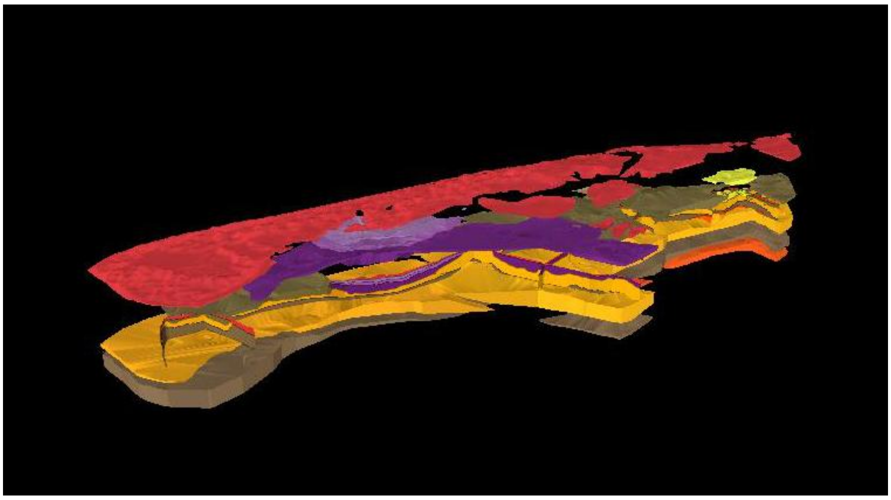
Model metadata report for the GSI3D model of shallow geophysical surveys of the ground seaward of the Drigg Low Level Waste Repository Site, West Cumbria

Geology and Landscape Programme

Internal Report IR/12/071



BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE PROGRAMME

INTERNAL REPORT IR/12/071

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Front cover

The calculated model viewed from the east.

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E Callaghan, T Kearsey, A Finlayson and C A Auton

Keyworth, Nottingham British Geological Survey 2012

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488

email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683

email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270

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

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

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

Tel 01793 411500 Fax 01793 411501

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Foreword

This report is the published metadata associated with a commissioned GSI3D model of shallow geophysical data for the Drigg Spit area of West Cumbria by the British Geological Survey (BGS).

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FIGURES

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Summary

This report describes the GSI3D model built from shallow resistivity sounding data acquired for ground seaward of the Drigg Low Level Waste Repository site, West Cumbria. The calculated 7-layer 3D model shows resistivity characteristics of Quaternary sequences overlying sandstone bedrock. This model was commissioned by the National Nuclear Laboratory (NNL) for Low Level Waste Repository Ltd (LLWR) and is Commercial in Confidence.

1 Modelled volume, purpose and scale

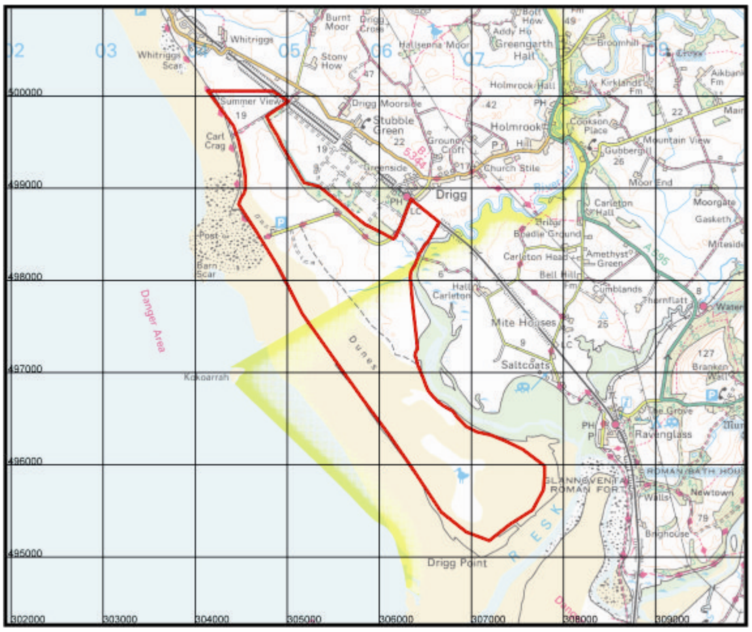


Figure 1: Location map showing area of study

The modelled area outlined in red is known as the Drigg Spit in West Cumbria.

The model was built to investigate the resistivity characteristics of the superficial deposits found in this area. The model has been constructed for use at 1:10,000 scale but can be studied in more detail; it was commissioned as part of a confidential report by the NNL for LLWR.

Smith, N. 2010. 3D geological interpretation of geophysical profiles and further 3D geological modelling at LLWR Site and surrounding area. National Nuclear laboratory Report NNL (10)11217; Issue 01. 142pp.

This model can provide the basis for use in other disciplines e.g. groundwater flow modelling.

2 Modelled surfaces/volumes

Old Drigg Site Lithostratigraphy (from Drigg Geology 1994-1997 reports)	Most recent lithofacies units	BGS lithostrat	Geophysical Units (divided on basis of colour and numbers of lines used in current interp)	
			Geophysical division currently on key on each profile	BGS/NNL division
Holocene and Recent Formation (HRF)	A		Post-glacial sands	A1 A2 A3 A4 A5 *A
			Recent Estuarine Drainage Sequence	B1 B2 B3
Lacustrine Fluvial Formation (LFF)	B2	Peel Place Sand and Gravel Mbr + Peckmill Mbr etc	Incised Sands and Gravels	C **
Pebbly Clay Formation (PCF)		Fishgarth Wood Till Mbr	Upper Till sequence	D1
Fluvial Outwash Formation (FOF)		Drigg Holme Sand Mbr		
Pebbly Clay Formation (PCF)		Drigg Beach Till Mbr		D2 D3
Fluvial Outwash Formation (FOF)		Kirkland Wood Sand and Gravel Mbr	Fluvial Outwash Sequence	E1
Main Diamict Formation (MDF)		Ravenglass Till Mbr		
Fluvial Outwash Formation (FOF)	B3	Barn Scar Sand and Silt Mbr		** E2 E3
Main Diamict Formation (MDF)	C	Holmrook Till Mbr	Lower Till Sequence	F
	Bedrock	Sandstone	Sandstone	PQU

* Assessed and coded as 5 superposed units however the complexity of contacts precluded modelling of individual layers, therefore modelled as a single unit.

** These layers contain lenses that are modelled individually

Figure 2: Division of Geophysical Units

name	id	code	old_drigg	2007_present	BGS_lithostrat	geological description
DTM	0	DTM	NULL	NULL	NULL	NULL
SITE	2	SITE	NULL	NULL	NULL	LLWR Site
A	5	A	HFF	A	DP_sand_lacustrine_etc	Post_glacial_sands
B1	25	B1	LFF	B2	PMS	Recent_estuarine_drainage_sequence
B2	30	B2	LFF	B2	PMS	Recent_estuarine_drainage_sequence
B3	35	B3	LFF	B2	PMS	Recent_estuarine_drainage_sequence
C	40	C	LFF	B2	PPG	Incised_sand_and_gravel
D1	45	D1	PCF	B2	FWT	Upper_Till_sequence
D2	50	D2	PCF	B2	DBT	Upper_Till_sequence
D3	52	D2	PCF	B2	NULL	Upper_Till_sequence
E1	55	E1	FOF	B2	KW	Fluvial_outwash_sequence
E2	60	E2	MDF	B3	RVT_BSS	Fluvial_outwash_sequence
E3	62	E3	NULL	NULL	NULL	Fluvial_outwash_sequence
F	65	F	MDF	C	HRT	Lower_Till_sequence
PQU	70	PQU	NULL	NULL	NULL	Pre_quaternary_rock
C_top	-100	C_top	NULL	NULL	NULL	C_lens
C_base	100	C_base	NULL	NULL	NULL	C_lens
E2_top	-150	E2_top	NULL	NULL	NULL	E2_lens
E2_base	150	E2_base	NULL	NULL	NULL	E2_lens

Table 1: GVS used for GSI3D model incorporating geophysical units

3 Modelled faults

Not applicable

4 Model datasets

General caveats regarding BGS datasets and interpretations can be described:

- Geological observations and interpretations are made according to the prevailing understanding of the subject at the time. The quality of such observations and interpretations may be affected by the availability of new data, by subsequent advances in knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations.
- Raw data may have been transcribed from analogue to digital format, or may have been acquired by means of automated measuring techniques. Although such processes are subjected to quality control to ensure reliability where possible, some raw data may have been processed without human intervention and may in consequence contain undetected errors.

Data for the model can be found at this link:

W:\Teams\CEC\LLWRCoastalErosion\RestrictedProjectInformation\Drigg_3d_model

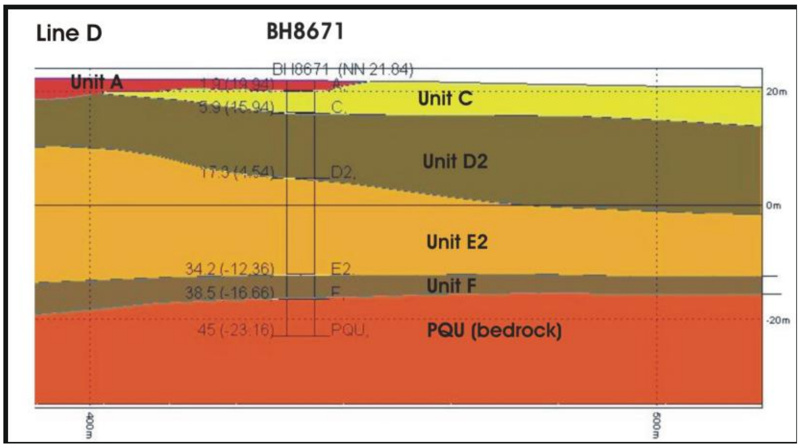
4.1 DTM

The DTM was created from LIDAR data provided by LLWR. The 2m cell size was resampled to 3m cell size in ARCGIS. This reduced the resolution and produced a smaller file size (required for GSI3D) but did not materially alter the XYZ values of the dataset.
The LIDAR raster was converted to ASCII, using ARC GIS, to enable its import into GSI3D and the ASCII grid was converted to a TIN in GSI3D.

4.2 GEOPHYSICAL DATA

Data were provided in the report "Low Level Waste Repository Ltd. Drigg Coastal Erosion, Geophysical Report, Halcrow Group Ltd, January 2010"; as well as separate pdf. files of each geophysical section line, provided by LLWR. These interpretations were provided by a team, led by Halcrow, tasked with interpreting the resistivity soundings calibrated by the logs of the boreholes (see Section 4.3 below) and from the geological mapping of the Drigg area (BGS, 2010; Auton, 2011).

Each of the 8 geophysical lines of section was identified by the data provided, e.g. Lines A-H, (see Figure 3).



True scale (no vertical exaggeration)

Figure 3: Borehole BH8671 as shown in geophysical line D

- Surface traces of section lines (A-H) were imported from supplied Arc shapefiles.
- Supplied .pdf's were converted to jpeg's of profiles; these were cropped, imported and attached to section lines in GSI3D; these provided guides for recreating profiles in GSI3D. Note that the 'Interpreted Geological Model' for each profile was used.

4.3 BOREHOLES

Borehole data – pre-existing logged boreholes and boreholes and trial pits sunk for the project by BGS. (Dobbs and Balson, 2010).

The 26 boreholes supplied (Halcrow), were coded with reference to the geophysical boundaries as portrayed on the Interpreted Geological Models (IGM) provided by NNL. Using the IGM key provided, (see Figure 2), the geophysical units were arranged in stratigraphical order and a letter assigned to each unit. For example, the uppermost unit, Post Glacial Sands (shown in red) was coded as A, the second unit; Recent Estuarine Drainage Systems (shown in purple) was coded as B etc. This resulted in 8 lines of section and a maximum of 6 'Major' Units, (A-F), extending from the surface into bedrock. Where bedrock was reached in the borehole the code PQU (Pre-Quaternary Undefined) was used.

Where any major unit contained more than one layer (boundary) in the geophysical cross-sections, they were divided and sequential numbering was used for each division. For example in Cross-Section A, there were three divisions of Major Unit B (Recent Estuarine Drainage Sequence); this led to B being split into B1, B2, and B3. All of the cross-sections were assessed together, to calculate the maximum number of divisions of each major unit. This controlled the number of divisions required for Generalized Vertical Section (GVS), which is used to generate the GSI3D model.

The generation of a complete GVS, file name (Drigg_Master_gvs.gvs), was achieved, (see Table 1). It included unique attributions of all the major units, divisions and lenses, a total of 17 layers. To accompany the GVS a legend file (Drigg_legend_v2.gleg), was created, using these 17 layers to enable GSI3D to produce coloured cross-sections and a coloured 3D model. The colours were chosen to match the supplied IGM as closely as possible.

The depths to the base of individual units were taken from the plotted position of the intersection of the geophysical boundaries with the borehole sticks given on the IGM. These were transcribed using the vertical scale provided on the geophysical cross-sections. The depths and codes were recorded in the following file, Drigg_Boreholes_BOGE_v4.blg, and the start heights were recorded in Drigg_spit_bores.bid, for entry into GSI3D.

- Note: Position of BH C (Profile A - c. 3600 m): plotted position corrected, from shapefile. This is different from the position shown along the profile - Offset is roughly 150 m.
- Note: BHs 8666 and 8667 are included in the supplied profile of Line C. However, both these boreholes lie a distance away (80 m and 60 m) from the profile lines in supplied shapefiles. Due to this uncertainty, these were not used in initial profile matching, but were incorporated within a ‘helper’ section at the final modelling stage.

5 Dataset integration

All data were brought together in the GSI3D modelling software where it can be viewed and interrogated in 2D and 3D.

6 Model development log

The process was initially undertaken in three stages. (1) Borehole coding (for details see above). This was undertaken to ensure that the geophysical unit bases were consistent with those identified on the borehole sticks hung from each ‘Interpreted Geological Model’. This was an iterative process which highlighted and solved a number of instances where boundaries on crossing profiles were offset. (2) Cases of misalignment at boreholes on profile intersections were resolved by moving one (or both) of the mismatched geophysical bases to produce an improved geometrical alignment along both intersecting profiles. (3) Similar realignments were made at all remaining localities where profiles cross, thus ensuring that the modelled unit boundaries were consistent across all 8 profiles.

7 Model workflow

The methodology for construction of models in GSI3D is described in great detail by Kessler et al. (2008; http://nora.nerc.ac.uk/3737/1/OR08001.pdf). It principally involves construction of cross-sections between the best quality borehole data followed by envelope construction around the limits of the geological units or in this case geophysical properties.

8 Model assumptions, geological rules used etc

A nominal depth of 35 m below Ordnance Datum has been taken for the model. This allows inclusion of data from the deepest profile. Boundaries have been extrapolated to this depth for other sections.

8.1 ENSURING A CONSISTENT GEOPHYSICAL ‘STRATIGRAPHY’

In order for the existing interpreted geophysical boundaries to work ‘stratigraphically’ in GSI3D: units D and E had to be subdivided so that they now comprise 3 sub-units each; similarly, unit A now comprises 5 sub-units.

The interpreted boundary configuration at c. 1350 m along Profile B had to be very slightly modified, so that the edge of the A3 impinges slightly on the channel infill (A4). A further slight modification was made at c. 1600 m, where a boundary was added (guided by GPR lines) to allow on-lapping of A1 onto A3, and consistency with the rest of the model.

8.2 ENVELOPING UNITS

Due to the complexity of the sub-units of Unit A and because the A1/A2 landforms did not correlate with the Lidar survey of the dunes or the mapped units on the geological map, it was decided that without further field investigation it would be impossible to resolve the extents of the individual A sub-units. Consequently, the subdivisions of Unit A were not modelled and it was treated as a homogenous entity.

Envelopes were created for all of the remaining Major units and sub-units within the model. ‘Helper sections’ were constructed around the model edges to enable the envelopes to be calculated.

9 Model recommendations

9.1 RECOMMENDATIONS FOR FURTHER IMPROVEMENT OF THE APPLICABILITY OF THE GSI3D MODEL FOR HYDROGEOLOGICAL MODELLING:

It is very unlikely that further basic data collection (boreholes, trial pits, and geophysical surveys) will be undertaken across the model area in the near future. It is also evident that the geophysical model cannot be directly equated with a 3D model of the near surface geology; it is a reflection of that geology as it is expressed in geophysical parameters (principally electrical resistivity). It can however provide an indication of the gross form and trend of the principal lithologies or lithological/stratigraphical packages across the area in 3D.

In order to produce a more relevant 3D visualisation of the distribution of the lithological packages across the model area, a GSI3D geological model could be produced. It should:

- Use all of the existing borehole data and the newly acquired trial pit data from the Drigg Spit area (the latter were not included in the present ‘geophysical’ model).

- These data should then be integrated with the new geological mapping and with selected representative 'on-site' boreholes with the 'typical' lithological/lithofacies packages currently being established. The model should be extended to below rockhead by incorporating the area rockhead contour data generated by Quintessa. Ground water data should also be included.

- This geological 3D model should then be compared with the geophysical 3D model and the modelled geophysics used as a guide to 3D correlations of the geology. This would be an iterative process. It would produce an internally consistent model that integrates both on-site and off-site datasets in true 3D space, in a holistic manner. Volumes could then be established for the packages of sediments and physical attributes (such as permeability) assigned to each package. This would enable the modelled 'layers' to be reattributed with their hydrogeological parameters and facilitate shallow groundwater modelling in 3D across the site boundary.

- This would provide a comprehensive 'local area' model of both geology and ground water which could be easily interrogated, and visualised, and within which the more detailed models of on-site geology and hydrogeology, that are currently being constructed, could be integrated.

10 Model images

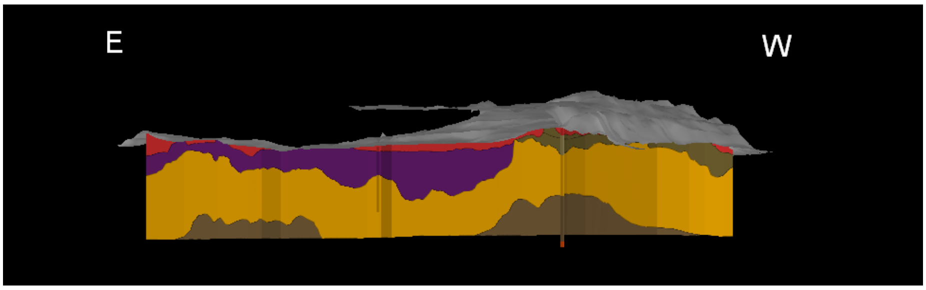


Figure 4: Model cross-section of geophysical Line G

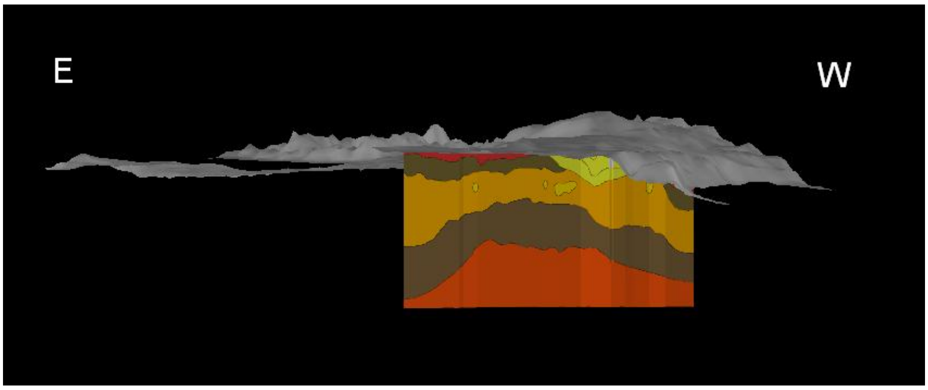


Figure 5: Model cross-section of geophysical Line C

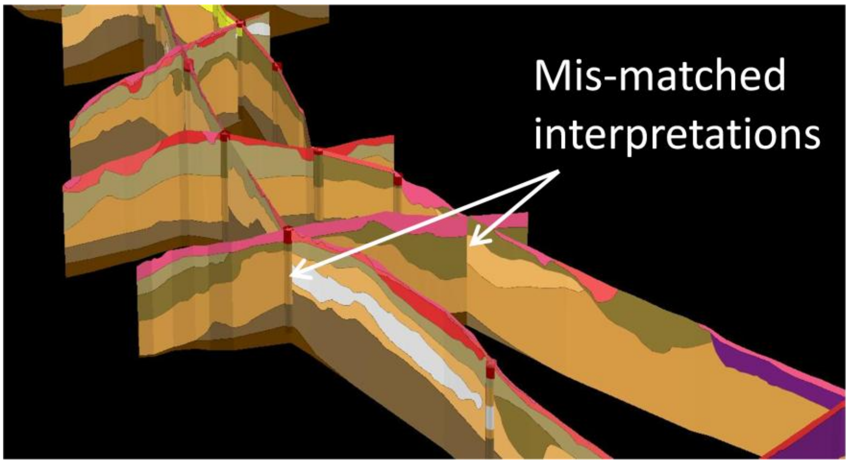


Figure 6: Mis-matches between initial interpretations on intersecting resistivity cross-sections were identified and resolved in GSI3D

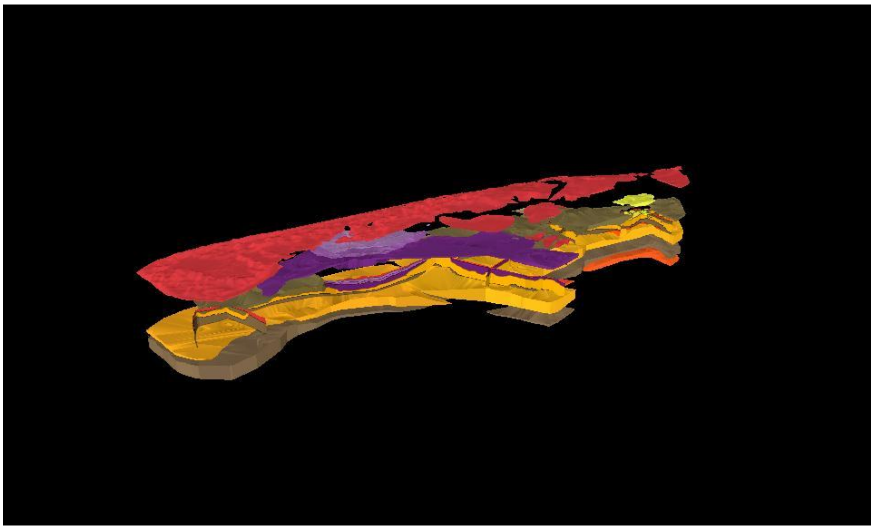


Figure 7: Final model viewed from the East

11 Model uncertainty

11.1 VOLUME CALCULATIONS

Volumes were automatically calculated for each of the modelled geophysical units.

Unit	Sub Unit	Area (km^2)	Volume (km^3)
A		**3.941733956**	**0.017471056**
B		**2.150171838**	**0.01228566**
	B1	*0.365856884*	*0.001350327*
	B2	*0.416244643*	*0.001365704*
	B3	*1.368070311*	*0.009569629*
C (and lense)		**0.132225209**	**0.000869927**
	C	*0.112635372*	*0.000809236*
	C_top	*0.019589838*	*6.0691E-05*
D		**2.728584326**	**0.022394893**

Table 2: Volumes of 'geophysical units'

These data (volumes of ‘geophysical units’) may not be of direct relevance in this report, but this type of data would be extremely valuable when applied to geological units or packages used for hydrogeological modelling.

Appendix 1 Borehole and trial pit locations used in the modelling

Bore_Name	Easting	Northing	Start Height (m)
QBH11	306763	497092	7.1
QBH12	304219	500031	5.18
QBH20	307297	497387	6.92
BH8673	305602	499707	18.5
BH8669	305502	499567	16.7
BH8668	305306	499974	20.03
BH8773	305382	499858	19.35
BH8667	304928	499981	18.71
BH8666	304798	499922	17.79
BH8670	304774	499535	20.75
BH8775	304662	499500	21.35
BH8671	304844	499361	21.84
BH8672	304940	499182	21.84
BH8776	304772	499149	24.88
BH8774	305062	498861	18.49
BH8772	305222	498794	16.12
BH004	305992	496509	4.25
BH005	305403	497333	4.72
TP013	304536	498750	2.15
TP014	304466	498748	1.67
TP014A	304415	498667	0.9
TP014B	304352	498628	0.37
TP015	304407	498937	1.38
TP016	304308	498941	0.1
TP017	304386	498997	1.12
TP018	304315	499010	0.59
TP019	304375	499592	2.61
TP026	306984	495842	5.04
TP027	307735	495794	4.57
TP028	307315	496233	3.85
TP029	306694	495503	3.89
TP029A	306602	495435	2.24
TP030	305982	496502	3.87
TP030A	305906	496427	1.22
TP030A2	305900	496422	1.61
TP031	305341	497405	4.09
TP031A	305272	497359	1.95
TP031B	305397	497329	4.21
TP033	304740	498445	3.91
TP033A	304645	498395	1.06
TP034	304629	498626	3.58
TP034A	304552	498579	1.34
TPBH001	307322	495315	4.29
TPBH003	307210	496286	3.38
TPBH006	306613	495612	4.27
BH002	307636	495550	4.18
7698	304788	499445	20.76
7517	304728	499750	18.78
7520	304894	499857	18.81
DDS117	304859	499844	18.77
CPTA13	305547	498746	10.1
ROF12	305195	498967	18.68
ROF17	304838	499048	23.55
ROF18	304743	498854	15.5
ROF22	304652	499588	21.7

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: http://geolib.bgs.ac.uk.

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