Indicators and trends

Monitoring climate change adaptation

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Indicator name				Version
NA10 Soil erosion risk				**28/03/16**
Indicator type:	**Risk/opportunity**	**Impact**	**Action**	
	X			

SCCAP Theme	SCCAP Objective	CCRA risk/opportunity
Climate Ready Natural Environment	N3: Sustain and enhance the benefits, goods and services that the natural environment provides	• AG19 Soil erosion and leaching • BD8 Changes in soil organic carbon • AG17/AG59 Increase in greenhouse gas emissions • BD13 Water quality and pollution risks

At a glance

- Extreme climatic events, particularly intense rainfall events, are important erosion triggers. Most climate change scenarios suggest that the magnitude and/or frequency of extreme precipitation events are likely to increase. However, observations have shown that there are many interacting drivers of soil erosion and that individual intense rainfall events may not always lead to large soil erosion events.
- There is currently no systematic assessment of actual soil erosion in Scotland. The evidence for, and measurements of, erosion are generally site specific and are often in response to a severe erosion event.
- Soil erosion modelling, suggests that much of eastern central lowlands where some of the greatest density of cultivation occurs, has some of the highest risk of soil erosion.

Latest Figure	Trend
The extent of erosion in Scotland is not known in detail at a national scale and most studies are of localised events or at the field-scale	Unknown

Why is this indicator important?

The report on 'The State of Scotland's Soil' identifies soil erosion as a major threat to loss of soil function (Dobbie et al., 2011) and a decrease in water quality. Specifically, soil erosion can lead to a reduction in soil quality with impacts on food security, the loss of soil carbon and off site impacts such as pollution of aquatic environments through enhanced sediment load and associated chemicals. Such erosion can also disrupt transport links and cause siltation of river beds and therefore has implications both on- and off-site.

Erosion can be initiated when rainfall intensity exceeds the infiltration capacity of the soil, however, it is probably more common in Scotland that heavy or prolonged rainfall events lead to the soil becoming saturated. When saturated, further rainfall is more likely to result in runoff which may cause erosion. Rapid snow melt can also lead to overland flow and to erosion (Wade & Kirkbride, 1998). Not all soils have the same capacity to absorb rainfall or snowmelt, so the risk of erosion is different depending on the soil type. This can be exacerbated where there is a slowly permeable layer or plough pan which restricts infiltration. Runoff often occurs in gullies, and, once initiated, any runoff tends to be focused in these thus increasing the risk of further erosion.

Although rainfall intensity can be an important factor, it is important to recognise that not all storm events lead to soil erosion. There is uncertainty about future climate but increased global temperatures are likely to lead to an increase in extreme rainfall events which may lead to increased erosion.

Soil erosion in agricultural land frequently occurs in the form of gullies which often develop in specific areas, e.g. along tramlines where the soil has been compacted. Other vulnerable areas within fields are between crop rows and where flow pathways converge, for example, at gates.

Soils are particularly susceptible to both wind and water erosion where fine seed beds have been prepared and before the crop has emerged, particularly if the crop rows run up and down the slope. Soils with little organic matter are often more likely to breakdown into smaller particles either due to direct impact by rain drops or when the aggregates become saturated. The smaller particles are then more easily transported by overland flow.

Tillage erosion also occurs where ploughing takes place across slope in the same direction gradually moving the soil downslope (Van Oost et al., 2006) and, to a lesser extent, by ploughing up and down slope which causes a gradual downward movement of soil under the influence of gravity.

Grieve (2000) showed that carbon losses of almost 50% can occur in upland soils with a peaty surface horizon when the protective vegetation cover is lost through natural or human-induced disturbance such as grazing, muirburn or forestry management. The incidence of erosion on peaty soils may be a contributory factor to the increases in fluxes of dissolved organic carbon (DOC) from upland peaty catchments.

Related indicators:
NA11 Total soil carbon concentration in arable soils
NA12 Agricultural production methods which reduce erosion risk (Proportion of arable land using reduced/zero tillage; soil cover)
NA14 Freshwater bodies affected by diffuse pollution due to agriculture

What is happening now?

Natural rates of soil formation can be used as a basis for setting ‘tolerable soil erosion’ rates, defined as ‘any actual soil erosion rate at which a deterioration or loss of one or more soil functions does not occur’ (Verheijen et al., 2009). Verheijen et al. (2009) state a tolerable soil loss of less than 1 t ha^{-1} yr^{-1}, providing a context for the estimated soil erosion figures below.

The extent of erosion in Scotland is not known in detail at a national scale and most studies are of localised events or at the field-scale.

- Bowes (2002) measured erosion and deposition rates due to water and tillage erosion at 4 sites in the Midland Valley. He found losses around buried archaeological sites attributable to tillage erosion alone of between 13 and 22 t ha^{-1} yr^{-1} (between 19 and 30 t ha^{-1} yr^{-1} overall).
- Davidson & Grieve (2003) summarised soil loss from specific, notable erosion events. Up to 80 t ha^{-1} was eroded in one erosion event in Kelso (Frost & Spiers, 1984) but these events are relatively rare and localised.
- Recently, Bowes (2010) assessed the erosion losses in three fields in eastern Scotland. The fields were selected as they had a history of erosion, however, the results show a pattern of both erosion and deposition with net mean erosion losses approximately double the deposition gains in two of the fields (erosion losses of 18 and 22 t ha^{-1}). Severe gullying (which followed the pattern of tramlines) was recorded at one of these sites. If no other erosion occurred at these sites throughout the year, then the annual rate is still below the tolerable loss, however, once initiated, erosion gullies can continue to focus runoff, making subsequent erosion more likely.

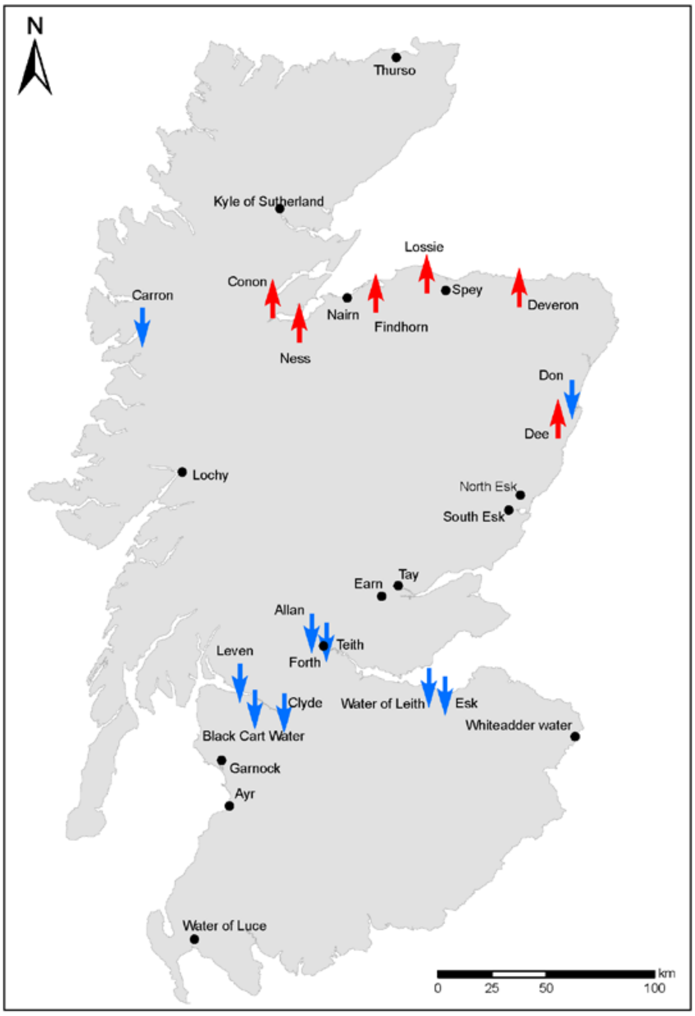

Figure 1 Location of HMS sites showing a significant trend in SS concentrations over time when the effects of month and flow have been removed. Red and blue arrows indicate increasing and decreasing trends, respectively, and black dots indicate no significant trend. (© Crown copyright and database right (2014). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294)

The Harmonized Monitoring Scheme (HMS), which provides long term data on suspended sediments (SS) in many Scottish rivers, shows that while some rivers have shown an increase in suspended sediment loads through time, others have shown a decrease (1980-2013) (Figure 1). In general, the greater the proportion of arable cropping in a catchment, the greater the increase in suspended sediment load (Lilly et al., 2009) but there was also a strong geographical distribution with catchments draining into the Moray Firth showing an increase in suspended sediment whilst those catchments in the central belt showed a decrease. Although suspended sediment gives indirect indication of trends in soil erosion, direct estimates are difficult to obtain especially in large catchments where many other factors such as runoff from urban areas may contribute to changes in suspended sediment loads.

What has happened in the past?

Although erosion is a natural process which occurs in all soils to a greater or lesser extent, it becomes a concern when the rate exceeds "natural" rates although it is often difficult to distinguish between natural and accelerated rates of erosion. In Scotland, much accelerated erosion is the result of human activities that lead to removal of the protective vegetation cover. We know erosion has occurred in the past with records dating back to medieval times, but data are not available on where, when and how often events have occurred or on the sediment yields from erosion. This means it is not possible to disaggregate the contributions of land cover and management, climate and soil properties and there is a lack of data with which to validate modelled approaches.

What is projected to happen in the future?

It is difficult to predict future trends in soil erosion. There is considerable uncertainty in the most recent UKCP09 climate change predictions particularly for the western seaboard though most predictions agree that there will be increased rainfall over eastern Scotland during the winter months. This increase is likely to increase the erosion losses particularly if current land use patterns remain the same, that is, a predominance of winter cereals. However, observations (Dobbie et al., 2011) have shown that there are many interacting drivers of soil erosion and that individual intense rainfall events may not always lead to large soil erosion events (see Table 1). Further data is needed with which to set a base line for soil erosion occurrence, be able to validate models and therefore be able to predict changes with any degree of confidence.

Table 1 Measured sediment yields and associated rainfall events (amount and duration) (from Davidson & Grieve, 2011; modified from Kirkbride & Reeves, 1993)

Location	Sediment yield ($t\ ha^{-1}$)	Rainfall amount (mm)	Duration (hr)	Date	Source
Kelso	80	28.1	24	28/12/82	Frost & Speirs, 1984
Kelso	48	12.7	n.d.	27/05/83	Frost & Speirs, 1984
Town Yetholm	75	110	72	30/03/92 to 1/04/92	Davidson & Harrison, 1995
Lambielethan	69	78.1	57	21 to 23/09/85	Duck & McManus, 1988
Barry	14.7	n.d.	31	20 to 23/09/85	Duck & McManus, 1987
Douglastown	1.7	55	24-27	31/03/92	Kirkbride & Reeves, 1993
Kincaldrum	1.2	55	24-27	31/03/92	Kirkbride & Reeves, 1993
Hatton	2.2	55	24-27	31/03/92	Kirkbride & Reeves, 1993

Note the three intense rainfall events of 55 mm (Table 1) where the sediment yield was only slightly above the tolerable loss threshold compared to the considerable sediment losses in fields near Kelso with considerably less rainfall.

Patterns of change

There are three national scale assessments of soil erosion in Scotland. Two of these are modelled estimates of erosion risk and one is a grid based survey associated with the National Soil Inventory of Scotland (NSIS) (Lilly et al., 2010). Lilly et al. (2002) produced a rule-based estimate of Inherent Geomorphological Erosion Risk based on soil runoff, soil texture and slope, and Lilly et al. (2009, 2011) used a process-based model to predict current and future erosion risks. However, both these models lack robust validation for Scottish conditions.

The Inherent Geomorphological Erosion Risk (Lilly et al., 2002) assumes that all soils are bare and that erosion can be modelled using the inherent characteristics of the soil to absorb water from rainfall or snowmelt. The likelihood that a soil would erode is determined according to the erosive power generated by soils becoming saturated and initiating overland flow. The steepness of the slope would determine the erosivity of this flow. The ability of the soil to resist this erosivity depends on the soil texture and the ability to form stable aggregates that are difficult to break down. If the aggregates do break down into the constituent primary soil particles, then these can be transported by the overland flow.

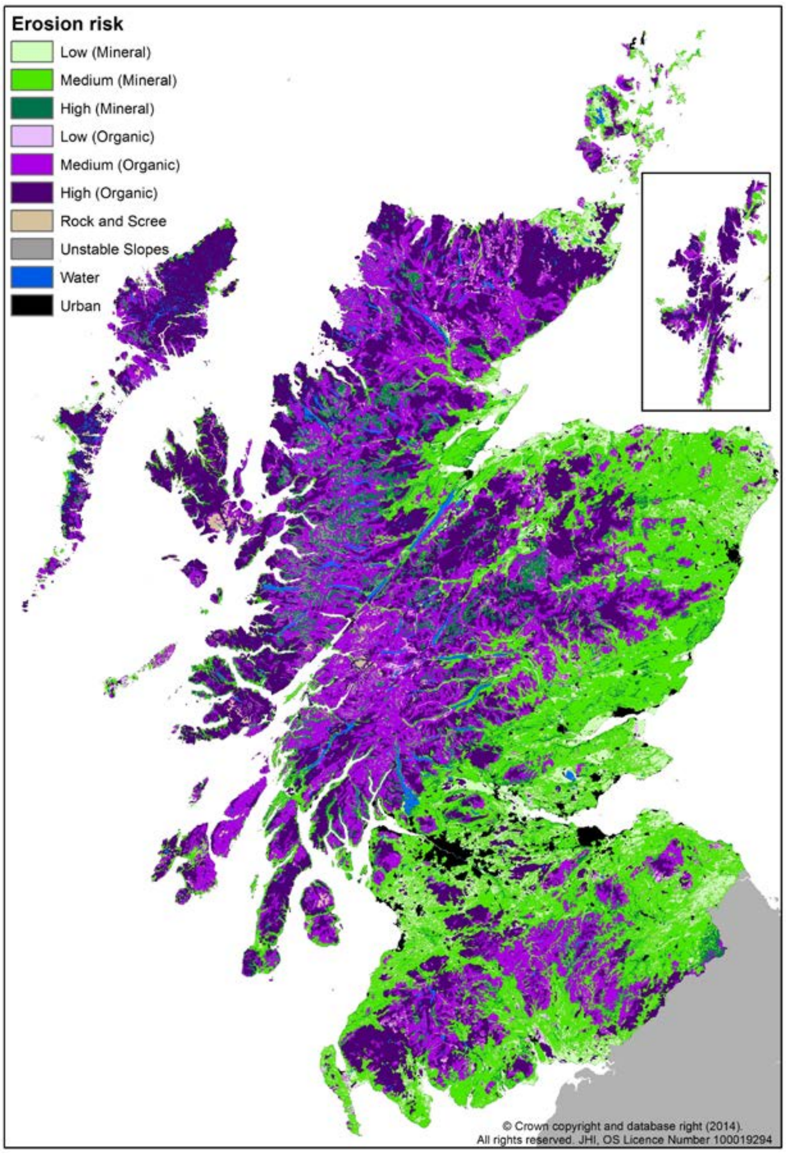

Figure 2 Inherent Geomorphological Erosion Risk (Lilly et al., 2002)

The Pan European Soil Erosion Risk Assessment model (PESERA), developed by Kirby, et al. (2004), has been applied nationally and suggests annual erosion rates less than 1 t ha^{-1} for the majority of Scotland under current (1971-2000) rainfall patterns and land uses, although the model potentially predicts greater losses for the arable areas of eastern Scotland (>2 t ha^{-1} yr^{-1}) depending on which crops are grown.

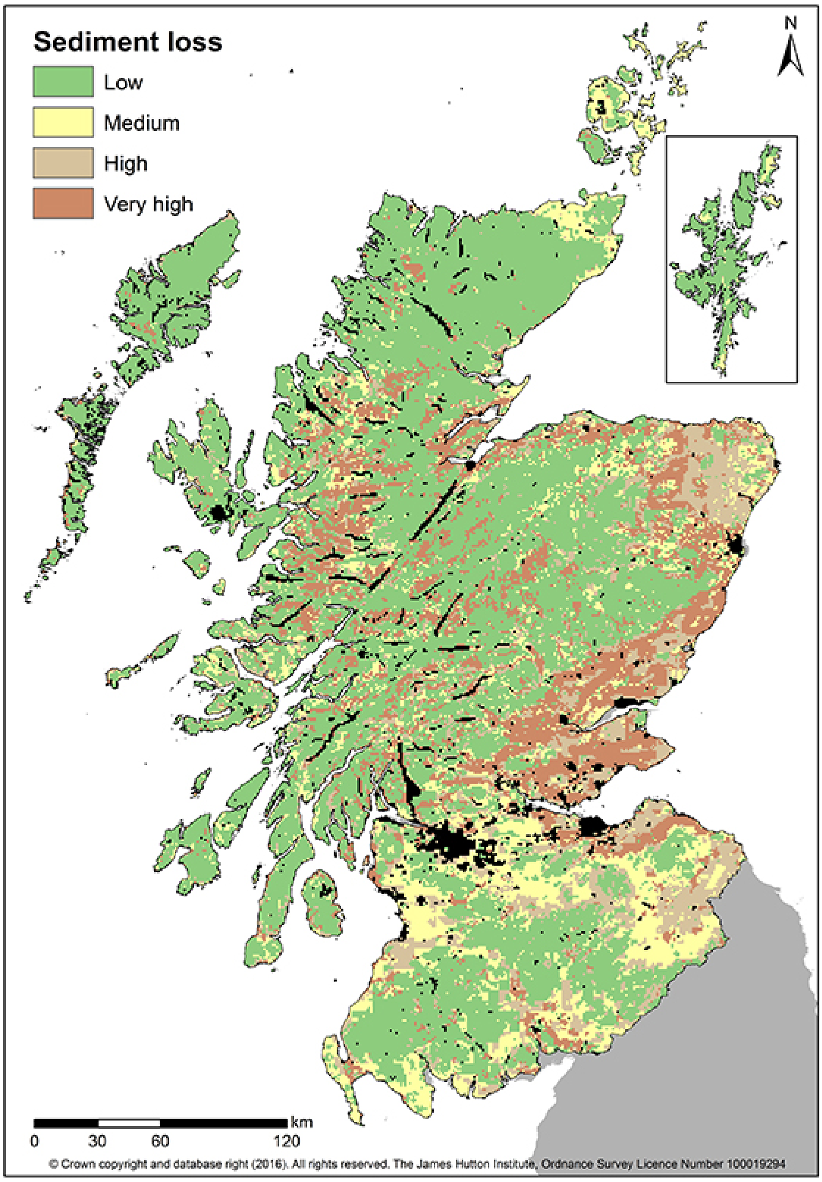

Figure 3 Pan European Soil Erosion Risk Assessment (PESERA) run with Scottish data on a 1 km grid (Dobbie et al., 2011)

The National Soil Inventory of Scotland (NSIS1) was carried out between 1978 and 1988 by the Soil Survey of Scotland who undertook an objective 10 km grid based sampling of Scottish soils, which was repeated (NSIS2) in 2007-2009 but on a 20km grid. Amongst the contextual information collected were observations of soil erosion at each site, recorded as: *None, Rill, Gully, Landslip, Sheet, or Wind*. Whilst this provided a reasonable estimate of erosion in the uplands, erosion on cultivated land was probably underestimated, because most of the sampling was done during summer and any evidence of erosion was most likely removed due to subsequent cultivation. Both these grid surveys may be considered to be at too coarse a resolution to constitute effective monitoring of soil erosion in Scotland.

It is clear that there is as yet no systematic assessment of actual soil erosion in Scotland. The evidence for, and measurements of, erosion are generally site specific and are often a response to a severe erosion event. Modelled erosion rates are difficult to validate and depend to a large extent on the scale of the data used.

Interpretation of indicator trends

The risk of soil erosion can be significantly influenced at a local level by management practices. Under Cross Compliance (a mandatory set of requirements and standards that land managers have to meet in order to receive support scheme payments) (Scottish Government, 2015), there are a range of standards to address, amongst other things, soil erosion. The survey of farm production methods carried out in Scotland in 2013 (Scottish Government, 2013) had a sampling size of around 13,600 holdings. This survey obtained a response rate of 69%[1], and although it did not specifically request information about erosion, it asked about farming methods that were being used to mitigate both erosion and sediment transport to water courses, namely tillage methods and soil cover over the winter. The results highlight that 41% of the land area surveyed had plant residues, stubble or a cover crop over the winter of 2012/2013 and reduced, conservation tillage was used on 11% of cultivated land and zero tillage on 8%.

In a survey in Fife, anomalous events (rain on snow for example) caused large scale erosion in areas that may not be predicted as high risk based on their inherent landscape characteristics (Wade & Kirkbride, 1998). Watson & Evans (2008) made annual observations of erosion in the Mearns between 1985 and 1989 and less frequent observations from 1990 to 2007 in order to study the influence of land management on erosion. They conducted the survey of fields bordering B class roads and recorded the presence or otherwise of erosion in between 600 and 700 fields annually from 1985 to 1989 with between 13-26% of the field showing some signs of erosion though less than 8.5% showed rills in excess of 1 cm deep. They highlight the link between winter sown crops and increased erosion occurrences and suggest that favourable weather conditions leading to early planting and therefore the good establishment of winter crops may cause the reduction in erosion.

Soil erosion modelling, corroborated by observed evidence of erosion events in cultivated fields, suggests that much of eastern central lowlands where the greatest density of the 30,000 ha of potato cultivation occurs, has high or very high soil erosion risk (Lilly et al., 2002, 2011). Crops such as potatoes tend to leave a bare compacted surface following harvesting, which is prone to run-off and soil erosion.

Further work could compare the observed occurrences of erosion in NSIS1 to those in NSIS2 to assess if changes have occurred and see if there are any links to factors such as changing land use at these sites.

[1] Non-response was imputed to provide a dataset for 13,600 holdings (weighted to provide figures for the 33,121 holdings eligible for the survey)

Limitations
The major limitation of the risk assessments that have been produced is that they are not validated. The information required for validation of risk based approaches and detection of both trends and the drivers of any trends would need to combine on-the-ground observations of management and vegetation coverage, as well as observations of the nature of the soil erosion. This data can then be linked back to terrain and meteorological data when it is processed and analysed. To validate process-based models measurements of sediment loss from fields are required. A further limitation of the national scale assessments is the scale at which the assessments have been made. The PESERA model is run on a 1 km grid, which means that the output may not pick up small areas of steep slopes or localised high risk soils. The inherent risk assessment is run at 100 m grid so small areas of steeply sloping ground are more likely to be identified but it uses the dominant soil in the 1:250 000 soil map polygons. Further work is being done to identify the effect of carrying out risk assessments at a coarse resolution by comparing them with assessments that incorporate a higher resolution of data. The need for more systematic data with which to assess the current state of soil erosion in Scotland is highlighted by the Soil Monitoring Action Plan (SoilMAP) (Black *et al.*, 2012). There is a proposal for Scottish Environment Protection Agency (SEPA) catchment officers to record the occurrence of erosion and provide spatial referencing, as well as photographs and information on the suspected cause of erosion, primarily in cultivated agricultural land (see Table 2). This monitoring would occur in the priority catchments[2] as a one-off spatial survey, as part of catchment walks and the observations made on farm visits. Some of the farms may have repeat observations if officers are required to return and check whether incidences of breaches of General Binding Rules (GBRs) have been addressed (SEPA, 2015b). Citizen Science approaches to collecting soil erosion data have also been considered and although observations could supplement SEPA data they are unlikely to provide the systematic assessment of soil erosion required for validating models or defining a baseline risk (Baggaley et al., 2014). **Table 2** Observations to be made by SEPA catchment officers as part of the soilMAP

[2] Priority catchments have been identified by SEPA as catchments failing to meet environmental standards (SEPA, 2015a)

What is the form of the erosion?									
Gully/Rill		Wind		Bank		Poaching		Other	
If it is gully or rill is it associated with semi-permennant wheel tracks (Tramlines)?									
What is the cause of the erosion?									
In field runoff		From gate		From above		From spring or drain		Other	
If it is from above where is it inititated?									
Road		*Field*		*Other*					
What is the vegetation coverage?									
None		Partial		Complete					
If it is partial or complete coverage what is the vegetation type?									
Cereal or Oil Seed Rape		*Root crop or potato*		*Grass*		*Stubble*		*Other*	
If the field is in cereals arethey spring or winter sown or unknown?									
What is the cultivation method?									
Ploughed		Seedbed		Not cultivated		Furrow		Other	

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SEPA (2015b) *Diffuse pollution in the rural environment.* Available online at:
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Further information

Scotland's Soils:
http://www.soils-scotland.gov.uk/
http://www.environment.scotland.gov.uk/get-informed/land/soils/
http://www.sepa.org.uk/media/138741/state-of-soil-report-final.pdf

Acknowledgements

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Appendix One: Indicator metadata and methodology

Table 1: Indicator metadata

	Metadata
Title of the indicator	Soil erosion risk
Indicator contact: Organisation or individual/s responsible for the indicator	Anna Moss (CXC/ University of Dundee)
Indicator data source	Pan European Soil Erosion Risk Assessment (PESERA) (Dobbie et al., 2011), Inherent Geomorphological Erosion Risk Assessment (Lilly et al., 2002)
Data link: URL for retrieving the indicator primary indicator data.	Hard copy maps can be found in the relevant reports

Table 2: Indicator data

	Indicator data
Temporal coverage: Start and end dates, identifying any significant data gaps.	The inherent Geomorphological Risk Assessment has no temporal component. The PESERA modelling used climate and land cover data for the period 1971-2000. Future predictions of erosion using this model are very uncertain due to lack of validation.
Frequency of updates: Planned or potential updates	Incorporation of land use into the Inherent Geomorphological Erosion Risk assessment. Exploration of the scale of input data into the outputs from PESERA leading a greater understanding of the uncertainty in the national scale outputs. Collection of data from the SoilMAP for validation of both assessments.
Spatial coverage: Maximum area for which data is available	Scotland
Uncertainties: Uncertainty issues arising from e.g. data collection, aggregation of data, data gaps	High uncertainty in the modelled soil erosion risk due to the lack of validation data.
Spatial resolution: Scale/unit for which data is collected	Inherent Geomorphological Erosion Risk Assessment is available on a 100 m grid for the whole of Scotland. PESERA on a 1 km grid

Categorical resolution: Potential for disaggregation of data into categories	Both models have been used to produce risk maps showing areas of High, Medium and Low Risk
Data accessibility: Restrictions on usage, relevant terms & conditions	The underlying Ordnance Survey Digital Terrain Model data may restrict the usage of the outputs.

Table 3 Contributing data sources

Contributing data sources Data sets used to create the indicator data, the organisation responsible for them and any URLs which provide access to the data.
Inherent Geomorphological Erosion Risk: 1:250 000 soil map unit data (Scotland's Soils: http://www.soils-scotland.gov.uk/) Ordnance Survey Digital Terrain Model PESERA: 1:250 000 soil map unit data (Scotland's Soils website), LCS88, Ordnance survey PROFILE ® Digital Terrain Model , Met Office 25 km gridded climate data

Table 4 Indicator methodology

Indicator methodology The methodology used to create the indicator data
Inherent Geomorphological Erosion Risk Assessment: Rule based risk assessment PESERA: Process based model