same site might be visited on several occasions. The same site number will be used but the dates will be different in each case.	Numerical value
Road name	Unique identifier – Shire road name	Text
View direction	Choice from cardinal and intercardinal points	Text e.g. SW
Land use	Land use at time of observation classified from: • Grazing • Irrigated crop • Dry cropping • Treed/Native	Text
Slope	Average incline of land surface, directly down slope, within the 100 m square sample area	Numeric value, %
Soil conservation structures	Refers to contour banks and choice from • Not present • Not maintained • Unknown maintenance • Maintained	Text
Groundcover	Choice from: • Bare • Under 30% cover • 30-50% cover • 50-70% cover • Over 70% cover as compared with photo standards	Text
Dominant height	Height of species that forms largest part of groundcover as opposed to the tallest species - often the height of the basal clump rather than the upright seed head which may only be small proportion of the groundcover – may be dead or alive.	Numeric, cm
Growing height	As for dominant height but only applies to the growing plants.	Numeric, cm
Proportion of cover growing	Choice of >50% or <50% as compared with photo standards.	Text
Environmental weeds	Weed species present (exotic and native)	Text (if common name used need reference list of those names to avoid later confusion)
Pasture condition	Choice from: • Good • Fair • Poor	Text

	• Very poor As compared with GLM description[1]	
Stock type	Choice from: • Unidentifiable • Beef cattle • Dairy cattle • Sheep • Horses • Other (note)	Text
Tillage practice	Choice from: • Zero tillage • Other tillage (Zero till defined as evidences of stubble retention through no cultivation)	Text
Growing crop	Choice from: • Not applicable • Nil growing • Cereal • Forage • Legume • Cotton • Sunflower • Horticulture	Text
Stubble crop	Choice from: • Not applicable • No stubble • Cereal • Forage • Legume • Cotton • Sunflower • Horticulture	Text
Row width	Average width between planting rows	Numeric, cm
Tree type	Choice from: • Native • Regrowth • Plantation	Text
Photo No.	Digital camera sequential number	####.jpg (use photo with date/time stamp to check with field recording time)
Other notes (e.g. erosion, strip cropping, salinity, pasture condition)	E.g. pasture yield estimates	Text

[1] GLM Grazing Land Management – a product of Meat & Livestock Australia (see website www.mla.com.au/default.htm) and the Queensland Department of Primary Industries and Fisheries (see www.dpi.qld.gov.au).

Appendix 2. Data collected within the Viable Farming Systems Group

- Site ID
- Location, site detail
- Soil type
- Land slope, - increments of 0.5%
- Land use, choice of 10
- Contour banks spacing
- Dead stubble cover level (%) and type (choice of 3)
- Canopy cover – level (%) and type by weeds (choice of broad/narrow leaf or both), crop (choice of 25) and pasture (choice of 5)
- Roughness, choice of 1 (smooth) to 5 (rough)
- Furrow gradient, across vs. up/downslope
- Fallow management, choice of 6
- Surface hardness, rated 1 (friable) to 3 (hard)
- Cracks – choice of none, some, many.

Appendix 3. Video coverage of Border Rivers, QMDC