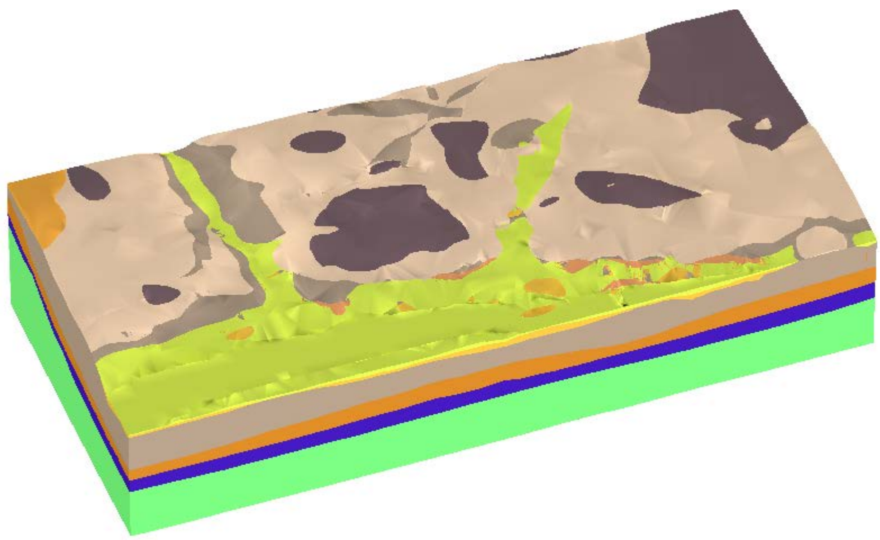
British Geological Survey
Expert | Impartial | Innovative

Metadata report for the City of London 3D geological model

GeoAnalytics and Modelling Programme

Open Report OR/18/030



BRITISH GEOLOGICAL SURVEY

GEOANALYTICS AND MODELLING PROGRAMME

OPEN REPORT OR/18/030

Metadata report for the City of London 3D geological model

H. Burke, C. Martin and R. Terrington

Keywords

City of London, geology, 3D model

National Grid Reference

SW corner 530900,180380
NE corner 533850,182210

Map

Sheet 256, 1:50 000 scale, North London

Front cover

3D view of the model viewed from the south-west. Artificial ground removed to show superficial deposits (vertical exaggeration x5)

Bibliographical reference

H BURKE, C. MARTIN AND R. TERRINGTON, 2018. Metadata report for the City of London 3D geological model. *British Geological Survey Open Report*, OR/18/030. 16pp.

Keyworth, Nottingham British Geological Survey 2018

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3100

BGS Central Enquiries Desk

Tel 0115 936 3143
email enquiries@bgs.ac.uk

BGS Sales

Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP

Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Cardiff University, Main Building, Park Place, Cardiff CF10 3AT

Tel 029 2167 4280

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB

Tel 01232 666595
www.bgs.ac.uk/gsni/

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

UK Research and Innovation, Polaris House, Swindon SN2 1FL

Tel 01793 444000
www.ukri.org

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by Constance Martin, a BSc student at the University of Birmingham, in collaboration with the British Geological Survey (BGS) to construct a 3D geological model of the City of London.

Contents

FIGURES

TABLES

Summary

This report describes the City of London 3D geological model, created by Constance Martin, a BSc student at the University of Birmingham, and Ricky Terrington and Helen Burke from the British Geological Survey. The work was carried out as part of a final year geology mapping project, using existing data held by the BGS and computer modelling in place of more traditional field mapping techniques to explore the subsurface geology of the developed area of the City of London.

The City of London model covers an area covering approximately 3km^2 in Central London, where the financial district, St Paul's Cathedral and the Tower of London are located. Eleven geological units are modelled, comprising artificial ground, superficial deposits and bedrock to a cut-off depth of 100 m below Ordnance Datum.

1 Modelled Volume, Purpose and Sale

The City of London geological model covers an area of approximately 3km^2 in central London (Figure 1) and comprises eleven artificial, superficial and bedrock geology units. The six modelled superficial deposits comprise alluvium and terrace gravels associated with the River Thames, which overlie three modelled Palaeogene bedrock units and a basal unit of Cretaceous Chalk. The model is suitable for use at scales between 1:10,000 and 1:50,000 to a depth of 100 m below Ordnance Datum (OD).

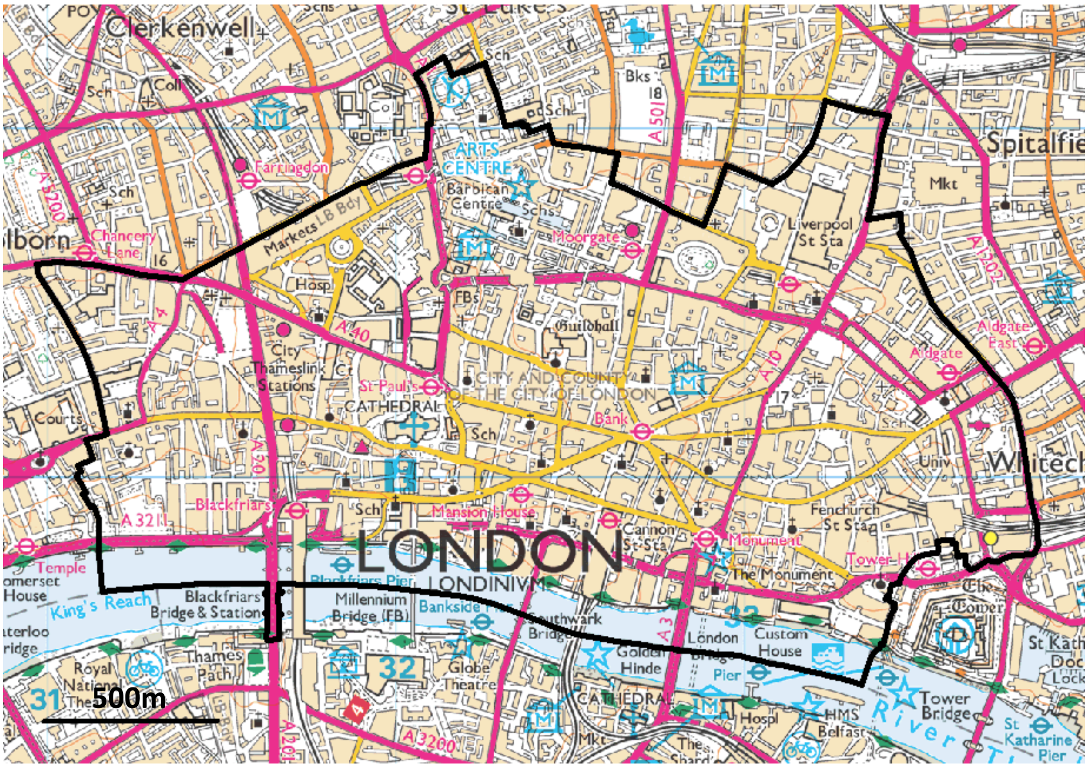


Figure 1 Location of the City of London model area (outlined in black). ***Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2018] Ordnance Survey [100021290 EUL]***

2 Modelled Surfaces/Volumes

Table 1 lists the modelled geological units in the relative stratigraphic order used in the model. Brief descriptions are provided below, with more detail available in the BGS Lexicon of Named Rock Units. The geological units in Table 1 are coloured as they appear in the model and serve as the legend when viewing images of the model later in this report.

Table 1 List of modelled units

Geological unit	Age	Model name	Comments
Artificial Ground	Quaternary	MGR-ARTDP	All subtypes of artificial ground are modelled as MGR-ARTDP (made ground, worked ground, infilled ground etc.). Variable composition and thickness.
Alluvium	Quaternary	ALV-XCZ	Mainly consists of silty clay and clayey silt.
Langley Silt	Quaternary	LASI-Z	Mainly composed of silt with minor amounts of gravel. Forms a veneer on the terrace gravels.
Shepperton Gravel	Quaternary	SHGR-XSV	1st Thames terrace (sub-alluvial gravel), composed of gravel and sand.

Kempton Park Gravel	Quaternary	KPGR-XSV	2nd Thames terrace, composed of gravel and sand.
Taplow Gravel	Quaternary	TPGR-XSV	3rd Thames terrace, composed of gravel and sand.
Hackney Gravel	Quaternary	HAGR-XSV	4th Thames terrace, composed of gravel and sand.
Lynch Hill Gravel	Quaternary	LHGR-XSV	5th Thames terrace, composed of gravel and sand.
London Clay Formation	Palaeogene	LC-CLAY	Mapped/modelled at rockhead throughout the model area. Composed of silty clay with occasional claystone bends.
Lambeth Group	Palaeogene	LMBE-CLSSG	Lambeth Group (undivided). Variable composition, including clay, sand and gravel.
Thanet Sand Formation	Palaeogene	TAB-SANDU	Primarily composed of grey to green sand with a distinctive basal bed of green coated flints.
Chalk Group	Late Cretaceous	CK-CHLK	Chalk Group (undivided). Composed of white chalk with flinty layers.

2.1 ARTIFICIAL GROUND

No artificial ground is mapped within the model area. However, artificial ground is known to be present through the vast majority of the model area because of its urbanised nature. Artificial ground is modelled based on its presence and thickness recorded in borehole logs. No distinction has been made on the type of artificial ground present or its composition; all types of artificial ground are modelled as the single unit MGR-ARTDP. The maximum thickness of made ground in the model is 12 m (Figure 2).

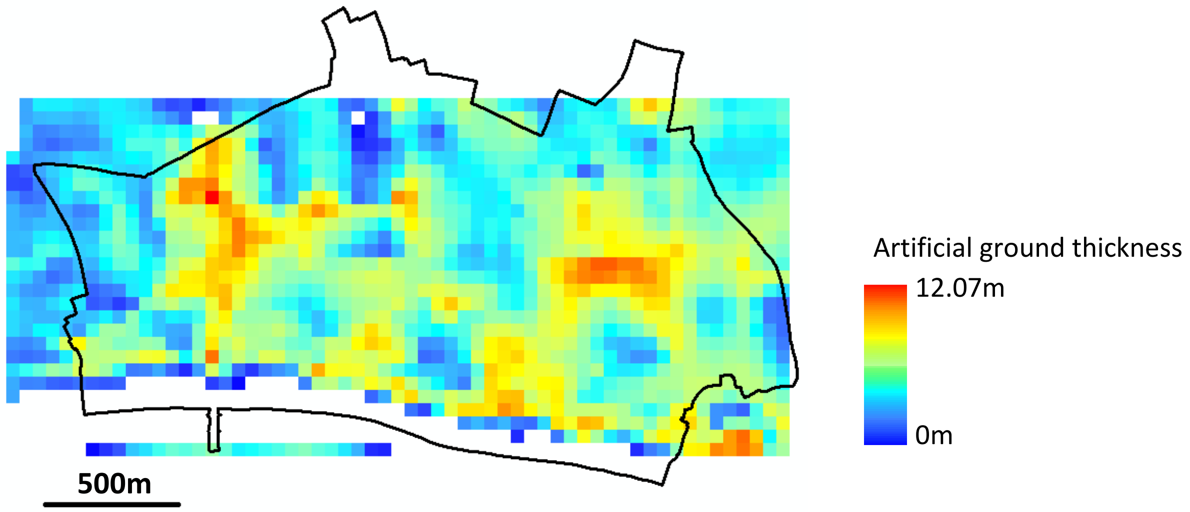


Figure 2 Artificial ground thickness grid derived from the model (50m cell size), shown with a blue to red colour ramp. Areas of thickest artificial ground are coloured red, thinnest in blue, white areas show where artificial ground is absent. Note that the model area does not cover the entire City of London area (outlined in black)

2.2 SUPERFICIAL DEPOSITS

A total of seven superficial units are mapped/modelled. These comprise alluvium associated with the River Thames and its tributaries, four Thames terrace gravels and Langley Silt (brickearth), which forms a thin veneer (up to 3.6 m thick) over the terrace gravels. The mapped distribution of Langley Silt is much wider than in the model because it is only modelled where proven in boreholes. Borehole evidence indicates that much of the Langley Silt has been removed through the emplacement of artificial ground.

2.3 BEDROCK

Four bedrock units are modelled. From youngest to oldest, these are: London Clay Formation, Lambeth Group, Thanet Sand Formation and Chalk Group. The London Clay Formation is composed of grey to bluish grey silty clay with a basal unit of sand, silty clay, sandy silt and silty sand (Ellison, 2004). The top of the London Clay Formation weathers to a brownish colour.

Lambeth Group (formerly named Woolwich and Reading Beds) underlies the London Clay Formation. Three subdivisions within the Lambeth Group are recognised in the literature (Upnor Formation, Woolwich Formation and Reading Formation), but are not separated out in the model. The Lambeth Group is lithologically variable, both vertically and laterally, consisting of mottled and laminated clays, sand, pebble beds, shell beds and limestone bands (Ellison, 2004).

The oldest Paleogene unit in the London area is the Thanet Sand Formation, which underlies the Lambeth Group and rests on the chalk aquifer. The base of the Thanet Sand Formation is defined by a distinctive layer of green coated flints (the Bullhead Bed), which is approximately 0.5 m thick (Ellison, 2004). The Thanet Sand Formation mainly consists of pale to medium grey to brown grey coloured fine grained sand, which can be clayey and silty towards the base (Ellison, 2004).

The basal unit in the model is the Upper Cretaceous Chalk Group. This is mapped as Lewes Nodular Chalk Formation, Seaford Chalk Formation and Newhaven Chalk Formation (undivided), previously the Upper Chalk. This is composed of fine grained white limestone with layers of flint.

3 Modelled faults

No geological faults are modelled

4 Model workflow

The standard GSI3D modelling workflow was followed for this project. GSI3D software utilises a range of data such as boreholes, digital terrain models (DTM) and geological linework to enable the geologist to construct a series of interlocking cross-sections. Borehole data is represented in GSI3D by two proprietary files: a borehole identification file (.bid) that contains 'index'-level information including location and start-heights; a borehole log file (.blg) that contains the borehole interpretation. Constructing cross-sections is intuitive and flexible, combining borehole and outcrop data with the geologist's experience to refine the interpretation.

Using both the information from the cross-sections and the distribution of each unit a calculation algorithm creates the triangulated surfaces for the top and base of each unit. In order to control the relative vertical ordering of the calculation, a generalised vertical section file (.gvs) is established. A proprietary legend file (.gleg) is created to control symbolisation of the cross-section and model. The modeller can view all the units in 3D and iteratively return to the cross-section to make amendments or add further cross-sections to refine the model. This process is a standard methodology within BGS for modelling Quaternary and simple bedrock horizons and is fully documented in Kessler *et al* (2009).

5 Model datasets

5.1 GVS AND GLEG FILES

The generalised vertical section (.gvs) and geological legend (.gleg) files were assembled using Notepad or Excel and iterated as the model expanded and new units were encountered. The GVS was based on DiGMapGB-50 data by identifying all geological units present within the model area to a depth of -100 m below Ordnance Datum. The City of London model GVS and Gleg are based on the existing London Basin geological model.

5.2 COLOURS FROM DIGMAP-50. GEOLOGICAL LINEWORK

The City of London model uses BGS DiGMap 1:10 000 scale superficial and bedrock geological mapping to inform the modelled units. In the absence of mapped artificial ground within the model area, boreholes were used to determine the distribution of artificial ground in the model.

5.3 DIGITAL TERRAIN MODEL

The model is capped by an extract from the Ordnance Survey Terrain 50 Digital Terrain Model (DTM). This represents the ground surface in the model, with the full resolution 50 m cell size used. This gives a ground elevation range for the model area of +25.0 m at Holborn in the north-west of the model area to -2.3 m along the River Thames. The DTM is shown in Figure 3 with a blue to red colour ramp (areas of low elevation are coloured blue and high areas are blue).

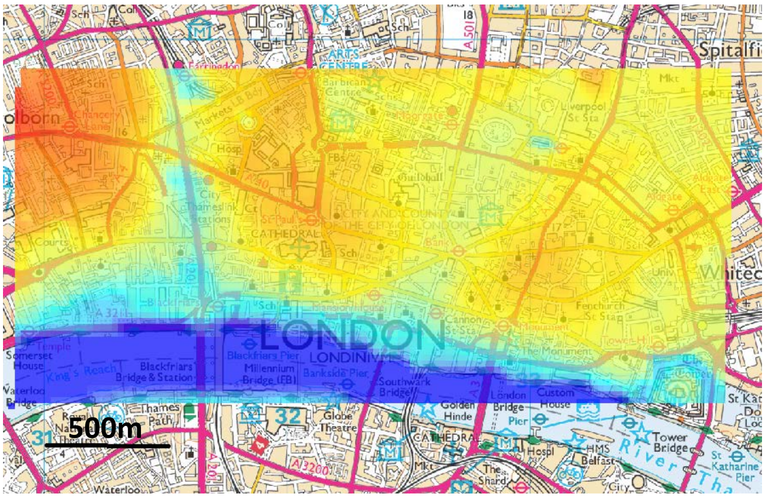


Figure 3 Ordnance Survey Terrain 50 DTM used in the model shown with a blue to red colour ramp. Areas of low elevation are coloured blue and high areas are shown in red. ***Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2018] Ordnance Survey [100021290 EUL]***

5.4 BOREHOLE DATA

A total of 303 non confidential boreholes in the BGS Single Onshore Borehole Index were used to constrain the City of London model (Figure 4). These were coded into text files for use in the 3D modelling software, with the .bid file holds the location information of each borehole (grid reference and start height) and the .blg file stores the downhole information. These downhole interpretations will be uploaded to the BGS Borehole Geology database in due course. Start heights were taken from the OS DTM-50 Digital Terrain Model (DTM) for boreholes where start heights are absent.

5.5 CROSS-SECTIONS

The City of London model area is located entirely within the pre-existing London Basin model area (Burke et al., 2014). Five cross-sections from the London Basin model were used in the City of London model, with an additional 22 cross-sections constructed in the City of London model area to form a framework (Figure 4). The City of London cross-sections are matched to the London Basin cross-sections, with minor amendments made to the London Basin sections using borehole evidence.

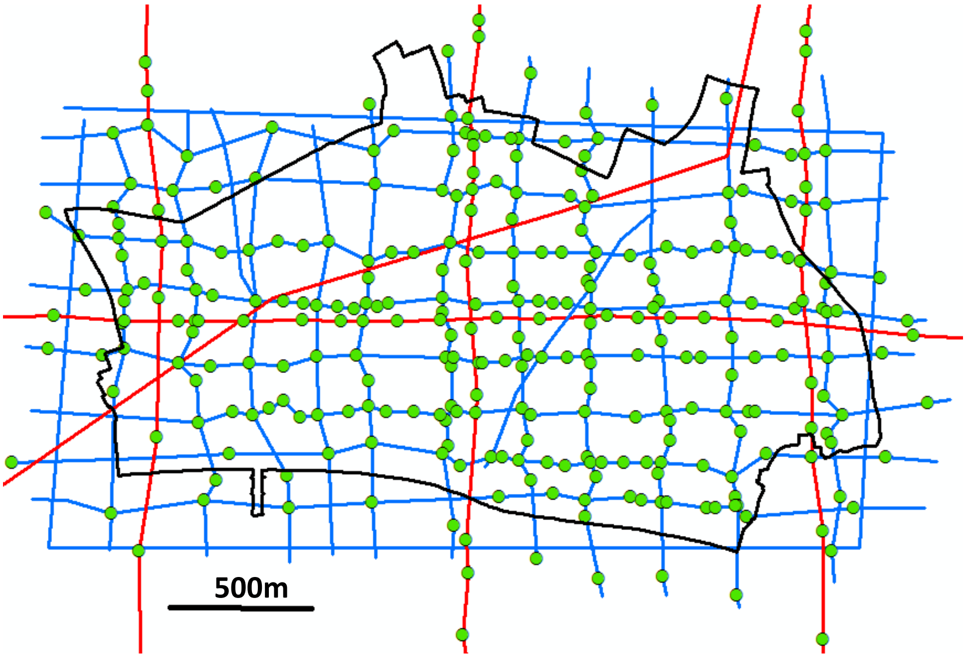


Figure 4 Cross-sections and boreholes (green dots) used to constrain the City of London model. City of London cross-sections are shown in blue, London Basin model sections in red

6 Model Development Log

Notes on the data used to construct the model and on the model QA process are available on request.

7 Model Assumptions, Geological Rules Used etc.

Wherever possible the start heights (ground levels recorded on the borehole logs) were obeyed during cross-section correlation. Borehole start heights are discussed in more detail in the Model Limitations section below.

Geology polygons from DiGMapGB-10 were used to constrain the model. However, there are occasions where the boreholes and geological mapping contradict one another. In these cases precedence is given to the boreholes and minor edits were made to the geological linework. For example, river terrace deposits may be mapped in an area but are not modelled if a borehole records only artificial ground or bedrock. Similarly, alluvium is not modelled where a borehole proves terrace gravel or artificial ground. Figure 5 shows the geological map data and cross-section *COL_WE_3* near Bank underground station, where changes have been made to the modelled distribution of alluvium using borehole evidence.

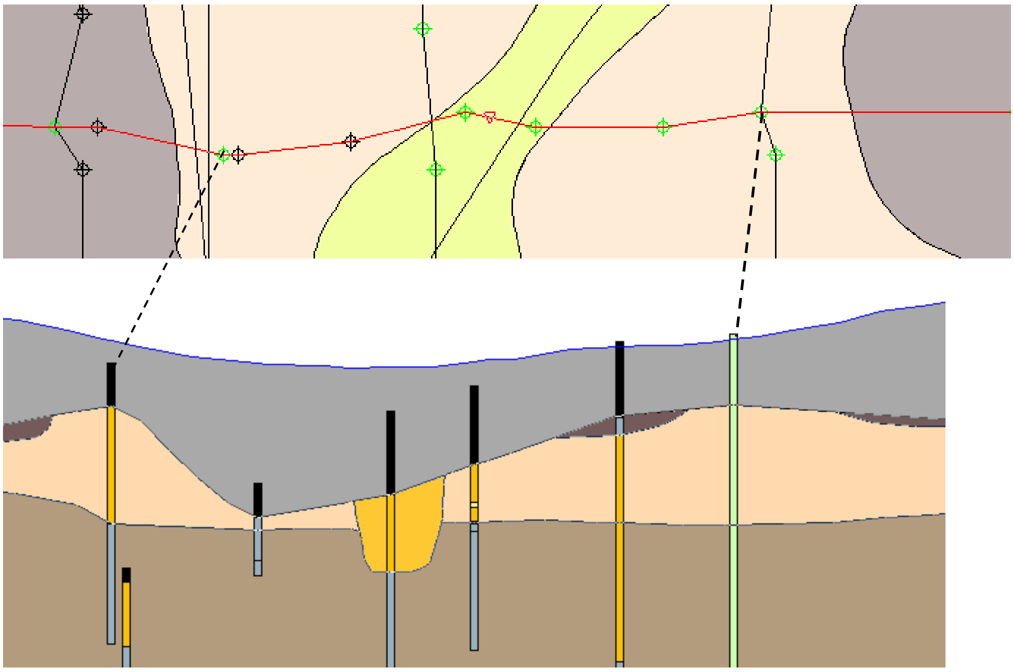


Figure 5 Top: DiGMapGB-10 geological map data shows alluvium mapped (pale yellow area in the map extract). Boreholes are shown as black and green dots. Cross-section COL_WE_3 is shown in red. Bottom: Alluvium is not modelled at this locality because boreholes used in cross-section *COL_WE_3* show the alluvium has been replaced with thick artificial ground

8 Model Limitations

8.1 MODEL SPECIFIC LIMITATIONS

Only non-confidential borehole records were used to constrain the model, which reduces the number of available boreholes in the model area.

As stated earlier, borehole start heights have been obeyed wherever possible. With this method of modelling dependent on borehole information to inform the bases of the geological units, obeying or overriding the borehole start heights can have a huge impact on the finished model. This particularly affects the bedrock units, such as the base of the Thanet Sand Formation, because fewer boreholes reach that far down, limiting the number of available boreholes.

Anomalies occur where a borehole site well above or well below the Digital Terrain Model (DTM). Inconsistencies between borehole start heights and the Digital Terrain Model (DTM) can be an issue in highly urbanised areas like Central London, where sites have been developed multiple times and several generations of site investigation boreholes are used. These DTM-start height discrepancies can reflect local anthropogenic changes in the ground elevation, or can be due to issues in the Single Onshore Borehole Index database, such as errors in feet to metres conversions. Each anomalous borehole was examined in the context of adjacent boreholes and nearby boreholes used in crossing sections when deciding whether to accept or overrule its start height. Figure 6 shows cross-section *COL_NS_8*, where many of the borehole start heights do not fit the Digital Terrain Model.

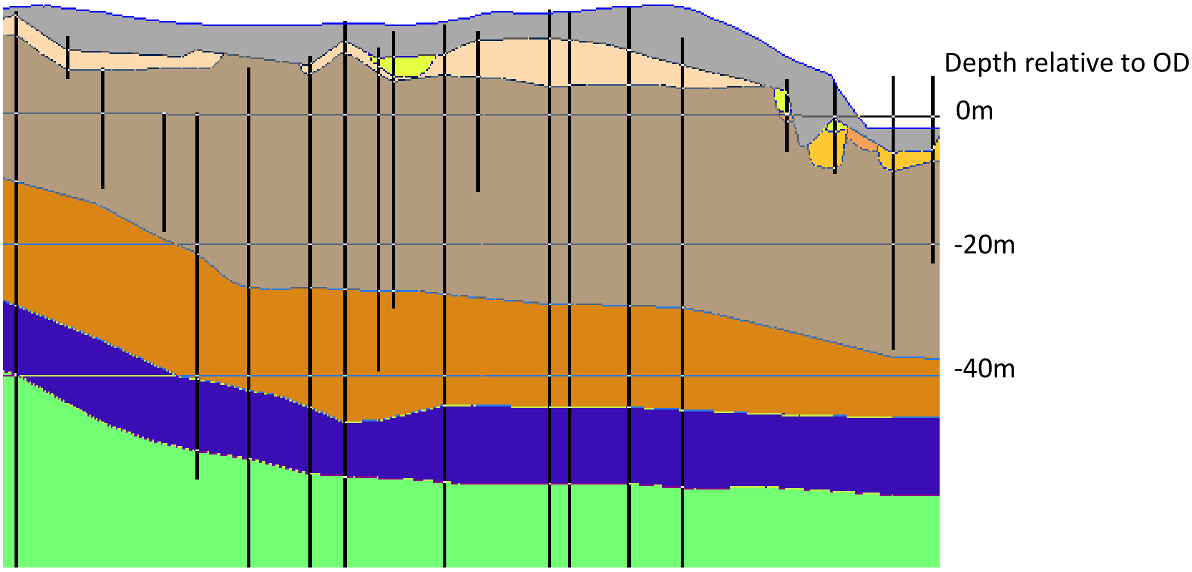


Figure 6 Cross-section *COL_NS_8*, showing discrepancies between borehole start heights and the Digital Terrain Model. Boreholes are shown as black vertical lines. Key to geology as per Table 1

The junction between the base of the Lambeth Group and the underlying Thanet Sand Formation can be difficult to determine in boreholes, particularly where the level of detail recorded in a borehole is minimal. Where green sand above a grey sand unit is recorded in boreholes

8.2 GENERAL MODELLING LIMITATIONS

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations. Therefore, geological modelling is an empirical approach.
- It is important to note that this 3D geological model represents an individual interpretation of a subset of the available data; other interpretations may be valid. The full complexity of the geology may not be represented by the model due to the spatial distribution of the data at the time of model construction and other limitations including those set out elsewhere in this report.
- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. boreholes locations, elevations etc.) Any raw data considered when building geological models may have been transcribed from analogue to digital format. Such processes are subjected to quality control to ensure reliability; however undetected errors may exist. Borehole locations are obtained from borehole records or site plans.
- Borehole start heights are obtained from the original records, Ordnance Survey mapping or a digital terrain model. Where borehole start heights look unreasonable, they are checked and amended if necessary in the index file. In some cases, the borehole start height may be different from the ground surface, if for example, the ground surface has been raised or lowered since the borehole was drilled, or if the borehole was not originally drilled at the ground surface.

- Borehole coding (including observations and interpretations) was captured in a corporate database before the commencement of modelling and any lithostratigraphic interpretations may have been re-interpreted in the context of other evidence during cross-section drawing and modelling, resulting in mismatches between BGS databases and modelled interpretations.
- Digital elevation models (DEMs) are sourced externally by BGS and are used to cap geological models. DEMs may have been processed to remove surface features including vegetation and buildings. However, some surface features or artefacts may remain, particularly those associated with hillside forests. The digital terrain model may be sub-sampled to reduce its resolution and file size; therefore, some topographical detail may be lost.
- Geological units of any formal rank may be modelled. Lithostratigraphical (sedimentary/metasedimentary) units are typically modelled at Group, Formation or Member level, but Supergroup, Subgroup or Bed may be used. Where appropriate, generic (e.g. alluvium – ALV), composite (e.g. West Walton Formation and Ampthill Clay Formation, undifferentiated – WWAC) or exceptionally informal units may also be used in the model, for example where no equivalent is shown on the surface geological map. Formal lithodemic igneous units may be named Intrusions or Dykes or may take the name of their parent (Pluton or Swarm/Centre or Cluster/Subsuite/Suite), or if mixed units Complex may be used. Highly deformed terranes may use a combined scheme with additional rank terms. Artificially Modified Ground units (e.g. Worked Ground – WGR, Landscaped Ground (undivided) – LSGR) are currently regarded as informal.
- The geological map linework in the model files may be modified during the modelling process to remove detail or modify the interpretation where new data is available. Hence, in some cases, faults or geological units that are shown in the BGS approved digital geological map data (DiGMapGB) may not appear in the geological model or vice versa. Modelled units may be coloured differently to the equivalent units in the published geological maps.

9 Model QA

In order for a geological model to be approved for publication or delivery to a client a number of QA checks are carried out. This includes visual examination of the modelled cross-sections to ensure that they match each other at cross-section intersections and fit the borehole and geological map data used. The model calculation is checked to ensure that all units calculate to their full extent within the area of interest and the modelled geological surfaces are checked for artefacts such as spikes and thickness anomalies. The naming convention of the modelled geological units is checked to ensure that recognised entries in the BGS Lexicon of Named Rock Units (http://www.bgs.ac.uk/lexicon/home.html) and the BGS Rock Classification Scheme (http://www.bgs.ac.uk/bgsrcs/) are used as far as possible.

Any issues found in the QA checking process are recorded and addressed before delivery/publication of the model.

During the QA process each borehole was re-coded to enable more detailed lithological information and text descriptions in the borehole logs to be viewed in the model. This enabled the bases of geological units to be modelled more accurately. Surfaces generated in the London Basin geological model (base London Clay Formation and base Thanet Sand Formation) were loaded into the City of London model workspace and used to adjust the bedrock units in the cross-sections where deep borehole data is sparse. Two ‘helper sections’ were added during the QA process to improve the calculation of alluvium.

The City of London model overlaps the Farringdon geological model area (Aldiss et al., 2012). No surfaces or cross-sections from the Farringdon model were used during construction of the City of London model. However, the base Thanet Sand Formation surface from the Farringdon model was used in the QA of the City of London model. Despite some differences in the depths of these units and the structural interpretation, no changes were made to the City of London model.

10 Model Images

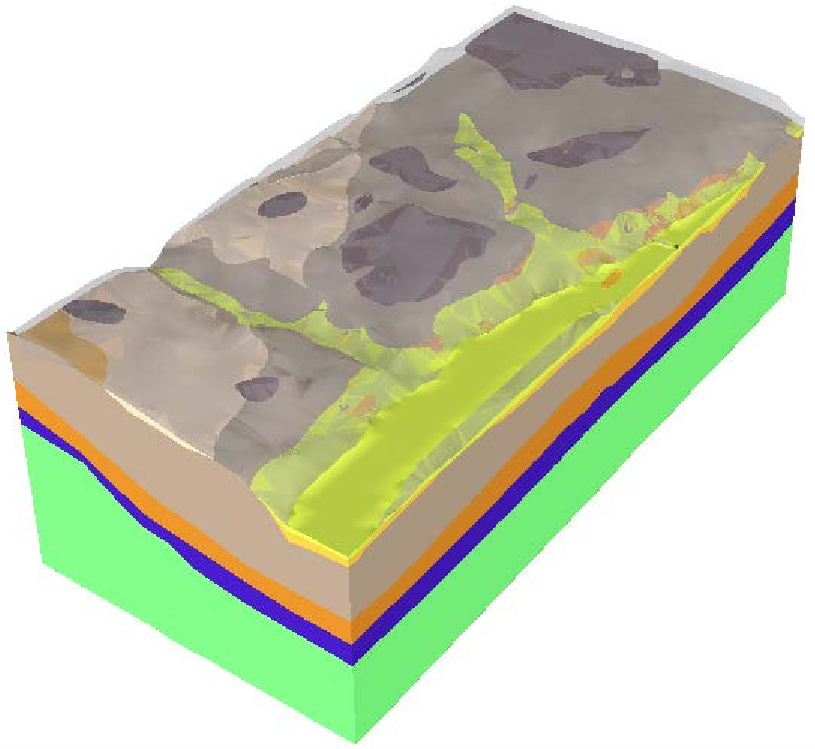


Figure 7 3D view of the City of London model, looking from the south-west. Made ground is transparent to enable the underlying superficial deposits to be seen (vertical exaggeration x8). Key as per Table 1

Figure 8 3D view of the river terrace deposits and Langley Silt, looking from the south-west. Alluvium is removed to enable the Shepperton Gravel to be seen (vertical exaggeration x8). Key as per Table 1

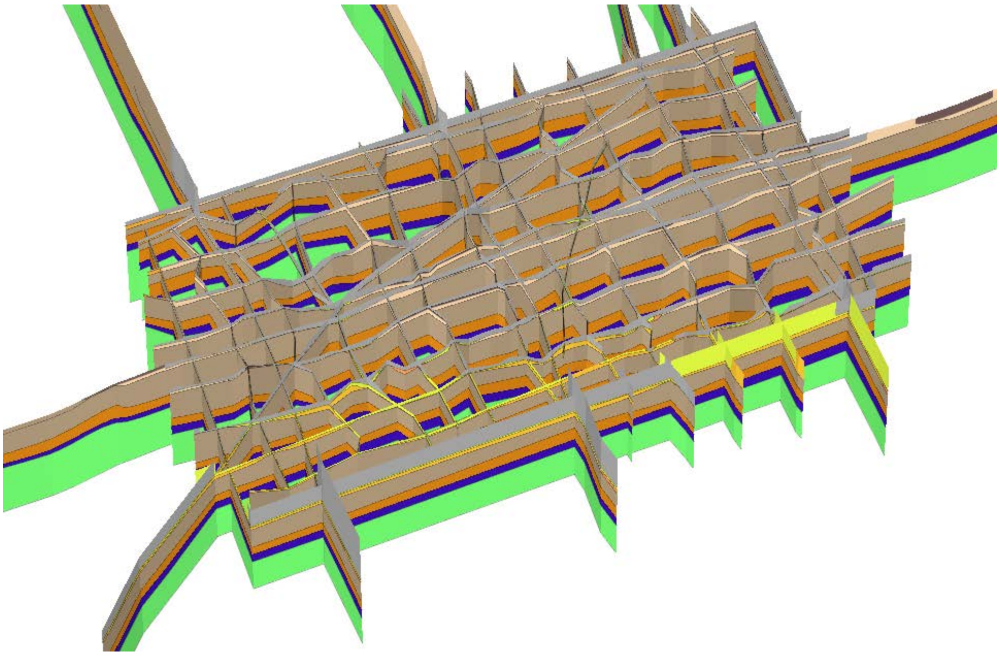


Figure 9 3D view of the cross-sections used to constrain the model, viewed from the south-west (vertical exaggeration x5). Key as per Table 1

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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

Burke, H., Mathers, S. J., Williamson, J. P., Thorpe, S., Ford, J. and Terrington, R. L., 2014. *The London Basin superficial and bedrock Lithoframe 50 model*. British Geological Survey Open Report no. OR/14/029. http://nora.nerc.ac.uk/id/eprint/507607/

Ellison, R. A., 2004. *Geology of London*. Special memoir for 1:50 000 Geological sheets 256 (North London), 257 (Romford), 270 (South London) and 271 (Dartford). British Geological Survey publication.

Kessler, H., Mathers, S. J. and Sobisch, H.-G., 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers & Geoscience*, **35**, 1311–1321 http://dx.doi.org/10.1016/j.cageo.2008.04.005