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GS SOIL

<D4.3 Data Harmonization Best Practice Guidelines>

Test Case Report:

Harmonisation of 1:250 000 scale soil maps and soil profile data in the Celtic Fringe of Europe: Scotland, Northern Ireland and Eire

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Author(s)	*Gordon Hudson[1]* *Allan Lilly [1]* *Alex J. Higgins[2]* *Crawford Jordan[2]* *Reamonn Fealy[3]* *Rachel E. Creamer[3]*

JHI - James Hutton Institute[1]
AFBI – Agri-Food and Biosciences Institute [2]
Teagasc[3]

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[1] OJ L 79, 24.3.2005, p. 1.

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3 Glossary of acronyms

Term	Description
SSS	Soil Survey of Scotland
JHISSD	James Hutton Institute Scottish Soil Profile Database
SSKIB	Scottish Soil Knowledge and Information Base
WRB_2007	World Reference Base Classification (2007 revision)
FAO_2006	FAO Profile Description Guidelines 2006

4 Introduction

The work on comparison of soil data across Europe in GS Soil offers a unique opportunity to embark on a programme of knowledge capture and systemisation for European soil maps and data with the aim of developing methods to ensure interoperability of various datasets and between data providers. As part of this initiative of the eContentplus programme, this report covers the test case on harmonisation of soil data in three of the Celtic Fringe countries of north-western Europe: Scotland, Northern Ireland and Ireland. This test case primarily investigated the issues which need to be considered during translation of the local soil classifications for each territory into the World Reference Base soil classification (IUSS Working Group WRB, 2007) - WRB_2007. The results will be presented as this report (downloadable from the project portal) and as maps viewable through the project portal.

5 Scottish soil forming factors

The soils in Scotland are classified using a genetic soil classification which takes account of the main soil-forming factors (Jenny, 1941). This focus on soil genesis means that a brief introduction to the climate, physiography and geology of Scotland is useful before describing the soil classification.

5.1 Climate of Scotland

The climate of Scotland is set in a European context by comparing the work done on climate classification and mapping in Scotland with that done on a European scale later.

5.1.1 Bioclimatic sub-regions of Scotland

In climatic terms, the soil regions of Europe were described and mapped at a continental scale of 1:5 000 000 (report: Hartwich et.al., 2005; map: Bundesanstalt für Geowissenschaften und Rohstoffe, 2005). According to this classification, the soil regions in Scotland are in two main groups: the northern half of Scotland has a boreal to temperate climate and the south has a temperate oceanic to sub-oceanic climate. Prior to this continental scale work, a local classification, with more detail (1:625 000 scale) was developed in Scotland (Birse, 1971) using underlying maps of accumulated temperature, potential water deficit, exposure and accumulated frost. These maps were derived from climate station measurements (1941-1970) augmented with field observations of the effects of climate on distribution and growth form of naturally-occurring plants. According to Birse, Scotland falls entirely within the oceanic sector of Eurasia (cf. Troll, 1925), with a local division into three sub-sectors of decreasing oceanicity: hyperoceanic, euoceanic and hemioceanic. Within these oceanicity sub-sectors, soils in Scotland are developed in Northern Temperate, Hemiboreal and Orohemiboreal, Southern Boreal and Lower Oroboreal, Upper Oroboreal, Orohemiarctic, Lower Oroarctic and Upper Oroarctic thermal sub-zones and Humid and Perhumid moisture subdivisions. The prefix 'oro' was used by Birse to indicate the influence of mountains on the climate. The local classification has rather more emphasis on the influence of mountain climates than the continental scale classification, with a significant area of mountain arctic climate (oroarctic of Birse) within the hemioceanic area of the central highlands.

5.2 Physiography and geology

5.2.1 Introduction

Scotland has a complex geological history with a wide variety of rock types, physical features and glacial deposits. Tectonic movements along two major dislocations of the earth's crust, the Southern Uplands Fault and the Highland Boundary Fault, created three principal structural and physiographic divisions, the Highlands, the Midland Valley and the Southern Uplands. These main physiographic regions are each dominated by their own characteristic rock types and drifts.

5.2.2 Scottish Highlands

In the Scottish Highlands metamorphic schists and gneisses of Moinian and Dalradian ages are predominant (Bibby et. al., 1984). Large areas of igneous rocks are also found, the distinction between those of dominantly basic nature (basalts, andesites and epidiorites) and those of acid (granite, trachytes and rhyolites) being important in terms of subsequent soil development. Rocks of Torridonian and Lewisian age form a wedge-shaped mass in the north but occur also on the islands of Coll, Tiree, Iona and Colonsay. Sediments of Triassic to Cretaceous and Old Red Sandstone age are restricted in extent, although distinctive in the landscape.

5.2.3 Midland Valley

The Midland Valley is a graben of broadly synclinal structure between the Highlands to the north and the Southern Uplands to the south (Bown et. al., 1984). Palaeozoic rocks accumulated to a great thickness in the graben and along the edges of the adjoining massifs, and in age intermittently span Cambrian to Permian times. The most extensive rocks, however, are sedimentary and igneous rocks of the Carboniferous system, and Old Red Sandstone rocks on the north side of the Midland Valley. The Carboniferous sediments comprise mainly shales and sandstones with some coals and occasional limestones and calciferous sandstones. They range in age from the earliest Carboniferous rocks in the Calciferous Sandstone Measures, through the Limestone Group and Millstone Grit to the Coal Measures. The predominant igneous rocks are basaltic lavas and sills. Desert sandstones of Permian age underlie much of southern Arran.

5.2.4 Southern Uplands

The Southern Uplands (Bown et. al., 1984) are predominantly composed of weakly metamorphosed, strongly folded and harder greywackes and shales of the Ordovician and Silurian systems. These rocks form the smooth rounded hills and steep-sided, narrow valleys typical of the Southern Uplands. At the western end of the Southern Uplands, the landscape is underlain by spilitic lavas and ultrabasic rocks of Arenig age and Lower Ordovician conglomerates with a high proportion of basic igneous stones. At the eastern end of the Southern Uplands the basin of the River Tweed was described by Sissons (1976) and summarised (Bown and Shipley, 1984), 'as having the lowest ground in the east mainly coincident with Carboniferous sedimentary strata largely concealed beneath thick drift having strong drumlin features. To the southwest a curved belt of low hills corresponds with a faulted outcrop of Carboniferous lavas. This is succeeded by an area of Old Red Sandstone age sedimentary rocks, interrupted by a series of intrusions that form conspicuous hills, composed of trachyte, felsite and agglomerate'. There are also Permian sandstones in the Nith Valley, and around Lochmaben, Thornhill and Stranraer. Granite intrusions form the hills Criffel, Merrick and Cairnsmore.

5.3 Parent materials

The types of parent materials have a strong dependence on lithology and glacial history in Scotland where a relatively short period has elapsed since the end of the last glaciations. Glacial erosion was predominant over most of the highlands and southern uplands with deep lodgement tills, some with late-glacial water-working or resorting, covering most areas of the Midland Valley. Raised beaches are extensive around the coasts and fluvioglacial outwash or alluvial deposits occupy the main river valleys. The short time-span for weathering since the end of glaciation means that textural differences in soil parent materials and soil geochemistry are related to the lithological composition of the parent rock or rocks and to glacial history (Glentworth and Muir, 1963).

6 Scottish Soil Classification

Soil classification in Scotland is typological rather than definitional, that is it is based on the recognition of morphological features and on the sequence and nature of different horizons within the soil profile. Although each profile has an individual identity, where they show a degree of similarity that matches the accepted concept for that soil they can be placed into the same category i.e. a soil series which comprises soils with similar type and arrangement of horizons developed on similar parent material. The soil series is the primary classification unit (Taxonomic unit) and it must be recognised that the same term is used to denote the primary mapping unit. Table 1 shows the hierarchy of soil classification used in Scotland. The series comprises those soils from a particular major soil subgroup, developed on the same parent material and with a similar natural drainage class. Soil series are generally named after the locality in which they were first described.

Table 1. The hierarchy of soil classification in Scotland

Level in Classification	Example	Hierarchy level
Division	Leached soils (3)	1
Major Soil Group	Podzols (3.3)	2
Major Soil Subgroup	Humus-iron podzols (3.3.2)	3
Series	Countesswells	4

The soil classification system used in Scotland is based on the description by a field surveyor of easily recognisable morphological features present in the vertical arrangement of soil layers or soil horizons - the 'soil profile'. The classification takes account of the whole profile and does not use diagnostic features or a key for soil recognition. The soil association is a grouping of soils developed in similar parent materials (based on lithology and mode of deposition). Each soil type in a soil association is a soil series, classified by major soil subgroup and drainage class. In summary, soils are classified into soil series in Scotland based on three main factors:

- Soil parent materials which are grouped into soil associations
- Genetic soil classification into major soil sub-groups
- Inherent natural drainage.

The genetic soil classification [2] for the mapping and representation of soils (Table 2) is hierarchical with three levels:

1. five divisions of soil (immature, non-leached, leached, gleys and organic soils)
2. 12 Major Soil Groups (MSG)
3. 41 Major Soil Sub-Groups (MSSG)

The soil series represents a lower (fourth) level and is defined by a unique combination of MSSG, natural drainage and parent materials, with over 800 individual soil series having been recognised. The soil association and MSSG form key components of the legend of the 1:250 000 scale soil map. Soil maps at higher resolutions (1:63,360) are generally able to represent individual soil series with the soil association still playing a key role in the formation of the map legend.

The number of series in any particular soil association depends on the bio-physiographic extent of the parent materials of the association. The semantics contained within the terms 'soil series' and 'soil association' are complex because, according to Glentworth and Muir (1963), "the soil series is the primary mapping unit and it is also the primary unit of classification". This means a single term, the soil series, has been used to define two concepts in Scotland, the soil type observed in the field and the soil mapping unit. The soil association inherits this dual role from this use of the soil series. The series within an association show differences in profile morphology, mainly because of differences in hydrologic conditions, and in some cases in glacial influences such as water-modification. The usefulness of the soil association and series for mapping is in grouping together soils

[2] http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/17852-1/CSavings/Handbook8

which occur in a related pattern in a landscape. The series and association are flexible units which were modified to suit the needs of a particular area and map scale. The soil type content within these map units is thus scale-dependent. This flexibility in the application of concepts from place to place was fine prior to the digital age of soils data but now causes conceptual problems for data consumers of digital soils data who expect more rigid data structures.

6.1 Soil associations

There are 150 soil associations mapped in Scotland. Soil associations having similar lithology or glacial history were grouped on the 1:250 000 scale map which had 110 cartographic association groups. On the previously-published 1:63 360 scale soil maps, 141 soil associations were identified and mapped. During mapping of new areas for the National Soil Map of Scotland, nine additional associations were identified and some pre-existing soil associations were merged into 23 combined soil associations. This exemplifies the pre-digital age where mapping units were used flexibly, with less regard for consistency between areas subsequently merged into this national map, now line-digitised as a single spatial data set.

6.2 History of soil classification in Scotland

The system adopted by the Soil survey of Scotland was published in various soil memoirs throughout the period of active soil survey (1940s until the 1980s) and culminated in a classification system adopted and used to map the soils of Scotland at 1:250 000 scale (Soil Survey of Scotland Staff, 1984). This classification has been used subsequently with minor name changes to some major soil subgroups (for example, Brown forest soils and Brown forest soils with gleying were renamed as Brown earths and Brown earths with gleying respectively to indicate that the soils were not specific to any particular land use or vegetation type. Other, additional soil types have also been recognised (see NSIS protocols; Lilly et al, 2010 and 2011).

Table 2. The Scottish soil classification system

Division	Major Soil Group	Major soil Sub Group	
1 Immature soils	1.1 Lithosols	1.1.1	Brown lithosol*
		1.1.2	Peaty lithosol*
	1.2 Regosols	1.2.1	Calcareous regosols
		1.2.2	Noncalcareous regosols
	1.3 Alluvial soils	1.3.1	Saline alluvial soils
		1.3.2	Mineral alluvial soils
		1.3.3	Peaty alluvial soils
	1.4 Rankers	1.4.1	Brown rankers
		1.4.2	Podzolic rankers
		1.4.3	Gley rankers
		1.4.4	Peaty rankers
		1.4.5	Humic rankers*
2 Non-leached soils	2.1 Rendzinas	2.1.1	Brown rendinzas
	2.2 Calcareous soils	2.2.1	Brown calcareous soils
3 Leached soils	3.1 Magnesian soils	3.1.1	Brown magnesian soils
	3.2 Brown Earth	3.2.1	Brown earths #
		3.2.2	Brown earths with gleying #
		3.2.3	Brown podzols*
	3.3 Podzols	3.3.1	Humus podzols
		3.3.2	Humus-iron podzols
		3.3.3	Iron podzols
		3.3.4	Peaty podzols
		3.3.5	Subalpine podzols
		3.3.6	Alpine podzols
		3.3.7	Peaty gleyed podzols*
4 Gleys	4.1 Surface-water gleys	4.1.1	Saline gleys
		4.1.2	Calcareous gleys
		4.1.3	Magnesian gleys
		4.1.4	Noncalcareous gleys
		4.1.5	Humic gleys
		4.1.6	Peaty gleys
	4.2 Groundwater gleys	4.2.1	Calcareous gleys
		4.2.2	Noncalcareous gleys
		4.2.3	Humic gleys
		4.2.4	Peaty gleys
		4.2.5	Subalpine gleys
		4.2.6	Alpine gleys
5 Organic soils	5.1 Peats	5.1.1	Eutrophic flushed peat
		5.1.2	Mesotrophic flushed peat
		5.1.3	Dystrophic flushed peat
		5.1.4	Dystrophic peat

* added since 1984
# name changed since 1984

7 Scottish soils data

The datasets describing Scottish soils are divided into primary and secondary data. The primary datasets consist of observations in the field, samples with analyses collected at known locations and times and the information on surveyor's field sheets and aerial photographs and field note books. The secondary datasets comprise derived data and semantic information. It is worth noting here that all of our digital soil map data sets were prepared manually for publication in paper form and subsequently digitised.

Many soil datasets are hybrid, being derived from combinations of primary and secondary data, often with expert interpretation. The semantics behind these derived data sets have to be gleaned from documents and sample data by the application of soils domain knowledge. The line-digitised soil map contains primary data in the form of polygon boundaries with semantic data to link soil profiles to polygon content. The link was made in Scotland by derivation of a simplified profile data set (see SSKIB described later). The primary data of polygon boundaries at any smaller map scale is derived either from primary data of polygon boundaries at a larger scale or from original field mapping. On the 1:250 000 scale soil map in Scotland, the generalisation process was manual and contains inherent spatial variability in the simplifications made by different soil surveyors or cartographers.

In order to explore and describe the relationships between primary data sets, derived data and derived information, we use four Soil Associations which exemplify a different aggregation process in compiling the 1:250 000 scale map.

- The Ashgrove Association only occurs on 1:63 360 scale maps which were simplified for the 1:250 000 scale map. The 1:63 360 map scale is backed up by detailed soil field mapping at the 1:25 000 scale. Air photographs were not used for mapping.
- The Lochinver Association occurs only on published 1:250 000 scale maps and was not mapped on the detailed 1:63 360 scale maps. New field mapping was carried out aimed at a reconnaissance scale of 1:50 000 for simplification to the 1:250 000 scale map. Air photographs were used over the entire Association mapping area.
- The Darleith and Arkaig Associations occur on published 1:63 360 and 1:50 000 scale maps, as well as in new areas of mapping for the 1:250 000 scale map. Some areas of this association were mapped using air photographs on the earlier series of maps, and all areas on the new areas.

The area covered by these associations, the number of soil profiles sampled and the square kilometres represented by each soil profile in the soil database are given in Table 3.

Table 3. Information on typical Soil Associations in Scotland

	Area estimates (sq. km.)			
Association	1:250 000 map	NSIS_1 5 km sites	Total number of Profiles *	Sq km of mapping per profile *
Ashgrove	137	50	28 [28]	4.9
Arkaig	12502	7900	588 [370]	21.3 [33.8]
Darleith/Kirktonmoor	2721	2275	358 [315]	7.6
Lochinver	3603	1500	89 [41]	40.5 [87.9]
Sub-total			[754]	
Total	77087	78175	14772 [10729]	5.2 [7.2]

* Numbers in square brackets [] refer to numbers of profiles with horizon samples

The Ashgrove Association is represented best by the number of sampled profiles, with each 4.9 sq. km. of mapping having a sampled soil profile and the Lochinver Association is least-well characterised, with 87.9 sq. km. of mapping represented by each soil profile. However, much of the mapped area of Lochinver Association is covered by soil mapping units with soil complexes having up to 35% peat and characterised by sampled peat profiles. There is thus wide variation in the amount of information for each soil association.

7.1 Primary datasets

The term primary dataset is used to indicate the pre-processed raw measurements and observational data from which summary statistics are derived, and the primary polygon data mapped in the field. In the soils domain, this is used for soil profile observations, measurements and classifications made at soil profile pits and soil profile sites and on samples collected from these sites. The meaning of primary data is extended from measurements to include the classification of the soil horizons and soil profile, if made while in the field, at each site. Measurements made in the laboratory from the samples are also included, but not any other data derived from them which refer to the soil profile or soil profile site.

7.1.1 The Scottish Soil Database

The James Hutton Institute is the data holder of the national Scottish Soil Database which currently contains soil profile data from 14722 soil profile locations. Soil profile descriptions were collected for all of these soil profiles and horizons were sampled in 10728 of the described profiles. In the database, field morphology data are coded and analytical data are recorded in the native format of the results. The profiles date from 1934 to the present day and comprise a number of categories, depending on the reason(s) for describing and sampling the profile. All the legacy analytical data were entered into the database in 1988 but field descriptions for 6000 of the oldest profiles have not yet been coded for database entry. Soil horizon samples are currently stored in the National Soils Archive of Scotland. There are approximately 43000 of these which are presently undergoing archiving and curation for the future. Once the archiving process is completed, the exact number of samples and their remaining weight will be catalogued. The horizon samples are stored in sealed containers in air-dried form. The legacy horizon data entry and archive sample weighing will take place over the next 5 years as part of the Scottish Government commitment to supporting the 'Underpinning Capacity' in Soils Information System development and nationally important datasets and archival material. The categories of soil profiles in the database are summarised below.

7.1.1.1 Subjective profiles chosen to represent soil series

These records are for 8010 representative soil profiles at subjectively-chosen sites. The profiles were collected during soil mapping to characterise a soil series by the surveyor responsible for the mapping. These include the 'type' profile as well as known variants. All the available analytical data for these samples has been entered in the Scottish Soil Database. The profile description data of only 1498 profiles have been coded and captured in the database. These are mainly those collected after 1978 when the computerised soil profile database was first populated.

7.1.1.2 Profiles for map unit variability characterisation

596 soil profiles collected on 5 transects of 1km length to characterise spatial variability in 3 of the most extensive soil series delineated at the 1:63 360 scale. These are Balrownie Series (2 transects), Corby Series (1 transect) and Caprington Series (2 transects). The transects were randomly selected from map unit polygons large enough to contain a 1-kilometre transect.

7.1.1.3 Experimental farm characterisation

Soil profiles to characterise experimental farms, using a combination of grid and transect sample designs. Several farms owned by research institutes in Scotland were characterised by this method.

Table 4. Experimental Farm surveys

Farm name	Sites	Sampling protocol
Lephinmore	1199	19 of the 1199 grid sites were selected randomly from within each soil type and re-visited to collect horizon samples
Mylnefield / Gourdie	325	Topsoil and subsoil layer samples from each profile. Sample depths were fixed, although the soil surveyor used discretion to alter the depths where the fixed depth crossed horizon boundaries.
Balruddery	118	Topsoil and subsoil layer samples from each profile. Sample depths were fixed, although the soil surveyor used discretion to alter the depths where the fixed depth crossed horizon boundaries.
Glensaugh	191	Sample depths were fixed, although the soil surveyor used discretion to alter the depths where the fixed depth crossed horizon boundaries.

7.1.1.4 National Soil Inventory of Scotland (NSIS)

This consists of 3127 soil profiles from the National Soil Inventory of Scotland baseline sample (NSIS_1), collected between 1978 and 1988. During this baseline survey, 33 locations on Orkney were not visited and the field data from these sites are missing. Soil horizon sampling was mandatory for the soil profiles at the 10km grid intersections. An additional 296 soil profiles on the 5km grid were sampled at the soil surveyor's discretion where sampling was thought to be adding useful data to the soils database.

7.1.1.5 National Soil Inventory of Scotland re-sample (NSIS_2)

A 20km grid subset of the NSIS_1 10km sampled profiles was re-visited and sampled between 2007 and 2009.

7.1.1.6 Rare soils re-sample

In 2010, 21 soil profiles representing soil types which are rare in Scotland were re-sampled.

7.1.1.7 Environmental Change Network soil profiles

The Environmental Change Network (ECN) was established at 8 sites in Great Britain to monitor change in a range of environmental phenomena. The JHI is responsible for describing and sampling soil profiles and properties at the three sites in Scotland.

7.1.1.8 Soil profiles from research experiment sites

Soil profiles were collected to characterise the soils at sites of research experiments or to characterise subjectively-selected profiles as part of the Institute research programme. The exact number is currently unknown although these are being catalogued within the National Soils Archive project.

7.1.1.9 Soil profiles in hardcopy (field observation data only)

In addition to the soil profiles descriptions recorded in the database there are hard-copy records of soil profiles for three main sub-sets of data:

- a 1km grid survey of the island of Mull with approximately 900 soil profiles
- stratified random sampling of mapping units in two areas in West Scotland (referred to as 'sample areas'). The soil map units for soil complexes on Mull and in Ardnamurchan and Morvern were studied by Bibby and Hudson (unpublished data, collected between 1973-1978) by using stratified random sampling of soil mapping units. This work to characterise soil map unit variability generated around 2000 soil profile descriptions and provides statistics for both intra- and inter-polygon variability in soil map units.
- many thousands of soil observations including a much reduced set of profile descriptions were recorded during soil mapping and are often referred to as

'inspection pits'. These exist as hand-written notes on 1:25 000 scale field-sheets adjacent to the locations (which are marked as dots) or in field notebooks with a link to the location on the field sheet or aerial photograph used by the surveyor.

Capturing this hard-copy information would be a particularly useful addition to the soil profile database. A start has been made with the scanning of the field note-books and the feasibility of geo-referencing this information will be evaluated during the underpinning capacity program.

7.1.2 Field maps

The field maps at 1:25 000 scale or larger contain the primary polygon data from which the derived maps for publication at 1:250 000, 1:63 360 and 1:50 000 scale were derived by manual generalisation and aggregation of the polygons.

7.2 Derived data sets

7.2.1 Soil maps of Scotland at 1:63 360 and 1:50 000 scales

At the date of this publication, the soil maps of Scotland at 1:63 360 and 1:50 000 exist in paper versions or as scan-digitised but not line-digitised electronic versions.

Polygons from the field map primary data (delineated at a scale of 1:25 000) were occasionally aggregated and generalised, often by a minimal amount, to prepare these maps for publication at the smaller scale. The underpinning 1:25 000 scale maps were often prepared for publication as uncoloured line copies, many of which have been subsequently digitised.

7.2.2 Soil Map of Scotland at 1:250 000 scale

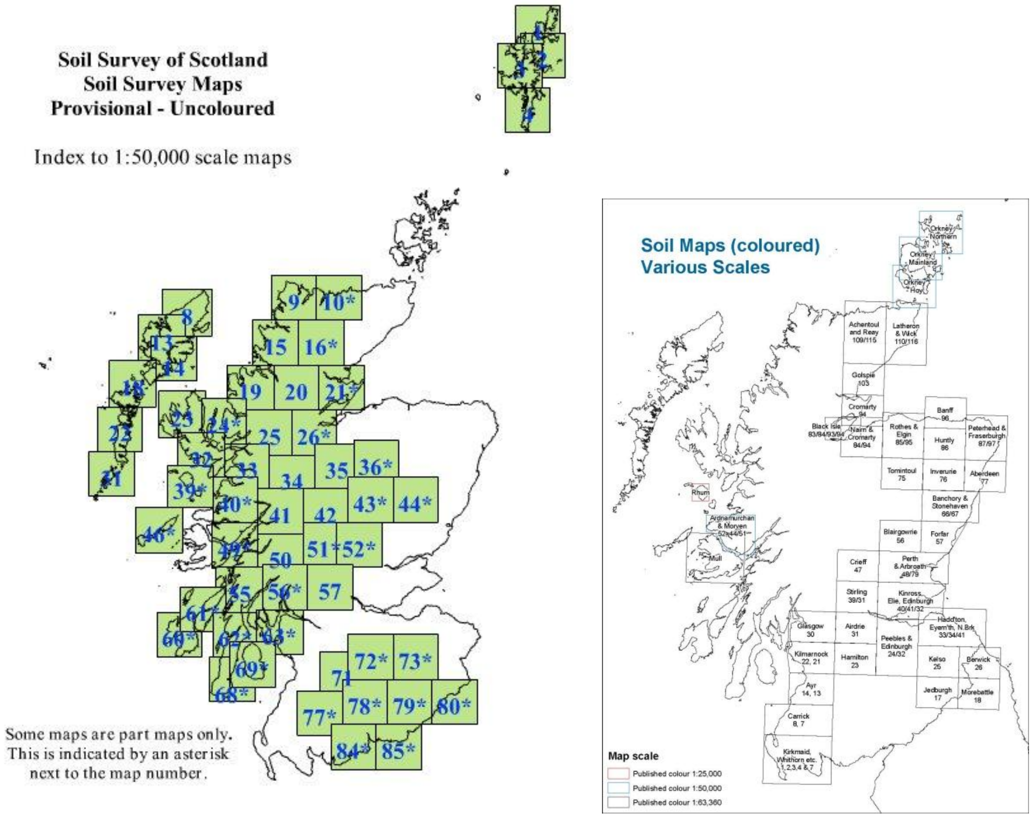
The paper Soil Map of Scotland at 1:250 000 scale was published in 1984 in a series of 7 paper map sheets. With each sheet there was a Land Capability for Agriculture map at the same scale and a sheet-specific handbook describing landforms, soils, vegetation and Land Capability for Agriculture. The soil classification and other information relevant to the whole series were published in a separate handbook, Number 8 in the series (Soil Survey Staff, 1984). The digital soil map content was line digitised several years after the maps were published.

7.2.2.1 Polygon generalisation for Soil Map of Scotland at 1:250 000 scale

The polygons on the Soil Map of Scotland at 1:250 000 scale were generalised manually from two more-detailed map series, with the spatial cover shown in Figure 1:

- Published paper 1:63 360 (some 1:50 000) scale soil maps of Scotland
- Provisional published 1:50 000 reconnaissance mapping, mainly in the uplands of Scotland.

Figure 1. Extent of the two map sets used to produce the Soil Map of Scotland at 1:250 000 scale



The polygons on Soil Map of Scotland at 1:250 000 scale were manually generalised from these two source maps by 20 individual soil surveyors using a minimal set of generalisation guidelines. The wide range in knowledge about previously mapped areas and the different approaches taken by the individual soil surveyors mean that the semantics behind polygon and boundary generalisation are spatially heterogeneous. Even in the areas of new reconnaissance mapping specifically for the Soil Map of Scotland at 1:250 000 scale, some soil surveyors developed very detailed reconnaissance maps while others produced reconnaissance maps with the final scale of 1:250 000 in mind. Also, but having less impact on the map generalisation process, the underlying soil profile data were spatially and temporally heterogeneous.

7.2.3 Scottish Soil Knowledge and Information Base (SSKIB)

The Scottish Soils Knowledge and Information Base (SSKIB; Lilly et al. 2004) holds statistical summary data for each soil taxonomic unit delineated on the 1:250 000 soil map of Scotland. This map has soil map units based on a combination of parent material (soil association) and landform and has a simple numeric key which contains 580 soil map units plus further subdivision of the organic soil units (Soil Survey Staff 1984). As the map units were based on landform units, they invariably contain more than one soil taxonomic unit and the proportions of each of these units in the map units were subsequently estimated. Also at a later date, the level of classification was improved by the identification of the specific soil series (based on major soil subgroup, parent material and drainage category) that comprised each soil map unit.

A digitized version of the 1:250 000 scale map comprises around 85 000 geo-referenced 1 km^2 grid cells and each has the proportion and name of all the individual soil taxonomic units in that cell. Overlaying with a land cover map allows the identification of the specific phases (cultivated or uncultivated) of each taxonomic unit within these grid cells. The distinction between cultivated and uncultivated versions of the same soil series is important as both the soil chemistry and horizon sequences differ. Many soil taxonomic units can occur as both a cultivated and an uncultivated phase therefore typical horizon sequences and horizon depths for both phases were derived from soil morphological information held in the Scottish Soils Database. Once the typical horizon sequence for each soil series had been derived using expert judgement and a review of soil profile descriptions, summary statistics were derived from the Scottish Soil Analytical Database using only those soil horizons with the same genesis and broad morphological characteristics to those identified as typical for these series for example Bs, Bsm, Bs1 or Bs2 horizons would be matched to a Bs horizon but not to a Bg horizon.

The number of observed soil profiles with horizon data in each soil series is very variable (from 0 to >100). Where there are no observed soil profiles, a process of selecting analogue soils from similar parent materials and characteristics was followed.

7.2.4 Classification of soil properties

The methods for measuring soil properties in the field and in the laboratory have evolved through time and a description of changes follows.

7.2.4.1 Soil colour

The Munsell colour system has been in general use in Scotland since around 1954. The description of colours in the earlier profiles was in general terms with no reference to colour charts. Profiles prior to 1954 have less reliable colours but air-dried samples in the National Soils Archive could be measured. The recording of air-dried colours is especially useful for allocating the Bs horizon designation in podzols.

7.2.4.2 Soil texture

Soil texture is described in two ways: field texture is recorded in the field and particle size classes are determined from laboratory determinations of particle size fractions.

7.2.4.3 Field texture

Field texture is determined by manipulating soil between the fingers and assessing a field texture class from the results of the manipulations. The field texture classification is ‘standardised’ by referencing against particle size measurements.

7.2.4.3.1 Mechanical composition or particle size class

The first memoirs of the Soil Survey of Scotland (Glentworth, 1954; Mitchell and Jarvis, 1956; used the International System for particle size measurement. Muir (1956) first noted that the USDA scheme would be used as well. Both sets of classes were used systematically from sample_id 103553 onwards. A comparison between USDA and International size ranges is in Table 5.

Table 5. Comparison of USDA and International particle size fractions

	USDA System		International System	
	Name of fraction	Size range in microns	Name of fraction	Size range in microns
	Very coarse sand	2000-1000		
	Coarse sand	1000-500	Coarse sand	2000-200
	Medium sand	500-250		
	Fine sand	250-100	Fine sand	200-20
	Very fine sand	100-50		
	Silt	50-2	Silt	20-2
	Clay	<2	Clay	<2

7.2.4.4 Soil Organic Matter

Methods for determination of soil carbon and nitrogen have been brought together recently by using a flash-combustion / gas chromatography method. Earlier, wet-chemistry methods were used for some of the measurements in the database.

7.2.4.4.1 Soil carbon

Soil carbon was measured by the wet combustion method using standard potassium dichromate solution (Walkley and Black, 1934)

7.2.4.4.2 Soil pH in water

Soil pH was determined using a glass electrode inserted into a suspension comprising 15g of <2mm air dried soil and 45 ml distilled CO_2 – free water. The soil and water were mixed, thoroughly shaken and left to stand for 4 hours before inserting the class electrode.

7.2.4.4.3 Soil base saturation

Base saturation is the ratio of the sum of the base cations (Ca, Mg, K, Na) to the sum of cations (Ca, Mg, K, Na, H, Al) expressed as a percentage. The exchangeable base cations in a soil are removed in solution by exchanging them with 1M NH_4 from an ammonium acetate solution (buffered to pH7 using ammonium acetate). About 10g of air dried soil is used and the soil/NH_4 solution is allowed to equilibrate overnight and this is repeated over 3 nights. The concentration of cations which are exchanged are then estimated using inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

In acid soils hydrogen ions are capable of releasing aluminium ions from clay minerals. The sum of these ions is known as the exchangeable acidity. Extraction of hydrogen and aluminium ions by a neutral salt solution and back titration with a known alkali solution enables an estimate of the exchangeable acidity present within the soil. Approximately 5g of air dried soil is mixed with 25 ml barium acetate buffered to pH 7 before use, using either ammonia solution or acetic acid. This is left overnight. Using an auto-titrator, barium hydroxide solution is added and the volume recorded.

8 Soils of Northern Ireland

The soils of Northern Ireland, like those of Scotland, are classified using a genetic soil classification system which considers the regional soil forming factors. A brief overview of the major soil forming factors will be given to contextualize the description of the soil classification system.

8.1 Climate

In terms of the Climatic Areas of Europe, (Hartwich *et al*, 2005) the entire island of Ireland is mapped as a region having a ‘temperate oceanic to sub-oceanic’ climate. With regard to Northern Ireland this equates to a mean average temperature in low altitude areas which varies between 8.5 ^{0}C and 9.5 ^{0}C, falling to 4.5^{0}C at its highest location. Rainfall is spatially highly variable, with high annual averages in the upland west of 1950 mm to just under 800 mm in the lowland east. [Met Office 2012]

8.2 Physiography and geology

With a land area of only 13,550 km^2, Northern Ireland has a complex solid geology, with rocks from every system apart from the Cambrian represented. Superimposed on this are widespread glacial deposits from the Midlandian glaciation, and more recent peat development and alluvial deposits.

Northern Ireland can be considered in terms of four broad blocks of geology, running from the oldest rocks to the youngest:

8.2.1 The metamorphic basement rocks of the North-West

Most of this block is made up of Dalradian period rocks, comprised of metamorphosed mudstones and sandstones with relatively thin interbedded limestones. Being some of the oldest rocks in Northern Ireland they have been subjected to past folding and faulting with much fluid movement within the rocks. These fluids have at times been mineralised and in some zones may be represented in soils as relatively high levels of trace elements.

8.2.2 The Lower Palaeozoic rocks of the South-East

The Lower Palaeozoic rocks are mostly greywacke sandstones with subordinate slaty mudstones. They have been strongly compressed and, having very few pore spaces, carry virtually no groundwater except in joints or in weathered zones. These rocks have been intruded in many places by narrow igneous dykes, mostly of dolerite. However, in south Down the massive intrusions of the late Lower Palaeozoic Newry granodiorite and the much younger Tertiary granites of the Mourne Mountains are found.

8.2.3 Devonian and Carboniferous rocks of the South-West

The highly complex and diverse Carboniferous sedimentary rocks include a relatively high proportion of limestones or lime-cemented rocks, although base-poor sandstones are also a feature of some areas in this region. The Devonian rocks (or Old Red Sandstone) and oldest Carboniferous rocks are mostly sandstones and conglomerates.

8.2.4 The Palaeogene volcanic lavas and Mesozoic rocks of the North-East

This area is the youngest geological entity in Northern Ireland. The Mesozoic rocks are mostly hidden by the later volcanic lavas but Triassic rocks, especially the Sherwood Sandstone, which is an important local aquifer, and Mercia Mudstone (marl on soil maps) significantly crop out over a sizeable area of the Lagan Valley. The Antrim Lava Group (of Palaeogene/Tertiary age), which covers most of County Antrim, part of County Londonderry, underlies much of Lough Neagh and extends to north County Armagh is mostly basalt lavas. Although divided into upper, middle and lower units the lavas are all of similar composition, to the extent that geochemically they are indistinguishable except perhaps for some of the trace elements. Above the basalts, under, and around part of Lough Neagh are Palaeogene clays and silts of the Lough Neagh Group. These clays are poorly consolidated and include brown coals (lignite) in places.

8.2.5 Glaciation.

Although numerous glacial events have occurred in Northern Ireland only the last of these glaciations, the Midlandian, has left widespread significant evidence. The final major re-advance of this ice took place about 25,000 years ago when ice moved generally northwards and southwards from the centre of the Province, depositing and moulding the till into drumlins and as the ice melted about 13,000 years ago, the resulting flood waters deposited moraine and outwash sands and gravels. Till from this glaciation covers up to 75% of Northern Ireland and is, in the vast majority of cases, sourced from the local underlying geology. Moraines and glacial sands and gravels are widespread throughout the Province and can be locally extensive. [Bazley 1997].

9 Northern Ireland Soil Survey Soil Classification

The soil classification used as the basis for Soil Survey in Northern Ireland was devised by Brian Avery in England in the 1960s, and published in different forms until its final refinement as the Soil Classification for England and Wales (Higher Categories), (Avery, 1980). The original classification had 10 primary categories, called Major Soil Groups, however, the Northern Ireland Soil Survey amalgamated the first three categories into one, covering all raw undeveloped and thin soils, and here called Rankers. Most of the rankers (except rare gleyed rankers) are freely draining, and so this category joins the Brown Soils (or Brown Earths) and Podzols as the three categories of freely draining soils identified in Northern Ireland.

Avery's Major Soil Group, Pelosols, which are red in colour, slowly permeable clay-rich soils, have been incorporated in the gley class in Northern Ireland as their gleyic features are masked by the red colouring. Avery has two further Major Soil Groups, "Surface water gleys" and "Ground water gleys", and while the Northern Ireland Soil Survey retains the concept of two types of soil water table being responsible for gleying, it is accepted also that the difference between the two situations may be academic at many sites in the Province. It was thought to be of greater practical and applied importance to divide the gleys, which cover 60 per cent of land area of Northern Ireland, into three degrees of gleying. Thus each surface or ground water gley was divided into either a class 1, 2 or 3. Peat soils were recorded at field inspection as any organic soil more than 50 cm deep (drained or undrained). The Northern Ireland soil classification system is summarized in Table 6.

Table 6. The Northern Ireland Soil Classification System.

Major Soil Group	**Soil Series**
Rankers	Rock Rankers
	Gleyed Rankers
	Brown Rankers
	Humic Rankers
	Ferric Rankers
	Podzolic Rankers
Brown Soils	Brown Earths
	Gleyed b-Horizon Brown Earths
	Shallow Brown Earths
	Calcareous Brown Earths
	Ferric Brown Earths
Podzols	Brown Podzolics
	Shallow Brown Podzols
	Podzols
	Peaty Podzols
	Stagnopodzols
Gleys	Pelosols
	Surface water gley class 1
	Surface water gley class 2
	Surface water gley class 3
	Ground water gley class 1
	Ground water gley class 2
	Ground water gley class 3
	Surface water humic gley
	Groundwater humic gley
Peat	Peat

Soil Classification in Northern Ireland is based on the identification of morphological features and sequence of diagnostic horizons at survey points. Soil series is the principal taxonomic unit and is defined as a grouping of soils with a similar type and arrangement of diagnostic horizons developed on the same parent material. The survey work for the Northern Ireland Soil Survey was carried out between 1988 and 1996.

10 Northern Ireland Soil Datasets

The AFBI Soil Attributes Dataset for Northern Ireland derives from samples taken during the course of the Soil Survey, principally at 5 km grid intersection points, although additional sampling points were taken for non-represented soil series. The dataset consists of field descriptions of the horizons and laboratory analysis of samples taken. In total, 553 profile locations are included in the dataset with 1590 horizons being represented.

10.1 Field and laboratory procedures

All field descriptions of horizon properties followed procedures described in Hodgson (1976) and laboratory determinations followed Soil Survey of England and Wales methods (Avery & Bascomb, 1982).

11 Technical interoperability

At the time of writing, no testing was possible using the HALE tool. A UML model was reverse engineered from the JHI soil profile data, but no comparison with Soil ML was made due to time constraints.

Two datasets were planned for use in the testing, both with relevance for development of a Scottish extension of SoilML:

- The National Soils Inventory 10 km intersect soil profile dataset. This dataset is the pilot dataset for Scottish Soil Database and Website, but was not compared to SoilML in time for this report.
- The shape file for the 1:250 000 soils dataset.

12 Translation of Scottish Soil Survey (SSS) data to WRB

The World Reference Base (WRB) soil classification (IUSS Working Group WRB, 2007) is based on diagnostic features in the soil profile and uses measurements of soil properties according to FAO Guidelines for Profile Description (2006). The SSS classification, which had its origins in the Canadian (and ultimately, the Russian system) is based on genetic features in the whole soil profile as viewed in the field. This differs from the FAO/WRB system which uses diagnostic features linked to individual horizons or combinations of horizons. In Scotland, the classification is based on an appreciation of the complete soil profile, rather than being built up from several diagnostic criteria, horizons or properties.

The measurements required to determine the WRB diagnostic criteria are incomplete in the Scottish Soils Database. There are three potential reasons for this:

- Property measurement was not carried out
- Different analytical methods
- Class limits were different

The WRB classification system uses the FAO (2006) properties for diagnostic horizons and criteria. The differences between the FAO properties and those of the Soil Survey of Scotland (SSS) are described first, followed by the assumptions made in estimating WRB diagnostic criteria and steps taken to align the SSS system of measurement to the FAO/WRB system.

12.1 Translation of soil properties from SSS to FAO

A description of the differences in term names and term descriptions for soil property measurements in Scotland from those given in the summary of analytical procedures for soil characterization (WRB, 2007) are listed here. The differences in morphological descriptions are also described.

12.1.1 Degree of decomposition of peat

Recording of the degree of decomposition in peat was simplified to 3 classes in SSS. The FAO system described 6 degrees of decomposition / humification, grouped into 3 classes for WRB. Only recently was the 10-part von Post scale of decomposition applied systematically in the field, during the NSIS_2 re-sampling campaign. The precise definitions for the 3 classes used in the WRB system are not identical to those used in Scotland, but the three terms are similar enough to use in a direct translation to WRB.

Table 6. Degree of decomposition of peat FAO compared to SSS

SSS		FAO / WRB	
Term	Description	Term	Description
Fibrous	Plant remains are easily recognised; the original structure and some of the mechanical strength of the plant materials are maintained.	Fibric	Having, after rubbing, two-thirds or more (by volume) of the *organic* material consisting of recognizable plant tissue
Semi-fibrous	Consists mainly of partially decomposed plant remains which are recognisable but fibrous in appearance only; when moist, peat is soft and plastic in character.	Hemic	Having, after rubbing, between two-thirds and one-sixth (by volume) of the *organic* material consisting of recognizable plant
Amorphous	Absence of recognisable plant remains and highly decomposed.	Sapric	Having, after rubbing, less than one-sixth (by volume) of the *organic* material consisting of recognizable plant tissue

12.1.2 Field texture and laboratory particle size classification

Until 1986, the SSS used the USDA classification system for particle size fractions measured in the laboratory. In January 1986, the classification system changed to the BSTC. For the practical purpose of mapping soil types at 1:250 000 scale the differences between these classifications and the FAO / WRB classification system are negligible.

12.1.2.1 Field texture

Field texture was calibrated against measured particle size and by comparison with experienced surveyors. Although not part of the field identification protocols, surveyors would make use of flow charts such as Table 7 to determine field textures.

Table 7. Flow chart to determine field texture

Number	Question	Answer	Go to
1	Does the moist soil feel or sound gritty?	Yes No	2 5
2	Does the soil lack all cohesion?	Yes No	Sand 3
3	Is it difficult to roll the soil into a ball?	Yes No	Loamy sand 4
4	Does the soil feel smooth and silky as well as quite gritty?	Yes No	Sandy silt loam/loam Sandy loam
5	Does the soil mould to form an easily deformed ball and feel smooth and silky but with some coarser grains?	Yes No	Silt loam 6
6	Does the soil mould to form an easily deformed ball and feel smooth and silky?	Yes No	Silt 7
7	Does the soil mould to form a strong ball that smears but does not take a polish?	Yes	8

		No	9
8	Is the soil also rough and gritty?	Yes No	Sandy clay loam 9
9	Is the soil also smooth and silky?	Yes No	Silty clay loam Clay loam
10	Does the soil mould like plasticine, polish and feel very sticky when wetter?	Yes No	11 **Start again!!**
11	Is the soil also rough and gritty?	Yes No	Sandy clay 12
12	Is the soil also smooth and buttery	Yes No	Silty clay Clay

12.1.2.2 Laboratory measurement of particle size

The laboratory measurement of particle size class followed the Bouyoucos method (1926 & 1927). Briefly, 50g of air-dried < 2mm soil was added to a litre flask along with 500 ml distilled water and 10 ml 1M Sodium hydroxide (latterly sodium hexametaphosphate, $[NaPO_3]_6$ was used. The solution was shaken end-over-end overnight. The suspension was then added to a cylinder containing a hydrometer and made up to 1l by the addition of distilled water. After removal of the hydrometer, the suspension was then thoroughly shaken for 1 minute, placed on a bench and a timer started. Readings were taken at specific intervals to match the particle size of interest. A correction was made for temperature differences and for organic matter contents.

12.1.2.3 Particle size and texture triangle

In Scotland, until 1986, the USDA texture triangle was used with particle size fractions measured in the laboratory for the allocation of a measured texture class. After 1986, the laboratory-measured particle size classes are interpreted on different texture triangles to the FAO and USDA systems. Additional textural qualifiers are used to distinguish between sand coarseness and organic-rich horizons.

Definition for texture qualifiers

F Fine – more than two-thirds of the sand fraction (0.06-2 mm) is between 0.06 and 0.2 mm.
M Medium – less than two-thirds of the sand fraction is between 0.06 and 0.2 mm and less than one-third of the sand fraction is larger than 0.6 mm.
C Coarse – more than one-third of the sand fraction is larger than 0.6 mm.
H Humose – has insufficient organic matter to be classed as organic but has:
a) more than 7% organic carbon (12% organic matter) if the mineral fraction (<2 mm) has 50% or more clay, or
b) more than 4.5% organic carbon (8% organic matter) if the mineral fraction has no clay, or
c) proportional organic carbon contents if the clay content is between 0 and 50%.

(from Hodgson, 1974)

Particle size is a diagnostic criteria for Alisols, Acrisols, Arenosols, Vertisols, Luvisols and Lixisols and for diagnostic horizons/qualifiers abruptic, acric, alic, arenic , aridic, argic, cambic, clayic, irragic, luvic, natric, nitic, plaggic, siltic, takyric, and vertic.

12.1.3 Soil structure

The main structure attribute used for WRB classification is the shape, with the strength mentioned as a qualification to the shape in only a few cases. Terms such as well-structured (in mollic and voronic horizons only) rather than strongly-developed are often used in the WRB classification. It is likely that the minor differences in description of the degree and size between SSS and FAO will have minimal impact on translation of soil profile data to WRB. According to FAO (2006) structure is used in the definition of cambic, mollic, umbric, anthric, voronic, natric, nitic, vertic, anthraquic, irragric, fragic, takyric and yermic horizons. Structure also features in the grumic, mazic and hyperochric qualifiers. Stratification, while not explicitly a structural attribute, is mentioned within structure in the definition for the fluvic qualifier (FAO, 2006).

12.1.3.1 Structure degree (SSS) or grade (FAO, 2006)

There is one additional class of 'Very weak' in the SSS description for structure degree. This difference is not likely to have an impact on WRB soil classification as structure is only used for diagnostic purposes when it is strongly- or well-developed.

Table 8. Comparison of structure degree (SSS) with structure grade (FAO)

Degree class name	SSS description (Degree)	FAO description (Grade)
Very weak	Poorly formed, indistinct, weakly coherent peds that are barely observable in place. When disturbed, the soil breaks into a few entire peds, many broken peds and much unaggregated material.	
Weak	Poorly formed, indistinct, weakly coherent peds that are barely observable in place. When disturbed, the soil breaks into a few entire peds, many broken peds and much unaggregated material.	Aggregates are barely observable in place and there is only a weak arrangement of natural surfaces of weakness. When gently disturbed, the soil material breaks into a mixture of few entire aggregates, many broken aggregates, and much material without aggregate faces. Aggregate surfaces differ in some way from the aggregate interior.
Moderate	Well formed moderately durable peds which are evident but not distinct in undisturbed soil. When disturbed, the soil breaks down into a mixture of many distinct entire peds, some broken peds and a little unaggregated material.	Aggregates are observable in place and there is a distinct arrangement of natural surfaces of weakness. When disturbed, the soil material breaks into a mixture of many entire aggregates, some broken aggregates, and little material without aggregates faces. Aggregates surfaces generally show distinct differences with the aggregates interiors.
Strong	Durable peds that are quite evident in undisplaced soil, adhere weakly to one another and withstand displacement, separating cleanly when the soil is disturbed. Disturbed soil material consists very largely of entire peds and includes a few broken peds and little or no unaggregated material. If the soil separates with little manipulation into entire, durable peds, the grade of the soil may be described as *very strongly developed*.	Aggregates are clearly observable in place and there is a prominent arrangement of natural surfaces of weakness. When disturbed, the soil material separates mainly into entire aggregates. Aggregates surfaces generally differ markedly from aggregate interiors.
Apedal or structureless - Single grain	No observable aggregation; without a definite orderly arrangement of natural lines of weakness. Soil which separates when disturbed into individual primary particles with such coatings as adhere to them. The primary particles may however be held together by surface tension when very moist or wet.	
Apedal or structureless - Massive	No observable aggregation; without a definite orderly arrangement of natural lines of weakness. When disturbed soil breaks into masses which may be easily crushed (or broken) into smaller pieces or may be strongly coherent. The ease with which they can be crushed is described under 'Consistence'. Massive soil materials can have a wide range of consistence properties".	

12.1.3.2 Structure size

The size range class depends on the structure shape. The FAO system has some additional shape classes, but the size classes are almost identical to those of the SSS.

Table 9. Comparison of SSS structure size with FAO structure size

		Size range in mm	
Size	Shape	SSS	FAO
Very fine	Platy and granular	< 1	< 1
	Prismatic	< 10	< 10
	Columnar and wedge-shaped		< 10
	Angular and subangular blocky	< 5	< 5
	Crumbly, lumpy, cloddy		< 5
Fine	Platy and granular	1 -2	1 -2
	Prismatic	10 - 20	10 - 20
	Columnar and wedge-shaped		10 - 20
	Angular and subangular blocky	5 – 10	5 – 10
	Crumbly, lumpy, cloddy		5 – 10
Medium	Platy and granular	2 – 5	2 – 5
	Prismatic	20 - 50	20 - 50
	Columnar and wedge-shaped		20 - 50
	Angular and subangular blocky	10 – 20	10 – 20
	Crumbly, lumpy, cloddy		10 – 20
Coarse	Platy and granular	5 - 10	5 – 10
	Prismatic	50 - 100	50 - 100
	Columnar and wedge-shaped		50 - 100
	Angular and subangular blocky	20 – 50	20 – 50
	Crumbly, lumpy, cloddy		20 – 50
Very coarse	Platy and granular	> 10	> 10
	Prismatic	> 100	100 - 500
	Columnar and wedge-shaped		100 - 500
	Angular and subangular blocky	> 50	> 50
	Crumbly, lumpy, cloddy		> 50
Extremely coarse	Prismatic, columnar and wedge-shaped		> 500

N.B. The FAO system uses thin or thick as additional descriptors for fine and coarse.

12.1.3.3 Structure shape (SSS) or type (FAO, 2006)

The descriptions of platy, prismatic, columnar, angular blocky, subangular blocky and granular are very similar for SSS and FAO profile description protocols. The FAO system makes additional descriptions of rock structure, wedge shapes and crumbs, lumps or clods.

Table 10. Comparison of structure shape (SSS) with structure type (FAO)

Shape or type	SSS description (Shape)			FAO description (Type)	
Platy	Plate-like with one dimension (the vertical) limited and much less than the other two; arranged around a horizontal plane; faces mostly horizontal			Flat with vertical dimensions limited; generally oriented on a horizontal plane and usually overlapping.	
Prismatic	Prism-like with two dimensions (the horizontal) limited and considerably less than the vertical; arranged around a vertical line; vertical faces well defined; vertices angular			The dimensions are limited in the horizontal and extended along the vertical plane; vertical faces well defined; having flat or slightly rounded surfaces that are casts of the faces of the surrounding aggregates. Faces normally intersect at relatively sharp angles. Prismatic structures with rounded caps are distinguished as Columnar.	
Columnar	Aggregates similar to prisms but with rounded tops are described as columnar. Columnar aggregates are rare in the British Isles.				
Angular blocky	Block-like, polyhedron-like, or spheroidal, with three dimensions	Block-like; blocks or polyhedrons having plane or curved surfaces that are	Faces flattened; most vertices	Blocks or polyhedrons, nearly equidimensional, having flat or slightly rounded surfaces that are casts of the faces of the	Faces intersecting at relatively sharp angles

	of the same order of magnitude, arranged around a point	casts of the moulds formed by the faces of the surrounding peds	sharply angular	surrounding aggregates.	
Subangular blocky			Mixed rounded and flattened faces with many rounded vertices		Faces intersecting at rounded angles.
Granular		Spheroids or polyhedrons having plane or curved surfaces with slight or no accommodation to the faces of surrounding peds		Spheroids or polyhedrons, having curved or irregular surfaces that are not casts of the faces of surrounding aggregates.	
Rock structure				Rock structure includes fine stratification in unconsolidated sediment, and pseudomorphs of weathered minerals retaining their positions relative to each other and to unweathered minerals in saprolite from consolidated rocks.	
Wedge-shaped				Elliptical, interlocking lenses that terminate in sharp angles, bounded by slickensides; not limited to vertic materials.	
Crumbs, lumps and clods				Mainly created by artificial disturbance, e.g. tillage.	

12.1.4 Consistence

As used by the SSS, consistence refers to soil characteristics determined by the kind of cohesion and adhesion. It describes the strength, characteristics of failure, stickiness, plasticity, cementation and induration. Strength and characteristics of failure vary widely with soil-water state and therefore the moisture status of the soil at the time of assessment is also recorded. In general, cohesion is assessed under conditions of the natural soil moisture status which has a degree of subjectivity though guidelines are given to assess this status in the field. The FAO Guidelines (2006) additionally state that consistence depends greatly on the amount and type of clay, organic matter and moisture content of the soil and includes soil properties such as friability, plasticity, stickiness and resistance to compression. The FAO also suggest that, in addition to the soil consistence in the natural moisture condition of the profile, where the soil is dry, wet consistence can always be described by adding water to the soil sample, and where applicable, the smeariness (thixotropy) and fluidity may also be recorded.

According to FAO Guidelines (2006) consistence is used to identify petrocalcic, takyric, fragic and petroplinthic horizons, although strictly a petroplinthic horizon is indurated or cemented, rather than hard

12.1.4.1 Field moisture state

The FAO system has two more classes than the SSS system.

Table 11. Field moisture state descriptors SSS

Category	Description SSS	Description FAO
Very wet		Free drops of water without crushing
Wet	Glistening water films visible on peds and particles	Free water on crushing
Very moist	At or near field capacity. Fingers quickly moistened when soil is handled	
Moist	Soil does not change colour when moistened	No colour change on wetting
Slightly moist	Soil only darkens slightly when moistened	Going slightly dark on wetting
Dry	Colour darkens when wetted	Goes dark on wetting
Very dry		Goes very dark on wetting

12.1.4.2 Consistence when dry

This is described when the moisture state of the field soil is dry.

Table 12. Comparison of dry consistence descriptions for SSS with FAO

Category	Description SSS	Description FAO
Loose	Non-coherent	Non-coherent
Soft	Only very weakly coherent, breaks very easily	Soil mass is very weakly coherent and fragile; breaks to powder or individual grains under very slight pressure.
Slightly hard	Weak resistance to pressure but broken easily between finger and thumb	Weakly resistant to pressure; easily broken between thumb and forefinger.
Hard	Moderate resistance to pressure, but can only just be broken between finger and thumb	Moderately resistant to pressure; can be broken in the hands; not breakable between thumb and forefinger.
Very hard	Very resistant to pressure but can be broken in the hands	Very resistant to pressure; can be broken in the hands only with difficulty.
Extremely hard	Cannot be broken by hand	Extremely resistant to pressure; cannot be broken in the hands.

Note: The FAO uses additional categories, needed occasionally to distinguish between two horizons or layers: SSH, soft to slightly hard; SHH, slightly hard to hard; and HVH, hard to very hard.

12.1.4.3 Consistence when moist

Table 13. Comparison of consistence when moist descriptions SSS to FAO

Category	Description SSS	Description FAO
Loose	Non-coherent	Non-coherent
Very friable	Crushes under very gentle pressure and coheres	Soil material crushes under very gentle pressure, but coheres when pressed together.
Friable	Crushes easily under gentle or moderate pressure and coheres	Soil material crushes easily under gentle to moderate pressure between thumb and forefinger, and coheres when pressed together.
Firm	Crushes under moderate but noticeable pressure	Soil material crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.
Very firm	Crushes only under strong pressure, but can only just be crushed between finger and thumb	Soil material crushes under strong pressures; barely crushable between thumb and forefinger.
Extremely firm	Crushes only under very strong pressure, cannot be crushed between finger and thumb	Soil material crushes only under very strong pressure; cannot be crushed between thumb and forefinger.

Note: Additional codes are: VFF, very friable to friable; FRF, friable to firm; and FVF, firm to very firm.

12.1.4.4 Consistence when wet

This is described in terms of plasticity and stickiness. There is very little difference between SSS and FAO guidelines.

12.1.4.4.1 *Plasticity*

Table 14. Comparison plasticity descriptions SSS and FAO

Category	Description SSS	Description FAO
Non-plastic	Will not form a 4 cm x 6 mm wire	No wire is formable.
Slightly plastic	Will form a 4 cm x 6 mm wire but easily fractured or deformed	Wire formable but breaks immediately if bent into a ring; soil mass deformed by very slight force.
Plastic	4 cm x 4 mm wire easily formed	Wire formable but breaks if bent into a ring; slight to moderate force required for deformation of the soil mass.
Very plastic	4 cm x 2 mm wire easily formed	Wire formable and can be bent into a ring; moderately strong to very strong force required for deformation of the soil mass

Note: for the FAO system, additional codes are: SPP, slightly plastic to plastic; and PVP, plastic to very plastic.

12.1.4.4.2 *Stickiness*

Table 15. Comparison of stickiness descriptions SSS to FAO.

Category	Description SSS	Description FAO
Non-sticky	Does not adhere to fingers	After release of pressure, practically no soil material adheres to thumb and finger.
Slightly sticky	Adheres to finger or thumb when pressed	After pressure, soil material adheres to both thumb and finger but comes off one or the other rather cleanly. It is not appreciably stretched when the digits are separated.
Sticky	Adheres to finger and thumb when pressed	After pressure, soil material adheres to both thumb and finger and tends to stretch somewhat and pull apart rather than pulling free from either digit.
Very sticky	Adheres strongly to finger and thumb	After pressure, soil material adheres strongly to both thumb and finger and is decidedly stretched when they are separated.

Note: for the FAO system, Additional codes are SSS, slightly sticky to sticky; and SVS, sticky to very sticky.

12.1.5 Induration, cementation and compaction

The SSS protocol makes a distinction between induration and cementation, while the FAO system describes induration, cementation and compaction together.

12.1.5.1 Induration as described by SSS

As described by the SSS, an indurated horizon has a high degree of compactness and density, which means that considerable physical effort is required to dig through these soil layers. Indurated horizons are much more resistant to vertical than horizontal disruption and will generally exhibit some degree of explosive (brittle) failure when small pieces are compressed along its horizontal axis. Strongly and moderately indurated horizons are generally not penetrated by roots even though a characteristic of these layers is the presence of narrow round holes.

Table 16. Induration description as described by SSS

Category	Description SSS
Weak	No great force is required to break the specimen, but a well defined brittle fracture is present
Moderate	Can be broken with some effort with the hands
Strong	Cannot be broken with the hands, can only be crushed under foot or with a hammer

12.1.5.2 Cementation as described by SSS

As described by the SSS, cementation of soil is caused by substances such as calcium carbonate, humus, silica or compounds of iron, manganese or aluminium. A cemented soil does not slake when an air-dried block is placed in water for one hour. However, if only weakly cemented, the hardness of the soil mass will be somewhat reduced by the same treatment, but the brittle fracture will be retained.

Table 17. Cementation as described by SSS

Category	Description SSS
Weak	Brittle and hard but can be easily broken by the hand. When placed between extended forefinger and thumb, the applied pressure will force the soil mass to explode rather than crumble
Moderate	Brittle but can only be broken with extreme pressure in the hand. Easily broken with a hammer
Strong	Can only be broken by a hammer, which generally rings as a result of the blow

12.1.5.3 FAO Classification of cementation/compaction

Table 18. Cementation as described by FAO

Category	Description FAO
Non-cemented and non-compacted	Neither cementation nor compaction observed (slakes in water).
Compacted but non-cemented	Compacted mass is appreciably harder or more brittle than other comparable soil mass (slakes in water).
Weakly cemented	Cemented mass is brittle and hard, but can be broken in the hands.
Moderately cemented	Cemented mass cannot be broken in the hands but is discontinuous (less than 90 percent of soil mass).
Cemented	Cemented mass cannot be broken in the hands and is continuous (more than 90 percent of soil mass).
Indurated	Cemented mass cannot be broken by body weight (75-kg standard soil scientist) (more than 90 percent of soil mass).

12.1.6 Biological activity

12.1.6.1 Roots

12.1.6.1.1 Root frequency

In the SSS protocols, root frequency is determined by estimating the number of roots in 100 cm^2 area of soil on the profile face or by comparisons with dot diagrams. See Table 19 (Taken from Soil Survey Field Handbook, Hodgson, 1974).

Table 19. Root frequency classes

Frequency Class	SSS number of roots per 100 cm^2		FAO number per decimetre square	
	Very fine and fine roots	Medium and coarse roots	<2mm	2mm
None	0	0	0	0
Very few			1-20	1-2
Few	1-10	1 or 2	20-50	2-5
Common	11-25	2-5	50-200	5-20
Many	26-200	>5	>200	>20
Abundant	>200			

12.1.6.1.2 Root size

Table 20. Root size classes

Size class	Size range SSS (mm)	Size range FAO mm
Very fine	<1	<0.5
Fine	1-2	0.5-2
Medium	2-5	2-5
Coarse	5-10	>5
Very coarse	>10	-

Note: Additional codes used by FAO are: FF, very fine and fine; FM, fine and medium; and MC, medium and coarse.

12.1.6.1.3 Root type

The FAO guidelines do not record the kind of roots present in the horizon.

Table 21. Root types

Root type	**Example root types SSS**
Fleshy	Tap roots or bracken root stock
Fibrous	Grass roots
Woody	Larger tree roots
Rhizomatous	Rhizomes

12.1.6.2 Other biological features

Other biological features are not systematically recorded in the Scottish Soil Survey but are sometimes recorded informally in profile notes. The FAO Guidelines stipulate recording of krotovina, termite burrows, insect nests, worm casts and burrows of larger animals, in terms of abundance and kind.

12.1.7 Stone and rock fragments

In the FAO Guidelines, human artefacts are included with stones for frequency, size and shape descriptions.

12.1.7.1 Stone and rock frequency

The FAO system uses 7 classes to describe stone frequency and the Soil Survey of Scotland system uses 6 classes (Table 22). The additional class in the FAO system, very few, with stone percentage between 0 and 2 percent is included in the class few, 0 – 5% in Scotland. The end-points of the classes many, abundant and dominant (very abundant in SSS) are within acceptable limits for the field observations to be considered identical between these systems.

Table 22. Stone frequency classes in FAO and Scottish systems

	Class Names		Percent range		Match
Class used in	FAO / WRB	SSS	FAO / WRB	SSS	
Both	None	None	0	0	Same
FAO / WRB	Very few		0 - 2		No
Both	Few	Few	2 - 5	1 - 5	Similar
Both	Common	Common	5 - 15	6 - 15	Same
Both	Many	Many	15 - 40	16 - 35	Similar
Both	Abundant	Abundant	40 - 80	36 - 70	Similar
Both	Dominant	Very abundant	>80	>70	Similar

Stone lines are also recorded in the FAO / WRB classification system
This attribute is used to assign the RSG Technosol or Arenosol and the qualifiers hyperskeletic, skeletic, endoskeletic, episkeletic.

12.1.7.2 Stone and rock fragment size classes

The names differ between FAO and SSS, but apart from the smallest class, the size ranges are identical (Table 23). Artefacts are not explicitly recorded by the Soil Survey of Scotland, but their presence is recorded in profile notes.

Table 23. Stone and rock size classes

	Class names		Size range in mm		Match
Class used in	FAO / WRB	SSS	FAO / WRB	SSS	
	Fine gravel	Very small	2 - 6	<6	Similar
Both	Medium gravel	Small	6 - 20	6 – 20	Same
Both	Coarse gravel	Medium	20 - 60	20 – 60	Same
Both	Stones	Large	60 - 200	60 – 200	Same
Both	Boulders	Very large	200 - 600	200 – 600	Same
Both	Large boulders	Boulder	>600	>600	Same
FAO only	Very fine artefacts		<2		
FAO only	Fine artefacts		2 - 6		
FAO only	Medium artefacts		6 - 20		
FAO only	Coarse artefacts		>20		

12.1.7.3 Shape of stones and rock fragments

Class names for flat or platy stones are different between FAO and SSS but the concept described by these terms is the same.

Table 24. Shape of stone and rock fragments in FAO and Scottish systems

Class used in	FAO / WRB	SSS	Match
Both	Flat	Platy	Same
Both	Angular	Angular	Same
SSS only		Subangular	
Both	Subrounded	Subrounded	Same
Both	Rounded	rounded	Same

12.1.8 Human-made or human-transported material

The FAO guidelines describe human-made or -transported material with the aim of categorising the Technosol RSG in detail. As mapping of soils in Scotland mainly covered natural, semi-natural or agricultural land, these categories did not feature in soil profile classification or soil mapping legends in Scotland though map units such as Built up Area, Made up Ground, golf courses are recognised.

12.1.9 Horizon depths and relative position in the profile

The top and bottom depths of horizons are recorded. Linking horizons to those above or below in the Scottish soils Database is now possible, due to the retrospective addition of horizon positions in the profile. The horizon position relative to other horizons and the horizon properties are used together to determine a number of WRB criteria.

12.2 WRB diagnostic criteria matched with SSS properties

To match the WRB criteria with the available SSS properties, some assumptions and data manipulations were made. There are also some WRB criteria that are not recorded explicitly in Scotland. The WRB diagnostic criteria are listed in the table with information on the SSS data required or used.

Table 25. WRB diagnostics matched to Soil Survey of Scotland properties

WRB Criteria	SSS observations to assess WRB Diagnostic Criteria	Comments
Abrupt textural change	Horizon designation and clay content	Direct translation
Albeluvic tonguing	Horizon colour and boundary form “irregular”. The requirement for an underlying argic horizon is not likely to be met in Scottish soils.	Criteria are present in the soil profile database
Andic properties	Not explicitly recorded, but could be inferred from parent material. May not be present in Scotland’s soils	Inferred
Aridic properties	Not likely to be present in Scottish soils and not explicitly recorded.	Not recorded
Continuous rock	Recorded in profile description	Direct translation
Ferralic	CEC method is the same as FAO method used for WRB, but there are no data for this property in the SSS database. A derived value for CEC could be used. Munsell chroma is recorded for moist soil.	CEC not recorded
Geric	ECEC possibly could be derived from our data, but the pH in Scottish soils is measured in CaCl2 not KCl.	Inferred
Gleyic	Assess from Munsell colours (or HOST classes?).	Direct translation
Lithological discontinuity	Of the 7 criteria, only criterion 2 “a relative change of 20 percent or more in the ratios between coarse sand, medium sand, and fine sand” is not recorded in Scotland	Direct translation, apart from the caveat about criterion 2 mentioned
Reducing conditions	The field tests for reducing conditions were not carried out in Scotland	Not recorded
Secondary carbonates	Not likely to be present in Scottish soils and not explicitly recorded.	Not recorded
Stagnic colour pattern	This is identifiable from the database. 607 horizons have ped colours recorded. Of these, 254 horizons from 214 profiles are lighter (chroma) and paler (value). select * from profile_horizons where col_ped is not null and (substr(col_ped,5,1)>substr(col_mat,5,1) and substr(col_ped,6,1)<substr(col_mat,6,1));	Direct translation
Vertic properties	Not likely to be present in Scottish soils, although recently the slickensides criteria has been relaxed and some soils might now be included	Inference from structure and clay content
Vitric properties	Not likely to be present in Scottish soils	Not recorded

12.3 WRB diagnostic materials

The diagnostic materials used in WRB are not always recorded in the Scottish Soils Database and must be inferred from other information.

Criteria	Diagnostic material	Note on whether recorded in Scottish Soil Database
Diagnostic materials	Artefacts	Are noted, rather than systematically recorded in Scottish soil profile descriptions
Diagnostic materials	Calcaric material	Presence can be inferred from a small number of parent material types in Scotland. Effervescence is not routinely observed.
Diagnostic materials	Colluvic material	Human-induced erosion is evident in Scotland, but not systematically recorded in our soil descriptions until recently during NSIS_2, where zero sites having colluvic material were recorded.
Diagnostic materials	Fluvic material	Not systematically recorded, but could be inferred from profile horizon descriptions and physiographic position of the site. For mapping, parent material origin is a potential surrogate.
Diagnostic materials	Gypsiric material	Not likely to be present in Scottish soils
Diagnostic materials	Limnic material	Not likely to be present in Scottish soils
Diagnostic materials	Mineral material	Recorded in Scottish soil data
Diagnostic materials	Organic material	Recorded in Scottish soil data
Diagnostic materials	Ornithogenic material	Not systematically recorded, but could be inferred from profile notes or descriptions
Diagnostic materials	Sulphidic material	Not likely to be present in Scottish soils
Diagnostic materials	Technic	Not systematically recorded, but could be inferred from profile notes or descriptions
Diagnostic materials	Tephric	Not likely to be present in Scottish soils

Some measurements / observations required for WRB classification are missing from Scottish data:

- Coefficient of linear extensibility (COLE)
- evidence of clay illuviation not recorded systematically, only in notes

12.4 Methods used to reclassify some Scottish soils into WRB classification

In order to generate a unified WRB soil map for the Celtic fringe of Scotland, Northern Ireland and the Republic of Ireland, the dominant soil taxonomic unit in each 1:250 000 scale soil map units were classified according to the diagnostic criteria laid out in WRB 2007 (IUSS Working Group WRB, 2007) and following the updated procedures for constructing small scale map legends (IUSS Working Group WRB, 2010). As the intention was to produce a map at a notional scale of 1:1 000 000, the Celtic soils were classified to the level of the Reference Soil Group and two qualifiers.

A set of rules were devised applied to the dominant soil type in each of the 580 soil map units of the 1:250 000 scale National Soil Map of Scotland (Soil Survey of Scotland Staff, 1981) for each of the broad land use phases (cultivated or uncultivated) where appropriate and using the summary analytical data contained within the SSKIB database. The rules for identifying Reference Soil Groups, diagnostic criteria and diagnostic horizons are listed below. The rules were implemented with an MS Access database wherever possible with some manual checking and updating. Additional information such as the HOST classification (Boorman, Hollis and Lilly, 1995) was used to provide additional information on soil wetness (colour pattern, gley and stagnic properties) as the soil morphological information required to classify soils according to WRB (such as stagnic or gleyic colour patterns and horizon permeability) had already been determined and were not part of the SSKIB database. Where chemical, texture or horizon type data were required; these were taken from SSKIB and therefore are median values for the specific property. Using median values to classify Scottish soil types into WRB soil types may mean that some soil profiles belonging to a taxonomic unit (Scottish soil series) may not meet the criteria in the WRB classification due to inherent variability in soil properties. This variability should be tested by selecting a number of profiles that meet the Scottish classification criteria for a specific soil type, for example, a humus iron podzol and assessing how many of these profiles fall into the same WRB RSG/qualifiers.

Table 26. WRB Reference Soil Groups and the rules applied to the Scottish Soils Knowledge and Information Base

Rules for classifying Scottish soils into WRB Reference Soil Groups	WRB 2007[1]
Must have an Organic horizon >= 10 cm immediately overlying rock OR >40 cm thick starting within 40 cm of the soil surface. This RSG will include soils not classified as peats under the Scottish System	Histosols
Shallow soils with rock <=25cm from the surface OR < 20% fine earth over depth of 75 cm or to rock and no calcic or spodic horizon. Soils on HOST[2] geology classes 5,6, 13 and some of 7 but all soils with HOST Class 22 are included	Leptosols
Soils developed on recent freshwater alluvial and marine alluvial sediments that are >50cm thick with weak soil development.	Fluvisols
Soils with Bg and/or Cg Horizons and are also classed as poorly drained and have developed on permeable substrates indicating that the gley morphology is due to a fluctuating groundwater. They are gleyed throughout indicating reducing conditions. Soils in HOST classes 10, 12 (where the peat layer is <40cm thick) 14 and 15.	Gleysols
Spodic horizons were equated with Bs horizons (and Bsh, Bhs etc) and evidence of podzolisation either through the presence of an E horizon, classified as a podzol under the Soil Survey of Scotland classification[3] ,uncultivated, pH <5.9, C>0.5% and designated as a Bs, Bsh, Bhs. There is an assumption that the colour criteria have been met. Where cultivated, the pH criterion was waived.	Podzols
Soils with gleyed mineral horizons within 50 cm of the surface including the presence of an albic horizon, stagnic colour patterns as indicated by the presence of Bg and/or Cg horizons and with specific HOST classes. The soils have a depth to a slowly permeable layer of <50cm which is determined by soil texture and structure and is a major component of the HOST classification. HOST classes 24 and 26 (where the organic topsoil is <40cm thick) with some HOST class 18. Soils are gleys (some brown earths with gleying).	Stagnosols
All soils with an Umbric horizon that do not meet the criteria to be placed in any previous RSG. These soils are primarily uncultivated brown earth or oroactic and hemi-oroarctic podzols. Not all the uncultivated brown earths meet the colour criteria to be classed as Umbric horizons so our brown earths may be split across this Reference Group and Cambisols, however, this was not soil series specific so strictly, classification by correlating the characteristics of a soil series to a WRB RSG led to a misclassification of some Scottish soil profiles.	Umbrisols

Texture more coarse than loamy sand and <40% gravels within 100cm and no fragic horizon. The requirement for having <40% gravels or coarse fractions, the absence of a fragic layer and the presence of anthric, mollic or umbric means that most of the glaciofluvial sands do not mean these criteria (these soils often also have spodic horizons). The main soils in the RSG are those developed on windblown sands.	Arenosols
Soils with an Anthric topsoil and weakly developed Bs or Bw or B horizon within 50 cm of the soil surface and designated as Brown earths in the Scottish soil classification system. The weak development of the Bs horizon is assumed as the soil is classified as a Brown earth rather than a podzol. A more strict interpretation of the colour criteria may indicate spodic rather than cambic.	Cambisols

Table 27. Diagnostic horizons and the rules applied to the Scottish Soils Knowledge and Information Base

Scottish rules - based on data and information from SSKIB[4]	Diagnostic Horizon
Soils with and E horizon (a light-coloured subsurface horizon from which clay and free iron oxides have been removed) and that meet the criteria to be classified as podzols under the Scottish soil classification system generally with an underlying Bs, Bsh or Bh horizon and evidence of leaching. Some of these E horizons are associated with wetness and contain evidence of reducing conditions (designated as Eg)	Albic
Any horizon that has been cultivated over a prolonged period (mainly arable, improved and long ley pastures - designated as Ap, Apg or Aph) having 1 or more of the following: abrupt boundary at ploughing depth, a plough pan OR mixing of soil layers by cultivation AND a thickness of >20 cm AND meets all colour, structure and organic matter requirements of a mollic OR umbric horizon. The organic matter content of these horizons is known from information within SSKIB and the colour/structure requirements are assumed from existing knowledge.	Anthric
Horizons that were classified as Bw or Bs or B and where the soil profile meet the criteria to be classified as a Brown Earth under the Scottish Soil classification system. A Cambic horizon has a sub-surface horizon showing evidence of alteration relative to the underlying horizon (Bw or Bs or lighter B horizon cf topsoil). Texture of v fine sand, loamy very fine sand or finer AND soil structure or absence of rock structure in >50% of volume AND shows evidence of alteration by: a) higher Munsell chroma, higher value, redder hue or higher clay content than underlying or overlaying layer OR presence of soil structure AND does not form part of a plough layer AND thickness > 15 cm. Colour criteria are assumed to be met due to the horizons being designated as Bw, Bs or B following the Scottish classification system.	Cambic
Gleyed soils with HOST classes 10, 12, 14 or 15 and permeable drift. Gleys are indicative of poor drainage and therefore have the full colour expression required for gleyic features. The soils had to have permeable drift to rule out stagnic properties and to indicate that the gleying was due to fluctuating a watertable	Gleyic
More than 20% carbon and designated as H or O and >10cm thick. Often associated with Histic, gleyic, stagnogleyic and podzolic horizons.	Histic
Soils having continuous rock starting within 100 cm of the soil surface	Leptic
A, Ah and Ag uncultivated horizon with C>0.6 % and base saturation >50% and >20cm thick	Mollic
Designated as a Bs horizon, classified as a podzol under the Soil Survey of Scotland, system, uncultivated, pH <5.9, C>0.5% and designated as a Bs, Bsh, Bhs. Those Bs horizons that met the criteria but were in cultivated profiles have also been classed as Spodic but many of the chemical criteria needs to be assumed and is somewhat at odds with the rather simple field recognition criteria.	Spodic

Presence of Bg and Cg Horizons and classed as imperfectly or poorly drained. Since gley features can be weakly expressed, other indications of stagnic properties used were specific HOST classes 18 and 24 as these are the classes where the soil texture and structure meet the ALC[5] criteria to be classed as slowly permeable and separate these soils from those affected by groundwater.	Stagnic
A, Ah and Ag uncultivated horizon with C>0.6 % and base saturation <50% and >20cm thick. The colour and structure requirements for this diagnostic horizon were assumed to be met based on experience in describing and classifying these soils.	Umbric

Table 28. WRB qualifiers

Description	Qualifiers[5]
Having an albic horizon starting within 100 cm of the soil surface.	Albic
Having calcaric material (> 2% calcium carbonate) between 20 and 50 cm from the soil surface or between 20 cm and continuous rock or a cemented or indurated layer, whichever is shallower. This applies to Brown calcareous soils with parent material derived from shelly sand.	Calcaric
Having within 150 cm of the soil surface a subsurface layer that is 30 cm or more thick, that has a Munsell hue redder than 7.5 YR or that has both, a hue of 7.5 YR and a chroma, moist, of more than 4. Bs and Bw horizons. It was difficult to apply the colour criteria on a series basis.	Chromic
Having a base saturation (calculated from sum of base cations) of less than 50 percent in the major part between 20 and 100 cm from the soil surface or between 20 cm and continuous rock or a cemented or indurated layer, or, in Leptosols, in a layer, 5 cm or more thick, directly above continuous rock.	Dystric
Not having an albic horizon and having a loose spodic horizon (in Podzols only).	Entic
Having a base saturation (as calculated from sum of cations) of 50 percent or more in the major part between 20 and 100 cm from the soil surface or between 20 cm and continuous rock or a cemented or indurated layer, or, in Leptosols, in a layer, 5 cm or more thick, directly above continuous rock.	Eutric
Having a folic horizon starting within 40 cm of the soil surface. Folic horizons consists of well aerated organic material (equates to Scottish H horizons) and are >10cm thick.	Folic
Having within 100 cm of the mineral soil surface in some parts reducing conditions and in 25 percent or more of the soil volume a gleyic colour pattern.	Gleyic
Having a typical expression of certain features (typical in the sense that there is no further or meaningful characterization) and only used if none of the preceding qualifiers applies.	Haplic
Having a histic horizon starting within 40 cm of the soil surface.	Histic
Having continuous rock starting within 100 cm of the soil surface.	Leptic
Having continuous rock starting within 10 cm of the soil surface (in Leptosols only).	Lithic
Having a mollic horizon.	Mollic
Having within 150 cm of the soil surface a subsurface layer, 30 cm or more thick, with a Munsell hue redder than 5 YR. This was difficult to apply to a soil series as individual profiles belonging to that taxonomic unit did not always meet this colour criteria.	Rhodic
Having, after rubbing, less than one-sixth (by volume) of the organic material consisting of recognizable plant tissue within 100 cm of the soil surface (in Histosols only). Well decomposed O horizons. Based on experience in sampling these soils.	Sapric
40 percent or more (by volume) gravel or other coarse fragments averaged over a depth of 100 cm from the soil surface or to continuous rock or a cemented or indurated layer, whichever is shallower.	Skeletic
Having within 100 cm of the mineral soil surface in some parts reducing conditions for some time during the year and in 25 percent or more of the soil volume, single or in combination, a stagnic colour pattern or an albic horizon.	Stagnic

Being flooded by tidewater but not covered by water at mean low tide.	Tidalic
Having an umbric horizon.	Umbric

Referenced documents in table:

1. IUSS Working Group WRB (2007)
2. Boorman, Hollis and Lilly (1995).
3. Soil Survey of Scotland Staff (1984)
4. Smith, et al. (2010)
5. MAFF (1988)
6. IUSS Working Group WRB (2010)

The application of these rules to the dominant soil series (for both cultivated and uncultivated phases in each of the 1:250 000 scale map units resulted in 75 unique WRB classes (Table 29).

Table 29. Translation of Soil Survey of Scotland classification to WRB at Major soil subgroup Level

Soil Survey of Scotland	WRB		
Lithosols	Lithic	Histic	LEPTOSOL
	Lithic	Umbric	LEPTOSOL
Regosols	Eutric		CAMBISOL
	Haplic		UMBRISOL
Saline alluvial soils	Tidalic	Gleyic	FLUVISOL
Mineral alluvial soils	Gleyic	Eutric	FLUVISOL
	Gleyic	Umbric	FLUVISOL
Rankers	Dystric		LEPTOSOL
	Eutric		LEPTOSOL
	Folic	Dystric	LEPTOSOL
	Umbric	Dystric	LEPTOSOL
Brown rankers	Eutric		LEPTOSOL
	Umbric	Dystric	LEPTOSOL
Podzolic rankers	Histic	Dystric	LEPTOSOL
Peaty rankers	Sapric	Leptic	HISTOSOL
Brown rendzinas	Leptic	Mollic	UMBRISOL
Brown calcareous soils	Calcaric	Eutric	ARENOSOL
Brown magnesian soils	Eutric		CAMBISOL
	Haplic		UMBRISOL
Brown earths			CAMBISOL
	Chromic	Dystric	CAMBISOL
	Chromic	Eutric	CAMBISOL
	Dystric		CAMBISOL
	Eutric		CAMBISOL
	Leptic		CAMBISOL
	Leptic	Dystric	CAMBISOL
	Leptic	Gleyic	CAMBISOL
	Rhodic	Dystric	CAMBISOL
	Rhodic	Eutric	CAMBISOL
	Skeletic		CAMBISOL
	Skeletic	Dystric	CAMBISOL
	Skeletic	Eutric	CAMBISOL
	Albic	Folic	PODZOL
	Albic	Umbric	PODZOL
	Entic		PODZOL
	Haplic		UMBRISOL
	Leptic		UMBRISOL
	Leptic	Gleyic	UMBRISOL
	Mollic		UMBRISOL
	Skeletic		UMBRISOL
	Skeletic	Dystric	UMBRISOL
Brown earths with gleying	Gleyic	Dystric	CAMBISOL
	Stagnic	Eutric	CAMBISOL

	Eutric		GLEYSOL
	Dystric		STAGNOSOL
	Eutric		STAGNOSOL
	Mollic	Eutric	STAGNOSOL
	Umbric	Dystric	STAGNOSOL
	Umbric	Eutric	STAGNOSOL
	Gleyic		UMBRISOL
	Stagnic		UMBRISOL
Humus-iron podzols	Dystric		CAMBISOL
	Eutric		CAMBISOL
	Skeletic	Dystric	CAMBISOL
	Stagnic	Eutric	CAMBISOL
	Dystric		GLEYSOL
	Albic		PODZOL
	Albic	Folic	PODZOL
	Albic	Gleyic	PODZOL
	Albic	Stagnic	PODZOL
	Albic	Umbric	PODZOL
	Entic		PODZOL
	Entic	Gleyic	PODZOL
	Entic	Leptic	PODZOL
	Entic	Skeletic	PODZOL
	Entic	Umbric	PODZOL
	Eutric		STAGNOSOL
	Mollic		STAGNOSOL
	Haplic		UMBRISOL
	Leptic	Gleyic	UMBRISOL
	Skeletic		UMBRISOL
	Stagnic	Folic	UMBRISOL
Peaty podzols	Albic		PODZOL
	Albic	Folic	PODZOL
	Albic	Gleyic	PODZOL
	Albic	Histic	PODZOL
	Albic	Umbric	PODZOL
	Entic		PODZOL
Subalpine podzols/soils	Albic	Folic	PODZOL
	Albic	Umbric	PODZOL
	Albic	Folic	PODZOL
	Albic	Umbric	PODZOL
	Entic	Folic	PODZOL
	Haplic		UMBRISOL
	Leptic		UMBRISOL
	Skeletic		UMBRISOL
Alpine soils	Albic	Folic	PODZOL
	Albic	Umbric	PODZOL
	Folic		UMBRISOL
	Haplic		UMBRISOL
	Leptic	Albic	UMBRISOL
Ground water Calcareous gleys	Calcaric	Eutric	GLEYSOL
	Mollic	Calcaric	GLEYSOL
Ground water Noncalcareous gleys	Dystric		GLEYSOL
	Eutric		GLEYSOL
	Histic	Dystric	GLEYSOL
	Mollic	Dystric	GLEYSOL
	Mollic	Eutric	GLEYSOL
	Umbric	Dystric	GLEYSOL
	Umbric	Eutric	GLEYSOL
Ground water Humic gleys	Eutric		GLEYSOL
	Mollic	Eutric	GLEYSOL

Ground water Peaty gleys	Dystric		GLEYSOL
	Eutric		GLEYSOL
	Histic	Dystric	GLEYSOL
	Histic	Eutric	GLEYSOL
	Mollic	Eutric	GLEYSOL
Surface water Saline gleys	Albic	Eutric	STAGNOSOL
	Histic	Albic	STAGNOSOL
Surface water Magnesian gleys	Eutric		STAGNOSOL
	Mollic	Eutric	STAGNOSOL
Surface water Noncalcareous gleys	Albic	Eutric	STAGNOSOL
	Dystric		STAGNOSOL
	Eutric		STAGNOSOL
	Histic	Albic	STAGNOSOL
	Mollic	Albic	STAGNOSOL
	Mollic	Dystric	STAGNOSOL
	Mollic	Eutric	STAGNOSOL
	Umbric	Albic	STAGNOSOL
	Umbric	Dystric	STAGNOSOL
	Umbric	Eutric	STAGNOSOL
Surface water Peaty gleys	Albic	Eutric	STAGNOSOL
	Histic	Albic	STAGNOSOL
	Histic	Dystric	STAGNOSOL
	Histic	Eutric	STAGNOSOL
Basin Peat	Sapric	Dystric	HISTOSOL
Blanket Peat	Sapric	Dystric	HISTOSOL

13 Northern Ireland 1:250,000 Soil Map conversion to WRB

A.Higgins and C. Jordan, AFBI

In Northern Ireland, the harmonization of soil classification systems with WRB was based on the 1:250,000 (250K) General Soil Map. The Northern Ireland 250K soil map is not a soil association map as such, but is a generalization of the more detailed 1:50,000 soil map series. The major unit of classification is based on parent material, with 31 classes being identified. Four of these parent materials, (Alluvium, Organic Alluvium, Peat and Diatomite) are recorded only as undifferentiated major units. For the remaining 27 major units, 1 level of subdivision was made, based on the profile descriptions as follow;

Humic Ranker
Other Rankers on Rock
Sand Rankers
Brown Earths (includes all variants)
Brown Podzolics
Podzols
Humic Gley
Mineral Gley

In this system, a unit (eg Mineral Gley on Basalt) of similar parent material and profile combination identified in one area may not contain the same underlying soil series combinations (or percentage composition) as a Mineral Gley on Basalt in another area; rather it is the modal soil series which gives the 250K unit its name.

13.1 WRB Harmonization

Reclassification of the 250K soil groups to WRB was made on the basis of those classes and diagnostic horizons identified in *World Soil Resources Reports 103* (2007), and using the map specific qualifier lists outlined in *Addendum to 'The World Reference Base for Soil Resources* (2010). Table 30 illustrates the identification process for the 8 WRB Reference

Groups identified from the 250K map units. A full list of the Reference Groups and qualifier classification can be found in Table 31.

13.1.1 Histosols

Within the 250K map, the undifferentiated 'Peats' unit refers to all soils composed of organic material which are more than 50 cm deep from the surface (drained or undrained). Thus, this class encompasses peat from both blanket and raised bog origins and covers all land usage (virgin bog, commercially exploited, drained and in agricultural use). As there is a wide range of decomposition represented in the class, the 'Hemic' and 'Dystric' qualifiers were used with the latter reflecting the oligotrophic origins of the vast majority of the peat.

13.1.2 Leptosols

The Ranker group is composed of soils <40cm to parent material, with a distribution mainly in the uplands, although there is also significant development in the ice-scoured east of the Province. These soils usually occur in a complex distribution with rock outcrops and Shallow Brown Earths. The majority of soils in the Ranker unit satisfied Leptosols classification requirements, although there may be an argument for classifying them as Cambisols with a 'Leptic' qualifier.

Table 30. Simplified key to the WRB Reference Groups identified in the Northern Ireland 250K soil map.

Organic matter > 40 cm deep	Yes →	HISTOSOLS
↓ no		
Depth < 25 cm	Yes →	LEPTOSOLS
↓ no		
Fluvic materials	Yes →	FLUVISOLS
↓ no		
Gleyic properties	Yes →	GLEYSOLS
↓ no		
Spodic horizon	Yes →	PODZOLS
↓ no		
Stagnic colour pattern	Yes →	STAGNOSOLS
↓ no		
Coarse texture > 100 cm	Yes→	ARENOSOLS
↓ no		
Cambic horizon	Yes →	CAMBISOLS

13.1.3 Fluvisols

The undifferentiated 'Alluvium' 250K unit satisfies the criteria for the Fluvisol Reference Group. The vast majority of soils within this grouping are groundwater-dominated gleys with a topsoil of generally high organic matter content. The undifferentiated 'Organic Alluvium'

250K unit is comprised of series where an organic horizon is present at any depth within the examined soil profile and is given the ‘Histic’ qualifier here.

13.1.4 Gleysols

The Gleysol Reference Group encompasses a number of 250K units. These parent materials generally have their provenance in either a lacustrine or marine environment.

13.1.5 Podzols

Both true podzols and podzolics are classified to this group. The ‘Stagnic’ qualifier reflects the development on slowly permeable substrates

13.1.6 Stagnosols

This reference group has by far the largest coverage in Northern Ireland, reflecting the widespread distribution of slowly permeable glacial till. The till tends to strongly reflect the properties of the local rock, with carry-over (in terms of gross matrix values) of more than a kilometre being rare. A major division in the 250K surface-water gleys is the humic subclass and, in the WRB conversion, this was given the ‘Histic’ qualifier, although a number were classified as ‘Umbric’ as the reference samples did not meet the ‘Histic’ criteria.
The ‘Gleyic’ qualifier with reference to Stagnosols was taken to mean soils which had both Stagnic and Gleyic properties. Although such soils exist in Northern Ireland, none are dominant in the context of the 250K groupings.

13.1.7 Arenosols

The distribution of Arenosols is restricted to a number of coastal dune areas.

13.1.8 Cambisols

All of the 250K units which are Brown Earths (including Shallow Brown Earths) were classified as Cambisols. While some of these soils could be seen to fall close to the boundary with Umbrisols, it was felt that considering the definition, ***‘Umbrisols accommodate soils in which organic matter has accumulated within the mineral surface soil (in most cases with low base saturation) to the extent that it significantly affects the behaviour and utilization of the soil’,*** Cambisols would be the more logical classification for these units.
The majority of the Cambisols are developed on glacial till, and the ‘Stagnic’ qualifier reflects the slowly permeable nature of the parent material. Those units where Shallow Brown Earths (by definition <60cm to rock surface) were dominant, were given the ‘Leptic’ qualifier.

Table 31. Northern Ireland 1:250,000 soil map unit names and the assigned WRB name.

250K Unit	WRB
Alluvium	Mollic Gleyic Fluvisols
Brown Earth ON Basalt	Eutric Stagnic Cambisols
Brown Earth ON Basic Igneous	Eutric Stagnic Cambisols
Brown Earth ON Carboniferous Sandstone	Dystric Stagnic Cambisols
Brown Earth ON Chalk	Eutric Stagnic Cambisols
Brown Earth ON Clougher Valley Limestone	Eutric Stagnic Cambisols
Brown Earth ON Dolerite	Dystric Stagnic Cambisols

Brown Earth ON Granite	Dystric Stagnic Cambisols
Brown Earth ON Limestone	Eutric Stagnic Cambisols
Brown Earth ON Marl	Eutric Stagnic Cambisols
Brown Earth ON Mica Schist	Dystric Stagnic Cambisols
Brown Earth ON Old Red Sandstone	Dystric Stagnic Cambisols
Brown Earth ON Red Limestone Mixed Till	Eutric Rhodic Cambisols
Brown Earth ON Red Trias Sandstone	Eutric Stagnic Cambisols
Brown Earth ON Rhyolite	Eutric Stagnic Cambisols
Brown Earth ON Sand and Gravel	Chromic Skeletic Cambisols
Brown Earth ON Sand and Gravel	Dystric Chromic Cambisols
Brown Earth ON Shale	Eutric Stagnic Cambisols
Brown Podzol ON Granite	Umbric Entic Podzols
Brown Podzol ON Mica Schist	Stagnic Entic Podzols
Brown Podzol ON Old Red Sandstone	Umbric Entic Podzols
Brown Podzol ON Sand and Gravel	Umbric Entic Podzols
Brown Podzol ON Shale	Stagnic Entic Podzols
Diatomite	Eutric Umbric Gleysols
Humic Ranker ; <40 cm mainly organic ON Basalt	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Basic Igneous	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Dolerite	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Felsite	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Granite	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Limestone	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Mica Schist	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Millstone Grit	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Old Red Sandstone	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Red Trias Sandstone	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Shale	Dystric Histic Leptosols
Humic Ranker ; <40 cm mainly organic ON Yoredale Sandstone	Dystric Histic Leptosols
Mineral Gley and Brown Earth ON Shale	Dystric Leptic Cambisols
Mineral Gley and Organic Alluvium ON Shale	Histic Gleyic Fluvisols
Mineral Gley and Ranker ON Shale	Dystric Umbric Leptosols

Mineral Gley ON Basalt	Eutric Mollic Stagnosols
Mineral Gley ON Basalt Till [Stone free]	Eutric Mollic Stagnosols
Mineral Gley ON Basic Igneous	Eutric Mollic Stagnosols
Mineral Gley ON Calp	Eutric Mollic Stagnosol
Mineral Gley ON Carboniferous Sandstone	Dystric Umbric Stagnosol
Mineral Gley ON Chalk	Eutric Mollic Stagnosols
Mineral Gley ON Clougher Valley Limestone	Eutric Umbric Stagnosols
Mineral Gley ON Dungiven Limestone	Eutric Umbric Stagnosols
Mineral Gley ON Granite	Eutric Umbric Stagnosol
Mineral Gley ON Lake Clay	Eutric Umbric Gleysols
Mineral Gley ON Lake Sand	Dystric Mollic Gleysols
Mineral Gley ON Limestone	Eutric Mollic Stagnosols
Mineral Gley ON Lough Neagh Clay Till	Eutric Mollic Stagnosol
Mineral Gley ON Marine Alluvium	Eutric Mollic Gleysols
Mineral Gley ON Marl	Eutric Mollic Stagnosols
Mineral Gley ON Mica Schist	Dystric Umbric Stagnosols
Mineral Gley ON Old Red Sandstone	Dystric Umbric Stagnosols
Mineral Gley ON Red Limestone Mixed Till	Eutric Mollic Stagnosols
Mineral Gley ON Red Trias Sandstone	Eutric Mollic Stagnosols
Mineral Gley ON Sand and Gravel	Eutric Mollic Gleysols
Mineral Gley ON Shale	Dystric Umbric Stagnosols
Mineral Gley ON Yoredale Sandstone	Dystric Umbric Stagnosols
Organic Alluvium	Histic Gleyic Fluvisols
Peats	Dystric Hemic Histosols
Podzol ON Basalt	Stagnic Albic Podzols
Podzol ON Basic Igneous	Stagnic Albic Podzols
Podzol ON Granite	Stagnic Albic Podzols
Podzol ON Mica Schist	Stagnic Albic Podzols
Podzol ON Sand and Gravel	Umbric Albic Podzols
Ranker ON Basalt	Eutric Mollic Leptosols
Ranker ON Basalt/Chalk	Eutric Mollic Leptosols
Ranker ON Basic Igneous	Eutric Mollic Leptosols

Ranker ON Calp	Dystric Umbric Leptosols
Ranker ON Chalk	Eutric Mollic Leptosols
Ranker ON Dolerite	Dystric Umbric Leptosols
Ranker ON Felsite	Dystric Umbric Leptosols
Ranker ON Granite	Dystric Umbric Leptosols
Ranker ON Limestone	Eutric Mollic Leptosols
Ranker ON Mica Schist	Dystric Umbric Leptosols
Ranker ON Old Red Sandstone	Dystric Umbric Leptosols
Ranker ON Shale	Dystric Umbric Leptosols
Sand Ranker ON Basalt	Dystric Protic Arenosols
Sand Ranker ON Sand and Gravel	Dystric Protic Arenosols
Surface & Ground Water Humic Gley ON Basalt	Eutric Histic Stagnosol
Surface & Ground Water Humic Gley ON Calp	Dystric Histic Stagnosols
Surface & Ground Water Humic Gley ON Carboniferous Sandstone	Dystric Histic Stagnosols
Surface & Ground Water Humic Gley ON Dungiven Limestone	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Granite	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Limestone	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Mica Schist	Dystric Histic Stagnosols
Surface & Ground Water Humic Gley ON Old Red Sandstone	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Red Trias Sandstone	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Rhyolite	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Sand and Granite	Dystric Umbric Stagnosols
Surface & Ground Water Humic Gley ON Shale	Dystric Histic Stagnosols
Surface & Ground Water Humic Gley ON Yoredale Sandstone	Dystric Umbric Stagnosols
Disturbed	Disturbed
Not sampled	Not Surveyed
Urban	Urban
Water	Water

14 Republic of Ireland WRB soil map

The Republic of Ireland is currently undertaking a mapping programme to provide a standardized soil map of the country by a process of digital soil mapping with field validation and making use of existing soil maps at the county level. Preliminary output of this mapping exercise was used to develop a soil map of Ireland using the WRB soil classification system.

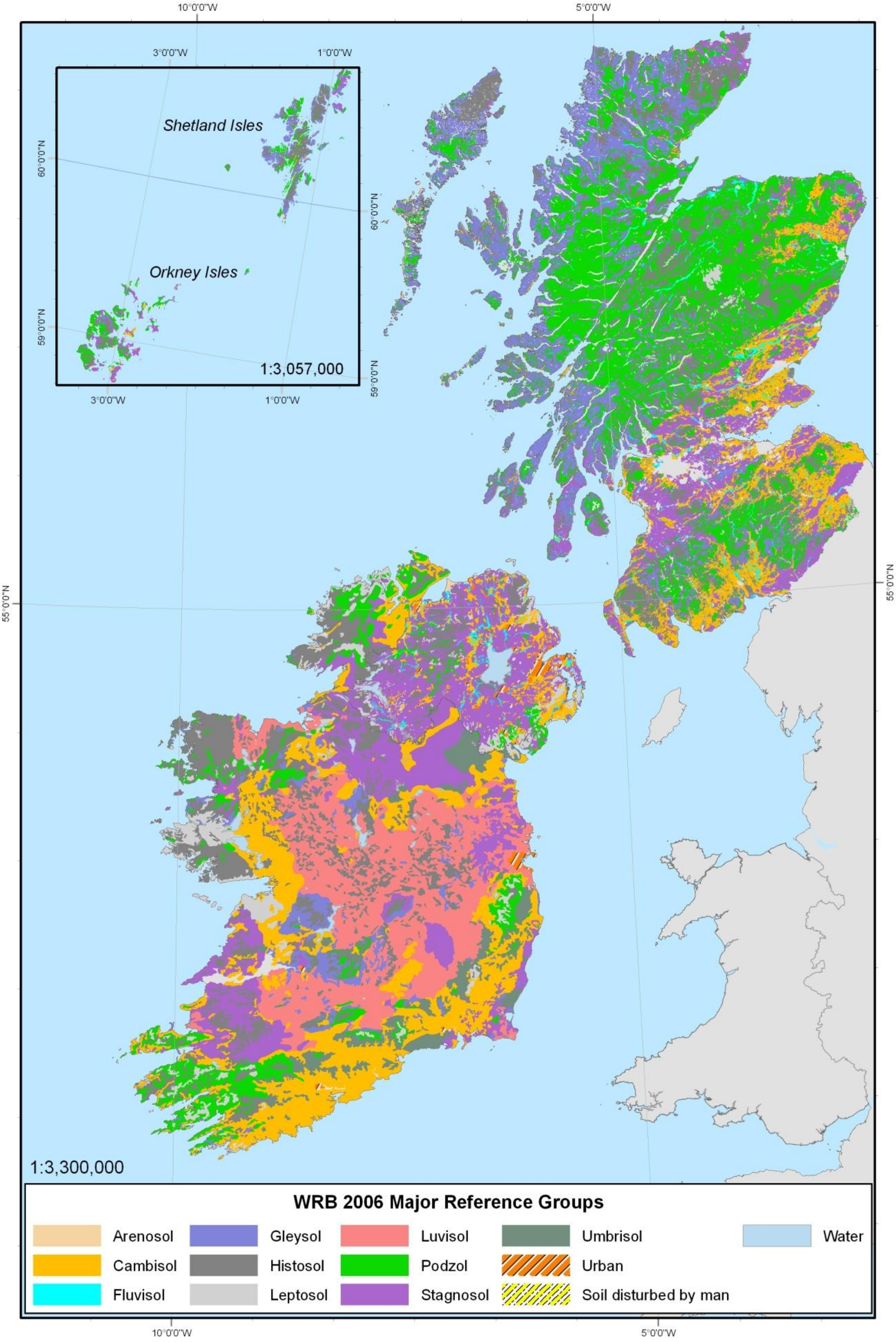
15 Harmonized WRB soil map of Republic of Ireland, Northern Ireland and Scotland; the Celtic fringe.

The ultimate aim of this test case was to develop a harmonized soil map of the Celtic fringe of Europe at a scale of 1:250 000 scale. As well as working together to correlate soil classification across the three territories of Republic of Ireland, Northern Ireland (part of the UK) and Scotland (a semantic harmonization), the Republic of Ireland and Northern Ireland share a border while Scotland uses a different geographical projection system from the other two territories.

The resulting map, which shows the WRB to the level of 2 qualifiers, was compiled by Teagasc and uses the ETRS89 coordinate reference system which is INSPIRE compliant. The resulting draft map (shown to the RSG level only in

Figure 2) demonstrates that a harmonized WRB database of the three territories can be developed

Figure 2. WRB soil map of the Celtic fringe (notional scale of 1:250 000)



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