IAEG2006 Paper number 286

The assessment of national scale geohazard potential through the application of GIS modelling

MATTHEW HARRISON[1] & ALAN FORSTER[2]

[1] *British Geological Survey. (e-mail: mharr@bgs.ac.uk)*
[2] *British Geological Survey. (e-mail: af@bgs.ac.uk)*

Abstract: Geological events with the potential to cause harm are commonly called 'Geohazards' and represent a significant, but often unrecognised, threat to people and property in Britain. This is most easily demonstrated in terms of the additional costs during construction incurred by the civil engineering industry due to unforeseen ground conditions and by post construction losses incurred by the insurance industries due to building damage. Home buyers are becoming aware of the dangers and an assessment of geohazards including swelling and shrinking clays, running sand, compressibility, landslide, collapsible ground and dissolution is being undertaken more frequently by conveyancers as part of the house-buying process.

To meet these increasing needs the British Geological Survey has been working since 2001 on an innovative assessment method to improve on and replace its existing and widely used GHASP dataset. The programme, called GeoHazarD, has created 6 national scale geohazard datasets that indicate the potential for these hazards to be a problem anywhere in Great Britain. For the first time these have been produced using a rule-based technique that assesses the whole country using standard GIS tools, building on the published digital vector geological data, DiGMapGB.

GeoHazarD integrates expert knowledge, national databases, multi-criterion analysis and a flexible rule-based approach to model the geohazard datasets. One of the major advantages of this system is that there is a now a fully auditable trail leading to the final classification. This allows the assessment to be updated automatically following a revision of the geological mapping, an improved understanding of the geohazard process and the inclusion of refinements based on local knowledge of an area.

This paper gives an overview of the techniques used and discusses the application of GIS to a project of this size and nature.

Résumé: Des événements géologiques avec le potentiel de causer le mal s'appellent généralement 'Geohazards' et de représenter un significatif, mais souvent non reconnu, la menace pour peuple et la propriété en Grande-Bretagne. Ceci le plus facilement est démontré en termes de coûts additionnels pendant la construction encourue par l'industrie de génie civil due aux conditions au sol imprévues et par la poste les pertes de construction encourues par les secteurs des assurances dus au bâtiment endommagent. Les acheteurs à la maison se rendent compte des dangers et une évaluation des geohazards comprenant le sable courant, la compressibilité, l'éboulement, la terre pliante et la dissolution est entreprise plus fréquemment par des conveyancers en tant qu'élément du processus maison-achetant.

Pour satisfaire ces besoins croissants que l'aperçu géologique britannique avait travaillé depuis 2001 sur une méthode innovatrice d'évaluation pour s'améliorer dessus et la remplacer est ensemble de données existant et largement répandu de GHASP. Le programme, appelé GeoHazarD, a créé 6 ensembles de données nationaux de geohazard de balance qui indiquent le potentiel pour que ces risques soient un problème n'importe où en Grande-Bretagne.

Pour la première fois ceux-ci ont été produits en utilisant une technique basée sur les règles qui évalue tout le pays à l'aide des outils standard de SIG, construisant sur les données géologiques éditées de vecteur numérique, DiGMapGB.

GeoHazarD intègre la connaissance experte, les bases de données nationales, l'analyse de multi-critère et une approche basée sur les règles souple pour modeler les ensembles de données de geohazard.

Un des avantages principaux de ce système est qu'il y a maintenant une traînée entièrement contrôlable menant à la classification finale. Ceci permet à l'évaluation d'être mise à jour automatiquement après une révision de tracer géologique, d'un arrangement amélioré du processus de geohazard et de l'inclusion des améliorations basées sur la connaissance locale d'un secteur.

Cet article donne une vue d'ensemble des techniques utilisées et discute l'application des SIG à un projet de ces taille et nature.

Keywords: geological hazards, geodata, landslides, subsidence, risk assessment.

INTRODUCTION

Geohazards in the UK represent a significant, but often unrecognised, threat to people and property. This is most easily demonstrated in terms of the additional costs during construction incurred by the civil engineering industry due to unforeseen ground conditions and by post construction losses incurred by the insurance industry due to building damage. Home buyers are becoming aware of the dangers and an assessment of geohazards including swelling and shrinking clays, running sand, compressibility, slope instability, collapsible ground and dissolution is being undertaken more frequently by conveyancers as part of the house-buying process. In 2007 this may be even more common as part of the Home Buyers Information Pack being introduced by the British Government.

These issues have been researched and reported upon for many years by the British Geological Survey (BGS), including the development of a National Landslide Database and research into shrink-swell clays. On-demand, Ground Stability Reports, are also produced of potential geological hazards for specific locations though an online application system, GeoReports.

Nation-wide digital data have also been available for certain hazards on a postcode sector basis using a system developed throughout the 1990's – GeoHAzard Susceptibility Package (GHASP) (Culshaw 1993, Culshaw & Kelk 1994). More recently, BGS completed a programme to model geohazard potential using it's modern DiGMapGB-50, vector digital geological mapping for Great Britain to create a dataset known as GeoSure. The results presented here are the work of the Natural Geohazard modelling team using these data to update the national digital geohazard datasets available from BGS.

BACKGROUND

To meet the requirement for a wider range of, and more detailed, national datasets to aid in the assessment of geohazards BGS initiated a new programme called GeoHazarD in 2001. The aim was to produce datasets that identified potential geohazards for Great Britain, within the constraints of the available data, in a format that was easily useable for both BGS and external customers. These broad goals were far reaching and go beyond the remit of this paper but in summary the datasets included:

- Natural Geohazards
- Mining-Related Geohazards
- Superficial Thickness Models
- Radon Hazards
- Ground Permeability and Fracturing
- Scanned Historic Maps
- Historic Mine Entrances and Springs
- Scanned Borehole Logs
- Scanned BGS reports
- Scanned 1:10000 BGS Maps

This was an ambitious undertaking and much of these data are now in daily use within BGS and by external customers. There have been delays in some areas, such as mining geohazards, and the capture of mine-entrance and springs from historic maps. The scanning of the 1:10 000 scale maps also will only start in 2006. The delays have been due to changing priorities agreed both within BGS and with stakeholders. The GeoSure natural geohazard data, the subject of this paper, was completed and released as version 1 in March 2004.

One of the principal advantages of releasing digital datasets for customers and BGS is the relative ease of frequent updates. Very shortly after the release of version 1 of the GeoSure data a project team was put in place to enhance and refine these data, incorporating new mapping, further superficial thickness data and a new, higher resolution, Digital Terrain Model (DTM). These new data were released as version 2 in the summer of 2005. The intention is to continue with this update and release cycle, allowing licensees access to the latest and best quality data available.

GeoSure is not the first attempt at geohazard potential assessment for the UK. GHASP was developed by the BGS in the 1990s as the geohazard assessment system and was first developed as a decision support system (DSS) that gave a weighted averaged result for each of c.10000 postcode sectors in the UK and was widely used within the UK's insurance sector (Culshaw & Kelk 1994). The DSS ran in either Intergraph's MicroStation GIS Environment or CAD plus databases. Postcode sectors were chosen, as this was the method that insurance companies used to calculate premiums.

GHASP provided national coverage for 6 geohazards:

- Shrink/swell clays
- Landslips
- Compressibles
- Cambering and Gulling
- Shallow mining
- Natural dissolution

Over the next decade, improvements were made in the scale of analysis for urban areas, the underlying software was changed many times and an SQL query interface was added. Significant improvements in GIS technology, better graphical interfaces and the availability of digital mapping for 98% of the country plus the recognition that such data could have a much wider use than the insurance industry caused BGS to decide to re-design the geohazard data supply and assessment from first principles.

Experience from the much wider application of GIS technologies and the recognition of the limitations of using postcode sectors led to the acknowledgement that these are not the best ways to deal with spatial geohazard data. Postcode boundaries change and evolve over time and geohazards are not confined to one postcode area. These arbitrary boundaries also introduce their own uncertainties, described by Openshaw & Taylor (1977) as the Modifiable

Areal Unit Problem (MAUP). However, geohazards are usually associated with certain lithologies, which means mapping them to lithologies is more logical than postcode regions and will make the resultant data much more applicable to a range of applications and accessible to the widest audience.

This became possible when DiGMapGB-50 was released in 2001. This provided a 1:50000 scale base map that any process-based modelling could be performed against. One of the disadvantages of GHASP had been that it was not possible to trace exactly why any threshold judgments had been made in assigning weightings between sectors. These judgments had been made by experts but the reasons had not been fully recorded. At the time it was seen as acceptable that an expert had made the judgment and we did not need to question that decision. The world is a very different place now and much more litigious, so GeoSure provides a fully auditable trail for these kinds of decisions through the use of metadata and a digitally captured methodology and expert knowledge.

GEOSURE

Within the GeoSure data six methodologies were developed to identify natural geohazard potential; these are described in further detail below:

- shrink-swell clays
- running sand
- compressible deposits
- slope instability
- collapsible ground
- dissolution

Swell-shrink hazards are caused by clay-rich deposits that can absorb and loose water with seasonal changes in moisture. Local changes, such as tree roots or leaking pipes can also be significant where the swell-shrink potential is high.

The collapsible hazard assessment in the project is based on the assumption that the only lithology that is prone to collapse hazard is loess (the collapse of underground cavities is considered under dissolution or mining). Loess in the UK is usually described as brickearth.

Compressible deposits are those that can compress or settle differentially on a site, such as peat or alluvial clay.

The dissolution hazard is caused by rocks that dissolve in the presence of water, such as gypsum, salt or limestone.

The slope instability hazard identifies areas with the potential for movement due to the combination of geology, slope and adverse groundwater conditions.

The running sand hazard describes the flow of sand into an excavation or void under the influence of a water pressure gradient.

THE ASSESSMENT OF HAZARD

If it can be shown where a hazard is likely to be present the use of the land can be designed or modified to ensure that the hazard is not triggered or the effects of the hazard are mitigated. Thus, the land can be brought into its optimum productive use and the threat to life and property is minimised. There are two commonly used approaches to assess the presence of hazards in an area; the probabilistic method and the deterministic method (Forster et al. 2002).

The probabilistic method is based on the collection of records of the occurrence of a hazard in time and space, which are used to generate a plot of the probability of the hazard occurring at a given place in specified period of time. This approach is the one commonly used by seismologists for earthquake hazard assessment (Forster et al. 2002) and leads to assessments such as an earthquake of magnitude 3 may be expected to occur once every 500 years in this area. This approach requires a large dataset of records of past events and the more complete the dataset the better is the prediction. However, even in the case of seismology where instrumental recording networks have been collecting data of seismic events at all scales for over 100 years there is still a lack of detail in older records where only felt or damaging events were recorded. This approach also assumes that conditions are largely constant and that, after the event, another event can happen at the same place. For example, it may be assumed that earthquakes will recur along a fault as stress builds up due to crustal plates moving at a constant rate. This is not necessarily the case for other geological hazards. Once a collapsible deposit has collapsed the material has assumed a new stable structure and cannot collapse again.

The deterministic approach looks at the presence of factors that bring about a hazard at the site being assessed. This methodology does not quantify the hazard at a site. It indicates the potential for such a hazard to be present and, thus, the relative importance of making a site-specific assessment of the hazard especially before making changes in land use. An accurate assessment may require some, or all, of the following:

- a desk study
- site visit
- sampling and geotechnical testing of the materials beneath the site

In the case of slope instability, for example, factors such as lithology, slope angle and groundwater conditions are of prime importance. The causative factors are dealt with separately, given a rating according to their relative importance in causing the hazard and then combined to give a rating of the relative susceptibility to the hazard. 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 or another factor is added the hazard may be triggered. For example, if we have identified a lithology susceptible to landsliding coincident with a steep slope it may remain stable until the groundwater conditions change, perhaps due to a series of wet winters, at which point movement will occur.

An advantage of the deterministic method over the probabilistic is the possibility of adding additional factors to the assessment as conditions change and new causal factors become significant, such as the effect of climate change.

GEOSURE NATIONAL ASSESSMENT

In each case, the causative factors are inherent in the lithology of the rock type and its setting within the 3D geological model. The BGS holds large amounts of information about the lithological nature of the rocks within the UK, their geographical distribution and physical properties. This information is held in maps, borehole logs, ground investigation reports and in the experience of staff, many of whom have detailed, long-term knowledge of large areas of the UK. Other necessary information such as slope can be easily obtained.

Procedure

At its simplest, a level of hazard can be assigned on the basis that, for example, granite is a solid rock and has no running sand hazard potential but that the Thanet Sand, which comprises uncemented sand, will have a potential for running sand hazard. In practice, it is rarely that simple and many geological units may comprise both sand and sandstone, or sand and clay and a judgment must be made in assessing the relative level of potential for the hazard to be significant.

For running sand, compressible deposits and slope instability hazard a scoring system has been devised based on the relative significance of the causative factors that apply to a geological formation and its setting. Shrinkable clay hazard is assessed based on the geotechnical properties of the geological formation. The properties are assessed according to the classification recommended by the Building Research Establishment (BRE, 1993)

The hazards associated with dissolution are rather more complex to assess than the other geohazards because they are intimately associated with the 3D structure of the ground to a greater depth and the geological formation that is the source of the hazard may not be exposed at the surface. Thus, a large amount of geological expertise is required to interpret the structural information and create the hazard zones. Rather than a scoring system of causal factors, a domain approach for dissolution hazards is used whereby a set of geological constraints is defined that encompasses a series of situations of increasing hazard (Table 1).

The geological methodologies for each of the hazards were implemented using GIS. This offered the only practical way that processing could be carried out at this scale for the whole of Great Britain. Starting with the deterministic approach to hazard assessment described above, Multi-Criterior Analysis (MCA) could be performed for each of 10000+ lithologies recorded in DiGMapGB-50. These analyses could then be combined with any other layer of relevant information to form a thematic map of potential hazard for each of the six geohazards.

There were several stages to the GIS processing of the data. These were necessary both for computing resource requirements and because Quality Control (QC) could be carried out at each stage allowing potential refinement of the geological methodology in an iterative manner. From a GIS perspective this was an obstacle to the full automation of the modelling process. The general workflow is simplified as in Figure 1. Once a hazard assessment had been made these results were databased separately for each hazard.

DiGMapGB-50, when collated for the whole country, has a file size of 2.4Gb. This proved to be a significant computer processing issue, especially as all work was carried out on standard desktop PCs. Processing was carried out in ESRI's ArcGIS 9.0 software using the "shapefile" data model. This also proved a significant issue as geoprocessing time using shapefiles can increase exponentially above a certain (undocumented) size threshold. Hazard assessments and DiGMapGB-50 datasets were joined and exported, attribute fields were minimised to reduce data volumes. A draft map could then be produced and queried; the results of this analysis would feedback into the assessment phase until a refined assessment was completed.

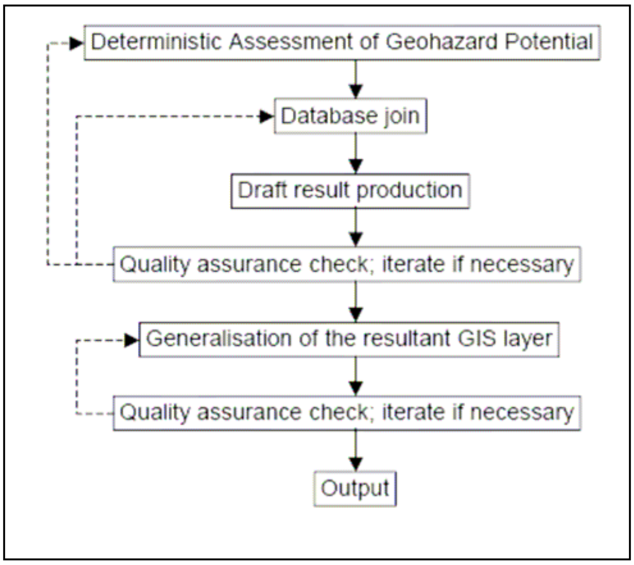

Figure 1. General hazard assessment workflow

Vector maps were generalized by conversion to a 25m cell grid because of the large data volumes and because of the computationally fuzzy nature of the geohazard assessment. This visually indicates the fuzzy nature of the data at high resolution within a GIS. It also allowed the data to be clipped to more manageable file sizes required for the geologist's validation phase.

The expert validation phase is a key QC procedure before the release of the data. The 18 geologists involved have different specialisms and were spread throughout the country. A validation application was written in ArcView for these individuals to check and comment on the GIS data, which allowed them to record their "expert knowledge". This could then be stored with the data as an extra input layer allowing future staff to understand more detail of refinements regarding these areas. Using the application geologists were able to use the standard editing tools within ArcView to identify an area and then add a text comment regarding their detailed knowledge. In this way, more data was captured than just that available on the digital map, based on geologists' extensive experience of the geology of an area. Data from below the ground surface could also be fed into the system as an attribute. This 3rd dimension is not available from a standard 2D vector map. The results of this procedure were reviewed and necessary amendments to the methodology completed.

The Definition of Level of Hazard

The output from the hazard assessment method is a large number of polygons each assigned to one of a small number of categories of relative potential for the hazard to be present or to occur in the future as illustrated in Table 1. Frequently, such classes are labelled 'low,' 'medium,' 'high' etc. However, this raises the question: 'How high is high?' 'What is a moderate hazard?' The creation of a geohazard potential assessment as a GIS layer or map is only one side of the process of communicating geohazard information to those members of society who need to know what problems they may face in their lives and work. The other side is the descriptive key that explains how the assessment was made and its implications for the user.

The traditional use of a 'low' to 'high' scale is often read as 'good' to 'bad' but this is not necessarily the case. A high level of shrinkable clay hazard may be seen as bad by a house-holder but good by a builder trying to find work installing underpinning. There are also issues of unnecessary planning blight when people do not fully understand the way assessments have been made.

Thus, explanatory keys that use ratings A to E defined by the assessment criteria and with additional text in each category that gives the implications for a particular user group, as appropriate, are less likely to invoke an inappropriate response in the reader (Table 1). User groups might include householders, financial institutions, civil engineers and land managers. As many or as few user implication columns could be included according to the interest of the user.

Results

As explained above, GeoSure data is premised and presented in a different way to previous hazard assessment datasets produced by BGS. Therefore, it is to be expected that external responses to the new data will require time to come back. Internally the results have been positively received. Part of the validation exercise was to compare these data against areas of known hazard from a geologist's experience and no areas were immediately identified where the GeoSure data had grossly under- or over-estimated the current perception of the hazard. In Figure 2 there is a strong correlation between those areas that have been recognised as landslides, and mapped in the field, and areas that the hazard assessment has indicated as having a high potential for movement.

Table 1. Slope Hazard assessment classes with implications to three potential user communities.

Class	Hazard rating	Implications for:		
		Planners	**Developers/Geotechnical Engineers**	**Householders**
A	No indicators for slope instability identified.	No constraints to land use due to slope instability within site.	Normal desk study and walkover survey of site.	No maintenance or use implications due to slope instability.
B	Slope instability problems are unlikely to be present.	No constraints to land use due to slope instability within site.	*Normal desk study and walkover survey of site. Consideration of stability of site surroundings.*	No maintenance or use implications due to slope instability.
C	Slope instability problems may be present or anticipated.	Report on implications for stability should be submitted if changes to drainage, construction or excavation are proposed.	Site investigation should consider specifically the slope stability of the site and surroundings.	Some consideration of implications for stability should be made if changes to drainage, construction or excavation are planned.
D	Slope instability problems are probably present or have occurred in the past.	Land use changes involving, loading, excavation or changes to drainage will affect stability and mitigation measures should accompany application.	Specialist site investigation for stability assessment necessary before construction.	Do not dispose of surface drainage to the ground. Do not undercut or load slopes.
E	Slope instability problems almost certainly present.	Permission for development may require remedial works as part of development. Permission for development may not be possible.	Specialist slope stability assessment necessary. Remediation and/or mitigation works may be necessary to stabilise the area.	Consider obtaining specialist advice to advise on need for stabilisation work and/or land management plan to maintain stability.

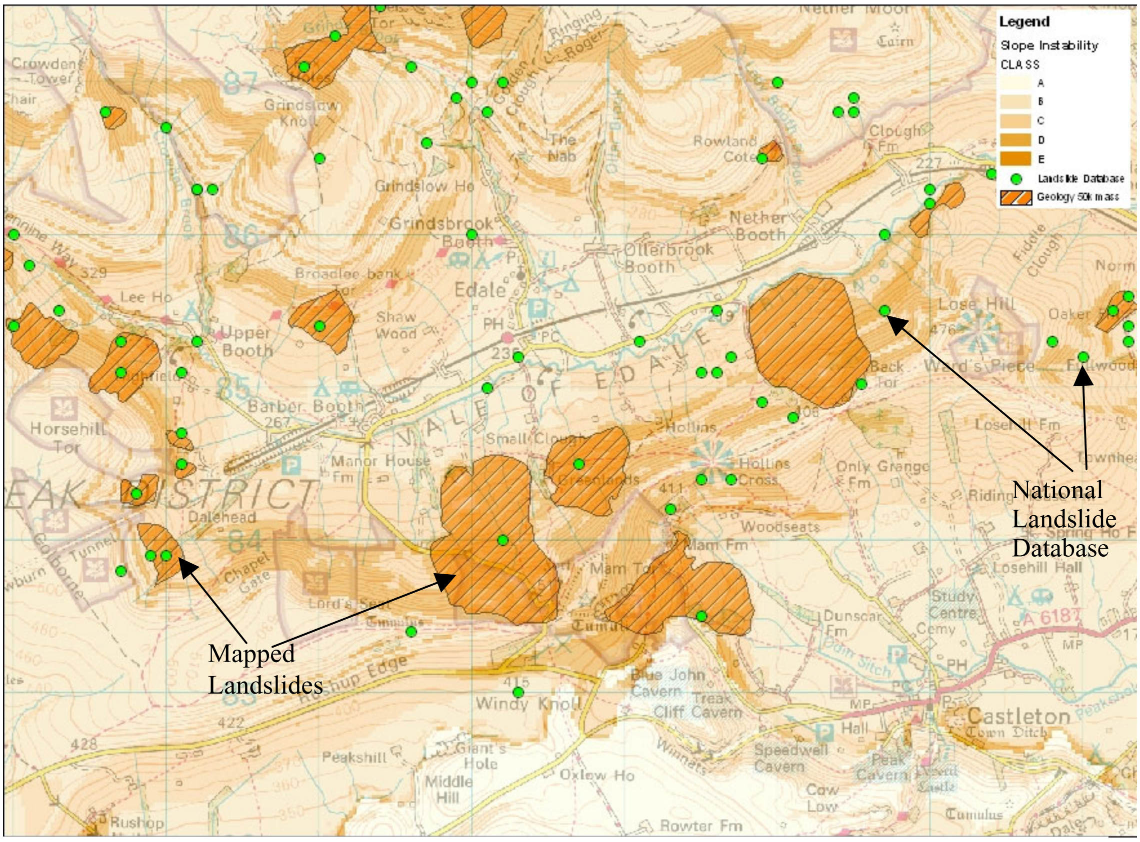

Figure 2. GeoSure map for Slope Instability with the mapped landslide occurrences for the same area. Cross hatched areas are landslides shown on 1:50 000 scale geological maps; green circles are entries in the National Landslide Database. © Crown Copyright. All Rights Reserved. ©NERC 2005

Where a mapped landslide falls within an area of high potential it may indicate two possible situations; the landslide may be the result of small local triggering factors, such as minor adverse variation in geological structure, that were absent in the adjacent area or the adjacent area may also have failed but has since become degraded to the extent that the landslide has no surface expression. In either case, both the landslide and the high slope instability potential area are likely to be close to the threshold of renewed movement as a result of small adverse changes in causative factors and fall equally within the higher potential hazard rating.

CONCLUSIONS

The BGS has the largest data holding of geological information and the widest range of geological expertise in the UK. This makes it ideally suited to play the major role in the assessment of national geohazards. Geohazards may be assessed using a probabilistic or deterministic method according to the nature of the hazard and the availability of information. Both methods require a detailed understanding of the causal factors that create the hazard and the process whereby it affects the environment. The deterministic method offers greater flexibility to deal with a changing environment's effect on the potential for geohazards in the future. The output of a hazard assessment, whether in text or graphic form, should convey fully and clearly the implications of the assessment for the user.

The use of the deterministic approach requires greater computing and geographical data handling ability than a probabilistic method. This has only become available at reasonable cost in the recent past.

One of the greatest strengths of this method of geohazard assessment is the potential to extend the work as an ongoing assessment. The methodology will be refined as the underlying geology mapped and published in more detail and the work could be extended to include data such as potential climate change scenarios along with many others.

Acknowledgements: The authors would like to thank the many colleagues who were involved in the work that is reported here. This paper is published with the permission of the Executive Director, British Geological Survey (NERC).

Corresponding author: Mr Matthew Harrison, British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham, NG12 5GG, United Kingdom. Tel: +44 115 936 3172. Email: mharr@bgs.ac.uk.

REFERENCES

BUILDING RESEARCH ESTABLISHMENT DIGEST. 1993. Low-rise buildings on shrinkable clay soils part 1. No. **240**

CULSHAW, M.G., 1993. Subsidence, geo-hazards and buildings insurance. In: Proceedings of a One Day Multidisciplinary Seminar on "Housing Subsidence," Leeds, April 1993. Editors: Cripps, J.C. and Dennis, J. A. Yorkshire Regional Group of the Geological Society. 5-8.

CULSHAW, M.G. & KELK, B., 1994. A national geo-hazard information system for the UK insurance industry - the development of a commercial product in a geological survey environment. In: Proceedings of the 1st European Congress on Regional Geological Cartography and Information Systems, Bologna, Italy, 13-16 June 1994. 4, Paper 111, 3p.

FORSTER, A. CULSHAW, M.G., STUART, M.E., DUNKLEY D.N., MUSSON, R.M.W. & HOOKER, P.J. 2002. Assessment of hazard and risk in the geological sciences; a guide to current practice. British Geological Survey Internal Report IR/02/169R. Keyworth, Nottingham.

OPENSHAW, S. & TAYLOR, P.J. 1979 A Million or So Correlated Coefficients: Three experiments on the modifiable areal unit problem. in Wrigley, N. and R.J. Bennet, (eds), Statistical Applications in the Spatial Sciences: Pion, London.