H. C. Bonsor, D. C. Entwisle, S. Watson, K. Lawrie, S. Bricker, S. Campbell, D. Lawrence, H. Barron, I. Hall and B. É. Ó Dochartaigh. 2013. Maximising past investment in subsurface data in urban areas for sustainable resource management: a pilot in Glasgow, UK. Technical note. *Ground Engineering*, February 2013.

Maximising past investment in subsurface data in urban areas for sustainable resource management: a pilot in Glasgow, UK

H. C. Bonsor [1*], D. C. Entwisle[2], S. Watson[3], K. Lawrie[1], S. Bricker[2], S. Campbell[1], D. Lawrence[1], H. Barron[1], I. Hall[4] and B. É. Ó Dochartaigh[1]

[1] British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK
[2] British Geological Survey, Keyworth, Nottingham, UK
[3] Glasgow City Council Geotechnical Department, Glasgow, UK
[4] Grontmij, Environment, Edinburgh, UK

[*] Corresponding author (e-mail: helnso@bgs.ac.uk)

Insufficient understanding of subsurface ground conditions places significant constraints on effective and sustainable development of urban areas, and is a key factor in overspend on construction projects. Recent collaboration between the British Geological Survey (BGS), Glasgow City Council (GCC) and the private sector (Grontmij Ltd) has demonstrated the potential for creating the conditions necessary for a major change in how subsurface data in urban areas are reported and exchanged between the public and private sectors. This is directly in line with the principles outlined by the EU INSPIRE Directive so that data can be re-used more effectively and have widespread benefit.

Uncertainty in subsurface conditions does not reflect a lack of data

Insufficient understanding of ground conditions is widely recognised by the construction industry across the UK and Europe as the largest single cause of project overspending, project delays, and overly conservative design (e.g. Clayton 2001; Parry 2009; Bayne 2010), potentially raising project costs by 10% or more (Paul et al. 2002; Greeman 2011). Uncertainty in ground conditions arises in construction and environmental remediation projects in part from a lack of re-use of ground investigation data both within projects (e.g. between specialist sub-contractors), and by subsequent projects (NCE 2011). One of the

most valuable sources of information for desk studies is previous ground investigation data; however, the difficulty of extracting the data from ground investigation reports, means re-use of the data within desk studies is surprisingly limited (Griffiths and Stokes 2008; Lelliot et al. 2009; Greeman 2011). Improving the accessibility of ground investigation data would, therefore, increase the use of data in desk studies, and should lead to improved ground investigation design and in turn reduce uncertainty in ground conditions.

In the UK, the Association of Geotechnical and Geoenvironmental Specialists (AGS) developed a digital data format for the transfer of data from ground investigations, to make the transfer of data between contractors, consultants and clients much more efficient during ground investigations, as well as in subsequent design, construction and engineering phases (Wolstenholme 2009; AGS 2010; Lawrence 2012). The transfer of data by electronic means reduces cost and time, and lowers or eliminates transcription errors in the data. The digital format has been widely adopted in ground engineering for the efficient preparation and presentation of reports in paper form. It has also been adopted by national bodies such as the Highways Agency, to supply ground investigation data to contractors, consultants and others within a project via the Highways Agency Geotechnical Management System (HAGDMS). However, despite the use of the AGS digital format, data from many ground investigations are still only used once by the client. After the life-span of an investigation, ground investigation data are rarely used to support wider planning decisions, environmental management, or other ground investigation. This is due largely to the absence of any requirement for most of the data to be submitted to a centralised data repository that can make the data readily available for re-use. A centralised repository would greatly improve the accessibility of ground investigation data and would enable it to be re-used for desk studies and, potentially, for wider planning and development decisions.

In the UK, the BGS operates the National Geoscience Data Centre (NGDC) on behalf of the Natural Environment Research Council (NERC) as the national collection of geoscientific environmental data and information. The National Geological Records Centre (NGRC) within the NGDC collects a wide range of geological data. Most data registered in the NGRC are received on a voluntary basis, with the exception of data from boreholes drilled for minerals greater than 30 m deep, or for water supply assessment boreholes greater than 15 m deep, which are required to be deposited with the NGRC under the Mining Act of 1926 and the Water Resources Act 1991. Any ground investigation data which are received by the BGS is indexed and stored within the NGRC. The BGS also manages the National Geotechnical Properties Database for the UK, which is a fully relational spatial database and stores geotechnical data derived from ground investigations (Culshaw 2005). However, Northern Ireland is the only place within the UK, at present, where *all* ground investigation data must be submitted to be stored within a centralised data repository; maintained by the Geological Survey of Northern Ireland (GSNI) to ensure long-term accessibility of data (Mineral Act Development (Northern Ireland) 1969; GSNI 2010).

A major step change in how ground investigation data are stored and transferred in the UK is required, to ensure better accessibility and use of ground investigation data (Wolf 2007; Campbell et al. 2010; Carneiro and Carvalho 2010). The UK Government Construction Strategy (2014) is likely to form a key driver for this change. This strategy will require all government construction contracts over five million pounds in value to have 3D Building Information Models (BIMs) to store and exchange all project data electronically, as a minimum by 2016. Integration of project data into a 3D BIM is akin to what is needed on a

larger scale in urban areas to hold data from all ground investigations to ensure the data remain accessible. The drive to move to 3D BIMs under the government strategy should provide an impetus for developing more effective data storage and reporting between public and private sectors in urban areas. The key difficulties to currently achieving this level of data and knowledge exchange, and to have 3D BIMs as industry standard, are discussed in the following sections of this technical note.

Use of 3D geological modelling

The development of 3D geological models has gone some way to facilitating more effective use of ground investigation data from urban areas and improving understanding of subsurface conditions (Chowdhury and Flentje 2007; Royse et al. 2008; Lelliott et al. 2009; Campbell et al. 2010; Aldiss et al. 2012). In Europe, geological surveys have been at the forefront of developing 3D geological models on citywide scales to underpin urban planning and sustainable development (e.g. Bridge et al. 2004; Bourgine et al. 2006; Neber et al. 2006), engineering hazard assessments (e.g. Culshaw 2005; Lelliot et al. 2006; Neumann et al. 2006), and groundwater management (e.g. Kessler et al. 2009; Carneiro and Carvalho 2010; Campbell et al. 2010). Within the UK, the BGS has produced attributed 3D geological models for various areas, including recently the Thames and Clyde basins in the UK, based largely on ground investigation data in these areas. The development of these 3D geological models has helped local authorities and environmental regulators meet the requirements of recent environmental legislation, such as the EU Water Framework Directive (European Union, 2000) that demand a 3D understanding of the geometry and properties of the main aquifers (Kessler et al. 2009), as well as providing a tool for desk studies for future site investigations (Campbell et al. 2010). The 3D geological model of Glasgow (Fig. 1) has also helped greatly to refine the geometry, and characterise the properties, of the very complex superficial deposits beneath Glasgow. For example, a laterally extensive buried valley

beneath the Kelvin valley on the north side of the city has been modelled in detail; this can contain sand and gravel deposits up to 80 m thick which can act as important aquifers – Fig 1. As a result, an improved understanding of groundwater flow beneath the city, and of the location of flooding, is developing in the Glasgow area.

The development of 3D attributed geological models has highlighted the large amount of high quality data generated in ground investigations, but also the difficulties in accessing and re-using it. Only a small proportion of the data are generally used to develop the 3D models in the UK at present, in part due to the time and cost required to extract the data from ground investigation reports (Lelliot et al. 2009). For instance, the Glasgow Conurbation model, developed by the BGS, was constructed from less than a third of the borehole data potentially available. Required data are often split between several volumes of ground investigation reports and in different formats making it time intensive to assimilate. Attributing 3D geological models with groundwater or engineering data from ground investigation reports demands more time, as the in situ data must be assimilated with the corresponding borehole and geological information before the data can be interpreted and included in a model. Ground investigation data in AGS digital data format are significantly faster to assimilate and more accurate (there is a much lower risk of transcription errors) and are of a standardised format. If readily accessible from a centralised database in a standardised format the data could be used to much better effect within future 3D attributed geological models.

Key issues in access and re-use of subsurface data

Making ground investigation data accessible for future desk studies and potentially via attributed 3D subsurface models, would allow an unbroken (virtuous) cycle of data acquisition, data storage and data re-use – Fig. 2. Work between BGS and GCC in 2010, under the Local Authorities and Research Council Initiative (LARCI), has highlighted in

Glasgow that there are three areas in the data generation and usage cycle where the links are weak – depicted by orange segments in Fig. 3.

- ***Data reporting.*** Ground investigation data are generally supplied to consultancies by contractors in AGS digital data files, and as paper or PDF reports. Consultancies report these data to clients within paper or PDF ground investigation reports. These reports require no additional software in order to be viewed, and as a result generally form the primary means of communicating and storing ground investigation data between consultancies and their clients. Within Glasgow, it is only the report which must be submitted to the local authority (e.g. GCC), for planning and regulation purposes.
- ***Lack of re-use of data after ground investigations***. The lack of re-use of ground investigation data by clients, or other third parties, stems from: (1) the difficulty in extracting and assimilating data from ground investigation reports, which is time consuming and prone to transcription errors; and (2) the lack of a centralised database making the data readily accessible.
- ***Need for a centralised repository*** in which all subsurface data from ground investigations in digital format can be stored, and accessed for re-use.

The extent to which these issues limit the re-use of ground investigation data in future desk studies or by other clients and third parties was highlighted in work the BGS undertook in 2009-2011, in partnership with GCC, to develop a pilot urban groundwater monitoring network in eastern Glasgow. 150 in situ groundwater data points (groundwater-level and laboratory data) were examined from ground investigation reports from several recent major infrastructure projects in eastern Glasgow to inform the design of the pilot network. A significant investment of time and money was required to extract and assimilate all the relevant groundwater data, corresponding borehole construction information, and to standardise the units and datum of measurements. Only 18% of the in situ groundwater data could be used with a high degree of confidence, due to the difficulty in accessing all the required data from the different volumes of the ground investigation reports and the disconnects between the data – Table 1.

The work highlighted that whilst ground investigation reports are comprehensive to the immediate client needs, and provide high quality data, the integrity and accessibility of ground investigation data could be greatly improved if it were assimilated within a centralised database in AGS digital format, from which all required data could be readily extracted in a usable, standardised, format. The work also highlighted the potential value in re-use of ground investigation data. The data assimilated, enabled for the first time, some quantification of the parameters of the shallow groundwater system in Glasgow. Average groundwater-levels were indicated to be 4-6 metres below ground level within the urban centre, but were highly variable spatially, depending on the lithology of the superficial deposits. In addition, groundwater-levels were found to show some hydraulic connection to the River Clyde within a range of 100 m of the river. This new information has significantly refined our understanding of the important characteristics of the shallow groundwater resource, as well as its vulnerability to contamination from surface activities.

Developing a major change in subsurface knowledge and data exchange, Glasgow

Geological surveys have a central role to play in achieving an unbroken cycle of data acquisition and dissemination in urban areas, as custodians and managers of a centralised repository for ground investigation data (separate to the ground investigation reports held by clients). Aggregating data from a raw AGS digital data format would reduce data transcription errors (found to affect 30% of data embedded within consultancy reports in the Glasgow groundwater study) and also ensure data are deposited in a consistent, systematic format, making insertion and storage of the data in a centralised database relatively quick and potentially automated. In the UK, the BGS already acts as custodian of some subsurface data and any ground investigation data donated by industry. It would be a natural extension to

extend this to *all* ground investigation data. It is proposed this will be achieved in the Glasgow area through the **A**ccessing **S**ubsurface **K**nowledge (ASK) network – www.bgs.ac.uk/asknetwork.

Accessing Subsurface Knowledge (ASK) network

The centralisation of ground investigation data for the Glasgow area is currently being developed by the BGS working in partnership with Glasgow City Council. By late 2012 a broad network of potential users of subsurface data and 3D subsurface models will be formed, which will aid regeneration planning and sustainable management of resources, and support construction – Fig. 4. The ASK network is intended to encompass a wide range of public and private sector organisations, ranging from major consultancies and contractors, to environmental regulators and transport agencies. Workshops and web tools will inform the user community, demonstrating the amount and type of subsurface data available from ground investigations and the depth of information that can be encapsulated within, and extracted from, 3D subsurface models. The overall aim of the network is to enable a better two-way exchange of new subsurface information between all users.

A standard for wider change

This major step change in data and knowledge exchange within Glasgow could enable: reduced uncertainties about ground conditions; improvement in risk management for construction projects and considerable cost savings and efficiency gains in planning and development.

Conclusion

Economic austerity is encouraging better collaboration and integration between public and private sector organisations involved in urban regeneration, and is making it essential to maximise past investment in subsurface data. A centralised repository of shallow subsurface data in a standardised digital format would increase vastly the accessibility, integrity, and re-use of subsurface data in urban areas. This is directly in line with the principles outlined by the EU INSPIRE Directive for better use and availability of data (European Union Directive 2007). The work underway in Glasgow could act as a standard for change, both within the UK and potentially further afield. It will also increase the reporting and exchange of ground investigation data, beyond current levels using the AGS digital transfer, and would lead to efficiency gains, reduced uncertainty in ground conditions, and significantly increase the amount of data available for ground engineering, monitoring and regulation of resources in the urban environment.

References

AGS. 2010. *Electronic Transfer of Geotechnical and Geoenvironmental Data (Edition 4.0).* Association of Geotechnical and Geoenvironmental Specialists (AGS) (www.ags.org.uk).

Aldiss, D.T., Black, M.G., Entwisle, D.C., Page, D.P., Terrington, R.L., 2012. Benefits of a 3D geological model for major tunnelling works: an example from Farringdon, east-central London, UK. Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 45 (4).

Bourgine B., Dominique S., Marache A. and Thierry P. 2006. Tools and methods for constructing 3D geological models in the urban environment: the case of Bordeaux, IAEG 2006 Paper no. 72, pp 12

Bridge D. McC. Hough E, Kessler H, Lelliot M Price S. J. And Reeves H J. 2004. Integrated modelling of geosciences information to support sustainable urban planning, greater Manchester areas, northwest England. *In:* Berg RC Russell H and Thorleifson LH (eds) *Extended abstracts of the 49th annual meeting of the Geological Association of Canda and the Mineralogical Association of Canada on: Three-dimensional Geologic Mapping for Groundwater Applications,* Illinois State Geological Survey, Open File Series 2004-8, 16-19.

Campbell S. D. G. Merritt J. E. O Dochartaigh B. E. Manour M. M. Hughes A. G. Fordyce F. M. Entwisle D. C. Monaghan A. A. And Loughlin S. C. 2010. 3D geological models and their hydrogeological applications: supporting urban development – a case study in Glasgow-Clyde, UK, *Zeitschrift der Deutschen Gesellschaft fur Geowissenschaften*, 161 (2), 251-262.

Carneiro J. and Carvalho J. M. 2010. Groundwater modelling as an urban planning tool: issues raised by a small scale model, *Quarterly Journal of Engineering Geology and Hydrogeology*, 43; 157-170.

Chowdhury R. and Fletnje P. 2008. Strategic approaches for management risk in geomechanics, in Conference Proceedings of The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, 1-6 October, 2008.

Clayton, C. R. I. 2001. Managing geotechnical risk: time for change? *Proceedings of the Institution of Civil Engineers, Geotechnical Engineering,* **149;** 1, 3-11.

Culshaw M. G. 2005. From concept towards reality: developing the attributed 3D geological model of the subsurface, *Quarterly Journal of Engineering Geology and Hydrogeology*, 38; 231-284.

European Union Directive 2007. *Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 – establishing an infrastructure for Spatial Information in the European Community (INSPIRE),* Official Journal of the European Union, pp14.

European Union 2000. *Water Framework Directive – Integrated River Basin Management for Europe. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the community action in the field of water policy.* Official Journal of the European Union L327, (23 October 2000).

Greeman A. 2011. *A new way of working*, New Civil Engineer magazine, September 2011. http://www.nce.co.uk/features/geotechnical/a-new-way-of-working/8624001.article

Griffiths J. S. And Stokes M. 2008. Engineering geomorphological input to ground models: an approach based on Earth systems, *Quarterly Journal of Engineering Geology and Hydrogeology*, 41; 73-91.

Geological Survey Northern Ireland (GSNI) 2010 Information service and management, http://www.bgs.ac.uk/gsni/services/home.htm

Kessler H. Mathers S and Sobish H-G. 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology, *Computers and Geoscience*, 35; 6, 1311-1321.

Lawrence U. 2012. *Crossrail: the engineering project.* Geoscientist, Geological Society of London, 22; 6, 12-7.

Lelliot M. R. Cave M. R. and Wealthall G. P. 2009. A structured approach to the measurement of uncertainty in 3D geological models, *Quarterly Journal of Engineering Geology and Hydrogeology*, 42; 95-105.

Lelliot M.R. Bridge D. McC. Kessler H. Price S and Seymour K. 2006. The application of 3D geological modelling to recharge assessments in an urban environment, *Quarterly Journal of Engineering Geology and Hydrogeology*, 39; 293-302.

Mineral Development Act (Northern Ireland) 1969[F001]. 1969. Chapter 35.

NCE editorial. 2011. *Ground Rules*, New Civil Engineer magazine, Editorial, November 2011.
http://www.nce.co.uk/features/geotechnical/ground-rules/8623967.article

Neber A., Aubel, J., Classon F., Hoefer S., Kunz A. and Sobisch H. G. 2006. From the Devonian to the present: Landscape and technogenic relief evolution in an urban environment. IAEG 2006 Paper no. 517, pp 12.

Neumann D., Schonberg G. and Strobel G. 2006. 3D-modelling of ground conditions for the engineering geology map of the city of Magdeburg, IAEG 2006 Paper no. 444, pp 7.

Parry S. 2009. Introduction to Engineering geology in geotechnical risk management, *Quarterly Journal of Engineering Geology and Hydrogeology*, 42; 443-444.

Paul T, Chow FC, Kjekstad O, Vahaaho I, Sellberg B, Haegeman W, Lemos L, Sleffert JG, Bucher F, and Feda J. 2002. *Hidden aspects of urban planning: surface and underground development,* Thomas Telford Publishing, London. pp 11-22.

Royse, K. R., Reeves, H. J. & Gibson, A. 2008. The modelling and visualisation of digital geoscientific data as an aid to land-use planning in the urban environment, an example from the Thames Gateway.of the Communicating Environmental Geoscience, Geological Society, London, Special Publication, Vol. 305, 89-106

Wolf L. 2007. Managing urban groundwater as a resource – hidden problems and hidden opportunities, *Water*, 21; 19-20.

Wolstenholme A. 2009. *Never waste a good crisis: a review of progress since Rethinking Construction* and Thoughts for Our Future. Constructing excellence, London, pp32.

Fig. 1 – The 3D attributed geological models of bedrock and superficial deposits in Glasgow. Coverage of the model is shown in Panel A. Panel B shows a block and exploded diagram view of the buried valley deposits beneath the Kelvin valley to the north of Glasgow, highlighting the extent and complexity of the deposits and the level of information shown by the model.

Fig. 2 – Proposed data delivery and exchange within Glasgow City Council and public and private sector organisations under the new data transfer mechanism.

Fig. 3 – Current data delivery and exchange within Glasgow City Council and public and private sector organisations. Green shading indicates areas functioning well; orange shading indicates areas which are beginning to function in the data delivery.

Fig. 4 – The ASK network will form a collaborative network between BGS the public, private and academic sectors, to enhance knowledge exchange and re-use of subsurface data in Glasgow.

Table 1 – Summary statistics indicating the degree of connection between key borehole index data and groundwater monitoring data from 153 boreholes across 3 major regeneration sites in Glasgow.

	% of boreholes in which this reported with raw groundwater monitoring data	% of borehole for which this data could be retrieved from readily available previous site investigation reports containing drillers logs
Grid reference of borehole	99%	100%
Depth of borehole	45%	80%
Screened interval of borehole	0%	71%
Datum of groundwater-level measurements	42%	58%
Monitored aquifer	0%	70% (only 50% of high-moderate confidence)