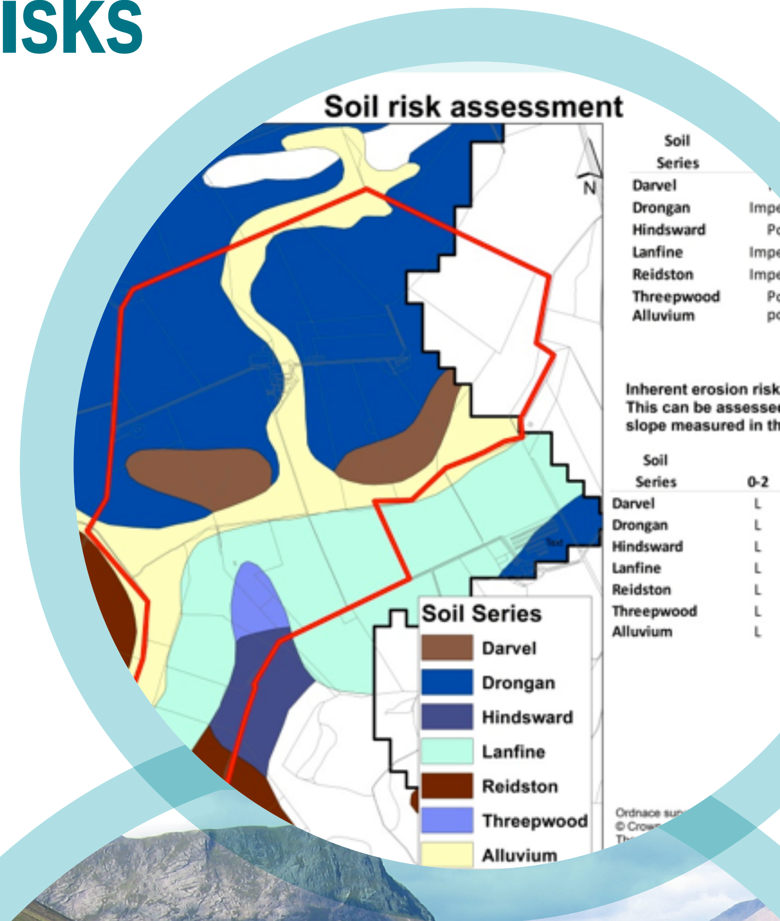
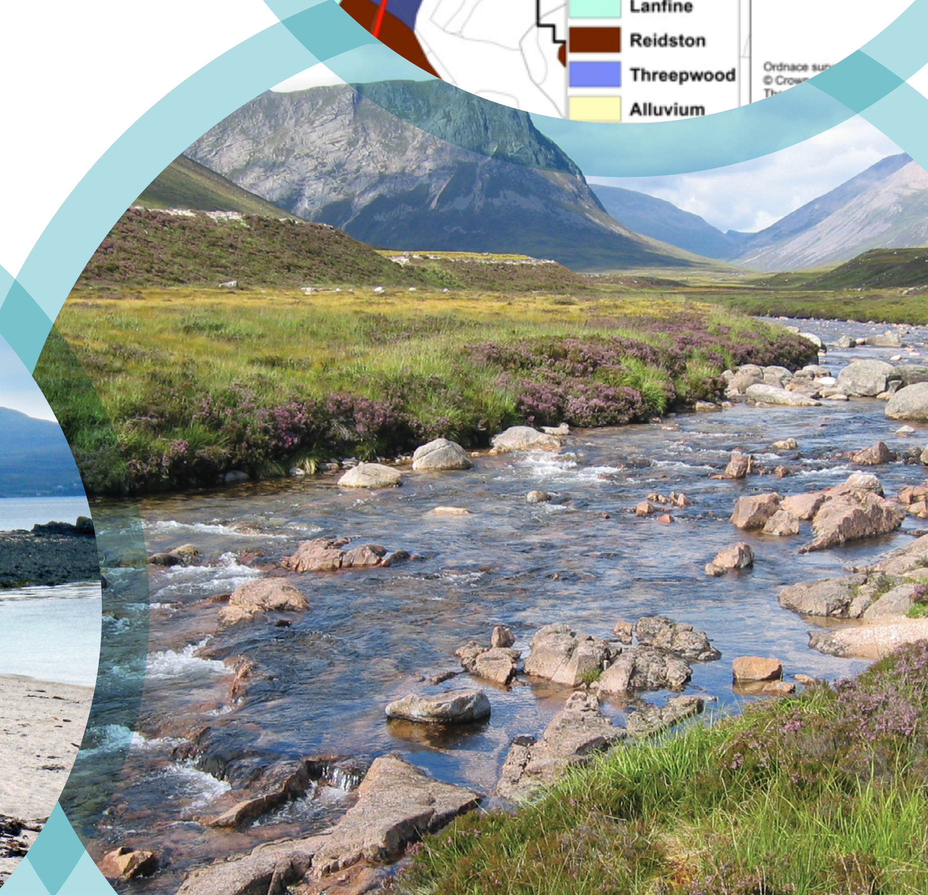
Scotland's centre of expertise for waters

Developing simple indicators to assess the role of soils in determining risks to water quality





Scotland's centre of expertise for waters

Published by CREW: Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes supported by MASTS. The Centre is funded by the Scottish Government.

This document was produced by:
Allan Lilly and Nikki Baggaley,
James Hutton Institute,
Craigiebuckler, Aberdeen
AB15 8QH

Please reference this report as follows: Lilly, A & Baggaley, N.J., 2014. Developing simple indicators to assess the role of soils in determining risks to water quality, CREW project number CD2012_42.

Available online at: crew.ac.uk/publications www.crew.ac.uk/publications

Dissemination status: Unrestricted

Contents

Executive Summary

Background to research

SEPA require guidance on how to use existing soil data to assess the risks to water quality from land-based activities. The information contained in generalised soil maps is often difficult to interpret by non-soil specialists. By deriving a suite of maps showing areas at risk of leaching, runoff and other soil characteristics that may have a negative impact on the aquatic ecosystem, soils information can be provided in a more user-friendly format.

Key findings and recommendations

The risk assessments were successfully applied to the 1:25 000 scale map data and there is no technical reason as to why these risk assessments could not be applied more widely. There are issues with data availability for some soil series where no data exists. In these soils analogous soil types would need to be used to provide the assessments. Also some data is available but has not yet been collated.

The rule-bases used were kept as transparent as possible to allow informed users to understand the process. However, while the rule-base to determine soil leaching potential is relatively simple, the collation of the underpinning soils data is quite complex and requires understanding on how soil colour, texture and structure combine to determine gleying and identify slowly permeable horizons. The HOST classification uses similar properties and requires comparable soils expertise to classify the soils into one of the 29 classes. Soil leaching potential is currently a component of the Private Water Supplies (Scotland) Regulations 2006 while HOST is embedded in a wide range of river flow estimators. As both these properties are part of current regulation or secondary products, they are unlikely to be modified in the short-term, so the risk mapping for these properties will be future-proofed. While there are no plans to modify the erosion risk and compaction risk rule-bases, these are not part of any regulatory or secondary products and are more vulnerable to change. The rule-bases for these risks are set out explicitly within the report so that they can be applied by a third-party who has access to the soils data.

There was no clear preference for a risk map-only product compared to an attribute table linked to the soil map and it may be that both approaches can be used simultaneously depending on the experience, expertise and willingness of the Catchment Officers. The attribute table was required as an intermediary product to prepare the risk maps and it is therefore comparatively simple to produce the data in both formats although the attribute-based approach may require more effort to produce maps with legends, scale bars and associated attribute tables. Additional processing of the terrain would be required to produce a risk map for erosion. The possibility of including an assessment of the risk of subsoil compaction in any future work should be explored, as this tends to be a more permanent feature once developed than topsoil compaction, which is more easily remedied by ploughing.

Objectives of research

This project set out to explore the possibility of producing a set of four risk maps that could be used to determine the risk of diffuse pollution occurring within Scottish agricultural catchments. The key soil-based factors likely to affect water quality were deemed to be:

- Sediment and pollutants being transported to water bodies by erosion events
- Compaction, which reduces infiltration and may exacerbate run-off
- Surface run-off
- Leaching of potential pollutants.

Two test catchments were chosen (the Coyle and the East Pow, both sub-catchments of SEPA's designated priority catchments) as a related project on soil nutrient management was already using these catchments as trial areas.

Rules to derive risk of erosion, run-off, leaching and compaction were already available but had not been applied to 1:25 000 scale soil map data. Maps (scale 1:25 000) of the risks of soil compaction leaching potential, runoff and erosion risk were derived for the two test catchments. Risk maps could be provided both as hard copy paper and as electronic maps with the intention that Catchment Officers could use the paper maps or have the electronic maps on tablet PCs to take into the field. In addition, for each pilot catchment, a series of attribute tables containing the risks of compaction, leaching and runoff and erosion were developed. The rules for determining erosion risk were re-structured to allow the assessment of risk, based on the measurement of slope angles in the field, to take account of local topographic heterogeneity that may not be apparent from the digital elevation models. These rules and tables are linked directly to the soil series depicted on the 1:25 000 scale soil map of the catchment. This approach allows a greater degree of flexibility (underlying maps and rules can be updated) and also allows Catchment Officers to develop an understanding of the relationship between individual soil types and the risks to water quality. This is a novel approach that requires to be trialled and assessed by SEPA.

Key words: *Erosion, leaching, runoff, compaction, risk maps, diffuse pollution.*

1.0 Introduction

Soil information is important in identifying areas where there is a risk of diffuse water pollution. However, the information contained in generalised soil maps is often difficult to interpret (and may require additional information and interpretation) thus making their use by non-specialists difficult, and potentially open to misinterpretation. To overcome this, maps showing areas at risk of leaching, runoff and other soil characteristics that may have a negative impact on the aquatic ecosystem can be produced by soil specialists for use by, amongst others, policy makers and regulators. These derived maps use the soil map as their basis but can also incorporate other important environmental information such as slope or the presence of groundwater. The resulting maps show areas at risk of contributing to diffuse pollution and can be class-based (for example showing areas of low, medium of high risk). They are also useful for communicating with land managers about the areas that can potentially contribute to diffuse pollution so that mitigation measures can be most effectively targeted.

The aim of this pilot study was to develop a series of derived, inherent risk maps based on existing 1:25 000 scale soil maps for two contrasting Scottish catchments; the Coyle and the East Pow, both sub-catchments of SEPA's priority catchments (http://www.sepa.org.uk/water/river_basin_planning/dp_priority_catchments.aspx). These maps were to identify areas at risk of:

- Surface runoff and erosion, therefore contributing sediment and nutrients to water bodies
- Leaching nutrients such as nitrates to groundwaters
- Compaction, which reduces infiltration rates and can increase the risk or erosion and runoff.

These maps would then be available to SEPA catchment officers to be used to assess the inherent risks for diffuse pollution in the field during farm visits. The maps assist in explaining these risks to land managers allowing objective discussions on the use of mitigation techniques and changes in land management practices to reduce the potential for pollution in nearby streams, rivers and lochs.

2.0 Test catchments

Two contrasting catchments, representative of differing land use, soils and water quality issues, were chosen to develop and demonstrate the methodology; the Coyle (NS395214) in Ayrshire and the East Pow (NO069256) in Perthshire. These catchments were also being used in a related study on soil and nutrient management. The land use in the Coyle is predominantly grassland and the soils mainly brown earths with gleying and noncalcareous gleys with slowly permeable subsoils and some alluvial soils. The East Pow, by contrast, has predominantly arable land use and a larger component of permeable soils compared with the Coyle, but also a large proportion of alluvial soils (Figure 1).

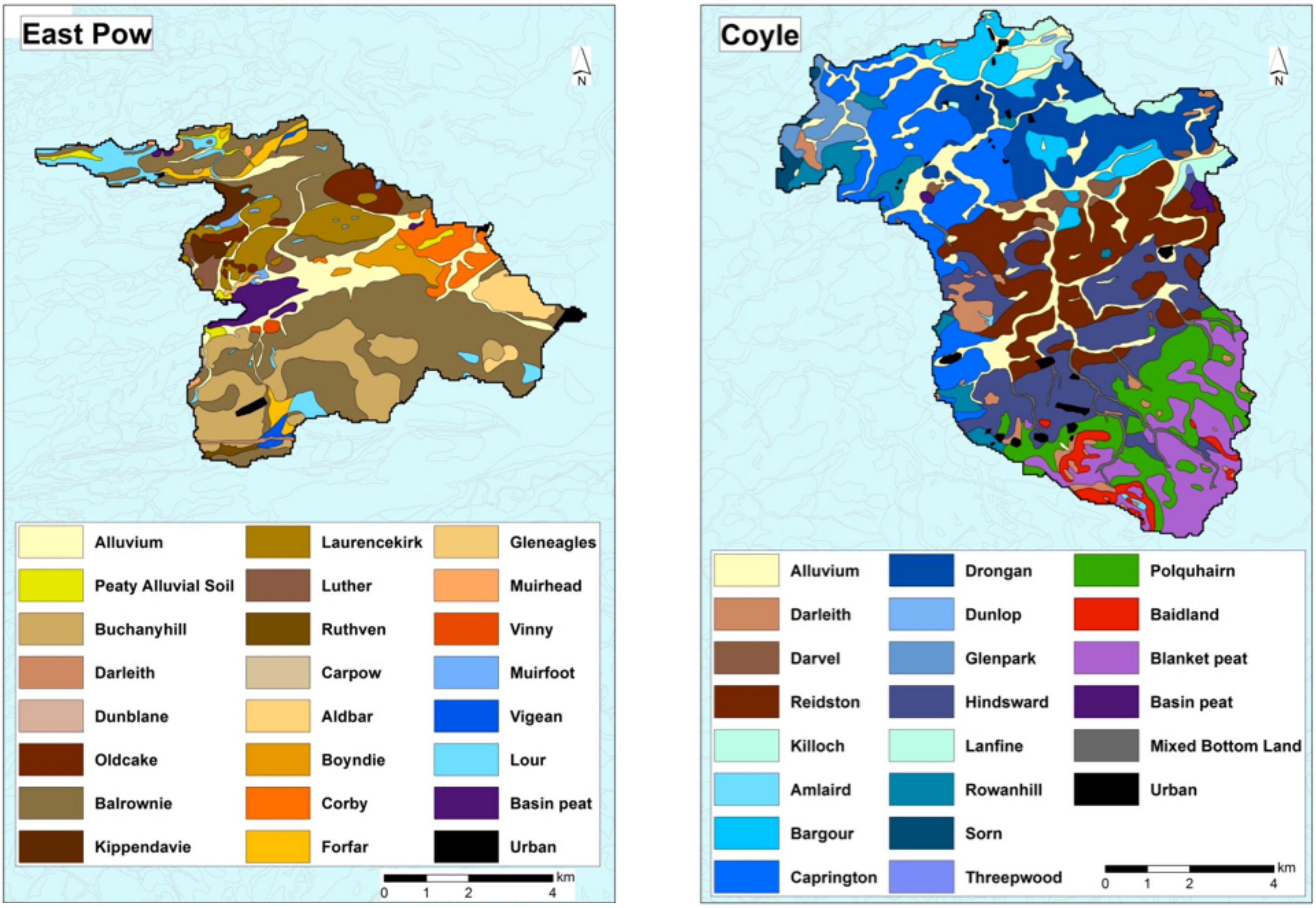


Figure 1 Distribution of soils in the Coyle Water and East Pow catchments based on 1:25 000 scale soil map data and SEPA derived catchment boundaries.

2.1 Soil data

Since the main aim of the project is to provide risk maps primarily for cultivated land at a farm scale, 1:25 000 scale soil maps were used as the underpinning soil map information. These maps (in combination with 1:63 360 scale soil maps) are available in digital format for around 95% of the cultivated land in Scotland (Figure 2) and most of the mapping units comprise only one soil type. Often termed 'generalised' soil maps, these maps show the distribution of soil types according to the Soil Survey of Scotland classification system (Soil Survey of Scotland Staff, 1984). While they contain valuable and useful information, they are often difficult for non-soil specialists to interpret.

When used in conjunction with the Scottish Soils Database held at the James Hutton Institute, these maps can be reinterpreted for a wide range of environmental properties. In terms of diffuse pollution, those areas at risk of erosion, leaching, compaction and surface runoff were considered to have the greatest impact on water quality. Methods to identify the areas of land susceptible to each of these had already been developed (see below) and so were applied in the test catchments to assess their suitability and practicality for assessing risks to nearby water bodies. Cultivated land as well as land with semi-natural vegetation (uncultivated) or forest was assessed to derive risk maps that covered the whole catchment. As there can often be a marked difference in the upper part of a soil profile between the cultivated and the semi-natural soil, the risk assessment may be different for these versions of the same soil.

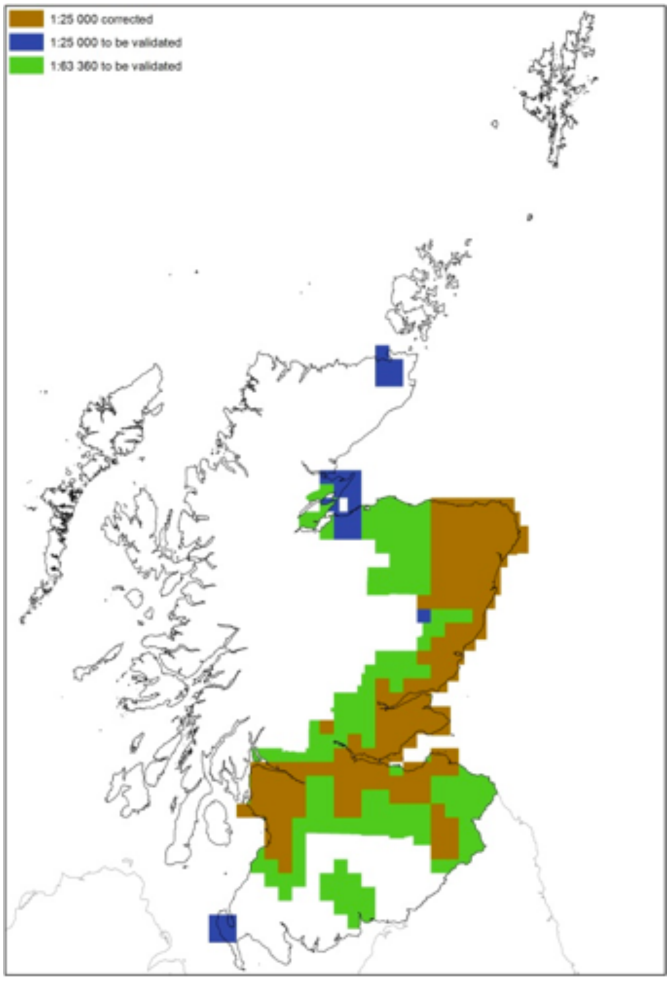


Figure 2 Extent of the digitised 1:1:63 360 and 1:25 000 scale soil maps.

2.2 Risk assessments

Four risk maps were identified as being important in both predicting the risk of diffuse pollution to water bodies within the catchment and as a tool in communicating risk to land managers. The fundamental principle was that the risk maps represented the inherent risk based on soil type and land form. However, certain land management practices could either enhance or reduce the risk of pollution and these would need to be taken into account when discussing mitigation strategies with land managers. The maps were the Runoff potential (surface flow), Leaching potential, Susceptibility to compaction and the Inherent erosion potential due to overland flow (surface runoff). The risk maps made use of the basic information held in the Scottish Soils Database and were directly related to the soil map units depicted on the 1:25 000 scale soil maps (Soil Survey of Scotland Staff, 1970-1987). This is generally a 1:1 reclassification of the map units except where soil complexes have been mapped or, in some cases, where the soil is uncultivated. A further exception is for the assessment of the inherent soil erosion risk which necessitated taking slope into account thereby subdividing the soil map units where appropriate.

An important component of the risk mapping was to make the link between the different soil types depicted on a soil map and their risk categories, as transparent as possible so that users could build up an understanding of how the underlying soils data and maps related to the risk categories. This has the added benefit of aiding non-soil specialists to interpret soil maps and to understand how soils and soil properties relate to land management and diffuse pollution issues.

2.2.1 Runoff

The assessment of runoff was taken directly from the Hydrology of Soil Types (HOST) classification of the hydrological response of UK soils (Boorman et al., 1995). The primary soils data used to derive this classification were soil morphological characteristics, soil porosity and soil texture together with hydrological data derived from river hydrographs. Eleven conceptual response models describe the pattern of flow through the soil and substrate. These flow patterns are influenced by the presence or absence of slowly permeable layers that restrict downward movement of water, by seasonal saturation within the soil profile and by the absence of groundwater or, where present, occurring within two metres of the soil surface (for example, in riparian zones) or deeper. Further subdivisions of the eleven conceptual response models based on factors such as the type and rate of flow or water storage capacity, result in the final 29 class system.

Each of these 29 classes was related to catchment- scale hydrological indices such as Base flow Index (BFI) and Standard Percentage Runoff (SPR) through a series of multivariate regression analyses. Although SPR is the proportion of any rainfall event that is effectively contributing to the fast response flow in a river network and, NOT strictly direct surface runoff, it is a reasonable approximation for the majority of soil types. The exceptions are the alluvial soils due to their close proximity to the river and the interaction with fluctuating groundwaters in the riparian zone. Three runoff classes were identified (low, medium and high) based on the SPR values where low was <20, moderate 20-40 and high >40% (see table 3).

2.2.2 Leaching

The ability of a soil to protect underlying groundwaters from contamination depends on the physical properties affecting the downward movement of water and the chemical attenuation of contaminants (Lewis et al., 2000). These include: texture (specifically clay and organic matter contents), structure, soil water regime and the presence of distinctive layers such as raw peaty topsoil and rock or gravel at shallow depth. All soils in Scotland can be grouped into one of six Soil Leaching Potential classes.

Many of the components of the soil used to derive the HOST classification were used to develop the Soil Leaching Potential and so, the assessment is largely based on morphological characteristics that are indicative of waterlogging, inhibited percolation or indicate the potential for by-pass flow to occur. Soils with moderate to high clay and organic matter contents will be able to chemically bind potential contaminants more readily than soils with coarse textures or low organic matter contents. The flow chart in Figure 3 outlines the soil information used to classify the soil's leaching potential into Low, Intermediate and High Risk. Much of the same information is used in developing the HOST classification and there is a broad relationship between HOST SPR and leaching potential. The Soil Leaching Potential classification was also used to determine potential groundwater contamination though the leaching of nitrates (Lilly et al, 2001). The Soil Leaching Potential is a component of the Private Water Supplies Regulations (Scotland) 2006 and, as such, will not be changed in the near future.

Soil leaching potential classification

Soils of high leaching potential (H)

Soils with little ability to attenuate diffuse source contaminants and in which non-adsorbed diffuse contaminants and liquid discharges have the potential to move rapidly to underlying strata or to shallow groundwater. Four subclasses (including one for Urban areas or highly disturbed soils) are recognised:

H1: Soils that readily transmit liquid discharges because they are either shallow or susceptible to by-pass flow directly to rock, gravel or groundwater.

H2: Deep, permeable, coarse textured soils that readily transmit a wide range of contaminants because of their rapid drainage and low attenuation potential.

H3: Coarse textured or moderately shallow soils which readily transmit non-adsorbed contaminants and liquid discharges but which have some ability to attenuate adsorbed contaminants because of their organic matter content.

HU: Soils over current and restored mineral workings and in urban areas that are often disturbed or absent. A worst case vulnerability classification (equivalent to H1) is therefore assumed for these areas, until proved otherwise.

Soils of intermediate leaching potential (I)

Soils with a moderate ability to attenuate diffuse source contaminants or in which it is possible that some non-adsorbed diffuse source contaminants and liquid discharges could penetrate the soil layer. Two subclasses are recognised based on the organic content of the surface layer:

I1: Deep, permeable, medium textured soils that can possibly transmit a wide range of pollutants.

I2: Deep, permeable, medium textured soils with high topsoil organic matter contents that can possibly transmit non- or weakly-adsorbed diffuse contaminants and liquid discharges, but are unlikely to transmit adsorbed contaminants.

Soils of low leaching potential (L)

Soils in which contaminants are unlikely to penetrate the soil layer due to the presence of a low permeability horizon. Water and contaminant movement is, therefore, largely horizontal but the soils may also have the ability to attenuate contaminants. Lateral flow from these soils may contribute to groundwater recharge elsewhere in the catchment. These soils may have a high clay or organic matter content.

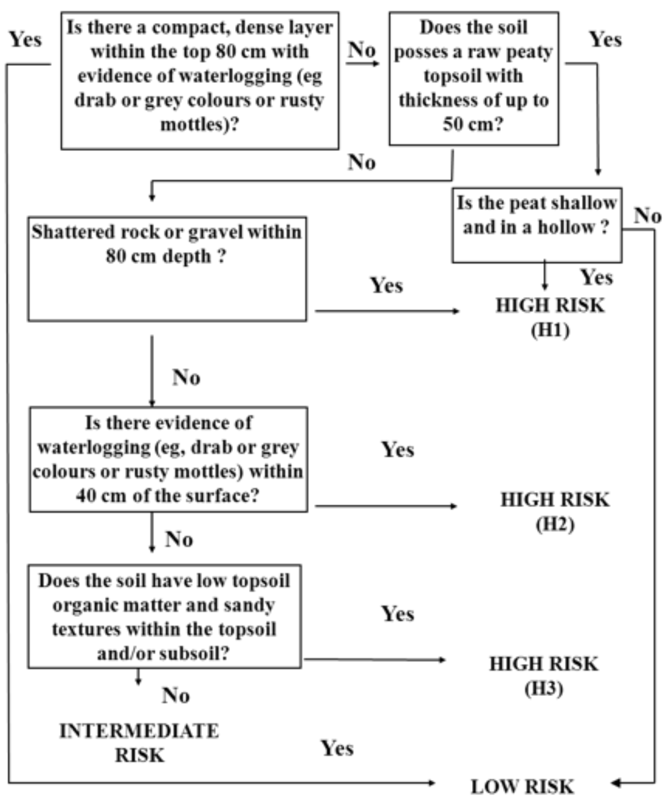


Figure 3 Flow chart for the classification of soil leaching potential.

2.2.3 Compaction

The assessment of the risk of soil compaction follows the guidelines published in Ball (1985, 1986). The classification uses two main soil properties, natural soil drainage class (as a surrogate for permeability) and topsoil texture, to classify soils into eight categories of risk of topsoil compaction occurring. The permeability classes (Table 1) used by Ball (1985, 1986) can be equated to the drainage classes used in the mapping of Scottish soils. Class 1 are freely or excessively drained soils and comprise those where there is no inhibition to the percolation of water through the soil and equate to the free and excessively drained categories as used by the Soil Survey of Scotland. Class 2 are moderately drained soils and are those described by the Soil Survey as imperfectly drained where the downward movement of water is restricted or where there is a high watertable. Class 3 (Slow) are represented by the poorly drained soils that have a saturated topsoil for a considerable period of time. They may be either influenced by groundwater or, more generally, by the presence of a slowly permeable layer near the soil surface.

The risk assessment uses the basic soil properties of soil texture class. The topsoil textures are grouped into three compaction sub-classes (Table 2) based on their ability to form stable aggregates that do not compact readily under pressure with the sandy loam texture class subdivided into those with organic matter contents greater than 5% and those with less organic matter (Table 2). The texture classes are those used by the USDA classifications (United States Department of Agriculture USDA, 1951).

The Drainage subgroup (Table 1) is then combined with the Compaction subclass (Table 2) to indicate the risk of topsoil compaction (Table 3; Ball, 1985, 1986). This is shown diagrammatically in Figure 4.

Table 1 Drainage subgroups used in assessment of topsoil compaction based on natural soil drainage class.

Natural Soil Drainage Class	Drainage subgroup
Free and Excessive	1
Imperfect	2
Poor	3
Very poor	3
Free below pan	3

Table 2 Compaction subclass based on soil texture (after Ball 1985, 1986).

USDA texture class	Compaction subclass
Sandy loam, Loam	A
Sandy loam (OM<5%), Loamy sand, Silty loam	B
Sandy clay loam, clay loam, Silty clay loam, Silty clay	C

Table 3 Final assessment of risk of topsoil compaction (after Ball 1985, 1986).

Combined class (texture and drainage)	Compaction class
A1	Low
A2, B1, B2	Moderate
A3, B3, C2, C3	High

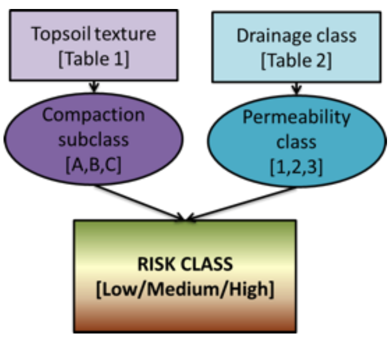


Figure 4 Flow diagram indicating how the component basic soil properties combine to assess risk of soil compaction.

Table 4 The erosive power of overland flow.

Percentage runoff	Slope categories					
	<2	2-4.9	5-9.9	10-17.9	18-30	>30
<20	a	b	c	d	d	slopes unstable
20-40	b	c	d	e	f	
>40	c	d	e	f	g	

NB: On January 1 1986, the Soil Survey of Scotland adopted the British Soil Texture Classification (BSTC) which was being used by both ADAS and the Agrochemical industry. This classification from the British Standards Institution (1981) has slightly different names for the texture classes and they are defined differently in terms of both the proportion of constituent clay, silt and sand particles and of the boundary between silt and sand sized particles (BSTC uses 60µm while USDA use 50µm). These boundary changes would tend to push soils towards the finer texture classes in terms of their classification which are the soils that are more prone to compaction and so there could potentially be a slight over prediction of the risk using BSTC classes. From the NSIS 2007-9 dataset, there was an average of 2.64% more sand where sand was defined using the UDSA system compared to the BSTC. However, the vast majority of the soil particle size analysis data held in the Scottish Soils Database uses the USDA definitions.

2.2.4 Soil erosion

Soil erosion is a naturally occurring process but its rate, intensity and location is strongly influenced by slope, soil type and land management practices. Only erosion by overland flow is considered in this assessment. The inherent soil erosion risk by overland flow is based on landscape characteristics such as slope angle and the physical properties of the soil and assumes the soil is free of a vegetation cover, and therefore it equates to the underlying background geomorphological erosion risk. Land management practices can be superimposed on to the underlying risk to protect water bodies from siltation and from pollutants bound to the sediment.

Soil erosion in Scotland is known to be triggered by events like rapid snow melt, high intensity rainfall and prolonged but low intensity rainfall indicating that the runoff potential of the soil has a primary role in determining the erosion risk (Lilly et al., 2002). Three categories of runoff taken from HOST Standard Percentage Runoff (see 2.2.1 Runoff) were identified which reflect the flow characteristics of the soil (Table 4). The first group (SPR<20 percent) represents soils with a relatively high infiltration rate (and therefore, low runoff potential), for example, soil derived from fluvioglacial sands and gravels. The second group (SPR between 20 and 40 percent) all have a mineral topsoil and allow some infiltration. The third group (SPR>40 percent) are slowly permeable and have primarily (but not exclusively) organic topsoils, which tend to inhibit infiltration and therefore more prone to generating surface runoff.

The slope categories selected are based on characteristic and limiting angles found within erosional environments (Table 4). Six classes were identified; the first, < 2°, describes the slopes where soil erosion is the least likely to occur while the last, >30° delineates those slopes which are approaching the limiting angle for unconsolidated material and are likely to be inherently unstable under all conditions. The remaining four classes (Table 4) represent increasing energy availability as the slope steepens. The unequal increments in slope classes reflect the fact that the increase in erosive power with an increase in slope is non-linear and so there is a greater rate of increase at lower angles than at greater angles (Figure 5).

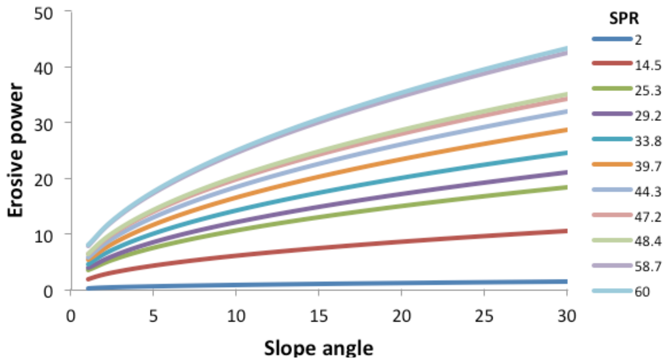


Figure 5 Relationship between the HOST Standard Percentage Runoff values (SPR) and erosive power as slope angle increases.

Table 5 British Standard Texture Classes grouped by Soil Erodibility class.

	Soil Erodibility class		
	Fine	**Medium**	**Coarse**
BSTC Texture Class	Clay	Sandy clay loam	Sand
	Sandy clay	Clay loam	Loamy sand
	Silty clay	Silt loam	Sandy loam
	Silty clay loam	Sandy silt loam	

As slopes increase, any potential runoff which is generated will have greater ability to erode. The rule-based model reflects this process by combining slope and runoff characteristics to estimate the erosive power of overland flow (Table 4).

Erosion of soils by overland flow involves the detachment of soil particles and their subsequent transport. Soil particle detachability describes the process by which soil aggregates disintegrate into their constituent parts (in the case of mineral soils) which can then be transported. Soil aggregate strength is a complex attribute influenced by the amount and type of clay and by the amount of organic matter and varies with moisture content. In many existing models, soil texture is seen as a surrogate for aggregate stability or as a carrier of this information.

A three-class system for mineral soils was devised from the ranked texture classes, with fine textured topsoils being the least erodible and coarse textured mineral topsoils the most. Table 5 details the British Soil Texture Classification (BSTC) soil texture classes in each group. There is uncertainty in the rules for allocating erodibility classes to the soil texture groups partly due to the need to draw a consensus from the disparate information available and partly due to the lack of corroborative evidence. Further uncertainty arises as the texture classes encompass a wide range of clay contents, it is the clay (along with organic matter) that binds the soil particles together and affects aggregate stability. Due to the distinctive nature of organic and organo-mineral soils (i.e. those with a peaty surface layer) these were classified separately.

Tables 6 and 7 show how the erosive power (slope and runoff) combine with soil texture to derive an inherent risk of erosion for mineral (Table 6) and both organo-mineral and organic soils (Table 7) using a simple numeric system.

Thus, the percentage runoff (SPR) from the HOST class gives the soils potential to generate overland flow. The slope angle modifies that runoff by increasing the power of overland flow as slope angle increases and the texture of the soil determines susceptibility of the soil to be eroded. However, the assessment of soil erosion risk is complex and it is important not to look in isolation at the individual tables but to follow the individual components through to tables 6 and 7 as many of the parameters are interlinked. Equally, apart from taking land cover into account (and possibly field observations on flow convergence) no other variables should be introduced to the classification.

Table 6 Erodibility classes for mineral soils.

Soil texture	Erosive power						
	a	b	c	d	e	f	g
Fine	1	2	3	4	5	6	7
Medium	2	Low	4	Moderate	6	High	8
Coarse	3	4	5	6	7	8	9

Table 7 Erodibility classes for soils with organic surface layers.

Type of organic surface layer	Erosive power						
	a	b	c	d	e	f	g
Peaty or humus topsoil	I	Low	III	IV	Moderate	VI	VII
Organic soils (Peats)	High VIII						

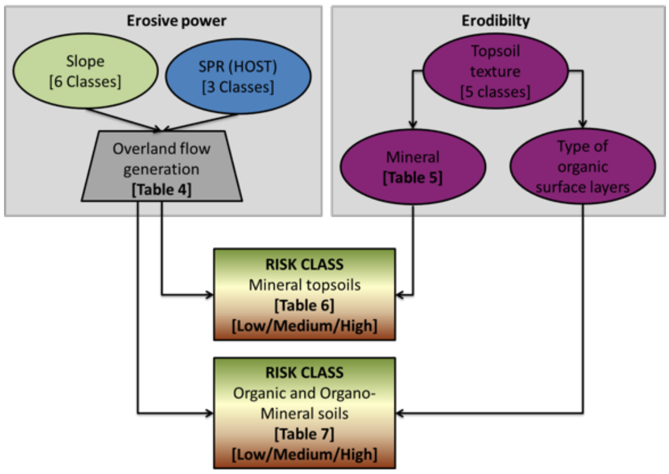


Figure 6 Flow chart for assessing inherent soil erosion risk.

The procedure for combining the information in these tables to derive a soil erosion risk class is shown in figure 6. The ability of the soil to generate overland flow (derived from the HOST SPR) is combined with the slope (Table 4). This combination gives an indication of the likelihood of overland flow being generated and the slope determines the power that flow will have. The erosive power is graded from a to g with g being the greatest.

The ability of the soil to resist detachment and transport (erodibility) depends on the soil texture (Table 5) with organic and organo-mineral soils treated separately (Table 7). The mineral soils are grouped into fine, medium and coarse (clayey to sandy). The coarse textured soils have the least coherence and can detach most readily where as the fine textured clayey soils are the most coherent. By combining the erosive power (a-g from table 4) with the erodibility (Table 6), the risk of erosion can be determined (Table 6) in 9 classes. These are then summarised into low medium and high risk.

Peats are considered to be highly erodible (Table 7) so, no matter what the erosive power is, peats are at a high risk of erosion. The organo-mineral soils are less likely to erode and table 7 shows how the risk of erosion increases with an increase in the erosive power.

Erosion risk is unique amongst the suite of risks in that it cannot be wholly determined from the soil characteristics alone, slope being a key component. Slope can be assessed in the field or calculated from Digital Terrain Model (DTM) prior to site visits. In order to facilitate the latter, tables 4-7 have been summarised into Table 8 which allows a user to identify the inherent erosion risk in relation to slope from the two soil characteristics (SPR and texture). This simplified table can be used without recourse to table 4-7 unless a greater understanding is required of how the soil properties and slope interact with respect to erosion risk.

2.2.5 Influence of digital elevation model on prediction of soil erosion risk

The assessment of the inherent soil erosion risk is unique amongst the four risks assessed in that it incorporates slope data in addition to soil data. This means the link between the erosion risk and the soil series is not as straight forward, as some series will occur on a range of slopes giving different levels of erosive power (see Figure 4).

Whilst the effect of slope on erosion risk can be estimated in the field, in order to provide a digital assessment on the same basis as the other three risk maps, the soil map needs to be overlain with a DTM to identify the erosive power categories and hence the erosion risk (Table 3). The Ordnance Survey ©Profile Grid-based DTM is at a 10 m resolution. The appropriate resolution for representing erosion risk and communicating with land managers was explored. There is likely to be more discrimination in slope classes at the finer resolution.

In order to assess the effect that these different resolutions of DTM had on the soil erosion risk map, three grid sizes were applied to the Coyle catchment erosion risk assessment, 10, 50 and 100 m grid cells (Figure 5). The 10m DTM seems to fragment the landscape such that it would be difficult to apply the risk assessment to management units (such as a field) with confidence. The 50 and the 100m DTM led to a more coherent and contiguous pattern of erosion risk meaning that larger areas were allocated to a particular risk class. This would have more applicability in the field when discussing risk with land managers and is more appropriate to the scale that land is managed. Clearly there was less detail and less fragmentation with the 100m DTM (Figure 7).

However when slope is combined with soil data to give erosion risk there appeared to be little impact on the proportion of the catchment designated as either Low, Medium or High risk (LM, MM, HM respectively, Figure 8) for mineral soils (M). The organic soils in the catchment were largely insensitive to changes in DTM resolution.

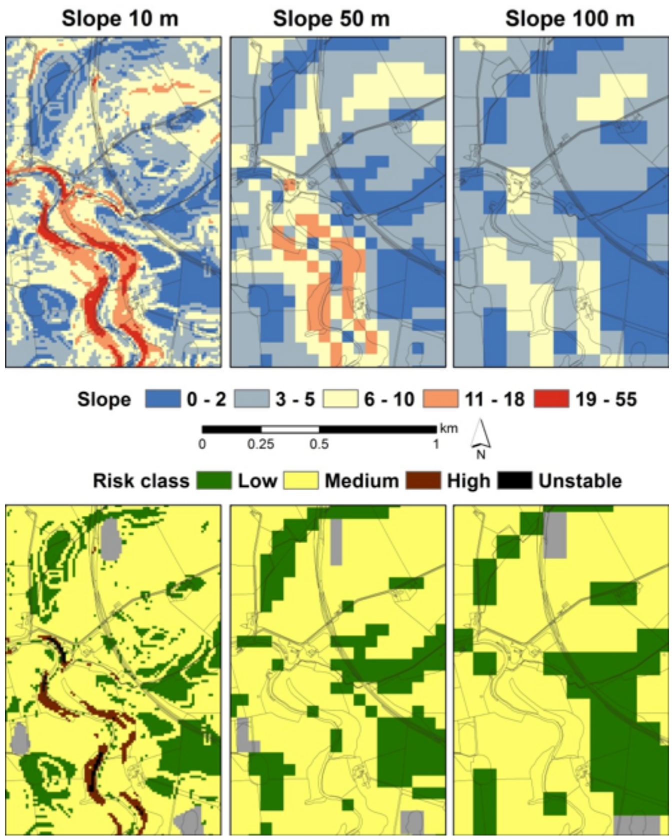


Figure 7 Effect of different resolution Digital Terrain Models on the assessment of erosion risk. Maps contain MasterMap ® and Land-Form PROFILE data © Crown copyright and database right (2014). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

SPR (%)	Texture	Slope 0-2°	2-5°	5-10°	10-18°	18-30°
0-20	Fine	L	L	L	M	M
	Medium	L	L	M	M	M
	Coarse	L	M	M	M	H
	Organic	L	L	L	M	M
20-40	Fine	L	L	M	M	H
	Medium	L	M	M	M	H
	Coarse	M	M	M	H	H
	Organic	L	L	M	M	M
40-100	Fine	L	M	M	H	H
	Medium	M	M	M	H	H
	Coarse	M	M	H	H	H
	Organic	L	M	M	M	M
Peat		H	H	H	H	H

Table 8 Relationship between SPR, texture and slope (degrees) in determining erosion risk.

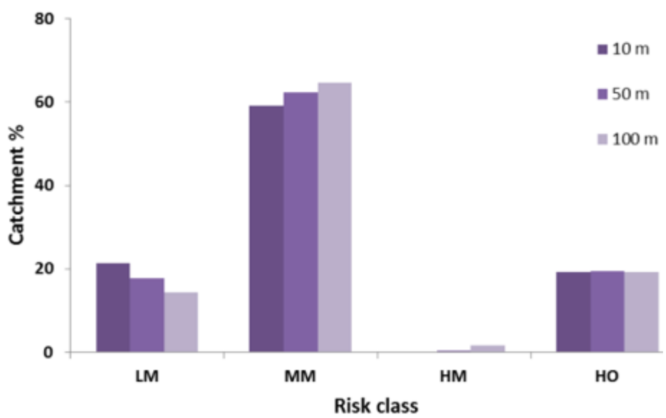


Figure 8 The effect of changing DTM resolution on the proportion of the catchment in each erosion risk category.

3.0 Data Presentation and risk maps

Throughout the project is was unclear as to whether a series of risk maps or a soil map with an attribute table would be the best way to present the data in a form usable by non-soil specialists. Both methods were developed, however, an attribute table is more difficult to relate to the erosion risk due to the need to include slope parameters.

3.1 Attribute tables

The soil map shows the distribution of the soil series (named soil types). By accessing existing soil data, the characteristics required for the risk assessment such as the inherent soil drainage, topsoil texture, topsoil carbon concentration and HOST class (to derive standard Percentage Runoff - SPR) can be determined for both cultivated soils and those with a semi natural vegetation cover. These soil attributes are the underlying input data required for all the risk assessments (with erosion also requiring information on slope). Thus an attribute table containing data and information for each soil series was developed (Table 9).

This information was then used to derive the risk classes for Runoff, Leaching and Compaction based on the tables given above. This generated additional attributes related to the soil series (Table 10).

These tables can be supplied alongside the 1:25 000 scale digitised soil map so that those using the classification can build up expertise on the relationship between the individual soil series and the risk categories. The basic information available from the soil map includes Soil Series, Soil Association (essentially a parent material type) and major soil subgroup (soil type). For example, see Figure 9.

Table 9 An example soil attribute table.

Series name	Land use	HOST class	SPR (%)	Topsoil texture	Topsoil C (%)	Natural drainage
Amlaird	cultivated	24	39.7	CL	6.39	Poor
Bargour	cultivated	24	39.7	SCL	2.8	Imperfect
Caprington	cultivated	24	39.7	SCL	3.875	Imperfect
Darleith	cultivated	17	29.2	SL	7.31	Free
Darvel	cultivated	5	14.5	SL	3.81	Free
Amlaird	Semi-natural	24	39.7	SL	9.31	Poor
Basin peat	Semi-natural	12	60	PEAT	51.31	Poor
Baidland	Semi-natural	15	48.4	PEAT	39.35	Free below pan
Bargour	Semi-natural	24	39.7	SCL	2.8	Imperfect
Caprington	Semi-natural	24	39.7	SCL	4.09	Imperfect

Table 10 An example additional soil attribute table.

Series Name	Land use	Runoff Potential	Leaching Potential	Compaction Risk‡
Amlaird	Cultivated	Moderate	Low	High
Bargour	Cultivated	Moderate	Low	High
Caprington	Cultivated	Moderate	Low	High
Darleith	Cultivated	Moderate	Intermediate	Low
Darvel	Cultivated	Low	High	Low
Amlaird	Semi-natural	Moderate	Low	High
Basin peat	Semi-natural	High	Low	Not applicable
Baidland	Semi-natural	High	Low	Not applicable
Bargour	Semi-natural	Moderate	Low	High
Caprington	Semi-natural	Moderate	Low	High

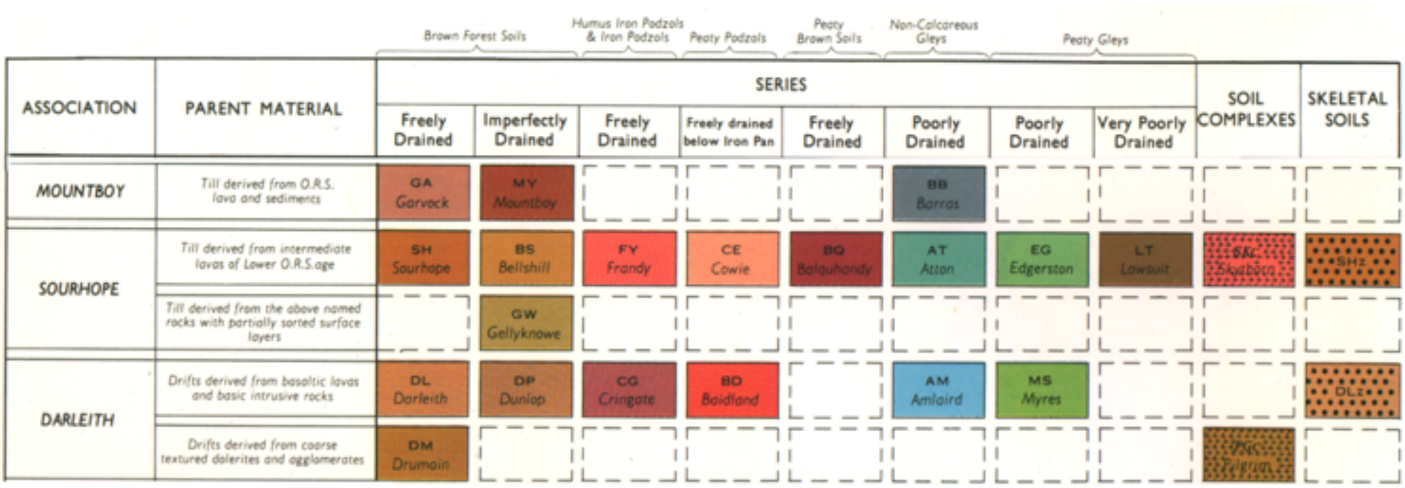


Figure 9 Part of a soil map key showing the basic information to accompany the attribute tables and risk classification.

As already stated, the inherent soil erosion risk requires information on slope categories as well as topsoil texture and runoff to be implemented. This makes it more difficult to present as an attribute table unless slope measurements are likely to be made in the field. Where this is the case, a simple look-up attribute table can be used (Table 11) where the soil series have been previously classified according to topsoil texture and runoff generation (see table 9 &10). This information would be available as, for example, a Microsoft Access database or as a Microsoft Excel spreadsheet and would be given as one large attribute table.

The 1:25 000 scale soil maps can be zoomed to show individual farms and fields (Figure 10) illustrating the type of output that could be taken into the field. It shows the underlying soil map, the farm boundary and two attribute tables with basic soil information on drainage and the risk categories for Runoff, Leaching and Compaction and the table to assign the erosion risk based on a local measurement of slope (that is, not derived from a DTM). These maps could be easily drawn up for each farm to be visited and the erosion risk completed in the field in discussion with the farmer/land manager. It may be that a combination of risk maps and attribute tables will be used depending on the circumstances. That decision rests with the ultimate user of the information.

Table 11 Look up table to determine the inherent risk of soil erosion according to slope categories.

Soil series	Land use	Slope [°]				
		0-2	2-5	5-10	10-18	18-30
Amlaird	Cultivated	L	M	M	M	H
Bargour	Cultivated	L	M	M	M	H
Caprington	Cultivated	L	M	M	M	H
Darleith	Cultivated	M	M	M	H	H
Darvel	Cultivated	L	M	M	M	H
Amlaird	Semi-natural	M	M	M	H	H
Bargour	Semi-natural	L	M	M	M	H
Baidland	Semi-natural	H	H	H	H	H
Basin peat	Semi-natural	H	H	H	H	H
Caprington	Semi-natural	L	M	M	M	H
Darleith	Semi-natural	M	M	M	H	H
Darvel	Semi-natural	L	M	M	M	H

3.2 Risk maps

An alternative approach is to provide individual risk maps for runoff, leaching potential, compaction and erosion. The disadvantage is that multiple copies of maps are required and the link between soil types and risk category are not as explicit for the user, making it more difficult to build up a body of soils knowledge that can be used where there are inaccuracies in the soil map.

In order to join the attribute data to the spatial data across a catchment, an intersection of soil and landuse polygons (classified into semi-natural or cultivated land) is required. This means that each polygon can be attributed with a numeric code that represents the soil and land use (semi natural or cultivated) combination. This numeric code is also added to the attribute table and used as the joining field between the spatial data and attribute data. There is a need to define land cover as it will, in some cases, change the risk class of the soil (See Amlaird, Table 11). The numeric code that includes land use is the soil series code modified by prefixing the soil series code with '100'. For example, Amlaird Series has code 12406 for cultivated soils and 10012406 for the semi-natural, uncultivated version. Where the cultivated soil series code is prefixed by '0' or '00', these leading zeros are dropped (e.g., '00313' becomes '313' but the uncultivated version remains as 10000313)

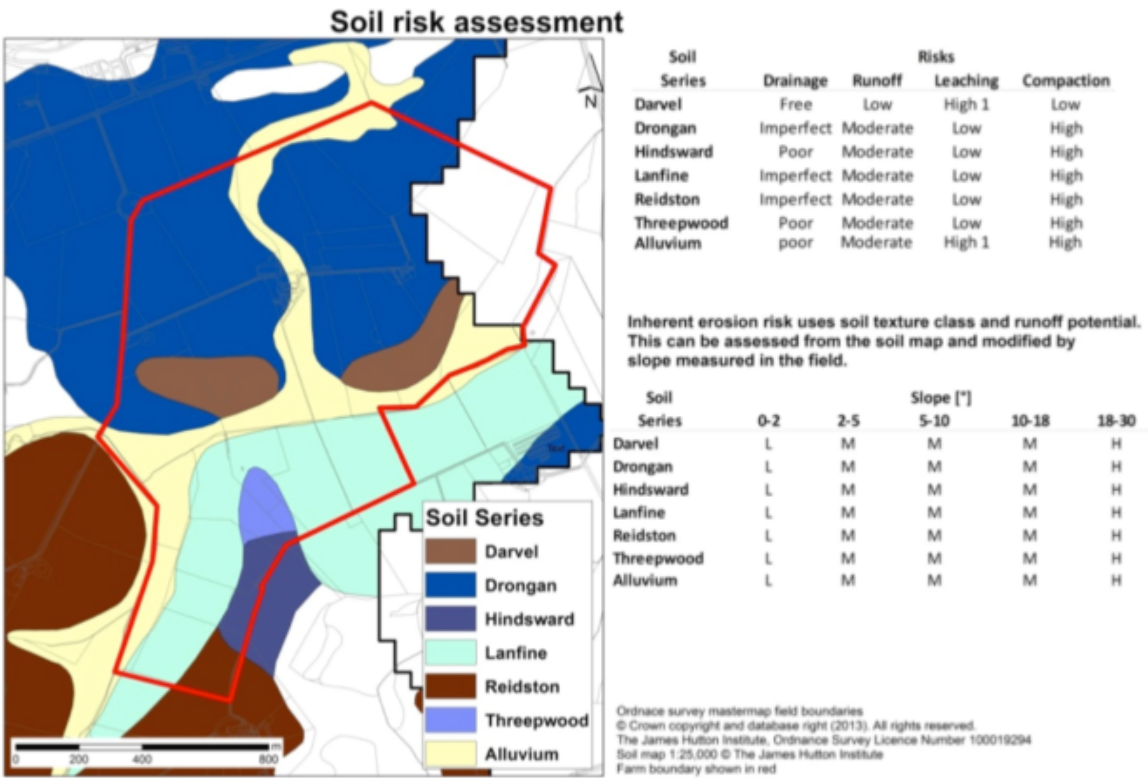


Figure 10 Farm scale risk assessment showing underlying soil map and attribute table.

How land use is mapped and represented in the risk maps will be considered as part of the subsequent work where data sets are developed for the full range of soil/land use combinations. This will include an assessment of the most appropriate land use data set used to define semi-natural and cultivated land for this application and what the effects of changing the land use data set are both for on the ground use of the maps and at a broader scale

Below (Figure 11 a-d) shows maps of the risk of Runoff (a), Leaching (b), Compaction (c) and Erosion (d) in the Coyle catchment based on a 1:25 000 scale soil map and the land cover of Scotland 1988 (LCS88). Figure 12 a-d shows the same for the East Pow catchment.

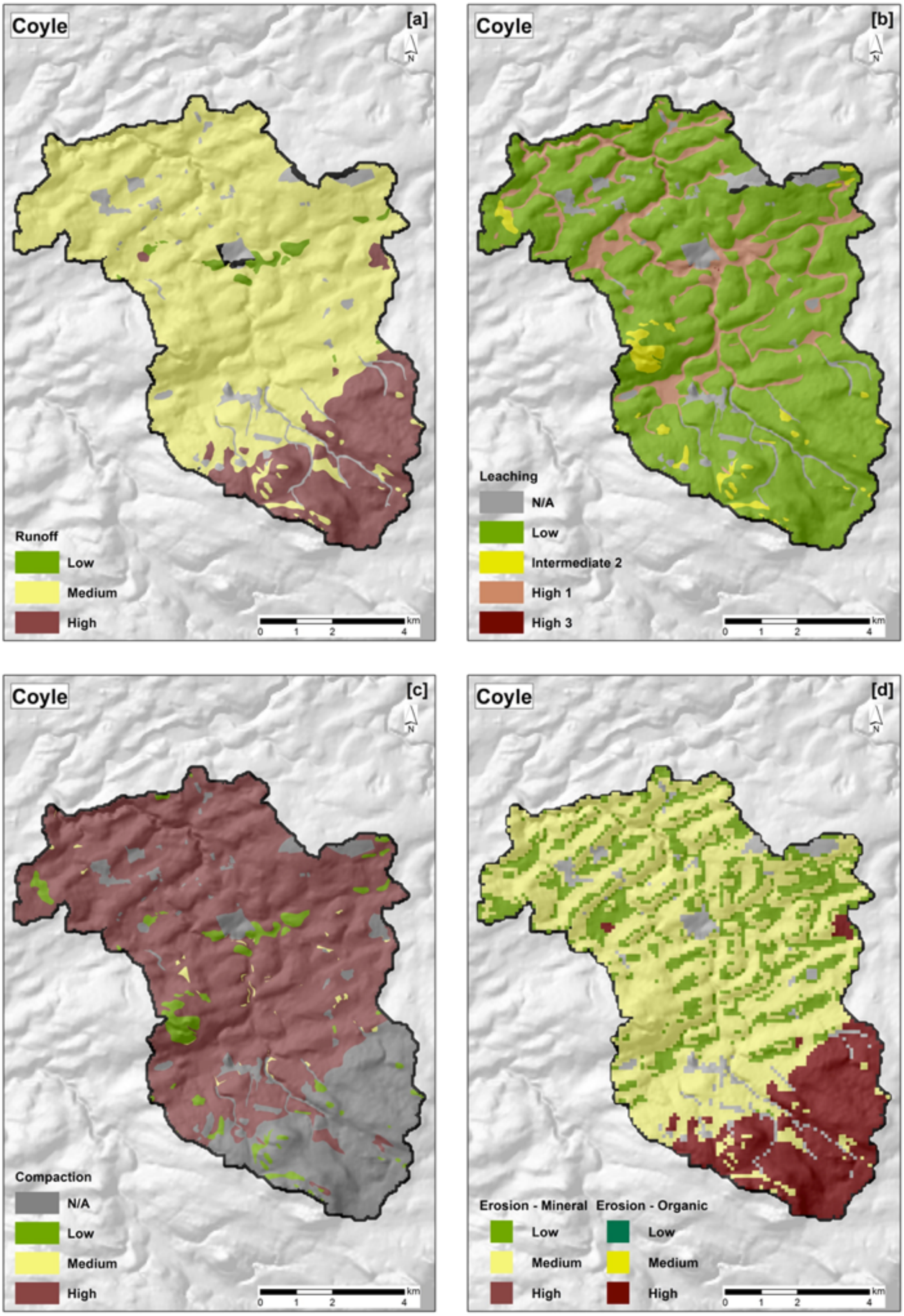


Figure 11 Risk of Runoff (a), Leaching (b), Compaction (c) and Erosion (d) in the Coyle catchment based on a 1:25 000 scale soil map combined with LCS88. Maps contain Land-Form PROFILE® data © Crown copyright and database right (2014). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

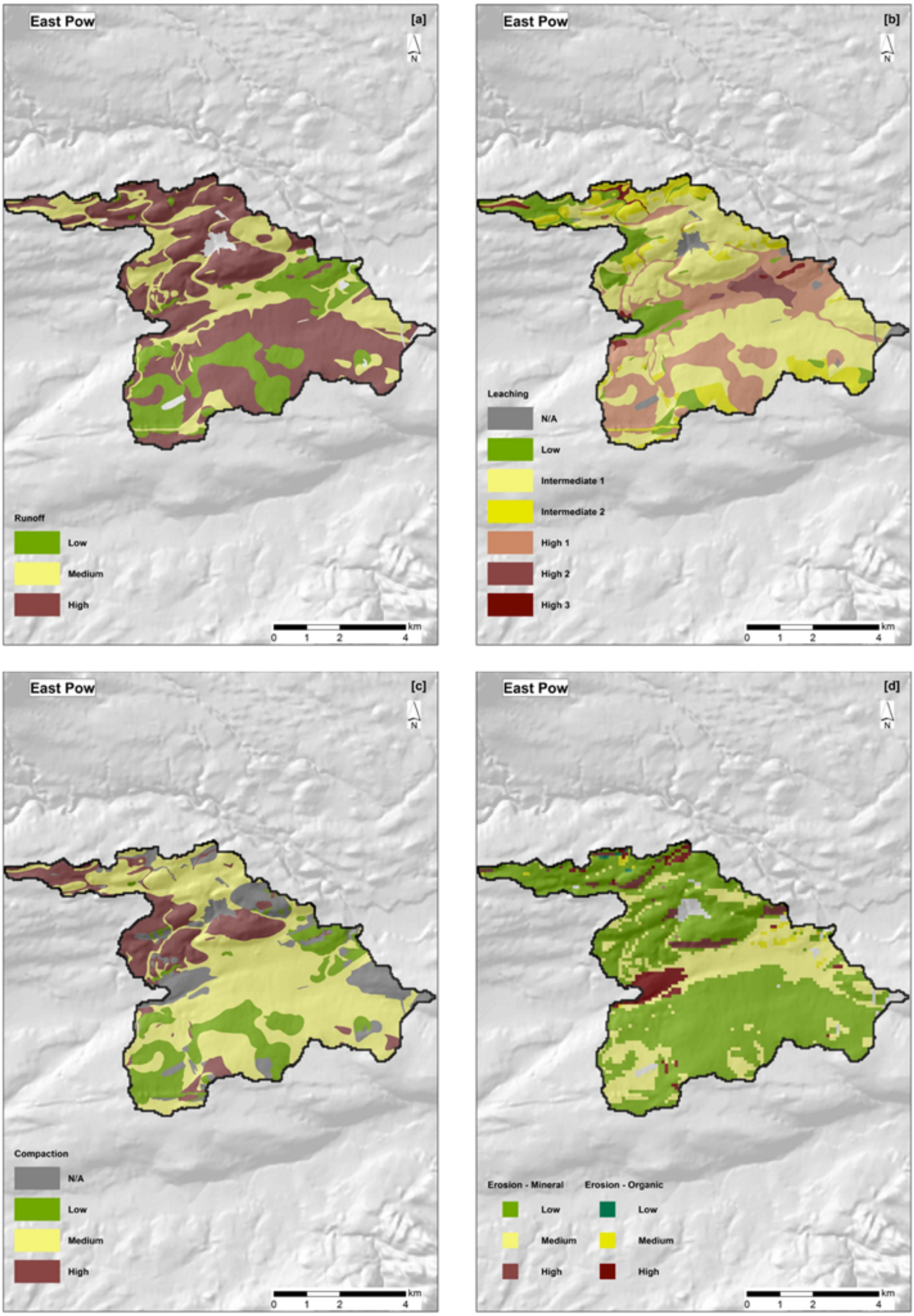


Figure 12 Risk of Runoff (a), Leaching (b), Compaction (c) and Erosion (d) in the East Pow catchment based on a 1:25 000 scale soil map combined with LCS88. Maps contain Land-Form PROFILE® data © Crown copyright and database right (2014). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

4.0 Cost of extending the risk assessments to all cultivated land in Scotland

An objective of this work was to scope the cost of extending the risk assessments to the remaining catchments in cultivated areas of Scotland. There are a number of factors that need to be taken into account; existence of updated 1:25 000 or 1:63 360 scale maps, the existence of sufficient, good quality soils data to derive the underpinning soil information, and an 'expert' to identify analogous soils where no data exist.

Revisions and updating of the 1:25 000 and 1:63 360 scale soil maps is currently underway, funded by the Scottish Government within the Underpinning Capacity programme of work.

Much of the data required already exist within the Scottish Soils Knowledge and Information Base (SSKIB). This database is a summary of the information held within the Scottish Soils Database for each soil series identified in Scotland. A typical sequence of soil horizons (layers) was identified for each soil series that was shown as a component part of the soil map units on the national scale 1:250 000 soil map (Soil Survey of Scotland Staff, 1981). The soil characteristics for these horizons were summarised from data on over 13, 000 soil profiles held within the Scottish Soils Database such that mean, median, standard deviation, maximum and minimum values for exchangeable cations, sand, silt, clay, pH and carbon concentration were calculated. However, there are approximately an additional 400 soils series that have been mapped at scales of 1:25 000 and/or 1:63 360 for which the summary data were not calculated. Additional work is required to disaggregate alluvial soils that were simply mapped as 'undifferentiated'.

Based on estimates for similar work, it would take around 40-45 person days to collate this additional information not including the time required to produce the risk maps. This could take an additional 10 days. It is envisaged that 2 people would be required to do the work, one a soil expert and the other a database/GIS expert. Assuming an equal share of the work load and with an average daily rate of around £460 (subject to change based on actual staff costs of persons involved), a total cost of the work would be between £23 000 to £25 300 for the production of an attribute database and digital risk assessment maps. This project would also explore how to incorporate the land use component into the mapping.

5.0 Conclusion

This pilot study demonstrated that the assessment and mapping of risks of diffuse pollution at a scale of 1:25 000 can be successfully applied. In this case in two test catchments, the Coyle and the East Pow, both sub-catchments of SEPA's designated priority catchments. The assessments runoff potential, leaching potential, erosion risk and risk of compaction were derived from already existing soil classification systems and made use of the existing 1:25 000 scale soil map and associated soil databases held at the James Hutton Institute. With the recent validation and updating of the 1:25 000 scale soil maps for Scotland, the assessments could be rolled out to other catchments relatively easily. , For some soils, there would be the requirement to collate the basic input data (for example, soil texture, HOST class, drainage category) prior to compiling the risk categories.

Two approaches were trialled, one where the user would be given a series of risk maps and the other where the user is given a soil map and an associated attribute table with the soil series categorised into the various risk classes. Both approaches have their merits with the former requiring less awareness from the user of the underlying soil map data. The latter approach clearly demonstrates the relationship between soil type and risk categories as well as building a body of knowledge about soils in general. This approach offers greater understanding of how the soils affect the risk category and may facilitate discussions with land managers and farmers as the properties of the soil (with which land managers are likely to be familiar) can be used to explain how the risk maps were derived and how mitigation strategies can be developed.

This pilot could be extended to apply these risk classification to the remaining 1:25 000 soil maps and, where these are not available, to the 1:63 360 scale soil maps. Again, as these maps are undergoing validation and revision, providing risk assessments as attribute tables means it is easier to revise the risk maps for a farm or catchment. The possibility of including an assessment of the risk of subsoil compaction in any future work should be explored, as this tends to be a more permanent feature once developed than topsoil compaction which is more easily remedied by ploughing.

Should these risk assessments be rolled out, training sessions for SEPA staff could be held to explain how the risk classes were derived, what information was used, where it can be accessed and what the underlying soil types are.

Finally, this pilot also provided basic input data for a project to develop farm nutrient management plans.

6.0 References

Ball, B.C. (Compiler) 1985. Cultivation requirements for Winter barley. SAC/MISR/SIAE publication 154. Scottish Agricultural Colleges. Edinburgh.

Ball, B.C. 1986. Provisional land grouping for selection of cultivation requirements for Winter barley in Scotland. Soil and Tillage Research, 7, 7-18.

Boorman, D.B., Hollis, J.M and Lilly, A. 1995. Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology Report No.126. Institute of Hydrology, Wallingford.

British Standards Institution. 1981. Code of Practice for Site Investigations. BS5930:1981 Second Edition. British Standards Institution, London.

Lewis, M.A., Lilly, A and J.S. Bell. 2000. Groundwater vulnerability mapping in Scotland: Modifications to classification used in England and Wales. In: Groundwater in The Celtic Regions: Studies in Hard Rock and Quaternary Hydrogeology. Eds. N.S. Robins and B.D.R. Misstear. Geological Society Special Publication No. 182. pp 71-79.

Lilly, A., Malcolm, A. and Edwards, A.C. 2001. Development of a methodology for the designation of groundwater nitrate vulnerable zones in Scotland. Report prepared for Environmental Protection Unit (Water Unit) Scottish Executive Rural Affairs Department.

Lilly, A., Hudson, G., Birnie, R.V. and Horne, P.L. 2002. Inherent geomorphological risk of soil erosion by overland flow in Scotland. Scottish Natural Heritage Research, Survey and Monitoring Report No. 183.

Soil Survey of Scotland Staff. (1970-1987). Soil maps of Scotland (partial coverage) at a scale of 1:25 000. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey of Scotland Staff, 1984. Organization and Methods of the 1:250 000 Soil Survey of Scotland. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey of Scotland Staff. (1981). Soil maps of Scotland at a scale of 1:250 000. Macaulay Institute for Soil Research, Aberdeen.

United States Department of Agriculture USDA, 1951. Soil survey manual, U.S. Dept. Agriculture Handbook No. 18. Washington, DC.

Appendix 1: Original brief

N.B. This original brief was modified during discussions with SEPA staff in light of overlap with a SAC-run project on farm-scale nutrient management.

Developing simple indicators to assess the role of soils in determining risks to water quality

Project outline

SEPA's use of JHI Soils data (under the new data sharing agreement) and the Hydrology of Soil Types database is extremely limited due to a lack of a method to translate the data into indicators of risk to water quality (susceptibility to erosion and compaction, for example). We propose that CREW develop a simple method to enable SEPA to use this data for risk identification then hold a small workshop with a range of SEPA staff to finalise the method. Subsequently this method should be applied to the data and a training course for SEPA staff on the use of the data delivered.

Background

SEPA now has access to a range of JHI Soil data (Annex 1). However, while it is useful for some staff to have access to raw data, a real need at present is for this information to be interpreted in a way to make it useful to SEPA staff on the ground to enable them to assess the risk of diffuse pollution occurring and to communicate this with farmers/landowners.

One of the key areas where SEPA staff need soil information is in assessing risk to water quality caused by diffuse pollution. Input of soil and contaminants bound to soil as well as dissolution and transport of contaminants via leaching and overland flow to water is a major risk to water quality.

Diffuse pollution priority catchments have been identified and co-ordinators appointed to investigate the issues each catchment faces. These include the inherent risk from the soil and how it sits in the landscape as well as the risk from land use and land management practices. The catchment co-ordinators therefore need to be able to assess the role of soils in determining risks within the catchment. They also need to be able to communicate these risks to the farmers/landowners.

Broad and simple indicators need to be developed to inform their assessment of the risks likely to be found in the catchments so they can advise on effective remedial action. These indicators need to be simple and easy to use.

The initial requirement is therefore to develop a method to allow SEPA staff to use the soil data available (and other (derived) data available) to assess the risk of diffuse pollution occurring.

It is envisaged that a potential methodology would be developed in advance by CREW which would then be presented at a workshop in mid-March 2013 to explore further needs and finalise a simple classification.

This may take into account risks of erosion, compaction, run off and leaching of potential pollutants.

Researchers should consider the potential for producing similar information for Scottish sites, as is currently available for England and Wales on LandIS (Land Information System; http://www.landis.org.uk/).

It is envisaged that following the identification of potential indicators there would be a need for training to be delivered to SEPA staff in how to use the indicators / apply the method developed. This would be a follow up project.

Annex 1: Soil data and information that SEPA has access to at present.

- NSIS_1: point dataset of a range of soil parameters
- 1:250,000 scale and 1:25,000 scale soil maps (soil map units).
- 1:250,000 Scale National Land Capability Classification for Agriculture (LCA) data
- 1:50,000 Scale Land Capability Classification for Agriculture (LCA) data
- 1:250,000 Scale National Land Capability Classification for Forestry (LCF) data
- Scottish Soils Knowledge and Information Base (SSKIB database). We already have access to this via the internet through the Soil Indicators for Scottish Soils (SIFSS) website.
- SNH's interpreted carbon richness map.
- Hydrology of Soil Types.
- Geomorphological inherent soil erosion risk.

crew

Scotland's centre of expertise for waters

CREW Facilitation Team

James Hutton Institute

Craigiebuckler

Aberdeen AB15 8QH

Scotland UK

Tel: +44 (0)1224 395 395

Email: enquiries@crew.ac.uk

www.crew.ac.uk

The James Hutton Institute

The Scottish Government

CREW is a Scottish Government funded partnership between the James Hutton Institute and Scottish Universities.