A national hazard assessment of coastal landslides using GI capture systems – a government dataset. **C. Foster, C.Poulton, M.Harrison. British Geological Survey, Keyworth, Nottingham, NG12 5GG.**

Introduction

Since its inception in 1835, the British Geological Survey (BGS) has been responsible for providing much of the earth science related information that is required by government, the public and institutions. These requirements have evolved over time, with emphasis shifting between information on coal, water supply, radioactive waste disposal, radon potential, aggregate resources, mineral resources, geotechnical information and planning information and many others (Culshaw, 2005). In order to satisfy its commitment to provide expertise and advice on the extent and severity of natural geohazards throughout the country, the BGS has built and currently maintains over 200 national strategic datasets. Providing information that helps to manage the impacts of geological hazards and climate change are now very important drivers for BGS. Indeed, BGS' parent body, the National Environmental Research Council (NERC) regards Natural Hazards and Environmental Change as two of the principal areas of research funding. This paper describes how one of those datasets is currently being developed, and how important GIS and digital capture technology has been to this process.

Previous National Assessments of Landslides in the UK

Slope instability, including landsliding is recognised as a significant geohazard across Great Britain. The first national focussed assessment of the hazard was undertaken under government contract in the mid to late 1980s by Geomorphological Services Limited. They provided the then Department of the Environment (DOE) with a digital database of known landslide information, with supporting information provided in paper form by Jones and Lee (1994). The review was used as the basis for government Planning Policy Guidance Note 14 (PPG 14) and Annex (Anon 1990, 1994). It was recognised by the review, and subsequent users of the 1994 released dataset that is was incomplete, and required a considerable amount of work to include information that, up until the release date, was unavailable, or had not been collected. PP14 state that in some instances it was appropriate to use deterministic data to indicate the potential for slope instability at any particular location.

BGS began developing a deterministic system to satisfy this requirement in the early 1990s. The Geo-Hazard Susceptibility Package (GHASP) dataset collated expert knowledge from regional geologists and other sources. This was output as a GIS layer, which displayed postcode sectors of England and Wales attributed with hazard levels, including landslide hazard. The dataset was later extended to include Scotland and was later again modified by the inclusion of large scale geological data.

National Landslide Database

The BGS National Landslide Database, running since 2002, currently documents over 14,000 landslides across Great Britain (Figure 1). The ORACLE database has a Microsoft Access front end and is interactively linked with a GIS where landslide identity points can be moved in the GIS which automatically updates several fields in the database including the grid reference field. The primary source of information is the National Digital Geological Map (DiGMap) at 1:10 000 (DigMap10) and 1:50 000 scale (DiGMap50). Other data is collected through media reports, site investigations, journal articles as well as new direct mapping in the field.

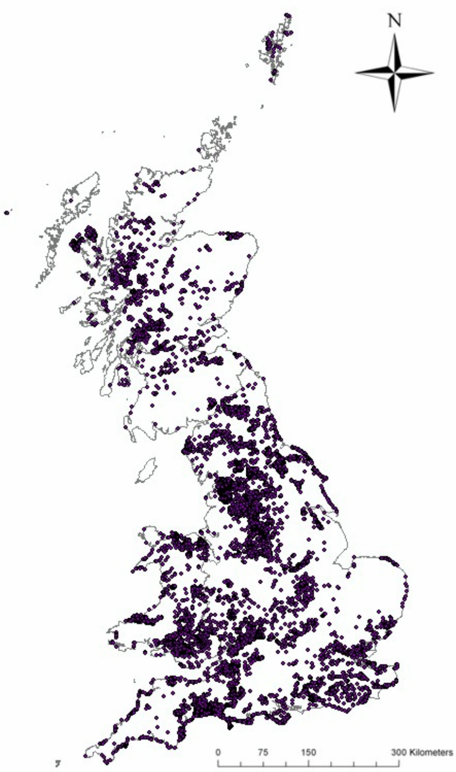

Figure 1 – Distribution of landslide records in the BGS National Landslide Database.

Mapping and Monitoring Active Landslides

Most of the landslides in the National Landslide Database are considered to be ancient and inactive, such as those associated glacial activity during the last 10 000 years. However, there are many landslides which are active, and affect people. England has some of the fastest retreating coastlines in Europe and active landslides commonly occur on the coast, where cliffs are under mined by coastal erosion, and fundamentally, where the ground tends to be steeper. At several coastal sites around Great Britain, BGS, and others have carried out detailed surveys to monitor, and better understand the activity and recession rates of landsliding and erosion along sections of soft cliffs around England. At these sites, such as Happisburgh, Norfolk (Poulton, *et al*., 2006), Aldborough and the East Riding of Yorkshire, coastal communities live with the threat of losing their houses and livelihood due to coastal erosion and landsliding. Predictions of rising sea level and increased precipitation associated with climate change may lead to increases in the level of landslide activity and erosion at the coast. An ongoing programme of new landslide mapping is currently being undertaken in order to determine a comprehensive landslide distribution model. Recent work carried out by the BGS landslide mapping teams has focussed on the Isle of Wight, Peak District, Yorkshire and Wales.

Current National Assessment of Landslides in the UK

The current GIS assessment of landslide hazard for the British Mainland, which supersedes the aforementioned GHASP system, is GeoSure. This layer includes information derived from a range of sources, including expert geological knowledge, DigMap, and the National Landslide Database. The Geosure assessment also covers the hazards posed by running sand, soluble rocks, compressible and collapsible deposits as well as shrink swell clay. A simplified GeoSure layer for landslide hazards in Great Britain is shown in Figure 2. The dataset is compiled by weighting polygons in DiGMap with 'landslide factors' and combining this with a Digital Terrain Model (DTM).

The GeoSure methodology was developed using elements of both a deterministic and heuristic approach. The heuristic approach uses expert judgement to asses and classify the hazard, as well as determining what are the causative factors of landsliding. Among the causative factors that were identified are lithology, slope angle and discontinuities. The deterministic side to the approach looks at the presence of these causative factors, giving each one a rating according to their relative importance in causing the hazard and then combining these in an algorithm to give a rating of the relative hazard susceptibility of the area. It does not necessarily mean that the hazard has happened in the past or will do so in the future but if conditions change and a factor intensifies, the hazard may be triggered. This method was presented at the AGI conference in 2005 (Wildman & Forster, 2005). Crucially, this joint approach does not rely on evaluating the significance of a history of past occurrences, and thus does not require a complete, uniform dataset to carry out the assessment. As with other datasets derived from geological information, the method also allows consideration of a variation in past and future climatic conditions that have shaped the landscape, including glaciations, and periods of desertification. However, if the changing circumstances are recognised, or can be predicted, additional assessments can be made for a range of different circumstances such as seasonal variations in groundwater level. The dataset is typically accessed directly through a GIS, operated by a licensee or through automatically generated reports, for instance as part of the Home Information Pack. In 2007/08 over 1 000 000 UK citizens accessed the dataset, most of them without any knowledge of doing so.

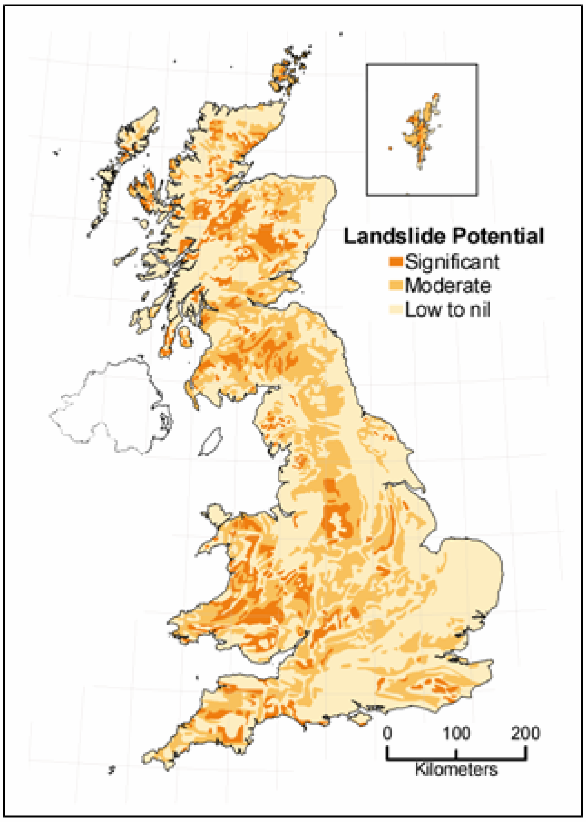

Figure 2: GeoSure layer showing the potential for landslide hazard.

Problems relating to automated landslide hazard assessment at the coast

As part of annual update and release, GeoSure undergoes a series of quality assurance procedures. Assessments have shown that one of the most significant problems in the ‘slope instability’ layer was indication of hazard at the coastline. The coast poses a number of specific problems that are not found elsewhere in the UK landmass:

1. *The rapid and complex nature of coastal processes*. Erosion and passage of groundwater occur more rapidly at the coast, and do so in a more complex way than inland. This is difficult to capture using a generic series of weighted, deterministic attributes.
2. *Issues relating to the accuracy of the DTM at the coast*. The model used is based upon remote sensing data that provides an excellent solution inland, but suffers inaccuracies at the steep coast. On a near vertical cliff airborne surveys will be able to collect more than one survey point (Figure 3A). However on a vertical cliff the survey points will pick up the base of the cliff as well as the top, leading to errors in the data (Figure 3B).
3. *The nature of vertical succession of geology at the coast*. Geological maps are essentially planimetric models of the geology at the ground surface or rockhead. Limitations of cartography mean that at a cliff edge, only the uppermost unit is portrayed. Thus, rock types or successions of rock types that may be particularly susceptible to landsliding are not portrayed on a two dimensional GIS and are therefore not included in the GeoSure assessment. This is shown in Figure 4 where formation A, at the top of the cliff would dominate the landslide assessment. However, the presence of a weak clay or water bearing body in

Formations B or C may be controlling landsliding in this instance. On the south coast of England at Folkestone Warren the importance of understanding the sequence of geological formations is illustrated by the Folkestone Warren Landslide. Here, the cliffs are formed in Chalk overlying Gault Clay and Folkestone Beds. It is thought that 3km long rotational slide in the 150m high cliffs is due to lateral expansion in the Gault beneath the Chalk (Hutchinson, 1969). The presence of the Gault is of essential in the propagation of the failures and therefore it is important that the presence of Gault below the Chalk is known and included within any landslide hazard assessment.

4. *The nature of geological structure.* At the coast structural controls may also have a greater bearing on the stability of a coastal slope, as they do in road cuttings for example or quarry faces. The 2-Dimensional nature of GIS assessment means it is difficult to represent these factors at the cliff where there is a rapid lateral variation in elevation and geology. The underlying problem is that there are factors, which directly affect coastal stability, which cannot be modelled in a two-dimensional environment.

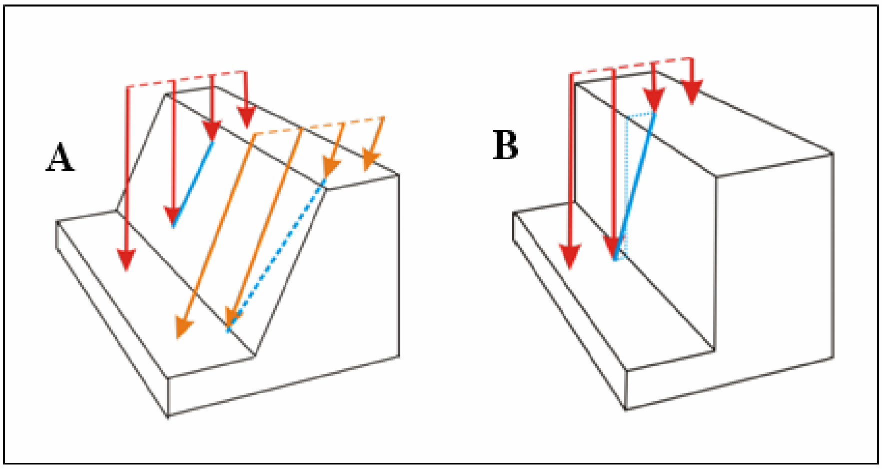

Figure 3: Error in derivation of slope angle in non vertical and vertical cliffs.

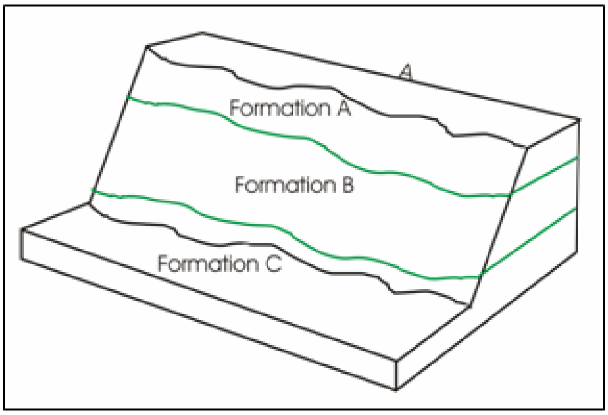

Figure 4: Geological sequence of multiple formations at the coast.

The difficulties of mapping coastal landslides with Geosure can be illustrated by the example of Aldbrough in the East Riding of Yorkshire (Figure 5). This area is undergoing rapid coastal erosion with the loss of properties and infrastructure at a rate of approximately 1 to 2 m a year. GeoSure currently ranks this section of coastline as not having slope stability issues. Obviously this is incorrect as the Holderness coast is one of the most rapidly eroding stretches in Europe. One of the issues here relates to the accuracy of the DTM on a vertical cliff but also the influence of coastal and marine conditions which are not currently taken into account in the present GeoSure model.

Figure 5: Photograph taken of the coastline at Aldbrough. Taken April 2008.

The new National Survey of Coastal Landslides and Landslide Hazard

The problems described above cannot be easily and appropriately resolved by manipulating the 2D attributes of the dataset. Such an approach would not allow the production of a model that could confidently incorporate factors of process or geological complexity found at the coast. To produce a dataset with an appropriate level of confidence, it was decided that a new national survey of coastal landslides was required. This is now in progress and the methodology is described here. Since the BGS is working towards an integrated digital work flow system of data capture, storage, display and output it was necessary to use methods of data collection that would produce data compatible with other areas of BGS.

The data collection phase of this project has two main outputs. As part of the national digital geological (DigMap 50) mapping programme a detailed digital landslide map for the whole of the British coast is being produced. Coupled with this the project is aiming to produce a numerical assessment of landslide hazards for the cliffed coastline around Great Britain. A line is to be digitised around the coast which is divided into a series of units that define stretches of coastline that are considered to be geomorphologically distinct but have the same stability characteristics, termed Coastal Stability Units (Figure 6). For a section of coastline these units are specified by examining, from aerial photographs, the current state of coastal stability. Each of these units is attributed according to the cliff material, recession mechanism, engineering works, cliff type, elevation and land use (Table 1).

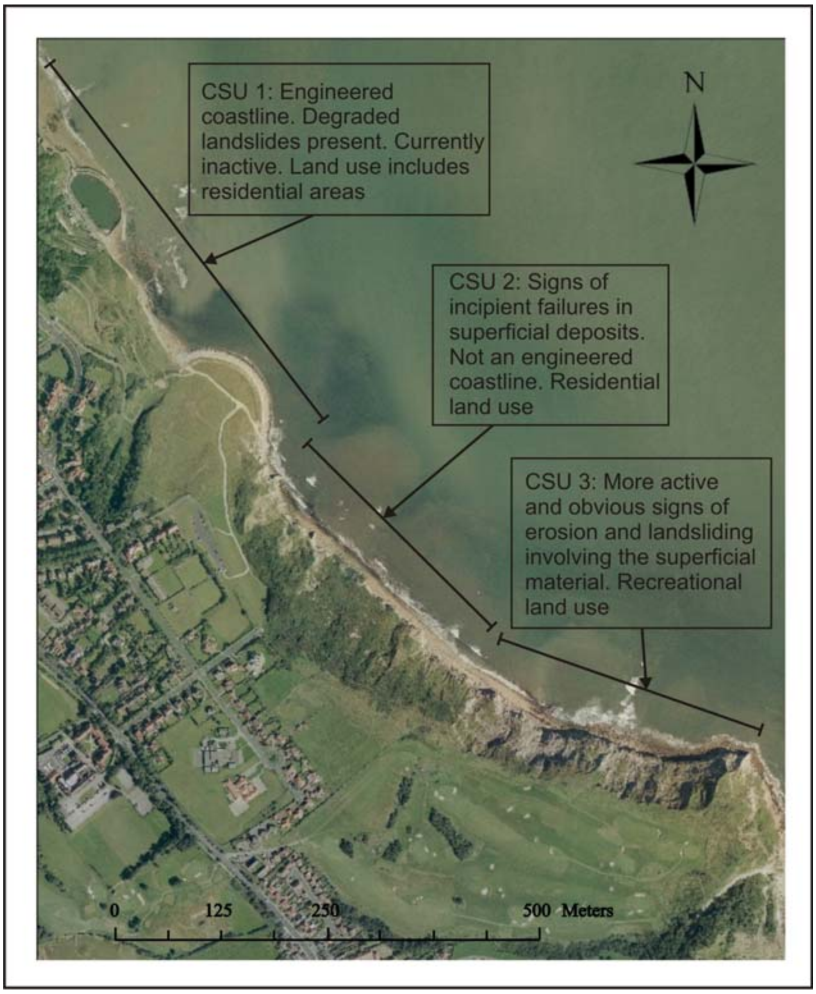

Figure 6: Examples of Coastal Stability Units, south of Scarborough.

Table 1. Characteristics captured by the Coastal Landslide Hazard Assessment

Cliff Material	Information on the bedrock, superficial, and artificial deposits is recorded. The database form allows the addition of more than one formation to take into account the possible layered nature of some cliffs. It can also be defined whether landslide activity is occurring within bedrock, superficial material or both. Other types of coastline (non cliffed) can be specified (for input into other national datasets).
Recession Mechanism	Option to record recession occurring through erosion, landsliding or both. The mechanism of landsliding is recorded, along with information on the activity level and stability development.
Engineering Works	The presence of engineering works at the coast may influence the potential for continued landsliding and erosion. A protected coastline, if the defences are in good working order and appropriate for the site, should protect the coastline from further recession for the life of he defences.
Cliff Type	The definition of cliff type follows the 2002 Soft Cliff report cliff behaviour units (CBU'S) (Lee and Clark, 2002).

Elevation	The minimum and maximum elevation of each stretch of coast digitised will be automatically recorded. This will provide information on the ranges of heights associated with different cliff types and formations. This information will be crucial in the hazard assessment phase of this work.
Land Use	Land use data is being collected in order to highlight the infrastructure and type of land use that are most at risk from landsliding and coastal erosion.

Using integrated photogrammetry and GIS to produce the New National Survey of Coastal Landslides and Landslide Hazard

Without GIS and photogrammetry technology this project would only have been possible through a lengthy process of field work and stereoscopic aerial photograph interpretation. The numerical modelling hazard assessment, and therefore the most valuable part of the project to the BGS data users, would simply not be possible. GIS has been a vital part of the project throughout each stage of the process:

Desk Study: Before the data collection phase begins a desk study is carried out. Digitally held data within the corporate GIS is analysed to provide a background to the study area. Data holdings which are interrogating at this stage include the historic map collection, field slips and digital geological maps. Other corporate databases are available in a GIS format including the previously discussed National Landslide Database.

Digital Landslide Polygon Mapping: The mapping of digital landslide polygons will be carried out primarily using digital photogrammetry which will enable a rapid identification, digitization and description of most landslides. This will be supported by a series of field surveys to validate the data, and, where knowledge is limited, to familiarise researchers with an area before they carry out any photogrammetry. Data collection takes place using the Socet Set for ArcGIS extension (BAE Systems). This enables users who are familiar with a GIS type interface to quickly capture accurately positioned digital landslide polygons, a process that would have been extremely time consuming using standard aerial photographs and a stereoscope. The polygons can be loaded into the portable MIDAS (Mobile Integrated Data Acquisition System), a rugged tablet PC which allows GIS to be used away from the office environment. In simple terms the MIDAS is a digital field slip which enables field staff to input data directly into a GIS when in the field, as well as checking data collected during remote sensing (Jordan *et al*., 2005).

Capturing of Coastal Stability Units: Early on in the project development phase it was decided that it would both impossible and impractical to capture every single landslide along the coast of Great Britain. At a national scale this amount of polygons would simply forma a strip around the country which could be misleading to the end users. The issue of mapping scale was therefore important and so previously established BGS mapping conventions were used. By defining Coastal Stability Units it is possible to collect relevant and useful slope stability data even if the landslides are too small to map individually. As mapping involves drawing around a deposit or a feature it is also not possible to map areas of erosion using digital polygons, as is possible with landslide deposits. By defining areas of coastal erosion within the Coastal Stability Units this data will be an additional source of information applicable in the coastal hazard assessment. Information on the Coastal Stability Units is captured through a simple series of drop-down menus (Figure 8) stored in an ORACLE database linked to the BGS Geodatabase. Once a Coastal Stability Unit has been drawn using the Socet Set for Arc extension the database form appears. Where possible, BGS corporate dictionaries are used, for instance when describing rock type, landslide type and land use. Landslide terminology uses the same terminology as the National Landslide Database.

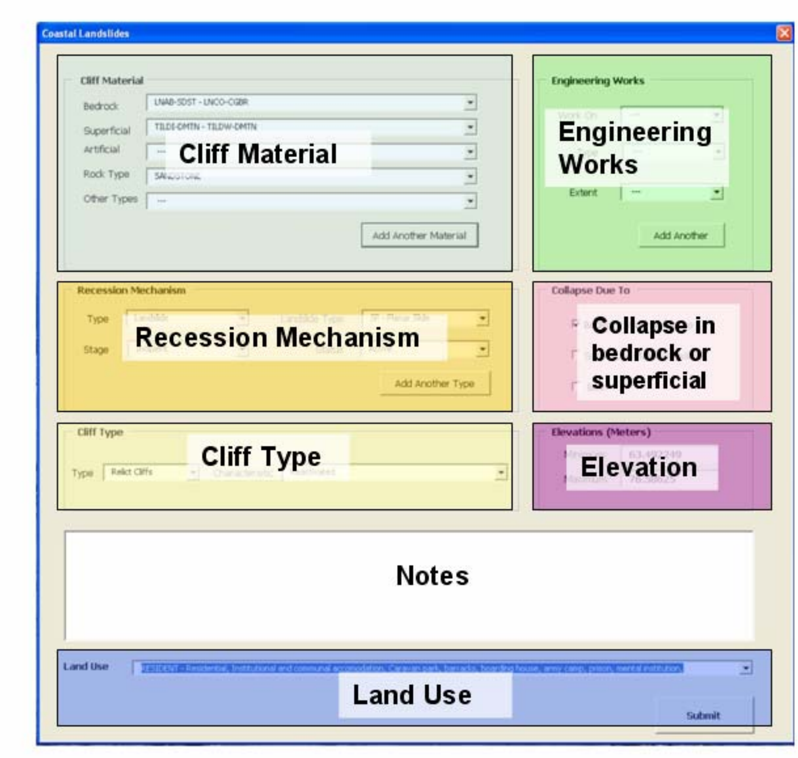

Figure 8: Coastal Stability Unit database form user interface.

Progress to Date

This coastal survey intends to assess coastal stability using direct observations drawn from aerial photograph interpretation, field work and the collection of raw data. Whilst it is recognised that the coast is a dynamic and changing environment the purpose of this project is to collect baseline information on the patterns of instability based on observations of the coastline. This data, and the geoscientific experience gained will form the basis of a GeoSure Exception Algorithm that will modify the hazard classification at the coast.

Although the concept and data collection phases of this programme are underway, it is not yet known exactly how they will relate to the GeoSure dataset. This algorithm be developed using an iterative scoring system developed using expert judgement gained during the projects life span. The final scores are likely to be held digitally and be represented by a scored ribbon which will stretch around the coast of Great Britain. This will be separate from the current GeoSure product and the nature of the interaction of these two schemes is yet to be decided.

The survey has now completed a pilot stage, carried out in 2007 on the North Yorkshire Coast. This was used to modify the data dictionaries where possible and to debug the computer application developed. The second phase, digitizing polygons and lines between Holderness and London is currently underway and will be completed by 2008. It is intended that the rest of the mainland coastline will be completed by 2011.

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