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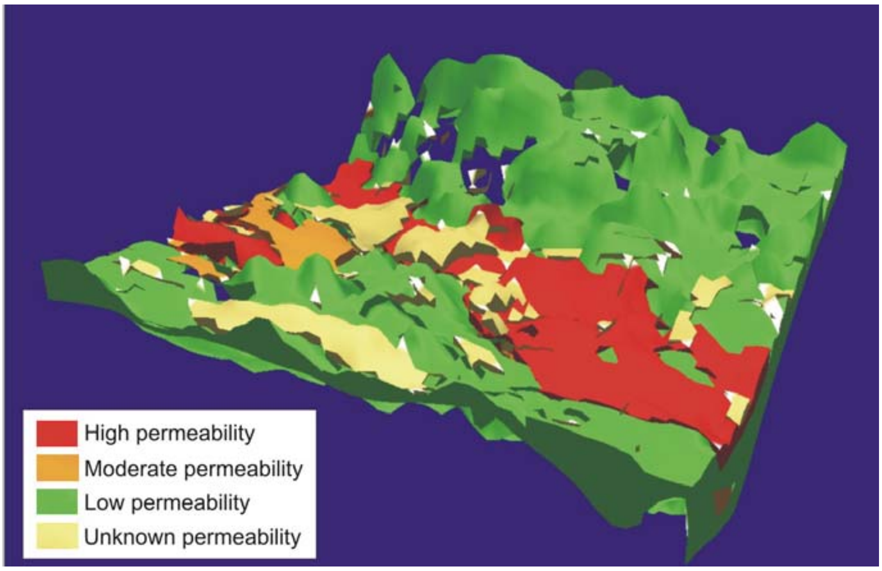
A summary of groundwater work within the Clyde Basin project, 2005-06

Groundwater Management Programme

Internal Report IR/07/042



BRITISH GEOLOGICAL SURVEY

GROUNDWATER MANAGEMENT PROGRAMME

INTERNAL REPORT IR/07/042

A summary of groundwater work within the Clyde Basin project, 2005-06

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Front cover

Illustration from GSI3D model of the superficial deposits in quarter sheet NS66SW, attributed by superficial deposits permeability.

Bibliographical reference

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1 Introduction

1.1 BACKGROUND TO THE CLYDE BASIN PROJECTS AND GROUNDWATER WORK WITHIN THE PROJECTS

The BGS Clyde Basin super project encompasses the current GLNB Clyde Basin project and the UGGH Clyde Basin and Clyde Basin Engineering Geology projects, as well as previous work including the Clyde Tributaries Geochemistry project, the GSUE Glasgow Soils Geochemistry project and the Clyde Estuary Geochemistry project. The overall aim of BGS work in the Clyde Basin is to help provide a range of geoscientific products and databases to facilitate a comprehensive geoenvironmental study of the Glasgow urban area and the lower part of the Clyde catchment. The BGS core programme work has been supported by co-funding from Glasgow City Council and by assistance in kind from SEPA.

Project tasks already completed or underway include geochemical surveys of the Clyde estuary and Clyde tributaries; a survey of urban soils; digitisation and integration of borehole data; detailed digital 3D geological modelling using the software package GSI3D; and the development of digital data on mine workings.

Groundwater issues have been relevant to the Clyde Basin projects from the start and continue to be of interest to both BGS and Glasgow City Council, a major stakeholder in the projects. Glasgow City Council (GCC) has declared particular interest in shallow groundwater and its interaction with surface water, linked to pressure to develop sustainable urban drainage systems, particularly in eastern Glasgow, and the impacts of groundwater on surface water courses. Of more general interest to GCC are issues of shallow groundwater contamination and how this may interact with soil and surface water contamination; the potential presence and impacts of poor quality groundwater in bedrock aquifers; the wider hydrogeological impacts of mining; and the hydrogeological characteristics of made ground. BGS has a general interest in improving overall understanding of the hydrogeology of Glasgow and the Clyde catchment, including the various superficial deposits and bedrock aquifers, and including groundwater flow systems and groundwater chemistry, and groundwater – surface water interaction.

The first groundwater work within the projects was a short review of the available hydrogeological data for and knowledge and understanding of the Clyde Basin, carried out in 2004-05, which also identified the scope for future groundwater work to address knowledge gaps (Ó Dochartaigh 2005). Recommendations for future work focussed on the development of hydrogeological conceptual models as a means of improving understanding of the hydrogeology of superficial deposits and bedrock aquifers, including groundwater chemistry, interactions between superficial and bedrock aquifers and groundwater and surface water, and the current and historic impacts of mining. It was clearly recognised that the lack of extensive, good quality groundwater data is a critical limitation on the development of conceptual models and improving hydrogeological understanding, and that model development would therefore need to be taken forward in stages. In the first instance, simple, large scale hydrogeological conceptual models should be produced using the available data. These would provide a necessary overview and act as the basis for future development of more complex, initially smaller-scale, numerical models as more data become available. It was recommended that the development of numerical modelling should be linked to the ongoing development of detailed digital 3D geological models. BGS have been developing 3D models of bedrock and superficial geology for part of eastern Glasgow (covering the Clyde Gateway development area), which could be used as the basis for the development of numerical groundwater modelling.

Further hydrogeological work in Glasgow and the Clyde Basin was carried out between March 2005 and April 2006 to follow up some of these recommendations. This report summarises the work carried out, which addresses a number of different aspects of the hydrogeology of the Clyde Basin. Most of the work has been preparatory to further studies that could be initiated in future years when funding permits. Such studies would include the development of numerical groundwater modelling; and investigations into the relationship between soil contamination and threats to shallow groundwater.

This report is therefore intended to be a record of interim work carried out as part of a long-term project.

Work was carried out in four main areas:

1. investigating hydrogeological aspects of soils and made ground;
2. investigating hydrogeological aspects of historical mining in the Carboniferous aquifer;
3. making a preliminary assessment of the risks to groundwater from contaminated land; and
4. preliminary hydrogeological parameterisation of the GSI3D model for NS66SW.

1.2 SUMMARY OF THE HYDROGEOLOGY OF GLASGOW AND THE CLYDE BASIN

The hydrogeology of Glasgow and the wider Clyde Basin is complex and as yet quite poorly understood. A review of current understanding is provided in Ó Dochartaigh (2005). The bedrock geology is dominated by Carboniferous sedimentary rocks, consisting largely of repetitive, cyclical sedimentary sequences of sandstone, siltstone and mudstone, with thin bands of coal. Contemporaneous igneous rocks, particularly basaltic lavas, are important in some areas, largely around the edges of the catchment. The sedimentary sequences typically form moderate productivity dual porosity aquifers, in which groundwater moves dominantly by fracture flow within relatively thin sandstone units, with a subordinate component of intergranular flow. Only the Passage Formation, which is dominated by sandstone units, forms a high productivity aquifer. The volcanic rocks form low productivity aquifers in which groundwater flow occurs almost entirely within fractures.

Little is known about the large-scale groundwater flow system, but it is likely that within the sedimentary aquifers, groundwater flow paths are relatively deep and long. Previous studies have concluded that Glasgow is the focal point for much of the groundwater discharge from the central coalfield, with prevailing groundwater flow from the east, northeast and southeast (Hall et al 1998). The limited available data on groundwater chemistry in the sedimentary aquifers indicates that the natural chemistry of groundwater is often moderately to highly mineralised, often with abundant iron and manganese in solution (Hall et al, 1998; Robins, 1986; Ball, 1999). Many of the Carboniferous sedimentary rocks have been extensively mined, leading to significant changes in the natural groundwater flow regime and notable deterioration in groundwater quality (Hall et al, 1998). Haphazard post-mining measures are also likely to have impacted on groundwater flow and chemistry. Mine dewatering, which continued throughout mining activities, finally ended in the 1980s (Robins, pers comm). There are no known problems caused by rising groundwater levels in the study area, but the lack of modern records of groundwater level in the bedrock aquifers means that current groundwater levels in the bedrock aquifer are largely unknown. Acid mine water discharge is not currently a known problem in the Glasgow city area, and investigations at a number of sites showed good quality groundwater in abandoned mine workings (GCC, pers. comm.).

Parts of former mine workings have been infilled, which may cause diversions in groundwater flow, leading to groundwater discharge and/or chemical degradation in unexpected places.

In the Clyde Plateau Volcanic Formation, groundwater flow is likely to be predominantly local, from high ground towards lower-lying areas, where discharge is likely to occur as baseflow to rivers. The chemistry of groundwater in the volcanic aquifers is unknown.

Superficial deposits in the Clyde Basin are dominated by glacial till, normally resting on bedrock and comprising a matrix of clay, sand and silt with pebbles, cobbles and boulders. The till, deposited during successive glaciations, is often heavily compacted. Overlying the till in many areas are glaciofluvial sands and gravels, and deltaic sands and gravels and glaciolacustrine silts and clays. Following deglaciation, when relative sea levels were higher than today, extensive spreads of raised marine deposits – sands, gravels, clays and silts – were laid down along the low ground adjacent to the present River Clyde. Once relative sea levels were closer to those seen today, alluvium began to be deposited on the flood plain of the River Clyde and other rivers in the area. The other main post-glacial deposit is peat, which occurs largely over upland areas. Little is known of the hydrogeology of the superficial deposits. It is likely that there is significant interaction between groundwater in bedrock and superficial aquifers, and between superficial aquifers and surface waters. The superficial deposits may play an important role in controlling recharge to the underlying bedrock aquifers, and in influencing surface water drainage. There are reports that flooding along the tributaries of the River Clyde has caused problems in some areas (GCC, pers.comm.), but a lack of hydrogeological understanding means that the role of groundwater in such flooding is unknown. Glasgow City Council is also interested in the possibility of discharging wastewater to the ground as part of managing a sustainable urban drainage system.

2 Hydrogeological aspects of soils and made ground

2.1 AIMS

The aim of this part of the work was to assess the hydrogeological aspects of soils and made ground in the wider Glasgow and Clyde Basin areas, using currently available data. The main aspects investigated were the permeability of soils and the permeability, thickness and type of made ground.

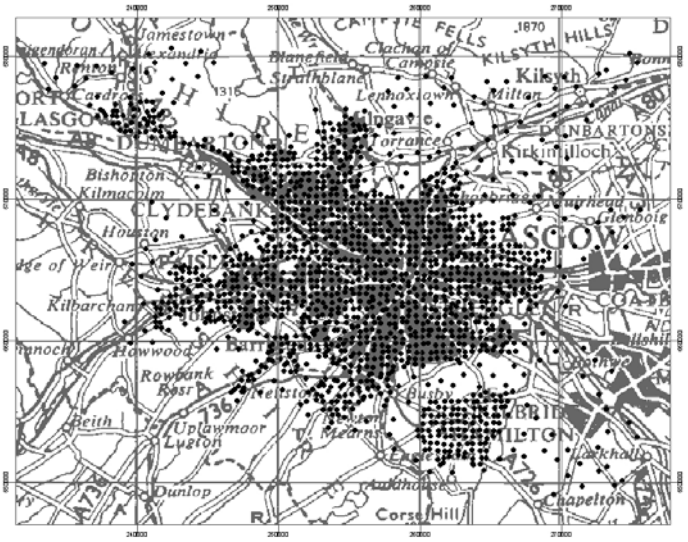
2.2 SOILS

As part of GSUE survey of urban soils in Glasgow and the peri-urban surrounding region, two soil samples were taken at each of over 1500 sites. Samples were taken from 0.15 m and 0.45 m depth. The texture of all the samples was recorded.

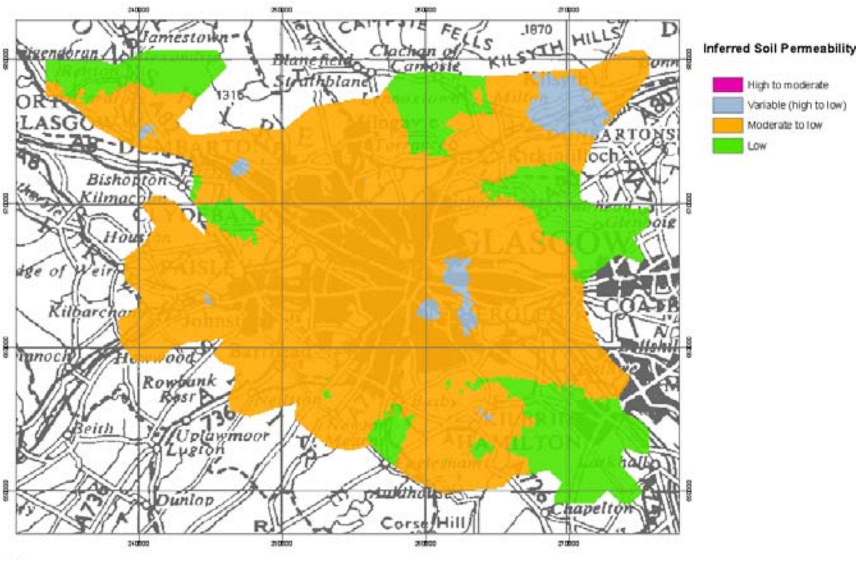
Soil texture is a key control on soil permeability: coarse textured soils tend to have larger and more well-connected pore spaces than fine textured, and therefore to have higher permeability. It is therefore valid to use soil texture as a proxy indicator of soil permeability.

The texture classifications of the Glasgow and peri-urban soil samples were interpreted in terms of soil permeability, by categorising each sample as belonging to one of five permeability classes: very high; high to moderate; variable (high to low); moderate to low; and low to very low. A map of soil permeability was then interpolated using these classifications. Two interpolation methods were trialled: inverse distance weighting and kriging. Kriging was preferred as it gives less weight to isolated data points, which otherwise produce skewed distribution. An interpolated map was produced for each of the soil sample depths (0.15 and 0.45 m).

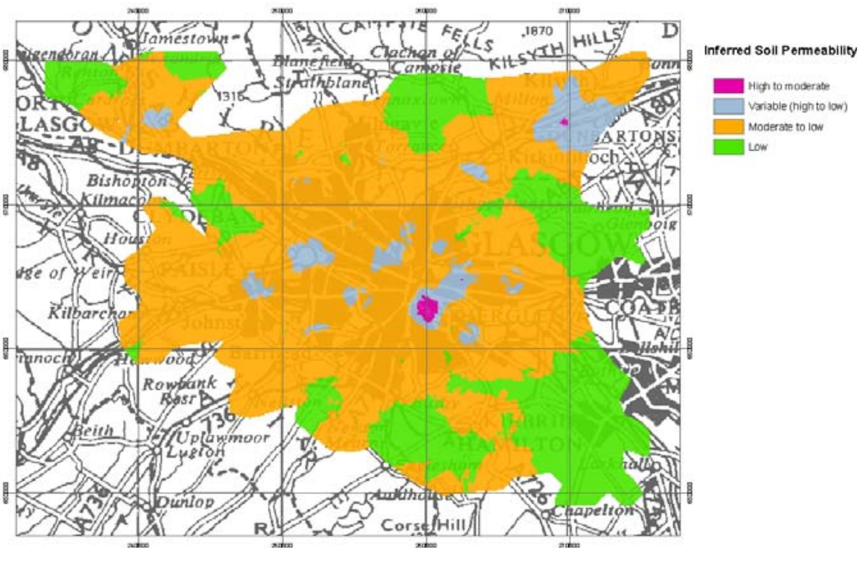
The data and interpolated maps (Figure 1) indicate that the majority of soils in Glasgow have moderate to low permeability, with distinct areas of low to very low permeability soils. Few soil samples were classified as more than moderately permeable, and of those that were, they tend to be isolated and scattered. However, there are a few areas where the data indicate that soil permeability may be more variable – these are suggested more strongly by the deeper (0.45 m depth) soil samples. The main areas are in the northeast (Kilsyth-Kirkintilloch area) of the study district and eastern Glasgow (Rutherglen area), where higher permeability soils may be more widespread.



(a)



(b)



(c)

Figure 1 The location of soil samples in the wider Glasgow area (a), and interpolated maps of soil permeability at 0.15 m depth (b) and 0.45 m depth (c)

2.3 MADE GROUND

2.3.1 Data Compilation and Classification

LANDUSE AND MADE GROUND

Historical OS maps of the Clyde basin area were studied in order to determine the presence and type of made ground deposits that are present. The marking of features such as quarries, sand pits and collieries on older maps, for example, pointed to the presence of made ground when these features were no longer present in later editions. The maps also showed the presence of significant and sudden depressions or rises in the ground, which would suggest them to be artificial. Such features often changed dramatically in shape and overall extent over time. The map of historical land use is presented in Figure 2.

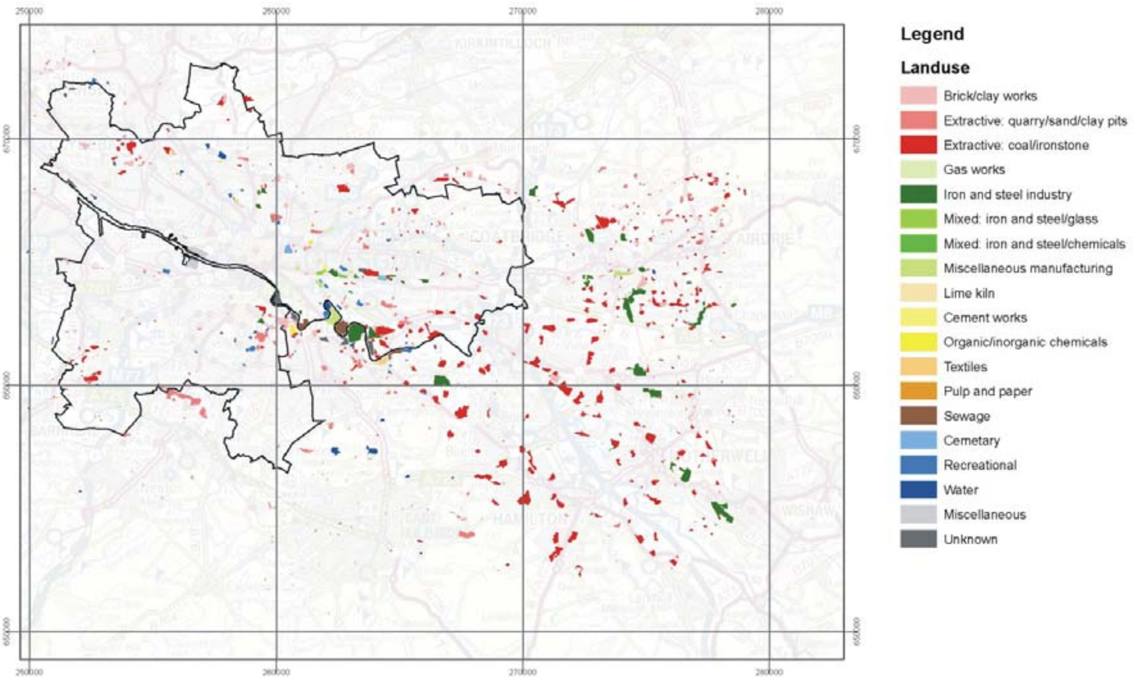


Figure 2 Historical landuse identified in the wider Glasgow area. The black line shows the outline of the Glasgow City Council area.

BOREHOLE RECORDS AND MADE GROUND

Borehole records with information on the presence and nature of made ground deposits in the Clyde Basin were also accessed. It became apparent that even where descriptions of made ground were made in the original borehole record, the descriptions have frequently not been entered when the lithological information from these records is manually entered into the BGS corporate database, Borehole Geology. This appears to be because the geologists leading the digitisation of borehole lithological data have historically not felt that information on made ground is as valuable as data on bedrock and natural superficial deposits. It is likely that because resources are limited, digitisation of data on bedrock and natural superficial deposits has been prioritised over that of made ground.

As part of the current work, therefore, all the scans of borehole records from the wider Glasgow area were examined, and where descriptions of made ground were present, these were manually entered into the Borehole Geology database.

Unsurprisingly, the majority of the 5000 boreholes are concentrated around the central built-up areas of Glasgow.

MADE GROUND THICKNESS

The total thickness of made ground in each borehole for which made ground data are available was plotted (Figure 3). This identified discrete areas of deeper (or shallower) made ground deposits.

The point data were interpolated to produce raster maps indicating the distribution of made ground thickness across the area where borehole data are available. Two interpolation methods were tested: inverse distance weighting and kriging. As for the soils example (above), the kriged map was preferred as it gives less weight to isolated data points. The interpolated map is shown in Figure 4.

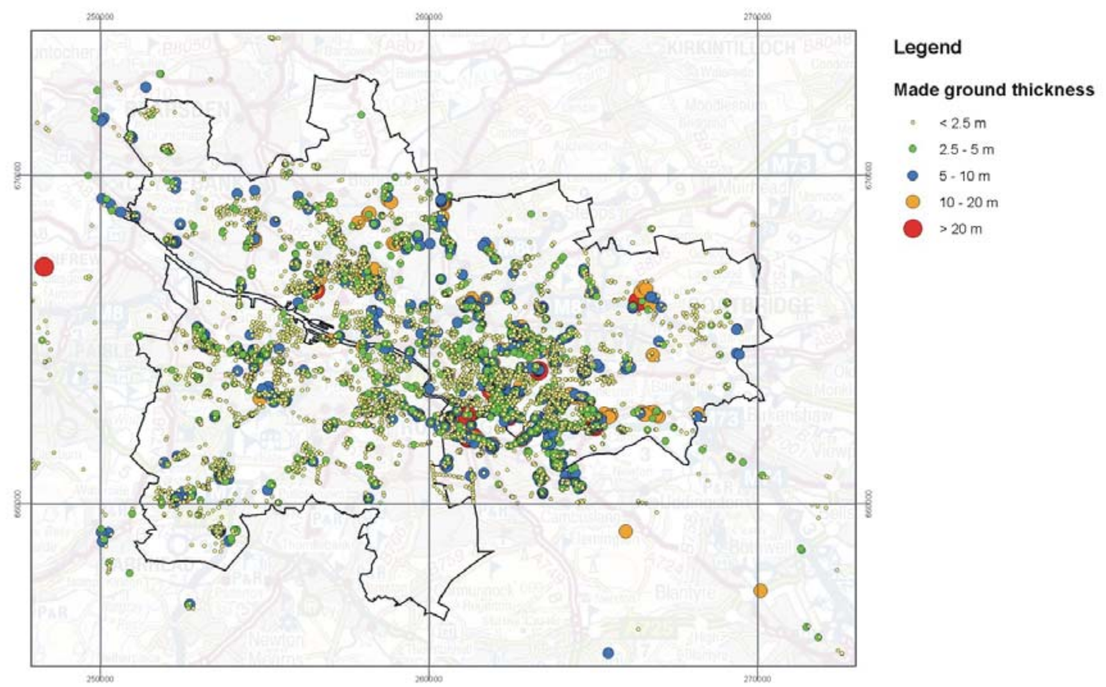


Figure 3 Thickness of made ground – borehole point data. Glasgow City Council area shown as for Figure 2.

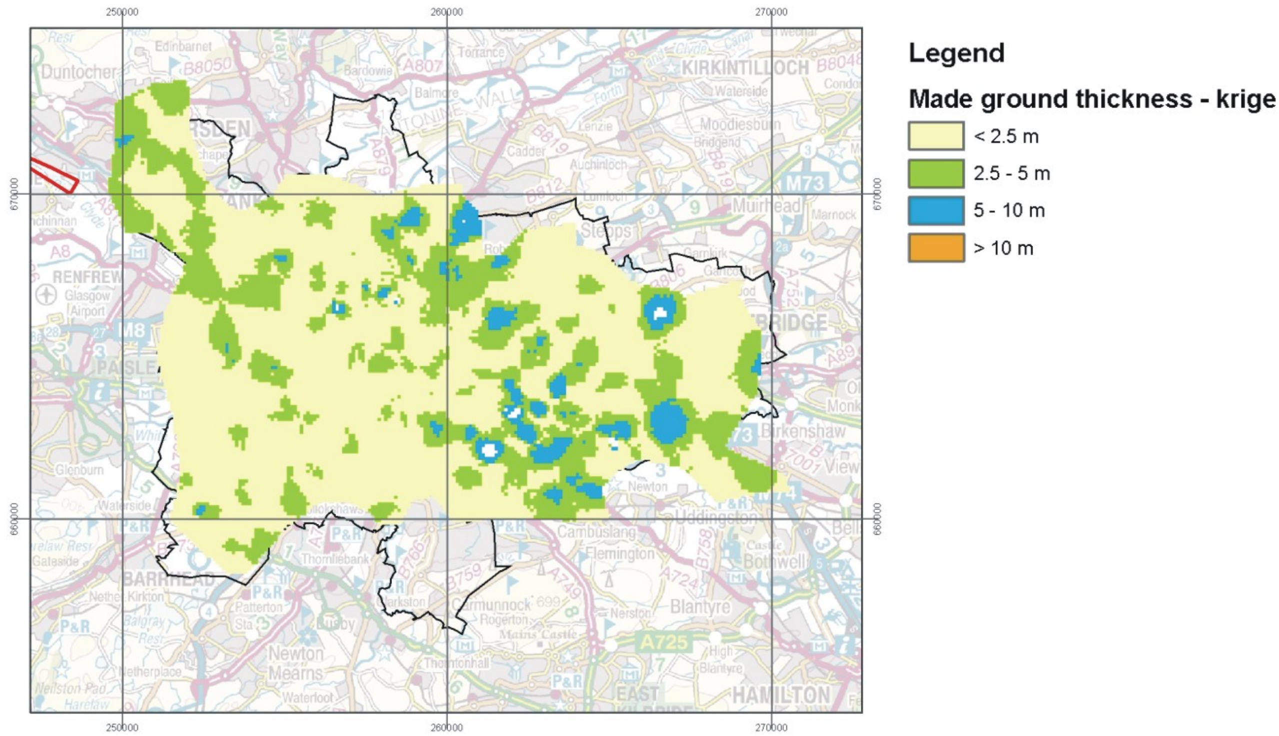


Figure 4 Thickness of made ground – interpolated map. Glasgow City Council area shown as for Figure 2.

MADE GROUND LITHOLOGY AND PERMEABILITY

The lithological descriptions of made ground in Borehole Geology were used to estimate the likely range of permeabilities of these deposits, assigning a maximum and minimum value to each lithological entry where possible. This was done primarily by treating the made ground material as natural material and using the permeability classifications established for natural superficial deposits as part of the GeoHazard project (Lewis *et al.* 2006). In this scheme, clays and silts are assumed to have the lowest permeability, and gravels to have the highest permeability. For the purposes of classifying the made ground deposits, ash was assumed to be of silt grade; clinker to be of gravel grade; and rubble to be of pebble or larger grade. It is recognised that these are generalisations and that they are likely to lead to incorrect classifications in some cases, but the overall approach was assumed to be valid.

For each made ground layer described in the borehole records, there were often combinations of materials, in which case an overall permeability range was assigned based on the respective permeabilities and proportions of the constituent materials.

In some cases, it was not possible to assign a useful permeability value to a made ground layer, either due to a lack of information or to difficulties in assessing the permeability of the material. For example, concrete may be either fractured and highly permeable or unfractured and impermeable.

For all the boreholes where it was possible to assign permeability values, a single value for the permeability of made ground at each borehole was then assigned. Where a borehole had more than one made ground layer with different permeability classifications, the lowest permeability layer was selected. This yielded a single permeability range (maximum and minimum permeability) for each of nearly 1500 boreholes. A single value was then applied to each borehole, based on the permeability range, as follows:

- Very high or high permeability
- Very high to moderate permeability
- Moderate to very low permeability
- Low to very low permeability

Boreholes where the assigned minimum to maximum permeability range was very wide (i.e. the minimum permeability is low or very low and the maximum is high or very high) were not assigned a single permeability value, but a range of values.

A map of boreholes with permeability data, showing assigned permeabilities, is presented in Figure 5.

MADE GROUND TYPE

The lithological descriptions were also used to identify the type of material deposited, relating them to the likely industry or activity which had created the made ground deposit. The main categories used were as follows:

- colliery waste
- construction waste
- reworked natural deposits

Combinations of these categories, as well as minor categories such as wood, were also used. In some borehole records, the presence of chemical waste was recorded. Due to its clear relevance to water quality in the surrounding area, these boreholes were collated to form their own data set. A map of boreholes with made ground data classified by made ground type is presented in Figure 6.

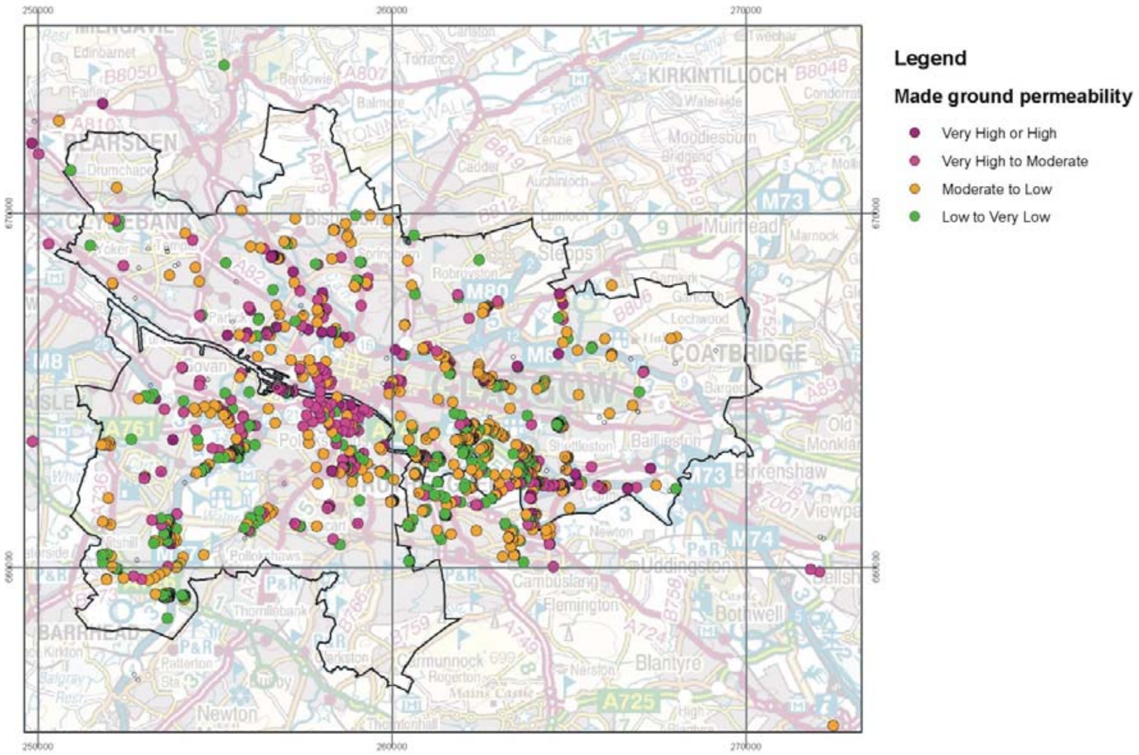


Figure 5 Permeability of made ground. Glasgow City Council area shown as for Figure 2.

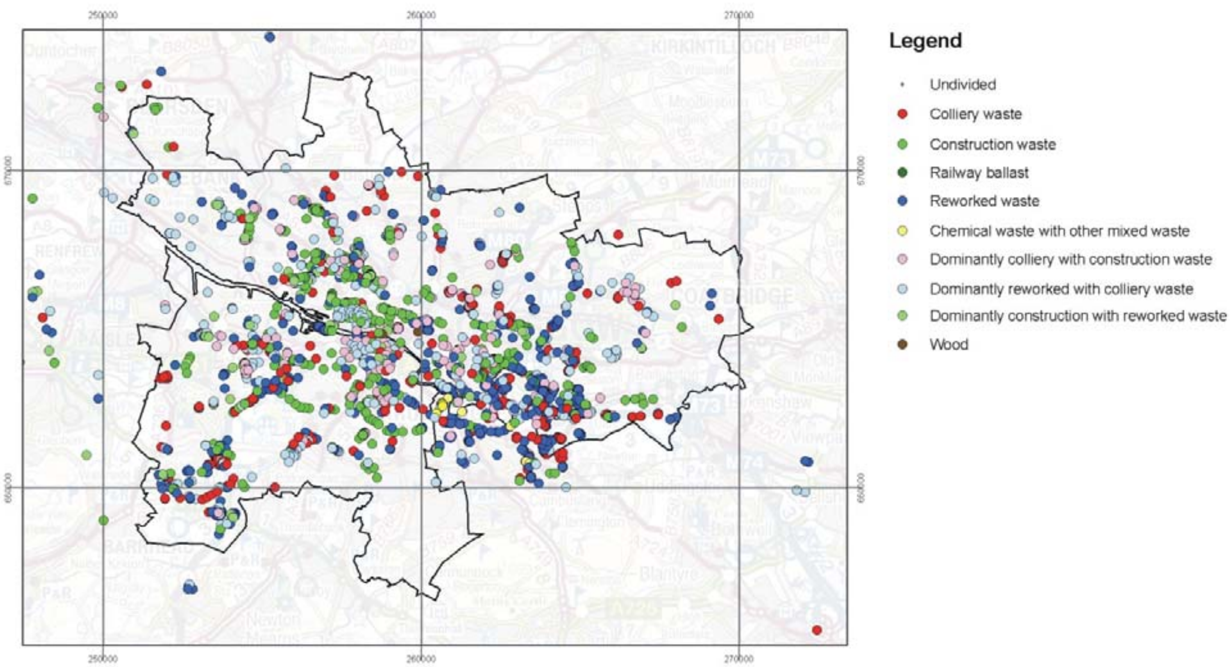


Figure 6 Type of made ground. Glasgow City Council area shown as for Figure 2.

2.3.2 Spatial Trends

OS MAP DATA

The majority of made ground identified from historic OS maps of the Clyde basin appears to lie in either central or eastern Glasgow (Figure 2). Most noticeably, the southeast is dominated by extractive industries (coal/ironstone mines; quarries and sand/clay pits), with a large number of iron and steel or brick and clay works also present. The centre of Glasgow shows a much wider range of land use, with most types represented, including recreational, water, miscellaneous manufacturing, sewage, cemeteries and brick/clay works.

MADE GROUND THICKNESS

The total depth of made ground at any site is predominantly less than 10 m, with a fairly even spread of values within this range. Although the spatial distribution of these values is somewhat patchy, made ground seems to be generally thicker in and around quarter sheet NS66SW, in the southeast of Glasgow (Figures 3 and 4).

TYPE OF MADE GROUND

Although some of the made ground materials appear to be distributed randomly around the Glasgow area, it is possible to pick out two main trends. Firstly, colliery waste dominates the south-eastern part of the city, around Rutherglen and Shettleston. Secondly, reworked material seems to have been commonly used to infill ground around major transport routes, such as railways or motorways (Figure 6).

PERMEABILITY

The interpreted permeability of made ground across the Glasgow area is shown in Figure 5. Permeability values appear to be highest in the centre of Glasgow and immediately to the north. Moving away from this area, the permeability of the lowest permeability layer tends to be low.

CHEMICAL WASTE

All but one of nearly 70 recorded occurrences of chemical waste were in the east of Glasgow (Figure 6), in quarter sheet NS66SW. Although this may have implications for the overall spatial distribution of chemical waste within Glasgow, it may simply highlight more detailed logging of the boreholes in this area.

2.3.3 Relating the Datasets

TYPE OF BOREHOLE MATERIAL AND OS MAP DATA

The data do not show any real correlation between the land uses identified from historic OS maps and those inferred from borehole records. The datasets do, however, show an increase in the number of collieries and colliery waste deposits to the southeast of central Glasgow, although there is little direct overlap between individual areas of made ground and borehole records in this regard.

It is unfortunate that the majority of borehole records yielding detailed information on made ground are located in central Glasgow, while many of the made ground deposits which could be identified from the OS maps lie to the southeast of the city. It may be that significant areas of made ground were not identified through use of OS maps due to the rapid development of derelict land in the city centre. This makes it difficult to compare the data sets over a wide area. It is not possible, therefore, to rule out a possible link between, for example, the presence of collieries and the presence of colliery waste which may infill them.

Made Ground Thickness and OS Map Data

Information from borehole logs does overlap significantly with historic OS map data to the southeast of the centre (NS66SW). In this area, large expanses of made ground identified from the historic OS maps coincide with particularly thick artificial deposits. The apparent lack of made ground found on the OS maps for other parts of central Glasgow may be explained by deposits which are either shallow or small in aerial extent. There is no obvious relationship between made ground thickness and land use.

Borehole Material and Made Ground Thickness

Many of the thickest made ground deposits appear to contain a large proportion of purely reworked natural deposits. To a lesser extent, colliery waste such as ash, slag and clinker tend to be present more commonly in areas of thick made ground. Construction waste tends to be present in shallower made ground deposits.

Permeability and Made Ground Thickness

There is a good correlation between the presence of impermeable material and thick made ground deposits. Given that thicker deposits tend to contain more layers of made ground material, this is perhaps not surprising.

Permeability and OS Map Data

There is insufficient spatial overlap between these two datasets to see any correlation between them.

Permeability and Type of Borehole Material

There are few obvious relationships between permeability and the type of borehole material present. Nevertheless, colliery waste tends to appear in areas of lower permeability, probably due to the high proportion of silt-grade ash. Construction waste is often related to areas of high permeability. It should be noted, however, that construction materials such as concrete, and tarmac, asphalt and other bituminous surfaces (commonly referred to in borehole logs simply as tarmac), were not classified. The remainder are mainly rubble and boulders, which are likely to have high permeability.

3 Hydrogeological aspects of historical mining

3.1 AIMS

The aims of this part of the work were:

- to identify and collate available data on the extent of historical mining in the area, and
- to identify, collate and interpret available data on the volume of historical mine water discharges from the Carboniferous aquifer.

3.2 EXTENT OF HISTORICAL MINING

The approximate outline of the extent of historical mining was taken from a map produced at a national level for SEPA. This shows probable areas of significant historic shallow mining, including coal, oil shale or limestone; metalliferous and other mineral mining; and of deep coal mining (more than 200 m deep). The map is described in detail in MacDonald *et al*. 2003, and its coverage of the Clyde area is shown in Figure 7.

The locations of boreholes encountering mine workings at shallow (less than 30 m) and deep (greater than 30 m) levels, and the locations of the mouths of abandoned mines and adits are shown on the Glasgow Environmental Geology series of maps (Institute of Geological Sciences/Forsyth 1983), and shown in Figure 8.

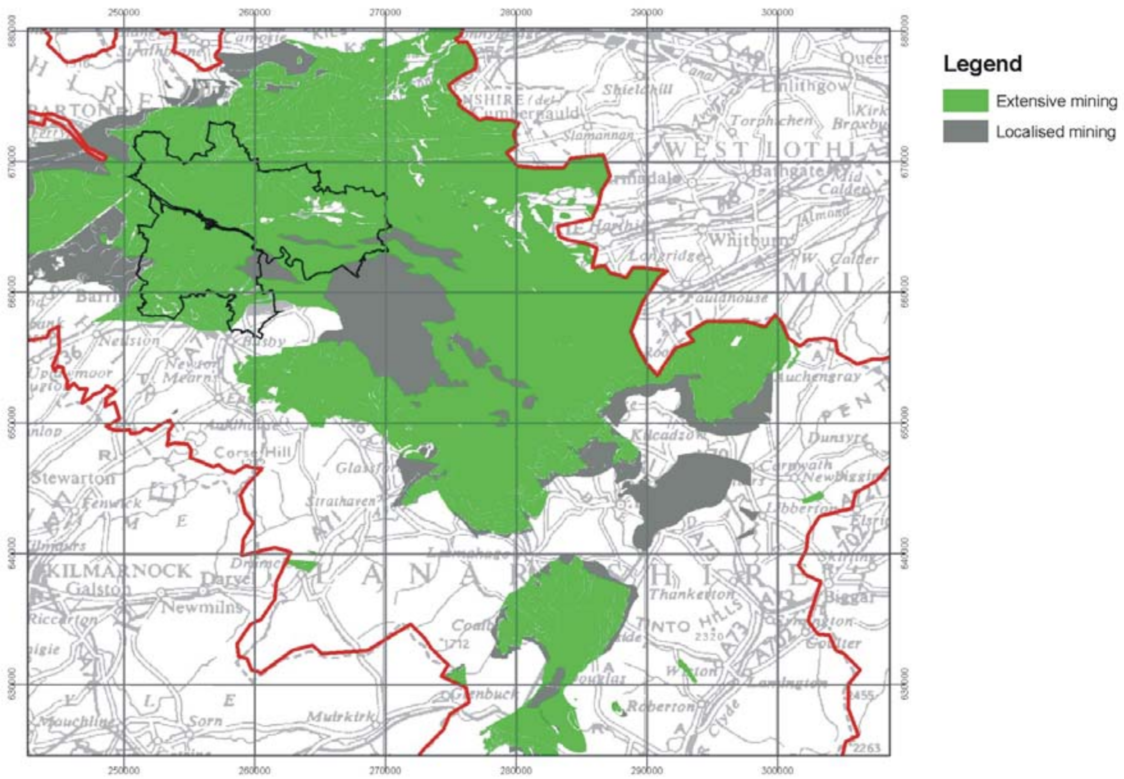


Figure 7 The extent of historical mining. The black line shows the Glasgow City Council area; the red line the extent of the Clyde catchment.

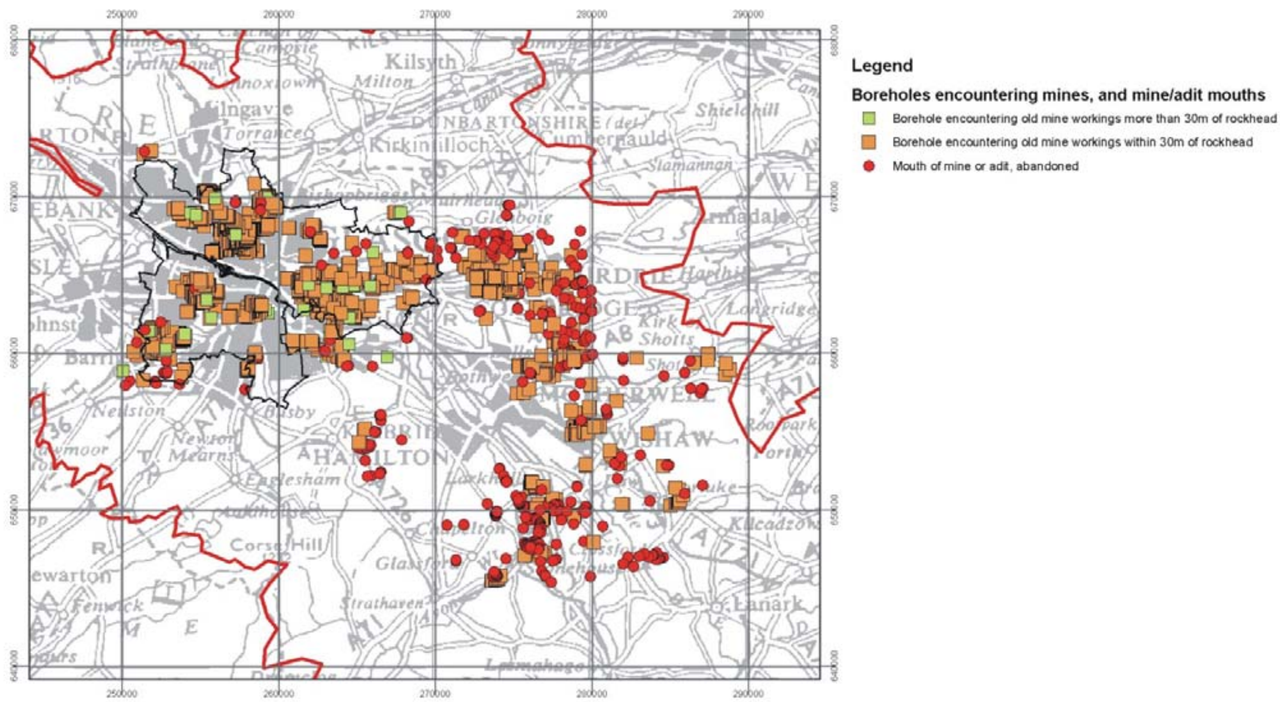


Figure 8 Boreholes encountering mines, and mine/adit mouths. Glasgow City Council and Clyde catchment areas shown as for Figure 7.

3.3 HISTORICAL MINE WATER DISCHARGES

The aim of this part of the work was to estimate the volume of mine water discharges from the Carboniferous bedrock aquifer in the Glasgow and wider Clyde Basin area, and thus to assess the importance of groundwater flows in the aquifer to the regional water budget. The limited availability of data means that the results of this part of the work are very much a first approximation.

Mine water discharge data are not consistently recorded. BGS hold a number of National Coal Authority records that record the volume of water pumped from named mined seams. However, these records generally do not make clear whether water was pumped out of the mine altogether or whether it was pumped from one part of the mine to another. The risk of 'double accounting' of pumped water means it is not possible to calculate the total volume abstracted. Additionally, the records generally do not specify when pumping from each mine finally stopped.

In order to make an initial approximation of the volume of groundwater pumped from mines in the Clyde Basin area, mine dewatering boreholes were identified from the BGS Scottish Water Boreholes database. The yields of these boreholes are recorded in the database. These were cross-referenced with the BGS records from the National Coal Authority to identify which mine each borehole was abstracting from. In the absence of records of when mine water dewatering ceased, it was assumed that it was stopped at the time of the last seam closing, which is recorded in the National Coal Authority records. Figure 9 shows the volume of water pumped from each borehole according to the decade it is assumed that mine water dewatering ceased.

An obvious drawback of this first approximation is that there are certainly more mine water dewatering boreholes in the Clyde area than could be identified in this initial assessment. A more comprehensive assessment would require more detailed scrutiny of National Coal

Authority records. However, even if this were done, it is not clear whether good data on mine water abstractions actually exists for many of the mine workings in the area.

Assuming that all of the identified boreholes were abstracting simultaneously at the recorded rates at some point – this would have been prior to 1950 – the total volume of water discharging from mines in the Clyde area would have been approximately 215 Ml d^{-1}. Given that in actual fact not all these boreholes are likely to have been abstracting simultaneously, but that a number of other boreholes as yet unidentified were also likely to be abstracting, this is likely to be a good first approximation of the volume of mine water discharge during the main period of mining in the Clyde area. This is a very large volume of water: to put it in context, the estimated total volume of groundwater abstracted in Scotland in 2005 for all supply purposes – public water, industry, agriculture and private – is 330 Ml d^{-1}.

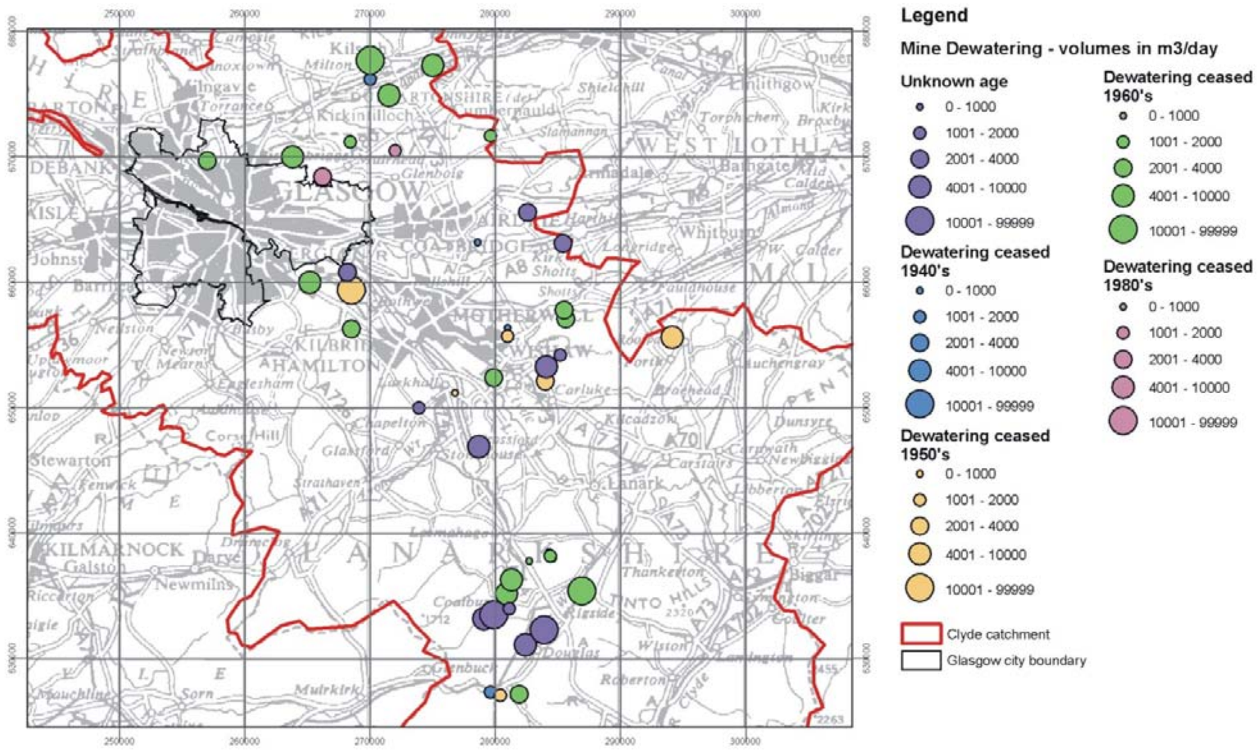


Figure 9 The volume of water pumped from each identified mine dewatering borehole according to the decade it is assumed that dewatering ceased. Glasgow City Council and Clyde catchment areas shown as for Figure 7.

4 Initial assessment of groundwater and contaminated land

4.1 AIMS

The aims of this part of the work were:

- to make a preliminary assessment of the extent and nature of contaminated land in the wider Glasgow area, based primarily on geochemical surveys carried out by BGS; and
- using this assessment, to make an initial assessment of the risks to groundwater in the area from contaminated land.

4.2 WASTE TYPES

4.2.1 Waste from iron/steel and other metal works

In comparison to other cities, Glasgow has been found to have particularly high levels of Cr and Ni, with moderately high levels of Se and some Pb. The levels recorded for Glasgow tend to be two to three times higher than those found in extra-urban areas across the country, indicating substantial urban contamination (Fordyce *et al.* 2005).

High levels of Cr and Ni are commonly associated with the presence of waste from former iron and steel works (Fordyce *et al.* 2005). A significant number of former iron and steel works were located in the southeast of Glasgow, particularly in and around quarter sheet NS66SW.

In a recent study of made ground in Manchester, Mn, Fe, V, Ni, Co, Ba and Sr were found to occur together in soils overlying former iron and steel works. Ge, Mo, As, Se and Tl were also found together in these areas (Fordyce *et al.* in prep.). The study also linked increased levels of Cr, Cu, Zn, Pb, Sn, Sb and W to mining and metallurgical industries.

Work carried out in Stoke-on-Trent found ironworks slag to contain the highest levels of As, Cd, Cr, Cu, Mo, Ni, V, Fe and Mg of any made ground type. Concurrently high levels of CaO and MgO suggest a higher pH in nearby groundwater, potentially lowering the mobility of metals in the subsurface.

The presence of a large number of iron and steel works in east and southeast of Glasgow suggests that the area is at risk of contamination from all of the above species.

Studies of landfills in Glasgow containing waste from high-lime chromite ore processing show high levels of chromite (up to 91 mg/l), more than 30 years after the cessation of dumping (Farmer et al., 2002). The vast majority of chromite (>90%) occurs in the highly toxic Cr^{-VI} form. This form of the metal is induced by high pH values, caused by the high lime content of the waste. It was found, however that the proportion of Cr^{-VI} was reduced in the presence of significant organic matter. The study also showed Cr concentrations of 6.7 mg/l occurring in a local tributary and 0.11 mg/l in the River Clyde itself, pointing to potentially large-scale consequences if the problem of chromium contamination is not addressed. The maximum allowable concentration of chromium in drinking water in Scotland, as in the rest of the UK, is 50 μg/l (Water Supply (Water Quality) (Scotland) Regulations 2001).

4.2.2 Colliery waste

Elevated Cr and Ni concentrations have also been linked to the presence of colliery waste (Fordyce *et al.* 2005). Again, a number of old collieries were recorded in the east and southeast of Glasgow and borehole records commonly show the presence of colliery waste in this area (ash/blaes/clinker/slag). It is noticeable that 66 out of the 67 recorded incidents of chemical waste in borehole logs of made ground in Glasgow lie within NS66SW.

Many of the waters draining from collieries and deposits of colliery waste may be extremely acidic due to the oxidation of sulphides. The increase in metal solubility in low pH environments can lead to high concentrations of Fe, Mn, Cu, Ni and Zn in these fluids, along with significant levels of other elements such as As and Pb (Fordyce and Ander 2003).

Data from borehole records of the Glasgow area suggest that the permeability of made ground deposits is lower on average to the southeast of the city centre and this may lead to an increased retention of some metals in the near surface. Low soil pH, which occurs across Glasgow (Fordyce *et al.* in prep.), tends to increase the solubility of metals and metalloids in soils and may lead to increased uptake of these substances by plants in gardens and allotments (Hough *et al.* 2004).

4.2.3 Construction waste

Work carried out in Stoke-on-Trent found clay, bricks and tile waste to be generally low in metal and metalloids such as As, Ba, Cd, Co, Cr, Cu, Sb, Sn, U, Mo, Ni, Pb, V, Zn and K_2O. Deposits of this type were also found to display the highest levels of SiO_2 when compared to other made ground types, reflecting their inert nature (Fordyce and Ander 2003).

4.2.4 Transportation routes

One area requiring further study is the level of contamination surrounding canals in the Glasgow area. The study in Manchester showed these areas to have highly elevated concentrations of a wide range of elements, due to their use as recipients of waste industrial fluids in the past (Fordyce *et al.* in prep.).

Elevated Br concentrations have been linked to road salting and traffic pollution, given the past use of bromine in petrol anti-knock compounds (Fordyce *et al.*, in prep.). The construction of road and rail networks, which involves ground disturbance, may lead to increased contamination. Vehicle emissions obviously tend to be highest along road and rail networks, and additionally they often occur in conjunction with the growth of industrial development alongside them.

4.3 CONCLUSIONS

Soils and shallow groundwater in Glasgow are potentially at risk from a wide range of contaminants. NS66SW, lying just to the southeast of the city centre is an area of particular concern, due to the presence of significant mining and metallurgical activity leading to probable high levels of Cr and Ni. The generally lower permeability of artificial deposits in this area suggests that soil in the area has the potential to be highly contaminated. In areas of high pH, often associated with high-lime concentrations within the waste, highly toxic Cr^{-VI} ions may be present in abundance. In areas of low pH the overall solubility of heavy metals and metalloids is liable to increase. This may lead to significant uptake by plants growing in these areas, causing potential danger for human consumption.

There are fewer data on the presence of old industries in the city centre itself and to the west of the city. This may be due to fewer industrial sites being present, although in the former case, it may well be due to rapid development of the area, meaning that any derelict land may not have been present for sufficiently long to be seen on historic maps. Similar problems were encountered during the Manchester study, in which areas experiencing numerous phases of demolition and redevelopment could not easily be classified by made ground type (Kessler et al., 2004). Any contaminated deposits of made ground which do exist in the centre of the city are liable to pose a significant threat to groundwater, due to the higher overall permeability of made ground in this area.

5 Hydrogeological parameterisation of the GSI3D geological model

5.1 AIMS

The aims of this part of the work were:

- to explore how we can add value to the existing GSI3D geological model for quarter sheet NS66SW by adding hydrogeological interpretations; and
- to explore how we can make use of the detailed geological framework provided by the GSI3D geological model to develop a better understanding of the hydrogeological system.

5.2 THE GSI3D GEOLOGICAL MODEL

The new software package GSI3D (Geological Surveying and Investigation in 3D) has been used to model the geology of quarter sheet NS66SW. This model was a pilot scheme undertaken by BGS during which software development and geological modelling evolved in parallel. The superficial geology has been modelled entirely using GSI3D. Limitations with the software mean that bedrock geology surfaces are currently modelled in detail using GoCad software, a dedicated 3D modelling package, and the surfaces then exported to GSI3D (Merritt et al 2005). Both superficial deposits and bedrock were considered in assessing how the hydrogeology can be parameterised in GSI3D.

5.3 HYDROGEOLOGICAL ATTRIBUTES

5.3.1 General

This is an initial stage to test the possibilities for hydrogeological attribution within GSI3D. It can be refined as more data become available. The groundwater datasets used in this attribution exercise are designed to be used at a national scale, and the local hydrogeological characteristics of the geological units may differ from the national-scale attribution. However, in the absence of detailed information on groundwater in the Glasgow area, this provides a suitable first description of the hydrogeology.

5.3.2 Permeability and productivity

The permeability and aquifer productivity of the superficial deposits and the aquifer productivity of the bedrock units was attributed based on the detailed lithological descriptions of each geological unit, referring to existing BGS datasets that cover the area of the model (Ó Dochartaigh 2005). An illustration of the permeability attribution is presented in Figure 10.

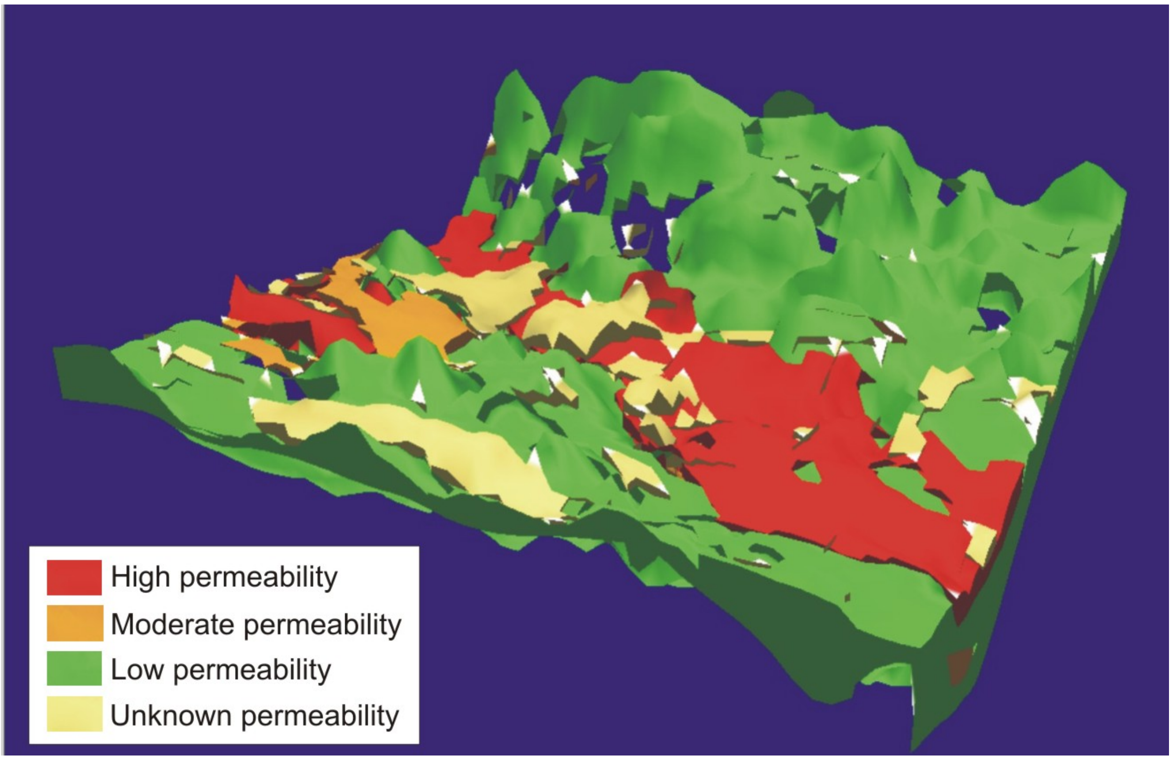


Figure 10 Illustration of GSI3D model for quarter sheet NS66SW, attributed by superficial deposits permeability.

5.3.3 Groundwater vulnerability

Groundwater vulnerability cannot be assigned for each geological unit, as it represents a combined assessment of the three dimensional geology at any point. It can be represented in GSI3D by importing a raster map of groundwater vulnerability to overlie the model.

5.3.4 Groundwater level surfaces

Groundwater level surfaces can be displayed in two ways

- by importing a raster map of groundwater level surface to GSI3D in the same way as the groundwater vulnerablity map can be imported, so that it overlies the model (see above); and
- by displaying water levels on borehole sticks.

As part of this exercise, an existing map of groundwater levels in superficial deposits was imported to GSI3D to demonstrate the technique. This map is based on an empirical estimate of the depth from the ground surface to the level of the nearest major surface water body, and is not based on measured borehole data, of which there are none available in the NS66SW area. The procedure for displaying available measured borehole water levels on borehole sticks was investigated.

6 Proposals for further work

The work described in this report represents an initial stage in developing a detailed conceptual model of groundwater in the Clyde Basin, and in the development of a numerical groundwater modelling. Much further work remains to be done. In particular, the following activities are proposed as an immediate follow-up to the work reported here.

6.1 INITIAL CONCEPTUAL MODELLING OF THE HYDROGEOLOGICAL SYSTEM

An initial conceptualisation of the hydrogeological system in Glasgow and the Clyde Basin should be developed. This will of necessity be simple, and based on the existing understanding of the hydrogeology of the area (e.g. see Section 1.2, above, and Ó Dochartaigh 2005). It should define the aquifer units in both the superficial deposits and the bedrock, and describe the current understanding of the groundwater flow system.

6.2 HYDROGEOLOGICAL DOMAINS OF SUPERFICIAL DEPOSITS

Using the available collated and interpreted hydrogeological data, a hydrogeological domains map could be developed to provide a partially 3D interpretation of groundwater vulnerability and groundwater pathways in the superficial deposits.

6.3 GROUNDWATER INPUT/OUTPUT: SUPERFICIAL DEPOSITS

A basic water balance for the superficial deposits aquifer(s) in Glasgow and the wider Clyde Basin should be developed based on available meteorological, hydrological, hydrogeological and other data (e.g. water supply and sewerage leakage rates). This should include a recharge model. Available data would need to be sourced and collated from a variety of sources, including SEPA, Glasgow City Council and Scottish Water. Such a water balance would serve both to indicate the importance of shallow groundwater in the overall hydrology of the area, particularly in areas of concern such as discharge to surface water courses, and as a precursor to a detailed water balance that would be required for numerical groundwater modelling.

6.4 FURTHER HYDROGEOLOGICAL DEVELOPMENT OF GSI3D MODEL

Further attribution of the GSI3D model should incorporate the following:

- refinement of permeability and productivity attributions as more detailed data become available, particularly for the superficial deposits;
- incorporation of available borehole aquifer properties data, such as transmissivity and permeability, in borehole sticks;

6.5 GROUNDWATER MODELLING

A numerical groundwater flow model for the Clyde Gateway area should be produced, using the existing GSI3D model as the geological framework. This should be done using the new, bespoke code to convert between GSI3D and the BGS groundwater modelling code ZOOM, which is scheduled to be available in summer 2006. It will require new hydrological and hydrogeological data to be collated or, if not available already, to be collected (in particular, stream flows and groundwater levels). Even with new data, any groundwater flow model produced is likely to be of necessity unvalidated, because of the current poor understanding of the groundwater system in the area. However, the model will itself improve our understanding of the likely groundwater processes operating in the area. The model could also be used to run future scenarios, for example to observe the potential impacts of sustainable urban drainage systems (SUDS), groundwater abstractions, or changes in rainfall or piped water flows.

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