Rationale and Methodology

Monitoring trends in wind and water erosion in South Australia

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Introduction

Natural rates of soil erosion are usually relatively low, but when natural vegetation is cleared and the soil cultivated for agricultural production, the rate of soil loss usually accelerates to many times natural levels. The productive capacity of the land can be seriously compromised.

Very large areas of South Australia's agricultural lands have suffered high levels of wind or water erosion in the past, particularly in the first half of the 20th century. However, agriculture has historically played an important part in the prosperity of the state and, since the 1940s, governments have invested substantial money into soil conservation regulation, extension and research to combat the problem.

Since 1980, investment by both the Commonwealth and state governments has escalated with various coordinated programs to encourage sustainable farming, such as the National Soil Conservation Program (NSCP), the National Landcare Program (NLP) and the Natural Heritage Trust (NHT). These programs have focused on education, research, demonstration and on-ground works, but there has been little evidence collected to demonstrate any landscape improvement.

There is widespread evidence of past water erosion in the undulating cropping districts of South Australia. This large gully began in thunderstorms in the summer of 1941, near Callington, South Australia.

While anecdotal evidence suggests that erosion has markedly reduced over the last 50 years there is no actual data to confirm this. Recently, the Department of Water, Land and Biodiversity Conservation (DWLBC) has established a program to begin to monitor key indicators of land condition in South Australia. Soil erosion is one of the most important issues.

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Monitoring Wind and Water Erosion

a). Rationale

Soil erosion results from a complex interaction of soil type, topography, climatic conditions and land management practices. The inherent susceptibility of a land surface to erosion is determined by soil type and topography. However, most agricultural soils are relatively resistant to erosion, provided that their surfaces are left undisturbed and a high level of surface cover is maintained. Once the surface is loosened, lower energy winds or water flows can detach soil particles to the full depth of the loosened soil.

Since management practices that loosen the soil almost inevitably result in loss of surface cover, the most critical factors determining the risk of soil loss involve the occurrence, intensity and timing of tillage operations (and excessive grazing), and the quantity and nature of surface cover. The timing of tillage operations is also of utmost importance because the longer a soil is in a loose and bare condition, the higher the probability of a coincident erosive wind or rainfall event.

Sheet and rill erosion is the most widespread type of water erosion in the cropping districts of South Australia. For this form of erosion, surface cover lowers the risk both by protecting the soil from direct raindrop impact and by reducing the velocity and energy of overland flows. The steeper the land, the more energy a water flow has for detachment and transport of soil particles, and the soil loss is exacerbated where the soil surface is already disturbed by excessive grazing or cultivation. On the other hand, soil loss is usually low for a highly erodible soil on a steep slope where the soil surface is completely covered by standing vegetation.

Sheet and rill water erosion on sloping land in the Northern and Yorke Region of South Australia.
Photo M-A. Young, PIRSA

In the case of wind erosion, surface vegetative cover significantly reduces wind velocity at the soil surface. Tillage intensity can also modify the risk because cultivation practices that result in a very finely divided soil make it much more susceptible to erosion than a single, no-till operation that only loosens the soil in relatively narrow slots. This means, for example, that sandy loams not normally prone to wind erosion can be placed at risk by aggressive tillage. In addition, wind erosion is most likely if strong winds occur when sandy soils are bare and loose, and is greatest on exposed dunes compared to flats or swales. On the other hand, soil loss is unlikely for similarly disturbed clayey soils.

This erosion occurred in the northern Murray Mallee in 2002, but there is plenty of evidence on roadsides across South Australia of the regular and extensive occurrence of wind erosion since clearing for agriculture.

Monitoring soil loss by direct measurement is technically impractical, because soil erosion events are highly variable, both temporally and spatially. Instead, assessing the trend in exposure of land has become the focus of a different approach to monitoring erosion in the South Australian Land Condition Monitoring Program. This approach does not provide a direct estimate of the amount of soil lost in any given erosion event or period, but it does provide quantitative indicators of changes in wind and water erosion risk. Over the longer term, any change in the risk of erosion is considered to translate into an equivalent change in overall quantity of soil lost from agricultural landscapes. In essence, if the landscape is continually exposed by management practices, soil loss is an inevitable consequence when severe climatic events coincide.

In practical terms, the factors considered to be most important in determining loss of soil by erosion are:

For sheet and rill water erosion —

- land slope
- cover
- disturbance

For wind erosion —

- soil and landscape type
- cover
- disturbance

b). Methodology

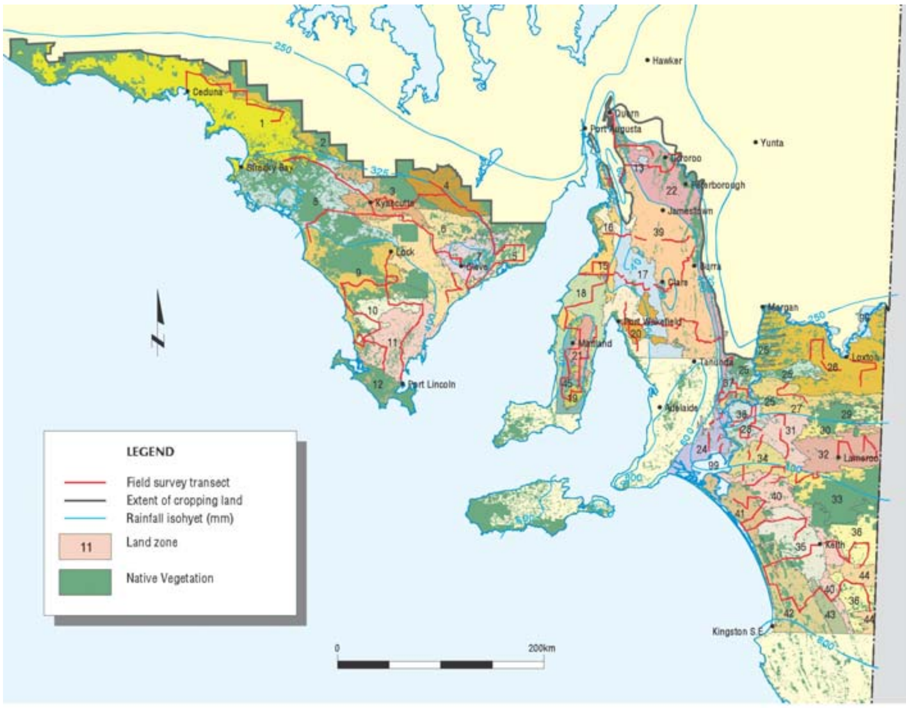
Background

The Department of Primary Industries in Victoria has conducted annual field surveys to assess the extent of wind erosion on cropland in the Victorian Mallee district since 1978. The initial methodology was primarily aimed at assessing the proportion of land eroding on a random sample of paddocks around key grain receival points. Since 1986, biannual surveys have been carried out along set transects to include around 800 paddocks to additionally gauge the length of fallow and crop variety across this landscape. Data from these surveys indicated that there was a reduction of 61% in the cultivated land eroding between 1978 and 1991 (Anderson et al. 1992).

Roadside paddock surveys have also been conducted in the United States of America to collect data on tillage and crop-residue management systems. The Ohio Department of Natural Resources has conducted random road transect surveys since 1986 to collect information on crops grown, tillage systems and residue cover in a watershed of 11 counties in the state (Kush & Crawford 1987). Similar surveys are used in key cropping areas of Iowa, Indiana and Illinois (Hill 1998). All vary slightly in the frequency of data collection and in the information they collect. In Illinois, the collection forms are even modified to include parameters that enable computer-generated soil loss estimates using the Universal Soil Loss Equation. Irrespective of the differences, the basic aims of all the surveys are to provide indicators to monitor progress in conservation farming and provide evidence to establish priorities in the provision of support service or education programs. The general methodology seemed to offer an effective and robust means of monitoring land management and erosion risk in the South Australian cropping districts.

Field Survey Framework

A rapid field survey methodology has been developed to collect key data related to soil loss risk. A land zone framework of over 45 zones has been defined across most of the agricultural areas of South Australia based on the DWLBC land description database (Soil and Land Information 2002a). Field surveys are undertaken along 14 transects (Figure 1) through 38 land zones considered to have a significant inherent potential for soil erosion. These include parts of the Lower, Mid and Upper Northern and Yorke Region, Eyre Peninsula, Murraylands and the Upper and Mid South East, representing about 8.5 million hectares of the 10.2 million hectares of cleared farming land in South Australia. To date, erosion risk data have not been collected in Lower Yorke Peninsula, Kangaroo Island, the southern Mount Lofty Ranges or the Lower South East, where either the inherent erosion potential is low, or where there is relatively little risk created because of high rainfall and low annual exposure of the soil for sowing crops or pastures.



/projects/land-condition/transect_zones/zonemap2/allzones/aml

Figure 1: Land zones and field survey transect locations for assessment of land cover in South Australia.

Observation Sites
The survey methodology is designed to assess agricultural land cleared for mixed farming with crops and livestock.

Pilot surveys
In the case of this monitoring program, bias was not considered to be an important factor. The surveys are not meant to necessarily be an accurate representation of erosion in the landscape. Indeed, the transect locations, and hence the data collected, are biased towards erosion-prone landscapes. They were purposely planned in order to target the districts where wind erosion was a known issue. In some areas they focused on water erosion as well. The overriding aim was to monitor change over time of surface residue management on erosion-prone land rather than provide a statement of change in the average condition in regions or state. It achieves this by assessing the proportion of sites at risk. The usual descriptive statistics (e.g. means) are of only secondary interest. This does not preclude the use of the data for average condition statements. However, the data are best used to compare changes over the monitoring years at any particular assessment time rather than as a ‘one-off’ cover value.

Sampling methodology and sampling density were the main issues addressed prior to implementation of the program. While other bias can occur in collecting data using fixed transects, they optimise field efficiency and maximise the amount of data captured in comparison to a set of random sampling sites in any given time period. During 1998–99, a series of pilot surveys were carried out to scope random and fixed transect methodologies in several land systems at Kapunda in the Northern and Yorke Region of South Australia, an example of predominantly undulating water erosion prone land, and at Karoonda in the Murraylands Region, an example of wind erosion prone dune and swale land.

Comparison of the cover rating data between successive pilot surveys indicated that the fixed transect methodology was best for assessing changes over time. The Cover Rating (range 1–8) was used to evaluate the sampling requirement for the planned land condition monitoring program. In comparing differences in the mean cover rating for zones sampled at different times, achieving a least significant difference at the 5% probability level of less than 1 unit required a sample size of 30–50 sites per zone. Random selection of sites required at least double that sample size. Fixed transects also proved to be almost three times as field efficient as random observations and it was therefore chosen as the field sampling methodology. This was easily achievable using continuous fixed transects because survey teams could simply record most paddocks along a route as they travelled, rather just a limited sample. To maximise data reliability, it was decided that 50–100 observations was the minimum desirable sample size for each erosion-susceptible zone. In fact, depending on the size and complexity of the landscape, there are currently nine zones with 50–100 sites, 22 zones with 100–200 sites, six zones with 200–300 sites, and one zone with over 500 sites.

Overall, data are currently recorded for around 6000 paddocks (sites). Small holding paddocks and areas covered by native vegetation are ignored but otherwise each paddock either side of the transect roads is a potential observation site representing typical broadacre farmland. An observation site is an imaginary 200 m square area that begins 50 m in from a subdivision fence that meets the road, denoting the start of the next paddock. To further avoid artefacts such as vehicular tracks, firebreaks, stock water troughs and areas affected directly by the roots of roadside vegetation, the first 10 m adjacent to the road are ignored. This was found to be the most satisfactory site area for visual observations of paddocks.

In dune and swale landscapes, data are recorded for both the dune and swale facets if they occur within the site and stored in the main database as one site number.

Survey Timing

Four surveys are carried out each year. Long fallows have traditionally begun the cropping land preparation cycle in late winter or early spring in the year prior to crop sowing, and they can still make a significant contribution to land exposure. The first survey is therefore carried out in the first week in October and is followed by surveys in the first week of March and May to assess the late summer to autumn period, when variable wind and rainfall conditions usually contribute directly to both wind and water erosion and determine the timing of tillage. These surveys are kept to the same time each year to more clearly demonstrate change during the early preparation stages. The final survey is undertaken in the middle of sowing when district staff consider that exposure of the land is greatest in their districts. Sowing time for the main cereal, oilseed and grain legume crops can range from early May to mid-July, but most frequently peak exposure occurs around early to mid-June.

Parameter Development and Use

All recorded parameters are briefly described in Table 1. They can also be found in the Field Manual on this web site, together with the protocols for transect and site selection. They were chosen and developed in consultation with the land management extension staff of Primary Industries and Resources South Australia (PIRSA) prior to implementation of the main survey program in October 1999.

Table 1: Identity and description of data captured by wind erosion risk surveys in South Australia

Site Data Recorded	Description
Date	Date of survey
TransectID	Transect number (range 1–14)
ZoneID	Zone number. Equivalent to Level 3 (Zone) in ASRIS (range 1–45)
SiteID	Site number. Values identify Transect as well as site number (e.g. Transect 1, Site 1 = 1001. Transect 2, Site 289 = 2289)
LandTypeID	Identifies which sites have dunes, i.e. whether a site comprises a dune (d), flat (n) or both, in dune–swale land systems
PhaseID	Identifies key rotational phases, i.e. cultivated fallow = f, chemical fallow = cf, pasture = p, stubble = s (March only), crop = c (any crop at sowing time), cereal = c in October, grain legume = gl in October, canola or other oilseed = ca in October
TopoRWind	Characterisation of inherent wind erosion susceptibility by texture x landscape rating (range 1–5)
TopoRWater	Characterisation of inherent sheet or rill water erosion susceptibility by slope rating (range 1–5)
WindSev	Record the severity rating of any wind erosion observed on-site (range 1–5)
SheetRillSev	Record the severity rating of any sheet or rill water erosion observed on-site (range 1–5)
DetachRating	Record detachment of surface soil by grazing or cultivation by intensity rating (range 1–3)
CoverRating	Record cover of surface residues by class rating (range 1–8)
Burn	Record evidence of burning observed by rating completeness Nil = n, 25% = mb (minor), 25–50% = pb (partial), >50% = cb (complete)
Comments	Short comments relating to land condition (tillage, hay cut, etc.)

The list of parameters is restricted to the most important attributes contributing to location and surface protection so that recording time is minimised. Ratings for each were developed using a demerit point concept and are designed to assess risk of erosion rather than amount of surface material. The rationales for the key condition parameters are:

1. Cover Rating

The Cover Rating is designed to be readily recognisable from the remote oblique view provided to the observer from the roadside in a moving or stationary vehicle, rather than as an in-paddock assessment. From a vehicle, cover cannot be directly assessed as a ground cover percent or dry weight of the residue or vegetation, although by implication it is based on these factors. Importantly, the classes used incorporate height together with the amount of cover to describe the protective surface material. The eight-class system has been found by users to facilitate a logical and easy classification of all paddock situations.

When assessing sites, the fundamental decision concerns whether or not there are any parts that are exposed. In this survey, land is exposed if soil colour predominates, and covered if residue colour predominates. The actual rating is then determined by amount of cover or amount of exposure. The covered classes range from 1 to 5 to describe heavy tall material through to critically low, respectively. On the other hand, once a soil has any exposure it is considered to be potentially at risk. Only three further classes are therefore required to adequately describe the extent of exposure, with ratings 6 to 8 representing from patchy to completely bare land.

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The eight-class system is used because it helps classify the range of observed cover, but there are effectively only three classes when selecting sites at risk:

1). Ratings 1–4	well covered
2). Rating 5	cover critical
3). Ratings 6–8	bare areas and at risk

2. Detachment

The Detachment Rating is designed to distil the soil disturbance that can be created, largely by a wide range of tillage equipment (and in extreme circumstances by livestock hooves), into a simple three-class system. Rating 1 indicates no disturbance at all while rating 3 represents complete disturbance of the plough layer and therefore indicates a very unstable soil surface condition. Rating 2 means some disturbance is obvious but there has been some factor that has reduced the extent of instability. Either the very unstable condition has not been created in the first place (e.g. No Till sowing with narrow points) or it has been modified over time (e.g. consolidation due to rainfall or crop growth).

3. Topographic Rating (TopoRWind and TopoRWater)

The Topographic Rating is designed to differentiate sites in terms of the inherent susceptibility to wind and sheet or rill water erosion. They are both five-class systems.

In the case of sheet and rill water erosion, essentially if there is no slope there is no erosion. Slope is therefore the important discriminator, ranging from rating 1 of 0–3% where erosion is considered unlikely, through 3–6%, 6–12%, 12–24% to a rating 5 of >24% for increasing likelihood.

For wind erosion, sites are classified with respect to the broad soil type of the area. Rating 1 indicates that soils are clays or loams which, in almost all circumstances irrespective of cover levels, are not prone to wind erosion. When cultivated, these soils generally form a predominance of clods on the surface. Rating 2 represents sandy loam soils that have some resistance to wind erosion and may even show minor amounts of aggregation when cultivated, but largely the micro-relief is due to rounded root-bound sods. Ratings 3–5 represent essentially single grain loamy sand to sand soils that are most at risk of wind erosion. Rating 3 represents sites that are relatively low lying in the landscape while ratings 4 and 5 indicate progressively higher dunes that are more exposed in the landscape.

The five-class system is used because it addresses the key soil and landscape features and helps classify them. However, similar to the situation with Cover Rating, ratings 3–5 are effectively treated as one highly susceptible group.

4. Erosion Severity Rating (WindSev and SheetRillSev)

As indicated in the rationale, the surveys are designed to assess the erosion risk and the trend over time rather than attempt to measure actual wind erosion and soil loss. However, they provide the opportunity for recording the occurrence of erosion if it is observed and the rationale is simply to use that opportunity to gather evidence whether erosion remains a degradation issue.

The five-class Erosion Ratings are designed to indicate at the same time both the occurrence and severity of erosion observed. They imply an increasing soil loss from rating 1 to 5 without attempting to place a real numerical value on the loss.

Data Recording

Protocols and monitoring parameters were determined after extensive discussions and training sessions with field staff from Rural Solutions SA (a business unit of PIRSA), who undertake most of the field surveys.

Data recorded are briefly described in Table 1 and can be found in the Field Manual. Data are recorded manually in the field, entered into a small spreadsheet on returning to the office, emailed to the project manager for checking and collation with data from all district centres, and then appended to the main database. The four field surveys are carried out by eight teams, comprising a driver and recorder, and the 14 transects involve around 140 person-days annually to electronically capture the data.

Future plans include electronic entry into handheld Personal Data Assistant's and GPS location of all sites.

Data Analysis

The data are simply stratified by collection from the land zones framework, and regional and state summaries are weighted based on zone areas.

Although mean data were used to determine sampling strategy, they are rarely used as key indicators of land condition. The most useful descriptors are the trends in the proportion of sites, and hence the proportion of land, that is at risk of erosion.

Table 2: Wind Erosion Risk Selection Matrix

TR	CR	DR	Risk
All TR	1–3	All DR	Safe
1–2	4–5	1	Safe
1	6–8	1	Safe
2	6–8	1	Safe to Slight
3–5	4	1	Safe
3–5	5	1	Slight
3–5	6–8	1	***Moderate to High***
1	4–5	2	Safe
1	6–8	2	Safe
2	4–5	2	Slight
2–5	6-8	2	***Moderate to High***
3–5	4	2	Slight
3–5	5	2	***Moderate***
1–2	4	3	Safe to Slight
3–5	4	3	Slight
1	5	3	Safe
2–5	5	3	***Moderate to High***
1	6–8	3	Safe
2–5	6–8	3	***High to Very High***

Indicators can be derived based on the proportion of sites where the Cover Rating indicates that the soil surface is exposed (CR>5; Appendix 1). However, the main indicators are estimated by using a matrix (Table 2) of Cover (range 1–8), Detachment (range 1–3) and Topographic Ratings (range 1–5). It is not intended to be a mathematical model. Based on what surface condition results, combinations of the matrix criteria have been specifically allocated to a potential erosion risk category. This enables the user to more closely target land that is actually at risk of erosion rather than simply exposed, if that is desired. For example, in wind erosion prone areas, sites with clayey soil, and therefore a Topographic Rating of 1 for wind erosion, are never included in the moderate to high-risk classification.

Since there are two records for sites where parts of both a sandhill and a flat occur in the same observation area, the first step in the data summary process is to select a single record to represent the site. The selection can be based on either the highest Cover Rating or an Erosion Hazard Index (Cover Rating x Detachment Rating) so that the facet at most risk is used in the analysis.

Since there are two records for sites where parts of both a sand dune and a flat occur in the same observation area, the first step in the data summary process is to select a single record to represent the site. The selection can be based on either the highest Cover Rating where only the groundcover is of interest, or an Erosion Hazard Index (Cover Rating x Detachment Rating) where the facet at most risk of wind erosion is used in the analysis. Dunes may in fact finish up representing a larger number of sites than their actual frequency in the landscape would suggest. However, each site represents a whole paddock area, since paddocks rarely have internal management differences, and where a dune presence is recorded it is assumed it still only represents a similar proportion of the land area as occurs in the zone. If the dune is chosen to represent the site because of its condition compared to the swale, it simply means it is representative of a risk within the paddock. The estimated proportion or area of land at risk effectively means the assessed risk occurring within an estimated cumulative paddock area.

Summary tables for the proportion of land at risk are calculated and compiled by a menu-driven database program at state, region and zone levels. Simple annual graphs can be generated directly by the program but primarily the data are used to compile other indicator graphs in spreadsheet templates.

Key indicators

- **Change profiles**
  - Annual erosion risk (as estimated from Cover Ratings)
  - Annual wind and water erosion risk

  These show the temporally and cyclic nature of the erosion risk changes in the agricultural districts of the state, particularly those resulting from preparation of land for crop. Over time, it is anticipated that an increase in the area sown by Direct Drill and No-Till farming systems will see a reduction in both the width and height of the annual graph peaks.

- **Peak risk trends**
  - Erosion risk
  - Wind and water erosion risk

  These illustrate the greatest amount of land that is placed at risk annually by current land management practices. Increasing use of new stubble and other residue retention tillage technology should see a downward trend in the peak risk, although the uptake of No-Till sowing systems will have the greatest influence. It is currently less influenced by seasonal differences because most land managers still strive to prepare normal amounts of land even in adverse seasons. No-Till technology means that land essentially remains undisturbed until sowing. It can be safely sown following the seasonal break in winter, even if the rain is relatively late. More importantly, land can be left unsown when rainfall is insufficient and it remains safely covered. In contrast, conventionally prepared land is cultivated bare in preparation for sowing crop and thereafter remains exposed and at risk of erosion until crop establishes to protect the ground. Erratic or low rainfall can delay or prevent sowing, or cause poor crop establishment, all of which increase the risk of erosion because the surface is exposed.

- **Estimated period of risk for zone, region or state** (see Appendix 1)
  - Erosion Risk Index
  - Wind and Water Erosion Risk Indices

  These are the most important indicators for the program because they integrate all the main monitoring elements. It is expected that cumulative erosion risk will decline in future if early tillage and burning residues declines and stubble and other residue retention becomes normal practice on farms, through more widespread use of direct drilling and, particularly, No-Till cropping systems. Extreme variability due to seasonal influences is expected to reduce as the use of new tillage methods becomes more widespread.

References

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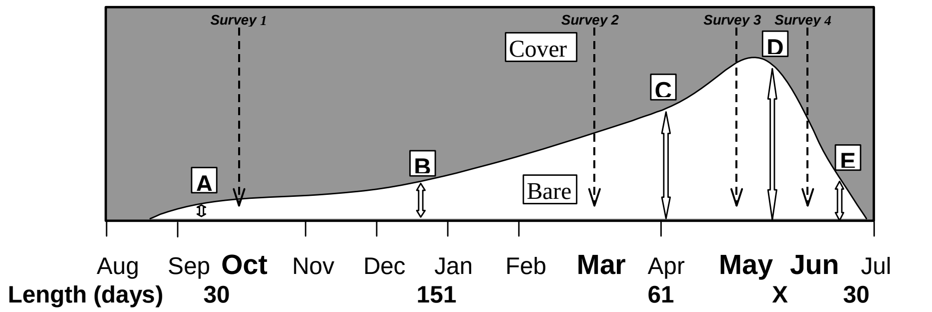
Appendix 1: Wind and Water Erosion Risk Indices

These are estimates of the average cumulative period of exposure, wind or water erosion risk in relation to the estimated June susceptible crop area in each region, zone or state. The area of exposure or moderate to high erosion risk is estimated from the proportion of sites in each zone at risk at each survey and averaged between surveys. The average risk is calculated between the surveys (average % land at risk x days between surveys) and the cumulative risk is then estimated by summing all the periods. In the absence of very frequent surveys (each month or every few weeks), it is assumed that land remains at risk once it is bared by cultivation or grazing and that there is a need for an estimated risk both for the period before the first (pre-October factor) and after the last survey (post-crop sowing factor).

Survey timing and period length



Pre-October factor

......assume that in the 1st week in September there was nil exposure but land recorded as bare in October would have begun to be exposed in the previous 30 days.

Average exposure pre-October survey = **[(0+ area in October) ÷ 2]** x **30 days** **(A)**

Between Survey period

Mean exposure/risk Oct–Mar = **[area Oct]** x **92 days+ [(area Jan + area Mar) ÷ 2]** x **59 days** **(B)**

Mean exposure/risk Mar–May = **[(area Mar + area May) ÷ 2]** x **61 days** **(C)**

Mean exposure/risk May–Last survey = **[(area May + area last survey) ÷ 2]** x **X days** **(D)**

(The last survey is carried out in the 1st week of June or later, depending on the season and the May–Last survey period is flexible and based on when the final survey occurs.)

Post-crop sowing factor

...... assume that after the last survey, exposure declines to nil in 30 days as crops establish.

Mean exposure/risk after the last survey = **[(area at last survey + 0) ÷ 2]** x **30 days** **(E)**

Erosion Risk Index

(An estimate using the proportion of sites where Cover Rating is >5)

ERI (days) = (A+B+C+D+E) ÷ June exposed crop area (ha)

Water or Wind Erosion Risk Index

(Estimate using the proportion of sites at moderate or greater risk of water or wind erosion)

Wind or Water ERI (days) = (A+B+C+D+E) ÷ June susc. crop area (ha)