Chapter 4 Terrestrial Data

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4.1 Introduction

The purpose of this chapter is to record the sources of data (with examples based on Irish resources) that can help a researcher's work. Its major beneficiaries are expected to be those who assemble Geographical Information Systems and those involved in the modelling process. A selection of topics has been chosen to show the range of information that is available and where shortcomings exist. Map data acquisition and storage, modern developments in spatial representation and the use of such data in land resource appraisal are introduced. Groundwater, surface water, marine resources, soil and vegetation resources are assessed. The discussion of land information and appraisal shows how data from a wide variety of sources, collected by personnel from disparate institutions and for widely differing purposes, can be assembled, reprocessed and interpreted for a range of uses – uses, perhaps, that the original surveyors never even dreamed of!

4.2 Map data and spatial representation

(M. Walsh)

4.2.1 Introduction

The earliest cartographers first established terrestrial databases in the form of maps which enabled mankind to extend the frontiers of human habitation and to further develop areas which were already known. During the nineteenth century and particularly in the twentieth century, large amounts of data in relation to terrestrial features, climate and the oceans accumulated. The interpretation of data, especially for areas which are distant from the points of collection, presents a challenge to modern scientists. This challenge has been met by the construction of various types of databases, models and expert systems.

4.2.2 Topographic Map Data

Maps are one of the primary methods for conveying the results of field studies. Scale and legibility determine the detail at which data and spatial information are presented. The myriad applications of maps is well demonstrated in modern atlases, e.g. Royal Irish Academy's *Atlas of Ireland* (RIA, 1979). The more recent *Agroclimatic Atlas of Ireland* (Collins & Cummins, 1996) presents a selection of over 100 maps showing a wealth of Irish data relevant to agriculture and the environment. Maps containing information on topography and administrative units generally form the base for interpretation and presentation of resource data.

The Ordnance Survey (OSI, 1998) is the principal producer of topographic maps for Ireland, the most popular scales being 1:2,500, 1:10,560, 1:50,000 and 1:126,720. They are available in hard copy and in a wide variety of electronic formats. The most detailed map scale with country-wide coverage is the six-inch (1:10,560) which is now being reproduced at a scale of 1:10,000. A wealth of information is contained in these sheets in the form of lines, symbols and text. Boundaries of counties, baronies, parishes and townlands have specific line representations and appropriate combinations of these where boundaries coincide. Roads, railways, rivers and streams and associated features as well as a variety of others such as quarries, gravel pits, antiquities, wells, pumps, trigonometrical stations and contours all have specific lines, symbols or combinations of both. Symbols for vegetative cover differentiate between coniferous, broad-leaved and mixed forestry, orchard, brushwood, rough pasture, osieries, reeds and marsh. Text often accompanies these symbols, indicating the names of the administrative units and the nature of a range of public buildings. The six-inch series is intensively used in a wide range of activities involving agriculture, engineering, forestry, environment and geography.

The "25-inch" series (1:2,500 scale) covers most of the intensively-farmed areas and omits the sparsely-inhabited areas of the country. It contains most of the same information as the 6-inch series but in greater detail. The area of each field, in acres, correct to the third decimal place is shown, but contour lines are omitted. The series is regularly used by farmers, local authorities, government officials and by most agencies and institutions that deal with land and property.

Both the 6-inch and the 25-inch maps are based on the Cassini Projection which is a version (conformal) of the Transverse Macerator Projection. A separate projection, i.e. standard latitude and longitude, is used for each county in order to limit scale errors. Within this scale range are the Area Aid maps (scales from 1:2,500 to 1:10,000, depending on size of holding) which show land parcels, currently the smallest administrative unit, complete with area (hectare), townland name, and alpha-numeric code. These are very useful aids for planning nutrient management, crop rotations, recording land use history, yields and similar types of information.

A new series of 89 topographic maps (Discovery Series (Republic)/Discoverer Series (Northern Ireland)) covering the whole island at a scale of 1:50,000 (2 cm to 1 km) has been completed which replaces the earlier half-inch coverage. An index to the sheets in the series is printed on the cover of each map. The earlier sheets were compiled from

1970s aerial photography (1:30,000 nominal scale) and later sheets from 1995 aerial photography (1:40,000 nominal scale). The map legend includes a range of features under the general headings: tourist information, roads, water, railways, antiquities, relief, boundaries and general features. Contours are inserted at 10 metre intervals and colour-layered at 100 metre intervals. The original Gaelic version is included for some of the place names. The National Grid at 1 x 1 km intervals is super-imposed in blue lining on all sheets. In addition, areas of particular interest are being published at a scale of 1:25,000, based on the same aerial photography. Lists of maps and related publications are available from both the Ordnance Survey of Ireland (OSI, 1998) and the Ordnance Survey of Northern Ireland (OSNI, 1994).

The island of Ireland is usually depicted on a single sheet at scales ranging from 1:500,000 to 1:750,000. General soil, land-cover and peatland maps are at 1:575,000; the 1997 edition of the O.S. Road Map is scaled to 1:600,000; administrative areas, index maps to 6-inch sheets and aerial photographs as well as the catchment basin map are depicted at "ten statute miles to 1 inch" (1:633,600) while the popular geological map was published at the slightly smaller scale of 1:750,000. The scales used in textbook-sized atlases (e.g. Aalen *et al.* 1997, Collins & Cummins 1996, Horner *et al.* 1984, Lafferty *et al.* 1999) range from c. 1:2,000,000 to 1:20,000,000.

4.2.3 Geo-referencing data and satellite positioning systems

In recent decades the establishment of accurate location, whether according to latitude, longitude or national grid co-ordinates is being overtaken by a combination of modern communication technology, photogrammetry, and both geostationary and orbiting satellites. There are currently two active positioning systems (the U.S.-administered Global Positioning System (GPS) and the Russian Federation Global Navigation System (GLONASS)), each with a world-wide coverage but separate constellations of satellites. A third system, EUSAT, is being developed by EU member states. Based on signals received at ground level from a number of these satellites the position of any point on the earth's surface can be established. The accuracy depends on the sophistication of the receiver, time of exposure, and number of satellites within range. The accuracy range for civilian uses is c. 10 m. Use of differential correction (DGPS) can improve this value to <1 m. Post-processed survey grade, carrier-phase receivers can achieve a static and dynamic accuracy measured in millimetres.

The software incorporated in GPS receivers is programmed so that the readout refers to the local National Grid system and hence longitude as the Easting, or x co-ordinate, latitude as the Northing, or y co-ordinate, and altitude as the z co-ordinate of the local system. The Irish national reference point is an OSI station at Malin Head (OSI, 1996). An example of GPS data for positioning is given in Table 4.1. It shows Easting, Northing and altitude co-ordinates for selected observation points on the Teagasc Hill Sheep Farm, near Leenaun Co. Mayo (Egan *et al.*, 1996). A control point (concealed concrete marker slab) which acts as a "base station" was established on the farm by DGPS, using the known co-ordinates of a nearby trigonometrical station.

A simple practical use of GPS is to locate a point in a landscape devoid of map reference features such as buildings, fences, rock outcrops or even large trees. Examples of such landscapes include large tracts of moorland, blanket or raised bog, and lakes. Large uniform fields (20 ha upwards) may be included. This technology has made the accurate mapping of natural resources possible. Problems posed by forest and urban areas as well as by electromagnetic interference are being researched. GPS is the standard georeferencing device in aircraft used for data capture and is being installed in equipment used in precision agriculture. Good quality GPS equipment can be purchased or hired from a number of specialist firms dealing with surveying. Data on GPS reference points, trigonometrical stations, and related services can be obtained from the Ordnance Survey Office.

Table 4.1: Some georeferenced data for the environmental monitoring site, Teagasc Hill Sheep Farm, Leenaun, Co. Mayo

Site Identification	Easting (m)	Northing (m)	Altitude (m)
Control	092,538.014	266,090.287	39.103
Peg L15	091,886.255	266,034.318	32.103
Peg F21	092,190.183	266,730.985	126.327
Peg H31	093,166.473	267,028.157	70.130
Peg C10	091,077.944	266,530.427	259.507

4.2.4 Aerial Photogrammetry

Modern map making is based on aerial photographs. Photographic film is exposed in a camera fixed to the underside of specially equipped planes and flown at a selected altitude under cloud-free conditions. Modern aircraft can carry a variety of sensors including conventional aerial cameras, small (35mm) cameras, video recorders, digital sensors, thermal cameras and radar sensors. Spatial resolution can range from a few centimetres to several metres.

Panchromatic aerial photography giving cloud-free stereoscopic coverage was obtained for the whole of Ireland in 1974-1977 at a nominal scale of 1:30,000 and in 1995 at a scale of 1:40,000. Most of the west coast of Ireland has similar coverage dating from the late 1940s to the early 1950s. More limited coverage, mainly for planning and environmental activities, has been completed for a number of areas. Ground truthing is essential to interpretation in all cases, and accurate positioning is recommended for geo-referenced ground control. A scanning and rectification procedure using computer hardware and software is now used to correct photographic distortion. (Developments in digital camera technology are replacing the need for scanning). The end-product, which is known as an orthophoto (or orthophotomap), is a medium suitable for many purposes such as plotting, mapping and measuring.

The 1995 aerial photography, at 1:40,000, has been used to compile the Area Aid maps which show individual land parcels. With adequate ground control, it can provide measurements of individual objects (buildings, trees, channels) to sub-metre accuracy. Photographic products also have specialised applications e.g. engineering, road planning, and monitoring land use changes. Photo-products can be purchased from commercial companies and from institutions such as GSI and OSI. A number of companies provide flying services, production of diapositives and prints, and facilities for scanning.

4.2.5 Surface Modelling

The data captured by aerial photography (and some satellite imagery) can be stored and processed by computer technology which manipulates and processes data describing the earth's surface. When an "actual" land (or sea-bed) surface is so created the product is referred to as Digital Elevation Model (DEM) or Digital Terrain Model (DTM). The data components used for modelling such surfaces are generally either: (1) *Grid Structure/Altitude Matrix*: the height of the surface is estimated on a regular grid basis over the area concerned; (2) *Contour Slice*: height data are provided by contour interval, e.g., 50m 100m. The product is essentially a thematic map which may be either in vector or raster format; (3) *Triangular Irregular Network (TIN)*: height data are chosen at random but increase in density with increase in complexity of the topography. They are then linked to form triangular facets. The TIN is generally a vector-based representation of a surface; or (4) *Digital Elevation Models (DEMs)*: help to highlight anomalous values and spurious patterns. They have been very useful in the study of hydrology, soil, topography, climate, interpretation of stereo models, interpretation of satellite imagery and visual-effect-simulated perspective views.

This technology improves the presentation of map data. The data can be enhanced in appearance by presenting them as a "shaded relief map" or a "simulated perspective view" (Figure 4.1). Different perspectives can be had by rotating the image so that the viewer can see it form any chosen point. Contour (10 m) and DTM (10 m grid) information, derived either from the 1974-1977 or from 1995 photography, is available in 20 x 20 km tiles, under a lease-purchase arrangement from the OSI.

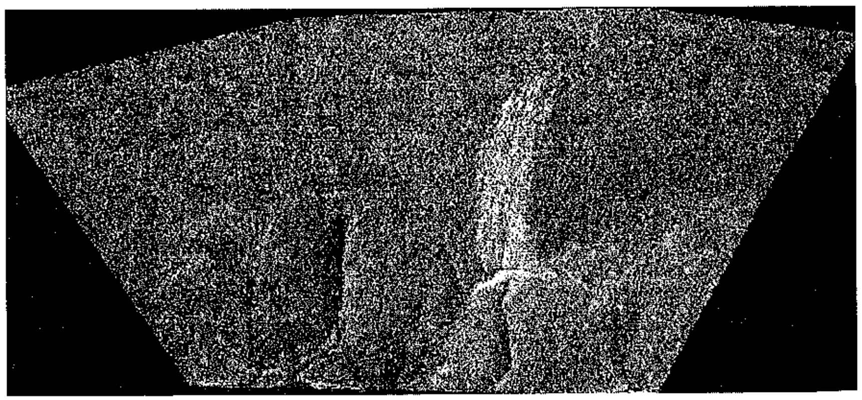

Figure 4.1: Draped perspective image of a portion of Derreens Hill, Co. Mayo

Maps are representations of reality, reduced in size. A well-made map is the product of a sophisticated range of procedures which may include recording, calculating, analysing, displaying, organising, and presenting, on paper or screen, the spatial relationships between things. Since maps are a system of communication in the same way as written and spoken languages, they demand that users are acquainted with graphicacy and the science of cartography. In the sections that follow there are many examples where familiarity with maps, their contents, usefulness and hidden limitations will become apparent to the reader. This understanding is necessary for reliable application of GIS technology (see Chapter 2).

4.3 Ground Water Resources

(G.R. Wright)

4.3.1 Introduction

Groundwater is generally taken to encompass all water below the water table. It is sometimes also taken to include water within the capillary fringe above the water table. Groundwater is stored within, and moves through, the spaces of granular deposits, and the fissures (fractures, joints) of rocks.

Groundwater contributes 20-25% of drinking water in Ireland, compared with about 33% in England and Wales, 3% in Scotland, and 7% in Northern Ireland. The percentage contribution in some European mainland countries is much higher; in Austria it reaches 99%. Although our major cities are supplied almost exclusively from surface water sources, many towns, villages and factories, and innumerable private homes and farms, depend on groundwater.

Fissure-flow aquifers predominate in Ireland. Aquifers with intergranular flow are restricted to scattered Quaternary sand and gravel deposits, which are locally important but rarely extensive enough to be major aquifers. The main fissure-flow aquifers are: (1) *Carboniferous limestones*, which are very widespread but form major aquifers only where they are sufficiently clean and fissured or dolomitised. In some regions, notably the north-west, west and south, the limestones are extensively karstified; (2) *Devonian, Carboniferous and Permo-Triassic sandstones*, some of which also have some degree of intergranular flow; (3) *Cainozoic fractured basalts* in north-east Ireland; (4) *Cretaceous chalk* in north-east Ireland; and (5) *Ordovician volcanic rocks*, strongly fractured, which form a narrow NE-SW-trending belt in south-eastern Ireland (mainly counties Wexford and Waterford).

Irish aquifers are predominantly shallow, so few wells are deeper than 120 metres, and the water table is generally high, thanks to abundant rainfall. Most aquifers are unconfined, although local confinement by glacial till is fairly common. These factors mean that many aquifers are highly or extremely vulnerable to pollution.

4.3.2 Data Sources

Tabular Data

The Geological Survey of Ireland (GSI) is the main repository of groundwater data in Ireland, but the Environmental Protection Agency (EPA) also collects water level and water quality data. The Geological Survey of Northern Ireland (GSNI) performs an equivalent function in its region. The GSI's groundwater data have accumulated over a period of about thirty years, and for the most part are contained in four principal databanks: (1) wells and pumping tests; (2) chemical analyses of groundwater samples; (3) groundwater level monitoring; and (4) karst features. GSI also has an extensive and growing collection of reports on hydrogeology and related topics. The EPA (which has a statutory responsibility to collect hydrometric and water quality data, including data on groundwater) has established a national monitoring network for groundwater levels and groundwater quality with some of the data now published.

As in many countries, groundwater data in Ireland are very patchy. In any given area, good data exist for only a few wells or springs where intensive investigations have taken place, but there are many wells and springs for which few data are available and probably many others which are essentially unrecorded. This situation has several causes, primarily the absence of any statutory reporting of well drilling, the general lack of concern about groundwater resources (at least until recently), and the lack of investment in groundwater studies. In this situation, groundwater investigators (needing answers in a relatively short time) must make the best of patchy data, resisting the temptations of, on the one hand, dismissing poor data as useless, and on the other, of over extrapolating good data. European groundwater legislation will be rapidly changing this in the years to come.

Well Data

About 30,000 records of water wells in the GSI data banks have been supplied on a voluntary basis, but may represent only 10-20% of the actual total in the country. Well data have been derived in different ways; by well drillers, local authorities, consultants, and by field surveys. In each case the type of information on record differs; for instance, records submitted soon after drilling may include some details of the geological formations penetrated, whereas field surveys do not usually unearth this information. On the other hand, a field survey provides a precise location and an accurate water level, often lacking in other records. Some details of pumping tests are available for about 1,200 wells. Of the GSI's well databank, about 25,000 are basic records with minimal data (generally lacking precise locations, geological or yield data), and about 5000 have more detailed information. In addition, detailed well surveys have been carried out in a few places. These approach 100% coverage of wells in their areas and achieve precise locations, but still record rather minimal data; geology or yields are rarely obtainable. The records are filed according to counties and by Ordnance Survey 6-inch sheet numbers. So far, all available groundwater data (30,000+ records) have been computerised for 13 counties where groundwater protection schemes have been undertaken. The well records are used for aquifer classification, drawing water table or piezometric maps, constructing depth-to-bedrock maps, and providing an initial list of possible sites for further data collection.

Hydrochemical and Water Quality Data

The GSI hydrochemical databank comprises some 3000 fairly complete groundwater analyses, plus a roughly equal number of partial chemical and bacteriological analyses. The records are filed according to counties and by Ordnance Survey 6" sheet numbers. Like the well records, these analyses are patchy; some are of doubtful validity (lacking ionic balance), some are not precisely georeferenced and some lack any details of the water source. In a few cases there are enough repeated analyses from a given source to examine changes in water quality over time. For counties where GSI has undertaken groundwater protection schemes, the hydrochemical data are entered into a computer database The analyses for the remainder of the country still await study, evaluation and processing.

The EPA has initiated a nation-wide network to monitor groundwater chemistry and quality, and as these data accumulate they will constitute the country's main groundwater quality database that might be supplemented by additional local authority data. Groundwater quality and chemistry data can be used to characterise the baseline water quality in aquifers, to define trends in water composition through space and time, to deduce the underground pathway which water has followed and to infer the vulnerability of aquifers

Groundwater Level Data

The GSI has a unique data collection recording groundwater level fluctuations in about 40 wells in seven counties. These records have been computerised and provide a good, though discontinuous, picture of groundwater levels in Ireland over the past 30 years, and yield valuable information about the nature of the aquifers and the groundwater regime. Groundwater level monitoring data are essential for: (1) calibrating many predictive groundwater models, which are increasingly required for Environmental Impact Assessments; (2) assessing the feasibility of landfills, quarries, septic tanks and other effluent disposal, excavations for roads and building foundations and amelioration of flooding problems; (3) characterising aquifer recharge and vulnerability to pollution; (4) observing major groundwater abstractions; (5) determine the minimum depths of wells; (6) measuring the effects of changes in surface water abstraction; and (7) are essential for water balance studies.

To date, long-term groundwater level monitoring data are available only for limited areas of Ireland, mainly from GSI work. A new national monitoring network has recently been established by the EPA, with involvement by GSI, Office of Public Works (OPW) and local authorities. This groundwater level network will complement the existing long-established networks for rainfall, evaporation and surface water flow, the other main components of the hydrological cycle.

4.3.3 Reports and Maps

Groundwater Reports

The GSI has a large number of reports, ranging in size from a few pages to two or three volumes, and in subject matter from very local issues of water supply or pollution to regional and national summaries. They are available on request.

National scale maps
The early 1970s saw the first serious attempts to compile aquifer maps of Ireland. Three versions were produced: (1) a 1:1.5 million, for the International Association of Hydrogeologists (IAH) International Hydrogeological Map of Europe. This was compiled around 1972 and published in 1976 and 1980, with explanatory memoirs published in 1978 and1980. The Northern Ireland portion of the map was compiled by GSNI; (2) a 1:2 million for the Royal Irish Academy's *Atlas of Ireland* (RIA, 1975); and (3) a simplified version at 1:2 million, showing rock aquifers only (omitting sands and gravels), reproduced in *Mining Ireland* (Aldwell, 1975), in *Technology Ireland* (Wright, 1976) and in *Water Wells* (Anon., 1977). The usefulness of these maps was limited by their small scale. In 1979 GSI produced a more comprehensive national aquifer map at 1:500,000 as part of a European Commission-sponsored project. This map was published (on parts of three sheets) in 1982 with an explanatory report. Again, the Northern Ireland portion of the map was compiled by GSNI. The aquifer classification system used was chosen specifically for the project, and ignored many minor aquifers. Additional maps showing hydrological data, groundwater abstractions and surplus groundwater resources were also published. A small scale (1:1.5 million) version of the map (with minor revisions) was produced by GSI, GSNI and K.T. Cullen & Co. in 1995.

A follow-up project sponsored by the EC produced a national map of Groundwater Vulnerability at 1:500,000, compiled in 1983 but not published. This was again accompanied by a report and a series of A4-size 1:500,000 maps of groundwater quality as represented by Hardness, Chloride, Total Dissolved Solids and "Excess Substances". These quality maps only dealt with the aquifers as designated by the earlier study. The Vulnerability definition used in this project depended on the vertical "Time of Travel" for infiltration from the ground surface to the aquifer or water table, and was different from that currently used in GSI.

A new national aquifer map, covering all types of aquifers, is planned by GSI at a scale of 1:625,000. GSNI has produced an aquifer map and groundwater vulnerability map of Northern Ireland at 1:250,000 where the definition of groundwater vulnerability used is the same as used in Britain but different from that used by GSI in Ireland.

Medium-scale maps (1:100,000 to 1:50,000)
Examples include: (1) the north-east Regional Development Organisation maps; (2) the Nore River Basin and associated maps; (3) Groundwater Protection Scheme maps currently available (at 1:50,000 or 1:63,360) for counties Claire, Cork (south), Laois, Limerick, Meath, Offaly, South Tipperary, Waterford, and Wicklow (draft). Each suite includes maps of bedrock geology, subsoils (Quaternary geology), depth-to-bedrock, hydrogeological data, aquifers, groundwater vulnerability, and groundwater protection zones. An earlier suite (1979) at 1:63,360 scale is available for County Dublin (bedrock geology, Quaternary Geology and Aquifers only); and (4) maps by consultants for various local areas.

Large Scale Maps (1:25,000-1:10,000 and larger)
GSI has produced maps in this scale range for Source Protection Areas around some major public groundwater sources. Other hydrogeological maps at these scales have been produced by consultants for various local areas and regions. Detailed information is available on request.

4.4 Surface Water Resources

(E. Daly)

4.4.1 Introduction

Surface water in the form of lakes and rivers is the most visible part of the hydrologic cycle on the global landmass. Here water is concentrated into relatively small areas of the earth's surface. In Ireland there are about 16,000 km of major and minor river channels and around 4,500 lakes and large ponds which occupy approximately 2% of the island's landmass.

Surface waters have numerous beneficial uses for the human population, such as water supply, waste attenuation, recreation and transport. There is a very definite seasonal aspect to water in this form. In Ireland much of the water in streams and rivers in the winter is derived from relatively recent rainfall whereas in summer the flow in rivers is maintained from drawdown of storage in geological strata. Extreme surface water levels often have a significant impact on the human consciousness. The floods of 1954, 1968, 1978, 1986 (Hurricane Charlie), 1989-'91 and 1995 (Gort) and droughts of 1959, 1975-1976 and 1995 are all remembered.

The natural chemical quality of surface waters is a function of the flow regime, the geology of the catchment area and the time of year. Water quality is also influenced by land use and the degree of human activity within the upstream catchment. Surface water bodies provide a rich habitat for fauna and flora; type and diversity are indicative of the health of waters. Wetlands which have characteristics half-way between land and surface water are often the last remaining remnants of the native environment in an area.

The use of surface water flow and quality data is now an integral part of the planning and regulatory process for most large developments and for the licensing of existing ones. Many industrial and commercial enterprises are required to monitor the receiving water quality into which they discharge treated effluents. Since the passing of Ireland's first Water Pollution Act, in 1977, many EU Directives, laws, statutory instruments, standards and guidelines have been enacted. A similar situation exists in Northern Ireland. Since the early 1980s water quality management plans or strategies have been prepared for many of the major catchments in the two jurisdictions. Ireland is divided into 40 hydrometric areas (Figure 4.2) each of which comprises a single large river catchment or a group of smaller ones. They are grouped into seven Water Resource Regions that are of such size that the water requirements of each region can be supplied from the available resources within that region (Department of Local Government, 1974). A considerable volume of data are available on Irish surface waters in both Ireland and Northern Ireland including flow, chemistry and biology. However, only some of the data, especially that of water quality, are available in a readily accessible form.

4.4.2 Tabular Data

Rivers and lakes in Ireland are regularly monitored at numerous locations for water level (stage), chemistry and biology. The basic water level data are subsequently manipulated to provide flow rates and other statistical information. Much of the chemical and biological data are concerned with water quality and the degree of deterioration relative to the natural state. These data are aggregated into chemical and biological quality ratings.

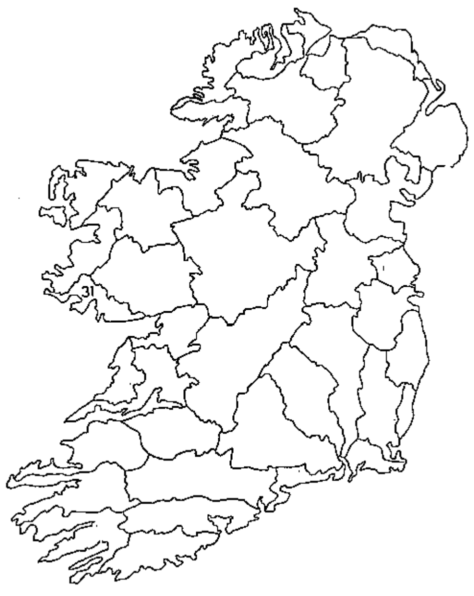

Figure 4.2: Hydrometric areas of Ireland

On a national scale surface water data (water level/stage) are collected mainly by the Rivers Agency (an agency of the Department of Agriculture) in Northern Ireland and by the Hydrometric Section of the Office of Public Works (OPW) in Ireland. Both the Environment and Heritage Service (EHS, an agency within the Department of the Environment for Northern Ireland) and the Environmental Protection Agency (EPA, formerly An Foras Forbartha [AFF] and the Environmental Research Unit [ERU]) in Ireland carry out extensive programmes for the collection of chemical and biological data. There are also a number of other organisations active in the collection of surface water data, but on a more local basis, or on specific aspects of surface water hydrology. Such organisations include the local authorities, the Electricity Supply Board, Fisheries Boards, third level colleges and some commercial organisations. Most of the data are contained within large databases operated by the OPW and EPA in Ireland and the Rivers Agency and EHS in Northern Ireland. The OPW and Rivers Agency supply flow data for particular stations on request. The EPA and its predecessors have regularly published both river flow and quality data on a national basis over the last 25 years. Since the 1980s, the EHS has published the results of its water quality monitoring programme in reports at regular

intervals. Data are also available in less formal databases in other organisations, especially the local authorities.

Water Flow
Systematic river flow recording began in Ireland in 1939. Automatic water level recorders were installed at locations on many rivers in the 1940s and 1950s. In many cases the site-selection and monitoring objective was to record high (flood) flows and aid drainage projects which resulted from the passage of the Arterial Drainage Acts in 1945. The Electricity Supply Board began river gauging in the late 1920s and a network of gauges was set up in the 1930s on rivers that had some potential for hydroelectric development. More recording stations were set up in the 1970s. Most of these stations were set up to record low flows with a view to ascertaining the assimilative capacity of streams and rivers for pollution studies and water quality management plans.

The 1,369 water level gauging stations in Ireland are located on rivers, lakes and at the coast. Of these, 539 are gauging stations fitted with automatic recorders (MacCarthaigh, 1999). A register of all hydrometric gauging stations in Ireland maintained by the EPA contains details of the type of installation and the length of the flow record. Automatic water levels recorders (now being upgraded to data loggers) have been in operation in Northern Ireland since 1970, where there are now over 100 automatic water level recorders. Seventy are used to monitor flow and the remainder are used to record water levels.

Types of data.
River flow data are initially collected as a water level (stage height) above a datum. It may either be in the form of a single value (graduated staff gauge) at a particular time or a continuous chart (autographic stage recorder). Each gauging station is calibrated by taking the results of a series of river flow measurements (with a current-meter) at different stage levels to compile a rating curve of water level versus river flow (stage-discharge relationship). The rating curve is then used to compute a discharge value for a particular stage or a whole series of values (discharge hydrograph) by digitising a continuous water level chart (stage hydrograph).

The Hydrometric Section of the Office of Public Works digitises the basic water level data recorded on continuous charts (more recently the use of data loggers permits the transfer of water level information directly to a computer) and with the aid of a rating curve computes the daily mean flows. Hydrographs of daily mean flows are also available. For a given period of years additional statistical information, such as flow duration curves, reservoir storage and sustained low flows are also available. The Rivers Agency in Northern Ireland provides similar information for its gauging stations. This information is available from both organisations on request.

Data availability
Data are available in a number of different formats and publication, the details of which are outlined briefly below. Although a considerable amount of water flow and level data has been collected since monitoring began not all have been digitised nor are available in a readily readable form. The data for over 125 automatic recording stations in Ireland

were published by An Foras Forbartha in Yearbooks for 1975, 1976 and 1977. In 1977 An Foras Forbartha published seven reports containing a summary of hydrometric records for each of the seven water resource regions in Ireland. These publications make readily available the results of flow measurements taken at various locations throughout the country. An Foras Forbartha (1984a) and the Environmental Resource Unit (1989) published reports on statistical analyses of river flows in three of the water resource regions. These publications are designed to provide details of the magnitude and frequency of occurrence of river flows (mainly low flows). In 1995 the Environmental Protection Agency published a text (MacCarthaigh, 1995) containing details of hydrometric stations (329, fitted with autographic recorders) and summary water balance and flow statistics. These stations are on natural rivers, i.e. rivers that are not affected by major water storage or river-flow regulation. Two reports have been published on the droughts in 1984 (An Foras Forbartha, 1984b) and 1995 (MacCarthaigh, 1995). These reports contain low-flow measurements at selected stations recorded in those years and also provide comparisons with other dry years. There is also a considerable amount of flow data, especially low-flow data for the smaller rivers, in local authority databanks. There are likely to be some low flow measurements available for most streams/rivers that receive a discharge from a local authority wastewater treatment plant. Flow data collected in Northern Ireland are sent to the National Water Archive maintained by the Institute of Hydrology at Wallingford in the United Kingdom. The data from Northern Ireland are included in annual publications (now digital) produced by the Water Archive. Data for specific sites can be obtained by e-mailing requests.

Characteristics of River Flows

Researchers in the EPA and its predecessors have compiled summary surface water statistics for the water resource regions in Ireland. The information is adapted for Table 4.2. Flow data are often required for ungauged river sections or small streams. Estimates of the flow in streams/rivers in Ireland, for which no data are available, can be obtained using water balance data, formulae and constants that are available in a number of publications. MacCarthaigh (1995) gives the long-term average runoff values calculated from rainfall and evapotranspiration data for 329 selected stations throughout Ireland. A publication by the Department of Industry and Energy (c. 1986) contains a formula for estimating the daily mean flow (DMF in $m^3 s^{-1}$), of a river/stream at a particular location, from the catchment area and average annual runoff. Martin & Cunnane (1977; 1994) and Martin (1992) provide methods for determining dry weather flow (DWF) based on runoff.

Table 4.2: Distribution of Surface Water Resources, Republic of Ireland

Water Resource Region	Area km^2	Precipitation 1931-1960 mm yr^{-1}	Average runoff $m^3 s^{-1}$	Specific runoff $l s^{-1} km^{-2}$	Low-flow runoff $m^3 s^{-1}$	Specific low-flow $L s^{-1} km^{-2}$
Eastern	7,878	954	127.6	16.2	7.3	0.9
south-eastern	12,710	1,009	209.2	16.5	20.9	1.6
Southern	11,920	1,383	283.0	23.7	20.4	1.7
Shannon	10,830	1,003	211.5	19.5	12.1	1.1
Mid-Western	7,640	1,141	101.9	13.4	2.5	0.3
Western	8,560	1,205	292.0	34.1	10.9	1.3
North-western	9,350	1,281	262.6	28.1	8.7	0.9
Ireland	68,888		1,487.8		82.8	

4.4.3 Data Uses

Surface water flow data are used for a variety of purposes such as, water abstraction, pollution control, designs for bridges and drainage works, flood prevention and alleviation, fishery management and amenity. One example described in the literature is the use of water level data to develop a flood warning system for Kilkenny City (Shine, 1987) on the River Nore. Analysis of the historical water level charts showed that there exists a definite relationship between the flood peaks at the station at Dinin Bridge (River Dinin), some 9 km upstream of Kilkenny, and the station at John's Bridge in the City. The pre-flood level of the River Nore in Kilkenny and the rise of the level of the River Dinin at Dinin Bridge are used to predict the rise in the water level in the City with a reasonable degree of accuracy (Shine, 1987). The system gives about four hours notice of flooding which is sufficient time for the emergency services and affected population to take action to limit the worst effects.

Water Quality

Water quality of rivers and lakes in Ireland has been monitored since the early 1970s. The results of the initial surveys were published by Flanagan & Toner in 1972 (rivers) and 1975 (lakes). The work was initiated by An Foras Forbartha and is continued by the Environmental Protection Agency. Since the late 1970s reports have been compiled every four to five years on surveys of river water quality carried out over a four-year period. The initial survey assessed the quality of the 121 major rivers with catchments generally in excess of 130 km^2 and covering some 2,700km of river channel. This was subsequently extended to 7,000 km in the 1982-1986 survey. The report of the latest survey period (1995-1997) covers about 13,200 km of river channel (EPA, 1999).

The original national lake survey (1973-1974) assessed the trophic status of 53 of the larger and more important lakes (McCumiskey, 1982). In the mid-1980s the survey had been extended to 90 lakes and to 135 in the most recent period (1995-1997). The water quality survey reported in 1986 included information on 19 estuarine and coastal areas. This has been extended to 26 areas reported in 1999.

River water quality is monitored at almost 300 stations in Northern Ireland (Environment and Heritage Service, 1996). Chemical monitoring increased from a total channel length of 1,685 km in 1991 to 2,353 km in 1995 and biological monitoring increased from 2,190 km to 2,331 km over the same period. There are also over 30 monitoring stations on estuaries throughout Northern Ireland (Environment Service, 1996).

Types of Data

Water quality assessment of surface waters is based on data collected from physico-chemical and biological surveys. The two methods complement each other and provide a more detailed and balanced picture of water quality than either one alone (McCumiskey, 1991). Sampling involves both river water and benthic substrate (sediment) in contact with the water. In Ireland, river water sampling is carried on throughout the year whereas the biological surveys are normally carried out between June and October.

River water samples are generally analysed for conductivity, pH, colour, alkalinity, hardness, dissolved oxygen, biochemical oxygen demand (BOD), ammonia, chloride, ortho-phosphate, oxidised nitrogen and temperature. In addition, lake water samples are also analysed for chlorophyll, transparency, and total phosphorus. The biological monitoring of rivers is based on the relationship between water quality and the relative abundance and composition of the macro-invertebrate communities in the sediment of rivers and streams. The macro-invertebrates include the aquatic stages of insects, shrimps, snails and bivalves, worms and leeches. The greater the diversity the better the water quality. The biological information is condensed to a 5 point numerical scale (biotic index or Q values), an arbitrary system in which community composition and water quality (1 = bad to 5 = good) are related (Table 4.3). The five grades used in the general assessment of river water quality have been grouped into four classes based on the water's suitability for beneficial uses (abstraction, fishery potential and amenity value). Water Quality Index (WQI) is used to simplify the large quantity of physico-chemical data and present it in a condensed form. The trophic status of lakes is classified according to a modified version of the OECD (1982) scheme based on values of annual maximum chlorophyll concentration.

In Northern Ireland the rivers are monitored for chemistry either fortnightly or monthly and for biology three times per year (spring, summer and autumn). Water quality of rivers within Northern Ireland and Ireland are assessed using different classification systems (Environment and Heritage Service, 1996). In Northern Ireland separate chemical and biological General Quality Assessment (GQA) classification schemes subdivide water quality into six bands (Table 4.4). For cross-border studies a classification system based on the systems used in both jurisdiction, including both chemical and biological aspects, was developed (Kirk McClure Morton, 1997).

Table 4.3: Relationships of water quality to the composition of macro-invertebrate fauna (McCumiskey, 1991)

	Water quality				
Macroinvertebrate fauna	Good (Q5)	Fair (Q4)	Doubtful (Q3)	Poor (Q2)	Bad (Q1)
Sensitive forms (A1)	+++	+	-	-	-
Sensitive forms (A2)	+++	++	-	-	-
Less sensitive forms (B)	++++	++++	+++	-	-
Tolerant forms (C)	+	++	+++	++++	?
Most tolerant forms (D)	+	+	+	++	++++

(key to Table 4.3)
++++ Abundant; +++ Common; ++ Present; +Sparse or absent; - Absent
A1 Plecoptera (excluding Leuctra), Ecdyonuridae, Ephemeridae
A2 Ephemeroptera (excluding Baetis rhodani, Cloeon, Caenis, Ephemerella)
B Leuctra, Baetis rhodani, Cloeon, Caenis, Emphemerella, Gammarus, uncased Trichoptera, Elminthidae larvae
C Chironomidae (excluding Chironomus), Hirudinea, Mollusca (excluding Physa)
D Chironomus, Physa, Eristalis, Tubificidae and other Oligochaeta.

Table 4.4: Likely Uses and characteristics of classified waters in Northern Ireland (EHS, 1997)

Chemical class	Likely uses and characteristics[1]
A (very good)	All abstractions Very good salmonid fisheries Cyprinid fisheries Natural ecosystems
B (good)	All abstractions Salmonid fisheries Cyprinid fisheries Ecosystem at or close to natural
C (fairly good)	Potable supply after advanced treatment Other abstractions Good cyprinid fisheries A natural ecosystem, or one corresponding to a good cyprinid fishery
D (fair)	Potable supply after advanced treatment Other abstractions Fair cyprinid fisheries Impacted ecosystem
E (poor)	Low grade abstraction for industry Fish absent, sporadically present, vulnerable to pollution[2] Impoverished ecosystem
F (bad)	Very polluted rivers which may cause nuisance Severely restricted ecosystem

1. Provided other standards are met.
2. Where the Class is caused by discharges of organic pollution.

The chemical GQA system uses three variables, ammonia, biochemical oxygen demand and dissolved oxygen to classify river reaches. The biological GQA system uses a computer model called RIVPACS (River Invertebrate Prediction and Classification System) which predicts the macro-invertebrate fauna that should be present at a site in the absence of pollution or environmental stress. Comparison of the predicted communities with the observed during sampling and analysis permits the calculation of ecological quality indices (EQIs). Full explanations of the various indices and classifications used are provided in a number of Environmental Protection Agency and Environment and Heritage Service publications.

Data availability

There is a large body of water quality data available on Irish rivers, lakes and estuaries. On a national scale the information is readily accessible in the national reviews of surface water quality undertaken by An Foras Forbartha (1972, 1974, 1975 (lakes), 1980, 1982 and 1986), by the Environmental Resource Unit (1992 (lakes) and 1992) and by the Environmental Protection Agency (EPA, 1995, 1996 and 1999). The data for the two most recent survey periods (1991-1994 and 1995-1997) are available on disc. The reports contain tables that show the channel length of individual rivers in each of the four quality classes. They include text describing trends in water quality and sources of any pollution detected. The reports provide the biological quality ratings (Q values), both current and historical for the sampling stations on individual rivers. The minimum, median and maximum values for the physico-chemical parameters and water quality indices at each sampling station are also given. Tables which contain information on lake waters and the trophic status of individual lakes are also included in these reports.

The Northern Ireland data derived from monitoring, are used to categorise river water quality into a number of classes (Table 4.4). Since the 1980s the results of river quality surveys undertaken at five-yearly intervals (EHS, 1994 and 1996) have been published. The reports contain tables which show the channel length of the seven main river systems in each of the six chemical and biological GQA classes. There are tables providing details of the numbers of private sector effluent discharges and sewage treatment works. The reports include text describing water quality in individual rivers and sources of any pollution detected. The EHS also publishes the results of investigations into particular aspects of surface water quality. Reports on Water Quality Management Plans and Strategy have been prepared for a number of large river catchments in both Ireland and Northern Ireland, which contain additional data and analysis, e.g. the Foyle (Kirk McClure Morton, 1997).

Additional information and data can be found in databases and reports in third level colleges, local authorities, fisheries boards and commercial enterprises that have to collect surface water data for planning applications, or to meet the terms of Integrated Pollution Control and waste or effluent discharge licences. The local authorities normally collect water samples upstream and downstream of their main wastewater treatment plants to determine the impact on receiving waters. They often sample streams and rivers downstream of licensed effluent discharges to monitor compliance. The fisheries boards sample surface waters with a view to prosecuting activities possibly causing pollution.

Trends in Surface Water Quality

McCumiskey (1991) compared river water quality from the initial survey in 1971 and the position in the same length of channel 20 years later. He found that both the length of seriously polluted channel and unpolluted channel had been significantly reduced. However, the corollary is that there has been a significant increase in the channel length that is both slightly and moderately polluted. McCumiskey (1991) concludes that "the main quality trend in Irish rivers over the last two decades has been a significant reduction in serious pollution and an increasing incidence of eutrophication". This trend has continued to the present (EPA, 1999). Similarly, the report on River Quality in Northern Ireland (circa 1996) noted "a decline in chemical quality, which is attributed largely to excessive nutrient enrichment (eutrophication), was evident in a number of rivers".

Data Uses

Surface water quality data has a wide variety of uses. For example it provides a baseline against which to measure subsequent improvement or deterioration in water quality, a measure of the success or failure of conservation and remedial measures, and an input into water quality management plans and calculations to assess the impact of discharges on receiving waters.

Maps

There are few national scale maps containing surface water information. The Ordnance Survey of Ireland published a map (OSI, 1958) showing the catchment areas of over 400 river catchments and coastal areas in the island. The map (scale 1:633,600) includes details of the length, in miles, of the main river channels and the altitude, in feet, of the highest ground near the source. The EPA (1995) published a map (scale 1:440,000) showing the hydrometric network in Ireland, and in 1994 it published a map at the same scale: "Ireland, River Quality 1991-1994". This map classifies the river water quality at the national survey sampling stations. Maps (scales 1:555,000) of river quality, chemical GQA and biological GQA are contained in the River Quality in Northern Ireland, 1995, report.

4.5 *Marine Resources*

(J. Sweeney)

4.5.1 Introduction

Ireland's continental shelf extends approximately 350 km offshore to the west, north and south of the island, consisting of mainly Palaeozoic rocks located on the slowly eastward moving edge of the European plate. More recent Tertiary-period tectonic spreading has created the Irish Sea and Celtic Sea basins to the east which are much shallower features, usually less than 50 m in depth. Ireland's marine territory encompasses some 900,000 km^2, about nine times the size of the island. This provides it with extensive marine resources in such categories as fisheries, minerals and aquaculture These resources are subject to increasing development pressures as their economic value is realised and new technologies appear to exploit their potential. Jurisdiction of the seas around Ireland has been a subject of contention since independence, particularly where unexploited energy resources or fish stocks may exist. While the maritime boundary in the Irish Sea and Celtic Sea can be relatively easily demarcated, the areas to the west are much more problematic. Competing claims from Denmark, Iceland, Ireland and the United Kingdom currently exist for parts of the Rockall Bank, an area thought to hold potential seabed wealth.

Whether the surrounding seas are considered to be a barrier, buffer, boundary or link to accessing these resources, an understanding of their potential for employment creation is important. More than any other EU country, Ireland's population consists predominantly of coastal dwellers. Over half live on the coast and some 86% live within 50 km of it. To maximise the potential benefits, and minimise the potential risks offered by this environment, good data are needed for management purposes.

4.5.2 Marine Meteorological and Climatological Data Sources

Ireland has benefited from a relatively good supply of marine meteorological data from the seas around. Fixed sources such as weather ships, manned lighthouses and light vessels have, however, dwindled as satellite platforms have increasingly rendered their role obsolete, and indeed all have now disappeared from around the Irish coast. Such sources, however, together with onshore coastal stations, have resulted in important data repositories being created at Met Éireann.

Fixed Observations
As part of a 13-station synoptic network, Met Éireann maintains five stations on, or very close to, the coast. These are manned on a 24-hour basis by trained observers who report conditions every hour. Observations include wind speed and direction, visibility, air temperature, dew-point, amount, type and height of clouds, atmospheric pressure, pressure tendency and weather conditions, as well as details of precipitation type and amount. Summaries of these observations, together with statistics on extremes are published by Met Éireann in their *Monthly Weather Bulletin*. A number of stations have also participated in programmes of chemical analysis of air and precipitation, of radioactivity levels, and of incoming solar radiation, some of which are also published in the *Monthly Weather Bulletin*. The data, which are quality-controlled, commenced mostly in the mid 1950s, and have been entered into a relational database. These coastal stations also include some of the longest records of climate available in Ireland with locations such as Valentia, Malin Head, Roche's Point and Belmullet having records spanning more than a century.

The importance of sea surface temperature (SST) for onshore weather over large areas has become much more widely appreciated in recent years, especially with the publicity accorded to recent El Niño events. Although near-real-time, satellite-derived estimates of SST for the seas surrounding Ireland can be obtained from the United States National Oceanic and Atmospheric Administration, land-based thermometer measurements are only conducted at relatively few locations. SSTs have been collected twice daily at Malin Head from 1957 to 1991 and once daily thereafter. The close correspondence between air and sea temperatures is striking (Figure 4.3) and is attributable to the North Atlantic Drift. This water takes about eight months to reach the Kerry coast from Florida, by which time its temperature in January is about 10°C, on average some 3-4°C warmer than the air over the land. Such a thermal contrast facilitates a transfer of sensible and latent heat to frontal and convective systems which are thus more active in winter along western coasts.

Five of the former fleet of eight light vessels provided wind speed (Beaufort) estimations twice daily off the eastern and southern coasts for various periods ranging from 1939 to 1982 when the last vessel, at Coningbeg, was withdrawn. Wave data were also reported from seven of the vessels over the period 1964-1975. Wind and wave data have also been recorded at the Marathon Gas Platform since 1979.

Automatic marine stations have become much more common in recent years as the data deficiencies from marine areas for input to numerical weather models have become apparent (see Chapter 8). The failure of such models to adequately predict explosive deepening of depressions is seen to be, in part, a consequence of poor input data for initialisation purposes from sea areas west of Ireland. As a consequence, a renewed interest has developed in moored buoys, automatic light vessels and other fixed platforms. The Irish Marine Data Buoy Network was inaugurated in October 2000 with the deployment of the first of a new generation of fixed buoys. The first two are located

80 km west of Inishmore and east of Dublin Bay, with further buoys intended to be deployed off the Wexford, Donegal and Kerry coasts. Reports are available on Weatherdial Fax and will become freely available on the Internet. Further afield, the UK Meteorological Office currently has 28 such stations, some as far west as 19°30' which are also used for wave model validation. Both past and near-real-time weather and wave conditions are available on the Internet from 11 of these locations around Ireland. Such buoys also have utility in other areas of coastal management nearer shore. Two buoys have been maintained since August 1998 by the Marine Institute in Bantry Bay and south of Sherkin Island, which are of particular use for forecasting blooms of toxic marine algae ("red tides").

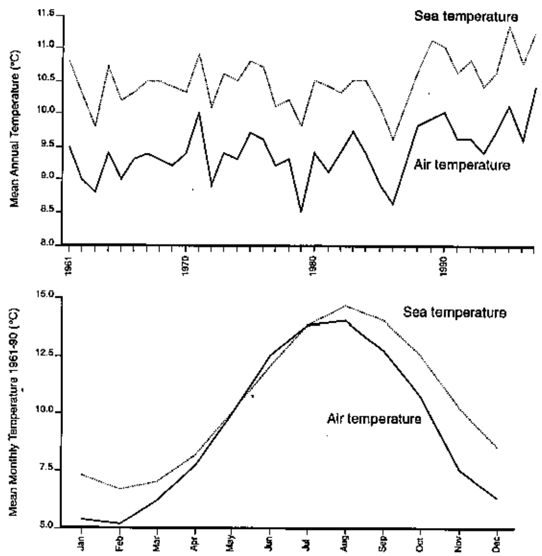

Figure 4.3: The relationship between air and sea temperature

Variable-Location Observations
A substantial data archive exists as a result of weather reports made from ships around the Irish coast. These extend back to 1854, and are more reliable after the mid 1940s. Logs were also required to be written up while ships were in port, and this often provides useful information from periods before regular meteorological observations commenced. In more recent times, ship observations usually include wind, temperature, visibility and cloud parameters, as well as SST, wave height, and swell height/period/direction. Regular voyages are particularly useful. For example, two

supply ships servicing the Marathon gas platform have provided an unbroken 4 times daily set of observations for over six years.

Among the most variable of reporting locations are a large group of drifting buoys which record air and sea temperatures, and occasionally wind. As with the moored buoys, satellite communications enable the data to be fed directly into forecast models.

Wave and Swell Data

Wave conditions are of considerable interest to activities such as aquaculture, fishing, offshore oil and gas activities, and leisure users of the coastal zone. Waves are complex phenomena, difficult to predict since they may arrive at the coast in response to a multiple set of distant events. It is now appreciated, for example, that waves breaking on the west coast may have started their journey as far away as the Caribbean. They subsequently arrive at the coast as different families, having different heights, wavelengths and speeds. Interaction between families may cancel out or reinforce the wave characteristics concerned. A computerised wave model can best disentangle this complexity, and in the case of Met Éireann, this has been done since July 1996. The WAM Model is centred on Irish waters and runs on a spatial grid of 0.25° latitude/longitude. Predictions are verified using ship and buoy data, and the ERS-2 Satellite Radar Altimeter. Nearer shore, the model accommodates itself to the bathymetry and provides a good archive of coastal wave climate. Wave energy around Ireland averages out at 50 kW m^{-2}, representing one of the highest wave energy climates in the world. Extreme value analysis reveals that the 50-year wave height off the west coast is 35 metres, over three times the equivalent value for the central part of the Irish Sea.

Swells are waves of long wavelength (300-600 m), often of only a few centimetres in amplitude which originate from disturbances perhaps several thousand kilometres distant. Swell can be a significant consideration for offshore structures where damage may occur from very low amplitude waves of a particular frequency. The WAM Model provides swell/wave energy forecasts over 25 frequencies, some corresponding to wave periods as long as 24 seconds.

Present and forecast wave conditions for the seas around Ireland are both available from the U.S. Navy. Private organisations such as Oceanweather, provide both observational data and forecasts ranging up to 7 days ahead for significant wave height and direction. The significant wave height is the average value of the vertical distance between the crest and trough of the highest one-third of all waves present.

Tides

The longest wavelength ocean waves are those associated with the twice-daily ebb and flow of the tides. After 170 years of use, the Palmer-Moray tide gauge is still the most widely used instrument for recording tidal elevation. This consists essentially of a wooden float that traces its rise and fall on a clockwork-powered rotating drum. Five tidal stations are maintained: Malin Head, Belfast, Larne, Galway and Dublin. At the discretion of the harbour-master, longer-term records may be made available. For predictive purposes, UK Admiralty Tide Tables provide specific information for Dublin

which enables tidal predictions for other parts of Ireland to be published. A tidal prediction programme is also available from the UK Hydrographic Office which can provide daily tidal predictions for a large number of locations in terms of timing and heights for an indefinite period into the future.

Tidal currents are of particular concern for activities such as aquaculture, though monitoring of them is much poorer than for tidal elevation. Data are very scattered, consisting of observations of floats and poles from a variety of sources. Occasional observations are available from some of the lightships and even more rarely, some current meter data from a 10 m depth are collected. Where a tidal wave enters a restricted bathymetry, tidal current streams tend to be faster and thus eastern coasts show significantly faster tidal current streams than occur on the west coast. The British Oceanographic Data Centre at the Proudman Laboratory provides a wide range of data, as do the Admiralty Tidal Stream Atlases.

Fisheries

The oceans surrounding Ireland support a diverse range of commercial pelagic, demersal and shell fisheries. Although fish yield per unit area is only 40% that of the North Sea, the Irish fishing industry provides employment for over 15,470 people, about 60% of whom work on the fishing fleet directly, with the remainder engaged in processing and other ancillary activities. For some small rural communities, up to a quarter of the workforce may be dependent on fishing. The marine food sector is worth about 0.5% of Irish GDP.

1,385 vessels are registered to the Irish fishing fleet. The main fishing grounds are in the Irish Sea, with offshore Atlantic areas becoming important during spring and summer. Whiting, cod and seasonal species such as herring, mackerel and sprat dominate the annual catch of 300,000 tonnes valued at over 250M Euros. Most demersal fish are caught in mixed trawl fisheries with a substantial proportion of the cod and whiting catch occurring in the spring. Herring fishing in the Irish Sea is targeted on pre-spawning and spawning shoals in the autumn, especially in the vicinity of the Isle of Man. Information concerning Irish fisheries is available from the Department of the Marine and Natural Resources, or from their National Fisheries Research Centre, Abbotstown, Co. Dublin. The latter also houses specialist facilities for fish stock assessment, fish health research, and a plankton laboratory.

Landings of shellfish such as nephrops, lobster, crab and whelk have a value of 40M Euros. Nephrops is the single most valuable species in the Irish Sea and over 80% of the catches are made on the muddy seabed between the Isle of Man and the Irish coast. Mussels are dredged close to the coasts of Donegal, Wexford and Louth, though increasingly shellfish are farmed.

Access to fisheries such as the Irish Sea is strictly controlled by quota limitations under the Common Fisheries Policy. This provides for access from other EU states, subject to a complex regulatory system which includes quotas, limits on access, and other measures to prevent over-fishing and protect spawning grounds. Three distinct fishing zones are demarcated for Irish waters (the imperial unit, the mile, is the legal unit): (1) *0-6 miles* (0-9.6 km) – Republic of Ireland and Northern Ireland boats only; (2) *6-12 miles* (9.6-19.2 km) – boats from Great Britain, France, the Netherlands, Belgium and Germany are permitted to fish in particular areas for particular species; and (3) *12-200 miles* (19.2-320 km) – All EU member states and some others, including Norwegian boats.

Aquaculture currently provides employment for about 3,000 people, of whom 860 are full time employees. Some 195 fish farming operations currently exist, many in peripheral coastal regions where alternative employment is scarce. Output valued at over 125M Euros represents about 50% of Irish fish production. Eighty percent of output is export markets in France and other EU countries.

Finfish production has grown rapidly from 20 tonnes in 1980 to a peak of 14,000 tonnes in 1993. In more recent years a slight decline has set in as a result of competition from countries such as Scotland and Norway which produce around 60,000 tonnes and 300,000 tonnes respectively. Activities centre mainly on salmon production (75%) with smaller quantities of sea trout, rainbow trout and turbot.

Farmed shellfish production amounting to approximately 14,000 tonnes currently takes place around the Irish coast. Mussels account for 80% of this with oysters making up most of the remainder. More so than finfish farming, shellfish farming lends itself to part-time employment and about 85% of the workforce is part time.

Finally, the Irish seaweed industry had a turnover of approximately 5M Euros. Almost 90% of production is exported and increasingly finds its way into new niche products such as pigments and in healthcare as well as in the traditional areas of fertiliser production, and seaweed meal. The potential for improved exploitation of this marine resource is increasingly being recognised, and a major study has recently been published by the Marine Institute. It is likely that a very significant increase in production will occur in the next few years, particularly of brown seaweed (*Ascophylum nodosum*).

The presence of aquaculture is ultimately indicative of good quality coastal waters and may also have beneficial effects for local tourism. The visual intrusion of many fish farms in scenic coastal areas has however raised issues which have not yet been resolved. Equally the siting of some operations has been unsuitable because of a failure to adequately understand coastal water circulation systems, and this has led to localised pollution problems which has in turn been associated with problems for the well-being of the stocks concerned. Similarly, the introduction of migrant species from ballast water, such as the zebra mussel, and new parasites such as Bonamia, have given cause for concern, as have suspicions that the expansion of the sea lice population in the vicinity of fish farms may have been associated with the collapse of wild sea trout stocks in western Ireland.

Map Data

In the absence of an Irish hydrographic service, the main cartographic sources of information for Irish offshore areas are located in the UK Hydrographic Office, at Taunton in Somerset. This organisation started surveying in the 18th century when marine survey techniques were becoming more developed and when military concerns emerged regarding the need for accurate charts. It was not unusual during the Napoleonic Wars for eight times as many ships to be lost through running aground as through enemy actions. Since 1823, the UK Admiralty Charts have also been available to merchant shipping, and by the end of Admiral Beaufort's term as hydrographer in 1855, a wide range of marine-related publications, including tide tables, were available. Today, over 3,000 charts at a variety of scales exist and some of these encompass Irish waters.

Updating of charts in the vicinity of Ireland has focused mainly on the east coast and at a scale of 1:500,000. Some charts of the western Irish Sea have also been updated at a scale of 1:200,000. More detailed charts of the south coast, from Kinsale to Power Head, have also been produced during the past five years at scales of 1:50,000. The increasing use of marine cartography for recreational users has also led a number of commercial chart producers. The most prolific of these is probably Imray, Laurie, Norie and Wilson Ltd. who produce charts for yachtsmen and who have recently produced a number of charts for coastal areas around Ireland at scales varying between 1:150,000 and 1:280,000.

Increasingly, marine customers demand cartographic products in digital format, and the UK Hydrographic Office now supplies digital charts on CD which can be used in conjunction with a Global Positioning System. The marine areas around Ireland are included in two of the 10 CDs in this series. This method of providing map data also lends itself to regular updating by constantly providing new versions of the product incorporating the latest information such as sea depths, buoys, lights, port developments, pipelines and cables.

4.6 Soil Resources

(J.F. Collins)

4.6.1 Introduction

Soils are the interface between the geosphere and the biosphere; they are modifiers of conditions in the upper terrestrial hydrosphere and in the lower reaches of the atmosphere. Soils are the core and buffer of many terrestrial changes, resilient to a range of long-term impacts (e.g. acid deposition) but sensitive to others in the short-term (e.g. surface wetness). Soils have attributes that determine the ratio of infiltration to run-off, the ratio of absorbed to reflected energy and the circulation of gases at ground level. The importance of soils for the support of plant and animal life is unquestioned; however they may be nutrient-poor or -rich, acid or alkaline, well- or poorly-drained, but in all circumstances they are involved in a variety of cycles and feed-back mechanisms that make this world a comfortable place in which to live.

The great variation in the earth's soil mantle is closely related to the geographic patterns of climatic and biotic zones, while at national level, geology and hydrology are more influential. Terrain attributes such as gas exchange and energy partitioning are greatly influenced by topsoil properties such as colour, texture, permeability and organic matter content. Topsoil and subsoil hydrological conditions are determined by properties such as hydraulic conductivity, pan layers and root volume. Crop-ecology and production capacity are often determined by conditions in the whole profile, such as rooting volume, water holding capacity, nutrient status, drainage and depth to water table.

The soil archives and data-bases of the world are replete with information on individual points (i.e. soil profiles) of the landscape. It has been the job of soil surveyors, not just to collect such data, but to relate them to mapping units, usually soil series. It has fallen to cartographers and others to reduce these data (categorically, cartographically or some other way) into more generalised units such as soil associations or terrain (physiographic) units. In order to facilitate managers, planners and others, an increasing amount of soil data (tabular, map and air-photo) is becoming available in digital formats at various scales. What follows is a short resume of the kinds and sources of information available on Irish soils at present.

The data assembled on the soils of Ireland in the great surveys of the last century (Royal Dublin Society (RDS); Geological Survey of Ireland (GSI), Ordnance Survey (OSI), Townland Valuation), while still very interesting, are of limited scientific value. As its title suggests, Kilroe's (1907) "Soil Geology of Ireland" is a geologically-biased view of soil resources. Some reference is made to soil conditions in the Drift map series of the GSI in the earlier decades of this century (Collins, 1981). The endeavours of that institution in studying soils culminated in their report of the soils of the Department of Agriculture farm, Ballyhaise, Co Cavan, the soil map (scale 1: 5,280) of which received a prize at a Franco-British exhibition in London in 1908 (Herries Davies, 1995). An overview of the modern era, which started about 1930, is given by Cruickshank (1984), while numerous individual references are cited in Hayes's (1965) massive compilation.

4.6.2 Soil Profile Data

Data exist for many hundreds, if not thousands of Irish soil profiles. Following international conventions, typical profile descriptions usually consist of four parts: (1) *Site data*, including data on location (National Grid reference, Ordnance Survey sheet number, townland name), altitude (feet or meters), slope or gradient (in degrees or percent), aspect, surface drainage and vegetative cover; (2) *Morphological data*, including data on profile depth, horizon thickness and arrangements; colours, structure, texture, consistence, stoniness and rooting; (3) *Compositional data*, including laboratory analysis of particle size distribution, cations, pH, organic carbon, free-iron and other parameters; and (4) *Occasional data* on trace elements or clay mineralogy. Peat soils data usually include ash content, rubbed and un-rubbed fibre, pyrophosphate index and macro-fossil data.

The horizon designation and taxonomic placement of soils change with time and with the system used (USDA, British, FAO, or other). Sources of soil profile data include: Soil bulletins of statutory bodies such as Teagasc (formerly An Foras Taluntais), Department of Agriculture Northern Ireland (DANI), Coillte Teo. and University College Dublin; theses, reports, papers of research personnel, usually associated with third level colleges; national and international journals, proceedings of conferences and workshops and similar media.

A substantial body of good information now exists for the soils of the following counties: Antrim, Armagh, Carlow, Clare, (London)Derry, Down, Fermanagh, Kildare, Laois, Leitrim, Limerick, Meath, Tipperary North Riding, Tyrone, Westmeath and Wexford. Information of similar quality is available for West Donegal, while soil maps of West Cork and West Mayo were published without soil profile data. Similar archives exist for most EU and US states. Journals which publish Irish soil data include *Irish Journal of Agricultural and Food Research; Irish Geography; Proceedings of the Royal Irish Academy; Biology and Environment* and any mainstream soil science journal to which Irish researchers submit.

Soil Sample (Test) Data

Soil testing schemes for farmers' samples have been operating since the 1940s in Ireland and since the 1930s in Northern Ireland. Under these schemes thousands of samples have been analysed yearly for properties important to growing crops. The information generally includes data on extractable nutrients such as Ca, Mg, K and P, as well as pH and lime requirement. Trace element composition, electrical conductivity and other measurements are occasionally reported for special situations such as horticultural crops.

The main sources of these data are: Teagasc (Johnstown Castle, Wexford) and Department of Agriculture, Northern Ireland (New Forge Lane, Belfast). In Ireland, commercial laboratories approved under Rural Environment Protection Scheme (REPS) are listed by Department of Agriculture, Food and Forestry (DAFF) (Anon., 1996). Summary tables and/or graphical representation of the results are occasionally published in journals, farming press, conference proceedings and similar outlets. Users of soil test data should be aware that laboratories use different extracting/analytical procedures and that the results are not always directly comparable. An example is the use of the "Olsen" method by DANI, the "Morgan" method by Teagasc and the "EUF" method by Greencore/IAS to measure available phosphorus.

Large-Scale Soil Maps (1:1,000-1:10,000 approximately)

Accurate mapping at this range of scales is limited to sites of special (pedologic) interest such as plots, fields and farms used for research and teaching (e.g. Animal Production Research Centre, Grange, Co. Meath; Agricultural and Horticultural College Farm, Piltown, Co. Kilkenny). Similar scales were used to depict the soils of parts of National Parks (e.g. Connemara, Killarney). The mapping units (series, phases, variants) are usually supported by morphological and analytical data. Specialist data such as hydraulic conductivity, micromorphology, and speciation of Fe and Al, may be reported occasionally. These soil map units do not usually carry an identifiable name but may be identified by capital letter (A, B, C...) or number (1, 2, 3....) or occasionally by both (1, 2A, 2B, C...). It should be noted that, while the O.S. topographic maps at a scale of 1:10,260, (6 inch to 1 mile) were used as field sheets by the National Soil Survey for county mapping in Ireland, soil maps of this scale were not published; the field sheets are available, however, for inspection at the Teagasc Research Centre at Johnstown Castle, Wexford, by appointment. However, as the field surveys were directed towards smaller-scale mapping, the additional unpublished information on these sheets is limited.

Medium Scale Soil Maps (1:25,000 to 1:250,000 approximately)

The most commonly available maps at this range are the 1:50,000 map series of Northern Ireland and the 1:126,000 (inch to 1 mile) maps of some of Ireland's counties. The former identify soils according to their great group (e.g. podzol) or subgroup (e.g. peaty gley) and are depicted on 17 colour sheets numbered consecutively form the NW to the SE. The soils of nine counties and parts of other counties (mapping unit: the soil series or combinations thereof) are published separately and in colour. Most of the Bulletins include, as well as a soil map, a soil suitability map and a soil drainage map. The counties published prior to 1980 are listed in the end-papers of Soil Survey Bulletin No.36, (Gardiner & Radford, 1980). Information on soil reports published since then is available from Teagasc. Soil series are named after some locality, usually where the soil was first mapped (e.g. Patrickswell) or where that soil is most extensive (Clonroche). Complex mapping units of two or three series (e.g.. Ladestown-Rathowen Complex) are common in midland counties. Phases and variants (as in Athy gravely phase; Ashbourne Shaly phase; Rathkenny sandy variant) are sometimes shown.

Ireland's county maps are each accompanied by a comprehensive bulletin, while the publication "Soils and Environment: Northern Ireland" acts as a bulletin for the soils of Northern Ireland. Northern Ireland's soil data are also available in digital format from the Ordnance Survey of Northern Ireland.

Small Scale Maps (1:250,000 and upwards)

The most widely known and used maps within this scale range are the two editions of the Soil Map of Ireland, dated 1969 and 1980 respectively, and the Peatland Map of 1981 (scale 1:575,000). The soil maps are composed partly of material generalised from the county soil maps which were completed before the dates in question, and partly from reconnaissance data for the remaining counties. The map units are mostly Associations of Great Groups and Subgroups.. The extent of each is given as a percentage of the land area represented by a Principal Soil and one or more Associated Soils. Both the 2nd edition of the Soil Map (Gardiner & Radford, 1980) and the Peatland Map (Hammond, 1980) were accompanied by bulletins (now out of print). The former includes data for forty-four soil profiles; the peatland map has an elaborate legend which includes vegetational, environmental and industrial information. Simplified, generalised, monochrome sketch maps of 16 of the 17 colour maps of Northern Ireland soils are presented in Cruickshank (1997). The generalisation is based on parent material and the scale reduction is from 1:50,000 to 1:250,000.

A single-sheet map of Land Drainage Problems of the Republic, based on questionnaires returned by Department of Agriculture officers was published at the scale 1:575,000 (Galvin, 1971). Also at the lower end of this range of scales (i.e. 1:250,000) are Grazing Capacity maps of soil series of four counties (Carlow, Clare, Limerick, Wexford) published with an accompanying Bulletin by Lee & Diamond in 1972. This Bulletin also included 3 colour maps at 1:1,000,000 – a general soil map, a grazing density map, and a grazing capacity map. The county maps were based on the 1:126,000 soil series maps of each county.

Soil Maps of Very Small Scale (1:2,000,000 :5,000,000, :10,000,000...)

Maps at these scales are of educational rather than of technical value; in the case of soil they show the general outline of Soil Orders and/or Suborders. They are usually found published in atlases and textbooks with the legend substantially modified and simplified. Examples at the lower end of this range include the Soil Map of Europe at 1;1,000,000 (Commission of the European Communities, 1985) and the Soil Map of the World at 1:5,000,000) (FAO, 1975), both printed on a number of sheets. In 1991 the FAO prepared a 1:25,000,000 map of the world's soil resources as well as a generalised version at 1:100,000,000 scale. A resume of FAO soil map series is given by Meyer-Roux & Montanarella (1998). Irish examples are found in the *Atlas of Ireland* (RIA, 1979) and *Agroclimatic Atlas of Ireland* (Collins & Cummins, 1996). Maps of these scales are also used to show the national outline of the fertility status or geochemistry of soils.

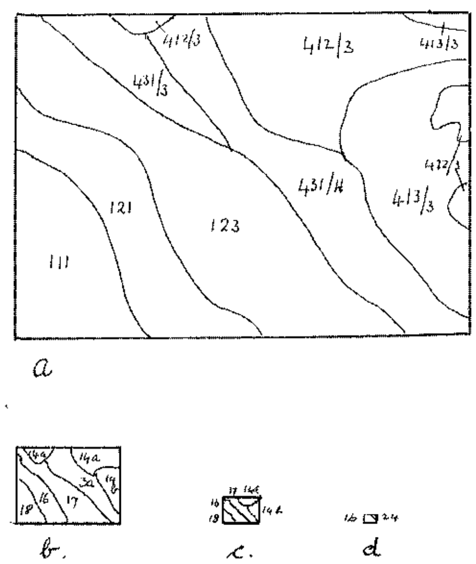

Figure 4.4: Effect of scale on soil depiction. Scale at "a" represents linework from a 1:10:560 map. Schematically, reduction to "d" results in a scale of approximately 1:575,000

All soil maps, regardless of scale, have their uses. The scale suitable for one purpose may be entirely unsuitable for another. The ideal map of soil type for general farming may be *c.* 1:10,000; that for a research plot *c.* 1:1,000, while the county planning office would prefer scales of 1:50,000 or smaller. Figure 4.4 shows the loss of precision suffered in reducing the information recorded in the 6-inch field sheets, (a) to the scale necessary to depict the area on the General Soil Map (d). In some instances a derivative map (e.g. soil slope or soil drainage map) may be most useful; in others, soil and environmental data may be combined to create a productivity map. Regardless of scale, maps without a reliable legend and supporting field and laboratory data are of little use. Combining geographical information with numerical and descriptive data, provides a sound foundation for interpretative uses. (see Chapter 2 and section 4.8).

4.7 *Vegetation Resources*

(J. White)

4.7.1 Introduction

The scientific study of Irish vegetation began in 1905 with the publication of The Vegetation of the District Lying South of Dublin (Pethybridge & Praeger, 1905). Until the 1960s, however, little systematic research was undertaken, as White (1982a) has documented. The first countrywide synopsis of a vegetation type (lowland grasslands) was by O'Sullivan (1965). Since then, several comprehensive accounts of various kinds of Irish vegetation have become available, mostly as University research theses; relatively few have been published in scientific monographs or periodicals. The overall position until 1982 was summarised by White & Doyle (1982) and by other papers in White (1982b). There has been no review or synthesis of the literature since then, a period during which there has been as much research on Irish vegetation as in the preceding 80 years. In this chapter, the several relevant papers in the book edited by White (1982b) are taken as a datum point for all earlier literature, which was comprehensively surveyed therein. Sources of post-1982 information are outlined below; but given their diversity, these are merely guides rather than a complete inventory. A somewhat fuller inventory is given of maps of all periods, but this is not exhaustive.

4.7.2 Tabular Data

"Vegetation" is a collective noun for the assemblage of plant species in a particular place. Vegetation scientists often refer to this assemblage as a "plant community", on the supposition that the species interact socially in some manner, although this is a matter of considerable debate. Essential to the definition of a plant community is a listing of the species growing together in a defined space, often with a quantitative or semi-quantitative assessment of their relative abundance. Rarely is an exact numerical estimate made of populations of each species (White, 1985); more subjective estimates suffice to characterise the ensemble of species present. The listing is usually comprehensive, ideally, all vascular plants (seed plants, ferns), bryophytes (mosses, liverworts) and lichens are recorded. The sample area chosen varies with the scale of the vegetation: larger for tall, structurally complex vegetation (e.g. forests) than for lower vegetation (whether rich or poor in numbers of species). In the scientific analysis of vegetation, each particular description is regarded as a statistical sample (sometimes referred to by the French term, relevé). Repeated samples of similar vegetation are assembled into a tabular form and sorted to highlight recurrent patterns of species occurrences and coincidences. If such patterns can be detected and distinguished from

other patterns in other types of vegetation, then the sorted and combined samples may be used to define a vegetation "association". This is a technical term (not synonymous with the more colloquial "plant community") to indicate a combination of species which together help to define a type of vegetation. Most significantly, not all particular, individual samples of a vegetation type may show all the defining characteristics (species) of the association; but they will have more species characteristic of that association than of any other association, defined by the same criteria.

Vegetation types are best defined not by one list of species, indeed they cannot be so defined, but by several lists combined into a tabular form (Figure 4.5). The degree of analysis of each table varies, however, with the research tradition or practical purpose of its compiler (see for example, White & Doyle, 1982). Tabular data of Irish vegetation are not necessarily precisely defined as associations; some are even poorly sorted lists of species, merely ranked from the most to the least abundant species in the data set. But the more critical investigator can use such partly sorted tables to advantage, and should be aware of them. Often, indeed, scraps of tables or even a single list of species can be combined with more comprehensive data obtained later to define or identify plant associations hitherto imperfectly known or unrecorded in Ireland (e.g. White, 1982c). There are probably about 220 vegetation associations in Ireland, of which some 150 may be regarded as being well-defined (White & Doyle, 1982). Others are provisional and need further research to confirm their status; many of these involve various types of aquatic and ruderal vegetation.

Most of the well-defined Irish vegetation associations show similarities to associations known also in Britain and north-western Europe. There is, however, some local Irish variation in species composition, typically an absence of species because of the relatively depauperate flora of Ireland (about 1350 native and naturalized species, depending on definitions. See Webb, 1978).

Vegetation scientists believe that associations reflect, in some manner, the complex interactions of climate, hydrology, soil, and biotic influences (including human management). Even when appropriate environmental data are available, it is a complex task to establish correlation between these variables and vegetation associations, except in some clear-cut instances: for example, major peatland associations are correlated with climate and hydrology, major grasslands associations with soil factors and management, some major coastal associations (of salt marshes and sand dunes) with substrate and tidal influences.

Information in tabular data

Vegetation tables are conventionally and universally arranged with species in rows and replicate samples in columns. The head of each column contains a variety of information, ideally the following: the number of the sample, aspect (compass point), inclination (slope), sample size, percentage cover of vegetation on the site, and number of species. The location of each sample is given at the foot of the table or in the text, keyed to sample number at the head of each column; additionally the date of sampling may be included. Models of this style are given by Braun-Blanquet & Tüxen (1952), which is the classic Irish exemplar and source reference (Figure 4.5). In fact, however, few tables meet these standards, but all will minimally have the sample number at the head of each column; further information, of variable quality, on each sample may be given in the text.

An association table may list numerous (perhaps hundreds) of field samples, each one a replicate of the type of the vegetation collectively characterised by them. For convenience, this table may be condensed into a single column, indicating the sample frequency of each component species, usually on a 7-point scale. By this means, the species composition of closely related associations may be compared in a so-called "synoptic" or "constancy" table (Figure 4.6). Furthermore, such a table may be used conveniently to relate vegetation samples to those of other counties, especially in the same region, thereby highlighting geographical or ecological gradients in species composition (Figure 4.7).

Sources of data

Vegetation tables, whether formally presented as plant associations or not, are abundant for a wide variety of Irish vegetation types. More recent work of good quality usually incorporates earlier, less comprehensive tables of similar vegetation. Most of them are in unpublished Ph.D. and M.Sc. dissertations or undergraduate theses in the Universities; they are not systematically catalogued, however, and many remain unpublished. The principal sources are the Departments of Botany in University College Dublin (National University of Ireland, Dublin), National University of Ireland, Galway, and University of Dublin, Trinity College. Some have been published in whole or in part in national or international journals, principally in *Proceedings of the Royal Irish Academy B* (latterly *Biology and Environment*), *Irish Naturalists' Journal* and *Journal of Ecology*. The National Parks and Wildlife Service (now part of Dúchas, The Heritage Service) has extensive relevé data on Irish vegetation, especially on types of conservation importance. Some of these have been published (O'Connell *et al.*, 1984; Cross 1990; Crawford *et al.*, 1996); all are available to researchers. Their database allows relevés to be sorted by habitat type, vegetation type, and grid reference. During the 1970s and 1980s a variety of theses (many of them doctoral) on Irish vegetation appeared from some Dutch universities, especially the Laboratory for Geobotany, Catholic University of Nijmegen, largely inspired by Professor Victor Westhoff who maintained an active personal interest in Irish vegetation at that time. These contain extensive primary field data and local vegetation maps.

Typically, earlier datasets are incorporated into more recent theses or publications, and are often re-interpreted in the light of more comprehensive knowledge. Examples of this practice include: O'Connell *et al.* (1984; 614 relevés of wetland vegetation); Heery (1991; 267 relevés of flooded grassland (callows)); Ó Críodáin & Doyle (1994; 511 relevés of small-sedge vegetation); Kelly & Iremonger (1997; 93 relevés of Irish wet woodlands). Nonetheless, much work remains to achieve a synthesis of very diverse datasets. To date, for example, although there are now thousands of available relevés, there is no synoptic table of Irish grasslands, which account for some 65-70% of the land area. The general features, distribution and ecology of grasslands have been best summarised by O'Sullivan (1982).

Not uncommonly, accounts of British or of Western European vegetation may include some descriptions of Irish vegetation, as part of wider synopses; such sources are usually cross-referenced in relevant publications by Irish scientists. No comprehensive account of Irish vegetation yet exists.

There has long been an ideal among European vegetation scientists to develop a pan-European synthetic framework of vegetation classes. (Associations are the basic units of a hierarchical classification, successively clustered into alliances, orders and classes). Attempts to realise such a project in the past thirty years have achieved little progress, perhaps being hampered by the diversity and scale of the undertaking. Instead, there has been an increasing number of published national vegetation inventories, two of which are of particular relevance to Ireland (Rodwell, 1991-1999; Schaminée *et al.*, 1995-1999). Clearly, a consensus on a stable description and classification of European vegetation is an essential prerequisite for trans-national vegetation mapping, nature conservation and monitoring environmental changes. This is currently being attempted by the European Vegetation Survey under the auspices of the International Association for Vegetation Science.

Small scale 1:500 000 and upwards

The *Atlas of Ireland* (RIA, 1979) contains four maps of various aspects of Irish vegetation-essentially the first multicoloured maps since 1907: (1) *The vegetation as a whole* (1:1,250,000) is indicated using major categories which account for some 90% of the non-arable cover: lowland and low-elevation grasslands, heathlands, and mires. The definition of boundaries is based on the Soils Map, compiled by the National Soil Survey, as a best approximation of these major vegetation types. This vegetation map is reproduced (c.1:2,600,000) in O'Sullivan (1982); (2) *The peatland map* (1:1M) depicts five major mire (bog and fen) types, together with the extent of their exploitation. This map (1:575,000) was revised subsequently by the National Soil Survey (Hammond, 1979); an amended version has been reproduced (1:2,000,000) by Aalen *et al.* (1997). A revised map of raised bogs (1:575,000) which accompanies a report by Cross (1990) carefully documents their serious depletion in recent decades; it is based on data collected during 1982-1987; (3) *A field boundaries map* (1:1,250,000), excluding unenclosed and upland areas, indicates the species composition of hedges, mostly planted since the early 18^{th} century, although some may represent the linear fragments of long-felled woodlands. The distribution patterns, based on extensive local sampling, are derived from the General Soil Map of Ireland; and (4) *A State forests map* (1:1,250,000) depicts essentially conifer plantations in public ownership in 1972, but this is seriously outdated.

4.7.3 Vegetation Maps

Large-scale (1:1,000-1:10, 000 approximately)

Accurate mapping at these scales is typical of sites of special botanical interest. Such maps commonly occur in unpublished research dissertations in University Departments. They exist also for grassland surveys conducted by Teagasc (formerly An Foras Talúntais) on various farms (e.g. Jaritz & Lee, 1968; O'Sullivan, 1986, both at 1:2,500), and for some sites of scientific interest (Dúchas, National Parks and Wildlife Service).

		58	70	73	74	142	149	150	246	299	313	321
	Nr. der Aufnahme	58	70	73	74	142	149	150	246	299	313	321
	Autor	Tx	BB	Tx	Tx	Tx	BB	BB	Tx	Tx	Tx	Tx
	Mähwiese (M), Weide (W)	W	MW	W	W	MW	—	W	M	M	W	W
	Exposition	N	—	SW	.	..	.	S	N	SE	SE	S
	Neigung	5°	—	5°	.	.	.	2°	5°	20°	3°	3°
	Grösse der Probefläche (m²)	30	100	50	.	.	.	100	.	.	.	.
	Artenzahl	33	22	30	25	29	15	20	34	38	23	26
Charakterarten:												
Hc	*Cynosurus cristatus* L.	1.2	3.2	2.2	2.2	2.2	2.1	3.2	2.3	2.2	.	3.2
Hrept	*Trifolium repens* L.	3.3	2.2	3.3	2.2	1.2	2.2	2.2	2.2	1.2	2.2	3.3
Hs	*Senecio Jacobaea* L.	+	+	2.1	+.2	.	.	.	.	.	+.1	+.1
Hc	*Phleum pratense* L.	.	.	.	.	.	.	.	.	.	.	.
Differentialarten der Assoziation:												
Hs	*Centaurea nigra* L.	.	2.1	+.1	+.1	+.2	.	.	+	1.2	.	1.1
Hros	*Leontodon taraxacoides* (Vill.) Mér.	.	.	.	.	.	.	2.1	.	.	1.1	.
Differentialarten der Untereinheiten:												
Chr	*Cerastium caespitosum* Gilib.	1.2	+	1.2	1.1	1.1	1.2	.	+.1	1.1	+.2	2.1
Hc	*Lolium perenne* L.	1.2	+	1.2	+.2	2.2	3.2	.	.	.	+.2	2.2
Hc	*Dactylis glomerata* L.	.	+	.	.	.	.	1.2	.	.	.	+.1
T	*Crepis capillaris* (L.) Wallr.	+.1	.	.	1.1	2.1	1.1	2.1	+.1	1.1	+	.
Brr	*Brachythecium rutabulum* (L.) Br. eur.	2.2	.	1.2	.	1.2	.	.	2.2	2.2	2.2?	2.2
Ordnungscharakterarten:												
Hs	*Chrysanthemum leucanthemum* L.	.	2.1	(+.1)	2.1	2.1	.	+.1	+.1	2.2	+	.
Hros	*Bellis perennis* L.	1.1	.	1.1	.	1.1	2.2	2.1	.	.	.	+
T	*Trifolium dubium* Sibth.	2.2	.	+.2	.	2.2	.	+	1.1	+.2	.	.
T	*Bromus mollis* L.	.	.	.	.	1.1	.	.	1.2	+.1	.	.
Hc	*Trisetum flavescens* (L.) P.B.	.	.	.	.	.	1.1	2.1	.	.	.	+.2
Hs	*Daucus carota* L.	.	.	.	.	.	.	.	.	.	.	.
Klassencharakterarten:												
Hs	*Prunella vulgaris* L.	2.2	2.1	2.2	2.1	1.1	.	+	+.1	2.2	+.1	2.1
Hc	*Holcus lanatus* L.	2.2	1.1	2.2	2.2	1.2	1.1	2.1	2.2	2.2	2.2	+.2
Hs	*Trifolium pratense* L.	.	2.2	+.2	1.2	2.2	2.2	+	1.3	2.2	.	2.2
Hs	*Rumex acetosa* L.	1.1	+	.	+.1	1.1	1.1	.	.	1.1	.	+.1
Hc	*Festuca rubra* L. ssp. *eu-rubra* Hackel var. *genuina* Hack.	1.2	+	2.2	1.2	1.2	.	.	.	1.2	.	.
Hs	*Ranunculus acer* L.	.	.	(+)	+.1	1.1	1.1	.	.	.	.	+.1
T	*Rhinanthus minor* L. s. str.	.	.	.	.	1.1	.	+	2.1	+	.	.
Hc	*Poa trivialis* L.	+.1	.	.	.	+.1	.	.	1.2	1.1	.	1.1
Hsc	*Vicia cracca* L.	.	.	.	.	.	.	.	+.2	.	.	.
Hc	*Juncus effusus* L.	2.2	.	.	.	.	.	.	+	.	.	.
Hs	*Cirsium palustre* (L.) Scop.	+	.	.	.	.	.	.	.	.	.	.
T	*Rhinanthus glaber* Lam. s. str.	.	.	.	.	+.2	.	.	.	2.1	.	.
Hs	*Lotus uliginosus* Schkuhr	.	.	.	.	.	.	.	1.2	.	1.2	.
Begleiter:												
Hros	*Plantago lanceolata* L.	1.1	2.1	+.1	1.1	2.2	1.1	+	2.2	1.1	2.2	2.1
Hc	*Agrostis tenuis* Sibth.	2.2	+	3.2	2.2	.	.	.	2.2	2.2	3.2	2.2
Hc	*Anthoxanthum odoratum* L.	1.2	+	.	.	1.2	.	.	2.2	2.3	2.2	+.2
Hros	*Hypochoeris radicata* L.	.	2.1	+.1	2.1	.	.	+	1.2	1.1	1.1	+.1
Hs	*Lotus corniculatus* L.	2.2	.	1.2	1.2	.	.	.	.	.	1.2	+.2
Hrept	*Ranunculus repens* L.	1.2	.	2.1	.	+.1	.	.	+.1	1.1	+.1	2.2
Hs	*Achillea millefolium* L.	.	.	.	.	.	.	+	.	1.1	.	+.1
Hros	*Leontodon autumnalis* L.	+	.	.	+.1	+.1	1.1	.	.	+	.	.
Chp	*Rhytidiadelphus squarrosus* (L.) Warnst.	.	.	2.2	.	.	.	.	+	2.2	3.3	.
Hs	*Ranunculus bulbosus* L.	.	+	.	+.1	.	.	+	.	.	.	.

Figure 4.5: Facsimile extract from Table 29 of Braun-Blanquet & Tüxen (1952) showing the classical layout of a sorted vegetation table. Each column represents a single field sample. Each species is given a 2 digit cover or abundance code and a morphological character code. Appropriate theory and methodology can be found in Mueller-Dombois and Ellenberg (1974)

	Puccinellietum maritimae	Halimionietum portulacoidis	Juncetum gerardii	Junco maritimi-Oenanthetum lachenalii	Artemisietum maritimae	Blysmetum rufi	Puccinellietum distantis	Atriplici-Agropyretum pungentis	Halo-Scirpetum maritimi
Number of relevés	225	22	159	13	8	11	2	3	17
Association character species									
Puccinellia maritima	V	IV	II		II	+	III		I
Halimione portulacoides	I	V	R					IV	
Juncus gerardii	R		V	II	II	V			III
Juncus maritimus	R		II	V	I	+			
Oenanthe lachenalii			R	V					
Artemisia maritima	R				V				
Blysmus rufus			R			V			
Puccinellia distans							V		
Spergularia marina	R		R	I			V		
Elymus pycnanthus								V	
Scirpus maritimus	R						III		V
Sagina maritima									
Asteretea tripolii Class character species									
Aster tripolium	IV	III	III	I	III		III	IV	III
Plantago maritima	IV	II	IV	III	IV	V		II	I
Triglochin maritima	II	II	III	I	I	III	III		III
Order species									
Armeria maritima	IV	I	IV		II	V			+
Glaux maritima	III	+	V	V	II	V	III		II
Alliance species – Puccinellion maritimae									
Spergularia media	IV	III	I						
– Armerion maritimae									
Festuca rubra	R	R	IV	V	V	IV		IV	I
Agrostis stolonifera	R		III	V	III	V	III		III

Figure 4.6: Edited extract from Table 28 of Wymer (1984) showing the layout of a synoptic or constancy table of Irish salt marsh vegetation. Each column is a vegetation association and each species is given a "constancy value" representing frequency. Reproduced with the permission of E. Wymer.

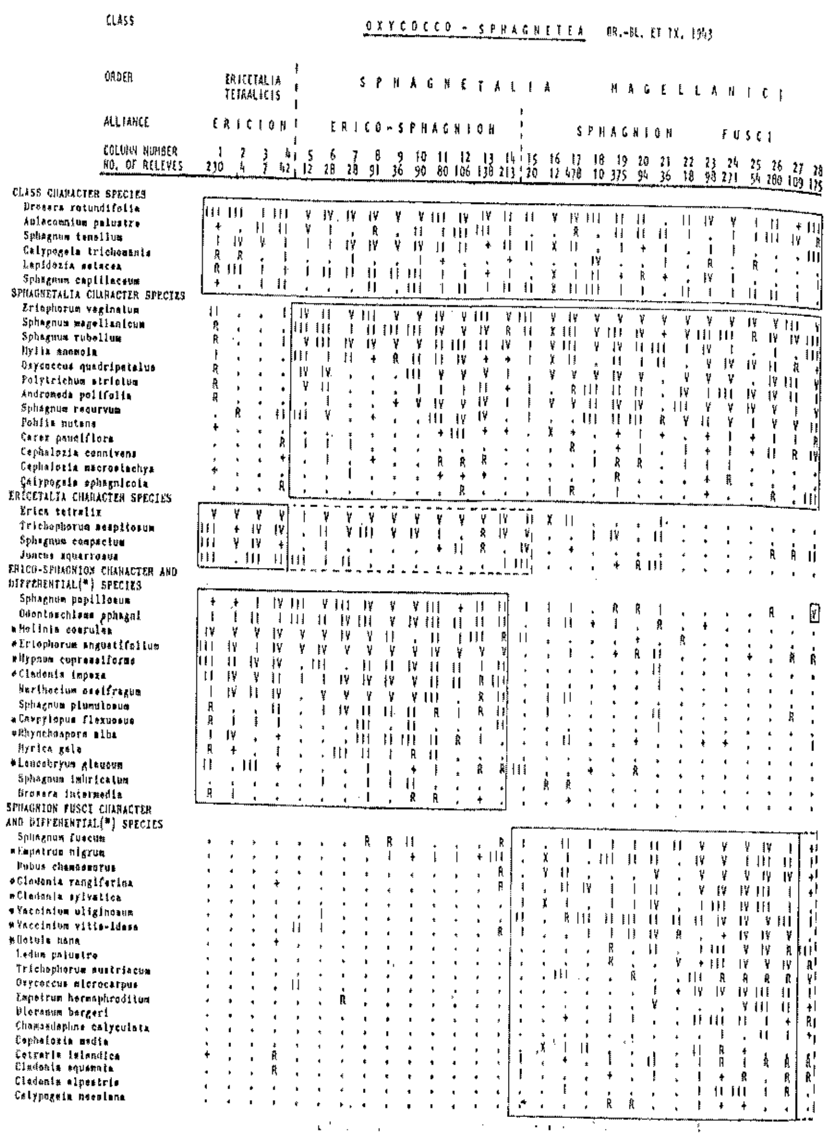

Figure 4.7: Edited extract of Table 1 from Moore (1968) showing the layout of a synoptic or constancy table of bogs and wet heaths of northern Europe. The table summarises data on 3135 relevés throughout the region. Columns 4, 8, 10 and 14 include data from Ireland

Published maps at this scale include, for example, vegetation of sand dunes and salt marshes at both North Bull Island (c.1:8,750) (Moore & O'Reilly, 1977) and Malahide Island, Co. Dublin (c.1:10,500) (Ní Lamhna, 1982); woodland vegetation at Derryclare, Co. Galway (c.1:8,000) (Ferguson & Westhoff, 1987); aquatic and wetland vegetation of Lower Lough Corrib, Co. Galway (c.1:8,000) (Mooney & O'Connell, 1990), and a polychrome map of vegetation around Mullach Mór, Co. Clare (1:7,500) (Moles & Travers, 1983).

Medium-scale (1:20,000-1:250,000 approximately)

The two earliest maps of Irish vegetation were at a medium scale. A map of an area (some 200 square miles) lying south of Dublin depicted 13 vegetation types at a scale of 1:63,360 (Pethybridge & Praeger, 1905); the original field-maps (1:10,560) are still available (National Botanic Gardens Library). The map was widely acclaimed for its technical excellence and was the first vegetation map printed (at the Ordnance Survey Office, Southampton [UK]) and published by the British government (White 1982a) Together with a map of vegetation (1:21,120) on Lambay Island, Co. Dublin (Praeger, 1907), these maps constitute the only polychrome vegetation maps published in Ireland until the 1970s. A map of the vegetation of Clare Island, Co. Mayo (1:31,680) (Praeger, 1911), depicting eight vegetation types, concluded the series of vegetation maps published by Praeger. Some further sources of maps made during the 1920s and 1930s by botanists at The Queen's University, Belfast are reviewed by White (1982a). A map of the vegetation of Carrowkeel, Co. Sligo (1:26,000) (Webb, 1947) is an isolated example during a long fallow period of Irish vegetation mapping, not revived until the 1960s. Moore (1960) resurveyed and remapped an upland area of 100 km^2, part of the district originally mapped by Pethybridge & Praeger (1905); his map (1:38,500) documented changes that had taken place in the intervening 50 years, and is the only published example of such a comparison based on mapping.

Peatlands in Northern Ireland have been comprehensively mapped at 1:20,000 using air photographs (Cruickshank & Tomlinson, 1990). Generalised vegetation categories have been recorded in the broad survey, but some field-based validation of the exact botanical composition of the air-photo images has been conducted, resulting in a vegetation map (1:26,500) of part of the Garron Plateau, Co. Antrim (Tomlinson, 1984).

It may be noted that localised maps of peatlands (at various scales) were published in the Reports of the Commissioners appointed to enquire into the nature and extent of several bogs in Ireland (1810-1814); but they treat peatlands as an economic resource, with little reference to their botanical variety. Examples have been reproduced in historical accounts of Irish peatlands (e.g. Feehan & O'Donovan, 1996; Aalen *et al.*, 1997). An attempt to represent the forests of Ireland (c. 1:1,860,000) (conifer plantations, broadleaf, and mixed) is given by Aalen *et al.* (1997). This is derived from the CORINE database of satellite imagery (with a minimum identifiable unit of 25 ha), and is the most comprehensive forest map now available at this scale. Woodlands in Co. Wicklow are represented (c. 1:590,000) in Aalen *et al.* (1997).

The CORINE database, used for the forest map mentioned above, employed a gross level habitat classification scheme based largely on plant formations well defined in western Europe (Devillers *et al.*, 1991). This permits accurate mapping (1:100,000) of major vegetation types, subject to field verification, but lacks the level of discrimination normally demanded by a vegetation scientist. Maps have been published at 1:500,000, and a composite (1:2.5M) is reproduced by Collins & Cummins (1996). Maps for specified areas are available to order commercially from ERA-Maptec, Dublin, which holds the CORINE database. Pasture grasslands, forests, heathlands, and peatlands, all of varying botanical composition, are discernible. It is not simple to relate the CORINE categories to particular vegetation associations; some of the problems involved have been outlined by Cruickshank & Tomlinson (1996). The Forest Service has developed a Forest Inventory and Planning System (FIPS) using a comprehensive combination of data bases, with satellite imagery as a primary source: all forest lots greater than 0.2 ha have been classified in one of twenty categories. Information may be obtained from FIPS Management Unit, Forest Service, Johnstown Castle, Wexford.

Ireland is represented on the vegetation map of the Council of Europe member states (1:3M) (Ozenda, 1979), but this map is grossly misleading, based as it is on a metaphysical conceit: the natural vegetation of Ireland as it might be in the future absence of man! Most of the island is shown covered by forests (ash or oak predominantly), heathlands and bogs, but even the latter (which are common) are poorly and inaccurately circumscribed. Further, more reliable refinements of this map have been made (Cross, 1998) but on the same principles; consequently, whatever its theoretical virtue, the map has dubious practical utility.

Distribution Maps

Inventories of sites have been occasionally compiled for particular vegetation types which are relatively infrequent or of small extent when compared to the predominant grassland cover of Ireland. Sometimes these are shown on dot distribution maps: for example, wet woodlands (Kelly & Iremonger, 1997), woodlands on esker ridges (Cross, 1992), wetland vegetation (O'Connell *et al.*, 1984). The distributions of most of the sand dunes (Curtis, 1991) and of salt marshes (Curtis & Sheehy Skeffington, 1998) have been mapped, thereby indicating the localities of potential vegetation types which are commonly found in these habitats. A comprehensive inventory of raised bogs is provided by Cross (1990). Dúchas, The Heritage Service has unpublished inventories of blanket bogs, turloughs and esker grasslands.

Some information on the distribution of vegetation types may be gleaned from *Atlas of the British Flora* (Perring & Walters, 1962): this shows for each species in the Irish flora its distribution within a 10 km x 10 km grid (c. 900 of which cover Ireland). The restriction of a particular species to a particular vegetation may, with the help of the distribution map, define the occurrence of the vegetation, at least at a relatively crude scale. But these are at best only guidelines, given the vagaries of species' distributions. Moreover, the recorded distributions may be imperfect; a revised edition of the Atlas is projected for publication in 2001, containing updated and expanded records.

4.8 Land information and appraisal of land resources

(J. F. Collins)

4.8.1 Introduction

Acquiring basic information on rocks, water, vegetation, soils and other resources is not an end in itself. The information is much more useful when individual parts are combined, analysed and interpreted to get "added value". Towards the end of the 20th Century there were major advances in land evaluation (e.g. concepts such as resilience and sustainability) which have benefited our understanding and management of land resources. To maximise these new-found benefits, particular attention must be given to efficient methods of archival and retrieval of data, as well as to the computing capacity for its processing and modelling. Beek (1978) purported that the concept of land quality emanated from the desire to reduce the enormous amount of land data to manageable proportions without loss of information. In its revised and enlarged *Soil Survey Manual*, the Soil Survey Division Staff of the US Department of Agriculture (Soil Survey Staff, 1993) devoted 170 out of 450 pages to the task of bringing soil survey information to the user. Chapter 6 (146 pages) deals with "Interpretations", while Chapter 7 is entitled "Disseminating Soil Survey Information". In the same year , 1993, the Land and Water Development Division of the FAO published a 250 page book in response to increasing demand for adequate information on computerised systems for land resources appraisal for sustainable agriculture (Chidley *et al.*,1993). In their introduction the authors drew attention to the issue of climate change and the need for timely, reliable and meaningful information on land resources potentials and limitations. More recently the European Soil Bureau (Heineke *et al.* 1998) published a 550 page treatise on land information systems, devoting sections to both national and European perspectives. In the latter section the authors discuss information policy, access to European databases, environmental applications and land evaluation.

Starting with the publication of its first Bulletin in 1964, Soil Survey Bulletins of the National Soil Survey of Ireland include a chapter headed "Soil Suitability". The preamble usually emphasises that the ratings assigned were qualitative rather than quantitative. In the 1970s and 1980s the ratings became more quantitative on foot of experimental data and yield measurements of grass, arable, forest and other crops. In their digest of Irish soil resources, Gardiner & Radford (1980) stated that Chapter 11 (pages 125-141) "attempts to interpret for practical use the basic data derived from the Soil Map." As well as grouping 44 Soil Associations according to physiographic location and administrative area, Irish land was classified either as "Marginal" or "Tillage", the latter being divided into four subclasses: highly suitable; suitable; moderately suitable; and marginally suitable.

4.8.2 Land resource appraisal

Chidley *et al.* (1993) define land as "An area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man". They listed 13 applications of land resources appraisal or evaluation, stating that the outputs are used by planners, economists, engineers, scientists, politicians and others. The most significant applications require quantitative knowledge of the input data – the kind of data that are the main focus of this chapter. These applications are listed below with a note attached to each showing current or past examples in Irish contexts where such data were used. Examples help to show how data from a wide variety of sources, collected by personnel from disparate institutions and for widely differing purposes can be assembled, reprocessed and interpreted for an ever-widening range of uses.

Land Suitability Assessment
Despite the early attempt by Storie (1933) to express soil/land quality numerically, ranking on an ordinal scale (e.g. low-medium-high) remains commonplace. Most rankings are connected to the use and management of land for production purposes, consistent with environmental conservation. Using climate, landform, crop yield and other data, most Irish county soil survey reports include tables and maps of suitability. The earlier of these indicated suitability for "all purposes"; more recent ones give separate ratings for general tillage, grassland and forest crops. Usually 5 or 6 Suitability Classes are recognised and their distribution shown on an accompanying map by categoric generalisation of the soil map units. The national picture was portrayed in map form by the Royal Irish Academy (RIA, 1979), and outlined in tabular and text form by both Gardiner & Radford (1980) and Cruickshank (1997). There is as reasonable degree of similarity between "Tillage Classes 1, 2, 3 & 4" of Gardiner & Radford and "Agricultural Land Grades 1, 2, 3A & 3B" of Cruickshank, and between "Marginal Land" of the former authors, and "Grades 4 & 5" of the latter. Both classifications are based on modifications of the original guidelines of Klingebiel & Montgomery (1961). The geographic distribution of suitability classes for tillage and grazing were depicted on maps of very small scale in recent AGMET publications (Keane, 1986; Collins & Cummins, 1996).

Land Productivity Assessment
Maps and tables compiled under this heading are generally quantitative; the data are given in units such as tons of dry matter/ha or livestock units/ha. Examples include: 6 classes of potential forestry yield in cubic metres per hectare per annum, and grazing capacity/stocking rates in Livestock Units per hectare under low and high nitrogen regimes. Irish data were summarised for the soils of four counties (Lee & Diamond, 1972) and continued in subsequent soil survey reports. Lee (1986) placed Irish grassland in 3 productivity classes (10,000-12,000; 6,000-12,000, <6,000 kg dry matter /ha) on the basis of moisture availability, poaching susceptibility, and access for machinery. When included, the scale of productivity maps may vary form 1:2,500 (institutional farms) to 1: several million (countrywide) i.e. they are governed by the scale of the main input which is usually a soil map. Research supporting these kinds of assessments includes that of Brereton (1972), Brereton & Keane (1982), Conry (1985,1996), Conry & Hegarty (1997), Lee & Ryan (1966) and McEntee (1979).

Population Support Capacity
While this heading is meant to assess land availability for human habitation, the concept could be extended to make assessments such as grass growing season (Connaughton, 1973; Betts, 1982), grazing season (Keane, 1998), risk of water pollution from septic tank disposal systems (Daly *et al.*,1993), and to the number of machine work days per year. The concept may also include the effect of cattle, pigs and poultry, fish farms, surface and groundwater supply, and even intensive conifer planting (Cullinan & Bulfin, 1996), on the environment. Such interpretations are becoming common-place in Environmental Impact Statements and are prerequisites for awarding Integrated Pollution Control licences in many instances (EPA, 1995a, b).

Land Evaluation and Land Use Planning
While there are virtually no limits to this theme (Convery & Feehan, 1995), major areas of interest under this heading in Ireland include: designation of Special Areas of Conservation (SAC) and Natural Heritage Areas (NHA); location of National Parks, zoning for development, (use of cut-over peatlands, location of sanitary landfills, golf courses, and arterial drainage schemes). All of these require an assessment of climatic, soil, hydrological, socio-economic, amenity and aesthetic parameters. The purchase of turbaries and turbary rights with a view to conserving even very small parcels of peatland needs accurate ground survey and large scale maps. However, the scientific bases which underpin some designations or delineations (especially the SACs) are often unspecified and lead to public disquiet. Using a much smaller scale view, Gardiner discussed the value of soil survey in regional development (1981) and climate modelling (1982).

Land Degradation Risk Areas
In common with many terms dealing with the environment, the word "degradation" has many meanings (McIsaac & Brun 1999). When used with "land" it involves defining soil qualities, attributes and processes, and introduces concepts of resilience and sustainability (Taylor et al., 1996). In Ireland examples of research effort (and concern) include atmospheric deposition and accelerated acidification (acid rain, conifer litter) (Farrell,1995), peat instability on slopes, excessive grazing, soil surface crusting (Hussain et al., 1985), subsurface compaction (Larney 1985), and water quality (Sweeney, 1997). Critical factors in understanding the causes and processes involve detailed knowledge of climate, soil and landforms (Wilcock, 1997).

Quantification of Land Resource Constraints
Constraints of a heritage or amenity nature are difficult to quantify; others are much easier but the variables may be of a long-term nature (return periods of droughts, floods, severe frost). Depending on location, constraints may include: nutrient deficiencies/plant health (Stanley *et al.*, 1996), declining carbon pools (Cruickshank *et al*, 1998), aquifer vulnerability (Daly & Warren, 1998), runoff risk (Sherwood, 1992) availability of irrigation water, grounds for waste disposal (Daly,1998), exposure (fish farming, tree-throw), migratory bird corridors and sanctuaries, amenity/aesthetic concerns (wind turbines, communication masts) and disease carriers (a wide range of biotic species). A combination of some of these constraints was used in compiling site types for afforestation (Cummins & Whelan, 1996). A comprehensive Irish study on

resource constraints (i.e., atmospheric inputs/forest health) was reported on by Boyle *et al.* (1997). However, not alone are we still lacking quantifiable data on most of the constraints listed above, but the guidelines necessary to measure them are also critically wanting.

Land Management

The everyday implementation of a land use (or farm) plan may need readily available information (on computer) and feed back, especially if a change has to be made due, for example, to unpredicted weather conditions. Day-to-day, even hourly, decisions must be made in light of weather outlooks as to timing of fertilising, sowing, spraying, mowing and many other weather-related farm operations. Large intensive enterprises such as pig and poultry units must keep daily records of where slurry wastes are being applied, and have contingency plans for possible outbreaks of certain diseases. Farmers in Rural Environmental Protection Schemes (REPS) who must farm within restrictive guidelines are among those in need of information and feedback (Maloney, 1994). The concept could be enlarged to include "crisis management" in events such as oil spills, fish kills, fire damage and related accidents.

Agro-ecological Characterisation for Research Planning

Since the findings of field research should have the widest possible applicability, the location of research stations, farms, catchment basins, monitoring sites and even single sampling sites must be chosen with reference to the most up-to-date information on the major components - water, soil, energy, ecology. It is economically ineffective to invest a large research effort in a site which extends to, say, 1% of a region when equally applicable results could be acquired in an adjacent site which represents 5%, 10% or more of the region in question. In acquiring the information needed to make the correct choice of site, the primary source/form of the data should be searched for, since a lot of information is lost in transferring to a smaller scale (through cartographic or categoric generalisation). For example, the 2-sheet CORINE map of Ireland (1:500,000) shows a national land-cover picture but the local details should be assessed by reference to the original data (O'Sullivan *et al.*, 1994). Thematic maps which are built on detailed base maps facilitate locational accuracy and are superior instruments in interpretation and planning routines.

Technology Transfer

Three examples are given:

(a) Agricultural advisors/consultants should have access to the data needed to create a land resource inventory of their area. A combination of the advisors' and clients' databases can be used to make on-the-spot decisions on a wide range of issues. Despite the widespread availability of Area Aid land parcel maps a limitation to this application in Ireland is the general absence of soil and other land resource information at farm level.

(b) Compared with earlier attempts, modern land drainage design is based on rigorous mathematical and physical principles. Drain size, depth and spacing are derived from a combination of site data (geology, topography, rainfall, soil), D'Arcy's Law and nomograms which obviate the calculation of cumbersome mathematical formulae. Summary details and some examples are given by Mulqueen *et al.* (1999).

(c) An almost instantaneous transfer of information with modern technology is exemplified in such new developments as: (1) harvesting of milled peat by bulk density/moisture content information rather than a pre-set depth method (Ward & Holden, 1998) and (2) in "precision agriculture" where crop (grain, grass) yield variation within a field can be measured swath by swath (by "yieldmeter") and the resulting yield map used to adjust future management (Bailey,1999). The aim of this technology is to reduce tillage, fertiliser and agrochemical costs and to promote the concept of "farming by the soil rather than by the field". In both examples onboard DGPS equipment and adequate computing facilities are essential.

Agricultural Inputs Recommendations

Appraisals under this heading are occasionally referred to as Nutrient Management Plans in which the land unit is generally a catchment or sub-catchment of a river. Recent examples in this country range from tributary catchments of the River Erne, to the Bellsgrove mini-catchment, Co. Cavan (Kirk McClure Morton, 1998). The plans involve an assessment of the soil, hydrological, climatological and topographical conditions of the area with a view to devising a sensible strategy for the timing and rates of application of nutrients to land The main focus is on land-spreading of farm wastes from pig and poultry units, with the desired intention of import substitution and prevention of water pollution. Such plans are now integral parts of Environmental Impact Statements and Integrated Pollution Control licences. At farm level the establishment of a *cordon sanitaire* (buffer zone), the choice of machinery and provision of winter storage facilities may be part of the plans. It is increasingly recognised that substantial variability, both vertically and horizontally, is an inherent feature of all resources, even at field level, and that a line on a map does not indicate an abrupt boundary. A recent seminar drew attention to the need to regard groundwater and surface water as a combined resource (Anon. 1999).

Farming Systems Analysis

Systems Analysis is a blurred version of land evaluation at farm level, the main aim of which is to match soils, crops and livestock. Hence it involves a detailed knowledge of soils and landforms (or Land Utilisation Types) within the farm. It is most useful in mixed farming systems where alternative crops, stocking rates, machinery and other factors can be interchanged. The concept of stocking rate/farm management is currently being applied on a broad scale, based on the perceived state of habitats, in the hill and mountain landscape. Another item of current interest is the assessment of soil-climate-animal requirements which would permit a longer grazing season and associated reduced fodder conservation and housing needs. Care must be taken lest the solution to one problem causes another; the "umbilical" system of slurry spreading mitigates soil compaction but increases the risk of runoff if used indiscriminately in wet weather.

Environmental Impact Analysis

Environmental impact studies and assessments are now commonplace requirements for licensing of large pig, poultry and other farming activities as well as for other land uses, such as motorways, landfill sites, mines, wind farms and fish farms. They are aimed at controlling possible occurrences of air, soil and water pollution. From an agricultural view point, a major focus is on BOD, N and P, and the likely consequences for ground and surface waters (Sherwood,1992). Information from a very wide range of sources must be collated and predictions made on various scenarios (Bradley *et al.*, 1991). The "Advice Notes on Current Practice" published by the Environmental Protection Agency (EPA, 1995b) include the following: (1) *on air*: "The general climate of the site is described as accurately as possible using existing climatic data..." there is an interpretation of the implications of the general climatic conditions for the behaviour of air on and over the development site; (2) *on soils* (and geology): "Suitability/capability classifications or ratings are drawn up for the appropriate land use, and the criteria used in compiling such ratings are specified"; (3) *on water*: "Maps, diagrams and sections illustrating the location and extent of all surface water bodies and aquifers on, or adjacent to, the site are included"; and (4) *on flora*: "It is essential to outline the plants that create or define the habitat...Adequate description may involve the measurement of abundance as well as presence. Such data are collected by standardised and reproducible methods, referenced if possible...".

Monitoring Land Resources Development

Reasons for monitoring land resources development may vary from academic enquiry into the implications of changing land use, to establishing compliance with rules and regulations. Hence historic/archived data of many sorts may have to be processed and compared with current data. The data can be in the form of satellite imagery (e.g. Stanley *et al.*, 1996), air photos, meteorological/hydrometric charts, and ground-truth data (Guinan *et al.*, 1998). Examples include compliance with set-aside agreements for tilled land, stocking rates of marginal land (Walsh & Collins, 1996, 1998), clear-felling of woodland, developments associated with mines and quarries, road construction and urban expansion.

4.8.3 Concluding comments

The contributing authors have searched the literature in their respective disciplines and have highlighted the more important kinds and sources of information relating to the environment they know best: the Irish environment. In doing so they have emphasised its holocoenotic nature, the interconnectedness between the various spheres and scientific disciplines, and the necessity to continually update the databases. They draw the reader's attention to the sources, scope and reliability of Irish data relating to its geological, topographical, hydrological, pedological and biological resources, and how each of these may have implications for agro-meteorological modelling activities.

Surrogates, proxies and transfer functions

Even though they were referring specifically to soils, the place of surrogates/proxies in landscape studies was described by Hole & Campbell (1985). Pointing out that scientists/surveyors cannot observe all properties at all locations, they state that substitutes can help in defining relationships between one property and another. A common example in soil studies is to use natural vegetation to infer soil drainage characteristics. These authors emphasise that the effectiveness of the concept depends

on the initial accuracy of the definition of the relationship between a property and a surrogate, and thereafter the astute application of the relationship.

Not withstanding the multitude of existing datasets, factual data may not be available on many subjects (usually explained on the basis of cost). Covariance and inter-relationships between properties allow estimates of particular probabilities from one, but more effectively from two, three or more, known variables. These mathematical "translations" have been described, with examples, by Bouma (1989) and Larson & Pierse (1994). In soil science jargon they are known as "pedotransfer functions". Two examples are: estimation of cation exchange capacity (CEC) from clay and organic carbon content, and rooting depth from bulk density, pH and available water capacity. Wagenet *et al.* (1991) have alerted readers to the limitations of static attributes of soil characteristics and properties since they tell little about soil processes that are use-dependent. These authors purport that pedotransfer functions and simulation modelling can bridge the gap between assessments of land characteristics and qualities such as trafficability and water supply capacity.

Map data: its use and abuse

Systematic field surveys of natural resources are mostly conducted for multi-purpose use. The data emanating from such surveys are usually in the form of sets of characteristics for specific locations, the sitings of which, amongst others, may be long-term (synoptic, hydrological), widely scattered (drifting buoys), site specific (bore holes), or taxonomically determined (soil augerings). The diagnostic criteria vary with the subject matter, but are usually chosen to allow subsequent interpretation for various types of application or use. Data processing takes the form of first classifying the recorded sets of characteristics and then constructing maps of appropriate scale and legend. The latter process involves spatial interpolation and/or extrapolation of a form specific to each medium: linear (stream quality, hedgerow composition); land surface-based; (soil type, water table depth); computer-generated (atmospheric pressure, wave characteristics), but greatly influenced by the map scale chosen. While there is always a trade-off between legibility and the amount of detail that can be portrayed on a map, the most useful maps are those that have the smallest internal variability. The greatest loss of information occurs when field data are condensed (generalised) for presentation at a much reduced map scale. However, it often happens that, once generalised, the original data source is ignored in any further processing or interpretation studies. Another common misuse of map data is to photo-reduce the original to such an extent that it becomes partially illegible and is accompanied by an absurdly long and inappropriate legend.

Excessive photo-enlargement of maps, especially reconnaissance-type ones, is also an abuse of data. There are numerous examples of attempts at making general data site-specific; even instrumental errors of graphology are often ignored (a line 0.2 mm thick on a 1:50,000 map represents 10 m on the ground; at 1:10,000,000 it represents 2 km). These and similar "mistakes" can be made when layering map data of incompatible scales in a geographic information system.

Over-interpretation and wrongful reading of the map face, legend or caption are commonly observed. Examples noted by the authors include: 1) reproducing the mean air temperature map of Ireland without the caption wording: "reduced to mean sea level"; 2) extrapolating the grazing season map of Ireland (scale c. 1:2,000,000), compiled from mean rainfall and temperature data only, to sheep grazing on specific mountain slopes; 3) basing individual farm management plans on small scale soil maps (at of scale 1:1,000, 000, the local road "occupies" a zone about 0.5 km wide!).

Spatial Variability

In concluding this chapter the authors wish to draw the attention of the reader to a seminal treatise on spatial variability by Mausbach & Wilding (1991). The work includes discussions on the need to quantify spatial variability, predicting soil variability from landscape models, spatial variability in geologic mapping, statistical methods and procedures for evaluating map data, sampling procedures, and quality control. In their abstract of Chapter 1, Arnold & Wilding state that "one of the continuing challenges for pedologists and allied earth scientists is to develop integrated system models to scale spatial knowledge of soils from micro-samples to pedons, landforms and the pedosphere. Quantification of the magnitude, location and causes of spatial variability is an essential but insufficient ingredient of soil surveys. The final payoff is to communicate this knowledge to user clientele in flexible formats that provide for probability risk assessments and alternative land-use decisions." Such sentiments are equally applicable to all the subjects in this chapter as is their axiom:- "Documenting reality to 'be sure' will always be good business and sound science".

Down the centuries man has acknowledged his dependence on the biological and physical resources of the planet. However, their resilience and sustainability has on occasion been stretched almost to the breaking point, neatly summed up by Bradley in 1935 (quoted by Miller *et al.*, 1975) thus:" The parade of civilisation has marched to the cadence of the resources trinity:- soil, water and climate; history is replete with attempts to march to different drummers ...." It is hoped that the data forms and sources assembled in this chapter will set the score for those who aspire to, and work towards, a holistic and non-reductionist view of the world in which we live. As we enter the third millennium, AD, we could profitably recall the elegant definition of the world, by Pliny, at the beginning of the first, and ask how well do we know our little bit of the planet? *Sacer est, aeternus, immensus, totus in toto, immo vero totum, finitus et infinito similis, omnium rerum certus et similus in certo, extra intra cuncta complexus in se, idemque rerum naturae opus et rerum ipsa natura.* Plinius (AD.23-79) Naturalis Historia (II:I).

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Mapping services

European Environment Agency, Kogens Nytorv 6, DK-1050 Copenhagen.
European Air Services, The Stables, Portmarnock, Co. Dublin.
ERA-MAPTEC, Ltd., Satellite Data, 36 Dame St., Dublin 2
Geological Survey of Ireland , Beggars' Bush, Dublin 4.
Ordnance Survey Office, Phoenix Park , Dublin 8
Ordnance Survey of Northern Ireland, Colby House Stranmillis Court, Belfast BT9 5BJ
Spectral Signatures Ltd., Roebuck Castle UCD, Dublin 4

Groundwater services

Groundwater Section, Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4. Tel: +353 1 6707444. Fax: +353 1 6681782. www.gsi.ie
Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS Tel: +00 44 02890 666595 Fax: +00 44 02890 662835
Environmental Protection Agency, Dublin Regional Inspectorate, St. Martins House, Waterloo Road, Dublin 4. Tel: +353 1 6602511. Fax: +353 1 6680009. www.epa.ie

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Groundwater Vulnerability Map of Northern Ireland (1:250,000) (1994) British Geological Survey & Department of the Environment for Northern Ireland, Environment Service
Soil Survey and Land Research Centre & Department of Agriculture for Northern Ireland
IHME (1980) International Hydrogeological Map of Europe, 1976.
NERDO (1981) North East Regional Development Organisation. An Foras Forbartha & Geological Survey of Ireland.

Marine services
An Bord Iascaigh Mhara, Crofton Road, Dun Laoghaire, Co. Dublin, Ireland.
British Oceanographic Data Centre, Proudman Oceanographic Laboratory,
Bidston Observatory, Birkenhead, Merseyside L43 7RA, United Kingdom.
Department of the Marine, Leeson Lane, Dublin 2, Ireland
Imray, Laurie, Norie & Wilson Ltd., Wych House, The Broadway, St. Ives, Huntingdon PE17 4BT, United Kingdom.
Irish Marine Institute, 80 Harcourt Street, Dublin 2, Ireland
Martin Ryan Marine Institute, National University of Ireland, Galway, Ireland
Met Éireann, Glasnevin Hill, Dublin 9, Ireland.
UK Hydrographic Office, Admiralty Way, Taunton, Somerset TA1 2DN, United Kingdom (http://www.hydro.gov.uk/home.htm)

Soil services
Agricultural and Environmental Science Division, Department of Agriculture Northern Ireland, Newforge Lane, Belfast BT9 5PX.
Agricultural and Environmental Science Department, The Queen's University, Newforge Lane, Belfast, BT9 5PX.
Teagasc (formerly An Foras Talúntais), H.Q. and library, 19 Sandymount Ave. Dublin 4.
Teagasc (formerly An Foras Taluntais), Soils and Grassland Division, Johnstown Castle, Wexford.
Coillte Teoranta, The Irish Forestry Board, Soils Laboratory, Newtownmountkennedy, Co. Wicklow.
Department of Agriculture and Food, Agriculture House, Kildare St., Dublin 2.
Independent Analytical Services (IAS), Bagenalstown, Co. Carlow.

Soil Science Laboratories, Agriculture Building, University College Dublin, Belfield, Dublin 4.

Outside Ireland
Food and Agriculture Organisation of the United Nations (FAO), Viale della Terme di Caracalla, Rome, Italy.
International Soil Reference and Information Centre (ISRIC), Agricultural University, Wageningen, The Netherlands
Office for Official Publications of the European Communities, Luxemburg.
The European Soil Bureau, Joint Research Centre, I-21020, Ispra, Italy.
United States Department of Agriculture (USDA), Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.