# Subgrade geology beneath railways in Manchester

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ABSTRACT
It is not sufficient to identify fine-grained soils, only, as locations for potential subgrade problems as could be done using a traditional 2D geological map. More information is required about the geological structure, lithological variability, mineralogy, moisture content and geotechnical properties of the soil, much of which can be supplied by modern 3D geospatial databases. These databases can be interrogated at key depths to show the wide variability of geological materials and conditions beneath the ground surface. Geological outcrop and thickness of bedrock an superficial deposits (soils), plus the permeability and water table level are predicted from the Manchester geospatial model that is based on 6500 borehole records. Geological sections along railway routes are modelled and the locations of problem soils such as alluvium, till and glaciolacustrine deposits at outcrop and shallow subcrop are identified. Spatial attribution of geotechnical data and simple methods to recast sections in engineering geological terms are demonstrated.

BACKGROUND TO APPLIED GEOLOGICAL STUDIES
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 (Culshaw *et al.*, 1990; Smith and Ellison, 1999). Since this work was completed, advances in the use of Geographical Information Systems (GIS) and modelling packages have meant that there is now a far greater opportunity to develop geotechnical and engineering geological 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. The purpose of this paper is to demonstrate the potential, using examples from a Manchester study area (Figure 1), that the 3D geological model and engineering geological appraisal can contribute to railway engineering.

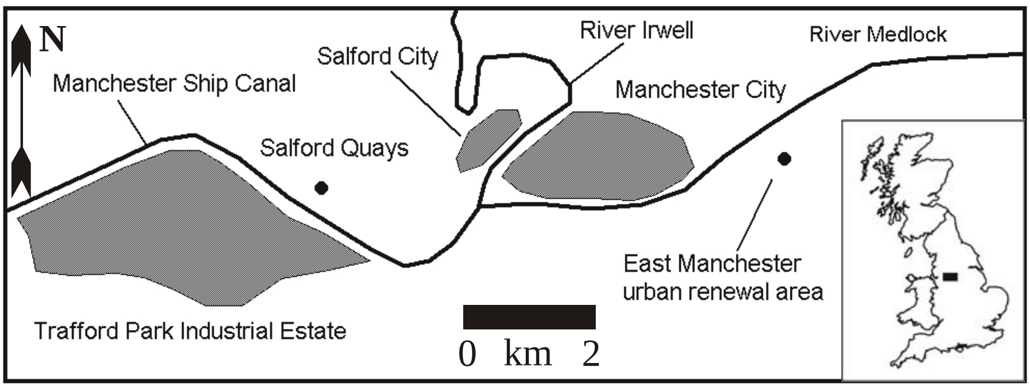


Figure 1: Key locations in the Manchester region of north-west England (from Hough *et al.*, 2003).

BACKGROUND GEOLOGY TO THE MANCHESTER STUDY AREA
Geologically, the Manchester region straddles the southern part of the Carboniferous South Lancashire Coalfield and the northern part of the Permo-Triassic Cheshire Basin (Figure 2). The coalfield was worked extensively 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 (gravelly and sandy clay), glaciolacustrine deposits (laminated clay and sand) and glaciofluvial outwash (sand and gravel). Post-glacial deposits, associated with the proto-Irwell include alluvium, river terrace gravel, and peat (Figure 2). Extensive areas of made ground are present including 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 River Medlock and its tributaries.

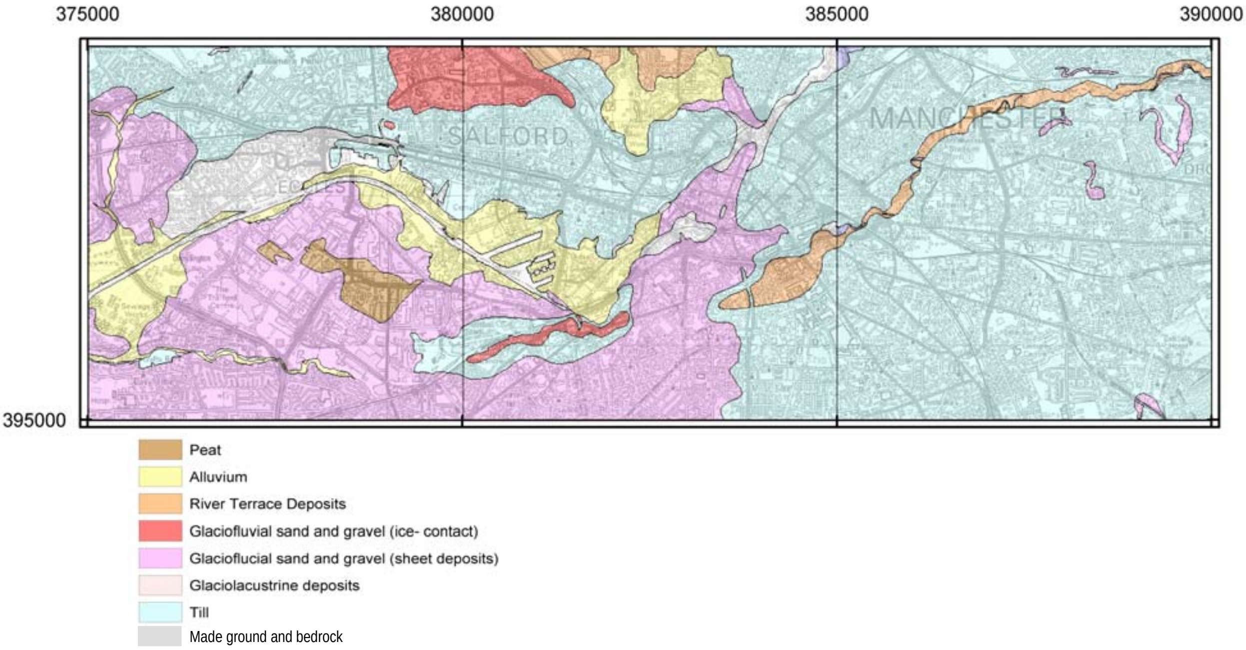


Figure 2. Geological map showing bedrock, superficial and artificial made ground deposits present at surface within central Manchester.

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## MODELLING GEOLOGY IN 3D

At BGS a specific Geological Surveying and Investigation in 3 Dimensions (GSI3D) software tool and methodology has been developed in collaboration with Dr Hans Georg Sobisch at the University of Cologne (Kessler *et al.*, 2004). Over the past 3 years BGS has acted as a test-bed for the accelerated development of the tool and methodology.

The primary and derivative datasets essential for modelling geological formations in 3D using GSI3D are:

- Digital terrain model (DTM) (the basis for 3D data modeling)
- Borehole database and extracted down-hole geological information (the basis for 3D geological characterization)

Of these, the borehole geology is the most fundamental, providing down-hole information, as well as other factual information including groundwater levels and in-situ geotechnical test data. For the Manchester model some 6500 borehole were used.

The three dimensional configuration of the geological units in the sub-surface is built up from serial cross-sections, drawn interactively using the mapface and down-hole 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 sub-unit is correctly attributed (Kessler *et al.*, 2004). 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 depending on a number of factors, such as the degree of consolidation. Eight surfaces describing the subsurface alluvial and glacial geology have been identified and modelled in the Manchester area. Figure 3c shows an extract of the 3D model.

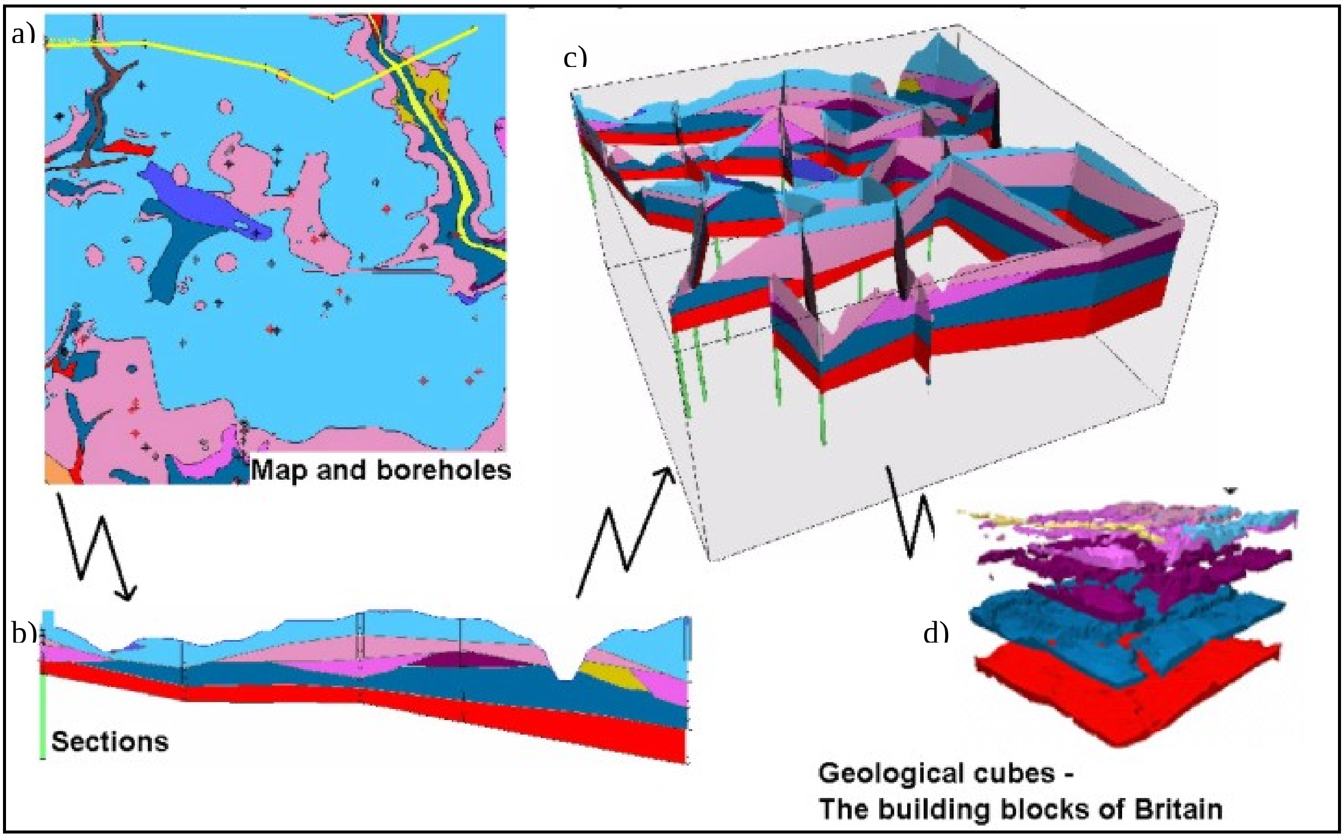


Figure 3: How a 3D geological model is produced: a) boreholes (black and red circles) are digitized and viewed enabling b) cross-sections to be produced. A network of cross-sections are then combined to produce the model (Kessler *et al.*, 2004).

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 borehole logs similar terms, but do not necessarily share the same depositional or hydrogeological characteristics. An understanding of the geological evolution of the area is, therefore, essential, to avoid creating spurious correlations.

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 is a particular problem with thin, near-surface deposits such as made ground, where discrepancies between the DTM height and that of the levelled borehole (e.g. 2 to 3 m) may be of the same order of magnitude as the deposit being modelled. Where possible these anomalies have been dealt with by ‘re-hanging’ the boreholes to the modelled 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 the site or regional scale, and also that data are not over-interpreted beyond their intended useful range.

## WHY IS THIS OF INTEREST TO RAILWAY ENGINEERING?

Once a 3D model has been developed it can be interrogated and used for different purposes. Synthetic geological cross-sections can be generated along a given route enabling an interpretation of the subsurface geology beneath the route to be formulated. For example, a synthetic section can be generated along a given section of railway track. Figure 4b shows an example of such a cross-section that was generated along the Manchester to Liverpool railway line (Figure 4a) using the Manchester 3D model.

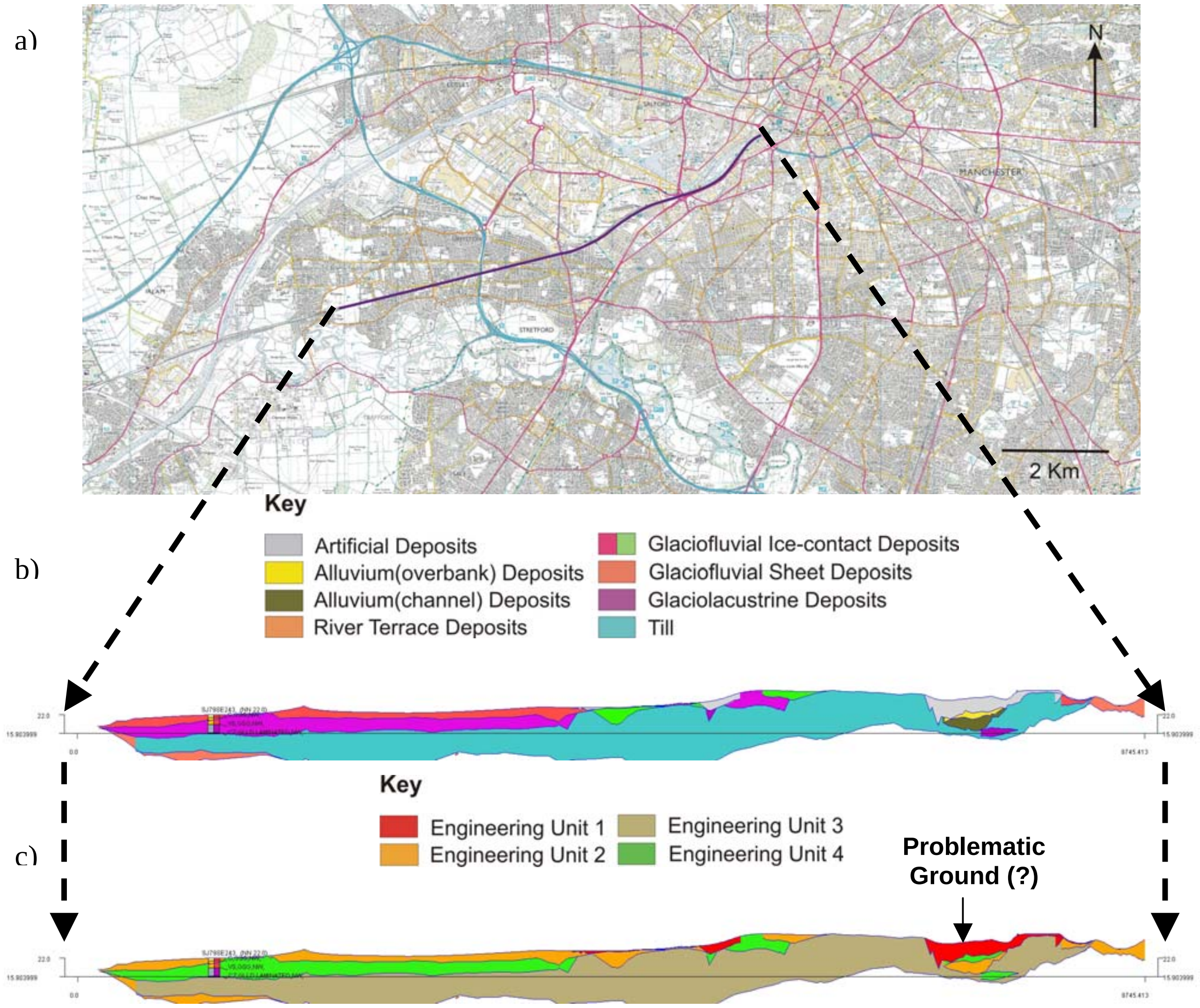


Figure 4a/b/c: a) Location of the synthetic cross-section in the Manchester area. b) Synthetic geological cross-section along the Manchester to Liverpool railway in Manchester. c) Synthetic cross-section representing the engineering geological units along the Manchester to Liverpool railway.



Once a geological appraisal of a section of track has been prepared, an engineering geological interpretation can be undertaken. This involves the use of different types of geotechnical data (e.g. standard penetration test, moisture content, particle size etc) to aid in the interpretation and assessment of the ground conditions. This assessment is undertaken in accordance with BS5930 (British Standards Institution, 1999) to determine the grain size (clay, silt, sand, gravel) and strength/density, thus enabling the ground conditions to be classified into a number of engineering geological units. An engineering geological appraisal of the synthetic geological cross-section was undertaken (Figure 4c). Here, the geological model was characterised using a mixture of particle size and standard penetration test data, derived from the British Geological Survey's Geotechnical Database. This enabled four engineering geological units to be identified (Table1). This classification was then applied to the synthetic geological cross section (Figure 4b) and an Engineering Geological section (Figure 4c) was produced. Visual inspection of Figure 4c allows regions of potentially difficult ground conditions to be immediately identified. For example, to the east of the cross-section (Figure 4c) an area of Engineering Unit 1 (Table 1 - Artificial Ground – Infilled Ground) can be identified at the surface with Engineering Unit 2 (Table 1 – Alluvium-River Channel Deposits or Glaciofluvial Ice-Contact Deposits) below. This area could have problems with variable ground conditions or contamination due to the Artificial Ground at the surface and possible differential settlement because there is a mixture of soft clayey and dense gravely Alluvial deposits. Table 1 highlights some of the likely engineering characteristics and potential problems, in terms of the performance in foundations, excavations and fill that could be encountered within each of the Engineering Units seen in Figure 4c. For example, there is a risk that River Channel Deposits and the Glaciofluvial Ice-Contact Deposits within Engineering Unit 2 will have a highly variable lithological character and contain many soil types that will be unsuitable as fill materials, thereby leading to potential problems such as differential compaction and perching water tables etc.

## DISCUSSION

3D geological modelling has revolutionised geological interpretation. For engineering applications it has provided a 3D framework for spatial geotechnical data to be presented and interpreted. From this spatial data engineering geological classifications can be formulated and the engineering geological ground conditions visualised in 3D. This can be used by engineers and geologists to: aid in the location of problematic ground conditions; be used as a tool to aid in the planning and location of ground investigations; and to ensure that the most economical and valuable information is obtained from these surveys.

Geology plays a significant role in subgrade and thus railway performance, and it should not be ignored during subgrade investigations. For instance, network maintenance programmes can also be improved with better integration of geological data from regional to site scales. Key to this improvement is the quality and the spatial attribution of data held in 3D geo-spatial databases that can be combined in rating schemes developed to predict subgrade problem susceptibility. Such schemes can begin at a regional scale but will still be applicable at the site scale. It is not sufficient to identify fine-grained soils as locations for potential subgrade problems as could be done using a traditional 2D geological map. More information is required about the geological structure, lithological variability, mineralogy, moisture content and geotechnical properties of the soil, much of which can be supplied by emerging 3D geospatial databases. These databases can be interrogated at key depths to show the wide variability of geological materials and conditions beneath the ground surface. Geological outcrop and thickness, plus the formation properties such as permeability of materials can be predicted from geospatial models based on thousands of borehole records where data are available and entered into the database. Detailed geological sections along railway routes can be modelled and the locations of potential problematic soils such as alluvium, till and glaciolacustrine deposits at outcrop and shallow subcrop can be identified. Spatial attribution of geotechnical data and simple methods to recast sections in engineering geological terms are also easily realised using these new systems. Such attributed sections can now become a key tool in strategic maintenance and network expansion plans.

For geological and engineering geological ground appraisal it is essential that information from previous boreholes, with down-hole geological and geotechnical information, are available. The British Geological Survey is the home of the National Geological Records Centre, which currently holds over 600 000 borehole records and 25 000 site investigation reports of the UK. Many of the borehole logs are available as digital scans and this information is now being used to develop 3D geological models around in the Thames Gateway (London), Clyde Basin (Glasgow), Mersey Corridor (Manchester-Liverpool) and the Vale of York. New studies have been initiated to investigate the relationship between the geology of the shallow sub-surface and track geometry along important railway routes in London, Glasgow and Manchester. This is part of a continuing programme of research into the impact of geology on railway performance and will lead to further engineering geological classifications of sections along railway routes in these urban centres. Further studies will include the correlation of the geology of key engineering units with poor track geometry and will form a basis for the development of susceptibility maps for strategic use in the assessment of subgrade problems over sections of the railway network.

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## References

British Standards Institution (1999). *Code of practice for site investigations. BS 5930*: London, British Standards Institution.

Culshaw, M.G., Forster, A., Cripps, J.C., and Bell, F.G. (1990). Applied geology maps for land-use planning in Great Britain., *in* Price, D.G., ed., *6th International Congress International Association of Engineering Geology*, **1**, Amsterdam, Netherlands, A.A. Balkema, pp. 85-93.

Hough, E., Kessler, H., Lelliott, M., Price, S.J., Reeves, H.J., and McC Bridge, D. (2003) Look before you leap: the use of geoenvironmental data models for preliminary site appraisal. *Land Reclamation Extending the Boundaries: Proceedings of the 7th International Conference of the International Affiliation of Land Reclaimationists., Runcorn, UK*, A.A. Balkema, pp. 369-375.

Kessler, H., Mathers, S.J., Sobisch, H.-G., Neber, A., and Wildman, G. (2004). GSI3D - The software and methodology to build systematic near-surface 3-D geological models - Version 1.5. *British Geological Survey Internal Report* **IR/04/029**

Smith, A., and Ellison, R.A. (1999). Applied geological maps for planning and developement: A review of examples from England and Wales, 1983 to 1996.: *Quarterley Journal of Engineering Geology*, **32**, pp. S1-S44.

| ENGINEERING GEOLOGICAL UNITS | GEOLOGICAL UNITS | DESCRIPTION/ CHARACTERISTICS | ENGINEERING CONSIDERATIONS | | | |
|---|---|---|---|---|---|---|
| | | | FOUNDATIONS | EXCAVATION | ENGINEERING FILL | SITE INVESTIGATION |
| ENGINEERING | | | | | | |
| **ENGINEERING UNIT 1** (HIGHLY VARIABLE ARTIFICAL DEPOSITS) | Disturbed Ground<br>Landscaped Ground<br>Made Ground<br>Worked Ground<br>Infilled Ground | Highly variable composition, thickness and geotechnical properties. | Highly variable. May be unevenly and highly compressible. Hazardous waste may be present causing leachate and methane production. | Usually diggable. Hazardous waste may be present at some sites. | Highly variable. Some material may be suitable. | Essential to determine depth, extent, condition and type of fill. Care needs to be taken as presence of pollution and contaminated ground likely. Essential to follow published guidelines for current best practice. |
| **ENGINEERING UNIT 2** (COARSE SOILS) | Alluvium - River Channel deposits<br>River Terrace deposits<br>Glaciofluvial Sheet deposits | Medium dense to dense SAND & GRAVEL with some buried channels and lenses of clay, silt & peat. | Generally good. Variable thickness of deposit. Thick deposits in buried channels may be significant in foundation design due to differential settlement. | Diggable. Support may be required. May be water bearing. | Suitable as granular fill. | Important to identify the presence and dimension of buried channels and characteristic of infilling deposits. Geophysical methods may be appliciable. |
| | Glaciofluvial Ice-contact deposits | Loose to medium dense fine to medium SAND. | Poor foundation. | Easily diggable. Generally poor stability. Running sand conditions possible below the water table and in pockets at perched water tables. | Unsuitable as granular fill . | Determine the presence, depth and extent of deposit and depth to sound strata. |
| **ENGINEERING UNIT 3** (FINE SOILS - FIRM) | Till | Firm to very stiff sandy, gravelly CLAY with some channels and lenses of medium dense to dense sand and gravel | Generally good foundation, although sand lenses may cause differential settlement. Possibility of pre-existing slips can also cause a strength reduction. | Diggable. Support may be required if sand lenses or pre-existing slips encountered. Ponding of water may cause problems when working. | Generally suitable if care taken in selection and extraction. Moisture content must be suitable. | Determine the depth and extent of deposit, especially the frequency and extent of lenses and channels. Investigate whether any pre-existing slips and shear planes are present. |
| **ENGINEERING UNIT 4** (FINE SOILS - SOFT) | Alluvium - Overbank deposits | Soft to firm CLAY occasional sand, gravel and peat lenses. | Poor foundation. Soft highly compressible zones may be present; risk of differential settlement. | Easily diggable. Moderate stability, decreasing with increasing moisture content. Running sand conditions possible below the water table and in pockets with perched water tables. Risk of flooding. | Generally unsuitable. | Determine the presence, depth and extent of soft compressible zones and depth to sound strata. |
| | Glaciolacustrine deposits | Soft to stiff laminated CLAY with occasional lenses of sand. | Generally poor foundation as long term consolidation and differential settlement possible. | Easily diggable. Support may be required if sand lenses encountered in deep excavations. Ponding of water or exposure to rain may cause softening of formation. | Generally suitable if care taken in selection and extraction. Moisture content must be suitable. | Determine the depth and extent of deposit, especially the frequency and extent of lenses. |

Table 1 – The engineering geological units encountered within the synthetic geological cross-section displayed in Figure 4b, and a brief overview into some of the engineering problems that maybe encountered within each of the Engineering Geological Unit.