



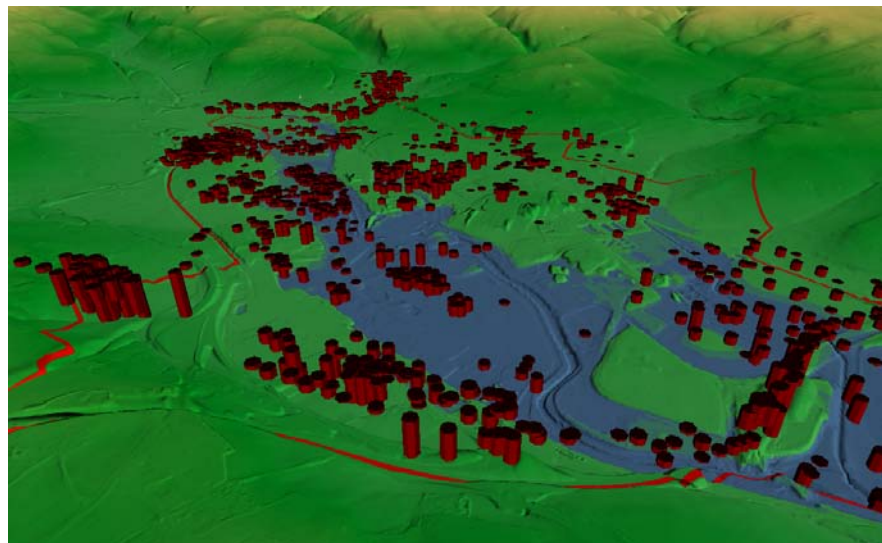
**British
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL

Enhanced Mapping of Artificially Modified Ground in Urban Areas; Using borehole, Map and Remotely Sensed Data

Engineering Geology Programme

Open Report OR/15/010



BRITISH GEOLOGICAL SURVEY

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Enhance Mapping of Artificially Modified Ground in Urban Areas; Using borehole, Map and Remotely Sensed Data

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Front cover

The amount of land level change visualised using the length of boreholes.

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) for the Urban Geoscience team of the Engineering Geology Directorate. The report describes the mapping and classification of Artificially Modified Ground in the Leeds area using boreholes and borehole properties as the primary data resource. This follows on from the AMG and landuse mapping in the Fleet and Rotherhithe areas of London, which used historical and modern maps as the primary data resource.

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Summary

The report described here is focused on how using boreholes and attributes from boreholes increased and enhanced the mapping of Artificially Modified Ground, and helped measure landscape evolution change in the urban environment. These attributes from boreholes include the presence of AMG in a borehole, the thickness of AMG recorded, the start height of a borehole and the location of boreholes (and other boreholes in close proximity) with modern topological features and geological maps.

1 Introduction

Rapid urbanisation has been driven by population change, socio-economic and technological development, and has impacted profoundly on the geological and geomorphological character of the urban environment. The deliberate, current and historical anthropogenic modification of the landscape and its subsurface creates sediments and landforms in the form of AMG (Price et al., 2011). Artificially Modified Ground (AMG) represents those areas where the ground has been significantly changed by human activity, usually divided into the following categories on BGS geological maps:

- Made ground — human-made deposits, such as embankments and spoil heaps on the natural ground surface
- Worked ground — areas where the ground has been cut away, such as quarries and road cuttings
- Infilled ground — areas where the ground has been cut away, and then wholly or partially backfilled
- Landscaped ground — areas where the surface has been reshaped
- Disturbed ground — areas of ill-defined shallow or near surface mineral workings where it is impracticable to map Made Ground and Worked Ground separately

AMG was not consistently mapped by BGS until the 1980s although many urban areas are built on AMG (http://www.bgs.ac.uk/products/digitalmaps/digmapgb_art.html), and even the modern AMG mapping has focused primarily on mineral workings, industrial areas and transport routes (Burke, H et al., 2014; Mathers et al., 2014). Therefore, AMG is an important but often under represented feature in geological maps and models (Aldiss et al., 2014; Ford et al., 2014). Some of the factors which have caused this include:

- Education that has primarily focused on naturally occurring Quaternary and Bedrock deposits
- Training in geological surveys and commercial organisations focused on Quaternary and Bedrock mapping and modelling
- Difficulties observing AMG boundaries and during geological surveying of areas
- Cartographic issues, such as AMG obscuring natural geology on geological maps in urban areas
- Some AMG features are already recorded on topographic maps

Recent progress made by the British Geological Survey (BGS) and others around the world in this field has meant that AMG is increasingly mapped and modelled, and is now regarded by many as an important deposit or excavation likened to natural geological processes (Bridge et al., 2005; Bridge et al., 2010; Burke, H F et al., 2014; Ellison et al., 2002; Price et al., 2012; Zalasiewicz et al., 2011). The study described here is mainly focused on how the mapping of AMG can be increased in urban environments using borehole index information and attributes from logged boreholes. These include the presence of AMG in a borehole, the thickness of AMG recorded, the start height of a borehole and the location of boreholes (and adjacent boreholes) with AMG recorded against the modern topological features and modern geological maps. This study follows on and compliments studies in the Fleet and Rotherhithe areas of London, which

focused on land use and AMG mapping from historical and modern topological maps (Burke, H F et al., 2014; Mathers et al., 2014; Smith and Burke, 2011; Thorpe et al., 2011). By improving our knowledge of the distribution and types of AMG in urban areas, it will improve our understanding of ground conditions, which will help in construction and regeneration projects.

1.1 WHY USE BOREHOLES?

There are a number of reasons to use borehole logs as a method for mapping and characterising AMG. Boreholes have been drilled for almost two millennia around the world (Loewe, 1968) and BGS has borehole records dating back over 200 years. These boreholes have been drilled for a number of reasons, including:

- extraction of water or other liquid substances, such as oil
- extraction of gases
- mineral exploration
- geothermal installations
- civil engineering and site assessment
- geotechnical investigation
- scientific investigation

Not only will the purpose of a borehole indicate which type of anthropogenic activity has occurred, many of these borehole records have some kind of drill date associated with them. This will usually precede some kind of anthropogenic development or activity, meaning anthropogenic many deposits can be dated fairly accurately.

Previous studies have established that boreholes are an essential data resource for mapping AMG in urban environments. In Ford et al. (2014) it was established that the distribution of boreholes and trial pits is generally concentrated in urban areas and centres of extractive industry in the UK. About 10% of registered boreholes and trial pits intersect categories of AMG on BGS 1:50 000 scale maps that are likely to include anthropogenic deposits. Although many records predate development activities (e.g. construction) that results in the subsequent creation of AMG, they provide useful information on the thickness and spatial extent of pre-existing anthropogenic deposits.

This has been supported further by Aldiss et al. (2014) who suggested that in the absence of a discernible associated landform, AMG can be mapped from records of boreholes and trial pits, where there is a sufficient density of such data. Usually this will be an instance of Made Ground, perhaps of engineered fill, although it is conceivable that boreholes could demonstrate the presence of a broad area of shallow excavation with little or no surface signature (Price et al., 2010).

Aldiss et al (2014) went further to say that some interpretation must be made concerning the extent between or beyond boreholes of, for example, an urban 'blanket' of Made Ground. Where borehole records are relatively closely spaced, show a consistent thickness of Made Ground, and where there is no landform or open space of undeveloped ground that might indicate the contrary, it may be assumed that the 'blanket' is continuous. This is found in central London, for example, where nearly all boreholes and trial pits encounter at least 1 m of Made Ground, and locally over 10 m is present. Therefore, boreholes are a useful indicator of AMG particularly in cities and towns, and certain assumptions can be made in urban areas between boreholes where it

is likely the AMG is continuous across the whole of that urban area, thus making it a mappable unit.

Ford et al. (2014) supports the view that borehole records are an important resource for indicating the presence of anthropogenic deposits. Compaction and diagenesis may reduce the thickness of these types of deposit, but, if preserved in the rock record, they would present a mappable unit similar in thickness to many natural deposits.

The following data from boreholes could be considered useful for classifying and assisting the mapped output of AMG in urban areas:

- Presence/absence of artificial AMG in borehole logs
- Thickness of AMG in borehole logs
- The start height of the borehole log
- Date of drilling
- The description of the deposits, e.g. waste, fly-ash, tipped natural materials

The presence or absence of AMG in borehole logs can be used to map out areas of continuous-semi continuous AMG and areas where it is absent. The thickness and any associated landform may indicate the type of AMG present. The start collar height of a borehole is usually the ground height in metres relative to OD. Using this start height we can infer former land levels where these have been modified, e.g. a borehole was drilled before a quarry was mined or as a cutting is excavated (Price et al., 2012). This is useful in assessing landscape evolution and classifying AMG. If this data is combined with drilling dates, then the AMG can be considered to represent a stratigraphical sequence in the landscape evolution.

In the following sections, the methods used, analysis and results are presented using the borehole information listed above for improving the mapping and classification of AMG in urban areas.

2 Study Area and Data Resources

2.1 STUDY AREA - LEEDS

The Leeds borough unitary area was selected to study the borehole mapping of AMG. The area is approximately 552 km² and is situated in West Yorkshire (Figure 1). Leeds was chosen as the project area as it has an estimated population of 757 700 people, making it the third largest city in the UK according to the Office for National Statistics (2012), and has a long history dating back to the 7th Century. Leeds initially developed as a market town and then played a pivotal role in the Industrial Revolution, centred on the production of wool, iron foundries, printing, flax and engineering. Following the decay of the post-industrial era, Leeds has become a banking, legal and retail centre, with much redevelopment occurring over the last 50 to 100 years in transport and infrastructure (Various, 2014). Much of this redevelopment has occurred on Brownfield sites, where at its peak up to 97% of new residential properties in Leeds were built on this type of land in line with UK legislation (Brannen, 2012) as opposed to being built on greenbelt. Leeds has many open cast coal mine operations, some of which have now been abandoned and reclaimed, particularly along the Aire Valley. In these areas artificial deposits can be variable in thickness and composition due to the variety of fill used (Waters et al., 1996) and if not properly engineered or restored can pose a geohazard, such as subsidence at the margins of excavations (Price et al., 2011). These factors make Leeds a logical choice as a case study for AMG.



Figure 1 Leeds Overall Project Area - UK

The project area has been split into two for the purposes of this study. The overall Leeds borough unitary area was used as the project area to assess the start heights of boreholes for AMG, which can be automatically obtained from existing BGS databases. A smaller area, covering 13.35 km² in the south west of the city along the Aire River valley was used to assess the presence/absence and thickness of anthropogenic deposits for mapping AMG (Figure 2) as these were coded manually into the BGS databases. The Aire Valley project area was incorporated within a larger zone of development in Leeds known as an Enterprise zone. This area will be the site for major development and redevelopment of industrial space, homes, and transport infrastructure from 2012 to 2015, with particular emphasis for ecologically sustainable options. This is part of a wider Government initiative rolled out to 21 other areas of the UK

(<http://airevalleyleeds.com/ez/>). In the south east of this enterprise zone there is a site of a former opencast mine, which has been redeveloped into a country park, resulting in a mixture of residential, industrial, open parkland and former mining areas all of which need to be taken into consideration when analysing the borehole data against geomorphological landscape features.

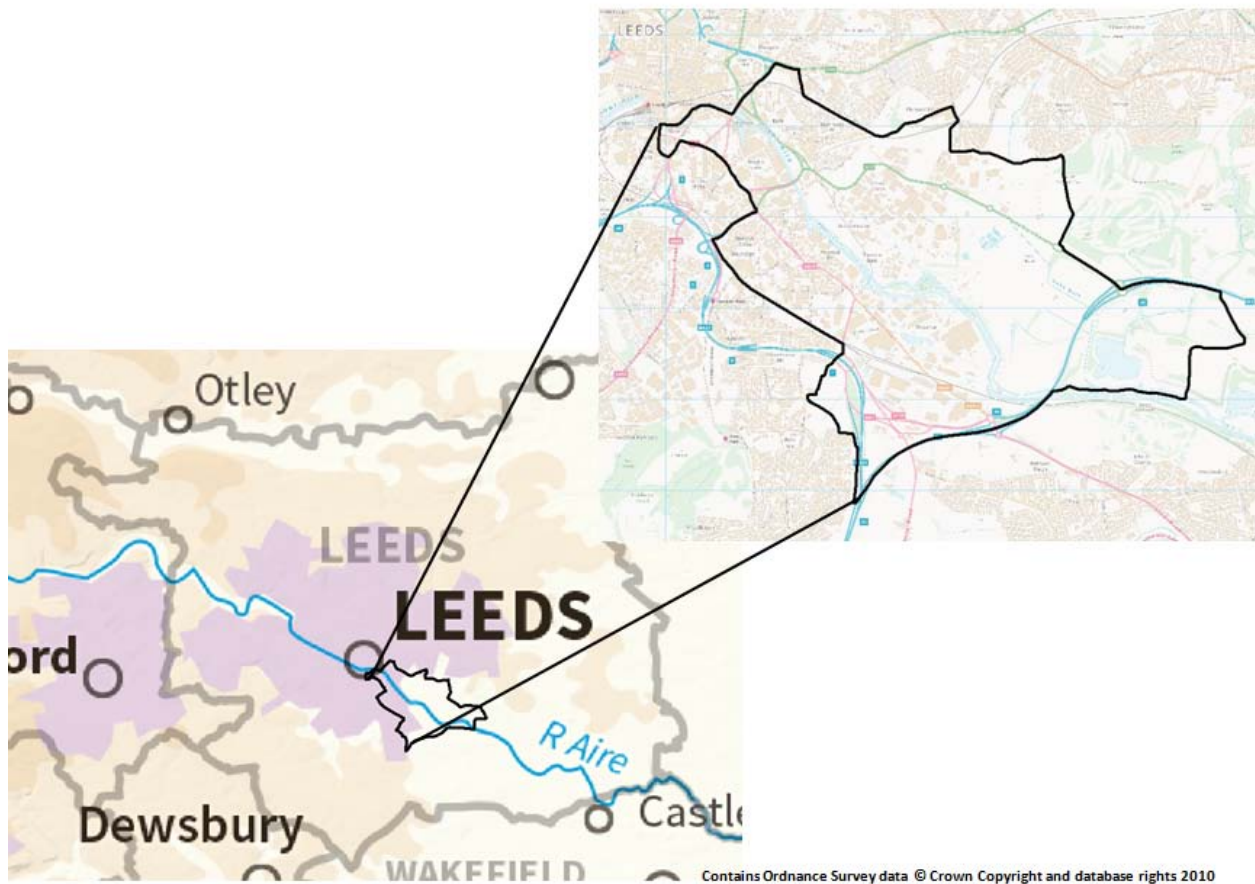


Figure 2 Leeds borough unitary (bottom left) and Aire Valley Project Areas (top right)

2.2 DATASOURCES

The following datasets were used in this study:

- NEXTMap[®] Britain Bald Earth Digital Terrain Model (DTM at 5 m resolution)
- LiDAR (DTM at 1 m resolution)
- Boreholes – data sourced from Single Onshore Borehole Index (SOBI) and Borehole Geology (BoGe) BGS databases
- Ordnance Survey topographic 1:10 000 and 1:50 000 scale maps
- Ordnance Survey Open data (Vector Map District and 1:250 000 colour raster data)
- DigMapGB 1:10 000 artificial layer (v2.18, released 15/01/2009)
- OS MasterMap[®] (for reference only)
- Aerial Photography (25 cm resolution)

The BGS Enhanced classification for Artificially Modified Ground, revised 2014 (Smith et al., 2014), was adopted in this study where possible. The classification scheme attempts to subdivide AMG (Superclass) into Class, Type and Unit by using information based on the origin and landform of the deposit and excavation. This arrangement allows multiple divisions at a lower level in the hierarchy to be assigned to a single division at a higher level. These levels are

analogous to the lithostratigraphical hierarchy of: Supergroup, Group, Formation and Member used to characterise bedrock and Quaternary geological units on BGS maps. Selected examples of this subdivision in the classification of AMG are shown in Figure 3. This classification does not consider actual Lithology of the material, but does indicate a landform type expression.

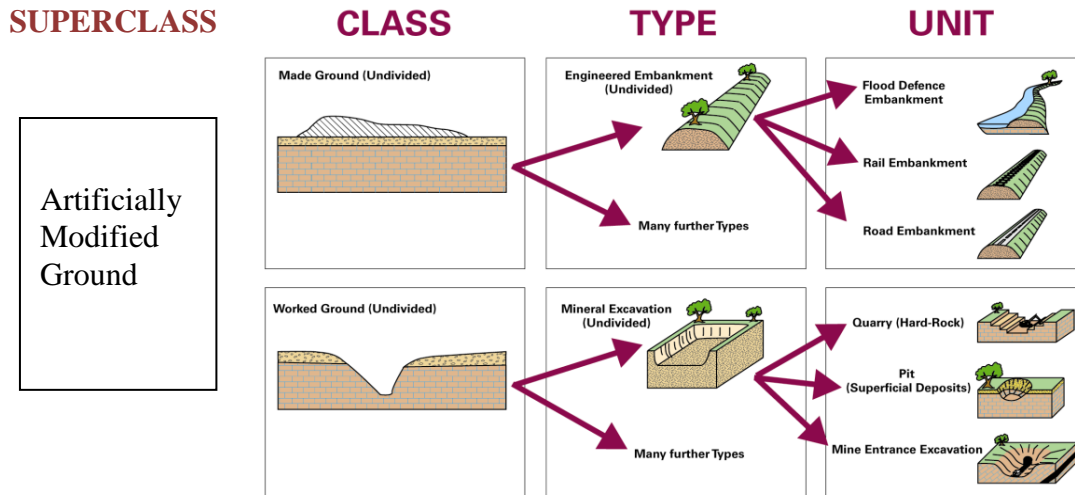


Figure 3 Selected examples of branches of the enhanced AMG hierarchy

2.3 SOFTWARE USED

- ArcGIS v10.1
- MS Excel, Word and Access
- GeoVisionary (GV) v2.3
- GSI3D v2013

3 Artificially Modified Ground Presence/Absence Map

Boreholes within the Aire Valley Enterprise Zone were investigated to see if AMG was recorded in the log. These boreholes were then mapped in a GIS showing the presence or absence of AMG recorded and how this relates to mapped AMG (DigMapGB 1:10 000 AMG theme), and AMG mapped virtually using GeoVisionary (GV). Where AMG occurred in logs, the thickness was recorded to see if any relationship existed between the type of AMG and thickness of AMG found in the log. Table 1 shows a summary of the boreholes used in the Aire Valley Enterprise Zone.

	Number of boreholes	Percentage of total boreholes
Total Number of Borehole logs in AOI	3897	N/A
Borehole logs with No AMG present	544	13.96%
Borehole logs with AMG recorded	1832	47.01%
Borehole logs that are not clear whether AMG was recorded or not*	1521	39.03%

*The majority of these borehole logs were in the opencast collection and either did not have a log or it was difficult to ascertain whether AMG was recorded or not. These are assumed to be in areas of Worked Ground, but not used in overall survey.

Table 1 Summary of boreholes used in the AMG presence and absence study

Approximately 47% of the 3897 borehole logs checked have had AMG recorded in them and less than 14% have no AMG present. Figure 4 shows the spatial distribution of borehole logs analysed for the presence and absence of AMG. Boreholes were classified into those with AMG recorded in the log, those with no AMG recorded in the log, and boreholes in which it is unknown whether AMG was recorded. The latter could include boreholes with artificial deposits and Quaternary deposits recorded together in one unit, or no geological description available. By plotting all of these boreholes on a topographic map, it was possible to make visual assessments of the types of AMG present from the density, proximity and distribution in relation to other boreholes. Areas of linear transport routes, such as roads and railways for example, were more easily identified. Areas in which no AMG was recorded in the borehole log are equally important as they indicate areas of natural geology only. In both cases, historical and modern maps would need to be cross-referenced with the boreholes to corroborate these findings. For example, those boreholes with no AMG recorded in the log could have been drilled before any anthropogenic development or could indicate where natural geology is at outcrop. Further virtual map or field based analysis would confirm whether these boreholes actually precede some form of anthropogenic activity.

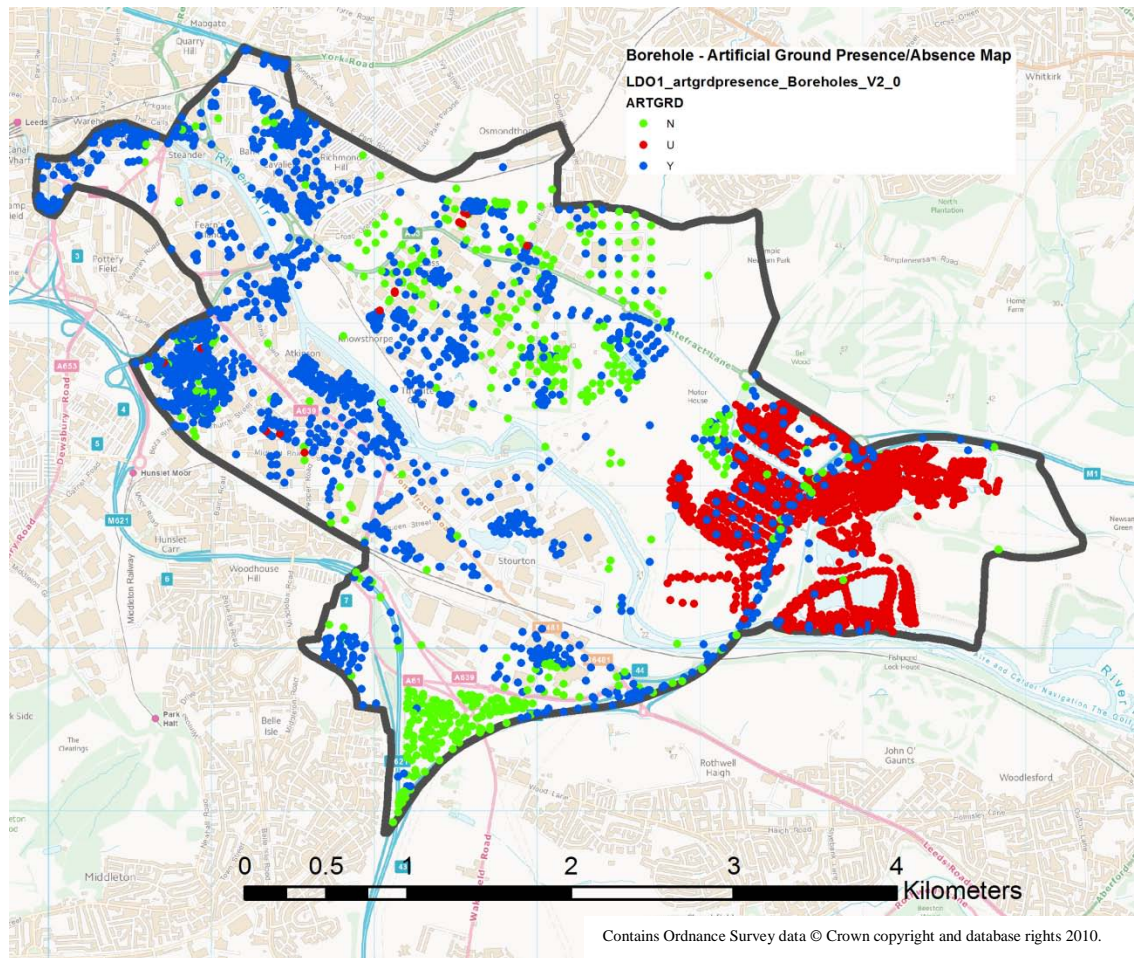


Figure 4 Map showing the distribution of boreholes with AMG (Y), no AMG (N) and those that are unknown or unrecorded (U)

The locations of these boreholes were compared against the current DigMapGB 1:10 000 Artificial Ground layer. Not only did this show where boreholes with AMG are encompassed by mapped AMG, but also where boreholes that record AMG exist but are not within mapped areas of AMG. Those boreholes outside of existing DigMapGB AMG areas, but have AMG recorded in the log enabled the identification of additional areas within the project area that could be mapped. Table 2 shows a summary of the number of boreholes that fall in these categories, and Figure 5 shows the distribution of these boreholes in the Aire Valley project area.

12.9% of the total borehole dataset (501 out of 3897 boreholes) were within the mapped DigMapGB AMG, which is comparable to the data analysed by Ford et al (2014), where 10% of boreholes recording anthropogenic deposits occurred within mapped areas of AMG. Conversely, boreholes with AMG recorded in the borehole log but fall outside of DigMapGB mapped AMG make up 34.2% of the total borehole dataset (1331 out of 3897 boreholes). This is a significant proportion of boreholes that could be used to aid the identification of additional areas of mappable AMG in conjunction with modern and historical topographic maps.

	Outside of DigMapGB AMG	Total inside DigMapGB 1:10000 AMG	DigMapGB – Made Ground	DigMapGB – Worked Ground	DigMapGB – Worked and Made Ground	DigMapGB – Landscaped Ground
No. of boreholes with AMG (Total = 1832)	1331	501	286	0	209	8
% of total of boreholes with AMG	72.7%	27.3%	15.6%	0%	11.4%	0.4%
% of total boreholes (3897)	34.2%	12.9%	7.3%	0%	5.4%	0.02%

Table 2 Borehole with AMG recorded totals and proportions relating to mapped AMG

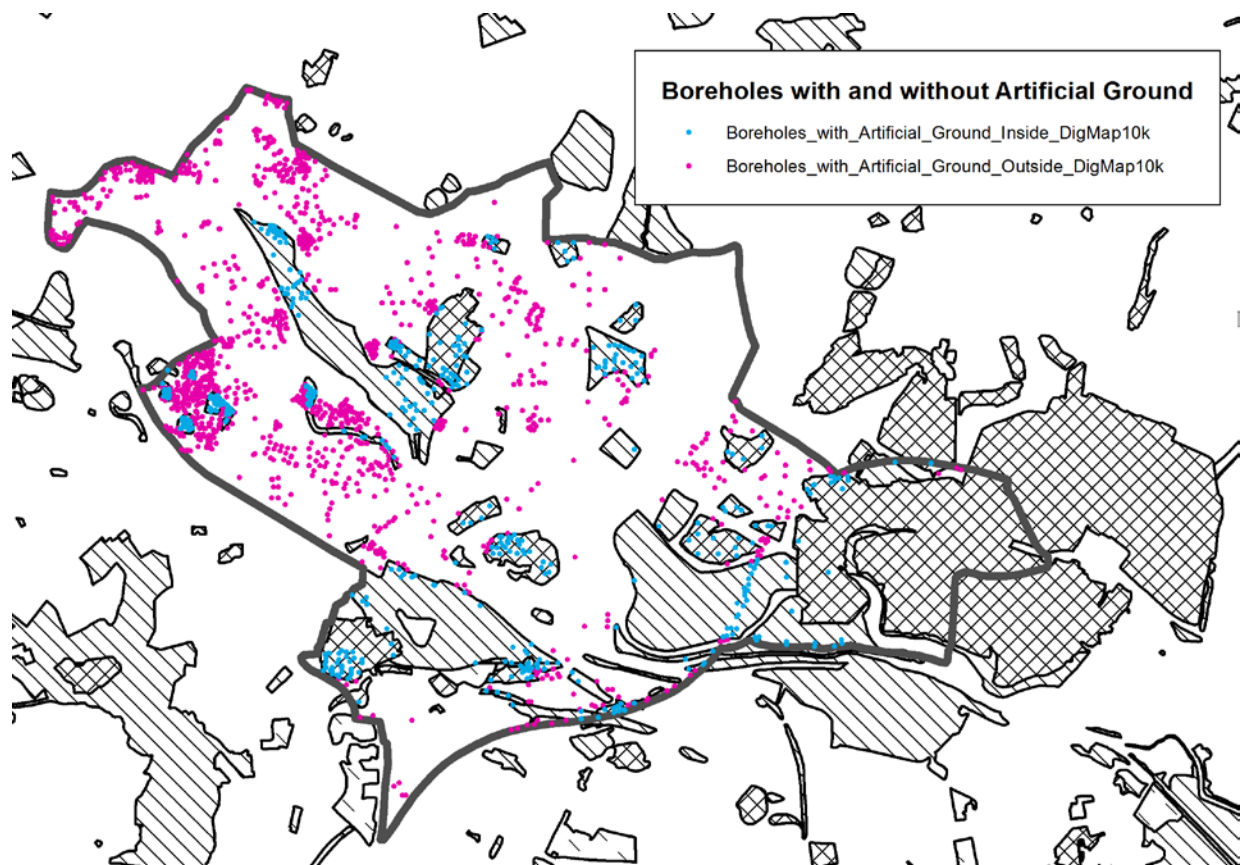


Figure 5 Boreholes with AMG recorded, inside (blue) and outside (pink) DigMapGB mapped AMG

Previous studies have used GIS to map the spatial extents of AMG and different types of land use using historical and modern topological maps. The spatial extents have been attributed using the Enhanced Classification for AMG and Landuse Classification schemes (Smith and Burke, 2011; Thorpe et al., 2011). In this study, boreholes with AMG recorded dictated where

envelopes of AMG were either selected using existing digital data (e.g. Ordnance Survey MasterMap®) or manually mapped using the virtual field mapping tools in GV.

3.1 ARTIFICIALLY MODIFIED GROUND PRESENCE/ABSENCE - MASTERMAP®

OS MasterMap® is a product that records every fixed feature of Great Britain larger than a few metres in one continuous digital map. The Topography Layer dataset was the most useful for this study as it provides the spatial extents of numerous buildings, transport networks, areas of water and even a Land theme, which is subdivided into human-made and natural features (<http://www.ordnancesurvey.co.uk/business-and-government/products/mastermap-products.html>). By intersecting the boreholes containing AMG with the MasterMap® Topography Layer, a spatial extent can be extracted that has been indicated as an area of AMG using the boreholes (Figure 6). Please note if the landuse polygon only contained one borehole with AMG, then it was assumed the entire polygon is associated with that AMG.

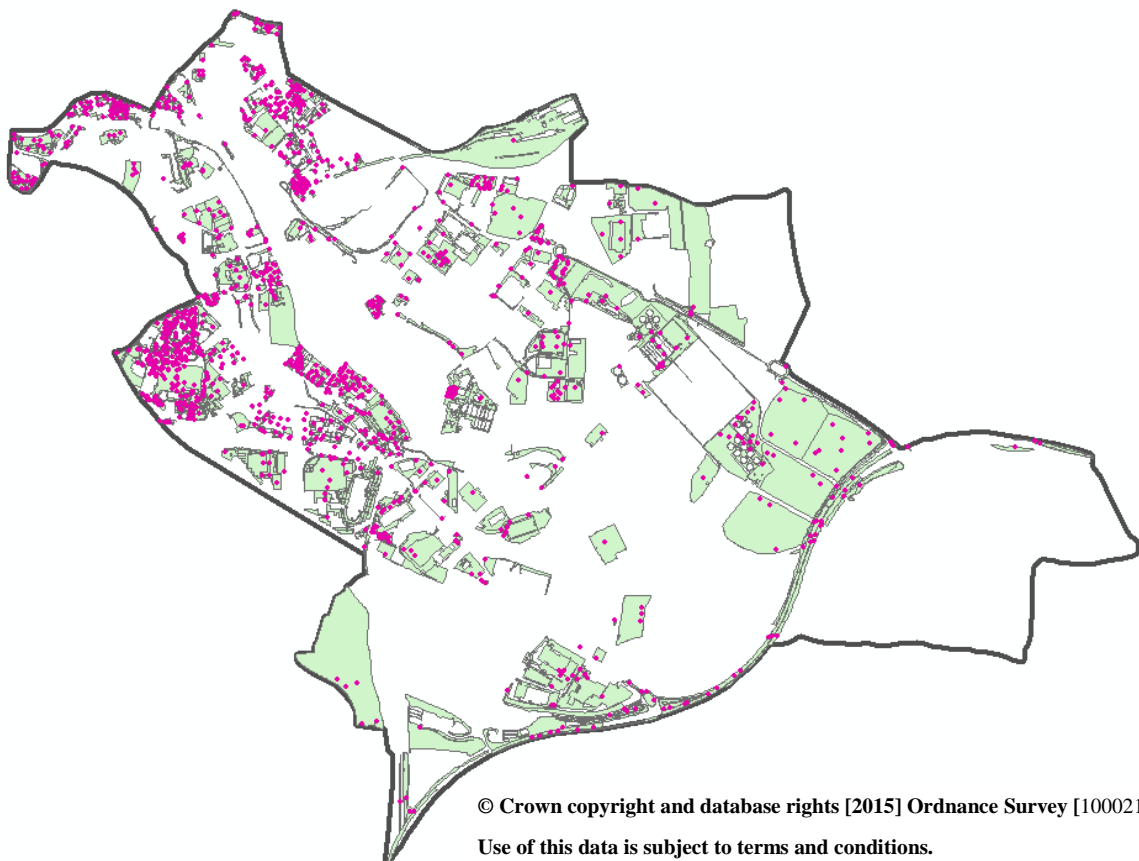


Figure 6 Boreholes (in violet) with AMG recorded that intersect with MasterMap® Topography Layer but are outside of currently mapped DigMap Artificial Ground mapped areas. These features include residential and industrial areas.

The polygons from MasterMap® Topography Layer were combined with the DigMapGB-10 AMG polygons, which increased the coverage of AMG from 30% for DigMapGB AMG to a combined 49.7% for the Aire Valley project area (Figure 7). By using boreholes to help identify areas of AMG, spatial coverage can be automated by using existing digital data, increasing the amount of mapped AMG as shown in Table 3.

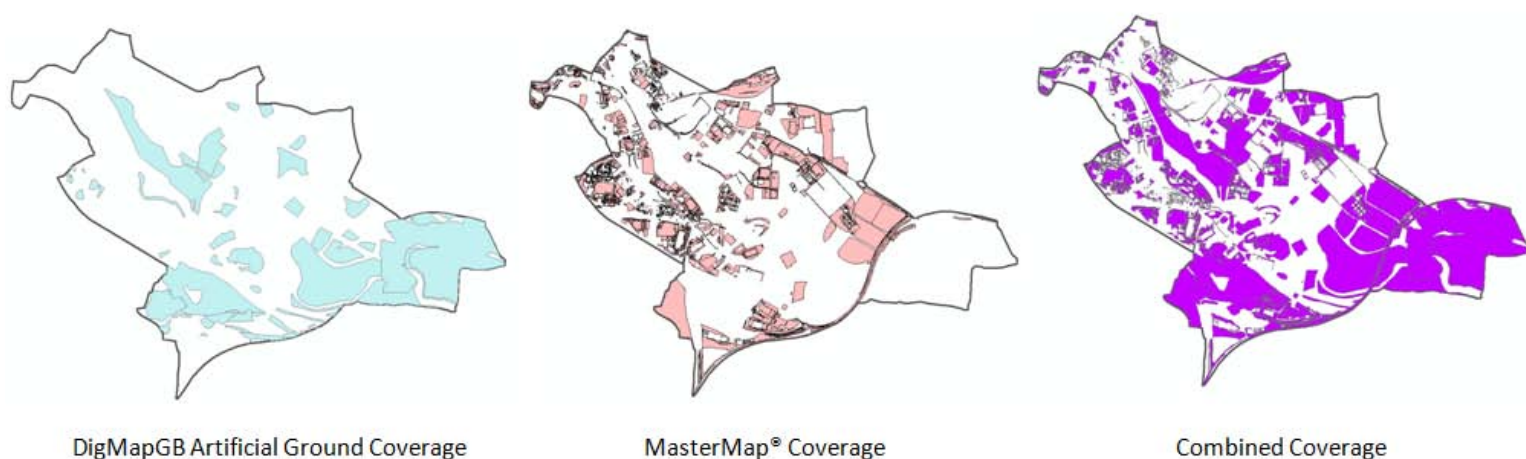


Figure 7 Coverage of AMG for DigMapGB, derived MasterMap® and a combination of datasets (© Crown copyright and database rights [2015] Ordnance Survey [100021290 EUL]. Use of this data is subject to terms and conditions.)

	Current DigMapGB 1:10 000 AMG Coverage	MasterMap® Coverage	Total Coverage Combined	Coverage Increase (Minus areas of overlap)
Km ²	4.06	3.19	6.64	2.57
Percentage of AOI (13.35 km ²)	30%	24%	49.7%	19.3%

Table 3 Summary of DigMapGB and MasterMap AMG coverage

There are limitations with this method. For example, the polygons extracted would have to be attributed according to the BGS classification scheme for AMG and this could not be automated using the attribute table of the Topography Layer, even at the Class Level because there is no indication of the process or origin for that artificially modified feature in the landscape. Some of the boreholes with anthropogenic deposits are isolated, but may intersect a polygon of the Topography Layer with a large area. This could introduce errors into the dataset if the data could not be corroborated by other boreholes. The MasterMap® Topography Layer contains huge swathes of AMG information, particularly for urban areas. It would be advantageous to use all of the data and re-attribute according to the AMG classification scheme rather than letting boreholes dictate which polygons should be used to enhance the DigMapGB Artificial Ground layer. However, MasterMap® might be cost prohibitive for such tasks to be undertaken, so using OS Open Data such as Vector Map could be a cost effective alternative.

3.2 ARTIFICIALLY MODIFIED GROUND DATA MAPPING USING GV

Using the boreholes that have AMG recorded, targeted spatial data mapping was completed using GV (GV) software. GV is a collaborative development between BGS and Virtualis (<http://www.virtualis.com/GV/>), and initially its primary use was virtual field data capture and

mapping. GV has further developed into an advanced suite for 3D and 4D visualisation and analysis of voxel models, time-series data and point clouds. These advances have come at no cost to software speed or performance as GV is able to stream these spatial data from micro to macro scale at full resolution (Napier, 2011). For this study, a mixture of LiDAR and aerial photography was used alongside the boreholes that indicated AMG to identify areas of anthropogenic activity.

The main land surface representation used in this study was Light Detection And Ranging (LiDAR). LiDAR is a remote sensing technique that measures distance by illuminating a target with a laser and analysing the speed at which light is reflected back. LiDAR is used to make high resolution maps with applications in geoinformatics, archaeology, geography, remote sensing, geology and geomorphology. High resolution digital elevation maps can be generated using LiDAR at sub-metre resolution, including Digital Terrain Models (DTMs). Subtle topographic features can be detected using LiDAR data, such as river terrace deposits, or landform breaks for slope analysis in soils. Repeat surveys using LiDAR are often used to monitor changes in coastal areas, glaciers and land level change. LiDAR was used instead of the lower resolution Bald Earth DTM because geomorphological features were more sharply defined, particularly for AMG (Figures 8 and 9).

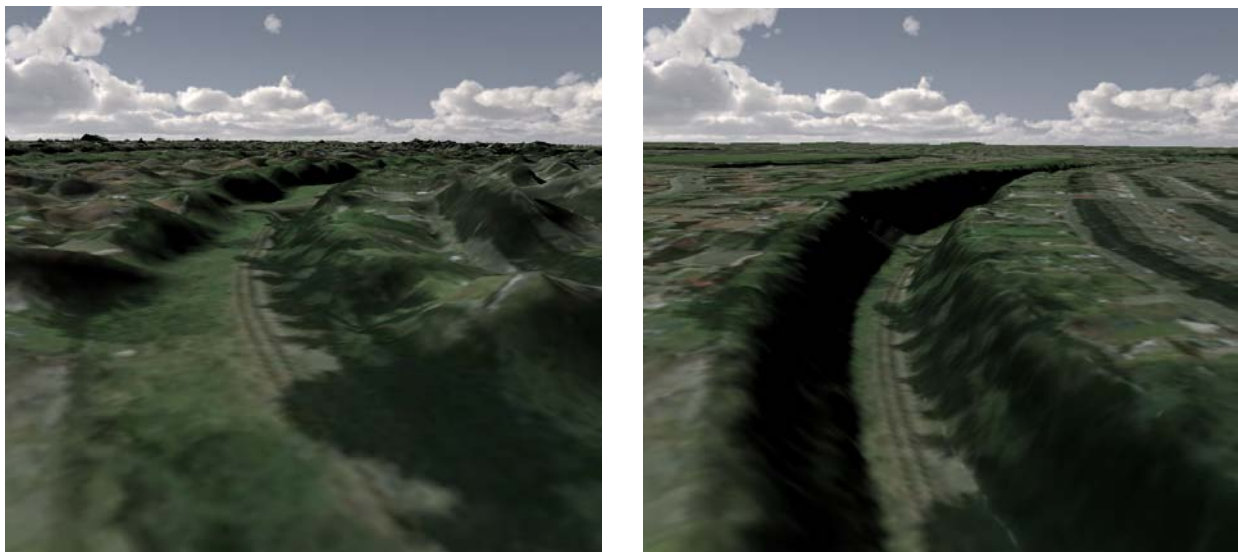


Figure 8 Example railway cutting (WGR) shown using BaldEarth DTM (left) and LiDAR (right)

Various tools exist in GV that aid the identification of geomorphological features in the landscape and are designed to enhance the most subtle of these features (Ford et al., 2012). Some of these AMG geomorphological features can be enhanced by changing the azimuth of the light reflecting from the terrain and increasing the vertical exaggeration (Figures 9 and 10)

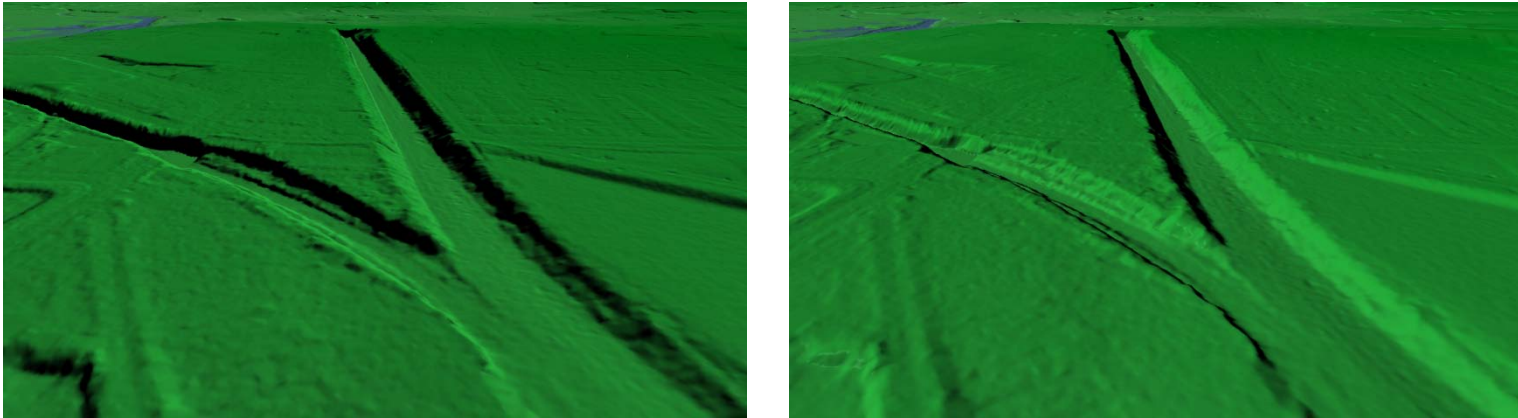


Figure 9 Changing the angle of light reflecting from the LiDAR DTM

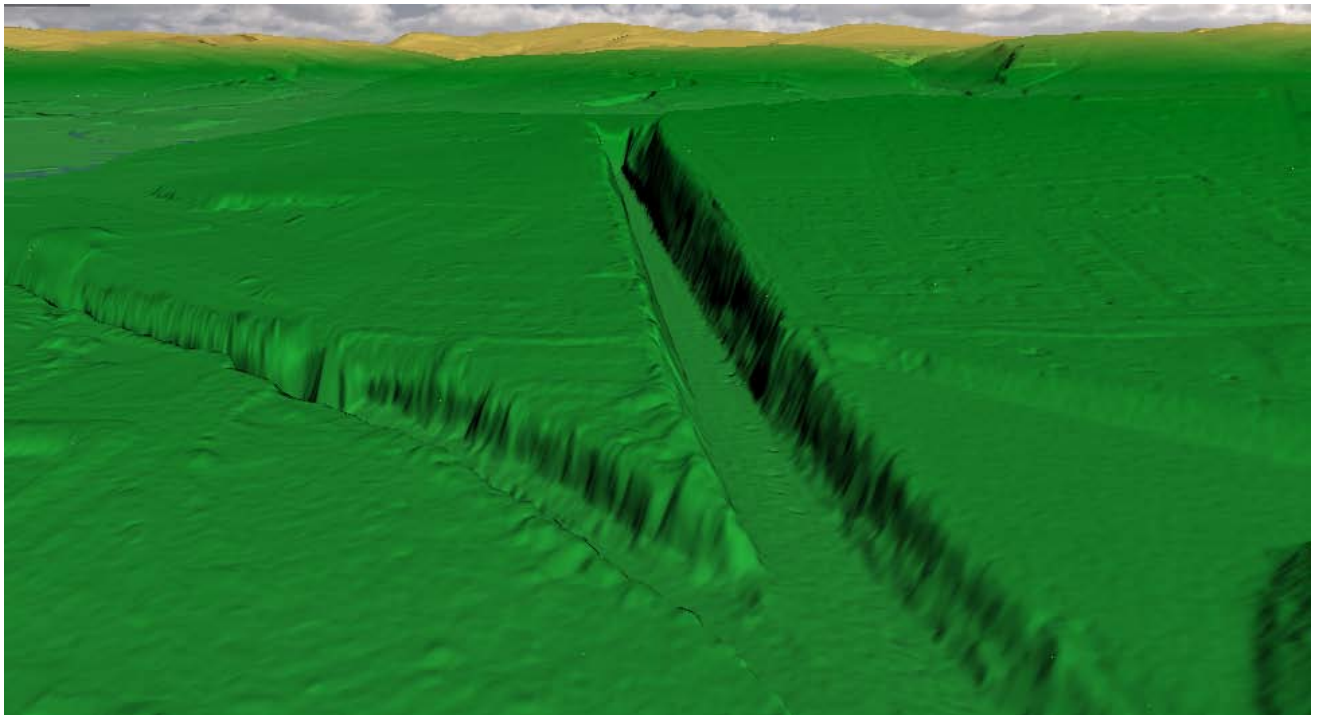


Figure 10 LiDAR (vertical exaggeration x3) compared to figure 9 which shows a vertical exaggeration of 1

Aerial photography was draped onto the LiDAR DEM to help identify the type of AMG down to unit level where possible. In the examples shown in figures 9, 10 and 11 the AMG Class is Worked Ground (WGR), the Type is Infrastructure Excavation (WEU) and the Unit is Rail Cutting (WERA). These features can be digitised as points, lines or polygons and attributed directly in GV according to this Worked Ground subdivision (Figure 12).



Figure 11 LiDAR with Aerial photography revealing the rail cutting

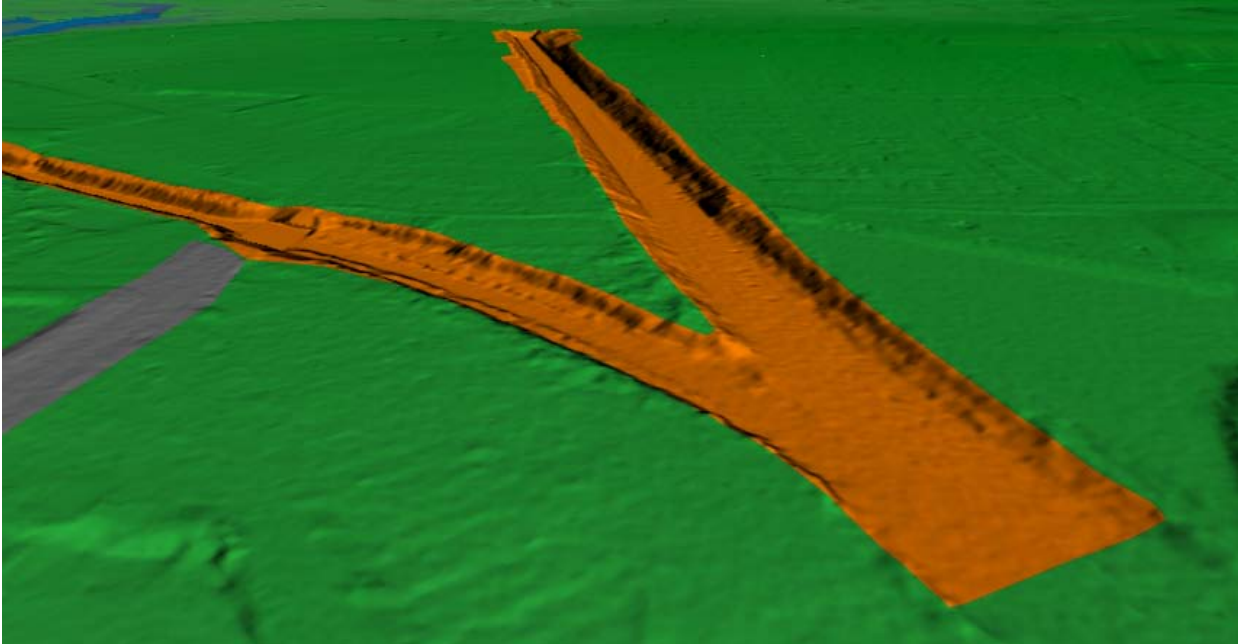


Figure 12 Digitised polygon of Rail Cutting

Borehole location data was visualised instantaneously across from ArcGIS to GV using the ArcMap Link toolbar which allowed fluent analysis of the boreholes against the slope and gradient of the LiDAR terrain model (Figure 13).

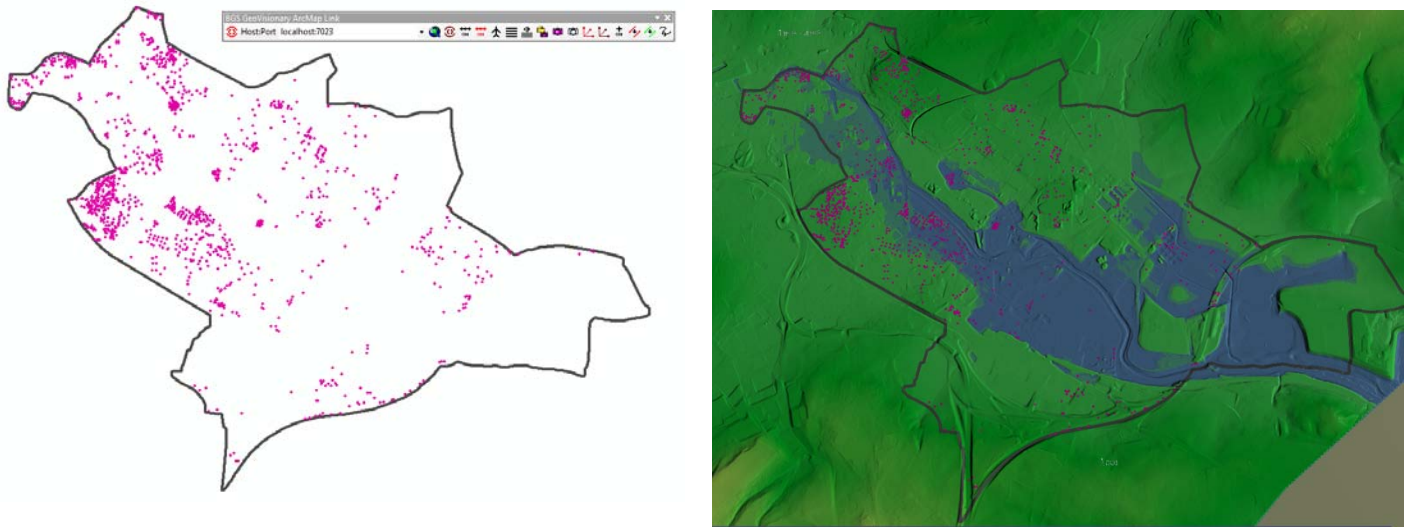


Figure 13 Boreholes with AMG outside of mapped AMG in ArcGIS (left) and GV (right) which shows low elevations in blue, and higher elevations in green

Once the boreholes (proving AMG but outside of current DigMapGB AMG areas) were imported into GV, parcels of land were digitised based on a combination of the location and proximity of the boreholes to each other, the geomorphological features in the LiDAR terrain model and the footprint on a certain land use shown in the aerial photography (Figure 14). This would be cross-referenced with modern topological maps when needed to establish the AMG and landuse type.

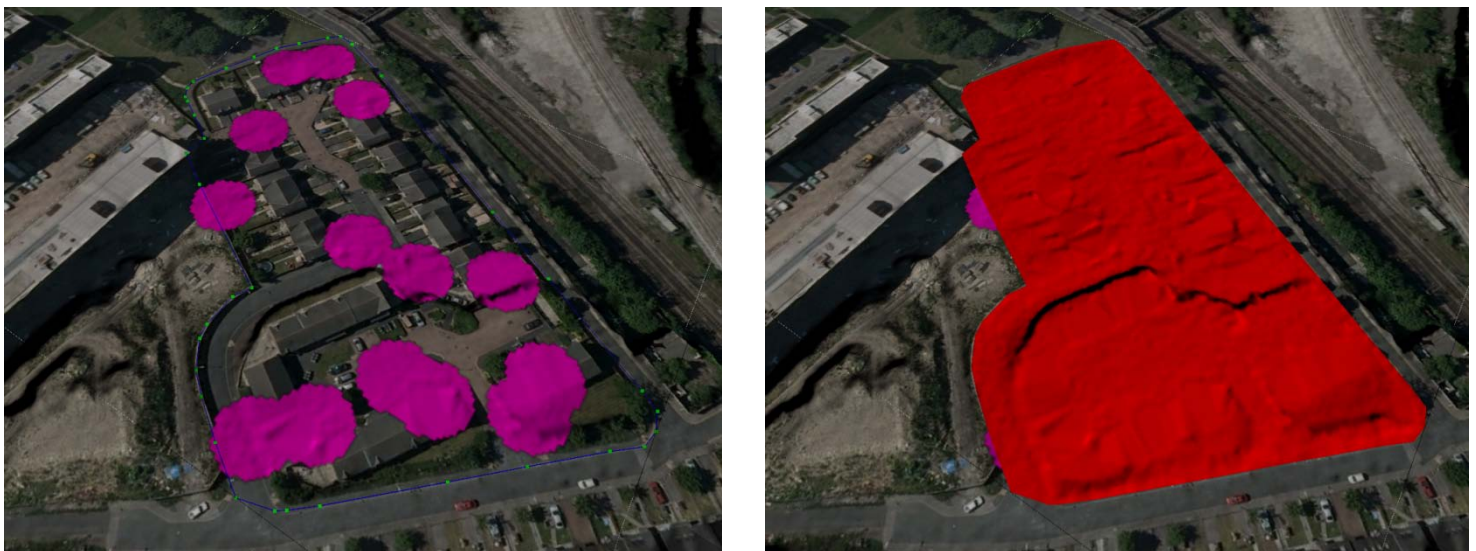


Figure 14 Borehole locations depicted on a residential development (left) and the residential development digitised (right) in GV

These were attributed according to their land use for further analysis in GIS. Initially only areas where boreholes proved AMG were digitised, however, where AMG features such as road or railway cuttings and embankments were easily identified using a combination of LiDAR and aerial photography, these features were also mapped extending away from the clusters of boreholes identified. The land use was then re-categorised based on the Enhanced Classification of Artificially Modified Ground (Smith et al., 2014), into class, type and where possible a unit description.

Once all of the mapping using GV was completed the results were compiled into the GIS for analysis. Figure 15 shows the total distribution of landuse mapped (including overlaps with (DigMapGB AMG) using GV. Landscaped Ground was by far the largest proportion of AMG mapped in GV, with smaller areas of Worked Ground and Made Ground. The high proportion of Landscaped Ground mapped could be due to it being a safer option when altering the land as there is not a significant deposit of AMG or excavation across an entire site.

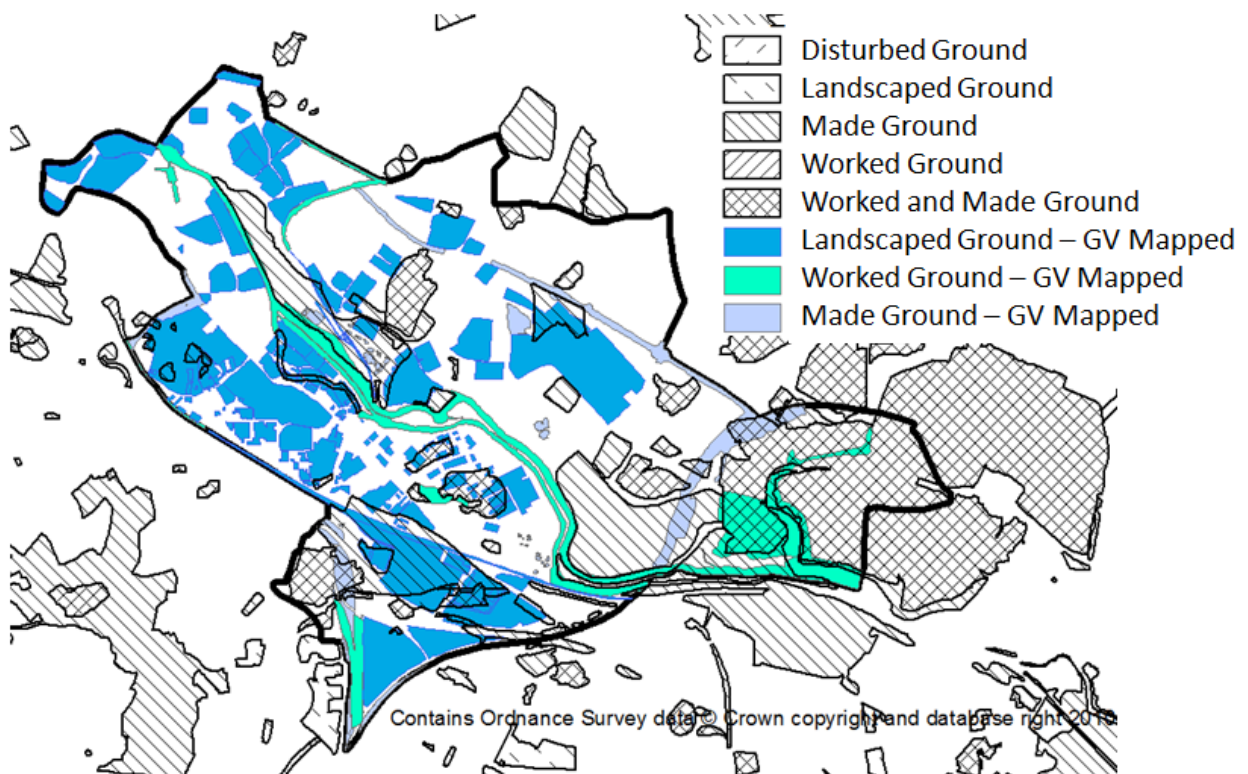


Figure 15 Total mapped capture of AMG in GV with DigMapGB 1: 10 000 Artificial Ground (Cross-hatch)

Worked-and-Made Ground (infilled ground) was not mapped, which was due to difficulty identifying it using only LiDAR, aerial photography and boreholes. Further contextual data was needed from field observations, field slips and modern and historical topographic maps to identify these types of landscape features. The Worked-and-Made Ground that has been mapped in DigMapGB occurs in much of the east of the area, at Skelton opencast coal mine. This is where many of the borehole scans were unavailable for appraisal, but their locations indicate where former open cast coal mining activity and workings have taken place. This data could be used to identify areas where the features of engineered infilled ground might be difficult to recognise in the natural surface morphology (Figures 16 and 17). Abandoned opencast mine

plans showing the location and depth of excavations using contours and supplemented by borehole data has been shown as a viable solution for mapping and modelling these types of AMG areas (Burke, H et al., 2014), as borehole logs by themselves do not provide enough information about the geometry and spatial extents of open cast mines.

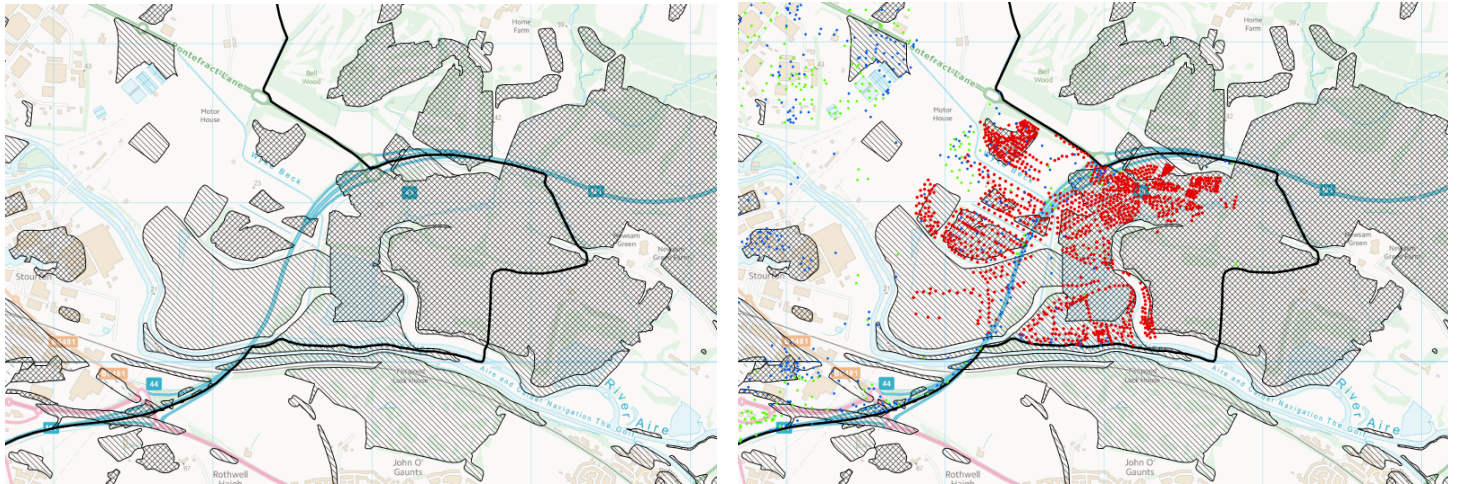


Figure 16 DigMapGB AMG of the Skelton Open Cast mine area (left) and borehole locations of open cast exploration in red (right)



Figure 17 Open Cast mine exploration borehole locations (in red) draped onto LiDAR DTM and modern aerial photography in GV

Further analysis reveals that some of the Landscaped Ground mapped in GV overlaps with mapped Made Ground, and highlights the difficulty of discerning between the two types of AMG in urban areas particularly for residential areas. For this study, Made Ground mapping was restricted to road and railway embankments, and easily identifiable waste/slag heaps.

Landscaped ground was used to map and describe industrial and residential areas based on the Enhanced Classification scheme for AMG (Smith et al., 2014), where it was difficult to differentiate between Worked Ground and Made Ground, particularly 'Landscaping for Site Formation' categories, which cover residential, commercial and industrial development.

Table 4 shows the individual and cumulative totals for AMG identified and digitised in GV compared against the DigMapGB 1:10 000 AMG theme. The numbers of boreholes with AMG present have been included. As mentioned, areas where boreholes that record AMG but were not in the existing DigMapGB AMG dataset were targeted, while other areas were digitised based on features identified using the LiDAR terrain model. Overall, an increase of mapped AMG of 26.5% was made possible through this method. The largest proportion of AMG mapped using this method was Landscaped Ground, particularly for residential areas, and industrial and commercial premises. Some of the mapped Landscaped Ground could be interpreted as Made Ground, but without further knowledge from other data sources such as OS maps (current and historical), these types of AMG are difficult to identify.

	Landscaped Ground- GV mapped	Made Ground – GV mapped	Worked Ground – GV mapped	AMG (combined) – GV mapped	DigMapGB 1: 10 000 AMG (combined)	AMG increase – GV (minus overlaps with DigMapGB)	Combined totals
Area (km ²)	3.34	0.56	1.1	5.00	4.06	3.54	7.6
Percentage of AOI (Total area = 13.35 km ²)	25.02%	4.2%	8.2%	37.6%	30%	26.5%	57%
Total number of boreholes intersected (with AMG present in borehole = 1832)	1181	98	23	1303	501	N/A	1551

Table 4 Comparison of boreholes with AMG recorded intersected with GV derived AMG against DigMapGB Artificial Ground

1181 boreholes underpin the AMG mapped and digitised using GV. Only 501 boreholes with AMG underpin the DigMapGB derived mapped AMG, although only a few boreholes would have been analysed in any detail and boreholes would not have been the primary dataset for mapping AMG. Using the borehole method of identifying and mapping AMG, targeted virtual field digital mapping can be applied to increase the distribution of mapped AMG and give an immediate indication of where the landscape has been artificially modified. Altogether, 1551 out

of 1832 boreholes have been encompassed by a combined DigMapGB 1:10 000 AMG and GV data mapping, and this method increased the total coverage of AMG from 30% to 57% for the study area.

The areas of Worked Ground that had 23 boreholes instances showing a thickness of artificial deposit (Table 5) should possibly be re-classified as Worked-and-Made Ground as this is probably material that has been removed in anthropogenic excavations at surface or underground. Using the dates that the boreholes were drilled and comparing them against historical and modern maps for land use development would be to re-classify the areas in which these boreholes exist. However, by investigating the borehole logs, it reveals that each of them had Made Ground logged, which indicates that these areas should be reclassified or that the borehole pre-dates the current landscape modification. Overall, these boreholes only represent just over 1% of the total sample number of boreholes with AMG so can be ignored as a means of mapping Worked Ground. As indicated, Worked Ground is likely to be more efficiently mapped in the field or using virtual field mapping technologies such as shown in GV.

Advantages of using boreholes combined with LiDAR for identifying and mapping AMG:

- Provides immediate visual evidence of where the landscape has been and not been artificially modified
- AMG - underpinned by borehole evidence/data
- Increases the distribution of mapped AMG
- Less commonly mapped AMG such as Landscaped Ground in commercial and residential areas are recognised more frequently
- Saves time and expenditure resources by using virtual field mapping technology
- LiDAR enhances AMG features such as embankments and cuttings, and subtle features, such as raised ground or lowered ground for commercial and residential development
- Using a combination of the tools in GV with LiDAR, aerial photography and boreholes, AMG can be mapped quickly and efficiently in urban areas
- 3D geological models rarely consider trial pits as they are often too shallow to model the natural geology in any detail

Disadvantages

- MasterMap – cost prohibitive
- No indication of when the borehole was drilled – adding drill date to boreholes would enable parcels of land to be dated

3.3 AMG THICKNESS

The thickness of AMG within a borehole was mapped when assessing whether the borehole had AMG recorded. Using the data mapped in the GV project combined with the existing DigMapGB 1:10 0000 Artificial Ground theme, the aim was to see whether the thickness of AMG in boreholes could be directly associated with certain types of AMG. Table 5 shows the results of this analysis. (Note – only boreholes that showed maximum thickness of AMG were included, all of those boreholes where the AMG reached the base of borehole and therefore did not represent the base of AMG were excluded).

	Landscaped Ground	Made Ground	Worked and Made Ground	Worked Ground (Boreholes found within WGR polygons)
Number of boreholes	1076	313	147	23
Average Thickness (m)	2.4	3.56	7.72	3.06
Median Thickness (m)	1.9	2.8	5.8	3
Minimum Thickness (m)	0.05	0.05	0.2	0.26
Maximum Thickness Recorded (m)	27.5	18.5	27.5	7.85
Standard Deviation (m)	2.44	2.95	6.26	1.97
Percentage below 3 m in thickness	81%	57%	27%	48%

Table 5 Types of AMG intersected by boreholes with AMG recorded

The results suggest that there is a relationship between the type of AMG and the thickness of AMG deposit. Landscaped ground had the smallest average thickness of AMG at 2.4 m and median thickness value of 1.9 m. These boreholes are relatively closely spaced (Figure 18) and show a consistent thickness of AMG (81% below 3 m in thickness). These areas of Landscaped Ground have little in the way of landforms to distinguish them from other types of AMG. This follows some of the assumptions made by Aldiss et al. (2014) in Central London, where urban areas have ‘blanket’ covers of AMG that are under-represented in modern geological maps. A terrain measurement over a densely populated area of boreholes over mapped Landscaped Ground reveals that the landscape changes subtly in elevation by less than 10 m over a distance of 1.3 km, making the landscape almost featureless in appearance (Figure 18). This supports the view of Price et al. (2011), that boreholes can demonstrate the presence of a broad area of shallow excavation or infill with little or no surface signature. This could potentially be re-worked Made Ground of a former Brownfield site which has been redeveloped, and may mean

that the AMG thickness is greater or lesser than indicated by these boreholes. Historical and modern maps with borehole dates may confirm this.

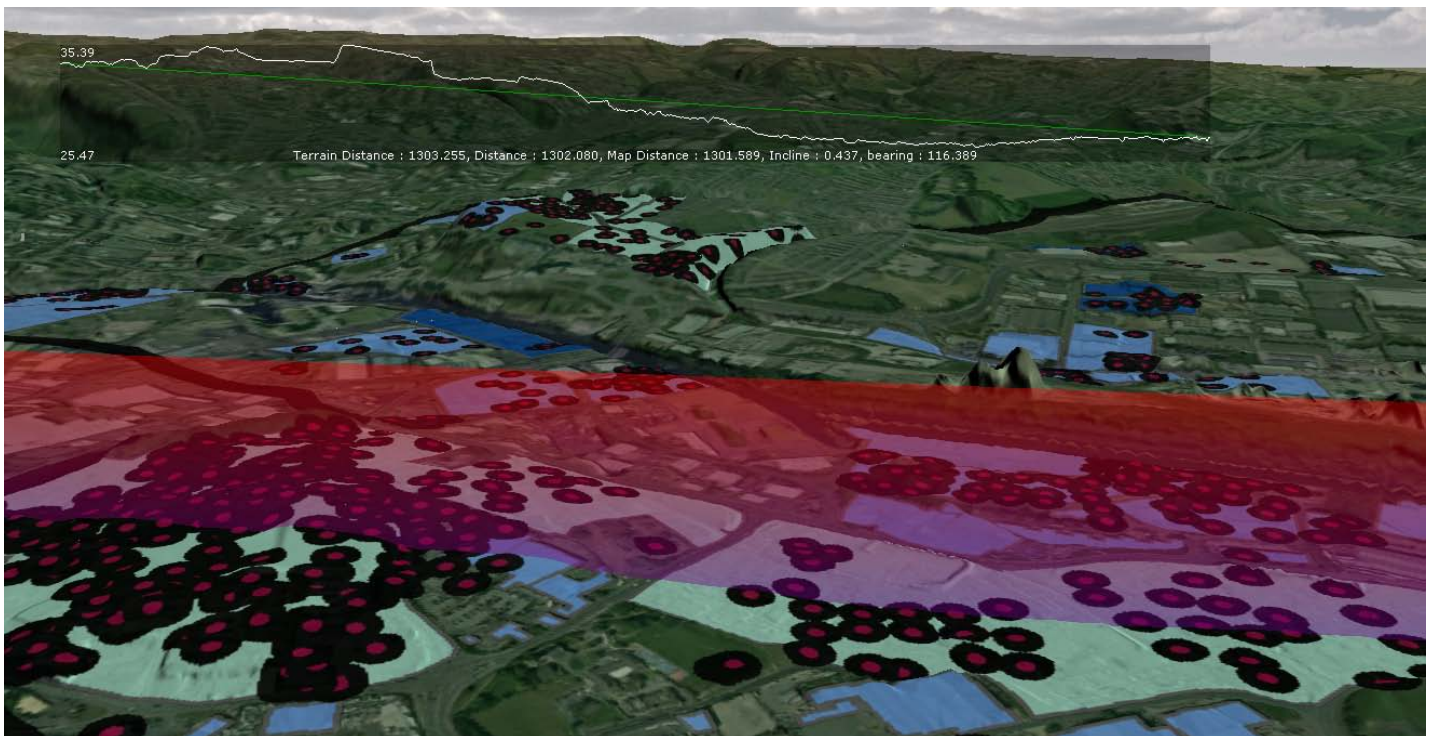


Figure 18 Terrain profile in area of closely spaced boreholes showing blanket cover of Landscaped Ground in GV (x5 vertical exaggeration)

These areas of Landscaped Ground have tended to be in low impact urban/residential areas (513 AMG boreholes intersected), commercial (431 AMG boreholes intersected) and industrial (76 AMG boreholes intersected) site developments. Figure 19 shows the distribution of AMG boreholes against these different types of Landscaped Ground mapped in GV.

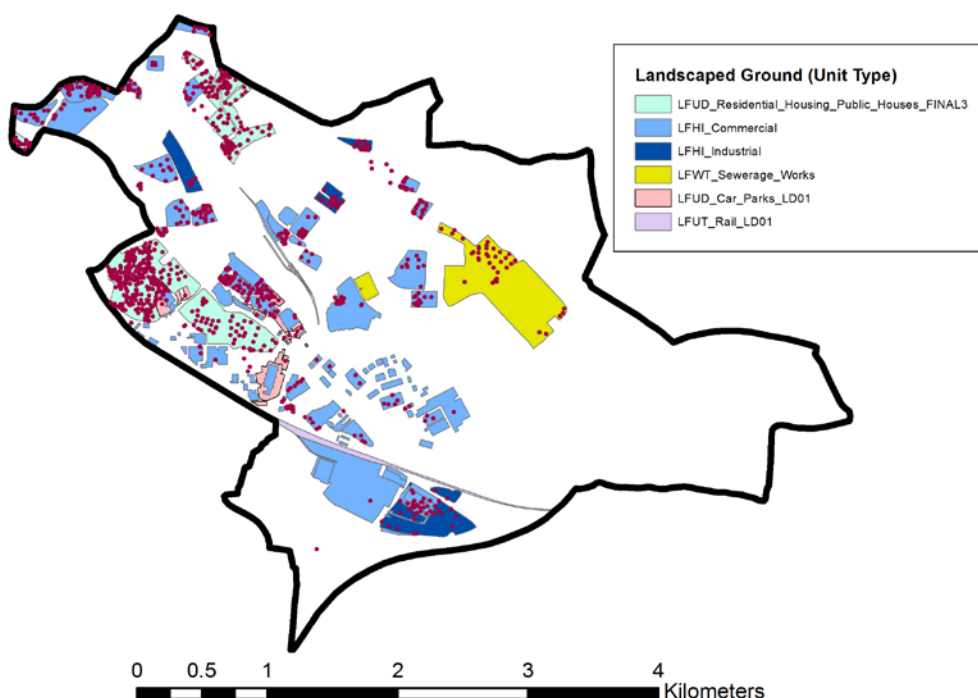


Figure 19 Landscaped Ground borehole locations with Landscaped Ground unit types captured in GV

Boreholes that were considered to be in areas of Made Ground had an average thickness of 3.56 m and a median thickness value of 2.8 m. In this study, some of what could be considered Made Ground was actually classified as Landscaped Ground, and only distinct landscape features were mapped and categorised as Made Ground where it was obvious that the topographic feature was generally thicker than the spread of materials that are classed as Landscaped Ground. These include engineered embankments such as roads, rivers and railway where the landscape has been raised for reclamation, landscape formation or construction, which could have been sourced from local colliery, quarry or inert fill, for example. Also, waste tips/heaps for municipal waste, colliery waste or metalliferous mine waste were mapped using the Made Ground classification. These Made Ground landform features are easier to distinguish than Landscaped Ground features as they are often identified by small distinctive areas of raised ground and tend to form noticeable features with distinctive slopes and gradient (Figure 20). Many of these features follow linear routes along major roads and railways (Figure 21). The standard deviation (variation) of thickness for Made Ground is greater than that of Landscaped Ground at 2.95 m and is probably explained by the fact that these features tend to be heterogeneous in thickness, height and geometry. For example, embankment structures are affected by the type of geology on which they are constructed, the thickness and type of fill material used and whether it is located at a junction with a natural or artificial feature (Bell, 2004). This method also assumes that at least some of these boreholes may have been drilled post embankment construction, but more often than not these boreholes would have been drilled prior to construction as part of a site investigation, therefore using the thicknesses of AMG recorded in boreholes on embankment features could be misleading and would need to be corroborated with other data, such as terrain profile measurements using GV.

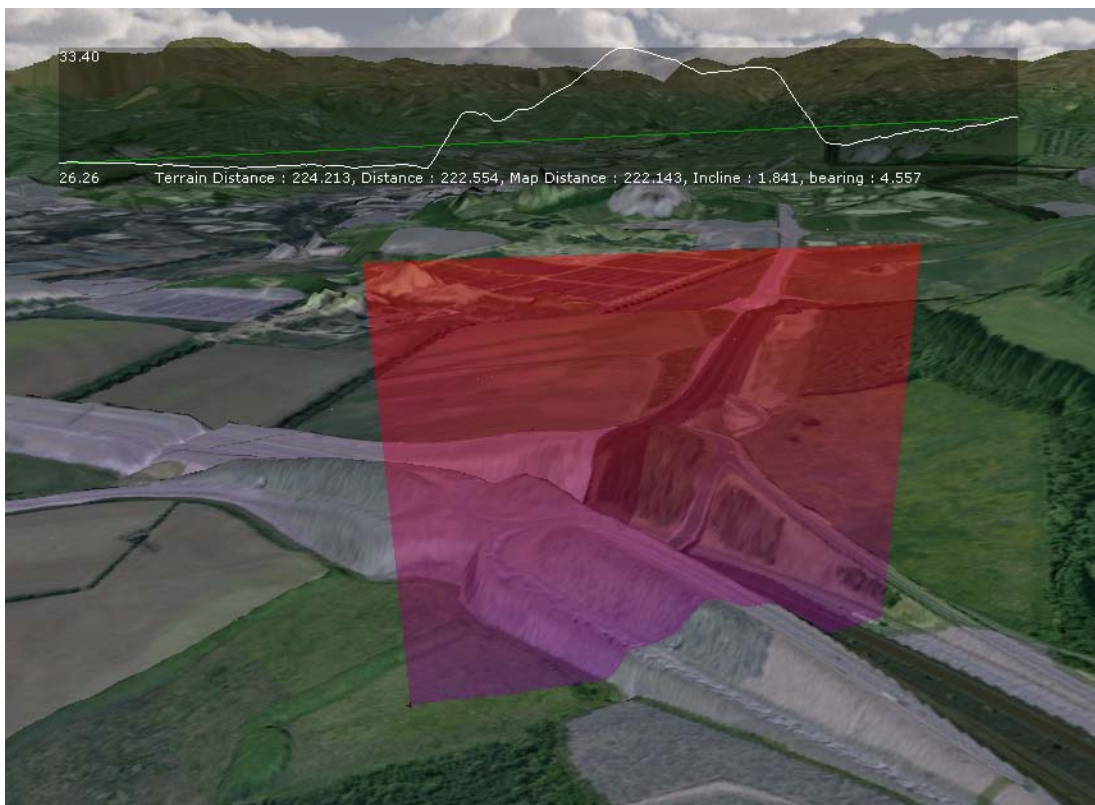


Figure 20 Terrain profile of a road embankment captured as Made Ground in GV

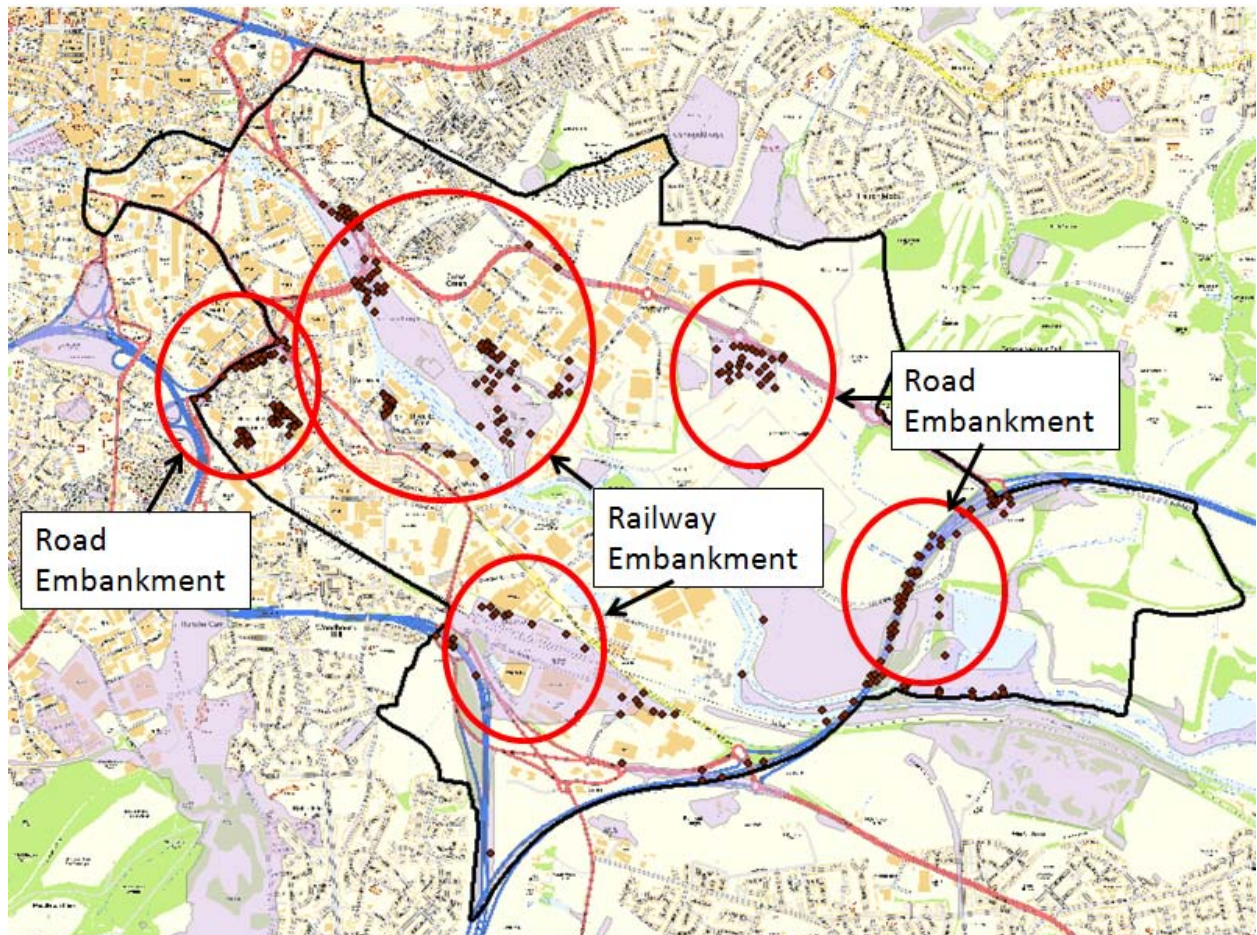


Figure 21 Borehole locations and GV mapped polygons of Made Ground features

By examining changes in the thickness of AMG recorded in boreholes, an indication of the type of ground conditions or different phases of anthropogenic activity could be derived using visualisation in GV. Figure 22 shows borehole locations with artificial deposit thicknesses ranging from 9.6 m to 12 m in red and thicknesses ranging from 0.6 m to 3.5 m in green along the road embankment (in grey). According to the DigMapGB 1: 10 000 AMG theme, those boreholes in red are in areas of Made Ground (the striped area), and those in green are in the vicinity or on Worked-and-Made Ground (the cross-hatched area). It appears that the road had been excavated into the pre-existing Worked-and-Made Ground and Made Ground from the earlier Skelton opencast coal mine. To explain the transient nature of the AMG here, a term such as 'Worked Ground within Made Ground' would need to be used for the area of thicker AMG boreholes in red. Boreholes within areas of the thinner AMG deposits (shown in green), the correct order of the processes would be 'Made Ground on Worked-and-Made Ground' as suggested by the Enhanced Classification for Artificially Modified Ground (Smith et al., 2014).

The large thickness differences between these groups of boreholes only gives an indication of the type of AMG and potentially the order of occurrence in areas that have had more than two phases of anthropogenic activity. In order to establish with more confidence the classification of these boreholes further evidence was required by assessing the LiDAR, aerial photographs and the mapped AMG, or if available, borehole drill dates as explained below.

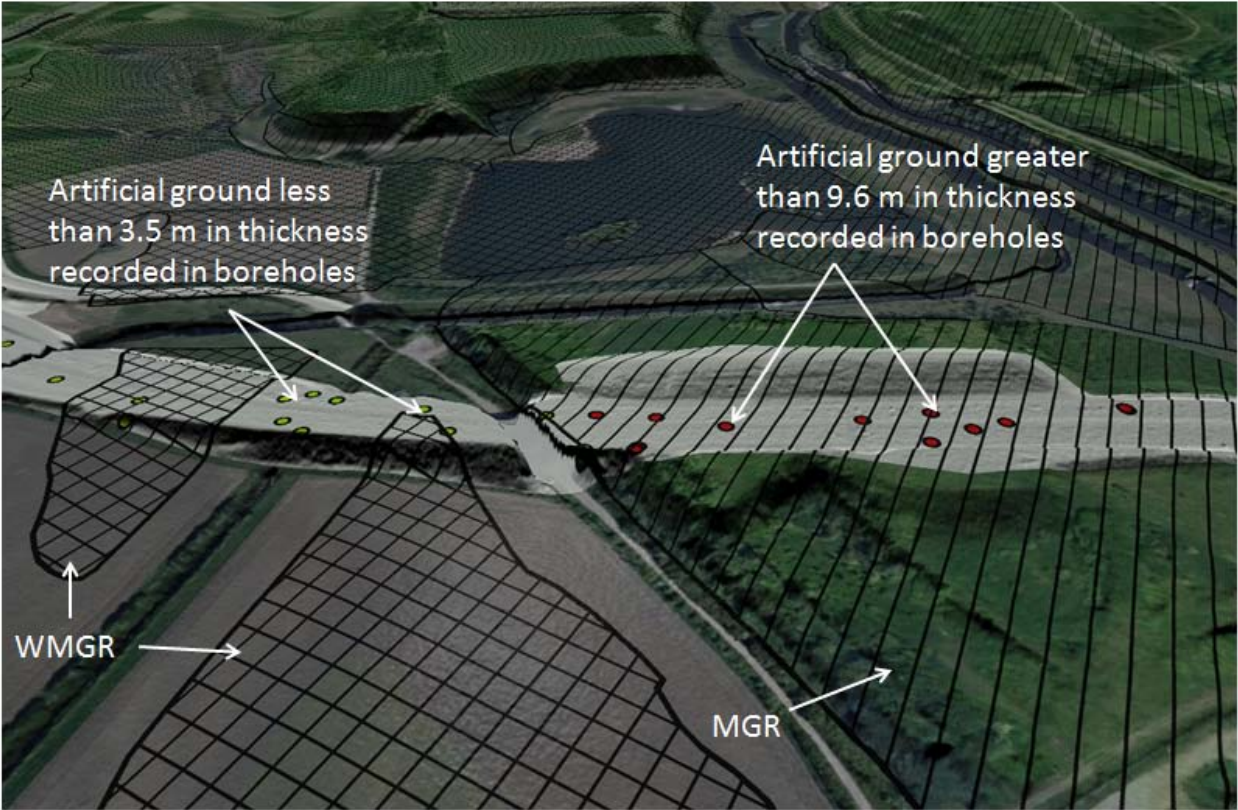


Figure 22 Comparing borehole AMG thicknesses of Road Embankment and Cutting mapped in GV (in grey) to cross-hatch/striped areas from DigMapGB artificial

3.4 BOREHOLE DRILL DATES

Borehole drill dates can corroborate different phases of AMG in urban environments. In the area shown in Figure 22, it was assumed that the motorway/road embankment was constructed subsequently to the Worked-and-Made Ground of the Skelton opencast mine. By comparing the drill dates of the boreholes we could confirm the phases of anthropogenic development (Figure 23). The boreholes for Skelton opencast coal mine, for example, were drilled in 1988 and the boreholes for the motorway (M1- A1 link road) were drilled in 1994, supporting the assessments made in GV. By associating a drill date with the type of AMG mapped, the evolution of the urban landscape can be explained. Although BGS records the drill date where known, it was found for this study area that only about a quarter of the boreholes had a known drill date. If the drill date is unknown, the date of the report or record is usually recorded by BGS, which could give an approximate date of drilling, or at least the latest date the borehole could have been drilled. Dates could be entered for other boreholes but with no indication of whether it is a drill date, a report or record date. Sometimes there has been no drill date entered for a borehole at all. Table 6 summarises the availability of borehole dates for the Leeds Aire Valley study area.

Total Number of Boreholes	Boreholes with drill date Recorded	Report or Record Date Only	Date with unknown source (drill date or record/report)	No Date recorded
3897	1007	893	346	1651

Table 6 Summary of borehole date descriptions available for the Aire Valley study area

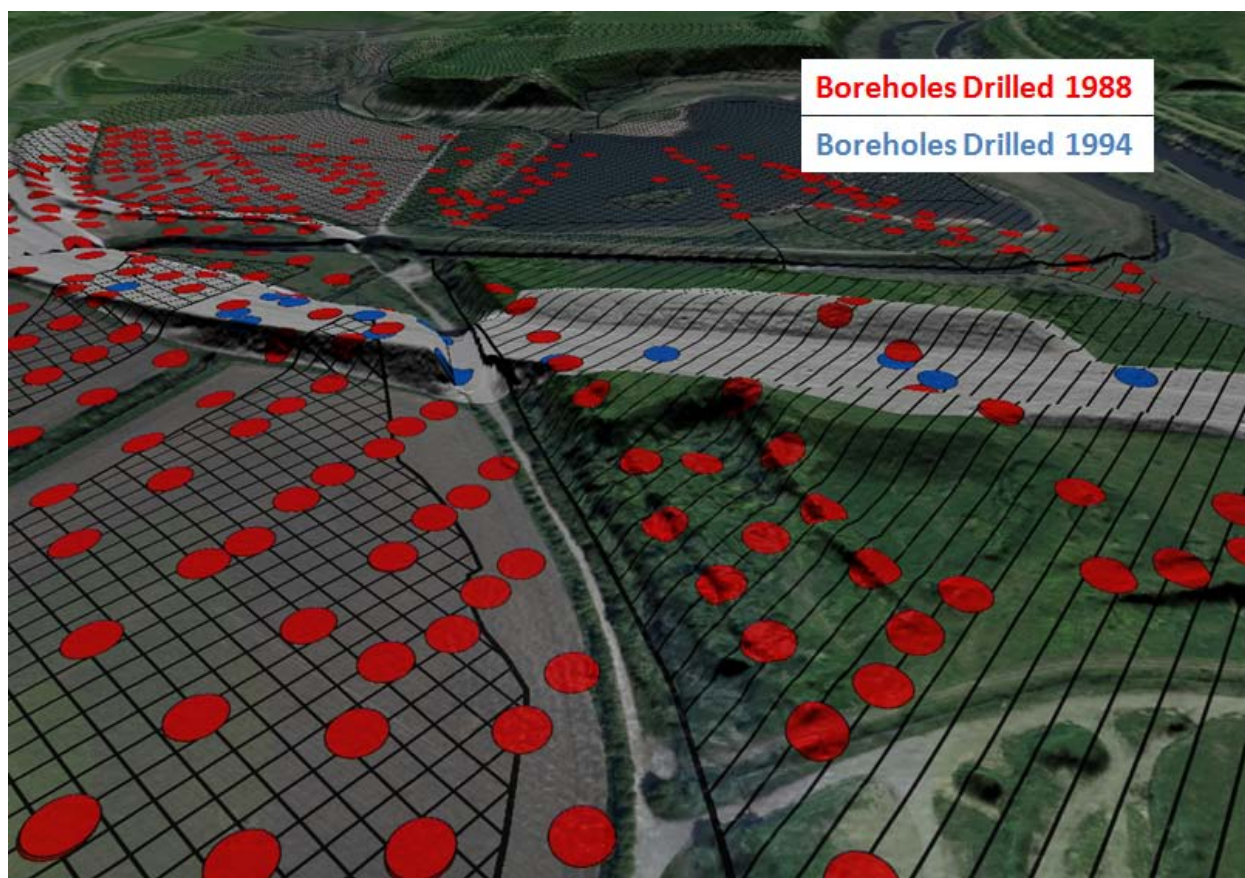


Figure 23 Boreholes locations with drill date for the Skelton opencast mine (in red) and for the M1-A1 link road (in blue)

Boreholes with a drill date can be grouped by date and displayed spatially to give an indication of the anthropogenic changes through time for a given area, and where there has been more than one phase of anthropogenic activity, exemplified in the Skelton example (Figure 24).

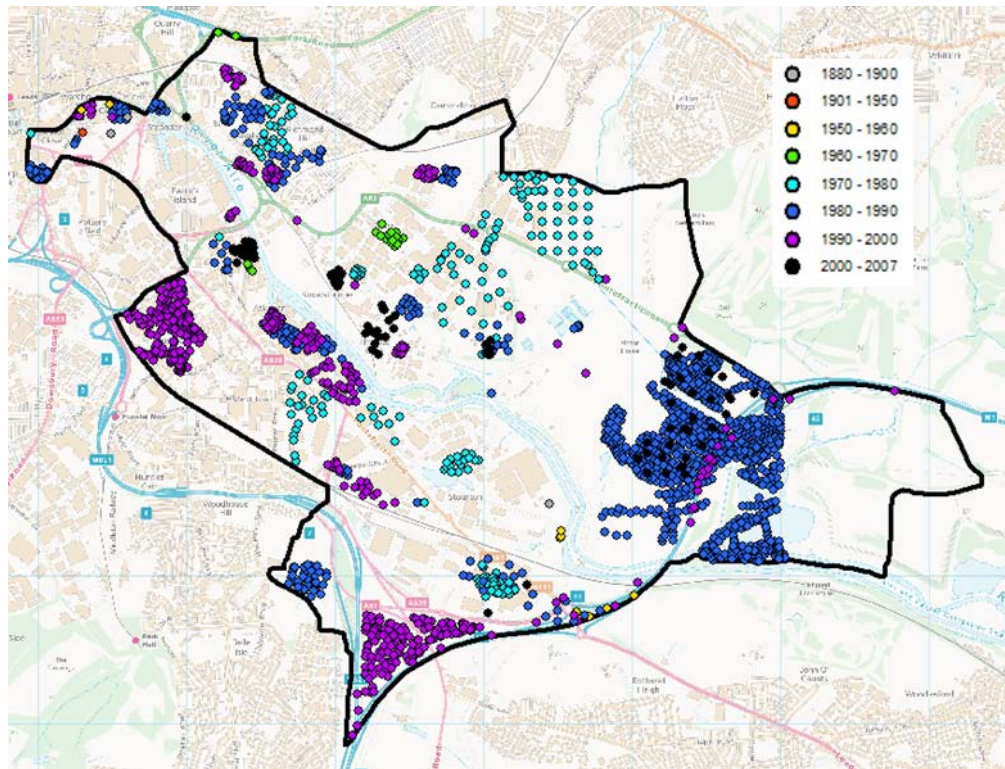


Figure 24 Borehole locations with drill date (grouped) – Leeds Aire Valley

By superimposing the boreholes with their drill dates against different types of AMG, the urban landscape evolution can be assessed in 2D (Figure 25). For example, in the northern part of the project area, three phases of residential development are recognised in the 1970s, 1980s and 1990s using the borehole drill date age. These phases of development do not occur in the same place, but showed continuous development in the same vicinity of other residential developments.

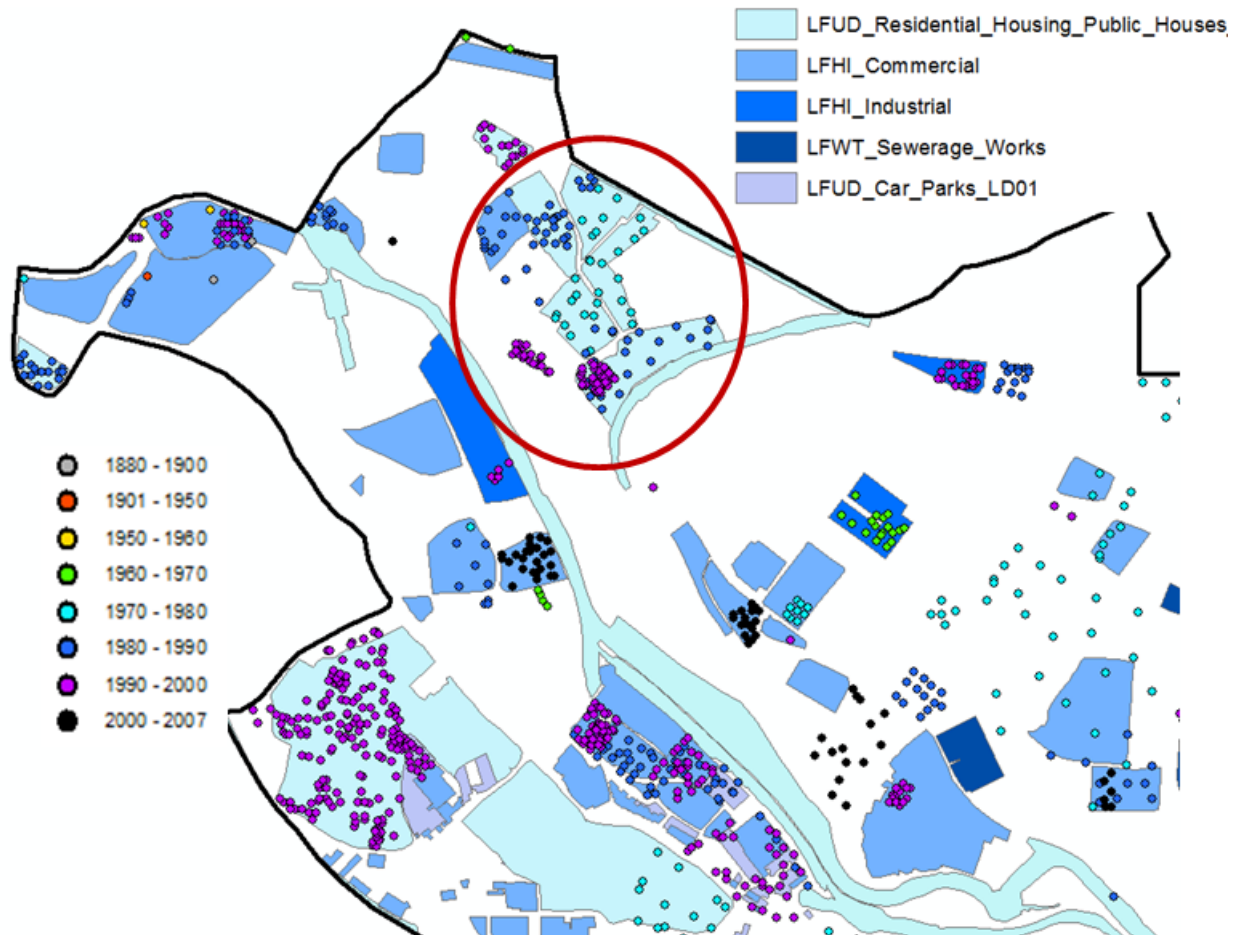


Figure 25 Mapped Landscaped Ground in GV with locations of boreholes with date drilled or date logged into SOBI

Advantages:

- Overall, these datasets increased our understanding of the ground conditions in the shallow subsurface. Used in conjunction, these datasets can reveal the thickness, composition and in some cases, the volume of fill materials, making them a potentially useful resource to planners and developers. However, to be of greatest potential benefit to planners and developers, these datasets should be consulted early in the planning process to identify potential problematic ground conditions and avoid the possibility of delays and spiralling costs associated with rectifying them (Burke et al, 2014)
- Potential impact on the BGS Rockhead model – thickness of AMG
- Accurate measurements of artificial features using LiDAR
- By combining the location of boreholes, categorising anthropogenic activity and adding an age to AMG, the process could be further refined by combining the 2D capture from DigMapGB, and virtually from GV with the borehole ages

Disadvantages

- Boreholes convey accurate information on the thickness and composition of AMG, often where none is indicated on the geological map. However, older borehole logs in

particular often convey scant information on AMG, or ignore it altogether, depending on the purpose of the borehole

- Borehole logs can quickly become outdated if a site is redeveloped, with each log representing the ground conditions at the time of drilling. AMG is generally associated with transient environments, can provide a snapshot of change over a specific period of time, or until new data is available
- The distribution of borehole data can help identify the function or type of AMG prior to the development activities and as such is clustered in urban areas, zones of mineral exploration and extraction, and along major transport routes (Burke et al, 2014)

Points for consideration:

- The proportion of boreholes with or without AMG could rise significantly for those that were in the open cast area. Many of these were drilled prior to the open cast mine, so historical maps would need to be cross-referenced in these areas to establish previous landuse.
- Is it easier to map AMG in open areas rather than those areas that are built up?
- Does borehole proximity and distribution indicate type of AMG?

3.5 ANTHROPOGENIC LANDSCAPE EVOLUTION STUDY

Borehole start height elevations, if measured accurately, can be compared against modern day DTMs to ascertain whether the land level has changed in elevation from when the borehole was drilled. Boreholes may have been drilled prior to some kind of engineered construction such as a road or railway embankment, or for mineral assessment before extraction. Sometimes, there might be more than one type of AMG change as shown earlier in Section 3.4. In all cases the land levels have been changed artificially and can be classified accordingly to the revised classification of AMG (Aldiss et al., 2014).

3.5.1 Factoring in Borehole Start Height and Digital Terrain Model Inaccuracies

Before attempting to quantify the amount of land level change using the difference between borehole start height elevations and DTMs, a number of factors that could affect the resulting differences had to be considered.

Borehole Start Height Factors:

- Above Assumed Datum (A.A.D) – Local/site elevations were calculated from a base station on site. Normally this will be a positive number far in excess of the actual ground elevation. A positive number was used so that negative elevations were not introduced into any of the calculations that were used on site. Start heights can still be derived from the site datum if there is a uniform and consistent elevation used.
- TBM – Temporary Bench Mark. Temporary Bench Marks are often established around the survey site. TBMs may be surveyed in to the OS Datum by levelling between the site TBMs and an OSBM.
A site datum may be established instead and all levels referred to a TBM that has been given an arbitrary value (usually 100.0 metres or a value that ensures all heights will be positive). The main site reference is often a steel pin set in a block of concrete but wooden pegs set in concrete with a nail head providing the reference level are often used. It is good practice to establish a number of TBMs around the perimeter of a building site as a precaution against the only site height reference being disturbed or dug up part way through the contract. http://www.levelling.uhi.ac.uk/tutorial1_9.html
- OSBM – OS Bench Marks. OS bench Marks are established by the Ordnance Survey to provide height references. They are usually carved into stonework or other stable material that is unlikely to be disturbed. Heights are given above OS Newlyn Datum on large scale OS plans and other references.
- An error that can creep into borehole dataset start height elevations is when the borehole elevation is measured in feet on the borehole log and is not converted into metres before entering into the borehole database. This means the elevation will be approximately 3 times greater than its actual value. By using the following formula some of these errors can be identified for those start heights which have been mistakenly recorded in feet instead of metres:
Start height of borehole * 0.3048
1 foot = 0.3048 metres
- Human error in the recording of the start height elevation and the coding of that start height elevation
- Boreholes in the same vicinity as each other can be given the same start height as the first borehole drilled on site, even though there might be differences of several metres in some cases.

Digital Terrain Model Factors:

A 5 m resolution BaldEarth Digital Terrain Model was used for comparison against the borehole start heights. This was acquired by NEXTMap[®] in 2002-2003 using airborne radar from a

Learjet, at an altitude of 20,000-28,000 ft. The DTM, also known as a ‘BaldEarth’ model, has had trees, vegetation, buildings and other artificial structures removed to expose the underlying terrain (<http://www2.getmapping.com/Products/NEXTMap>). Reported accuracies are:

- Horizontal accuracies: +/-2.5m horizontal (1 sigma) on slopes less than 20 degrees
- Vertical accuracies: When flown at 30,000 feet the vertical accuracy is +/-1.0m RMSE. When flown at 20,000 feet the vertical accuracy is +/-0.7m RMSE

LiDAR data was not available when this initial part of the research was undertaken. If it was used, the accuracy would have been +/-0.1 m. However, it was used at a later stage, to corroborate the elevations of the BaldEarth DTM.

3.5.2 Ascertaining reasons for differences between start height elevation of the borehole and elevation from the Bald Earth DTM

1762 borehole start heights were compared against the BaldEarth DTM elevation where the difference was greater than 1 m. Table 7 shows the result of checking the borehole start height against the Bald Earth DTM, to ensure that any differences were real, and not a result of an error in the start height of the borehole or BaldEarth DTM.

Difference categories	Occurrences	%
BaldEarth incorrect	108	6
Borehole predates negative landscape change	683	39
Borehole predates positive landscape change	366	21
Corrected	462	26
No reason for negative difference	51	3
No reason for positive difference	92	5
Total	1762	100

Table 7 Proportions of boreholes start height differences to the BaldEarth DTM

Below are further explanations of the checks performed:

- ‘BaldEarth incorrect’; represents a BaldEarth elevation error, for example where some of the tree canopies have not been removed from the DTM, or where the BaldEarth DTM incorrectly represents a slope gradient has returned an inaccurate elevation.
- ‘Borehole predates negative landscape change’; means that the borehole has been drilled before the ground has been cut away or lowered for example a road cutting or quarry. These areas would be represented by WGR on geological maps.
- ‘Borehole predates positive landscape change’; has been used for locations where sites have been built on and has occurred post-borehole drilling, such as a road embankment. This would be represented by MGR or WMGR on a geological map.
- ‘Corrected’: in this study, these mainly represent confidential Open Cast borehole data, where details of the original start height data were restricted and a standard start height (A.A.D.) was recorded for all boreholes. These were rectified for this study.
- ‘No reason for negative/positive difference’ means that it was difficult to determine the reason for the difference in start heights, but it was ascertained that the start height of the borehole recorded was correct and viable to use.

Checks were performed using aerial photographs, historical and modern topographical maps in ArcGIS and GV, and cross-referencing the original scan of the log and the start height recorded

in the database. By using this combination it was possible to determine the majority of the reasons why there were differences between the start height elevation of the borehole and the elevation from the BaldEarth DTM. Of the 1762 borehole investigated, 1049 (60%) showed a definite positive or negative change in the landscape elevation. From these results, we were able to further investigate whether these differences would; a) Enable the identification of new areas of AMG that does not currently exist in DigMap, and b) Reconstruct the former DTM elevations from the start heights of the boreholes where there is a definite negative or positive change from the modern BaldEarth DTM.

Table 8 shows a summary of difference between the recorded start height of the borehole and the modern BaldEarth DTM. Differences in the amount of change were similar, showing the land level has changed on average by approximately +/- 5 m since the date of drilling.

	Number of boreholes	Mean difference (m)	Median Difference (m)	Standard Deviation	Min Value	Max Value	Percentage of total sample (1049)
Negative Difference (Land has been lowered/flattened since the borehole was drilled)	683	-4.94	-3.83	3.35	-2	-27.56	65%
Positive Difference (Land has been raised or made artificially since the borehole was drilled)	366	5.01	3.59	4.77	1.01	38.02	35%

Table 8 Summary of borehole start height difference against the BaldEarth DTM

3.5.3 Identifying new areas of AMG using differences between borehole start heights against the BaldEarth DTM

By using the DigMapGB 1:10 000 AMG mapped geology and spatially intersecting it against those boreholes that showed definite landscape difference in start height elevation and BaldEarth DTM elevation (boreholes that predate negative or positive landscape change from Table 7), it is possible to identify boreholes that are outside mapped AMG (Figure 26). Of the 1049 boreholes that showed this confirmed difference, 715 boreholes were outside mapped AMG.

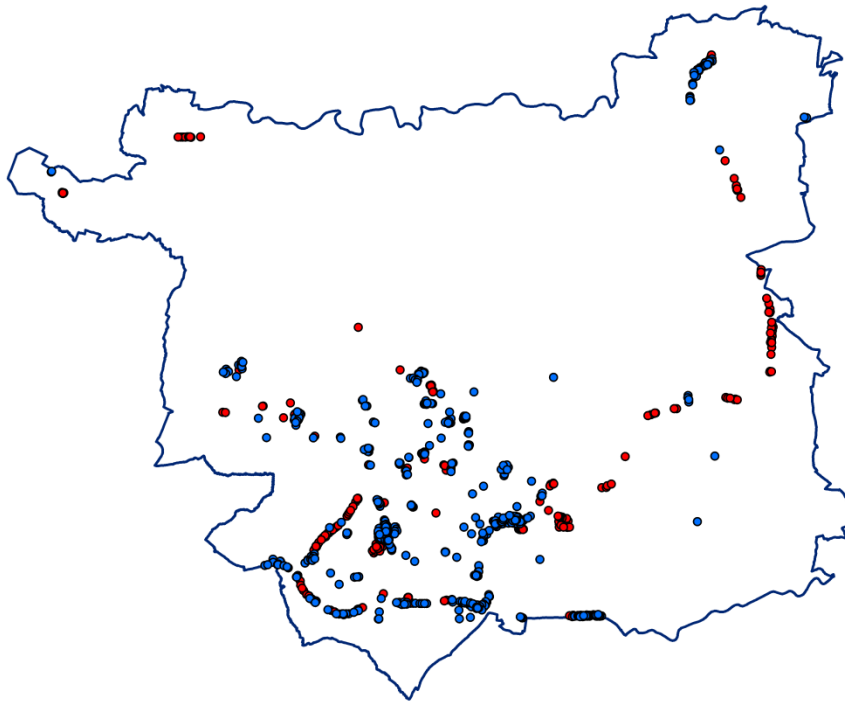


Figure 26 Distribution of boreholes with start heights showing definite elevation difference compared to the BaldEarth DTM. Red points indicate boreholes that were within mapped AMG, blue points represent boreholes that were outside mapped AMG

New areas of AMG can be identified and digitised using the borehole start height differences compared to the BaldEarth DTM as indicators of positive elevation change in the landscape. Clusters of boreholes with similar elevation differences to the BaldEarth DTM aided the digitising of new areas of AMG as the spatial orientation gave an indication of the distribution and possible limits of the AMG (Figure 27)

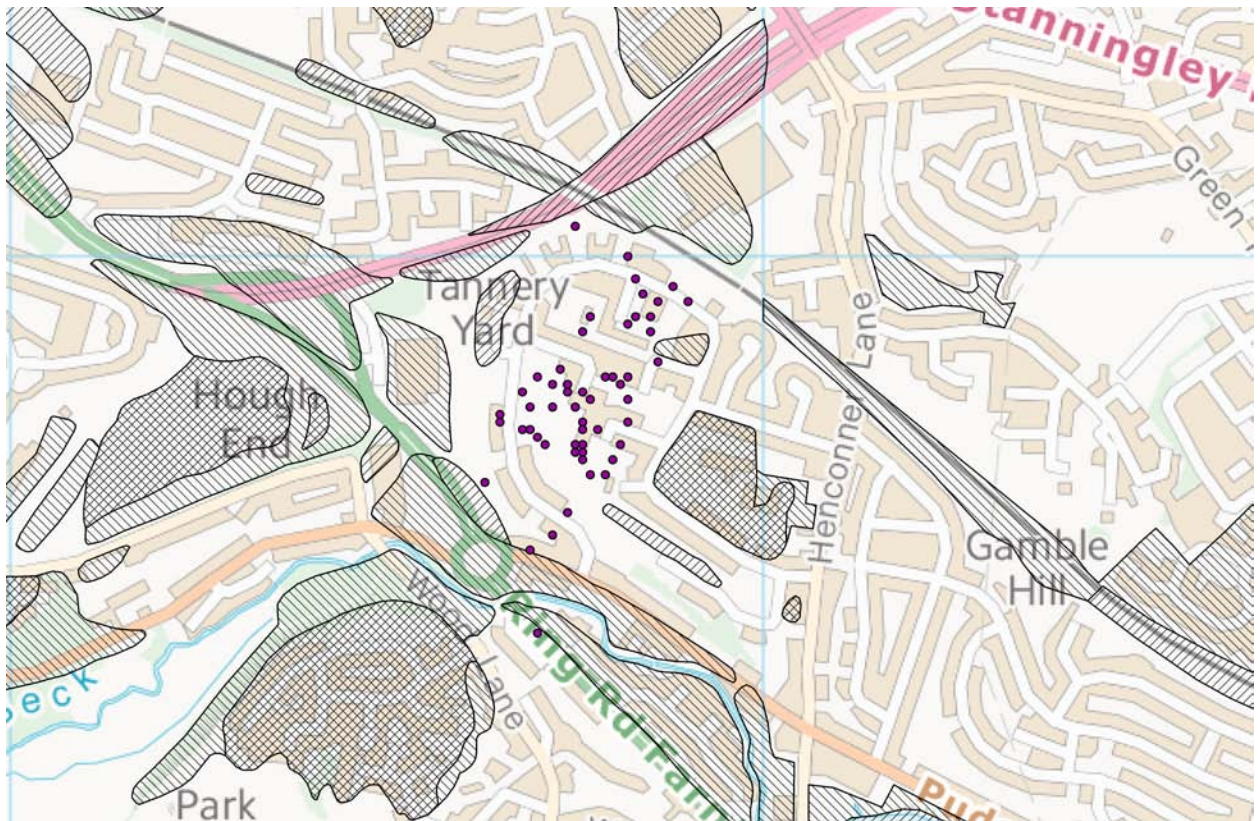


Figure 27 Boreholes with start heights that are significantly different to the BaldEarth DTM used for identifying new areas of AMG

The boreholes shown in Figure 27 have been categorised with a negative landscape change, in this case where the ground surface has been excavated to flatten and level for a housing development. The AMG digitised should probably be categorised as Worked Ground or Landscaped Ground and could be classified further to the Residential LFUD code, which represents an Urban Development according to the Enhanced Classification for Artificially Modified Ground (Smith et al., 2014). Figure 28 gives a snapshot showing the locations of where there has been negative or positive elevation change in the landscape. Although this study has not mapped and digitised all of these AMG features identified through this process, it does give an indication of the potential use of this method for enhancing the AMG geological map with further data. If this is combined with other known data such as the drill date of the borehole, historical maps, and modern topological and aerial photography it would be possible to reconstruct past land levels and describe the evolution of the landscape through the Anthropocene. This is further discussed in Section 3.5.4.

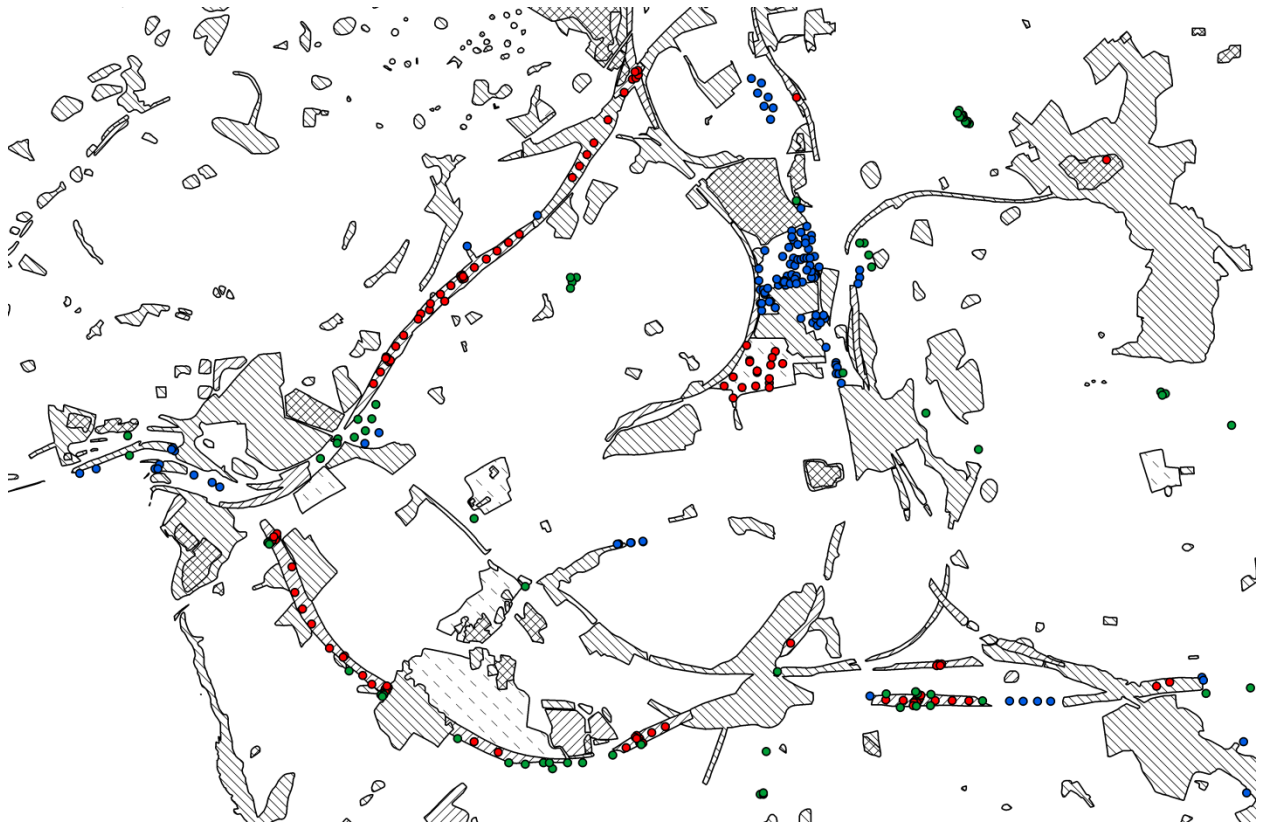


Figure 28 Locations where there has been positive elevation landscape change (in blue), locations with negative elevation landscape change (in green), and those locations where AMG has already been mapped (in red)

3.5.4 Reconstructing former land surfaces using the start heights of boreholes

As shown in section 3.5.3, borehole start heights are a viable dataset for capturing the difference in elevation between former and recent land surfaces, and potentially increasing the amount of mapped AMG. Using this data, it was also possible to recreate former land surfaces using clusters of these borehole start height elevations to replace elevation values in the modern BaldEarth DTM. The following workflow was used to capture this data:

1. Borehole clusters were identified that showed definite elevation change between the start height and the BaldEarth DTM elevations
2. Using a combination of ArcGIS and GV, polygons were drawn around these clusters, using modern topological maps and aerial photography to define the limits of the polygons drawn
3. These polygons were used to cookie cut out the elevation values in the BaldEarth DTM and these were replaced by the elevation values from the borehole start heights
4. The BaldEarth DTM surface was re-calculated using GSI3D with the spliced in elevation values from the start heights
5. The resulting DTM which is made from a combination of the original BaldEarth DTM and start height elevations from boreholes is corroborated in GSI3D and in GV using profile tools to show the elevation differences (Figure 29)

An example of this is shown in Figure 29, where the modern topology shows an artificial lake, its geometry depicted by the grey area in the upper image in GSI3D. The red line shows the location of the profile drawn in GSI3D in a North-South direction, with the locations of boreholes showing a difference in start height to the BaldEarth DTM in green. The profile drawn in the cross-section window of GSI3D shows the area that has been excavated after drilling to

form the modern artificial lake. The lower image shows the same line of section drawn in GV across the lake, which allowed the visual verification of the landscape surface against the model in GSI3D, showing that the elevation has changed by approximately 7 m in this area. The area itself is approximately 500 m x 500 m, meaning approximately 1 750 000 cubic meters of material has been excavated from this site.

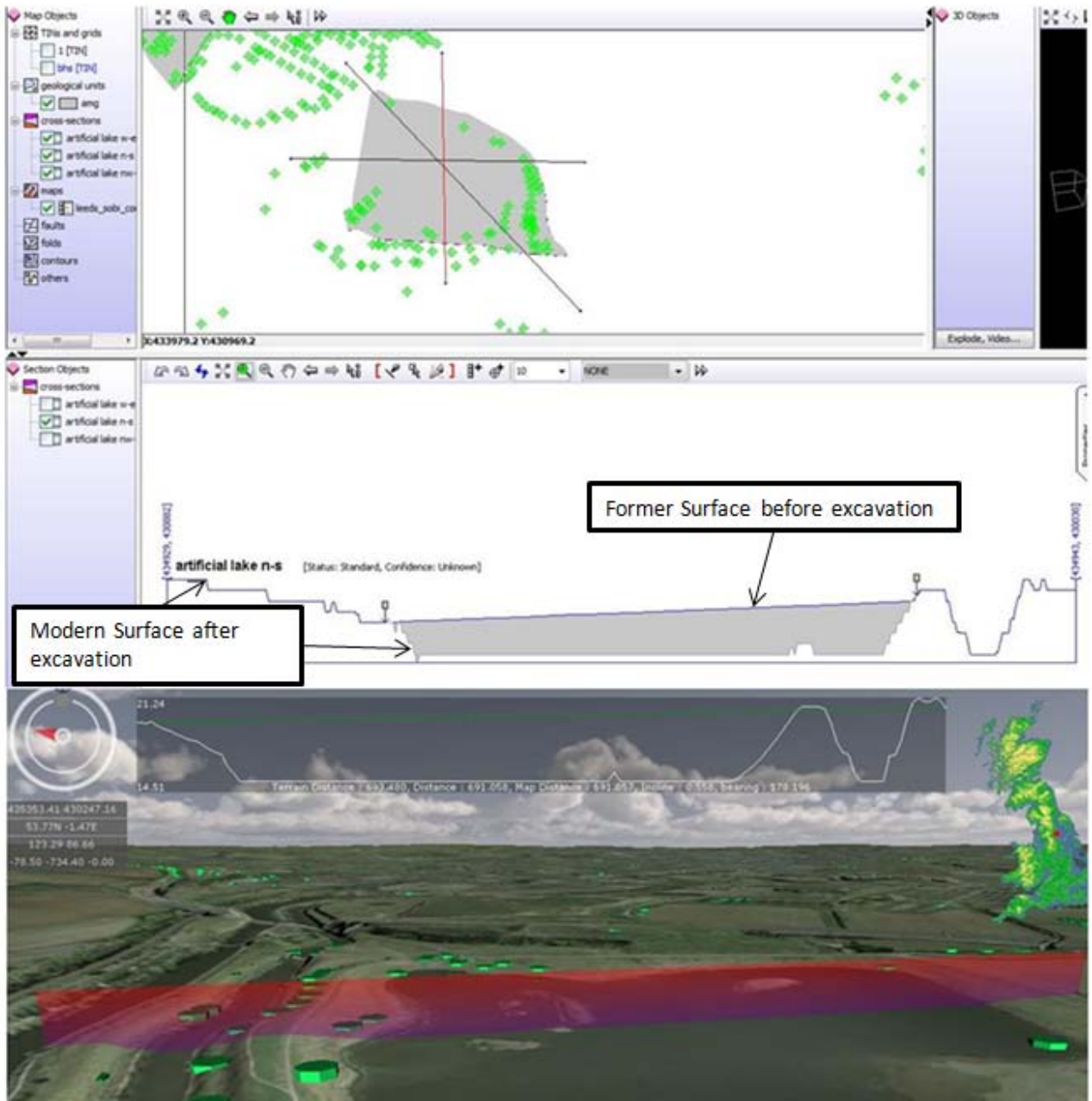


Figure 29 North-South cross section drawn in GSI3D and GV to demonstrate the past and present surface of the landscape of an artificial lake.

This method shows that it is possible to reconstruct former land surfaces using start heights of boreholes and comparing to modern land surface elevation models. This method can also be used to estimate the amount of material excavated or deposited, particularly in areas where boreholes have been drilled prior to any development.

Advantages:

1. Hard data is used to reconstruct former land levels alongside conceptual understanding
2. Would help corroborate other data sources such as historical maps when reconstructing past land elevations and understanding the anthropogenic changes on the landscape

Disadvantages:

1. Borehole start heights can be unreliably recorded due to factors listed section 3.5.1
2. The DTM used will have inaccuracies or errors associated which could exaggerate differences between the start height recorded in the boreholes and the land elevation from the DTM
3. In less densely populated areas of start height data, it would be difficult to replicate the past land surface and fit to the high density elevation data

Glossary

Artificially Modified Ground An area where the pre-existing (natural) land surface or geological succession is modified by anthropogenic processes of material removal or deposition and may include Made Ground, Worked Ground, Disturbed Ground, Landscaped Ground and Infilled Ground.

Borehole any hole drilled or dug into the sub-surface for the purpose of extracting or investigating the material at that particular point. Commonly cylindrical the length of the hole will always be several orders of magnitude greater than its width or diameter.

GeoVisionary Stereo enabled 3D Visualisation software for 2D, 3D and 3D geospatial data.

GSi3D 3D modelling software by Insight GmBH

LiDAR Light Detection and Ranging is a technique that measures distance by illuminating a target with a laser is reflected back to measure surface elevations to create a Digital Surface Model from which a Digital Terrain Model is derived.

Start Height The elevation at which the drilling and logging of a borehole has started. The elevation can be relative to a local datum or temporary benchmark or a national datum.

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