British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

Ground characterisation of the urban environment: a guide to best practice

Urban Geoscience and Geological Hazards Programme

Research Report RR/02/05

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Ground characterisation of the urban environment: a guide to best practice

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Redevelopment around the former Manchester and Salford docks and the Manchester Ship Canal.

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Foreword

This report draws together the conclusions and recommendations made in three earlier generic studies, available as BGS Internal Reports, concerning the development of improved IT systems for Urban Geoscience, 3-D rock mass characterisation and superficial deposits characterisation. This report is the culmination of the generic studies, carried out in the first two years of the Urban Geoscience Sub-programme and managed in the Environment and Hazards Directorate. It provides an outline of the best practice adopted by the BGS for thematic urban projects. A generic methodology is described, including a description of the basic geoscientific data and the recording standards to be used, the IT systems that are being developed, and guidance on the range of outputs. The approach is illustrated with specific examples from current and past projects in the urban environment.

Acknowledgements

Twenty-six individuals have contributed to this report, through their work in the three earlier generic studies carried out in the Urban Geoscience Subprogramme. They form a part of the highly experienced, multidisciplinary core of BGS staff whose collective thoughts, advice and ideas give this report a high level of credibility across the whole of the BGS. The ready cooperation of external contributors is also acknowledged. In particular, Mr Chris Taylor together with Professor Mike Rosenbaum and Dr Ping Lu, formerly of Nottingham Trent University, and Professor Jim Rose of Royal Holloway University of London are thanked for constructive discussions during work on the earlier generic studies. Professor Rosenbaum is thanked for a review of a draft of information on charaterisation of superficial deposits.

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Summary

This report sets the framework for the means to provide information and advice about all aspects of the ground in the urban environment.

In order to understand properly the interaction of the ground and human activity in urban areas it is necessary to gather information on, and map out the properties of, the ground. The BGS undertakes such work in a series of thematic urban geoscientific projects.

This report describes the methodologies and datasets relating to superficial deposits and bedrock geology relevant to urban geoscientific projects. The rationale for carrying out such projects is explained and the basis for good practice is laid out in generic terms. The report provides guidance on sources of information and recommends procedures and standards that should form part of best practice when undertaking a project. Examples of this good practice are given in the form of illustrations of a range of outputs from a current project being carried out in Manchester and Salford.

It is recognised that although some outputs may vary depending on the ground-related issues in a particular urban area, there are a number of topics that should be encompassed regardless of the local conditions. In all cases the underpinning practices, methods, recording standards and classifications need to be defined, and this report describes these parameters and highlights areas of future generic work that will enhance the output concerning urban areas in particular.

1 Introduction

About 80% of the UK population lives in towns and cities of over 10 000 people (DETR, 2000). The character of the ground in these urban areas directly or indirectly influences the lives of all these people and those who travel into the urban areas to work. For example the stability of the ground, the availability of drinking water and the safe drainage of rainwater are taken for granted but are dependent on an understanding of the composition of the ground at the surface and beneath the urban areas.

The BGS strategy, *Foundations for a Sustainable Future,* published in September 1999, identified applied geoscience as one of the four main elements of a new British Geological Survey (BGS) programme, to be delivered by the Environment and Hazards Directorate. One of five programmes that make up the work of the Directorate covers Urban Geoscience and Geological Hazards within which was established a subprogramme concerning urban geoscience.

The initial work to be carried out in the Urban Geoscience Subprogramme was determined by a Programme Development Group (PDG) whose report was completed in November 1999. It recognised that many of the geoscience capabilities of the BGS are directly relevant to the challenges of urban development and renewal. It was perceived that the lack of specific and consistent products is a barrier to the appropriate use of geoscience information in addressing problems of cities. For this reason the PDG recommended that the BGS should develop a new set of products, comprehensively applying geoscience information in built up areas.

An initial principal focus of the subprogramme, was to establish the underlying scientific basis for research in specific urban areas. This involved an assessment of good practice in the 3-D characterisation of the rock mass and superficial deposits. These assessments identified the key datasets that should be collated in an urban project and the standards in place for gathering new information. Recognising that the use of IT is now fundamental for the collation, manipulation, interpretation and visualisation of geoscience data, a review was made also of the key issues for the development of IT in the urban programme. The results of this work were published in three internal BGS reports:

Ellison, R A, Lawley, R S, Kessler, H, Jordan, C J, Monoghan, A A, Laxton, J L, and Adlam, K A M. 2001. Development of improved IT systems for Urban Geoscience. *British Geological Survey Internal Report,* IR/01/067.

McMillan, A A, Ellison, R A, Fordyce, F, Golledge, N R, Holmes, K A, Jordan, C J, Kessler, H, Monoghan, A A, Northmore, K J, Robins, N S, and Taylor, C. 2001. Superficial deposits characterisation in the urban environment; a best practice guide to mapping and research. *British Geological Survey Internal Report,* IR/01/68.

Lott, G. 2001. 3-D Rock Mass Characterisation in the Urban Environment. *British Geological Survey Internal Report,* IR/01/69.

This report summarises the key recommendations made in the three earlier reports. It also gives information on the current best practice to be adopted in the Urban Geoscience Subprogramme for thematic projects in specific urban areas.

2 Requirement for urban geoscientific information

The provision of reliable and up-to-date geoscientific analysis and interpretation for the urban environment has assumed increasing importance in recent years as towns and cities have become the focus for regeneration and development. Proposed new urban development, in existing towns and beyond, demands the best available geoscientific advice (Table 1).

Clearly the properties of naturally occurring superficial deposits and solid rocks need to be defined and understood. But the anthropogenically-created legacy needs to be addressed also. The legacy includes former quarrying, mining subsidence, derelict industrial ground, treated ground, engineered and nonengineered fill, variably consolidated made ground and contaminated groundwater and

Development issue	Key documentation
Provision of land suitable for development	DETR Planning Policy Guidance (see Table 4) http://www.planning.detr.gov.uk/ppg/index.htm Evaluation of Environmental Information for Planning Projects - a Good Practice Guide - HMSO, 1994.
Protection and development of mineral resources	DETR Minerals Planning Guidance (see Table 5) http://www.databases.detr.gov.uk/planning/npp/ListPublications.asp?thisCategory=MPGS)
Protection and development of water resources	http://www.environment-agency.gov.uk/gwcl/ngwclc.htm
Provision of waste disposal sites	Waste Management: Department of the Environment Waste Management Paper No 26 – Landfilling Wastes, HMSO, 1986. http://www.environment-agency.gov.uk/epns/licence.html
Control of pollution and contaminated land	Framework for Contaminated Land, Department of the Environment and Welsh Office, November 1994. Contaminated Land. Department of the Environment, Transport and the Regions. 2000. 162p.(Great Britain, Department of the Environment, Transport and the Regions circular; 2000/02). (London: Stationery Office) – ISBN 0117535443 http://www.environment-agency.gov.uk/gwcl/ngwclc.htm
Control of flooding	An online EA interactive GIS-based system called 'find your environment' shows distribution of areas liable to river and sea flooding, indicative floodplain maps, location of sites in an inventory of pollution sites, river quality information and groundwater protection zones. http://www.environment-agency.gov.uk/gwcl/index.htm http://www.maff.gov.uk/environ/fcd/default.htm The Government has implemented the Integrated Pollution Prevention and Control Directive (IPPC) through the Pollution Prevention and Control Regulations (the Regulations) from 1August 2000. The Environment Agency has produced a Regulatory Package that gives guidance about preparation of site assessment for contaminated sites that are regulated by the Agency (A1 installations): http://www.environment-agency.gov.uk/epns/package.html
Conservation of sites	Current information about fossil collecting, non aggregate mineral extraction, SSSIs, waste management and sustainable development on English Nature Web pages: http://www.english-nature.org.uk/news/position.asp

Table 1 Key development issues relating to urban ground information and information on where to find guidance on these issues.

soils. All need to be systematically assessed to inform the planning process and provide the basis for engineering solutions. The effects of climate change which may result in wetter and stormier seasons and sea-level rise with the resultant frequent inundation of floodplains and coastal areas is another topic with high priority.

Thus, as major initiatives are taken to encourage greater usage of ‘brownfield’, ‘inner city greenfield’ and ‘urban ring greenfield’ sites for industrial redevelopment and for new housing (Department of the Environment, Transport and the Regions, 2000) so the demand grows for up-to-date information on ground conditions, geomorphology and topography together with base line data against which contaminated land and derelict land may be assessed. Site specific investigation needs to be conducted based on good quality geoscientific data resulting from desk study (historical and archival data search), ‘field’ survey, remotely-sensed data interpretation, soil geochemical sampling and geotechnical survey. The 3-D characterisation of artificial and superficial deposits and bedrock is required to understand spatial lithological variability and the geometry of important boundary surfaces. Definitions of rockhead and the weathered rock profile need to be established. Climatic changes and time also need to be considered for example in relation to groundwater vulnerability, flooding, weathering processes and ground stability.

The relationship between geoscience and key development issues for the urban environment (Table 1), has been explored by Thompson et al. (1998) and Ellison et al. (1997). Assessment of these issues is underpinned by government guidance, advice and best practice, also listed by the above authors.

3 Applied geological mapping

Since the early 1980s, the Department of the Environment has commissioned over 50 applied geological mapping studies of selected areas of Great Britain. Many of these were undertaken within coalfields and improve available information on areas that might be liable to mining subsidence. The remainder of the areas, however, were selected to show a broad range of geological characteristics and planning issues. The aim of all these studies was to develop better approaches to the collection, collation and presentation of geological information as a basis for planning, development and conservation. Useful reviews of them include Monro and Hull (1986), Culshaw et al. (1990) and Smith and Ellison (1999). As a consequence of applied geological mapping studies McMillan and Browne (1987) and Browne and McMillan (1989) published papers respectively on mining information and on Quaternary thematic maps in Scotland.

In 1990, a seminar was held at the Geological Society in London to consider the results of the applied mapping projects to date, and the next steps. As a result of the discussions, it was decided that sufficient area-based studies had been commissioned to identify good practices for the use of geological data. The few projects of this type, which were approved at that time but for which contracts had not been let, were to be broadened to take account of a wider range of earth science factors. In addition, it was decided that the whole initiative should be brought to a close by commissioning a small number of research projects with the aim of demonstrating the circumstances in which earth science information is needed in planning, development and conservation and best ways of presenting and using it. Therefore, four projects were commissioned to deal, respectively, with use of earth science information in: coastal planning, urban planning, rural and upland planning, and major development initiatives. The principal documents arising from these studies are given in Table 2.

The terms of reference for all the applied geological mapping work concerned particularly the requirements of the funding government department, namely the former Department of the Environment and its successor the former Department of the Environment, Transport and the Regions (DETR). These were principally to provide geoscientific information in a form that could be used in regional and local planning and development. The new BGS Urban Geoscience Programme is directed at a wider user base to include all professions that deal with a broad range of basic and interpreted geoscientific information. Projects now deal with issues that may not be currently topical, but will be of concern in the future. For example the European Water Framework Directive has focussed attention on groundwater in urban areas. This in turn leads to questions about urban groundwater vulnerability and sustainable urban drainage. The mechanism of, and potential for, reactivation of faults in abandoned mining areas, perhaps as a result of rising mine water levels, is another area of investigation.

Table 2 DETR planning and earth science information project reports.

Coastal Planning and Management: A Review of Earth Science Information Needs. Rendell Geotechnics for DoE, 1995. (ISBN 0 11 753111 1)
Environmental Geology in Land Use Planning: Advice for Planners and Developers. Symonds Travers Morgan on behalf of the DETR (ISBN 0 9522345 7 2).
Environmental Geology in Land Use Planning: A Guide to Good Practice. Symonds Travers Morgan on behalf of the DETR (ISBN 0 9522345 3 X).
Ellison, R A, Arrick, A, Strange, P J and Hennessey, C. 1998. Earth science information in support of major development initiatives - Summary Report for the Department of Transport, Environment and the Regions. British Geological Survey Technical Report WA/97/84, 60pp. (ISBN 0 85 2723 10 5).

4 Objectives of the Urban Programme

The BGS has a reputation for the provision of impartial advice and information in the urban environment, based on a broad understanding of geoscience issues. The Urban Geoscience Subprogramme is carried out through a series of thematic projects each of which either has a specific focus such as urban groundwater, mining legacy or contaminated land, or a more general approach that deals with all ground-related issues. The thematic projects are regional and holistic in approach, rather than site specific. Consequently, the principal objectives of the projects in general are to provide a wide range of basic and interpreted information about the ground on a regional and local level that can be used as the basis for more detailed site-specific investigations that, in general, are carried out by consultants and/or local authorities.

5 Outputs from the Urban Programme

Databases, GIS and 3-D models form the principal output from the Urban Programme. A standard set of information layers in a GIS, described below, is determined with reference to maps and reports published in the former DoE applied mapping projects carried out in the 1980s and 1990s (Smith and Ellison, 1999). An optimum scale of 1:10 000 is likely to be adopted in most cases for dealing with the majority of data, and for output. Hard copy output will continue to be an essential means of illustrating the content of the GIS, but the main output will be in digital format, disseminated by CD Rom or other suitable means.

Maps that display geoscience information were the focus of applied geological mapping projects. In a GIS environment they are now regarded as the base to which is attached a great range of other attributes, and the means to generating a new range of digital output. The increasing use of GIS is enabling greater integration and manipulation of datasets concerning the ground. Combined with visualisation techniques, that are currently improving rapidly, GIS presents increasing opportunities for information to be shown in ways that give a great range of users a better perspective and understanding about how ground information can be applied to a wide range of issues. Examples of this are the relationship between ground surface topography and water levels, and the spatial relationship between potentially contaminating land use, current brownfield sites and near-surface deposits that might allow transmission of contaminants.

Examples of information held in a GIS covering central Manchester and Salford and 3-D models of the area are given in following sections of this report.

6 Recording and observation standards

The purpose of recording and observation standards is to ensure that heterogeneity is properly defined. Requirement for conformity of standards in the recording and classification of strata leads to problems particularly with the superficial deposits because of their variability. Standardisation of lithostratigraphical nomenclature of these deposits is a continuing process (see for example Bowen 1999; McMillan et al, 1999). The BGS standards that provide the basic platform for recording and classification, and give recognised terms for description of the lithology of all deposits, are published in a four-volume BGS Rock Classification Scheme (RCS) (http://www.bgs.ac.uk/bgsrcs/home.html)

- Volume 1 Igneous rocks
- Volume 2 Metamorphic rocks
- Volume 3 Sediments and sedimentary rocks
- Volume 4 Artificial man-made ground and natural superficial deposits

There are minor variations between the RCS and British Standard 5930 (British Standards Institution, 1999) with respect to sediment description and classification. These arise because of differences between a geological and an engineering approach to description. Urban geoscience projects follow the British Standard for lithological description as far as possible, so that data provided by the projects are interchangeable between most users.

Colour is recorded using the widely-adopted Munsell soil or rock colour charts. Texture, discontinuities (fractures) and weathering are described also using British Standard 5930:1999 descriptors.

More information about standards and methodologies is given in the following descriptions of the range of data used in urban projects.

7 Urban geoscience datasets

This section of the report deals with the principal datasets, listed in Table 3 below, that are being brought together in a GIS for a typical urban geoscience project. Some of the datasets are available in digital format; others are digitised specifically for the project, and non-digital maps are scanned, warped and registered. The primary datasets, denoted 'P' in Table 3, are available off the shelf; others, denoted 'D' are derived by interpretation or modelling from primary datasets, for example for depths to first water strike contours and rockhead contours. Visualisations of 3-D geological models, and water level are generated by interpretation of these principal datasets. Examples of the datasets and, where appropriate, standards and methods used to interpret, collate and model them are given in the following pages. The numbers given to each dataset in Table 3 below are used as reference numbers in the text.

Further information about the sources of primary data are given by Hooker et al, 1999; Ellison and Smith, 1997; McMillan et al, 2001; Lott, 2001 and Ellison et al, 2001. In the BGS much of the information is delivered via a corporate Intranet or internal shared drives. Some of it is restricted to internal use because of external licence agreements.

7.1 MAPS

Small-scale Ordnance Survey (1) and geological maps (2) are included in the GIS to enable a clear overview of an urban area, particularly those covering more than 25 km^2. Visualisation of large-scale topographical and geological maps in an overview is not usually suitable, particularly in urban areas where topographical information is dense, or in areas of complex geology.

At the beginning of a project an assessment is made of the existing large-scale geological maps (6) (Figure 1) to determine the degree of updating required. This is dependent on the amount of borehole and other information that has become available since the date of the geological survey. The

	Dataset		Uses for the dataset
1	1:50 000 current OS Landranger maps	P	Regional illustrative overview
2	1:10 000 current OS Landplan topographical maps	P	Backdrop for thematic mapping
3	6" to one mile (1:10 560) Ordnance Survey historical topographical maps	P	Historical land use Contaminating industry Water courses
4	1:50 000 BGS digital geological map data: solid and drift geology and artificial deposits layers (DigMap50)	P	Regional illustrative overview
5	1:10 000 BGS digital geological map data: solid and drift geology and artificial deposits layers (DigMap10)	P	Detailed local geology Distribution of aquifers Surface lithology
6	6" to one mile (1:10 560) BGS geological maps	P	Basis for new geological maps Detailed local geology Historical details e.g. about pits and exposures
7	1:50 000 scale or smaller Soil Survey (NSRI) maps (limited coverage of urban areas)	P	Indication of potential for downward passage of water and contaminants
8	Orthorectified aerial photographs at 1:10 000 scale	P	Current land use Surface sealing determination Visualisation
9	Digital Terrain Model	P	Visualisation 3-D models

Table 3 Primary and derived information for a typical urban geoscience project
P: principal dataset D: derived dataset.

10	Borehole database (BGS holdings)	P	3-D geology characterisation
11	Rockhead contours	D	Visualisation of geology
12	Mine plans and mine shaft locations (Coal Authority)	P	Distribution of workings Ground stability assessment Planning and development
13	Baseline BGS geochemical data (G-BASE); (limited availability in urban areas)	P	Historical land use Contaminated land study Characterisation of geological units and soils
14	Water abstraction points (Environment Agency)	P	Water balance model
15	Groundwater protection zones (Environment Agency)	P	Groundwater vulnerability models
16	Areas susceptible to flooding (Environment Agency)	P	Groundwater vulnerability Ground stability assessment Planning and development
17	Water well data (BGS WELL MASTER)	P	Water balance models
18	Water levels database	D	Water balance models Indication of near surface water Ground engineering Groundwater vulnerability models
19	First water strike model	D	Groundwater vulnerability Ground engineering
20	Geotechnical database (BGS holdings)	D	Ground stability assessment
21	Current land use	D	Backdrop for other themes Assessment of surface sealing
22	Historical land use	D	Contaminated land assessment
23	Property damage information	P	Effects of unstable ground

Table 3 *continued.*

superficial (drift) deposits normally require amendment to ensure good 3-D visualisation (see section 8.3) whereas in the majority of urban areas the current bedrock geology model, derived from surface geology and borehole data, is likely to be satisfactory to use for modelling purposes.

At this assessment stage a conceptual regional model for the Quaternary deposits is established with reference to Geological Survey Memoirs, Regional Guides and other published geological literature. The conceptual model aids decisions about which lithological units in the superficial deposits will be defined in the borehole database (Section 7.4).

7.1.1 Standards and methodology in mapping and fieldwork

The methodology for updating and mapping in a fully digital environment is explained in Howard et al. 2001.

Updating of the geological maps involves limited fieldwork to confirm the distribution of artificial deposits, essentially made and infilled ground. Mapping of these deposits is carried out initially using stereo air photographs (8), and later by field checking.

An assessment of the accuracy of existing geological maps is made with reference to geomorphological features and borehole records. Mapping in the field of features caused by bedrock geology and superficial deposits, in conjunction with borehole data and surface information, even in built-up areas, is routinely used to map accurately the geological units at the surface.

In areas with strong topographical relief the relationship of geological boundaries and geomorphological features is visualised in the digital environment by draping a scanned image of the large-scale geological map (5) onto a digital terrain model (9).

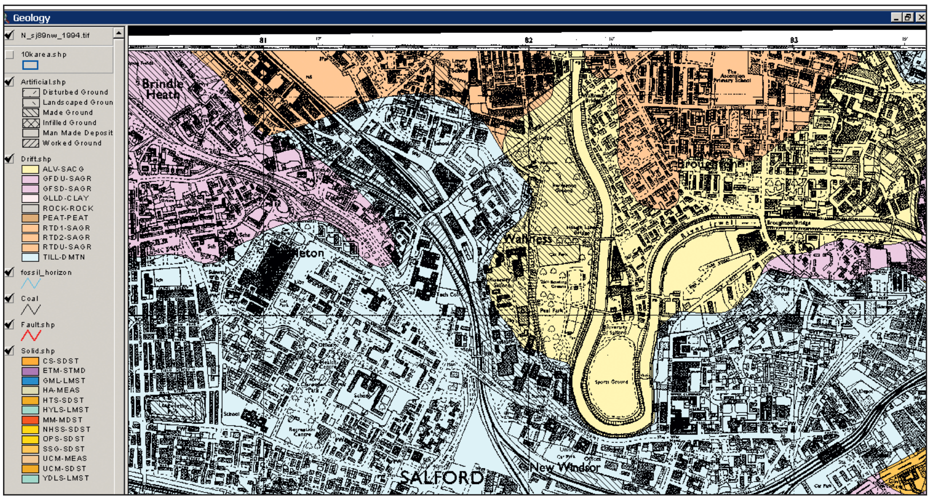


Figure 1 Example of superficial geology map for Manchester and Salford.

Detailed descriptions of the geological units and their hydrogeological (Section 7.10) and engineering characteristics (Section 7.7) are made at temporary and permanent exposures available during fieldwork. In addition, boreholes are drilled (usually by light cable percussion methods) to recover 'type' sequences, mainly in superficial deposits. Where appropriate undisturbed samples are collected for further research and a photographic record made of typical lithologies. Representative samples of the entire sequences are curated for reference in the BGS collections. Rotary cored boreholes are too expensive to drill specifically for an urban geoscience project. Cores that provide a standard succession, where they are available from site investigations, are obtained for curation in the BGS core store.

All geological maps are digitised to current BGS corporate standards. The units of bedrock and superficial deposits geology are given names in the BGS Lexicon of Named Rock Units. Some units may have full formal descriptions in the Lexicon, with type sections and references to papers in the geological literature, others have a brief, generalised, lithological description. All digital geological maps are underpinned by tables containing codes for each rock unit (Lex Code) and the principal lithology (Rock Type) (Figure 2).

7.2 VERTICAL AERIAL PHOTOGRAPHY (8)

Stereoscopic aerial photographs are used to distinguish and map geological (natural) deposits and various categories of artificial (man-made) ground either using conventional stereoscopes or digital photogrammetry. The accuracy and level of geological detail attained is often a function of the time available and the experience of the interpeter. Experience of interpreting air photos in urban settings has shown that most geological features are difficult if not impossible to distinguish, but aerial photography can still be of use in four main ways:

- location of regional geological patterns that can be traced through the urban environment
- visualisation of orthorectified photographs against topographical maps (Figure 3)
- classification of the urban environment (e.g. in terms of the capping protection (sealing) it might provide the superficial sediments and aquifers)
- delineation of made ground.

7.3 DIGITAL TERRAIN MODEL (DTM) AND DIGITAL ELEVATION MODEL (DEM) (9)

A DTM is a model of the earth's surface with some features, such as forestry and buildings/embankments, removed, whereas a DEM contains all such data. In the urban context, there may be a requirement for both a DEM and a DTM. For example, assessment of borehole start heights is made easily by plotting them onto an accurate DTM. In mapping made ground, a DEM is preferable as it includes features such as embankments.

A major aspect of the characterisation of geological units is knowledge regarding their exact location in vertical space. An accurate and consistent DTM is essential for draping with the 2-D geological maps (and other 2-D map-based information) and for reviewing in a 3-D environment, map linework, particularly of geological maps. Ordnance Survey LandForm Panorama 1:50 000 scale contours at 10m intervals are used routinely for the DTM. Ordnance Survey LandForm Profile 1:10 000 scale contours at 5m intervals are used when more detail is appropriate and funds permit its purchase.

7.3.1 Standards and methodology

A DTM is made from the contours in a variety of different ways, and using a variety of software packages. The methodology for producing DTMs and DEMs in the BGS is currently being standardised to eliminate proliferation of different models for the same area. Preliminary tests indicate that Delaunay Triangulation, used by MapInfo's VerticalMapper, provides the best results for urban projects in terms of being true to the original data points and producing a visually pleasing model. ERDAS Imagine has superior 3-D viewing, data integration and animation capabilities and may be more appropriate for analysis and interpretation of data.

7.4 BOREHOLE DATABASE (10)

A borehole database, in conjunction with a Digital Terrain Model (DTM) and geological maps, is essential to enable 3-D relationships of the geology and other datasets to be visualised and better understood.

The amount of information to be entered in the borehole database is determined at the start of the project. This depends on the project objectives, the complexity of the geology and the resources available. However, the principal 'keep it

Figure 2 Part of the LexRock sheet for the 1:50 000 scale geological map of the Bournemouth district (sheet number 329). The approved lithostratigraphy is recorded in the Lexicon of named rock units.

		DiGMapGB-50 Version 1	V1	V1		V1
Sheet name	Sheet No.	Approved Lithostratigraphy	Comment B on V1 lithology or lithostratigraphy	Lex code	-	RockType
Bournemouth	EW329	Made Ground		MGR	-	MGRD
Bournemouth	EW329	Worked Ground		WGR	-	OPEN
Bournemouth	EW329	Landslip		SLIP	-	CLAY
Bournemouth	EW329	Blown sand		BSA	-	SAND
Bournemouth	EW329	Peat		PEAT	-	PEAT
Bournemouth	EW329	Alluvium		ALV	-	SACG
Bournemouth	EW329	River Terrace Deposits 1		RTD1	-	SAGR
Bournemouth	EW329	River Terrace Deposits 2		RTD2	-	SAGR
Bournemouth	EW329	River Terrace Deposits 3		RTD3	-	SAGR
Bournemouth	EW329	River Terrace Deposits 4		RTD4	-	SAGR
Bournemouth	EW329	River Terrace Deposits 5		RTD5	-	SAGR
Bournemouth	EW329	Headon Formation		HE	-	CLAY
Bournemouth	EW329	Lyndhurst Member		LY	-	SACL

simple' is usually followed in the determination of information to be included in the borehole database.

The amount of detail within the superficial deposits included in the database varies, but is determined initially with reference to the conceptual depositional model for the superficial deposits, referred to in section 7.1. Normally the top and base of units dominated by clay (e.g. till), sands and gravels (e.g. river terrace deposits and glaciofluvial deposits), silts (e.g. glacial lacustrine deposits) and sand (e.g. moraine deposits) are databased. The selection process inevitably requires simplification of many of the more detailed borehole logs.

The solid geology is dealt with in a similar way to the superficial deposits. It is generally sufficient to enter key stratigraphical horizons rather than attempt to model relatively minor lithological variation within the main solid formations. Where Coal Measures are present, a decision is made about which main coal seams and sandstones to input. One guiding principal is to identify geological boundaries that are of major hydrogeological, geotechnical or economic importance. Another is to bear in mind that, in general terms, strata more than 50m below the surface have relatively little bearing on the ground characterisation in most urban areas, exceptions being aquifers and strata that have been mined.

7.4.1 Standards and methodology

Borehole data are entered into the BGS corporate SOBI (Single Onshore Borehole Index) and downhole Borehole_Geology tables. The most important attribute in the downhole geology table is the code abbreviation for the dominant lithology. It uses rock names, with or without standard qualifiers, from the corporate BGS Rock Classification Scheme (see Section 6) and lithologies that conform to BS 5950:1999 (British Standards Institution,

Figure 3 Example of visualisation of aerial photography against a large-scale topographical map.

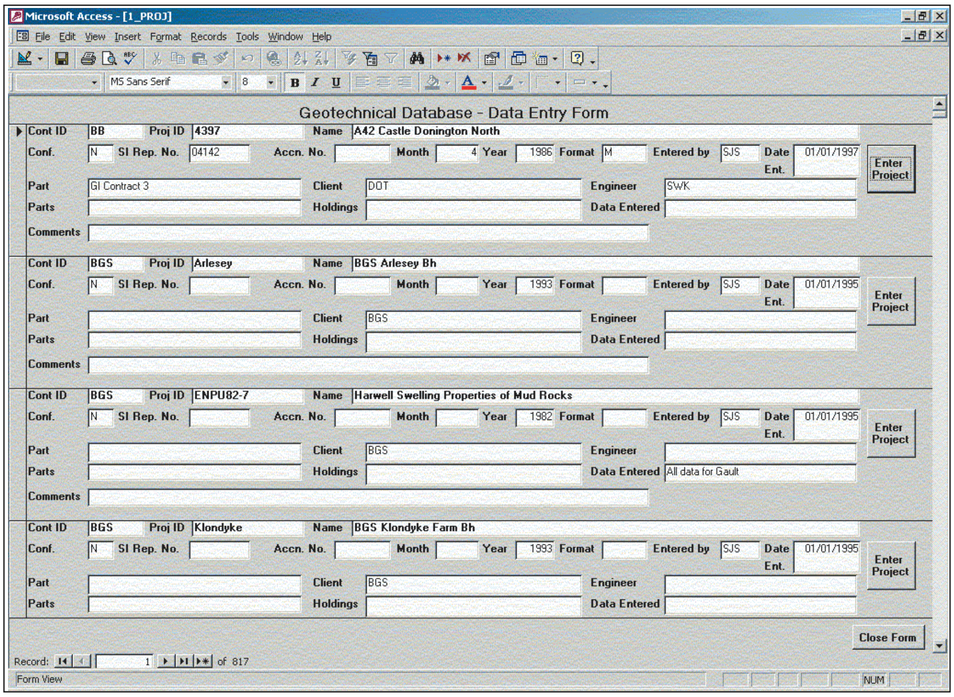


Figure 4 Engineering properties data entry form for index information.

1999). The codes used for rock types and rock units are common to those used in attribution of the digital geological maps (4; 5) (Figure 2).

7.5 ROCKHEAD CONTOURS (11)

The position of rockhead is one of the key horizons entered into the borehole database to enable modelling of this most important interface. The **geological rockhead** horizon is defined fairly precisely as the base of the Quaternary deposits (notwithstanding the difficulties, in some cases, of recognising this boundary) and can thus be modelled with a degree of certainty.

The definition and criteria for recognising **engineering rockhead** is arbitrary and may be difficult to determine from borehole logs alone. Broadly defined, engineering rockhead is the surface of material that has the geotechnical properties of rock. The depth of commencement of rotary core drilling, usually determined by the driller on the basis of resistance to the light cable percussion boring, is probably a good indication of engineering rockhead, and may be included in a borehole database. The reliability of such a surface is less than for the geological rockhead, particularly when the boundary lies within a complex weathering profile, of the Triassic Sherwood Sandstone for example.

In addition to borehole data, information on engineering rockhead is obtained from careful logging of weathering profiles (Anon, 1995), following the BS5930:1999.

The methodology for modelling this horizon and others is dealt with in Section 8.

7.6 INFORMATION ON URBAN SOILS

Soil is defined in pedological and geological terms as superficial deposits or rock that has been affected by the process of physical reorganisation and/or chemical change dependent on their continued proximity to the atmosphere and biosphere.

The main soil forming processes are weathering, reduction/oxidation, leaching/precipitation, humification and peat formation. A soil profile comprises various horizons each of which can be distinguished by texture, structure, colour, consistency, stoniness, organic matter and degree of root development.

Consideration is being given by the BGS to producing provisional soil maps in urban areas (see Bullock and Gregory, 1991) in collaboration with the National Soil Research Institute (NSRI), although the cost of detailed mapping is prohibitive. More appropriate is the recording of soil profiles in the principal geological units and characterising them in terms of pH of the topsoil and subsoil, organic matter status, field capacity, stone content and $CaCO_3$ content. This is information that can be derived from soil maps (7), although unfortunately they have been produced in only a few urban areas.

7.7 BGS GEOTECHNICAL PROPERTIES DATABASE (20)

One of the objectives of an urban geoscience project is to characterise the main rock units in terms of their engineering characteristics. The corporate BGS geotechnical database input tables (Figure 4) are used to build a database of properties derived from selected representative site investigation data. These are collected from reputable, known companies. A shortcoming of this approach is the variable quality of engineering test data in site investigation reports, despite the requirement to adhere to the BS5930 recommendations

Many of the more recent site investigation records are available in AGGS (Association of Geotechnical and Geoenvironmental Specialists) digital format. These data are entered directly into the BGS geotechnical database using a data manipulation procedure in Excel. In addition, an AGGS software programme enables a hard copy of whole SI reports to be reproduced, including the borehole logs.

One potential advantage of data in the more recent site investigation logs is that, notwithstanding a degree of

Data entered
Stratum descriptions
Rotary core information
Fracture spacing
In situ permeability
Standard penetration test results
Classification tests
California bearing ratio (CBR) test – general
Compaction test – general
Consolidation tests
Particle size distribution analysis data
MCV test
Point load tests
Rock testing
Shear box testing – general
Triaxial tests
Chemical tests

Figure 5 List of tables in the BGS Geotechnical database.

inconsistency, the descriptive information and numerical geotechnical property parameters, all relate to methods or units of measurement in BS5930:1999 and BS1377:1990). For example, lithological and discontinuity descriptions (joint, fissure and bedding spacing) are described to a uniform format and standard; descriptive strength data (e.g. weak, strong, very strong, etc.) has a specific meaning; particle size data relate to the British Standard.

To supplement site investigation data, information on the engineering characteristics is collected also from exposures. Density/compactness/field strength measurements are taken using pocket penetrometers or hand vanes and discontinuities, including bedding styles, are recorded using BS5950:1999 standards.

7.7.1 Thematic output

Three of the most important engineering considerations with respect to construction and development are the suitability of the ground to support structural foundations, the ease with which it can be excavated and the suitability of the ground materials for use in engineered earthworks and fills. Information on these aspects is derived from the geotechnical properties database and field observations and is best summarised on thematic maps such as those for Bradford (Waters et al, 1996). Smith and Ellison (1999) reviewed the availability of such information in England and Wales.

In order to rationalise this derived information, the principal bedrock units are divided into major engineering categories, for example, mudrocks or 'strong' sandstones. Typically, information in each category refers to representative test results from site investigations, geological faulting, weathering, field permeability, strength and compressibility. Engineering soils (mainly superficial deposits) are divided, for example, into mixed cohesive–non-cohesive soils (e.g. till), soft-firm soils (e.g. Head), soft–loose soils (e.g. Alluvium), non-cohesive soils (e.g. River Terrace Deposits), organic soils (e.g. Peat) and highly variable artificial deposits. Information on the three main engineering considerations is given for each of these (Figure 6).

7.8 HISTORICAL LAND USE (22)

Historical Ordnance Survey maps are used to delineate areas of former contaminating land use. The areas are classified according to guidelines set out by the former Department of the Environment (DoE, 1991) and modified by the BGS to suit the requirements of local authorities for carrying out their obligations under Part IIA of the Environmental Protection Act (1990). The categories of land use that are mapped are listed in Table 4 below.

At least two ages, preferably three, of six inch to one mile historical OS maps are used, typically 1890s, 1920s, 1950s. Each area identified is given a unique number, an address and a DoE category as illustrated in Table 5 and digitised as a polygon. The information is interrogated using the GIS.

7.9 CURRENT LAND USE (21)

Current land use is categorised using the National Land Use Database (NLUD) scheme, also adopted by local authorities for providing central and local government with key information on the amounts of previously developed land (PDL) that may be available for redevelopment. Returns to the NLUD Partnership (comprising DTLR, English Partnerships, the Improvement and Development Agency and Ordnance Survey) from 345 local authorities have identified more than 30 000 such sites throughout England.

Two important research projects aimed at developing the National Land Use Database have been awarded recently to the National Remote Sensing Centre. The projects will investigate methods for producing urban and rural baseline land-use datasets for the whole of England and are significant next step towards the long-term aim of NLUD, to provide a complete and consistent geographical record of land use at the national level, which is kept up-to-date. The main objectives of the research are to deliver complete data specifications, one urban, one rural, capable of providing a national land-use dataset, initially for England. The research will use the new Ordnance Survey Digital National Framework (DNF) data as the underpinning base map. Once completed these datasets, consistent with the Ordnance Survey digital maps, will be a valuable resource for the BGS urban programme.

The urban geoscience projects employ the 13 main categories in the NLUD scheme (Table 6) to characterise the entire urban area using 1:10 000 scale base maps and air photography. An example of the coverage for part of Manchester is shown on Figure 7. In some areas it may be appropriate to further subdivide certain land-use types (also following the NLUD scheme) for example using 'industrial' and 'commercial' as a basis for determining contaminating industry. Another type of subdivision (not in the NLUD scheme) is to identify different ages of housing as the basis for determination of the proportion of land covered by property.

ENGINEERING GEOLOGICAL UNIT		GEOLOGICAL UNIT	DESCRIPTION / CHARACTERISTICS	ENGINEERING CONSIDERATIONS			
				Foundations	Excavation	Engineered Fill	Site Investigation
BEDROCK							
'STRONG' SANDSTONES		All sandstones of the Millstone Grit and Coal Measures	Moderately to well-jointed, thinly to thickly – bedded, fine to coarse – grained SANDSTONES, with mudstone and siltstone interbeds. Strong to moderately strong when fresh or slightly weathered.	Usually good foundation conditions. Bed thickness and depth of weathered zone important in design.	Dependent on joint spacing. Ripping, pneumatic tools or blasting.	Suitable as high grade fill if care taken in selection and extraction; suitable as bulk fill if uneconomic to separate from mudstone interbeds.	· Important to determine depth and properties of lithologically variable weathered zone. · In situ loading tests advisable to assess bearing strengths at selected sites.
MUDROCKS		Remainder of Mudstones, shales and siltstones of the Millstone Grit and Coal Measures	Fissured, weak to moderately strong, Shales, Mudstones and SILTSTONES weathering to a firm to stiff silty clay. Tendency to deteriorate and soften when wetted on exposure.	Generally good foundation conditions. Dependent on nature and thickness of weathered zone. Foundation levels may need protection in open excavations.	Weathered mudrocks are diggable; ripping or pneumatic breakers may be required at depth or for major excavations.	Suitable as fill under controlled compaction conditions.	· Important to determine depth and properties of lithologically variable weathered zone. · In situ loading tests advisable to assess bearing strengths at selected sites.
SOILS							
MIXED COHESIVE / NON – COHESIVE SOILS	STIFF / DENSE	Till (Boulder Clay)	Stiff to very stiff, stony, sandy CLAY (boulder clay), with bands of laminated clays and interbeds and lenses of sand and gravel.	Generally good foundation conditions but dependent on presence of water-bearing sand and silt layers/lenses.	Diggable. Ponding of water may cause problems during working. Excavations in clays generally stable in short term. Running conditions may occur in sands below water table.	May be suitable if care taken in selection and extraction. Laminated clays and clays adjacent water-bearing sands/gravels may be unsuitable.	· Important to determine till thickness and lithology, particularly presence of laminated clays and water-bearing sands/silts
	SOFT/ FIRM	Head	Soft to firm sandy silty CLAY with stones, of low to medium plasticity and compressibility; locally may be silty sand or gravel. Clays may contain relict shear surfaces of low shear strength.	Generally poor foundation conditions. Shallow thickness usually allows economic removal prior to placing shallow foundations.	Diggable.	May be suitable as bulk fill, but may be too wet to achieve satisfactory condition.	· important to determine thickness/extent of Head and presence of any relict shear surfaces which may adversely affect stability of cuts in Head-covered slopes.
	SOFT/ LOOSE	Alluvium Glaciolacustrine Deposits	Very soft to firm, occasionally laminated, sandy, silty CLAYS and SILTS, with impersistent peat: and loose to dense fine to coarse – grained SANDS and GRAVELS with clay lenses	Poor foundation conditions. Soft, highly compressible zones with risk of severe differential settlements. Rafts or piles to dense gravels or sound bedrock usually required.	Diggable. Immediate trench support required. Running conditions likely in granular material. Cutoffs and/or dewatering usually required due to high water tables.	Generally unsuitable	· Important to ascertain the presence, depth and extent of soft compressible zones and depth to sound strata. · Closely-spaced boreholes may be required.
NON–COHESIVE SOILS	MEDIUM / DENSE	Glaciofluvial Deposits River Terrace Deposits Hummocky Glacial Deposits	Medium dense, fine to coarse – grained SANDS and medium dense to dense GRAVELS with occasional cobbles. Sandy clays and silts, sometimes laminated, occur locally.	Generally good foundation conditions. Thick deposits in buried river channels may be significant in foundation design.	Diggable. Trench support required. May be water bearing.	Sand and gravels suitable as granular fill	· Important to identify presence and dimensions of buried channels and characteristics of infilling deposits. · Geophysical methods may be advisable.

Figure 6 Example of a table of engineering considerations underpinning a digital geological map (Waters et al, 1996).

DoE code	Category
C1	Agricultural land
C2	Extraction industries and mineral processing
C3a	Gas works, coke works and coal carbonisation works
C3d/e	Power stations
C4b	Metal works
C5b	Asbestos manufacture
C6a	Glass making
C7b	Chemical works
C7a	Oil refineries
C8a	Engineering works
C8b	MoD land
C9	Food industry
C9b	Animal and animal products processing works
C10a	Pulp and paper works
C11a	Timber works
C12b/d	Textile industry
C14a	Docks, dockland and council depots and warehouses
C14c	Petrol filling stations and bulk storage of oil/petrol products
C14e	Railway land
C14c	Road vehicle maintenance
C14d	Airports/airfields
C15a	Sewage treatment
C15c	Waste management sites
C16	Works (non-specified)
C16d	Laundries
C16e	Hospitals and cemeteries

Table 4 Categories of potentially contaminating land use.

7.10 WATER LEVELS DATABASE (18) AND FIRST WATER STRIKE MODEL (19)

The water levels database contains all information relating to water depths proved in boreholes in the urban area, from site investigation records, water abstraction borehole records from the Environment Agency, and well information from the National Well Record Archive at BGS Wallingford (currently being digitised).

The data are summarised in six tables containing borehole registration information, water strike detail, and rest water levels, pumping tests, casing information and water analysis. These are compatible with the engineering properties database described above. An indication of the fields included the tables is shown in Table 7.

An initial assessment of the geological units in which water might be expected is made with reference to the 3-D solid and superficial geology. The water level database is used to model the depth of first water strike (19). It provides an indication of, for example, the depth at which groundwater is likely to be encountered in an excavation or ground investigation. The first water strike model illustrated in Figure 8 is derived from about 1300 data points in Manchester. The surface is independent of whether the water is in a perched water table within superficial or solid strata, or a major or minor aquifer. This is inferred from knowledge of the 3-D geology. Also, it does not take into account seasonal groundwater fluctuations. Refinement of the model is achieved using subsets that relate to particular periods, although the model for Manchester is sufficiently coarse to smooth out seasonal change and long term trends.

7.11 GEOCHEMICAL DATA (13)

The concentrations of many substances are raised in the urban environment as a result of atmospheric and terrestrial contamination. The ground is often disturbed and infilled and has a different geochemical signature to the surface deposits of the surrounding rural hinterland. Even in undisturbed urban areas, many potentially harmful substances (PHSs) are enhanced relative to the rural background, for example due to atmospheric contamination, littering, and surface run-off. A baseline urban geochemical survey can highlight areas of high potentially harmful elements (PHE) concentration, and provide background values against which the results from detailed site-specific contamination studies can be assessed and compared to the rural background.

Baseline geochemical sampling in the urban environment (GSUE) is part of the BGS national strategic geochemical survey of the UK (G-BASE) that began 30 years ago. As a consequence of increasing government interest in the redevelopment of inner cities and brownfield sites the need for urban geochemical baseline information was recognised, and in the early 1990s sampling commenced in selected urban centres. These surveys aim to provide a systematic overview of the city environment as a framework and context to more detailed contaminated land investigations.

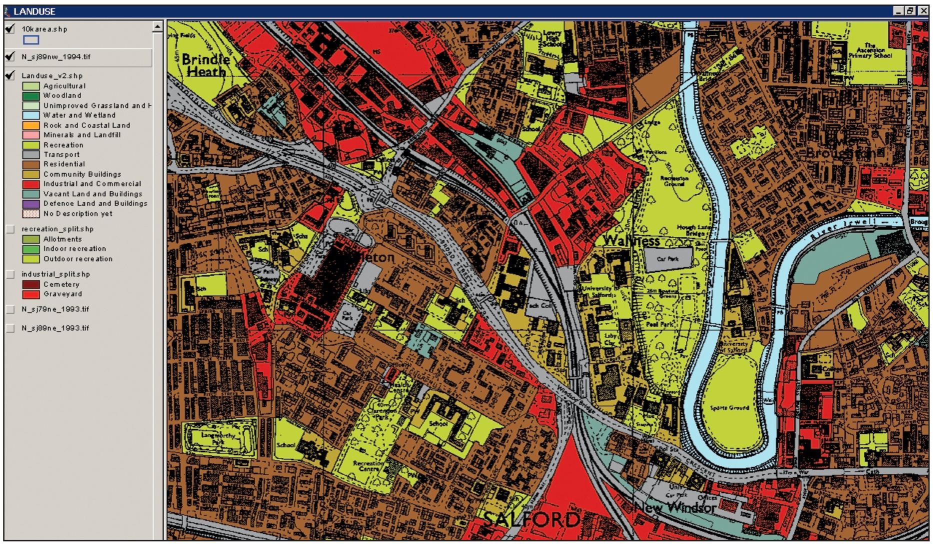
In the BGS urban geochemical sampling programme one urban sample site is selected at random in every 500 x 500 m grid square, a density of 4 per km^2. This compares with a density of 1 per 2 km^2 in rural areas. The urban sites, often constrained by the accessibility of soils in the city environment, commonly include gardens, parks, road verges, allotments, open spaces, schoolyards and waste ground.

Table 5 Example of spreadsheet for past land use in Manchester.

Unique ID: a number linked to each polygon on the map database; Site: information on the land use determined from the topographical map and other documentary evidence.

Unique ID	Site	Details 1	Address	DOE class
1	Brick works		Flixton Road	C2
2	Nursery		Gladstone Road	C1
3	Nursery		Granville Road	C1
4	Flixton Mill	Cotton?	Flixton Road	C12b/d
5	Railway land	Cheshire Lines		C14e
6	Park Road Farm		Park Road	C1
7	Cemetery		Brook Bridge	C16e
8	Brookhouse Farm		Liverpool Road	C1
9	Sandon Engine Works		Green Street	C8a
10	Leigh Silk Mills		Legh Street	C12b/d

Figure 7 Example of current land-use information in Manchester and Salford.



The geochemical sampling methodology, documented by Flight and Lister (2000), operates to international collection standards. At each sample site, samples are collected 0.1 to 0.2 m and 0.4 to 0.5 m deep in auger holes and information on soil clast lithology in order of relative abundance, soil colour and texture are input to the database (Figure 9). Improvements made recently to the method include the recording of land use according to NLUD classification scheme and the lithology description to BS5950 standards.

The standard element suite analysed by XRF is MgO, P_2O_5, K_2O, CaO, TiO_2, MnO, Fe_2O_3, V, Cr, Co, Ba, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Pb, Bi, Th, U, Ag, Cd, Sn, Sb, Cs, La, Ce, and W. Analysis of up to 50 elements is now possible. In addition analyses of pH and loss on ignition (as a measure of organic matter content) are made.

Data from urban areas are presented on proportional symbol maps. This method avoids uncertain extrapolation between sampling points and the data are in a form that better represents the spatial relationship of urban samples (Figure 10). Interpolated maps are used only for comparison between rural background and urban baseline data (Figure 11).

G-BASE data provide an overview of element distributions in the urban environment. For example, Figure 10 shows high arsenic values in surface soils in Swansea, related to the dockland area and the Tawe and Neath river valleys, at the location of former heavy industrial activity.

NLUD land use division reference	Description	Rules for digitising
1	Agriculture	
2	Woodland	· Check O S maps for definitive woodland class (not just trees in a park) · Apply minimum area rule*: if too small combine with recreation polygon where possible
3	Unimproved grassland and heathland	
4	Water and wetland	· Digitise rivers/canals that are indicated with two lines, ignore streams indicated by one drawn line · Apply minimum area rule* to ponds where appropriate
5	Rock and coastal land	
6	Minerals and landfill	· Compare polygons to Environment Agency data
7	Recreation	
8	Transport	· A-roads and Motorways are digitised · If land use is different on either side of a minor road , draw the polygon boundary along the centre of the road · Railways the embankments (made/cut ground) are included
9	Residential	· Digitised in its entirety (split into different types/ages of housing at a later date if required)
10	Community buildings	
11	Industrial and commercial	
12	Vacant land and buildings	· Compare to the local authority development plans
13	Defence land and buildings	

Table 6 NLUD categories and the methodology adopted for mapping them in Manchester.
*Minimum area is 50 x 50 m = 0.25 Ha

Table 7 Fields used in a database to characterise urban groundwater levels.

Rest water level (RWL) information

The rest water level information is less reliable than other measurements because some depths are recorded before the borehole casing is removed, others when it is in place, although the timing is not in all cases recorded on the borehole log

RWL_ DATE: date when the rest water level was observed, in the format MM/DD/YYYY.

RWL_DATE_-ACCURAC: accuracy of the date, including a field for unknown data.

RWL_MBG: the RWL in metres below the ground level.

RWL_MAOD : the RWL in metres below Ordnance Datum.

ARTESIAN: denotes an artesian condition for each RWL.

Water strike information

WSRK_DEP: the depth to water strike.

WSTK_NMIN: the number of minutes after water strike.

WSTK_CAS: depth of the casing when water is struck.

WSTK_DATE: date of the water strike in the format DD/MM/YYYY.

WSTK_TIME: time of day when the water was struck.

WSTK_POST: depth from ground level to the water surface at NMIN. This is used to infer an artesian condition.

WSTK_FLOW: contains observations made by drillers on the flow into the borehole or pit.

WSTK_SEAL: depth at which the water strike is sealed by the casing.

CASED_OUT is a check box that indicates that the water strike has been sealed. It should be noted that water is not always sealed from a borehole by the casing.

Pumping test information

PUMP_DATE: the date of the test.

PUMP_TIME: the time of reading.

PUMP_DPTH: depth to the water surface at the start of the test.

PUMP_QUAT: rate at which water is pumped during the test in litres/second.

PUMP_ REM: remarks concerning the test. This will include the recovery time after cessation of pumping and the level of the water during the test.

Whilst this distribution might have been anticipated from land-use information, the G-BASE results provide quantitative data on contaminant levels and the extent of element dispersion that, compared to other parts of the city, confirm that these locations should form the focus of more detailed contaminated land investigations.

One of the main applications of the G-BASE data is comparison between element concentrations in the urban area versus the rural hinterland. This helps to determine the extent of contamination and likely sources of contaminants. Figure 11, an example of rural/urban soil comparisons for copper from Stoke-on-Trent, shows this element has elevated values in the urban environment compared to the rural background.

7.11.1 Enhancement of geochemical sampling in the urban environment (GSUE)

Closer integration of field data recording with BS5950 standards, and the use of codes compatible with the NLUD scheme for land use at each sample site are enabling the geochemical sampling databases to be integrated with other urban geoscience datasets.

Projects within the Urban Geoscience Subprogramme may require geochemical samples to be taken in addition to those taken for the baseline geochemical sampling programme. For example, at each sample site, one sample of the soil/made ground in the top 45 cm and, where encountered, one sample of the underlying material (often the natural parent material) could be taken. This may entail augering deeper than 45 cm (to a suggested maximum of 100 cm) to obtain a sample from the underlying parent material. Where parent material is not encountered only one sample (of soil/made ground) would be collected. Samples taken in this way would permit direct comparison of the geochemical signature of surface deposits and the underlying parent material. In areas where this strategy is adopted, samples of parent material from all principal rock units (superficial and solid geology) present at the surface in the urban area could be collected also.

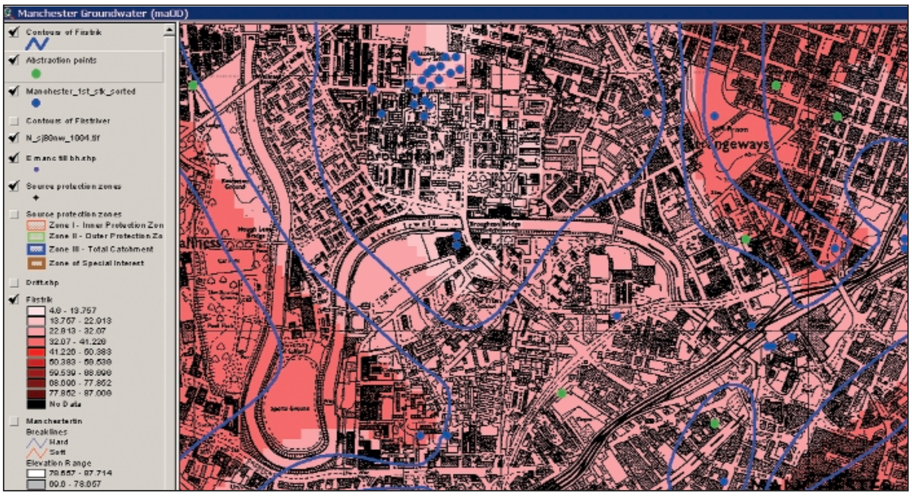
Sites particularly relevant to human contact, for example allotments, playing fields, and parkland are potentially of most interest to possible users of geochemical data. Most of these locations are sampled during the routine urban geochemical sampling programme. Any that fall outside the standard G-BASE sample network should be visited and sampled also. The results would not be included in the regional geochemical statistical analysis but used with a subset for analysis of concentrations on a particular land use.

7.12 PROPERTY DAMAGE INFORMATION (23)

Visible building subsidence damage, caused for example by shrinking and swelling clays, undermining or landslide damage, is assessed as part of an urban geoscience project.

Figure 8 Example of first water strike contours in Manchester and Salford

Contours are at 5m intervals; the area of depressed water strike in the north-west of the view is caused by water table draw-down around the Boddingtons Brewery abstraction wells (shown as green spots).



The ideal method is to collect data from a systematic walk-over survey, civil engineering companies that carry out remediation, mining records and other historical documents. Observations are entered in a database linked to a topographical map for display and analysis. A standard scheme for recording the severity of damage is given in Table 8.

Categories are based on The Institution of Civil Engineers, Institution of Structural Engineers and Building Research Establishment publications in: Freeman, et al. (1994), the National Coal Board (1975) and Geomorphological Services Ltd (1991).

7.13 MINERAL RESOURCES

Current urban geoscience projects are not being carried out in areas where mineral resources are of importance. Information on a county-by-county basis for England is being compiled by the BGS and published as 1:100 000 scale maps and will ultimately be made available over the Internet. The maps show the distribution of mineral resources, the areas of past and present planning permissions and the location statutory constraints on their exploitation (e.g. SSSIs and Ancient Monuments).

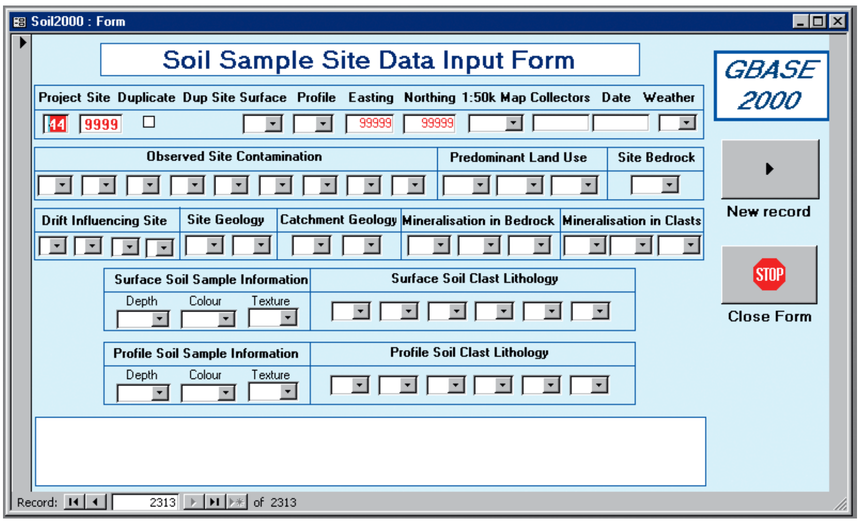
Urban geoscience projects add to these overviews by providing more accurate information on the thickness and extent of resources and their relationship to past and present land use and groundwater. This more detailed information will help to ensure that resources are not sterilised by new development.

7.14 GEOLOGICAL HAZARDS

All urban geoscience projects are concerned with geological hazards. Smith and Ellison (1999) summarised the range of information on principal hazards and examples of best practice in displaying them in map form. The most important of them occur in areas with ground that is susceptible to landsliding, swelling and shrinking, significant compaction due to loading (compressible strata) and dissolution (giving rise to karst features). Urban geoscience projects utilise information on the solid and superficial geological units, their geotechnical properties, the slope steepness, and in some cases the hydrogeological conditions to determine the geohazard susceptibility of an area.

Underpinning the specific urban geoscience studies is a national collation of information, in digital form, on geohazards being made in the BGS GeoHazarD project. A description of how such information can be further assesses and a 'hazard rating' allocated, is given in Culshaw and Ellison, 2002.

Figure 9 Geochemical sampling programme (G-BASE) field database soil data entry form.



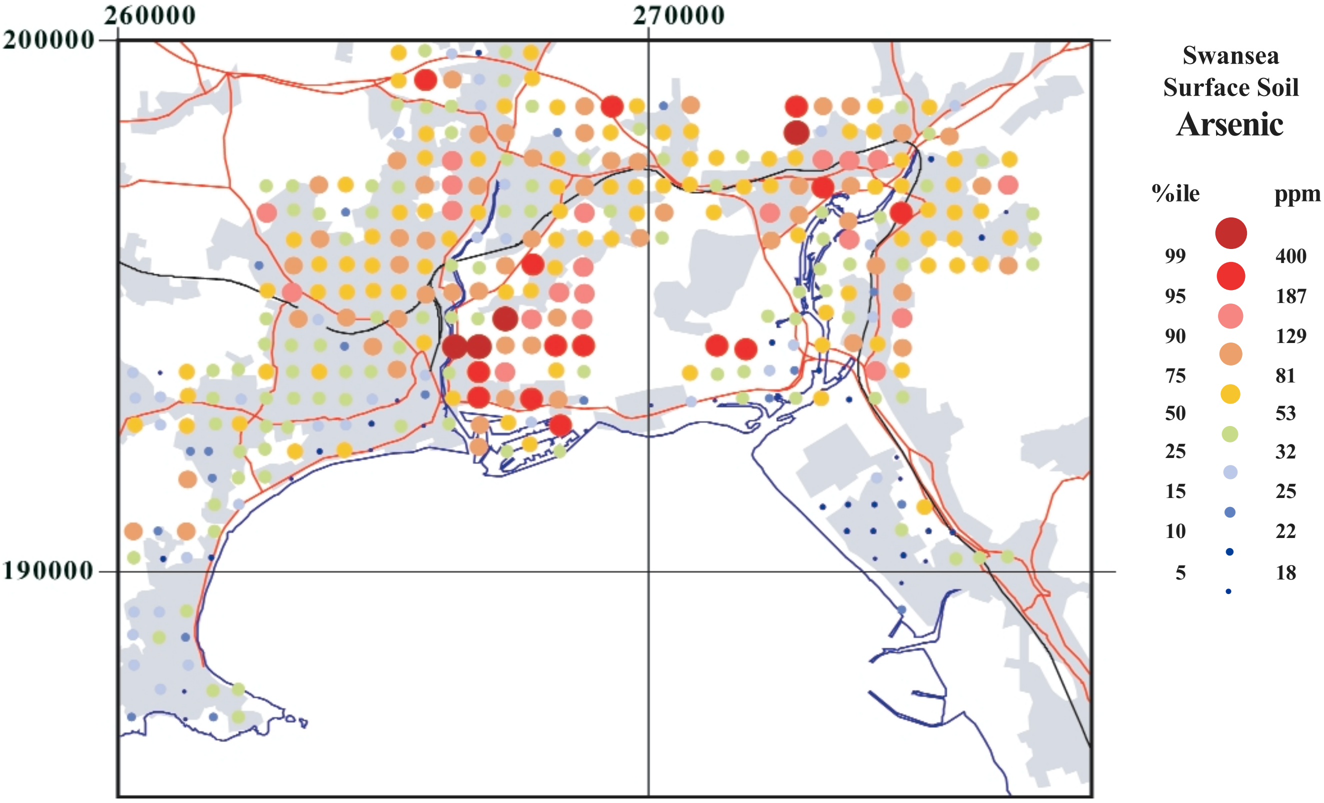
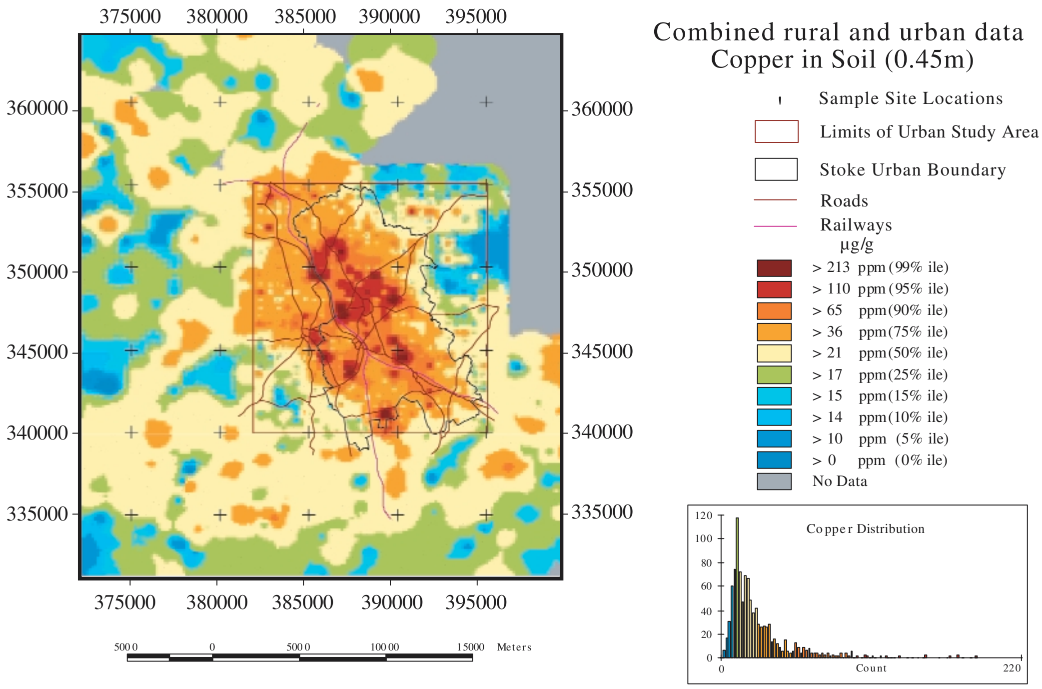


Figure 10 Example of a proportional symbol map showing total arsenic concentrations in surface soils in Swansea. The ICRCL (1987) threshold for domestic gardens and allotments for As is 10 µg/g (ppm).

7.15 LEGACY OF MINING

The principal data brought together in areas of former mining are mine plans and shaft locations (12). Issues that are investigated by urban geoscience projects in areas of former mining include rising mine water and related effects such as gas emissions and fault re-activation, and subsidence (see section 7.12). The scope for interrogating in a GIS three dimensional data on the superficial and solid geology, the principal mining-related datasets, fault data and hydrogeological information is currently being investigated in an urban geoscience project in south east Northumberland.

Figure 11 Interpolated geochemical map of total copper in rural and urban profile soils from Stoke-on-Trent showing the extent of copper enhancement in the urban environment.



Damage category	Description of typical building damage	Description of associated damage to roads and pavements
1 very slight	Fine cracks, generally restricted to internal wall finishes: cracks rarely visible in external brickwork. Typical crack widths up to 1mm. Generally not visible from outside.	Not visible
2 slight	Cracks not necessarily visible externally, some external repointing may be required. Doors and windows may stick slightly, typical crack widths up to 5mm. Difficult to record from outside.	Generally not noticeable
3 moderate	Cracks which can be patched by a builder. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking, slight tilts to walls, service pipes may fracture. Typical crack widths are 5 to 15mm, or several of, say 3mm. Visible from outside.	Slight depression in open ground or highway, noticeable to vehicle users, but may not be obvious to casual observers. Repairs generally superficial, but may involve limited local pavement reconstruction.
4 severe	Extensive damage which requires breaking-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably; some loss of bearing in beams, distortion of structure. Service pipes disrupted. Typical cracks widths are 15 to 25mm, but also depends on number of cracks. Noticeable from outside.	Significant depression, often accompanied by cracking, in open ground or highway. Obvious to the casual observer. Small open hole may form. Repairs to the highway generally require excavation and reconstruction of the road pavement.
5 severe	Structural damage, which requires a major repair job, involving partial or complete rebuilding. Beams loose bearing walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm, but depends on the number of cracks. Very obvious from outside.	Rotation or slewing of the ground or significant depression, often accompanied by cracking, in open ground or highway; open crater formed often with large void. General disruption of services in highways. Significant repair required.
6 partial collapse	Partial collapse	Collapse of ground or highway, significant open void, services severed or severely disrupted.
7 total collapse	Total collapse	Large open void or landslip scar

Table 8 Ranking scheme for building damage caused by mining subsidence, shrink-swell and landsliding.

8 Modelling and visualisation

The methodology, limitations and requirements of geoscientific modelling are reviewed in other BGS reports (Monaghan, 2001a, 2001b; McMillan et al., 2001; Ellison et al., 2001).

Models of the geology are based largely on structure contours of geological surfaces, in metres relative to Ordnance Datum (OD). They are the location in 3-D space of surfaces such as a coal bed, limestone unit, an unconformity or rockhead interface. Properties between such geological surfaces, for example permeability, and first water strike have also been modelled in urban areas (Figure 12).

8.1 MODELLING ARTIFICIAL GROUND

Artificial ground or worked ground is difficult to model because it is often of small dimensions and has sharp edges (e.g. railway embankments and cuttings). Where a large number of borehole data are available a model can be made although small features such as railway embankments cannot be modelled to acceptable standard.

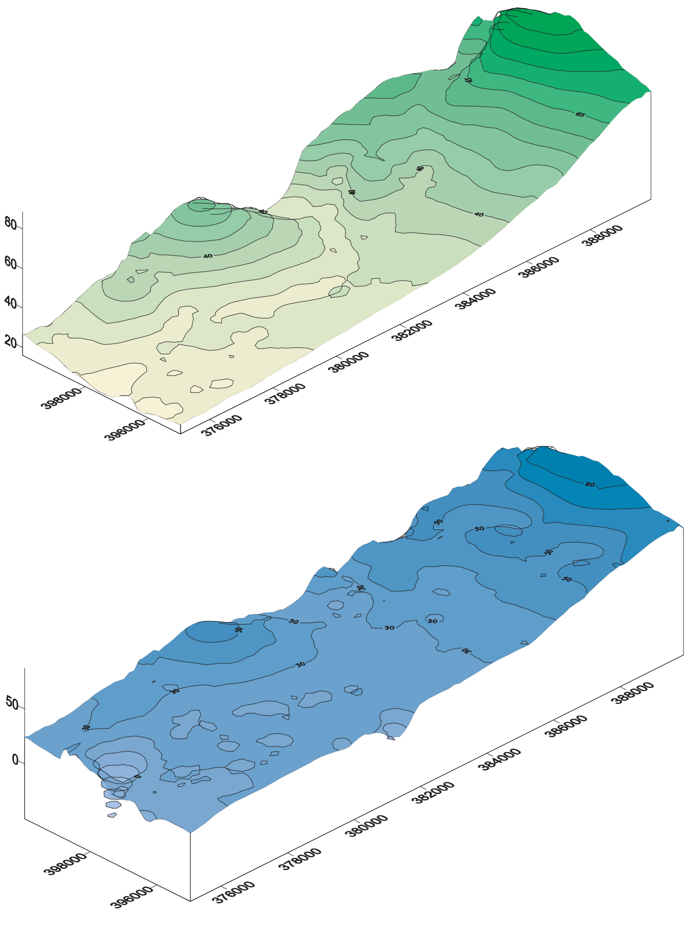


Figure 12 Example of visualisation of modelled surfaces in Manchester.

The top illustration is the DTM; the lower one is the first water strike surface; both are the same area, viewed from the south-west.

8.2 MODELLING ROCKHEAD

Models of rockhead and drift thickness are generated using common datasets (borehole/site investigations and surface distribution). Subtraction of a rockhead model from a DTM gives a drift thickness model; subtraction of a drift thickness model from a DTM gives a rockhead model. Some users prefer a rockhead model (e.g. ground engineers), others (e.g. the aggregate industry) drift thickness.

One method of creating a rockhead model is to draw freehand isopachytes of drift deposits and then calculate a rockhead model from the intersections of drift thickness and topographic contours. This is most appropriate where superficial deposits form constructional features, mainly in the north of Britain. Another method is to draw rockhead contours relative to Ordnance Datum directly from levels in boreholes and outcrops. This is most appropriate in southern Britain where the rockhead surface is fairly smooth and the deposits do not, in general, form irregular constructional features.

In most situations, even in urban areas, data density is highly variable and the rockhead surface may be intricate. Thus, the approach taken by many projects is:

- plot all the borehole data points and their values
- superimpose digitally generated contours in areas with dense data
- determine points that constrain the model (the heights with respect to Ordnance Datum of the base at outcrop)
- hand draw rockhead contours using the above data, using regional knowledge of channels etc and/or use gridding software to produce rockhead contours
- ensure that digitally produced contours have geological integrity and adjust accordingly.

8.3 MODELLING SUPERFICIAL DEPOSITS

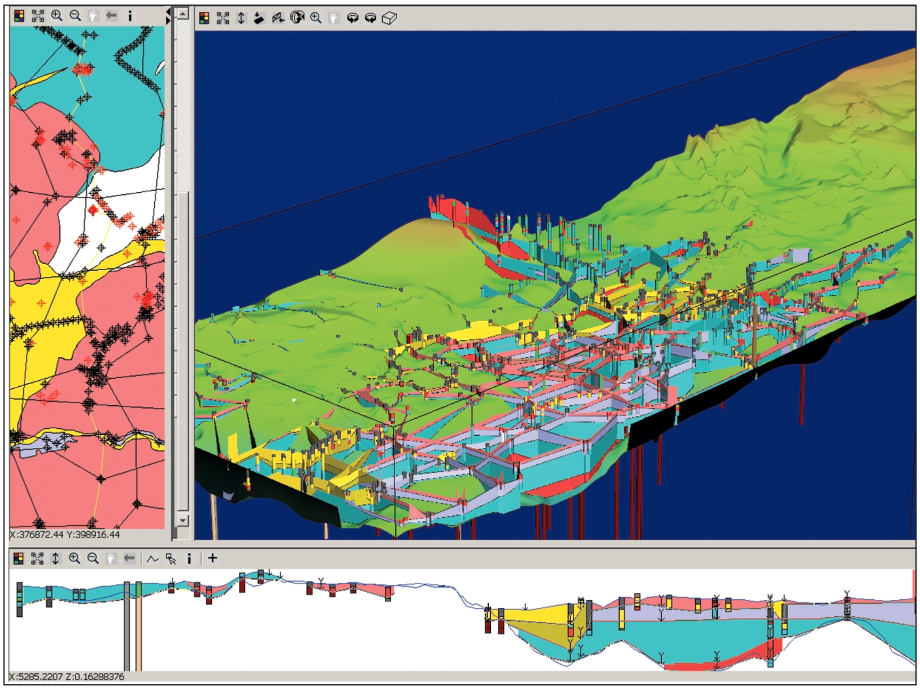
Models of the superficial deposits are probably the most important in urban areas. Visualisation, in many cases in relation to the ground surface represented by the DTM, is becoming routine.

Dependent on user requirements, the superficial deposits are modelled on the basis of:

- lithology (see below)
- profiles of superficial deposits (e.g. the extent of fine-grained sediment over till, as applied to Glasgow (Browne and McMillan, 1989)
- drift domains applied to the Upper Severn Valley and the Cumbrian coast (McMillan et al., 2000).

Modelling of lithological units within superficial deposits is currently being carried out using borehole data from Manchester (Figure 13). The software interactively uses the DTM, a digital geological map, contour models of rockhead, and the borehole database. Graphical lithology logs of coded boreholes selected for correlation are displayed on screen, and correlation between them is made interactively. Several intersecting cross-sections are corre-

Figure 13 Example of borehole correlation and interactive modelling of superficial deposits in Manchester.
The illustration in the top left shows the borehole distribution; in the top right is the 3-D visualisation including the DTM (red and yellow), the rockhead surface (pink) and the borehole graphical 'sticks'; the bottom of the illustration shows the borehole graphical section with principal lithological units and the lines of correlation.



lated in this way. Each correlation tie line, between the major lithological units, automatically has a position in 3-D in the model. This enables the top and base surfaces of, for example, a sand and gravel unit to be determined in three dimensions using known points in the boreholes and extrapolated points on the tie lines. Several lithological surfaces in the superficial deposits are built up iteratively from the ground surface downwards. In this way the subcrops of discontinuous lithological units can be defined.

8.4 RELIABILITY INDICATORS

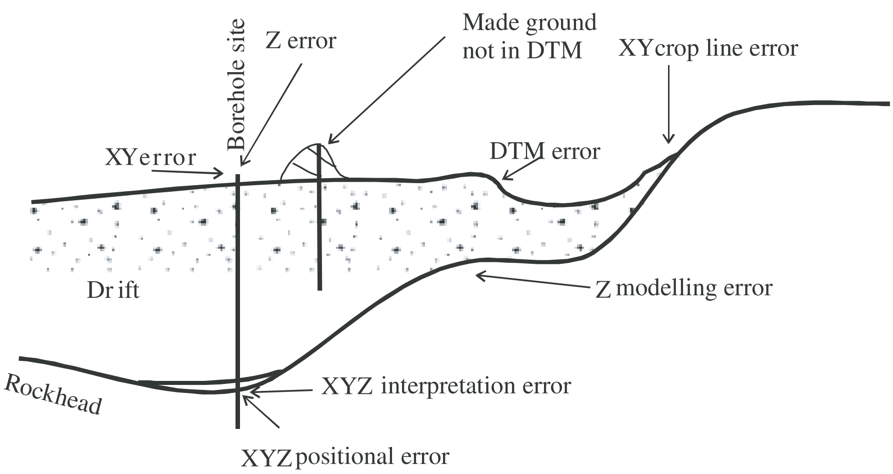
A suitable contour interval for modelling rockhead in most areas is 5 m or, where data are dense and of good quality, 2 m. In general terms, the inaccuracy of drillers' logs and uncertainties about borehole start heights means that accuracy of $\pm$ 2 m is an acceptable accuracy for most models.

Users of 3-D models require some indication of the confidence of different parts of the model. The error/uncertainty of a 3-D model (Figure 14) and therefore the reliability placed on it depends on many different factors such as:

- The errors in the original data points and interpretation (e.g. borehole start height etc) which may be difficult to quantify and will be cumulative.
- The errors created due to the generalisation of data during modelling/gridding which can be estimated by back interpolation of data points to the model.
- Variable certainty due to patchy distribution of data which can be shown by plotting the data points on the model.
- Variable certainty of contours drawn manually but with an element of geological knowledge that is not apparent in the raw data; an example of this is contours drawn to reflect the edges of subglacial drainage channels.

Not all errors and uncertainties in a model can be shown explicitly, but future research will focus on the provision of reliability indicators for basic and derived data, including models.

Figure 14 Diagrammatic illustration of a cross-section through superficial deposits showing the location of some of the errors involved in modelling.



9 Methods for systematic attribution, derivation and display of attributes of a wide range of geoscientific data

Attribute information is usually viewed by querying maps and tables within a GIS. Queries enable information held in different databases, on for example lithology, and geochemical analyses and geotechnical engineering properties, to be spatially analysed and then combined to provide new types of classification and new datasets. Analysis and interrogation frequently requires the conversion of point information (e.g. borehole data) to a polygon attribute (e.g. engineering hazard or rock type). This conversion is known as 'upscaling'.

Using an example (Figure 15) of four site investigation (SI) sample points with lithology and engineering parameters, typical queries that can be made about non-numeric point information (e.g. lithology) are:

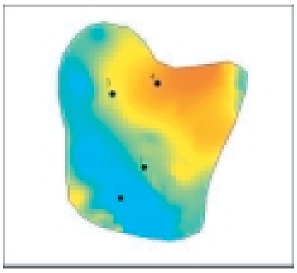
- pick one point at random to represent the polygon (i.e. clayey gravel)
- create a list of all possible values from each point (i.e. clay and silt, sandy clay, clayey gravel)
- pick the most frequently used (i.e. sandy clay)
- generalise the terms (for example use the term diamict)
- reclassify on an arbitrary scale/ranking system, in character or number format (e.g. Fine……..Coarse or 1 to 10)

Typical queries about numeric point information (e.g. shear strength) are

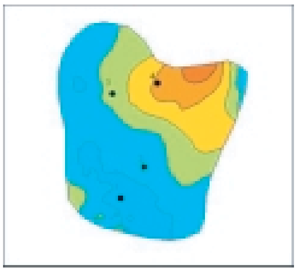
- average the data (mean = 11.75, mode = 11, median = 11)
- use the data range (10–15…this being held either as a single non-numeric field or as two fields)
- use the minimum or maximum (ten or 15)
- sum certain data (sum all samples with pebbles)
- count certain data (four 'site investigations' in area)
- use standard deviation (suitable for high numbers of points)
- use natural break (suitable for high numbers of points)
- use percentiles/quartiles (suitable for high numbers of points).

The point data can be considered spatially in several ways within the polygon as illustrated by Figure 16.

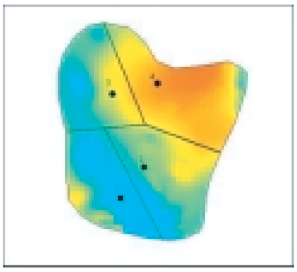
Upscaling is applied also from one polygon to another as illustrated in Figure 17.



Applying continuous gridding to the points. This is not used for data upscaling.



Subdivision of the polygon into contoured areas so that the polygon becomes many separate units. Each point is upscaled into one of the units.



The point data upscaled to Voroni-type regions whose edges bisect the distance between any two points; this method requires the original polygon to be split. It can also be applied to non-numeric point-data.

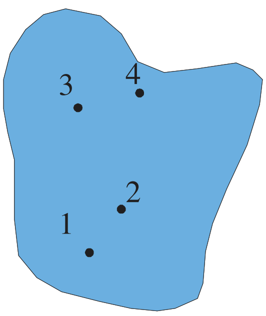
Figure 16 Types of spatial illustration of point data within a polygon.

9.1 RESCALING DATA

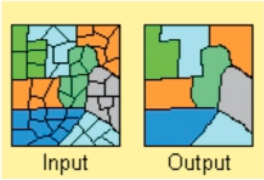
One method for upscaling point, line and polygon information into a new thematic map, is to use a 'uniform spatial referencing system' based on a geometric grid, a statistical grid or random geometrical objects (Figure 18). The last of these has been the traditional way of displaying applied geological information.

In urban areas, many types of geoenvironmental information are best displayed on the basis of a statistical grid. The grid is developed from the subdivision of the urban area into parcels of land with a common land use and/or building type (Figure 19). Past and present land use and

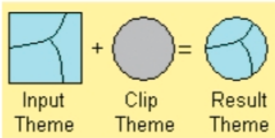
Figure 15 Point to polygon analysis.



	Lithology in SI	Shear strength
Point 1	clay and silt	15
Point 2	sandy clay	11
Point 3	sandy clay	11
Point 4	clayey gravel	10

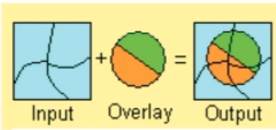


Dissolve:
This is suitable for coalescing groups of related data, i.e. grouping all polygons of sand, gravel, pebbly sand into a unit called 'coarse deposits'.



Clip:
This is suitable for extracting specific interactions of data i.e. generate geology polygons of London Clay where slope maps.

Intersect:
This is suitable for subdividing datasets by other data, i.e. splitting drift polygons by the type of underlying solid geology.



Union:
This is suitable for combining datasets to provide 'one-layer-for all' answers, i.e. split a landuse map to show properties built on former landfill.

Figure 17 Arcview tools for joining multiple layers of data.

aerial photographs are used to determine the extent of these parcels or blocks of land. The size of them depends on the scale of land-use surveys and the user requirements. Insurance companies may prefer postcode areas (area specific); neighbourhood areas may be more appropriate for city and regional planning, and information on individual parcels (site specific) might be required for homeowners and Estate Agents.

9.2 USE OF ATTRIBUTE INFORMATION

Current urban geoscience projects are using some of the analytic methods outlined in the previous section to display information derived from databases and GIS. For example, comparing the first lithology proved in boreholes that have been drilled since a geological map was last revised can indicate the accuracy of the solid geology or superficial deposits shown on the map. In the digital environment this entails comparing the attributes of an individual polygon of solid geology or superficial deposits against the first lithologies in a digital downhole borehole database from within that particular polygon.

Contouring is the usual method for analysing point data within a particular polygon or set of polygons. The most commonly used examples are rockhead contours and plots of thickness variation (isopachytes) based on borehole

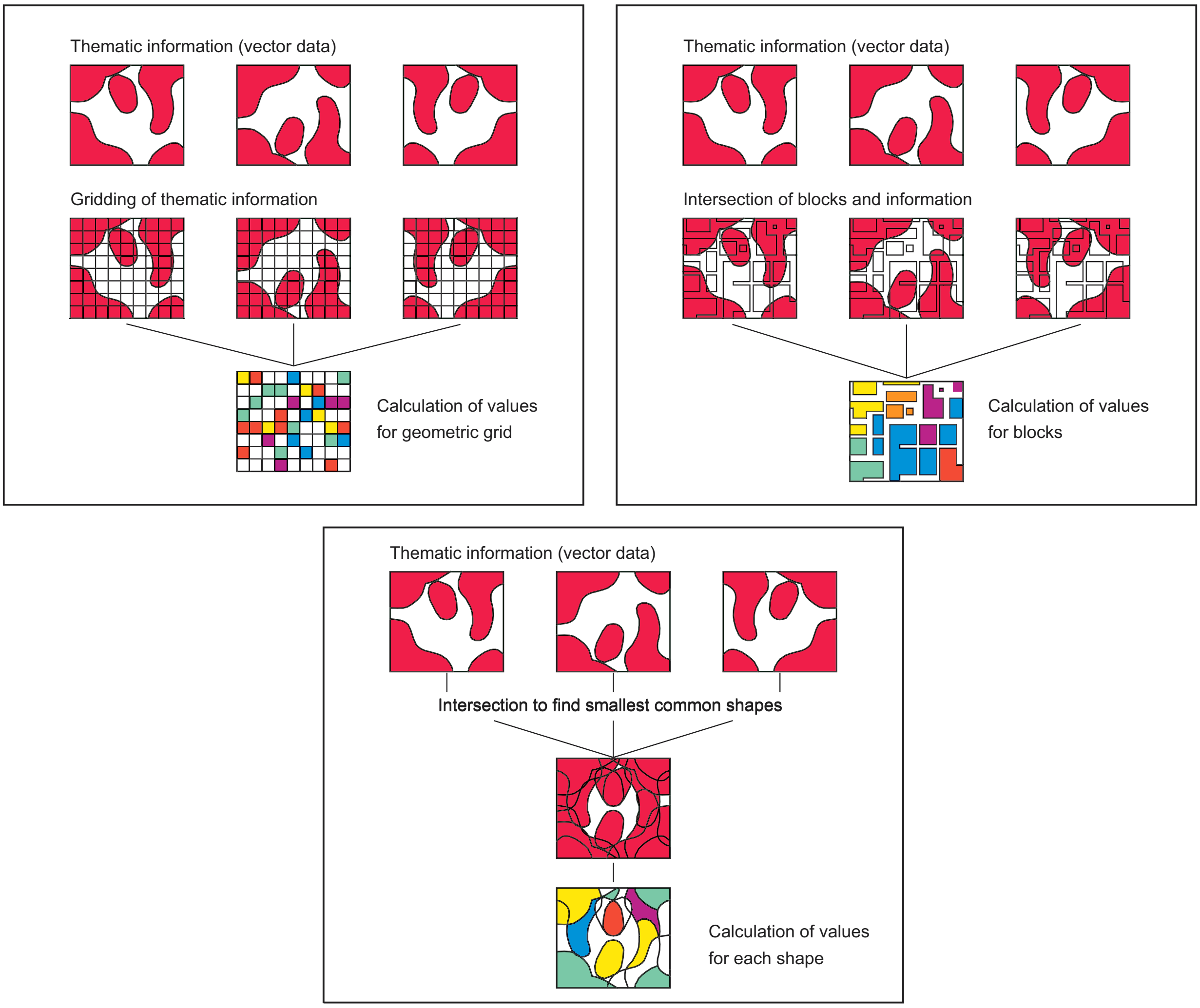


Figure 18 Methods of rescaling information.
Based on Senatsvervaltung fur Stadtentwicklung und Umweltschutz, 1990.

point data. In the case of upscaling, the ‘clip’ routine is used to produce slope maps that relate to specific polygons (e.g. rock units). In the Manchester urban geoscience project the statistical grid (Figure 19) is the basis for a uniform reference system. It has been used to develop, for example, a prototype map to show areas of suitability for Sustainable Urban Drainage Systems (SUDS) (Figure 20) by combining information derived from the superficial deposits, the digital terrain model and a contour map of the depth to the water table.

Figure 19 Example of a statistical grid, represented by parcels of land with consistent land characteristics, in Manchester and Salford.
Outlines of the grid polygons are red.

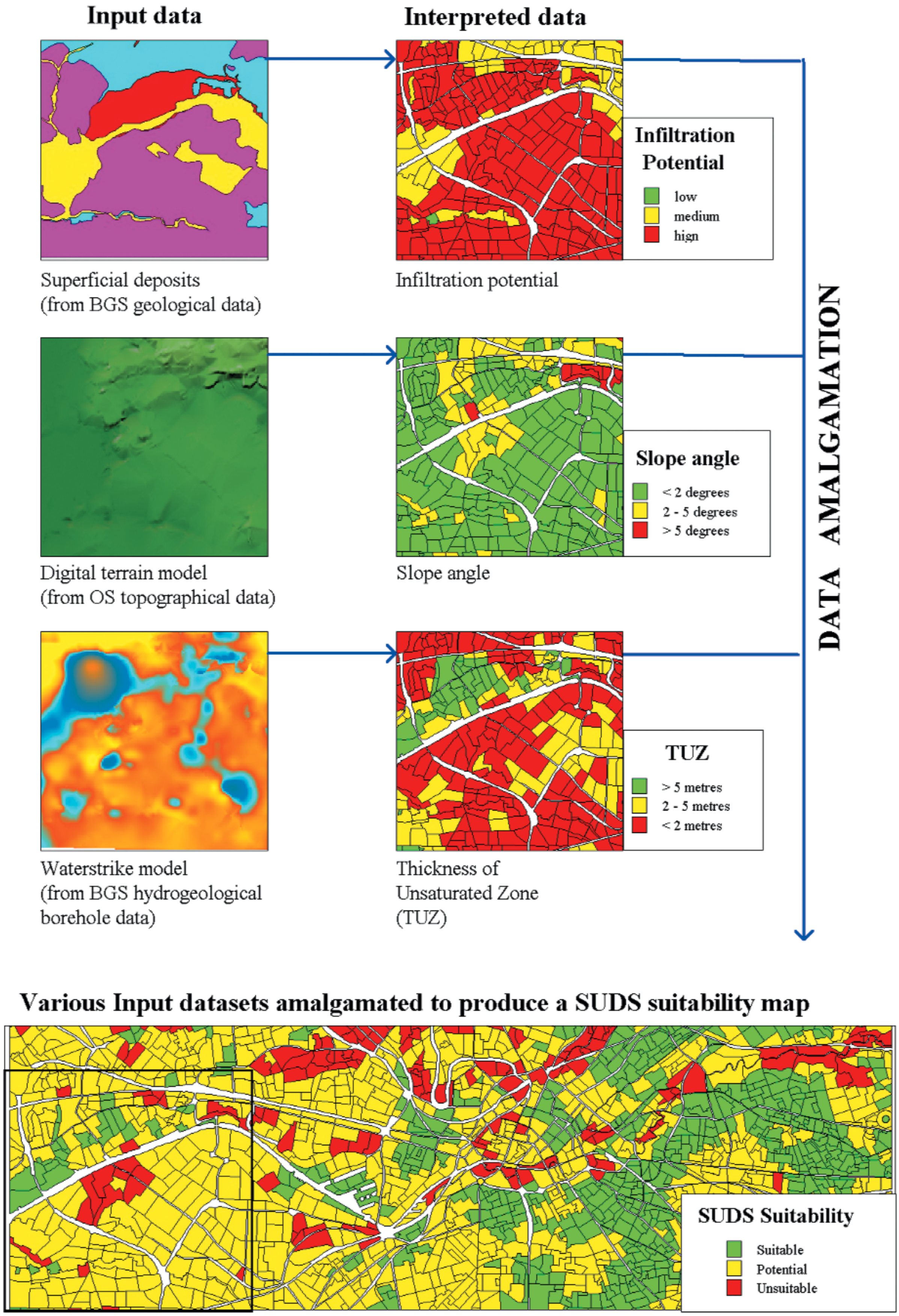


Figure 20 Illustration of the use of raw data to produce derived data on a statistical grid. The example shows the methodology adopted for the development of a map showing areas of suitability for Sustainable Urban Drainage Systems (SUDS) in Manchester and Salford.

Conclusions

This report sets the framework for the provision of information and advice about all aspects of the ground in the urban environment.

A multidisciplinary approach is being taken by current urban geoscience projects in the BGS. This builds on the experience gained, and the best practices adopted, in carrying out applied geological mapping projects completed in the 1980s and 1990s. A broad range of data about the ground, concerning the geology, hydrogeology, geochemistry, soils, geotechnical properties, past and present land use, and topography, are being brought together in a GIS. Interpretations of these data and its presentation are being made in a regional and local context, rather than on a site specific basis.

The needs of users of geoscience data now are driving the development of new and innovative outputs in digital format, such as urban groundwater vulnerability assessments, and the depiction of information relating to blocks of ground with particular past and present land-use characteristics. British Standards are used to describe the properties of geological units, and the mapping and naming of them, and the coding of borehole data, is carried out to BGS corporate standards.

Modelling and visualisation of the datasets and information derived from them is becoming increasingly relevant, the ground surface and rockhead surface models being the most important. A database of water strike information is proving to be valuable for a range of interpretive uses such as assessment of pollution hazard, groundwater vulnerability, shallow engineering hazard, and sustainable urban drainage. It is recommended therefore, dependent on the budget available, that these data are also tabulated and a surface produced for visualisation.

Modelling of lithology variation in the superficial deposits is important in many urban areas. Advances made in interactive on-screen modelling of information in the borehole database, surface geology and a digital terrain model are being applied in a trial area of Manchester, and will form the basis for a methodology to be adopted more widely in urban projects.

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