Look before you leap: the use of geoenvironmental data models for preliminary site appraisal

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ABSTRACT: In the urban environment, site investigation studies provide a wealth of information about the ground conditions of the shallow sub-surface. However, from the developers perspective, there is generally little incentive to integrate this information beyond the boundaries of the development site. By taking a more holistic view and combining knowledge of the near-surface geology with information on former landuse and groundwater regime across a wider area, it is possible to predict geological scenarios that may better inform ground investigation and reclamation strategies.

As part of its urban research programme, the British Geological Survey is currently integrating its data holdings across 75 km^2 of central Manchester and Salford. The aim is to develop a fully attributed 3D model of the shallow sub-surface that will provide information on the thickness, composition and geotechnical properties of the Quaternary superficial 'drift' deposits and any artificial cover. It will also provide, at lower resolution, information on groundwater vulnerability, soil geochemistry and the potential of the ground to support Sustainable Urban Drainage Systems (SUDS). The model is based around a nucleus of 6500 boreholes, and is being developed with a range of 3D visualization and processing software.

This approach provides a means of identifying potential problems and opportunities at the desk study stage in any proposed development and, if implemented over a wider area, it could assist in designing site investigation strategies and reduce costs by ensuring a more focused approach to site appraisal.

1 INTRODUCTION

The role of geoenvironmental information is becoming increasingly important as legislative changes have forced developers, planning authorities and regulators to consider more fully the implications and impact on the environment of large-scale development initiatives. To comply with the principles of sustainable development, developers are increasingly required to demonstrate that proposals are based on the best possible scientific information and analysis of risk. Nowhere is this more relevant than in the context of urban regeneration.

The case for using geoenvironmental information to underpin preliminary site appraisal and for developing regional strategies has been made elsewhere (e.g. Bobrowsky 2002 and references therein; Culshaw and Ellison 2002; Ellison et al. 1998; Ellison et al. 2002; McKirdy et al. 1998; Thompson 1998). In the UK, studies commissioned by the Department of the Environment in the 1980s and 1990s paved the way and promoted the use of applied geological maps to identify the principal geological factors which should be taken into account in planning for development (e.g. Forster et al. 1995).

Since this work was completed, advances in the use of Geographical Information Systems (GIS) and modeling packages have meant that there is now far greater opportunity to develop geoenvironmental products that take greater account of the third dimension. Because the information is captured and manipulated digitally, the outputs can be tailored to user needs, and more readily updated. This has clear advantages over hard copy maps and reports, which are difficult to update and provide limited flexibility in terms of usage.

The purpose of this paper is to demonstrate the potential that the new technology offers, and to illustrate, using examples from a major conurbation, the role that the 3D geological model is playing in deriving bespoke thematic products.

The area chosen for the study covers 75 km^2 of central Manchester and Salford (Figure 1). It is a predominantly urbanized area with a long history of intense, largely unrestrained industrialization, founded on coal-mining, chemical manufacture and the textile industry (including the bleaching and dyeing of cotton). These activities have left a legacy of contaminated land and groundwater pollution in

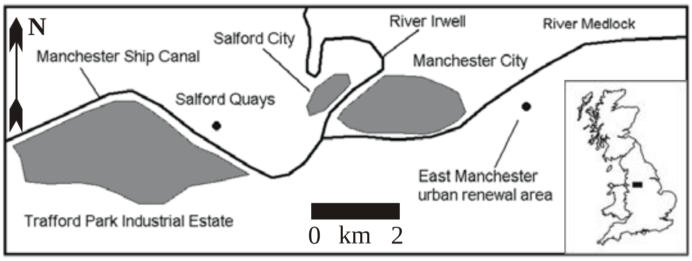

Figure 1. Key locations in the Manchester and Salford region of north-west England.

what is one of the most densely populated areas of the UK.

The area includes Trafford Park, the largest industrial estate in Europe, Manchester city centre, still undergoing redevelopment following the 1996 terrorist attack, and east Manchester, an industrially-depressed area destined for urban renewal aided by £2bn of public and private investment over the next 15 years (Carroll 2000). Smaller areas of intense redevelopment include the former Bradford Colliery and gasworks, redeveloped as the focal site of the 2002 Commonwealth Games, and Salford Quays, formerly the Manchester Ship Canal docklands, but now home to the Lowry Centre and the Imperial War Museum North.

1.1 *Background to the study area*

Geologically, the Manchester and Salford region straddles the southern part of the Carboniferous South Lancashire Coalfield and the northern part of the Permo-Triassic Cheshire Basin. The coalfield was extensively worked up until the late 1970s from numerous collieries within the northern and eastern parts of the study area including Patricroft, Agecroft and Bradford. To the south and west, the Carboniferous Coal Measures are overlain by Permo-Triassic rocks of the Sherwood Sandstone Group, which is the second most important aquifer in the UK. Quaternary superficial deposits laid down during the Devensian glaciation mantle most of the area, locally reaching thicknesses in excess of 40 m. The deposits include glacial till (pebbly and sandy clay), glaciolacustrine deposits (laminated clays and sands) and glaciofluvial outwash (sands and gravels). Post-glacial deposits, associated with the proto-Irwell include alluvium, river terrace gravels, and peat (Figure 2). Extensive areas of made ground are present, and include colliery spoil tips, material dug during the construction of the Manchester Ship Canal and general inert and biodegradable fill. Many of the watercourses in south Lancashire have been culverted and their valleys infilled, as for example, at Crofts Bank and along much of the course of the lower Medlock and its tributaries.

1.2 *Issues*

Some of the geoenvironmental factors likely to influence the cost of developing a site in Manchester or Salford are known from anecdotal and published accounts. Difficult ground conditions are a material consideration throughout much of the region, because of the heterogeneous nature of the superficial deposits and the significant thickness of man-made deposits in certain areas. Damage caused to housing and roads in parts of Salford, as a result of piping or collapse of glaciofluvial sands, is well documented (Harrison & Petch, 1985), as are the subsidence effects caused by undermining. There are also issues of contamination and groundwater protection. On a regional scale, uncertainty about the shallow groundwater regime, and the role played by the Manchester Ship Canal on aquifer recharge are issues of strategic concern.

- The present study is currently addressing a number of these issues, although some are still at an early stage of development; these are summarized below along with the main uses for the dataset. Topographic basemaps: various scales and vintages (backdrop for thematic mapping; historic and present-day landuse; potentially contaminating past landuse; hydrology, including springs and watercourses)
- Digital terrain model (DTM) (basis for 3D data modeling)
- Orthorectified aerial photographs (current landuse; surface sealing; visualization)

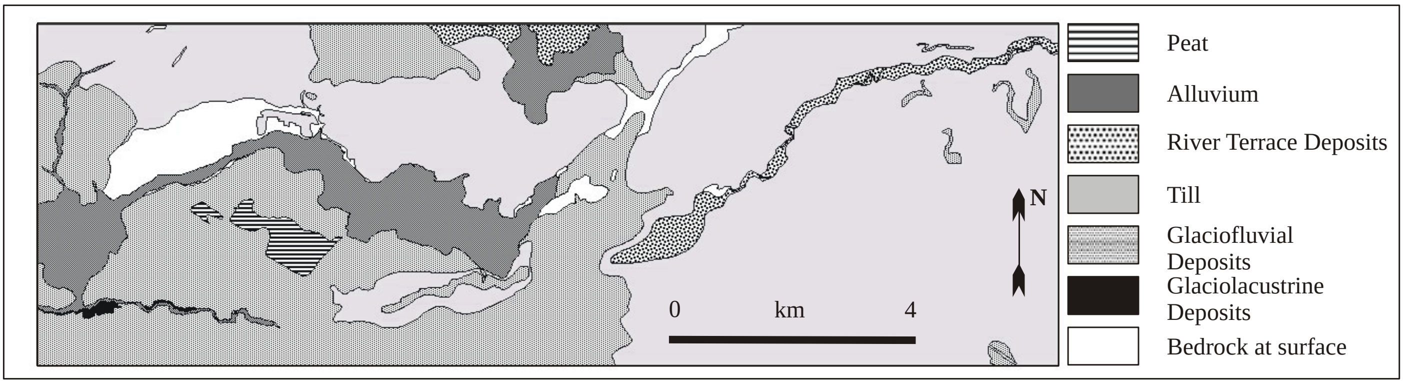

Figure 2. Geological map showing bedrock and superficial deposits present at surface within Manchester and Salford

- Geological maps: various scales and vintages (regional illustrative overview of geology; details of local geology; distribution of aquifers; surface lithology; historical details about, e.g., pits and exposures)
- Borehole database and extracted downhole lithological information (3D geological characterization including rockhead)
- Baseline geochemical data (characterization of soils and geological units; contaminated land study)
- Geotechnical properties database (ground stability and strength assessment)
- Water levels data (water balance models; indication of near-surface water; ground engineering; groundwater vulnerability models)
- Seismic events database (history of seismic activity)

1.3 Building the 3D model

Software currently under development by Dr Hans Georg Sobisch of the University of Cologne is being used to construct a model of the superficial and artificial deposits. Eventually, the aim will be to extend the model to include the underlying solid geology.

Primary and derivative datasets essential to the model are listed in the previous section. Of these, the borehole geology database is the most fundamental, providing downhole information for some 6500 borehole sites, as well as other factual information including groundwater strikes and geotechnical test data.

The three dimensional configuration of the geological units in the sub-surface is built up from serial cross-sections, drawn interactively using mapface and downhole data (figures 3a, b). Correlated surfaces are then gridded, and stacked to produce the final geological model. Accurate borehole correlation is critical to the final model, and care must be taken to ensure that each lithostratigraphical subunit is correctly attributed. This invariably involves some degree of subjective analysis to discriminate between deposits that are lithologically similar but may have been deposited in very different environmental settings (e.g. fluviatile, glacigenic, anthropogenic). Such deposits could reasonably be expected to exhibit different geotechnical or hydrogeological characteristics. Eight surfaces describing the subsurface alluvial and glacial geology have been identified and modeled in the Manchester and Salford area.

Figure 3c is an extract of the 3D model covering the western end of the project area. For clarity, only one lithostratigraphical unit (glaciolacustrine clay) is shown. The entire model, when fully attributed, will provide a greater level of understanding of the shallow sub-surface than is currently available for an urban centre in the UK.

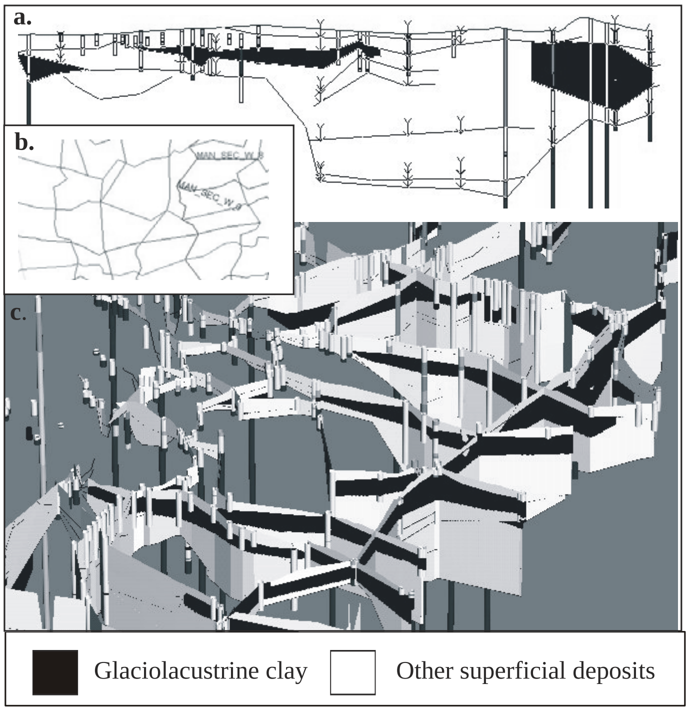

Figure 3. (a) A cross-section showing the distribution of glaciolacustrine clay proved by boreholes. (b) A plan view of the cross-sections that prove the distribution of glaciolacustrine clay in the south-western part (Trafford Park) part of Manchester. (c) Interrogation of the network of cross sections gives a representation of the 3D distribution of glaciolacustrine clay.

1.3.1 Limitations of the model

The glacial deposits are represented by a range of lithofacies that were deposited in different environmental settings. Many of the deposits are laterally impersistent and their geometry is unpredictable. In such areas, borehole correlation becomes uncertain and the approach has been to combine genetically-related sequences into domains rather than to try and map out individual lithofacies.

The validity of the model also depends on accurate borehole-to-borehole correlation. Lithological descriptions, in themselves, do not necessarily provide an adequate basis for correlation as many geological units, such as river terraces, glacial ice-contact deposits and intra-till sand bodies are described in similar terms, but do not necessarily share the same depositional or hydrogeological characteristics. An understanding of the geological evolution of the area is, therefore, important, to avoid creating spurious linkages.

There are practical difficulties in recreating the ground surface. The Digital Terrain Model derived from Ordnance Survey 5m contour data does not necessarily reflect the detailed variations observed in boreholes that have been levelled during the site investigation process. This a particular problem with thin, near-surface deposits such as made ground, where discrepancies between the DTM height and that of the levelled borehole (2 to 3 m) may be of the same order of magnitude as the deposit being modeled. Where possible these anomalies have been dealt with by re-hanging the boreholes to the modeled surface.

A further limitation of the model relates to its effective resolution. At a borehole density of between 1 and 257 data points per square kilometre, coverage in some parts of the study area is quite poor. This has a bearing on the applicability of the model at different scales of usage. It is important that data are processed in a way that ensures important relationships are not obscured at site or regional scale, and also that data are not over-interpreted beyond their intended useful range.

2 USE OF THE 3D MODEL FOR THEMATIC MAPPING

The potential of the model to deliver information relevant to a range of applications is illustrated by reference to three issues:

- Ground conditions
- Groundwater protection, and
- Sustainable Urban Drainage Systems

2.1 Prediction of ground conditions

2.1.1 Natural superficial deposits

The superficial drift deposits of the area cover a spectrum of engineering soil types, some of which may not offer good foundation conditions. Coarse (0.06 – 60 mm) soils, represented by glaciofluvial sands, tend to be loose- to medium-dense and well graded with practically no binder. As noted earlier, these deposits are responsible for ground movements in parts of Salford. Excavations in these deposits may encounter problems from running sand and cut face instability may occur when the excavation is below the water table.

Similarly, soft fine-grained (less than 0.06 mm) soils (alluvium and glaciolacustrine clay) may pose problems due to their low strength giving a generally low bearing capacity.

By assigning geotechnical properties to particular sub-units of the model, very specific information can be displayed about the nature of the sub-unit, and its likely geotechnical performance. Plasticity is an important engineering characteristic of fine-grained soils and is commonly measured during routine ground investigations. It gives an empirical understanding of engineering soils behaviour, and their susceptibility to deformation and shrink- swell. In the example (Figure 4a, b), plastic and liquid limit test results (British Standards 1990) are compared for the alluvial silts and clays of the River Irwell floodplain and the glaciolacustrine deposits that subcrop to the south of the Irwell. The alluvial deposits display low- to medium-plasticity, except for one or two samples with a high organic (peat) content, which fall into the high plasticity category. The glaciolacustrine clays cover similar fields, but generally have a higher plasticity. The implication is that, under normal ground conditions, the alluvial silts and clays have a lower shrink-swell potential than their glaciolacustrine counterparts.

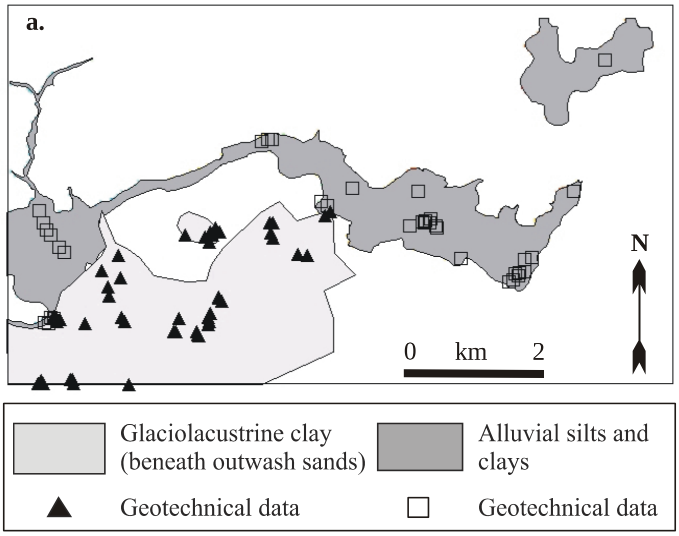

Figure 4 (a). Distribution of subsurface glaciolacustrine clay and surface alluvium in the south-western part of Manchester (Urmston), along with data points giving information on the geotechnical characteristics of the clays. The glaciolacustrine clay unit is almost entirely concealed by a thin veneer of glaciofluvial outwash sands which are shown (as Glaciofluvial Deposits) in Figure 2.

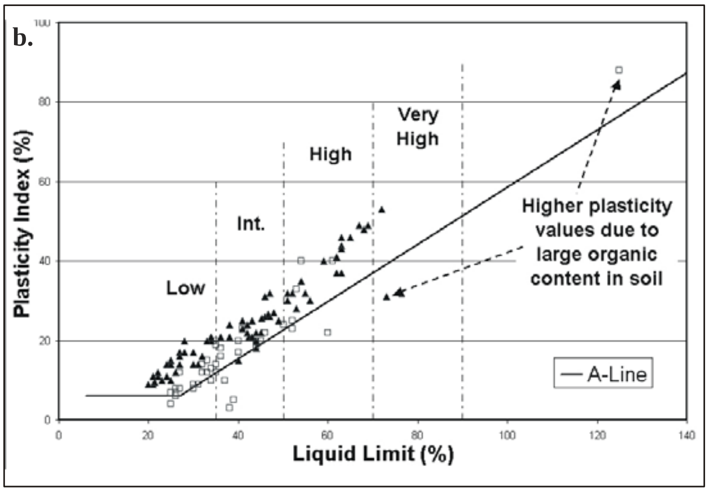

Figure 4 (b). Plasticity chart of the alluvial silts and clays of the Irwell floodplain and the glaciolacustrine clays. The alluvial silt and clay displays low- to medium-plasticity; higher plasticity samples have a high organic (peat) content. The glaciolacustrine clay displays a low- to high-plasticity; higher plasticity samples again have a high organic (peat) content. In normal ground conditions, low plasticity values generally indicated a low shrink-swell potential and high plasticity values generally indicated a high shrink-swell potential.

By extending this work, it is hoped to characterize the foundation conditions across the whole of the urban area, and building on earlier studies (e.g. Paul

& Little 1991), produce a predictive model that links the geotechnical performance of the glaciogenic deposits to their mode of deposition. This may shed light on the continuing debate as to whether the Cheshire Plain glacigenic sequences were deposited by more than one ice advance.

2.1.2 Assessing the subsurface morphology of made ground

An awareness of the presence, extent and composition of made ground is important, particularly as in areas of long historical development, like Manchester, made ground will be present beneath much of the urban area. The deposits are notoriously difficult to model because of their patchy distribution, but in areas of high borehole density, they can be delineated with some certainty. Made ground in excess of 0.5 m is recorded in 48% of the boreholes used within the study area. One of the largest backfilling operations involved the wholesale infilling of part of the River Irwell, which took place when the Manchester Ship Canal was cut in the late 19th century. The 3D model (Figure 5) depicts the morphology of the original river basin in the Salford Quays area prior to infilling.

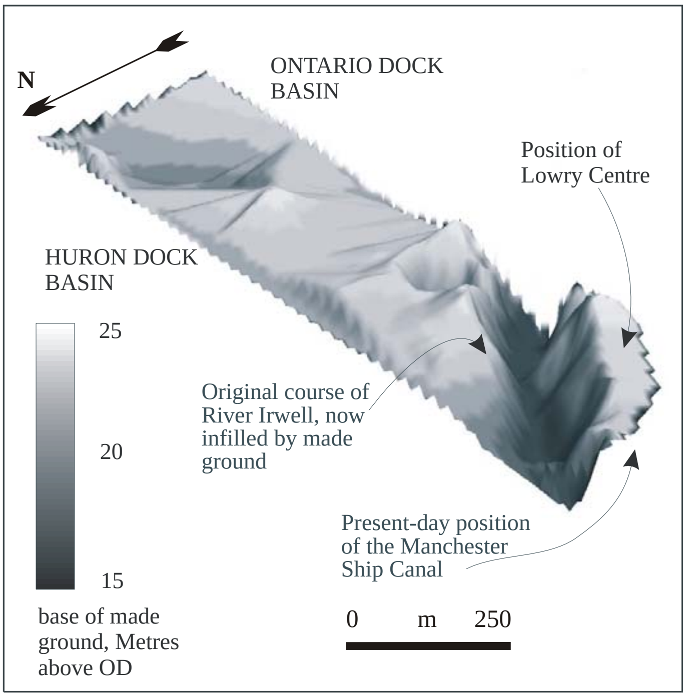

Figure 5. 3D representation of the base of made ground infill at Salford Quays. The base of the made ground has been modeled by geostatistitial triangulation of provings from boreholes. The base of made ground is flatter in the east and drops considerably in the west, where the former channel of the River Irwell has been infilled during construction of the Manchester Ship Canal.

2.2 The protection and management of groundwater in an urban setting

The European Water Framework Directive is due to be implemented in several key stages, commencing in 2003. The precise definitions used in the framework are currently ambiguous. However, one likely consequence is that surface and groundwater safeguards will become more stringent and cover all subsurface water within the saturation zone, regardless of potential yield of the host water-bearing unit, or potability. There will also be a requirement to ensure that the quality of existing groundwater bodies, classified as ‘good status,’ is maintained, and those that are of ‘poor status’ will have to be improved.

In the UK, aquifer vulnerability maps, (e.g., Environment Agency 1996) provide basic information on the sensitivity of an aquifer to pollution. However, they take little account of the role of superficial deposits in determining recharge and run-off potential. Increased interest in the use and management of urban ground water for public and industrial supply and river augmentation has meant that drift characterization (thickness, lithology, grain size, porosity and hydraulic conductivity) is essential for a meaningful appraisal of aquifer sensitivity (Berg 2002).

The use of domain maps in this context is now well established, particularly at catchment scale or larger (McMillan et al. 2000). The domain map constructed from the 3D geological model (Figure 6) provides a qualitative guide to aquifer sensitivity. The domains are based primarily on lithological criteria, associated with an estimate of the relative proportions of sand to clay in the sub-surface. It shows that the main areas of potential recharge occur along the River Irwell and beneath the Trafford Park Industrial Estate, where sandstone crops out or is overlain by permeable material (i.e., sandstone is in

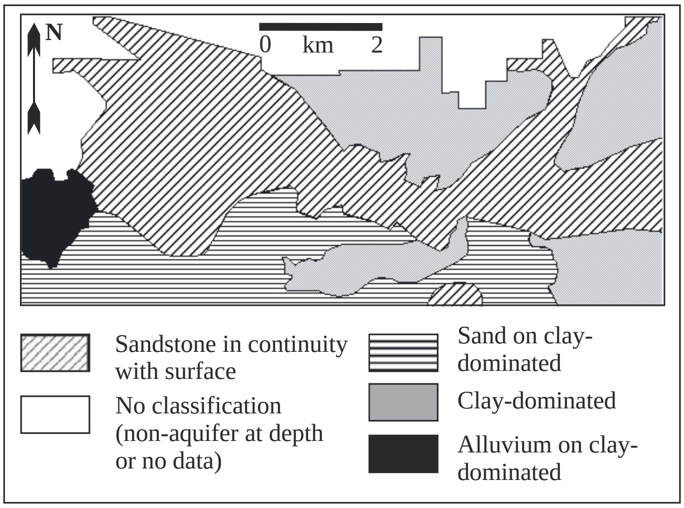

Figure 6. Extract of a map showing hydrogeological domains for Manchester and Salford. Recharge of the aquifer will occur where sandstone outcrops or is overlain by permeable material. Substantial infiltration through the sand on clay-dominated, clay-dominated and alluvium on clay-dominated domains to

the aquifer is unlikely as they contain clay-rich layers over 5 m in thickness. Perched water bodies are likely within the sand and alluvium on clay-dominated domains which, depending on local groundwater flows and overlying seals to the groundwater body, may be susceptible to contamination.

continuity with the surface). The potential for a pollution incident contaminating the groundwater in these areas must be a consideration.

Substantial infiltration to the aquifer through the ‘sand on clay-dominated’, ‘clay-dominated’ and ‘alluvium on clay-dominated’ domains is unlikely as they contain clay-rich layers over 5 m thick. Perched water bodies are likely within the ‘sand’ and ‘alluvium on till domains’, which may be susceptible to contamination, depending on local groundwater flows and overlying seals to the groundwater body.

One aim of the project will be to refine the domain model with surface sealing data, and information on potential sources of pollution and their pathways. This will help delineate recharge areas more accurately and possibly restrict adverse land-use practices within sensitive areas.

2.3 *Sustainable Urban Drainage Systems (SUDS)*

SUDS are an alternative approach to conventional drainage systems, which replicate, as far as possible, the natural drainage and deal with runoff where it occurs. The successful implementation of SUDS techniques, including swales, balancing ponds and porous pavements can save money, reduce pollution and alleviate flood risk (CIRIA 2001). The system design and choice of devices depends on local factors but essentially relies on attenuation, treatment and infiltration techniques to deal with surface runoff.

The applicability of SUDS techniques to a particular geological situation can be assessed by reference to the 3D geological model. Information critical to the assessment includes the topographic slope angle, the transmissivity of the near-surface deposits, and the thickness of the unsaturated zone. Slope information can be calculated from the DTM; estimates of transmissivity for different lithologies are published in the hydrogeological literature (e.g. Allen et al. 1997; McMillan et al. 2000); an indication of the thickness of the unsaturated zone (or the depth to water table) may be derived from careful screening of first water strike as recorded in borehole logs. By combining this information as a simple tri-category map, areas more suited to infiltration techniques can be identified. Additional constraints (potential for contamination, surface sealing) can be incorporated to make the model more robust. In the example (Figure 7), the susceptibility polygons are based on present day land-use, rather than on a conventional rectangular grid. This approach allows areas of similar surface sealing (e.g. sealed: predominantly tarmac or unsealed: mostly grass) to be grouped. The preliminary results from Manchester using a simple weighting system indicates that SUDS techniques may be successful in up to 37% of the ground analyzed.

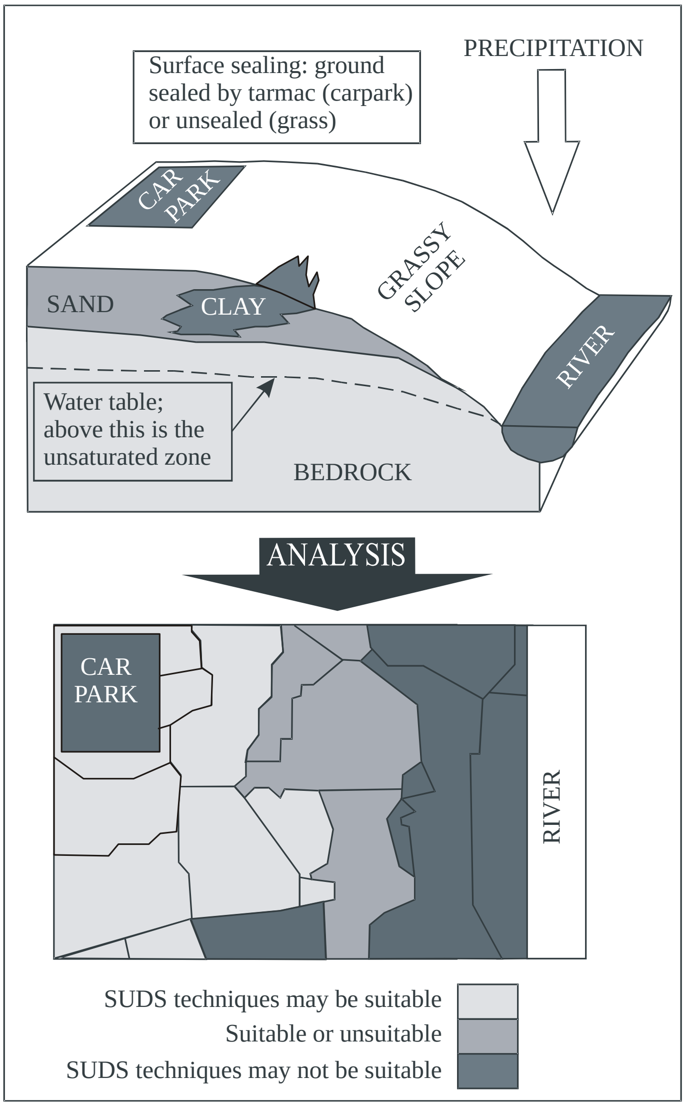

Figure 7. Schematic representation of a SUDS suitability model. SUDS techniques are unlikely to be applicable near the river due to the effect of the slope and the close proximity of the water table to the ground surface. The sealing effect of the carpark, and clay-rich superficial deposits also make the success of SUDS techniques less likely. SUDS techniques in this setting are more likely to be successful where topographical gradients are low and the ground is unsealed and underlain by porus deposits such as sand-rich superficial deposits.

3 CONCLUSION

This paper illustrates some of the potential uses and benefits of utilizing readily available information relating to the ground in the preliminary stages of site development. The opportunity exists to provide a more relevant input of geoenvironmental data into the planning decision making process in the Manchester and Salford area, and to extend this methodology to other urban areas.

Geological and topographic data along with downhole information extracted from site investigation reports can be collated in a GIS and displayed in

3D to delineate areas that may be susceptible to a wide range of geohazards. These include ground instability and aquifer vulnerability, factors that may place additional financial and/or time costs early on in the site development process if not identified at an earlier stage. This study will provide a valuable set of background data to developers, local consultants and local planning authorities, outlining the general subsurface conditions that may be expected, so that these may be considered and, if necessary, mitigated during the planning stage of site development.

The models developed would benefit from the integration of additional datasets and this must be considered as a main area of future work in Manchester and Salford. These include the input of surface sealing data into the SUDS model, and information concerning past and present landuse and the geochemistry of the near-surface soils and fluids into the groundwater vulnerability models. A programme of ground truthing in order to adjust and refine the algorithms used (for example, defining the local transmissivity of the superficial deposits, and the properties of different surface sealing media in the urban area) would also provide a level of confidence to the historic third party data that has been used.

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