British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Geoscience for our changing Earth

Glasgow CITY COUNCIL

CUSP

cost
European Cooperation in Science and Technology

Sub-Urban

From geological maps to 3D and 4D models - transforming the delivery and relevance of geological knowledge for practitioners

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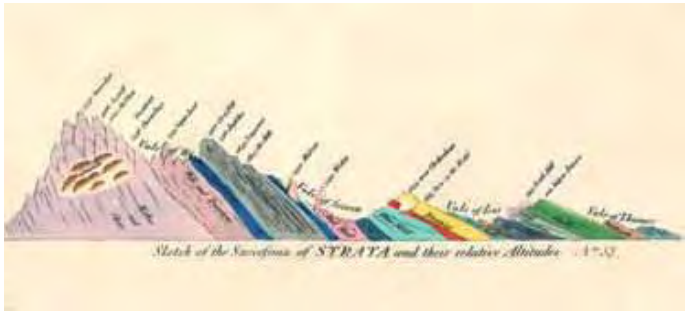
With particular thanks to BGS colleagues Steve Mathers, Hugh Barron, Helen Bonsor, Alison Monaghan, and many others

Evolution of the Geological Map

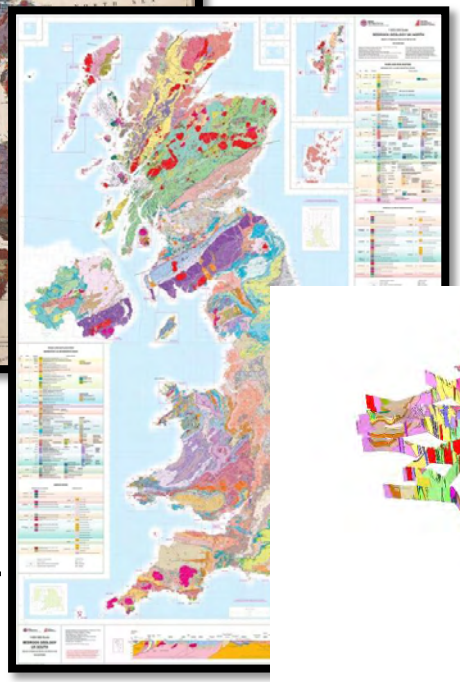
1815



1874

1939

2007

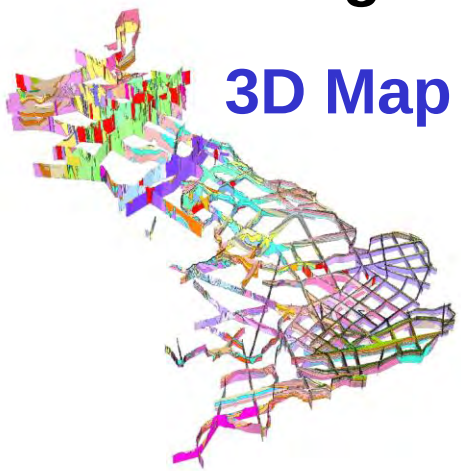


2012

The mission has remained constant

Step change

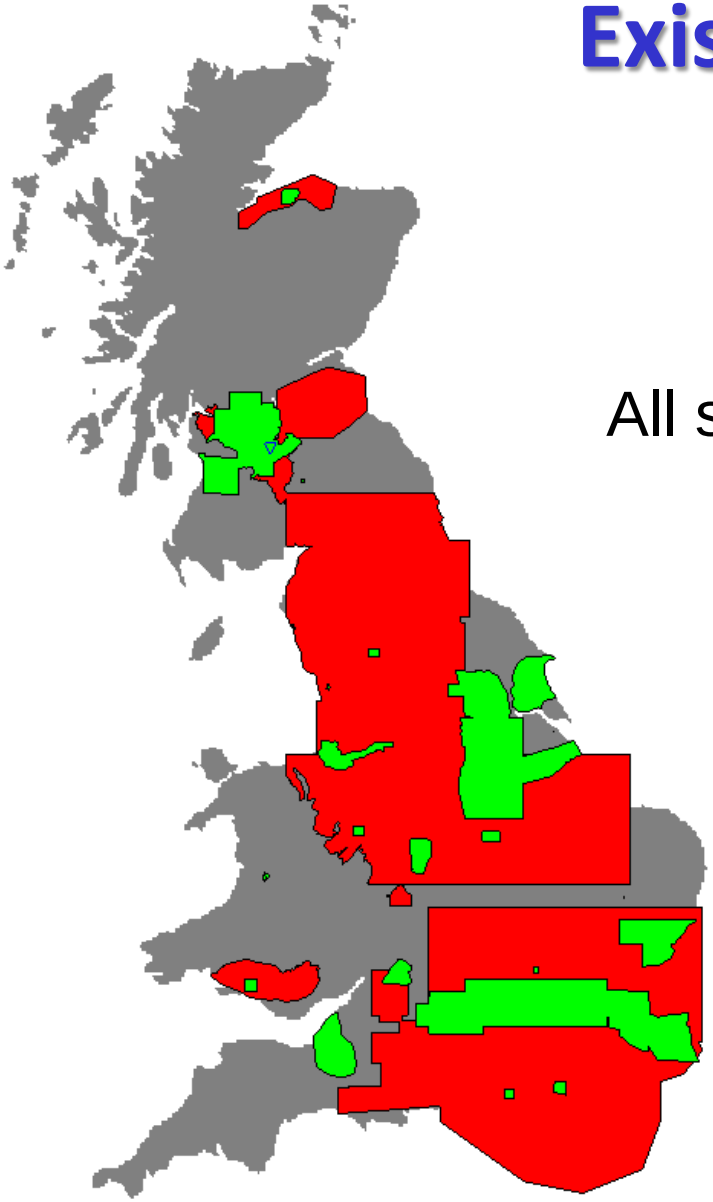
3D Map



Shaping a new culture
The National Geological Model (NGM)

- **Tools for 3D Mapping (fit for any purpose)**
- **GOCAD** Framework models especially basin scale
- **GSI3D** Framework models Quaternary & Anthropocene
- **Petrel** Stochastics, Groundwater flow (4D)
- **Isatis** Statistics
- **Geovisionary** Fly through and visualisation
- **GIS** Data conditioning

Existing Framework Models

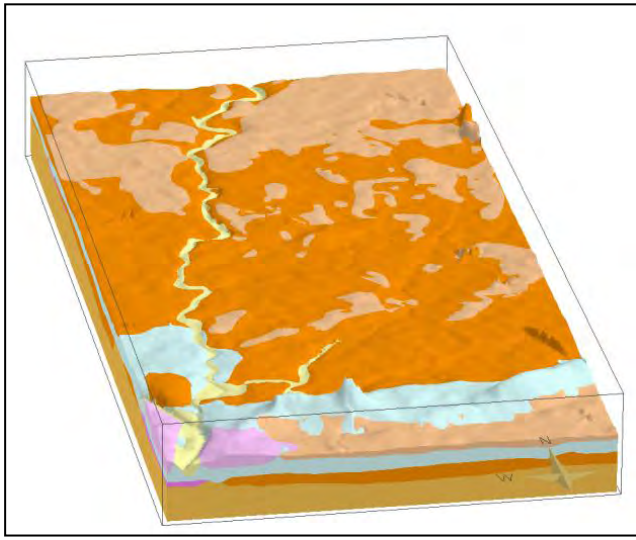


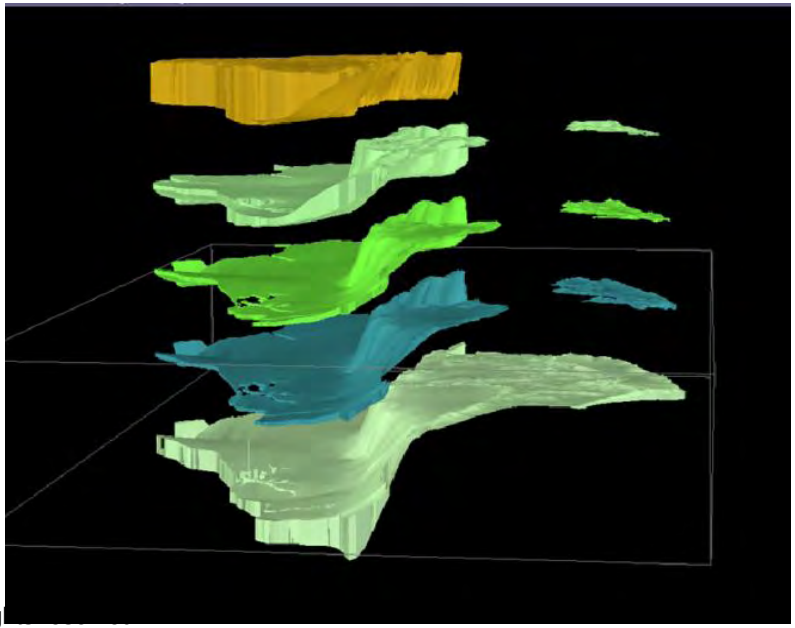
GSI3D & GoCAD

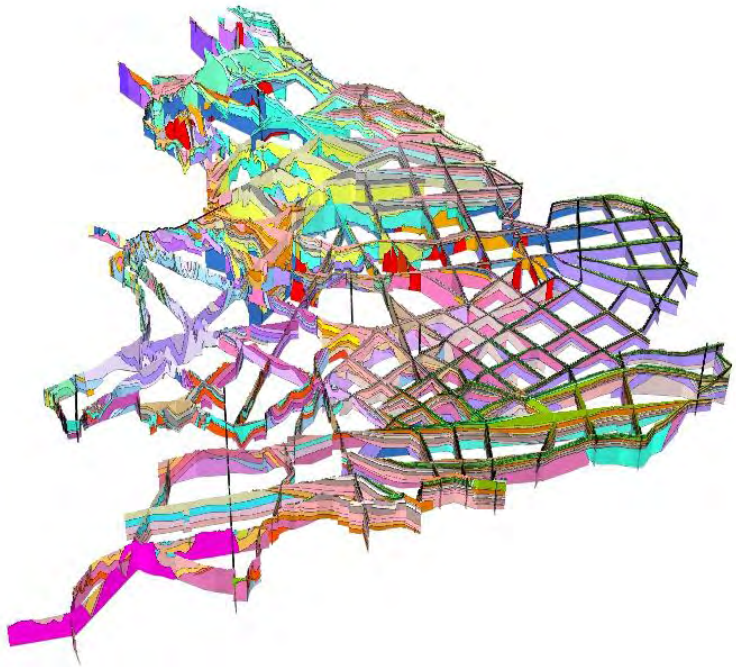
All sizes, shapes, depths and drivers

The Models

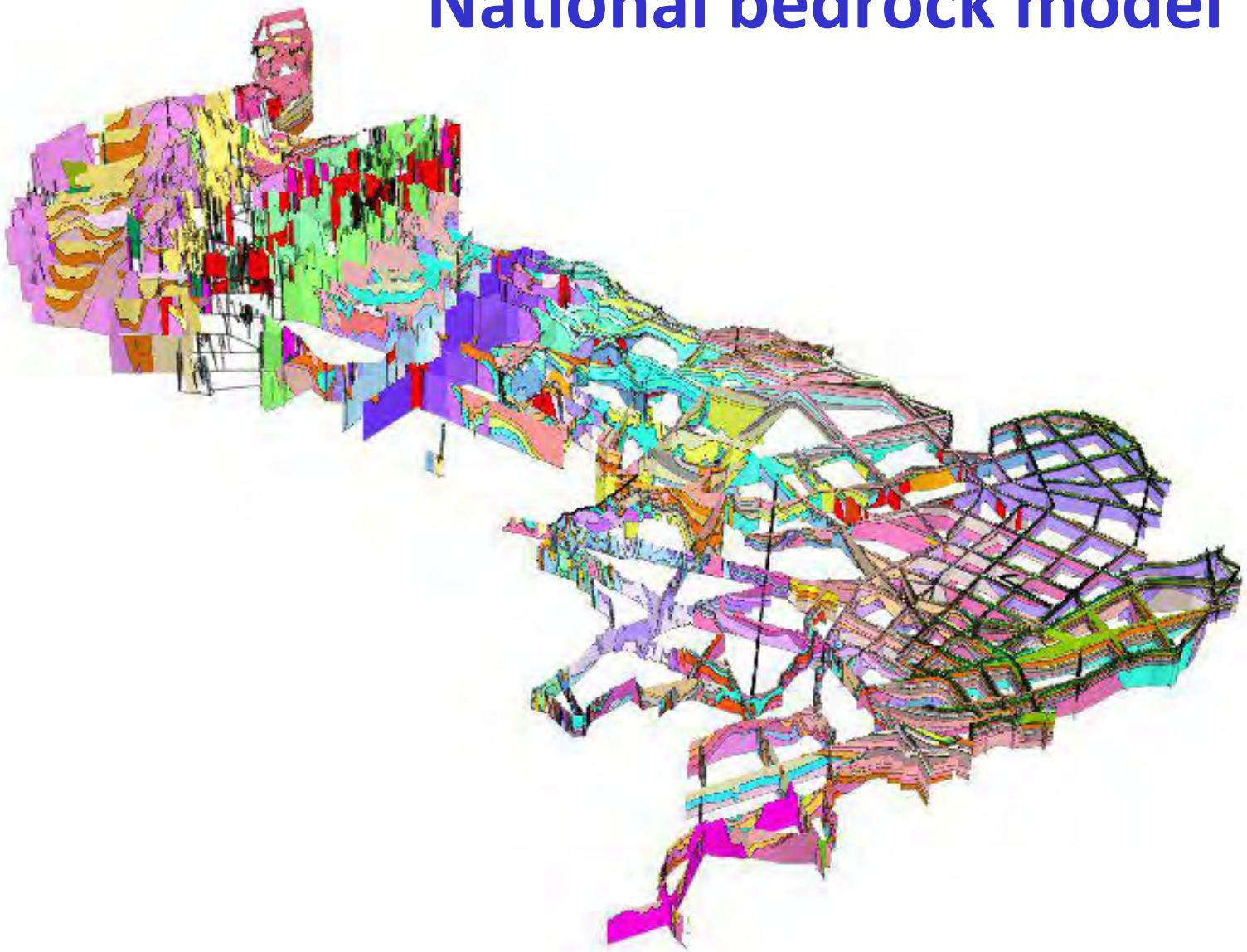
- National bedrock
- National crustal
- National Quaternary & Anthropocene
- Educational
- Collaborative
- Commercial







National bedrock model

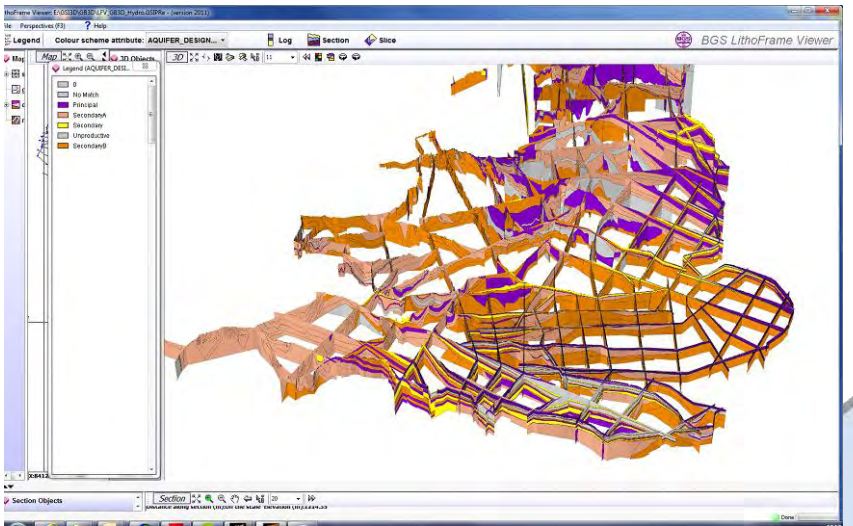


“Sharing our understanding”

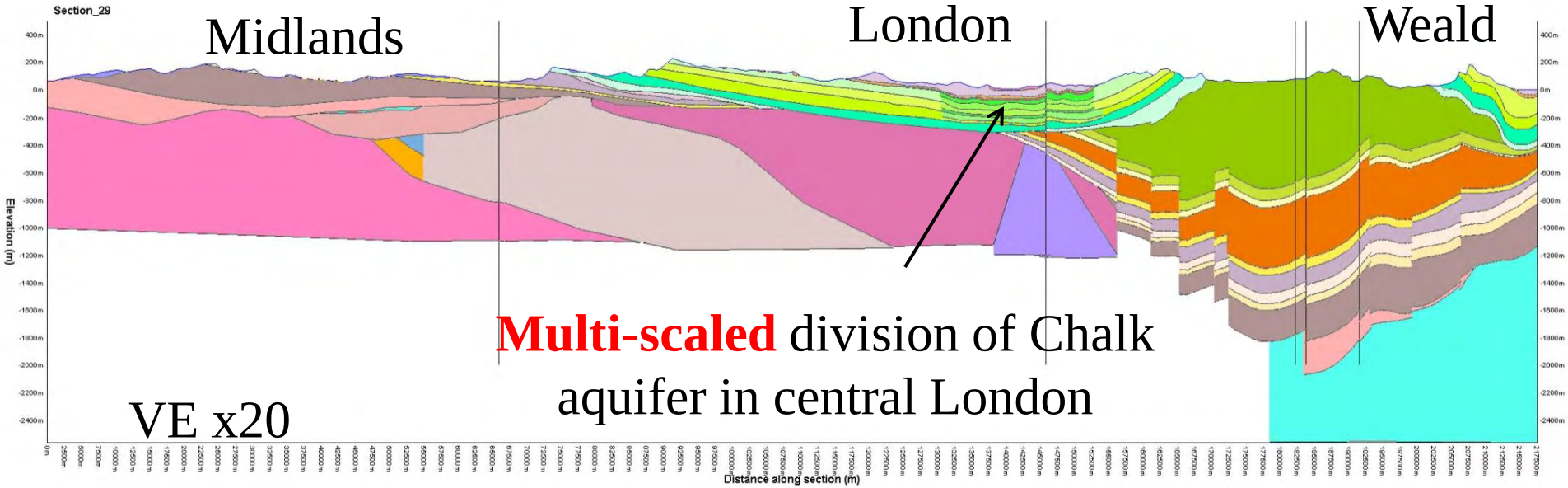
NGM- Key elements

- These 125 sections are intelligent, **utilising c. 20 existing models, 100's of existing sections contour and isopach maps**
- Measure 21,365 linear km's
- Based loosely on 625K maps & schema of 341 units,
- 14 expert regional geologists plus 3 data managers
- Already used for national and regional assessments, e.g.: Groundwater, Radwaste storage, Shale Gas, Geoscience Education (free download)
- Average **depth 2km**

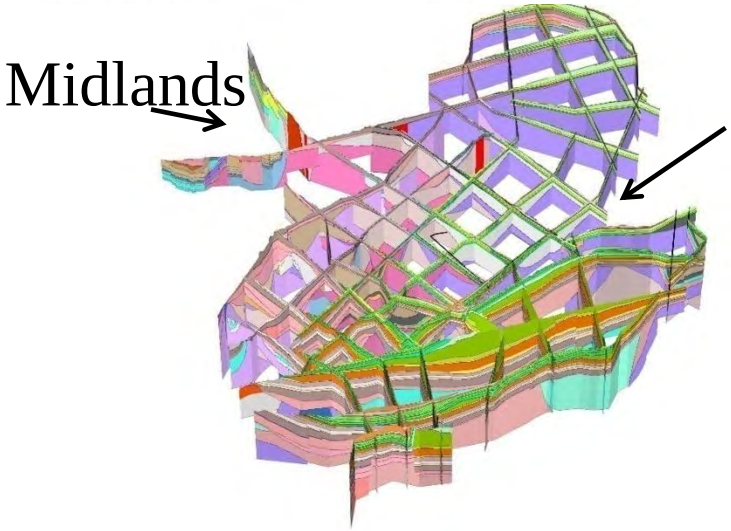
Parameterized
(e.g. aquifer type)



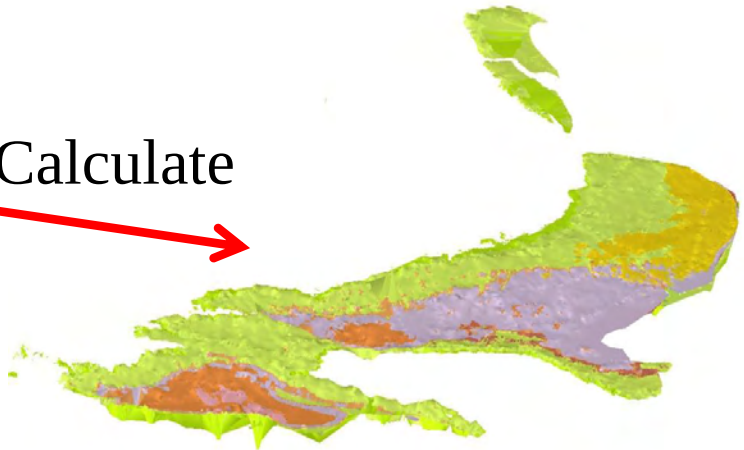
Regional context



Multi-scaled division of Chalk aquifer in central London

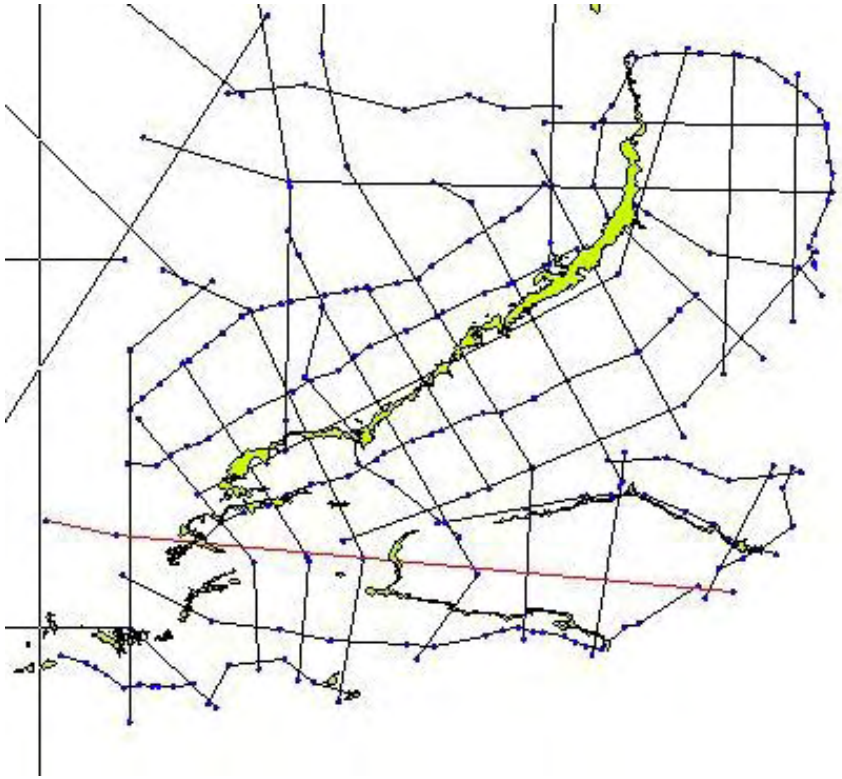


Calculate

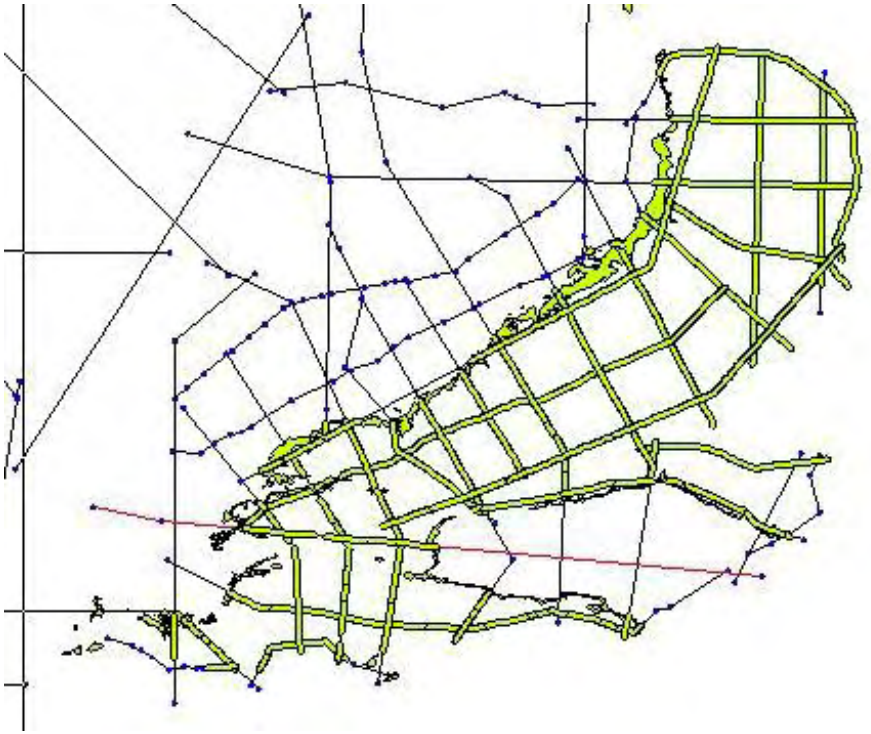


3D Volumes

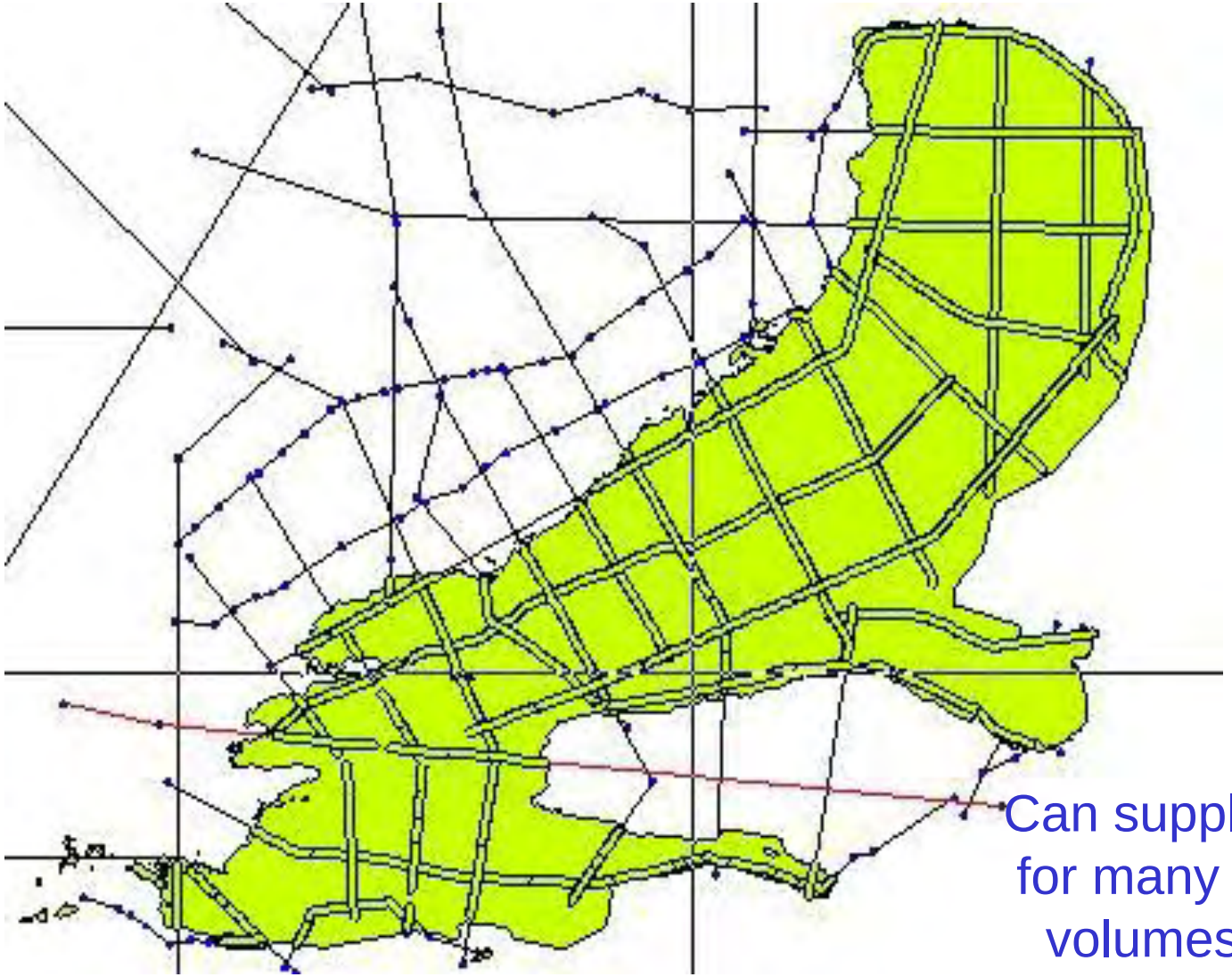
What can the NGM be used for



Outcrop Grey Chalk
From shp file attribute table



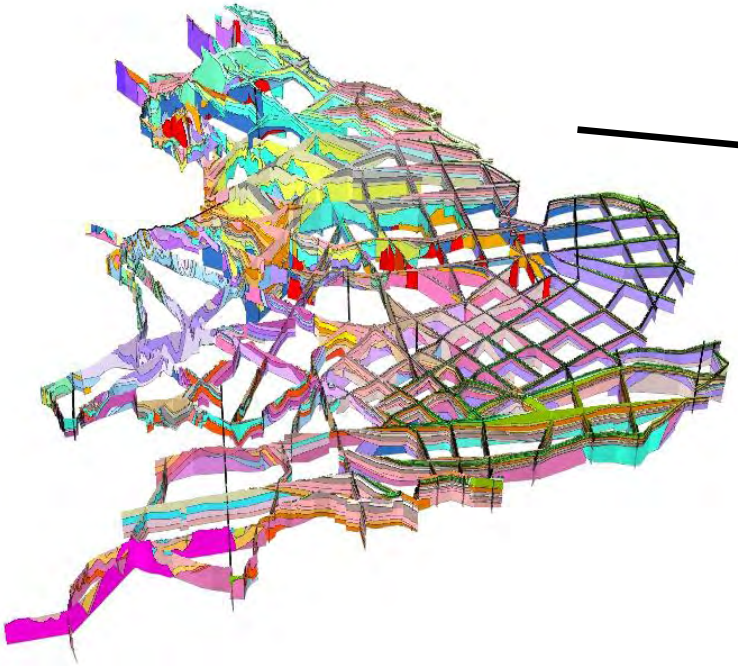
Distribution in sections
(defines subcrop)

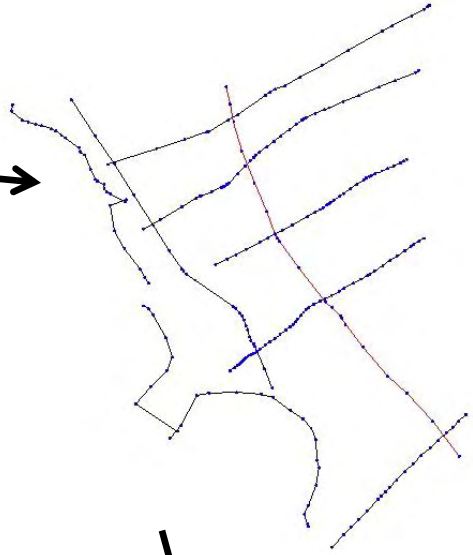


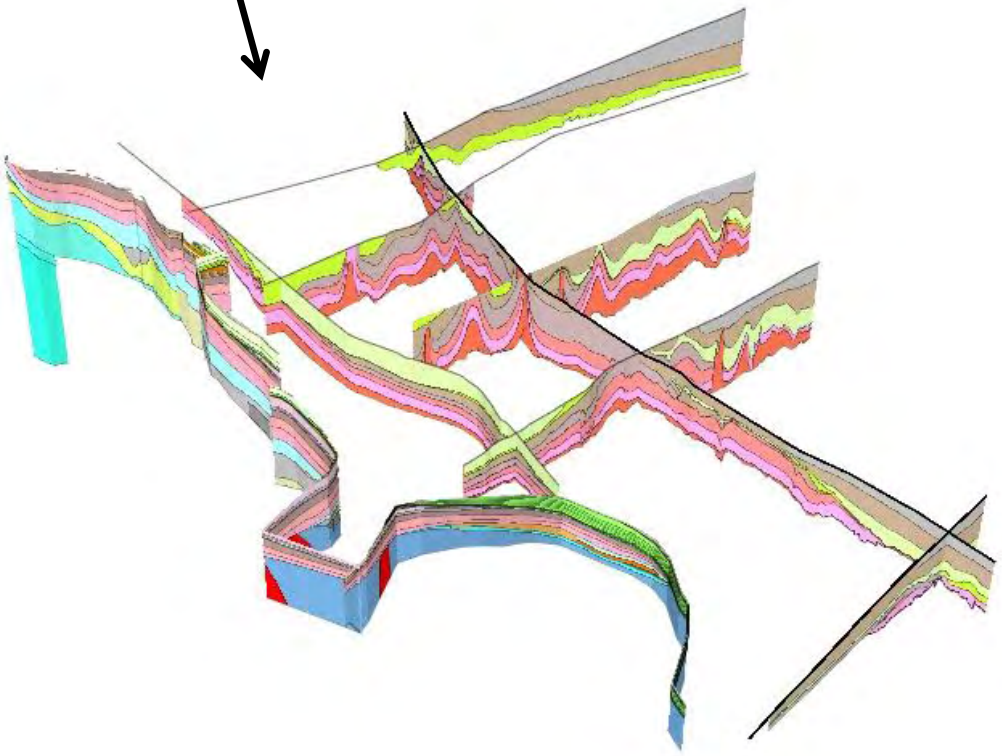
Can supply on demand for many units and 3D volumes for simpler bedrock

Outcrop and subcrop combined = **envelope** (unit distribution)

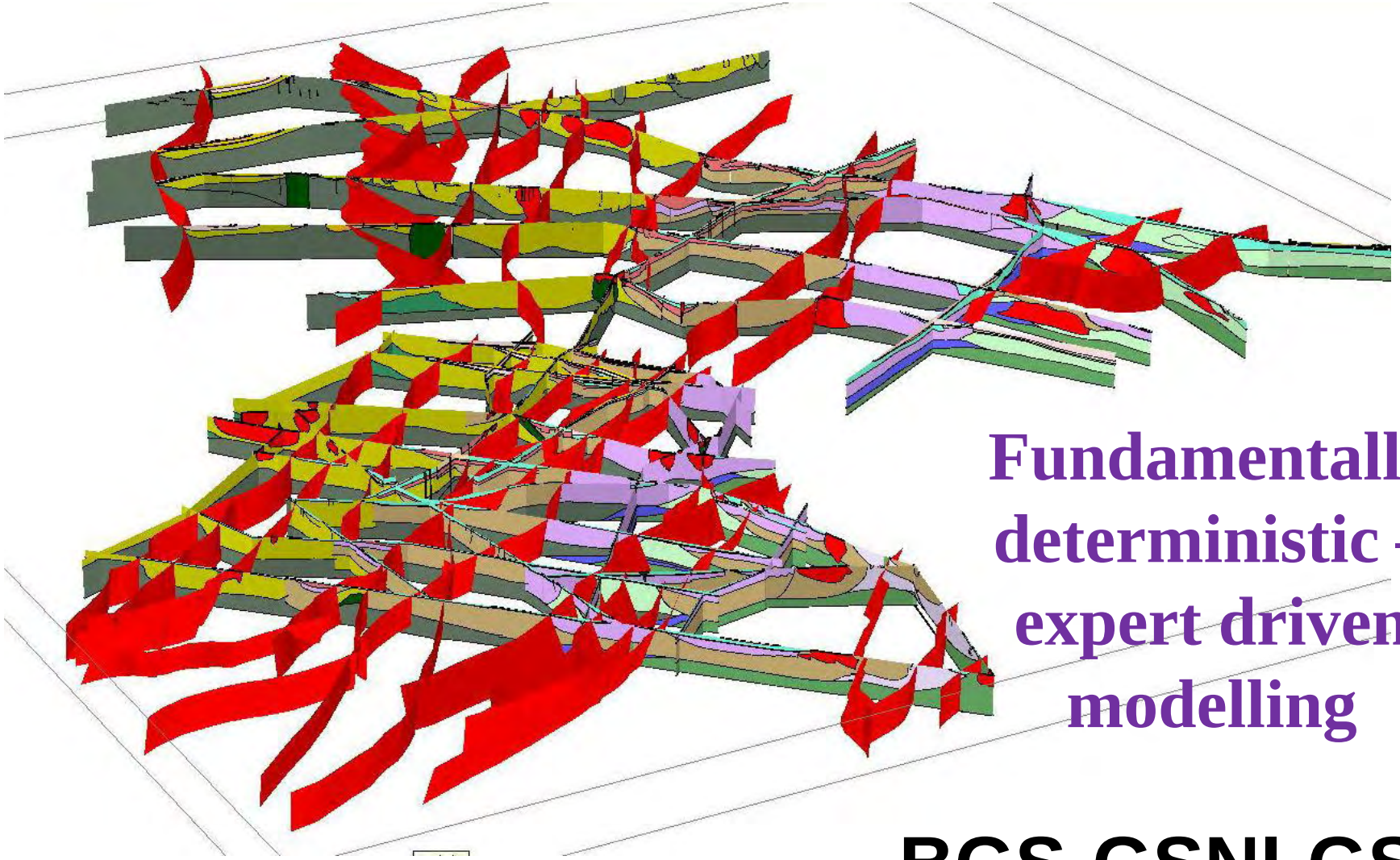
Recent **EA Shale gas study** used these







Moving offshore



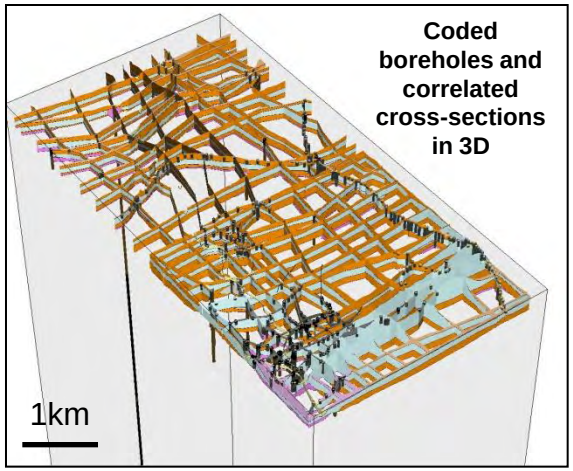
Fundamentally deterministic – expert driven modelling

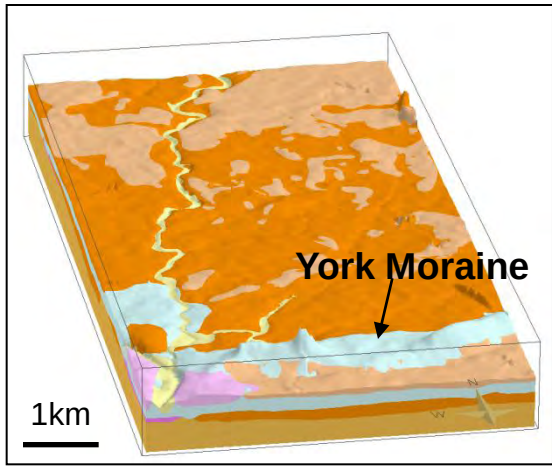
BGS-GSNI-GSI

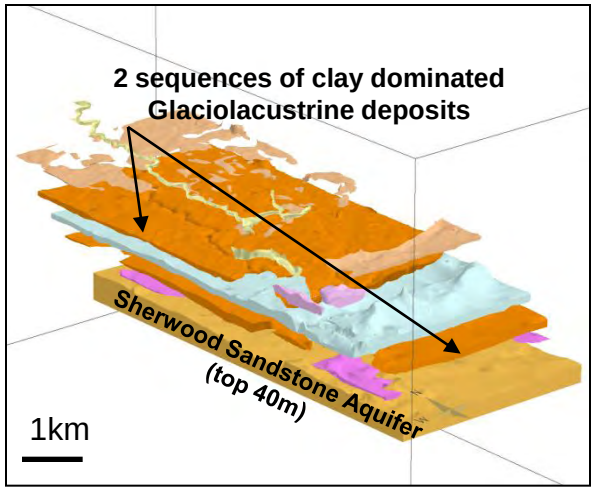
National Crustal Model

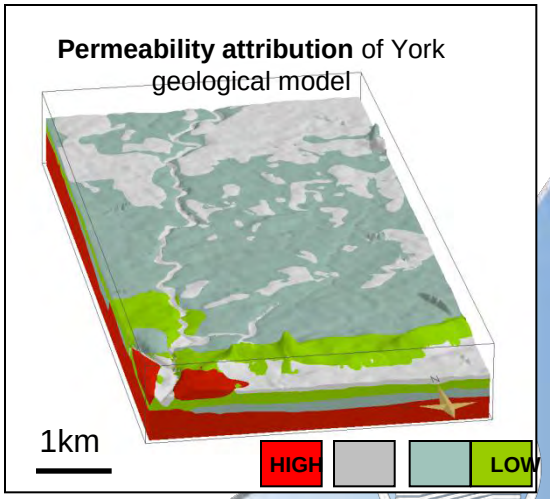
National 3D Quaternary & Anthropocene

- Unified 3D geological models of natural and artificial Quaternary deposits and landforms
- To develop 3D modelling methodologies for natural and man-made Quaternary deposits
- To build a common Quaternary 3D lithostratigraphic framework through model integration and ‘arterial’ cross-section construction along major infrastructure routes

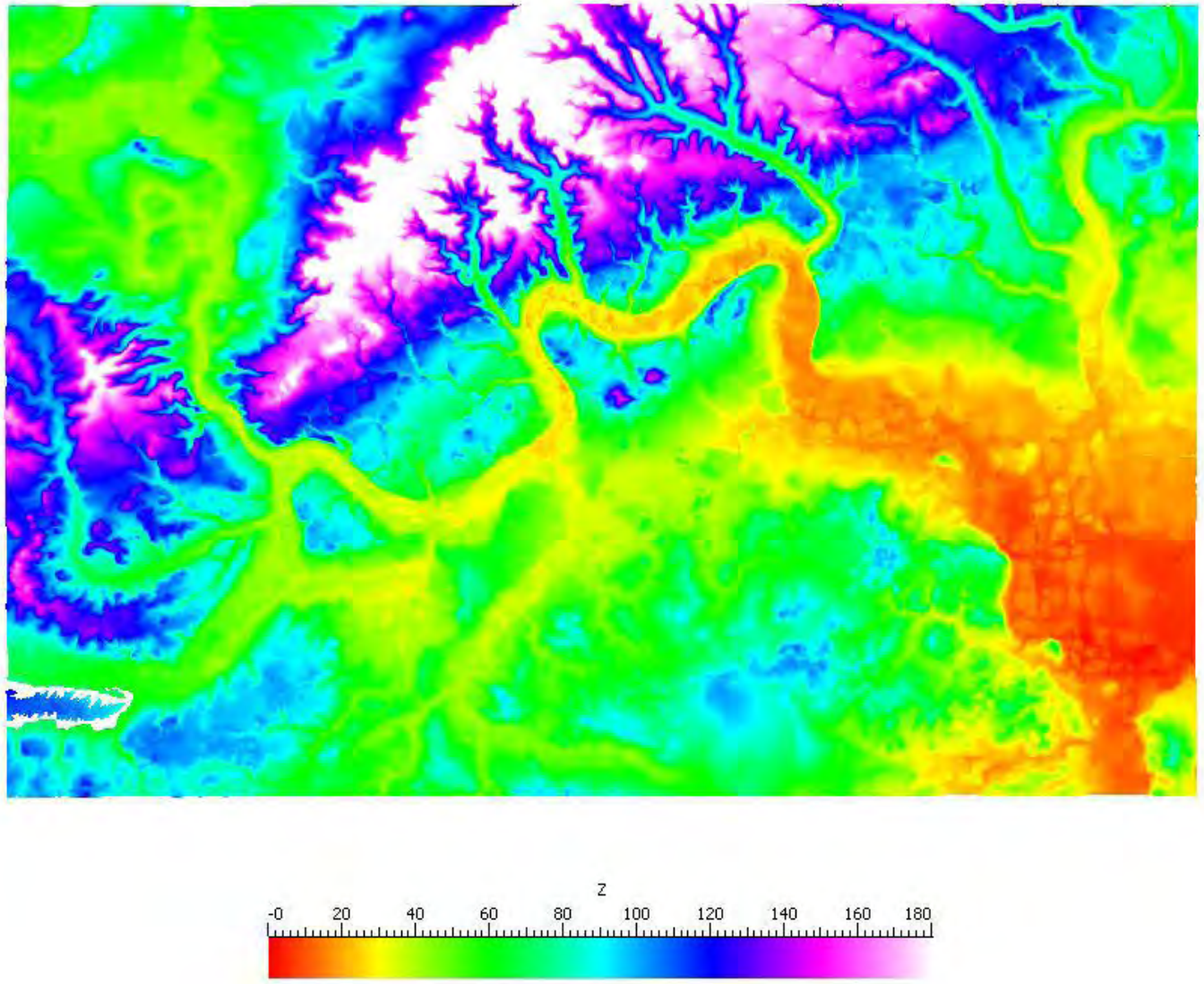






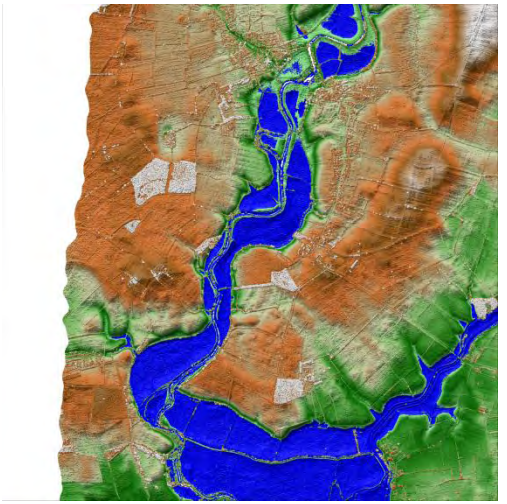


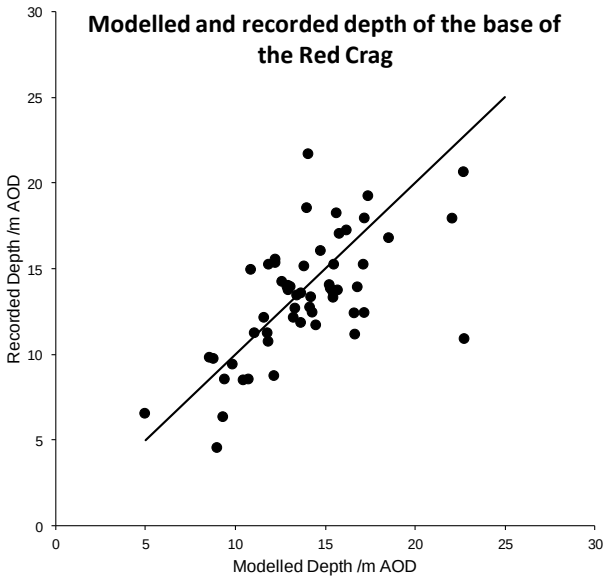
Base Quaternary surface



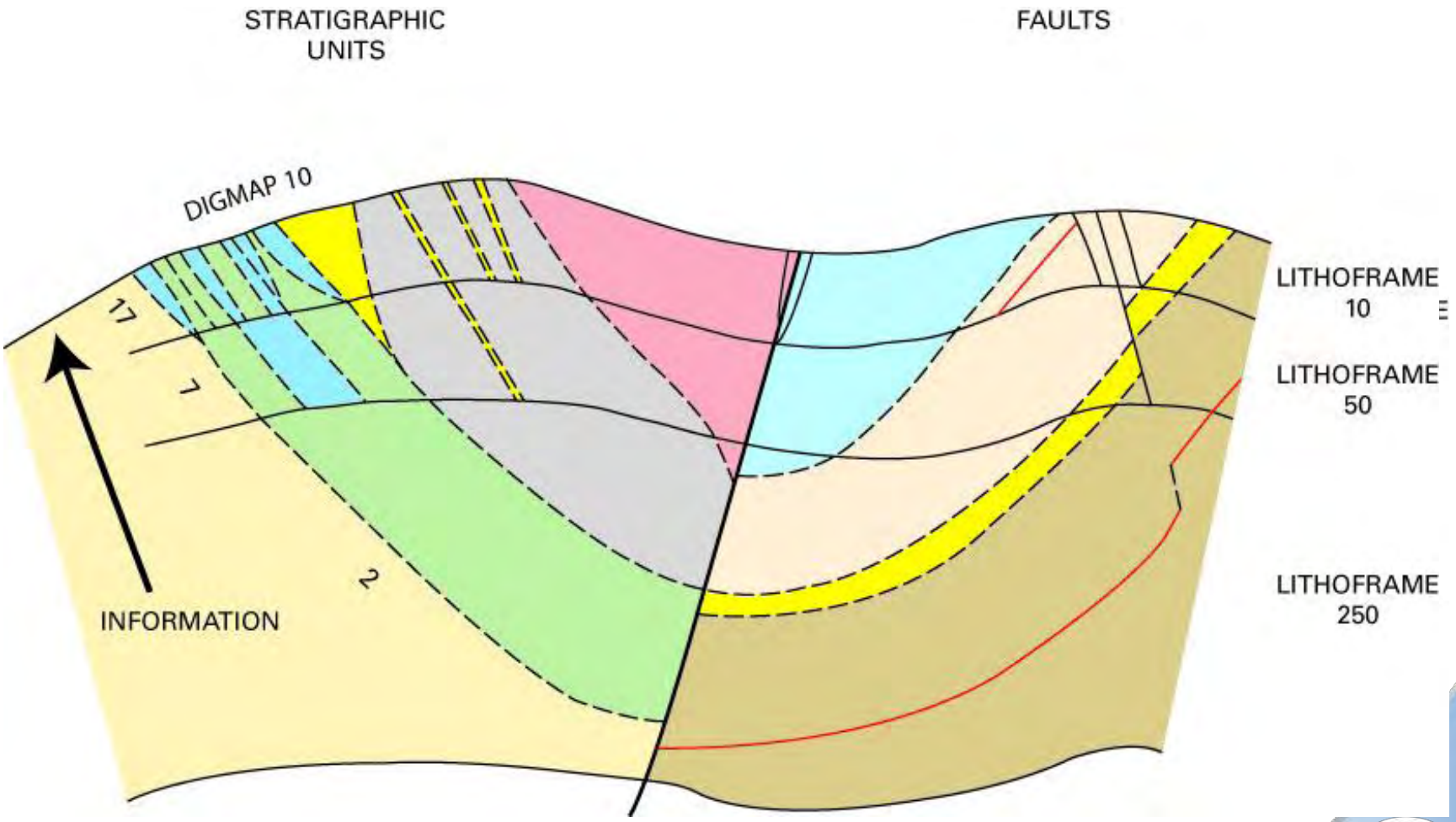
Generic issues and resources

- Model integration **multiscalar**
- DTM's
- 3D National library
- Model metadata & QA
- Uncertainty studies
- Property models, voxels and stochastics
- Model delivery
- Corporate workflow



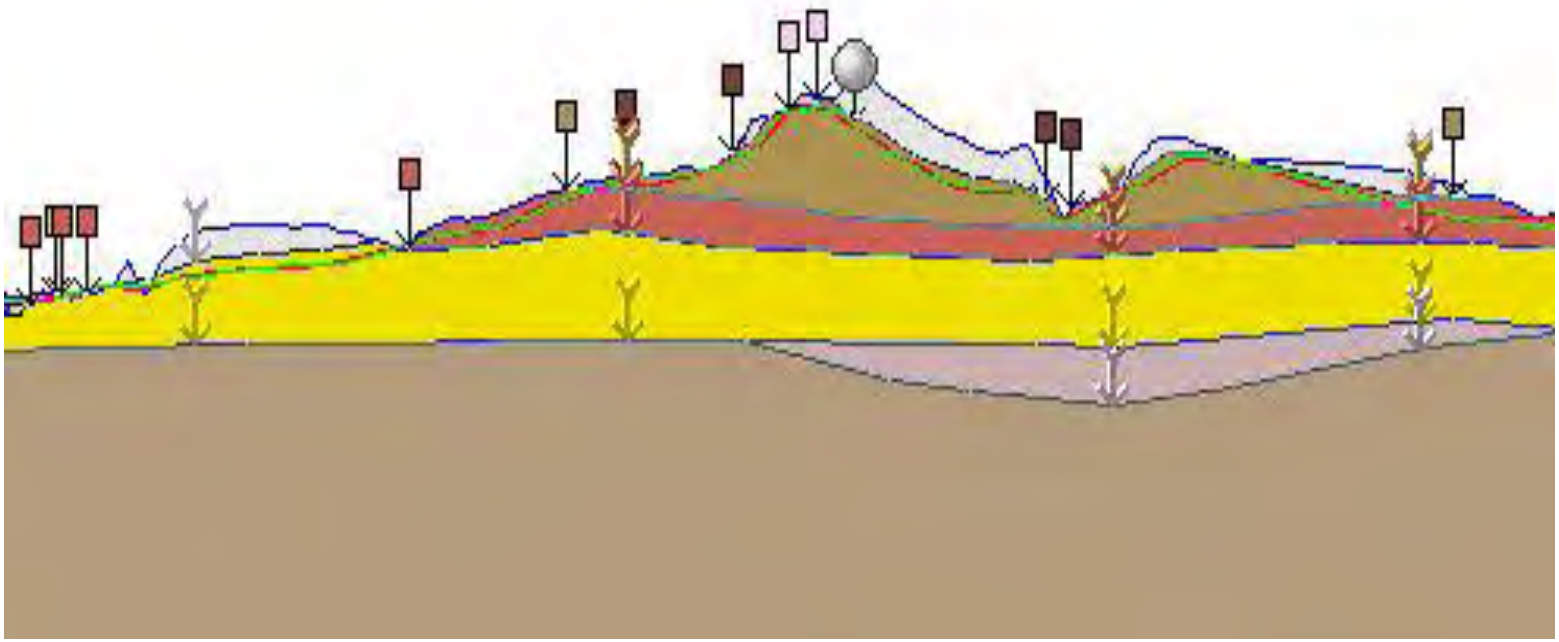


Nesting stratigraphies, compromises will be necessary



Easiest to do for Stratified rocks – stratigraphers permitting

The Search for the holy grail
Bald Earth dtm and multi-patches



Blue = NextMap with woods included

Green = OS Panorama

RED = Merged BGS Bald Earth Model

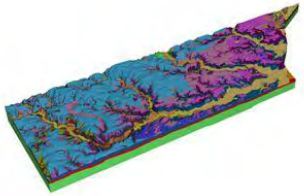
Aspiration a perfect high resolution seamless dtm-dbm

“We are passionate about metadata!!!”

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Model summary report for the Ipswich-Sudbury model

Geology and Landscapes Programme
Internal Report XX/00/00

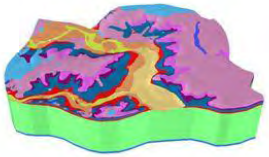


BRITISH GEOLOGICAL SURVEY

WHATEVER PROGRAMME
INTERNAL REPORT XX/00/00

Model summary report for the Ipswich-Sudbury model.

S. Mathers



Keyworth, Nottingham British Geological Survey 2012

Summary Metadata & Model Approval Form

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

This form will comprise an important part of the model metadata. On completion it should be forwarded to the TL NGM with all the other model files and documentation for incorporation into the National Geological Model.

Model name	
Model file name including version	
Link to model folder	
Link to model internal report	
Lead modeller (name or code)	
Model resolution	
Scale of use	
Grid (BNG to be onshore default and should be used in future where possible)	
Datum used (OD Newlyn to be onshore default wherever possible)	
DEM - Capping surface	
Cell size used for calculation (in metres)	
Geology (select all that apply)	Bedrock ☐ Artificial ☐ Superficial ☐ Mass Movement ☐
Extent	BOTTOM LEFT COORDINATE X Y — TOP RIGHT COORDINATE X Y
Depth range (in metres from highest surface point)	
Purpose	
Intended Output (select all that apply)	TINs-Grids ☐ Viewer Model ☐ Images on web ☐ 3D PDF ☐ Groundhog ☐ Report ☐ Other (please specify)
Software(s) used including version	
Other Models fitted to, superseded or included	
IPR status	
Confidentiality status	

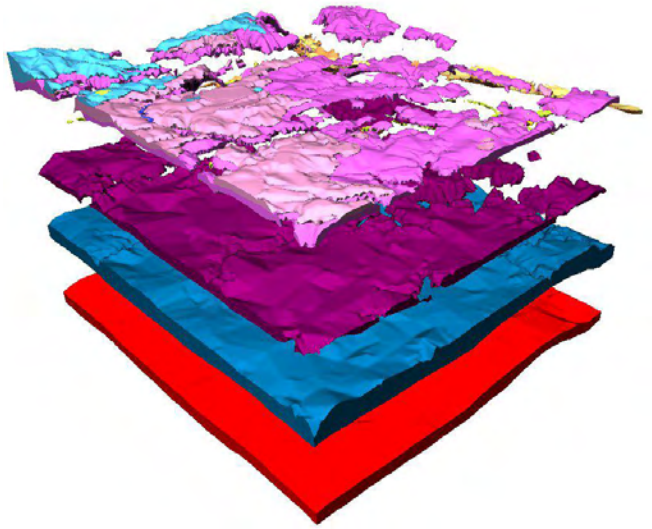
Dated signatures required:

1. Lead Modeller	
2. Project Leader (responsible for final checking of model)	
3. IPR Manager (as required)	
4. Team Leader/Chief Geologist	
5. HOS (for high profile or sensitive models when referred by the TL NGM)	

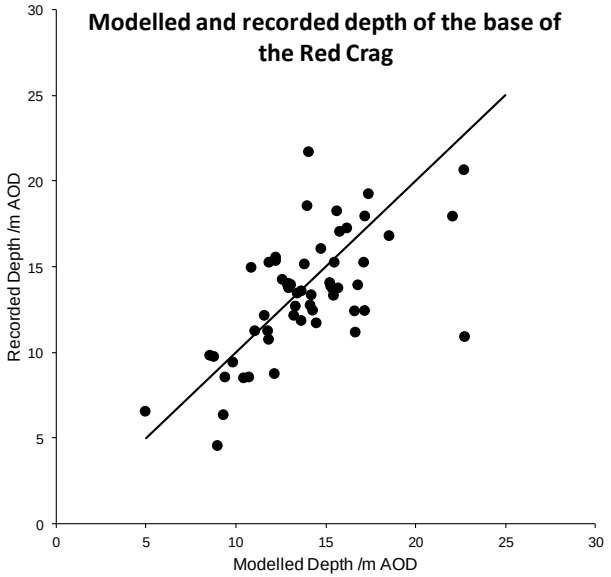
Models published as citable reference

Uncertainty studies

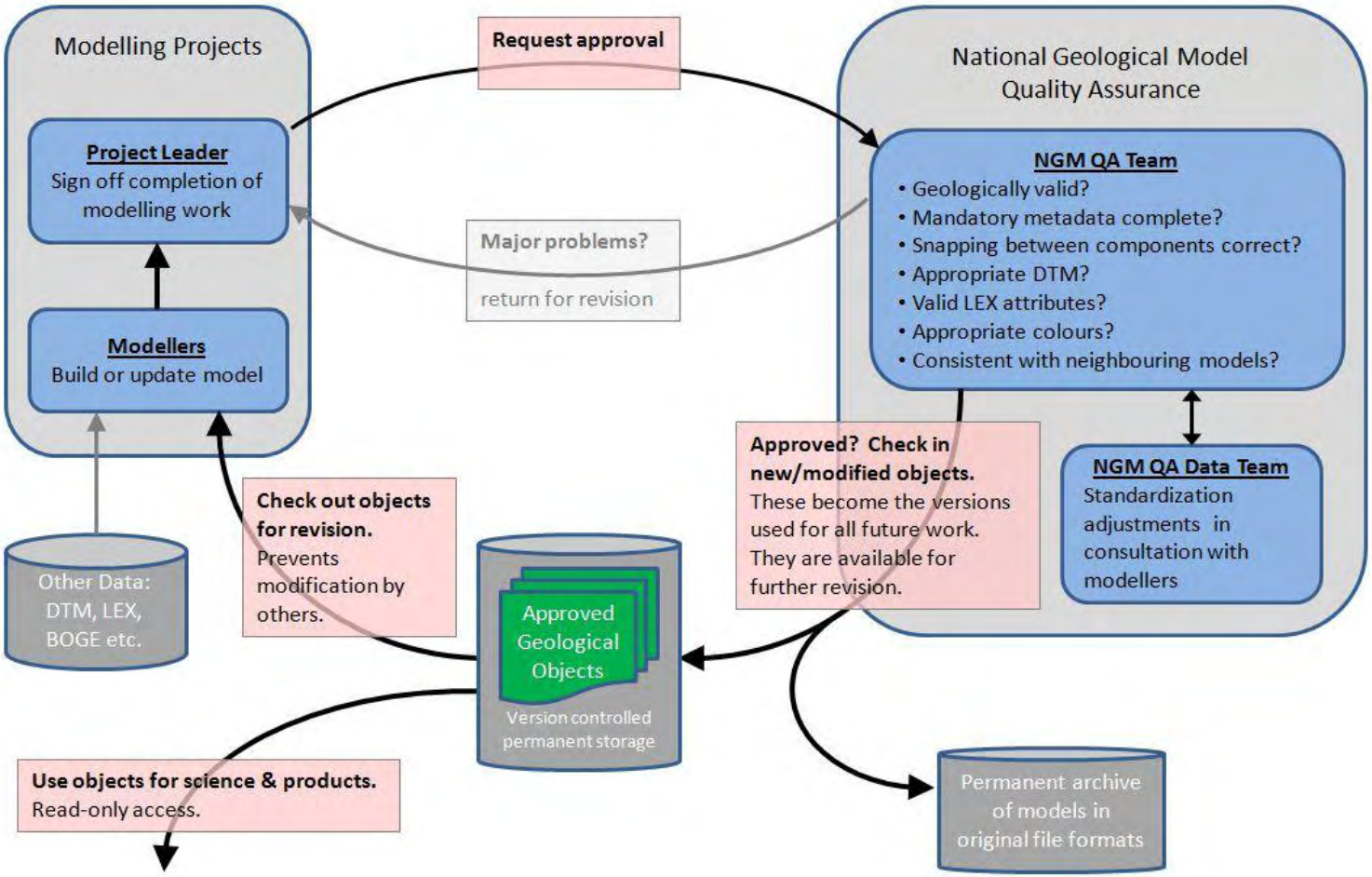
$$y_{\mathrm{b}}(\mathbf{x}) - y_{\mathrm{m},i}(\mathbf{x}) = \mu_{\mathcal{B}} + a_i(\mathbf{x}) + \varepsilon_i(\mathbf{x})$$

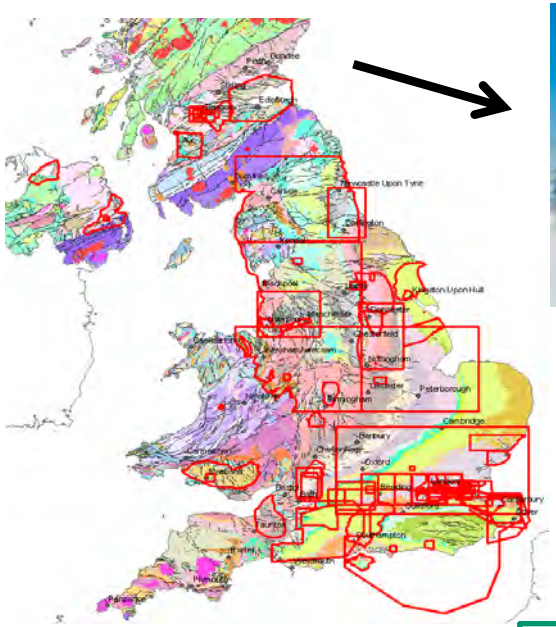


- 5 modellers modelled 6 formations in test area each using a unique subset of available boreholes from which a test set was withheld
- Each model can be compared with its test boreholes, to provide an overall data set on discrepancies between the model prediction and the corresponding observations.
- Analysis of these data enable us to quantify the overall model error, and contributions made to it by variation between modellers and how model uncertainty varies with factors such as depth and distance to boreholes.



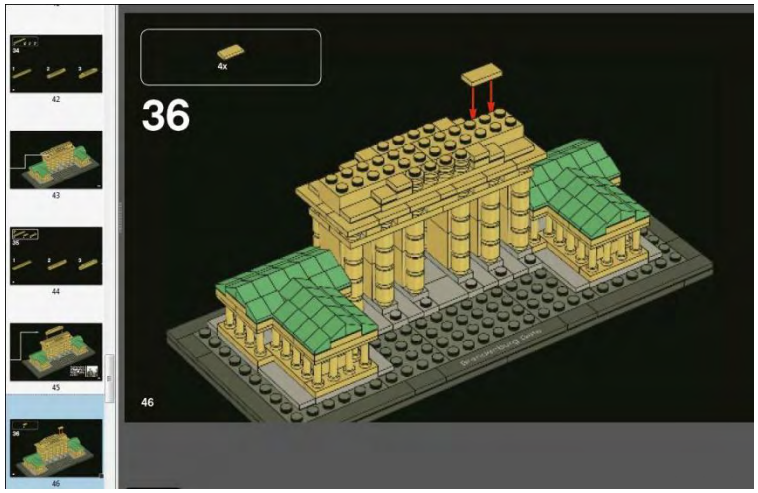
Model build & storage workflow





Existing models

Jumble of Lego bricks



Assembly instructions & QA

The National Geological Model

Frozen models

Objects Datastore

New models

Model Delivery

Baseline Data:
Boreholes, DTMs, geological maps, geophysics etc.

Plus geological concepts and knowledge

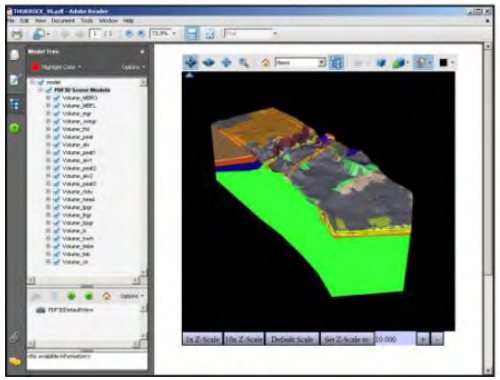
3D Geological Model

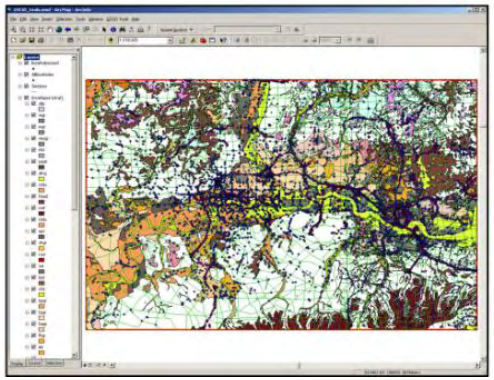
Publish

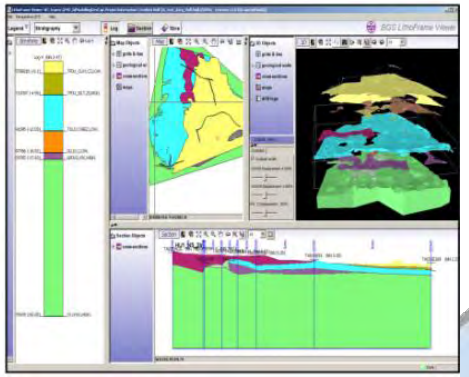
Visualisations e.g. 3D PDF

GIS data (shapes and grids)

3D Geological Map
Sub-surface Viewer



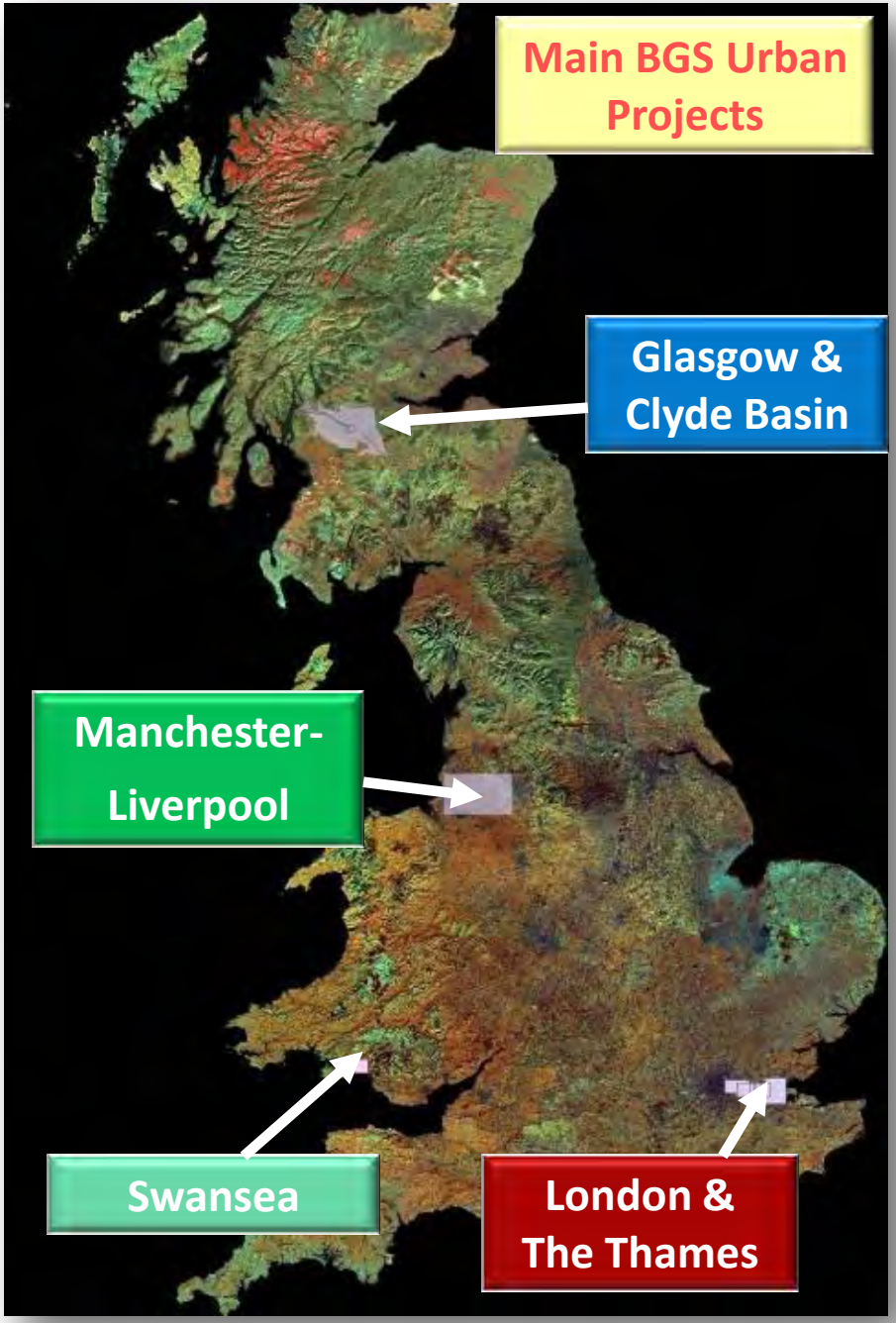




BGS's Urban Strategy

Why?

- >80% UK population
- Environmental impacts
- Abundant subsurface data
- Ideal test bed for predictive 3D/4D modelling



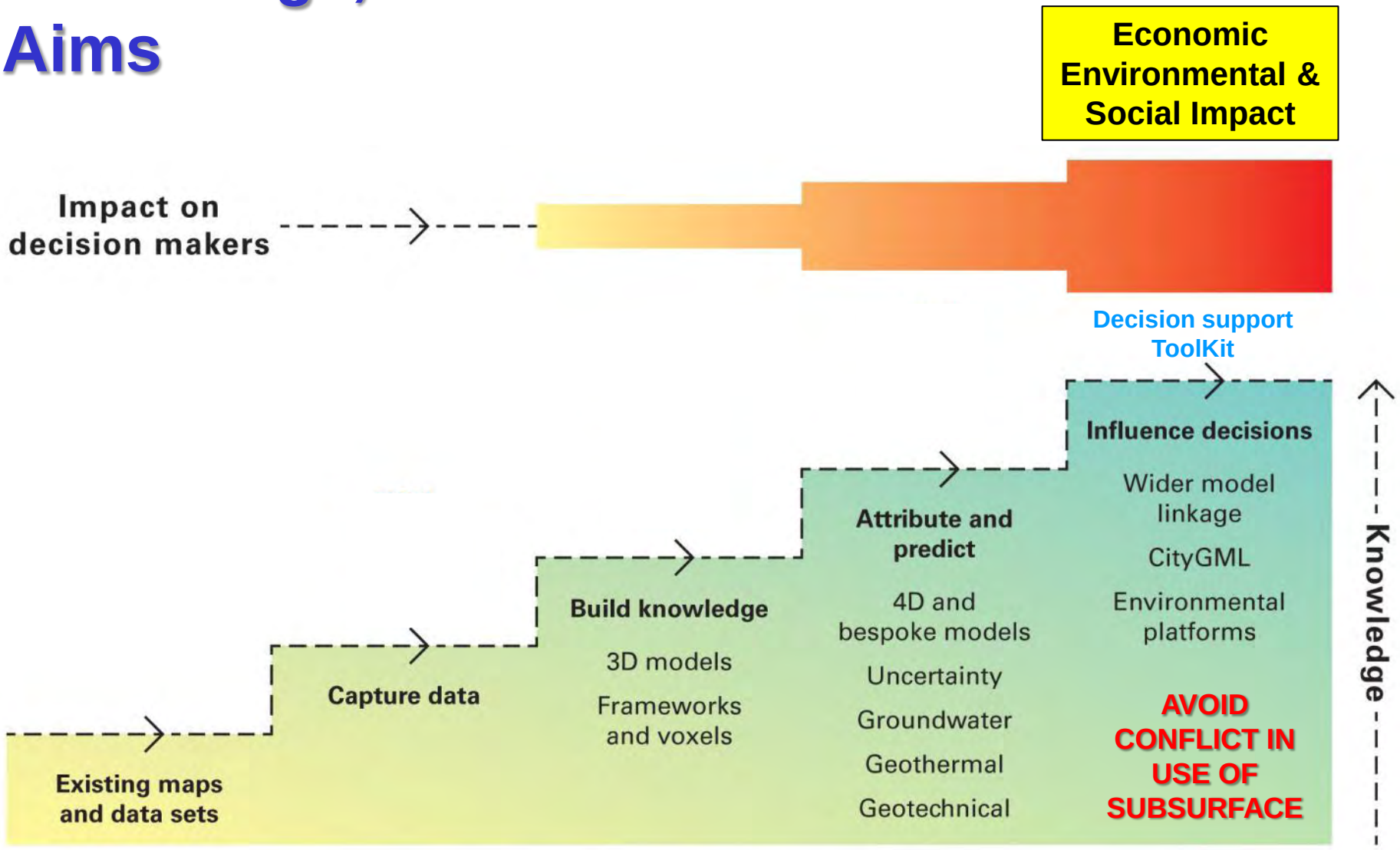
Key drivers (Glasgow)

- Glasgow regeneration
- BGS data & knowledge can support needs
- Local partners – Glasgow CC etc
- Complex industrial legacy

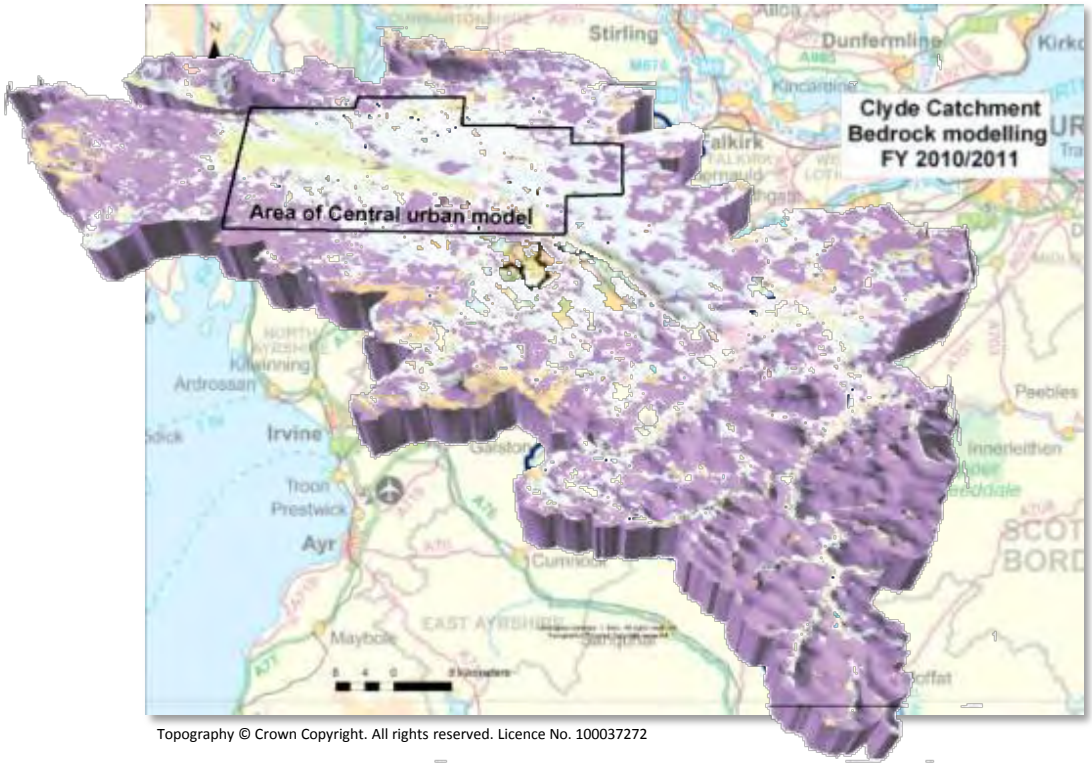
Urban Sub-Surface Knowledge, Needs and Aims

cost
European Cooperation in Science and Technology

Sub-Urban



BGS's Clyde / Glasgow Project - CUSP



Clyde Catchment
Glasgow conurbation
Development & Regeneration areas

3D geological models to help address:

Ground conditions
Contaminated Land
Land Use change impacts
Flooding
Sustainable drainage (SuDS)
Ground Source Heat resource

Clyde Gateway and 2014 Commonwealth Games

Multi-agency project regenerating east Glasgow and S Lanarkshire

Budget: £2.5 billion over 25 years

Targets: 10,000 new houses, 400,000 sq m business/commercial property
50,000 sq m retail outlets, M74 extension and new roads.

Sports arena, velodrome and athletes village
COMMONWEALTH GAMES 2014

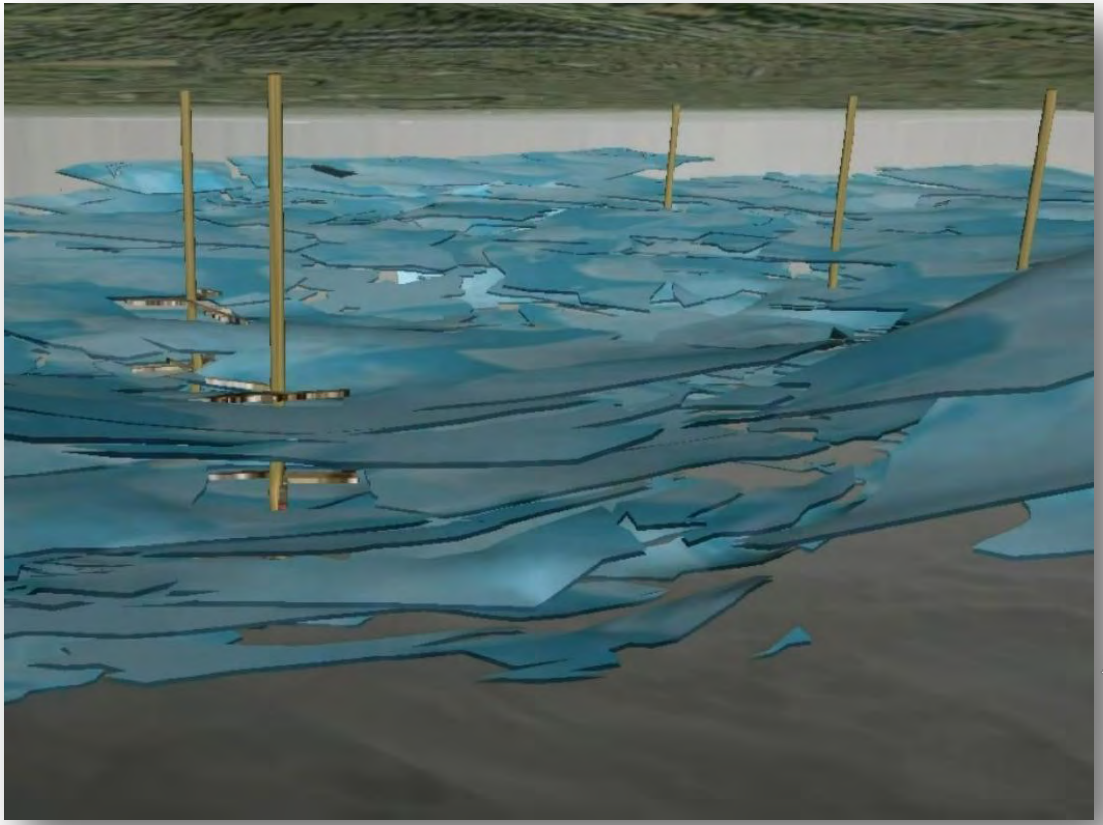
Glasgow 3D models

- synthesis of current knowledge of Glasgow's subsurface
- most ambitious yet completed in the UK
- conurbation-wide
- multi scalar multi-attributed
- >50,000 coded boreholes used
- Models used by GCC and for groundwater research

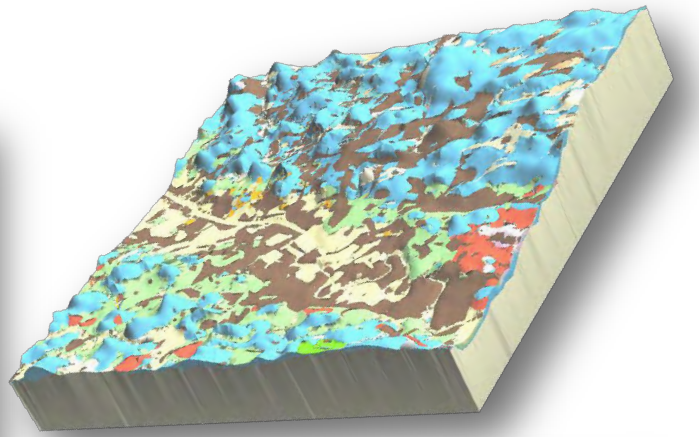
full potential is yet to be realised
by the wider community

A range of 3D models

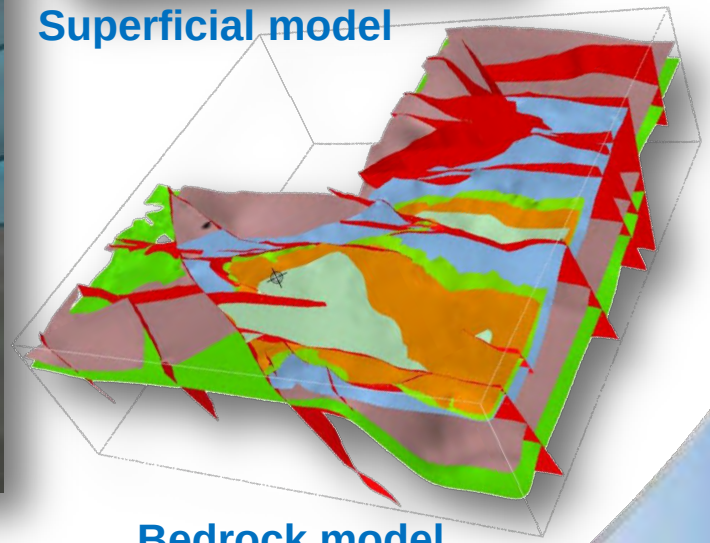
3D geological framework models



Coal seam model



Superficial model



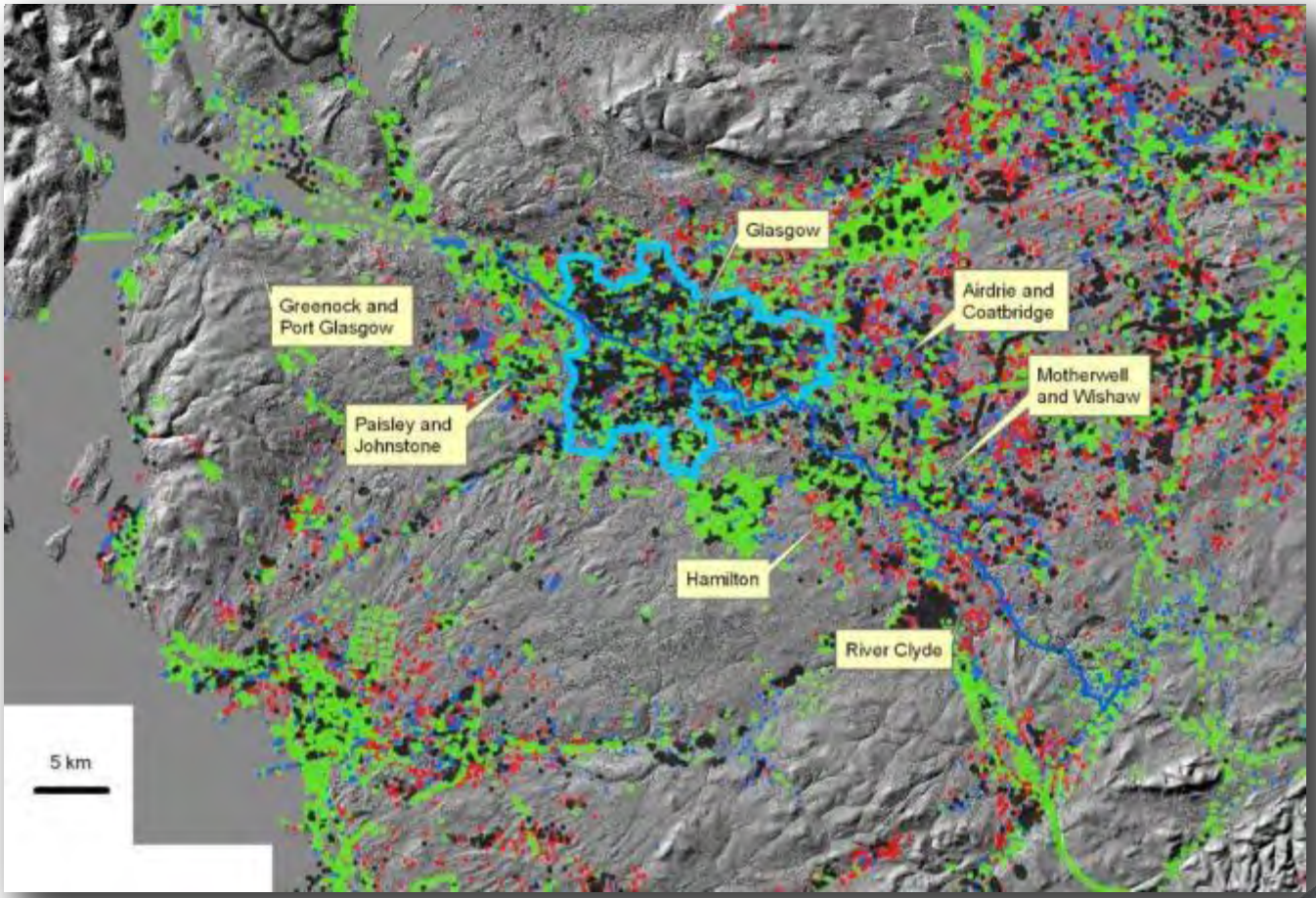
Bedrock model

Key Glasgow 3D model requirements

Detailed ground height data (Digital Terrain Model)

Ground investigation data and information

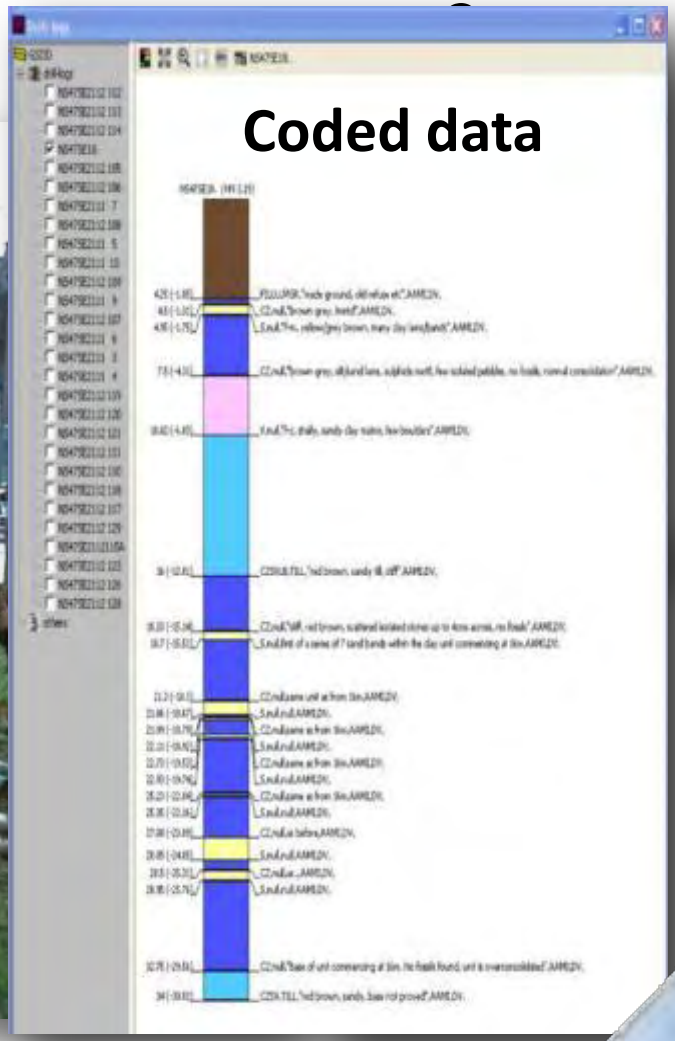
Boreholes provide most depth information
36,000 in BGS archives for Glasgow City



NEXTMap DTM (Intermap Technologies Inc)

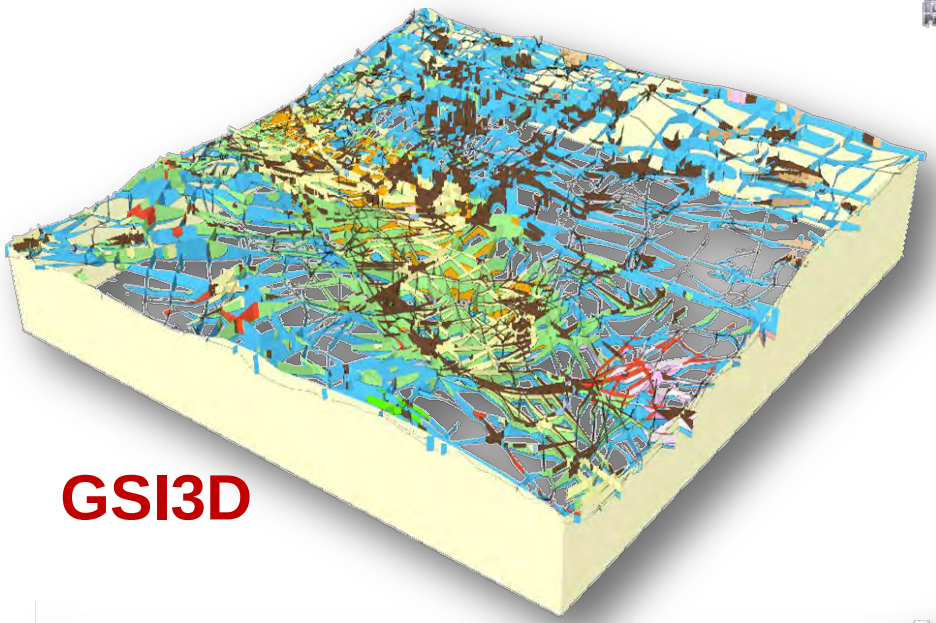
Borehole locations (green, red, black, blue) with archived data

Information from boreholes



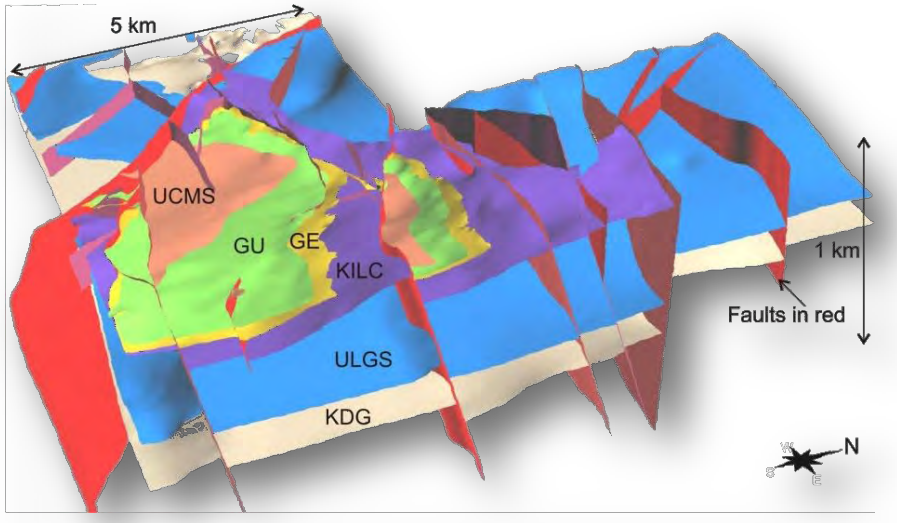
Glasgow 3D geological modelling

variety of methods and software depending on local geology and information available

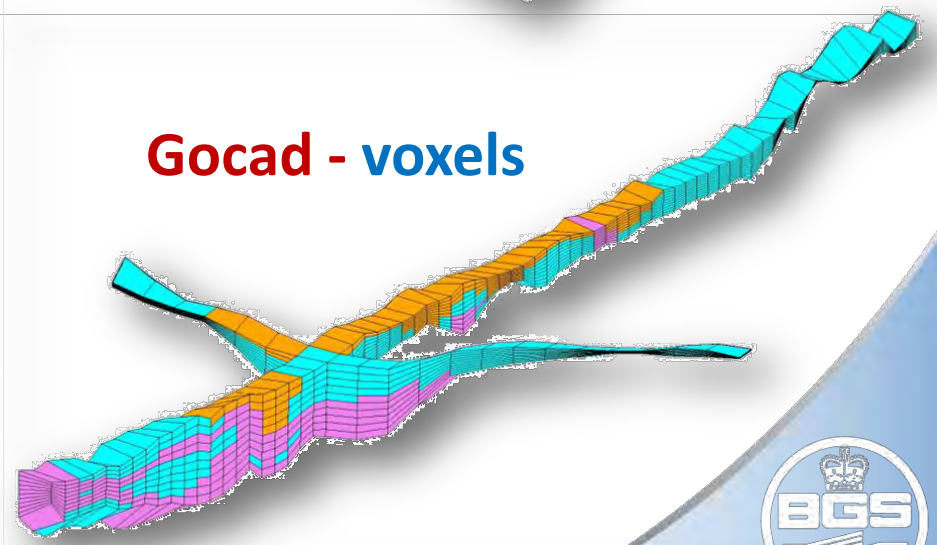


GSI3D

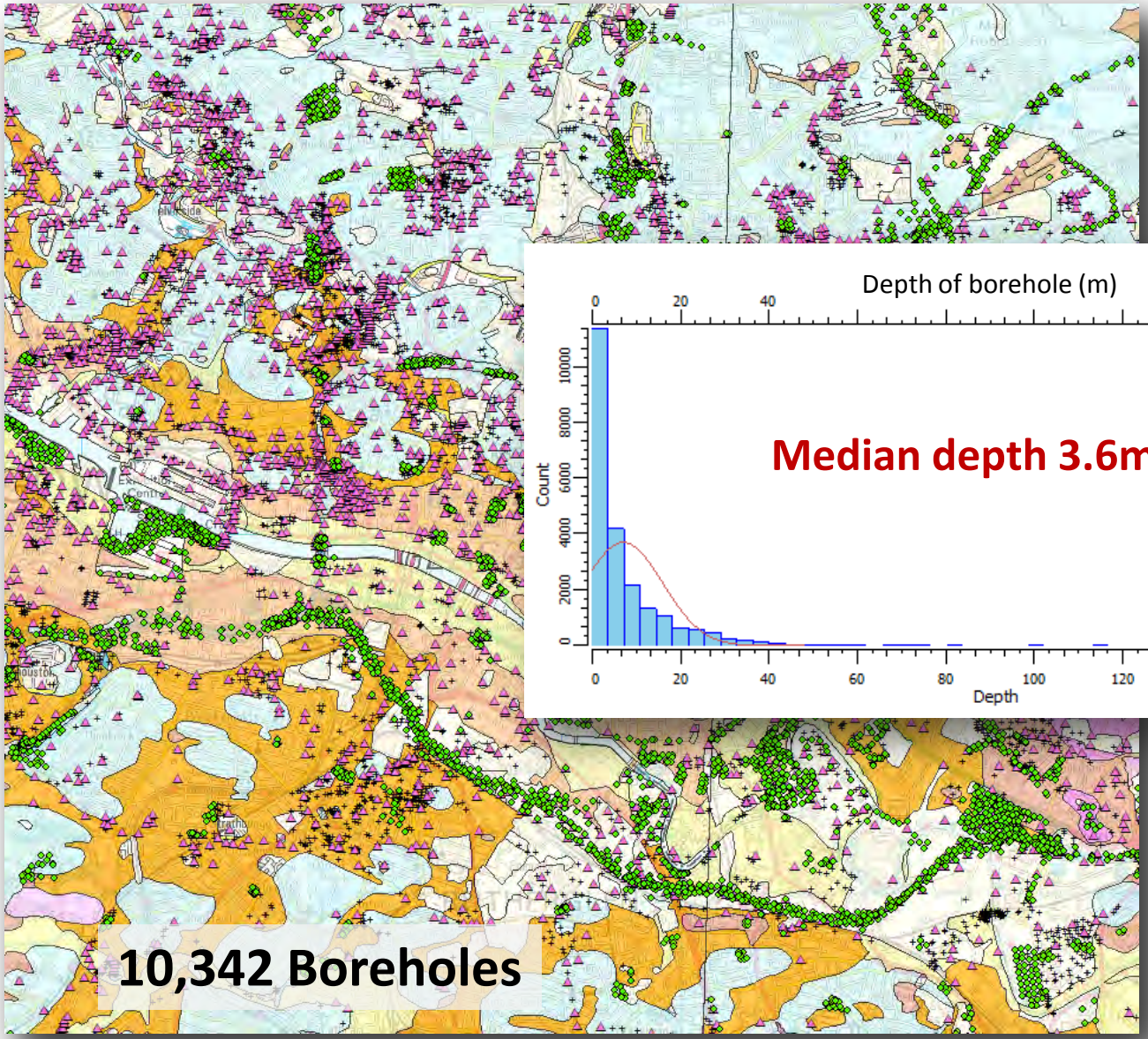
Gocad - surfaces



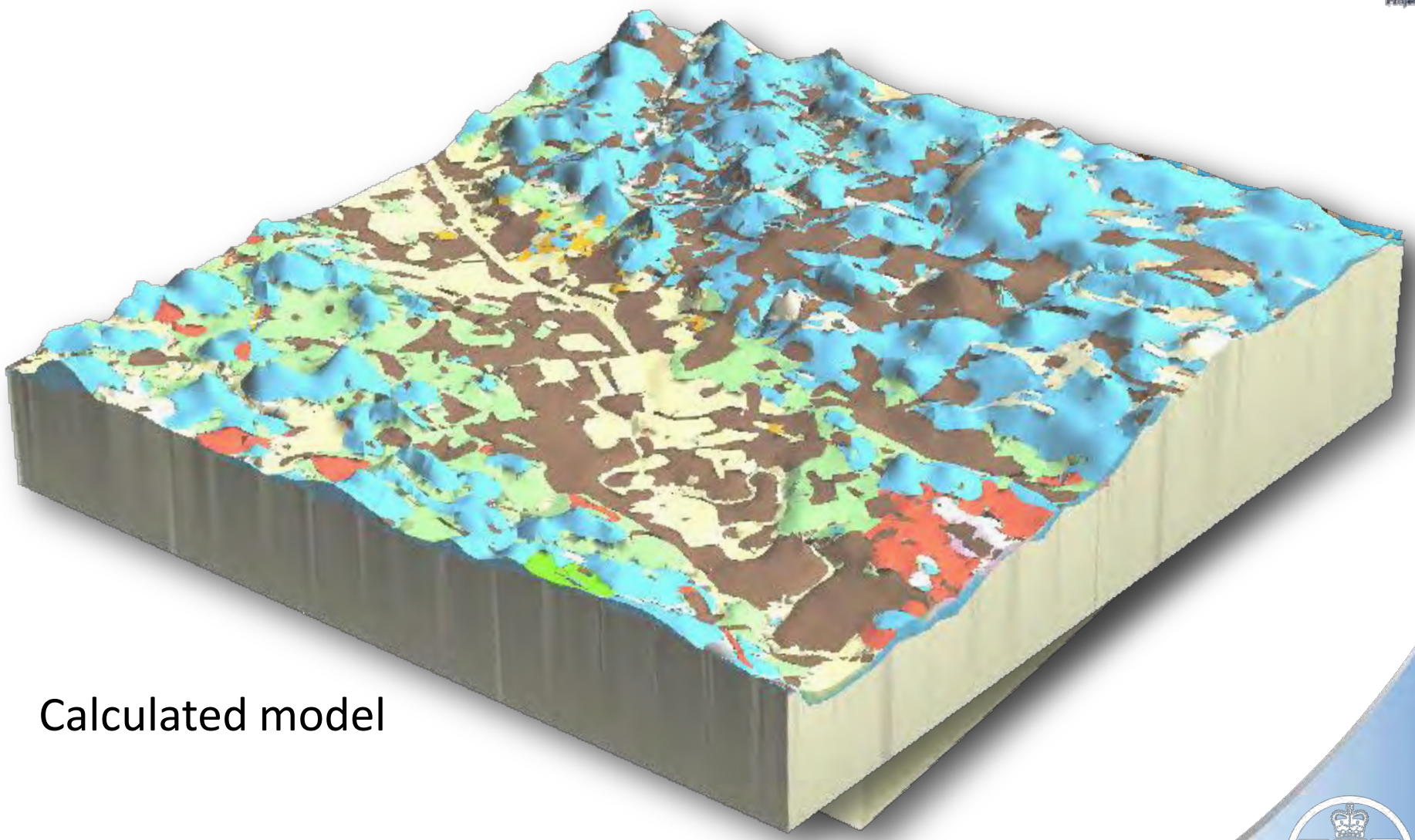
Gocad - voxels



Central Glasgow superficial deposits

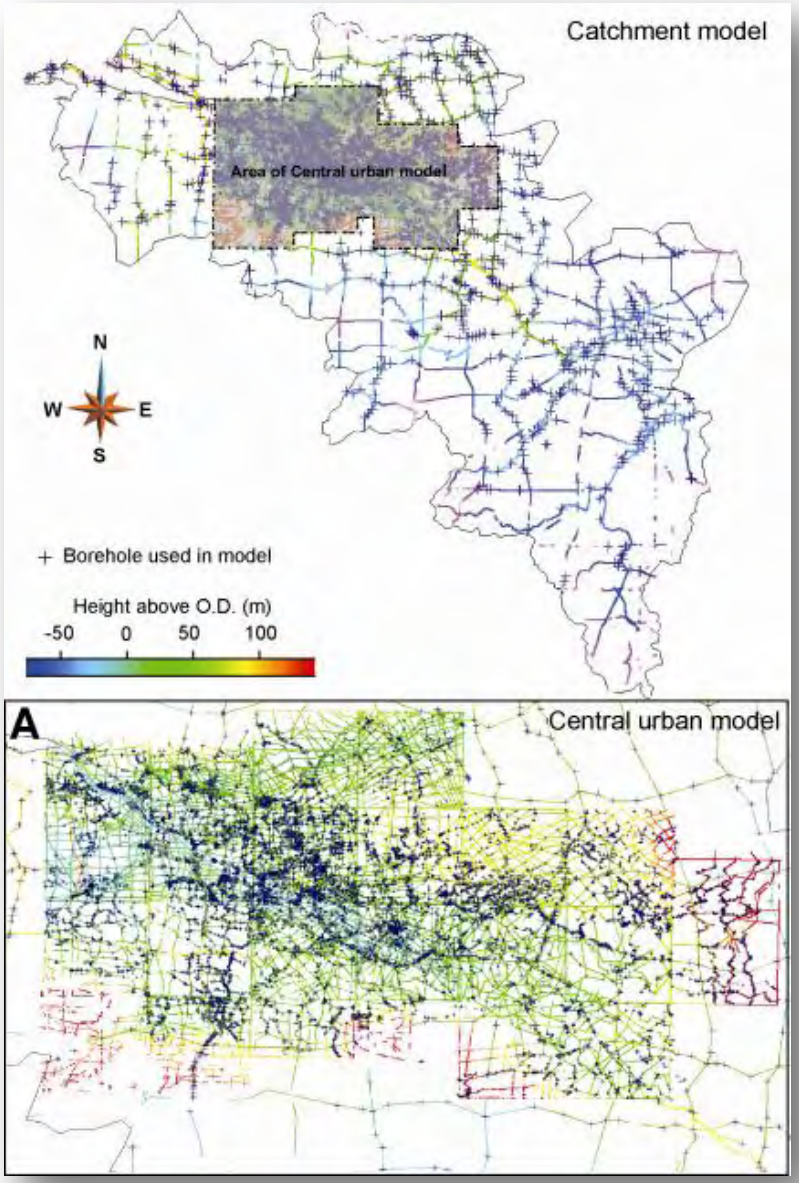


GSI3D Modelling process



Calculated model

Superficial Deposits model



Catchment model

85 cross sections

1066 boreholes

41,727 surface control points

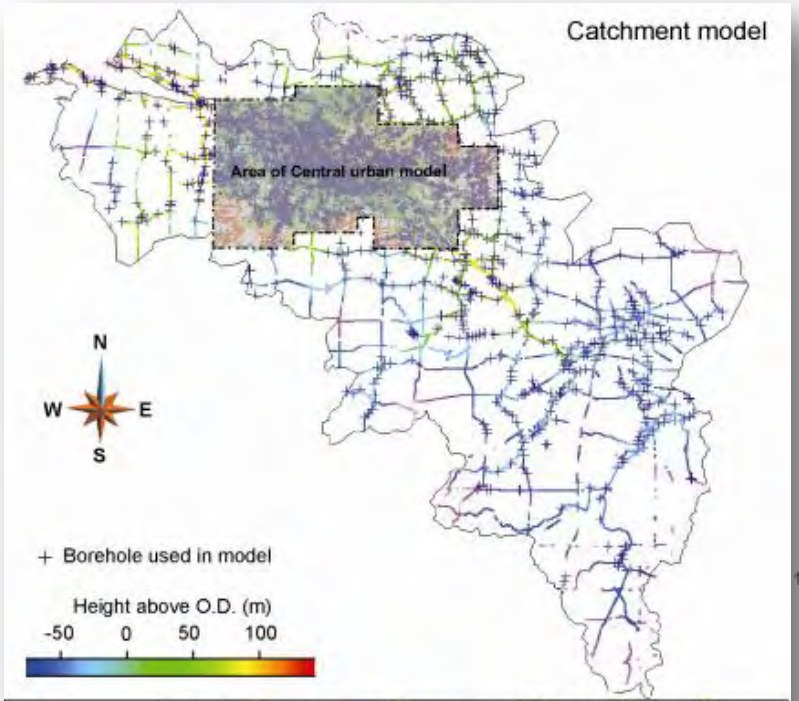
Conurbation model

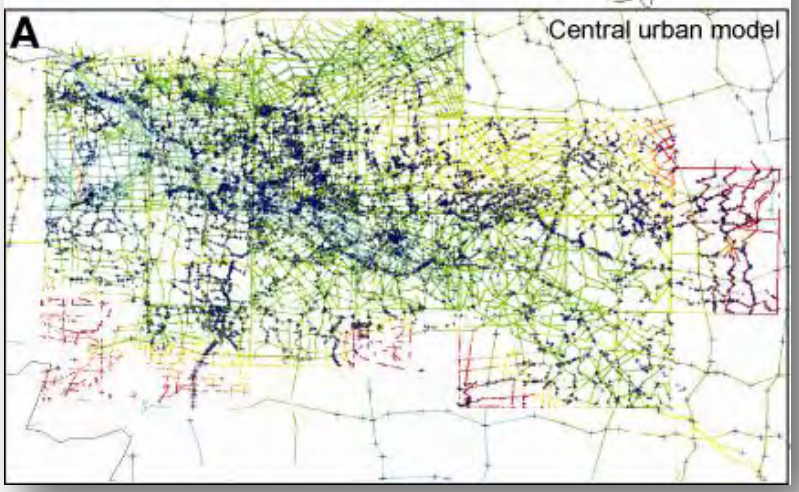
1167 cross sections

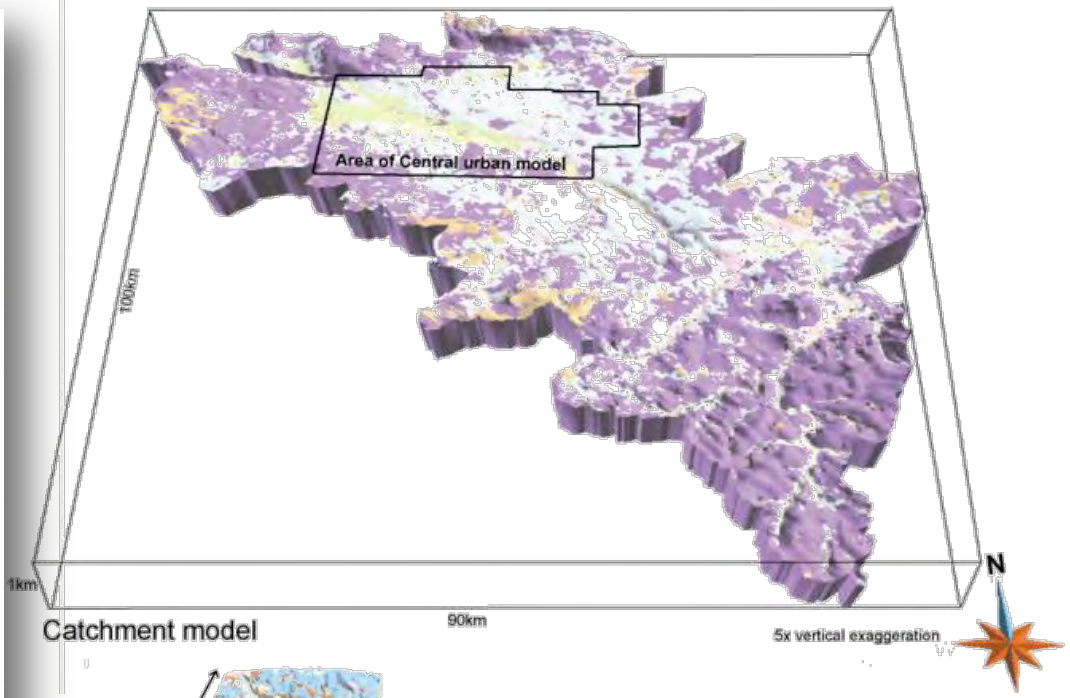
11,570 boreholes

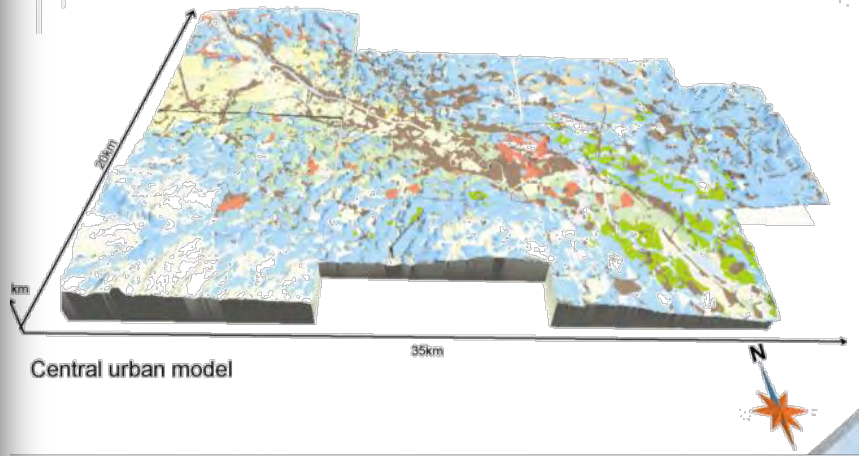
326,942 surface control points

Superficial Deposits model

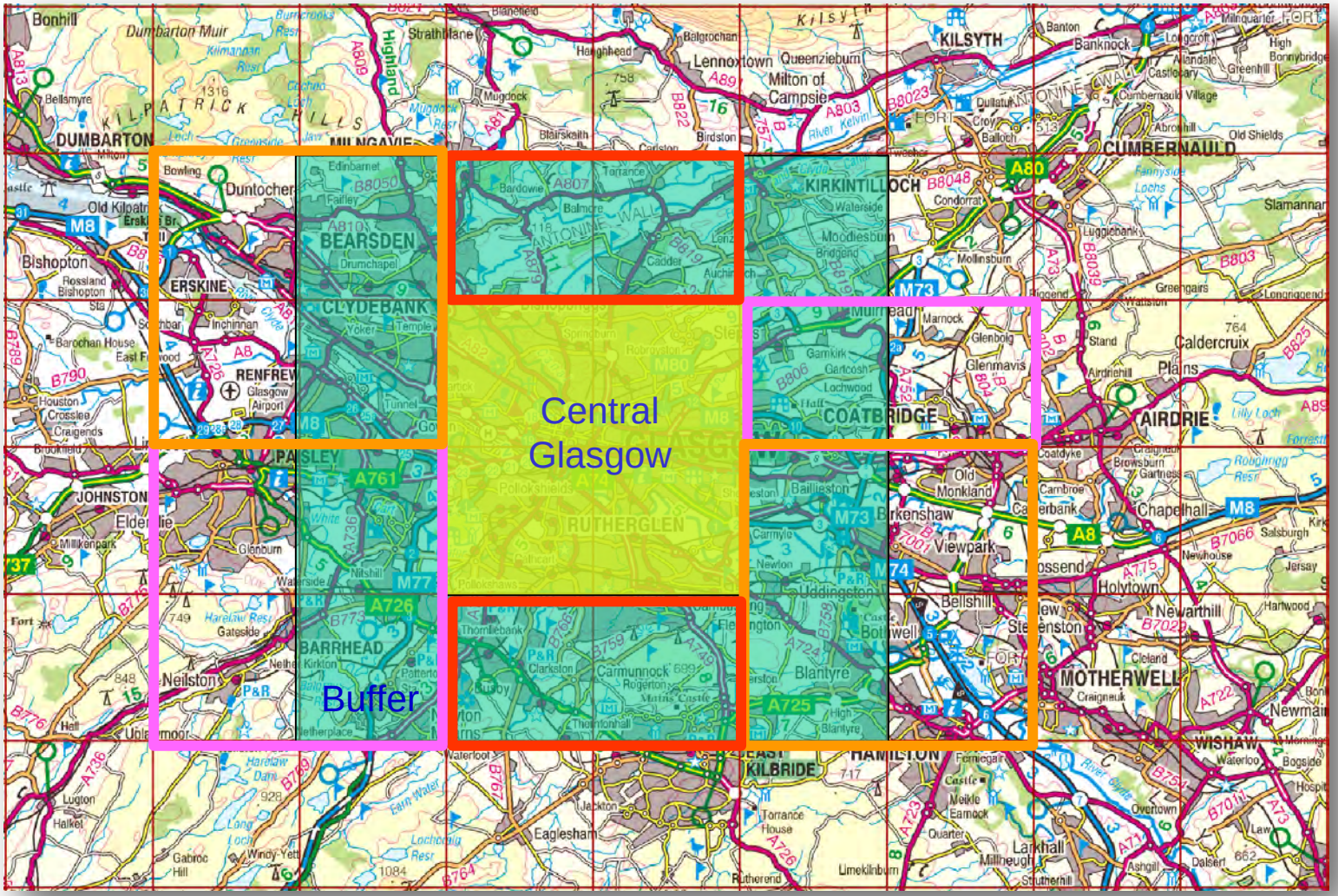






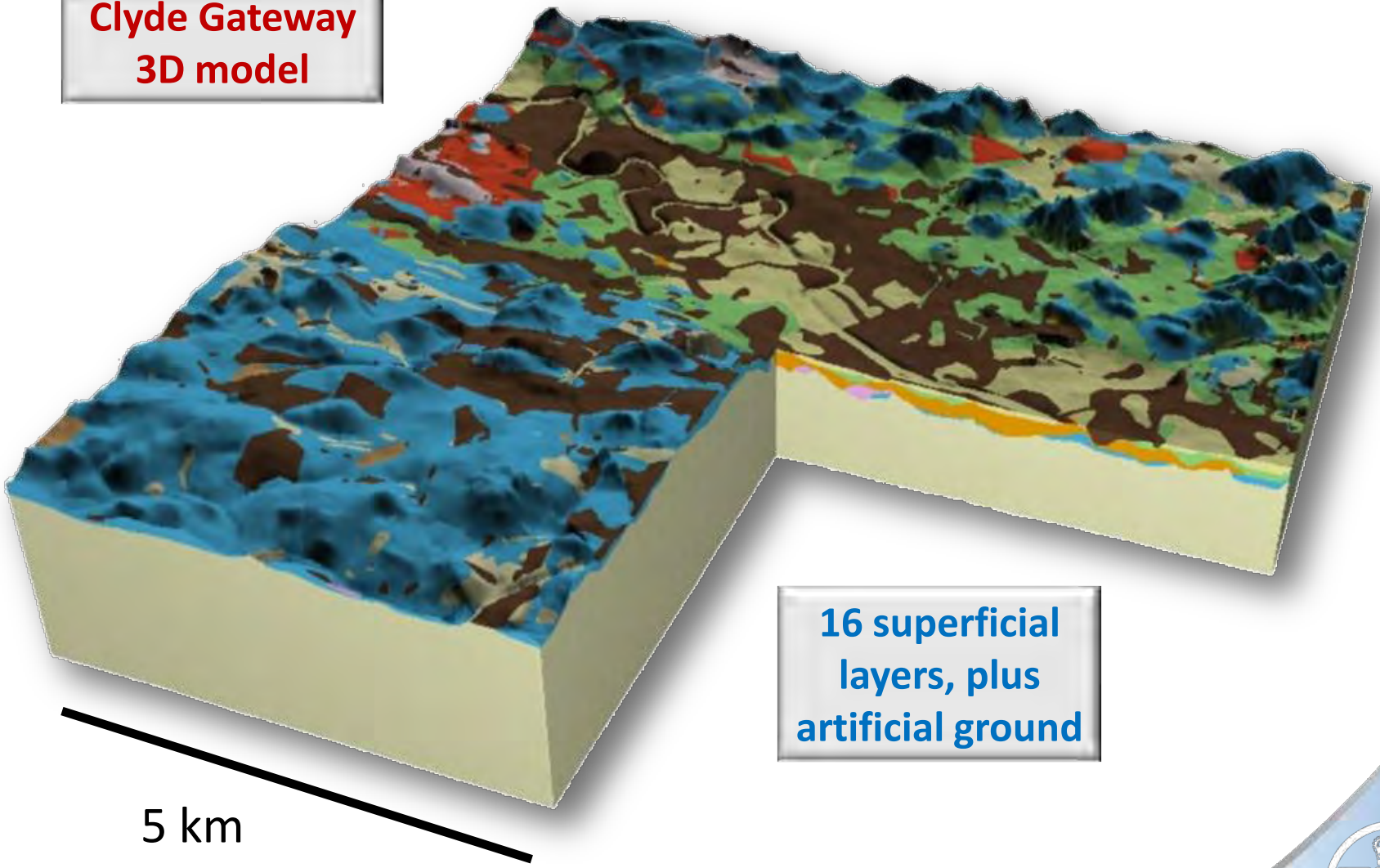


ASK Superficial Deposits model (s)



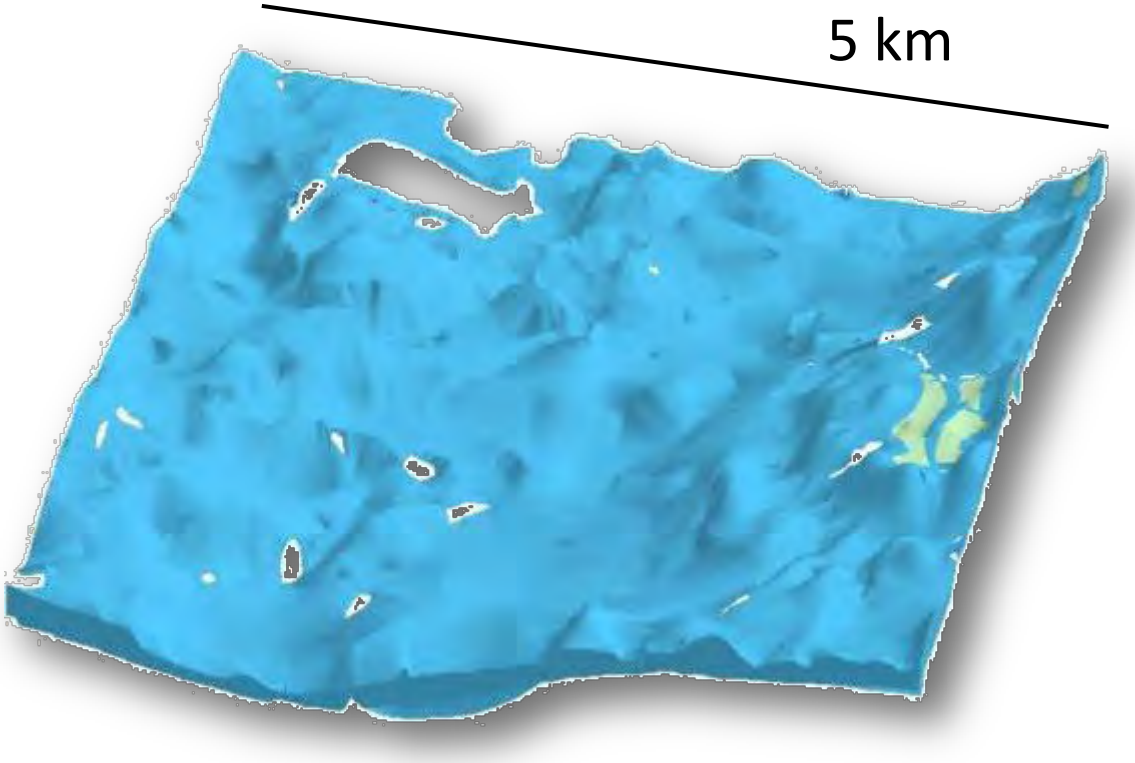
Superficial Deposits model

Clyde Gateway 3D model



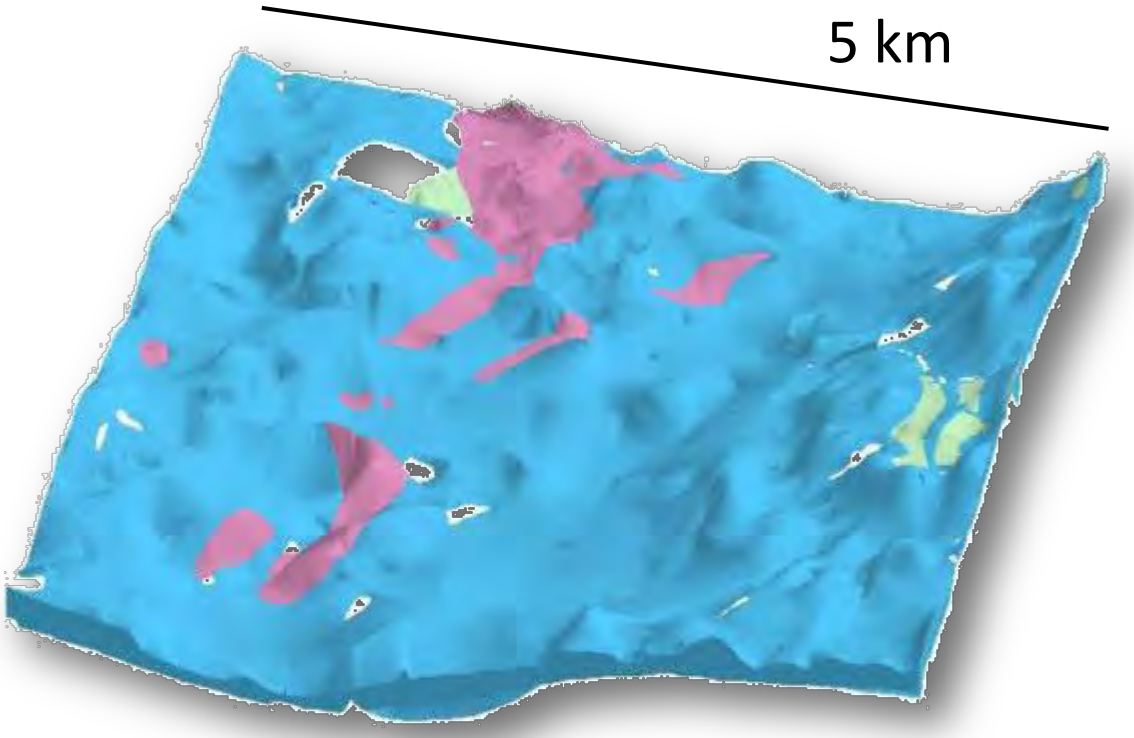
16 superficial layers, plus artificial ground

Engineering property attribution



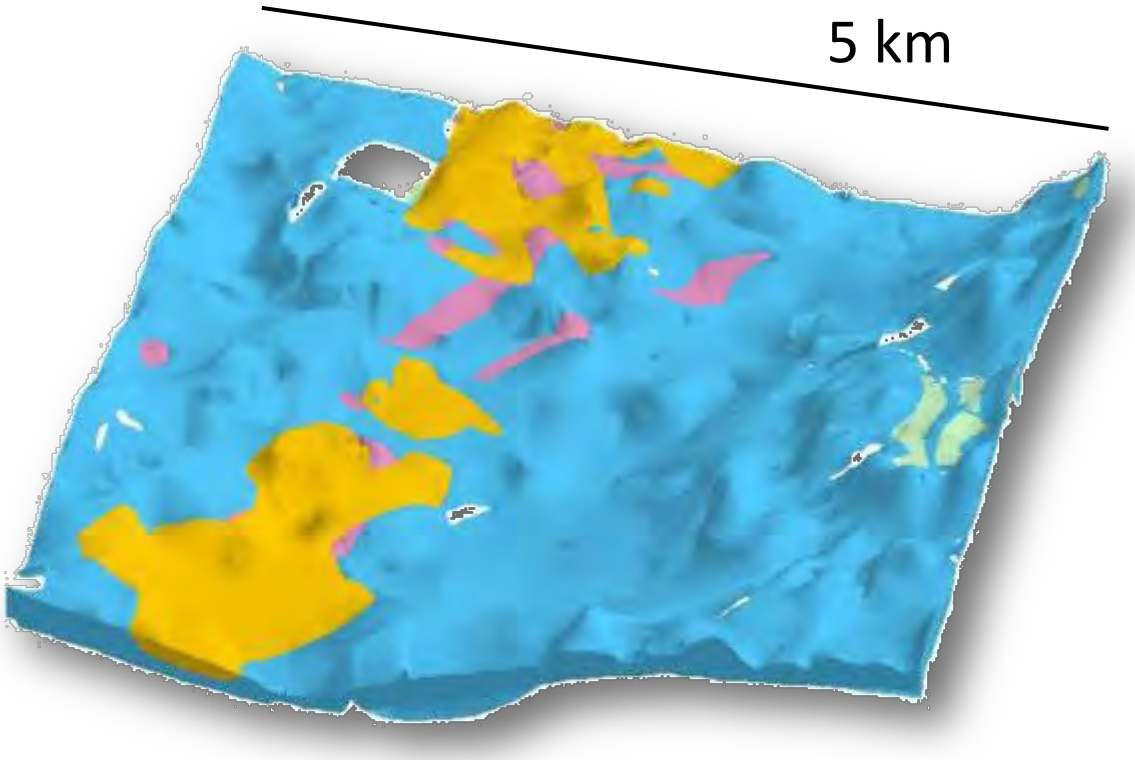
e.g. STRENGTH (or texture, grainsize, SPT, permeability)
Firm to stiff laminated CLAY and SILT

Engineering property attribution



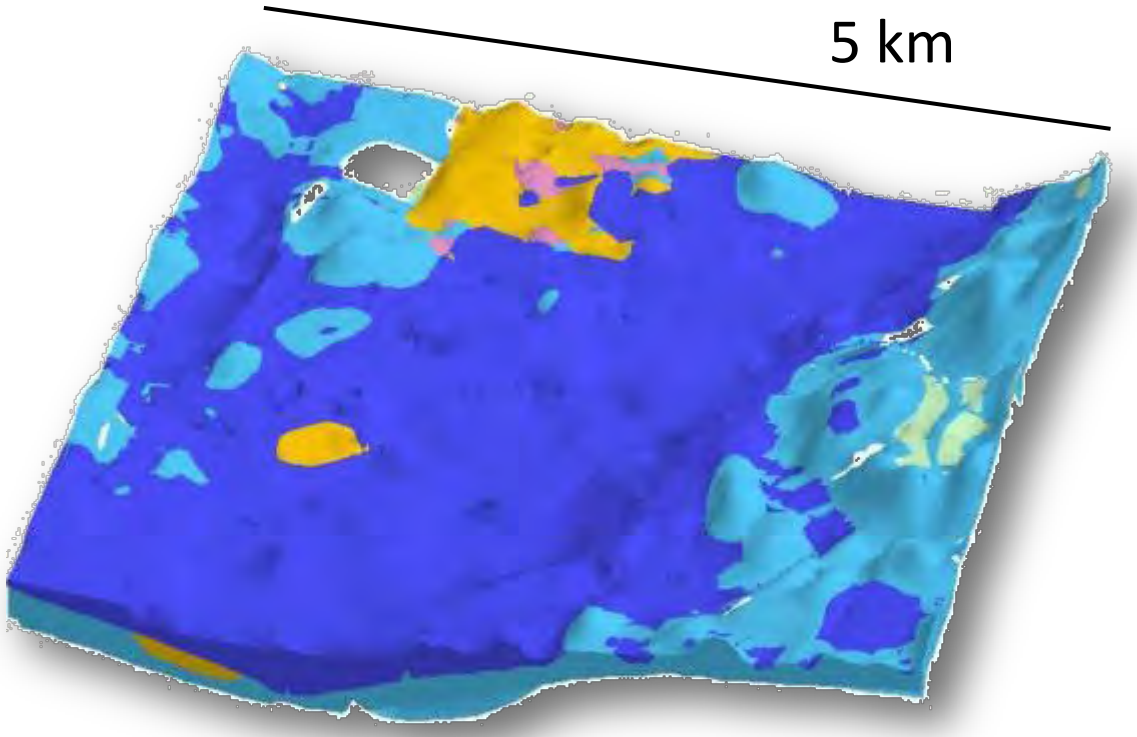
Medium to very dense silty SAND and GRAVEL with coarser particles

Engineering property attribution



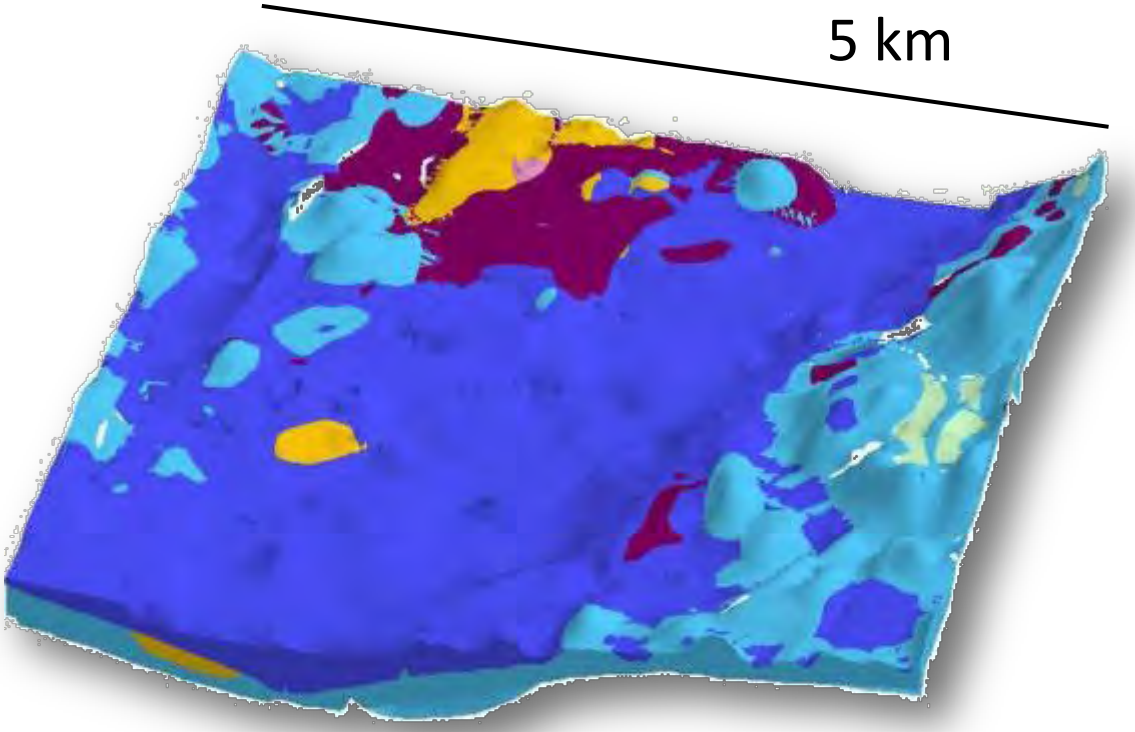
Loose to medium dense silty SAND and SAND

Engineering property attribution



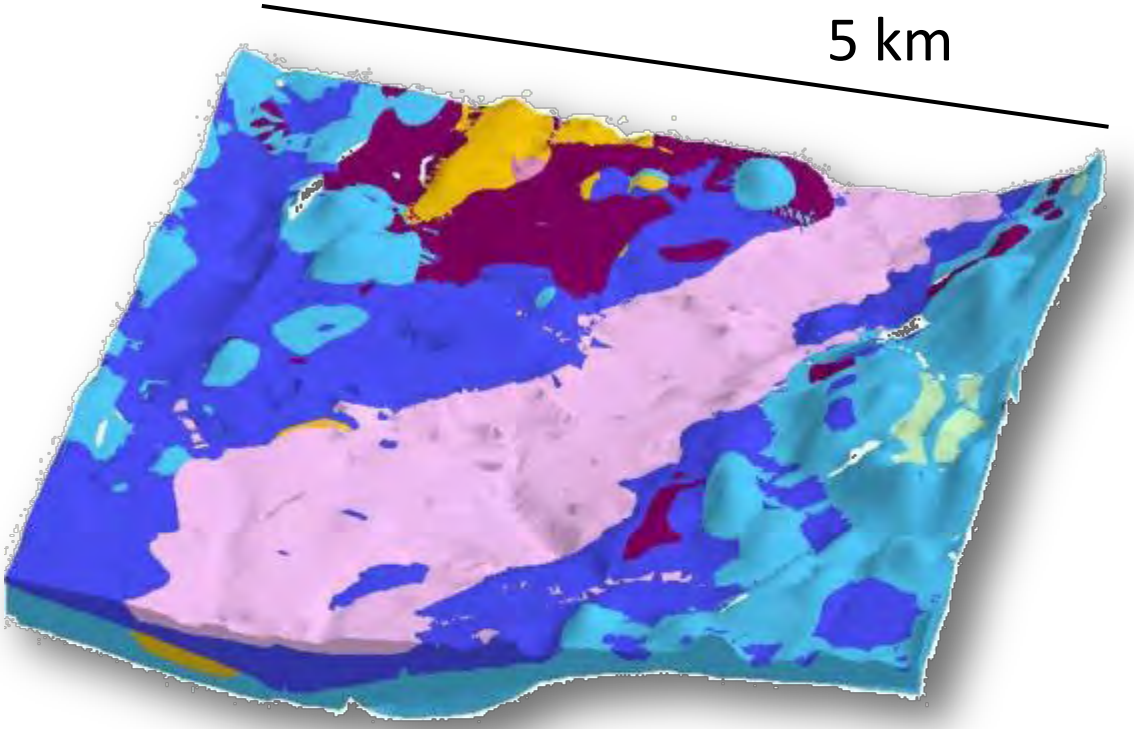
Very soft to firm laminated CLAY and SILT some local sand beds

Engineering property attribution



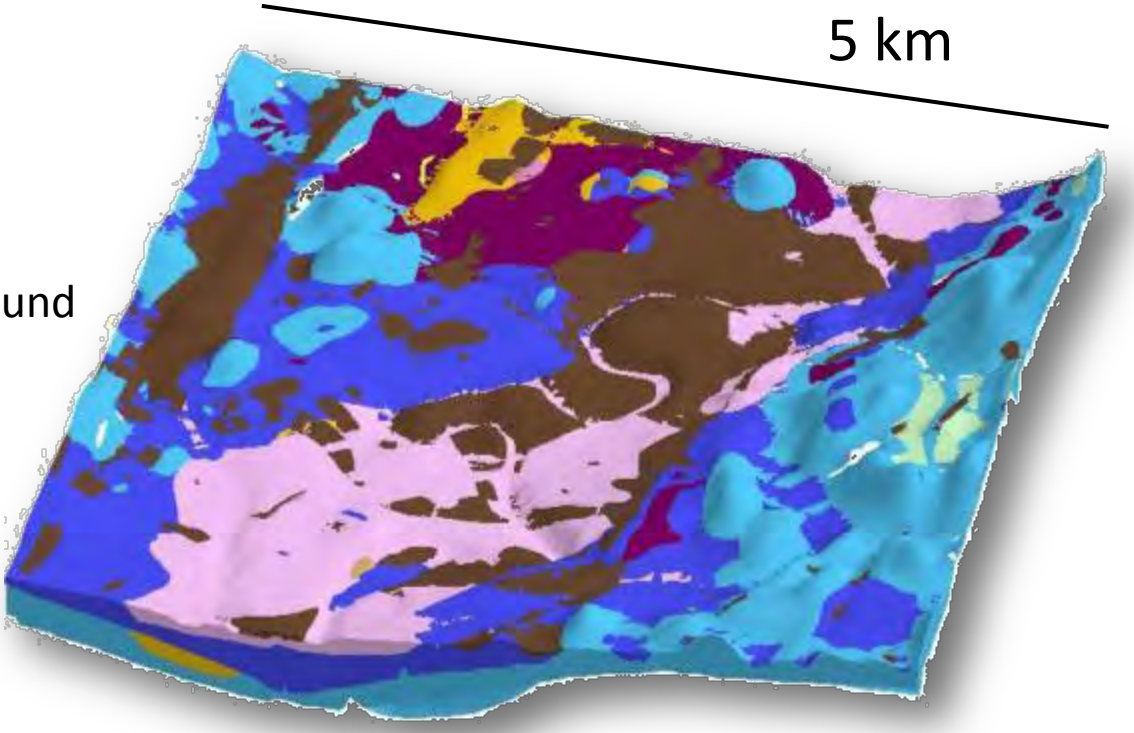
Loose to medium dense silty sand and sand

Engineering property attribution



Upper part very soft to very stiff CLAY and SILT occasional peat
Lower part loose to medium dense SAND and GRAVEL,

Engineering property attribution

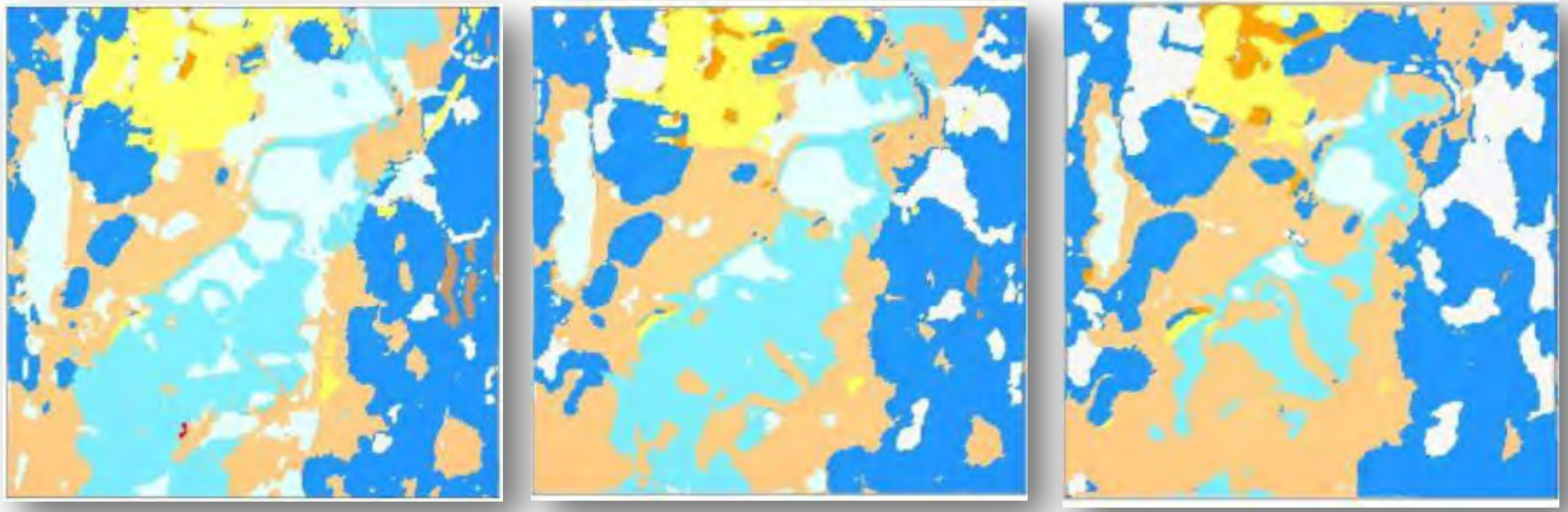


Artificial ground

Highly variable, very loose to very dense sand and gravel
or very soft to stiff CLAY and SILT, natural or man-made materials

Predicting conditions below ground

Horizontal slices from 3D Model of south-east Glasgow attributed with strength properties – e.g. for foundations



Ground level | 2 m depth | 5 m depth

Organic

- Organic, Highly compressible (Peat)

Mixed fine and coarse

- Very soft to very stiff/ loose to very dense
- Very soft to very stiff/loose medium dense
- Firm to stiff/dense very dense

Mostly fine grained

- Very soft to firm (loose) laminated (sand) SILT and CLAY
- Firm to stiff laminated SILT and CLAY

Mostly fine grained

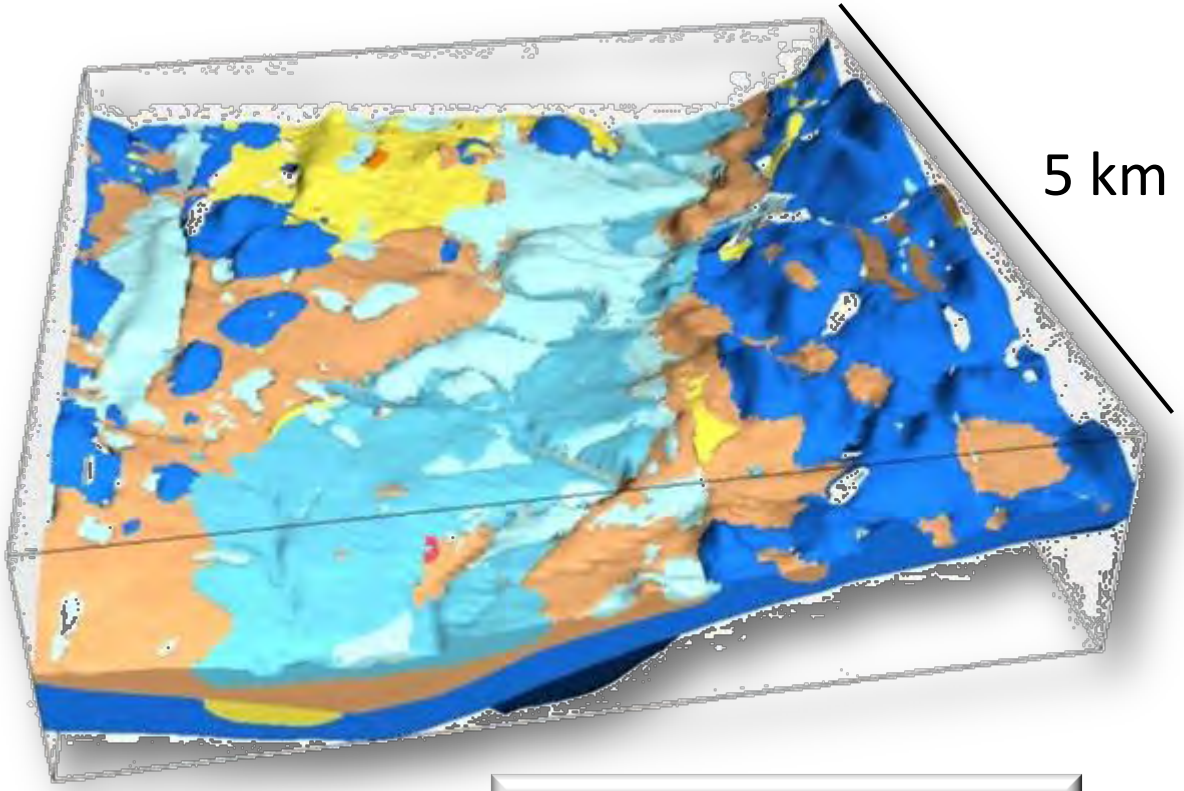
- Loose to medium dense silt SAND and SAND
- Medium to very dense silty gravelly SAND and/or GRAVEL:

Rock

- Coal Measures

3D Engineering geology model

Valuable predictive tool but not substitute for ground investigation



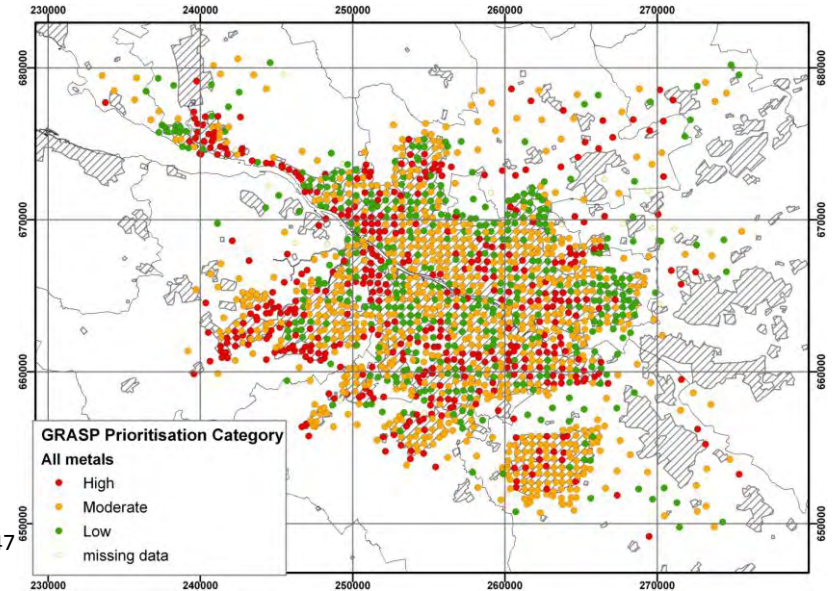
attributed with strength properties

Groundwater monitoring

Aim – *develop pilot urban groundwater monitoring network in East End area of Glasgow, utilising existing monitoring boreholes*

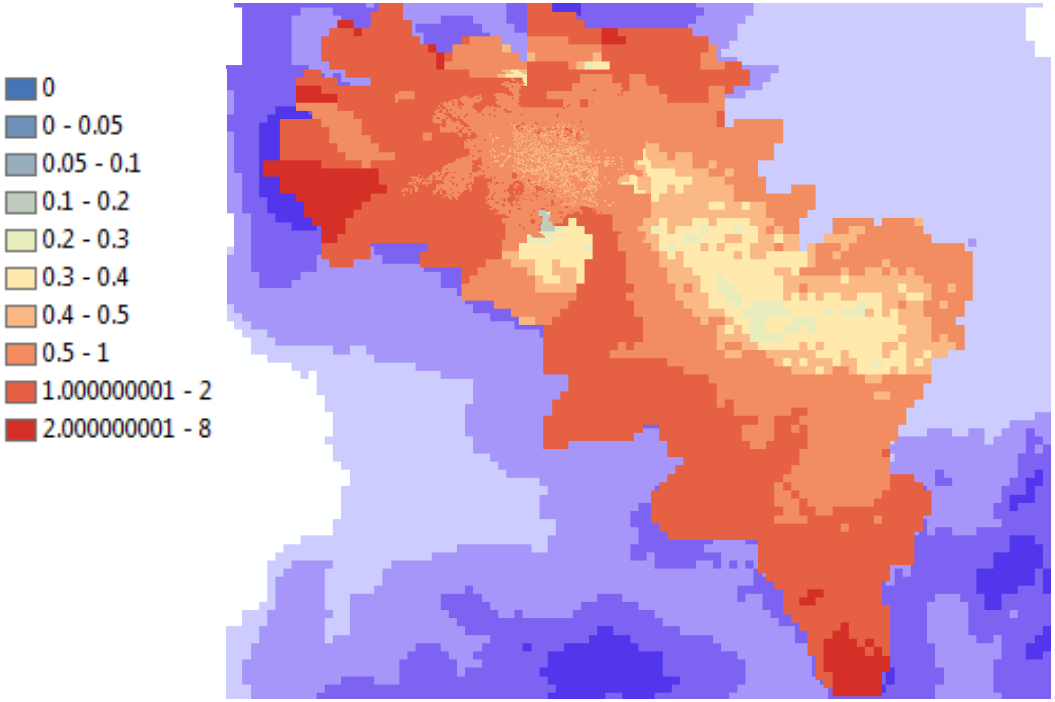
Drivers

- Need for baseline urban groundwater data
- Sustainable urban development & management – SuDS, flooding, soil contamination
- Assist stakeholders to meet future legislation of the EU Water Framework Directive



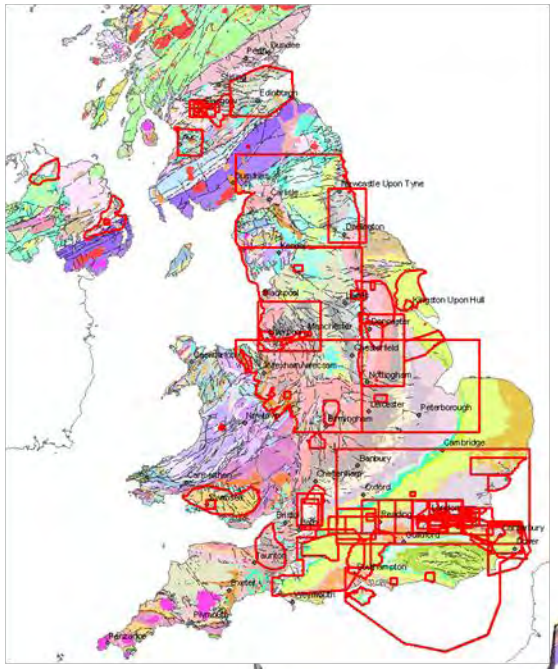
Groundwater Recharge Model

TOTAL WATER BALANCE									
			% of Total Inflows			Average daily		Average Yearly	
Total Rainfall	17847486	Ml	100 %	5400.637	mm	3.696535	mm	1350.159323	mm
Total Evaporation	5884994	Ml	33 %	1780.795	mm	1.218888	mm	445.1988336	mm
Total Runoff	7041304	Ml	39 %	2130.694	mm	1.45838	mm	532.6734741	mm
Total Recharge	4955857	Ml	28 %	1499.639	mm	1.026447	mm	374.9097794	mm
Total Outflows	17882156	Ml	100 %	5411.128	mm	3.703716	mm		
Net water	-34670	Ml	0 %	-10.4911	mm	-0.00718	mm		



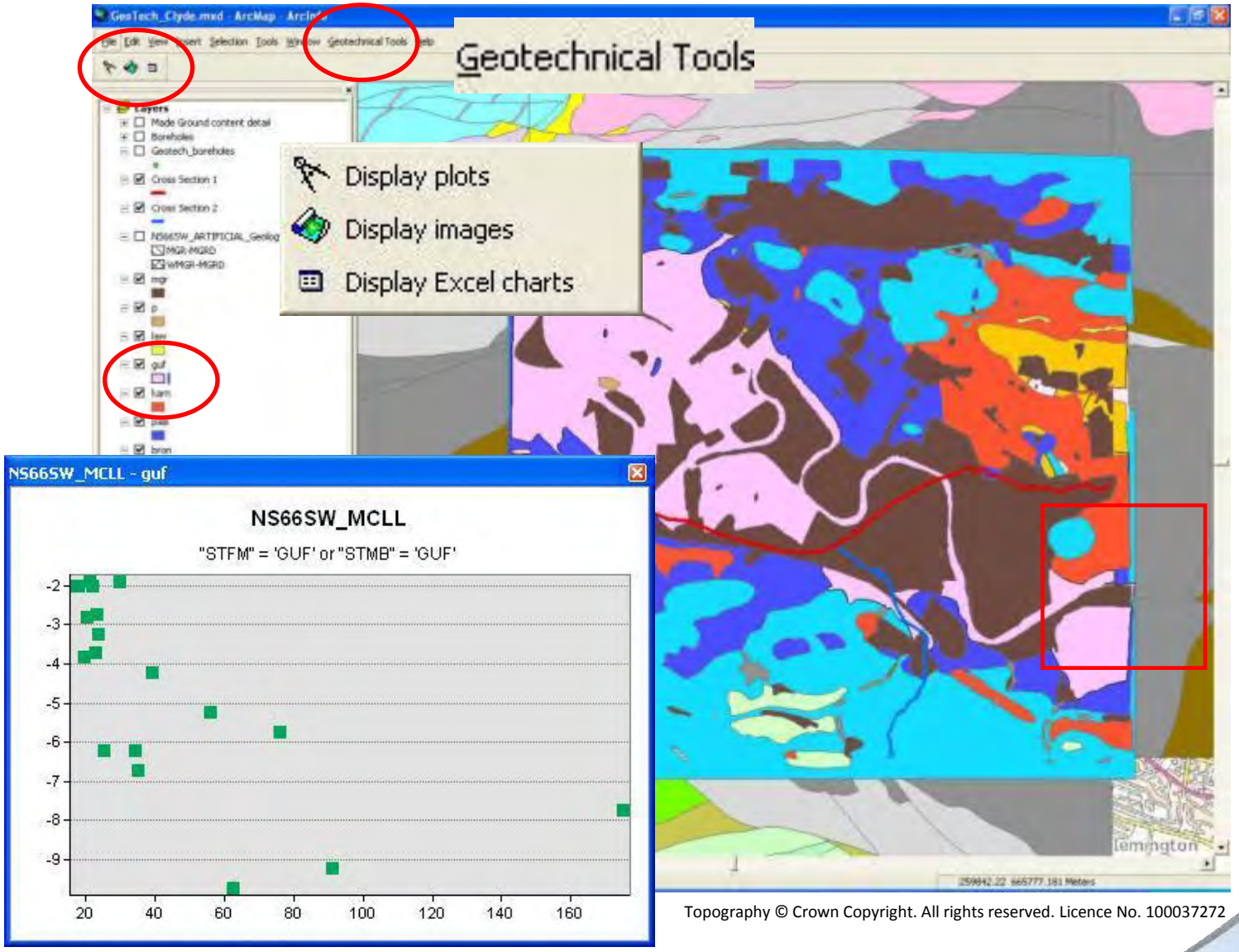
- Calibrated simulated surface flows to observed records
- Finally arrived at estimated recharge distribution which feeds into the groundwater model

Limitations of 3D geological modelling



- Powerful tool but:
  - No consideration of intra-unit heterogeneity
  - Time consuming to undertake in dense borehole fields
  - Transects determined by borehole locations not lines of interest
  - Not always well suited to process model integration
  - Other modelling technologies are required in addition to fully understand UK geology

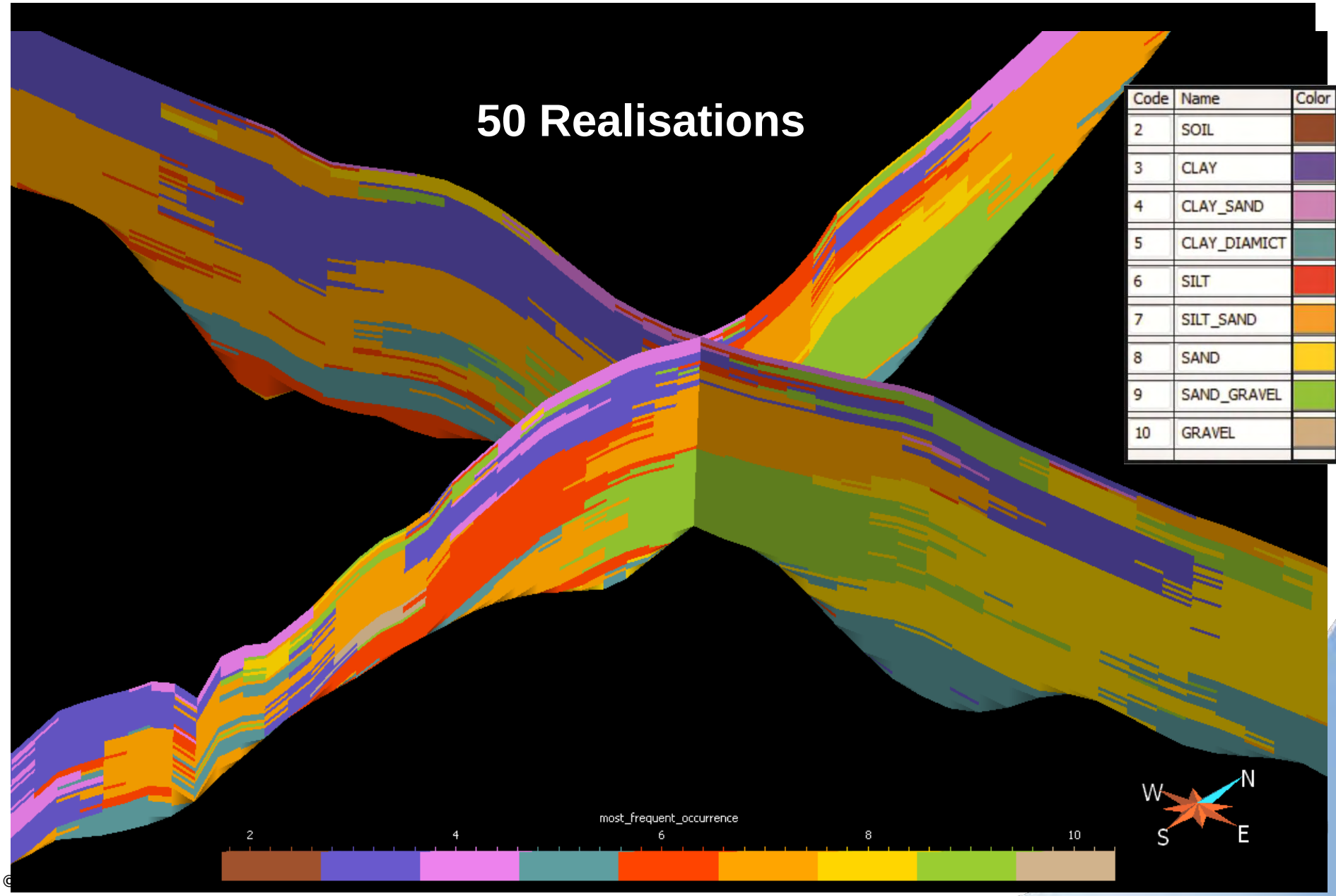
Engineering data GIS



Glasgow Stochastic Modelling

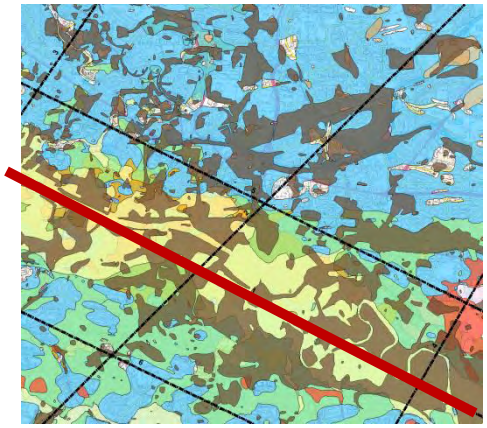
- Limits to capabilities of deterministic modelling at resolving complex superficial deposits
- Stochastic models using voxels a possible alternative
- Glasgow superficial deposits geology provides ideal test for new modelling techniques
  - Dense borehole field spanning city area
  - Major redevelopment projects means high resolution property data derived from geotechnical testing
  - Close cooperation between BGS and Glasgow City Council
- Apply standard oil industry reservoir modelling techniques to shallow unconsolidated sediments
- Simulation methods derive statistical information from boreholes and develop models of how these vary spatially
- Analyse vertical and horizontal spatial patterns of variance and populate a 3-D grid statistically using the variograms

Compilation of most likely lithology

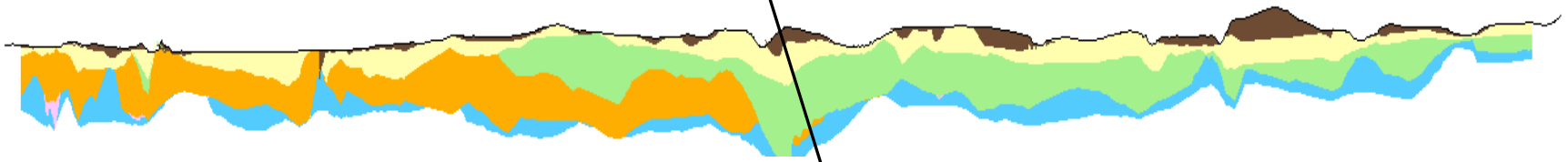


Comparing deterministic & stochastic models

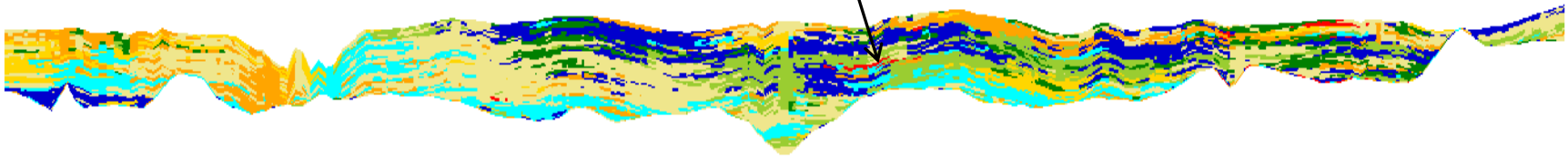
Captures greater lithological variability than the stratigraphy



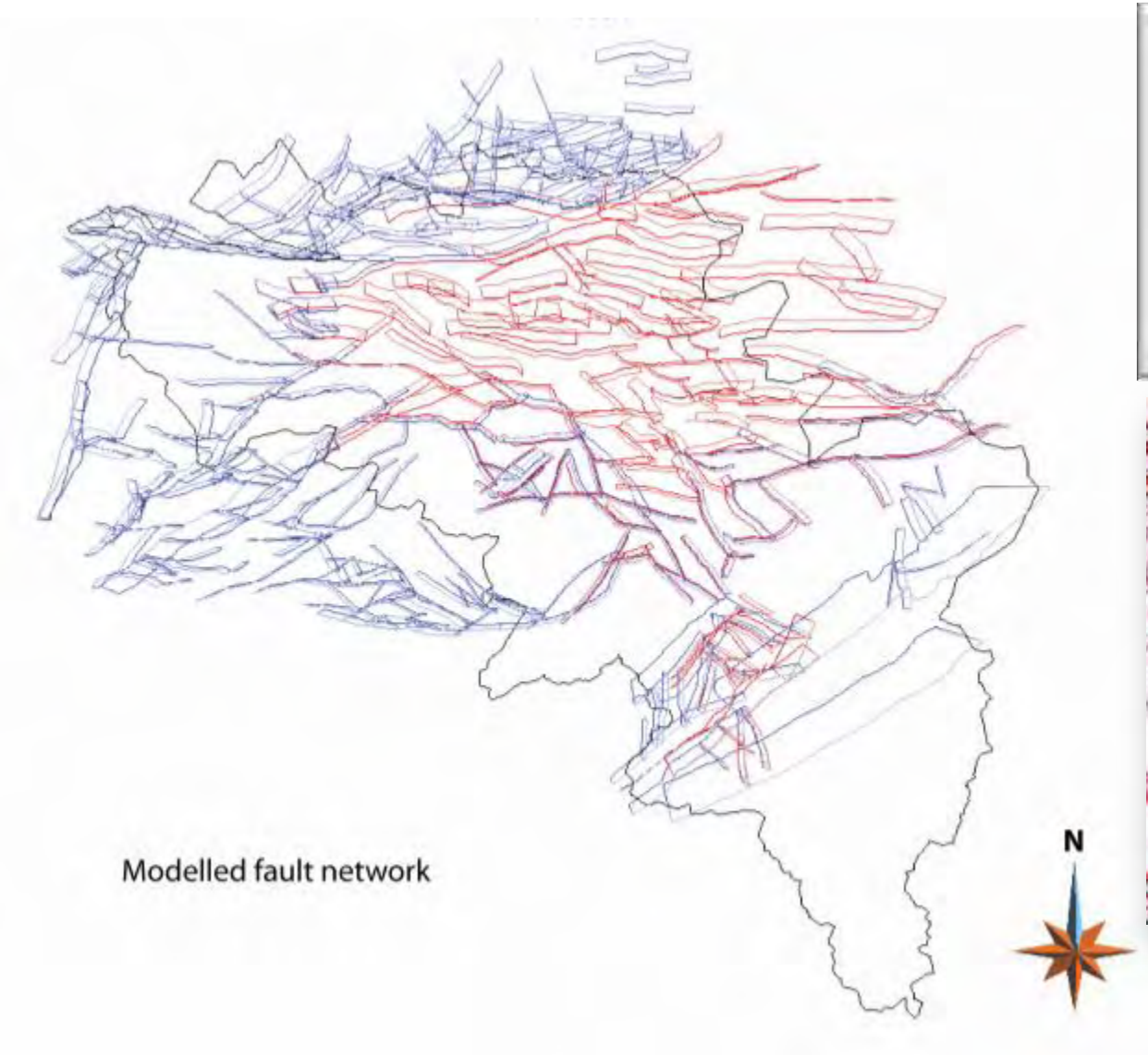
Deterministic



Stochastic



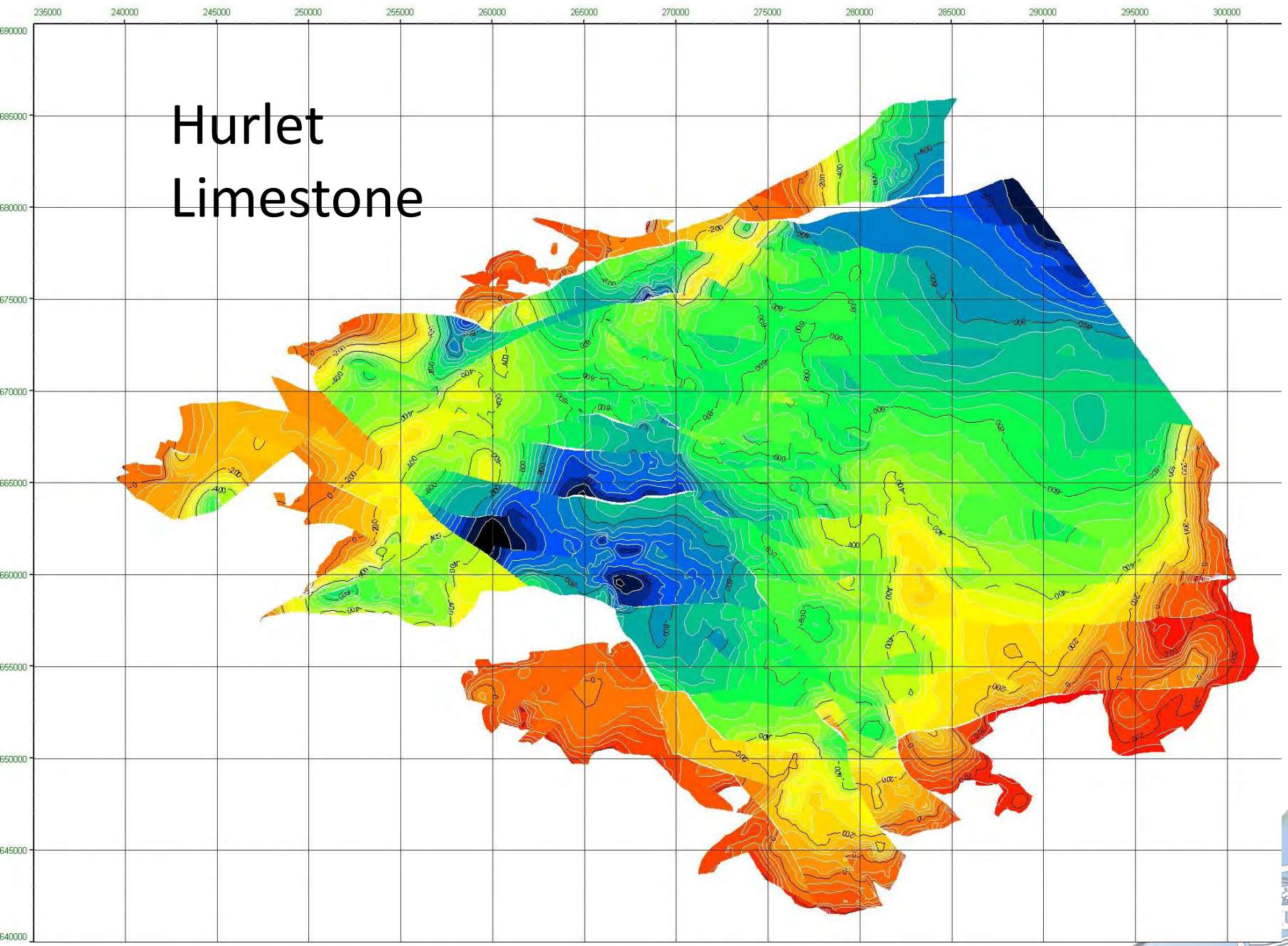
Bedrock model



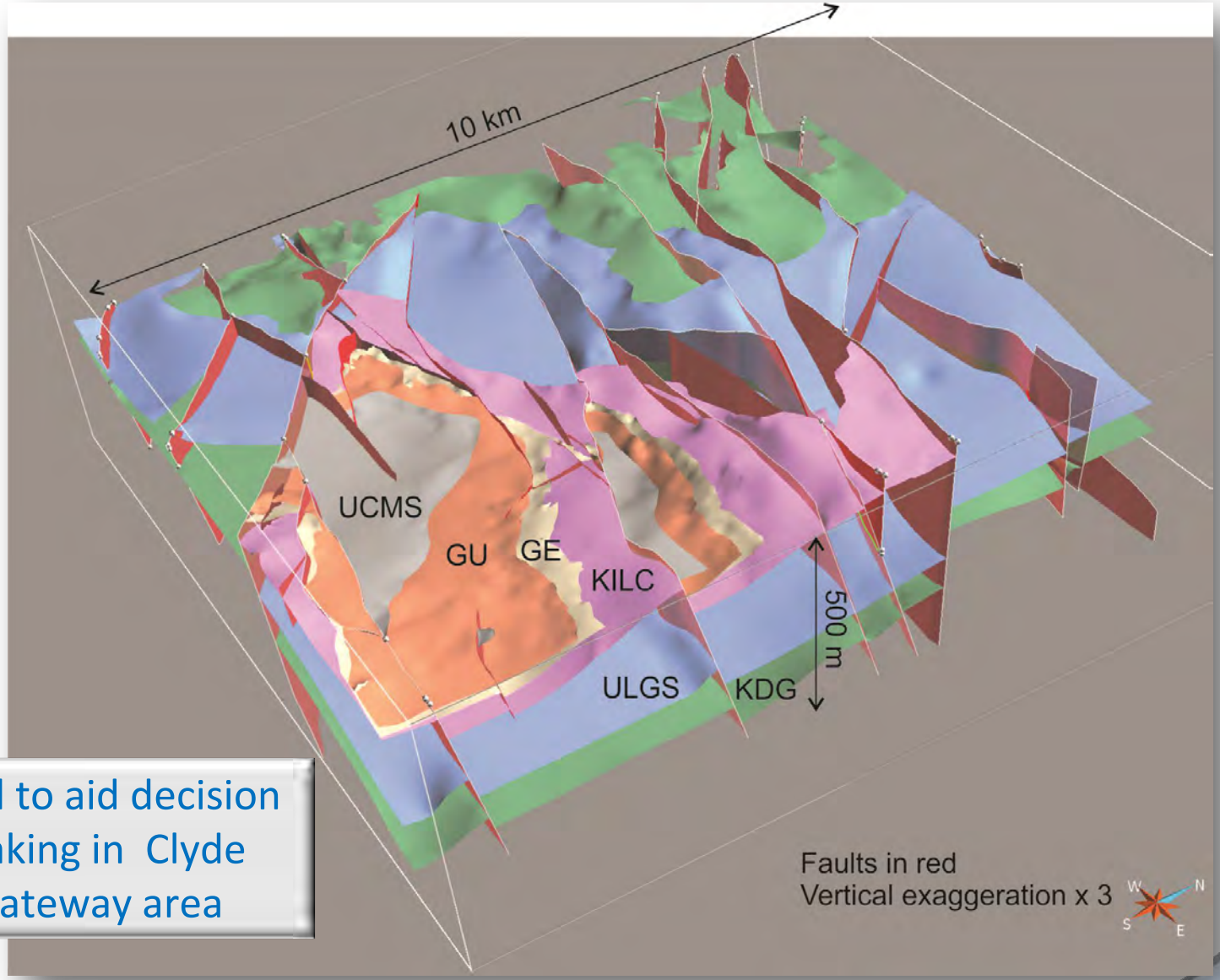
85 cross sections
1066 boreholes
>106,000 control points
Extends to 1.39km depth
794 faults
47 stratigraphic surfaces

Mine plans

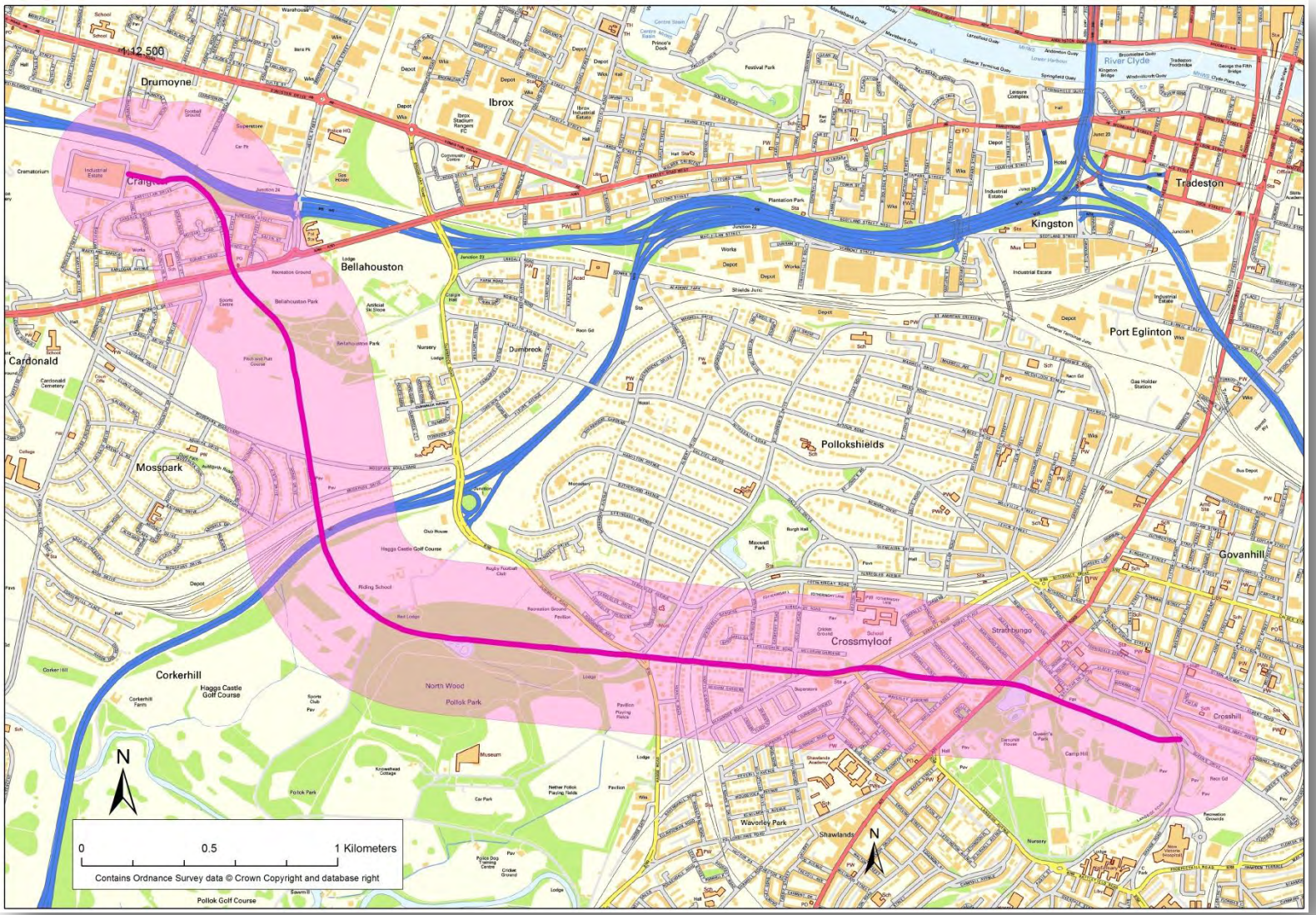
Hurlet Limestone



Central Glasgow bedrock model

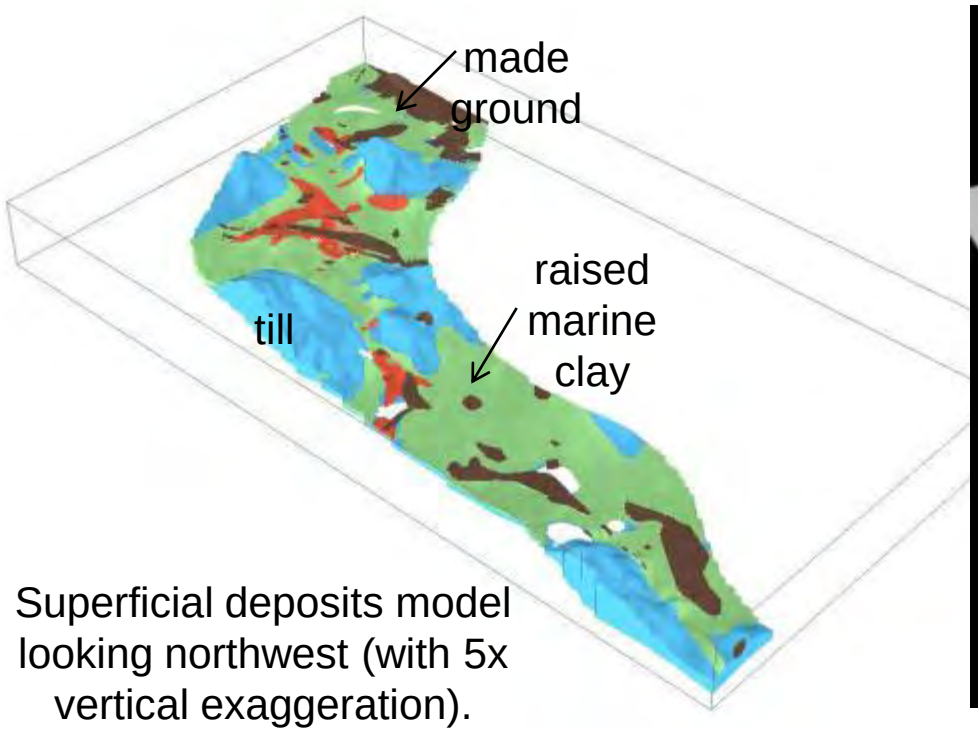


Used to aid decision making in Clyde Gateway area

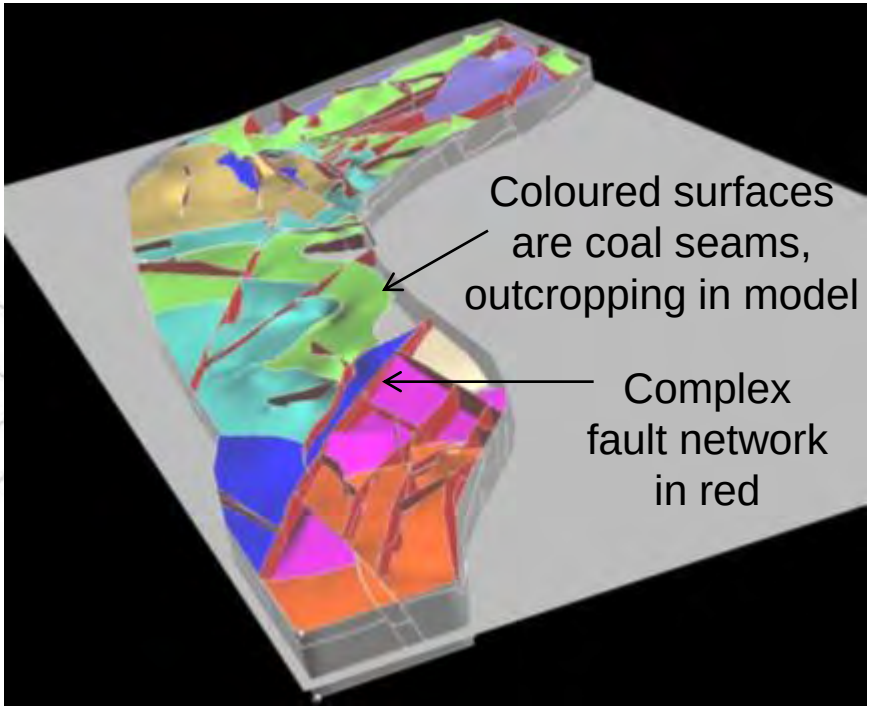


Bespoke Modelling for Linear Route Assessment

SW Glasgow – superficial and bedrock linear route model



Superficial deposits model looking northwest (with 5x vertical exaggeration).

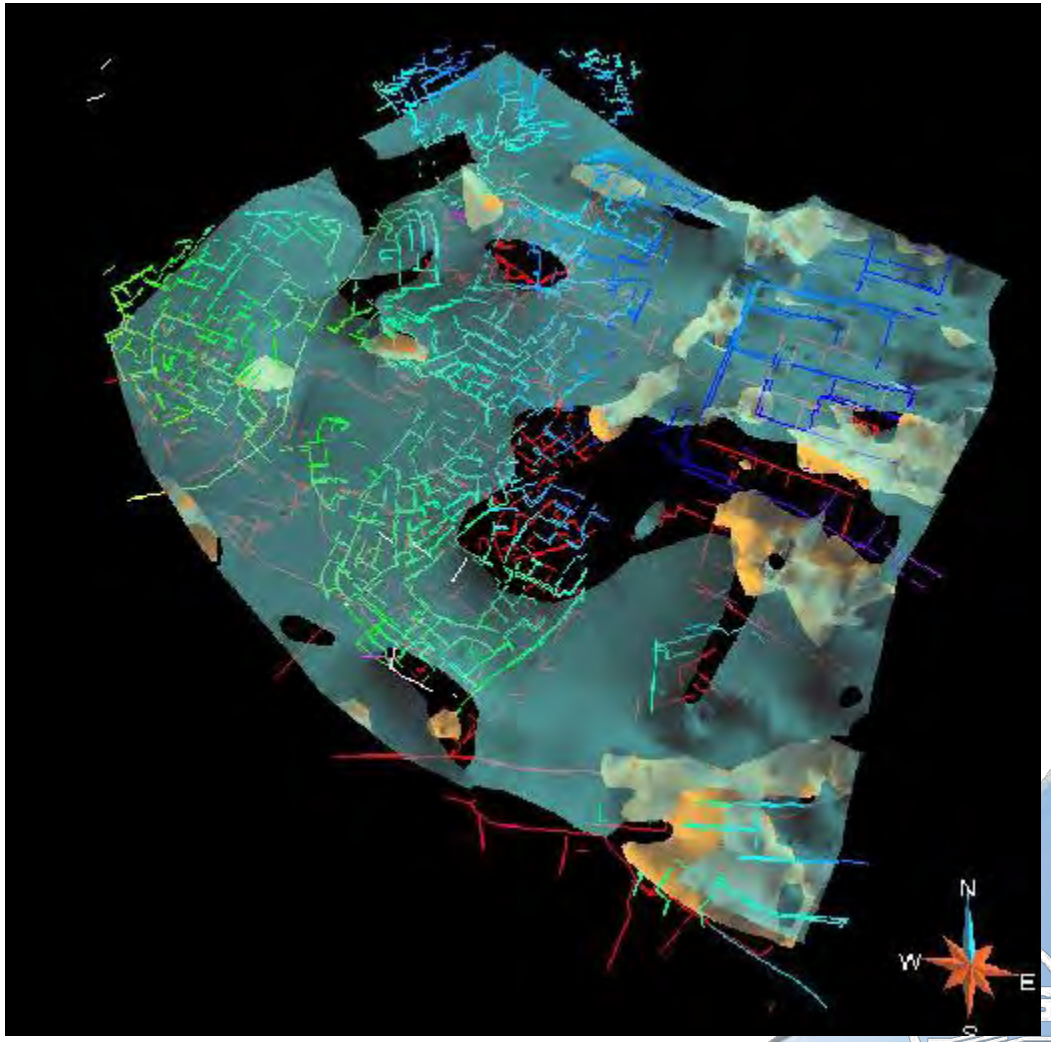


Faulted bedrock model looking northwest (with 2x vertical exaggeration).

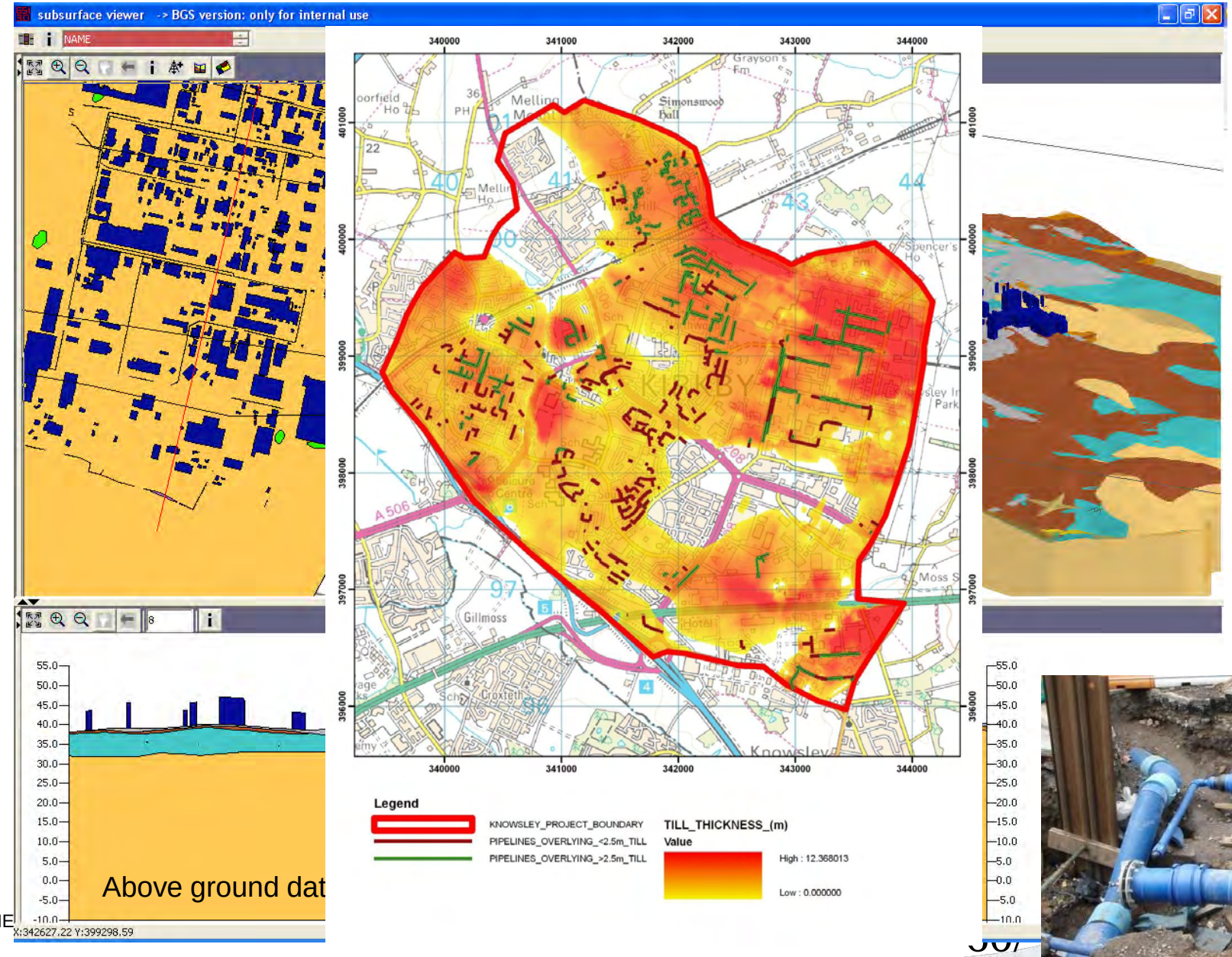
- 'High resolution' model used to inform a linear route assessment – complex faulting, mined strata

Buried Infrastructure

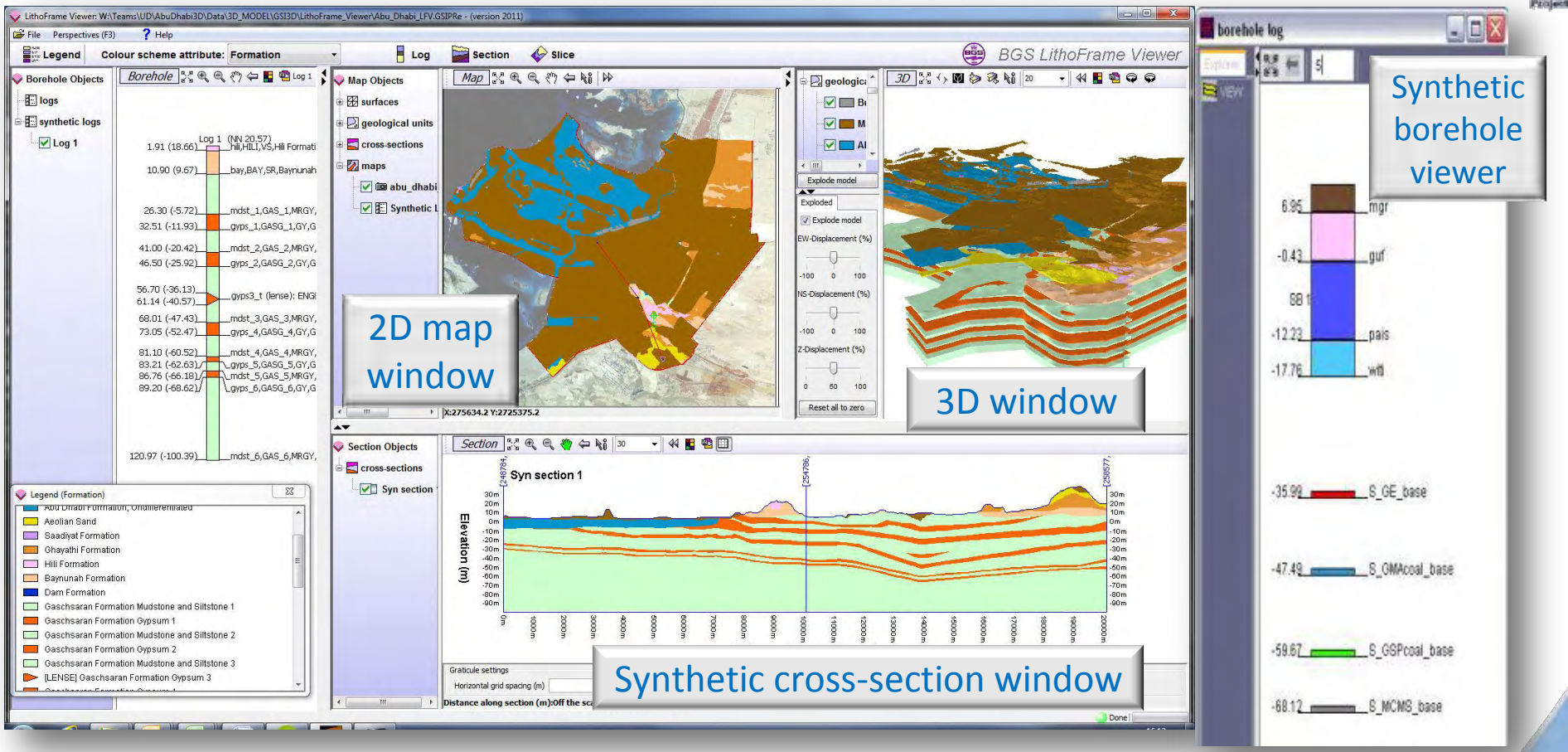
- Industrial park in North-West England
- Understand relationship between subsurface infrastructure (drain pipes) and geology
- Provide customer-focussed decision support tools
- 3D modelling to address real world problems



Urban Geology – integration of infrastructure

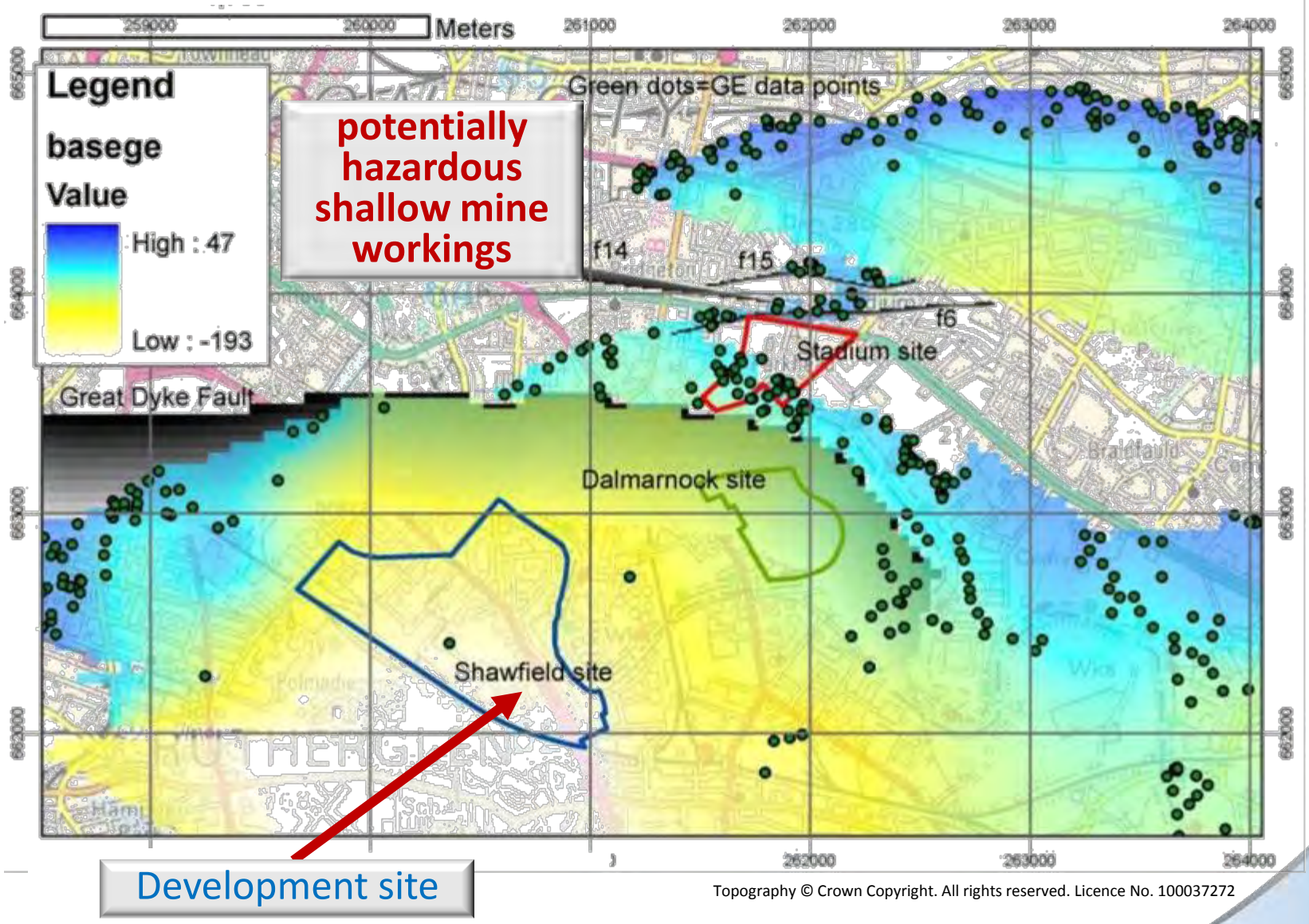


Model delivery: LithoFrame Viewer

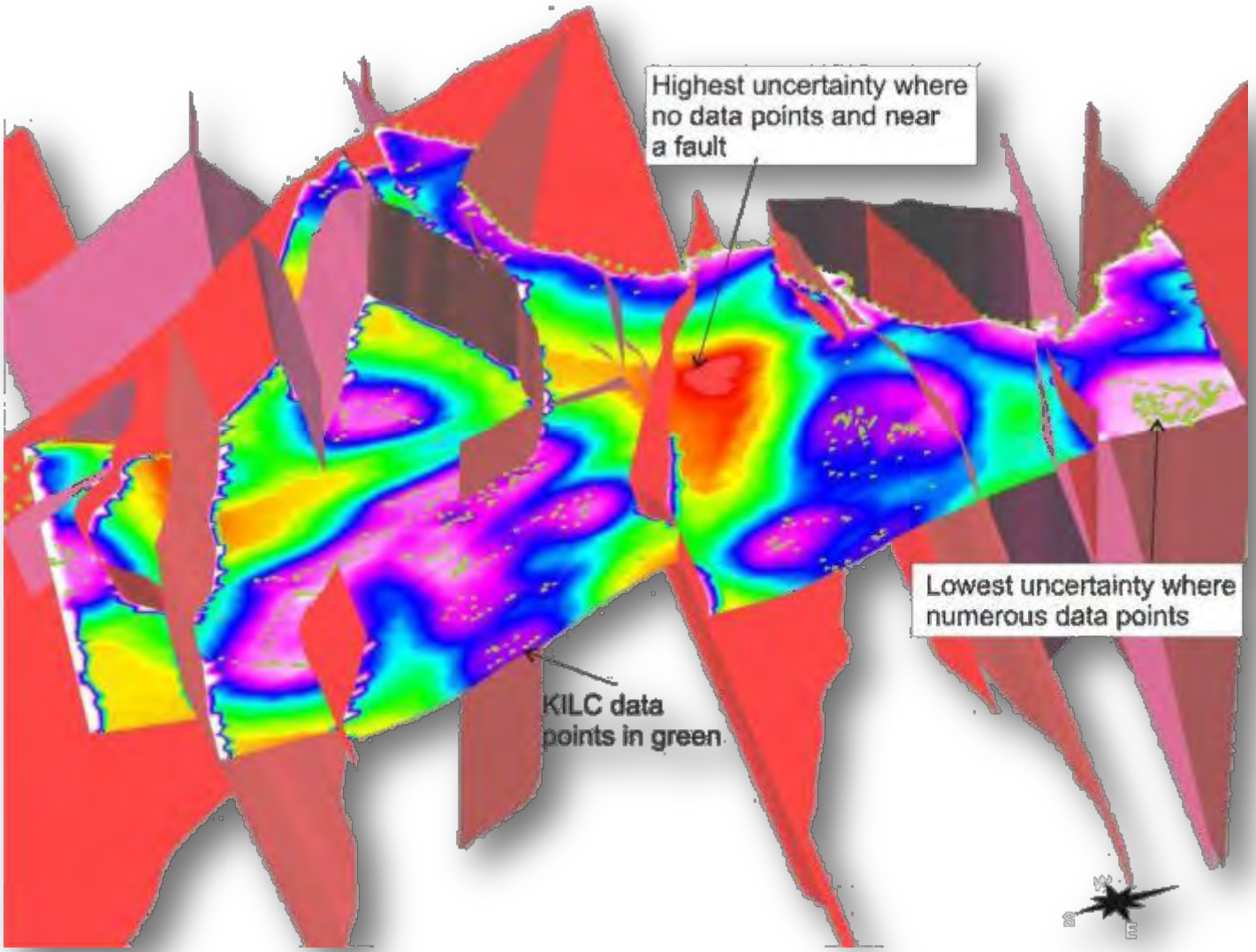


Custom output to: 3D PDF; 2D GIS; other software applications as layers or themes

Model delivery: GIS output



Model delivery: uncertainty

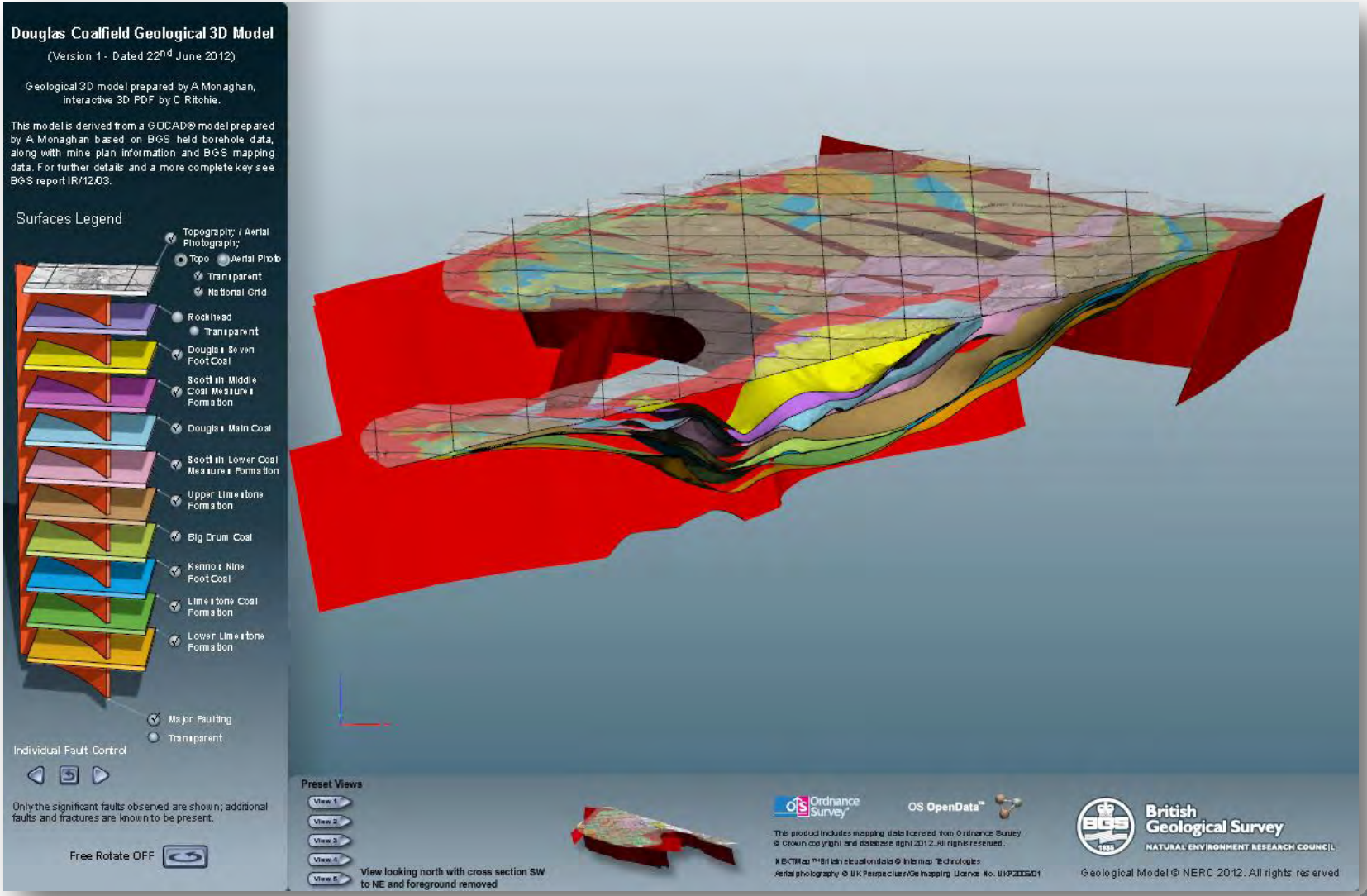


Calculated from data density and geological complexity

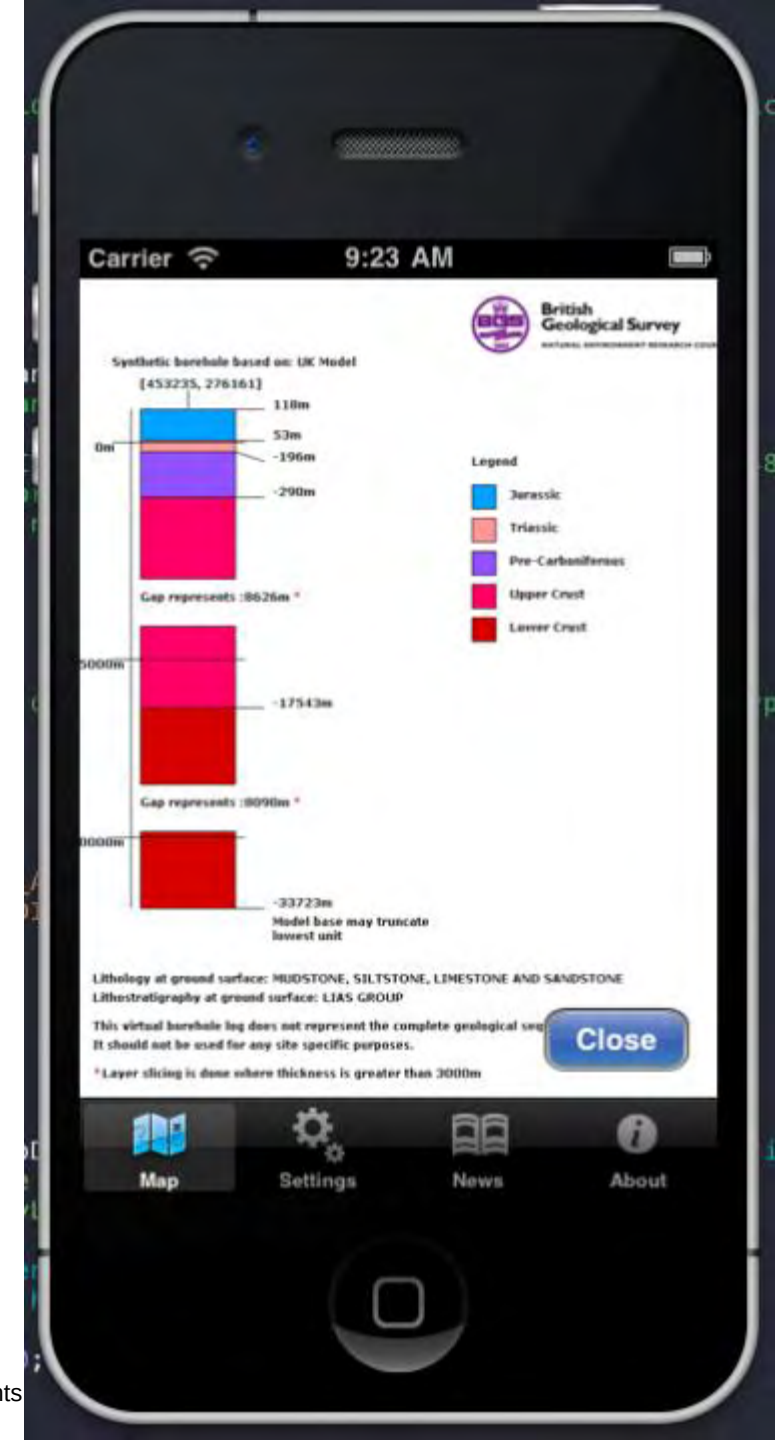
High uncertainty up to 10s m in XYZ

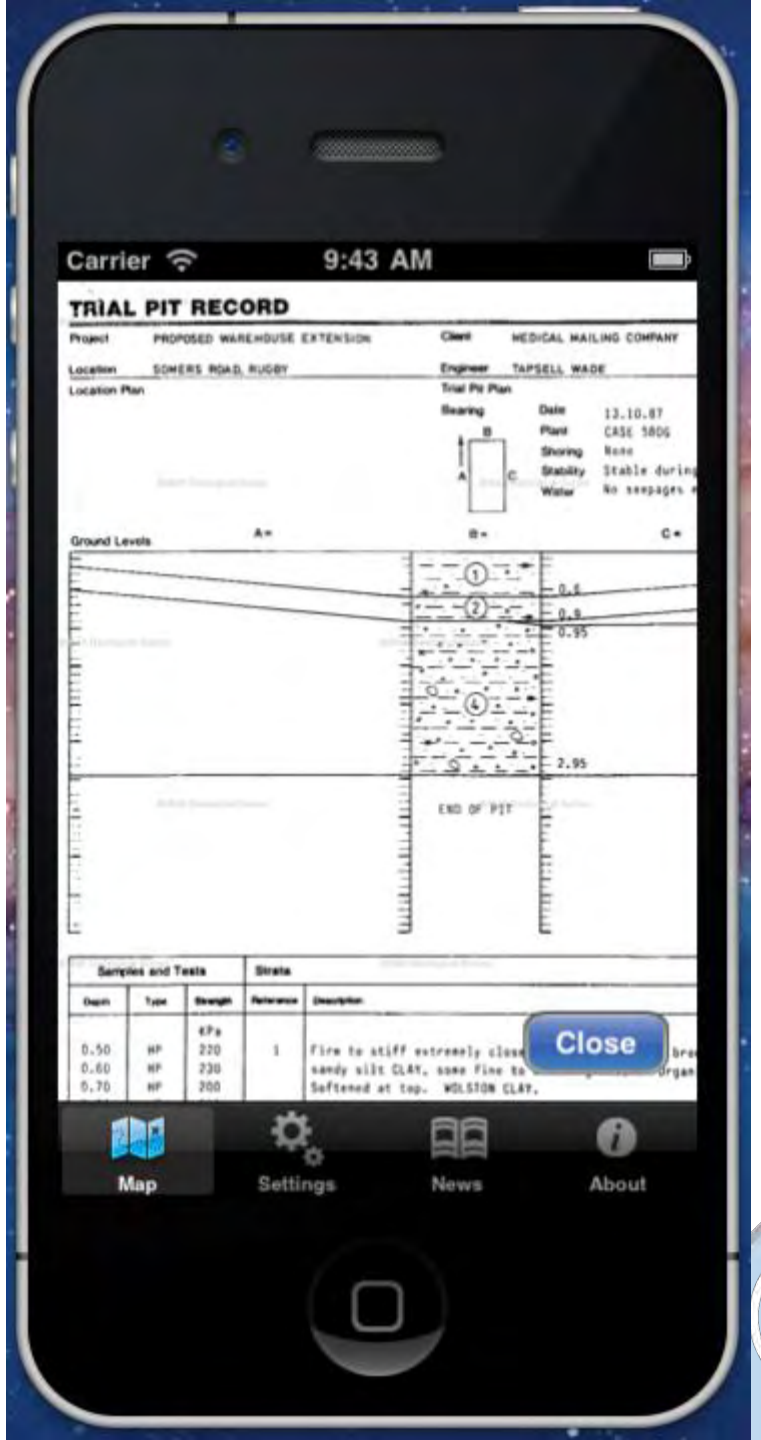
Low uncertainty c.<10m in XYZ

Model delivery: 3D PDF

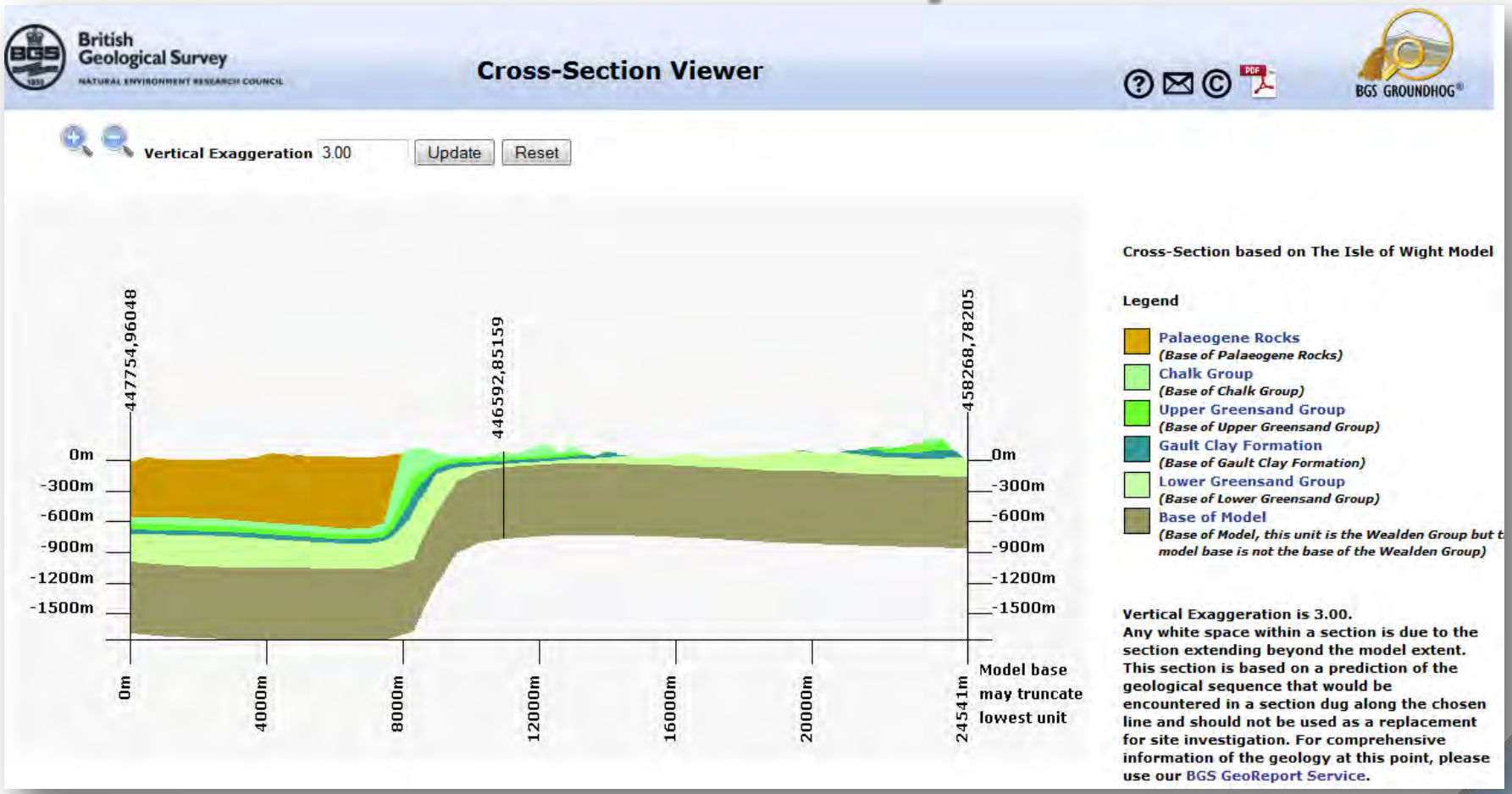


GeologyViewer3





Groundhog Web/Mobile tools for virtual cross-sections/boreholes

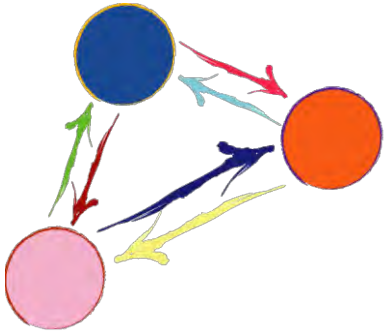


www.bgs.ac.uk/services/3Dgeology/virtualBoreholeViewer.html

Model Delivery via ASK

Accessing Subsurface Knowledge

ASK – a knowledge exchange network for public & private sectors



Aims

– foster free-flow of subsurface data and knowledge

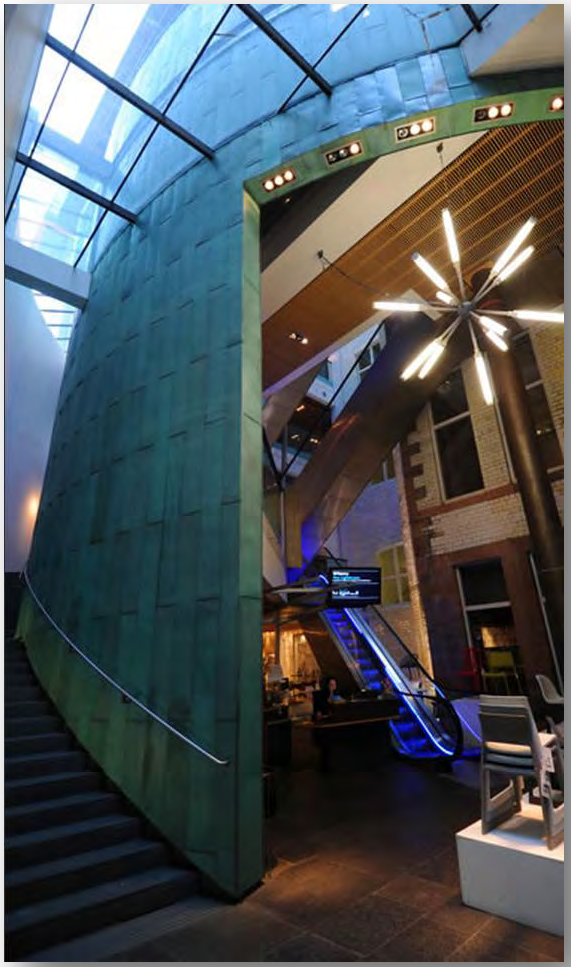
– improve efficiency of ground investigation

Breaking news……

Glasgow wins the UK TSB “future city demonstrator”

ASK Network is part of this £24 million award

ASK Network Partnership



launched at The Lighthouse, Glasgow on 16 November 2012

Hosted by

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Glasgow CITY COUNCIL

With support from

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Jacobs
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Mott MacDonald
Parsons Brinkerhoff
Scottish Coal
Scottish Power
Soilutions Ltd
URS Scott Wilson
Raeburn Drilling and Geotechnical

Glasgow & Clyde Valley Structure Plan Committee, incorporating:
Glasgow City Council
Inverclyde Council
North Ayrshire Council
North Lanarkshire Council
South Lanarkshire Council
West Dunbartonshire Council
Scottish Water
Transport Scotland

Glasgow Caledonian University
Glasgow University
Newcastle University
University of Strathclyde
University of the West of Scotland

Those in bold have joined or are in the process of joining

ASK Knowledge Exchange opportunity

Research community:

platform for wider environmental modelling

Decision makers (local and regulatory authorities):

regeneration and sustainable development

BGS - transforming user relationships:

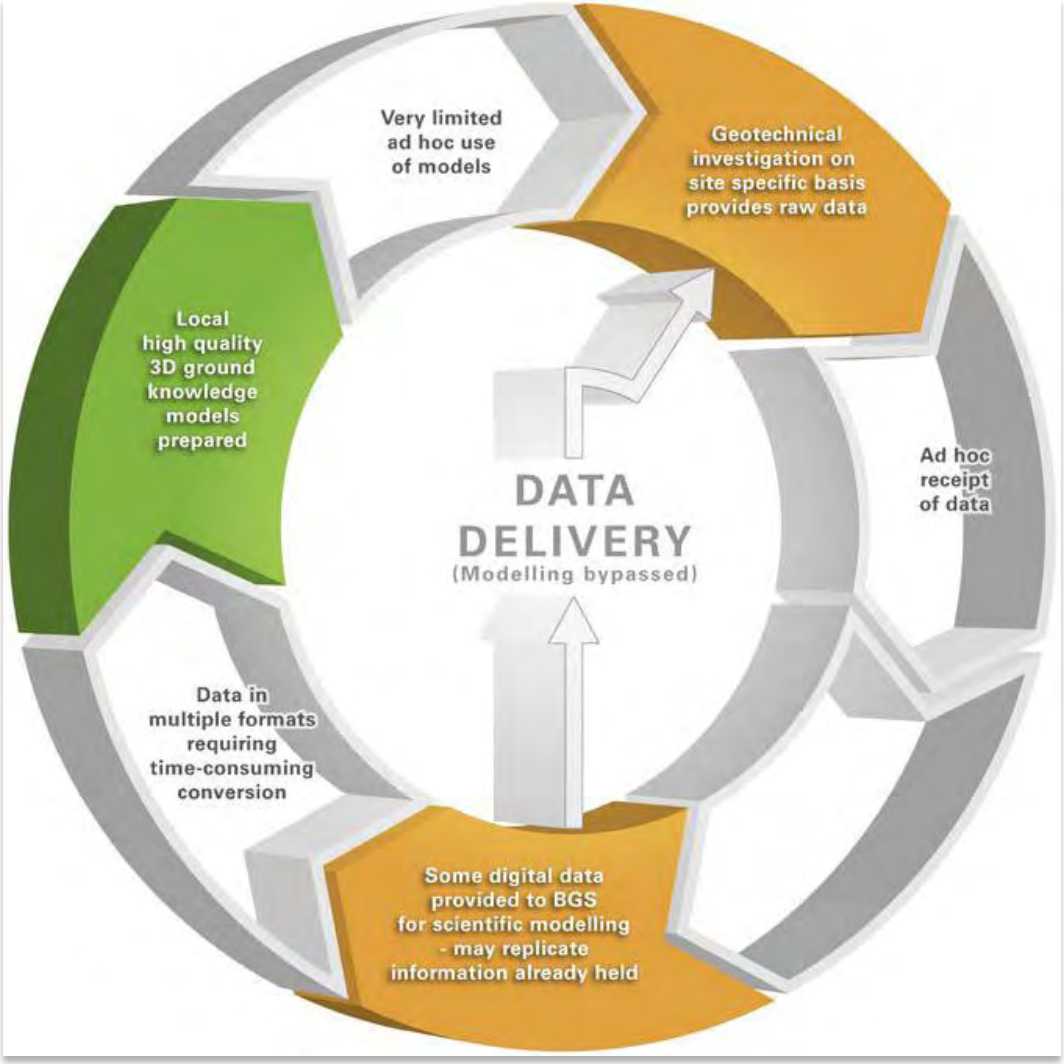
- *providing archival data*
- *3D models for planning, development & decision making*
- *receive new data more efficiently from end-users*

Industry (developers, consultants and contractors):

support investment and construction

Why we need the network?

High quality models produced by BGS but only limited use of models



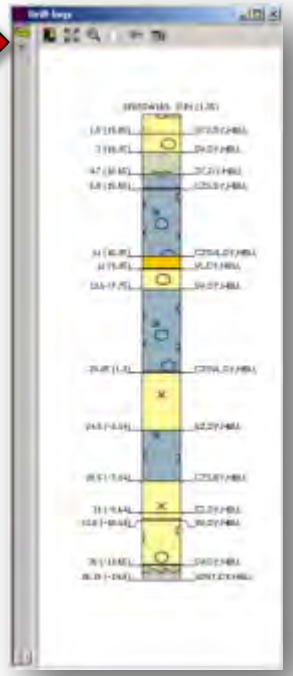
Planning and engineering decisions are based on local, self contained datasets – not seen in context of 3D models or all potentially available data

Data often in unsuitable format for immediate use

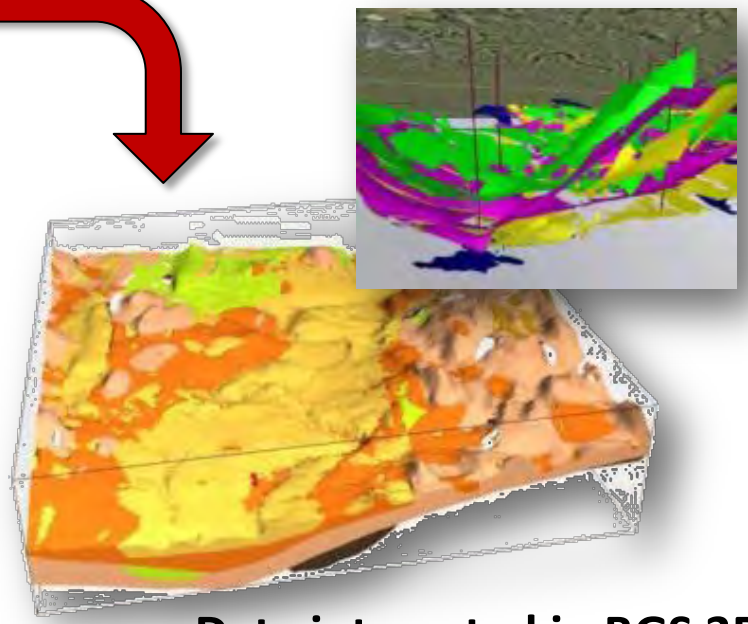
Newly acquired data not routinely fed into models

Functioning well | Beginning to function | Functioning less well

The Glasgow experience……



BGS recoding of logs – very resource intensive



Data integrated in BGS 3D models for GCC & others – **maximise benefit of past investment , but resource intensive to produce and update**

Site investigation
Data
Poor accessibility

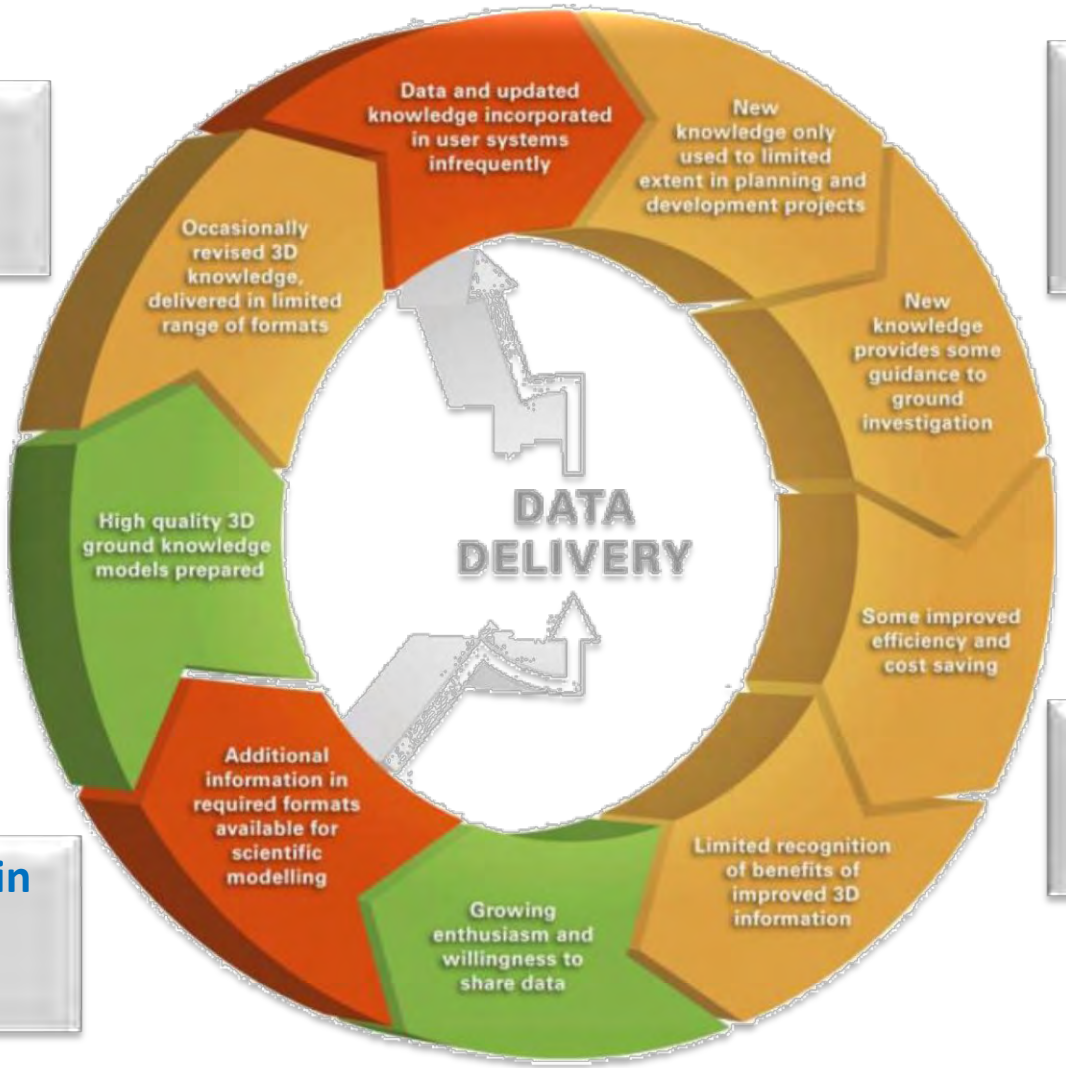
Consultants
contractors

Glasgow CITY COUNCIL

Current Glasgow situation

Limited revision of models

GCC and others use knowledge contained in 3D models



Greater willingness to share data

Data still in multiple formats

Functioning well

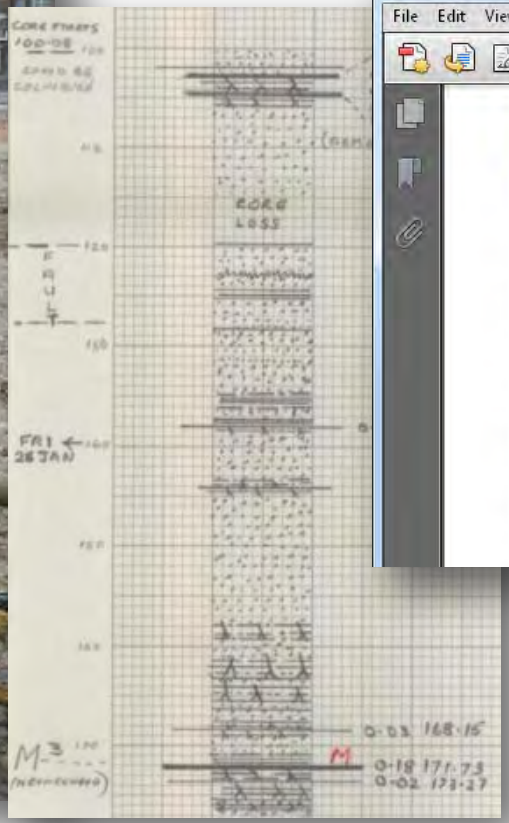
Function improving

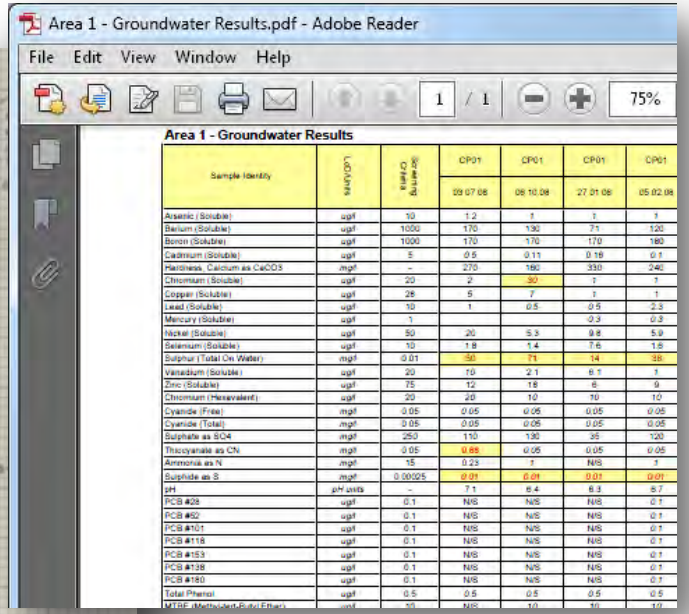
Beginning to function

Wealth of subsurface data unaccessed

Large amount of high quality ground investigation data only used once

Key access issues: data reporting and storage





GSPEC: Glasgow SPEcification for data Capture

Stems from GCC led project funded by Local Authorities Research Councils Initiative (LARCI)

Developed by BGS in partnership with GCC to address shared needs

Data deposited as raw digital data in standardised AGS forms (not PDFs)

Key metadata (e.g. grid reference, borehole ID, borehole construction) reported with all associated data

Full compliance and completeness of AGS format files

GSPEC: facilitating improved knowledge exchange

GCC now require all ground investigation data to comply with GSPEC protocols

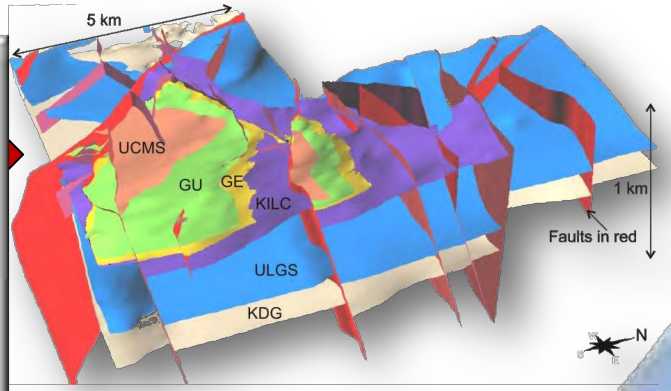
Data submitted to BGS for validation, confirmed to GCC if standards met

Web portal for submission and validation under development SG e-Planning portal involved

Other parties can submit GI data to BGS on a voluntary basis

Data accessible for long term re-use, and efficiently transferred between:

- Consultants
- contractors
- GCC
- BGS



Future Glasgow – a Virtuous Circle based on ASK

3D models updated and delivered to users by BGS

3D models routinely used for planning & decision-making by ASK partners

Data captured efficiently for re-use by BGS

GI Data acquired by ASK partners channelled through GCC/SG/BGS

Functioning well

ASK Network: how members join

Sign an Innovation Agreement

Allows BGS to supply 3D geological models and other information to Network members free of charge

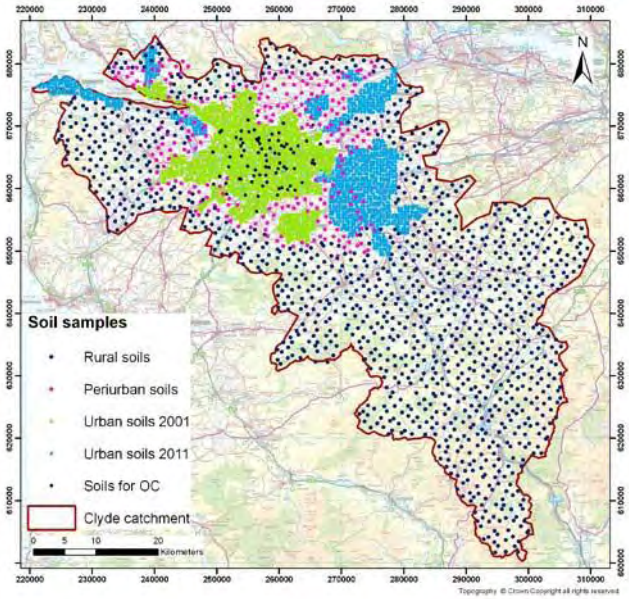
In return BGS would like:

- **feedback from members on how models are used,**
- **what could be improved, and**
- **willingness to help establish a *"virtuous circle of data and knowledge exchange"***
- ***GSPEC use encouraged, but not compulsory***

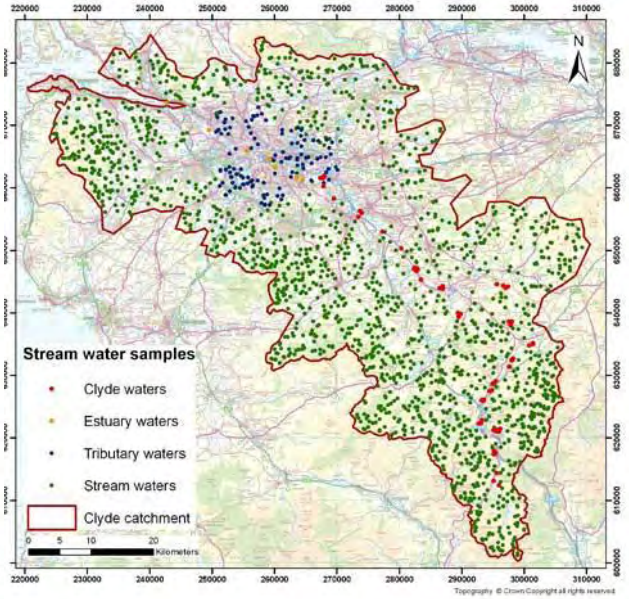
bgs.ac.uk/asknetwork


CUSP
City Urban Super Project
Our ultimate objective
fully integrated surface-subsurface environmental models interoperable in BIM systems

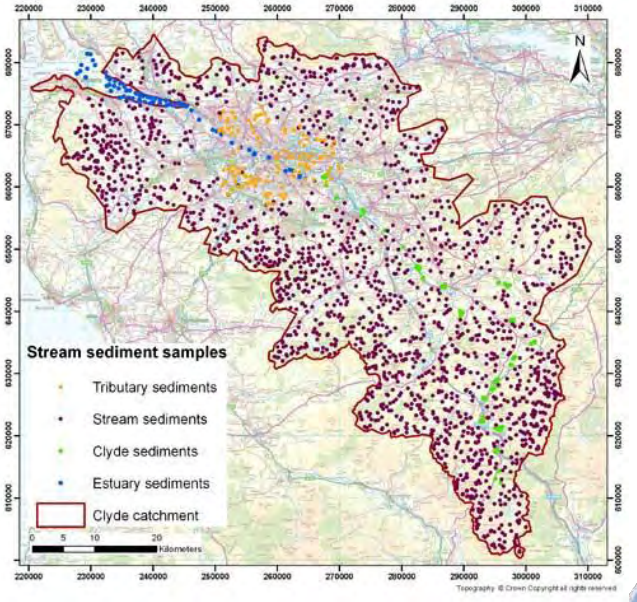
Clyde Geochemistry



Soil



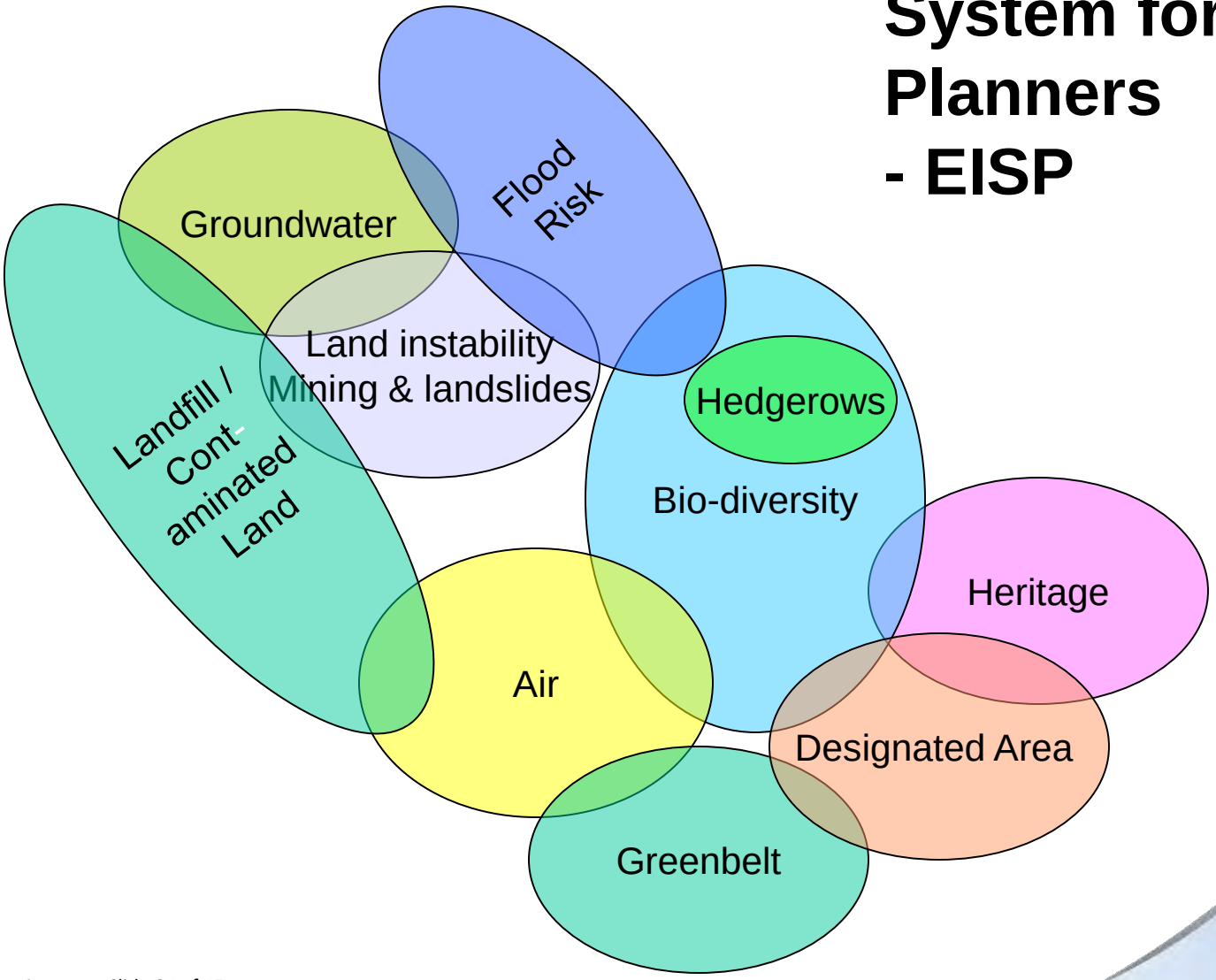
Stream Water



Stream Sediment

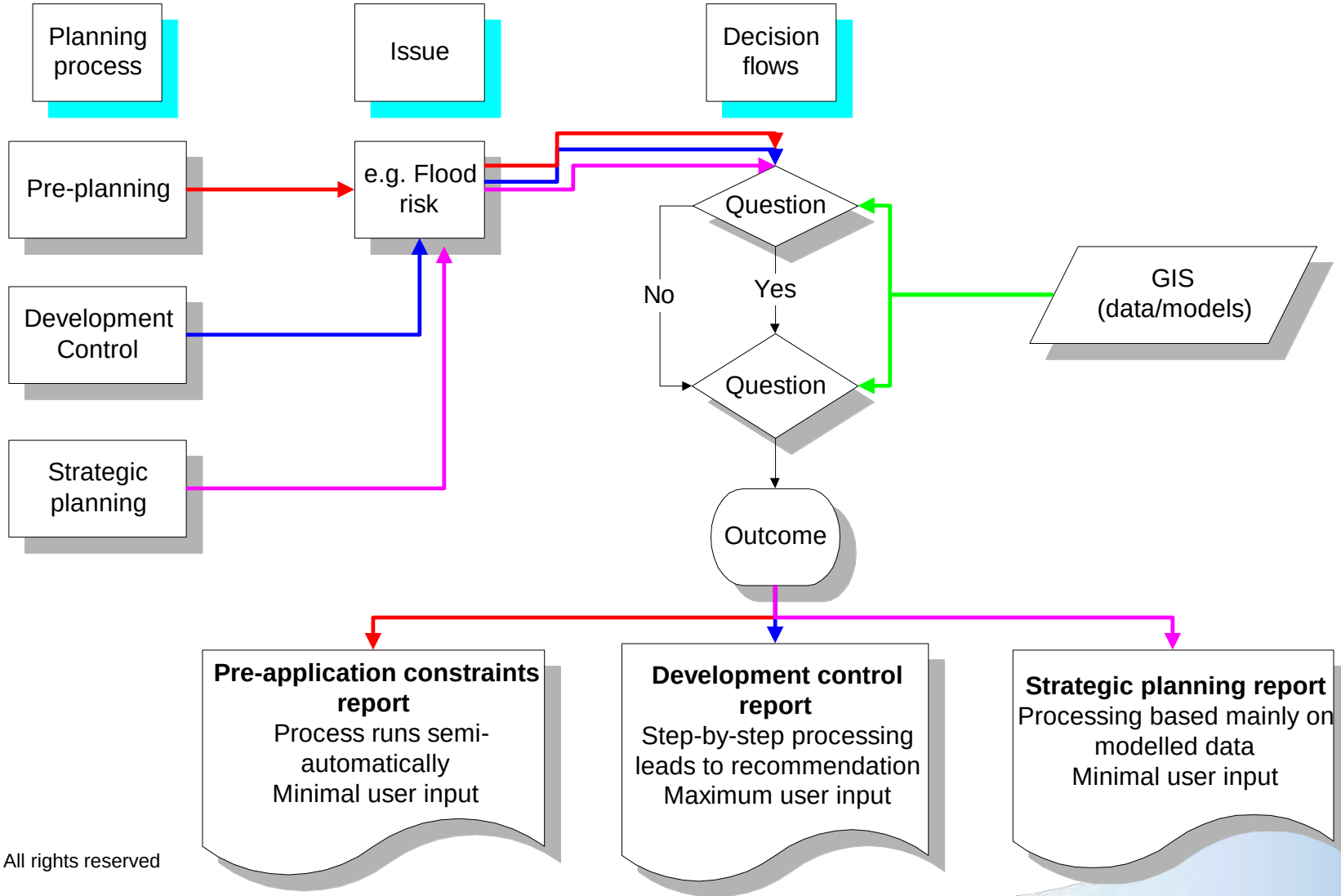
Which environmental issues?

Environmental Information System for Planners - EISP



EISP

Design overview: the system



EISP

Application determination

Defining conditions *Show Guidance Notes*

Shallow undermining has been identified as a constraint

Shallow undermining has been identified as a constraint.
Please refer to the linked condition.

Show Conditions

Defining Conditions - Shallow undermining

No. Additional measures against shallow undermining are not necessary

Any relevant mining reports and ground stability reports should be passed to a geotechnical engineer for their consideration.

Is there adequate information to assess mining issues identified in geotechnical brief?

Yes - 1. Advise negligable risk of subsidence. Proceed without special precautions

Application Result **Following the guidance, procedures and local authority practices represented here, EISP determines that in the absence of all other factors to be taken into consideration, normal practice would be to:**

1. Grant Permission ***Grant Permission.***

Model integration