British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Centre for Ecology & Hydrology
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Investigating BGS and CEH data integration; using DiGMapGB and Land Cover Map 2000 as a test case

A joint report between:

The British Geological Survey, National Geoscience Information Service, Information Services & Management Directorate

The Centre for Ecology & Hydrology, Integrated Applications Group, Section for Earth Observation

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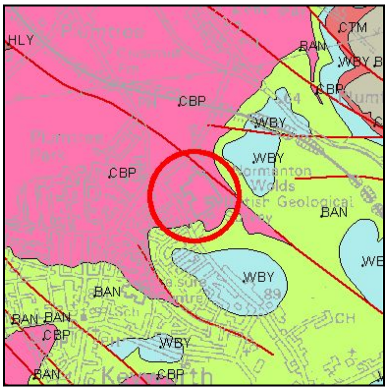

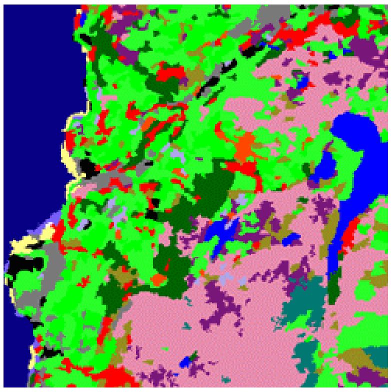

BRITISH GEOLOGICAL SURVEY
CENTRE FOR ECOLOGY & HYDROLOGY

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Investigating BGS and CEH data integration; using DiGMapGB and Land Cover Map 2000 as a test case

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- To secure and manage environmental data and provide access to academia, governments, industry and the public.
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Foreword

This report is the published output of a joint study by the British Geological Survey (BGS) and the Centre for Ecology & Hydrology (CEH), looking at ways to scientifically compare and integrate their digital data holdings.

The project was funded for the latter half of FY 2003-4 by the NERC Executive Board and was carried out under a joint Memorandum of Understanding between BGS and CEH signed in October 2003.

The project looked at how two core digital datasets, the CEH Land Cover Map 2000 (LCM2000) and the BGS Digital Geological Map of Great Britain (DiGMapGB), could be scientifically compared and integrated, and also looked in detail across the two organisations at other areas of potential collaboration based on integration of digital datasets.

This work shows how two NERC Centre / Surveys can work closely together to improve communication and scientific links, and paves the way for future exciting scientific collaborations between the BGS, CEH and other Centre / Surveys.

The results of this study, in particular the extensive review of potential areas of joint work, will be crucial for programming any future collaborative activities between BGS and CEH

This data-sharing project was run alongside a technical project looking at how to use the Web more effectively to share GIS data, which is written up in the accompanying report IR/04/153/R.

Acknowledgements

This report collates input from a number of BGS and CEH staff; the names of individual staff involved in exploring potential CEH and BGS collaborations are acknowledged in the relevant parts of the text. The BGS strand of the data integration work was lead by Alan Smith (BGS) and the CEH strand by Ross Hill (CEH).

This data integration project and the accompanying data-sharing project were managed by Keith Westhead (BGS, and overall project leader) and Geoffrey Smith (CEH), who have been responsible for co-ordinating the work and compiling the report from contributions made by the project staff.

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This report describes the results of a joint project between CEH and BGS. The project ran from October 2003 to March 2004 and was funded by NERC Executive Board.

The first aim of the project was to carry out focussed scientific comparisons of two key datasets, the BGS Digital Map of Great Britain (DiGMapGB) and the CEH Land Cover Map 2000 (LCM2000).

The second aim was to build on this by investigating other areas of potential scientific and data integration between BGS and CEH, to see how much potential there is for future collaborative work.

In terms of achieving the first aim, the project has shown successfully how a variety of statistical GIS, database and manual ('by eye') techniques can be employed to compare the two major datasets, DiGMapGB and LCM2000, providing valuable lessons for future similar work on other combinations of NERC data.

The comparison work between DiGMapGB and LCM2000 has demonstrated that the distribution of land cover types is not random when compared to geology, but any natural correlations tend to be heavily masked by anthropogenic effects.

The project has been very successful in achieving the second aim; with a wide-ranging review across both BGS and CEH demonstrating how much could be gained from bringing the environmental data and expertise of the two organisations more closely together.

An extensive list of potential areas of collaborative work, which would benefit from sharing of BGS and CEH environmental datasets, has been produced. This should prove invaluable for planning any future collaborative programmes within and between BGS and CEH. These include various aspects of hydrogeology and groundwater contamination, biogeographical and ecological risk assessment, heavy metal critical load mapping, urban planning, prediction of natural ground instability, and even forensic science.

1 Introduction

This report describes the results of a joint project between CEH and BGS. The project ran from October 2003 to March 2004 and was funded by NERC Executive Board. A Memorandum of Understanding (MOU) was signed accordingly between the two organisations in October 2003.

The main aim of this project was to assess the opportunities for scientific exploitation of BGS and CEH data through their integration within an Internet-based data-sharing environment

Two ‘core’ datasets were used as a basis for testing: the BGS Digital Geological Map of Great Britain (DiGMapGB) and the CEH Land Cover Map 2000 (LCM2000).

1.1 BACKGROUND & CONTEXT

The BGS and the CEH, as two principal centres within NERC, hold key digital environmental datasets and related expertise that if brought more closely together would have clear benefits for characterising the environment. New Internet and digital technologies are emerging rapidly that allow easier sharing of such digital data, so it is crucial for NERC centres to work together and to ‘stay ahead of the game’ when understanding and exploiting such technologies, so that the maximum benefit can be gained from any related scientific collaborations. The accompanying project, written up in report IR/04/153/R, looks closely at these data-sharing technologies.

This project looks at what is, and might be, possible scientifically if data and expertise are shared efficiently between centres / surveys. A detailed case study, looking at two key datasets, the BGS’s DiGMapGB and the CEH’s LCM2000, demonstrates techniques that can be used for comparing and integrating major digital datasets, and also illustrates some immediate benefits in terms of potential ‘product’ outputs. The project also extensively reviews ongoing and potential collaborative work between BGS and CEH and the benefits that would be gained from improved sharing of the digital data.

1.2 DATA INTEGRATION PROJECT OBJECTIVES

The objectives of this project were to:

- Identify and exchange high-resolution versions of DiGMapGB and LCM2000 datasets for science investigation.
- Examine relationships between these datasets using a combination of ‘by-eye’ and GIS statistical techniques.
- Investigate and review wider potential science applications and derived outputs based on combined BGS geology and CEH environmental information.

1.3 THE KEY DATASETS

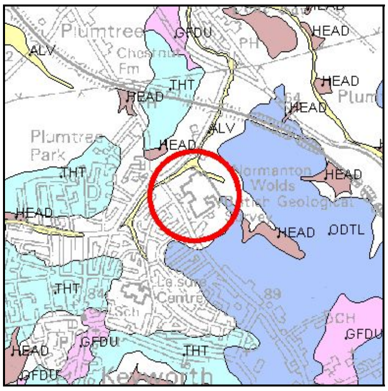
The BGS DiGMapGB and the CEH LCM2000 represent core environmental datasets underpinning a range of activities with both organisations. These two datasets were targeted during this study in order to explore the techniques that might be involved in comparing digital datasets between two organisations such as BGS and CEH.

1.3.1 BGS Digital Geological Map of Great Britain (DiGMapGB)

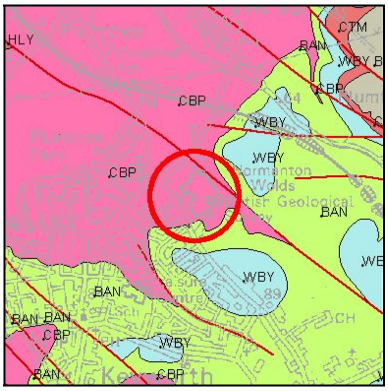
The DiGMapGB project has completed 1: 50 000 scale parcel-based data (DiGMapGB-50) for most of England, Wales and Scotland. The parcels are attributed with lithostratigraphical and lithological information arranged in up to four themes as available: bedrock geology; superficial deposits; mass movement deposits and artificial ground. This information is currently being used widely within BGS and the general geoscience community. For example, extracts of the DiGMapGB-50 maps are used by the BGS GeoReports service for displaying site geology for a wide variety of users, including geotechnical and environmental consultants involved in site investigations. The bedrock geology of this data set is also available at a reduce scale of 1:250 000 (DiGMapGB-250).

Figure 1. Example of DiGMapGB-50 data: Bedrock & Superficial Geology Layers

Superficial Deposits



Bedrock



Key to Superficial deposits:

Map colour	Rock name	Rock type
	ALLUVIUM	SAND AND SILT
	HEAD (UNDIFFERENTIATED)	CLAY AND SILT
	GLACIOFLUVIAL DEPOSITS (UNDIFFERENTIATED)	SAND AND GRAVEL
	OADBY MEMBER (LIAS-RICH)	DIAMICTON
	THRUSSINGTON TILL	DIAMICTON

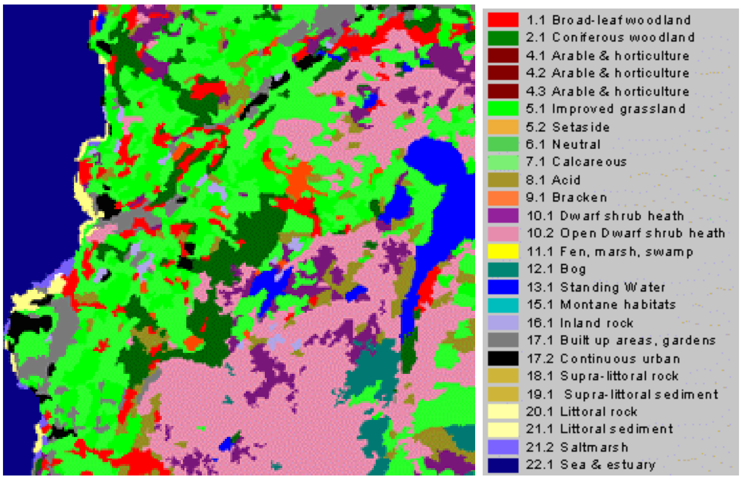
Key to Bedrock geology:

Map colour	Rock name	Rock type
	BARNSTONE MEMBER	MUDSTONE AND LIMESTONE, INTERBEDDED
	COTHAM MEMBER	MUDSTONE
	WESTBURY FORMATION	MUDSTONE AND SILTSTONE
	BLUE ANCHOR FORMATION	MUDSTONE
	CROPWELL BISHOP FORMATION	MUDSTONE AND SILTSTONE
	HOLLYGATE SANDSTONE MEMBER	SANDSTONE

1.3.2 CEH Land Cover Map 2000 (LCM2000)

LCM2000 was based on the analysis of satellite image data with a spatial resolution of 25 m and used image segmentation to identify relatively uniform areas within the images that were essentially distinct parcels (e.g. fields). The parcels were classified using the spectral character of the image data (i.e. surface reflectance, often from two different seasons) and enhancements provided by knowledge-based corrections (e.g. elevation, soil sensitivity). LCM2000 used a hierarchical classification scheme consisting of 16 target classes, which were further subdivided to make 24 subclasses, with these in turn subdivided to give up to 72 class-variants. For this project a version of the data was created from a 1 km resolution dominant land cover summary.

Figure 2. Example of full resolution LCM2000 level-2 vector data



2 Data Integration Project Results

Correlations between DiGMapGB and LCM2000data were examined by both BGS and CEH teams, using a variety of manual (‘by eye’), and GIS and database techniques, summarised in Sections 2.1 to 2.3 below, and detailed in the Appendices.

These strands of work were accompanied by a wider review across the two organisations, looking at other areas of potential data integration and scientific collaboration, which is detailed in Section 2.4.

Two case studies, described in sections 2.5 and 2.6, provide more in-depth illustrations of what might be achievable with further collaboration and data integration between BGS and CEH. The first looks at how land cover data could enhance ground stability information, and the second looks at how land cover information might be presented in a combined BGS-CEH commercial GeoReports product.

2.1 RESULTS OF DIGMAPGB-LCM2000 COMPARISON BY BGS

Firstly, the DiGMapGB-50 geological map data and the LCM2000 land cover data were compared ‘by eye’ (Appendix 1). An initial general overview of the Ordnance Survey 100km square ST and the whole of the south-west (S-W) was carried out to look for any obvious patterns in the CEH dataset that might readily be correlated with the geology, whether in the Bedrock, Superficial Deposits, Mass Movement or Artificial Ground theme. This was then followed by a more systematic study, selecting each Broad Habitat (or related ones) of LCM2000 in turn, and examining the underlying geology.

The best correlations between geology and land cover occur where the land has remained “natural” or “seminatural”. This correlation is readily lost where farming or other human intervention has changed the landscape. Where farming is difficult because of topography or other factors some ‘natural correlations’ may persist.

Secondly, the data for ST and square SX (within the S-W) were analysed statistically using a GIS package (Appendix 2). A simple SQL query was used to determine the degree of correlation between the two datasets; that is the percentage of each land cover Broad Habitat corresponding to each lithology.

Some correlations were noted above between lithology and land cover, or lack of cover. However, it is not generally possible to predict geology from land cover or land cover from geology with precision.

2.2 RESULTS OF DIGMAPGB-LCM2000 COMPARISON BY CEH

In order to carry out a simple statistical examination of the relationships between LCM2000 and the DiGMapGB-50 data layers on *bedrock* and *superficial* geology, all three datasets were rasterised to 100 m spatial resolution. The land cover and bedrock geology have complete spatial coverage for both test areas, whereas superficial geology does not. Therefore, a subset of LCM2000 data was generated using a ‘cookie cutter’ to match the partial coverage of the superficial geology for both test areas.

Four studies were carried out:

a. Bedrock geology & land cover for the area of OS 100km tile ST (Bristol area).
b. Superficial geology & land cover for area ST.
c. Bedrock geology & land cover for area SW (South West England).

d. Superficial geology & land cover for area SW.

Detailed statistics are provided in Appendix 3. In a general sense, though, this analysis has shown that the distribution of land cover types is not random when compared with bedrock or superficial geology. Both have an influence on land cover distribution, and perhaps surprisingly, this is clearer and more intuitive for the bedrock geology than for the superficial geology.

However, other environmental factors have to be considered in determining land cover distribution, including topography (although this is strongly influenced by bedrock geology), micro-climate, tidal inundation, and human intervention (both historical and current). As a result, it is not possible to predict land cover type from bedrock or superficial geology alone with any degree of certainty.

At best, it is possible to predict the probability of a particular land cover type occurring on a particular bedrock formation or superficial deposit.

2.3 CONCLUSIONS FROM COMPARING OF LCM2000 AND DIGMAPGB-50

The distribution of land cover types is not random when compared with geology. However, there is a weak correlation between land cover and geology which tends to be masked by the influences of man; the best correlation occurs where the land has remained most “natural”.

In general, using the current datasets, it is not possible to predict land cover from geology, or geology from land cover; at best, it is possible to predict the probability of a particular land cover occurring on a particular geology, and vice versa.

2.4 REVIEW OF POTENTIAL WIDER APPLICATIONS OF INTEGRATED GEOLOGY & LAND COVER DATA

Data on bedrock geology, superficial deposits and land cover, together with information on soils, topography and climate are key to understanding and modelling in numerous environmental disciplines, notably hydrology, biogeography, and geohazards. In many cases, the modelling of environmental phenomena within a landscape, river catchment, or even at a regional or national scale has been impaired by restricted (or cost prohibited) access to datasets held by different public sector organisations. The examples below follow from a CEH-wide and BGS-wide survey on current or potential applications of integrated geological and land cover data (staff members consulted and who contributed to the various sections are indicated in brackets).

2.4.1 River catchment hydrogeology

CEH Wallingford and BGS intend to develop a project to combine geological and soils data to derive a combined hydrogeological classification for water resources research and application purposes. A link with land cover (mapped to an appropriate hydrological classification of land cover) would be a useful extension of this (Dr Andy Young, Head of the River Regimes Group, CEH Wallingford). This would provide a useful method of characterising river catchments and modelling processes and events, such as surface water infiltration and runoff, and flash flooding. In addition, given that stream water chemistry is a function of land cover and use, soils and geology, such data would be invaluable for catchment-scale water quality projects (Dr David Cooper, CEH Wallingford).

Identifying the representativeness of gauged catchments across the UK is essential to support stakeholder decision making. The National River Flow Archive (NRFA) maintains a database of hydrological information for around 1500 gauging stations in the UK. Hydrometric data reflects the characteristics of the catchment above the gauging station. There is increasing demand for hydrological data and economic constraints on maintaining gauging station networks. An understanding of how representative individual river flow records are is important in river management, model development, interpretation of hydrological trends and demonstrating compliance with regulatory mechanisms.

Specific needs would be:

- Network design and evolution

  (which stations to close/maintain, where to open new ones?).
- Identification of catchments to address particular applications

  (which data to use?).
- Delivery of spatial information to guide user analyses

  (how the data should be used?).

An on-going project at CEH Wallingford is currently demonstrating the potential of integrated topographic and land cover data for developing catchment representativeness indicators. This work would benefit from additional environmental data; for example rainfall, soil type, bedrock and superficial geology (Cedric Laize, National River Flow Archive, CEH Wallingford).

Sue Crooks (CEH Wallingford) has developed, and continues to upgrade, a rainfall runoff model (CLASSIC) that operates on a grid system (5 to 40 km^2 depending on catchment area). This has been used for simulating impacts of climate and land use change on flood frequency and flow duration. The model is partly calibrated and set up using GIS land use and soils datasets. It would improve the accuracy of the simulations to link the land use with the geology in a grid cell, particularly to distinguish between areas with, and without, underlying aquifers.

2.4.2 Groundwater hydrogeology/aquifers

The National Groundwater Survey is responsible for providing information on the hydrogeology of the major aquifers in the UK. This requires information from a variety of sources, including: bedrock and superficial geology, river networks, NFRA, land cover and use, etc. Of particular current interest is the ability to identify catchments with a particular breakdown of geology (Ian Gale, BGS Wallingford).

Land use change can have a large impact on water resources (both quantity and quality). One aspect is that land use alteration can change the evaporative losses which, for example, could change the annual groundwater recharge by 25%. The impact of such changes is often quantified using numerical models. An essential component of such studies is to be able to analyse the spatial distribution of the geology, land cover and topography in an integrated way across landscape domains that can vary from a few km^2 up to 10x5 km^2. With such spatial data, it has been shown possible to parameterise a soil water balance model for estimating change in groundwater recharge for a study catchment (Jon Finch, CEH Wallingford).

In related work by BGS, EA and the University of Birmingham, rainfall recharge models have been developed using object oriented techniques. This approach permits flexibility for the recharge is calculated at a node on a grid and changes to the recharge mechanism can be made at a recharge node. Data are held on grids in separate objects and calculations are carried out at the grid nodes. The model was applied to a case study area on the Chalk aquifer in Kent on the edge of south-east London. It used the 1km land cover data, amalgamating the categories into 5 main types (urban, riparian, arable, pastoral and forested) and calculating the percentage of each. These percentages were then used to calculate the recharge at each 1km node. Other data included were rainfall, potential evaporation and runoff. The results were then used in the regional groundwater model and compared with field data; and this led to further improvements in the recharge model. It helped identify, for example, local recharge "hotspots" where water diverted from the Clay-with-Flints was routed on to uncovered Chalk (Helen Rutter, BGS Wallingford).

Some BGS mapping projects have considered the variable rates of water **infiltration**, and hence flooding risks, associated with different types of artificial or disturbed surfaces in urban areas like Manchester. To date BGS has not, in similar mapping projects, considered how infiltration varies in a largely rural area as a result of differences in plant cover (Simon Price, BGS Keyworth).

There is great potential to incorporate LCM2000 data into BGS studies of aquifers and river catchments where, as already noted above, vegetation cover has an effect on surface runoff, river levels and flooding; the infiltration of rainwater in to the ground and its effects on groundwater levels, aquifer recharge and vulnerability, and water quality and contamination. Theoretically this should be an area of investigation that could best be undertaken by staff at Wallingford, not least because BGS and CEH staff share the same site and communication between the two institutes should be easier.

2.4.3 Nitrate in groundwater

BGS is carrying out a project on nitrate in groundwater in the Eden Valley, Cumbria. This will use LCM2000 data as the land cover classifications can be related to potential sources of nitrate pollution. When combined with other factors including bedrock and superficial geology it can be used to model the groundwater quality distribution (Adrian Lawrence and Andrew Butcher, BGS Wallingford).

Previously LCM2000 data has been used with digital geological maps for Northern Ireland to model nitrate concentrations in groundwater for NI Environment and Heritage Service to implement the EU nitrates directive. However, the existing land use dataset for NI (Corine), was found to be more useful. Similarly in Scotland another project has used land use data from the Macaulay Land Use Research Institute (MLURI) in preference to LCM2000 to produce the nitrate vulnerable zones for Scotland (Alan MacDonald, BGS Murchison House).

2.4.4 Cryptosporidium risk in ground water

Some research has been carried out to assess the risk of Cryptosporidium oocysts reaching public supply boreholes or spring waters. Whilst somewhat subjective and difficult to quantify this assessment of risk is based on the “source-pathway-receptor” principle.

One of the most common sources is intensive livestock farming and this can be assessed from the land cover data, with, for example, livestock unlikely in forested areas. Another source of Cryptosporidium oocysts is sewage leakage and this may be related to the urban areas in the land cover data. Thus, one of the initial parts of the risk assessment was to extract areas of improved grassland and urban areas.

A key factor in determining the pathway is the transmissivity of the aquifer and this is based on the geology. When combined with other factors such as aquifer vulnerability and groundwater protection zones as well as water quality, rainfall, topography and many other site specific details it was possible to assess the relative Cryptosporidium risk to various public water supply sources (Rosemary Hargreaves, BGS Wallingford).

2.4.5 Biogeography

Environmental Change Network (ECN) undertakes research and monitoring aimed at detecting and interpreting environmental change in terrestrial and freshwater ecosystems. The ECN coordinates the collection of high-quality long-term data from a network of integrated monitoring sites in the UK (12 terrestrial and 42 freshwater); contributes to the analysis and interpretation of the data; and disseminates data, information and research products to users in scientific and policy institutions. Access to the proposed integration of LCM2000 and DiGMapGB-50 would provide the basis for projects relating catchment-scale geology and land cover to water quality at ECN freshwater sites, changes in which (recorded over time spans of up to 30 years) drive changes in the aquatic biota measured by ECN (Andy Scott, CEH Lancaster).

Research projects in the Biological Records Centre (BRC) at CEH Monks Wood regularly require an analysis of species occurrences in relation to environmental factors. Land cover and geology are both important factors, especially in relation to plant distributions and potential for spread. In a range of on-going projects, the BRC aim to link the occurrence of organisms to environmental variables, notably climate, soil type and landform, as well as to human impacts such as land use and its effects on land cover. Solid and surface geology have a major effect on the organisms that are found; geological data can help understanding of where species occur and where they might occur under scenarios of climate change and land-use change (Mark Hill, Head of BRC, CEH Monks Wood).

A particular example is work integrating environmental data such as; land cover, climate, and topography with British Trust for Ornithology (BTO) Breeding Bird Atlas data to identify the major environmental factors influencing breeding bird distribution in the UK and potentially validating bird guild structures (Dr Shelley Hinsley, CEH Monks Wood).

2.4.6 Ecological Risk Assessment

Ecological risk assessment is an increasingly important part of the decision-making process for managing environmental problems. Risk assessments can be used retroactively, prospectively and for ongoing activities of concern. The UK Environmental Agency ERA framework document (under review) suggests a four-tiered iterative approach, starting with a conceptual site model to identify sources of contaminants, pathway and receptors at risk. Background data on the site will be required in terms of geology, soil and land cover types. Other datasets considered will be data on the receptor at risk and pathway. The framework is under review and development but it highlights the need not only for this kind of data integration but the integration with other datasets such as soil properties, etc. (Joseph Fawehinmi, CEH Monks Wood).

2.4.7 Heavy Metal Critical Load Mapping

Critical load methods for toxic metals are currently being developed within United Nations Economic Commission for Europe (UNECE) with a view to applying them in a revised protocol on the control of emissions in 2004/5. The UNECE protocol on Heavy Metals, Article 6, encourages parties to develop “an effects based approach”, for the purpose of formulating future optimised control strategies for emission of these toxic metals, especially: lead, cadmium and mercury. The calculation of critical loads depends on: the receptor ecosystem (terrestrial or aquatic), the receptor, land cover type and indicator of impact. However, the critical loads method is not applicable to:

- Sites with negative water balance, because there is no leaching but a seepage of water leading to accumulation of salts and high pH.
- Soils with reducing conditions, because transfer functions do not apply to such soils.
- Sites where weathering input of metals are high and therefore the relative contribution from long-range transport is negligible.

From the last point, it is important to exclude sites with high geogenic metal input and this is more important due to the unique nature of UK soils. Integrated geology and land cover data will help to identify these potential sites for exclusion from the Heavy metal critical load directives (Joseph Fawehinmi, CEH Monks Wood).

The revised Mapping Manual currently under development requires the geology of the site, as part of the inputs required, during data and information gathering.

2.4.8 Microbiology

On-going research at CEH Oxford is attempting to understand the structure and dynamics of indigenous microbial populations as they are exposed to pollutant and natural fluxes of carbon. They have already identified the fact that geology plays an important role in determining carbon flux and microbial activity. Due to differential sorption/desorption of pollutants and bacteria to surfaces (i.e. geological features) and the obligatory chemical impact of the geology on its surroundings (i.e. pH, "active" ions), different microbial populations develop. These populations, because of the above features, will have an easier/neutral/harder time at degrading pollutants, depending also on the recalcitrance of the pollutant. Access to geology and land cover data for ecological microbial studies would be invaluable. Microbiology and remediation within a particular river/estuary can be compared to another with dissimilar geology (Andrew Singer, CEH Oxford).

2.4.9 Urban planning

Land cover data from CEH (LCMGB 1990) and information on geohazards (e.g. ground instability) derived from BGS geological data were incorporated into a recent URGENT funded project that developed an Internet-based environmental decision support system for urban planners. The Environmental Information (Decision Support) System for Planners (EISP) in the UK incorporated environmental information in the form of data, maps and computer models relating to:

- the distribution of contaminated soil.
- the vulnerability of groundwater and surface water to pollution.
- the impact of unstable ground on construction.
- flood risk and drainage.
- air quality.
- ecological conservation/enhancement of bio-diversity.
- conservation of cultural and natural heritage.

To produce an environmental decision support system for use in planning it was necessary to combine spatial and geographically represented environmental information and models within a planning framework (Graham Leeks, CEH Wallingford).

2.4.10 Natural geological ‘subsidence’ hazards

BGS is currently developing digital geohazard data including such factors as slope stability, shrink swell clays, compressible strata and running sand conditions. It is likely that CEH LCM2000 data could be used to improve the existing applied geology or geohazard information available, particularly on **slope stability**. This is determined by the strength of the slope-forming materials and the stress caused by gravity acting on those materials. Vegetation has an influence on slope stability by affecting its moisture content, its mass, and the strength of the soil. Such information is already included in reports where appropriate e.g. a confidential report for The Woodland Trust (Wilby and others, 2002). This includes a section on the effects of vegetation and discusses the importance of its nature and extent on a number of factors that influence slope stability as described below:

Vegetation affects the **soil moisture content** by intercepting rainwater, and by removing ground water; thus broad-leaf woodland intercepts more rainfall and takes up more water from the soil than coniferous woodland. A lower moisture content means less mass of soil and therefore less **load or stress**. A lower water table gives an increase in soil strength and hence greater stability. An increase in the mass of vegetation causes an increased load or stress to the slope. Plant roots can significantly reinforce the **strength** of soils by increasing cohesion depending on the type of vegetation, the number, size and strength of roots, and the depth to which they penetrate relative to potential shear surfaces. Roots may also penetrate into bedrock, particularly where fractured, and thereby **anchor** overlying superficial deposits. Clear-felling of trees will tend to decrease the stability of steep slopes and may induce erosion and formation of gullies.

Samples of three GeoHazarD datasets on slope stability, shrink swell and permeability were provided to CEH by Jenny Walsby of BGS for the south east quarter of ST in order for BGS and CEH to derive some example integrated datasets, particularly dealing with the incidence of unstable slopes and woodland. The results are discussed in the Case Study in Section 3.7.

BGS are currently investigating ways of incorporating information from the Meteorological Office, especially rainfall data, to improve BGS's geohazard layers on slope stability; increased rainfall and infiltration will give higher loads and pore pressures, resulting in greater slope instability. Infiltration, as noted above is affected by plant cover.

Soil erodibility is not currently included in the GeoHazarD/GeoSure dataset but it is potentially important, particularly in some more rural areas where it can have a significant effect on farming – a potential market not so far exploited by BGS. Many of the factors are similar to slope stability, though it is more often associated with farmland; arable fields may suffer erosion if subjected to excessive rain or wind when loose and 'bare' after ploughing. Different patterns of cropping and farming methods are subject to different risks of erosion. Also, if the weather is about to undergo significant 'climate change' some factors may become more important, others less so.

(Alan Forster, Engineering Geologist; David Bridge, Mapping Geologist; and Jenny Walsby, Manager of GeoHazarD Project, all at BGS Keyworth)

2.4.11 G-Base and forensic geology

The LCM2000Land Cover Map of Great Britain (1990) with a 1km pixel resolution has been used by BGS in its G-Base regional geochemical atlas of Wales (British Geological Survey, 2000), though it formed little more than a backdrop to the sample sites at that time. Land Cover is routinely recorded by BGS at geochemical sampling sites, using a similar, but not identical, classification to CEH.

More interestingly LCM2000 data could be integrated with BGS datasets in the field of forensic geology. Suppose for example that soil trapped in the tread of a car tyre contains both fragments of chalk, and pine needles and pollen. By examining DiGMapGB-50 for the distribution of chalk and LCM2000 for the distribution of coniferous woodland it is possible to select locations where the two occur close together, and which might then be used to more closely define a number of search areas.

This area of research is in its infancy at present and it offers a real opportunity to display the power of integrating diverse NERC digital datasets (Barry Rawlins, BGS Keyworth).

Figure 3 shows how knowledge of the spatial distribution of just two independent factors, in this case the intersection of chalk bedrock and pine woodland, can greatly reduce the higher priority areas for search. In a GIS other relevant factors could also be incorporated to further restrict the key areas.

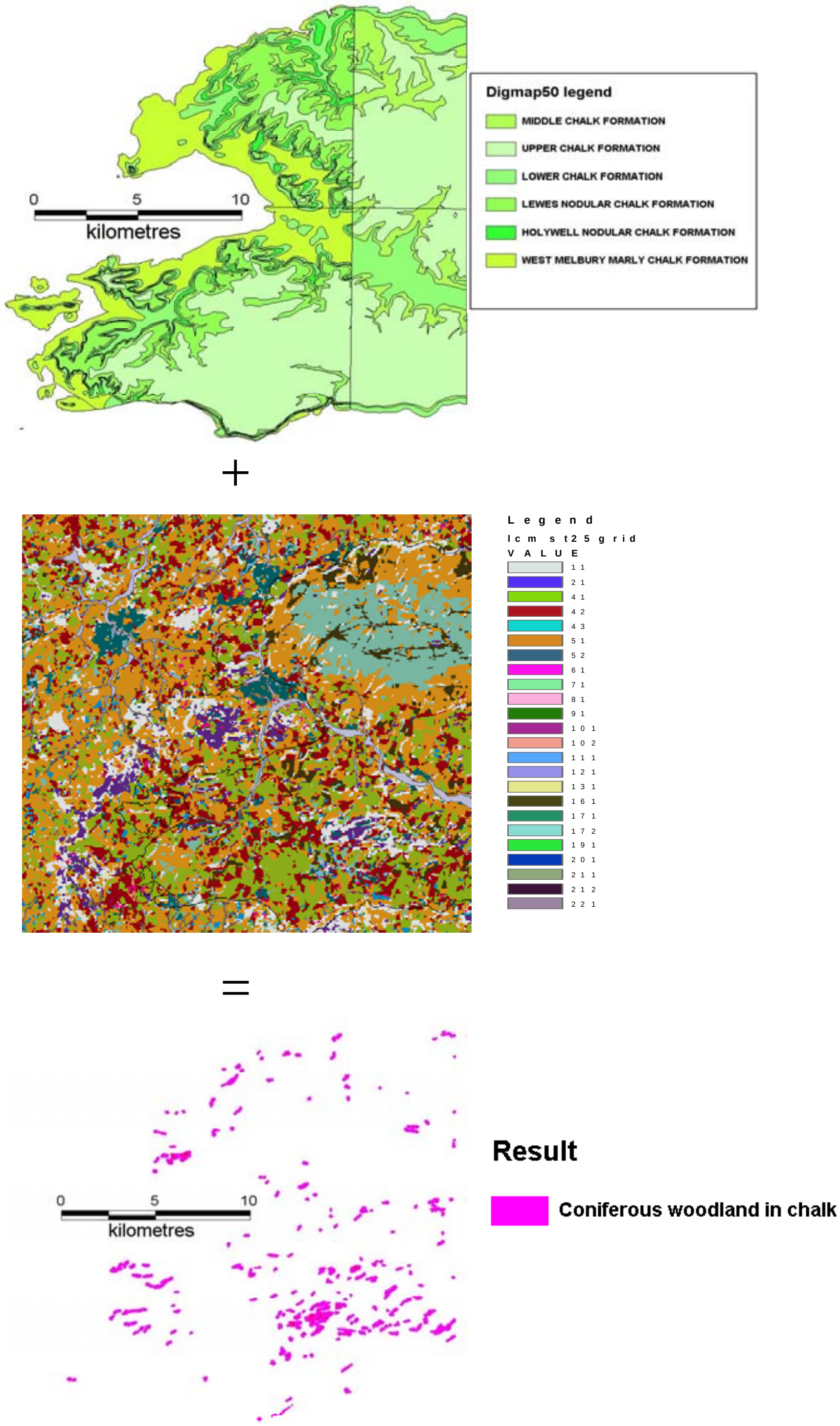


Figure 3. Incidence of pine woodland on chalk bedrock - example of forensic geology application.

2.4.12 Coastal erosion and flooding

Vegetation around the coast can have a significant impact on coastal erosion and flooding by the sea. Use of LCM2000 data may help define areas most at risk and those where a change in vegetation could reinforce the coastal defences.

These ideas have come to public attention recently with the introduction of managed retreat concepts in the re-creation of salt marshes by the artificial flooding of reclaimed coastal flats that had been transformed into arable fields or pasture. Such matters are now high profile topics in the media and are particularly associated with the perceived effects of global warming, where there is much debate on the best way to address the problems.

(John Rees, BGS Keyworth, Head of the Coastal Science and Global Change Programme)

2.5 CASE STUDY 1: SLOPE STABILITY IN RELATION TO LAND COVER: A DEMONSTRATION OF COMBINED GEOLOGICAL AND LAND COVER DATA

One of the issues identified above is the possible use of LCM2000 data to improve applied geology or geohazard information that BGS currently provides. Slope stability and soil erodability are two key topics for data integration. Slope stability is determined by the strength of the slope forming materials and the stress caused by gravity acting on those materials. Vegetation has an influence on slope stability by affecting its moisture content, its mass, and the strength of the soil. Vegetation affects the soil moisture content by intercepting rainwater, and by removing ground water; thus broad-leaf woodland intercepts more rainfall and takes up more water from the soil than coniferous woodland, for example. A lower moisture content means less mass of soil and therefore less load or stress. A lower water table gives an increase in soil strength and hence greater stability. An increase in the mass of vegetation causes an increased load or stress to the slope. Plant roots can significantly reinforce the strength of soils by increasing cohesion depending on the type of vegetation, the number, size and strength of roots, and the depth to which they penetrate relative to potential shear surfaces. Roots may also penetrate into bedrock, particularly where fractured, and thereby anchor overlying superficial deposits. Clear-felling of trees will tend to decrease the stability of steep slopes and may induce erosion and the formation of gullies.

An example geohazard dataset currently provided by BGS is slope instability. This product is based primarily on lithology (obtained from DiGMapGB) and slope angle (obtained from a Digital Elevation Model). This information is combined into five classes of slope instability. Figure 4 shows a copy of this data set for the south east corner of OS map tile ST. LCM2000 data for this same area can provide important land cover information that, as described above, can have a significant influence on slope stability. In the absence of detailed data on how individual land cover types influence soil moisture content, mass, strength and cohesion the information content in LCM2000 was simply combined into four separate classes. These were: land cover which is non-vegetated for at least part of the year, urban/suburban land surfaces, vegetated surfaces (shallow rooted), and vegetated surfaces (deep rooted). In Figure 4, the two vegetated surfaces are combined as one class, and for each slope instability class these vegetated areas are shown in pastel colours representing mitigated slope instability compared with the urbanised or temporarily bare land surfaces. Interestingly, the proportion of each slope instability class with a land cover involving bare surfaces for at least part of the year declines with increasing slope instability severity; from 45% for class A, to 44% for class B, 48% for class C, 35% for class D and 21% for class E. It is the areas shown in bright yellow and bright red at the bottom of Figure 4 that have the greatest slope instability hazard and where land management change should be focussed for this sample area.

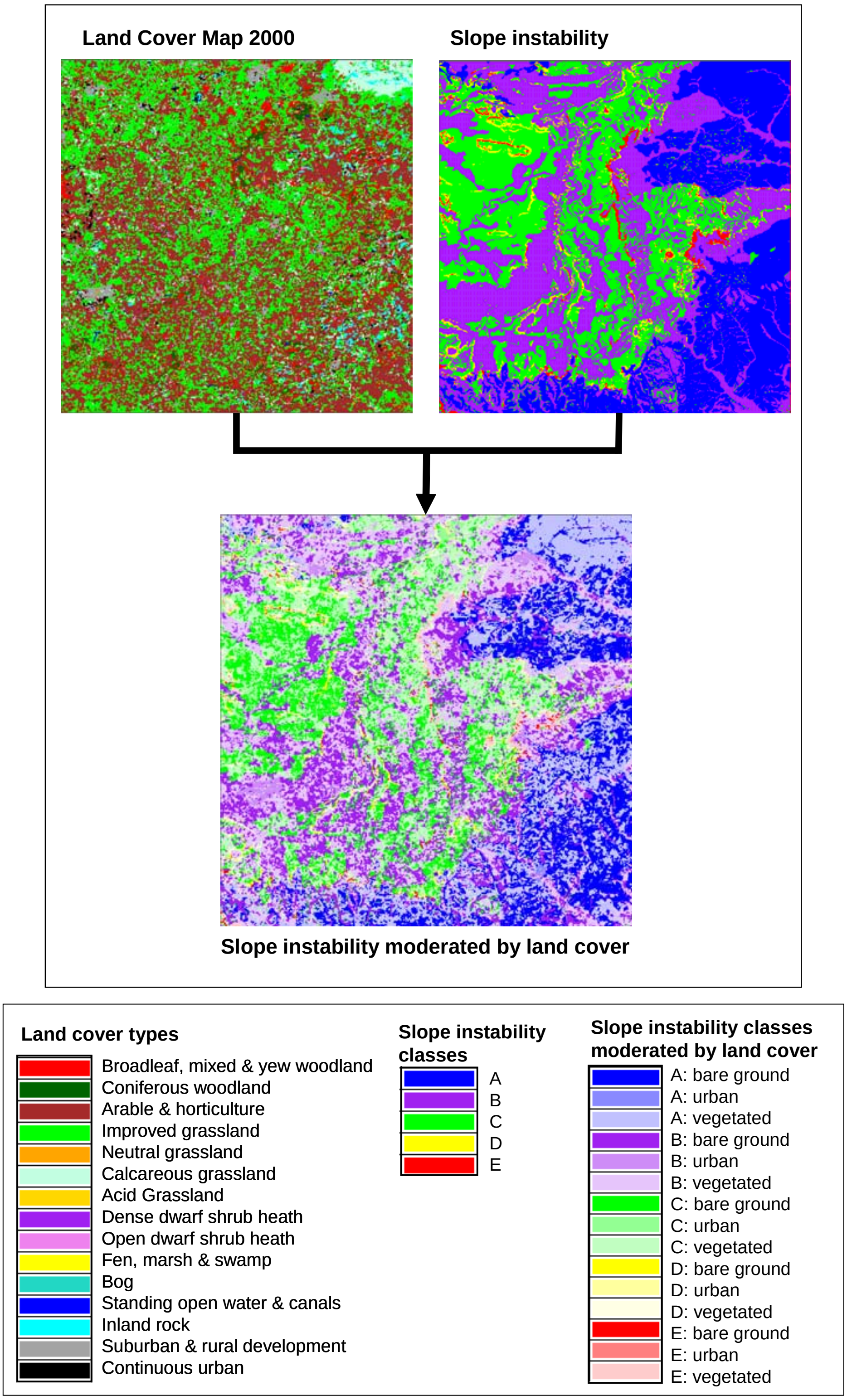


Figure 4. A sample 50 by 50 km area showing how LCM2000 data can be used to moderate slope instability data.

The potential effect of vegetation on slope stability can be further examined by looking at a small part of the data in greater detail. In Figure 5, Frame 1 shows the distribution of the most unstable slopes in the sample. Frame 2 shows the distribution of arable crops and horticulture; areas where the farming activity (ploughing etc) will break up the soil and shallow binding roots and bury any plant material. The surface is therefore loosened periodically and the protective effect of vegetation removed so that rainfall will be more likely to infiltrate the ground. Those areas where arable farming takes place on unstable slopes (where the polygons in Frames 1 and 2 in Figure 5 overlap) are shown (in red) on Frame 3. Here the farming activity will tend to increase the slope instability (including a higher risk of direct surface erosion).

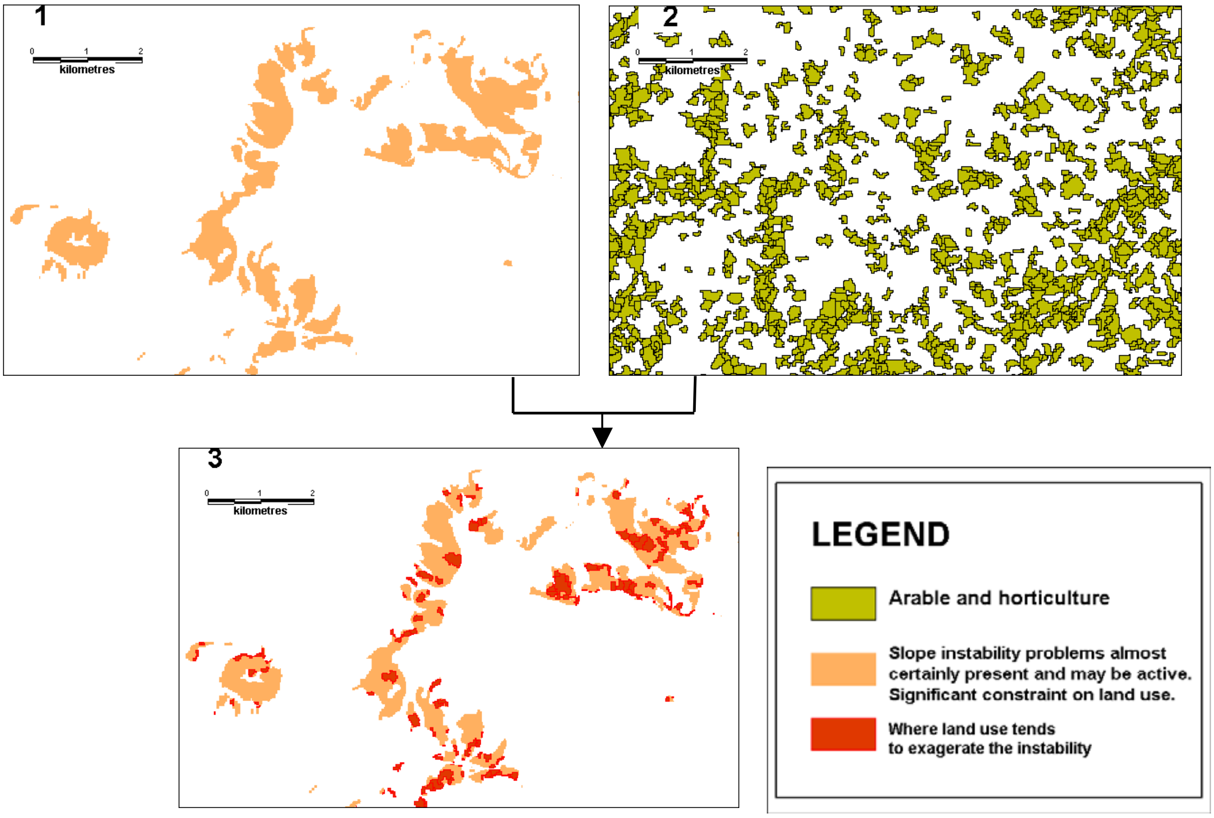


Figure 5. Potential effect of arable farming to decrease slope stability: Ground loosened by arable farming techniques

In contrast, in Figure 6, the same unstable slopes are shown in Frame 1 whilst woodland is shown in Frame 2. The areas of woodland on unstable slopes are shown, where the polygons in Frames 1 and 2 overlap, are shown in Frame 3 (in yellow). These are areas where the vegetation, in a number of ways noted previously, will tend to reduce the instability of the slope.

There is no attempt here to quantify the degree to which the slope instability might be increased in Frame 1 or decreased in Frame 2 in Figure 6. It is possible that such effects could be quantified with more detailed studies.

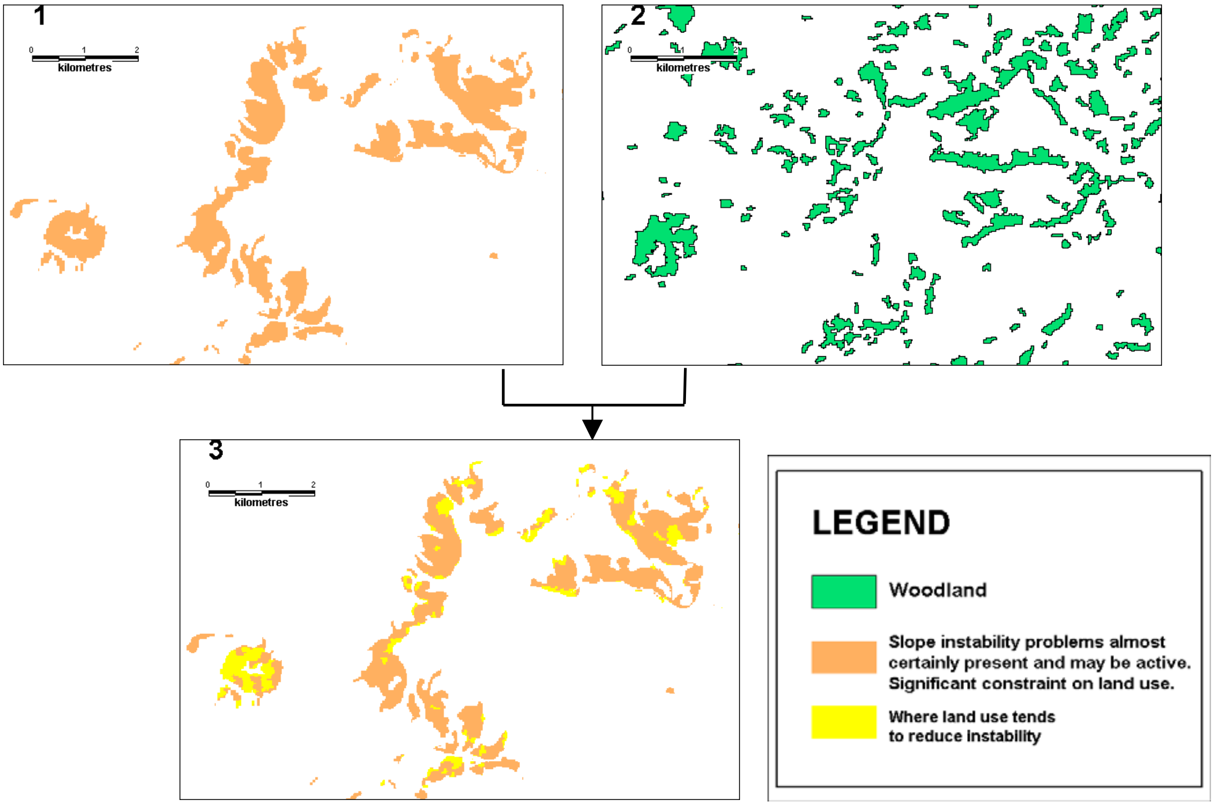


Figure 6. Potential effect of woodland to increase slope stability

2.6 CASE STUDY 2: USING LAND COVER INFORMATION IN BGS GEOREPORTS; AN EXAMPLE OF POSSIBLE COMBINED BGS-CEH PRODUCT OUTPUT

The BGS GeoReports system, as seen at http://www.bgs.ac.uk/georeports/, provides an easy way of integrating BGS and CEH datasets when answering enquiries concerning specific locations. There are now a number of different GeoReports variants including the Detailed Geological Assessment and the Natural Ground Stability report. These rely on varying combinations of automatically generated components, together with manual geological review, interpretation, compilation, check/approval. They can be compared at

http://www.bgs.ac.uk/georeports/components.cfm

From a search of enquiries by Anthea Brown at BGS it is apparent that some potential customers are also interested in information across a range of disciplines other than geology including:

- Land use, agricultural use, historic use, land classification.
- Water quality, surface water, groundwater vulnerability.
- Soil type, contamination.
- River discharge, climate.
- Subsidence, landslip.

In view of the interest shown in land use above (accepting that much of this may be with regard to urban industrialisation and land or water contamination) it would seem that two approaches could be implemented with relative technical ease.

2.6.1.1 LINKS TO OTHER DATA SOURCES

BGS should investigate adding links to the GeoReports pages on the Internet to send interested customers directly to Website pages of other NERC Institutes.

2.6.1.2 ADDING CEH INFORMATION TO GEOREPORTS

BGS should investigate adding LCM2000 data as an optional extra within GeoReports. If CEH are in agreement this could be delivered automatically with supporting documentation and contacts at CEH where customers can get additional information and interpretation. Perhaps it could be delivered free for a trial period with a request for feedback on its usefulness. Figure 7 shows how the LCM2000 data might look within a GeoReport.

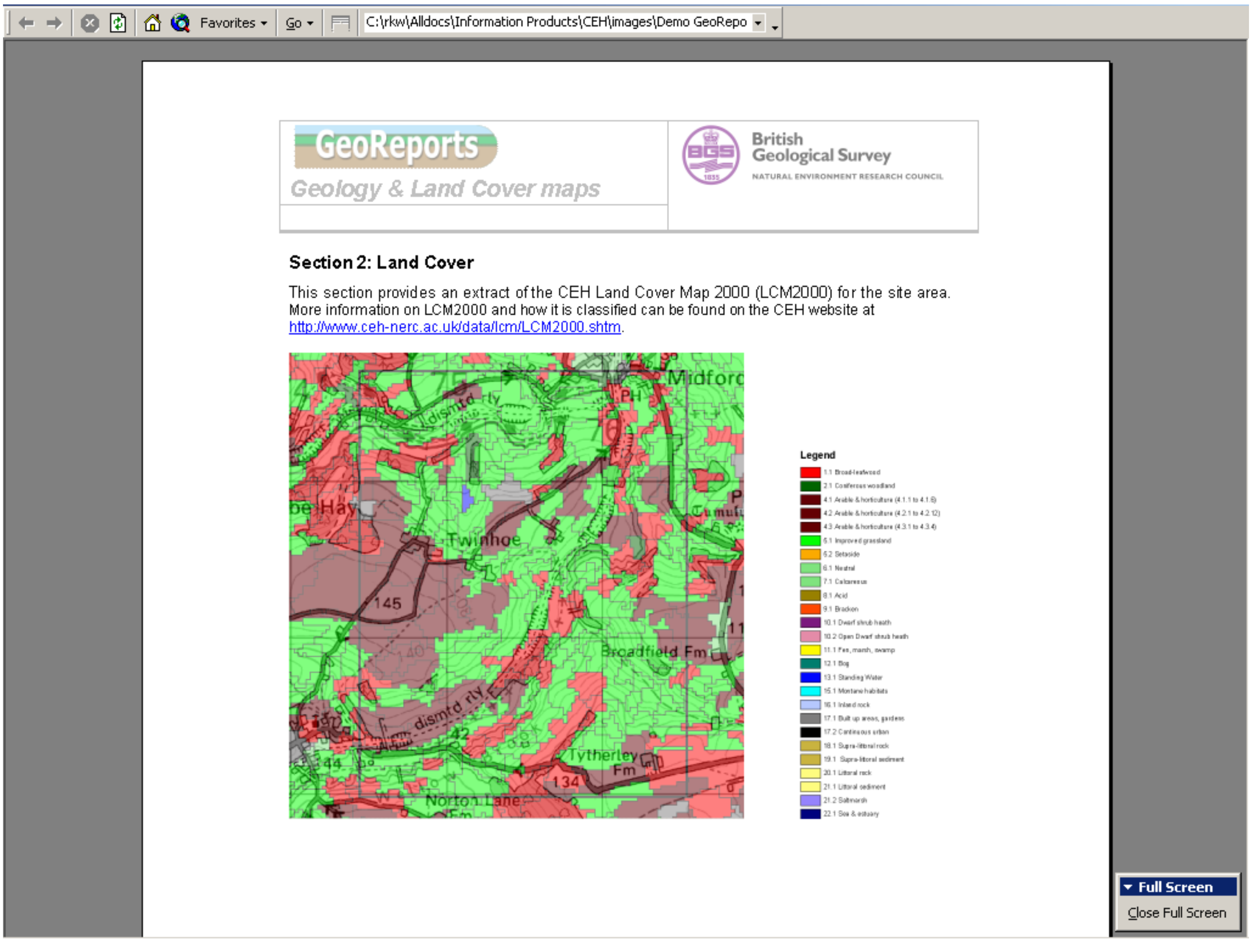


Figure 7. How LCM2000 data might look within a GeoReport. The example shows a prototype Land Cover image for a rural area in the South-West of England

3 Conclusions

- This project has shown how key NERC datasets can be scientifically compared using a combination of 'by-eye' and GIS statistical techniques
- Correlations between the two datasets examined in this study - DiGMapGB and LCM2000 – are not strong, but the lessons learned will be valuable for future similar work on other combinations of NERC data.
- What has been shown, however, is that the distribution of land cover types is not random when compared to geology, but any natural correlations tend to be heavily masked anthropogenic effects.
- A key success of this project has been to identify how much potential there is for extending such data correlation work to other data and areas of BGS and CEH work – it is obvious that much could be gained from bringing the environmental data and expertise of the two organisations together.
- A valuable list of potential BGS-CEH collaborations and outputs has been produced which will prove invaluable for the future programming of joint activities between BGS and CEH.
- Areas of potential work that would benefit from joint initiatives between BGS and CEH include hydrogeology, biogeography, ecological risk, urban planning, ground stability prediction and even forensic science.
- Two case studies, the first looking at how land cover data could be used to enhance BGS landslip hazard information, and the second at how BGS and CEH information might be sold through GeoReports, illustrates what could be achieved through closer collaboration between BGS and CEH.

4 References

BRITISH GEOLOGICAL SURVEY. 2000. Regional geochemistry of Wales and part of west-central England; stream sediment and soil. (Keyworth, Nottingham: British Geological Survey.)

WILBY, P.R., FORSTER, A. & BOOTH, K. A. 2002. Geology and slope instability survey of Causeway, Cadora and Bigswear Woods, Gloucestershire. British Geological Survey Commissioned Report, CR/02/044.

Appendix 1 BGS Initial 'by–eye' comparison of DiGMapGB-50 and LCM2000

BGS SUMMARY OF RELATIONSHIPS BETWEEN BEDROCK GEOLOGY AND LAND COVER FOR ST

From the initial overview there were few striking correlations between Bedrock geology and Land Cover although one area especially was recognised where a distinctive package of vegetation corresponded to an outcrop of mainly Devonian sandstone (Table 1). However, similar geology elsewhere did not give rise to a corresponding pattern in the vegetation and it was concluded that the correlation was primarily with the higher more rugged topography of the Quantock Hills, formed from Devonian sandstone, rather than the bedrock geology itself.

The results of the more systematic examination are summarised in Table 1. This shows that the most striking correlations occurred between, for example, broad-leaved woodland and the Blue Anchor Formation (Table 2) but only where it formed steep slopes unsuited to modern arable machine-dominated farming. Where this formation did not form a steep slope, then the preferred association with woodland ceased.

BGS SUMMARY OF RELATIONSHIPS BETWEEN SUPERFICIAL GEOLOGY AND LAND COVER FOR ST

Some Land Cover features gave a good correlation with Superficial Deposits by definition; thus areas mapped as Peat by BGS often corresponded with areas classified as Bog by CEH. However, this correlation is reliant upon the degree to which the land has been improved for use in farming. Thus where the land has been drained for arable fields or improved pasture the correlation ceased abruptly.

The initial conclusion was that the best correlations between geology and vegetation occurred where the vegetation remained 'natural' or 'semi-natural'; otherwise farming had a major impact on the vegetation, often seemingly irrespective of geology.

The use of different 'Low Water Marks' in the two datasets was apparent. DiGMapGB uses a line digitised around the margins of 'tidal flat' shown on the OS topographic base. In contrast CEH data are based on imagery and the extent of the littoral zone shown (rock or sediment) is dependant on the time of day relative to the tide; larger mudflats are shown when tide is low.

Also apparent in this analysis was the dramatic effect on the CEH classifications of the date of imagery with some habitats recognisable on say the spring image part of the composite but not the winter image part.

BGS SUMMARY OF RELATIONSHIPS BETWEEN BEDROCK GEOLOGY AND LAND COVER FOR S-W

A similar comparison was made of the data for the South–West. It was thought, in choosing this area with its distinctive outcrops of granites and geologically unusual ultramafic rocks of the Lizard, that that there might be a much clearer correlation between land cover and geology. However, the initial overview that these did not give rise to simple correlations was later confirmed by a more systematic study.

The granite of Dartmoor gave a distinctive pattern of unimproved habitats in the Land Cover data but this was not replicated on the similar granitic geology of Bodmin moor. Here the relief was significantly lower than Dartmoor allowing a greater range of farming activities to take place and the granite outcrop was barely discernible in the vegetation pattern. It was concluded that the dominant element was the topography which determined the type of farming activity.

Similarly, the ultramafic rocks of the Lizard, which often gives rise to distinctive plant assemblages in the wild, could not be discerned in the farmed landscape.

Table 1. Summary of BGS 'by eye' review of CEH data for 100km square ST, by Broad Habitat.

LCM code	**Land Cover Map 2000 Variant**	**Correlation**	**Comment**
01.1.1	Broad-leaf woodland deciduous	wide distribution especially upper slopes below Clay with Flints	too steep to farm
01.1.4	Broad-leaf woodland scrub	wide distribution especially upper slopes below Clay with Flints	too steep to farm
04.1.1	Arable barley	avoids steep ground	prefers low slope angles
04.1.2	Arable maize	avoids steep ground	prefers low slope angles
04.1.4	Arable wheat	very little in S Wales	
04.1.5	Arable cereal (spring)	avoids steep ground	prefers low slope angles
04.2.7	Arable peas	avoids steep ground	prefers low slope angles
04.2.10	Arable unknown	avoids steep ground	prefers low slope angles
04.2.11	Arable mustard	avoids steep ground	prefers low slope angles
04.3.2	Arable arable grass (ley)	poor cover	little in N & W, dense areas on winter image, composite image artefact
04.3.4	Arable set-aside (undifferentiated)	poor cover	little in N & W, dense areas on winter image, composite image artefact
05.1.1	Grass improved intensive	avoid built up areas	by definition should be good
05.1.2	Grass improved (hay/ silage cut)	avoid built up areas	by definition should be good
06.1.1	Grass rough (unmanaged)	two big areas	follows chalk scarp in places
06.1.2	Grass (neutral / unimproved)	two big areas	follows chalk scarp in places
07.1.1	Grass calcareous (managed)	Salisbury Plain	army camp
07.1.2	Grass calcareous (rough)	no correlation with chalk or limestone	
08.1.1	Grass acid	crosses both Carboniferous sandstone and limestone	contrary to expectation no correlation with limestone
08.1.2	Grass acid (rough)	poor cover	
08.1.4	Grass acid *Nardus/Festuca/Molinia*	poor cover	
10.1.1	Dwarf shrub heath dense (ericaceous)	poor cover, scattered across range of lithologies, some correlation with SST (Carboniferous and Devonian)	little in NE, composite image artefact
10.1.2	Dwarf shrub heath gorse	poor cover, scattered across range of lithologies, some correlation with SST (Carboniferous and Devonian)	little in NE, composite image artefact
10.2.1	Dwarf shrub heath open	poor cover, scattered across range of lithologies, some correlation with SST (Carboniferous and Devonian	little in NE, composite image artefact
12.1.1	Bog (shrub)	small part of BGS peat polygon	
12.1.2	Bog (grass/shrub)	small part of BGS peat polygon	
12.1.3	Bog (grass/herb)	small part of BGS peat polygon	
16.1.1	Inland bare semi-natural	commonly on chalk, due to ploughing	
17.1.1	Suburban/rural developed	includes motorways	
17.2.1	Urban residential/commercial	city centres	by definition should be good
17.2.2	Urban industrial		
21.1.1	Littoral mud	good with TFD or BTFU etc	by definition should be good
21.2.1	Supra-littoral saltmarsh	good with TFD or BTFU etc; we rarely map SM	by definition should be good
22.1.1	Sea		by definition should be good but CEH coastline depends on time of imagery
NB1	all arable land (4.1, 4.2 & 4.3) absent from Salisbury Plain army training ground and built up areas		
NB2	steep slopes below Clay with Flints	fairly good with broad leaved deciduous	

Table 2. Summary of BGS 'by eye' review of CEH data for 100km square ST, by Geology.

Lex Code	Geology on DiGMapGB-50	Correlation	Comment
PEAT	Peat	fairly good correlation with unimproved grass	
ALV	Alluvium	fairly good correlation with unimproved grass	
BAN	Blue Anchor Formation	good correlation with broad leaf deciduous but only where it forms steep slope	
various	Carboniferous limestone	some acid grassland	contrary to expectations
various	Devonian sandstone	package of acid grass, broad leaf woodland, conifer, arable unknown, dwarf shrub-heath	correlation actually with the high rugged relief, not the geology itself

BGS SUMMARY OF RELATIONSHIP BETWEEN SUPERFICIAL GEOLOGY AND LAND COVER FOR S-W

In the superficial deposits the areas of peat on the moors were usually associated with Bog plants, but at lower elevations similar deposits were often farmed for arable crops.

Appendix 2 BGS Statistics for comparison of DiGMapGB-50 and LCM2000

The total area covered by each lithology was measured and the most common lithologies, each with a minimum area of 10km^2 on SX and 1km^2 on ST, were selected. An SQL query was then used in a GIS application to extract the relationships between geology and land cover. For each of the most common bedrock lithologies Tables 3 and 4 below show the percentage of that lithology covered by each Level 2 broad habitat type of land cover for ST and SX respectively. Areas of water and urban developments are not included so the totals down the right hand side may be significantly below 100. Similar tables could be generated for the superficial deposits but are not shown here. Graphs were also created from the data as an alternative way of showing the relationships and highlighting those of greater significance.

BEDROCK GEOLOGY AND LAND COVER FOR ST.

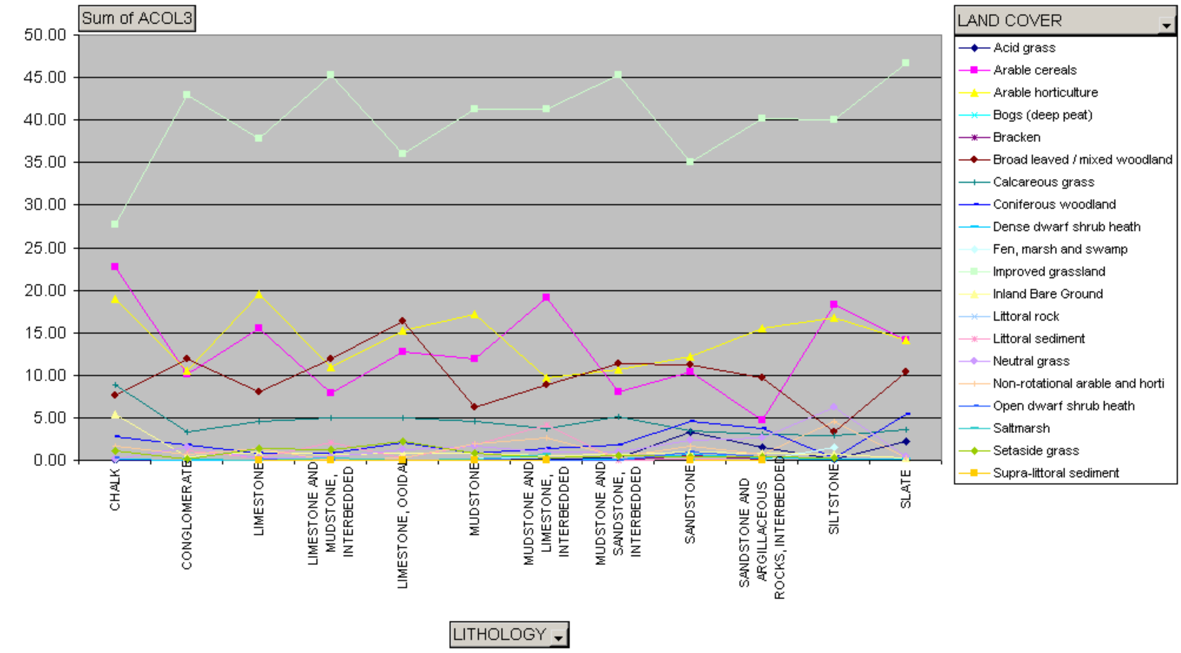
- In square ST mudstone covers 40% of the area, sandstone 14%, chalk 9% and limestone 9%, with other lithologies 27%.
- Improved grassland is the most common of broad habitats, appearing on nearly all lithologies.
- Arable cereals and arable horticulture are equally present in the area. Arable cereals are more common on ‘mudstone and limestone interbedded’ than arable horticulture; arable horticulture is more common over ‘sandstone and argillaceous rocks’ than arable cereals.
- Broad-leaved/mixed woodland and coniferous woodland have nearly the same shape on the graph (Figure 8) but there is much less coniferous than mixed woodland.
- Calcareous grass covers all the main lithologies (typically about 5%).

A more exhaustive study of these statistics is recommended, including other factors that affect land cover such as topography, human intervention and climate.

Table 3. Showing bedrock lithology and land cover by percentage for ST.

LITHOLOGY	Acid grass	Arable cereals	Arable horticulture	Bogs (deep peat)	Bracken	Broad leaved / mixed woodland	Calcareous grass	Coniferous woodland	Dense dwarf shrub heath	Fen, marsh and swamp	Improved grassland	Inland Bare Ground	Littoral rock	Littoral sediment	Neutral grass	Non-rotational arable and horti	Open dwarf shrub heath	Saltmarsh	Setaside grass	Supra-littoral sediment	Total
CHALK	0.00	22.72	19.00			7.64	8.93	2.78	0.15	0.08	27.70	5.38			0.17	1.67	0.30		1.05		98
CONGLOMERATE	0.07	10.12	10.53			11.87	3.34	1.83	0.01		42.89	0.48		1.08	1.46	0.69		0.10	0.10		85
LIMESTONE	0.04	15.57	19.59		0.00	8.07	4.62	0.77	0.05	0.02	37.76	1.02		0.23	0.29	1.33	0.15	0.03	1.33	0.01	91
LIMESTONE AND MUDSTONE, INTERBEDDED	0.00	7.88	10.89		0.00	11.93	4.94	0.89	0.01	0.01	45.33	0.65		2.05	0.37	0.06	0.00	0.24	1.25	0.01	87
LIMESTONE, OOIDAL		12.79	15.30			16.39	4.95	2.08	0.05		35.96	0.81		0.29	1.27	0.22	0.03	0.06	2.24	0.02	92
MUDSTONE	0.25	11.90	17.23	0.06	0.00	6.19	4.55	0.83	0.12	0.30	41.26	0.83	0.00	1.87	1.60	1.92	0.13	0.14	0.78	0.00	90
MUDSTONE AND LIMESTONE, INTERBEDDED	0.08	19.05	9.70			8.83	3.71	1.36	0.01	0.25	41.29	0.56	0.01	4.17	0.91	2.63	0.00	0.70	0.28	0.00	94
MUDSTONE AND SANDSTONE, INTERBEDDED	0.31	8.05	10.63		0.02	11.32	5.15	1.86	0.08		45.31	0.75		0.02	1.01	0.37	0.01		0.50		85
SANDSTONE	3.38	10.45	12.24	0.00	0.53	11.26	3.40	4.61	0.66	0.00	35.01	0.98		0.13	2.37	1.69	0.95	0.01	0.48	0.00	88
SANDSTONE AND ARGILLACEOUS ROCKS, INTERBEDDED	1.48	4.66	15.51		0.15	9.70	3.04	3.74	0.22	0.01	40.18	0.90		0.01	2.60	0.64	0.41	0.01	0.40	0.00	84
SILTSTONE	0.19	18.28	16.73	0.11		3.39	2.95	0.27	0.10	1.51	40.03	0.74			6.21	4.61	0.21		0.32		96
SLATE	2.21	14.12	14.09			10.34	3.55	5.42	0.15		46.61	0.33			0.43	0.25					98

The data in Table 3 are also shown in graphic form in Figure 8; two graphs – one with lithology or Rock_D (for Rock_Description) on the horizontal axis and the other with land cover for ease of comparison.



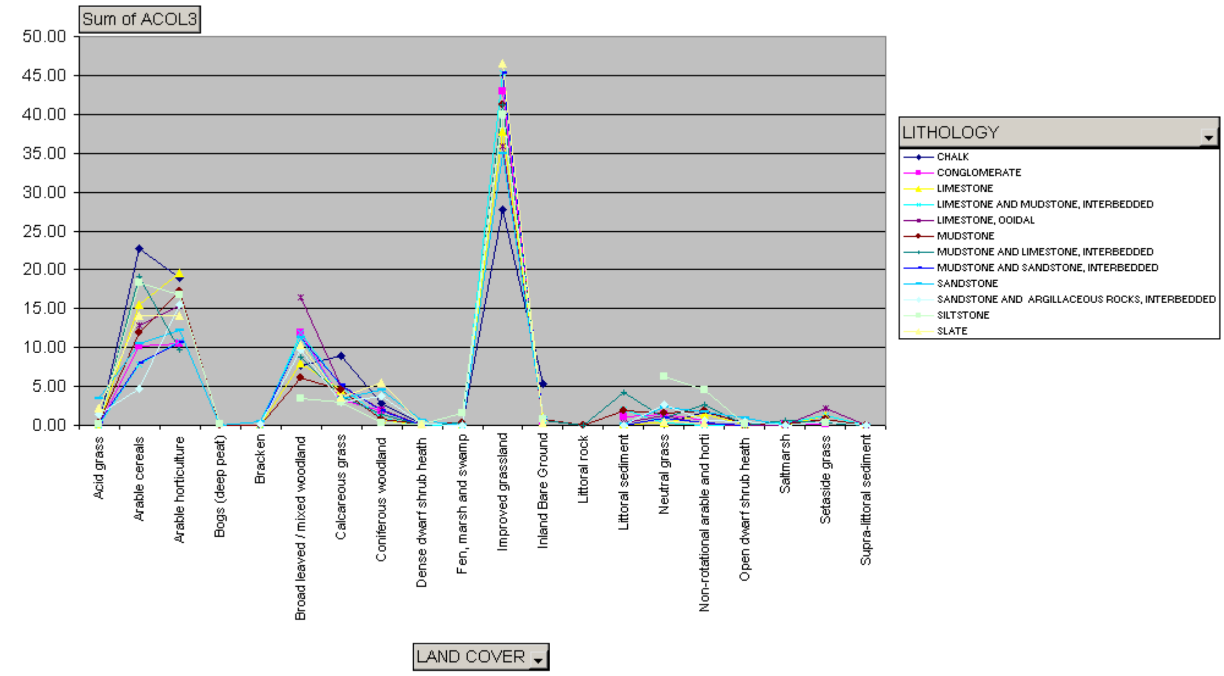


Figure 8. Graphs showing the relationship between Bedrock lithology and Land Cover % for ST.

BEDROCK GEOLOGY AND LAND COVER FOR SX.

- Statistical analysis shows that improved grassland is the most common of broad habitats, appearing on nearly all lithologies.
- Granite has a high percentage 34% of acid grass coverage, 10% open dwarf shrub heath, 10% broad leaf woodland and 8% bogs.
- Metasiltstone and metamudstone have a preference for neutral grass.
- Coarse-grained granite has 22% broad leaf woodland, 7% acid grass and 14% arable.
- Siltstone has 71% coverage in improved grassland.

Table 4. Table showing bedrock lithology and land cover by percentage for SX.

LITHOLOGY	Acid grass	Arable cereals	Arable horticulture	Bogs (deep peat)	Bracken	Broad leaved / mixed woodland	Calcareous grass	Coniferous woodland	Dense dwarf shrub heath	Improved grassland	Inland Bare Ground	Littoral sediment	Neutral grass	Open dwarf shrub heath	Saltmarsh	Supra-littoral sediment	Total
BASALTIC LAVA	0.1	8.8	10.6			8.0	2.0	0.5		64.5	0.1		0.2				94.8
BASALTIC TUFF AND BASALTIC LAVA	0.7	16.3	13.1			5.1	5.8	1.1	0.0	48.0	0.5	0.2	0.2		0.1		91.1
BRECCIA	0.4	23.6	13.2			7.2	3.6	2.8	0.1	27.9	0.7	0.5	0.8		0.2	0.0	80.9
CHERT	1.4	13.2	10.6			14.4	2.6	3.8	0.1	50.2	0.2	0.0	0.3				96.9
CONGLOMERATE AND SANDSTONE, INTERBEDDED	0.3	15.9	11.3			2.0	3.5	0.2		21.9	0.7	0.7	0.9		0.4		57.8
DOLERITE	1.2	13.7	9.3	0.0		12.0	6.4	1.5	0.3	47.2	0.4	0.3	0.5	0.0	0.1		93.0
GRANITE	33.9	0.7	2.4	7.8	0.0	10.8	0.1	2.6	1.1	18.5	1.2	0.0	7.7	10.9			97.8
GRANITE, COARSE-GRAINED	7.0	5.4	6.1			22.3	0.1	5.4	0.4	39.8	8.1		0.2	0.0			94.9
LIMESTONE	2.1	9.2	9.9			11.7	5.3	1.9	0.2	29.1	2.4	0.3	0.5		0.1		72.6
METAMUDSTONE	9.4	4.5	7.8	0.1		17.3	4.2	5.1	0.6	38.7	1.9		4.4	1.0			95.2
METAMUDSTONE AND METASANDSTONE	6.1	6.4	9.2	0.1		24.8	2.2	2.5	0.3	38.7	0.2		0.8	0.2			91.4
METAMUDSTONE AND METASILTSTONE	6.2	2.6	5.3			16.2	2.5	0.2	0.3	61.7	0.2		2.7	0.1			97.9
METASANDSTONE AND METAMUDSTONE	10.7	4.4	8.6	0.1		8.8	5.9	0.5	0.1	46.0	0.2		7.7	2.2			95.2
METASILTSTONE AND METAMUDSTONE	8.9	0.8	1.6			13.0	17.2			38.2			18.3	1.2			99.1
MUDSTONE	0.7	12.8	9.7			10.9	4.8	1.9	0.1	51.9	0.4	0.2	0.4		0.0		93.9
MUDSTONE AND SANDSTONE	1.6	16.0	12.3			10.9	6.3	1.2	0.2	42.9	0.6	0.5	0.4		0.1		93.0
MUDSTONE AND SANDSTONE, INTERBEDDED	0.5	16.0	8.7			17.4	5.1	4.9	0.2	39.2	0.2		0.3				92.4
MUDSTONE AND SILTSTONE	1.2	13.7	12.6			10.4	3.7	1.7	0.1	44.2	0.6	0.8	0.1		0.1		89.4
MUDSTONE, SILTSTONE AND SANDSTONE	0.8	18.3	14.0			10.6	5.5	2.1	0.1	37.0	0.5	1.9	0.3		0.3		91.3
SAND AND CLAY	1.0	10.2	8.0			15.8	4.1	11.5	0.7	24.4	2.2		0.5				78.5
SANDSTONE	1.5	17.7	14.8			9.3	2.7	3.8	0.6	31.9	1.3	1.5	2.4	0.1	0.3	0.0	87.7
SANDSTONE AND ARGILLACEOUS ROCKS, INTERBEDDE	2.8	6.8	11.4			11.1	3.1	7.2	0.2	45.8	0.2	0.0	6.1	0.9	0.0		95.9
SANDSTONE AND SUBORDINATE BRECCIA	0.2	1.7	2.1			0.8	2.3			5.2	1.0	35.6	0.2		0.3	0.0	49.4
SANDSTONE, SILTSTONE AND MUDSTONE	0.9	16.0	13.3			11.2	4.9	2.1	0.1	43.3	0.2	0.2	0.4		0.0		92.8
SCHIST, MICA	0.1	28.7	20.1			8.9	5.6	0.6	0.5	21.2	0.7	1.4	0.7		0.5		89.2
SILTSTONE	0.2	8.7	8.2			4.7	3.5	0.5		71.8	0.2		0.0				97.7
SILTY MUDSTONE	1.2	13.5	12.5			10.5	3.8	2.8	0.1	37.7	0.5	1.3	0.6		0.2		84.6
SLATE	2.6	13.2	13.6			6.0	6.5	1.6	0.0	42.9	0.7	0.7	0.4		0.2		88.3
SLATE AND SANDSTONE, INTERBEDDED	1.3	26.1	13.2			5.5	5.3	0.2	0.1	34.4	0.9	2.4	0.4		0.4	0.0	90.1

The data in Table 4 above are also shown in graphic form in Figure 9.

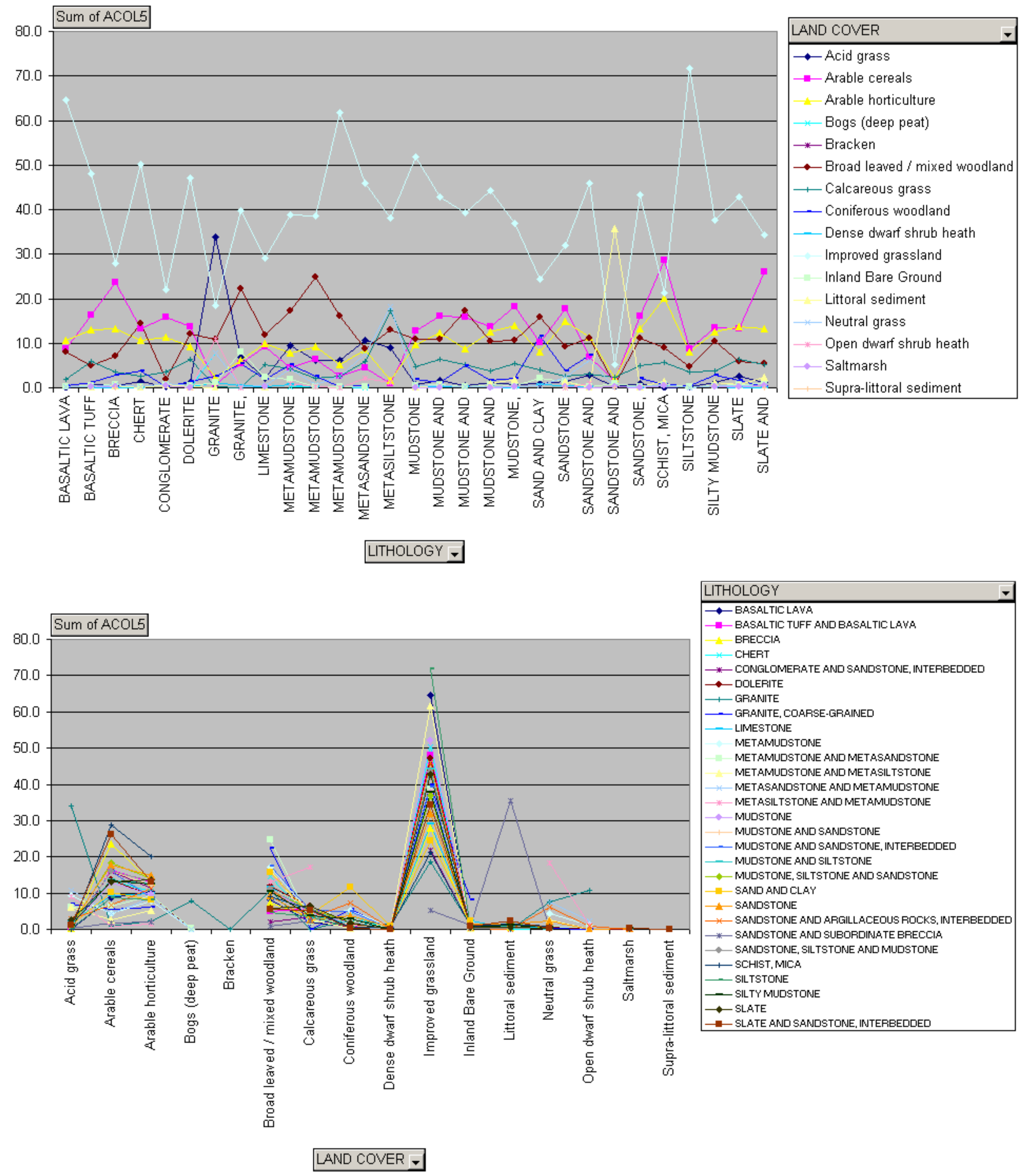
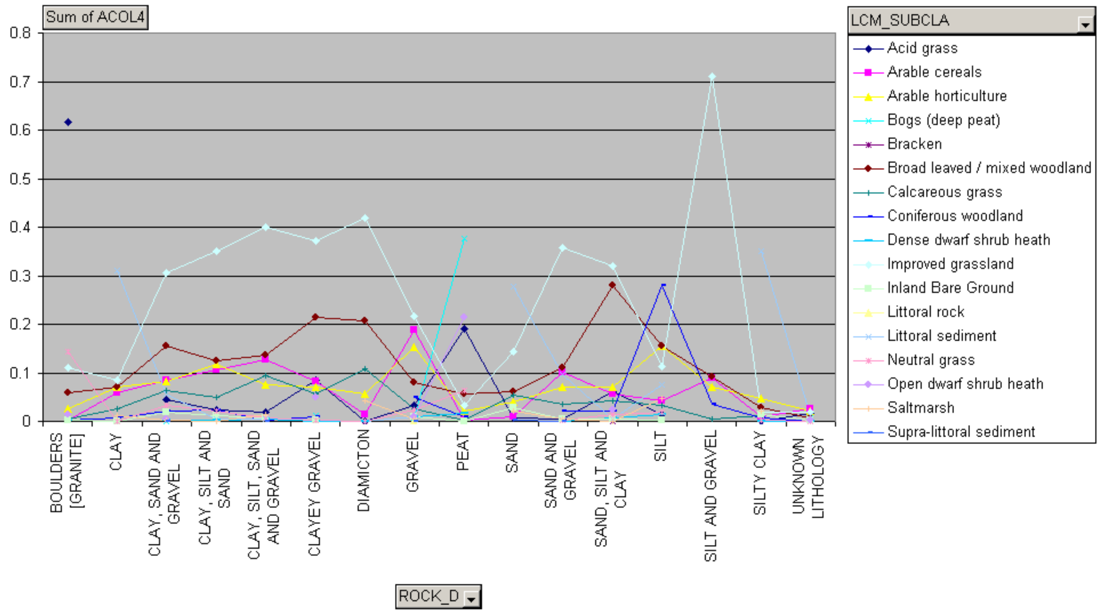


Figure 9. Graph showing the relationship between Bedrock lithology and Land Cover % for SX.

SUPERFICIAL DEPOSITS AND LAND COVER FOR SX.

- Improved grassland is the most common land cover across all the lithologies.
- Peat shows a 40% correlation with bogs, and an absence improved grassland.
- No acid grass on clay.
- Granite boulders are over 60% covered by acid grass.

The data for superficial deposits in SX are shown in graphic form in Figure 10.



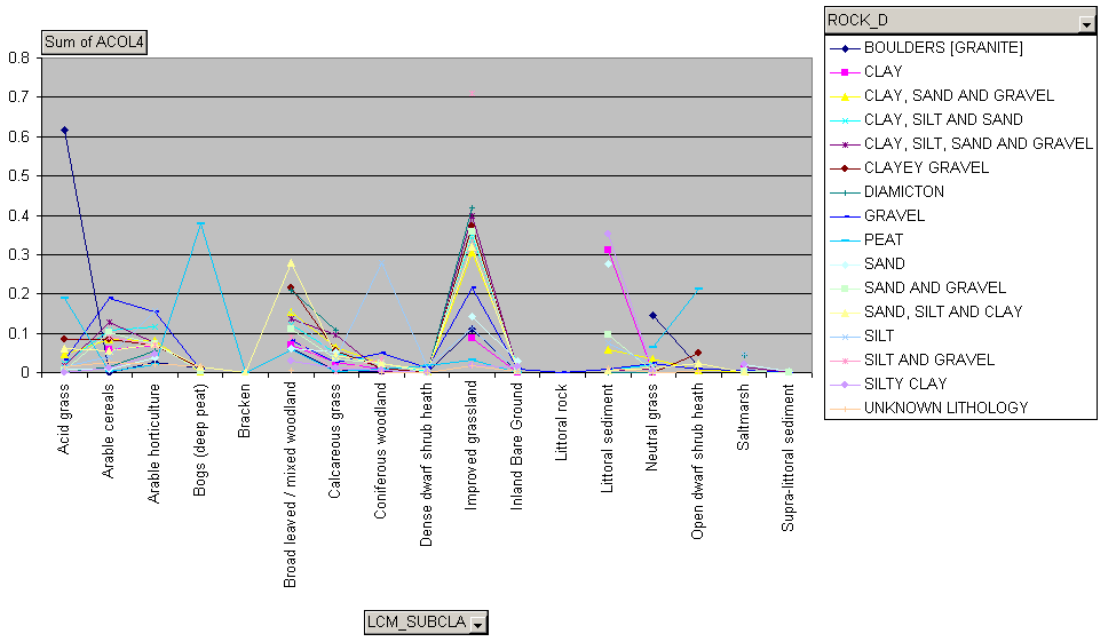


Figure 10. Graph showing the relationship between Superficial Deposits and Land Cover % for SX.

Appendix 3 CEH Statistics for comparison of DiGMapGB-50 and LCM2000

BEDROCK GEOLOGY AND LAND COVER FOR AREA ST

Rasterised at 100 m spatial resolution, OS map tile ST has 24 different land cover types (including sea & estuary) and 57 different bedrock formations.

The proportional composition of land cover is shown in Table 5. Just five land cover types occupy 82% of the total area of OS map tile ST: improved grassland (38%), arable horticulture (16%), arable cereals (13%), broadleaf, mixed & yew woodland (8%), and suburban & rural development (7%).

The proportional composition of the bedrock formations is shown in Table 6. Of the 57 different bedrock formations, only 13 occupy more than 1% of the total area of OS map tile ST. The four most prevalent rock formations occupy a combined 72% of the area of ST, these are: mudstone (39%), sandstone (14%), chalk (10%) and limestone & mudstone (9%). A further 19% of the area of ST is made up by just nine additional bedrock formations.

Broad Habitat (BH)	BH code	# 100 m pixels	%
Broadleaf, mixed & yew woodland	1.1	77189	8.44
Coniferous woodland	2.1	18564	2.03
Arable cereals	4.1	118219	12.93
Arable horticulture	4.2	144098	15.76
Arable non-rotational horticulture	4.3	14949	1.63
Improved grassland	5.1	345711	37.81
Semi-improved or reverting grassland	5.2	7695	0.84
Neutral grassland	6.1	13067	1.43
Calcareous grassland	7.1	43045	4.71
Acid grassland	8.1	7000	0.77
Bracken	9.1	1003	0.11
Dense dwarf shrub heath	10.1	1699	0.19
Open dwarf shrub heath	10.2	2422	0.26
Fen, marsh & swamp	11.1	1584	0.17
Bog	12.1	236	0.03
Standing open water & canals	13.1	2562	0.28
Inland rock	16.1	11703	1.28
Suburban & rural development	17.1	64801	7.09
Continuous urban	17.2	16377	1.79
Supra-littoral sediment	19.1	27	0.00
Littoral rock	20.1	6	0.00
Littoral sediment	21.1	17518	1.92
Saltmarsh	21.2	981	0.11
Sea & estuary	22.1	3884	0.42

Table 5. The proportional composition of land cover types in OS tile ST.

Bedrock type	# 100 m pixels	%	Bedrock type	# 100 m pixels	%
Andesite	97	0.01	Micritic limestone	2	0.00
Andesitic lava	33	0.00	mudstone	355435	39.34
Arg. Limestone	7862	0.87	Mudstone & limestone	30447	3.37
Basalt	104	0.01	Mudstone & sandstone	14589	1.61
Basaltic lava	4	0.00	Mud-, sandstone & cong.	279	0.03
Breccia	5081	0.56	Mud-, silt- & sandstone	2697	0.30
Calc. mudstone	4227	0.47	Pebbly sand	15	0.00
Calc. sandstone	231	0.03	Sand	3035	0.34
Chalk	86404	9.56	Sand & silt	548	0.06
Chert	5713	0.63	Sandstone	128552	14.23
Chert & mudstone	567	0.06	Sandstone & cong.	370	0.04
Clay	2444	0.27	Sandstone & mudstone	1545	0.17
Conglomerate	14808	1.64	Sanstone & siltstone	250	0.03
Cong. & sandstone	2326	0.26	Sandstone & arg. Rock	14740	1.63
Dolomite	228	0.03	Limestone & sandstone	3275	0.36
Dolomite mudstone	450	0.05	Sand-, silt- & mudstone	1199	0.13
Dolomite limestone	1053	0.12	Sandy mudstone	6628	0.73
Dolomite limestone	3998	0.44	Shelly limestone	1139	0.13
Glauconitic sandstone	6281	0.70	Siltstone	21921	2.43
Ironstone	64	0.01	Silt- & limestone	623	0.07
Lamprophyre	13	0.00	Silt- & mudstone	517	0.06
Lime mudstone	16	0.00	Silty clay	3737	0.41
Limestone	82885	9.17	Silty mudstone	5229	0.58
Limestone & mudstone	23355	2.59	Slate	16909	1.87
Limestone & arg. Rocks	1841	0.20	Slate & sandstone	801	0.09
Limestone	19798	2.19	Tuff	116	0.01
Marl	750	0.08	Sedimentary	11002	1.22
Micaceous sandstone	6234	0.69	Unknown	988	0.11

Table 6. The proportional composition of bedrock formations in OS tile ST.

The relationship between land cover and bedrock for OS map tile ST was examined by performing a cross tabulation between the two 100 m spatial resolution raster datasets. If there were no relationship between the two, then the distribution of land cover types should be in approximate proportion to the distribution of bedrock formations. Table 7 plots the percentage cover of each land cover type across the four most prevalent bedrock formations. Any deviation in the proportional coverage of a particular land cover type from the proportional coverage of a particular bedrock formation of greater than 5 percentage points is highlighted as representing a bedrock formation on which the land cover is either over- or under-represented. For example, for broadleaf, mixed & yew woodland, 65% of the coverage in OS map tile ST occurs on the four most prevalent bedrock formations. The percentage coverage on sandstone, limestone and chalk is very similar to the proportional coverage of those bedrock formations. However, the proportion of broadleaf, mixed & yew woodland that occurs on mudstone (28%) is notably lower than the proportional coverage of mudstone (39%). Thus, broadleaf, mixed & yew woodland, it may be argued, is under-represented on mudstone in OS map tile ST, and must therefore be slightly over-represented on other bedrock formations. However, this does not necessarily suggest a direct cause and effect, e.g. that broadleaf, mixed & yew woodland does not grow well above mudstone bedrock, as issues such as the relief, shelter, tidal inundation, and micro-climate of the mudstone terrain and anthropological impacts will influence vegetation growth.

Broad Habitat (BH)	Mudstone	Sandstone	Chalk	Limestone	TOTAL (%)
Broadleaf, mixed & yew woodland	28	19	9	9	65
Coniferous woodland	16	32	13	4	65
Arable cereals	36	11	17	11	75
Arable horticulture	43	11	12	11	77
Arable non-rotational horticulture	46	15	10	8	77
Improved grassland	42	13	7	9	71
Semi-improved or reverting grassland	37	8	12	15	71
Neutral grassland	42	23	1	2	68
Calcareous grassland	38	10	18	9	75
Acid grassland	13	63	0	0	76
Bracken	1	72	0	0	72
Dense dwarf shrub heath	24	50	8	2	85
Open dwarf shrub heath	19	51	11	5	86
Fen, marsh & swamp	69	0	4	1	74
Bog	89	1	0	0	90
Standing open water & canals	55	7	4	4	70
Inland rock	26	11	40	7	84
Suburban & rural development	39	20	2	10	70
Continuous urban	44	15	4	8	71
Supra-littoral sediment	28	6	0	28	61
Littoral rock	33	0	0	0	33
Littoral sediment	69	2	0	2	72
Saltmarsh	54	1	0	2	58
Sea & estuary	90	1	0	0	91
% cover for rock type	39	14	10	9	72

(blue) land cover type under-represented on this bedrock
(yellow) land cover type is over-represented on this bedrock

Table 7. Cross tabulation of percentage land cover for the four most prevalent bedrock formations.
(If all 57 bedrock formations were shown in the table, the row percentages would sum to 100%. The percentage cover of OS map tile ST for each of the bedrock formations is given at the foot of the table).

The pattern of blue and yellow cells in Table 7 indicates that the distribution of land cover types in relation to bedrock formations is far from random. Furthermore, the patterns are precisely as would be predicted. Thus, mudstone has a disproportionately high coverage of Fen, marsh & swamp, bog, standing open water & canals, littoral sediment (which includes mudflats), saltmarsh and seas & estuary. Sandstone has a disproportionately high coverage of, in particular, acid grassland, bracken, open and dense dwarf shrub heath, and also neutral grassland and conifer plantation. Chalk a disproportionately high coverage of calcareous grassland, arable cereals and also inland bare; whilst limestone has a disproportionately high coverage of supra-littoral sediment (which includes dunes) and semi-improved or reverting grassland. Only in the case of littoral rock is the total coverage on the four most prevalent bedrock formations significantly lower than the 72% combined coverage of those bedrock formations. In this particular case, 67% of littoral rock occurs on the mudstone & limestone formation.

The distribution of land cover types across the seven most prevalent bedrock formations (which together total 80% of the area of OS map tile ST) and the remaining 50 bedrock formations grouped into 'other' is shown in Figure 11. This, once again highlights that certain land cover types occur preferentially on certain bedrock formations. However, it should be stressed that the distribution of vegetation types is influenced not just by bedrock geology, but also by topography, micro-climate and human intervention (past and present). Thus, whilst Figure 11 clearly highlights that land cover distribution is influenced by bedrock geology, it is not possible to predict land cover type from bedrock geology alone with any degree of certainty. At best, it is possible to predict the probability of a particular land cover type occurring on a particular bedrock formation.

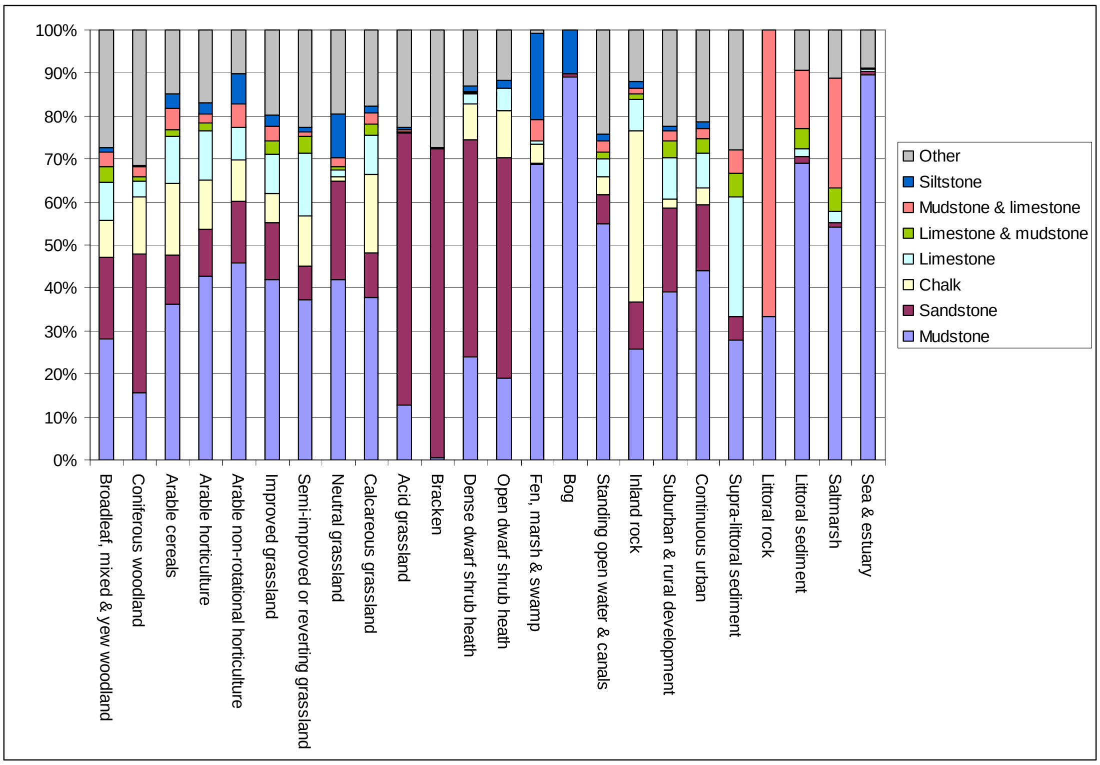


Figure 11. The distribution of land cover types across the seven most prevalent bedrock formations and a combined 'other' class (composed of the remaining 50 bedrock formations) for OS map tile ST.

BEDROCK GEOLOGY AND LAND COVER FOR AREA SW

Rasterised at 100 m spatial resolution, the South West (SW) has 22 different land cover types (including sea & estuary) and 104 different bedrock formations.

The proportional composition of land cover is shown in Table 8. As with OS map tile ST, five land cover types occupy 81% of the total area of the SW, and once again these are: improved grassland (41%), arable horticulture (12%), arable cereals (12%), broadleaf, mixed & yew woodland (11%), and suburban & rural development (5%).

The proportional composition of the bedrock formations is shown in Table 9. Of the 104 different bedrock formations, only 18 occupy more than 1% of the total area of the SW. The four most prevalent rock formations occupy a combined 53% of the area of the SW, these are: mudstone (21%), sandstone (18%), granite (9%) and slate (6%). A further 18% of the area of the SW is made up by just four additional bedrock formations which are composed of various combinations of mud-, silt- and sandstone.

Broad Habitat (BH)	BH code	# 100 m pixels	%
Broadleaf, mixed & yew woodland	1.1	107715	10.86
Coniferous woodland	2.1	20852	2.10
Arable cereals	4.1	122149	12.31
Arable horticulture	4.2	116098	11.70
Arable non-rotational horticulture	4.3	68	0.01
Improved grassland	5.1	405539	40.89
Neutral grassland	6.1	15796	1.59
Calcareous grassland	7.1	41169	4.15
Acid grassland	8.1	54360	5.48
Bracken	9.1	25	0.00
Dense dwarf shrub heath	10.1	6081	0.61
Open dwarf shrub heath	10.2	13404	1.35
Bog	12.1	6505	0.66
Standing open water & canals	13.1	1681	0.17
Inland rock	16.1	7337	0.74
Suburban & rural development	17.1	45842	4.62
Continuous urban	17.2	12549	1.27
Supra-littoral sediment	19.1	806	0.08
Littoral rock	20.1	576	0.06
Littoral sediment	21.1	6995	0.71
Saltmarsh	21.2	1746	0.18
Sea & estuary	22.1	4592	0.46

Table 8. The proportional composition of land cover types in the SW study area.

Bedrock type	# 100 m pixels	%	Bedrock type	# 100 m pixels	%
Agglomerate	3	0.00	Metalimestone	499	0.05
Aplite	1	0.00	Metamafic rock	14	0.00
Basalt	661	0.06	Metamorphosed basaltic rock	424	0.04
Basaltic lava	3211	0.31	Metamorphosed limestone & pelite	1486	0.14
Basaltic pillow lava	196	0.02	Metamorphosed tuff	220	0.02
Basaltic pyroclastic rocks	98	0.01	Metamudstone	16576	1.59
Basaltic rock	1031	0.10	Metamudstone & metasiltstone	31632	3.03
Basaltic tuff	86	0.01	Metasandstone & metasiltstone	3431	0.33
Basaltic tuff & basaltic lava	6708	0.64	Metasiltstone & metamudstone	1304	0.12
Basaltic volcanic breccia	9	0.00	Microgranite	704	0.07
Basic rock	632	0.06	Mudstone	216039	20.69
Breccia	31001	2.97	Mudstone & chert	95	0.01
Breccia & sansdtone	1047	0.10	Mudstone & limestone	14680	1.41
Chert	6049	0.58	Mudstone & sandstone	27717	2.65
Chert & slate	654	0.06	Mudstone & sandstone	43303	4.15
Chert, limestone & mudstone	1872	0.18	Mudstone & siltstone	45300	4.34
Clay & lignite	270	0.03	Mudstone, lava & tuff	854	0.08
Clay & sand	596	0.06	Mud-, sandstone & cong.	294	0.03
Clay, sand & gravel	41	0.00	Mud-, sand- & limestone	86	0.01
Clay, silt & sand	808	0.08	Mud, silt- & sandstone	51563	4.94
Clayey gravel	163	0.02	Oliststrome	2762	0.26
Conglomerate	2849	0.27	Peridotite	125	0.01
Cong. & sandstone	2682	0.26	Peridotite & serpentinite	5383	0.52
Dolorite	3280	0.31	Picrite	15	0.00
Felsic tuff	6	0.00	Quartz-feldspar porphyry	6	0.00
Felsite	1323	0.13	Quartzite	717	0.07
Gabbro	1762	0.17	Rhyolite	53	0.01
Gabbro & dolerite	212	0.02	Rhyolite pyroclastic rock	12	0.00
Granite	97279	9.32	Sand & clay	2499	0.24
Granite & granitic gneiss	395	0.04	Sand & silt	686	0.07
Granite (coarse grained)	21969	2.10	Sandstone	179837	17.23
Granite (fine grained)	3929	0.38	Sandstone & mudstone	13138	1.26
Granite (medium grained)	4241	0.41	Sandstone & breccia	1609	0.15
Granophyre	3	0.00	Sandstone & argillaceous rocks	11063	1.06
Gravel	853	0.08	Sand-, silt- & mudstone	47177	4.52
Gravel, silt & clay	39	0.00	Schist	32	0.00
Gravelly sand	94	0.01	Schist, hornblende	3418	0.33
Igneous rock	150	0.01	Schist, mica	3584	0.34
Hyaloclastite	90	0.01	Sedimentary rock	630	0.06
Lamprophyres	231	0.02	Serpentinite	1	0.00
Lava & tuffs	776	0.07	Siltstone	1927	0.18
Limestone	6759	0.65	Silt- & mudstone	2974	0.28
Limestone & mudstone	34	0.00	Silty mudstone	20115	1.93
Limestone & arg. rocks	8	0.00	Slate	63211	6.05
Mafic lava & mafic tuff	697	0.07	Slate & sandstone	16943	1.62
Mafic tuff	42	0.00	Trachyte group	4	0.00
Meta-olistostrome	159	0.02	Trachytic lava	3	0.00
Metabasalt	854	0.08	Tuff	398	0.04
Metabasaltic rock	825	0.08	Tuff & agglomerate	705	0.07
Metachert	964	0.09	Ultramafic rock	1	0.00
Metadolerite	575	0.06	Unknown	211	0.02
Metagabroic & metadoleritic rocks	310	0.03			

Table 9. The proportional composition of bedrock formations in the SW study area.

Table 10 plots the percentage cover of each land cover type across the eight most prevalent bedrock formations (which together total 71% of the SW study area). As with Table 7, any deviation in the proportional coverage of a particular land cover type from the proportional coverage of a particular bedrock formation of greater than 5 percentage points is highlighted as representing a bedrock formation on which the land cover is either over- or under-represented.

Broad Habitat (BH)	Mudstone	Sandstone	Granite	Slate	Mud, silt- & sandstone	Sand-, silt- & mudstone	Mudstone & sandstone	Mudstone & siltstone	TOTAL (%)
Broadleaf, mixed & yew woodland	19	19	9	5	4	4	6	4	70
Coniferous woodland	19	23	10	4	4	4	8	2	75
Arable cereals	22	18	2	2	8	6	4	5	68
Arable horticulture	17	17	5	4	8	5	3	7	66
Arable non-rotational horticulture	19	3	0	0	0	12	37	3	74
Improved grassland	24	19	5	8	4	6	4	4	74
Neutral grassland	6	18	41	8	2	2	2	2	79
Calcareous grassland	22	14	0	5	8	5	5	6	66
Acid grassland	2	12	54	7	1	1	2	1	81
Bracken	0	0	88	0	0	0	0	0	88
Dense dwarf shrub heath	3	37	24	4	1	1	2	1	73
Open dwarf shrub heath	0	16	67	3	0	1	0	0	87
Bog	0	0	96	2	0	0	0	0	98
Standing open water & canals	20	7	33	7	1	0	0	3	72
Inland rock	8	7	13	2	3	1	1	4	39
Suburban & rural development	17	11	3	4	5	4	4	7	56
Continuous urban	16	13	4	3	6	3	2	9	57
Supra-littoral sediment	40	0	0	0	15	0	0	12	67
Littoral rock	2	1	11	0	20	3	0	19	57
Littoral sediment	17	12	1	4	9	1	0	19	63
Saltmarsh	9	6	6	4	12	1	0	13	50
Sea & estuary	6	3	0	4	13	2	0	13	40
% cover for rock type	21	17	9	6	5	5	4	4	71

(blue) land cover type under-represented on this bedrock
(yellow) land cover type is over-represented on this bedrock

Table 10. Cross tabulation of percentage land cover for the eight most prevalent bedrock formations in the SW study area.
(If all 104 bedrock formations were shown in the table, then the row percentages would sum to 100%. The percentage cover of the SW for each of the bedrock formations is given at the foot of the table).

Once again, the pattern of blue and yellow cells in Table 10 indicates that the distribution of land cover types in relation to bedrock formations is not random, and the patterns are as would be predicted. The granite outcrops on the moors have a disproportionately high coverage of semi-natural land cover types (i.e. neutral grassland, acid grassland, bracken, open and dense dwarf shrub heath, bog, and standing open water & canals). Sandstone has a disproportionately high coverage of dense dwarf shrub heath and conifer plantation. Mudstone has a disproportionately high coverage of supra-littoral sediment, whilst all of the coastal land cover types occur preferentially on mudstone and siltstone bedrock formations.

The distribution of land cover types across the eight most prevalent bedrock formations (which together total 71% of the SW study area) and the remaining 96 bedrock formations grouped into ‘other’ is shown in Figure 12. As with the example for ST, this highlights that certain land cover types occur preferentially on certain bedrock formations but that at best, it would only be possible to predict the probability of a particular land cover type occurring on a particular bedrock formation.

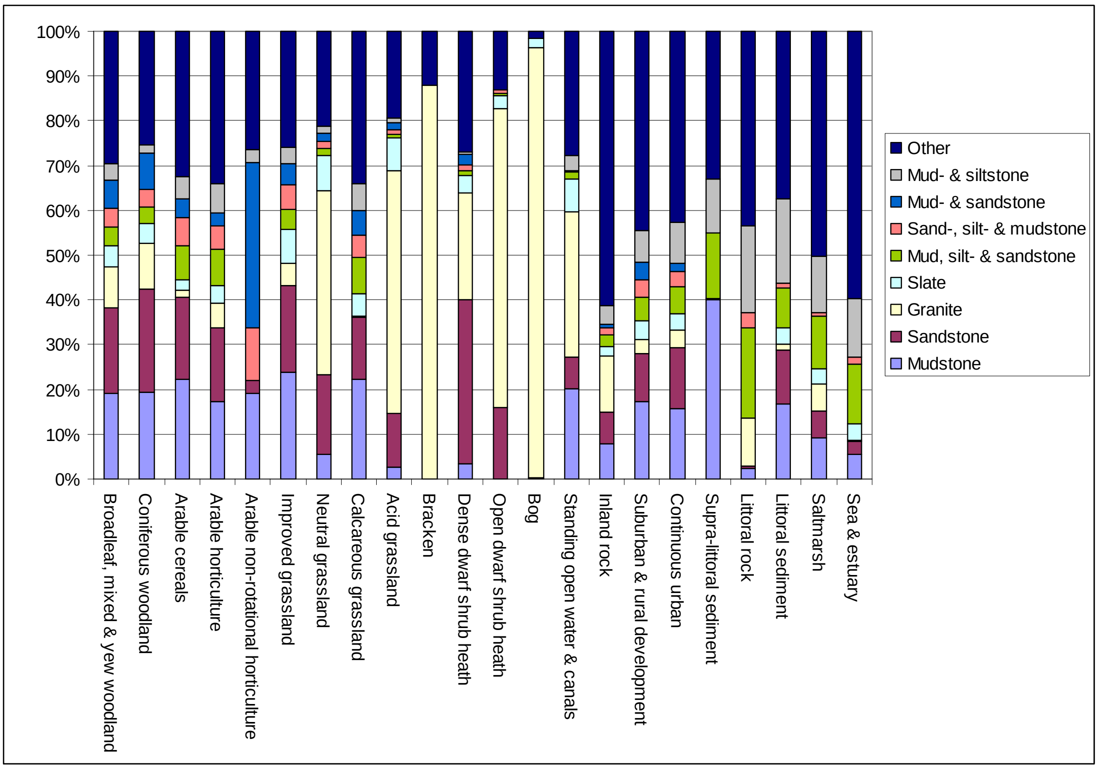


Figure 12. The distribution of land cover types across the eight most prevalent bedrock formations and a combined 'other' class (composed of the remaining 96 bedrock formations) for the SW study area.

SUPERFICIAL GEOLOGY AND LAND COVER FOR AREA ST

For the extract of LCM2000 and the superficial geology, rasterised at 100 m spatial resolution, OS map tile ST has 24 different land cover types (including sea & estuary) and 25 different superficial deposits.

The proportional composition of land cover for the subset area of map tile ST is shown in Table 11. Similarly to the situation with the complete tile coverage, five land cover types occupy 78% of the total area of OS map tile ST; these are: improved grassland (40%), arable horticulture (13%), arable cereals (10%), broadleaf, mixed & yew woodland (6%), and suburban & rural development (8%).

The proportional composition of the superficial deposits for OS map tile ST is shown in Table 12. Of the 25 different superficial deposits, eight occupy more than 2% of the total area of the subset OS map tile ST. The seven most prevalent superficial deposits occupy a combined 94% of the subset area of ST; and these are: tidal flat deposits (23%), alluvium (21%), head (16%), till (10%), clay with flint (9%), river terrace deposits (9%), and peat (5%).

Broad Habitat (BH)	# 100 m pixels	%
Broadleaf, mixed & yew woodland	15274	6.42
Coniferous woodland	2664	1.12
Arable cereals	24547	10.31
Arable horticulture	31486	13.23
Arable non-rotational horticulture	4969	2.09
Improved grassland	95948	40.30
Semi-improved or reverting grassla	1439	0.60
Neutral grassland	7811	3.28
Calcareous grassland	9743	4.09
Acid grassland	1591	0.67
Bracken	160	0.07
Dense dwarf shrub heath	296	0.12
Open dwarf shrub heath	443	0.19
Fen, marsh & swamp	1365	0.57
Bog	233	0.10
Standing open water & canals	1370	0.58
Inland rock	3113	1.31
Suburban & rural development	18216	7.65
Continuous urban	7395	3.11
Supra-littoral sediment	10	0.00
Littoral rock	1	0.00
Littoral sediment	8272	3.47
Saltmarsh	696	0.29
Sea & estuary	1013	0.43

Table 11. The proportional composition of land cover types in OS tile ST for a subset area for which information on superficial deposits exist.

Superficial deposits	# 100 m pixels	%
alluvial fan deposits	346	0.14
alluvium	50855	21.04
beach & tidal flat deposits	5885	2.43
beach deposits	218	0.09
blown sand	901	0.37
brickearth	1	0.00
burtle beds	1487	0.62
sand & gravel	73	0.03
clay with flint	22379	9.26
glaciofluvial deposits	3468	1.43
glaciofluvial sheet deposits	854	0.35
glaciolasuctrine deposits	85	0.04
head	37492	15.51
marine deposits	306	0.13
peat	12880	5.33
raised tidal flat deposits	674	0.28
river terrace deposits	22162	9.17
saltmarsh deposits	12	0.00
sand & gravel	259	0.11
storm blown deposits	144	0.06
submerged forest	6	0.00
superficial deposits	682	0.28
tidal flat deposits	56558	23.40
till	23927	9.90
tufa	45	0.02

Table 12. The proportional composition of superficial deposits in OS map tile ST.

The cross tabulation of percentage land cover for the most eight prevalent superficial deposits gives a varied set of results (Table 13). The coastal land cover types occur preferentially on beach and tidal flat deposits as would be expected. The terrestrial land cover types show some expected correlations and some surprising ones. The tidal flat deposits also have a disproportionately high percent coverage of semi-improved or reverting grassland (which includes grazing marsh) and calcareous grassland. Peat deposits have a disproportionately high percent coverage of fen, marsh & swamp and bog, as may be expected, but also of neutral grassland, which should not be expected. Till has a disproportionately high percent coverage of woodland (broadleaf, mixed & yew and conifer) and the more acidic semi-natural vegetation types (i.e. acid grassland, bracken, open dwarf shrub heath). Head has a disproportionately high percent coverage of arable land covers, bracken and dwarf shrub heaths, whilst clay & flint has a disproportionately high percent coverage of coniferous woodland, arable land covers and dense dwarf shrub heath. River terrace deposits and alluvium are notable for having a disproportionately high percent coverage of arable land covers.

Broad Habitat (BH)	alluvium	head	till	clay & flint	river terrace	peat	tidal flat	beach, tidal flat	TOTAL (%)
Broadleaf, mixed & yew woodland	22.23	15.30	24.81	12.81	6.21	3.14	10.57	0.06	95.12
Coniferous woodland	15.50	15.84	18.36	25.26	4.43	2.10	13.78	0.26	95.53
Arable cereals	20.33	24.75	2.10	18.16	11.88	4.88	15.70	0.04	97.84
Arable horticulture	21.51	23.49	4.86	12.98	16.91	2.23	15.99	0.08	98.05
Arable non-rotational horticulture	26.26	19.18	0.00	23.34	10.53	10.28	8.59	0.00	98.19
Improved grassland	24.31	15.82	9.74	8.32	8.19	4.75	26.62	0.02	97.77
Semi-improved or reverting grassland	20.36	16.40	0.00	9.80	11.74	0.00	41.28	0.00	99.58
Neutral grassland	22.76	2.20	12.02	2.50	3.96	42.47	9.35	0.01	95.26
Calcareous grassland	25.73	15.39	6.84	6.27	8.90	1.41	31.85	0.13	96.51
Acid grassland	16.59	3.71	39.60	7.98	3.90	11.69	3.65	0.57	87.68
Bracken	1.88	33.13	55.63	0.00	0.00	1.25	0.00	0.00	91.88
Dense dwarf shrub heath	18.92	22.64	3.72	34.80	12.16	5.41	1.01	0.68	99.32
Open dwarf shrub heath	13.32	27.77	26.41	8.80	14.00	9.71	0.00	0.00	100.00
Fen, marsh & swamp	15.75	1.90	0.15	1.03	0.15	64.76	14.43	0.29	98.46
Bog	0.43	0.00	0.00	0.00	0.00	97.42	0.00	0.00	97.85
Standing open water & canals	20.44	26.57	1.31	0.36	2.12	11.24	26.86	0.15	89.05
Inland rock	14.39	12.88	6.10	7.42	9.28	5.49	37.62	0.13	93.32
Suburban & rural development	18.06	10.23	25.91	2.56	11.27	0.66	20.82	0.00	89.51
Continuous urban	19.65	3.56	11.82	1.70	7.73	1.61	39.69	0.26	86.02
Supra-littoral sediment	0.00	0.00	0.00	0.00	0.00	0.00	60.00	40.00	100.00
Littoral rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
Littoral sediment	0.10	0.01	0.00	0.00	0.21	0.00	59.63	34.93	94.87
Saltmarsh	0.00	0.43	0.00	0.00	1.72	0.00	66.38	21.55	90.09
Sea & estuary	0.00	0.00	0.00	0.00	0.00	0.00	96.45	2.96	99.41
% cover for superficial deposit	21.04	15.51	9.90	9.26	9.17	5.33	23.40	2.43	96.04

(light blue) land cover type under-represented on this bedrock
(yellow) land cover type is over-represented on this bedrock

Table 13. Cross tabulation of percentage land cover for the eight most prevalent superficial deposits in OS tile ST.
(If all 25 superficial deposits were shown in the table, then the row percentages would sum to 100%. The percentage cover of the OS map tile ST for each of the deposits is given at the foot of the table).

The distribution of land cover types across the eight most prevalent superficial deposits (which together total 96% of OS map tile ST) and the remaining 17 superficial deposits grouped into 'other' is shown in Figure 13. As with the examples for bedrock formations, this highlights that certain land cover types occur preferentially on certain superficial deposits but that at best, it would only be possible to predict the probability of a particular land cover type occurring on a particular superficial deposit.

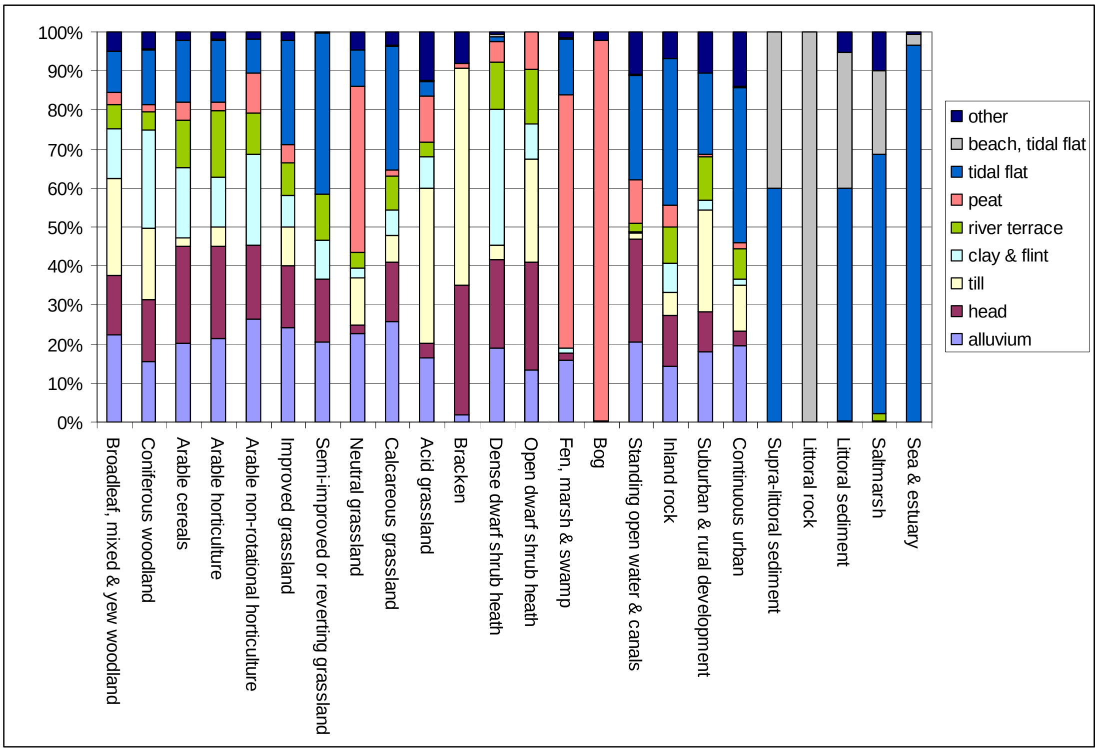


Figure 13. The distribution of land cover types across the eight most prevalent superficial deposits and a combined 'other' class (composed of the remaining 17 superficial deposits) for OS map tile ST.

SUPERFICIAL GEOLOGY AND LAND COVER FOR THE SW

For the extract of LCM2000 and the superficial geology, rasterised at 100 m spatial resolution, the SW has 22 different land cover types (including sea & estuary) and 24 different superficial deposits.

The proportional composition of land cover is shown in Table 14. Here, in contrast to the situation with the complete tile coverage, six land cover types occupy 73% of the total area of the SW; these are: improved grassland (27%), arable horticulture (8%), arable cereals (8%), broadleaf, mixed & yew woodland (17%), suburban & rural development (5%), and acid grassland (8%). In addition, a further three land cover types (calcareous grassland, bog and littoral sediment) make up a further 13% of the total area of SW.

The proportional composition of the superficial deposits is shown in Table 15. Of the 24 different bedrock formations, 6 occupy more than 2% of the total area of the SW subset. The six most prevalent superficial deposits occupy a combined 84% of the subset area of the SW; these are: alluvium (44%), head (17%), river terrace deposits (13%), peat (10%), tidal flat deposits (4%), and blown sand (3%).

Broad Habitat (BH)	# 100 m pixels	%
Broadleaf, mixed & yew woodland	19970	17.03
Coniferous woodland	2168	1.85
Arable cereals	8848	7.55
Arable horticulture	9937	8.47
Arable non-rotational horticulture	5	0.00
Improved grassland	31372	26.75
Neutral grassland	3302	2.82
Calcareous grassland	4864	4.15
Acid grassland	9129	7.78
Bracken	1	0.00
Dense dwarf shrub heath	650	0.55
Open dwarf shrub heath	3660	3.12
Bog	5178	4.42
Standing open water & canals	925	0.79
Inland rock	864	0.74
Suburban & rural development	6102	5.20
Continuous urban	2022	1.72
Supra-littoral sediment	790	0.67
Littoral rock	227	0.19
Littoral sediment	4738	4.04
Saltmarsh	829	0.71
Sea & estuary	1683	1.44

Table 14. The proportional composition of land cover types in the SW for a subset area for which information on superficial deposits exist.

Superficial deposits	# 100 m pixels	%
alluvial fan deposits	87	0.07
alluvium	56735	43.90
beach & tidal flat deposits	1217	0.94
beach deposits	2203	1.70
blockfield	1227	0.95
blown sand	3945	3.05
glaciofluvial deposits	4	0.00
head	21686	16.78
intertidal deposits	732	0.57
loess	259	0.20
marine deposits	850	0.66
peat	13248	10.25
raised beach deposits	53	0.04
river terrace deposits	16598	12.84
saltmarsh deposits	771	0.60
sand & gravel	92	0.07
shoreface & beach deposits	38	0.03
storm beach deposits	164	0.13
superficial deposits	868	0.67
talus	31	0.02
talus cone	2	0.00
tidal flat deposits	5373	4.16
tidal river / creek deposits	2304	1.78
till	741	0.57

Table 15. The proportional composition of superficial deposits in the SW study area.

The cross tabulation of percentage land cover for the six most prevalent superficial deposits once again gives a varied set of results (Table 16). The coastal land cover types of littoral sediment, saltmarsh and sea & estuary occur preferentially on tidal flat deposits, whilst supra-littoral sediment occurs almost exclusively on blown sand, all as would be expected. As with OS map tile ST, the terrestrial land cover types show some expected correlations and some surprising ones with superficial deposits. Peat deposits have a disproportionately high percent coverage of acid grassland, dwarf shrub heaths and bog, as may be expected, but also of neutral grassland, which should not be expected. Alluvium has a disproportionately high percentage cover of broadleaf, mixed & yew woodland, improved grassland, calcareous grassland and bracken. Head has a disproportionately high percent coverage of arable non-rotational horticulture, neutral and acid grasslands; whilst river terrace deposits have a disproportionately high percent coverage of arable cereals and horticulture.

Broad Habitat (BH)	alluvium	head	river terrace	peat	blown sand	tidal flat	TOTAL (%)
Broadleaf, mixed & yew woodland	67.15	17.04	7.54	3.57	1.85	0.86	98.00
Coniferous woodland	48.80	22.79	13.01	4.80	0.05	1.25	90.68
Arable cereals	46.44	18.09	26.76	0.31	1.41	2.36	95.38
Arable horticulture	48.61	16.79	18.50	2.60	4.61	4.34	95.43
Arable non-rotational horticulture	0.00	100.00	0.00	0.00	0.00	0.00	100.00
Improved grassland	57.25	17.88	16.71	1.57	2.28	1.96	97.65
Neutral grassland	22.41	23.32	5.06	26.92	10.63	1.15	89.49
Calcareous grassland	60.83	18.36	12.17	0.53	1.56	3.50	96.96
Acid grassland	29.55	27.31	2.60	30.43	1.24	0.62	91.75
Bracken	100.00	0.00	0.00	0.00	0.00	0.00	100.00
Dense dwarf shrub heath	43.85	16.77	0.77	31.38	0.00	0.62	93.38
Open dwarf shrub heath	16.39	3.06	1.56	78.11	0.00	0.00	99.13
Bog	6.78	1.12	0.42	91.14	0.00	0.00	99.46
Standing open water & canals	33.08	2.05	6.92	0.54	0.00	1.95	44.54
Inland rock	35.53	24.07	17.36	1.27	6.02	7.06	91.32
Suburban & rural development	46.28	20.30	18.47	2.57	3.21	2.84	93.67
Continuous urban	49.80	11.52	14.39	0.35	4.30	5.84	86.20
Supra-littoral sediment	0.89	0.13	0.00	0.00	97.34	0.38	98.73
Littoral rock	1.76	7.93	0.00	0.00	3.08	0.44	13.22
Littoral sediment	4.73	0.95	0.19	0.00	4.98	40.84	51.69
Saltmarsh	10.62	3.98	0.72	0.00	16.16	35.10	66.59
Sea & estuary	6.00	0.83	0.06	0.00	0.06	49.14	56.09
% cover for superficial deposit	43.90	16.78	12.84	10.25	3.05	4.16	90.98

(light blue) land cover type under-represented on this bedrock
(yellow) land cover type is over-represented on this bedrock

Table 16. Cross tabulation of percentage land cover for the six most prevalent superficial deposits the SW study area.
(If all 24 superficial deposits were shown in the table, then the row percentages would sum to 100%. The percentage cover of the SW study area for each of the deposits is given at the foot of the table).

The distribution of land cover types across the six most prevalent superficial deposits (which together total 91% of the SW study area) and the remaining 18 superficial deposits grouped into ‘other’ is shown in Figure 14. As with the example of OS map tile ST, this once again highlights that certain land cover types occur preferentially on certain superficial deposits but that at best, it would only be possible to predict the probability of a particular land cover type occurring on a particular superficial deposit.

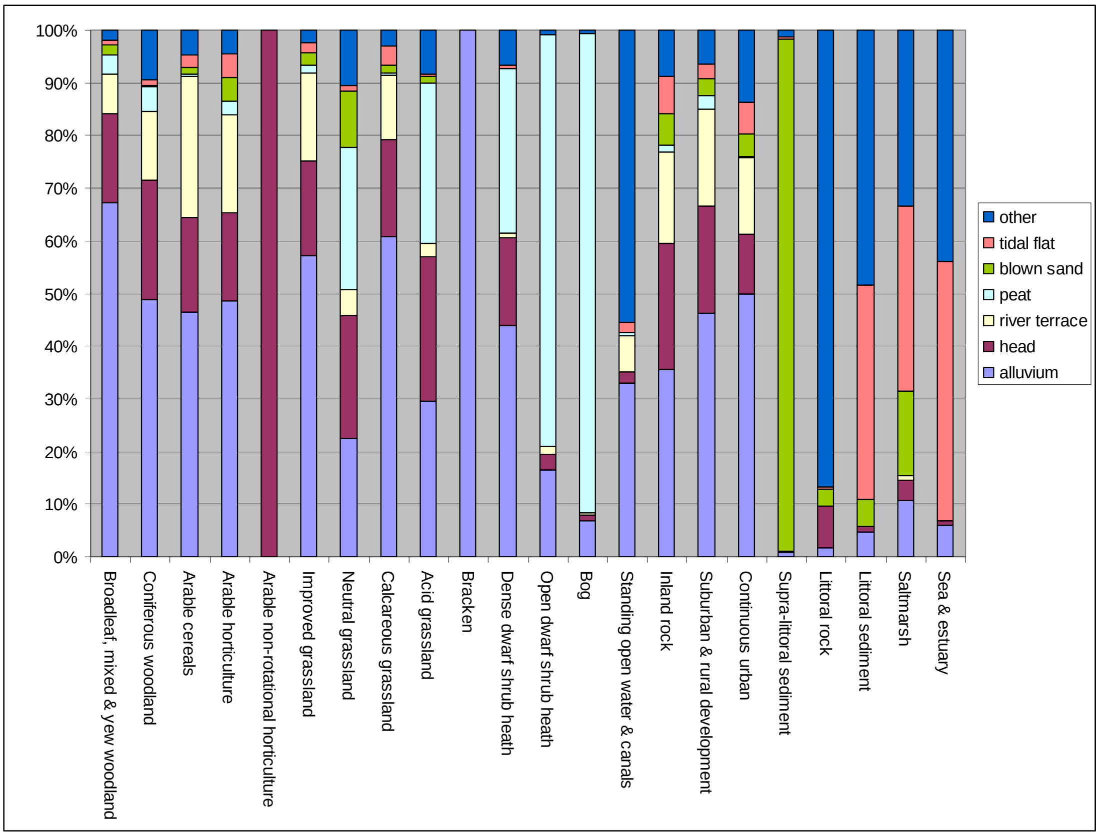


Figure 14. The distribution of land cover types across the six most prevalent superficial deposits and a combined 'other' class (composed of the remaining 18 superficial deposits) for the SW study area.