Teagasc-EPA Soils and Subsoils Mapping Project

Final Report

Prepared for the Department of Environment, Heritage and Local Government and the Environmental Protection Agency

By

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Key Points

Subsoils Map	• Teagasc has created the first national subsoils map to a standardised methodology. • The Teagasc Subsoils map classifies the subsoils of Ireland into 16 themes, using digital stereo photogrammetry supported by field work • The subsoils map has a nominal working scale of 1:50,000 • The subsoils maps for each county are now freely available to all researchers
Landcover Map	• Teagasc has created the first and only national landcover map for an Irish project. • The Teagasc Landcover 1995 (TLC95) map classifies the landcover of Ireland into 16 themes. • It maps to a minimum size of 1 Ha. • Landcover maps for each county are now freely available to all researchers
Indicative Soils Map	• Teagasc has developed a national indicative soils map to a standardised methodology. • The indicative soils map classifies the soils of Ireland on a categorically simplified but cartographically detailed basis into 25 classes, using an expert rule based methodology • The soils map has a nominal working scale of 1:100,000-1:150,000 • The soils maps for each county are now freely available to all researchers
Habitat Indicator Map	• Teagasc has created the only national habitat map for an Irish project. • The Teagasc Habitat Indicator Map 1995 (THIM95) map classifies Ireland into 27 habitat themes. • It maps to a minimum size of 1 Ha. • Habitat maps for each county are now freely available to all researchers

Background

The Water Framework Directive (2000/60/EC) came into force on its publication in the Official Journal of the European Communities on 22 December 2000. The Directive establishes a strategic framework for managing the water environment and sets out a common approach to protecting and setting environmental objectives for all groundwater and surface waters within the European Community.

A Groundwater Working Group was established under the aegis of the WFD Co-ordination Group to provide guidance for River Basin Projects in the delivery and implementation of groundwater work requirements. The Working Group specified the technical requirements of the WFD for groundwater, and provided practical guidance on the importance to the initial characterisation of groundwater bodies of the overlying strata (soils and subsoils), or the geological materials overlying the water table in groundwater bodies.

The National Soil Survey was initiated in 1959, shortly after the establishment of An Foras Talúntais the precursor organisation to Teagasc. During the period of operation of the NSS, a number of soil survey outputs were produced at varying scales. At its close in the 1980s, detailed reconnaissance mapping of 44% of the country had been completed with resulting maps published at 1:126,720 scale.

To meet the guidance on the requirement of knowledge on the overlying strata, a key recommendation of the Groundwater Working Group proposed that the Spatial Analysis Unit at Teagasc, Kinsealy produce soils and subsoils maps for the entire country using a consistent, standardised method. As less than half of the country's soils had been surveyed and published and due to the constrained timeline for development the necessity of incorporating remote sensing and Geographical Information System (GIS) techniques into the project methodology was immediately apparent. This objective was met by extending the research and mapping efforts as specified and delivered under the previous FIPS-Irish Forest Soils project to the remaining areas of the country which were not previously mapped by that project.

Parent Material/Subsoil mapping

The Quaternary is the most recent period of the Earth's geological history. It began approximately 1.65 million years ago and extends to the present day. The Late Quaternary period stretches from 130,000 years ago to the present. During this period most of the surficial sediments in Ireland were deposited. Most Quaternary sediments owe their genesis in one way or another to the action or melting of ice. Ireland was covered by ice, just as many high latitude regions are nowadays, for long periods in the last 130,000 years. The last glaciation occurred between 73,000 years ago and 10,000 years ago and Ireland has very rich legacy of glacial deposits and landforms relating to this recent glaciation. Over 90% of Ireland's area is covered by deposits from this period.

As ice flows out towards its margins, pieces of rock and soil over which it flows become attached to its base by freezing on, and they may become incorporated into the lower layers of the ice. This in turn makes the base of the ice very abrasive and it can erode, polish and mould the landscape into the forms that we see today. In this way the substrate is eroded, picked up and transported and redeposited by the ice. Soil-landscape studies require adequate Quaternary geology maps and morphological maps, as well as the related model for the Quaternary history of an area. Quaternary deposits in Ireland are the most important of all geological materials, as they comprise what lies immediately below the surface over approximately 96% of the country with bedrock outcrop comprising the remaining 4%.

The mapping of subsoils involves the integration of a number of suites of data. Initially, all available Quaternary information for the county being mapped is compiled. Data consulted includes soil survey maps, Quaternary maps and published and unpublished reports. Following this initial compilation of these data, boundaries between sediment types are interpreted and mapped using photo-interpretation in a soft copy photogrammetric workstation with digital stereo-pairs of black and white photography acquired at a scale of 1:40,000.

Following the drawing up of preliminary boundaries, fieldwork is carried out which concentrated on areas within the boundary zone between differing subsoil types. Further to this, fieldwork is also undertaken around the flanks of the larger bogs to delineate the exact boundary between peat and mineral soils. Important in this is the recognition of peat areas with peat soils which have been reclaimed for agriculture. . The field mapping also allows for the checking of the ground for areas mapped during the photogrammetric analysis, and is therefore crucial in increasing the accuracy of the maps. Methods adopted during field mapping include reconnaissance mapping, auger sampling, trenching, digital photography and GPS data recording.

The classification of subsoils is based on the classification used by the Geological Survey of Ireland Quaternary Section in mapping Quaternary sediment types. This classification has been altered only to ensure utility specific to the requirements of the EPA Soil and Subsoil Mapping Project.

Landcover Map

The Teagasc Land Cover Map 1995 (TLC95) was produced to aid in the discrimination of well drained and poorly drained mineral soils throughout Ireland. The TLC95 map was produced using aerial photography and satellite imagery. The land cover mapping methodology exploited the known ecology of grassland types in Ireland in relation to soils. *Land cover* is defined as the dominant surface cover type or class of a homogeneous area of land

At the projects start there was only one national, thematically exhaustive Landcover data set, *CORINE 1990 Ireland*. However the minimum mapping unit of 25Ha and the thematic classification of this European scale project were deemed to be inappropriate for the soils project.

The TLC95 map was produced using automatic classification of satellite images. Supervised classification is the process of using samples of known identity (training areas *i.e.* pixels assigned to themes) to classify unknown pixels from a satellite image (*i.e.* to assign unclassified pixels to themes). In total a mosaic of 20 Different LANDSAT TM satellite images were used in the project.

One of the core tasks in Land Cover Classification of satellite imagery is the collection of training data – geographically specified areas of known landcover. In this project, training data (areas of known Landcover) were collected using softcopy photogrammetry. In total over 15,000 points were manually collected as training data. These have been stored as county based point shape files and are a very valuable dataset survey of Landcover as it existed in 1995.

The maps were tested for accuracy against 800 field points and 10000 air photo observations and reached satisfactory levels of accuracy. The county landcover maps are distributed by the EPA with full metadata documentation

Soil Mapping/Soil Modelling

The aim of soil survey is to describe and map the soils in the survey area. As soil is a continuous entity in the environment, soil maps, out of practical necessity, are based on surveyors predicting what soils occur on those parts of the landscape that they cannot visit. The methodology employed in this project was analogous to the survey methods of the traditional soil surveyor. Key soil forming factors such as vegetation (landcover) and geology (parent material) were mapped and a set of rules (termed a "rule-base") applied to these datasets to predict the soils that may occur at any given location in the landscape .The core technologies involved in this process were remote sensing and GIS-based. The development of a Level 2 model with increased map accuracy involved expanded inputs and included topographical variables, previously mapped soil data and other geologically based variable such as subsoil permeability. Key inputs to the predictive soil model included data on soil parent material, vegetation and topography.

Parent material is the material from which soils are formed. The subsoils map relates to the soil classification in a number of ways. The geological composition of the subsoil type has a very strong influence on the characteristics of the mapped soils overlying these deposits. Texture types can often be interpreted and these related to the drainage status of developed soils. For example, granite till is suggestive of acidic, mostly free-draining soils. Limestone dominated till will tend to show higher free carbonate content but varied drainage. Shale tills will generally have acidic soils overlying them, with a tendency towards impeded drainage resulting from higher clay content.

The relationship between soils and vegetation is extremely important. As part of the soil modelling development these relationships have been stated explicitly and incorporated into the modelling process. However, the existence of artificial drainage will influence the current behaviour of the soil and land management practices will affect overlying vegetation. The influence of land management therefore has a complicating effect on soil mapping and prediction.

The effects of topography on soil formation are chiefly expressed through the influence of slope and slope shape on water and soil movement. The analysis and extraction of terrain-based attributes or indices can aid in the modelling of soil-topographic relationships. Digital topographic analysis in the context of soil-landscape relationships relies on the use of digital elevation models/digital terrain models (DEM/DTMs). Primary attributes are those that are extracted directly from the DEM. These include the first order derivatives, slope and aspect, and second order derivatives, plan, profile and tangential curvatures. Secondary attributes are generally compound attributes based on some combinations of primary attributes.

As is familiar to anyone working in the Irish environment, the Irish landscape is extremely complex and this complexity posed a significant challenge in developing and refining the topographic component of the soil model. The development of a clustering approach, which integrated a number of topographic attributes from the EPA DTM, was found to be a particularly useful technique for developing compound classification of landscape and in segmenting the landscape for Level 2 modelling. In turn this segmentation was found to be particularly effective in determining certain areas which were predisposed to gleying due to the nature of their topography.

Quantitative methods involving GIS in soil survey have been ongoing for a number of years. They have probably been most investigated in Australia and New Zealand and the current developments in this field, which is termed "Pedometrics", are led mainly from there. A lack of extensive data at appropriate scales prevented the transferring the adoption of a pedometric approach to this project. As the project was required to map as a first requirement the entire country, in a manner that was a uniform as possible, a pragmatic approach was required to enable model development. The approach taken in developing the delivered soil model was therefore primarily a qualitative one, with predictions based on expert judgement in combination with pre-existing, mapped data.

This application of a software-based expert classification approach to develop the soil mapping has proved extremely useful in formalising the knowledge of previous soil surveyors and facilitating its integration into a classification process for areas where no or little previously mapping existed. For the first time since the conclusion of the National Soil Survey detailed mapping exists for areas in Ireland such as Monaghan where previously the only map data available was highly generalised in nature. While not as categorically detailed as previous mapping in unmapped counties the level of soil map resolution and availability is now greater than existed previously. It is also worth noting that the level of accuracy and detail of the linework delineation for particular classes is considerably higher than existed previously, even for previously mapped areas.

Production of the indicative soil map employed a simplified classification scheme devised as part of the original project specification. This classification developed for the project differs from traditional soil survey classifications and that used by the National Soil Survey in Ireland. A key difference is that the indicative soils map is based on a very simplified classification of soil type and does not contain soil property information which would require soil sampling and laboratory analysis. The indicative soil maps produced are based primarily on a functional subdivision of soils. This is reflected in the legend, which differs from traditional legends referring to soil series used in

soil mapping in Ireland. Despite the differences however a key feature of the IFS classification scheme is that each of the classes has a very close relationship with the Great Soil Groups that occur in Ireland. This classification scheme design facilitates broad level interpretation and comparison with previously mapped areas.

The project had accessibility to possibly the most extensive collection of national digital datasets but a significant amount of dataset preparation and repair had to be undertaken before full use could be made of this data resource. Datasets were supplied in widely differing formats and in various conditions. Differing standards of data accuracy in received datasets also required correction through a combination of automatic and manual processes. The majority of project GIS work over the course of a number of person-years consisted of efforts to convert, edit, integrate and data manage the large data volumes available to the project. As part of the ongoing efforts throughout the project to ensure maximum efficiencies in data handling and processing a number of software tools were written and incorporated into the project workflows. These were in addition to a range of customised batch processes which were developed on an as-needs basis to enable the importation and conversion of datasets delivered to the project.

Habitat Map

The Teagasc Habitat Indicator Map (THIM95) map was not originally part of the project deliverables but was fully completed as a value added product after the project end date.

The aim of the habitat indicator mapping was to indicate the likely distribution of particular habitats throughout Ireland. The map is essentially an enhancement of the land cover map by increasing the classification and spatial resolution of many of the land cover thematic classes, namely; *Bog & Heath, Cut Bog, Cut & Eroding Bog, Wet Grassland* and *Dry Grassland*. These land cover classes are indicative of habitat type in a very broad sense only in that they represent combinations of more detailed habitat classes.

The habitat indicator mapping exercise exploited the known associations of land cover, subsoil, elevation and location with habitat in Ireland.

The core element of the habitat indicator mapping methodology is the design and execution of an expert rule base. The expert rule base is a series of conditions which dictate the mapping of particular habitat indicator classes.

There are over 160 conditions defined to model the Habitat Indicator Map. Fourteen new habitat indicator classes are modelled from five land cover classes. The county habitat maps are distributed by the EPA with full metadata documentation.

1 BACKGROUND

1.1 Introduction

The Water Framework Directive (2000/60/EC) came into force on its publication in the Official Journal of the European Communities on 22 December 2000. The Directive establishes a strategic framework for managing the water environment and sets out a common approach to protecting and setting environmental objectives for all groundwater and surface waters within the European Community. The Directive is probably the most comprehensive piece of EC water legislation to date.

A Groundwater Working Group was established under the aegis of the WFD Co-ordination Group to assist in the technical interpretation of the Directive, and to provide guidance for River Basin Projects in the delivery and implementation of groundwater work requirements. The report from this Working Group specified the technical requirements of the WFD for groundwater, and provided practical guidance on the work to be undertaken as part of River Basin Projects. Of particular importance to the initial characterisation of groundwater bodies were the 'overlying strata', or the geological materials overlying the water table in unconfined groundwater bodies and overlying the top of the geological unit forming confined groundwater bodies. These strata consist of soils (top-soils) and subsoils such as till, alluvium, lake and estuarine fine-grained sediments, peat and sand/gravel deposits that are not classified as aquifers or groundwater bodies.

According to the report, identification of the general character of overlying strata was required to enable:

- Assessment of potential pathways of contaminants to groundwater,
- Evaluation of the vulnerability of groundwater to contamination and
- Analysis of recharge to groundwater.

To enable these criteria to be identified, a number of datasets were specified as being required. Included in these were soils maps and parent material (subsoils) maps of the River Basin Districts (RBDs). A recommendation of the Groundwater Working Group proposed that the Spatial Analysis Unit (SAU) at Teagasc, Kinsealy produce the soils and subsoils maps of the RBDs, for the following reasons:

- to maintain consistent standards in these datasets
- to ensure that soils and subsoil boundaries match across RBD boundaries;
- to enable efficient access to relevant Teagasc databases, maps and expertise;
- facilities to undertake the required work are already at Teagasc, Kinsealy;
- it would be impracticable for another organisation to begin to undertake such work given the expertise and facilities housed in Teagasc.

1.2 National Soil Survey in Ireland

The National Soil Survey (NSS) was initiated in 1959, shortly after the establishment of An Foras Talúntais (AFT), the precursor organisation to Teagasc. During the period of operation of the NSS, a number of soil survey outputs were produced at varying scales.

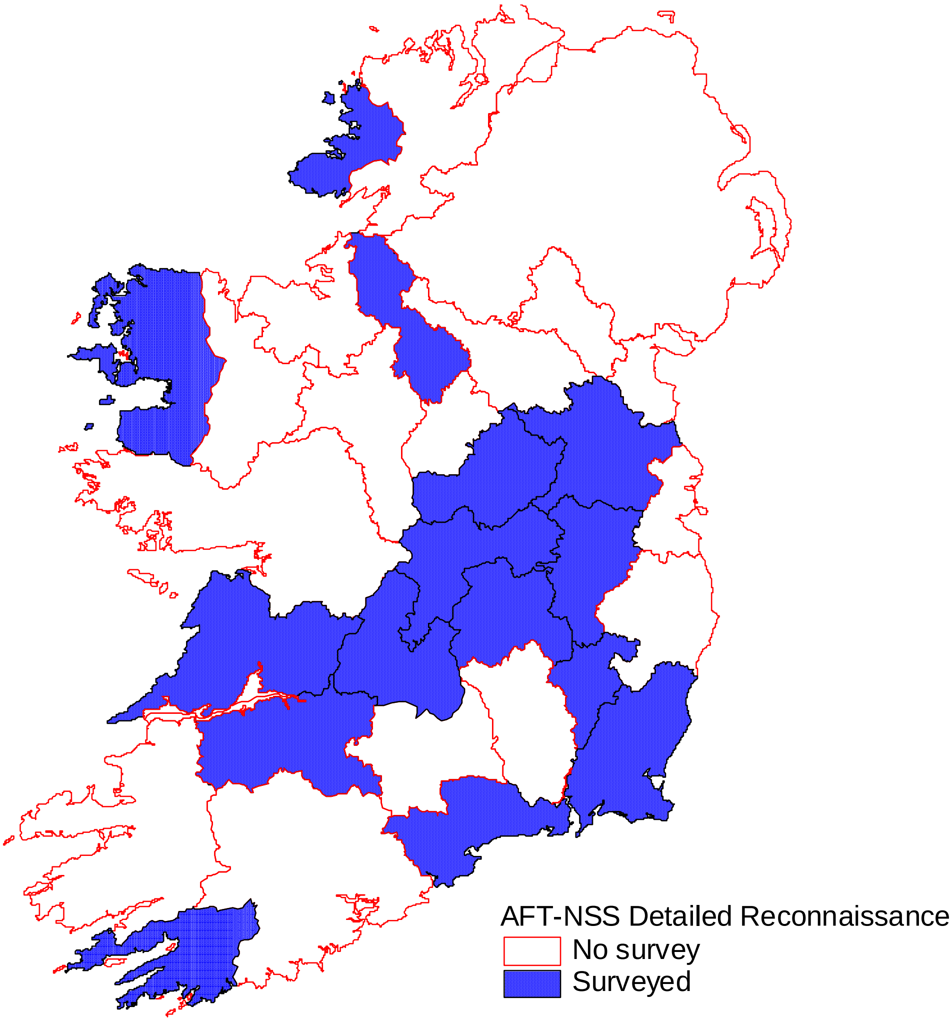


Figure 1.1 Extent of National Soil Survey detailed reconnaissance (1:126,720) mapping

Detailed studies of research stations/experimental stations. These were mostly completed at 1:2,500 scale.

Detailed reconnaissance mapping of 44% of the country. Resulting maps were produced at 1:126,720 scale, often with an accompanying bulletin (Figure 1.1).

A General Soil Map of Ireland was first produced in 1969 based on a combination of the detailed and general reconnaissance work. A second edition followed in 1980 at 1:575,000 scale with an explanatory bulletin (Gardiner and Radford 1980a,1980b).

A peatland map of Ireland was published at the same scale in 1978, with an accompanying bulletin (Hammond, 1978).

1.3 The FIPS-IFS project

The Forest Inventory and Planning System (FIPS) project, of the Forest Service, Department of the Marine and Natural Resources was the result of strategic actions designed to implement forestry policy on inventory and planning as outlined in a Strategic Plan for the Development of the Forestry Sector in Ireland (Anon, 1996). The main elements of FIPS arising from the strategic actions included a forest inventory and classification project and a forest soils classification project. This latter element was called the Irish Forest Soils project (FIPS-IFS) which was undertaken by the SAU at Teagasc, Kinsealy. The primary deliverable from the FIPS-IFS project was a national forest productivity map. As soil is one of the major factors in determining the productivity of any planted crop, the determining of a productivity map for forestry was contingent on the availability of soil data at an appropriate scale.

At the outset of the FIPS-IFS project less than half of the country's soils had been surveyed and published at detailed reconnaissance (1:126,720) scale. This necessitated the development of soil mapping for the remainder of the country at a similar scale. Due to the fact that the productivity mapping project was to be completed within three years the necessity of incorporating remote sensing and Geographical Information System (GIS) techniques into the project methodology was immediately apparent.

The FIPS-IFS project resulted in a methodology for the creation of a first-approximation soil classification for those areas not previously surveyed by the NSS, using a methodology based on remote sensing and GIS. Inherent in this was the production of a soil parent material[1] map. A potential forestry productivity ranking was then attached to these mapped soils to complete the requirement of the FIPS-IFS project.

The primary objective of the Teagasc Soil and Subsoil Mapping project was the continued development and delivery of soil and subsoil/parent material maps for the remainder of the country as proposed by the Groundwater Working Group. This objective was met by extending the research and mapping efforts as specified and delivered under the FIPS-Irish Forest Soils project to the remaining areas of the country which were not previously mapped by that project.

This document reports in detail on the project methodology and results of this project. The production of a suite of environmental map covering the themes subsoils, landcover and soils are the primary deliverables of this project. As the project progressed, an opportunity was identified to produce predictive habitat maps for the country using the other output data layers. This additional suite of mapping is also described here. Project team members with responsibility for particular areas of work have authored the original text of the relevant sections in this document. Subsequent editing for the production of the final report has taken place by the editors.

[1] The term 'parent material' is treated as being synonymous with 'subsoil' in this report. The terms are used interchangeably throughout this document.

2 PARENT MATERIAL/SUBSOIL MAPPING

2.1 Introduction

Soil landscapes around us are the product of soil forming factors acting on surface geological deposits over time. Factors influencing soil formation and development include kind of parent material, topography, climate, vegetation, time and the activities of man. The surficial deposit which comprises the parent material of soil is characterised by its physical and chemical properties such as soil texture, reaction and chemical composition. Dominant petrographical component is also important, but to a lesser degree. This surficial material is shaped by geological processes operative during deposition to its present surface form. The resultant forms of these materials are further influenced by the prevailing climate and vegetation that it supports over time to develop soils which reflect the intensity and geographical distribution of the above factors.

Soil properties vary laterally with topography resulting in patterns of soil development, a relationship that facilitates, at least to some degree, the prediction of soil attributes from landscape position. Soil-landscape studies explore the relationship between earth system processes, geomorphology and soil development. Knowledge of pedology, Quaternary geology and sedimentology, geomorphology, hydrology and vegetation, as well as an intuitive knowledge of Quaternary history, allows us make assumptions about soil attributes.

This requires that we have adequate Quaternary geology maps and morphological maps, as well as the related model for the Quaternary history of an area. Quaternary deposits in Ireland are the most important of all geological materials, as they comprise what lies immediately below the surface over approximately 96% of the country (bedrock outcrop comprises the other 4%). As well as forming the parent materials for most Irish soils, Quaternary deposits:

- Provide the second most important aquifer in the country after limestone
- Are the medium through which all groundwater systems are recharged and therefore provide protection for groundwater resources
- Afford the foundation for almost all major engineering undertakings and contribute our basic building materials through sands, gravels, limestone etc

This, combined with the fact that glacial landforms largely make up the Irish landscape, illustrate the huge importance of the effect the Quaternary period and its related geological processes have had on our country.

2.1.1 The Quaternary Period

The Quaternary is the most recent period of the Earth's geological history. It began approximately 1.65 million years ago and extends to the present day. It is divided into two Epochs, the Pleistocene and the Holocene. The Pleistocene Epoch lasted from 1,600,000 to 10,000 years ago. It consisted of alternating glacial and interglacial periods, during which ice sheets grew and decayed as a result of varying global climates. The Holocene Epoch covers the last 10,000 years, and is characterised by the relatively warm postglacial climate of today.

The Quaternary may also be subdivided into the Early, Middle and Late Quaternary. The Late Quaternary period stretches from 130,000 years ago to the present. During this period most of the surficial sediments in Ireland were deposited.

Quaternary sediments differ from earlier sediments in that they are generally unlithified. Most other earlier Irish sediments are much older. In general, late Quaternary sediments are thousands of years old, whereas older, solid rock sediments are millions of years old.

Most Quaternary sediments owe their genesis in one way or another to the action or melting of ice. Ireland was covered by ice, just as many high latitude regions are nowadays, for long periods in the last 130,000 years. The last glaciation occurred between 73,000 years ago and 10,000 years ago. This had a huge influence on both the landscape and underlying geology of the country. Since 10,000 years ago the action of modern rivers, the infilling of lakes and the reworking of our coastline, along with the formation of peat bogs, have been the main natural processes affecting both our landscape and geology.

2.1.2 Glaciation in Ireland

There is direct evidence in Ireland of no more than two glacial periods. There may have been more, but due to the destructive power of ice sheets, any earlier evidence has been removed. Ireland has, though, a very rich legacy of glacial deposits and landforms relating to the most recent glaciation. Over 90% of Ireland's area is covered by deposits from this period.

The most recent glaciation lasted for about 63,000 years and ended only 10,000 years ago, when our climate warmed again. The maximum extent of ice occurred sometime between 22,000 years ago and 20,000 years ago. At its maximum extent ice covered the vast majority of the country, apart from isolated mountain peaks and a small area in north and west Kerry and west Limerick. This massive ice sheet comprised several domes which coalesced to cover the country. These ice domes were not stagnant. Their ice flowed outward from their centres under the influence of gravity and pressure from surrounding ice during the last glacial period (something like wet concrete will if it is laid on top of itself with a trowel).

As ice flows out towards its margins, pieces of rock and soil over which it flows become attached to its base by freezing on, and they may become incorporated into the lower layers of the ice. This in

turn makes the base of the ice very abrasive and it can erode, polish and mould the landscape into the forms that we see today. In this way the substrate is eroded, picked up and transported by the ice. Striae are grooves or scratches cut into bedrock by abrasive ice which passed over it. These are aligned along the plane of ice movement and are therefore an excellent indicator of past ice movements. Roches moutonnées are another indicator of ice flow direction. These are moulded rock forms generally polished on the up-ice side (direction from which the ice flowed), and plucked on the down-ice (lee) side. When the ice melts, the material is left in one of the many landforms caused by glacial ice. From this we see that rocks can be carried far away from their source and left as erratics, either at the surface or incorporated into the subsurface.

2.1.3 Quaternary sediments

Quaternary sediments are categorised according to their genesis. Eight main types of sediment are recognised. These are:

- Diamictons (mostly tills)
- Glaciofluvial sands and gravels
- Esker sands and gravels
- Glaciolacustrine deposits
- Alluvium
- Marine deposits
- Peat
- Other Quaternary deposits
-

Bedrock at or close to the surface, is also mapped

2.1.3.1 Diamictons (mostly tills)

Diamictons are unsorted deposits with a wide variety of particle sizes. They include tills and head deposits, but in the Irish context most diamictons are tills. Till is sediment deposited by or from glacier ice. Glacial ice is the principal depositional agent, but gravity and, in some cases, water, also play a part. Tills are often over-consolidated, or tightly packed, unsorted, unbedded, possessing many different particle and clast (stone) sizes, and commonly have sharp, angular clasts. Tills are often termed ‘boulder clays’ by engineers. Tills may be categorised according to their dominant petrographical component. Examples are Lower Carboniferous limestone till and Lower Palaeozoic shale till. Tills can also be categorised according to the grain size of the matrix, or the texture of the till. This determines permeability, which is important for soil forming processes. Thus, tills may be described as gravelly till, sandy till, silty till or clayey till.

Within different till types, a wide variety of permeabilities are possible. In the case of the tills examined in this project, generalisations will made to classify the tills as stony, bouldery, gravelly, sandy, silty or clayey. Where it is impossible to gauge the texture the till will be classified as ‘undifferentiated’.

Irish Sea Till is a till type characterised by its brown, clay-silt matrix and erratic of northern and Irish Sea Basin provenance including shell fragments, shells and flint. The Irish Sea Till is largely confined to the coastal zone, it extends about 12 km inland. The till is highly over-consolidated and very poor draining, usually resulting in low permeability and consequently gleyed topsoils.

Tills include glaciomarine sediments, which are deep-sea sediments that have originated in glaciated land areas and have been transported to the sea by glaciers or icebergs. These sediments are present along certain portions of the Irish coast and have the same geotechnical (and hence soil-forming) characteristics as tills.

In describing the textures of tills that have been sampled in the field for this project, the British Standard Soil Description Classification System was used. This system places soils into groups defined by the grading of their coarsest particles and the plasticity of their finer particles, characteristics that play a major role in determining soil engineering properties. The main attributes of the subsoil described include the mass characteristics, material characteristics, geological deposit type and age and classification.

The till types delineated from the photogrammetric modelling of aerial photographs were classified according to their dominant petrography, as this can be used to estimate their textural characteristics and chemical reaction properties. These dominant petrographical components were estimated to a high degree of accuracy from the photogrammetric modelling, combined with data from the bedrock geology maps.

2.1.3.2 Glaciofluvial sands and gravels

Glaciofluvial sands and gravels are different from tills in that they are deposited by running water only. The gravels usually possess stratification (layering) and usually have rounded edges. Glaciofluvial deposits are usually loosely packed. When the huge amounts of meltwater produced by the melting of the ice sheets that covered Ireland at the end of the last glacial period are considered it is not surprising that these deposits are very common in Ireland. They represent the stagnation and decay of the ice sheets. On the maps they are represented as ‘sands and gravels’ and are also categorised according to dominant petrography e.g. Lower Carboniferous limestone sands and gravels. They give rise to a variety of different landforms, including kames, kame terraces, sandar, moraines and, in some cases, drumlins.

Esker sands and gravels are laid down by glacial meltwaters in tunnels and crevasses in stationary or retreating ice sheets, and are seen on land as long, narrow, sinuous ridges. They commonly possess rounded boulders and cobbles. Clasts are usually much larger overall than in other glaciofluvial deposits. Sand may or may not be present. The esker alignment usually shows a close correspondence with the ice flow direction. The gravels are usually bedded, the beds often slumping towards the flank of the esker, indicating collapse as the confining ice walls melted. Esker gravels, as with all glaciofluvial sands and gravels, have very high permeabilities.

2.1.3.3 Glaciolacustrine deposits

Glaciolacustrine deposits were deposited into a large number of meltwater-fed lakes during and shortly after deglaciation. Deposits consist of sorted gravel, sand, silt and clay. They are found normally in wide flat plains, or in small depressions in the landscape. The deposits have different permeabilities depending on the dominant grain size. Deltas (or other near lake shore or beach deposits), which are formed as sediment is deposited at a river mouth on entry into a glacial lake, usually contain interbedded sands and gravels which dip lake-ward. These are left as sand and gravel hills when the ice disappears and the lake drains away. Lacustrine basins, which are distal parts of the lake system, usually contain finer sediments, such as clays and silts which have settled from suspension from the water body. The differentiation of the dominant grain sizes within lacustrine sediments is imperative as such a wide variety of grain size combinations is possible, each resulting in a different texture and thus soil type.

2.1.3.4 Alluvium

In the Holocene Epoch, the warmer climate effected a large change on the environment. The modern fluvial systems were superimposed on but largely controlled by the pre-existing glacial landscape. The floors of these modern valleys take the form of alluvial floodplains. Alluvium is a post-glacial deposit and generally consists of gravel and sand with a minor fraction of silt and clay. However, this deposit may consist of gravel, sand, silt or clay in a variety of mixes and usually consists of a fairly high percentage of organic carbon (10%-30%). The alluvial deposits are usually moderately to well sorted and are bedded, consisting of many complex strata of water-lain material left both by the flooding of rivers over their floodplains and the meandering of rivers across their valleys. Alluvial fans and modern deltas are included as part of this deposit type.

2.1.3.5 Marine deposits

Marine deposits are found along the coast and usually take the form of beaches, spits and bars. These deposits are continually reworked by the sea today. Beach sands and gravels are the most common deposits. Estuarine silts and clays are also included, which have settled from suspension in salt or brackish water bodies, through shoreline processes such as wave action and longshore drift.

2.1.3.6 Peat

The change in climatic conditions also resulted in the growth of peat (bog). Peat is also a post-glacial deposit, consisting mostly of vegetation which has only partially decomposed in an ombrotrophic (nutrient poor) environment. Bog peats are formed in acidic waters and vary according to the main plants involved in their growth.

Blanket bog is associated with highland areas where poor drainage enabled the build-up of oxygen-starved, partially decomposed biomass. This is thought to have begun approximately 4,000 years ago.

Raised bogs developed in many small lake basins, spreading over time to the surrounding land. Vegetation fills and compacts in marshes, ponds and other lakes carved out and left by Quaternary ice sheets. Thus, on the lowlands in Ireland, peat usually overlies badly drained glaciolacustrine silts and clays. In the last few centuries, much of Ireland's peat has been cut away for burning as solid fuel. For this project it was decided after trialling the mapping methodology that distinguishing intact from drained or partially modified raised bog was not possible. For this reason nearly all areas of peat that would be traditionally known as Raised bogs have been mapped as "Cut" to indicate that they have in some way or other, even if only at their fringes, been modified in some way.

Fen peats consist of unspecified organic materials formed in a minerotrophic environment due to the close association of the material with mineral rich waters. In fen peats the presence of calcium in the groundwater neutralises acidity, giving a black, structure-less peat. The material is normally moderately to well decomposed, with decomposition greater at later depths.

2.1.3.7 Other deposits:

Aeolian sediments are deposits that generally consist of medium to fine sand and coarse silt, and are generally extremely well sorted and poorly compacted. The deposit may be massive, or show internal structures such as cross bedding or ripple laminae. These materials have been transported and deposited by wind action. Examples are dunes, shallow deposits of sand and loess.

Colluvium is a sediment which is moderately well-stratified, non-sorted to poorly sorted, and contains any range of particle sizes from clay to boulders that have reached their present position only by direct, gravity-induced movement. Processes include creep, solifluction and earth-flows. Colluvial deposits are most common where the bedrock is very friable, for example in areas underlain by shale. The deposit varies in texture from being very flaky to very muddy, depending on the petrography of the local bedrock and the amount of weathering that has affected the deposit. Head is included in this type of deposit, and is laid down during the severe cold climate (similar to the tundra of today) which occurs during and shortly after deglaciation. During this time, the frozen ground thaws in spring and becomes very mobile and a slow flow of shattered fragments of rock, which are also a result of the intense cold conditions, occurs from higher to lower ground.

Marl is significantly calcareous clay that originates from deposition in lacustrine conditions. The deposit contains over 65% calcium carbonate, with the rest of the particles comprised of clay or silt.

Scree is an accumulation of coarse rock debris that accumulates at the base of an inland cliff or steep mountain slope. The scree is added to by the weathering and release of fragments from the cliff face. Scree is found in upland areas that have been affected by past periglacial conditions.

Made ground consists of materials modified by people, including those associated with mineral exploitation and waste disposal. They include materials deposited as a result of human activities or geological material modified artificially so that their physical properties (structure, cohesion and compaction) have been drastically altered. Examples are areas of landfill spoil heaps, open-pit mines and levelled irrigated areas.

Tidal marsh is an intertidal marsh developed in tidal areas with narrow tidal ranges, or in bays and estuaries of regions with high tidal ranges.

Bedrock consists of a consolidated rock layer that is too hard to break or to dig with a spade when moist. Bedrock at, or close to (within 1 metre of) the surface is also mapped. This is a vital ingredient of the soils map. The rock outcrops were mapped according to the type and petrography of the rock.

2.2 Subsoil mapping

The mapping of subsoils involved the integration of a number of suites of data. Initially, all available Quaternary information for the county being mapped was compiled and any relevant information on sediments portrayed on a paper 1:50,000 map. The list of final subsoil classification categories with their map codes is detailed in table 2.1 at the end of this chapter.

2.2.1 Soil Survey maps

Published county soil maps produced by the National Soil Survey were consulted, where available. The legend accompanying these maps also describes the parent materials/subsoils for each mapped soil series. Areas of peat are shown quite precisely, as are alluvial soils.

2.2.2 Quaternary maps

Quaternary maps from the Geological Survey of Ireland (GSI), where available, show most of the information needed to draw the subsoil map. There are differences in some cases, though. As some of the maps were drawn up in part using satellite images, many of the areas classified as peat on the GSI maps are in fact areas of heath vegetation but not necessarily peat. Furthermore, some of the tills mapped as basic are actually acidic (dominated by sandstone or granite) and hosted acidic soils. This is owing to the fact that the GSI classify tills based on their dominant phenoclast petrography, using clasts 5mm-10mm across as the basis for subdivision. It was seen in the field that many of these sites, which may have had more fine gravel clasts of, for example, cherty limestone, had a matrix derived from granite which gave the soils their acidic characteristics. From this, it was decided to describe tills based more on their 'bulk' overall characteristics (especially of the matrix) rather than based on stone counts. The GSI maps served as a helpful guideline during fieldwork in this area nonetheless and many of the boundaries correspond almost exactly to those drawn using photogrammetry.

2.2.3 Academic papers

Academic papers on Quaternary glacial reconstructions and Quaternary sediments may cover topics as diverse as the mapping of corries to analysis of esker gravels to drilling results from peat bogs. A graphic example list of these sources for County Mayo is portrayed in Figure 2.1. Many of these publications included maps of small areas which delineated features such as till moraines in the uplands, eskers, marl areas in turloughs, *etc*. These were again incorporated into the analysis but as with the other sources the final boundaries were all drawn within the photogrammetric medium to ensure consistent mapping.

2.2.4 Photogrammetric mapping

Following this initial compilation of these data, boundaries between sediment types are interpreted and mapped using photo-interpretation in a soft copy photogrammetric workstation with digital stereo-pairs of black and white photography (acquired in 1995 at a scale of 1:40,000) using ATLAS software. Boundary polygons are therefore accurately located in the Irish National Grid in three dimensions. In areas where previous mapping had taken place and data have been compiled in the initial stages of work on that county the boundaries were re-digitised using the ATLAS software. This ensured the accuracy of the boundaries on the finished map and ensured that they relate correctly to the landforms and deposits that they are supposed to.

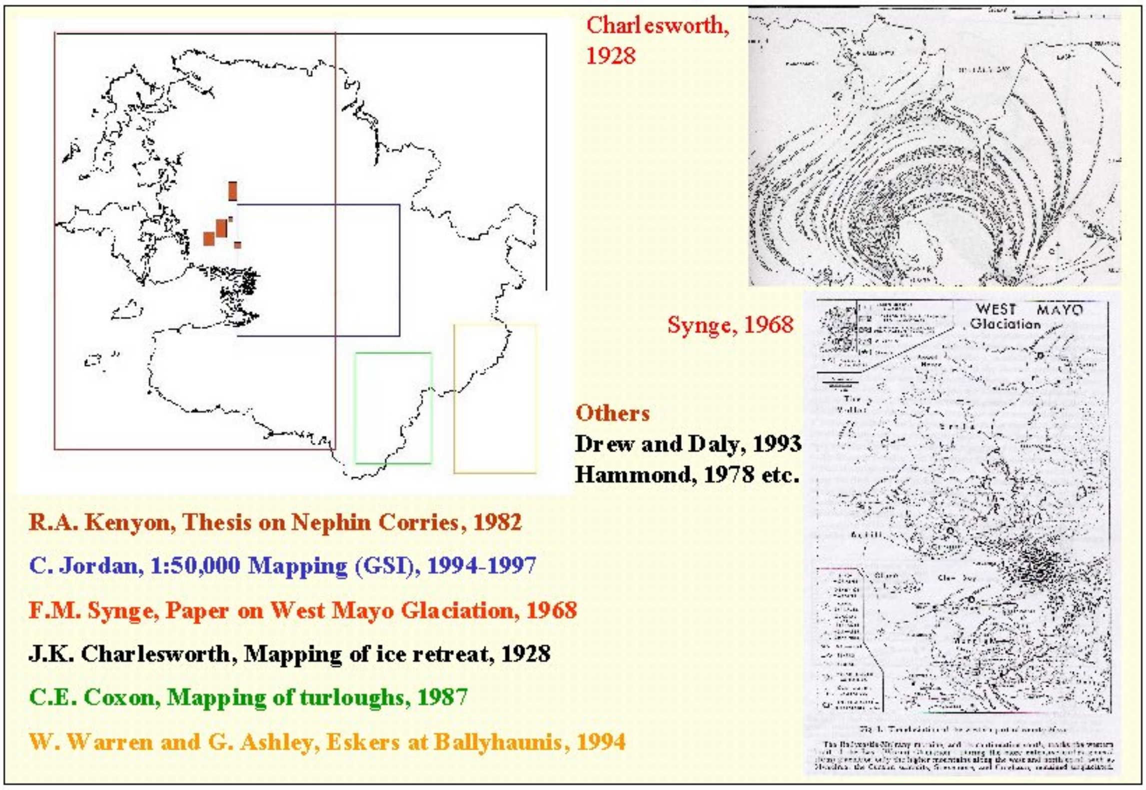


Figure 2.1 Main sources of subsoil data for County Mayo, with examples of range of information available.

While mapping, the minimum unit depicted was abut 30m x 30m for some rock outcrops *i.e*. 900 square metres. This is at quite a detailed scale as the majority of this information comes from GSI archive outcrop data. Over the remainder of the subsoil map, units are generally no more than 100m x 100m across, equating to a mapping scale of around 1:50,000. The ATLAS coverage produced consists of lines that constitute polygons, and text labels. The completed ATLAS file for each county was exported as a DXF file. This was imported into ERDAS Imagine software where the linework was cleaned and built into a full GIS polygonal coverage. On exportation from ATLAS an algorithm converted the 3D subsoil coverage into 2D to be used as a planimetrically correct map theme for subsequent display and analysis in ArcView GIS software.

Following the drawing up of preliminary boundaries, fieldwork was carried out. Many of the sediment types were visited and sampled, but work concentrated heavily on areas within the boundary zone between acid and basic mineral subsoils. The boundary between the two bedrock types and the associated former ice flow directions and interpreted subglacial processes in that area guided the location of sampling. For example, in Mayo the area of transition between till derived from Old Red Sandstone and till derived from limestone was visited a number of times. Further to this, fieldwork was also undertaken around the flanks of the larger bogs to delineate the exact boundary between peat and mineral soils. Recognition of peat areas with peat soils which have been reclaimed for agriculture was an important part of this data collection.

The classification of subsoils used in mapping Quaternary sediment types was based on the classification used by the Geological Survey of Ireland Quaternary Section. This classification has been altered only to ensure utility specific to the requirements of the EPA Soil and Subsoil Mapping Project.

2.2.5 Morphological analysis

Landforms, added to the Quaternary sediment geology, help in reconstructing the nature of the glacial and deglacial pattern in the area, which is important in understanding the stratigraphy and sedimentology of the deposits. Furthermore, breaks in slope are an important aid in identifying boundaries between different deposits, as morphological lineations often correspond with Quaternary sediment (subsoil) boundaries.

Visualisation of the DEM aided this element of the mapping of subsoils considerably. Recognition of drumlins, of ribbed moraine fields and of flutings all suggested areas of subglacially deposited diamictons *i.e.* till. Hummocky areas suggested sands and gravels or normally consolidated diamictons deposited during ice melt out. In addition, eskers which contain gravels could usually be seen on the DEM. Furthermore, the DEM allowed the quick visualisation at a broad scale of former ice flow sets, which aided in the process of delineating carry-over of erratic-dominated sediments. This technique was especially important in Ireland in the areas of drumlins with varying flows, as the country is an area of considerable bedrock geological complexity.

Morphology was later checked in the field during field verification. In some cases it was possible to infer the sediment type from the geomorphology; *e.g.* eskers are composed of sands and gravels; river floodplains are composed of alluvium; and infilled lacustrine basins are usually made up of clay. The recognition of breaks of slope, especially around the base of landforms, identified in many cases: the boundary between the primary sediment types *i.e.* between bedrock crags and soft sediments; within these soft sediments the boundary between mineral material and raised peat; and within the mineral between diamictons and sorted sands and gravels and also allowed differentiation between both of these and alluvial and lake sediments.

2.3 Field programme

The preliminary identification of subsoil boundaries within the photogrammetric medium means that problem areas, especially transitional zones between acidic and basic subsoils, could be focused on during fieldwork. The field mapping also allowed for the checking of the ground for areas mapped during the photogrammetric analysis, and was therefore crucial in increasing the accuracy and defensibility of the maps. Methods adopted during field mapping were as follows.

2.3.1 Reconnaissance mapping

Mapping in the field involved travelling around the field area, often on foot, and surveying all quarries, gravel pits, stream cuttings, drains, house foundations, trenches, or any other cutting into the subsurface, which were of use in determining the underlying subsoil. In almost all cases it was important to find some exposure.

2.3.2 Auger Sampling

This was important in determining textural characteristics of the topsoils, as well as the soil type. Lithological analyses of matrix and augered clasts helped determine the dominant lithology within the subsoil. This was important in the areal subdivision of tills and gravels into lithologically similar zones. In some places preliminary stone counts were carried out in the field to ascertain initial till lithologies. Samples were usually taken from till deposits, but were also taken from glaciofluvial, glaciolacustrine and alluvial deposits. Auger samples were taken from individual deposit areas where little exposure was present.

2.3.3 Trenching

Trenching was also carried out where there was no adequate exposure available to collect samples, or where no exposure whatsoever existed and the subsoil was in doubt. Trenching was carried out in other areas where lithological boundaries were in doubt. Here, a small 0.5m-0.8m deep hole is dug in a field by hand to examine the soil 'B' horizon and, if visible, the 'C' horizon.

2.3.4 Digital photographs

Where exposure exists, digital photographs were taken of the profile. Photos were also taken of specific landforms and landscapes of different soil types. The photos could be grid referenced and are available for inclusion as point data, which can be overlaid on the final GIS coverage. They

also served as an accurate visual record of the variation in subsoil type across the landscape that can be easily accessed and reviewed.

2.3.5 GPS data collection

At each site visited, a Global Positioning System (GPS) point was logged and recorded (See Figure 3.9). This meant that all points visited in the field could be added to the digital map in the office following fieldwork and that attributes collected in the field could be visualised on-screen (Figure 4.7). Attributes recorded included subsoil type, soil, drainage characteristics, topographic data, land cover information and general environmental conditions at the site.

Table 2.1 Parent material/Subsoil categories

Tills:

Till type	Map code
Sandstone and shale till (Cambrian/Precambrian)	TCSsS
Sandstone till (Lower Palaeozoic)	TLPSs
Shale till (Lower Palaeozoic)	TLPS
Sandstone and shale till (Lower Palaeozoic)	TLPSsS
Sandstone till (Lower Palaeozoic/Devonian)	TLPDSs
Sandstone till (Devonian)	TDSs
Sandstone till (Devonian/Carboniferous)	TDCSs
Sandstone and shale till (Devonian/Carboniferous)	TDCSsS
Limestone till (Carboniferous)	TLs
Shale and sandstone till (Namurian and Carboniferous)	TNCSSs
Shale and sandstone till (Namurian)	TNSSs
Chert till	TCh
Carboniferous sandstone and Chert till	TCSsCh
Quartzite till	TQz
Acid volcanic till	TAv
Granite till	TGr
Basic igneous till	TBi
Metamorphic till	TMp
Sandstone and shale till (Cambrian/Precambrian) with matrix of Irish Sea Basin origin	IrSTCSsS
Sandstone till (Devonian) with matrix of Irish Sea Basin origin	IrSTDSs
Sandstone and shale till (Lower Palaeozoic) with matrix of Irish Sea Basin origin	IrSTLPSsS
Limestone till (Carboniferous) with matrix of Irish Sea Basin origin	IrSTLs
Sandstone till with matrix of Irish Sea Basin origin	IrSTSs
Acid volcanic till with matrix of Irish Sea Basin origin	IrSTAv

Glaciofluvial sands and gravels:

Sands and gravels type	Map code
Acidic esker sands and gravels	AcEsk
Basic esker sands and gravels	BasEsk
Sandstone and shale sands and gravels (Cambrian/Precambrian)	GCSsS
Sandstone sands and gravels (Lower Palaeozoic)	GLPSs
Shale sands and gravels (Lower Palaeozoic)	GLPS
Sandstone and shale sands and gravels (Lower Palaeozoic)	GLPSsS
Sandstone sands and gravels (Lower Palaeozoic/Devonian)	GLPDSs
Sandstone sands and gravels (Devonian)	GDSs
Sandstone sands and gravels (Devonian/Carboniferous)	GDCSs
Limestone sands and gravels (Carboniferous)	GLs
Shale and sandstone sands and gravels (Namurian)	GNSSs
Chert sands and gravels	GCh
Quartzite sands and gravels	GQz
Granite sands and gravels	GGr
Basic igneous sands and gravels	GBi
Metamorphic sands and gravels	GMp

Glaciolacustrine deposits:

Sorted sediment type	Map code
Lake sediments undifferentiated	L
Sandy	Ls
Silty	Lsi
Clayey	Lc

Alluvium:

Sorted sediment type	Map code
Alluvium undifferentiated	A
Gravelly	Ag
Silty	Asi
Clayey	Ac

Marine deposits:

Sorted sediment type	Map code
Raised beach sands and gravels	MGs
Beach sand	Mbs
Marine silts	Msi
Marine clays	Mc
Estuarine sediments (silts/clays)	Mesc

Peat:

Peat type	Map code
Blanket peat	BktPt
Raised peat	RsPt
Fen peat	FenPt
Cutover peat	Cut

Other categories:

Aeolian sediment type	Map code
Aeolian Sediments undifferentiated	Aeo
Blown sand	Ws
Blown sand in dunes	Wsd
Material type	**Map code**
Marl (Shell)	Mrl
Scree	Scree
Made ground	Made
Marsh	Marsh
Tidal marsh	TdlMr
Bedrock at surface	Rck
Bedrock at or near surface-Non calcareou[1]	*RckNCa*
Karstified limestone bedrock at surface	KaRck
Bedrock at or near surface-Calcareous[2]	*RckCa*

[1] Appears only in "Par_mat" field of soil maps. "Rck" and "KaRck" in the subsoils map were recoded to "RckNCa" and "RckCa" in the soil maps using inputs from Geological Survey of Ireland datasets

3 LAND COVER MAPPING

3.1 Introduction

The aim of the land cover mapping element of the project, Teagasc Land Cover Map 1995, **TLC95**, was to aid in the discrimination of well drained and poorly drained mineral soils throughout Ireland. The TLC95 map was produced using aerial photography and satellite imagery. The land cover mapping exercise exploits the known ecology of grassland types in Ireland in relation to soils. There are three main elements to the land cover mapping; training data, classification of satellite imagery and accuracy assessment.

3.2 What is Landcover

Land is divided up into areas: Administrative areas such as electoral divisions or ownership "parcels" like a farm holding, each of which can be assigned a cover or covers. Land cover on a large scale can involve concepts such as eco-zones. These of course overlap at different scales and are not exclusive; examples like commonage or designated areas such Natural Heritage Areas illustrate lines on a map, along with farm boundaries, of competing "ownership".

Attribution of a landcover label can be confusing. A field of pasture can be labelled in different ways depending on ones interest: It maybe enough to label as grassland, but more detail might be "Improved pasture"; we could be concerned with management practice (silage cutting or grazing); an ecologist may not see a field but an assemblage of habitats; perhaps the boundary (hedgerow or stonewall) is more important than the field for some purposes; an archaeologist might only be interested in the standing stone in the middle of the field or a landscape professional may not see the field as separate from a larger designation of a lowland pastoral landscape.

For the purpose of this project, we defined

Land cover – the dominant surface cover type or class of a homogeneous area of land. Classes can be refined at different levels.

- Level 1: Vegetation
  - Level 2: Grassland
    - Level 3: Intensive grassland
      - Level 4: *Lollium* dominated grassland

Cleary there can be some overlap in landcover and use. They can be quite different however and the choice of whether to map use or cover can have major implications on how maps and statistics from the maps are perceived.

Land Use - the dominant use or occupation of a parcel of land. Often broad classes are used, with different levels of class refinement:

- Level1: Agricultural land

Level2: Pasture

Level 3: Permanent Grazing

A land cover map is therefore a map of object with ascribed labels of landcover (e.g. LPIS) or dominant land cover over a minimum mapping unit (e.g. CORINE). The TLC map is an example of the latter.

3.3 Landcover Mapping in Ireland

At the projects start there was only one national, thematically exhaustive Landcover data set, CORINE 1990. However the minimum mapping unit (mmu) of 25Ha and the thematic classification was deemed to be inappropriate for the project. CORINE 2000, published in 2003 did not alter these parameters (Bossard, Feranec et al. 2000).

There were other national but thematically narrow data sets available, such as the Forest Inventory Parcel System, FIPS (Gallagher et al. 2001). Other datasets were in existence but were not available to the project because of licence restrictions (Land Parcel Information System- LPIS) or because due to being unavailable in digital form (e.g. AFT General Soil Map of Ireland-Soil Bulletin, Gardiner & Radford, 1980)

Landuse and cover information at a various scales and levels of completeness is held by a variety of public bodies:

Ordnance Survey Ireland (OSI)
Property Registration Authority (PRA)
Department of Agriculture Food & Fisheries (DAFF)
Environmental Protection Authority (EPA)
Forest Service
National Parks & Wildlife Service (NPWS)
Office of Public Works (OPW)
Bord na Mona (BnM)
Electricity Supply Board (ESB)
Geological Survey of Ireland (GSI)

Some of these data have been used in the project (see sec. 3.7) but it was realised early in the project that no national dataset existed that held the necessary data at the necessary scale. Thus the project needed to create its own national Landcover dataset.

3.4 Role of Landcover map within project

Optical Remote sensing records only surface response. In Ireland vegetation or man made surfaces cover most of the land surface, most of the time. Therefore direct remote sensing of soils is not possible (Mulders, 1987). We can however infer some characteristics of the soil properties based on landcover and land use.

The landcover map was used within the project rule base to help locate wet soils, shallow rocky soils and reclaimed peaty soils. For further information on the soil mapping methodology, see chapter 4 of this report

It was also used within the forest potential productivity element to define “previous land use” for sites. The landcover map also became the primary basis for the Teagasc Habitat Map (Chapter 5, this report)

3.5 Specifications of Landcover Map

The specifications of the final Landcover map were drawn up over a number of months, as the role of the TLC map within the project solidified, the capabilities of the software were examined and the availability of ground control was established. As the mapping process was examined fully in the trial county, Mayo, refinements were made in the thematic information contained and the map production process. The final specifications of the Landcover product at the end of the Mayo trial are detailed below. See Table 3.1

The minimum mapping unit (MMU) was established as the practical lower limit for processing TLC within the soils rule database: if the MMU were smaller than that finally chosen, (the satellite data used has a pixel size of 30m by 30m with minimum object size for recognition of 5 pixels) then the number of polygons involved in produced in the final soils map would have become unwieldy.

The thematic classes were selected for utility in the project and relative ease with which they could be discerned in the classification process. The existing international landcover schemes did not meet the requirement of the map within the soils project (Hansen et al, 2000). It proved difficult with a single summer Landsat image to distinguish, reliably, across a whole county between bogs and heaths. See Figure 3.1 for example photographs of landcover themes. Since such a distinction was not needed with respect to the role of the TLC map within the soils project, it was decided to conflate the two classes. (These classes are expanded in the national habitat indicator map.)

Geographic Characteristics	
Direct Spatial Reference System	Irish National Grid
Geographic Extent	County admin boundary, as created within the project-
Storage Format	ESRI GRID
Minimum Mapping Unit	1 Ha

Table 3.1a: Basic Specifications of the TLC

Class	Number	Code IFS
Bare Soil	901	BC
Bog&Heath	201	PH
Bog	200	P
Cut Bog	202	PBC
Cut & Eroding Bog	203	PBCE
Bare Peat	204	PBCEBC
Wet Grassland & Heath	103	GSWH
Wet Grassland	102	GSW
Dry Grassland	101	GAGS
Water	910	FM
Shallow Water	910	FM
Bare Rock	600	ER
Rocky Complex	601	CR
Mature Forest	700	WNWD
Forest(U) & Scrub	701	WSWL
Built Land	909	BL
Sand	800	CD
Coastal Complex	801	C
No Data	999	ND
Cloud Shadow	997	CS
Unclassified	998	UN

Table 3.1b: Thematic Specifications of the TLC

Figure 3.1a Landscape with Wet Grassland (GSW) in the foreground, then scrub (WSWL), Dry Grassland (GAGS), Mature Forestry (WNWD) and Water (FM). Co.Clare 2001.

Figure 3.1b: Rocky Complex (CR) in foreground, Mature Forestry (WNWD) in mid and Bog & Heath (PH) in Back Ground

Figure 3.1c: Wet Grassland (GSW) foreground, Cut&eroding peat (PBCE) & Scree middle ground, bare rock (ER) background

Figure 3.1d: Cut bog (PBC) with mature forestry (WNWD) in background

3.6 Overview of Supervised Classification of Satellite Imagery

At the start of the project, the concept of object orientated mapping was investigated. However the absence of availability of a cadastre to the project (Câmara, Souza et al.1996, Walter, 1998) and the immaturity of image segmentation approaches (Ryherd and Woodcock 1996) for a national project meant that conventional image classification techniques, robust and suited to national scale projects were applied (Colpaert, 1993; Haack and English 1996, Vogelmann, Sohl et al. 1998).

Supervised classification is the process of using samples of known identity (training areas *i.e.* pixels assigned to themes) to classify unknown pixels from a satellite image (*i.e.* to assign unclassified pixels to themes). The analyst defines training areas by identifying regions on the image that can be clearly matched to areas of known identity from training data (see section 3.7) (Mather 1999). Such areas typify spectral properties of the categories they represent and are relatively homogeneous in respect of the information category to be classified. (See section 3.8). This process of *automatic* classification is much quicker than conventional digitising by manual interpretation of imagery.

Within the project, training data were used to produce a supervised classification of satellite imagery collected by the Thematic Mapper (TM) sensor on board Landsat 5. The imagery was chosen, where possible, to be contemporary with the aerial photography (1995). The resolution of the imagery is 30m, resampled to 25m. See figure 3.2. The positional accuracy of the imagery is quoted as approximately one and a half times that of the resolution of the imagery or approximately 40m (RMS).

The resulting land cover thematic map illustrates the distribution of land cover classes. They represent groupings of vegetation classes from the image training data, they are therefore indicative of vegetation type in a broad sense only. These land cover classes are indicative of land cover in a very broad sense only in that they represent conflations of more detailed habitat classes (Loftus *et al* 2000). For enhanced classification and spatial resolution of the land cover classes, the user should refer to the Habitat Indicator Maps.

Figure 3.2: Example Satellite Image of the Burren. Landsat 5 TM , 1995, True colour composite (Bands 1,2,3)

3.7 Ground Truth collection

One of the core tasks in Land Cover Classification of satellite imagery is the collection of training data – geographically specified areas of known landcover (Campbell 1996). In this project, training data (areas of known landcover) were collected using softcopy photogrammetry. The underlying dataset used was the national monochrome aerial photography survey of 1995. Campbell (1996) has argued that it is a well established principle that remote sensed data of high spatial resolution (aerial photography) can be used to ground truth data of a lower spatial resolution (satellite images).

Softcopy photogrammetry does not require the physical (hardcopy) form of the photograph necessary for traditional photogrammetry. Instead the digital ("soft") version of the image is used as input for a series of mathematical models that reconstruct the orientation of each image to create planimetrically correct representations. This process requires specialised computer software and hardware, installed in workstations, which analyses digital data specifically acquired for the purpose of photogrammetric analysis presenting the operator with a 3D aerial view of the landscape. Softcopy photogrammetry offers advantages of speed and accuracy and also creates output data that are easily integrated into other production and analytical systems, including GIS

The initial training data was collected in Co. Mayo (See figure 3.3). The first collection campaign involved the mapping of 1 km cells using habitats (as defined by Fossitt, 2000). The interpreter examined the areas in 3D and using traditional air photo-interpretation skills mapped homogeneous areas of dominant habitat (See figure 3.4).

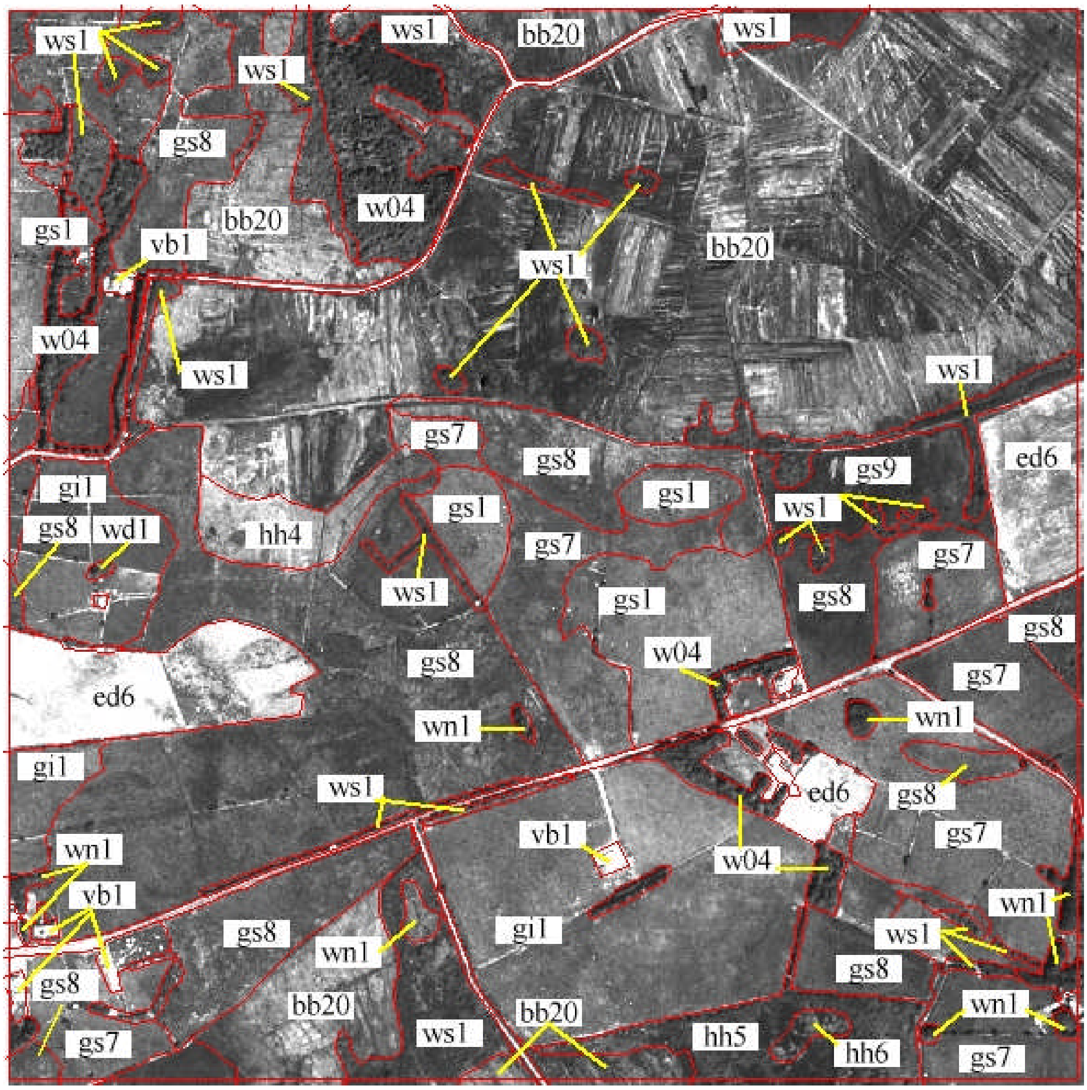


Figure 3.3: 1km square photo-interpreted habitat map, Co. Mayo. See Table 3.2 for description of codes.

These maps formed the basis of training areas for the creation of supervised classification of mayo satellite imagery (see section 3.8). The very detailed Fossitt habitat classes were conflated into the agreed TLC classes with the look-up table 3.2. Whilst this form of mapping is very useful it is time consuming and did not give a full picture of Landcover classes as distributed about the county.

Therefore a systematic point sample approach was developed, examining the Landcover/habitat at a point on a uniform grid. In order to ascertain the correct sampling density, we initially over-sampled the next trial county, Co. Cork. A Grid 1km cells was built and imported into the photogrammetry software, the intersection of every 1km cell was examined (see fig 3.6) and the dominant Landover / habitat was identified (dominant within a 50m radius of the point), see Figure 3.7

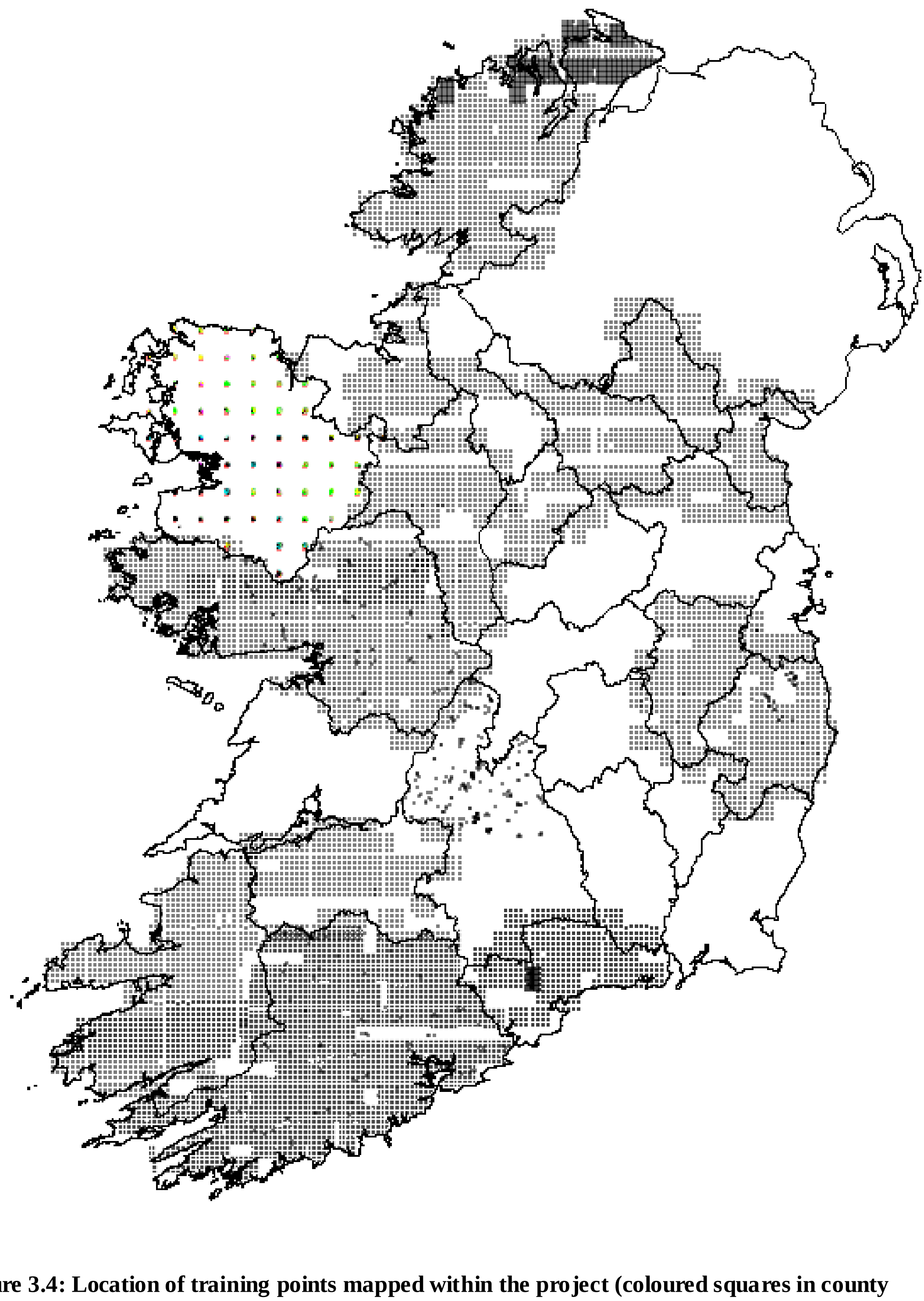


Figure 3.4: Location of training points mapped within the project (coloured squares in county Mayo show location of mapped areas).

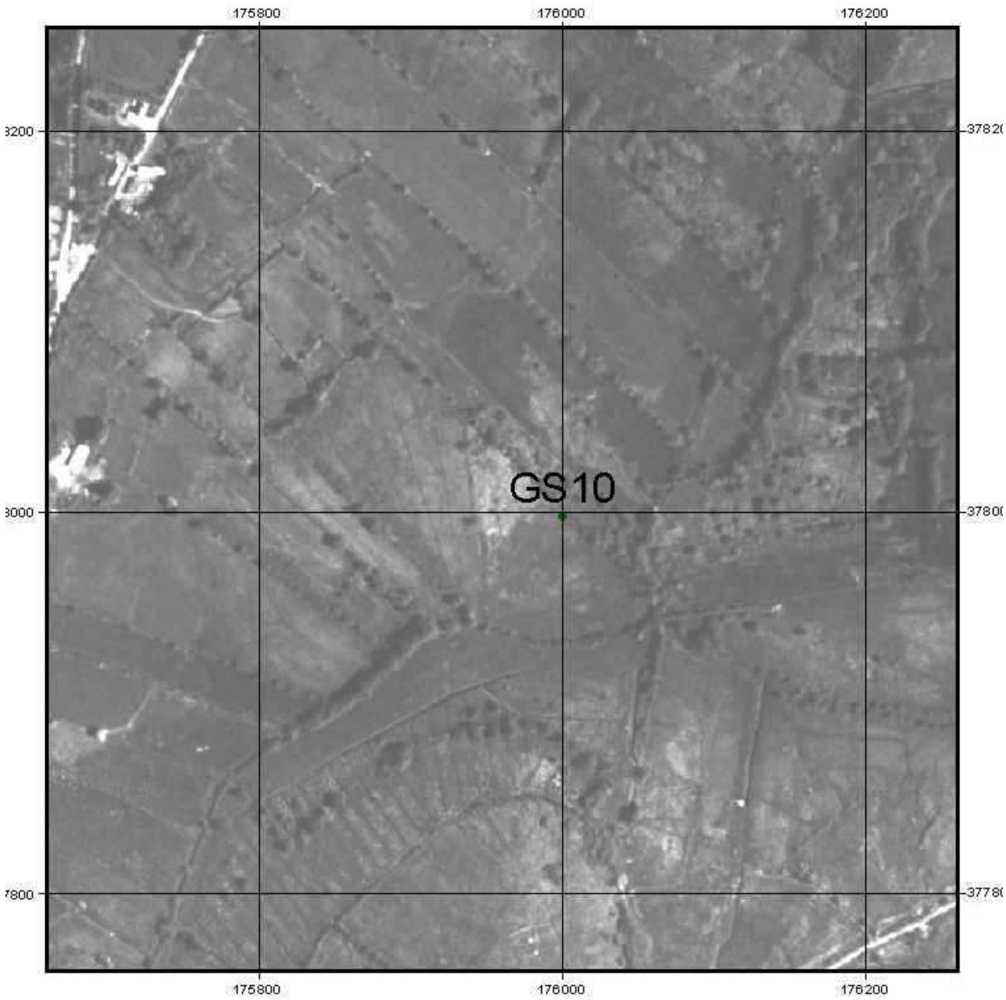


Figure 3.6: Sample of labelling a point intersection with the dominant habitat (GS10: rush dominated grassland)

A statistical analysis of the 7,000 grid points recorded on screen for Cork (see figure 3.7) indicated that the grid density was higher than required for rigorous statistical purposes (Isaaks and Srivastava 1989). This allowed the grid intensity for vegetation analysis to be set at the intersection of every 2 km square for future surveys (thus reducing the number of points need by a factor of 4) whilst maintaining the same distribution of habitat types. This frequency was applied to Donegal (See figure 3.8) and subsequent counties and it reduced the workload in this area to manageable proportions. Once a sample of the grid points had been verified in the field (see section 3.9) then the point data was fed in to train the satellite image interpretation.

In total over 15,000 points were manually collected as training data. These have been stored as county based point shape files and are a very valuable dataset survey of Landcover as it existed in 1995.

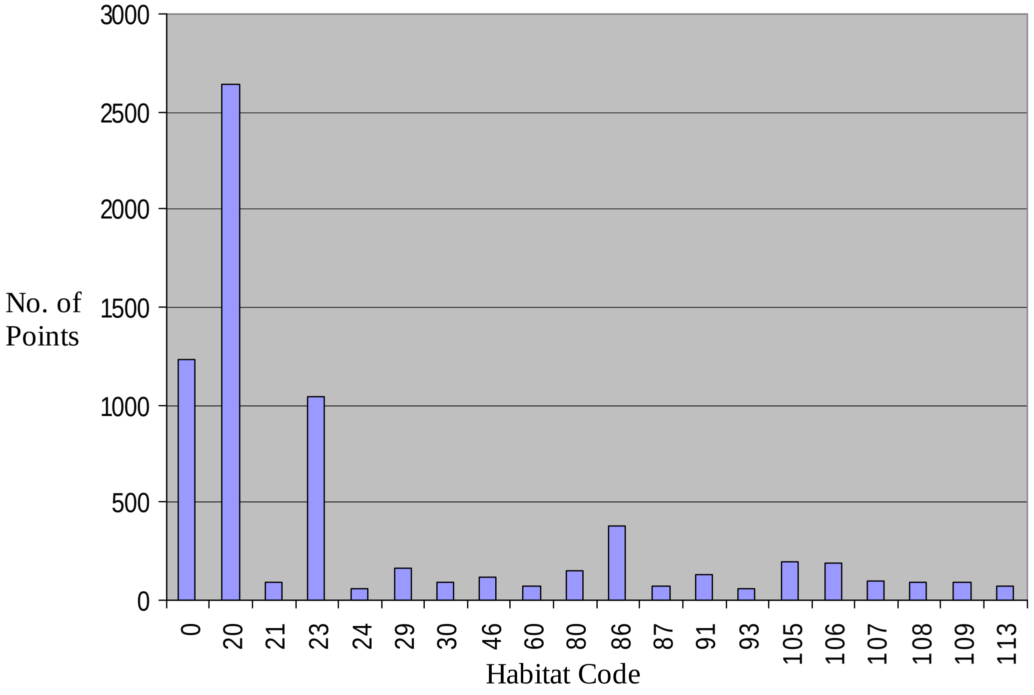


Figure 3.7: Bar chart showing number of points of given habitat (see table 3.2) occurring in Co. Cork

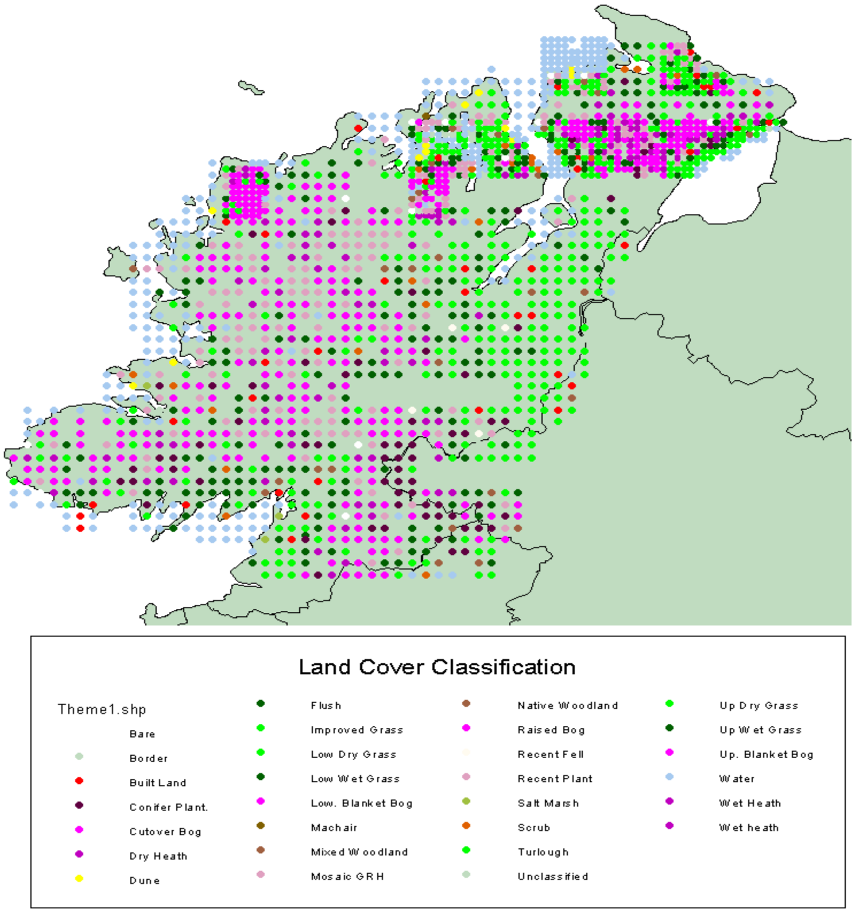


Figure 3.8: Collected training points for creation of the Landcover map of County Donegal.

No.	Habitat	TLC Code	Heritage Council Code	Satellite class
11	Not applicable	NA	N/A	N/A
12	Salt Marsh	CM1	CM1,2	Sand
13	Foredune	CD1	CD1,2	Sand
14	Fixed dune	CD2	CD3	Sand
15	Dune heath and scrub	CD3	CD4	Scrub and immature woodland
16	Dune slack	CD4	CD5	Wet grassland
17	Machair	CD5	CD6	Dry Grassland
18	Turloughs	FL7	Fl6	Dry Grassland / Water
19	Reedbeds	FS1	FS1	Wet Grassland / Water
20	Improved Grassland	GI1	GA1	Dry Grassland
21	Improved Grassland, Peaty	GI2	GA1	Dry Grassland
22	Amenity Grassland	GI3	GA2	Dry Grassland
23	Lowland Dry	GS1	GS2	Dry Grassland
24	Lowland Dry0-25% scrub	GS2	GS2	Dry Grassland
25	Lowland Dry25-50% scrub	GS3	GS2	Scrub and immature woodland
26	Upland Dry	GS4	GS3	Dry Grassland
27	Upland Dry0-25% scrub	GS5	GS3	Dry Grassland
28	Upland Dry26-50% scrub	GS6	GS3	Scrub and immature woodland
29	Lowland Wet 10-30% rush	GS7	GS4	Wet Grassland
30	Lowland Wet 31-50% rush	GS8	GS4	Wet Grassland
31	Lowland Wet 51-100% rush	GS9	GS4	Wet Grassland
32	Lowland Wet 0-25% scrub	GS10	GS4	Wet Grassland
33	Lowland Wet 26-50% scrub	GS11	GS4	Scrub and immature woodland
34	Upland Wet 10-30% rush	GS12	GS3,4	Wet Grassland
35	Upland Wet 31-50% rush	GS13	GS3,4	Wet Grassland
36	Upland Wet 51-100% rush	GS14	GS3,4	Wet Grassland
37	Upland Wet 0-25% scrub	GS15	GS3,4	Wet Grassland
38	Upland Wet 26-50% scrub	GS16	GS3,4	Scrub and immature woodland
39	Coarse, Rank Grassland	GS17	GS2	Dry Grassland
40	Marsh	GM1	GM1	Wet Grassland
41	Marsh 0-25% scrub	GM2	GM1	Wet Grassland
42	Marsh 26-50% scrub	GM3	GM1	Scrub and immature woodland
43	Dry Heath	HH1	Hh1,2	Bog & Heath
44	With scattered scrub 5-25%	HH2	Hh1.2	Bog & Heath
45	With scattered scrub 26-50%	HH3	Hh1,2	Scrub
46	Wet Heath	HH4	Hh3	Bog & Heath
47	With scattered scrub 5-25%	HH5	Hh3	Bog & Heath
48	With scattered scrub 26-50%	HH6	Hh3	Scrub and immature woodland
49	Montane Heath	HH7	Hh4	Bog & Heath
50	With scattered scrub 5-25%	HH8	Hh4	Bog & Heath

Table 3.2: Codes used in ATLAS software for Landcover training identification (after Fossitt)

No.	Habitat	TLC Code	Heritage Council Code	Satellite class
51	With scattered scrub 26-50%	HH9	Hh4	Scrub and immature woodland
52	Dense Bracken	HF1	Hd1	Dry Grassland
53	Lowland Blanket Bog smooth	BB1	Pb3	Bog & Heath
54	Lowland Blanket Bog	BB2	Pb3	Bog & Heath
55	With scattered scrub 5-25%	BB3	Pb3	Bog & Heath
56	With scattered scrub 26-50%	BB4	Pb3	Scrub and immature woodland
57	Eroding Lowland Blanket Bog <25%	BB5	Pb5	Bog & Heath
58	Eroding Lowland Blanket Bog <50%	BB6	Pb5	Bog & Heath
59	Upland Blanket Bog smooth	BB7	Pb2	Bog & Heath
60	Upland Blanket Bog	BB8	Pb2	Bog & Heath
61	With scattered scrub 5-25%	BB9	Pb2	Bog & Heath
62	With scattered scrub 26-50%	BB10	Pb2	Scrub and immature woodland
63	Eroding Upland Blanket Bog <25%	BB11	Pb5	Bog & Heath
64	Eroding Upland Blanket Bog <50%	BB12	Pb5	Bog & Heath
65	Raised Bog smooth	BB13	Pb1	Bog & Heath
66	Raised Bog	BB14	Pb1	Bog & Heath
67	With scattered scrub 5-25%	BB15	Pb1	Bog & Heath
68	With scattered scrub 26-50%	BB16	Pb1	Scrub and immature woodland
69	Eroding Raised Bog <25%	BB17	Pb5	Bog & Heath
70	Eroding Raised Bog <50%	BB18	Pb5	Bog & Heath
71	Transition Bog / Quaking Mire	BB19	Pf3	Bog & Heath
72	Cutover Bog Traditional	BB20	Pb4	Bog & Heath
73	Cutover Bog Machine Profile	BB21	Pb4	Bog & Heath
74	Cutover Bog Machine Plan	BB22	Pb4	Bare Peat
75	Cutaway	BB23	Pb4	Bog & Heath
76	Abandoned	BB24	Pb4	Bog & Heath
77	Bare Peat	BB25	Pb4, Pb5	Bare Peat
78	Fen	BF1	Pf1,2,3	Bog & Heath
79	Flush and Spring	BF2	Pf1,2,3	Bog & Heath
80	Native Woodland	WN1	WN	Mature Woodland
81	Native Wetland Woodland	WN4	WN4-6	Mature Woodland
82	Native Bog Woodland	WN5	WN7	Mature Woodland
83	Mixed broadleaved woodland	WO1	WN1,2	Mature Woodland
84	Mixed broadleaved/conifer woodland	WO2	WD2	Mature Woodland
85	Mixed conifer woodland	WO3	WD3	Mature Woodland
86	Conifer Plantation	WO4	WD4	Mature Woodland
87	Recently Planted	WO5	N/E	Scrub and immature woodland
88	Recently Felled	WO6	Ws5	Bare Soil
89	Recently Prepared for Planting	WO7	N/E	Bare Soil
90	Windthrow	W08	N/E	Mature Woodland

Table 3.2 cont.: Codes used in ATLAS software for Landcover training identification (after Fossitt)

No.	**Habitat**	**TLC Code**	**Heritage Council Code**	**Satellite class**
91	Native Scrub	WS1	Ws1	Scrub and immature woodland
92	Ornamental/non-native shrub	WS3	Ws3	Scrub and immature woodland
93	Exposed Bedrock	ER1	Er1,2	Rocky Complex
94	Exposed scree and loose rock	ER3	Er3,4	Rocky Complex
95	Exposed sand, gravel and till	ED1	Ed1	Bare Soil
96	Bare ground and spoil	ED2	Ed2	Bare Soil
97	Recolonising bare ground	ED3	Ed3	Bare Soil
98	Refuse and other waste	ED4	Ed5	Bare Soil
99	Active quarries	ED5	Ed4	Rocky Complex
100	Recently Cleared / Reclaimed	ED6	Ed1, Bc3	Bare Soil
101	Arable crops	VC1	Bc1	Bare Soil / Dry Grassland
102	Horticultural land	VC2	Bc2	Bare Soil / Dry Grassland
103	Ploughed fields	VC3	Bc3	Bare Soil / Dry Grassland
104	Flower beds and borders	VC4	Bc4	N/E
105	Built land	VB1	Bl	Built Land
106	Ro Grassland	CR1	MOSAIC	Rocky Complex
107	Ro Grassland Dry Heath	CR2	MOSAIC	Rocky Complex
108	Ro Grassland Wet Heath	CR3	MOSAIC	Rocky Complex
109	Ro Wet Heath	CR4	MOSAIC	Rocky Complex
110	Ro Scrub	CR5	MOSAIC	Rocky Complex
111	Wet Heath / Dry Heath	CH1	MOSAIC	Bog & Heath
112	Wetland	CW1	MOSAIC	Bog & Heath
113	Border	Border	N/E	N/E
114	Unsure	Unsure	NR	N/E
115	Built land (building and curtilage)	Vb2	Bl	Built Land
116	Unclassified Woods	Wn2	N/E	Mature Forestry
117	Grassland dry heath	Ch2	MOSAIC	Bog & Heath
118	Grassland wet heath	Ch3	MOSAIC	Bog & Heath

Table 3.2 cont.: Codes used in ATLAS software for Landcover training identification (after Fossitt)

3.8 Field Survey

Within the project, field data were collected to validate the various thematic maps. Another aim of field survey was to gather information on the relationship between these thematic elements as mapped and soil type. Finally fieldwork facilitates the air photo-interpreters work in relating the image from above to reality on the ground.

In reviewing data collection and management systems for field work, a number of criteria were selected. The system should be portable and convenient to use on rough terrain and in poor weather conditions. A field data acquisition system should have good spatial accuracy for navigation or recording grid coordinates. Data logging should be fast and efficient. The system should allow data recorded in the field to be downloaded readily to a computer, in formats that are readily compatible with mainstream GIS packages. Finally the system should be flexible in

allowing for the design of databases relevant to the different themes being mapped, and at the same time ensure consistency in records across a core of common attributes.

Using these criteria to review a number of systems the GPS Pathfinder Pro XRS™ was chosen and three units were purchased. It was an advanced geographic data acquisition tool that used differential GPS (DGPS) to provide sub-metre (50 cm RMS) positional accuracy on a second-by-second basis by combining a GPS receiver, a beacon differential receiver, and a satellite differential receiver. The pathfinder office software facilitated the design of databases known as data dictionaries and transfer of field data to computer in mainstream GIS formats. The data logger, which is robust and water-proof, allowed for efficient data collection. The data collection for land cover refers to an area circumscribed by a radius of 50m from the survey point.

Field protocols were established for all themes in the project, the relevant protocols for the Landcover included:

- *AREA:* When ascribing a land cover code to a site, consider a 50m radius (0.785ha) from your standing point.

- *HETEROGENEOUS LAND COVER:* Ideally a site will have a homogeneous land cover within a 50m radius from the standing point, and one recording of land cover will be sufficient to describe that site. If more than one land cover type occurs within the area, and the lesser area is greater than a 28.2m radius or 0.25ha make a note.

Recorders measured over 40 parameters at every field point collected (see Appendix 1, this volume for example of field sheets used – note the data was collected in an electronic version of this field sheet with the GPS data logger). Over 800 detailed field point observations at level 3 were collected by the landcover team. Landcover data at level 2 was also collected by the other team members when field working for soils, sub-soils and forestry, comprising a further 2,500 points. See figure 3.9

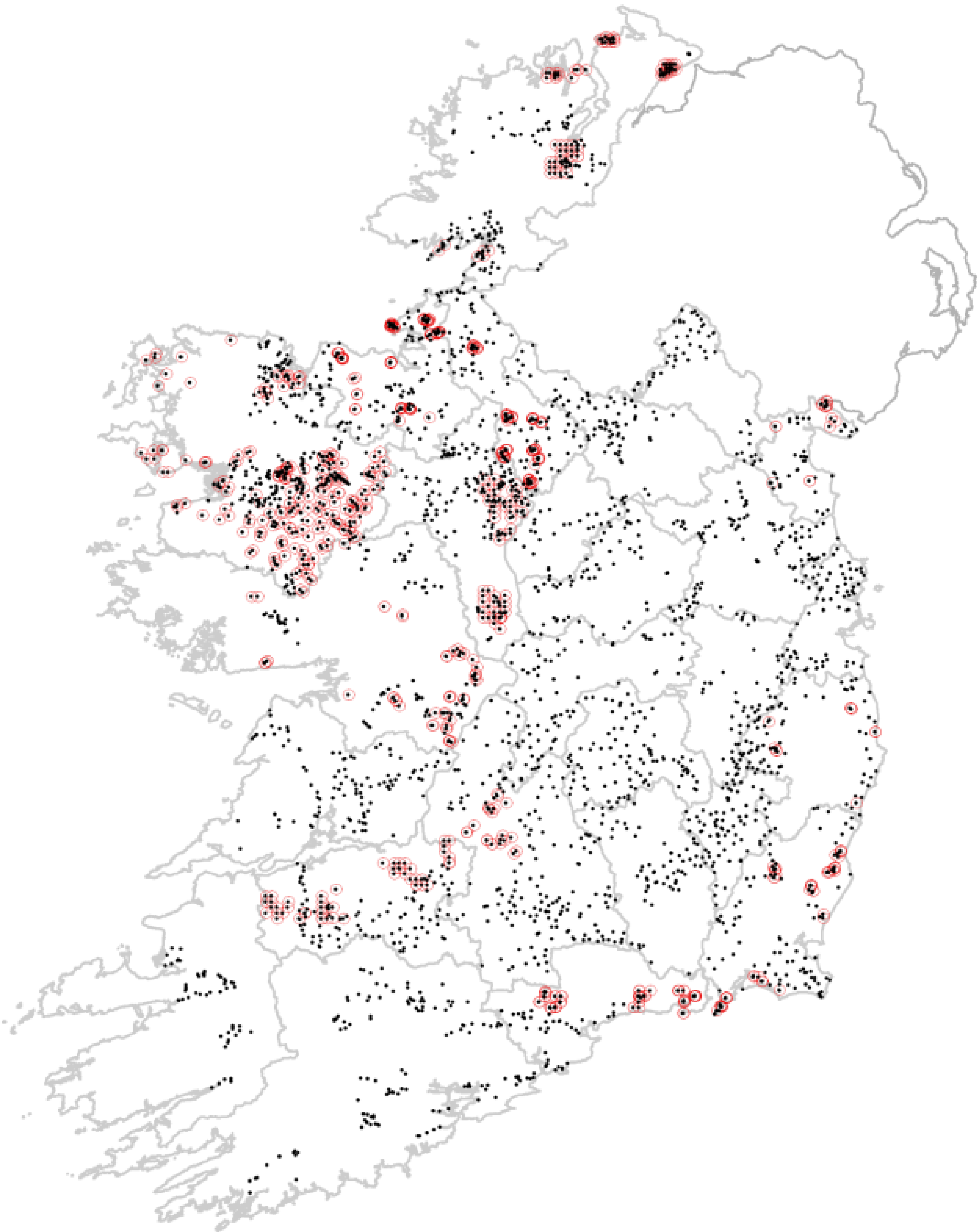


Figure 3.9: Location of field point observations collected during the project. Specialist landcover points circled in red.

There are several issues to be considered when comparing remotely sensed data with information collected in the field or indeed using field data to assess the accuracy of a thematic map. Principal among these is that caution should be exercised when using field data collected in the year 2000 to assess land cover classifications gleaned from aerial photographs which were acquired during 1995. Land cover change can occur over this time frame, which can be categorised as discrete and abrupt or gradational and successive.

Discrete and Abrupt.

Discrete and abrupt change refers to a transfer from one land cover class to another, often very different, class over a relatively short period of time. Afforestation, urbanisation, infrastructural development, peatland exploitation and land reclamation are the principal sources of absolute and abrupt land cover changes in Ireland.

Gradational and Successive.

Gradational and successive change refers to transfer from one land cover to another, often similar, class over a relatively long period of time. Gradual and successive changes in land cover often occur as a natural process due to a change in land management. Transfers of land from improved grassland to rush infested pasture, grassland to heath, grassland and heath to native scrub, native scrub to woodland, and intact bog to eroding bog are the main types of gradational and successive changes in Ireland. These changes are brought about by alterations to the land management regime, principally the grazing regime.

In the Irish Countryside, habitats intergrade continuously over short distances. These habitats include bog, heath, lowland wet grassland, upland wet grassland and scrub. Wet and Dry Grasslands intergrade continuously over short distances in the field. Furthermore images are rectified with some RMS error, and map coordinates for each pixel are an estimate with unknown positional error.

3.9 Production process

The development of a suitable production method to generate a county landcover map from satellite imagery went through a number of iterations until the final agreed process was chosen. Figure 3.11 shows a flow chart of production. Broadly, the satellite images were quality controlled with shadow eliminated, and the geo-referencing refined. The acquired training data grid of points was used to acquire signatures form the satellite. These signatures were appraised, refined and conflated, then a classification run. The classified draft was quality controlled and specific themes were reclassified if needed. Ancillary data was then used to further refine and enhance the classification. Standard cartographic raster processing was then applied to produce a good quality map and then the final accuracy assessment carried out.

3.9.1 Satellite Imagery

The satellite imagery used was a national coverage of Landsat 5 data originally acquired for the FIPS project, see figure 3.10. It proved necessary in the project in order to fill gaps left by cloud to order more non-contemporary data (1998-2000). The exact image used to map each county is given in the county metadata document.

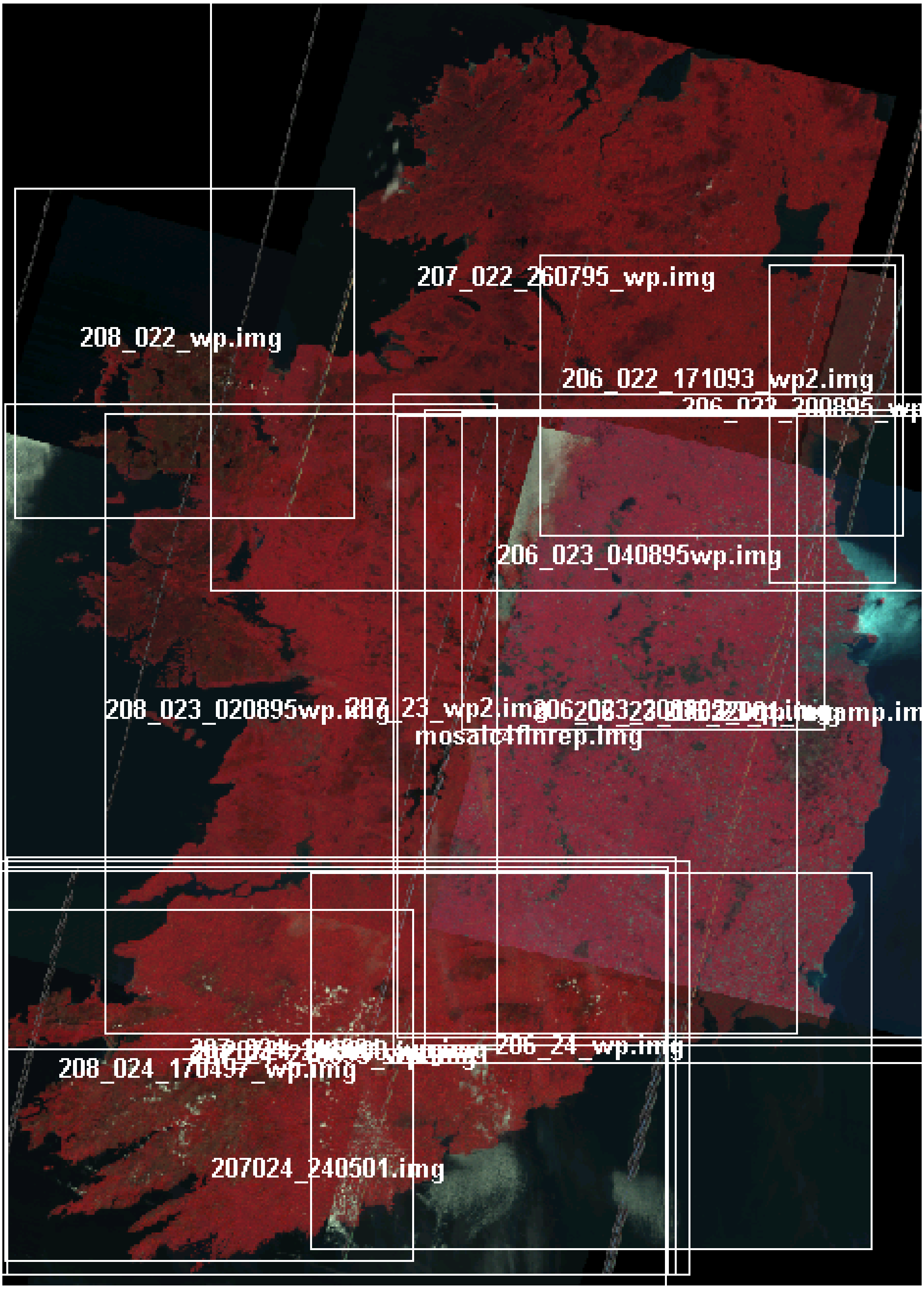


Figure 3.10: Mosaic of satellite images used in project, file outlines in white.

When cloud and shadow had been masked out the process of interpretation began (there was no attempt to merge images if more than one image was need to map a county- each image-county segment was mapped separately).

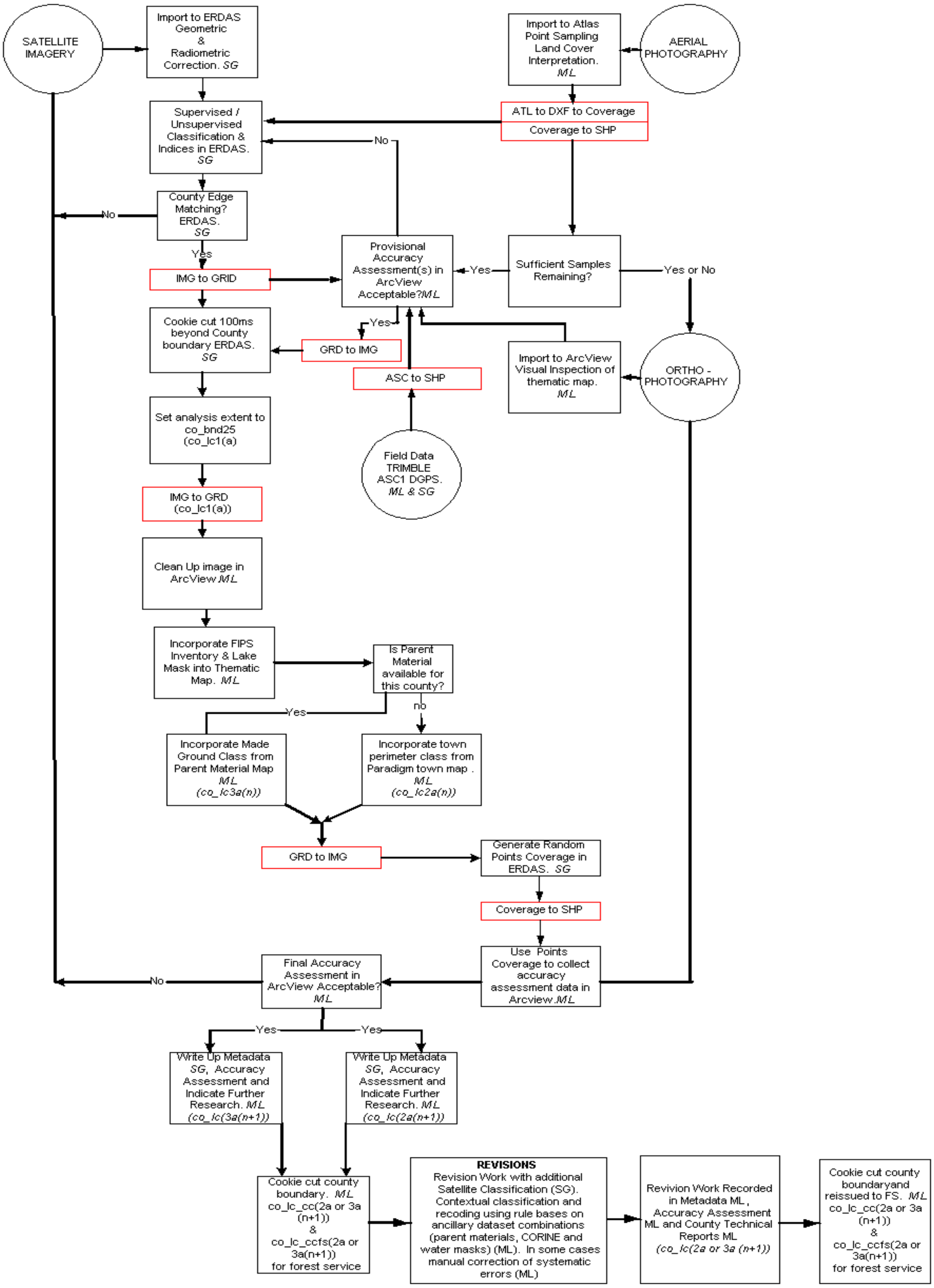


Figure 3.11: Flowchart showing Landcover map production process

3.9.2 Supervised Classification

The training points collected in section 3.7 were used to identify training areas on the image. All classification was carried out in ERDAS Imagine Professional (ERDAS, 2008).

For all of the TLC classes the points were examined and a homogenous area with appropriate pixel statistics was delineated following standard image classification criteria. See figure 3.12 When all points of a given class had been delineated, for instance bog and heath, the signatures were analysed for spectral distance and differences, some signatures were amalgamated as they were similar while others were kept separate. There could be 10-15 classes representing bog and heath in the image, as there are many legitimate reasons why any given class should have a number of signatures associated.

Areas of tillage and bare soils were mapped at this level but subsequently amalgamated into the Dry Grassland class due primarily to the practical requirements of the TLC map to the soils classification aspects of the project.

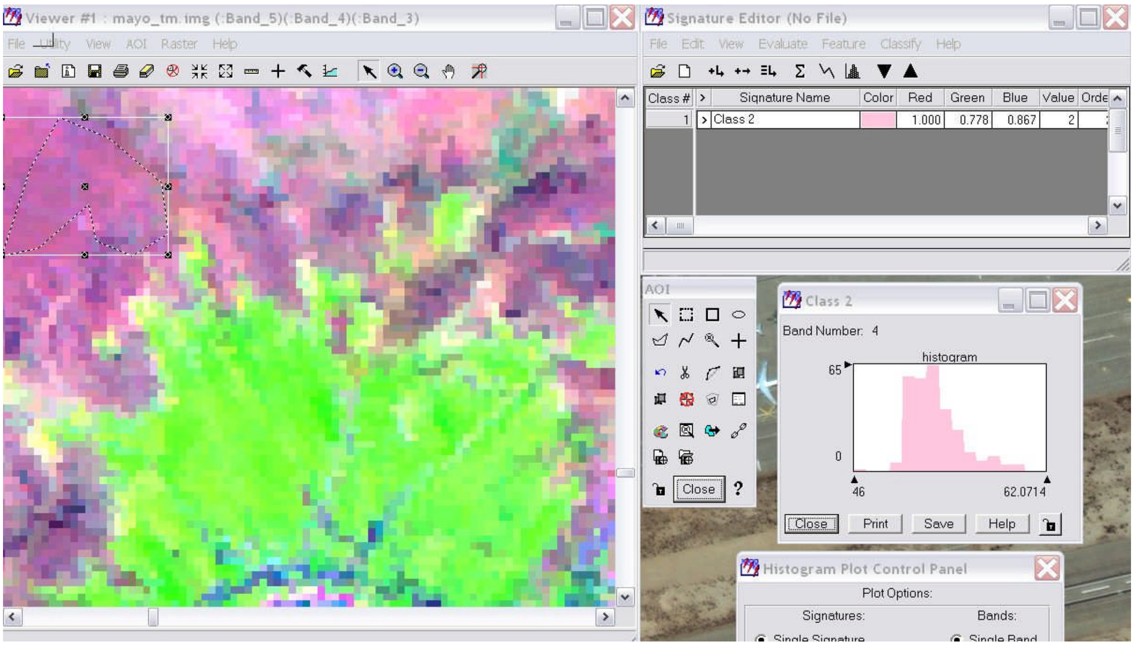


Figure 3.12 Screen grab showing training signature collection

Once all signatures were collected a supervised classification, using maximum likelihood classifier (likelihood statistics based on Landcover occurrence frequency in the training points) was run and an initial map produced.

A number of quality checks were performed and signatures re-evaluated in light of their performance and a revised supervised map produced where necessary.

This map was then given a draft accuracy assessment (30 random points from each class was examined against the available orthophotography) and the map was then revised further or passed to the next phase involving the incorporation of ancillary data. The classification was further enhanced with the use of these ancillary data to constrain the thematic classes.

Typical errors that were eliminated in this way included:

- The FIPS map of forestry in the country allowed for the elimination of some tillage crops being identified as forestry. If the area mapped as MATURE FOTREST (*WNWD*) was not within a FIPS parcel it was reclassified as DRY GRASSLAND (*GAGS*).

- Coastal areas being predominantly sand/stone would occasionally be misclassified in built up areas. Thus a distance to the coast rule was applied.

Data sets used to constrain the classification in rule based system included: the FIPS inventory, OSI 50,000 maps, DTM and the Hammond Peat map (Hammond, 1978). The implementation of these rules within a supervised classification (using ERDAS Knowledge Engineer; the exact rules and datasets for each county are recorded in the county Landcover progress reports) means that the final maps are best described as hybrid supervised classification and rule based maps. See Figure 3.13

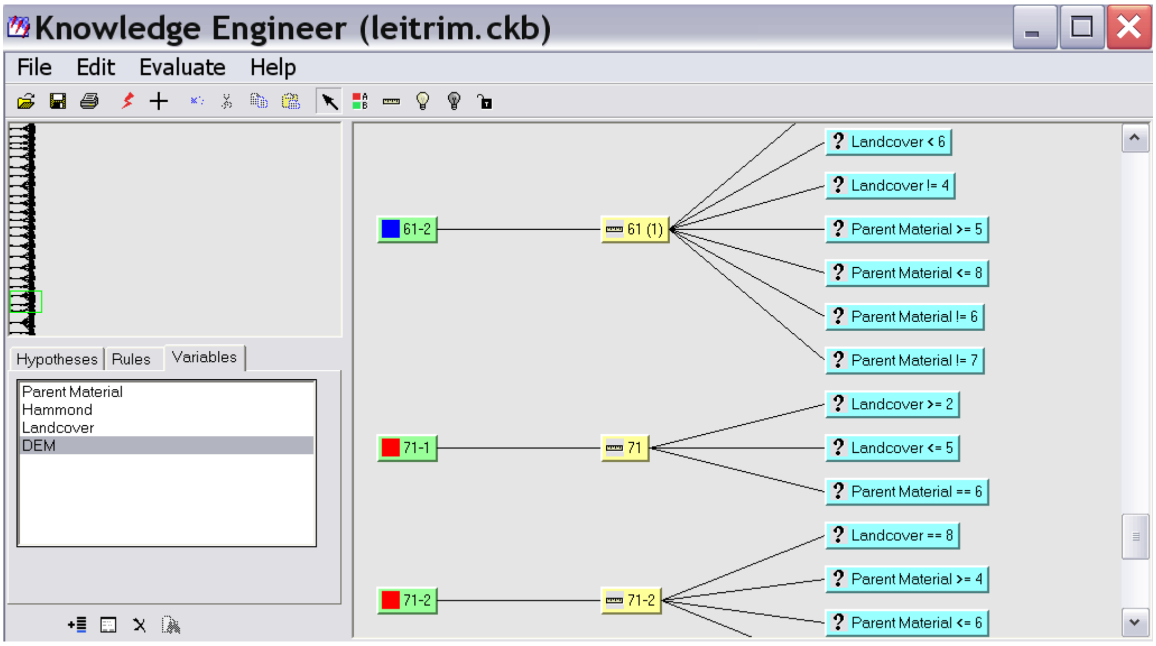


Figure 3.13: Knowledge engineer to implement ancillary data rules for constraining the classification.

There were typically five draft revised maps per county. Significant changes could be made between the first and final draft. See Figure 3.14

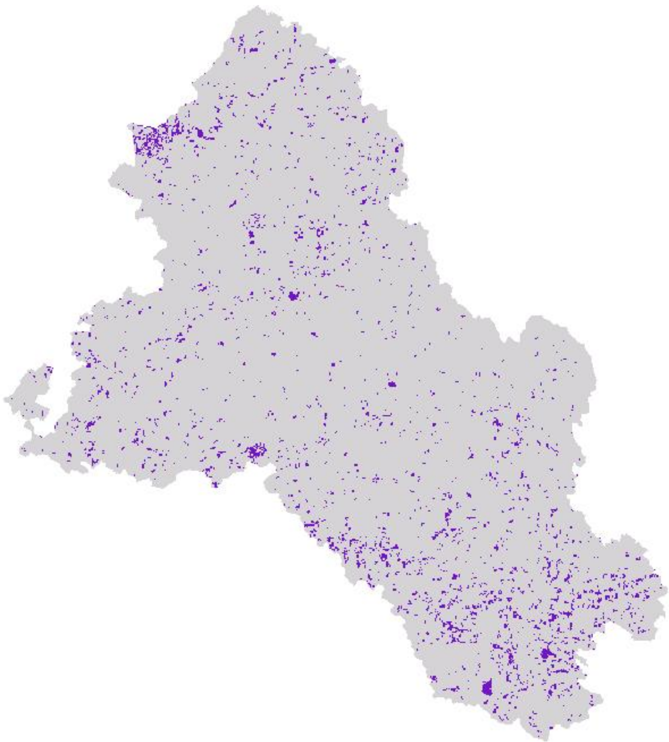


Figure 3.14: County Monaghan showing, in blue, areas that changed classification between the first draft and final map.

3.9.3 Cartographic processing

The classification process is a pixel by pixel approach, in that every pixel is put into a class, this can mean that the map produced looks noisy. This noise can be eliminated using standard GIS cartographic processes such as *Clump* and *Eliminate*.

Using this approach the GIS software (ArcView 3.2) examines every pixel in turn and determines weather it is the same class as a direct neighbour. If it is these pixels are labelled as belonging to the same clump. The software then measures the size of all clumps. We can then put a minimum size on the clumps we want to retain. In our case 16 pixels was the minimum size. The software then eliminated these clumps filling in the gaps with neighbouring values. When cut to the county boundary a map was then ready for the final accuracy assessment. Only if production accuracy for the relevant classes exceeded 75% was the map passed. This is illustrated in figure 3.15:

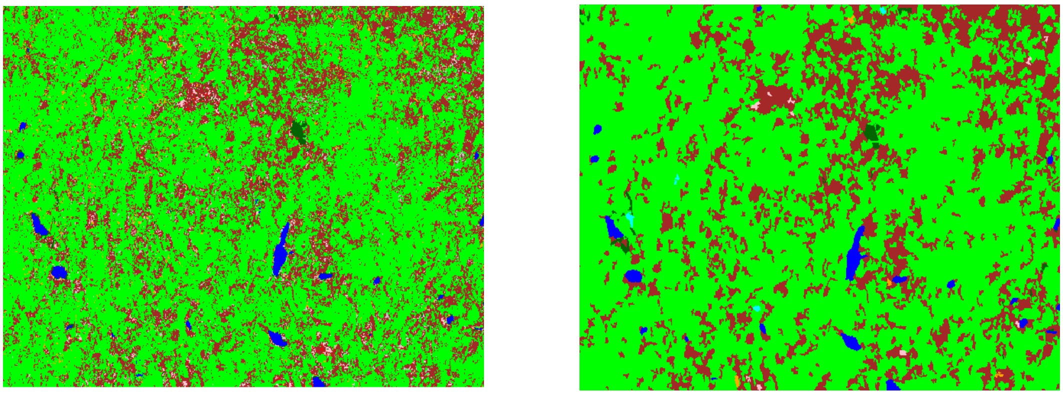


Figure 3.15: Section of Co. Cavan TLC95 before (left) and after (right) cleaning

3.10 Accuracy Assessment

Accuracy assessment is critical before accepting image classification results. The error matrix is typically the foundation of accuracy assessment because it compares predicted with true cover types (Verbyla and Chang, 1997). Reference data is required as "truth" for comparison with predictions in the error matrix. Ideally reference data are derived from many randomly selected samples independent from training areas. With random sampling image pixels are selected in the field to determine their actual cover type. However there are several considerations which need to be borne in mind when using this approach.

Sample Size

Accuracy assessment data is derived from interpretation of landcover at randomly selected sites using orthophotography. Congleton (1991) suggests that a good rule of thumb for sample size "seems to be collecting a minimum of 50 samples for each vegetation or land use category in the error matrix". He goes on to say "if the area is sufficiently large (i.e., more than a million acres) or the classification has a large number of vegetation or land use categories, (i.e., more than 12 categories), the minimum number of samples should be increased to 75 or 100 samples per category". The USGS–NPS Vegetation programme, in Chapter 4 of their document "Accuracy Assessment Procedures" recommends that some weighting factor be applied that allocates a larger number of samples to the abundant classes. They advocate approaches that may be taken toward the weighting of sample size as follows:

1. Sample size can be made proportional to the abundance and frequency of the class. With this approach, the rarest classes would probably never be sampled. This is unacceptable, since it is desirable to be able to associate at least a point accuracy estimate with each class.
2. Maximum and minimum sample sizes can be established, taking into account statistical as well as cost constraints and probable class abundance and frequency.

If the second approach is taken, it is recommended that 30 samples be specified as the maximum sample size for abundant classes, and that 5 samples be specified as the sample size for the rarest classes.

Therefore depending on the size of the county and the number and distribution of classes the number of accuracy assessment points required varied (see individual county accuracy reports). In total for both the draft assessment and the final statements we collected more than 10,000 observations form the air photographs, in addition to the 15000 points collected as training data. See Figure 3.16

Temporal Issues

The aerial photographs from which the orthophotographs were created and the satellite imagery from which the thematic maps were generated are, in the main, contemporary (c. 1995). The temporal acquisition of the two data sets differs by months rather than years. In some cases more recent satellite scenes were ordered to supplement existing scenes.

Spatial Considerations

Any points, which fell on the border between land cover classes were labelled as "border". Other points where orthophotographs were not available to the interpreter were labelled as "no data". Data classified as "border" or "no data" have been removed from the analysis.

Once the number of required points had been established, random stratified points were generated in ERDAS and passed to air-photo inspection. The interpreter then labelled these points with the interpreted landcover class from the aerial photography (at the broad TLC level and not the detail Fossitt level 3, for sake of speed). The comparison of the interpreted observation and the extracted mapped value then allowed the calculation of error

Appendix 2 of this volume contains an example County Accuracy Statement.

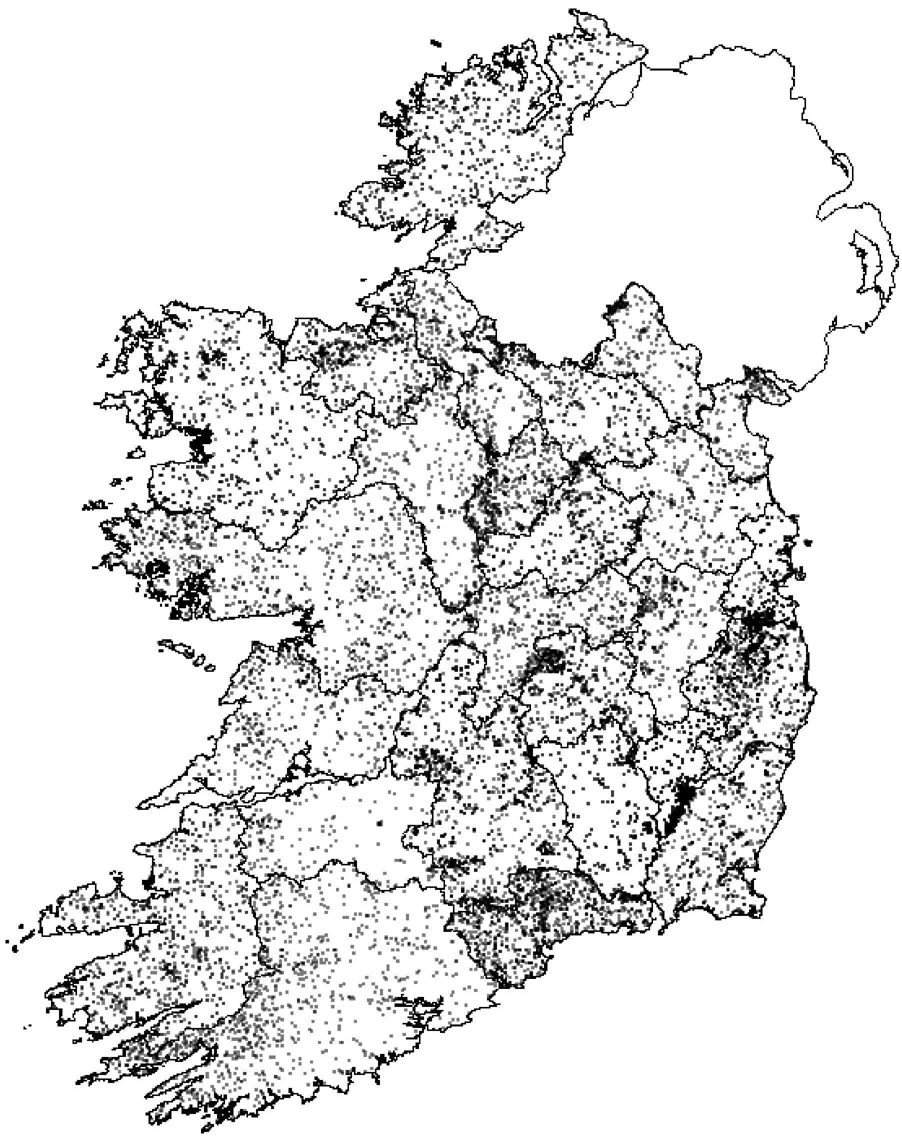


Figure 3.16: Location of ~15,000 assessment points collected from air photographs

3.11 Results

Outputs to EPA

County	Map File	Metadata
CARLOW	LC_cw_f1	LC_cw_f1
CAVAN	LC_cn_f1	LC_cn_f1
CLARE	LC_ce_f1	LC_ce_f1
CORK	LC_ck_f1	LC_ck_f1
DONEGAL	LC_dl_f1	LC_dl_f1
DUBLIN	LC_dn_f1	LC_dn_f1
GALWAY	LC_gy_f1	LC_gy_f1
KERRY	LC_ky_f1	LC_ky_f1
KILDARE	LC_ke_f1	LC_ke_f1
KILKENNY	LC_kk_f1	LC_kk_f1
LAOIS	LC_ls_f1	LC_ls_f1
LEITRIM	LC_lm_f1	LC_lm_f1
LIMERICK	LC_lk_f1	LC_lk_f1
LONGFORD	LC_ld_f1	LC_ld_f1
LOUTH	LC_lh_f1	LC_lh_f1
MAYO	LC_mo_f1	LC_mo_f1
MEATH	LC_mh_f1	LC_mh_f1
MONAGHAN	LC_mn_f1	LC_mn_f1
OFFALY	LC_oy_f1	LC_oy_f1
ROSCOMMON	LC_rn_f1	LC_rn_f1
SLIGO	LC_so_f1	LC_so_f1
TIPPERARY	LC_ty_f1	LC_ty_f1
WATERFORD	LC_wd_f1	LC_wd_f1
WESTMEATH	LC_wm_f1	LC_wm_f1
WEXFORD	LC_wx_f1	LC_wx_f1
WICKLOW	LC_ww_f1	LC_ww_f1

Table 3.3 Landcover map files delivered to EPA. The maps are held as ESRI GRID files whilst the metadata and other accompanying documentation are held as MS Word.

As a primary output, the entire country was mapped for Landcover, the first and only time this has been done in Ireland for an Irish project. See Figures 3.17 and 3.18

National Statistics for Landcover distribution are given in Table 3.4

Value	Number	Code	Class	Sq-Km
2	201	PH	Bog&Heath	7668
3	200	P	Bog	389
4	202	PBC	Cut Bog	676
5	203	PBCE	Cut&Eroding Bog	1268
6	204	PBCEBC	Bare Peat	139
8	102	GSW	Wet Grassland	6278
9	101	GAGS	Dry Grassland	43768
10	910	FM	Water	1293
12	600	ER	Bare Rock	247
13	601	CR	Rocky Complex	2556
14	700	WNWD	Mature Forest	2543
15	701	WSWL	Forest(U) & Scrub	2113

16	909	BL	Built Land	841
17	800	CD	Sand	7
18	801	C	Coastal Complex	78

Table 3.4: National area Coverage statistics for TLC95

The occurrence (at the designated mapping scale) of the landcover themes is given in table 3.5

County.	Bog& Heath	Bog	Cut Bog	Cut& Eroding Bog	Bare Peat	Wet Grassland	Dry Grassland	Water	Bare Rock	Rocky Complex	Mature Forest	Forest &Scrub	Built Land	Sand	Coastal Complex
ce	Y			y		y	y	y	y	y	y	y	y	y	y
ck	Y			y		y	y	y	y	y	y	y	y		y
cn	Y			y		y	y	y	y	y	y	y	y		
cw	Y			y		y	y	y		y	y	y	y		
dl	Y			y	y	y	y	y	y	y	y	y	y	y	y
d	Y			y		y	y	y		y	y	y	y		y
gy	Y		y	y		y	y	y	y	y	y	y	y		y
ke		y	y	y		y	y	y		y	y	y	y		
kk	Y		y	y		y	y	y		y	y	y	y		
ky	Y			y		y	y	y	y	y	y	y	y		y
ld	Y	y	y	y		y	y	y		y	y	y	y		
lh	Y			y		y	y	y		y	y	y	y		y
lk	Y			y		y	y	y	y	y	y	y	y		
lm	Y	y		y		y	y	y	y	y	y	y	y		
ls	Y	y	y	y		y	y	y	y	y	y	y	y		
mh		y	y			y	y	y	y	y	y	y	y		y
mn	Y			y		y	y	y		y	y	y	y		
mo	Y		y	y	y	y	y	y	y	y	y	y	y	y	y
oy	Y	y	y	y		y	y	y	y	y	y	y	y		
rn	Y	y	y	y		y	y	y	y	y	y	y	y		
so	Y			y		y	y	y	y	y	y	y	y		y
ty	Y		y	y		y	y	y		y	y	y	y		
wd	Y			y		y	y	y		y	y	y	y		y
wh		y	y	y		y	y	y		y	y	y	y		
ww	Y			y		y	y	y		y	y	y	y		y
wx	Y					y	y	y		y	y	y	y		y

Table 3.5: Occurrence (Y), per county, of different landcover themes from TLC95

Information on area coverage can be extracted form the maps, as seen in Table 3.6. For example, Wicklow has the highest amount of Mature Forest as a percentage of the county area but Cork has the largest percentage of the national resources of Mature Forestry. In terms of overall assessment of landcover at a county scale Donegal has the most diverse collection of landcover whilst Wexford is the least diverse landcover (diversity as measured as standard deviation of % county covers)

Class	County with highest % of class within county	County with highest % Of the national resources
Bog&Heath	Mayo	Mayo
Cut Bog	Offaly	Offaly
Cut&ErodingBog	Donegal	Cork
Wet Grassland	Leitrim	Donegal
Dry Grassland	Meath	Cork
Water	Galway	Galway
Bare Rock	Clare	Clare
Rocky Complex	Donegal	Donegal
Mature Forest	Wicklow	Cork
Forest(U)&Scrub	Laois	Cork
Built Lands	Dublin	Dublin
Coastal Complexes	Donegal	Donegal

Table 3.6: Counties showing the highest area coverage's of the different landcover themes as percentages of the county area and the national resource.

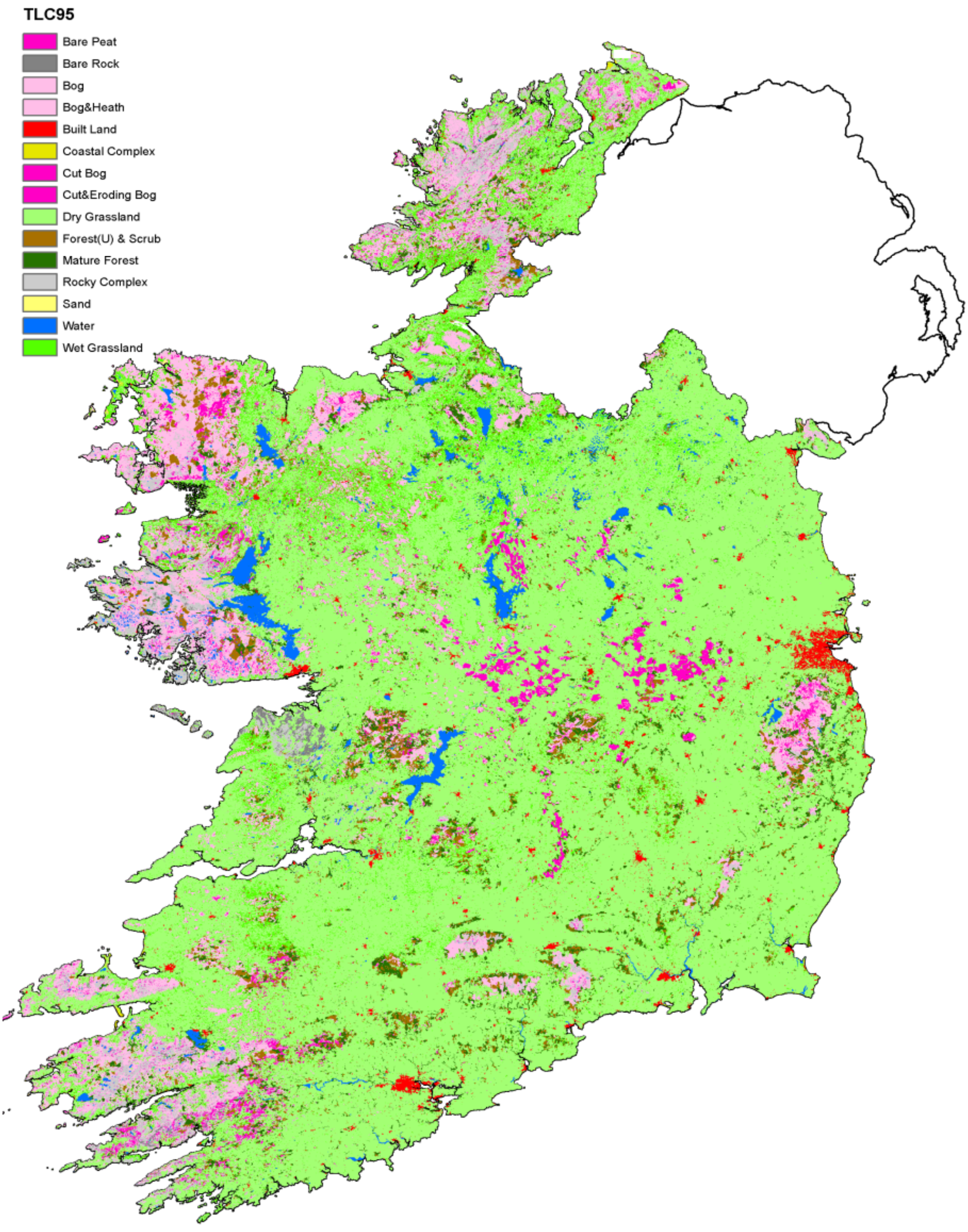


Figure 3.17 Landcover map for entire country with legend

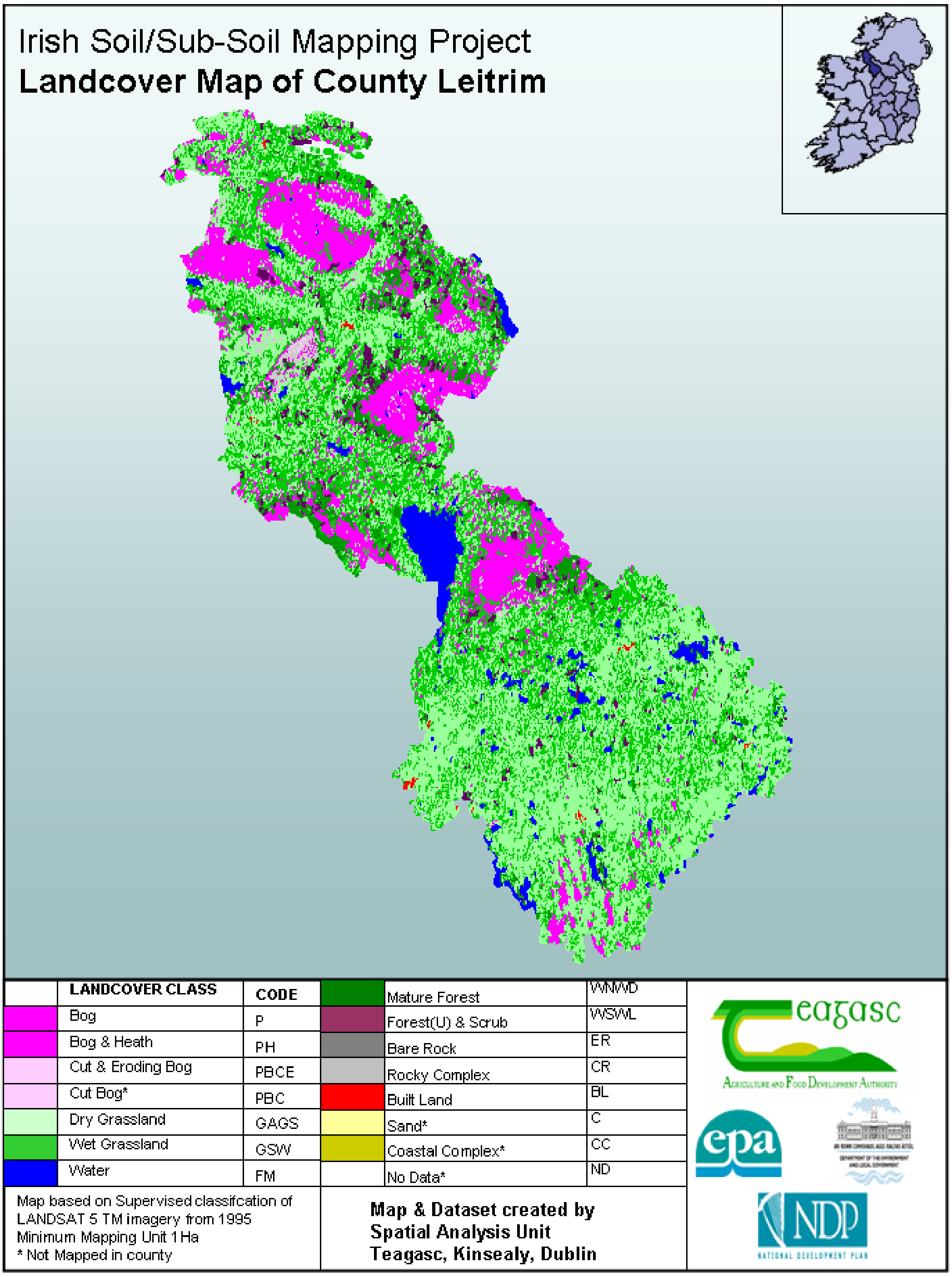


Figure 3.18 An example of an individual county landcover map: Co. Leitrim with Legend

4 SOIL MAPPING/SOIL MODELLING

4.1 Introduction

The aim of traditional soil survey is to describe and map the soils in the survey area. As soil is a continuous entity in the environment, soil maps are out of practical necessity based on surveyors predicting what soils occur on those parts of the landscape that they cannot visit. The traditional method of soil survey involves the surveyor visiting key reference areas or sites in each particular landscape type in his survey area. At these locations sample pits or auger boreholes are excavated and the soil examined. In tandem with laboratory analysis, soils are classified according to various characteristics that include chemical, morphological and structural properties. The surveyor free-samples (non-random, directed sampling) the survey area and using the derived soil classification, relationships between the classes and their environment are investigated and recorded.

These investigations form the basis for the construction of what have been termed the "mental models" of the soil surveyor. The models constructed are part of the expert knowledge developed by the surveyor and are applied implicitly in his survey method. The application of this survey method in the field is largely based on Jenny's (Jenny 1941) classic functional factorial model of soil development. Restated simply the model appears in the form:

$S_i = (P_i, R_i, B_i, C_i, T_{i.....})$

where
S_i = soil occurring at landscape position i results from a combination of:

P_i = parent material at i
R_i = topography at i
B_i = biotic factors at i
C_i = climatic factors at i
T_i = time over which soil forming factors have operated

Jenny's rule was preceded by the early nineteenth century Russian school of pedology which recognised that soils tend to display consistent patterns in the landscape which were related to the soil forming factors mentioned above. It is the presumption of this relationship that facilitates the construction of the mental models of the field soil surveyor.

4.2 Soil modelling methodology

4.2.1 Background

In Ireland, traditional soil survey has classified and mapped soils based on the character of the soil profile and laboratory analysis of soils sampled from horizons in the profile. Similarities in soil characteristics at different sites, which reflect similar development history, are often expressed in the profile, allowed grouping and mapping of these sites into similar map units. The primary map category for the published county soil surveys in Ireland has been based on the soil series. A soil series is generally named after the locality where it was first identified and the soils that it represents are best expressed.

The methodology employed by the project team was in essence analogous to the survey methods of the traditional soil surveyor. Key soil forming factors such as vegetation (landcover) and geology (parent material) were mapped and a set of rules (termed a "rule-base") was applied to these datasets to predict the soils that may occur at any given location in the landscape. The core technologies involved in this process were remote sensing and GIS-based. The approach was a modular one in which sub sections within the project mapped the different soil forming factors. These maps were then combined to create a predicted model of soil occurrence, which is represented in map form. The soil forming factors used in the first phase of modelling were parent material and land cover. Combination of these inputs provided for a modelled output of predicted soils, with this model output termed Level 1. The development of a Level 2 model with increased map accuracy involved expanded inputs and included topographical variables, previously mapped soil data and other geologically based variables such as subsoil permeability. Key inputs to both model levels (and in any soil mapping effort) include information on soil parent material, vegetation and topography. These elements and their relevance to soil mapping are briefly discussed below.

4.2.2 Parent material/subsoils

Parent material is the material from which soils are formed. They may be composed of either weathered solid rock or other surficial deposits such as glacial till or alluvium, which in turn have been derived from weathered rock and transported. The character of the rock types represented in the subsoil has a very strong influence on the developed soil. Highly resistant rocks such as quartzite weather very slowly and release very little clay materials through weathering. Soils developed on subsoils developed from such rocks are poor and very prone to degradation through leaching. Generally the composition of glacial tills is very varied and this is reflected in the diversity of soils developed on such material. This diversity makes soils mapping particularly difficult in Ireland.

The subsoils underlying the majority of the land-area of the country are comprised of Quaternary deposits, with the remainder composed of bedrock outcrop. The majority of Quaternary sediments have resulted from the actions of ice in the Irish landscape both during glaciation and subsequent to it during phases of glacial melting. Quaternary mapping therefore serves as a prime mechanism for elucidating the subsoils that exist in Ireland.

Quaternary sediments are categorised according to their genesis. Within the subsoil mapping programme these have been further subdivided into classes depending on the main geological constituents (See Table 2.1).

The subsoils map relates to the soil classification in a number of ways. The geological composition of the subsoil type has a very strong influence on the characteristics of the mapped soils overlying these deposits. Texture types can often be interpreted and these related to the drainage status of developed soils. For example, granite till is suggestive of acidic, mostly free-draining soils. Limestone dominated till will tend to show higher free carbonate content but varied drainage. Shale tills will generally have acidic soils overlying them, with a tendency towards impeded drainage resulting from higher clay content.

4.2.3 Vegetation

The relationship between soils and vegetation is extremely important. Biotic factors are of direct relevance to soil formation, with the addition of organic matter and nutrient cycling being very important factors in soil formation after the influence of parent material. However, the majority of soils in Ireland are for the most part man-modified with the exception of those soils occurring at the higher elevations. Because of the modifications resulting from both modern and historical land use, the original influence of vegetation on soil formation is very difficult to elucidate.

In this project's methodology the relationship between soils and vegetation was used in an inverted sense. As much as vegetation influences soil development the occurrence of particular vegetation types is often strongly dependent on the underlying soil. Phytosociological studies recognise that particular floral assemblages occur in particular environmental settings. The degree of association between plant communities and different soil types was investigated as part of the vegetation studies and land cover classification component of the project. These relationships form an important part of the mental model of the field soil surveyor. As part of the soil modelling process these relationships have been stated explicitly and incorporated into the modelling process.

A land cover classification was developed to facilitate the mapping of soils using soil-vegetation associative rules (chapter 3, this report). This classification was developed specifically for use in the project. It was designed to align with the Guide to Habitats in Ireland which was developed by the Heritage Council (Fossitt, 2000). Given that this classification was for use in the field, there were inevitably adjustments required to make to cater for the limitations of remote sensing as a mapping tool.

The association between vegetation and underlying soil types is theoretically straightforward. Where land cover classes such as bog and heath occur on the ground, the soils underlying such cover will be either peats or organic mineral soils. Where wet grassland exists on the ground, underlying soils will almost exclusively be poorly drained in terms of soil classification. However, the existence of artificial drainage will influence the current behaviour of the soil and land

management practices will affect overlying vegetation. Poorly drained soils that are well managed may therefore support vegetation which is suggestive of well drained soils. The influence of land management therefore has a complicating effect on soil mapping and prediction.

Figure 4.1 Example of land management controlling rushes. This location is on poorly drained drumlin soils in Donegal. The field on the right hand side of the drumlin flank has had intensive management while the field on the left is less well managed and rushes are appearing due to reversion.

4.2.4 Topography

The effects of topography on soil formation are chiefly expressed through the influence of slope and slope shape on water and soil movement. In its simplest expression this relationship considers the movement of water towards lower elevations as critical in the processes of translocation of various elements and subsequent hydromorphic differentiation in soils. Therefore crests and topographic highs are generally associated with drier soils and depressions with wetter soils. Similarly, steeply sloping areas are generally associated with dryer soils and flat areas with wet soils. In reality the relationship is extremely complex and understanding the interactions between surface water and groundwater through the soil medium and their relevant effects on soil development and its subsequent classification can be extremely difficult.

A number of systems have been proposed to aid in the modelling of soil-topographic relationships. These systems rely on the analysis and extraction of terrain-based attributes or indices. The underlying processes are expressed as topographic indices to aid in the calculation of spatial patterns over large areas. The use of terrain analysis in predictive soil mapping depends on the main assumption that topography controls water movement in the landscape. However this

assumption can be violated e.g. where there are strong geological controls on subsurface flow, such as in karst areas.

Digital topographic analysis in the context of soil-landscape relationships relies on the use of digital elevation models/digital terrain models (DEM/DTMs). The various terrain attributes that can be derived from DEMs are generally subdivided into primary and secondary groupings (Wilson and Gallant, 2000). Primary attributes are those that are extracted directly from the DEM. These include the first order derivatives, slope and aspect, and second order derivatives, plan, profile and tangential curvatures. Secondary attributes are generally compound attributes based on some combinations of primary attributes.

Investigations during the project focussed on the relationship of both primary and secondary attributes with soils in the landscape. Compound curvature maps (Figure 4.1) are an example of a derived datasets that were used in the soil-landscape analysis.

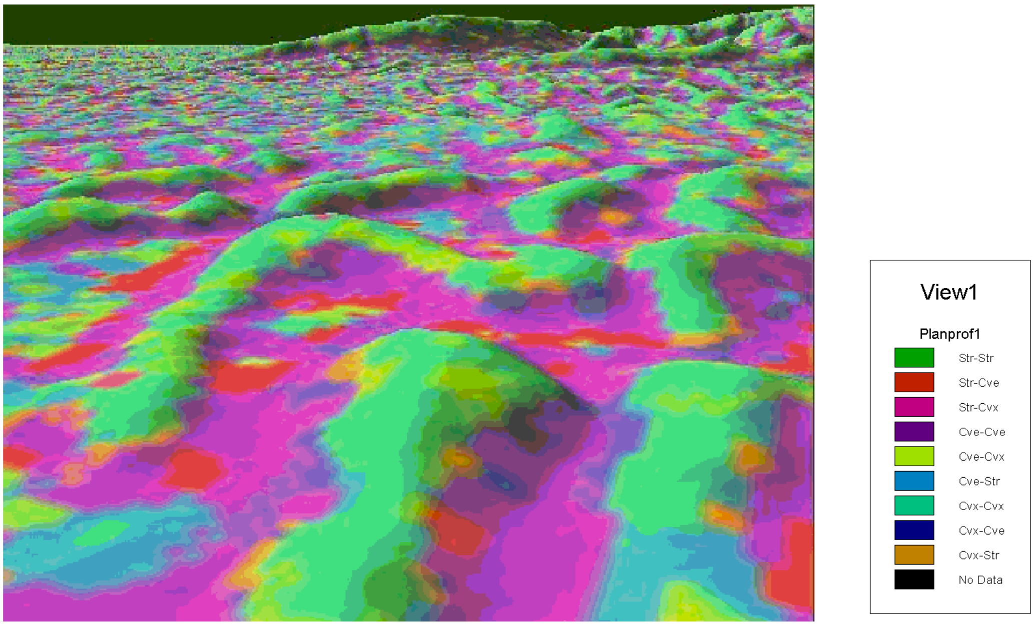


Figure 4.2 Compound curvature map of a drumlin field in Mayo. The categories shown are combinations of profile and plan curvature. Drumlin crests (green shades) and interdrumlin hollows (purple shades) are clearly depicted.

Profile curvature is the rate of change of slope along a flow line. It is closely related to flow acceleration and deceleration and soil erosion and deposition. Plan curvature is the rate of change of aspect. It serves as a measure of the tendency of water to converge or diverge. The development of compound curvature map is based on the assumption that the combination of these two measures of curvature serves as a descriptor of the morphology of landforms.

The application of secondary attributes such as the Topographic Wetness Index has also received investigation in soil type prediction. Most secondary indices that have been developed elsewhere have been developed for particular conditions and will not apply uniformly across the Irish landscape. It was felt that their utility was restricted to particular landscape types in Ireland,

generally those with medium to high relief. Work during the project showed that these topographic measurements, while helpful, required additional contextual parameters e.g. geology, subsoils etc.

Clustering

As proved by initial project work in Mayo and as is familiar to anyone working in the Irish environment, the Irish landscape is extremely complex. The singular application of particular indices cannot address this complexity in any predictive model and it is this complexity that posed a significant challenge in developing and refining the topographic component of the soil model. While topography was not incorporated into the Level 1 soil products, it was subsequently included as an important variable used in Level 2 output through the application of clustering.

The development of a clustering approach, which integrated a number of topographic attributes from the EPA DTM, was found to be a particularly useful technique for developing a compound classification of landscape and in segmenting the landscape for Level 2 modelling. In turn this segmentation was found to be particularly effective in determining certain areas which were predisposed to gleying due to the nature of their topography. These areas are generally downslope and are comprised primarily of toe, foot and lower midslope components. Gleying in these areas, which equates to the poorly drained soil classes in the project soils classification scheme, can be due to ground-water influence, surface water gleying due to downslope accumulation of fines or a combination of both.

The clustering developed for the project used the SAGA GIS product. The algorithm used iterative minimum distance to means clustering operating on four key topographic measures. These measures were chosen based on their performance in a number of trials in successfully leading to cluster outputs which could be used for landform classification. The inputs to clustering were:

- Topographic Wetness Index
- Slope
- Horizontal distance to streamlines
- Vertical distance to streamlines

Based on experimental running of the clustering, the number of output clusters was set at ten. This was found to be the most practical trade-off between computing resource use and sufficient resolution of the output clusters. A number of the clusters were subsequently recombined based on an interactive assessment of the clusters in relation to the DTM. Figure 4.3 shows an example of the reclassified output for County Monaghan.

Recognition and effective prediction of gleyed or hydromorphic soils was a very important goal of Level 2 mapping, due to the challenges of trying to predict these soils where there was a high level of land management. However not all soils in a mainly lower lying topographic setting will be gleyed. The nature of the subsoils and local geology also play a role in determining the drainage

status of a soil. Equally, soils situated in a topographic setting comprised of upper midslope, shoulder slope or crest positions are not necessarily all well drained. Again, other factors such as subsoil, geology, mode of deposition, rainfall etc play a role in determining the drainage status.

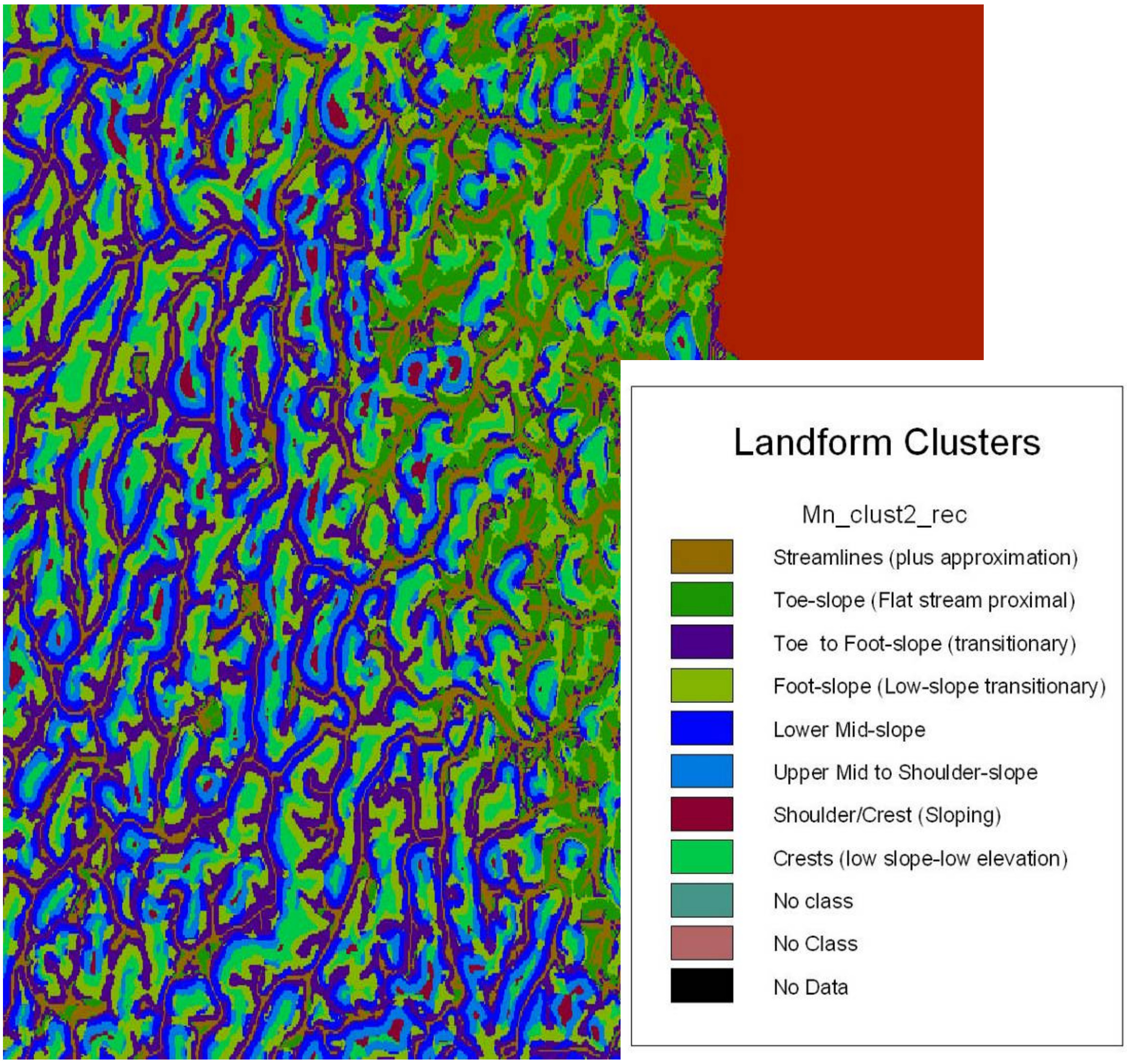


Figure 4.3 Subset of Monaghan showing clustered topographic output reclassified into landform types

It should be borne in mind that the issues and problems posed by this natural variability and sometimes chaotic nature of soil were not unique to this mapping effort. It is this variability that presents the greatest challenge to any soil mapping/modelling programme. In the same manner that other map products produced using traditional means contain variability, the output of this project's predictive approach will also have inherent variability and error in the produced map units.

4.2.5 Predictive Modelling

Quantitative methods involving GIS in soil survey have been ongoing for a number of years. They have probably been most investigated in Australia and New Zealand and the current developments in this field, which is termed "Pedometrics", are led mainly from there. Pedometrics is a relatively

recently-coined term, which refers to the application of geostatistical techniques to soil survey. Most researchers have tended to recently focus on geostatistical approaches, mainly involving different types of kriging, with varying results. In general, what most of these projects have in common is the large scale, small area focus of their work. These techniques can generally only be applied to plot or field size areas due to the requirements for intense sampling. At greater areas the models become less robust and often cease to produce reliable results. This is due primarily to the fact that studies of large areas have a requirement for large volumes of initial sample data, which is expensive to collect. The modelling investigations that have been completed are generally focussed on the prediction of quantitative soil attributes across relatively small survey areas.

As previously reported by Daly and Fealy (2007), during the lifetime of this project and since the completion of the mapping component, there has been a growing tendency towards the promotion of predictive soil mapping methods that seek to derive outputs such as those developed under the European Soil Information System (EUSIS) initiative (Le Bas et al, 1998). Rossiter (2005) examined the growing demand for interpreted information from soil data users. He distinguishes between the traditional supply-driven approach where presented data products were of a form chosen by the data creators and the newer demand-driven approach where demand for soil data is being driven increasingly by environmental modellers, land use planners, engineers and hydrologists. These potential stakeholder groups tend to want soil data supplied to them in interpreted form, as derivatives from the original soil maps. Their expected use of the maps has led these groups to look for functional reclassifications of the soil map unit classes as produced by traditional mapping efforts.

McBratney et el. (2002) proposed the use of pedotransfer functions in developing a first approach to what they termed soil inference systems. McBratney et el. (2003) expanded on this theme and went further to propose a *scorpan*-SSPF approach which would “replace the polygon-based soil maps of the past” (2003, 39). Lagacherie and McBratney (2006) in elaborating on the earlier formulation of the *scorpan approach* concluded that Soil Information Systems must now extend their functionality and begin to not only reproduce static digital soil data but to begin creating new maps based on the suggested *scorpan*-SSPFe approach. In essence the *scorpan*-SSPFe approach was a theoretical revision of Jenny's formulation which included the following factors:

s: soil, other properties of the soil at a point;
c: climate, climatic properties of the environment at a point;
o: organisms, vegetation or fauna or human activity;
r: topography, landscape attributes;
p: parent material, lithology;
a: age, the time factor;
n: space, spatial position.

With SSPF soil referring to spatial prediction functions (SSPF) and spatially autocorrelated errors (e). Of particular interest in this approach is the recognised role that previously mapped soil data could have in predicting soil classes or properties using this modelling approach. This fact was acknowledged by this project's team members a number of years before publication of McBratney et al's influential paper when a decision was taken to include previously mapped datasets of soil in Ireland into the predictive modelling approach. The role of expert rule modelling, one of the chosen approaches for this project, has also been acknowledged as a useful tool in the realm of predictive soil mapping.

While the proposed approaches emanating from the literature offer an exciting view of the future of Soil Information Systems and predictive mapping, some care needs to be taken in the context of Irish digital soil mapping. Lagacherie and McBratney (2006) themselves concede that there are important issues to be addressed before the suggested convergence in inferential soil mapping can take place. The input data required to drive such inference engines such as actual soil observations are often scarce and nearly always costly to acquire. Developing appropriate sampling strategies is therefore important but is not easily achieved. The choice of inference pathway requires optimising which is not straightforward. Ultimately the proposed soil inference systems will also face the same challenge of demand for interpretation by users that current, simpler soil information systems face.

In reality in Ireland, similar to many other countries, it is probable that the area of soil inference and digital soil mapping systems will remain in the research domain for a number of years. This is probably especially the case in Ireland where we still lack an extensive core database of observed soil properties for over 56% of the country and are therefore missing a fundamental input into any inference system. The soils research community in Ireland should monitor developments in this area, and perhaps should be encouraged to do so by client agencies. Support for the collection of soil observations would greatly enhance the potential for further inference system development.

This lack of data at the project outset meant that there were specific challenges in transferring a pure pedometric approach to this project. As the project was required to produce a map as a primary deliverable for the entire country, in a manner that was a uniform as possible, a pragmatic approach was required to enable model development. Using counties to frame and build model application areas meant that the application of the modelling efforts was at far larger spatial extents than previous efforts reported in the literature. Furthermore, the classification scheme used by the project was nominal/categorical in nature. The approach taken in developing the delivered soil model was therefore primarily a qualitative one, with predictions based on expert judgement in combination with pre-existing, mapped data and supported by field work.

4.3 Project modelling approach

One of the advantages of traditional survey is that the "mental map" of the soil surveyor i.e. the knowledge held by the surveyor is dynamic in the sense that it is constantly evolving. A soil surveyor brings *a priori* knowledge to the field site, which is then added to by his experience there

and modified accordingly. This new body of knowledge is then applied to the next survey site and a chain of knowledge-acquisition, synthesis and model-improvement becomes established. One of the advantages of this approach is its flexibility. This flexibility is also built into in the soils modelling/mapping methodology employed by this project. Development of the soil model was an ongoing, iterative process. As described above the theoretical core is closely related to traditional soil survey. As knowledge of the environmental conditions associated with the occurrence of particular soil types improved, or as more data became available, the expert rule base was modified to take account of these developments.

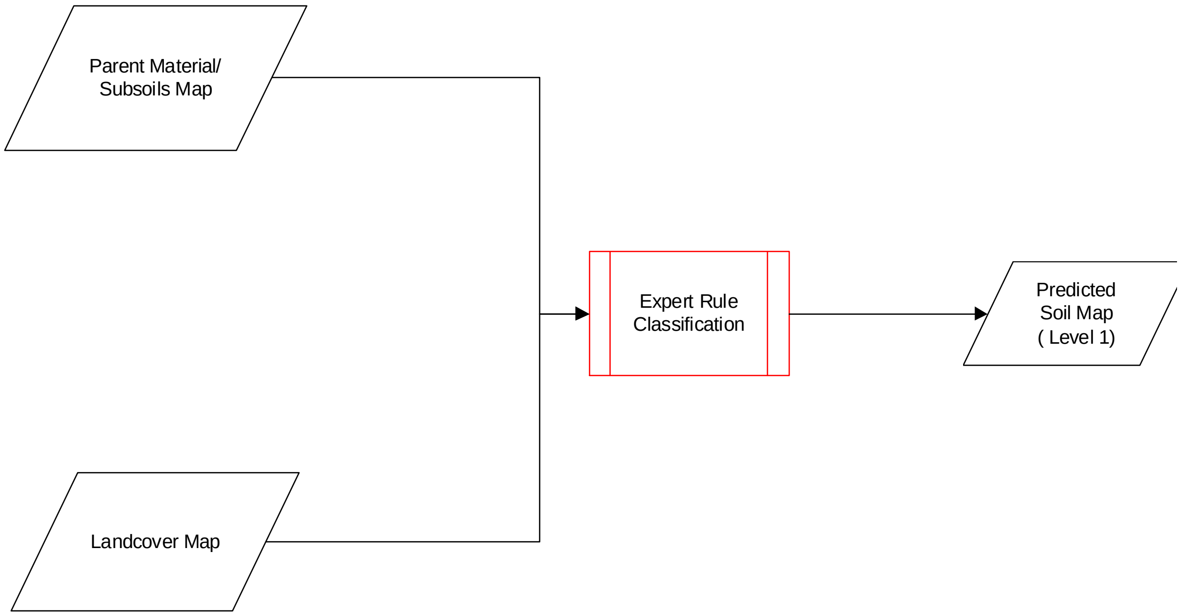


Figure 4.4 Simplified representation of soil modelling process for Level 1 output

4.4 Level 1 Model

The soil model used for the Level 1 implementation soil maps was a deterministic expert–rule based classification. In GIS modelling terminology, the model is a Boolean logic classifier. The model currently combines two major inputs (subsoils map and land cover map) and produces an output (soil map). The underlying technology of the classification process was based on a Microsoft Access database. The database was constructed in a manner that facilitated ease of integration with the GIS based on a SQL connection. The database holds every possible combination of subsoils and land cover classes and the soil most likely to occur, given those input conditions, based on expert judgement (fig 4.2). In developing the predicted output, published and unpublished maps and reports have been collated and reviewed. This information was combined with the expertise of the project team, which includes members of the former National Soil Survey to form the first layer of a rule set for the classification of Irish soils. The Level 1 model was initially designed as an intermediate phase of development and was formally withdrawn as an output product on completion of Level 2 modelling.

4.5 Level 2 Model

4.5.1 Background

Predictive modelling even when using a comprehensive collection of environmental covariates is not a straightforward process. For example the theoretical association between vegetation and underlying soil type has been mentioned above. However the existence and prevalence of artificial drainage greatly complicates this relationship from the viewpoint of its utility for predictive modelling due to the resulting impacts on overlying vegetation. The influence of land management therefore has a complicating effect on soil mapping and prediction and leads to a decrease in predictive accuracy for the Level 1 map output. This complicating influence is most obvious in the main agricultural areas where management efforts have been most focussed and the impact of this issue becomes more pronounced as mapping progresses in an easterly direction across the country. However the problem exists wherever land is intensively managed. Particularly good examples can be often be seen in the west of the country (fig 4.1 above)

The natural variability of soil occurrence in the landscape must always be borne in mind when considering and comparing the potential role of other datasets in the predictive process. Maps depicting such thematic layers as subsoil and subsoil permeability can sometimes belie the true extent of soil variability which can exist on the ground. A key fact is that the overlying soil is a highly variable entity due to the complexity of the various processes that lead to the development of the soil profile (Fig 4.5 below).

Figure 4.5 Short soil range variability. The photo on the left shows a brown earth and on the right a lithosol. These photos were taken in the same profile pit approximately 2 metres from each other.

The result is that an expected soil condition, based on a mapped environmental covariate, may not always be as expected by theory. For example subsoil permeability maps may show an area classed as having low permeability but the soils in that area will not always be poorly drained. This can be due to a number of reasons which may include the influence of topography on drainage, regional rainfall receipt and internal soil characteristics. The situation is similarly complicated with subsoil and/or other geological maps. Subsoil classes are mapped based on what is thought to be the dominant lithological influence. For example an area mapped as limestone till will in many cases not be composed exclusively of limestone. In most cases due to glacial entrainment and transport processes there will be mixes of other lithologies. In traditional soil surveying these subsoil types would be referred to as parent materials containing and admixture of the various contributing lithologies. The nature and amount of these other constituents will have an influence on soil formation

The advantage of the simple process used in the production of the Level 1 indicative soil maps was its consistency and its repeatability. The rules were transparent and were based on expert judgement on what combinations of the existing environmental conditions were most likely to be associated with particular soils. The disadvantages of the method are primarily that it was dependent on the reliability of the inputs and whether the inputs are adequate at representing the true ground conditions. It is primarily because of the challenges outlined above that a research component was written into the application for the current project.

> *"It should therefore be a second objective of the project to continue research where possible into mapping and modelling methods to ensure that best available technology and best practice are employed at all times."*
> (Project Description: Soil and Subsoil Classification for RBDMS, 2002)

In aiming to produce predictive map of soil types for Ireland it was recognised that the disadvantages present in the Level 1 output required a deeper investigation into refining the modelling procedures. To this end modelling was undertaken with a view to delivering an indicative soil layer to a higher specification of predictive accuracy. In order to ensure efficient use of the time available to the project, it was decided that the most pragmatic approach should be used to deliver indicative soil maps to the best accuracy achievable, given the inputs and technology available. With agreement from the project Steering Committee it was decided that the approach should involve the inclusion of best available data. It was recognised however that this would involve moving away for a standardised approach for all counties due to the fact that national coverage did not exist for all potential input datasets. This second implementation of soil predictive modelling is termed "Level 2" output.

In developing Level 2 predictive modelling, a preliminary assessment of the potential relationships between soils and other mapped environmental variables such as bedrock geology and subsoil permeability was undertaken using data from the Geological Survey of Ireland and the mapped datasets existing produced by the National Soil Survey. The development of national geological/hydrogeological datasets such as bedrock geology at 1:100,000 scale and the subsequent release of a draft aquifer mapping for Ireland further facilitated these investigations.

Whilst it was hoped that the inclusion of such additional data would improve the predictive accuracy of the soil model some key challenges were met by the project team when assessing the datasets potential utility.

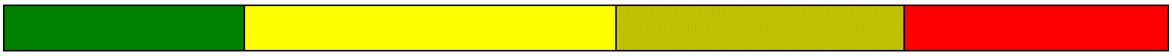
To refine the "best available" approach a number of essential questions were developed to assess the usefulness of proposed ancillary datasets. These included:

- For the county in question, what datasets are available?
- Of what quality are they?
- What is their proposed utility in predicting soil classes?
- How can they be combined to produce an indicative soil map?
- Are there ways to improve the datasets that are available?

4.5.2 Dataset availability

To help answer the first question, table 4.1 and map 4.6 were prepared. Table 4.1 shows the potentially useful information that was available for each county at the time of assessment. Map 4.6 represents this information using a generalised legend. In this map, the counties are toned by prioritising in the following order: the green tones show counties where AFT 6" information was available. The amber tones show counties where AFT preliminary reconnaissance mapping was available and the amber-hatched tones show counties where GSI permeability mapping only was available.

AFT 6" > AFT Preliminary Reconnaissance > GSI Permeability > None



This means that counties that are amber-hatched had GSI permeability mapping and did not have AFT 6" or Preliminary reconnaissance soil mapping. West Donegal is green toned to reflect that fact that AFT 6" mapping was available, as well as GSI Permeability mapping. The remaining areas of Donegal are amber-hatched to show the absence of AFT mapping and the existence of permeability mapping.

This scheme also reflected the assessed usefulness of these ancillary datasets for the purposes of Level 2 soil mapping. (Due to their availability nationally, datasets such as the DEM, General Soil Map, and 1:100,000 scale Bedrock Geology are not represented on the map).

4.5.3 Quality of available datasets

The determination of quality of the various datasets was not easily fully resolved. No comprehensive quantitative assessment of map quality had been carried been carried out by the map producers or subsequent users and in many cases the datasets had been accepted and employed in other projects without the quality being questioned or formally assessed. For both the

National Soil Survey detailed reconnaissance and the preliminary reconnaissance mapping, qualitative assessment by team members, including personnel involved in the original mapping programme, deemed these to be very useful. The consensus was that as the information resulted from organised field programmes under the auspices of the National Soil Survey, and notwithstanding the fact that some outputs were preliminary in nature, the incorporation of these datasets with direct field surveyed output was a preferred option

As there had been various phases in the development of the GSI permeability mapping under differing mapping regimes and approaches it was decided that discussion on a case by case basis with GSI personnel would help to determine the various quality issues that might arise with this mapping.

County	AFT 6"	AFT Reconnaissance	GSI permeability	Quality index
Waterford	Y	N	Y3	a
Offaly	Y	N	Y3	a
Meath	Y	N	Y3	a
Laois	Y	N	Y2	a
Clare	Y	N	Y2	a
W_Donegal	Y	N	Y1	a
Kildare	Y	N	Y1	a
W_Mayo	Y	N	N	a
W_Cork	Y	N	N	a
N_Tipperary	Y	N	N	a
Wexford	Y	N	N	a
Carlow	Y	N	N	a
Westmeath	Y	N	N	a
Leitrim	Y	N	N	a
Limerick	Y	N	N	a
Wicklow	N	Y	Y3	b
Roscommon	N	Y	Y1	b
Longford	N	Y	N	b
Sligo	N	Y	N	b
Galway	N	Y	N	b
E_Mayo	N	Y	N	b
Kerry	N	Y	N	b
Louth	N	Y	N	b
Cavan	N	Y2	N	c
Monaghan	N	Y2	Y1	c
E_Donegal	N	N	Y1	c
Kilkenny	N	N	Y1	c
E_Cork	N	N	Y4	d
S_Tipperary	N	N	N	e
Dublin	N	N	N	e

Table 4.1 Data sources available for inclusion in modelling. (Numeric coding indicates partial availability or available to differing standards)

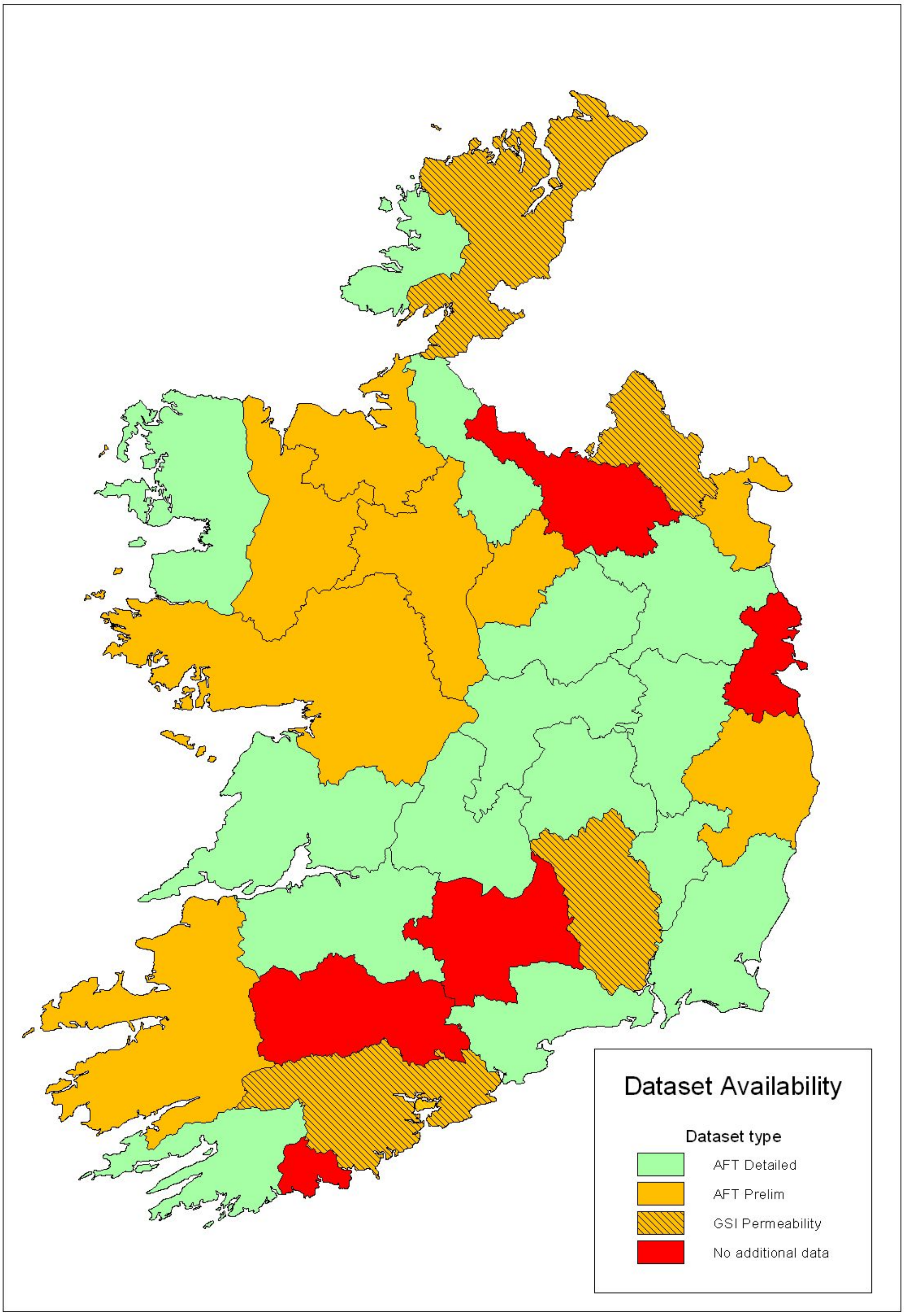


Figure 4.6 Status of availability of ancillary data in October 2004

4.5.4 *Usefulness of available datasets*

4.5.4.1 AFT detailed reconnaissance soil Maps

The National Soil Survey (NSS) was established in 1959. This marked the first real attempt to survey, classify and map the soils of Ireland in a systematic manner. As part of its programme, it undertook a detailed reconnaissance survey of the soils of Ireland at a published scale of 1:126,720 (Lee and Coulter, 1999). The detailed reconnaissance survey characterised and identified the soils of Ireland at on a county-by-county basis completing approximately 44% of the country before the field programme was wound up in 1988. Surveyed areas are shown in figure 1.1

The original mapping was conducted using the Ordnance Survey of Ireland's 1:10,560 scale map series as base mapping. These field maps, more commonly referred to as the 6" series (from 6 inches to a mile scale) are archived in the Teagasc offices in Johnstown Castle, County Wexford along with other unpublished data from the National Soil Survey. In order to utilise the high level of map detail in the projects predictive model a digital data capture programme was initiated to incorporate these maps to a format suitable for use in the project GIS.

A detailed protocol was developed for the data capture and a tender process initiated to both scan and digitise the map detail. The field maps (approximately 600) were scanned and a clear transparent acetate of each map on a 1:1 scale was then printed. This map was overlaid over the paper map and the integrity and attributes of each soil polygon checked against the published Soil Series. Where dubious linework existed this was corrected through addition, amendment or removal through etching or "x"-marking directly on to the transparency. All attribute codes were examined and modified to ensure compliance with standardised format. The amount of work involved in this preparatory phase was considerable with the checking and editing of these maps taking approximately 9 months of a staff member’s time. Once the maps had been checked and verified they were ready for the development of the main digitising and data capture.

On completion of cleaning, the original transparency maps were rescanned to Tiff format. These Tiff images were georeferenced and then used as backdrop to a heads-up digitising process to capture the mapped linework as digital vector linework and the labels for each map unit recorded. The county boundaries used were the administrative boundaries which were supplied by the Forest Service and formed the boundary datasets for all map coverages in this project. The digitised files were delivered on a county basis, fully georeferenced and in the Irish National Grid co-ordinate system.

Preparation of this dataset was supervised closely to ensure a high standard of delivered data. Statistical assessment methods were developed to test the delivered digitised maps and to ensure adherence to the tender specification. A number of meetings were held with the contractor to advise on compliance with the standards as detailed in the tender document. All maps entered an iterative testing and improvement process on receipt from the contractor and map sheets that did not meet required standards were returned to the contractor for further development. On

completion all field sheets had been digitised, joined for each county, checked and had final linework editing completed. Attribution of these sheets was also completed and fully checked.

As a by-product of the digitising process, the scans of the original field sheets have been georeferenced. These scans, which were delivered in CIT format (similar to the 25" raster maps), have also been imported and converted to GeoTIFF format. This has enabled these maps to be used in the GIS as backdrop mapping, which can be displayed with other datasets such as the orthophotos to facilitate GIS research of soil-landscape relationships.

4.5.4.2 AFT preliminary reconnaissance soil Maps

The preliminary soil maps were also considered to be very important to the development of the Level 2 indicative soil mapping. In counties where AFT 6" mapping is available it had been decided that the mapped poorly drained soil components should be incorporated directly into the modelling process. On consideration of the available preliminary reconnaissance mapping, it was felt that these maps were produced by soil surveyors mapping in the field. As such they represent actual mapped data and for the most part would be considered to be higher order information than purely modelled information. It is certainly the case that in areas where the model is not functioning well (managed agricultural areas) use of these maps was very important.

It was decided that the impact of varying quality of the preliminary maps would only be adequately answered by ongoing field work. Any questions arising from potential variations in mapping quality were assessed in the field and decisions then taken as to whether they were appropriate and suitable for inclusion in the soil model.

These maps were mainly available in half inch to 1 mile scale. As with the AFT 6" series, map sheets were scanned and georeferenced, again according to a developed protocol and appropriate accuracy standards. These georeferenced scans were used as backdrop for heads-up digitising of the linework representing soil map units. Captured linework and attribute data were subjected to iterative accuracy checking and editing before being finalised and output in ESRI shapefile format.

4.5.4.3 Classifying Complexes for the purpose of Level 2 Soil modelling

Due to the variability in the Irish landscape many soil map units in existing maps are not composed of one soil type or series only but may in fact be in composed of a number of soil types which co-occur in a an intricate pattern in the landscape.. A complex is mapped where two or more dissimilar components occur in a regularly, repeating pattern, which cannot be separated at the scale of field mapping. Although not immediately useful because of their mixed composition it was felt there was a great deal of information contained in complex map units. It was decided to re-examine complexes with a view to extracting as much of this information as possible. It was judged that in many complexes where the occurrence of elements such as outcropping rock, alluvial or peat was the reason for complex status, that in fact these components would be successfully mapped through the subsoils mapping process. In such cases it was therefore deemed that the remaining components of the soil complex could be directly used in the derivation of the soil

classes used in the Level 2 mapping. On further analysis a protocol was derived for assessing and using soil complex data. The assumptions and reclassification decisions are described below.

- The acid/basic component of the complex description was ignored in assigning Status. This is because the subsoil mapping dictated the acid/basic classification in the output map. Status refers to whether complex is “WD” (well drained), “PD” (poorly drained), PDPT (Poorly drained, Peaty), PT(Peaty) or “U” (drainage cannot be classified).
- In those complexes, where Peat is a component, it was generally assumed that subsoil mapping had successfully mapped out the peat areas within that complex. This was verified through GIS analysis comparing AFT 6" soil maps with subsoil maps. Therefore the status was based on the remaining mineral soil components and the Peat component was ignored.
- In those complexes where Alluvium is a component, it was assumed that subsoils mapping has successfully mapped out the alluvium within the complex. Therefore the status was based on the remaining mineral soil components and the alluvium was ignored.
- In certain complexes, both peat and alluvium are given as the soil components. PD (poorly drained) status was assigned if the alluvium is classed as PD in the accompanying bulletin or report, or if the complex is assigned a PD status. If Alluvium is classed in the bulletin as WD, then U (undefined) status was assigned to the Complex.

WD (Well drained) was assigned in the following situations:
Complexes where each constituent soil component is well drained.
Complexes where each constituent soil component (excluding Peat or Alluvium) is well drained.
Complexes where the percentage well drained soil component(s) exceed 70%.
WD soil components are considered to be the dominant soil by reference to the Bulletin.

PD (Poorly drained) was assigned in the following situations:
Complexes where each constituent soil component is poorly drained.
Complexes where each constituent soil component (excluding Peat or Alluvium) is poorly drained.
Complexes where the percentage poorly drained soil component(s) exceed 70%.
PD soil components are considered to be the dominant soil by reference to the Bulletin.

PDPT (Poorly drained, peaty) was assigned in the following situations:
Peaty Gleys (excluding Peat/Alluvium) are classed as PDPT.
Gleys and Peaty Gleys together (excluding Peat/Alluvium) are for the purposes of this exercise all classed as PD (this is based on the assumption that PDPT is a subset of PD soils). Note: If the landcover map showed Peat in those areas, then the soil is classed as PDPT. However if landcover map doesn’t pick out Peat, then those soils are PD anyway, and no distinction between PDPT and PD is made.
Peaty Podzols (wet) and Peaty Gleys (PDPT), occurring together were classed as PDPT.

PT (Peaty) was assigned in the following situations:
In areas showing a mixture of all/any of the following: rock, lithosols, podzols, peats, peaty podzols and peaty gleys. Commonly found in mountainous/hill locations.

U (Undefined) was assigned in the following situations:

Poorly drained soil component cannot be extracted from the well drained component.

Percentages of poorly drained or well drained soil components is not given in accompanying bulletin/map.

The reclassification of complexes using the above approach enabled their inclusion into the modelling process. Having been reclassified, the *Status* attributes described above were incorporated directly into the modelling approach in the same manner as consociation (non-complex) map unit drainage attributes were used.

4.5.4.4 GSI permeability mapping

The role of the GSI permeability maps is theoretically obvious. There is a clear conceptual link between the notion of low permeability sub soils and wet soils. However this link does not hold universally on the ground. While most low permeability sub soils may underlie poorly drained soils not all poorly drained soils are underlain by low permeability subsoils. As the permeability mapping to date (October 2004, when assessed) had either incorporated in a somewhat deterministic manner the available soil maps in published counties or not had soil maps available, the potential to examine the inter-relationships had been restricted.

Figure 4.7 Rush dominant vegetation with outcropping limestone pavement areas

There are further issues concerning the fact that permeability mapping was an input to the process of GSI Vulnerability mapping. Due to the specific requirements of vulnerability mapping, permeability maps with uniform coverage across counties often did not exist. To facilitate infilling 'Low and 'Moderate' permeability classes could be interpreted from vulnerability mapping in the areas of the map not classed as 'Extreme'. Areas where rock is at <3m are classed 'Extreme' in vulnerability mapping, suggesting rapid drainage to subsurface. However in reality it is possible for poorly drained soils to develop in such a setting. Figure 4.6 shows a dramatic example where rush dominated Gley soils predominate over limestone pavement in County Clare. In this example a thin veneer of low permeability Namurian till has been deposited over the rock surface and Gley soils have developed in this till. This aspect of subsoil permeability/vulnerability map classes, and perhaps more importantly of natural soil variability, created challenges in using the permeability mapping and in trying to develop consistent predictive rules for indicative soil mapping based on the permeability maps. This precluded the use of available permeability mapping in a direct deterministic manner although certain areas of the mapping were used in tandem with other inputs in some counties which had limited availability of other data.

4.5.5 Method development

In light of the potential challenges in trying to develop indicative soil mapping across a varied landscape such as Ireland, a key issue was the prioritisation of the research and development aspects of the work effort. It was deemed reasonable that efforts should focus initially on those areas that had no prior soil or GSI data. These areas are mapped in red in Map 1 and were north Cork and a smaller area in the south of the county; south Tipperary and Dublin. While Cavan and Monaghan are shown on the map as not having ancillary soil data, preliminary soil mapping does exist for these counties but it is classed as "Schematic" level. It is the most generalised of the mapping available. Some discussion ensued on the inclusion of these maps in the modelling process but eventually it was decided to proceed on the basis that no useful soil information for these two counties was available beyond the GSM.

For Cork, South Tipperary and Dublin modelling proceeded in the following way:

The General Sol Map and other available material such as the subsoils and geology maps were consulted to develop a conceptual model of the soils and landscapes in each of the areas. Soil information, such as AFT detailed reconnaissance mapping for adjacent areas was consulted to establish a suite of preliminary expert rules which might be applicable in the neighbouring unmapped areas. Based on the result of this rule gathering exercise, primary environmental covariates for soils were defined. It some areas topography may have a strong influence; in others it may be geology or distance to stream or drainage density. In most areas it was anticipated that it would be some combination of the above.

The area was then subdivided into working soil-landscape units guided by the identified significant environmental covariates. An example might be using the aquifer map and a slope category map to sub-divide a county into various units. This might give units such

Pu/Pl (Aquifer) + Slope < 7deg = Landscape unit 1
Pu/Pl (Aquifer) + Slope =>7deg = Landscape unit 2

Following from this subdivision, a fieldwork programme for each county was designed. The aim of this fieldwork was to establish in as far as possible what the dominant soils types are in each landscape unit. The possibility of establishing a sampling regime from which sampling inference could be determined was considered but was deemed not to be practical in the time available.

Areas of complexity, previously mapped as complexes in National Soil Survey mapping programmes needed to be considered but it was decided that the classification in the new model should proceed with assigning soil classes based on the dominant soil class, as had been the existing project approach. This decision was based primarily on the requirement where possible to map within the constraints of the project soil class legend and also on time and resource constraints. The requirement to subdivide areas into complexes or associations would have required extensive further detailed fieldwork and time resources did not facilitate this approach. Ideally it was considered that on completion of the map in the lab a further field visit would take place for verification purposes. In some instances it was found that again time resources did not permit a full field based verification but it was possible in places where multiple trips to the field took place to overlap with previously mapped areas and in this manner a qualitative assessment of the mapping could be conducted.

4.5.6 Model implementation

A key goal of the Level 2 research was to determine in so far as possible the various influences that the environmental covariates had on the effectiveness of soil predictive mapping and to provide the best possible mapping at the working project scale. To facilitate the inclusion of an increased number of variables in the predictive soil modelling approach, significant modification of the methodology operational at Level 1 production was required. The Level 1 model used a Microsoft Access database to manage the predictive rulebase which was created by combining the subsoil and landcover classifications. The number of rules resulting from the combination of just these two inputs was approximately 2000. The addition of other variables acted as a multiplier of this total e.g. to add 15 geology classes and 8 topographic classes would result in 2000 x 15 x 8 (=240000) rules. This was not practical to implement in the Level 1 model configuration and a new method needed to be developed.

After investigation and detailed testing the Expert Classifier software module in ERDAS Imagine was used to produce Level 2 model output for research counties (those counties where no previous mapping was available and therefore deemed a priority for modelling) Despite the fact

that these tools have certain disadvantages, mostly in the sense of their ease of use, they proved capable of delivering the output required. The fact that the ERDAS software was very familiar to the project team was a distinct advantage. A number of authors have reported on the successful use of the ERDAS Knowledge Engineer and knowledge Classifier software (Michel, 2004; Zhou et al., 2004; Zhang and Liu, 2005).

The new, revised methodology for production of Level 2 mapping (summarised schematically in Figure 4.8) was a hybrid of the Level 1 model with the new expert classification input from the ERDAS software. This combination was found ultimately to produce the best compromise between the use of the newly developed predictive rules and the retention of the detailed geometry of those areas considered 'PM_DOM' in the Level 1 classification. 'PM_DOM' (Parent Material DOMinant) subsoil classes are those that are deemed predictively 'strong' and so can be used to directly predict a soil output under the project soil classification scheme. 'PM_DOM' classes include rock, peat, marine/estuarine sediments etc. Alluvial and esker subsoils were re-categorised and also included in the 'PM_DOM' category.

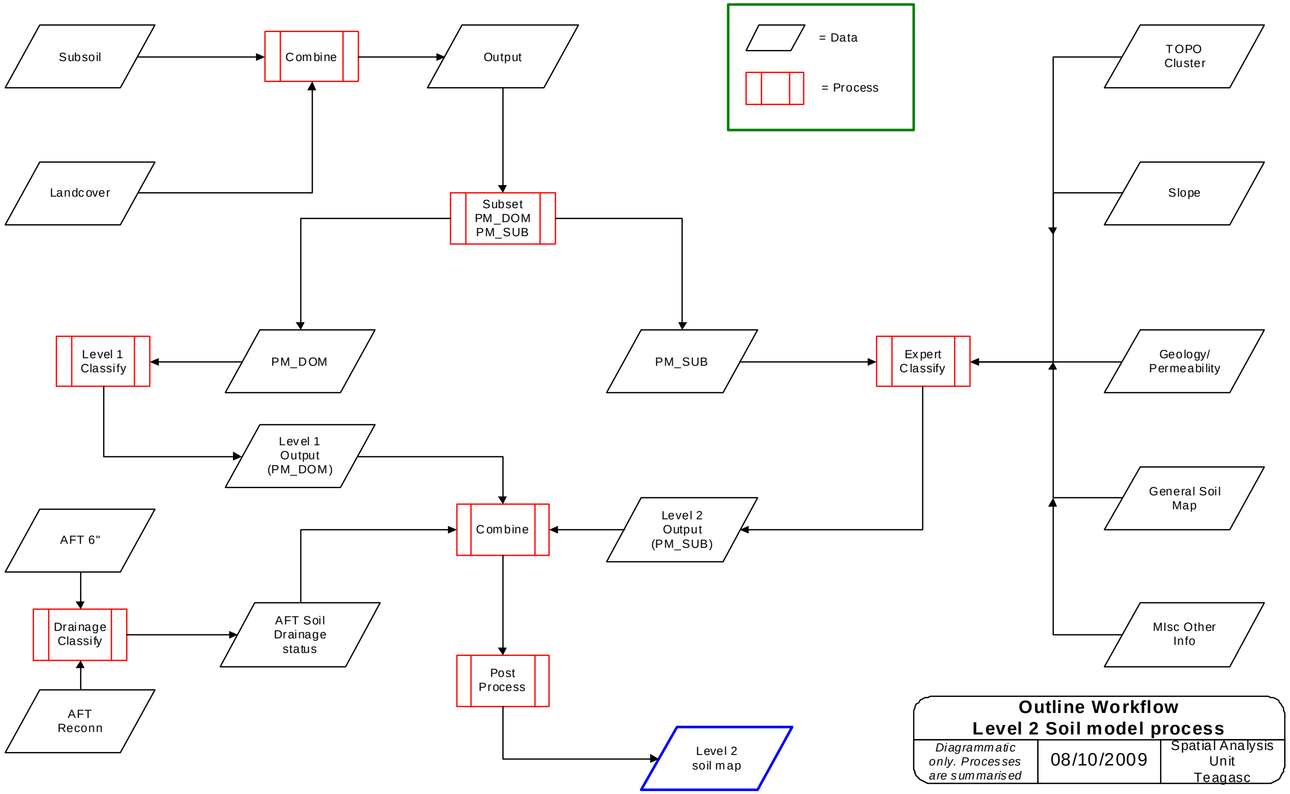


Figure 4.8 Level 2 mapping workflow

The expert rule based software used is comprised of a 2 primary components. The Knowledge Engineer facilitates the building through a graphical user interface of a knowledge or rule base. The rule base is represented as a tree diagram containing final and intermediate class definitions (hypotheses), rules (conditional statements concerning variables), and variables, which are the input datasets in raster, vector or scalar form (figure 4.9). Hypotheses are evaluated by the use of rules if one or more rules are true, then that hypothesis may be true at that particular location. To determine if a rule is true, the rule is evaluated based on input variables. Variables can also be defined from vectors and scalars. If the variable's value indicates that the rule is correct, this (combined with other correct rules) indicates that the hypothesis (class allocation) is true.

Rule Base: Monaghan
Condition: Poorly Drained
Version: Final

Rule No.	**Rule Description**	**Result (Hypothesis)**
1	TDCSs AND (GSI_Perm= L)	AminPD
2	TDCSsS AND (GSI_Perm= L)	AminPD
3	(GSM = 27) AND (GSI_PERM = L) NOT (MN_add_info = 2)	AminPD
4	TLPSsS AND (GSI_PERM = L) AND (Slope < 7deg)	AminPD
5	TLPSsS AND (GSI_PERM = M) AND (CLUST<=2)	AminPD
6	(MN_add_info = 2) AND (GSI_PERM = L) AND (Slope < 10)	AminPD
7	TLs AND (CLUST<=2)	BminPD
8	TLs AND (MN_add_info = 1)	BminPD

Figure 4.9 Extract from the expert rule base developed for classification of poorly drained soils in County Monaghan. The numbered rules correspond with those displayed in Fig 4.10

An important benefit of the software implementation of Knowledge Engineer is that it facilitates examination of the output class assignment in relation to the input rule base. The pathway cursor tool in the Knowledge Engineer enables the examination of any pixel in the output classified image and the exact path that was taken in the decision tree to arrive at this classification from the input rule base. This proved important for both testing and fine-tuning the soil classification rule base when in development.

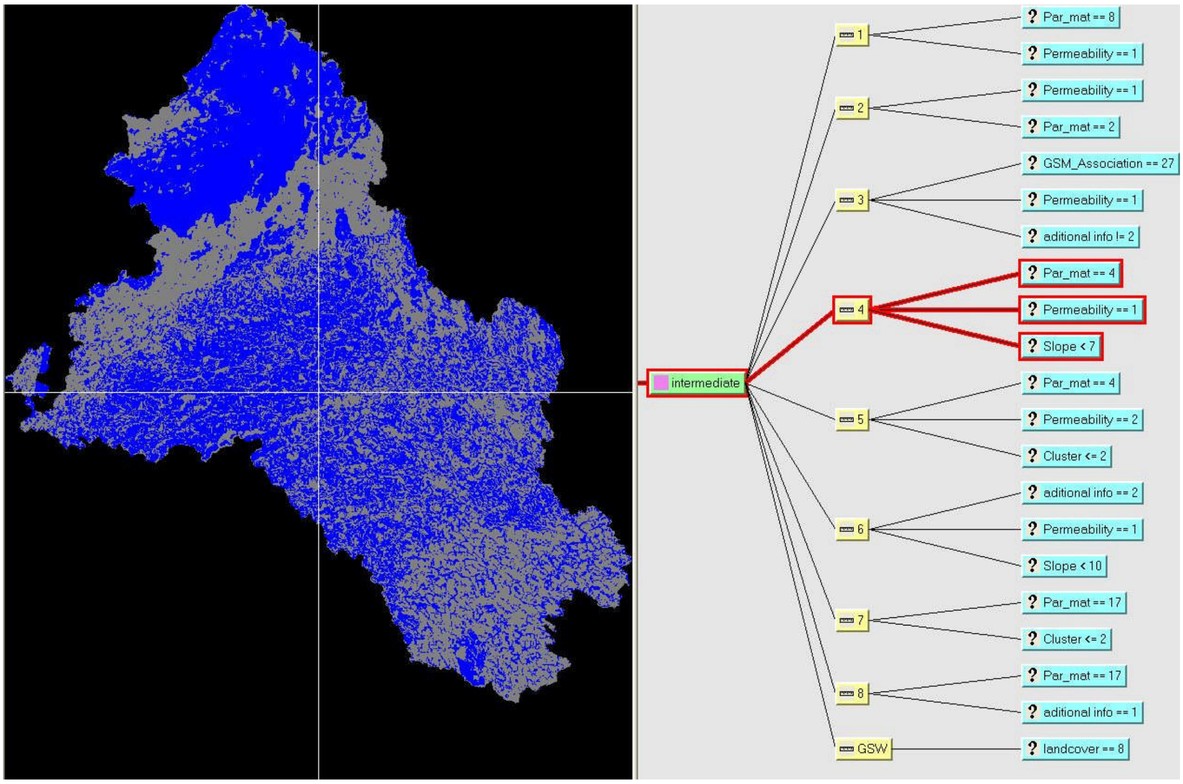


Figure 4.10 Highlighting the pathway cursor element of the Knowledge Classifier.

Figure 4.10 illustrates the pathway cursor utility in the Knowledge Classifier. By placing the cursor on the output classification surface on the left, the decision tree pathway used in arriving at the class assignment for that pixel is highlighted on the right. Rule 4 is highlighted in red in figure 10 above and is outlined below with an explanation of the inputs in italics beneath:

County Monaghan Rule 4:

Par_mat = 4

if parent material map is Till (Lower Paleaozoic Sandstone and Shale)

Permeability =1

and GSI subsoil permeability map is "L"

Slope < 7

and slope is less than 7°

THEN soil is poorly drained

Figure 4.11 below shows an extract from the indicative soils map as an output from the expert rule modelling process. The highlighted area shows the level of detail attainable, where drumlin sides with better drainage can be identified. Lee and Ryan (1965) previously recorded a similar soil-hydrological toposequence on a Cavan drumlin in sandstone till.

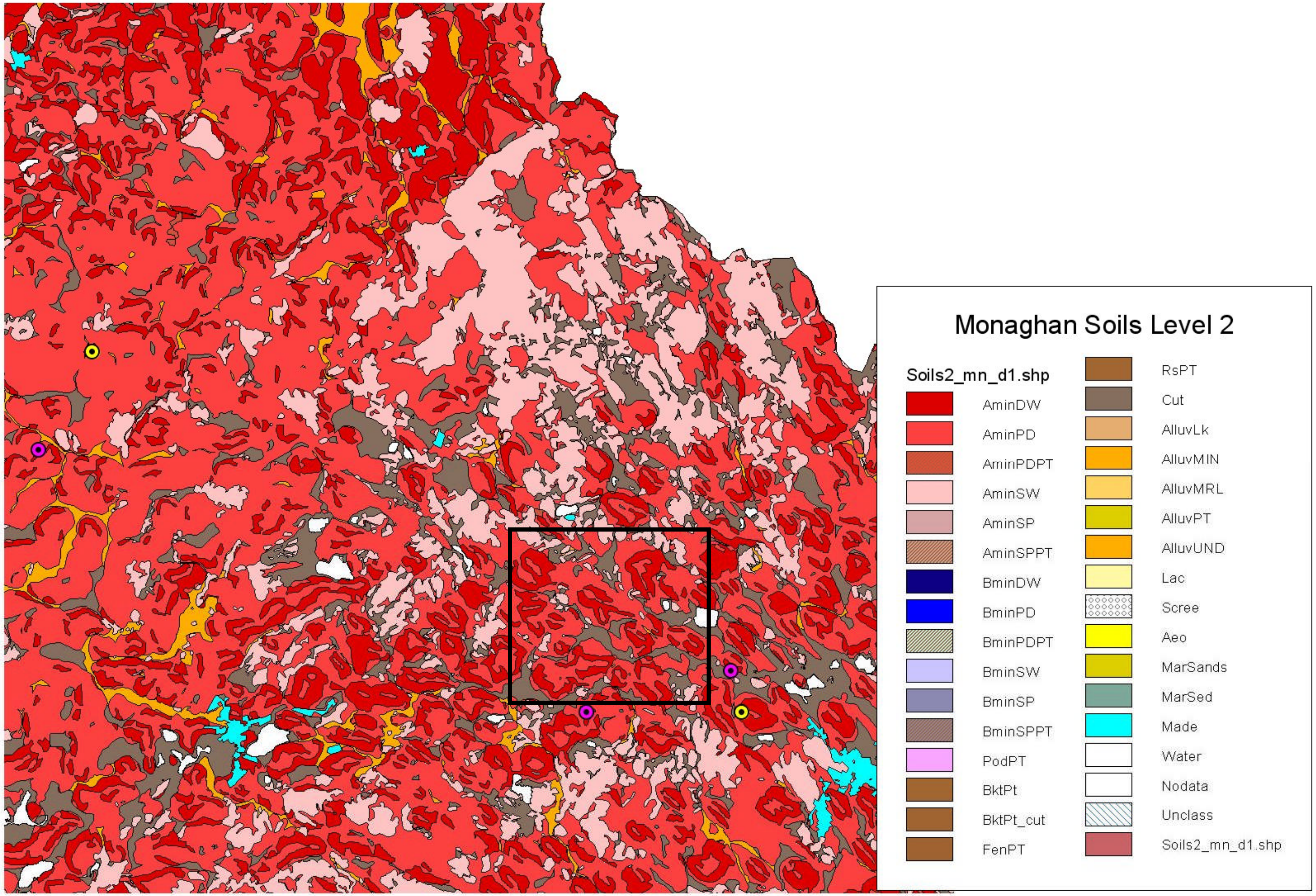


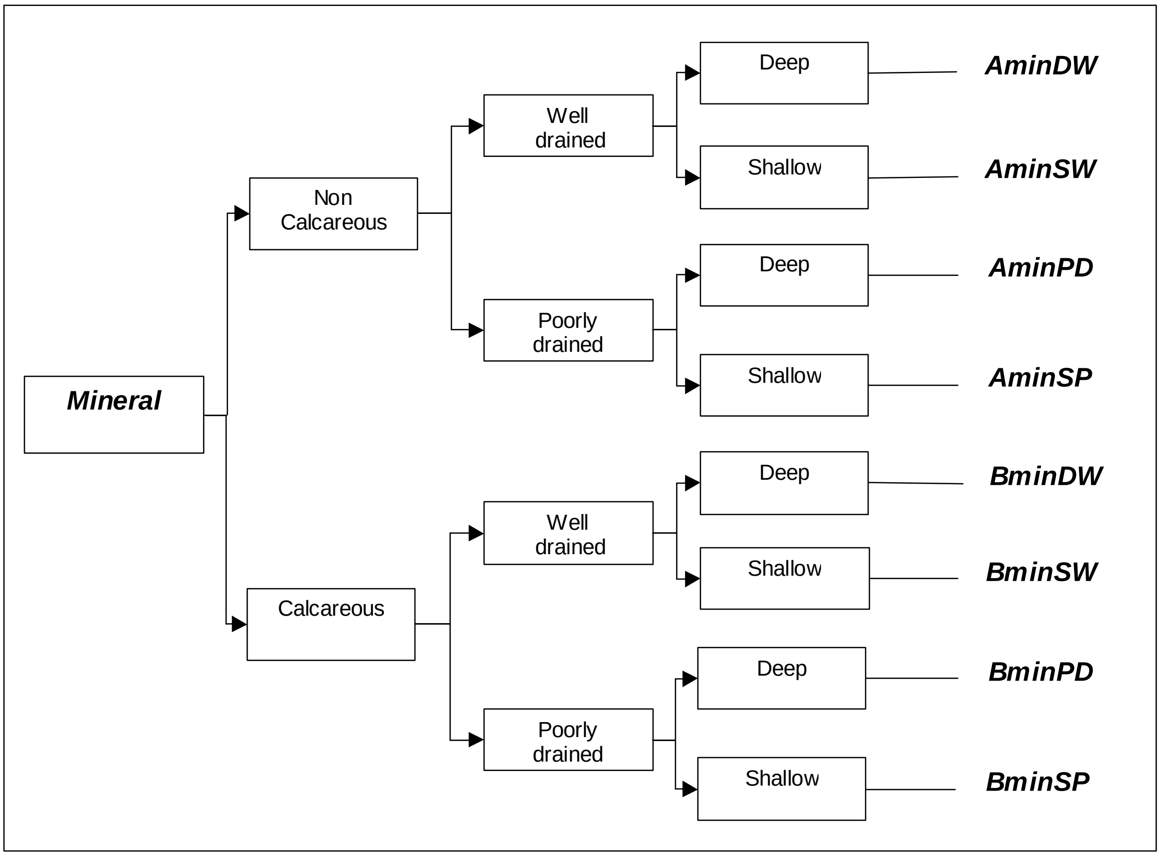
Figure 4.11 Monaghan detail showing drumlins with poorly drained crests, better drained soils on drumlin flanks and poorer drainage on lower slopes

This classification approach has proved extremely useful in formalising the knowledge of previous soil surveyors and facilitating its integration into a classification process for areas where no or little previously mapping existed. While it is worth noting that the classification process is only as reliable as it inputs, both in the sense of the quality of input data and the rules constructed, notwithstanding these challenges impressive results have been obtained from this research. For the first time since the conclusion of the National Soil Survey detailed mapping exists for areas in Ireland such as Monaghan where previously the only map data available was highly generalised in nature. As discussed earlier, the soil classification used in this projects mapping approach is functional in nature and some way removed from the level of detail contained in previous soil series level mapping conducted for 44% of the country. However it is worth stating the obvious that in unmapped counties the level of resolution is now greater than existed previously i.e. where there was little or no mapping. It is also worth noting that the level of accuracy and detail of the linework delineation for particular classes that were relatively easily defined such as peats, alluvials etc is considerably higher than existed previously, even for areas mapped previously using traditional methods.

4.6 Project soil classification details

Production of the indicative soil map employed a simplified classification scheme devised as part of the original project specification. This specification was initially designed for implementation in a forest productivity context but its potential utility as a unified national classification was recognised and recommended for use in Article 5 characterisation under the requirements of the Water Framework Directive. This classification developed for the project differs from traditional soil survey classifications and that used by the National Soil Survey in Ireland in that soils are not characterised to soil series level based on a range of soil properties but are inferred as types, based mainly on a set of soil forming factors. These are modelled and subsequently mapped using an expert rule base to predict soils occurring at all locations on the target landscape. The classification is represented schematically in Figure 4.12 below. The soil classification system initially subdivides mineral and organic soils that are further categorised based on the nature of the subsoil (calcareous/noncalcareous), drainage (well drained/poorly drained) and depth (shallow/deep).

Some key differences exist between traditional soil survey in Ireland and the output from this project. Chief amongst these is that the indicative soils map is based on a very simplified classification of soil type and does not contain soil property information which would require soil sampling and laboratory analysis. The indicative soil maps produced are based primarily on a functional subdivision of soils. This is reflected in the legend, which differs from traditional legends referring to soil series used in soil mapping in Ireland. Despite the differences however a key feature of the project classification scheme is that each of the classes has a very close relationship with the Great Soil Groups that occur in Ireland. For example, the class "Acidic Mineral Deep Well Drained" (AminDW) is theoretically composed of the Great Soil Groups (Acid) Brown Earths and Brown Podzolics (see table 4.9). This classification scheme design facilitates broad level interpretation and comparison with previously mapped areas.


Mineral
Non Calcareous
Calcareous
Well drained
Poorly drained
Well drained
Poorly drained
Deep
Shallow
Deep
Shallow
Deep
Shallow
Deep
Shallow
AminDW
AminSW
AminPD
AminSP
BminDW
BminSW
BminPD
BminSP

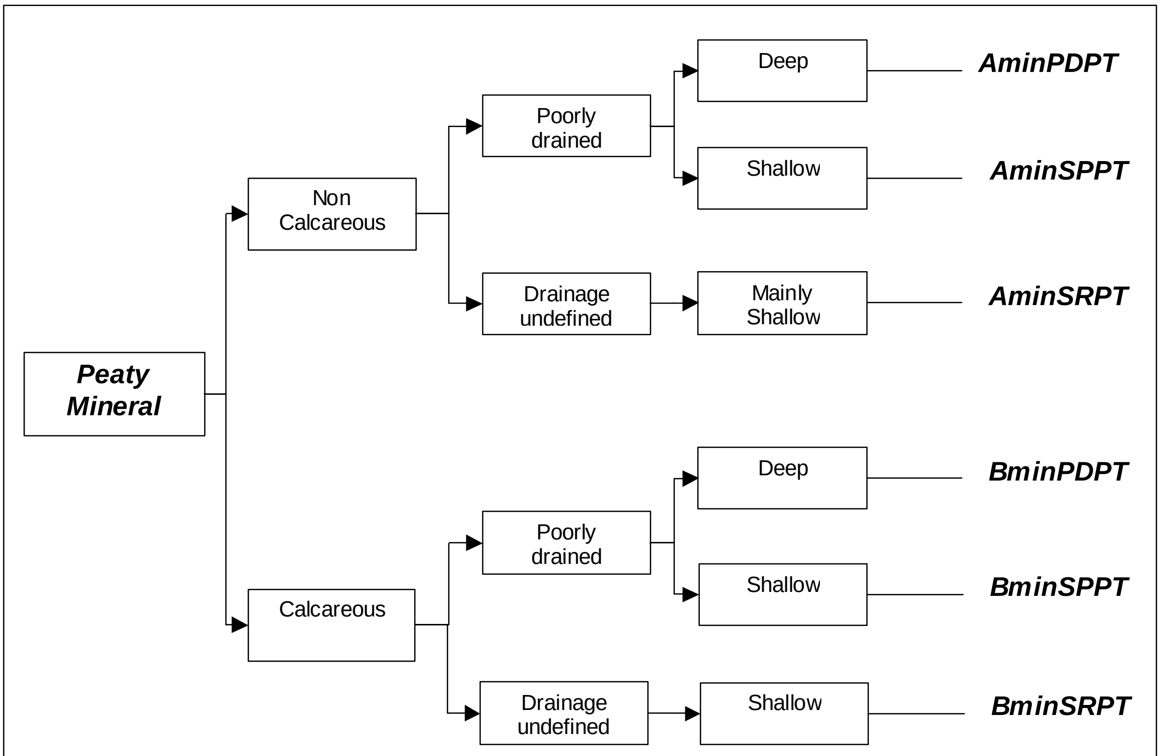

Peaty Mineral
Non Calcareous
Calcareous
Poorly drained
Drainage undefined
Poorly drained
Drainage undefined
Deep
Shallow
Mainly Shallow
Deep
Shallow
Shallow
AminPDPT
AminSPPT
AminSRPT
BminPDPT
BminSPPT
BminSRPT

Fig XXX

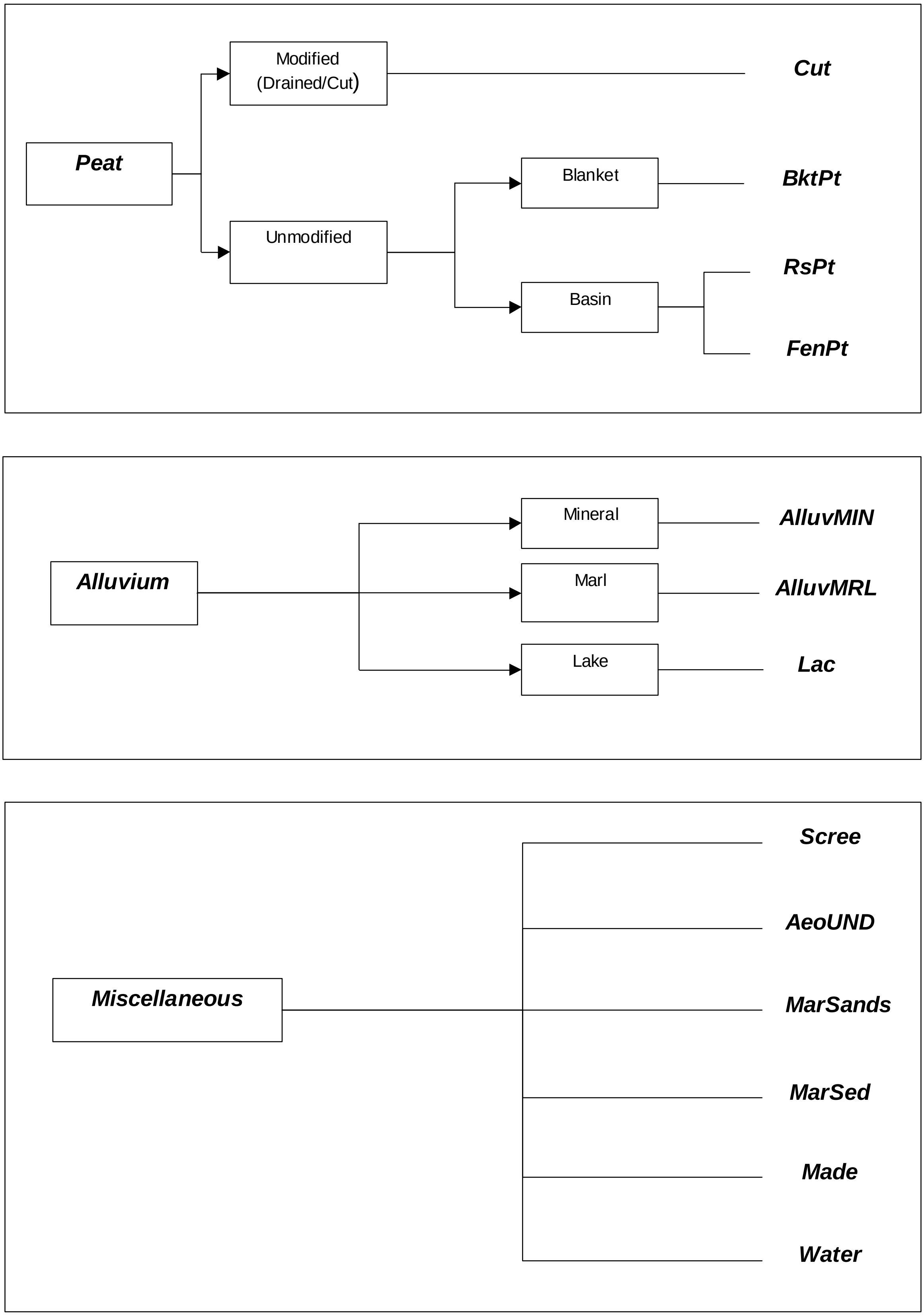


Figure 4.12 Conceptual flow of indicative soils classification through to classes used (on right)

4.6.1 Drainage classification

In traditional soil survey, drainage categories are based on examination of the soil profile. Inspection pits are dug and the features in the soil observed and recorded. For soil survey in Ireland a drainage classification was assigned based on the presence or absence of features visible in the profile. The drainage categories used to classify the drainage status of the soils are described below.

Drainage category	Description
Excessively Drained	Mostly coarse textured (sandy), skeletal soils on porous parent materials, in upland positions
Well drained	No obvious sign of impeded drainage (mottling etc) throughout the solum. Exception where under pasture, sparse mottling may occur in topsoil
Moderately well drained	Background colour of entire profile as for 'Well drained' with limited faint mottling allowable above 45cm; more distinct common mottling below 45cm
Imperfectly drained	General background colour below 30cm partly reduced (grey colour with some grey-brown and brown), with mottling. Above 30cm natural colours (grey–brown and brown) with or without mottling
Poorly drained	General background colour throughout profile a reduced grey with many prominent mottles to the surface or a definite reduced layer at any depth below 30cm and mottling to the surface
Very poorly drained	Background colour of entire profile a reduced grey or grey-blue throughout with few mottles allowable; with or without organic surface layer

Table 4.2 Drainage categories definitions as used in National Soil Survey

The classification of imperfect, poorly drained and very poorly drained soils in traditional survey is field based and relies on the interpretation of the morphological characteristics of the soil. Essentially it is based on the presence or absence of mottling and gleying characteristics within specified reference zones in the examined profile.

The methodology involved in producing the indicative soil map for the current Soil & Subsoil Mapping project is based on a modelling approach using remotely sensed data, topographic derivatives and field verification.

The first tier of classification used in the production of the indicative soil mapping Level 2 differentiated the subsoil categories in the primary classes *Mineral*, *Peaty Mineral* or *Peat* with

additional miscellaneous classes such as *Water*, *Made*, *etc.* A drainage classification was subsequently assigned using a combination of vegetation data derived from satellite interpretation and the inclusion of various topographic parameters such as slope and topographic wetness index where appropriate. For the production of the Level 2 maps, the indicative soil classes were derived using an expert rule based classification method. Indicative soil classes as mapped are therefore *predicted* classes presented in map form.

For the classification of Level 2 map units, Poorly Drained soil classes are defined as being equivalent to *imperfect drained, poorly drained or very poorly drained* in traditional Irish soils classification terms. In other words these are the target characteristics of any map unit *predicted* to be a member of any the Poorly Drained classes. Confirmation of this Poorly Drained class in the field was based on the existence of soil morphological characteristics indicative of impeded drainage. The reference morphological characteristics used for field verification were identical to those used by the traditional soil survey in Ireland.

4.6.2 "Acidic/Basic" status classification

4.6.2.1 Definitions and terms

For the purposes of this project the terms Acidic and Basic soils are used in the classification. These were essentially inherited terms that were included in the original project specification and are largely retained for that reason. While their meaning will be relatively familiar to most people as they are used colloquially it is probably more correct to speak of non-calcareous and calcareous soils. The project took these terms as the underlying meaning to Acid and Basic soils in the classification. The standard international approach of an effervescent reaction to the application of a 10 per cent HCL to the soil surface was taken as a positive test for the presence of calcium carbonate (CaCO3). In turn this was taken to imply a calcareous soil. Non calcareous soil was defined by the absence of effervescence. In practise this approach generally leads to the differentiation between soils derived from limestone based and non-limestone based parent material although it is acknowledged that there can be exceptions to this rule

4.6.2.2 Subsoils

With respect to the mapping of subsoils for the EPA Soil and Subsoil mapping project, the classification and field mapping methodology is closely aligned with that of the Geological Survey of Ireland. Of critical importance here is that the deposit categories are mapped where they are ≥ 1m in thickness and that they are subdivided on the basis of the dominant parent rock from which they are derived. The major difference is that the dominant parent rock in tills and sands and gravels is determined by field assessment of bulk physical properties, and not stone counts.

In general, in areas where acidic soils overlie acidic subsoils which again overlie acidic bedrock, the overriding expectation will be that the soil/subsoil environment will be acidic, and vice versa for basic/calcareous areas. Complications arise, however, where subsoils of a different chemical reaction to the local bedrock are in evidence. This complication in categorisation is broadened if

several subsoil strata are in evidence e.g. several metres of peat over limestone-derived tills over limestone bedrock, thin sandstone-derived tills over limestone tills over limestone bedrock.

In areas such as these, only the upper subsoil is depicted on the map, where it is >1m in depth. From this, there may be areas where deeper subsoils occur which may affect the chemical reaction at varying depths. The implications of this are that differing lithologies, with different calcareous/siliceous characteristics, can be found at varying depths at the same map location. In traditional soil survey terms is referred to as a litho logical discontinuity. For subsoil investigation below 1-2m users should be aware of this issue and use the GSI bedrock maps as supporting data. As a result of this complex relationship it is possible to find areas on the Level 2 map mapped as limestone till in areas where the corresponding geology might be mapped as sandstone or other siliceous type lithologies. The reverse is also possible.

This direct control exerted by the subsoils map in the soil modelling process is reflected in the categories used in the soil map. Where the subsoils map shows acid subsoil the resultant soil class will also be 'Acid' and similarly for basic subsoils.

Till type	Text on map	Reaction class
Sandstone till (Cambrian/Precambrian)	TCSs	Acid
Shale till (Cambrian/Precambrian)	TCS	Acid
Sandstone and shale till (Cambrian/Precambrian)	TCSsS	Acid
Greywacke till (Cambrian/Precambrian)	TCGw	Acid
Sandstone till (Lower Palaeozoic)	TLPSs	Acid
Shale till (Lower Palaeozoic)	TLPS	Acid
Sandstone and shale till (Lower Palaeozoic)	TLPSsS	Acid
Greywacke till (Lower Palaeozoic)	TLPGw	Acid
Sandstone till (Lower Palaeozoic/Devonian)	TLPDSs	Acid
Sandstone till (Devonian)	TDSs	Acid
Sandstone till (Devonian/Carboniferous)	TDCSs	Acid
Sandstone and shales till (Devonian/Carboniferous)	TDCSsS	Acid
Limestone till (Carboniferous)	TLs	Basic
Sandstone till	TSs	Acid
Shales and sandstones till (Namurian)	TNSSs	Acid
Sandstone till (Triassic)	TTrSs	Acid
Chert till	TCh	Acid
Quartzite till	TQz	Acid
Acid volcanic till	TAv	Acid
Granite till	TGr	Acid
Basic igneous till	TBi	Acid
Metamorphic till	TMp	Acid
Sandstone and shale till (Cambrian/Precambrian) with matrix of Irish Sea Basin origin	IrSTCSsS	Basic
Sandstone and shale till (Lower Palaeozoic) with matrix of Irish Sea Basin origin	IrSTLPSsS	Basic
Sandstone till (Devonian) with matrix of Irish Sea Basin origin	IrSTDSs	Basic
Limestone till (Carboniferous) with matrix of Irish Sea Basin origin	IrSTLs	Basic

Sands and gravels type	Text on map	Chemical reaction
Acidic Esker sands and gravels	AcEsk	Acid
Basic Esker sands and gravels	BasEsk	Basic
Sandstone sands and gravels (Cambrian/Precambrian)	GCSs	Acid
Sandstone and shale sands and gravels (Cambrian/Precambrian)	GCSsS	Acid
Sandstone sands and gravels (Lower Palaeozoic)	GLPSs	Acid
Shale sands and gravels (Lower Palaeozoic)	GLPS	Acid
Sandstone and shale sands and gravels (Lower Palaeozoic)	GLPSsS	Acid
Sandstone sands and gravels (Lower Palaeozoic/Devonian)	GLPDSs	Acid
Sandstone sands and gravels (Devonian)	GDSs	Acid
Sandstone sands and gravels (Devonian/Carboniferous)	GDCSs	Acid
Limestone sands and gravels (Carboniferous)	GLs	Basic
Shales and sandstones sands and gravels (Namurian)	GNSSs	Acid
Sandstone sands and gravels (Triassic)	GTrSs	Acid
Chert sands and gravels	GCh	Acid
Quartzite sands and gravels	GQz	Acid
Granite sands and gravels	GGr	Acid
Metamorphic sands and gravels	GMp	Acid

Peat type	Text on map	Chemical reaction
Blanket peat	BktPt	Acid
Raised peat	RsPt	Acid
Fen peat	FenPt	
Cutover peat	Cut	Acid

Other deposit type	Text on map	Layer code
Marl (Shell)	Mrl	Basic
Bedrock at surface	Rck	
Karstified limestone bedrock at surface	KaRck	Basic

Table 4.3 General outline of application of acid/basic subdivision to subsoil categories

For alluvial, lacustrine and marine sediments, the chemical reaction depends on the parent rock from which the material are derived and a variety of other factors. No general assumptions can therefore be made on the chemical reaction of these sediments.

The 'Rck' class was not subdivided on the basis of constituent dominant petrology at the subsoil mapping level. Further classification was used in producing the predictive soil maps as described below.

4.6.2.3 Soils

The soil classification scheme used in the Soils and Subsoils Mapping Project provides a functional subdivision of soils. This is reflected in the legend, which differs from traditional legends used in soil mapping in Ireland. A key feature of the classification scheme is that each of the classes has a very close relationship with the Great Soil Groups that occur in Ireland. For example, the class "Acidic Mineral Deep Well Drained" (AminDW) is theoretically composed of the Great Soil Groups (Acid) Brown Earths and Brown Podzolics. This has been designed to allow for broad level interpretation and comparison with previously mapped areas.

The soil classification relates to the subsoils map in a number of ways. The soil classification is qualitative and is reliant on the input of the subsoils map to guide the predictive process. Quantitative soil analysis for pH is not part of the mapping specification and the determination of the 'Acid/Basic' nature of the soil class relies on the presumed relationship between parent material type and resulting soil type. In particular, the geological composition of the subsoil/parent material type has a very strong influence on the characteristics of the soils overlying these deposits. For example, granite-dominated subsoil suggest overlying acidic soils; limestone dominated subsoil will have a general tendency towards higher pH values and shale subsoil will generally have overlying acidic soils.

To date, the following subsoil classes have had overlying soils classed as 'Basic':

TLs	Limestone till (Carboniferous)
GLs	Limestone sands and gravels (Carboniferous)
BasEsk	Basic Esker sands and gravels
KaRck	Karstified limestone bedrock at surface
IrSTLs	Limestone till (Carboniferous) with matrix of Irish Sea Basin origin

All remaining mineral subsoil classes (except miscellaneous classes such as alluvials etc. discussed further below) have been mapped with overlying soils as acid. Table 4.2 outlines this general aspect of the classification.

The category 'Rck' which previously defaulted to the 'Acid' soil class in earlier map drafts has been reclassified in the final map draft for all delivered Level 2 soil maps. Where the subsoil is mapped as 'Rck' or 'KaRck', the GSI bedrock geology maps at 1:100,000 were used to further define this class with an 'acid/base' categorisation in the output soil map.

The predicted soil categories used in the soil classification are shown in full below.

Soil Description	**Legend Class**
Deep well drained mineral (Mainly acidic)	AminDW
Deep well drained mineral (Mainly basic)	BminDW
Shallow well drained mineral (Mainly acidic)	AminSW
Shallow well drained mineral (Mainly basic)	BminSW
Mineral poorly drained (Mainly acidic)	AminPD
Mineral poorly drained (Mainly basic)	BminPD
Shallow poorly drained mineral (Mainly acidic)	AminSP
Shallow poorly drained mineral (Mainly basic)	BminSP
Peaty poorly drained mineral (Mainly acidic)	AminPDPT
Peaty poorly drained mineral (Mainly basic)	BminPDPT
Shallow peaty poorly drained mineral (Mainly acidic)	AminSPPT
Shallow peaty poorly drained mineral (Mainly basic)	BminSPPT
Shallow, rocky, peaty/non-peaty mineral complexes	AminSRPT
Raised Peat	RsPT

Cutover/cutaway peat	Cut
Fen peat	FenPT
Blanket peat	BktPt
Alluvial (mineral)	AlluvMIN
Alluvial (peaty)	AlluvPT
Alluvial (marl)	AlluvMRL
Alluvial (lacustrine)	AlluvLk
Alluvial (undifferentiated)	AlluvUND
Scree	Scree
Aeolian undifferentiated	AeoUND
Aeolian sand	AeoSands
Marine sand and gravel	MarSands
Marine/estuarine sediments	MarSed
Swamp	Swamp
Made ground	Made

Table 4.4 Summary description of soil classes and acid/basic map status

4.6.2.4 Acid/Basic classification of other Subsoils and Soils

A number of soil and subsoil categories were not assigned an acid/basic classification in the original mapping. The composition of alluvial and lacustrine deposits is usually related to the geological formation in their vicinity but not necessarily so. Marine deposits may be derived from locations that are geographically distant from their current location, which makes it even more difficult to predict what their acid/basic classification might be.

To illustrate these difficulties table 4.4 based on data from the National Soil Survey report "Soils of County Meath" (Finch etc al, 1983) on alluvial soils in County Meath is included below.

Series	Parent material	pH by Horizon				
Camoge	Derived from limestone till with some shale	Depth (cm)	0-16	16-47	47-57	57+
		pH	5.6	6.4	8.2	8.3
Drombanny	Derived mainly from Limestone	Depth (cm)	15-0 (Organic)	0-18	18-32	32-54
		pH	7.1	7.7	8.0	7.4
Dunsany	Derived from carboniferous limestone, shale and sandstone	Depth (cm)	0-15	15-35	35-40	40-50
		pH	7.0	7.8	7.9	8.6
Feale	Predominantly shale and limestone	Depth (cm)	0-7	7-15	15-27	27-39
		pH	6.8	6.3	5.6	6.2
Feale (Var.)	Predominantly shale and limestone	Depth (cm)	0-7	-	-	-
		pH	6.0	5.0	5.5	4.5
Boyne	Boyne alluvium	Depth (cm)	0-12	12-56	56-93	93+
		pH	8.3	8.4	7.9	7.9
Boyne (Var.)	Boyne alluvium	Depth (cm)	0-40	40-55	55-70	70+
		pH	5.8	6.0	6.5	-
Boyne (Var.2)	Boyne alluvium	Depth (cm)	0-9	9-33	33-44	44-60
		pH	7.6	7.8	7.9	7.7
Boyne (Var. 3)	Boyne alluvium	Depth (cm)	0-20	20-40	40-58	58-86
		pH	5.3	5.5	5.9	7.1

Table 4.5 Alluvial soils in County Meath

The table highlights the inherent difficulties in any attempt to classify alluvial depositional material in a generalised way. The same conclusion, based on expected variability, will hold for lacustrine and marine sediments. As can be seen from the table, pH within soil series can vary between 5.6 and 8.3. Variations across soil series range between 5.3 and 8.3 on a general horizon basis.

For the following reasons it is therefore not possible to accord an acid/base classification to the listed soil and subsoil types:

- the high variability of pH in alluvial, lacustrine and marine deposits.
- quantitative soil analysis for pH is not part of the mapping specification

- the acid/base classification used in the soils maps is qualitative and is reliant on the input of the subsoils map to guide the predictive process.

4.6.2.5 Fen peat

The classification of fen peat is somewhat complicated. In general discussions, fen peat tends to be traditionally referred to as basic. This follows from the idea that true fen peat develops in an environment where locations are continually flushed with base-rich groundwater and are classified as minerotrophic peats. However as table 4.5 shows, the actual measured pH of fen peats shows that the upper horizons, and sometimes all horizons, can be below pH7.0. It should be noted that these pH values are very close to pH7.0 and are substantially higher than the pH generally recorded in blanket peat and raised peat.

Series	**pH by Horizon**						
Banagher (Shallow)	Depth (cm)	0-10	10-20	20-40	40+		
	pH	6.79	6.5	6.96	8.28		
Banagher (Deep)	Depth (cm)	0-10	10-20	20-25	25-35	35-45	45-60
	pH	6.64	6.46	6.88	6.41	6.35	6.34
Pollardstown	Depth (cm)	0-15	15-45	45-100			
	pH	6.28	6.5	7.27			

Table 4.6 Fen peats in Offaly

Due to the variation outlined above we do not classify fen peats as acidic or basic.

The following tables detail the categories of soil and subsoil which were not given a classification and a comment explaining the reasons for not doing so.

PAR_MAT	pH_CAT	Type/Reason
Lake	n.a.	Water
A	not-stated	Alluvial sediments
Ac	not-stated	
Asi	not-stated	
L	not-stated	Lacustrine sediments
Lc	not-stated	
Lsi	not-stated	
Lk_isle	not-stated	Lake island where subsoil not mapped
MGs	not-stated	Marine sediments
Mbs	not-stated	
Mesc	not-stated	
Msi	not-stated	
Scree	not-stated	Not classified
Ws	not-stated	Essentially marine sediments (Blown)
Wsd	not-stated	
Made	not-stated	Built land

Table 4.7 Subsoil categories and reasons for non-classification of acid/basic status. Some types are self-evident e.g. 'Made'

IFS_SOIL	pH_CAT	Type/Reason
AlluvMRL	not-stated	Alluvial/Lacustrine sediments
AlluvLk	not-stated	
AlluvUND	not-stated	
Cut	not-stated	Acidic
FenPT	not-stated	Variable
MarSands	not-stated	Marine sediments
MarSed	not-stated	
AeoSands	not-stated	
PodPT	not-stated	Acidic
Scree	not-stated	Not classified on the basis that GSI Bedrock Geology map would be used, when available
RsPT	not-stated	Acidic
Swamp	not-stated	This category is not used in the maps and will be removed from future documentation
Made	not-stated	Built land
NoRule	not-stated	No data

Table 4.8 Soils and reasons for non-classification of acid/basic status. Some types are self-evident e.g. 'Made'

4.6.3 Depth categories

4.6.3.1 Subsoils

The guiding principle for mapping subsoils was the extraction of data relevant to soil formation. Essentially the subsoil mapping sought to map soil parent material, which is the material in which soils form.

The Rck and KaRck classes were defined as outcropping or subcropping rock occurring at or within 1m of the surface.

4.6.3.2 Soils

For soil mapping purposes the depth terms in the classification used for Level 2 indicative soils maps are qualitative. The subsoil map was key to driving the predicted overlying soil class and associated depth qualifier. The class 'Shallow' was assigned to soils that overlay subsoil classes perceived to provide a shallow soil-formational environment. These classes comprise in summary: eskers, gravels and rock outcrop/subcrop (table 4.8). All other soils occurring on tills are assigned the qualifier 'Deep'.

PAR_MAT	IFS_soil	PAR_MAT	IFS_soil
AcEsk	AminSW	GLPDSs	AminSW
BasEsk	BminSW	GLPGw	AminSW
G	AminSW	GLPS	AminSW
GAv	AminSW	GLPSs	AminSW
GBi	BminSW	GLPSsS	AminSW
GCGw	AminSW	GLs	BminSW
GCh	AminSW	GMp	AminSW
GCS	AminSW	GNSSs	AminSW
GCSs	AminSW	GQz	AminSW
GCSsS	AminSW	GTrSs	AminSW
GDCSs	AminSW	RckCa	BminSW
GDSs	AminSW	RckNCa	AminSW
GGr	AminSW		

Table 4.9 Relationship between subsoils and output soil depth categories

4.6.4 Rock classes-additional information

For the purposes of the soil maps, the subsoil classes which mapped outcropping/subcropping rock ("Rck" and "KaRck") were reclassified into "RckCa" (Calcareous rock) and "RckNCa" (Non-calcareous rock) based on the 1:100,000 digital geology maps supplied by the GSI.

The Level 1 model defaulted "Rck" subsoils to shallow, well drained soils e.g. "AminSW" or "BminSW". However at Level 2, previously mapped soil information from the National Soil Survey was incorporated. In cases where gleys or peaty gleys (both poorly drained) had been mapped we elected to include this information even if this was over areas that the subsoils mapped as "Rck". This is acceptable as poorly drained soils can occur over shallow (<1m) rock (figure 4.7).

So where "Rck" + previously mapped gleys then this gives "AminSP" in the Level 2 output
and "Rck" and previously mapped peaty gleys this gives "AminSPPT" in the Level 2 output.

The difference between "AminPDPT" and "AminSPPT" is the fact that the latter occurs on "Rck" parent material class and the former on tills and so is notionally one of the depth of formational environment.

"AminSRPT" soils are classified as described in the supplied table 4.9. They are mapped as "Rck" subsoils (but can include the particularly acid-type TGr, TMp, TQz and TDSs (granitic, metamorphic, quartzitic and Sandstone tills). It is important to read the "-SRPT" prefix as "Shallow and/or Rocky and/or Podzols with/or without a peaty/organic horizon". The "-SRPT" class is best understood if the main setting for these soils is visualised. These soils are mainly montane-type soils occurring on mountain slopes. The soil varies widely and across short distance intervals in these settings from peat to outcropping rock and shallow soils, including Lithosols, to podzols and peaty podzols. In other words, though the description may appear broad it is the best fit for these areas. Sometimes nature will not perform or present itself in a manner amenable to analysis or report-writing. To describe these areas as any one soil type might seem desirable but would be wholly inaccurate.

"BminSRPT" occur in similar settings but with subsoil mapped as calcareous rock "RckCa". Examples of this (largely limited class) occur on Ben Bulbin in County Sligo and the existence of soils like these in such a setting has been previously mentioned by Culleton and Gardiner (1985). One apparent difficulty with the implementation of this particular rule is that the BminSRPT output is derived from a combination of subsoils = "KaRck" and landcover = "CR" (rocky complex) and "ER" (exposed rock). Along the Clare-Galway border there is an apparent mismatch between BminSW, mapped on the Clare side and BminSRPT on the Galway side. An analysis of this issue has suggested that issue results from the use of the Aft 62 soil data for Clare. If the AFT soil class "Burren extremely rocky phase" which is classified as Renzina but with 75% rock was classified according to the project classification, then this too would be classed as "BminSRPT" due to the amount of exposed rock. This would resolve the mapping "anomaly" as it appears in the current map version.

IFS Soil Description	IFS_soil	IFS_Code	Included Great Soil Groups
Deep well drained mineral			
Derived from mainly non-calcareous parent materials	AminDW	11	Acid Brown Earths Brown Podzolics
Derived from mainly calcareous parent materials	BminDW	12	Grey Brown Podzolics Brown Earths
Shallow well drained mineral			
Derived from mainly non-calcareous parent materials	AminSW	21	Shallow Acid Brown Earths/Brown Podzolics Lithosols Regosols Some outcropping rock
Derived from mainly calcareous parent materials	BminSW	22	Shallow Brown Earths/Grey Brown Podzolics Rendzinas Lithosols Some outcropping rock
Deep poorly drained mineral			
Derived from mainly non-calcareous parent materials	AminPD	31	Surface water Gleys Ground water Gleys
Derived from mainly calcareous parent materials	BminPD	32	Surface water Gleys Ground water Gleys
Shallow poorly drained mineral			
Derived from mainly non-calcareous parent materials	AminSP	33	Surface water Gleys (Shallow) Ground water Gleys (Shallow) Some outcropping rock
Derived from mainly calcareous parent materials	BminSP	34	Surface water Gleys (Shallow) Ground water Gleys (Shallow) Some outcropping rock
Poorly drained mineral soils with peaty topsoil			
Derived from mainly non-calcareous parent materials	AminPDPT	41	Peaty Gleys
Derived from mainly calcareous parent materials	BminPDPT	42	Peaty Gleys
Derived from mainly non-calcareous parent materials	AminSPPT	45	Peaty Gleys (Shallow)
Derived from mainly calcareous parent materials	BminSPPT	44	Peaty Gleys (Shallow)
Shallow, lithosolic or podzolic type soils potentially with peaty topsoil			
Predominantly shallow soils derived from non-calcareous rock or gravels with/without peaty surface horizon	AminSRPT	43	Podzols (Peaty) Lithosols Peats Some outcropping rock
Predominantly shallow soils derived from calcareous rock or gravels with/without peaty surface horizon	BminSRPT	46	Lithosols Peats Some outcropping rock
Alluviums			
Mineral alluvium	AlluvMIN	51	Variable
Marl type soils	AlluvMRL	53	Variable
Lacustrine–type soils	Lac	56	Variable

Peats			
Raised bog	RsPt	61	Basin Peats
Blanket peat	BktPt	63	Blanket Peats
Cutaway/cutover peat	Cut	65	Basin Peats Blanket Peats (some)
Fen peat	FenPt	66	Basin Peats
Miscellaneous			
Scree	Scree	70	
Wind-blown sands undifferentiated	AeoUND	71	
Beach sand and gravels	MarSands	72	
Marine/ Estuarine sediments	MarSed	73	
Reed Swamp/Marsh	Swamp	75	
Made/Built land	Made	74	
Water (including lakes, reservoirs and larger rivers)	Water	76	
Unclassified	Unclass	77	

Table 4.10 Soil classification and description used in indicative soil mapping

4.7 GIS and Soil modelling

The project in both its phases (Irish Forest Soils Classification project and Teagasc/EPA Soils & Subsoils Mapping project) was fortunate in having accessibility to possibly the most extensive collection of national digital datasets in the country at the time. While having access to these datasets had obvious potential benefits, an enormous amount of dataset preparation and repair had to be undertaken before full use could be made of this data resource. A significant amount of time was required to both correct and manipulate these datasets so that they were usable by the project Geographic Information System (GIS) technology.

Datasets were supplied in widely differing formats and in various conditions. The different formats required conversion to those GIS formats used by the project. Differing standards of data accuracy in received datasets also required correction through a combination of automatic and manual processes. Following the conversion and correction stage of data preparation, data management issues were then addressed. Many of the complete datasets were very large e.g. the Ordnance Survey Ireland (OSI) digital orthophotography dataset, which is approximately 70 gigabytes in size. To facilitate efficient use of datasets of this size, solutions were developed to optimise storage and retrieval mechanisms for this dataset.

The majority of project GIS work over the course of a number of person-years consisted of efforts to convert, edit, integrate and data manage the large data volumes available to the project. Some of these efforts and the datasets to which they were directed are described below.

4.7.1 Datasets

4.7.1.1 Orthophotography

In 2001 the vast majority of the national 70 GB orthophoto dataset was integrated to the project GIS. This import work involved the scripting of customised batch files to convert the orthophotos from the delivered HMR format to GeoTiff format. GeoTiff has been chosen as the base format for the majority of raster files in the project. This is due to the fact that it is now generally considered to be industry standard and can be read by all of the project software. By choosing a format that does not require further conversion, the initial time overhead involved in converting the large image datasets ultimately facilitates efficiency in processing and data-use.

4.7.1.2 25" Raster mapping

The Forest Service, as part of the agreed deliverables, supplied raster maps at 25" scale to the FIPS-IFS project. The mapping was supplied in .CIT format, a native Intergraph image format. A number of issues required consideration in the use of the raster maps as delivered. The CIT format was only directly readable by Bentley Microstation and was not readable by either ERDAS Imagine or ArcView, the key project GIS platforms. It was essential, therefore, to convert these files to enable access from ERDAS Imagine and ArcView, which are used far more extensively within the project than Bentley. After investigation, GeoTiff was considered to be the most appropriate format to enable access from Bentley, ERDAS and ArcView.

Because conversion to GeoTiff, even when CCITT4 compression was maintained tended to almost double the average file size of each raster image, it was estimated that storage total for the full set of raster for the country could approach 40GB. This was considered too high so an alternative approach was considered necessary.

After investigation a two-step procedure was developed. The first stage involved conversion of the raster CITs to GeoTiff format. This was achieved by writing Microstation BASIC macros to batch the conversion process. The second stage involved a resolution-degrade which brought the maps from 500dpi to approximately 133dpi. This step was achieved by modifying an ERDAS Imagine procedure using the ERDAS macro language, EML, to work with GeoTiff files. The results of this procedure suggested that full country raster map set could be accommodated on the server with approximately 10GB of storage.

Times for conversion runs on Cork, which consists of approx. 1800 25" raster files, took 15 hours for the CIT to GeoTiff conversion and 25 hours for the resolution degrade.

Due to the amount of work and time required in converting the raster dataset, it was decided to trial the utility of the maps in the four counties where project work was ongoing at that time. These were Cork, Kerry, Wexford and Galway.

The mapping was assessed in the following potential application contexts:

- as an interpretation aid in the photogrammetric collection of land cover training data
- as an aid to distinguishing wet areas for the construction of soil rules
- as a guide to the location of field sampling.

During the assessment process, the Forest Service indicated that they would like the whole national dataset of 25" raster mapping to be converted to GeoTIFF and delivered to them. This was eventually completed through running a number of machines in batch processing mode on 24hour rotating cycles.

4.7.1.3 Geological Survey of Ireland (GSI) Bedrock data

Research work on the datasets input to the modelling work for the initially researched counties Mayo and Cork was carried out and this showed that additional data such as geological mapping might prove useful in the soil model. This was thought to be particularly so in the case of potential karstic areas where the hydrological regime is complex and ordinary mapping rules may not hold. In these areas, enlargement of sub-surface conduits typical of karstic regimes, may influence water movement through the soil solum. Even in areas that are not karstified, the permeability of various underlying bedrock lithologies is presumed to have an effect on the soil and subsoil drainage status.

This was initially found in areas of Waulsortian Limestone in Cork. Initial model results from the mapped parent material and topography combination strongly suggested that poorly drained soils should predominate. This rule was found to hold generally in the region except over areas of Waulsortian limestone. It was hypothesised that this lithological unit, with its associated permeability, facilitates enhanced drainage through the soil profile and keeps the drainage status in the well drained class.

The bedrock maps were acquired from the GSI to facilitate further research. Although the maps were supplied in ArcInfo coverage format, which was readable by the project GIS, a number of issues remained with the integration of these datasets. The data was supplied digitally but was cut to the same extents as the 1:100,000 paper map series. The data needed to be joined and edgematched before use, and stratigraphic codes standardised to enable single attribute tables to be used for the joined coverages. This work was completed initially for available GSI maps for Cork. Research efforts focussed on how to apply the potential predictive gains, made through incorporating the geology layers into the rule-base construction, into areas for which geology maps are not available at 1:100,000 scale.

4.7.1.4 OSI 1:50,000 vector mapping

Updates to the initially distributed OSI 1:50,000 digital vector mapping were received during the project. These were checked and incorporated into the GIS. Previous work on server storage procedures and file indexing ensured that update incorporation was a relatively smooth. This dataset was made fully accessible through the customised software package *'Mapsheet Manager',* available in the project's ArcView interface.

4.7.1.5 County lake datafiles

The original Digital Elevation Model (DEM) supplied through the Forest Service for Phase 1 of the project required extensive correction.. As part of this correction process, lake areas required particular attention. Due to the semi-automated extraction process used to develop the DEM initially, water bodies affected the accuracy of elevation extraction. This resulted in a 'mountain-in-lakes' effect. To correct this error, the mapped lake areas from the OSI 1:50,000 mapping were extracted from the dataset and elevations attributed to these polygons. Two versions of the lakes file for each county were prepared. The first was a base level (Level 0) file which included all lake and lake island information as it appears on the OSI mapping. The second version (Level 1) included only those lakes greater than 1 hectare in area. The level 1 file was used in the DEM correction work.

4.7.1.6 OSI Digital Terrain Model (DTM)

The Forest Service delivered a DTM developed by OSI to the project. The resolution of an alternative OSI DTM was 50 metre horizontally and 1 metre in the vertical. The intention was to supplement the project DEM with the OSI DTM for TOPEX and windthrow hazard investigations. The OSI DTM as received, was in a particularly difficult format to work with. A requested reissue of the DTM was delivered in the same format so it was necessary to write an import procedure in ERDAS to import each of the 20x20km tiles. This procedure also georeferenced each tile as part of the import process. On completion of importation the tiles were checked and joined to create a national mosaic in ERDAS Imagine format. Software tools, described below, have been written to facilitate use of the DTM in ArcView Spatial Analyst. Phase 2 of the project used a DTM created for other EPA/Teagasc projects and developed from the OSI 1:50,000 contour data.

4.7.1.7 Subsoils/Parent Material

One of the core areas of dataset development was required by the internally produced subsoil/parent material dataset. A considerable amount of time was required to integrate the digitised parent material maps, derived from the digital stereo photogrammetric software, into the project GIS. This process of integration was constantly under review throughout the project to seek improvements and ensure efficient processing. Close liaison with the project subsoils mapping personnel sought to ensure that the process of both parent material mapping and GIS integration were streamlined and enhanced. The time required both for mapping and post-processing reduced dramatically during the project due to efforts in this area. Figure 4.12 shows the developed workflow for the production and GIS integration of the subsoil dataset.

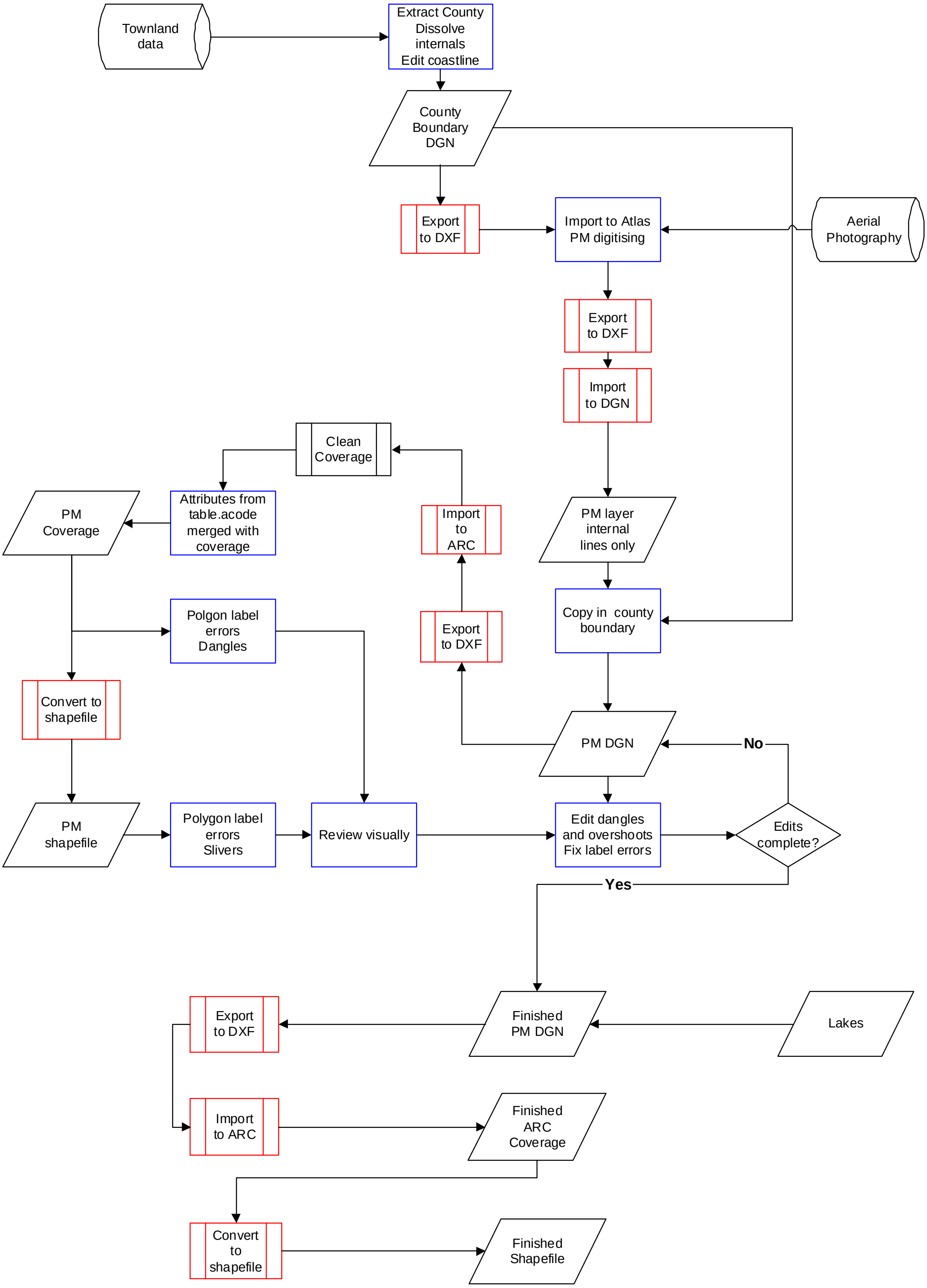


Figure 4.12 Subsoils mapping primary workflow

4.7.2 Software development

As part of the ongoing efforts throughout the project to ensure maximum efficiencies in data handling and processing a number of software tools were written and incorporated into the project workflows. These were in addition to a range of customised batch processes which were developed on an as-needs basis to enable the importation and conversion of datasets delivered to the project. These scripts were developed using the BASIC macro language in Bentley Microstation, Batch Command Files (BCF) in ERDAS and the Avenue programming language for ArcView.

A number of dedicated extensions have been written for ArcView. These include:

FIPS Admin Tools 3.2	The toolset includes a townland search tool, a DED search tool and 25" raster mapping attachment tool. Townland and DED searches can be by county or nationally. This toolset is comprised of updated coding developed for previous applications. Performance bugs have been removed and memory issues resolved.
FIPS OSI DTM Tools1.0	This tool allows point and click attachment of OSI DTM tiles. By clicking at any location on screen, the correct tile is found on the server and displayed as an ESRI GRID file. By using the native GRID format, the tile can immediately be manipulated in ArcView Spatial Analyst. As an aesthetic enhancement, a legend file, which approximates the elevation legend of OSI Discovery mapsheets, was created and is automatically applied to the loaded DTM GRID.
FIPS DXF Tools 2.0	An updated toolset to enable efficient search and display of DXF by entity type. This tool was particularly valuable when browsing whole DXF tiles from the Ordnance Survey 1:50,000 mapping, which is supplied in DXF format.
AFT_6"_Attach	This tool allows point and click attachment of AFT 6" scanned mapsheets. By clicking at any location on screen, the correct mapsheet is found on the server and displayed in the ArcView view interface.

These extensions were written in the ESRI ArcView native scripting language Avenue and compiled as extensions for use in ArcView 3.x. While many of the functions undertaken by these extensions such as point and click attachment of datasets by location are now standard, or superseded, in the latest implementations of ArcView through the use of geodatabases, the

functionality of these extensions were novel at the time of their development and led to enhanced efficiencies across various project GIS processes

The idea of developing software to enable the semi-automated construction of the soil classification maps was reviewed around 2003 based on the expectation that such software could facilitate the rapid testing and development of maps using modified rule-bases. This review led to the development of soil modelling extension for ArcView which ran the model to build Level 1 output. The output from the software extension was a cleaned ESRI grid file which was ready for conversion to ESRI Shapefile

Soil_Mod_Lev2	Software tool written to automate the processing of data for production of Level 2 mapping. The required inputs were selected, converted and combined and the predicted rule class applied. Incorporated cleaning of the resultant predicted class grids.

Software issues

Some software issues proved to be very time consuming during the project. The discovery of a labelling issue with the parent material maps caused considerable problems during the period 2000-2001. After detailed investigation, the problem was discovered to be occurring in the translation process from the ATLAS photogrammetric software to DXF format. The problem was referred to the software suppliers. To facilitate undisrupted editing, a temporary workaround was developed in Kinsealy. This involved the editing of the DXF file directly in a text editor.

A noteworthy issue that occurred during the project was the solving of an ongoing GIS issue that has affected project progress since start-up. This problem involved the introduction of small mismatches in datasets due to co-ordinate shifts when transferring from different formats. This was finally discovered to be a software bug in ERDAS Imagine 8.4, which involved the software importing double precision shapefiles as single precision. ERDAS technical support staff were notified and consulted throughout this period and this problem has finally resolved by the release of Imagine version 8.5.

5 HABITAT INDICATOR MAPPING

5.1 Introduction

The aim of the habitat indicator mapping element of the project was to indicate the likely distribution of particular habitats throughout Ireland. The map is an enhancement of the land cover map achieved through increasing the classification and spatial resolution of many of the land cover thematic classes, namely; Bog & Heath, Cut Bog, Cut & Eroding Bog, Wet Grassland and Dry Grassland. These land cover classes are indicative of habitat type in a very broad sense only in that they represent combinations of more detailed habitat classes (Loftus *et al* 2000).

The map was produced using the land cover classes in combination with other thematic maps, including: subsoil maps Digital Elevation Model (DEM) derivatives and a derived line from the Ireland Peatland Map (Hammond, 1978) demarking the limit of lowland blanket bog.

The focus of the habitat indicator mapping exercise was to exploit the known associations of land cover, subsoil, elevation and location with habitat in Ireland. The core element of the habitat indicator mapping methodology was the design and execution of an expert rule based classifier through a spatial modelling component of ERDAS Imagine.

5.2 Expert Rule Base

The developed expert rule base contains a series of conditions which dictate the mapping of particular habitat indicator classes. For example in indicating the likely presence of lowland blanket bog as a thematic class the expert rule classifier required the following conditions: "Bog & Heath" as a thematic class from the land cover thematic map; "peat" from the parent material/subsoil map; elevation less than 150ms from the DEM; and location west of a line defined in the Ireland Peatland Map to mark the eastern limit of lowland blanket bog. (Hammond 1978).

There are over 160 conditions defined to model the Habitat Indicator Map. Fourteen new habitat indicator classes are modelled from five land cover classes (See Table 5.1). While the habitat indicator model is too detailed to present in this overview, the following enhancements to land cover classes made using the constructed rule base should be noted:

Bog & Heath in peat settings are reclassified to; "Upland Blanket Bog", "Lowland Blanket Bog" and "Raised Bog / Fen". **"** In non-peat settings it was subdivided and reclassified to "Heath".
Cut Bog in peat settings was reclassified to; "Cutover Raised Bog / Fen", "Cutover Upland Blanket Bog" and "Cutover Lowland Blanket Bog".
Cut & Eroding Bog in peat settings was reclassified to; "Cutover / Eroding Lowland Blanket Bog", "Cutover Raised Bog / Fen" and "Cutover / Eroding Upland Blanket Bog".
Wet Grassland and **Dry Grassland** in peat settings were reclassified to;
"Reclaimed Raised Bog / Fen", "Reclaimed Upland Blanket bog" and "Reclaimed Lowland Blanket Bog".

Wet Grassland in alluvial and lacustrine settings were subdivided and reclassified to "Wetland".

Habitat Indicator Classes

The habitat indicator classes reflect habitat type in a broad sense and represent conflations of more detailed habitat classes (Loftus *et al* 2000). The habitat indicator classes are listed in Table 1. The corresponding codes from "A Guide To Habitats In Ireland" (Fossitt 2000) are presented in Table 5.1 under the column "CODE" and that publication should be consulted for ecological and botanical description of the classes mapped.

5.3 Classification Accuracy Enhancement.

Each class within the input Land Cover Map has an associated user accuracy and producer accuracy statement. These statements also relate to the accuracy of the classes within the habitat indicator maps[4]. The results of accuracy assessment are presented in short reports on a county basis. For each land cover class there are two types of prediction error omission error and commission error. The accuracy associated with omission errors is referred to as producer's accuracy. The accuracy associated with commission errors is known as consumer's accuracy or user accuracy. This process affords the opportunity to address some classification error, which occurred in the supervised classification of Landsat TM imagery. Some of the error associated with the land-cover thematic classes "Rocky complex"[5], "Cut Bog"[6] and "Cut & Eroding bog"[7] are corrected within the habitat indicator model using the rule base.

Spatial Modeller

The input files originate in different formats; Land-cover (ArcView GRID), Subsoil (ArcView shapefile), Hammond Line (ArcView shapefile) and DEM (ERDAS image). The processing involves ArcView and ERDAS Imagine 8.5. The model is run through Imagine's Spatial Modeller module after each input has been converted to Imagine's native .img file format. The output is converted to ArcView's native GRID file format

5.3 Results

The more detailed thematic separation of the landcover maps into habitats gives a better understanding of the distribution at a county scale of these habitats (figure 5.2)

A National Habitat Indicator map has been created, in county format (figure 5.3). Statistics on the national distribution of habitats are given in table 5.2

[4] See Accuracy Assessment accompanying each Land Cover map.

[5] "Rocky Complex" can be classified erroneously as "Cut Bog" or "Cut & Eroding Bog".

[6] "Cut Bog" can be classified erroneously as "Rocky Complex"

[7] "Cut & Eroding Bog" can be classified erroneously as "Rocky Complex"

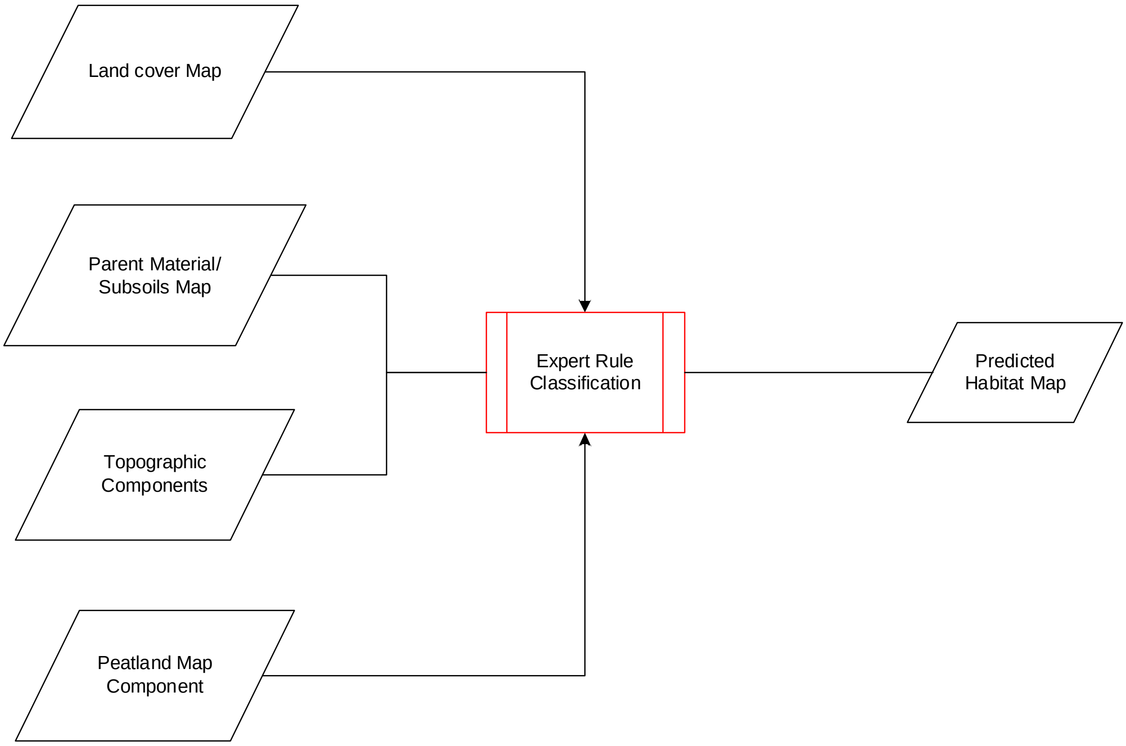


Figure 5.1 Simplified representation of habitat indicator modelling process

CODE	HABITAT INDICATOR CLASS	CODE (Fossitt 2000)
GSW	*Wet Grassland*	GA1, GA2, GS4
GAGS	*Dry Grassland*	GA1, GA2, GS1-3, BC1-4
FM	*Water*	FL1-8, CW1-2
ER	Bare Rock	ER1-4, CS1-3
CR	*Rocky Complex*	ER1-4, HH1-HH4, HD1
WNWD	*Mature Forest*	WN1-7, WD1-4
WSWL	*Forest (unclosed canopy) & Scrub*	WS1-5
BL	*Built Land*	BL3, GA2
CD	*Sand*	CD1-3
C	*Coastal Complex*	CD1-3, L
F	*Fen*	PF1-3
FC	*Cutover Fen*	PB4
FR	*Reclaimed Fen*	PB4
RBF	*Raised Bog / Fen*	PB1 PF1-3
RBFC	*Cutover Raised Bog / Fen*	PB4
RBFR	*Reclaimed Raised Bog / Fen*	PB4
UBB	*Upland Blanket Bog*	PB2
UBBC	*Cutover Upland Blanket Bog*	PB4
UBBCE	*Cutover / Eroding Upland Blanket Bog*	PB4, PB5
UBBR	*Reclaimed Upland Blanket Bog*	PB4
LBB	*Lowland Blanket Bog*	PB3
LBBC	*Cutover Lowland Blanket Bog*	PB4
LBBCE	*Cutover / Eroding Lowland Blanket Bog*	PB4, PB5
LBBR	*Reclaimed Lowland Blanket Bog*	PB4
H	*Heath*	HH1-HH4, HD1
W	*Wetland*	GS4, GM1, PF1-3, FS1-FS2
CM	*Salt Marsh*	CM1-2

Table 5.1 Thematic classes continued in the Habitat Indicator Map. Corresponding habitat classes from Fossitt (2000) are also presented.

Image Value	Class	Code	Area km^2	% Of National Land Area
2	Bog & Heath	PH	0.01	0.00%
6	Bare Peat & Soil	PBCEBC	140.33	0.20%
8	Wet Grassland	GSW	4,014.03	5.74%
9	Dry Grassland	GAGS	41,063.93	58.76%
10	Water	FM	1,358.86	1.94%
12	Bare Rock	ER	99.88	0.14%
13	Rocky Complex	CR	2,229.04	3.19%
14	Mature Forest	WNWD	2,548.95	3.65%
15	Forest (U) & Scrub	WSWL	2,123.09	3.04%
16	Built Land	BL	847.35	1.21%
17	Sand	CD	6.89	0.01%
18	Coastal Complex	C	75.91	0.11%
21	Fen	F	17.76	0.03%
22	Cutover Fen	FC	3.20	0.00%
24	Reclaimed Fen	FR	113.84	0.16%
31	Raised Bog / Fen	RBF	1,197.58	1.71%
32	Cutover Raised BOG	RBFC	785.46	1.12%
34	Reclaimed Raised	RBFR	3,326.81	4.76%
41	Upland Blanket Bog (UBB)	UBB	2,354.77	3.37%
42	Cutover UBB	UBBC	5.42	0.01%
43	Cutover / Eroding UBB	UBBCE	399.63	0.57%
44	Reclaimed UBB	UBBR	479.35	0.69%
51	Lowland Blanket Bog (LBB)	LBB	2,251.41	3.22%
53	Cutover / Eroding LBB	LBBCE	327.10	0.47%
54	Reclaimed LBB	LBBR	719.41	1.03%
61	Heath	H	2,883.22	4.13%
71	Wetland	W	377.20	0.54%
81	Salt Marsh	CM	3.80	0.01%
91	Karst Bare Rock	ERK	126.02	0.18%

Table 5.2 National Habitat Statistics derived from THIM95

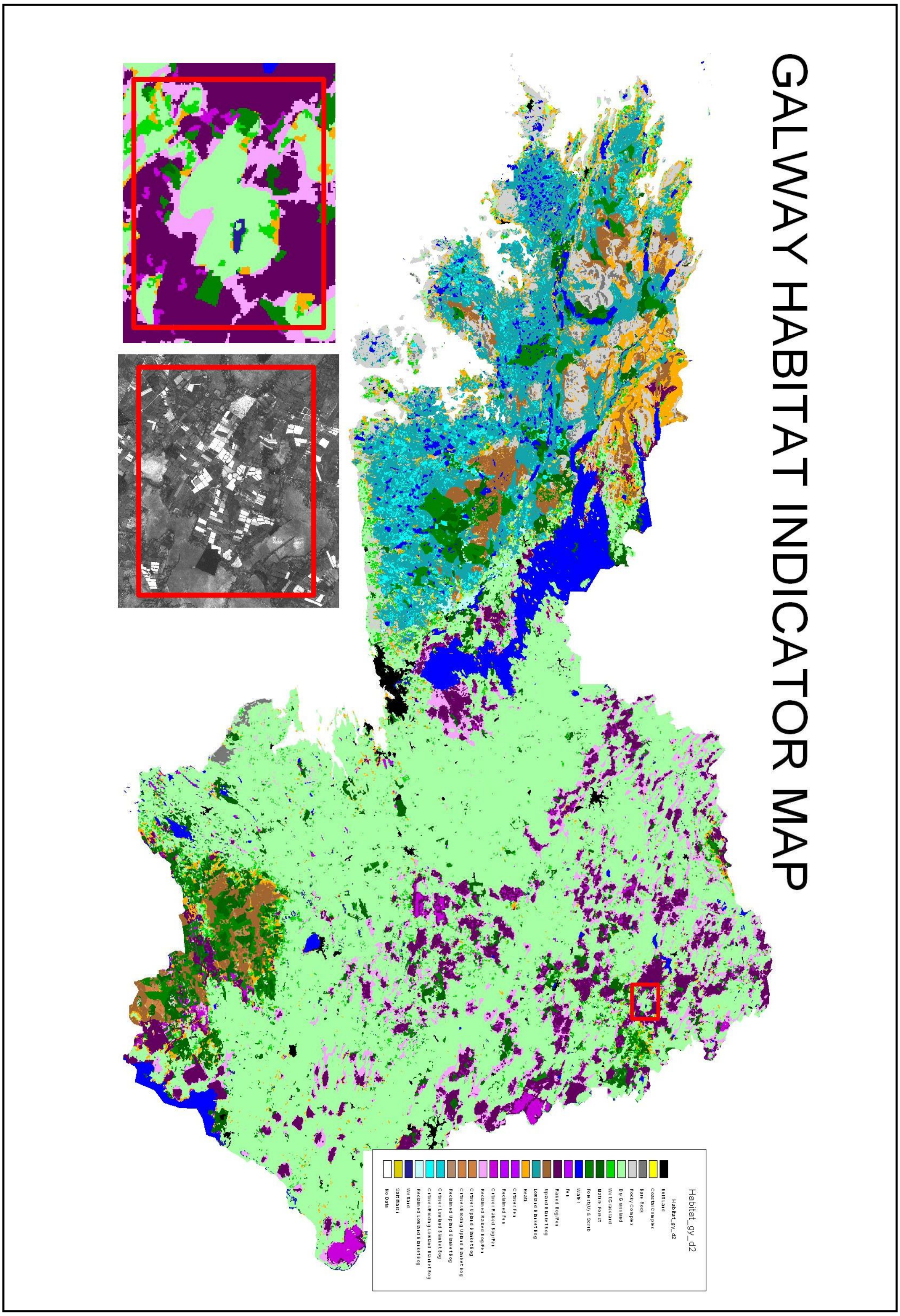


Figure 5.2: THIM95 Galway, with insets showing close up with corresponding aerial photography from 1995

Figure 5.3a Legend to National Teagasc Habitat Indicator Map for 1995 – THIM95

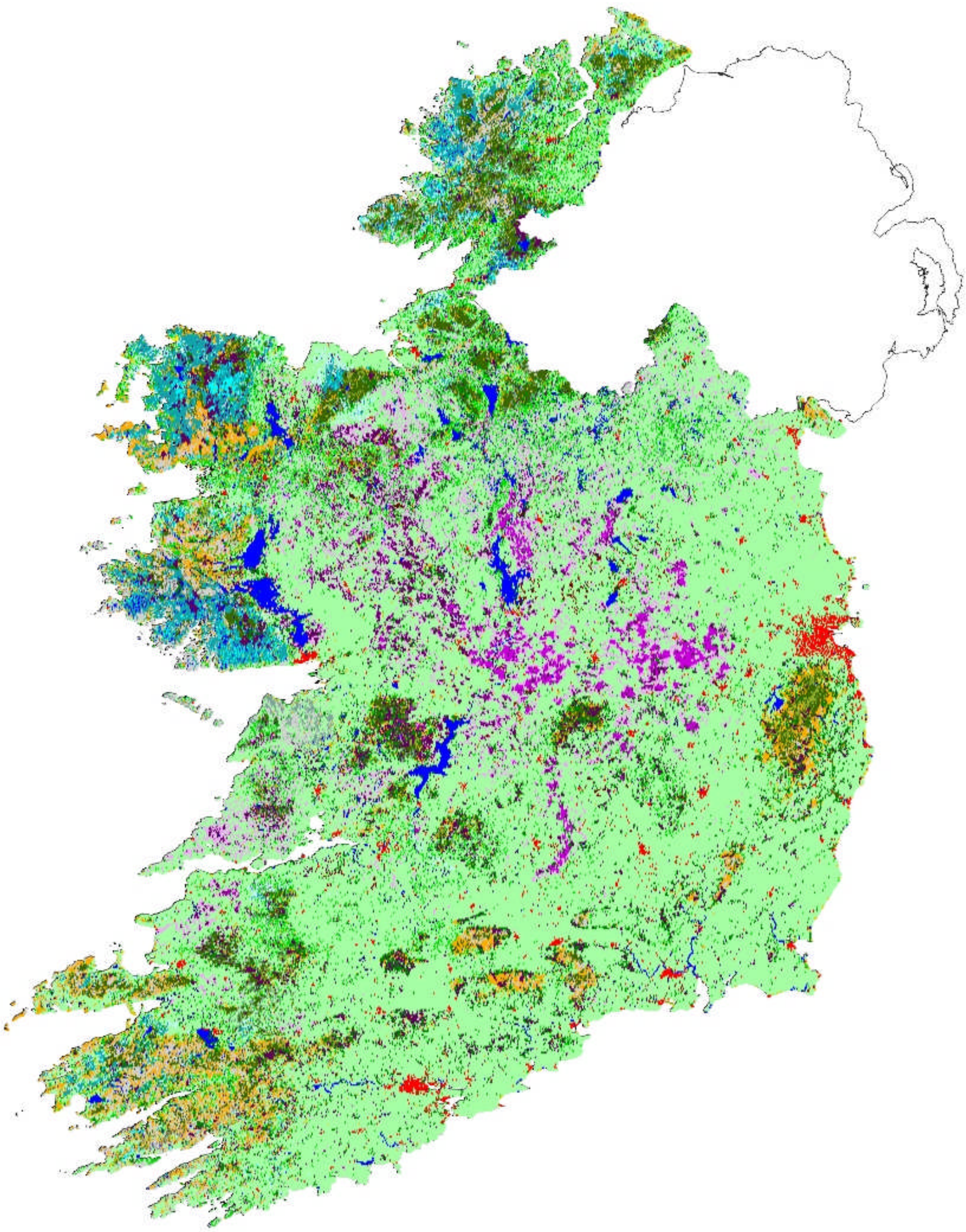


Figure 5.3b National Teagasc Habitat Indicator Map for 1995 – THIM95

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APPENDIX 1: FIELD SHEETS FOR DATA COLLECTION

This data collected in the field electronically in Trimble ProXR DGPS datalogger – field sheet created for training purposes only

FIPS - IRISH FOREST SOILS

FIELD OBSERVATION SHEET

Recorded by (Name and organisation):____________________________

Video No

Photo No.

Date:	Project Name:		Site No.		1:50,000 Sheet No:	
NGR (6 fig to site centre):		Weather (current):	Weather (last 48 hours):			

Landscape type (Topography)	Mountain and Hill		Drumlin		Hummocky Rockland			
	Upland Hill		Rolling lowland		Undulating		Flat/level plain	
	Ridged lowland		Kame/kettle		Gently Undulating			
Landscape component (Landform)	Mountain		Ridge		Esker		Interdrumlin hollow	
	Col		Valley		Kame		Floodplain	
	Corrie		Hill		Kettle hole		Lacustrine flat/basin	
	Gully		Drumlin		Rock crag		Domed peat bog	
Landscape element (Slope)	Summit slope		Backslope		Toeslope			
	Shoulder slope		Footslope					
Curvature	*Profile*	Convex		Concave		Straight		
	Plan	Convex		Concave		Straight		
Slope angle	Flat (0° slope)		3° – 8° slope		16° – 25° slope			
	1° – 2° slope		9° – 15° slope		25° + slope			
Site exposure	Very exposed		Moderately exposed		Sheltered		*Aspect:*	
	Exposed		Moderately exposed		Very sheltered			
Ground conditions	Ponded water		Soft		Hard			
	Wet		Firm		Dessication cracks			
Drainage density	High (>80m / ha)		Medium (20m – 80m / ha)		Low (<20m / ha)		Drainage absent	

Bedrock type if known): __________________ *Depth to (from well record etc.):* __________________

Soil parent material (subsoil)	Diamict (boulder clay)		Sand		Alluvium		Bedrock			
	Gravels		Silt/Clay		Peat		Other			

Characteristics of parent material (if exposed)

t No.	Depth/Thickness (m bgl)	Density/ Compactness	Colour	Type (*e.g.* diamict, sand)	Dominant petrography	Additional details (*e.g.* pans, sorting, discontinuities *etc.*)

	Mineral, deep, well drained		***Mineral, shallow, well drained***		***Mineral, poorly drained***		***Peaty/Mineral***		***Peat***

Soil type				
Grey Brown Podzolic	Regosol	Gley	Peaty Podzol	Basin Peat
Acid Brown Earth	Lithosol		Peaty Gley	Basin Peat Cut
Brown Earth Hi-Base	Rendzina			Climatic Peat
Brown Podzolic				Climatic Peat Cut
Podzol				

Soil drainage status	*Well drained*	*Poorly drained*	*Soil surface stoniness*		Few	1-5
	Excessively drained	Imperfectly drained			Many	6-15
	Well drained	Poorly drained		None	Plentiful	16-40
	Moderately well drained	Very poorly drained			Abundant	41+

Soil texture	***Sandy soils (light)***	***Loamy soils (med.)***	***Loamy soils (med.)***	***Clayey soils (heavy)***	***Organic loam***
	Sand	Loam	Clay loam	Sandy clay	
	Loamy sand	Silt loam	Silt clay loam	Silty clay	
	Sandy loam	Silt	Sandy clay loam	Clay	

Land cover – Level 1					
	Salt marsh	Marsh	Native woodland	Built land	Fen
	Sand dunes	Heath	Other woodland	Rock complex	Flush
	Lakes and ponds	Fern	Scrub	Heath complex	Disturbed ground
	Swamps	Bog	Exposed rock	Wetland complex	Cultivated land
	Improved grassland			Semi imp grassland	

Land cover – Level 2				
	Coastal	***Freshwater***	***Grassland***	***Heath and Fern***
	Salt marsh	Turlough	Improved grassland	Dry heath
	Foredune	Reedbed	Improved grassland - peat	Wet heath
	Fixed dune	***Miscellaneous***	Lowland dry grassland	Montane heath
	Dune heath and scrub	Expos. bedrock	Upland dry grassland	Dense bracken
	Dune slack (Machair)	Scree/loose rck	Lowland wet grassland	***Woodland/scrub***
	Bog, fen and flush	Bare ground	Upland wet grassland	Oak birch holly
	Lowland blanket bog	Spoil	Coarse grassland	Oak ash hazel
	Upland blanket bog	Recol. Ground	Marsh	Yew woodland
	Raised bog	Refuse	***Complex***	Bog woodland
	Transition bog	Active quarries	Comp. Grassland/Rock	Mx broadleaf
	Cutover bog	Rec. reclaimed	Comp. Grass/dry heath/rck	Mx broad conif
	Bare peat	Arable crops	Comp Grass/wet heath/rck	Mx conifer
	Fen	Horticulture	Comp. Wet heath/rck	Conifer wood
	Flush and spring	Ploughed fields	Comp. Wet/dry heath	Native scrub
		Built land	Comp. wetland	Ornam. scrub

Grazing/ Silage	Cattle	Sheep	Cattle and sheep	Silage	Horses	Other
Cultivation	Cereals	Roots	Potatoes	Vegetables	Setaside	Other

Sward height ______ *% Poaching* ________ *%* ________ *% Scrub* __ *Scrub* Gorse

	______		________ *Bare* ________		__		
				4.7.1.1	*Species*	Blackthorn	
% Rush	_____	*% Fern*	_____	*% Dock*	___	*% Thistle*	_______	Hawthorn	
						Juniper	
Bog erosion	_____	*Bog erosion*	_____	*Bog*	____	*% cutaway*	__	Brambles	
% anastom.		*% parallel*		*% Hand cut*		*abandoned*		Willow	
						Birch	
Bog, % machine cut profile	____________	*Bog, % machine cut plan*	____________			Hazel	
						Bog myrtle	
Recent burning	Bog		Heath		Scrub	Broom	

Forest property:	______________	*Rotation:*	______________	*Age (Estimated):*	

				Species		
Conifer *species*	**Conifer present**		Douglas Fir	Larch	Lodgepole pine	
			Sitka spruce	Norway Spruce	Other Conifers (*species* __________)	
Broadleaf species:	Broadleaf **present**		Beech	Oak	Spanish Chestnut	
				Ash	Other broadleaf (*species* ____________)	

Mixtures:	Conifer/Conifer		Broadleaf/Broadleaf		Broadleaf/Conifer		
Planting method:	Mound		Plough		Ripper		Pit		Not apparent
Thinned/Felled:	Thinned		Unthinned		Felled		Replanted	
Failure:	Severe		Moderate		None		*Windthrow:* Severe		Moderate	
Potential YC Sitka:	Very poor, 0-10		Poor, 12-14		Moderate, 16-18		Good, 20-22		Very good, 24+	
Conifer Suitability:	Ss/Lp		Diverse (non Ss/Lp. Dry)		Diverse (non Ss/Lp.) moist	
Broadleaf	Birch/Alder		Ash/Sycamore		Oak		Beech	

APPENDIX 2: EXAMPLE ACCURACY STATEMENT

Included below is an example of a county accuracy statement for the landcover mapping. Each county has a similar statement included in its accompanying documentation.

County Westmeath Teagasc Landcover 1995 Map Accuracy Statement

Background

The land cover maps were originally generated as a component of the Irish Forest Soils (IFS) project, itself an element of the Forest Inventory and Planning System (FIPS) (Bulfin 1998; Department of Agriculture, Food and Forestry 1996). The work continued as the Soils and Subsoils Mapping project under the Water Framework Directive (2000/60/EC) which came into force on its publication in the Official Journal of the European Communities on 22 December 2000.

The maps were generated using supervised, unsupervised and indices classification of Landsat TM imagery. The supervised classification was performed in ERDAS using training data collected from a soft copy photogrammetric station. The training data classes were strongly aligned, making allowances for the limitations of remote sensing and the requirements of the IFS project, to a national habitat classification standard (Fossitt 2000). The thematic maps contain land cover thematic classes, which represent an amalgam of the training data classes. In this sense the thematic land cover classes represent broad groupings of habitat types which could act as potential indicators of more specific habitat types. These maps could therefore be viewed as a contribution to existing data on habitats and / or land cover in Ireland (Heritage Council 1999, O' Sullivan 1994, Wildlife Service 1989).

Introduction to Westmeath Thematic Map

This accuracy assessment is based on the files wh_lc_ccfs3a1.img / lc_wh_d1.grd. The thematic map for Westmeath illustrates the distribution of ten thematic classes; pbc, gags, gsw, p, pbce, fm, cr, wnwd, wswl & bl (Table1; Figure 1).

The land cover types occupy 183,956 hectares / 454,555 acres (Table 1). The minimum mapping unit is 1ha and smaller areas are dissolved into the background thematic class. The dominant land cover classes are; pbc, gags & gsw. Combined they occupy 89.1% of the thematic classes in Westmeath. This accuracy assessment concentrates on these classes.

Accuracy Assessment

Accuracy assessment is critical before accepting image classification results. The error matrix is typically the foundation of accuracy assessment because it compares predicted with true cover types, (Verbyla, L. and Chang, K.T. 1997). Reference data is required as “truth” for comparison with predictions in the error matrix. Ideally reference data are derived from many randomly

selected samples independent from training areas. With random sampling you select image pixels in the field to determine their actual cover type, however there are several considerations with this approach:

Thematic Class	Code	Hectares	Acres	% Cover
3 Bog	P	4,415	10,909	2.4
4 Cut Bog	Pbc	5,561	13,741	3.0
5 Cut&Eroding Bog	Pbce	149	367	0.1
8 Wet Grassland	Gsw	9,463	23,383	5.1
9 Dry Grassland	Gags	148,756	367,576	81.0
10 Water	Fm	7,484	18,493	4.1
13 Rocky Complex	Cr	90	223	0.0
14 Mature Forest	Wnwd	4,312	10,654	2.3
15 Forest (U) & Scrub	Wswl	1,863	4,602	1.0
16 Built Land	Bl	1,864	4,606	1.0
Total		183,957	454,554	100.0

Table 1: Area of thematic classes in the Westmeath Land Cover Thematic Map.

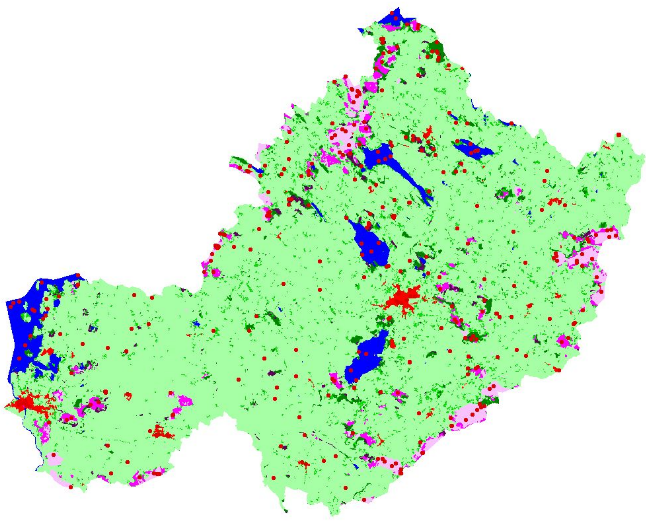

Figure 1: Land Cover in County Westmeath from a classification of LANDSAT TM imagery and distribution of randomly selected sites selected for collection of accuracy assessment data from orthophotography.

Accuracy assessment data

Sample Size

Accuracy assessment data is derived from interpretation of land cover at randomly selected sites using orthophotography. Congalton (1991) suggests that a good rule of thumb for sample size "seems to be collecting a minimum of 50 samples for each vegetation or land use category in the error matrix". He goes on to say "if the area is sufficiently large (i.e., more than a million acres) or the classification has a large number of vegetation or land use categories, (i.e., more than 12 categories), the minimum number of samples should be increased to 75 or 100 samples per category". The USGS (1999) Vegetation program in Chapter 4.0 of their document Accuracy Assessment Procedures recommended that some weighting factor be applied that allocates a larger number of samples to the abundant classes. They advocate approaches that may be taken toward the weighting of sample size as follows:

1. Sample size can be made proportional to the abundance and frequency of the class. With this approach, the rarest classes would probably never be sampled. This is unacceptable, since it is desirable to be able to associate at least a point accuracy estimate with each class.
2. Maximum and minimum sample sizes can be established, taking into account statistical as well as cost constraints and probable class abundance and frequency.

If the second approach is taken, it is recommended that 30 samples be specified as the maximum sample size for abundant classes, and that 5 samples be specified as the sample size for the rarest classes.

The sampling approach taken here satisfies the criteria outlined above. Given that terrestrial thematic classes in Westmeath comprises 183,956 hectares/ 454,555 acres with ten land cover classes the minimum number of samples sought for the dominant thematic classes is 50. The number of samples sought for the classes of smaller areal extent is 30. However, so as not to dominate the error matrix in relation to producer accuracy, the smaller thematic classes are down-weighted to 5.

Temporal Issues

The aerial photographs from which the orthophotographs were created and the satellite imagery from which the thematic maps were generated are, in the main, contemporary (1995). The temporal acquisition of the two data sets differs by months rather than years. In some cases more recent satellite scenes were ordered to supplement existing scenes.

Ancillary Data

Ancillary data has been incorporated into the thematic map to improve thematic accuracy and to make optimum use of land cover work completed by others. "Mature Forest" incorporates the following classes in the FIPS dataset (2,4,6,8,10,12,14,16,18,19). "Forest (U) and Scrub" includes the following classes in the FIPS dataset (1,3,5,7,9,11,13,15,17) as well as areas classified as Scrub during the satellite image classification process. (See FIPS Notes).

Urban areas from the FIPS/IFS parent materials map for Westmeath where available have been incorporated into the thematic map as “Built Land”. In those Counties where parent materials have not been mapped, urban areas from the OS 1:50,000, vector dataset, which was supplied to the project by the FS, are incorporated.

User accuracy for “Mature Forest”, “Forest (U) and Scrub” and “Built Land” is not assessed during this accuracy assessment. These classes do however occur in describing user error in the other thematic classes.

Spatial Considerations

The sampling strategy for assessment data is outlined below. 50 points were randomly selected for each of the ten main land cover classes. The number of samples randomly selected for the classes of small areal extent is 30. Any points, which fell on the border between land cover classes, were labeled “border”. Other points where orthophotographs were not available to the interpreter were labeled as “no data”. Data classified as “border” or “no data” have been removed from the analysis.

In the Irish Countryside, habitats intergrade continuously, over short distances, these habitats include bog, heath, low wet grassland, upland wet grassland and scrub, e.g. wet and dry grasslands intergrade continuously over short distances in the field. Furthermore images are rectified with some RMS error, map coordinates for each pixel are an estimate with unknown positional error. The Landsat image(s) for Westmeath, from which the thematic map has been generated, have a Root Mean Square Error of about 20ms but may be out by about 40ms at the periphery of the image(s). The positional accuracy of the training data derived from soft copy photogrammetry is in the order of 10m Root Mean Square.

Allowances, outlined below, are made for the possible effect of the positional error of the thematic maps and the training data and the effect of inter-grading habitats in the field, in assessing the accuracy of the thematic maps.

Therefore randomly selected points which lie within a clump with a majority theme are used in the assessment. In practice the point coverage for assessment data is converted to polygon coverage with each point represented by a 100m by 100m polygon, centered on the point.

In keeping with the above considerations a dataset of 360 points has been created. The assessment classes are equivalent to the supervised classification thematic classes. These are then used to perform the accuracy assessment. The accuracy assessment matrices are presented in table 2.

Classification.

The classification used with the orthophotographs in collecting accuracy assessment data reflects the thematic class names. The classes are;

GRASSLAND & ARABLE		
gags	101	Dry grassland, recently harvested arable or horticultural.
gsw	102	Wet grassland.
BOG & HEATH		
p	200	Intact smooth surfaced bog.
ph	201	Bog & heath including revegetated turbary and eroding peat.
pbc	202	Large areas of bare peat which have been machine cut.
pbce	203	Areas of bare turbary and eroding peat
pbcebc	204	As 203 but includes bare soil in till areas.
ROCK AND ROCK COMPLEXES		
cr	601	Where rock is a substantive but not dominant component.
er	600	Where rock is a dominant component.
WOODLAND AND SCRUB		
wswl	701	Scrub and young unclosed plantations.
wnwd	700	Mature forest.
COASTAL		
cd	800	Sand.
c	801	Coastal Complex.
MISCELLANEOUS		
bl	909	Built land
cs	997	Cloud Shadow
fm	910	Water
no data	999	No orthophotographs available for sample.
border		border between types

Application of Rules to Westmeath Training Data Set.

In all 360 accuracy assessment records were collected using the orthophotography. The number of records for smaller thematic classes was down-weighted to 5 and 0 records classified as “no data” (where no orthophotographs existed) were removed from the analysis. Therefore 185 records were finally used in the accuracy assessment. The name of the file containing the accuracy assessment data is lc_wh_d1_aa.shp.

Accuracy Assessment and the error matrix were produced using the orthophotography derived dataset on ten thematic classes. An error matrix for the thematic classes can be produced based on accuracy assessment data (Table 2).

Thematic Class / Orthohotography Class	Pbc	Gsw	Gags	P	Pbce	Fm	cr	wnwd	wswl	bl	Total
Bl										28	28
Cr							19				19
Fm		1				30					31
Gags		2	43	1	1		11			2	60
Gsw		36	7	1	2						46
P		1		16							17
Pbc	46										46
Pbce	4	2		12	27						45
Wnwd		2						27			29
Wswl		6						3	30		39
Total	50	50	50	30	30	30	30	30	30	30	360

Table 2: Error matrix for thematic classes in County Westmeath.

Thematic Class / Orthohotography Class	Pbc	Gsw	Gags	P	Pbce	Fm	cr	wnwd	wswl	bl	Total	Omission Error	Producer Accuracy %
Bl				0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.7	0.0	100
Cr				0.0	0.0	0.0	3.2	0.0	0.0	0.0	3.2	0.0	100
Fm		1		0.0	0.0	5.0	0.0	0.0	0.0	0.0	6.0	1.0	83
Gags		2	43	0.2	0.2	0.0	1.8	0.0	0.0	0.3	47.5	4.5	91
Gsw		36	7	0.2	0.3	0.0	0.0	0.0	0.0	0.0	43.5	7.5	83
P		1		2.6	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.0	72
Pbc	46			0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.0	0.0	100
Pbce	4	2		2.0	4.5	0.0	0.0	0.0	0.0	0.0	12.5	8.0	36
Wnwd		2		0.0	0.0	0.0	0.0	4.5	0.0	0.0	6.5	2.0	69
Wswl		6		0.0	0.0	0.0	0.0	0.5	5.0	0.0	11.5	6.5	43
Total	50	50	50	5.0	5.0	5.0	5.0	5.0	5.0	5.0	185.0		
Commission Error	4	14	7	2.4	0.5	0.0	1.8	0.5	0.0	0.3		30.5	
User Accuracy %	92	72	86	52	90	100	64	90	100	94			
Overall Accuracy %													83

Table 3: Error matrix for thematic classes in County Westmeath, with rarer classes weighed to 5 samples. * Unclassified removed.

The diagonal cells of the error matrix represent the correct predictions. Normally the overall accuracy of a classification is expressed as the proportion of correct predictions times 100. In table 3 the total correct predictions is 154.5. Thus the overall classification accuracy is estimated as (154.5/ 185) * 100 or 83%.

For each cover type there are two types of prediction error.

<u>Omission error</u> occurs when a predicted pixel class does not agree with the true class.

The accuracy associated with omission errors is referred to as producer's accuracy. Respectively the omission errors associated with the dominant land cover classes; pbc, gags & gsw determine that the producer accuracy for each class is; 100%, 91% & 83% .

Respectively the omission errors associated with the less dominant land cover classes; p, pbce, fm, cr, wnwd, wswl & bl determine that the producer accuracy for each class is; 72%, 36%, 83%, 100%, 69%, 43% & 100%.

<u>Commission error</u> occurs when the number of predicted pixels exceeds the true class number.

The accuracy associated with commission errors is known as consumer's accuracy. Respectively the commission errors associated with the dominant classes; pbc, gags & gsw determine that the attendant user accuracy for each class is 92%, 72% & 86%.

Respectively the commission error associated with the less dominant land cover classes; p, pbce, fm, cr, wnwd, wswl & bl determine that the user accuracy for each class is;52%, 90%, 100%, 64%, 90%, 100% & 94%.

DISCUSSION

It is clear that pbc, gags & gsw are the important land cover classes in the thematic map which combined comprise 89.1% of the areal extent of thematic classes in Westmeath. In thematic maps it is important to describe the user accuracy *i.e.* how much of the resource specified on the map is actually present on the ground. The user accuracy for the dominant land cover classes pbc, gags & gsw is relatively high; 92%, 72% & 86% The associations between land cover type mapped and certain soil classes adopted in the project indicative soil classification has been established through literature review and field work. For example Bog & Heath as a thematic land cover class is typically associated with organic and peat over mineral soils, dry grassland with well drained soils (shallow and deep) and wet grassland with poorly drained soils. It might be assumed therefore that these classes are appropriate and relevant to modelling indicative soil types.

However it is also important to review producer accuracy which describes how much of the resource on the ground is actually captured on the map. The producer accuracy for the dominant land cover classes; pbc, gags & gsw is relatively high; 100%, 91% & 83%

CONCLUSION:

pbc, gags & gsw are the important thematic classes from a soil modelling perspective, in that they are indicative of soil type. These thematic classes are the dominant land cover classes in the thematic map of Westmeath. The user accuracy for these land cover classes is relatively high. The producer accuracy for these land cover classes is also relatively high.

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