Monitoring soil condition across Australia

Recommendations from the Expert Panels

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Prepared on behalf of the National Committee on Soil and Terrain for the National Land and Water Resources Audit

Contents

Executive summary

This report recommends a range of protocols and actions required by a number of agencies that will ensure the successful long-term monitoring of soil condition across Australia. The four priority processes which potentially have a major impact on the welfare of the Australian population are wind erosion, water erosion, soil acidification, and soil organic carbon change.

These processes are difficult to monitor because they usually affect large areas and are either irregular or progress very slowly. The monitoring protocols released in 2003 did not adequately address these difficulties.

The Expert Panels identified a range of factors which require attention.

- The current institutional framework within Australia is unsuited to long-term monitoring and a long-term mandate is required.
- The biggest advances in monitoring soil condition are likely to come from improved data for modeling.
- There are dual objectives for monitoring: local monitoring for project management and accountability, and broader monitoring for the purpose of managing the national soil resource base. These two objectives often demand different approaches.

Recommendations specific to each of the four processes appear in the appropriate chapters.

Chapter 1 Monitoring soil condition

J Dixon and NJ McKenzie

1.1 Introduction

This report recommends a range of protocols and actions required to ensure the successful long-term monitoring of some important aspects of soil condition across Australia. Information from these systems is essential for resolving large uncertainties about the current status of, and trends in, soil processes that have the potential to be extremely costly to the nation in economic, environmental and social terms.

The report has its origins in two main lines of work. The first was formalised in May 2002 when the Natural Resource Management Ministerial Council (NRMC) released the National Natural Resource Management Monitoring and Evaluation Framework. The purpose of the Framework was to guide the monitoring activities of major programs for natural resources including the National Action Plan for Salinity and Water Quality (NAP) and the Natural Heritage Trust (NHT).

The second line of work started with the initial phase of the National Land and Water Resources Audit (NLWRA). Final reports (e.g. NLWRA 2001) highlighted the extent of some forms of soil degradation (e.g. acidification, soil erosion by water) and identified strategies for monitoring soil change. McKenzie et al. (2002) provide an extended review of the principles and practices for monitoring soil change – the technical context for the present report.

In 2005, the NLWRA, through its National Committee on Soil and Terrain (NCST), convened four Expert Panels to provide advice on methods for monitoring soil acidification, soil organic carbon change, and soil erosion by water and wind, from local through to national scales. Panelists were individuals with national recognition in one of the four processes and were predominantly from state or territory agencies, universities and CSIRO. No attempt was made to represent individual states and territories. However, the breadth of experience resident in each panel ensured that the major landscapes and systems of land use were thoroughly considered.

1.2 The challenge

The four processes (soil acidification, dynamics of soil organic carbon, and erosion by wind and water) were recommended by in the Framework as having highest priority. Other aspects of soil condition will need to be considered in the near future including nutrient balance, soil physical quality, contamination and soil biology. The four considered here are complex biophysical processes and the Panels’ task was to express the essential features of each in terms of useful and readily understood indicators (e.g. hectares affected, tonnes per hectare, change in pH, or change in carbon percentage).

These processes and their indicators can be difficult to monitor because they often occur as irregular catastrophic events or progress very slowly. The main technical challenges are as follows (McKenzie 2006).

- A large sampling effort is often required to distinguish the relatively small changes over time from the typically large spatial fluctuations over a range of scales.
- Some soil properties can be readily monitored (i.e. those that are responsive to management, easy to measure and less spatially variable) while others are impractical because of the large spatial variation and cost of measurement.
- It is practical to monitor soil change at local and regional scales. However, it is essential to repeat measurements over time at the *same* site and to then analyse differences between individual sites over time. The alternative method of comparing the mean value of a soil property across all sites at time zero with the mean value for all sites at a later time is inefficient and ineffective.
- Monitoring soil condition relies ultimately on good quality measurement at representative field sites over extended periods (i.e. decades).
- Information on land management is critical for interpreting the results of monitoring.
- Maps of soil properties, land types or so-called sustainability indicators are an inefficient means for detecting change because their predictive capability for a given location is low, so comparisons of maps prepared for different times will have a very low accuracy and precision. However, the maps are valuable because they show patterns of resource condition and provide an essential tool for designing and prioritising monitoring efforts. They are also necessary for analysing and generalising results from a monitoring program.

At a more general level, programs for monitoring soil condition must have the following features.

- A clear purpose should be defined, one which is closely linked to a scientific goal or decision-making process at the local, regional or national level.
- Monitoring sites should be established *after* surveys of land resources are completed to ensure the sites represent well-defined landscape units and systems of land use. This procedure allows results to be extrapolated with confidence to other locations.
- Complementary programs for monitoring and computer simulation should be developed to assess whether soil change can be detected in a reasonable time. Modelling is used to determine the location of monitoring sites and to specify the frequency of measurement. Modelling can also be used to extrapolate results from monitoring sites.
- Monitoring should be weighted towards regions where early change is likely (Vos et al. 2000, Tegler et al. 2001). This targeting avoids wasting resources on

measurement programs and ensures that monitoring provides an early warning system.

1.3 The demand for information on soil condition

A wide range of individuals, community groups, industries and public agencies require information on soil condition. The Expert Panels focused primarily on the following two groups.

- The 56 Natural Resource Management Regional Bodies newly constituted across Australia require a basis for setting investment priorities and assessing the benefits accruing from these investments. The Regional Bodies are closely linked to land managers and have a strong focus on practical, on ground actions.
- State, territory and federal agencies responsible for managing natural resources require a broader picture of soil condition for assessments (e.g. state of the environment reporting) and for policy formulation which includes expenditure allocation.

These two groups require information at different scales in space and time. Regional Bodies work within administrative boundaries and indications of change are needed in the short term, often just a few years. In this case it is more logical to monitor changes in the drivers of soil change (i.e. land management practices) with the expectation that changes in soil condition will occur in the long term. Of course, monitoring of soil condition at a few locations remains essential to understand the relationship between management practices and soil condition.

State, territory and federal agencies are often interested in changes across large areas over longer periods of time (e.g. acidification across the cropping lands of southern Australia). Although these agencies are also governed by budget cycles they generally have the responsibility and potential capability to undertake the long-term programs required to monitor soil condition over decades, for example.

1.4 Soil condition: economic, environmental and social significance

In many cases, change in soil condition can have a major impact on the welfare of Australians. Some significant examples are as follows.

- Atmospheric dust arising from accelerated wind erosion is an important factor in climate change (Chapter 4) and better information is essential for reducing the uncertainty of change forecasts.
- Atmospheric dust due to accelerated erosion causes damage to infrastructure and affects human health.
- Degraded land is difficult, expensive or impossible to repair. For example, severe declines in pH throughout the soil profile are practically irreversible and the soil will not grow the same range of crops that was originally possible. This compromises the farmer's flexibility and ability to respond to changing market conditions. Industry groups and land use planners need to understand rates of

change so they can avoid irreversible degradation. Information at a more general scale is relevant to infrastructure planning and policies relating to natural resource management. For example, Australia needs to apply between 12 and 66 million tonnes of lime to adjust soil to pH 4.8 and 5.5, respectively, with a further 1–3 or 2–12 million tonnes, respectively, required for pH maintenance (NLWRA 2001).

- Increasing the content of organic carbon in Australian soils will generate substantial benefits through the improvement in soil fertility, better protection against erosion and increased crop yield. More importantly, soil plays a major role in the global carbon cycle and it has the potential to be a large carbon store and mitigator of climate change. It is imperative for the scientific community in Australia to provide accurate estimates of the current store of soil organic carbon and then track changes in the future.

1.5 Concerns with existing protocols

The monitoring protocols released by the Monitoring and Evaluation Working Group in 2003 did not result in reliable systems for monitoring soil condition for several reasons.

- They were as much discussion papers as they were practical plans for action.
- They mostly failed to address the need for different strategies for monitoring at different scales in space and time.
- Most Regional Bodies did not have the technical capacity to implement the programs necessary to detect changes in soil condition. The challenge is substantial for even a well-resourced agency with good scientific services.
- It was wrongly assumed that data gathered by a Regional Body could be simply aggregated to provide a state and national picture. Apart from a range of technical issues, the simple fact that each Body was free to choose its own subset of indicators meant that there would be gaps and complete regional or national view could be developed.
- It was not fully appreciated that it is more cost-effective for some aspects of monitoring to be handled by one or two expert groups which service all Regional Bodies. Remote sensing is a prime example.
- Limited attention was given to the scientific and technical infrastructure necessary to support such systems.

1.6 Data and their management

1.6.1 Interim arrangements

The significant number of agencies potentially involved in monitoring soil condition under the current institutional arrangements creates difficulties for data collection and management. These difficulties relate to agreed methods for measurement, quality control, data exchange, database design, definitions of entities, continuity of data collection and uploading. A major quality assurance effort will needed if data from disparate sources are to be combined.

The most logical repository for data from a monitoring program at present is the Australian Soil Resources Information System (ASRIS – www.asris.csiro.au). ASRIS is a project managed by CSIRO. A more permanent basis for funding is required along with secure institutional support. In the immediate term, ASRIS will need a limited amount of redesign to accommodate data from the proposed soil condition monitoring systems.

1.6.2 Collateral datasets

The biophysical understanding of soil erosion, carbon dynamics and acidification is quite advanced and several robust simulation models exist. The biggest advances in tracking and forecasting changes in soil condition are likely to come from improved data to feed these models.

The Expert Panels identified several critical sets of data relating to climate, vegetation and land management that largely define the causes of soil change. The data sets provide estimates of:

- land use and land management practices
- Normalised Difference Vegetation Index (NDVI) and related indices
- surface cover or its inverse, bare ground
- various climatic parameters including rainfall amount and intensity
- various terrain variables including slope and slope length.

These data sets are relevant to several processes and, as noted earlier, it is most cost-effective to have only one or two groups producing and maintaining these datasets.

1.7 Implementation and institutional issues

The Expert Panels recognised that different approaches to monitoring soil change were usually needed at different scales. The Panels aimed to recommend methods with complementary links between local, regional and national scales.

The Panels identified a range of research or developmental tasks that must be completed before the monitoring systems can be implemented. These are identified in the following chapters. In all cases rigorous field testing is necessary prior to implementation.

Monitoring soil condition is difficult for both technical and institutional reasons. While the Expert Panels were concerned with the former, it was apparent to all that the current institutional framework for long-term monitoring within Australia is uncertain and unsatisfactory for the following reasons.

- Restructuring of agencies and frequent changes to priorities for natural resource management is widespread and destabilising. Monitoring requires agencies with a formal mandate (e.g. Bureau of Meteorology) and a culture of the long term (e.g. some state forestry agencies).
- Monitoring with its long-term benefits suffers in the competition for funds with projects that return benefits in the short term (e.g. those responding to immediate priorities or problems).

- Monitoring systems require several generations of staff and those responsible today may not be the beneficiaries of the effort.
- Individuals take on new assignments, transfer or retire, and the charters of agencies evolve. Long-term contracts are needed to ensure that the commitment is ongoing.
- Data are lost over time unless the monitoring program is always active. Rapid developments in computer hardware and software can easily lead to catastrophic losses of data such as has occurred several times in recent years with land resource surveys.
- Standardisation of sampling, measurement, analysis and reporting is difficult in the current system due to the number of agencies at the regional, state, territory and national level.
- In some instances issues relating to intellectual property must be resolved before the method in question can be recommended and further developed.

During the Expert Panel discussions it became evident that if monitoring of soil condition in Australia is to be successful then long term responsibility needs to be assigned to a specific agency to ensure:

- standardisation and quality control of the primary data collected
- good quality management of data over the long term
- maintenance of core skills, with staff development and viable career paths
- coordination of the ‘cells’ of expertise across the nation
- efficient distribution of reports from the monitoring systems
- resident expertise to analyse, forecast and inform policy.

The administrative arrangements for an agency with responsibilities for monitoring soil (and other natural resources) were beyond the terms of reference for each Expert Panel. However, it is central to success. Two existing agencies may be able to play a more formal role: the Bureau of Meteorology with its expertise with monitoring networks, numerical prediction and reporting, and Geoscience Australia with its experience in managing spatial data and reporting on natural hazards.

1.8 Long-term research sites to support monitoring

There is a need for a restricted number of substantial long-term scientific studies of ecosystem and landscape processes in catchments that represent, in the first instance, the main regions used for agriculture, urban development and forestry in Australia. These studies need to measure and model the dynamics of water, sediment, nutrients, contaminants, biological production and related processes. These studies are essential for an improved understanding of processes controlling the sustainability of current and planned systems of land use. In particular, it is important to understand the impacts of changing land use (e.g. urbanization, revegetation, acidification, increasing use of fertilizers, intensification of farming systems) on nutrient loss from soil systems, catchment water-balance and the ecology of waterways and land management systems.

Excellent prototypes for such studies exist in the United States, with the 24 Long Term Ecological Research sites (LTERs),[1] and in Canada, with the Ecological Monitoring and Assessment Network (Vaughan et al. 2001[2]). Some long-term studies have been established in Australia, particularly in relation to forest management (e.g. the Warra site in Tasmania[3] and others documented by House and Simpson (1998)). However, a far more comprehensive approach is required both in terms of the regions represented and the range of processes measured.

These long-term research sites will generate many benefits. The most relevant here is the gathering of evidence to support the underlying assumptions of the proposed methods. The Expert Panels identified a range of questions that can only be answered by long-term studies and these are outlined in the following chapters.

1.9 General recommendations

Many challenges were common to all the Expert Panels. The responses to these challenges are presented here as general recommendations both to avoid repetition and to emphasize their importance to the design of a cost-effective approach to monitoring soil condition across Australia.

Recommendation 1

Develop a permanent monitoring agency with links to relevant research, academic and other institutions. This agency is needed to maintain a national capability to measure and analyse changes in soil condition and to provide a basis for formulation of policy. A formal process to promote the formation of this agency is needed.

Recommendation 2

Formalise the Expert Panels (e.g. membership, terms of reference) so they can oversee implementation of the methods proposed here for soil acidification, soil organic carbon, and soil erosion by wind and water.

Recommendation 3

Enhance the Australian Soil Resource Information System so it can receive and report on data from monitoring programs.

Recommendation 4

Plan an initial set of long-term ecological research sites.

Recommendation 5

Prepare collateral datasets that characterise the drivers of soil change, most notably land management practices, vegetation cover, fine-resolution terrain information and climate.

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[1] http://lternet.edu/

[2] www.eman-rese.ca/eman/

[3] http://www.warra.com/

Recommendation 6

Commission a series of research and development projects immediately to enable implementation of the methods for monitoring soil condition. Two priorities are calibration of mid infrared spectroscopy to enable efficient measurement of soil organic carbon pools, and development of robust methods for estimating bare ground from remotely sensed imagery to predict soil erosion by wind and water.

Other recommendations

1. Test the updated protocols within selected regions in collaboration with the relevant Regional Bodies.
2. Publish the methods for monitoring soil condition as part of the Australian Soil and Land Survey Handbook Series.
3. Advise Regional Bodies of the recommended approach and provide technical advice and quality assurance for monitoring soil condition.

1.10 References

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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.

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NLWRA (2001) 'Australian agricultural assessment 2001.' National Land and Water Resources Audit, Canberra.

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Appendix 1: Membership of the Expert Panels

Expert panels were formed to recommend methods of monitoring soil organic carbon, soil acidification, and soil erosion by wind and water, at the local and the broad scale. Jim Dixon and Neil McKenzie convened each Panel.

Panel	Panel members	Organization	Meeting
Soil erosion by water	Dr David Freebairn	Department of Natural Resources, Mines and Water, Queensland	13–15 Feb 2006
	Dr Guy Geeves	Lachlan Catchment Management Authority	
	Dr Peter Hairsine	CSIRO Land and Water	
	Emer. Prof. Robert Loughran	School of Environmental and Life Sciences, The University of Newcastle	
	Emer. Prof. Calvin Rose	Faculty of Environmental Sciences, Griffith University	
Soil organic carbon	Dr Ram Dalal	Department of Natural Resources, Mines and Water, Queensland	28 Feb–2 March 2006
	Dr Pauline Mele	Department of Primary Industries, Victoria	
	Mr Jan Skjemstad	CSIRO Land and Water	
	Dr Bill Slattery	Australian Greenhouse Office	
	Dr Brian Wilson	Department of Natural Resources, New South Wales	
Soil acidification	Mr Doug Crawford	Department of Primary Industries, Victoria	28–30 March 2006
	Mr Chris Gazey	Department of Agriculture and Food, Western Australian	
	Mr Chris Grose	Department of Primary Industries, Water and Environment, Tas	
	Mr Brian Hughes	Rural Solutions, SA	
	Mr Richard Merry	CSIRO Land and Water (retired)	
	Dr Phil Moody	Department of Natural Resources, Mines and Water, Queensland	
	Dr Brian Wilson	Department of Natural Resources, NSW	
Soil erosion by wind	Dr Harry Butler	Faculty of Sciences, University of Southern Queensland	10–12 April 2006
	Dr Dan Carter	Department of Agriculture and Food, Western Australian	
	Dr John Leys	Department of Natural Resources, New South Wales	
	Mr Andy McCord	Department of Water, Land and Biodiversity Conservation Information Management, South Australia	
	Prof. Grant McTainsh	Faculty of Environmental Sciences, Griffith University	
	Mr Alan Wain	Bureau of Meteorology	

Chapter 2 Soil acidification

Expert Panel on Soil Acidification

PW Moody, RH Merry, C Gazey, BR Wilson, B Hughes, CJ Grose, J Dixon, NJ McKenzie

2.1 Introduction

Acidification affects about half of Australia's agriculturally productive soils. The severity and extent of acidification are increasing due to intensification of land management (e.g. use of high analysis nitrogen fertilisers, increased rates of product removal). The most recent assessments (NLWRA 2001) estimate the annual value of lost agricultural production due to soil acidity to be $1585 million, about eight times the estimated cost of soil salinity. The potential for irreversible soil damage and off-site impacts due to acidity are increasingly being recognised (Lockwood et al. 2003).

Compared to most indicators of soil condition, monitoring of soil acidification is technically tractable and economically feasible although simply measuring soil pH is not sufficient and other ancillary datasets are needed. The process can be summarised by measuring:

- the time before critical pH[4] values are reached
- the rates of ameliorants (e.g. lime) required to maintain pH at a specified value.

Ideally, these measures are determined at local, regional and national scales, albeit with different degrees of spatial accuracy and precision. The main datasets required to achieve this are:

- soil pH over time (preferably with pH measured at several depths in the soil profile)
- pH buffering capacity of each soil layer
- net annual acidification rate (NAAR) of different land management practices
- critical pH for the nominated crops or land use.

This chapter presents methods for gathering these data to estimate the time before critical pH values are reached and required rates of ameliorants at local, regional and national scales. Recommendations for the responsibilities of different agencies are given and links are made to the other monitoring programs for soil organic carbon and erosion.

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[4] pH values cited are in 0.01M $CaCl_2$

2.2 Reasons for monitoring soil acidity

Monitoring soil acidification is of obvious benefit to a farmer seeking to maintain the productivity of the soil on which his or her livelihood depends. The broader need for monitoring soil acidification has often been neglected because of the expectation that industries will look after the problem. This view is mistaken because of major issues relating to off-site impacts and to irreversible degradation when the problem is recognised too late.

The problems arise because soil acidification is an insidious process that develops slowly and, if not corrected, can continue until the soil is irreparably damaged. NLWRA (2001) estimated soil acidity affected 50 million hectares of surface layers and 23 million hectares of subsoil layers of Australia’s agricultural zone. Other information on the current extent and implications of soil acidity appear in Lockwood et al. (2003).

The decline in pH affects the availability of plant nutrients and can lead to some elements, particularly heavy metals, being mobilised at toxic levels. pH therefore has a direct relationship to the sustainability of farming systems and a decline in pH reduces agricultural production, damages acid-sensitive plants, affects biodiversity and diminishes ecological services. Ultimately soil acidification restricts options for land management because acid-sensitive crops and pastures cannot be grown.

While the NLWRA (2001) was an important step in assessing the magnitude and distribution of soil acidification in Australia, there is a clear need to establish accurate baselines against which to measure future change and determine whether the problem is increasing, stabilising or decreasing. More specifically, managers of natural resources require information to:

- forecast trends in soil acidification and their likely impacts
- enable a preventative approach to acidification rather than a reactive one, thereby avoiding irreversible damage
- improve options for land use
- identify systems of land management that reduce the potential for acidification
- reduce off-site impacts on habitats, waterways and groundwater systems.
- target investment (e.g. funds from the Natural Heritage Trust) towards priority areas.

The major clients for information on soil acidification are similar to those identified in Chapter 1 with one important addition: farmers and land managers wishing to make informed decisions. The information they collect is valuable for broader assessments by Regional Bodies and natural resource agencies at the state, territory and national level. The Expert Panel concluded there was an excellent opportunity to build partnerships between private industry and public agencies. However, some issues relating to privacy and the commercial sensitivity of the information need to be resolved. (Recommendation 1).

NLWRA (2001) and Lockwood et al. (2003) provide thorough reviews of soil acidity as a component of soil condition. While impacts are well understood, quantitative assessments are often lacking. On-site, irreversible (or difficult to reverse) effects on the soil resource include:

- development of subsoil acidity
- loss or changes in soil biota involved in nitrification
- accelerated leaching of Mn, Ca, Mg and K and anions
- induced nutrient deficiencies or toxicities
- breakdown and subsequent loss of clay materials from the soil
- erosion following decreased ground cover that may follow acidification.

The end result is reduced biological productivity and fewer options for land use.

Soil acidification can have a range of off-site effects including:

- mobilisation of heavy metals into water resources and the food chain
- acidification of waterways as a result of leaching of acidic ions
- increased siltation and eutrophication of streams and water bodies.

2.3 Approaches to monitoring

2.3.1 Direct measurement

The Expert Panel defined three approaches to measuring acidification directly. There is a direct trade off between the three in terms of their expense and the utility of the data.

Surveillance sites

Surveillance sites involve measurement of the minimum number of variables to estimate the time before critical pH values are approached or the rates of ameliorants required to avoid further decline.

Sampling is confined to soil layers near the surface and measurement is restricted to just a few variables. Surveillance sites rely on global positioning systems (GPS) for accurate geo-referencing, along with automated methods for collecting and processing soil specimens. At least one Australian soil testing company has the required technology for rapid and economic sampling at surveillance sites. Commercial sampling of this type is mainly for individual farms. However, the Expert Panel was convinced that the same approach could be applied to broader surveys for Regional Bodies. Specific sampling strategies are require and McKenzie et al. (2006) provide a starting point but statistical advice will be needed on a case-by-case basis. Again, this highlights the need for a scientific services group to support monitoring activities across Australia.

Permanent monitoring sites

Permanent monitoring sites are measured in more detail than surveillance sites. This requires good scientific and technical support. The design of permanent monitoring sites was outlined by McKenzie et al. (2002).

Permanent monitoring sites are necessary for measuring NAAR via direct measurement of soil properties (pH, ΔpH, pH buffering capacity, bulk density) and also via Helyar and Porter's (1989) model for the carbon and nitrogen cycles (see Moody and Aitken (1997) and Recommendation 3a).

The soil profile at each permanent monitoring is characterised in terms of its physical, chemical and morphological properties. This more thorough characterisation (compared to surveillance sites) enables extrapolation of results. If the initial estimates of acidification rate indicate further monitoring is worthwhile then soil pH will be measured at each site every 5 years or so.

Decisions will be needed on depth increments, replication and bulking strategies. Overseas experience with acidification (e.g. Skinner and Todd 1998) indicates that sampling every 5 years is appropriate. Specimens will be collected according to the agreed method. They will be air-dried and then analysed. Measurements from all sites used for permanent monitoring need to be done at a single laboratory to minimise error. The selected laboratory will need to have performed to a high level in the ASPAC inter-laboratory comparisons and demonstrate excellent quality control and assurance.

All specimens collected from permanent monitoring sites will be stored in a central archive (preferably the CSIRO National Soil Archive). The archiving and data management systems will be linked. Sufficient material will be stored to enable retrospective analysis for a range of soil properties. Experience has shown that archives in long-term monitoring programs become as valuable as the field sites and associated data.

Monitoring of land-use practices will be via landholder interviews and to a lesser extent by remote sensing. Permanent monitoring sites can potentially include more than one land management practice (e.g. both standard and recommended practice).

These sites will often be suitable for monitoring other aspects of soil condition, particularly for soil organic carbon and soil fertility.

Long-term research sites

As noted in Chapter 1, this level of investigation will facilitate detailed process studies and modelling (Robertson et al. 1999; http://lternet.edu and Recommendation 3b). These studies need to address the following topics:

- The NAAR of current and new systems of land management to confirm the more approximate methods used at permanent monitoring sites
- The evolution of acidification throughout the soil profile (e.g. some systems of land use can continue to acidify subsurface layers even though lime may have been applied)
- The options for remediation to be developed and tested (e.g. deep-rooted perennials that recycle bases from deeper in the profile)
- The degree to which acidification induced by land management affects waterways across a range of environments.

2.3.2 Models

All three of the following models require minor adjustments before they can be released for general use. (Recommendation 4)

Optlime

Optlime is a bio-economic spreadsheet model which aims to:

- explore the chemical, biological and financial responses available when managing soil acidity using lime
- assess and compare different management options (e.g. aim for increased tolerance to acidity in the rotation versus management of acidity through topsoil or subsurface liming).

Users establish scenarios and the outputs are dynamically linked and updated as the scenario is altered. The following analyses are available:

- relative yields with annual and accumulated cash flow
- investment appraisal
- limed soil pH-profile versus unlimed soil pH-profile (select from 4 years up to 30)
- effects of treatments on toxic aluminium by soil layer
- lime removal (separated into total, product, fertiliser and leached contributions)
- fate of applied lime.

The model has certain strengths and weaknesses. It uses information developed specifically for conditions in Western Australia and some training is required.

The Lime Application Model (Merry 1997)

This publicly available[5] calculator estimates the time for significant changes in soil pH. It uses Microsoft Excel™ and consists of two spreadsheets. One calculates whether the inputs are causing the soil to become more acidic or more alkaline. If the soil is acidifying, the time in years until the soil reaches critical pH is calculated. The other spreadsheet calculates the lime required to adjust the soil pH to the required level. Although the Lime Application Model was designed to assist management of soil acidity and alkalinity in vineyards, it could readily be adapted to other soils and land uses.

Helyar and Porter

The Helyar and Porter (1989) model is used to describe the acidification and alkalisation of soil. This model has the advantage of simplicity and ease of use but does rely on a large number of assumptions which may need to be tested depending on the circumstances.

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[5] www.lwa.gov.au/downloads/information/SRH12_calculator.xls

2.3.3 Lime sales

Lime production and sales are a potential way of monitoring the adequacy of response to acidification. Unfortunately, acquiring useful data is a difficult task. However, direct surveys of producers and agents are unreliable because some will not provide data on the grounds of commercial confidentiality. Others supply to very large regions (e.g. interstate) and may not be able to differentiate sales by specific location. Some state agencies (mining and extractive industries) also keep production records, but these are known to be underestimates and they may not differentiate agricultural uses and by-product limes may not appear in these records.

In the past, the ABS Agricultural Census returns have not distinguished lime from other soil 'conditioners', such as gypsum. Future ABS surveys need to obtain more accurate assessments of lime use and other ameliorative actions, presented by region and land use (Recommendation 5).

2.3.4 Land management practices

Information on land management practices is needed to estimate the NAAR which is affected by rates of product removal, additions of organic matter, fertiliser rates and ameliorative practices (e.g. addition of lime or dolomite).

The only feasible way of obtaining accurate information on land management practices is by surveying land managers. Such surveys provide a cross-section of current land management practices and landholder attitudes. The ground-based surveys described by McCord and Payne (2004) provide a good model. The surveys are needed to determine the NAAR and also the rates of lime application. Note that ground-based surveys are part of the strategies for the other indicators of soil condition (Chapters 3–5) resulting in potential economies through a coordinated approach.

The Executive Steering Committee for Australian Land Use Mapping (ESCALUM) is investigating methods for mapping land management practices (Recommendation 6).

2.4 Monitoring at the local scale

Changes in pH[6] can be estimated using data from surveillance, monitoring and research sites. Our focus in this section is on surveillance sites because hundreds and, in some cases, thousands of sites can be established across a region. As a result, accurate estimates of baseline pH and subsequent changes are possible for individual regions.

Data from surveillance sites can be used to estimate the time to a critical pH as well as the rate of ameliorant (e.g. lime) required to maintain pH at a specified value (see the simple models in Section 2.3.2). However, these estimates can only be approximate because of the need to use relatively imprecise estimates of the soil buffering capacity and a crude estimate of the NAAR for the systems of land management. While mid-infrared spectroscopy might improve the estimate of buffering capacity (see Chapter 3), these data and information on the NAAR have to come from permanent monitoring sites and research landscapes.

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[6] This is not the same as the rate of acidification because of the differing buffering capacity of soils

The Panel recommends trials of the method for estimating acidification at *local* scales (Recommendation 7. The trials need to assess whether the current methods for on-farm monitoring can be applied by a Regional Body across a much larger area. The methods for specimen collection and processing need to be assessed for robustness across a range of soils, so parallel trials are required in states and territories where acidification is an issue.

2.5 Monitoring at the regional and national scale

The Expert Panel concluded that estimation of acidification at regional and national scales has to draw on several lines of evidence:

- collation of pH data from surveillance sites (preferably from both commercial and public sources)
- collation of pH data from permanent monitoring sites
- estimates of NAAR from permanent monitoring sites and long-term research sites
- surveys of land use and land management practices to enable production of maps at regional and national scales
- estimates of pH buffering capacity from ASRIS to enable production of maps at regional and national scales.

The Expert Panel agreed that priority must be given to planning the network of permanent monitoring sites and long-term research sites. This includes determining arrangements for data collection, database development, analysis and archiving of specimens (Recommendation 8). McKenzie et al (2002) outline the technical requirements and the task now is to develop a project proposal with a clear set of priorities for funding.

The permanent monitoring sites need to be located in regions where acidification is already an issue and under systems of land management where data are lacking on the NAAR. The Panel identified several of these systems:

- dryland cropping systems with zero tillage or permanent beds
- systems which incorporate a legume break crop and trash blankets (e.g. minimum-till sugarcane)
- irrigated cropping systems (e.g. cotton)
- horticultural tree and row crops (e.g. tropical fruits, vegetables)
- natural systems (native forests, woodlands and grasslands)
- regions where acid rain is a possibility (e.g. weakly-buffered Kandosols between metropolitan Sydney and the Hunter Valley).

Developing a reliable understanding of acidification at regional and national scales depends heavily on land management information. Providing this information is a major undertaking which will need to be addressed in an iterative manner. The Panel recommends that the NLWRA submit a formal request for this information to the Australian Collaborative Land Use Mapping Program (ACLUMP) (Recommendation 9).

2.6 Outputs

2.6.1 Time to critical pH

The time to critical pH is a forecast value that is useful for land-use planning, as a sustainability measure, and as a guide to crop and plant requirements. It can be calculated at local, regional and national scales, albeit with different degrees of accuracy and precision.

Estimating the time to critical pH for a specific soil layer requires knowledge of the pH at a stated time, the pH buffering capacity, the bulk density and the NAAR for the land use in question. The value selected for the critical pH will depend on context. It may need to be relevant to a specific crop or a desired resource condition (e.g. 90% of a region with pH > 4.8).

Outputs of 'time to critical pH' could be as both statistical summaries by regions (notionally Level 4 in ASRIS) and as generalised maps (again at Level 4 in ASRIS). The standard values for critical pH will be 4.8 and 5.5 with other values for regions with particular requirements e.g.

- pH = 4.2 for regions with naturally acid soils and intensive agriculture
- pH = 4.8 – 5.0 in Western Australia if only the topsoil is acid. If the subsoil pH is less than 4.5, then the topsoil critical pH needs to approach 5.5 to ensure the surface pH will allow alkalinity to move down and maintain the subsoil pH at greater than > 4.5 – 5.0.

2.6.2 Projected lime needs to off-set annual and historic soil acidification

If information is available to calculate time to critical pH, it is then easy to calculate the amount of lime (calcium carbonate) needed to counteract the historical profile acidification, and also the amount needed on an annual basis to maintain the current soil condition without further acidification. When expressed in terms of lime, treatment of soil acidification is readily understood in terms of resource requirements and treatment cost. Again, this measure can be presented at the local, regional and national scale.

Outputs will be in the form of maps and statistical summaries of the amount of lime needed to rectify the acidity problem as well as the annual amount necessary to maintain the current pH.

2.7 Trials

It is recommended that the approaches suggested here be tested by one or more NRM Regional Bodies which are addressing soil acidification within their Investment Plans (see Recommendation 7). The Regional Body will already have budgeted for this monitoring and therefore the cost to NLWRA will be limited to the cost of the additional work involved in assessing and reporting the approaches suggested here.

These preferred regions will

- represent large areas of agricultural lands affected by soil acidification.
- have regional bodies responsible for land management, and
- have potential to lever local funding.

The trials will reflect the local soil acidification context, the monitoring requirements of the Regional Bodies, and the methods recommended by the Soil Acidification Expert Panel.

2.8 Recommendations

Australia needs a reliable baseline for assessing soil acidification and a system for forecasting at regional and national scales. To achieve this, the Expert Panel offers these recommendations:

Recommendation 1

Build partnerships between private industry and public agencies and resolve privacy and commercial sensitivity issues.

Recommendation 2

Test sampling and geo-referencing technologies available in the private sector for their general applicability and develop guidelines for statistically acceptable sampling regimes.

Recommendation 3

Establish a network of permanent monitoring and long term research sites. Permanent monitoring sites are necessary for measuring NAAR through direct measurement of soil properties and via the model of Helyar and Porter (1989). Long research sites are required for detailed process studies.

Recommendation 4

Perform minor adjustments on the Optlime, the Lime Application Model and the Helyar and Porter model before they are released for general use.

Recommendation 5

Ensure future ABS surveys obtain accurate assessments of lime use and other ameliorative actions, presented by region and land use.

Recommendation 6

Support the Executive Steering Committee for Australian Land Use Mapping (ESCALUM) which is investigating methods for mapping land use and land management practices.

Recommendation 7

Test methods for estimating acidification at local scales through a set of trials.

Recommendation 8

Establish a network of permanent monitoring sites and long term research sites.

Recommendation 9

The NLWRA formally request ACLUMP to consider collecting land management information for soil condition monitoring, including pH monitoring.

The Expert Panel made several other more general recommendations

Recommendation 10

Establish a permanent operational base to provide the technical and scientific services to monitor soil acidification.

Recommendation 11

Address deficiencies in the way soil pH is collected in the soil mapping process so that the utility of the soil mapping for soil pH modeling is not compromised.

Recommendation 12

Convene a national expert group to review the concept of critical pH and develop guidelines for presenting national forecasts of acidification including:

- maps of time to critical pH according to soil type and land use
- projected lime needs on an annual basis to maintain pH and to fix historical problems.

Recommendation 13

Configure the ASRIS database to receive soil pH monitoring data and to facilitate reporting.

Recommendation 14

Analyse (from an economic standpoint) liming and other changes in management for a range of farming practices and lime quality.

2.9 References

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Table 2.1: Monitoring of soil acidification: summary of indicators, methods and outputs

Local			Regional and national		
Indicator	Method	Outputs	Indicator	Method	Outputs
Baseline pH	Commercial soil testing for pH at surveillance sites with geo-referencing (Time = t_0)	Baseline estimates of pH at farm and local scale	Baseline pH	Collation of commercial and public soil testing data at t_0 Networks of permanent monitoring sites in highest priority regions	Baseline estimates of pH(t_0)
Change in pH (ΔpH)	Commercial soil testing for pH at surveillance sites with geo-referencing $\Delta pH = pH(t_1) - pH(t_0)$	Estimates of pH (t_0 , t_1 , t_2 , …) and ΔpH expressed as summary statistics (e.g. by farm, soil type, management system) and generalised maps	Change in pH (Δ pH)	Collation of commercial and public soil testing data Networks of permanent monitoring sites in highest priority regions $\Delta pH = pH(t_1) - pH(t_0)$	Estimates of pH (t_0 , t_1 , t_2 , …) and ΔpH expressed as summary statistics by region and generalised maps (e.g. Level 3 or 4 in ASRIS)
			Net acid addition rate (NAAR) for systems of land management	NAAR based on data from permanent monitoring and research sites. Outputs rely on these data, maps of management practices, and soil data from ASRIS	Regional and national maps of NAAR
Estimated time to critical pH for chosen combinations of land use and soil type	Simple models (Optlime or the Merry Model) relying on estimates of buffering capacity and NAAR	Estimates of time to critical pH expressed as summary statistics (e.g. by farm, soil type, management system) and generalised maps	Estimated time to critical pH for chosen combinations of land use and soil type	Helyar and Porter models based on ASRIS soil data, land use data and other data	Generalised maps of buffering capacity Generalised maps of time to critical pH based on models
Lime use and other land management practices	Local surveys	Statistics of lime use and other land management practices	Lime use and other land management practices	ABS statistics of lime use and other land management practices	Tabulations of lime requirements Statistics of lime use and other practices

Surveillance sites have the minimum amount of measurement (essentially geo-referenced soil testing to a maximum depth of ~0.3 m). *Permanent monitoring sites* have full characterisation of the soil and management system and are designed for repeated measurement. *Long-term research sites* are where the fluxes of water and nutrients are monitored.

Appendix 1: Comparison of site types for monitoring

Task	Surveillance sites	Permanent monitoring sites	Long-term research sites
Selecting site	Stratified sampling based on land use and soil type	Selected according to identified gaps based on land use and soil type or new cropping systems. Stratification and nested design Unrestricted access	Selected to address soil acidification processes and implications of new land use systems
Site management	Farmer	Farmer/investigator (opportunity to incorporate replicated test strips which may compare ‘improved practice’ with current practice)	Research agency
Measuring frequency	5 yr	5 yr	Real time
Time of sampling	Crop dependent (e.g. pre-sowing for broad-acre cropping or pasture but pre-fertiliser for sugar cane)	Crop dependent (see surveillance example)	Frequent according to design and research schedule
Depth of soil sampling	Dependent on crop: Pasture/broad acre: 0–100 mm, 100–200 mm, 200–300 mm Horticulture: 0–150 mm Sugar: 0–250 mm, 250–500 mm Vines: 0–150 mm, 150–300 mm (at least 200 mm off-set from dripper) Horticulture (trees): 0–150mm, 150–300 mm (record position) Forestry trees: see AGO protocol Dryland farming: 4–6 geo-referenced sites per paddock with minimum of 10 cores per site, each depth bulked (pending assessment of variation)	Sample soils to <1m in 100 mm increments using intact cores (Geoprobe/hydraulic corer) Method of McKenzie et al. (2002)	Sample soils to <1m in 100 mm increments using intact cores (Geoprobe/hydraulic corer) Surface sampling in finer increments and also lateral samples from rows.
Measurement and recording	Geo-referencing of sites to sub-metre accuracy (where available) Record broad scale land use, as detailed as possible (e.g. cultivation, fertiliser/lime history, stocking rate) Record soil sample depth, soil type, gravel percent Record any evidence or incidence of erosion events, to ensure that the consistency of the datum level has not been compromised. Specimen analysis at ASPAC accredited laboratory with proficiency in analysis in pH	Geo-referencing of sites to sub-metre accuracy including a physical permanent marker (e.g. buried metal marker). Annual land use report Yield of exported product Ash alkalinity of exported material Fertiliser/stock feed inputs Describe soil profile morphologically and characterise soil chemical and physical properties Record any evidence or incidence of erosion events, to ensure that the consistency of the datum level has not been compromised Specimen analysis at ASPAC accredited laboratory with	Detailed measurements to fill gaps in process knowledge Link sites with those used for carbon (Chapter 3)

		proficiency in analysis in pH Measure buffer capacity (BC), bulk density Link sites with those used for carbon (Chapter 3)	
Data analysis	Spreadsheet for GIS Data saved to local database with necessary metadata Transferred to ASRIS after quality assurance	Initial pH of soil profile Calculate change in pH over each interval Calculate acidification rate Calculate NAAR	
Specimen storage	Recommend long-term storage of at least 10% of specimens in sufficient quantities to allow at least three repeat measurements to check new methods against current methods	Long-term storage of specimens in the national soil archive Follow current biosecurity protocols	As per permanent monitoring sites
Quality assurance	Data collected to a level required to satisfy scientific peer review		
Data ownership and privacy	To be defined (although data are subject to the requirements of privacy laws)		

Chapter 3 Soil organic carbon

Expert Panel on Soil Organic Carbon

JO Skjemstad, RC Dalal, WJ Slattery, BR Wilson, PM Mele, DV Murphy, J Dixon, NJ McKenzie

3.1 Introduction

Organic matter is an essential soil component which plays a critical role in a variety of soil processes and functions. It is important to soil structure and stability because it binds soil particles into stable aggregates. It is also a critical link in the nutrient cycling processes that operate in soils, and greatly influences soil water-holding capacity. The concentration of organic matter also provides an indirect measure of the extent of biological activity.

The single largest component of soil organic matter is soil organic carbon. This is relatively simple to measure in soils and its concentration or quantity in the soil is a useful indicator of soil condition and the state of the soil with respect to these various processes and functions.

The largest concentrations of soil carbon are generally found in the uppermost layers of the soil since this is where the bulk of organic inputs occur although the distribution of soil carbon through the soil profile is determined by a range of factors. The overall quantity of organic carbon in a given soil is determined largely by climate and organic inputs but can also be significantly affected by land-use. For example, soil organic carbon is usually greater under forest and pasture than areas of cropping although considerable variation also exists within these broad management types.

Monitoring and forecasting changes in soil organic carbon are feasible because it responds to changes in land management and environmental conditions at rates that are neither too fast nor too slow. Responses typically occur over years and decades. The cost of measurement is also quite small compared to other soil properties, so sufficient sampling is possible in time and space to produce useful information on trends (Bellamy et al. 2005). While robust methods are available for measuring total soil organic carbon, the Expert Panel firmly believes that it is the different pools of soil carbon which need to be monitored.

The Panel concluded that the demand for more accurate information on soil organic carbon was inevitable given the uncertainties surrounding the debate on climate change. Soil organic carbon is both a source and a sink of greenhouse gases. Emissions typically occur after clearing and tillage, while some land management practices, such as improved pasture and minimum tillage, may increase soil organic carbon.

The Panel agreed that a system of permanent monitoring sites was required to detect trends in soil organic carbon and that public agencies in Australia must act now to install the monitoring systems and establish the baselines necessary to inform future analysis and decision making.

Monitoring soil carbon for a range of soils across Australian catchments can provide valuable validation of data in models such as the National Carbon Accounting System (NCAS), that is used to estimate Australia's national inventory on carbon stocks.

The Australian Government through the Australian Greenhouse Office provides on-line access to the NCAS database which consists of soil estimates for carbon at a 250 meter resolution. Data obtained through a national monitoring program on soil carbon could be easily accommodated into the NCAS database and thus add significant value to what is already a powerful tool for estimating national stocks and fluxes of terrestrial carbon.

3.2 Reasons for monitoring soil organic carbon

3.2.1 Definition and role in bio-physical processes

Soil organic matter is the sum of all natural and thermally altered biologically derived organic materials found in soil (Baldock and Skjemstad 1999). The materials, in various states of decay, include leaf litter, plant roots, branches, living and dead organisms, and excreta. Although normally constituting less than 5% of the soil, soil organic matter is the master soil variable controlling a set of biological, chemical and physical functions that sustain plant productivity and contribute to stability and resilience of natural and agricultural ecosystems.

Accurate measurement of the mixture of materials that constitute the pool of soil organic matter is not possible and so soil organic carbon is considered the best representative measure. Soil organic carbon has been used extensively to measure landscape condition and function and to inform land management and planning decisions.

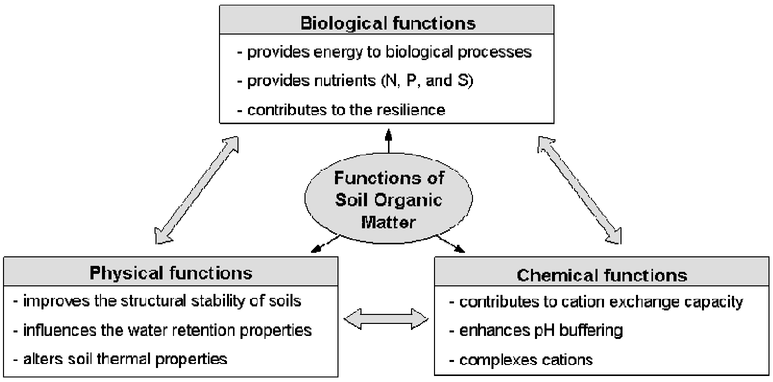

Figure 3.1: Functions of soil organic matter. The black arrows represent the various classes of functions and the grey arrows indicate the interactions which can occur between the classes (Baldock and Skjemstad 1999).

The value of soil organic carbon as a primary indicator for a long-term monitoring program relates to its inherent value as a surrogate for other attributes. Increasing soil organic carbon invariably leads to an increase in:

- energy supply for biological processes
- direct nutrient supply to plants (particularly nitrogen, phosphorus and sulfur)

- capacity to retain and exchange nutrients
- aggregation of soil particles and stability of soil structure
- water storage and availability to plants
- beneficial thermal properties
- pH buffering.

3.2.2 Benefits of monitoring

Monitoring soil organic carbon provides useful information to the following groups for different reasons.

- Land managers, particularly farmers and graziers, can use soil organic carbon to indicate whether more conservative forms of land use are needed and whether these (e.g. minimum tillage) are having the desired effect. The target value for soil organic carbon depends on the soil layer of interest (normally the surface A1 horizon), system of land use, soil type and climate.
- Natural resource planners require baseline estimates of for different landscapes in order to set realistic resource condition targets.
- Agronomists, foresters, soil scientists, terrestrial and freshwater ecologists and other scientists involved in many aspects of the biophysical sciences require information on the dynamics of soil organic carbon. The most urgent demand at present is for more certain predictions of the potential for carbon sequestration to support analyses of climate change.
- Policy makers involved in greenhouse gas abatement need reliable evidence to guide investments and assess risks (e.g. whether targets for emission can be reached).
- Carbon traders require methods at the local to regional scale to determine the potential for carbon sequestration and also to reliably and accurately reflect any change in soil carbon status.

3.3 Approaches to monitoring

Soil organic matter is best monitored by measuring soil organic carbon and, more specifically, the pools of soil organic carbon. To describe the behavior (dynamics) of soil organic carbon and its impact on soil properties, three major pools of carbon are recognised. These can be loosely defined by their turnover time in soil and can be termed:

- labile carbon
- decadal carbon
- ‘passive’ carbon (which is not equivalent to the specific definition used by the Century model).

As a minimum, therefore, monitoring of both total and labile carbon will provide the best measure of organic matter and the potential for that carbon to decline or increase in the shorter term (Recommendation 1).

3.3.1 Surveillance sites

Surveillance sites rely on global positioning systems for accurate geo-referencing and sampling is confined to soil layers near the surface where measurement is restricted to a few variables. However, measurement of soil organic carbon for monitoring purposes requires an accompanying measurement of bulk density so the results can be expressed on the appropriate volumetric basis. This extra work slows field operations considerably (e.g. compared to surveillance sites for pH). The Expert Panel was therefore not convinced that a large program of surveillance sites would yield the data necessary for unambiguous detection of trends in soil organic carbon (Recommendation 2a). Instead, most effort should be devoted to permanent monitoring sites similar to those found in successful international systems for monitoring soil condition (Skinner and Todd 1998, Bellamy et al. 2005) (Recommendation 2b).

3.3.2 Permanent monitoring sites

The design of permanent monitoring sites was outlined by McKenzie et al. (2002). As noted in Chapter 2, the soil profile at each site is characterised at the time of establishment. The soil physical, chemical and morphological properties are necessary to calculate the total carbon content in the profile. Guidelines on sampling and measurement are presented in Section 3.4.

All specimens collected from monitoring sites will be stored in a central archive (preferably the CSIRO National Soil Archive). The archiving system will be linked to the data management system. Sufficient material will be stored to enable retrospective analysis for a range of soil properties. The CSIRO National Soil Archive has been a critical resource for the National Carbon Accounting System because it has enabled testing of new methods for measuring various aspects of soil organic carbon.

Land management practices play an important role in organic carbon dynamics. Monitoring of these will be via landholder interviews and, to a lesser extent, by remote sensing. Permanent monitoring sites could potentially include more than one land management practice (e.g. minimum tillage and conventional cultivation). However, thorough investigation of how management practices and other environmental variables control soil organic carbon will only be possible at research sites.

3.3.3 Long-term research sites

Long-term sites are critical to our understanding of soil organic carbon for a range of reasons:

- Predicted warming and drying across large parts of Australia during coming decades is likely to cause decreases in soil organic carbon. Long-term research sites are needed to detect these changes and provide a means of estimating carbon emissions.
- The direct impacts of land management on soil organic carbon need to be understood so that conservative practices can be developed to maximise the beneficial aspects of organic carbon. Changes in the dynamics of soil organic carbon related to land management practices occur over an extended timeframe and quantifying this change requires monitoring of sites where treatment integrity is preserved.

- Models of organic carbon dynamics provide a valuable technique for forecasting change under a wide range of conditions. These models require calibration with data from long-term research sites from a wide range of soil types and environments.

The Expert Panel concluded that at least ten long-term research sites were required in the first instance (Recommendation 3). These sites would also be used for studies of acidification, erosion and other processes. A priority is to establish studies in landscapes where soil organic carbon stores are sensitive to environmental change. Examples include alpine systems, wet sclerophyl forests, wetlands, agricultural systems and the rangelands.

3.3.4 Modelling

It will not be practical or even possible to monitor all soils in all management situations for changing soil carbon levels over time, and therefore model outputs will be frequently used to estimate changes in soil carbon stocks based on management practice, plant growth, soil type and climate.

Models, ranging from simple spreadsheet calculators to complex simulations, are important to enable early predictions assisting land managers in making decisions to reduce fertility decline, erosion and greenhouse gas emissions.

The Expert Panel agreed that a simple spreadsheet model (e.g. Skjemstad's CRC GA Calculator (in prep.)) was useful for calculating likely maximum organic carbon contents across a wide range of soil types, climates and system of land use. This calculator provides a tool for Regional Bodies to set realistic targets for resource condition (Recommendation 4).

For prediction of likely future changes in soil organic carbon, conceptual models of carbon turnover are needed. These include RothC (Jenkinson 1990), Century (Parton et al. 1987) and the ICBM (Andrén and Kätterer 1997). Operation of these models requires good technical support and estimates of the respective carbon fractions or pools.

National scale models provide estimates of carbon stocks for both above ground and below ground stores. The Australian Government has a special program (The National Carbon Accounting System - NCAS) that has enabled Australia to become a world leader in emissions accounting. The model relies on data inputs of vegetation type and biomass, soil type and soil carbon content, and climate factors (such as rainfall and frost). NCAS benefits from data provided through a range of agencies and clearly a national monitoring program on soil carbon would ensure the ongoing value of this model for soil carbon accounting purposes.

The National Carbon Accounting Toolbox (NCAT) is now available for soil carbon modeling and draws on the central modeling component of the NCAS fullCAM and its accumulated data.

3.4 Monitoring at the local scale

This type of monitoring is useful for tactical decisions on land management. In combination with the simple spreadsheet model (previous section), land managers can decide when to adopt more conservative practices. The Expert Panel agreed that insufficient evidence exists at present to set critical thresholds for soil organic carbon contents (e.g. to ensure aggregate stability, nutrient supplies or other functions). The

Panel also agreed that compilation of data from surveillance sites is only worthwhile if there are accompanying measurements of bulk density and coarse fragment contents to at least 300 mm. These accompanying measurements are time consuming and rarely performed during routine soil testing. These factors led the Expert Panel to conclude that most public investment should be devoted to permanent monitoring sites.

3.5 Monitoring at the regional and national scale

The Expert Panel concluded that monitoring of soil organic carbon at regional and national scales has to draw on several lines of evidence:

- collation of soil organic carbon data from permanent monitoring sites
- forecasts of changes in soil organic carbon using models. These models are calibrated at the permanent monitoring sites and long-term research sites and rely on input data from ASRIS and surveys of land use and land management practices.

3.5.1 Frequency

The appropriate frequency of sampling at permanent monitoring sites depends on the environment and history of land use. The Panel concluded that the minimum frequency should be 5 years for cropped lands, and 10 years for forests, grazing lands and savannas. The Panel firmly believes that the sampling interval must be regular, even to show that change is not occurring.

Practicality dictates a staggered approach to sampling. The baseline year for different landscapes will need to be in successive years to avoid the overload of work that would be needed if all sites were to start the same year.

Land management between sampling dates will require consistent recording at the permanent monitoring sites.

3.5.2 Sampling

Detailed sampling guidelines are provided by McKenzie et al. (2000). The recommended sampling procedure assumes trained operators (land resource officers, field ecologists, soil scientists, experienced or trained field technicians) and a quality assurance protocol. The following comments augment the existing guidelines and details are provided in Table 3.1.

Site dimensions

Dimensions of the permanent monitoring site depend on patterns of vegetation and litter. The current recommendation of a 25 m × 25 m plot may fail to be representative. Different layouts will be necessary to capture the patchiness of land cover. The Expert Panel concluded that a pilot study is needed to evaluate the pros and cons of different layouts for a wide range of environments. Considerations include differences between strategies in terms of their cost, precision and accuracy for estimating soil organic carbon.

Time of sampling

In landscapes used for cropping, the time of sampling for soil organic carbon should be close to sowing. In landscapes with perennial and permanent vegetation, sampling should be in the coolest month. The aim is to measure during the period of minimum biological activity to avoid rapid changes in the pools of soil organic carbon.

Depth and interval

Sampling depth and interval is a critical issue which depends on the management system and soil. For most systems, 0–50 mm, 50–100 mm and 100–300 mm is adequate. However, permanent monitoring sites need to be sampled from 300–1000 mm depth every 10 years.

For calculation of mass of soil organic carbon in a soil volume (area and depth), bulk density at the sampling site must be measured on the actual core used for collecting the soil specimen (McKenzie and Cresswell 2002, Cresswell and Hamilton 2002).

It is recommended that a minimum of 5 soil specimens be bulked to form a single composite specimen, thus obtaining 5 composite specimens for each depth from a site.

Specimen preparation

Soil specimens should be air-dried below 40°C, preferably in a draught oven. The complete specimen is crushed and passed through a 2-mm sieve. For analysis of organic carbon, a sub-sample is further ground to pass a 0.5-mm sieve. For analysis of the carbon pools with mid-infrared spectroscopy, the specimens are ground again in a puck mill to <0.05 mm. Specimens are to be stored in air-tight containers. Where possible, consideration should be given to collecting a small sub-sample that is frozen at -80 C and archived for DNA-based microbial analyses at a later date.

All soil specimens must be archived. The minimum weight for the archived specimen is 500 g (after bulking of 5 composite specimens).

Table 3.1: Recommended sampling methods for major land uses

Agro-ecological zone/land use	Plot area (ha)	Depth	Sampling time	Number of samples
Forest	0.1	0–50 mm 50–100 mm 100–300 mm 300–1000 mm	Just before sowing of crops or coolest month	25 (5 composites with 5 bulked per composite)
Farmed	0.1	0–50 mm 50–100mm 100–300 mm 300–1000mm	Coolest month	25 (as above)
Savanna	1.0	0–50 mm 50–100 mm 100–300 mm 300–1000 mm	Coolest month	25 (as above)

3.5.3 Carbon pools

Total carbon is inadequate for understanding the role of carbon in many soil processes. It is more appropriate to partition organic carbon into a number of pools with varying degrees of biological stability. These pools can be modelled with computer simulations. The Expert Panel recommends (Recommendation 5) the following pools:

- labile organic matter from plant debris: particulate organic carbon (POC)
- moderately to highly resistant humified organic matter: humus carbon
- inert or highly protected organic matter: inert carbon or charcoal (char-C).

Skjemstad et al. (2004) used these pools in the RothC model to initialise, calibrate and verify the model for Australian soils. POC and char-C are directly measured and humus carbon is calculated as the difference between total carbon and the sum of POC and char-C.

Total carbon

Total carbon is measured using the dry combustion method. The specimen is finely ground (<0.5 mm). If the $pH_{H2O} > 7.0$, test for effervescence with a few drops of sulfurous acid (H_2SO_3). If the test is positive, either pre-treat the specimen to remove carbonates (with H_2SO_3 until effervescence ceases), or measure the carbonate content with a calcimeter and subtract the carbonate-carbon from the total carbon.

Particulate Organic Carbon (POC)

POC is measured as the soil organic carbon size fraction with size greater than 53 µm. Air-dried and finely ground soil sample is completely dispersed in Calgon (sodium hexametaphosphate) and the dispersed sample suspension is poured over a 53-µm sieve (Cambardella and Elliot 1992).

Humus carbon

Humus carbon is calculated as total carbon less POC and char-C.

Inert carbon (char-C)

Char-C is determined routinely using high energy ultraviolet photo-oxidation and ^{13}C NMR spectroscopy. This fractionation scheme is therefore very time consuming and expensive due to the difficulty of separating enough material to obtain an acceptable NMR spectrum.

Infrared spectroscopy offers a low-cost and relatively simple alternative, with a further advantage that it is sensitive to both organic and mineral components in the soil. Mid-infrared (MIR) spectroscopy can identify specific soil minerals as well as functional groups such as alkyl, carboxylic (protonated and non-protonated), glycosidic, amide, amine, and (most importantly) aromatic chemical functional groups.

3.6 MIR-spectroscopy

Measurement of pools and structure is best achieved with well-calibrated MIR spectroscopy. The advantage of MIR spectroscopy is its analytical speed and simplicity, since neither chemical nor physical fractionation are required, although air-drying and grinding is advantageous. The MIR-partial least squares (PLS) technique has already been shown to be sufficiently accurate for the prediction of total soil organic carbon from spectra of whole soils (Janik et al. 1995, 1998) and should, in principle, be sensitive to the proportion of carbon in each of the three carbon pools. However, direct measurement of pools is needed to prepare MIR calibration sets.

Janik et al. (2006) provide a detailed MIR protocol.

The Expert Panel concluded that MIR-spectroscopy is critical to monitoring soil organic carbon at the permanent monitoring sites. However, a reliable calibration set that suits this purpose is not yet available. The Panel recommends as a matter of priority that a robust calibration set for MIR is obtained as soon as possible (Recommendation 6). This calibration set will generate many benefits beyond the current work (e.g. rapid soil measurement for soil survey).

3.7 Trials

An important aspect of these methodological developments will be demonstrating their utility in regions where soil carbon changes are an issue. To this end, pilot studies are suggested. These would be in areas where soil carbon change is a concern and which

- represent large areas of the agricultural and pastoral lands
- have regional bodies actively involved in land management including soil carbon
- can potentially lever local funding.

The trials will reflect the local soil carbon context, the monitoring requirements of the regional bodies, and the methods recommended by the Expert Panel.

3.8 Recommendations

Recommendation 1

Monitoring of both total and labile carbon will provide the best measure of organic matter and the potential for that carbon to decline or increase in the shorter term.

Recommendation 2a

A large program of surveillance sites would not yield the data necessary for unambiguous detection of trends in soil organic carbon.

Recommendation 2b

Effort should be devoted to permanent monitoring sites similar to those found in international systems for monitoring soil condition.

Recommendation 3

At least ten long-term research sites are required in the first instance These sites would also be used for studies of acidification, erosion and other processes.

Recommendation 4

A simple spreadsheet model (e.g. Skjemstad's CRCCA calculator) is required for calculating likely maximum organic carbon contents across a wide range of soil types, climates and land uses.

Recommendation 5

Total organic carbon should be partitioned into labile organic matter from plant debris, moderately to highly resistant humified organic matter, and inert or highly protected organic matter.

Recommendation 6

A robust calibration set for MIR should be obtained as soon as possible.

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Chapter 4 Soil erosion by wind

Expert Panel on Soil Erosion by Wind

G H McTainsh, J Leys, D Carter, H Butler AK McCord, A Wain, J Dixon, NJ McKenzie

4.1 Introduction

Wind erosion is an important geomorphic process in dry environments and, as such, is an important part of the Australian landscape. Wind erosion occurs intermittently and at different points in the landscape and is also strongly influenced by land management which also changes rapidly in space and time. For these reasons it is necessary to monitor continuously and over long time periods.

These protocols provide a quantitative basis for assessing wind erosion in Australia and for identifying whether improved agricultural and pastoral land management practices are successfully reducing wind erosion. Relatively minor forms of wind erosion, such as that of coastal dunes, were excluded from consideration. The protocols will provide data on wind erosion at space and time scales appropriate to the needs of national agencies, state and territory governments, regional bodies, landholders and the general public.

No single approach to monitoring is perfect and it is therefore necessary to use a combination of methods, some of which can be implemented in the short term while others will require further development over the next five years.

Wind erosion is very sensitive to land management practices since these are able to change the ground cover and soil surface condition at a much faster rate than natural climatic conditions. The monitoring challenge is to separate the management-induced erosion from the naturally occurring background erosion.

In the Australian context, monitoring and assessment of wind erosion must cover a wide range of spatial and temporal scales. The Expert Panel recommends three spatial scales for measurement, analysis and reporting.

- **Local:** Within paddock or on-farm information to determine the severity of erosion and to compare the benefits of improved land management systems.
- **Regional:** Within or between major regions (e.g. the cereal growing areas of Western Australia, South Australia and Victoria). The finest resolution of information at this scale is between 1 and 25 km^2.
- **National:** A broad overview and the finest resolution of information is between 25 and 100 km^2.

Monitoring needs to be maintained over the long term to produce useful trend information and to separate out the influence of climate change. To date, the understanding of wind erosion in Australia has relied on a small group of specialists, using short-term funds and informal support. This is an inadequate basis for monitoring the status and impact of wind erosion across Australia and formal institutional responsibilities need to be assigned.

4.2 Reasons for monitoring wind erosion

The significance of wind erosion (e.g. lost productivity, human health, and its uncertain influence on forecasts of climate change) demand a permanent system for acquiring wind erosion data, reporting on trends and assessing impacts. Wind erosion can be a potent reminder of inappropriate land use. It has the on-site effect of degrading soils at source and destroying infrastructure. However, the biggest effects are off-site from suspended and deposited dusts.

4.2.1 On-site effects

The fertility of Australian soils is amongst the lowest in the world and is considerably lower than our competing export countries in North America and the European Union. Therefore any diminution of the fertility of our soils (e.g. winnowing due to wind erosion) will affect our competitiveness in the export market and reduce ecosystem services provided by soils.

Wind erosion selectively removes fine particles from soils (McTainsh and Leys, 1993) which contain up to nine times the nutrient concentration of underlying soils. Higher concentrations are found for the critical nutrients of nitrogen, phosphorus and potassium (Leys and Heinjus 1990) as well as soil organic carbon. The loss of these nutrients decreases the productivity of crops (McFarlane and Carter 1989) unless there are supplementary additions of artificial fertilisers. Loss of clays and organic carbon winnowed out of the soil in the fines (dust) reduces nutrient holding capacity, water holding capacity and the cation exchange capacity of the eroded surfaces, further decreasing the soil’s biological productivity (Leys and McTainsh 1994). The transport of organic carbon in dust is a significant process but has received little attention (Boon et al. 1998). The impact of organic carbon loss is considered in Chapter 3.

4.2.2 Off-site effects

The products of an eroding soil can be moved a few metres or many kilometers, depending on the strength of the wind, particle size and rain.

In South Australia, Williams and Young (1999) estimated the ratio between off-site and on-site effects of wind erosion to be 10:1, with total direct market costs averaging $23 million per year but with maximum yearly costs of up to $56 million per year.

Dust storms travelling over major population centres significantly reduce air quality (Chan et al. 2005) and present a considerable risk to those susceptible to particulates (e.g. asthmatics) (Rutherford et al. 1999).

The major costs can be divided into the following areas:

- health services due to increases respiratory disease. Particles of 10 microns or less (PM_{10}) can enter the lungs and cause significant health problems (the smaller $PM_{2.5}$ fraction is most active in lung penetration). In industry, these particles have to be excluded from the workplace but they are regularly produced in dust storms.
- individual households due to clean up costs.

- the power grid which is regularly damaged or interrupted by dust-induced short circuits and fires on power poles.
- reduced air and road safety due to low visibility in dust storms.
- locally significant costs due to sand drift from eroding paddocks which can cover fences, roads and roadside vegetation. The result can be a loss of biodiversity and an increase in fire hazards on road easements due to weed growth and increased nutrition from transported fertilisers.
- One of the most important applications of information on wind erosion and atmospheric dust is in relation to climate change. Current models for estimating global circulation and climate are sensitive to current uncertainties over atmospheric concentrations of dust. This dust has a potential effect on the global energy balance similar in magnitude to that of CO_2 (IPCC 2001) and is the only atmospheric aerosol that can have both positive and negative effects upon global temperatures.

4.3 Definitions

'Wind erosion is the process by which soil is detached and transported from the land surface by the action of wind. Transport occurs by suspension, saltation, or creep' (Houghton and Charman 1986).

Suspended dust is the major component of soil loss because it leaves the site and travels well beyond the paddock boundary.

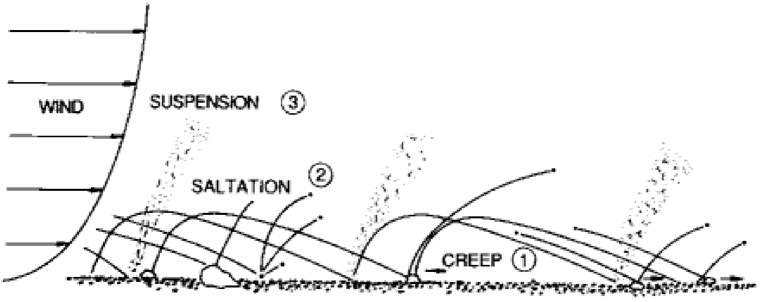

Figure 4.1: Modes of aeolian sediment transport (after McTainsh and Leys 1993)

Creep and coarser saltation sands are only moved metres or tens of metres in a wind erosion event. For the purposes of the suggested indicator of soil loss in Table 4.1 they are not considered to be soil loss even though they may lead to fence-line deposits.

Monitoring is defined as measurements – repeated in time and space using the same or comparable techniques – of soil conditions which are influenced by wind erosion.

Modelling is defined as the simulation of wind erosion processes and their environmental controls using numerical techniques, or statistical methods or both.

4.4 Approaches to monitoring

There are several approaches to monitoring wind erosion. An integrated set of methods is proposed here, some of the methods can be implemented in the short term while others require further development before they can become operational. The scheme is summarised in Table 4.1 and comprises a suite of direct measurements and models.

4.4.1 Direct measurement

At the local scale, direct in-paddock measurements include severity of erosion, area of eroding land, soil cover and dry aggregation.

The local measurements are currently undertaken by a wide variety of groups using different methods; thus, individual groups achieve a level of monitoring that is suited to their needs. Problems, however, can arise when comparing many local sites because of the different methods. For this reason, the Expert Panel suggests minimum standards for local measurements. The Panel does not recommend that all groups use them, only those who have wind erosion identified as a catchment priority.

At the regional and national scale, observational data are available from the Dust Event Database (DEDB), the Bureau of Meteorology (BoM), the DustWatch network of volunteer observers, and the DustWatch Nodes with dust monitoring equipment (PM_{10} and Total Suspended Particulate (TSP) dust monitors).

These measurements are used to:

- construct historical trends of wind erosion activity locally (over the past 10 years in some areas) and regionally and nationally (over the past 45 years).
- provide objective data for model validation and comparison with other monitoring programs (e.g. EPA air pollution monitoring for health based on PM_{10})
- discriminate the impact of land management on wind erosion
- engage the community in wind erosion monitoring and raise awareness of the problem.

The regional and national measurements are currently undertaken by state agencies and Griffith University. The Dust Event Database (DEDB) is the responsibility of Griffith University and the Panel recommends that a formal relationship be established with the Bureau of Meteorology for data updates and quality control (Recommendation 1). It is further proposed that these monitoring products be made publicly available through a national level natural resource information agency with formal linkages with Bureau of Meteorology, Griffith University (Dust Event Database and DustWatch), and the New South Wales Department of Natural Resources (DustWatch Nodes) (Recommendation 2).

4.4.2 Models

Wind erosion can be modelled at local scale using the Wind Erosion Assessment Model (WEAM) of Shao et al. (1996) and at the regional and national scale using the Integrated Wind Erosion Modelling System (IWEMS) of Lu and Shao (2001). These models can be better calibrated for Australian conditions with improvements in input data and test data from the DEDB (Recommendation 3). These models are currently the responsibility of Dr Yaping Shao (City University of Hong Kong) and negotiations are underway for their regular use in Australia through collaborative relationships with the University of Southern Queensland, Griffith University and the New South Wales Department of Natural Resources.

4.4.3 Complementarity between methods

No one method can measure wind erosion across the full range of space and time scales required. A suite of direct measurements and modelling is needed to understand changes in the indicator and for mapping and reporting. Local monitoring at a site uses more direct measurements (soil cover and dry aggregation) while regional and national monitoring uses more spatially continuous dust concentration, climate data, remotely-sensed data and models.

Soil loss can be modelled at a variety of scales, but the validation at each scale will involve several methods; for example, at regional and national scales, dust concentration data can be produced from the DEDB for model testing. The DEDB could eventually be used to calculate soil loss in conjunction with methods that describe the eroding areas. Similarly, measurements and models can quantify the effect that land management has on the indicator, and trends can then be compared with geo-referenced information on land management.

4.5 Monitoring at the local scale

4.5.1 Estimation with WEAM

WEAM is a numerical model of physical processes that calculates soil transport (horizontal) and dust emission (vertical) rates based on site data (wind speed, air density, soil moisture, soil particle size, particle density, soil ground cover and distribution of that cover). The model is described by Shao et al. (1996). The New South Wales Department of Natural Resources has a desktop version of the model which has only been used for research purposes to date. Before WEAM could be freely distributed, intellectual property negotiations with Dr Shao would be required.

WEAM is an emission model with no depositional functions. To use WEAM locally, continuous hourly meteorological weather files are required (from the Bureau of Meteorology or a local automatic weather station) as well as measurements or estimates of soil cover and soil water content (Recommendation 4). WEAM is useful for evaluating management practices that create different degrees of cover because the same climate can be used to evaluate the influence of different management practices on wind erosion.

4.5.2 Ground observation of erosion or ground cover as a surrogate

The amount of erosion can be estimated using a set of photo standards and a rating scale (Semple et al. 1988). Similar rating scales are used in roadside surveys (described below). The aim is to observe the condition of the soil surface and then estimate the amount of erosion that *has* occurred (erosion status) or the amount of erosion that *could* occur should a strong wind occur (erosion hazard).

Measuring ground cover locally is generally achieved by either the point intercept method (i.e. hit or miss along a tape or step-point transect, Laflen et al. 1981) or by quadrat estimation of cover (Murphy and Lodge 2002).

Ground cover targets to control erosion vary depending on soil type, exposure and residue type; however, it is generally accepted that for wind erosion control about 50% cover (when laid flat) is required to control erosion (Leys 1991, 1985).

4.5.3 Rapid roadside survey

Rapid field surveys across the cropping districts can be undertaken 4 times a year to assess the proportion of land at risk of erosion (both wind and water). Cover, detachment and broad soil type ratings can be assessed via transects of soil landscape zones. Summarised results may be presented at local, regional or national scales. The most important indicator is a calculated Wind Erosion Risk Index (WERI). WERI may be used for setting resource condition targets within the state and catchment management framework.

$$\text{WERI} = \frac{\text{Estimated cumulative risk (ha days)}}{\text{Estimated susceptible land sown to crop (ha)}}$$

All sites should be geo-located to allow ground truthing of remote sensing and to provide site-based data over time. Other data to be recorded includes wind erosion presence/severity, presence of burning and agricultural phase (e.g. crop, pasture, fallow).

Roadside survey methods are currently used in South Australia, north-west Victoria and south-west New South Wales. Each method is slightly different due to local needs; however, each has similarities. All methods use road transects and undertake observations of adjoining paddocks from the car. Generally, observations are taken one to four times per year using repeatable guidelines. All observation sites need to be geo-reference and be restricted to a single land unit with a limited variation in erodibility.

The Expert Panel recommends establishment of a working group to define minimum standards and definitions for roadside surveys (Recommendation 5).

4.5.4 Survey of land management practices and/or project output reporting

In roadside surveys, data on land management are also collected, but as for the erosion surveys, definitions and methods differ between users. Minimum standards and definitions are required

At the local scale, point-based measurements are generally informal and applied as part of an environmental management system.

Land management practices are a surrogate for estimating likely soil loss. NAP/NHT2 projects which are investing in the control of wind erosion must report regularly on their outcomes and these may include the adoption of practices such as wind breaks, reduced tillage, stubble retention and withholding of livestock.

4.6 Monitoring at the regional and national scale

From the Dust Event Database (DEDB a range of directly measured wind erosion monitoring products are currently available or could be developed relatively quickly (Tables 4.1 and 4.2). Similarly, some modelling outputs are available and others can be developed in conjunction with outputs from the DEDB.

4.6.1 From the Dust Storm Index (DSI) to Dust Concentration then Soil loss

The Dust Storm Index (DSI) is a weighted index of the intensity of wind erosion events (McTainsh 1998) and has been used in most recent national environmental audits. Data are obtained from approximately 110 Bureau of Meteorology stations across Australia. Large temporal and spatial gaps still exist in the data, particularly in the arid zone, and more observation stations are needed.

In 2002, a trial community network of dust observers was established in New South Wales. This program (called DustWatch) was successful in improving the number of observations and thus the understanding of the distribution and severity of wind erosion events. In 2005, DustWatch was expanded to the rest of Australia through the Desert Knowledge Cooperative Research Centre. While the participant numbers are growing, it would be an on-going exercise to maintain and attract new participants in the broader community.

A disadvantage of the DSI is that it is a dimensionless parameter which, without explanation, has little meaning to the public. Further research effort is needed to convert DSI to dust concentration (a measure of sediment in the air) and then to soil loss (t/ha). Dust concentration is the indicator used for urban air quality studies and for assessing health impact. The capacity to produce dust concentration maps would be a major advance as – in addition to providing a more meaningful measure of wind erosion rate –IWEMS could be directly tested and rural and urban data could be compared. These developments would require significant improvements in the data quality and data analysis techniques within the DEDB as well as an increased number of instrumented sites for monitoring dust (DustWatch Nodes) to measure dust concentrations.

Dust concentration maps can be converted into soil loss maps by mapping the area of eroding land using roadside surveys, remote sensing of dust storms and vegetation cover, and the Australian Landscape Erodibility Model (AUSLEM) (Webb et al 2006). These maps and direct measured data could be made available to the public on a regular basis through a national natural resource information agency.

4.6.2 Remote sensing of ground cover as a surrogate

Recently the Earth Observation Centre (EOC) of CSIRO assembled a 20-year time series of satellite data (AVHRR). These data can be used to infer ‘green’ cover through the Normalized Difference Vegetation Index (NDVI). This currently offers the best method for estimating soil cover however soil cover that controls erosion is not always green (e.g. dead plant material, stone and rock cover and biological crusts). There is an urgent requirement for methods that measure these other types of cover. Such methods are also needed for monitoring soil erosion by water.

4.6.3 IWEMS

The physical processes that drive wind erosion are fairly well understood (Lu and Shao 2001) and modelling is one means of assessing the impact of wind erosion at local, regional and national scales. Physically based models can also forecast wind erosion events and assess land management strategies under different environmental scenarios.

The accuracy of such models depends on the quality of the input data and field validation of outputs (i.e. wind erosion rates etc.). A strategy must be established for collecting field data which can be used to validate both the inputs and outputs.

Since modeled wind erosion rates depend on our knowledge of climate, soil properties and surface characteristics (Figure 4.1), the accuracy of IWEMS can be improved in the short term by increasing the spatial and temporal resolution of these input data. Improvements required are listed below (Recommendation 6).

- soil physical properties mapped at national scale
    - resolution required: 1 to 25 km^2.
    - high-resolution particle size distributions (i.e. many fractions per soil)
    - physical strength of soil crust
- soil water content of the upper 10 mm
    - resolution required: 1 to 25 km^2, every 3 hours
    - data expressed as a percentage
- surface cover
    - resolution required for the dynamic vegetation cover (i.e. groundcover such as grasses, forbs and sub-shrubs): 1 to 25 km^2, every month. Data expressed as percentage ground cover (10% increments), leaf area index and frontal area index
    - resolution required for more static vegetation cover (trees and shrubs): 1 to 25 km^2, every 5 years. Data expressed as descriptions of vegetation structure (woody cover) in terms of height and density
    - resolution required for stone cover (e.g. gibber) and biological crusts: 1 to 25 km^2, every 5 years. Data expressed in terms of distribution and density
- land management practices
    - resolution required: 1 to 25 km^2, every year
- dust monitoring sites
    - in addition to basic national network, need about 15 more observation sites (some total suspended particulate, some PM_{10}) at either Bureau of Meteorology or DustWatch sites
- meteorological data
    - resolution required for gridded wind (speed and direction) data: 156 km^2, every hour
    - resolution required for visibility data from nephelometer network: every 1 minute above a threshold of 100 bsp

- roadside survey
  - expansion of current coverage into priority areas

The above improvements will require the cooperation of agencies, such as ACLUMP and AGO. Many of these parameters are needed by other groups participating in the Audit and helping NRM Regional Bodies.

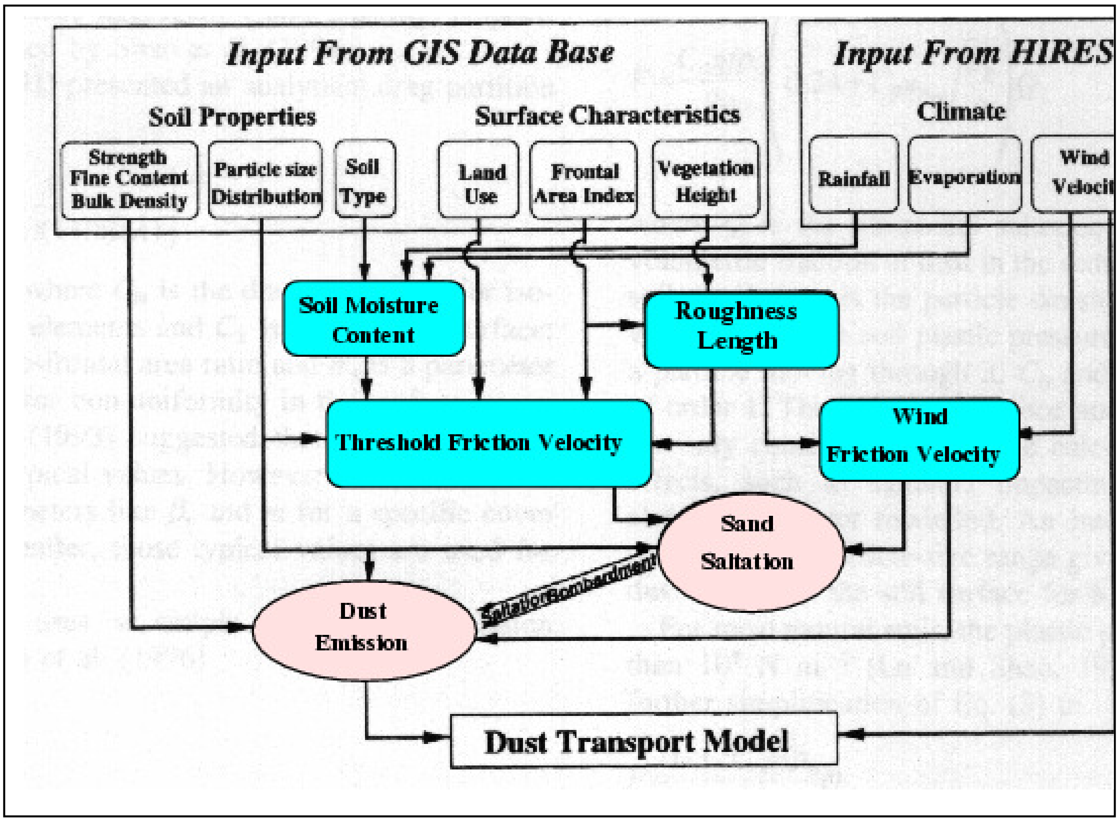

Figure 4.1: Schematic showing how input parameters relating to soil, surface and climatic conditions affect modelled dust emissions (Lu and Shao 2001).

It is recommended that a quantitative dust modelling capability based on IWEMS (Lu and Shao 2001) be established at the University of Southern Queensland and Griffith University where further development and field validation can be undertaken. Later, the responsibility for regular publication of outputs could pass to a national agency, such as the Bureau of Meteorology, Geoscience Australia, or a new national natural resource information agency. The outputs disseminated by such a national agency could include wind erosion maps as well as tabulated estimates of wind erosion rates at key sites across Australia. A national agency would maintain an archive of these outputs.

Ideally these outputs should be updated on a monthly basis, coinciding with the availability of new ground cover data (mostly likely sourced from NDVI data in the short term). Acquisition of the necessary input data to run the model on such a regular basis would also be the responsibility of the national agency. Long-term inter-agency agreements will be required to ensure ongoing access to this data.

4.6.4 Quantifying the effects of land management upon wind erosion rates

Wind erosion is a natural geomorphic process which has been accelerated by agricultural, pastoral and other land uses. While the wind erosion rate measurements and outputs outlined above are essential to an understanding of the dynamics of wind erosion, sustainable land management also requires the quantification of both the component of wind erosion rates that have been accelerated by land management, as well as the effects of improvements in land management. Earlier attempts produced encouraging results (McTainsh 1998) and conceptual development of a new suite of data analysis methods using the DEDB is at an advanced stage (with funding support of the Desert Knowledge CRC). Similarly, the wind erosion modelling techniques outlined above are capable of further development to provide independent estimates of land management impacts upon wind erosion. These direct measurement and modelling approaches to quantifying land management impacts can also be compared with independent data on changes in land management practices.

The model will assist in the assessment of the effect of global climate changes on wind erosion.

4.7 Outputs

The development of methods for monitoring wind erosion has been underway in Australia for about two decades. As a result, there are tools that are: available from now to three years with some investment (interim) and available with significant development in about 6 years (recommended). The interim tools are described in Table 4.1 and the recommended tools are described in Table 4.2.

Table 4.1: *Interim system* for monitoring wind erosion

Site or local			Region			Nation		
Indicator	Method	Outputs	Indicator	Method	Outputs	Indicator	Method	Outputs
Wind erosion rate (*Interim indicator I* - Dust Storm Index)	DSI method (McTainsh 1998)	DSI time series for selected BoM sites only	Dust Storm Index (DSI) (dimensionless)	DSI method (McTainsh 1998)	Maps and tables of DSI	Dust Storm Index	DSI method (McTainsh 1998)	Maps and tables of DSI
Wind erosion rate (*Interim indicator II* - dust concentration)	Installed instrument	Time series of dust concentration (ug/m3)	Dust concentration (ug/m3)	DEDB*** with *limited* Australian calibration data	Provisional maps of dust concentration	Dust concentration (ug/m3)	DEDB* with *limited* Australian calibration	Provisional maps of dust concentration
Wind erosion rate (*Interim indicator III* – modelled soil loss)	Estimation with WEAM* *	Tables of modelled soil loss	Soil loss (t/ha/year)	Estimation with IWEMS ** with *limited* Australian calibration	Maps and tables of modelled soil loss	Soil loss (t/ha/year)	Estimation with IWEMS *** *model with limited Australia calibration*	Maps and tables of modelled soil loss
Area of eroding land (ha)	Ground observation of erosion levels and/or ground cover as a surrogate (WERI)^	Time-series statistics of observed soil erosion or areas at risk of erosion (i.e. less than critical cover level)	Area of eroding land (ha)	Ground observation of erosion levels and/or ground cover as a surrogate (WERI)^	Time-series statistics	Area of eroding land (ha)	Remote sensing of ground cover as a surrogate	Time-series statistics
Land management practices	Survey of land management practices and/or project output reporting	Statistics	Land management practices	Survey of land management practices and/or project output reporting	Statistics			

* Dust Event Database (DEDB

*** Integrated Wind Erosion Modelling System (IWEMS – Lu and Shao 2001)

** Wind Erosion Assessment Model (WEAM) Shao et al (1996))

^ Wind Erosion Risk Index (WERI)

Table 4.2: Recommended system for monitoring wind erosion and the impact of land management after further of investment

Site or local			Region			Nation		
Indicator	Method	Outputs	Indicator	Method	Outputs	Indicator	Method	Outputs
Wind erosion rate - modelled soil loss	Estimation with WEAM	Tables of modeled soil loss	Soil loss (t/ha/year)	Estimation IWEMS *with Australian calibration*	Maps and tables of modelled soil loss	Soil loss (t/ha/year)	Estimation with IWEMS *with Australian calibration*	Maps and tables of modelled soil loss
Wind erosion rate - measured soil loss			Soil loss (t/ha/year)	DEDB *with complete dust concentration calibration*	Maps of soil loss	Soil loss (t/ha/year)	DEDB *with complete dust concentration calibration*	Maps of soil loss
Wind erosion rate – dust concentration			Dust concentration (ug/m3)	DEDB *with complete dust concentration calibration*	Maps of dust concentration	Dust concentration (ug/m3)	DEDB *with complete dust concentration calibration*	Maps of dust concentration
Area of eroding land (ha)	Ground observation of erosion and/or ground cover as a surrogate (WERI)		Area of eroding land (ha)	Ground observation of erosion and/or ground cover as a surrogate (WERI)	Time-series statistics	Area of eroding land (ha)	Remote sensing of ground cover as a surrogate	Time-series statistics
Land management practices	Survey of land management practices	Statistics	Land management practices	Survey of land management practices	Statistics			

4.8 Trials

An important aspect of these methodological developments will be demonstrating their utility in regions where wind erosion is known to be a problem. To this end, pilot studies are suggested. These would be in areas that

- exhibit high wind erosion activity
- represent large areas of the agricultural and pastoral lands affected by wind erosion
- possess regional bodies responsible for land management
- can potentially lever local funding.

The trials will reflect the local wind erosion context, the monitoring requirements of the regional bodies, and the methods recommended by the Expert Panel.

4.9 Recommendations

The Expert Panel offers the following recommendations:

Recommendation 1

Establish a formal agreement between Griffith University and the Bureau of Meteorology for the regular provision of data updates, quality control and other data-related support for the Dust Event Database (DEDB).

Recommendation 2

Develop direct linkages between the DEDB and the field monitoring of dust to enable proposed methodological advances of indicators of wind erosion activity (i.e. from DSI to dust concentration and then to soil loss). This linkage should be made by setting up an arid zone network of DustWatch Nodes, including high volume air samplers (TSP) and DustTrak dust sensors (PM_{10}) at BoM meteorological stations and other DustWatch locations.

Recommendation 3

Establish an Australian wind erosion modelling capability based on the Integrated Wind Erosion Modelling Systems (IWEMS) at the University of Southern Queensland and Griffith University, where the model would be validated and further developed. Discussions would initially be required with Dr Yaping Shao.

Recommendation 4

Reprogram the Wind Erosion Assessment Model (WEAM) and distribute input data files for use in local assessment by Regional Bodies of wind erosion.

Recommendation 5

Let a small contract to document the *Rapid roadside survey technique of Wind Erosion Risk Assessment* so that the method is available for wider application. Groups in the three states currently undertaking such surveys would be involved.

Recommendation 6

The greatest initial advances in wind erosion modelling will come from improvements in the input data as a result of improvements in remote sensing, numerical weather prediction, and data collection methods. The most important data sets are land use, management practices, vegetation cover (static and dynamic layers), soil texture and crusting potential (both physical and biological), nephelometer data weather predictions from BoM. With the exception of the nephelometer data, these are required for monitoring other soil condition indicators and should be considered as essential collateral data sets.

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Chapter 5 Monitoring soil erosion by water

Expert Panel on Soil Erosion by Water

PB Hairsine, DM Freebairn, CW Rose, GW Geeves, RJ Loughran, J Dixon, NJ McKenzie

5.1 Introduction

Soil erosion by water takes many forms. Here, sheet and rill erosion, gully erosion and streambank erosion are addressed as being the most significant forms of water erosion in Australia. The erosion of forestry tracks, for example, is not considered.

Characteristically, water erosion is exacerbated by poor land management and only a small proportion (the delivery ratio) of eroded soil is delivered to streams. Removal of topsoil and organic matter is often imperceptible and fine particles and nutrients are removed selectively.

5.2 Reasons for monitoring water erosion

Two main groups of clients require information on the status and progress of water erosion:

- Regional Bodies need to apply adaptive management approaches to their erosion control work and are accountable for their erosion control investments. They require a basis setting priorities and assessing impacts of investments. Regional Bodies are directly linked to land managers and have a strong focus on on-ground actions.
- State, territory and national agencies require a broader picture of soil erosion by water. These agencies have formal responsibilities for reporting (e.g. state of the environment) and policy formulation.

5.3 Definitions

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 300 mm deep. The gully consists of a head-cut scarp, as well as eroded walls and floor. The gully 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 banks which are often made up of floodplain sediments. Undercutting and saturation slumping are common mechanisms of streambank erosion, especially on the outside bends of meanders.

5.4 Approaches to monitoring

5.4.1 Direct measurement of soil loss

Monitoring of soil erosion by water can be achieved by direct local measurement with devices such as flumes and sediment traps or water sampling techniques. However, erosion events tend to be highly episodic and at any given location long intervals may persist between successive events. It is common for a research project not to register significant erosion for several years even though the average erosion rate may be 10–50 t/ha/year. Few local bodies are interested in monitoring over many years while nothing is happening and direct measurement of erosion has been limited in the past to a few sites where institutional support has been available over the long term.

In addition, while direct measurement might be satisfactory for local monitoring, an impossibly large number of observations would be required to build a regional or national picture through such approaches. A limited number of direct measurement sites would, however, be invaluable as benchmarks where erosion processes and management options can be studied in detail and erosion models – which have broader application across many different landscapes – can be calibrated.

5.4.2 Vegetative ground cover as a surrogate

Vegetation responds to seasonal and management conditions over a shorter time frame than soil erosion and corresponds more closely with the time frame of most on-ground projects operated by farmers and Regional Bodies. Locally, ground cover can also be assessed more readily than physical soil loss. Hence ground cover may be a more useful parameter than soil loss for local monitoring purposes particularly since remote sensing can potentially estimate ground cover across large areas, even nationally.

Two forms of cover are recognized: green and dry vegetation. Changes in green vegetation can be readily observed using satellite imagery. Note that the projected foliage cover of trees may be a poor measure of the effective ground cover relevant to erosion (e.g. bare ground under woodland may have large rates of erosion). Dry, bleached vegetation is difficult to observe and some development work is required to improve its recognition by satellite imagery (Recommendation 1).

Here ground cover is used as a surrogate for soil loss. It is correlated with soil loss via models such as the Universal Soil Loss Equation (USLE) or the Revised Universal Soil Loss Equation (RUSLE).

5.4.3 Management practices as a surrogate

Programs for natural resource management normally report regularly on their outcomes which will include the adoption of practices such as conservation tillage for erosion control.

Management practices are relatively easy to monitor regularly at the local level (e.g. McCord and Payne 2003) and in the time scales of most projects (generally 3–7 years). As with ground cover, management practices have a large impact on rates of erosion so they provide a key to predicting longer term changes to soil condition.

The relationship between management practices, cover and soil loss is well-established (Rattray et al. 2005). However, these surrogates always need to be correlated with actual soil loss. One advantage of using management practices as an indicator rather than cover or soil erosion itself is that it links directly with farmer attitude and practices (Freebairn and King 2003).

5.4.4 Aggregating local monitoring to develop a broad picture

It is difficult to aggregate local observations to develop reliable national views of soil erosion by water. Most Regional Bodies will only monitor where they are investing, leaving large parts or even complete regions without any data. Alternative methods for obtaining the complete national view are considered below.

5.5 Monitoring at the local scale

The dominant process of soil erosion by water depends on topography and land use. In some situations, sheet and rill erosion may dominate while in others it may be gully or streambank erosion.

5.5.1 Sheet and rill erosion at the local scale

The recommended methods for monitoring sheet and rill erosion at the local level are:

- ground cover estimated by comparison with published standards
- ground-based surveys of land management practices (c.f. Chapter 4).

The assumption is that ground cover is a surrogate for soil loss and that the change in estimated soil loss is more important than the absolute value. Cover can be estimated in several ways:

- visual cover standards
- airborne or satellite-based remote sensing
- modelled estimates such as those based on crop yield
- expert opinion based on land management practices.

A set of curves based on the USLE and its sequel (the RUSLE), suggests the likely relationship between ground cover and erosion on various slopes. Different curves apply in different environments and the absolute quantity of soil removed depends on the delivery ratio.

Elements of the USLE which are ignored in this approach are soil erodibility (K) and slope length (L). Erodibility values are generally not well known and the model is least sensitive to slope length.

This information can be aggregated to catchment scale and further and reported as statistics or maps of cover change. The following data will be collected at the scale of the land unit (preferably Level 6 in ASRIS which equates with the landform element in McDonald et al. 1990):

- area within the land unit affected by the management action
- dominant slope of the land unit
- ground cover at successive times
- change in cover (Δ Cover) as a consequence of land management practices – (the primary determinant of change in soil erosion)

- practice factor (P) for the land unit if management actions are present that are not captured by cover (e.g. construction of contour banks)
- change in erosion as a consequence of changes in ground cover.

The link between soil erosion and management practice is based on the proposition that more is better (i.e. more conservation tillage, more grazing management, more ground cover), and a general relationship is presented in Figure 5.2. Trends in soil management practices are a valuable monitoring device.

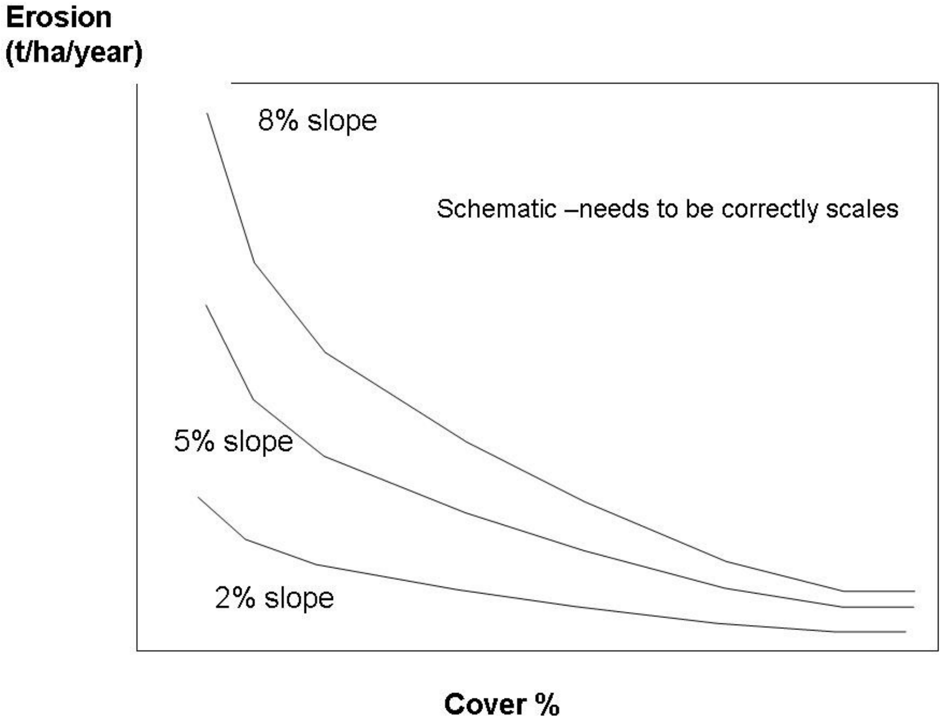

Figure 5.1: Conceptual model for estimating hill-slope erosion under different combinations of slope and ground cover.

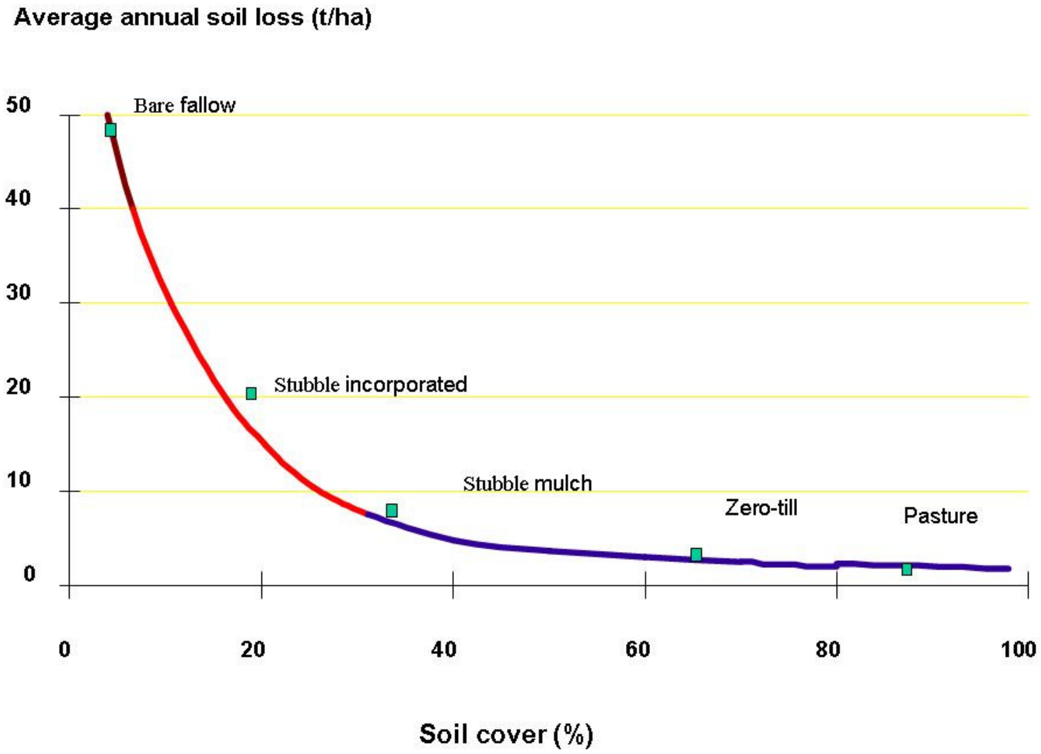

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Figure 5.2: Relationship between soil cover and erosion on the eastern Darling Downs (Freebairn and Wockner 1986).

5.5.2 Gully erosion at the local scale

The recommended methods for monitoring gully erosion at the local level are:

- ground observation of total gully length in the project area
- project reporting of management practices adopted.

Ground observation of gully length

Ground observation of gully length at the local level will necessarily be opportunistic. Typically, aerial photographs will be used as base maps and the value measured will be the total gully length in the project or sample area.

Difficulties arise because gully expansion is often in response to extreme climatic events. Aerial photography is required shortly before and after the erosion event being assessed.

Individual or small numbers of gullies can be monitored using benchmarks and fixed photo points.

Project reporting of gully erosion practices adopted

Given the short-term nature of many projects and the sporadic expansion of gullies, the gully length might not change during a project. The adoption of practices known to reduce gully expansion may be more informative.

As with sheet and rill erosion, NAP/NHT2 projects which are investing in gully erosion control must report regularly on outcomes which may include the adoption of practices to control gully erosion such as gully interceptor banks, headworks and artificial waterways.

5.5.3 Streambank erosion at the local scale

The recommended methods for monitoring streambank erosion at the local level are:

- ground-based surveys
- project reporting of management practices adopted.

Ground observation of streambank erosion

There are no established standards for gauging the degree of streambank erosion but at the local project level the same techniques as for gully erosion can be applied. Small sections of streambank such as those undergoing repair can be monitored using benchmarks and fixed photo points.

Project reporting of streambank erosion control practices adopted

As with the other two forms of water erosion, where projects are addressing streambank erosion, they can report on management actions being implemented for its control. The most common measures will be fencing, revegetation and, in some cases, revetment.

5.6 Monitoring at the regional and national scales

CSIRO Land and Water modelled the risk of sheet and rill, gully erosion at the continental scale for the National Land and Water Resources Audit (2001). These broad-scale models show where erosion is likely to be a problem, helping regional and national agencies set priorities for investment. The models also estimate baseline rates of erosion against which the likely benefits of new land management practices can be assessed (Recommendation 3).

Vegetation cover is the single most important factor in determining whether soil erosion will occur. Unfortunately there is no wholly satisfactory method of estimating vegetation cover or linking vegetation cover with actual soil loss at broad scales.

Satellite techniques for estimating green vegetation are well established. It is feasible to report on changes in green vegetation cover every five years (e.g. including rangelands, forests and farming lands). The Australian Greenhouse Office already collects the necessary data. However, additional techniques are needed to estimate the percentage cover of dry, bleached annual vegetation because the dry vegetation signal is difficult to distinguish from the background soil signal.

Regional Bodies could possibly use national standards to describe ground cover, thus assisting in calibrating the satellite imagery. However this technique requires further investigation. The imagery for both the green and dry vegetation needs to be routinely available across large areas at reasonable cost.

5.6.1 Sheet and rill erosion at national scale

The indicators of sheet and rill erosion are:

- estimates from broad-scale models
- ground cover.

Broad-scale models of soil erosion

A baseline assessment of sheet and rill erosion was produced by Lu et al. (2001a) and updated by Wilkinson and Read (2006). These assessments rely on national data for climate, terrain, soils and ground cover. The approach is based on the USLE as adapted for Australia by Lu et al. (2001a). Soil cover and rainfall erosivity are assessed seasonally and combined with the other time-invariant terms to produce maps of sheet and rill erosion hazard.

The Expert Panel recommends that ground cover (by vegetation, stubble and/or litter) is assessed using remote sensing (according to the method of Lu et al. 2001b) for each month of a five year assessment period. The months are combined using the relative rainfall erosivity for each region. To improve the assessment of cover, the Expert Panel recommends that these data are provided to the Regional Bodies for checking. Potential errors include bleached stubble on dry soil being represented as bare soil.

The proposed method only includes mitigation practices that change ground cover. Techniques such as strip cropping, contour banks and alley farming are not accounted for; these are covered by the 'practice factor' (P) in the final assessment.

Table 5.1: Method of calculating P effects for sheet and rill erosion

Total Cropping area (km^2) (1)	Cropping area with recommended hillslope erosion mitigation measures (2)	Percentage of total area treated 100* (2)/(1)	P factor	Mitigation factor applied to all cropping areas P*(2)/(1)
			0.7	
Total grazing area (km^2) (a)	Grazing area with recommended hillslope erosion mitigation measures (b)	Percentage of total area treated 100* (b)/(a)	P factor	Mitigation factor applied to all grazing areas P*(b)/(a)
			0.5	

Current activities

CSIRO Land and Water is currently updating the sheet and rill erosion maps it compiled for the NLWRA (2001). These updates for the National Water Commission use finer resolution digital elevation models and better maps of land use but the assessment of ground cover is the same (Recommendation 2). The update will not address gully erosion or streambank erosion at either the national level or regional level. However, some of the datasets may be useful for this purpose[7].

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[7] For further information, contact Dr Scott Wilkinson (scott.wilkinson@csiro.au)

Vegetation cover assessment

Using vegetation cover as a predictor of soil loss is possible through the USLE. The assessment of soil cover used in the soil erosion component of the NLWRA (2001) is described in Lu et al. (2001a). Their approach did not deal well with bleached dry grass or stubble on dry soil, however new forms of remote sensing are now available.

Synoptic monitoring of green vegetation cover is feasible through remote sensing but while NDVI is the starting point, significant effort is needed to translate surface reflectance into a measure of effective vegetation cover that is relevant to water erosion. Substantial effort would be required to make a national assessment of cover at a suitable resolution for each month in a five year monitoring period (Recommendation 3). A mechanism is also needed to incorporate land management practices into the P factor. The resolution of other USLE input variables (e.g. terrain) is steadily improving.[8]

5.6.2 Long-term studies to understand processes and calibrate models

The existing national baseline assessment evaluates the seasonally variable erosion hazard over the Australian continent. This assessment is however constrained by limited data from experimental sites. A set of permanent sites representing priority geomorphic provinces is required to better understand sediment transport and hydrology. The Expert Panel suggests 20 sites of about 10 000 hectares each. These long-term sites would be used for other indicators of soil condition such as wind erosion, soil acidification and soil organic carbon (Recommendation 4).

5.6.3 Gully erosion at the national scale

The gully mapping protocol used in NLWRA (2001) is described in Hughes et al. (2001). This approach combined existing gully mapping with the interpretation of 460 air photos to improve the prediction of the occurrence of gullies across the Australian landscape.

A baseline assessment of gully erosion which also combined data on gully erosion from state and territory agencies was produced by Prosser et al. (2001) as part of the NLWRA. Prosser et al (2001) produced a national map of gully erosion by applying models linking soil type, terrain, land use and gully formation, and aerial photo interpretation of gully features.

Table 5.2: Method of calculating P effects for gully erosion

Total Length of gullies in cropping area (km) (1)	Length of gullies in cropping areas that are fenced (2)	Percentage of length of gullies fenced 100* (2)/(1)	Maximum Mitigation factor 0.8	Mitigation factor applied to gully erosion map for all cropping areas 0.8*(2)/(1)
Total length of	Length of	Percentage of	Maximum	Mitigation

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[8] For further information, contact Dr Tim McVicar (tim.mcvicar@csiro.au)

gullies in grazing area (km^2) (a)	gullies in grazing areas that are fenced (b)	length of gullies fenced 100* (b)/(a)	Mitigation factor 0.8	factor applied to gully erosion map for all grazing areas P*(b)/(a)

However it is very difficult to quantify gully volumes from aerial photographs. As gullies are near-permanent features, their erosion rate is taken to be that of bare soil and the rate of expansion as their volume divided by time since European clearing. While it is widely recognised that the erosion rates of most gully networks are decreasing, the actual amount is not currently well quantified.

The baseline assessment does not include measures to manage gully erosion in which the gully is fenced to avoid from disturbance by grazing animals. Credit for these measures is recognised by a ‘gully mitigation factor’ (GM) in the actual assessment.

At the national level, the ASRIS database, climatic and topographic data could be used to identify high-risk areas for reinterpretation.

5.6.4 Streambank erosion at the national scale

Streambank erosion is considered to be an important form of soil erosion in the Australian landscape and in some environments is the dominant contributor to in-stream sediment (Wallbrink et al. 1998). However, monitoring of streambank erosion at a national level is not considered feasible at this stage.

5.7 Outputs

Local reporting for water erosion will be in the form of:

- sheet and rill erosion
  - maps and statistics
  - survey statistics of management actions adopted
- gully erosion
  - marked aerial photographs and statistics
  - survey statistics reporting management actions adopted
- streambank erosion
  - anecdotal or ad hoc reports of local observations
  - survey statistics of management actions adopted.

Broad-scale monitoring data will be presented as text, maps, tables and graphs in the manner of the National Land and Water Resources Audit’s Australian Agriculture Assessment 2001.

The ASRIS database needs to be extended to receive and manage monitoring data (Recommendation 5). Coupled with this should be a data quality assurance and correlation function with data responsibility being assigned to an Australian Government agency.

Table 5.3: Summary of indicators, methods and outputs for the three types of erosion at the two scales of analysis

Type of erosion	Local			Regional and national		
	Indicator	Method	Outputs	Indicator	Method	Outputs
Sheet and rill	Ground cover (%)	Ground observation compared with published vegetation cover standards	Maps and statistics	Erosion hazard derived from broad-scale models	Models based on USLE run at regular intervals using data from LTER plots, updated ground cover, land use and other information	Erosion hazard maps based on model results.
	Adoption of sheet and rill erosion management practices	Project reporting of management practices adopted	Survey statistics of management actions adopted	Ground cover (%)	Time series satellite imagery	Satellite images classified according to veg cover and veg cover change
Gully	Total gully length in project area	Ground observation of gully expansion	Marked aerial photographs and statistics	Total gully length at representative sites	Models used to select representative sites followed by aerial photograph interpretation	Statistics based on air photo interpretation
	Adoption of gully erosion management practices	Project reporting of management practices adopted	Survey statistics reporting management actions adopted			
Streambank	Kilometres of eroded streambank		Anecdotal or ad hoc reports of local observations	No indicator proposed	No monitoring method proposed	
	Adoption of streambank erosion management practices	Project reporting of management practices adopted	Survey statistics of management actions adopted			

5.8 Trials

It is recommended that the approaches suggested here be tested within one or more Regional Bodies which are addressing water erosion within their Investment Plans. The Regional Body would monitor:

- sheet and rill erosion using ground cover as a surrogate
- sheet and rill erosion using management action reporting
- gully erosion using ground-based surveys
- gully erosion using management action reporting
- streambank erosion using local observations
- streambank erosion using management action reporting.

The Regional Bodies have already budgeted for this monitoring and therefore the cost to NLWRA will be limited to the cost of the additional work involved in assessing and reporting the approaches recommended here.

5.9 Recommendations

Table 5.3 provides a summary of the recommended indicators, methods and outputs for the three types of erosion at the two scales of analysis.

Recommendation 1

Commission research to determine the relationships between remotely sensed data and dry vegetation cover at the local, regional and national scales.

Recommendation 2

Update the National Baseline Assessment of Soil Erosion Hazard completed in 2001 by using improved methods and better input data being developed under the National Water Initiative Baseline Project. Commission CSIRO Land and Water to prepare specifications for a re-run in 2010, while, in the interim, improved methods and datasets will be developed, including incorporation of land management practices into the P factor of the USLE.

Recommendation 3

Develop collateral datasets including a five-yearly national inventory of vegetation cover suitable for modelling water erosion at a national scale.

Recommendation 4

Establish a set of long-term ecological research sites representing geomorphic provinces to better understand sediment transport and hydrology.

Recommendation 5

Extend the ASRIS database to receive and manage monitoring data. Establish a data quality assurance and correlation function for the database and assign data responsibility to an Australian Government agency.

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Chapter 6 Testing the protocols for monitoring soil condition

Expert Panel on Soil Condition Monitoring

J Dixon, NJ McKenzie

6.1 Introduction

For each of the four processes (soil acidification, dynamics of soil organic carbon, and erosion by wind and water) the Expert Panels have recommended a series of indicators with corresponding protocols for monitoring. The next stage is to test these protocols in the field.

Some of the indicators and protocols are intended for local use by NRM Regions, while others are intended for broader application, most likely by state or national agencies or universities under contract.

Some of the monitoring protocols require further development, checking, or documenting before they will be suitable for more general use. This is part of the purpose of the trials.

Other monitoring protocols, particularly those for broad scale monitoring, require further research or coordination of effort across agencies (e.g. Bureau of Meteorology and ABS) before they can be applied. The interim methods for wind erosion can be applied at broad scales now.

The purpose of the trials is to test and document the practicality or otherwise of the proposed protocols. It is not to demonstrate the success of a particular agronomic or engineering treatment.

Some trials will be conducted at the NRM Regional level. Other arrangements will be made for testing the broad scale protocols.

6.2 Selecting trial areas

Given the relatively small sums of money available for each trial, the NRM Regions have been nominated by the appropriate Expert Panel, the National Committee for Soil and Terrain or the Audit Advisory Council. Nominations were on the basis of the land degradation being active in the Region and Region's expected to be willing to participate in the trial.

The contracting NRM Region may or may not have the immediate operational capacity to undertake the monitoring. This is part of the trial and the Region may choose to outsource the work to a state government agency or to the private sector. The contract is for the extra monitoring work involved, improving the description of methods and reporting the experience. Members of the Expert Panels may be involved in organising and managing these collaborative arrangements.

6.3 Terms of reference

In conjunction with its existing monitoring program, the Trial Region will apply the local soil monitoring protocol and report on:

- the technical feasibility of monitoring the indicators using the recommend protocols
- the utility of the information generated by the monitoring for both accountability and adaptive management
- the outputs produced by the monitoring effort
- the availability and adequacy of collateral data sets and other supporting information or documentation
- the staff, skills and budget required to successfully undertake the monitoring should it become an ongoing exercise
- the issues surrounding the transfer of data and outputs onto local databases and ultimately a national system such as ASRIS
- any other general experience and relevant information from the monitoring trial.

The Trial Region will also provide documentation to enable practical application by other regions.

6.4 Recommended trial sites for each indicator and method

The following tables, one for each of the four processes, list the indicator and protocol, and suggest where they might be tested. The tables also detail where preparatory work is required. Each table is divided into two parts. The first lists the indicators and protocols believed to be suitable for local monitoring. The second lists indicators and protocols believed suitable for broad-scale monitoring.

Testing of these methods will involve the relevant state and national agencies.

Table 6.1 Recommended trial regions and budgets

Process	Region/Agency	Budget ($'000)	
Acidification	Avon Catchment Council	60	
	Murray/Murrumbidgee CMA	40	
			100
Carbon	Northern Rivers / Gwydir	30	
	Cradle Coast	20	
	CSIRO	30	
			80
Wind erosion	NT Alice Springs	10	
	NACC	30	
	Mallee (tri-state)	25	
	Australian continent	15	
			80
Water erosion	Condamine	20	
	Daly Douglas	20	
	CSIRO	60	
			100
			360

Table 6.2a: Local-scale monitoring of soil acidification

Indicator	Method	Development work still required before trials commence	Trial locations
pH at surveillance sites	Commercial soil testing for pH with geo-referencing (Time = t_0)		Avon Catchment Council Murray/Murrumbidgee CMA
ΔpH at surveillance sites	Commercial soil testing for pH with geo-referencing (Time = t_1) $\Delta pH = pH(t_1) - pH(t_0)$		Avon Catchment Council Murray/Murrumbidgee CMA
Estimated time to critical pH for chosen combinations of land use and soil type	Simple models (Optlime or the Lime Application Calculator) relying on estimates of buffering capacity and NAAR	Review and update Optlime Model. (WADAF) Review and update Lime Application Calculator (CSIRO) Review and update guidelines for estimating buffering capacity and net acid addition rate. (WADAF)	Avon Catchment Council Murray/Murrumbidgee CMA
Lime use and other land management practices	Local surveys		Avon Catchment Council Murray/Murrumbidgee CMA

Table 6.2b: Broad-scale monitoring of soil acidification

Indicator	Method	Development work still required before trials commence	Trial locations
pH at surveillance, permanent monitoring and Long Term Ecological Research sites	Networks of surveillance, permanent monitoring sites and Long Term Ecological Research sites and collation of commercial and public soil testing data at for priority regions at t_0	Establish surveillance, permanent and Long Term Ecological Research sites	
pH at surveillance, permanent monitoring and Long Term Ecological Research sites	Networks of surveillance, permanent monitoring sites and long term research sites and collation of commercial and public soil testing data at for priority regions at t_1 $\Delta pH = pH(t_1) - pH(t_0)$		
Net acid addition rate (NAAR) for systems of land management	NAAR based on data from permanent monitoring and research sites. Outputs rely on these data, maps of management practices, and soil data from ASRIS	Upgrade ASRIS to receive monitoring information (CSIRO/ACLEP) Review ASRIS data to generate soil buffering capacity and net acid addition rates	
Estimated time to critical pH for chosen combinations of land use and soil type	Models based on ASRIS soil data, land use data and other data	Review and update Helyer and Porter Model. (Vic DPI) Negotiate with ESCALUM for improved land use and land management data	
Lime use and other land management practices	ABS statistics of lime use and other land management practices in full national census years	Negotiate with ABS for the provision of statistics relating to lime sales.	

Table 6.3a: Local-scale monitoring of soil organic carbon

Indicator	Method	Development work still required before trials commence	Trial locations
Labile C	Sequential extraction method MIR	Finalise the development of the Skjemstad CRCCA Calculator for estimating the maximum percentages of organic carbon possible over a range of soil types and land uses (CSIRO). Develop calibration sets for MIR within regions	Border Rivers / Gwydir Cradle Coast
Total C	LECO MIR	Develop calibration sets for MIR within regions	Border Rivers / Gwydir Cradle Coast

Table 6.3a: Broad-scale monitoring of soil organic carbon

Indicator	Method	Development work still required before trials commence	Trial locations
Labile C	Sequential extraction method MIR	Scope the development of national calibration sets for MIR – and implement the development of same.	
Total C	LECO MIR	Scope the development of calibration sets for MIR – and implement the development of same. Establish permanent and long term ecological research sites. Analysis of Australian soils using the FULCAM model to identify sensitive areas for monitoring	

Table 6.4a: Local-scale monitoring of wind erosion

Indicator	Method	Development work still required before trials commence	Trial locations
Wind erosion rate (*Interim indicator I* - Dust Storm Index)	DSI method (McTainsh 1998) for a few sites in an NRM region	None	Alice Springs
Wind erosion rate (*Interim indicator II* - dust concentration)	Dust Watch and DustWatch Nodes with Installed instruments	DustWatch coordinator, buy and install equipment	NACC
Wind erosion rate (*Interim indicator III* – modelled soil loss)	Estimation of soil loss at a site with the WEAM model	Finalise and distribute the WEAM model (1–2 years)	Mallee (Vic, NSW, SA)
Area of eroding land (ha)	Ground observation of erosion levels and/or ground cover (WERI)	Review, standardise and update the guidelines for roadside survey (SA Department)	Murraylands
Land management practices	Survey of land management practices and/or project output reporting	As above. Negotiate with ABS and/or ESCALUM for the provision of statistics relating to land management practices relevant to managing wind erosion	Murraylands

Table 6.4b: Broad-scale monitoring of wind erosion

Indicator	Method	Development work still required before trials commence	Trial locations
Soil loss (t/ha/year)	Estimation with the IWEMS model with limited Australian calibration	Local adaptation and calibration of IWEMS Model (USQ) Finalise arrangements to run model at Griffith Uni/Uni of Sth Qld	
Dust concentration (ug/m3)	Dust Event Data Base with limited dust concentration calibration data	Visibility – dust concentration relationship to be established from data already available from LMD CMA. Need to develop WA and VIC relationship from instruments at DustWatch Sites	
Dust Storm Index (DSI) (dimensionless)	Dust Storm Index method (McTainsh 1998)		
Area of eroding land (ha)	Satellite imagery of vegetation cover	Develop spectral signatures for green and dry vegetation (not feasible with current funds)	
Land management practices	Survey of land management practices and/or project output reporting	Negotiate with ABS and/or ESCALUM for the provision of statistics relating to land management practices relevant to managing wind erosion	

Table 6.5a: Local-scale monitoring of water erosion

	Indicator	Method	Development work still required before trials commence	Trial locations
Sheet and rill	Vegetation cover (%)	Ground observation compared with published vegetation cover standards		Condamine Daly Douglas
	Adoption of sheet and rill erosion management practices	Project reporting of management practices adopted		Condamine Daly Douglas
Gully	Total gully length in project area	Ground observation of gully expansion		Condamine Daly Douglas
	Adoption of gully erosion management practices	Project reporting of management practices adopted		Condamine Daly Douglas
Stream bank	Kilometres of eroded streambank			Condamine
	Adoption of streambank erosion management practices	Project reporting of management practices adopted		Condamine

Table 6.5b: Broad-scale monitoring of water erosion

	Indicator	Method	Development work still required before trials commence	Trial locations
Sheet and rill	Erosion hazard derived from ‘broad scale’ models	Models based on USLE run at regular intervals using data from LTER plots, updated vegetation cover, land use and other information		CSIRO L&W
	Vegetation cover (%)	Time series satellite imagery	Develop spectral signatures for green and dry vegetation Provide monthly NDVI data for green vegetation and comparable data for dry vegetation	
Gully	Total gully length at representative sites	Models used to select representative sites followed by aerial photograph interpretation		
Stream bank	No indicator proposed	No monitoring method proposed		

6.5 Comments on the selected regions

Soil acidification	The Avon Catchment Council Region (WA) The ACC Region is a large cereal growing area with a very significant soil acidification problem which is being addressed through the ACC Investment Plan project. Murray and Murrumbidgee CMAs (NSW) The Murray and Murrumbidgee CMAs have large investments in soil condition and a significant soil acidification problem. Catchment Action Plan Targets specifically address soil acidification.
Soil Carbon	Border Rivers / Gwydir (NSW) The Border Rivers / Gwydir CMA contains a diverse range of landscapes including tablelands, slopes and plains. It has invested considerable resources in on-ground works to improve soil condition and in developing monitoring procedures. Catchment Action Plan Targets specify improved soil condition measured by soil carbon content. Tasmania Tasmania has a statewide soil condition evaluation and monitoring project which includes the Cradle Coast CMA where soil carbon is being monitored.
Wind erosion	Alice Springs (NT) CSIRO and the NT Department of Natural Resources, Environment and the Arts are working on wind erosion in this region. Northern Agricultural Catchment Council (WA) Although wind erosion is not emphasised in the NACC investment plan, wind erosion is a major form of land degradation in the region. The Department of Agriculture and Food has staff skilled in the wind erosion area and who could work alongside the Regional Body. Murraylands (Murray Mallee) Wind erosion is the most important degradation issue in this region. Murraylands is also adjacent to the Victorian Mallee which would permit some synergies while still allowing testing in different NRM regions. The most detailed monitoring is currently done in SW NSW in the Lower Murray Darling CMA. The Victorian Mallee CMA want to be involved in monitoring.

	Mallee (Vic) See above
Water erosion	Condamine (NSW) A progressive CMA with a diverse landscape ranging from rolling hills in the east to floodplains in the west. A generally high rainfall with significant erosion. The Condamine CMA also has a major project entitled ‘ Repair of unacceptable degradation’ Daly Douglas (NT) The Daly Douglas Group has an active program to control water erosion and is anxious to monitor its success.