British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Project progress report 2010-11: Groundwater monitoring in urban areas - a pilot study in Glasgow, UK

Land Use and Development / Groundwater Programmes

Internal Report IR/10/087

BRITISH GEOLOGICAL SURVEY

LAND USE AND DEVELOPMENT / GROUNDWATER PROGRAMMES

INTERNAL REPORT IR/10/087

Project progress report 2010-11: Groundwater monitoring in urban areas - a pilot study in Glasgow, UK

H C Bonsor, S H Bricker, B É Ó Dochartaigh and K I G Lawrie

Keywords

Urban groundwater; groundwater monitoring; Clyde Basin; urban observatories.

Front cover

View of Glasgow city centre.

Bibliographical reference

BONSOR H C, BRICKER S H, Ó DOCHARTAIGH B É AND LAWRIE K I G. 2010. Project progress report 2010-11: Groundwater monitoring in urban areas - a pilot study in Glasgow, UK. *British Geological Survey Open Report*, IR/10/087. 63pp.

Keyworth, Nottingham British Geological Survey 2010

BRITISH GEOLOGICAL SURVEY

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

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

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

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

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

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

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

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

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

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

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

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

Foreword

The work described in this progress report is part of ongoing efforts to develop a better conceptual understanding of the groundwater system in Glasgow. It is also aimed at developing protocols for improved groundwater monitoring in urban areas, which is a key step in improving hydrogeological understanding.

In 2009-2010 BGS began a pilot project to examine the potential for the development of a long-term groundwater monitoring network within the Glasgow urban area. Drivers for this work are primarily:

- the need to address the existing gaps in basic hydrogeological data for Glasgow, which currently limit our understanding of the groundwater system;
- the need to understand the effects of urban regeneration on the groundwater system, and in particular the effect of Sustainable Drainage schemes (SuDs); and
- the requirement of stakeholders for assistance in regulating impacts on the groundwater system and meeting Water Framework Directive (WFD) and other regulatory requirements.

The project has close links to a number of BGS projects: the Clyde Urban Super Project (CUSP) and the Industrial Legacies project; a project being carried out jointly between Glasgow City Council (GCC) and BGS under the Local Authorities and Research Councils Initiative (LARCI); and wider research into groundwater monitoring and SuDS within the BGS Urban Development and Groundwater Systems and Monitoring teams.

During 2009-2010 we set out the long-term aims and objectives of this project, and identified and collated existing groundwater monitoring data from GCC for the Glasgow urban centre dating from 2004-2009 (Bonsor and Ó Dochartaigh 2010). Work in 2010-11 has focused on:

- designing, developing and populating a dedicated database, to BGS corporate standards, to store groundwater monitoring data for Glasgow;
- setting up a protocol for the long-term transfer of groundwater monitoring data between the consultancies who collect the data, GCC and BGS;
- preliminary analysis of collated groundwater monitoring data towards developing an improved conceptual model of the shallow groundwater system in central and eastern Glasgow, with reference to the latest 3D geological models of Glasgow; and
- the preliminary design of a pilot groundwater monitoring network in central and eastern Glasgow, including the key Clyde Gateway regeneration area.

This report documents the above tasks and results from this year's work.

Acknowledgements

As with all projects we would like to thank are a number of BGS and external colleagues for their help and assistance:

- Simon Watson, Glasgow City Council for assistance with data collation and the management of groundwater data between GCC and BGS.
- Vincent Fitzsimons and Paul Morrison at SEPA for their helpful comments on the study,
- Andrew McKenzie for his help and advice on increasing the corporate value of the database.
- Diarmad Campbell for his comments on this report.
- Jon Ford for his useful input to discussions to setting up a pilot urban groundwater monitoring network in Glasgow.

Contents

FIGURES

TABLES

Summary

The work described in this progress report is part of ongoing efforts to develop a better conceptual understanding of the groundwater system in Glasgow. It is also aimed at developing protocols for improved groundwater monitoring in urban areas, which is a key step in improving hydrogeological understanding.

In 2009 BGS started a pilot project to examine the potential for the development of a long-term urban groundwater monitoring network in Glasgow, using existing monitoring boreholes. The project has close links to a number of BGS projects: the Clyde Urban Super Project (CUSP) and the Industrial Legacies project; a project being carried out jointly between Glasgow City Council (GCC) and BGS under the Local Authorities and Research Councils Initiative (LARCI); and wider research into groundwater monitoring and sustainable drainage systems (SuDS) within the BGS Urban Development and Groundwater Systems and Monitoring teams.

Project aims

- Identify and collate existing groundwater monitoring data (groundwater level and chemistry data) for Glasgow
- Design, develop and populate a dedicated database to store the groundwater monitoring data (and associated borehole data), and make it easily available for analysis and interpretation
- Interpret the collated data, in conjunction with related datasets (e.g. 3D geological models), and so develop an improved conceptual model of the shallow (superficial deposits) groundwater regime in Glasgow
- Use the collated data and hydrogeological interpretation to design a pilot groundwater monitoring network in a selected area in Glasgow, using existing monitoring boreholes, and specify a monitoring regime and protocol.
- Make recommendations for a future longer-term (>10 yrs) and larger scale (Glasgow-wide) groundwater monitoring network.

Why monitor groundwater in Glasgow?

Drivers for long-term groundwater monitoring in Glasgow have been identified in consultation with stakeholders, in particular GCC and the Scottish Environment Protection Agency (SEPA). There is a wide range of groundwater issues, each of which requires slightly different hydrogeological information to properly address. Any one groundwater monitoring network cannot capture data to address all of these issues. It is important, therefore, that monitoring is targeted to one or two key drivers is essential so that the monitoring network can capture data that is both representative of the groundwater system and appropriate to the monitoring need. The two key drivers identified are:

- the need to address the existing gaps in basic hydrogeological data for Glasgow, which currently limit our understanding of the groundwater system; and
- the need to understand the effects of urban regeneration and development on the groundwater system, and in particular the effect of sustainable drainage schemes (SuDs).

Other related drivers for monitoring groundwater across Glasgow are:

- the requirement of stakeholders for assistance in regulating impacts on the groundwater system and meeting Water Framework Directive (WFD) and other regulatory requirements
- the need to better understand the impact of contaminated land on groundwater

- the need to understand the impact of heat engineering schemes and existing groundwater abstractions on the groundwater system
- the need to understand the role of groundwater in flooding.

Why set up a pilot monitoring network?

A pilot monitoring network is being designed, set up and run for a trial period before plans for a long-term monitoring network across Glasgow are finalised. Setting up a large scale monitoring network across a large urban area is a major undertaking. As the above list of drivers shows, a wide range of groundwater issues exist in Glasgow. Many aspects can impact on the design, implementation and management of such a network, including the quality of collected data; data transfer protocols; how representative data are; and exactly what hydrogeological information is needed to properly address specific monitoring drivers. Strategic urban groundwater monitoring is not yet common (Bonsor and Ó Dochartaigh 2010), and, for example, the optimum spatial and temporal density of boreholes needed for a monitoring network to provide representative and appropriate (to particular drivers) data is not yet known. The design and implementation of the pilot network during this project will allow us to test and refine the optimum monitoring strategy for Glasgow.

Project activities

The main activities on the project in 2010-11 have been:

- designing and developing a dedicated database, to BGS corporate standards, to store groundwater monitoring data for Glasgow;
- populating this database with groundwater monitoring data for Glasgow collated to date;
- setting up a protocol for the long-term transfer of groundwater monitoring data between the consultancies who collect the data, GCC and BGS;
- preliminary analysis of collated groundwater monitoring data, with reference to the latest 3D geological models of Glasgow and to other BGS and external datasets, which has led to an improved characterisation of the spatial and temporal variability of the shallow (superficial deposits) groundwater regime in Glasgow; and
- the preliminary design of a pilot groundwater monitoring network in the key regeneration area of the Clyde Gateway in eastern Glasgow.

In addition to these activities, the project has also benefited from support from an internal BGS Opportunities Fund which has enabled the purchase of approximately 10 automatic loggers which measure and record groundwater level, temperature, and in some cases conductivity. They will be installed in selected boreholes within the pilot monitoring network.

Future work

The work in 2010-11 will feed into the next phase of the project, which will see the final design and setting up of the pilot groundwater monitoring network in the Clyde Gateway area; the collection of new high quality groundwater data; further improved understanding of the groundwater system in this area; and assessment of the potential for developing a larger, long-term (>10 years duration) groundwater monitoring network across the whole of the Glasgow urban area.

New data from the pilot network and any future city-wide network will be used in a number of associated projects, including the development of a city-wide numerical groundwater model; investigation of the potential impacts of SuDS on shallow groundwater in Glasgow; and validation of GRASP, a screening tool developed by BGS to assess the threat to shallow groundwater quality from metal pollutants leaching from soils in Glasgow.

Report structure

This report documents the work carried out in 2010-11 and is split into four sections describing the main activities:

- *Section 1* discusses the design, development and population of the groundwater monitoring database.
- *Section 2* discusses work done towards setting up a long-term protocol for the transfer of groundwater monitoring data between consultancies, GCC and BGS, in conjunction with the Local Authorities and Research Councils Initiative LARCI.
- *Section 3* discusses the stakeholder involvement in identifying key groundwater data needs.
- *Section 4* outlines the methodology for, and preliminary results of, the preliminary analysis of the groundwater monitoring data.
- *Section 5* sets out the process of designing a pilot monitoring network, using existing monitoring boreholes, in the key regeneration area of the Clyde Gateway in eastern Glasgow.
- *Section 6* sets out the further work required to complete the objectives of this project.

1 Background

This internal report is designed to document the work carried out on this project in financial year 2010-11, for the purposes of BGS staff and colleagues with an interest in groundwater and related issues in Glasgow and/or the related BGS projects. As such, this report is part of a series of internal reports written on groundwater-related work on Glasgow and the wider Clyde Basin over a number of years (e.g. Ó Dochartaigh 2005; Ó Dochartaigh et al. 2007; Graham et al. 2008; Ó Dochartaigh 2009; Bonsor and Ó Dochartaigh 2010). This report is not designed to be a comprehensive description of groundwater monitoring in Glasgow, nor a comprehensive, detailed conceptual model of Glasgow's groundwater system. It is a preliminary stage in developing such conceptual models, and these will be a future output of the project.

Having said this, it is recognised that readers may not be familiar with the hydrogeology of the study area and may not have access to the associated earlier reports. For this reason we have provided here a brief description of the hydrogeology of the area.

The study area broadly includes eastern and central Glasgow (Figure 1). Within eastern Glasgow is an area known as the Clyde Gateway, which is the focus of major urban regeneration and development, including for example the creation of the Commonwealth Games Village for the 2014 Commonwealth Games. The Clyde Gateway has been the focus of much recent BGS work, including the development of the first detailed 3D geological model for Glasgow (Merritt et al. 2009).

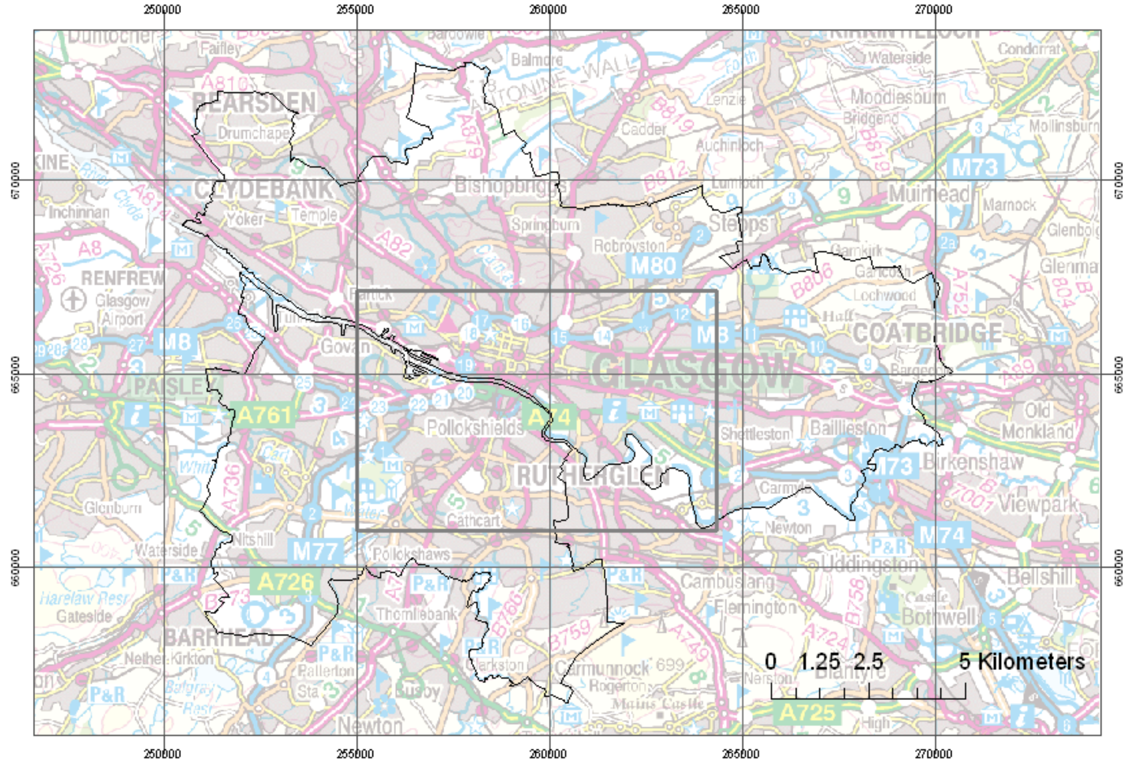

Figure 1 The general area of interest in Glasgow is highlighted by the grey rectangle

The superficial deposits geology comprises a bedrock valley, trending southeast to northwest, infilled by a complex sequence of superficial deposits (Figure 2). The River Clyde flows northwestwards within this valley and into the Clyde estuary in the western part of Glasgow. It is tidal in the downstream parts of the study area. The simplified superficial deposits geology shown on the BGS 1:50,000 scale maps (Figure 2) has been extensively refined and in the GSI3D model includes subdivisions into a number of lithostratigraphical formations, which are discussed in more detail later in this report. The main formations of interest in the study area are listed in Table 1.

Preliminary groundwater conceptual (e.g. Ó Dochartaigh 2009) and numerical modelling (Merritt et al. 2009) have investigated urban recharge processes and indicated general groundwater flow directions down valley towards the northwest. However, because of the lack of hydrogeological data until recently, this is largely unvalidated. Work towards a more detailed conceptual model of the hydrogeology of the study area has formed a part of the work reported on here (Section 5.3).

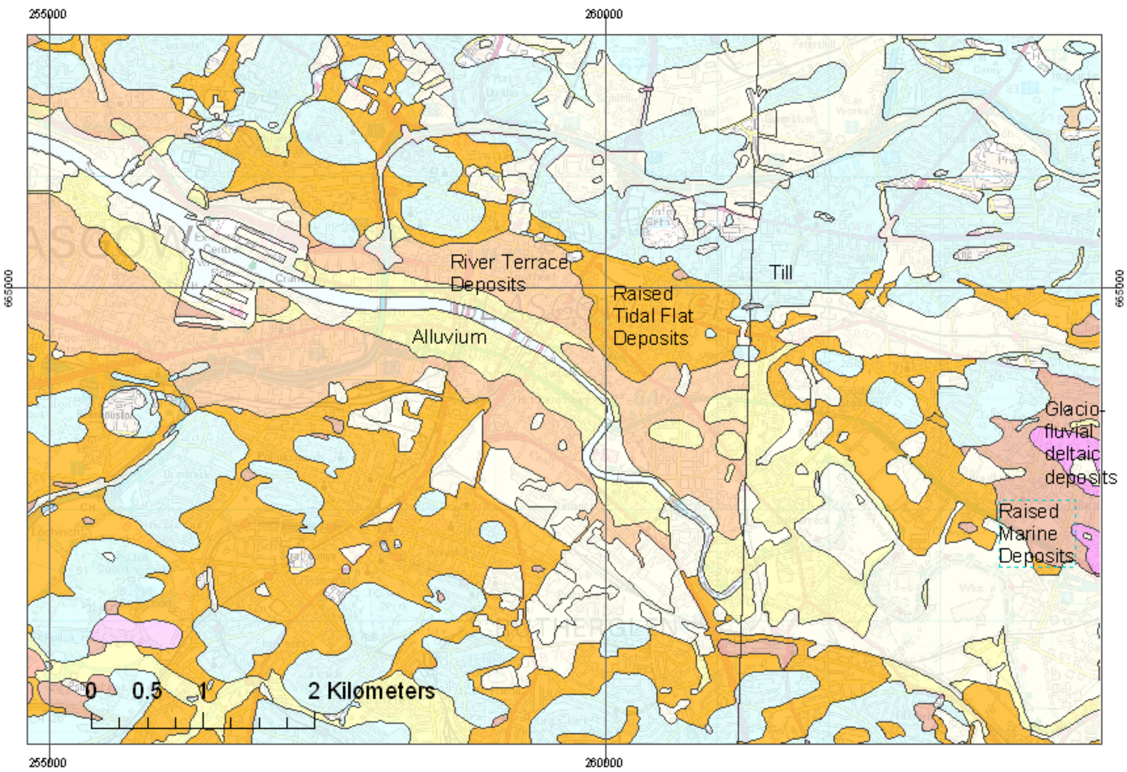

Figure 2 Simplified superficial deposits geology of the area of interest

Table 1 The main lithostratigraphic formations of interest in the study area, in descending order of age

Formation name	Brief age and origin
Gourock Sand Member	Flandrian; Marine
Paisley Clay Member	Devensian; Marine
Bridgeton Sand Member	Devensian; Marine
Ross Sand Member	Devensian; Lacustrine/Fluvial
Wilderness Till Formation	Devensian; Glacial

2 Groundwater monitoring data and database

2.1 GROUNDWATER DATA COLLATION AND DATA QUALITY

Work in 2009-10 identified over 300 short- or medium-term (monitored for <1-5 years) monitoring boreholes currently being used within central-eastern Glasgow – most notably from ongoing works on the M74 motorway extension and from the three major urban regeneration sites of the Clyde Gateway, Shawfield, and the Commonwealth Games village (Table 5). Other data sources identified in 2009-10 included smaller regeneration and development sites, Part IIA contaminated land assessments, and a small number of boreholes monitored directly by GCC. Groundwater level and chemistry data were collated from all these sites in 2009-10 from GCC. All of the collated data was collected in or after 2004. In 2010-11, updated additional monitoring data received by GCC in the last 12 months from the main regeneration sites (Clyde Gateway, Shawfield and the Commonwealth Games village) were collated.

The quality, detail and sampling frequency of the collated monitoring data are highly variable. The highest quality data are from the three major regeneration sites, where groundwater monitoring has been carried out for a relatively long time period (generally 2-5 years) and the frequency of monitoring (typically every 3 months) and number of different parameters measured is greatest (Table 2). At these sites, detailed inorganic and organic water chemistry data from laboratory analysis and field measurements of groundwater chemistry and groundwater levels are available quarterly from a high density of monitoring points (typically >30 monitoring boreholes per km^2). Occasionally there are inconsistencies in the reported data from these large regeneration sites (e.g. data columns missing) and sometimes important metadata is absent (e.g. borehole location (grid reference), depth and screened interval). Generally, however, the quality of the monitoring data from the major regeneration sites is good, and in most cases there are sufficient metadata to allow interpretation of the groundwater data. Table 1 outlines the typical types of groundwater data collated from the major regeneration sites in Glasgow, and general data quality issues.

The majority of groundwater monitoring data collated from outside the major regeneration sites are of relatively low quality and most data are ‘one-off’ measurements of groundwater levels sourced from Part 2A investigation reports from smaller regeneration and development sites (Table 1). Often, key index data are absent (e.g. borehole grid references, borehole depth, geology, datum of water-level measurement), reducing the value of the groundwater data significantly, and occasionally making it useless. The boreholes have often been destroyed after the site investigation is completed, so it is unlikely any of these monitoring boreholes are still available to be adopted into a long-term monitoring network.

Table 2 Typical types, frequency and quality of groundwater monitoring data identified from different regeneration and development sites in Glasgow. Only monitoring data designated as 'good quality' (highlighted grey) will be collated regularly from GCC in the future (Section 2)

Monitoring data source	Monitoring data	Metadata	Quality and value of monitoring data
Major regeneration and remediation sites	• Groundwater level and detailed inorganic and organic groundwater chemistry – frequency every 4 months • Groundwater levels manual measurements only • Field and laboratory groundwater chemistry data	• Borehole grid references usually known, but borehole depth unknown for ~50% of monitoring boreholes. • Casing interval rarely known	Generally good.
Small development and regeneration sites	• Monthly groundwater level data for 3 month investigation period • Manual water-level measurements only	• Borehole grid references usually known, but borehole depth generally unknown • Datum of groundwater-level measurements sometimes unknown • Casing interval rarely known	Moderate to poor – depending on level of metadata known
Part 2A investigations	• 'One-off' groundwater level data site investigation • Manual water-level measurement only	• Piezometer grid references usually known, but depth generally unknown • Datum of groundwater-level measurements sometimes unknown	Poor

Long-term data capture

As a result of the limited amount of groundwater monitoring data collated from outside the major regeneration sites, and the often poor quality of these data, it was decided that within this project, from 2010-11 ongoing monitoring data collected by consultancies will only be routinely collated from the main regeneration sites (highlighted in grey in Table 1). These sites include the vast majority of groundwater monitoring in the main Glasgow urban area.

However, these main regeneration sites are relatively small, and even within the relatively small Clyde Gateway area there are spatial gaps where no groundwater monitoring data have so far been identified. To try and fill in these gaps we will be carrying out a one-off targeted data search for all potential sources of groundwater monitoring in these areas (e.g. short-term Part 2A investigation boreholes). Any current or still existing monitoring boreholes in these gaps will be assessed for their suitability for becoming part of the pilot monitoring network (Section 5), in which case arrangements will be made for the routine collection and collation of monitoring data from these boreholes.

Long-term data capture is discussed in more detail in Section 2.

2.2 DATABASE DEVELOPMENT IN 2010-2011

2.2.1 Database construction

The database structure was designed in 2009-2010, with input from both groundwater and data management staff at BGS. The structure enables both time-series data (data collected at regular or irregular time intervals, or properly called interval data) and one-off monitoring data to be stored for each monitoring point, alongside key metadata or index information (geology and borehole construction details) (Figure 3). The database has been developed in Microsoft Access, which means data held within it can be easily spatially interrogated within GIS software, and compared or potentially merged with other BGS datasets – e.g. Wellmaster and groundwater chemistry datasets (e.g. collected during BGS's Baseline Scotland project). It was originally envisaged that the database would be primarily created in Oracle, and Microsoft Access would only be used a front end. However, due to time constraints the database is not yet linked to Oracle and groundwater data is held only within Access. Transferring the database to Oracle is a key future task.

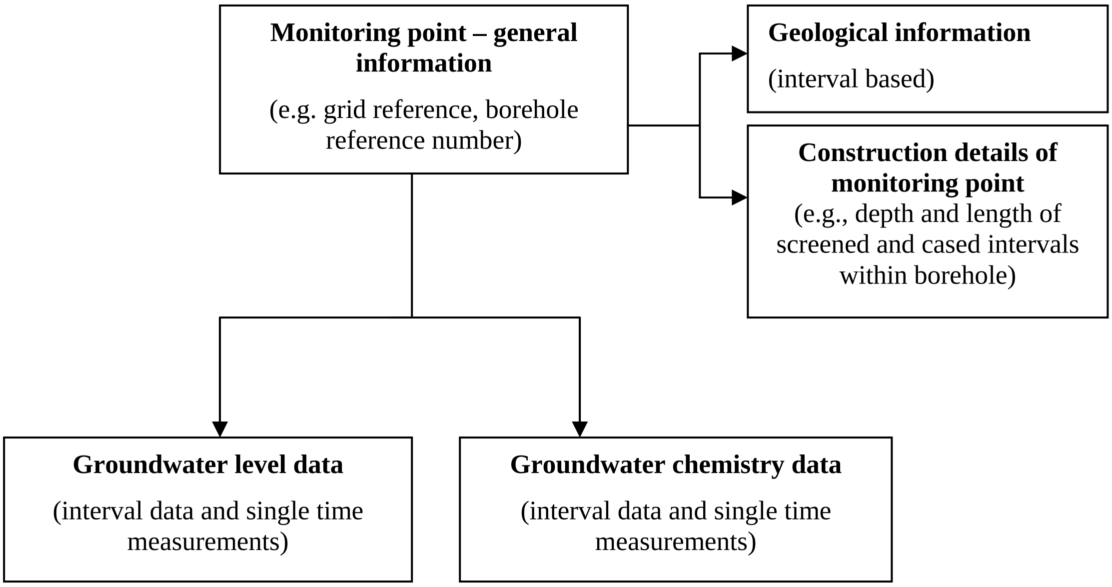

Figure 3 Logical schematic showing the main data structures (the boxes represent entities) of the Glasgow groundwater monitoring database

The database design enables cross-querying of the groundwater monitoring data, so that, for example, a search can be made of 'all boreholes over 15 metres deep, currently monitored, with time-series pH and water-level data'. The database structure was also developed to facilitate:

- Interrogation of intervals of groundwater-level through time and/or groundwater chemistry data within ArcGIS.
- Easy exportation of the location and depths of monitoring points and groundwater-level data to the existing 3D GSI3D geological model of Glasgow. Easy exportation of data into ArcGIS, where choropleth maps of groundwater-level and groundwater chemistry data can be generated for any time period, and use of data for geostatistics.

The database is designed so that it can be easily migrated to a corporate-standard BGS Oracle Schema, with the potential for integrating it with existing corporate databases, such as Wellmaster and the Single Onshore Borehole Index (SOBI).

2.2.2 Population of the database

The database has been populated with all the groundwater monitoring data for Glasgow collated in 2009-2011 (Section 2.1), all of which were measured since 2004.

A number of significant issues have arisen during the process of populating the database, which not only impact this project but have wider relevance to other data sharing projects between BGS and other organisations (e.g. Local Authorities and private consultancies). The two main issues are **a lack of systematic data formats**, and **variable data quality**, and are discussed below.

Lack of systematic data formats

Populating the database took a considerable amount of effort, due to both the variation in the types of groundwater data and, more critically, the formats they were stored in. The aim in creating the database was to be able to automate the process of data entry as far as possible, to minimise the amount of staff time and effort needed. However, almost every datasheet of groundwater monitoring data provided by consultancies to GCC, or from GCC's own collected data, had a different style and format. Many bespoke operations and queries had to be developed to extract and transfer each data array. The variability in data formats arises mainly because groundwater monitoring is the responsibility of individual consultancies and contractors, not a single organisation with consistent and systematic methods of recording and presenting data. However, even data from the same monitoring site and collected by the same organisation were often reported differently over time, as different individuals within a consultancy became responsible for the monitoring, or as different reporting formats were adopted.

Some of the main problems in processing the groundwater monitoring data received by GCC are listed below:

- monitoring data are reported as both Excel spreadsheets and Adobe pdf tables;
- there is no consistent format to any of the datasheets that hold monitoring data, either between different monitoring sites, or from individual sites;
- time series monitoring data is often reported left-to-right in data arrays, not top to bottom as is standard in database design. This means the datasheets have to be inverted before the data arrays can be read into the database.

The staff effort required to write separate queries to read so many different data formats into the database was significant. The current project had the resources to do this as part of our exploration of the issues involved in generating, storing, managing and interpreting groundwater monitoring data from disparate organisations. However, in the long-term, effectively using and managing such variable, individualised data storage formats is notfeasible for GCC, or for most organisations elsewhere in other monitoring and data collation activities. The widespread adoption of agreed, universal data output templates is needed to facilitate the automation of data capture for future database updates as new information becomes available.

Variable data quality

The quality and accuracy of groundwater monitoring data collated from the main regeneration sites in Glasgow have so far generally been good. However, the value of the data is often reduced, as key index data are missing for many of the monitoring boreholes. The most common missing index data are:

- borehole depth
- borehole grid reference (location/coordinates)
- the depth and geology of the borehole screened interval
- the measurement datum (e.g. reference datum for groundwater level measurements; reference datum for borehole depth).

The minimum level of index information required for any groundwater data to be of value is:

- a unique borehole identifier
- accurate borehole location (grid reference/coordinates)
- borehole depth
- the depth and geology of the screened interval of the borehole
- the datum or reference level of groundwater level measurements

This key index information is only rarely reported alongside ongoing groundwater monitoring data. Generally, it is reported within the text of large one-off consultancy reports, or initial drillers' logs, which are often archived early in the regeneration process, and not readily available throughout the monitoring period. **The value of groundwater monitoring data would be enhanced significantly if all key index data were reported alongside groundwater monitoring datasheets.**

Significant time (5-10 days) was spent this financial year to collate missing index data (e.g. borehole depths, casing intervals) for key boreholes identified for potential inclusion in the pilot monitoring network. Collating the missing data required BGS staff members visiting GCC to spend considerable time reading archived site reports and drillers' logs.

In addition to the poor reporting of index data, inconsistencies between reported data from individual sites also raise doubts about data accuracy, and so reduce the potential value of the monitoring data. Some common errors found in groundwater monitoring reports are:

- Different borehole depths for the same unique borehole identifier (ID) on a site reported on different datasheets/reports. This may arise from confusion between borehole depth and depth of sample measurements.
- Borehole identifiers (IDs) are often inconsistently recorded between reports. Even minor differences in these vital references raise doubts as to whether the monitoring data in successive reports relates to the same borehole or not.
- Columns of data randomly missing from datasheets for the same monitoring site in successive years. This may be most likely due to copy errors between Excel spreadsheets and the final consultancy reports.

Errors and inconsistencies such as these could be minimised if data were handled in properly constrained database tables, rather than in Excel.

2.2.3 Inclusion and confidence criteria for monitoring data in the database

Because the project has been faced with inconsistent datasets and variable data quality, explicit criteria have been developed to ensure only data for which a minimum confidence could be assigned were included in the monitoring database (Table 3).

Groundwater monitoring data were excluded if:

- the location of the borehole was unknown
- the borehole ID was non-unique within an individual regeneration site
- the measurement date of the monitored parameter was unknown

Data which were included within the database were assigned a confidence value, which gives a quick indication of both the intrinsic quality of the data, and of the level of available associated index data (e.g. screened interval of borehole). These confidence values were applied using set and explicit criteria (Table 3). Highest confidence was assigned to data where all the required index data were known (e.g. borehole location, depth, and screened interval), and there are no inconsistencies within the monitoring data reports from a site.

Table 3 Confidence criteria applied to groundwater monitoring data

Confidence	Confidence rank	Confidence criteria
High	1	• Borehole grid reference and depth known • Geology and depth of casing interval known • Ownership of monitoring borehole(s) known • No inconsistencies within original datasheets (e.g. columns of data occasionally omitted) • Units of all measurements known and are accurate. Relevant datum known (e.g. measuring reference of groundwater level). • Groundwater level data recorded by automatic diver device and periodic manual dips
High-moderate	2	• Borehole grid reference and depth known • Monitored geology unit known • Some inconsistencies within original datasheets (e.g. columns of data occasionally omitted) • Units of all measurements known and are accurate. Relevant datum known (e.g. measuring reference of groundwater level). *Plus any of the below:* • Depth of casing interval known • Ownership of monitoring borehole(s) known • Groundwater level data recorded by automatic diver device and manual dips
Moderate	3	• Borehole grid reference known, but borehole depth unknown • Some inconsistencies within original datasheets (e.g. columns of data occasionally omitted) • Units of all measurements known and are accurate. Relevant datum known (e.g. measuring reference of groundwater level). *Plus any of the below:* • Monitored geology known • Ownership of monitoring borehole(s) known • Groundwater level data recorded by manual dips only
Low	4	• Borehole grid reference known, but borehole depth unknown • Very limited monitoring data – e.g. a one-off measurement of groundwater-level. • Some units of measurements missing/inaccurate. Relevant datum unknown (e.g. measuring reference of groundwater level). *Plus any of the below:* • Monitored geology known • Ownership of monitoring borehole(s) unknown

The key assumptions made when populating the database were:

- that borehole grid references were correct
- that the borehole IDs were correct
- that any key depths recorded (e.g. depth of borehole or screened interval) were correct and measured to the same datum
- that groundwater level depths were correct and measured from a consistent datum (especially where key index data on borehole construction were missing)

2.3 FUTURE DATABASE DEVELOPMENT WORK

The main future need is to ensure the database is regularly updated so that the value of the groundwater monitoring dataset is maintained. Mechanisms for ensuring this are discussed in Section 3.

Additional data are also needed to fill in the gaps where no groundwater monitoring data have so far been identified, even in the relatively small Clyde Gateway area. To try and fill in these gaps we will be carrying out a one-off targeted data search for all potential sources of groundwater monitoring (e.g. short-term Part 2A investigation boreholes, or new regeneration sites). This will be done first for the Clyde Gateway area, and later for the whole of the Glasgow urban area. Any current or still existing monitoring boreholes in these gaps will be assessed for their suitability for providing high quality monitoring data for the database, and/or for becoming part of the pilot monitoring network (Section 6).

Work is also required to integrate the groundwater monitoring database with BGS corporate databases, such as SOBI and Wellmaster. This could increase the amount of index data held for the groundwater monitoring boreholes, and reduce duplication of data between different BGS datasets.

3 Long-term transfer of groundwater data between GCC and BGS – role of LARCI initiative

To maintain the value of groundwater monitoring database, it must be regularly updated with the latest monitoring data as received by GCC. For this to happen there must be a quick, efficient and non-time consuming mechanism for data transfer and data entry to the database. As has been discussed (Section 2), at present such a system does not exist, but is being developed through the BGS-LARCI initiative. The outcome of this initiative on groundwater monitoring data practice in Glasgow and on the current and envisaged data transfer mechanisms are described here.

3.1 LARCI INITIATIVE

The Local Authorities and Research Council Initiative (LARCI) was set up in response to the growing demand on local authorities in the UK for evidence-based policy making. The initiative is designed to help develop working partnerships between local authorities and research councils to foster better knowledge exchange, informed research and increase evidence-based policy making. More information on the LARCI initiative can be found at: http://www.rcuk.ac.uk/innovation/partnership/larci/default.htm

GCC and BGS gained funding from LARCI to support a part-time secondment of a BGS data management specialist (Ken Lawrie) for six months during 2010 to help improve the handling and storage of geological and geotechnical data within GCC. The aim is to transfer data management knowledge from BGS to GCC, and emplace more effective data management systems within the geological and geotechnical departments of GCC. In the long term it is hoped a more 'integrated Geodata system' can be extended in GCC which will lead to more effective use of the council's datasets to manage and inform regeneration and other infrastructure development activities.

Role of the LARCI initiative in the groundwater monitoring work

Management of groundwater monitoring data within GCC was used as a case study for the LARCI project, due to the large volume of the data which the GCC geotechnical department currently receives.

To enable GCC to capture, and use, borehole and groundwater data much more efficiently and effectively, GCC and BGS devised templates for recording borehole data (including groundwater monitoring data) as part of the LARCI project, which consultancies will be required to use to report data to GCC. It is envisaged that use of the templates will improve the both the quality and consistency of groundwater monitoring data from the major regeneration sites, and make data management much easier.

Two main subsets of templates have been developed under LARCI so far: one for borehole index information (borehole ID, location, depth and casing interval), and one to capture groundwater monitoring data (groundwater-level data, field chemistry data and main inorganic chemistry data). Examples of these templates are shown in Appendix 1.

Future work

In the future it is hoped there will be an extension to the LARCI work, most likely under NERC knowledge exchange funding, so that a much more complete sub-set of templates can be developed for GCC – for example engineering, geotechnical, or geophysics data templates.

3.2 CHANGING MECHANISMS FOR MONITORING DATA TRANSFER

3.2.1 Current GCC groundwater data capture

At present GCC receives groundwater monitoring data from consultancies from all regeneration, remediation and development sites in Glasgow as required under contaminated land and redevelopment legislation. Within this project, therefore, it was initially envisaged that GCC would act as the primary data holder, and that there would be a manual transfer of monitoring data between GCC and BGS each year in order to update BGS's new groundwater monitoring database. Work this year has, however, highlighted the huge amount of time and effort required to deal with the many different formats of monitoring data received by GCC from regeneration sites (Section 1). For an annual transfer of data to be feasible in the long term, monitoring data needs to be reported to GCC in a much more consistent format, so that an automated read-in of the data to the database is possible.

3.2.2 Long-term GCC groundwater data capture

GCC and BGS have devised templates for recording borehole data (including groundwater monitoring data) as part of the LARCI project (Section 3.31), which consultancies will be required to use to report data to GCC. Final drafts of the groundwater subset of these templates, as output from BGS, can be seen in Appendix 1.

The groundwater templates were presented to senior management at GCC on 28 March 2011, for formal adoption, following approval by the executive. The templates have now been passed out for comment to consultancies and contractors within the Glasgow area. It is hoped the feedback from the consultancies will help improve the design of the templates, and ensure they do not make data reporting more difficult for the consultancies and associated laboratories.

It is hoped the templates will not only systemise borehole datasets making data capture much easier, but also that they will ensure key borehole index data is reported alongside all other datasets, such as groundwater monitoring data. In this way, the value of the engineering and groundwater datasets will by hugely increased, compared to present.

3.3 INTERIM PRIORITY DATA

In 2009-2010 BGS collated all groundwater monitoring data for the central part of Glasgow which had been received by GCC from various sources since 2004.

Due to the variable quality of these initial data, and the amount of effort and time needed to input them to the database, it is not feasible for this project to continue to routinely capture all monitoring data from Glasgow. For the immediate future, therefore, ongoing monitoring data will only be routinely collated from the main regeneration sites (highlighted in grey in Table 2). These sites include the vast majority of groundwater monitoring in the main Glasgow urban area and generally provide the highest quality and quantity of groundwater monitoring so far observed within Glasgow, and they have the longest monitoring records so far identified in Glasgow.

It is envisaged that in one to two years time, the LARCI initiative (Section 3.1) will have set up a more systematic data capture and transfer protocol, so that monitoring data and associated borehole index information will be reported in consistent data arrays, which can be quickly and easily read into an Access or Oracle database. It is envisaged that then, monitoring data from a larger number of sites, and ideally all monitoring data reported to GCC, will be able to be routinely captured by the monitoring database.

4 Stakeholder collaboration

In order that the pilot groundwater monitoring network planned for Glasgow captures data which is representative of both of the groundwater system and the monitoring needs, it must take into account:

- the major drivers identified in collaboration with key stakeholders (GCC and SEPA), which are listed below; and
- the minimum density of monitoring required to sufficiently capture and characterise natural variation in the hydrogeological regime.

Work in 2009-10 highlighted the need to engage major stakeholders in Glasgow (GCC and SEPA) to identify the key monitoring data needs. A list of several drivers was identified:

- the need to better understand the hydrogeological regime in Glasgow
- the need to better understand the impacts of urban regeneration and development on the groundwater system, and in particular the impact of Sustainable Drainage schemes (SuDs)
- the need to better understand the impact of contaminated land on groundwater
- the need to understand the impact of heat engineering schemes and existing groundwater abstractions on the groundwater system
- the need to understand the role of groundwater in flooding

Further consultation with the main stakeholders – GCC and SEPA – in 1010-11 confirmed that they are very supportive of this project. SEPA are keen to become increasingly engaged with the project, both to take responsibility for long-term monitoring (both groundwater level and groundwater chemistry monitoring) within the pilot network, and to assist in the design of any future, longer-term (> 10 yrs) monitoring network across Glasgow. The single most important driver for groundwater monitoring in Glasgow highlighted by this further consultation is **the overall need to gain a better understanding of the urban groundwater resource in order to meet regulatory requirements**. The second most important driver based on the perception of the major stakeholders is **the need to understand the effects of regeneration on the groundwater system, in particular the impacts of SuDs**. More detail on stakeholder comments is in Table 4.

Table 4 Summary of the main drivers for groundwater monitoring, as reported from stakeholders

Stakeholder	**Key driver for groundwater monitoring in Glasgow**
Glasgow City Council / Development and Regeneration Services (Geotechnical)	The need to **understand hydrogeological regime**(s) in order to **fulfil statutory requirements/regulation** (e.g. European Directives); **understand infiltration to culverted watercourses and the sewer network** ("...monitoring network is a prerequisite for even attempting to fulfil statutory requirements"; "…only when a satisfactory level of hydrogeological understanding is reached can an appropriate implementation plan of measures be devised for the achievement of policy objectives")
Glasgow City Council / Development and Regeneration Services (Strategic Drainage)	The need to **understand the role of groundwater** in **flooding;** the **hydrogeological regime**; and **the effects of regeneration and development on groundwater, in particular related to SuDS.**
Scottish Environment Protection Agency / Groundwater Team	**Understanding of the factors influencing groundwater behaviour**; assist impending assessment of Groundwater Body boundaries.

5 Initial analysis of collated monitoring data

5.1 HOW THE DATA HAVE BEEN INTERROGATED

The purpose of analysing groundwater monitoring data from Glasgow has been two-fold. Firstly, it is a case study that provides an opportunity to examine whether groundwater information acquired from site investigations can be used in a meaningful way to understand the wider urban groundwater environment. Secondly, it allows specific interpretation of the hydrogeological regime in the study area of Glasgow itself – i.e., the Clyde Gateway area.

To these ends, groundwater monitoring data from all four major regeneration sites in the study area have been interpreted: the M74 motorway extension, the Commonwealth Games Village, Shawfield and the Clyde Gateway site. All of the monitoring boreholes within these sites lie close to the River Clyde and there is significant clustering (Figure 3). It can be seen from Figure 3 that characterising groundwater levels spatially over the wider Glasgow city area is significantly hampered by the clustering of the available monitoring points.

We have already discussed the issues of making use of third-party site investigation/groundwater monitoring data, and in particular the lack of borehole construction information (Section 3). More information about the collated data on groundwater level, chemistry and borehole construction for the four main sites that are available for interpretation is presented in Table 3. The amount and type of available data differs greatly between the sites, and so each site needs to be treated independently. Different analysis methods are appropriate for different sites: e.g., statistical analysis of quarterly-measured groundwater levels collected for a single year is of less value than an equivalent statistical analysis of groundwater levels measured at 15 minute intervals by an automatic borehole logger.

A major part of analysing the Glasgow groundwater monitoring data has been to use the available 3D geological model for central Glasgow to interpret the geological framework within which the groundwater system exists. The 3D geological model provides the best available indication of the horizontal and vertical variations in geology, indicating what geological units each monitoring borehole is likely to be encountering at depth and particularly in which unit(s) the borehole piezometer (screened interval) is.

Identifying which geological unit the piezometer (screened interval) is within is vital to interpreting groundwater data from a borehole. Particularly in an area of complex geology like Glasgow, where different lithologies are interbedded and change significantly both with depth and laterally, there can be a number of different effective groundwater, or aquifer, units, which can act largely independently of each other, with potentially different groundwater levels and chemistry. For example, a high permeability sand/gravel unit sandwiched between two lower permeability silt/clay units may form a distinct semi-confined aquifer unit. An unconfined sand/gravel unit overlying a silt/clay unit but with no low permeability cover may show quite different groundwater levels. Two adjacent boreholes of different depths can therefore be monitoring quite different geological units, with different groundwater level and other hydrogeological responses. Without a knowledge of which geological unit is being monitored, any interpretation of groundwater monitoring data from these boreholes will be limited, as it might not be appropriate to compare them directly. The use of the 3D model to define the monitored geological units for each borehole is described in detail in Section 5.3.

Despite the differences in data between the four regeneration sites, overall a consistent approach to interpreting the data has been followed, as follows:

- Data are validated to check they are likely to be correct (Section 5.2)

- Borehole construction information and groundwater levels are imported into the central Glasgow GSI3D geological model (Section 5.3)
- Each borehole is assigned to the geological unit which it is thought to be monitoring (i.e., where the borehole screened section, or piezometer, is), based on the 3D geological model. A geological unit is a named lithological or geological formation (type of sediment) (Section 5.3)
- Basic statistical data analysis is carried out (Section 5.4)
- The groundwater levels in boreholes monitoring each of the geological units are exported to ArcGIS, where groundwater contours are derived if sufficient good quality groundwater level data are available (Section 5.5).

Table 5 Summary attribute data for the four main regeneration sites for which groundwater monitoring data are available

	M74	**Commonwealth Games Village**	**Shawfield**	**Clyde Gateway**
Number of boreholes with groundwater level data	21	62	43	15
Monitoring frequency	Monthly	Weekly - monthly	Quarterly	15-min automatic logger data
Monitoring duration	May 2007 - Feb 2008	July 2008 - Feb 2009	Dec 2007 - Oct 2008	May 2003 - Feb 2006
Monitoring on-going	Yes, informal arrangement between client and GCC.	Yes, for a further 2 years	Yes, for a further 2-3 years	Potentially: boreholes owned by GCC
Borehole depth available	Yes	Known for 4 boreholes	Known for 33 boreholes	Yes
Piezometer (screened interval) depth available	No	No	No	Yes
Datum for measurements	Known (reported)	Derived from the Digital Terrain Map (DTM)	Derived from the Digital Terrain Map (DTM)	Known (reported)

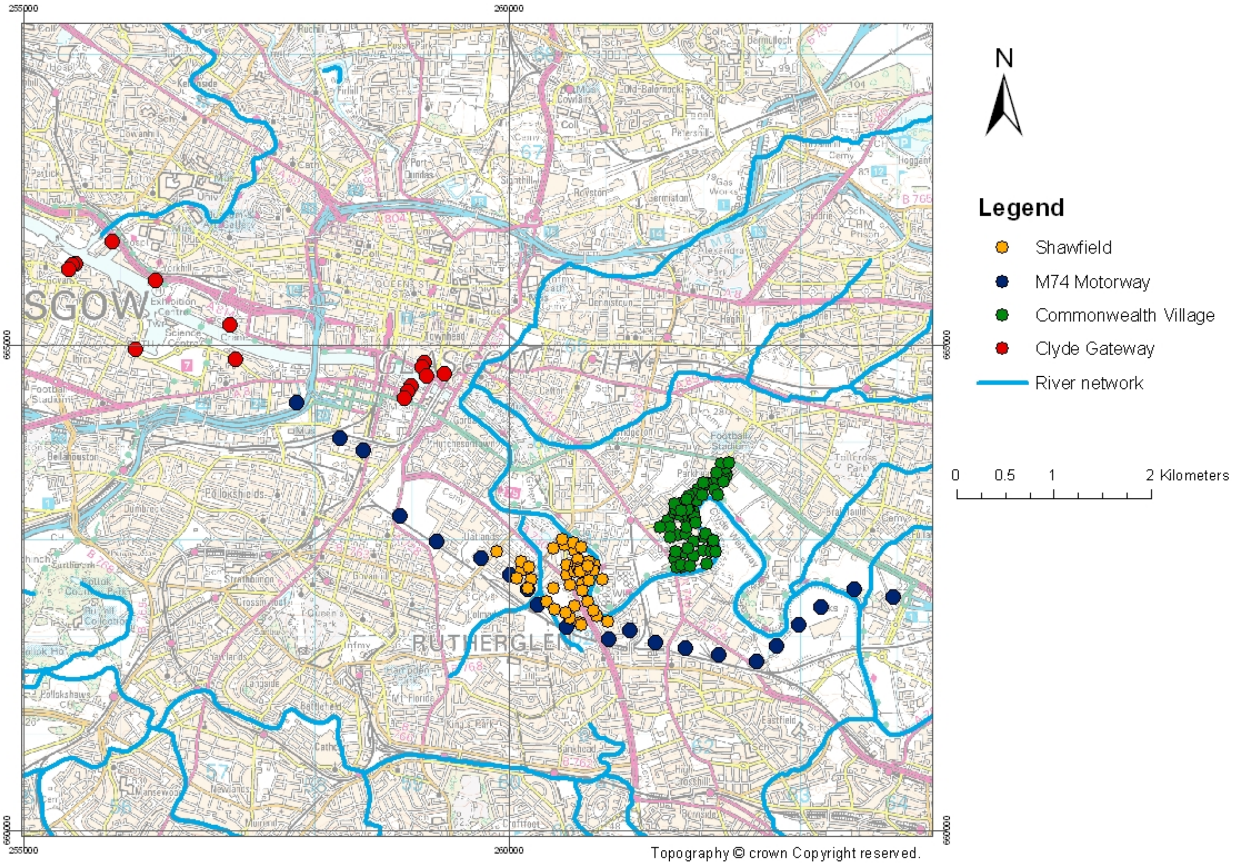

Figure 4 Location of the monitoring boreholes for the major regeneration sites

5.2 DATA VALIDATION

Groundwater monitoring data from the four main regeneration sites are all of comparatively high quality, and within the database were assigned a confidence rating of either *high-moderate* (M74, Shawfield, Clyde Gateway) or *moderate* (Commonwealth Games Village). Despite this level of confidence, a visual validation of groundwater levels from individual boreholes was also carried out before any data analysis was done. In the very few cases that there were serious doubts about the validity of individual data points and/or longer-term time series data – e.g., the recorded groundwater level lies below the recorded base of the borehole – the data were removed from the dataset. Only one borehole time series was discounted completely: Clyde Gateway borehole 236, which recorded an instantaneous increase in groundwater levels of approximately 2.5 m half way through the monitoring period – no other borehole in the area recorded a similar increase, and the feature is likely to be related to an error in data capture. As well as this case, only two individual data points from other data series were removed.

The format in which the groundwater levels were originally recorded varies: some were recorded as metres below ground level (mbgl), some as metres above Ordnance Datum (mAOD) and some provided as both. For the Commonwealth Games Village and Shawfield sites, no measurement of the datum (e.g. borehole top and/or ground elevation) was provided for any of the monitoring boreholes. Instead, a ground surface datum for each borehole was determined from the NextMap 25m Digital Terrain Model (DTM). For both the Commonwealth Games Village and Shawfield sites, the purpose of relating data from the monitoring boreholes to the Central Glasgow GSI3D geological model, the ground reference point was taken from the DTM. The ground surface value taken from a DTM for any borehole site may not be accurate for any particular borehole site, particularly in heavily urbanised areas where there is significant made and/or excavated ground, so that a potential error is introduced when using a ground surface datum from a DTM to interpret measured groundwater levels and relate these to the surrounding geology. An assessment of the potential error in the DTM has been made by comparing measured ground surface elevation data for the M74 monitoring boreholes, with values for the same points taken from the DTM. Based on 19 of the M74 boreholes, the average difference between the observed datum and the datum derived from the DTM was 1.2 m. The largest error was 4.1 m, for M74 Borehole 3.

5.3 USING THE CENTRAL GLASGOW GSI3D GEOLOGICAL MODEL

A 3D geological model, developed by the BGS using the software package GSI3D, is available for central Glasgow and covers the major urban regeneration sites for which groundwater level information is available. Because of the lack of geological logs for the monitoring boreholes the GSI3D geological model has been used as a proxy to determine which geological unit each borehole is monitoring. Seven geological units exist in the area of the monitoring boreholes: bedrock (only three boreholes penetrate bedrock); made ground; and five distinct superficial deposits (Quaternary) units (Table 4). More detail on the GSI3D model and the geological units modelled is given in Merritt et al. (2009).

For each borehole, the borehole total depth, piezometer depth (if known) (i.e., the depth and length of the screened interval in the borehole: i.e. the depth to which groundwater measurements relate) and a representative average groundwater level was imported to the model (Figure 4). For nearly all of the boreholes within the Commonwealth Games Village site the borehole depth was unknown and therefore they could not be compared to the geological model. It is therefore not currently possible to establish which geological units the boreholes at the Commonwealth Games Village site are monitoring. The borehole depth and groundwater level information were used together to define the geological unit that each borehole is most likely to be monitoring. In many instances, when boreholes intersect more than one geological unit and the borehole casing and screened interval is unknown, it is difficult to identify which geological unit is being monitored. For the boreholes at the Shawfield regeneration site a limited amount of information was provided about the lithology of the screened interval: e.g. '*sandy gravel*' or '*made ground*'. Where possible these descriptions have been used to validate the monitored geological unit that was defined using the GSI3D model.

To reflect the level of uncertainty in identifying the monitored geological unit, confidence criteria were applied to each unit defined. Low confidence was applied if the borehole intersected more than one geological unit and the unit could not be validated using any available borehole lithological descriptions, or if the lithological descriptions and the GSI3D model contradicted each other. Medium confidence was applied if there was reasonable certainty in the geological unit based on the observed groundwater levels but it could not be verified by lithological descriptions. A high level of confidence was assigned if the borehole intersected only one geological unit or if there was good agreement between the GSI3D model and the lithological descriptions. Table 4 summarises the number of boreholes identified for each of the geological units along with the level of confidence that was applied.

Using data from the M74 motorway extension boreholes, further consideration was given to the seasonal variation in groundwater levels and the effect this could have on the defined monitored geological unit. For each of the M74 boreholes the 10th and 90th percentile were added along with an upper and lower groundwater level limit (Figure 5). The upper and lower limits are a function of the seasonal maximum and minimum and the error in the observed maximum and minimum associated with a monthly sampling interval as opposed to a daily measurement (Section 5.4.1). Including representative maximum and minimum values might also help to examine whether boreholes went dry or whether overlying strata act as a potential confining layer.

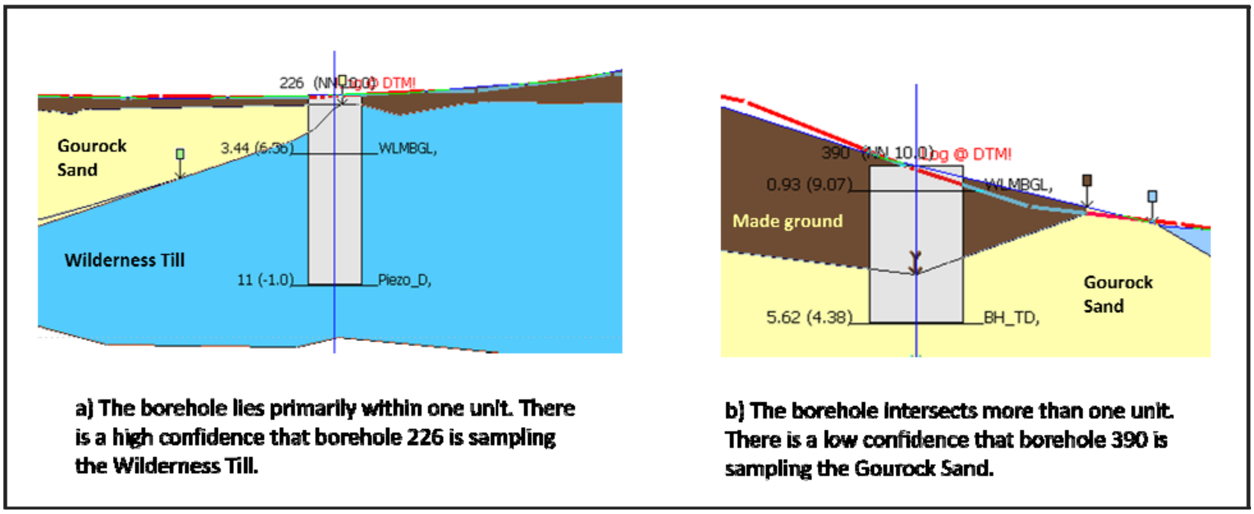

Figure 5 Incorporation of the monitoring boreholes within the GSI3D geological model to determine the monitored geological unit

Table 6 Number of boreholes identified within each geological unit and confidence levels applied

	Total number of boreholes	Number of high confidence boreholes	Number of medium confidence boreholes	No. of low confidence boreholes
Made Ground	38	19	2	17
Gourock Sand Member	20	3	6	11
Paisley Clay Member	9	6	2	1
Bridgton Sand Member	2		2	
Broomhouse Sand and Gravel	1		1	
Wilderness Till Formation	3	1	1	1
Bedrock	3		1	2
Unit not identified	65	-	-	-

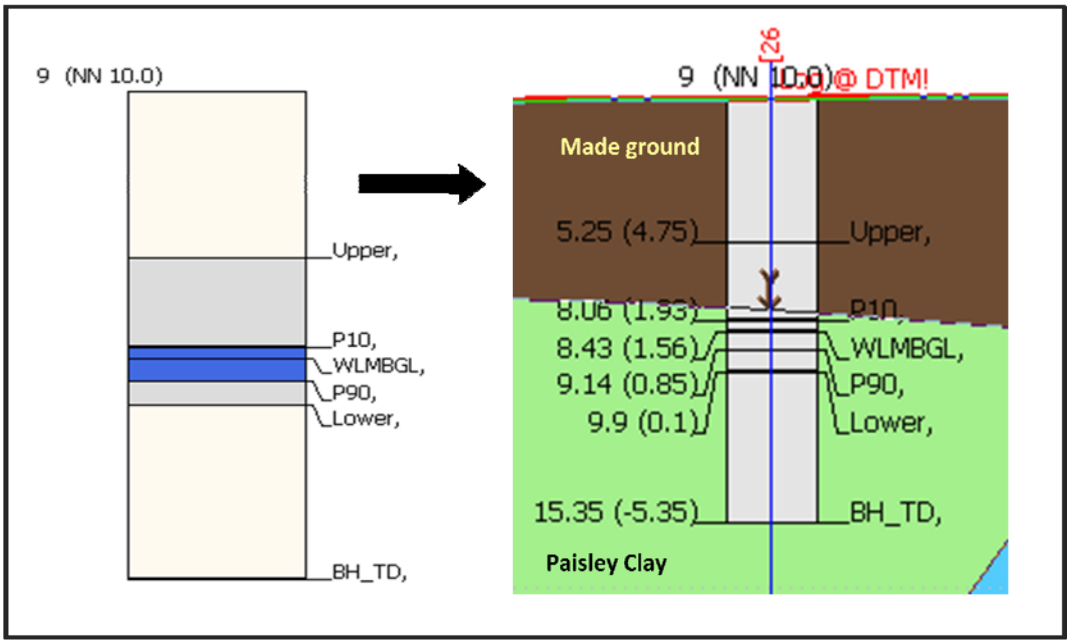

Figure 6 Incorporating seasonal fluctuations in groundwater level within the GSI3D model

5.4 PRELIMINARY ANALYSIS

The following analysis and interpretation of the groundwater level data is a starting point for further work in future years, when more data become available. In particular, detailed geostatistical analysis of the data will be done in the next financial year.

5.4.1 Clyde Gateway

High quality groundwater level data measured by automatic borehole loggers at 15 minute intervals is available for 15 boreholes from the Clyde Gateway regeneration site for a period of nearly three years, from May 2003 until February 2006 (Figure 7). Rainfall data for a nearby rain gauge (Rg661218 at NGR 247800, 664200 in Paisley, owned by Renfrew DC) are also presented with the groundwater level data. There appears to be good correlation both between groundwater levels in individual boreholes and between rainfall and groundwater level variations.

The groundwater level series were also examined in relation to the defined geological unit for each borehole (Section 5.3). All the boreholes show similar trends despite the monitored aquifer being different.

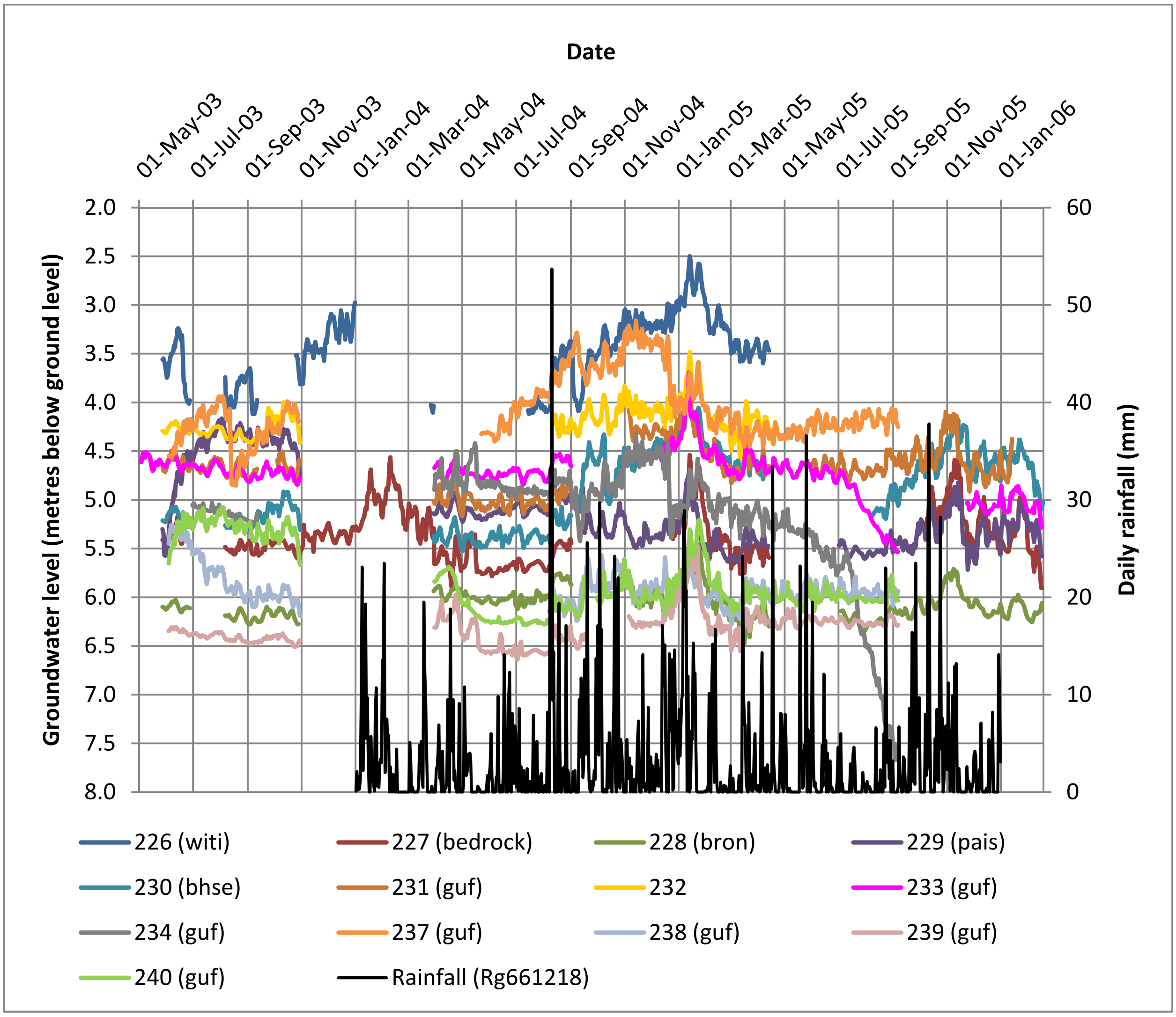

Figure 7 Groundwater levels for boreholes from the Clyde Gateway development shown along with rainfall

Because of the high monitoring frequency of groundwater level data from the Clyde Gateway site (15 minute intervals) it is possible to interrogate these data further to examine what influence the sampling frequency has on the observed groundwater levels. Summary statistics for the data from this site are in Appendix 2. For example, this lets us examine whether we would capture groundwater levels in sufficient detail if we sampled every month, or whether we should monitor more frequently. To address this, the 15-minute interval data from the Clyde Gateway boreholes were filtered to produce three new time-series datasets: a daily average; a monthly measured value taken as the value for the first day of every calendar month; and a measured value taken every 3 months (quarterly) or as near as possible. All three of these new datasets are shown for Clyde Gateway Borehole 226, monitoring the Wilderness Till Formation (Figure 8), Clyde Gateway Borehole 229, monitoring the Paisley Clay Member (Figure 9) and Clyde Gateway Borehole 237, monitoring the Gourock Sand Member (Figure 10). It can be seen from these charts that while daily data provide the most detailed representation of groundwater level variations, monthly measured values also characterise seasonal variations reasonably well. However, quarterly measurements are not sufficient to characterise the observed seasonal variations, and would lead to significant underestimation of both the maximum and minimum groundwater level.

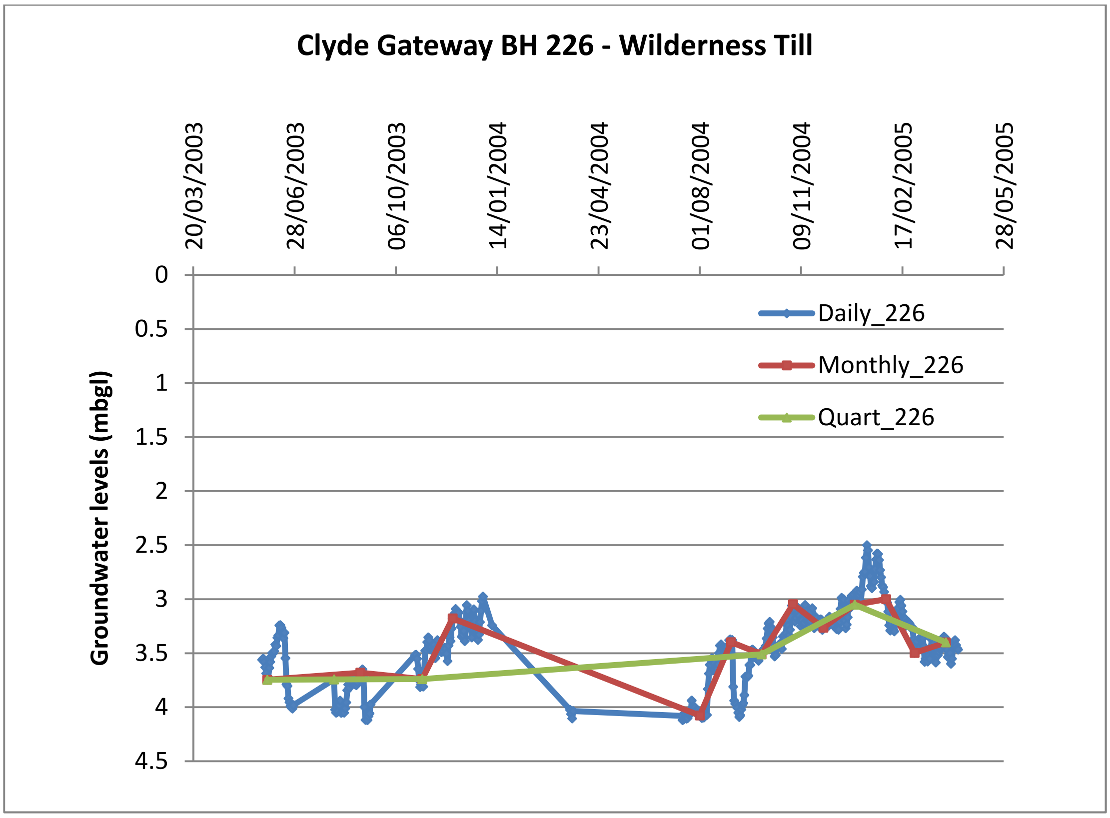

Figure 8 Daily, monthly and quarterly time-series data for Clyde Gateway Borehole 226 (Wilderness Till Formation), derived from 15 minute interval data

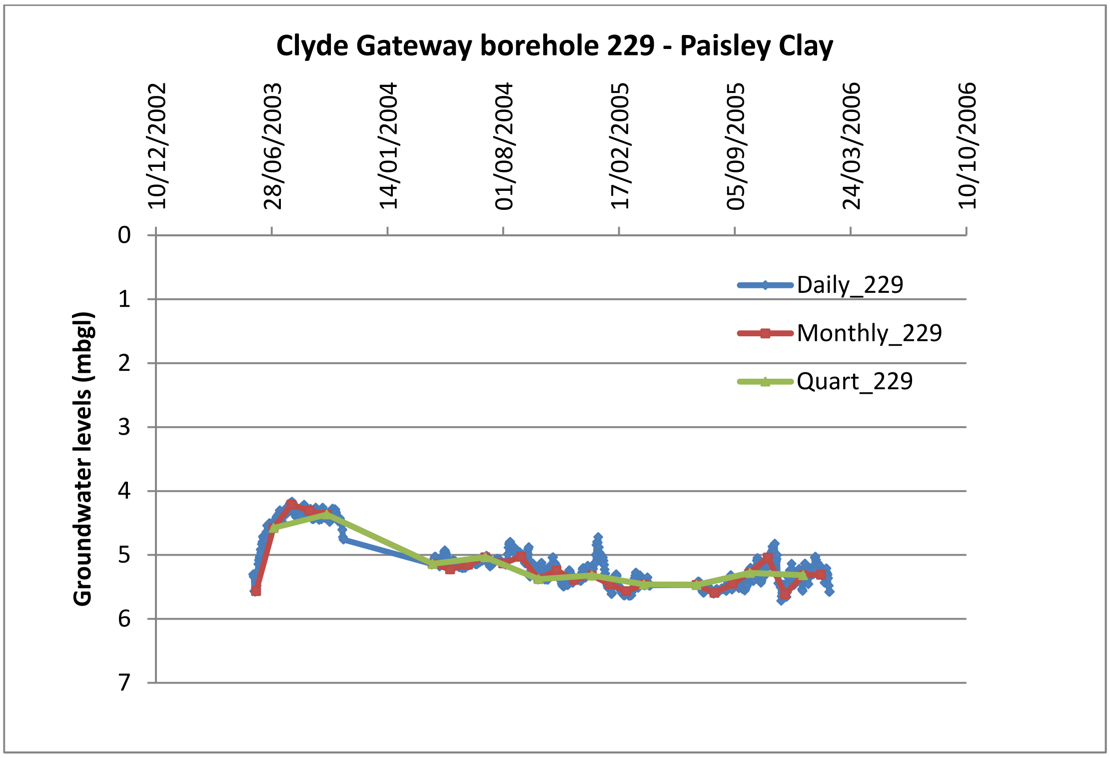

Figure 9 Daily, monthly and quarterly time series data for Clyde Gateway Borehole 229 (Paisley Clay Member), derived from 15 minute interval data

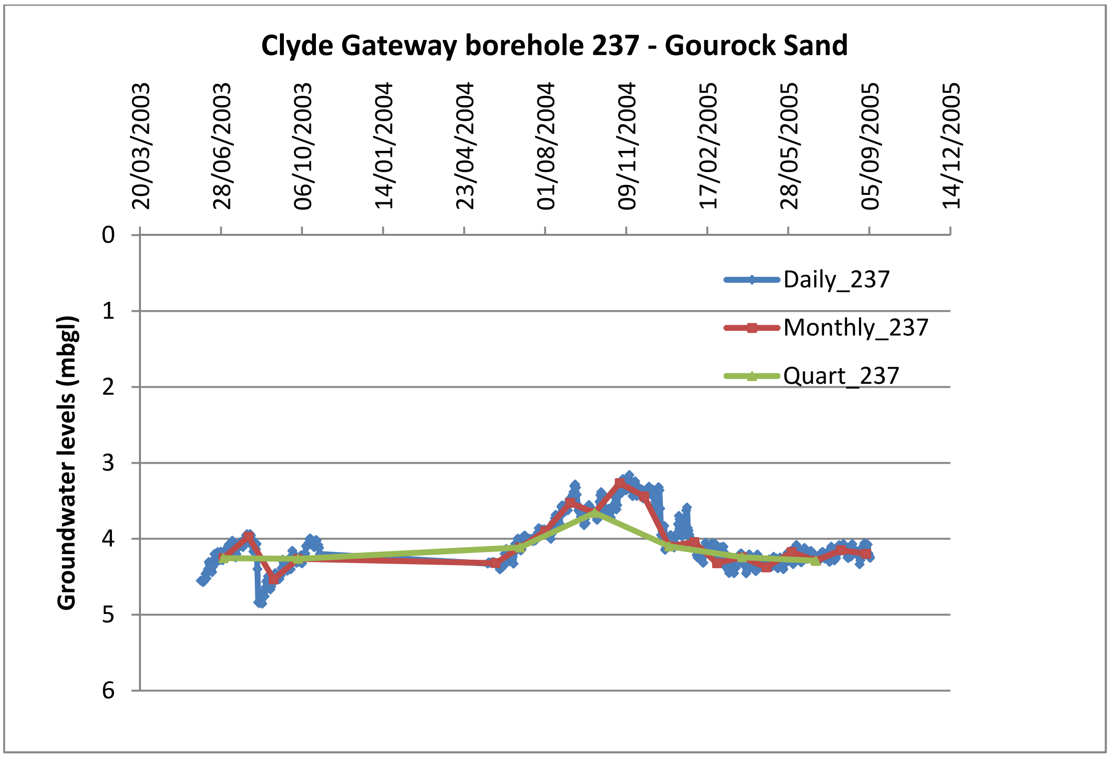

Figure 10 Daily, monthly and quarterly time series data for Clyde Gateway Borehole 237 (Gourock Sand Member), derived from 15 minute interval data

The extent to which both a monthly and quarterly sampling interval would underestimate the seasonal variation in groundwater levels is summarised in Table 5 and illustrated graphically in Figure 10. For each of the Clyde Gateway boreholes a representative average groundwater level has been derived, equal to the mean of the 10th–90th percentile range of the groundwater level dataset (thus removing the effect of any outliers). For each of the three time series (daily, monthly and quarterly) the maximum and minimum deviation from the average has been calculated (Figure 11) and the difference between the time series deviations has been derived (Table 7). Monthly measurements on average underestimate the maximum groundwater level by 0.34 m and underestimate the minimum groundwater level by 0.08 m (Table 7). Quarterly measurements on average underestimate the maximum groundwater level by 0.49 m and underestimate the minimum groundwater level by 0.38 m. While an infrequent sampling interval always introduces a small amount of error in the observed data, these calculations would suggest they would always be within 0.5 m of daily measured data.

Table 7 Summary data showing the influence of groundwater level sampling frequency on the maximum and minimum levels observed

Borehole ID	Monthly underestimation of max GW level	Monthly underestimation of min GW level	Quarterly underestimation of max GW level	Quarterly underestimation of min GW level	Monitored Unit
226	0.50	0.04	0.55	0.37	Wilderness Till
227	0.36	0.18	0.76	0.18	Bedrock
228	0.40	0.16	0.51	0.29	Bridgeton Sand
229	0.04	0.10	0.20	0.25	Paisley Clay
230	0.56	0.00	0.56	0.11	Broomhouse Sand and Gravel
231	0.51	0.02	0.52	0.15	Gourock Sand
232	0.36	0.07	0.60	0.29	
233	0.69	0.06	0.69	0.67	Gourock Sand
234	0.18	0.15	0.41	1.96	Gourock Sand
235	0.00	0.01	0.35	0.05	Gourock Sand
237	0.11	0.32	0.50	0.56	Gourock Sand
238	0.34	0.00	0.34	0.30	Gourock Sand
239	0.61	0.03	0.61	0.03	Gourock Sand
240	0.06	0.00	0.21	0.07	Gourock Sand
Average	**0.34**	**0.08**	**0.49**	**0.38**	

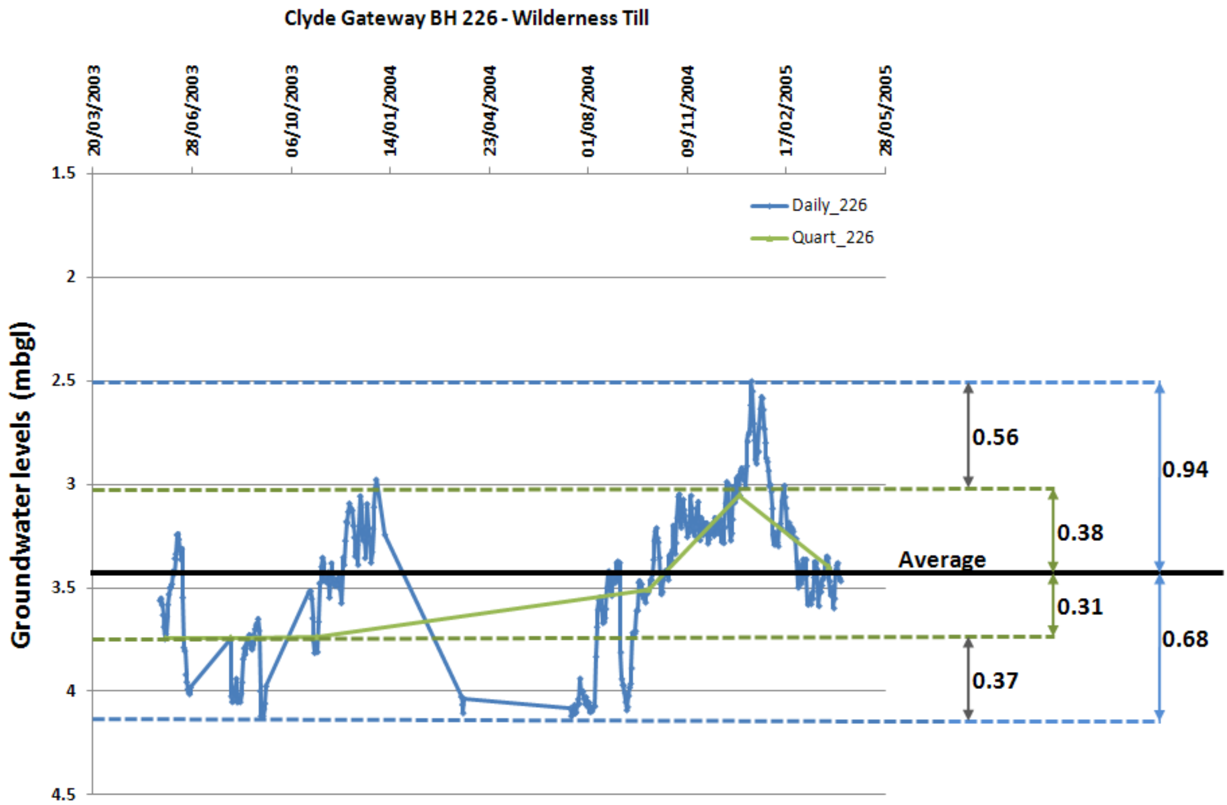

Figure 11 Estimation of the influence of sampling frequency on groundwater levels collected from Clyde Gateway boreholes

5.4.2 M74 Motorway Extension

Groundwater levels in the M74 motorway extension monitoring boreholes were measured monthly and are available for a period of 10 months from May 2007 until February 2008. The boreholes lie along a line that stretches some 7.5 km, with nearly all boreholes lying to the south of the River Clyde (Figure 3). Groundwater level data is displayed graphically in Figures 12 and 13 and summarised in Appendix 2. With a short monitoring period and monthly monitoring interval very little can be deduced about seasonal fluctuations in water levels. However, the data from individual boreholes are generally consistent and therefore seem to provide a reliable picture of groundwater levels. Over the monitoring period groundwater levels generally fluctuated by just a couple of metres. Several of the boreholes – all located close together – (Borehole IDs 14 – 20) show a steep rise in groundwater levels of 2 to 4 m between May and June 2007. As the nearest rainfall data (from raingauge Rg661218 at NGR 247800, 664200 in Paisley) for the study area is not available after 2005, it is unclear whether the rise in groundwater levels is attributable to a natural recharge event or occurred as a result of local activities e.g. as a result of nearby abstraction. The difference in trends between individual boreholes may be a function of the monitoring frequency; of the lateral distribution of the boreholes (e.g. related to distance from the River Clyde); or the different behaviour of groundwater in different geological units. More frequent and longer time series measurements are needed to start to unpick these differences.

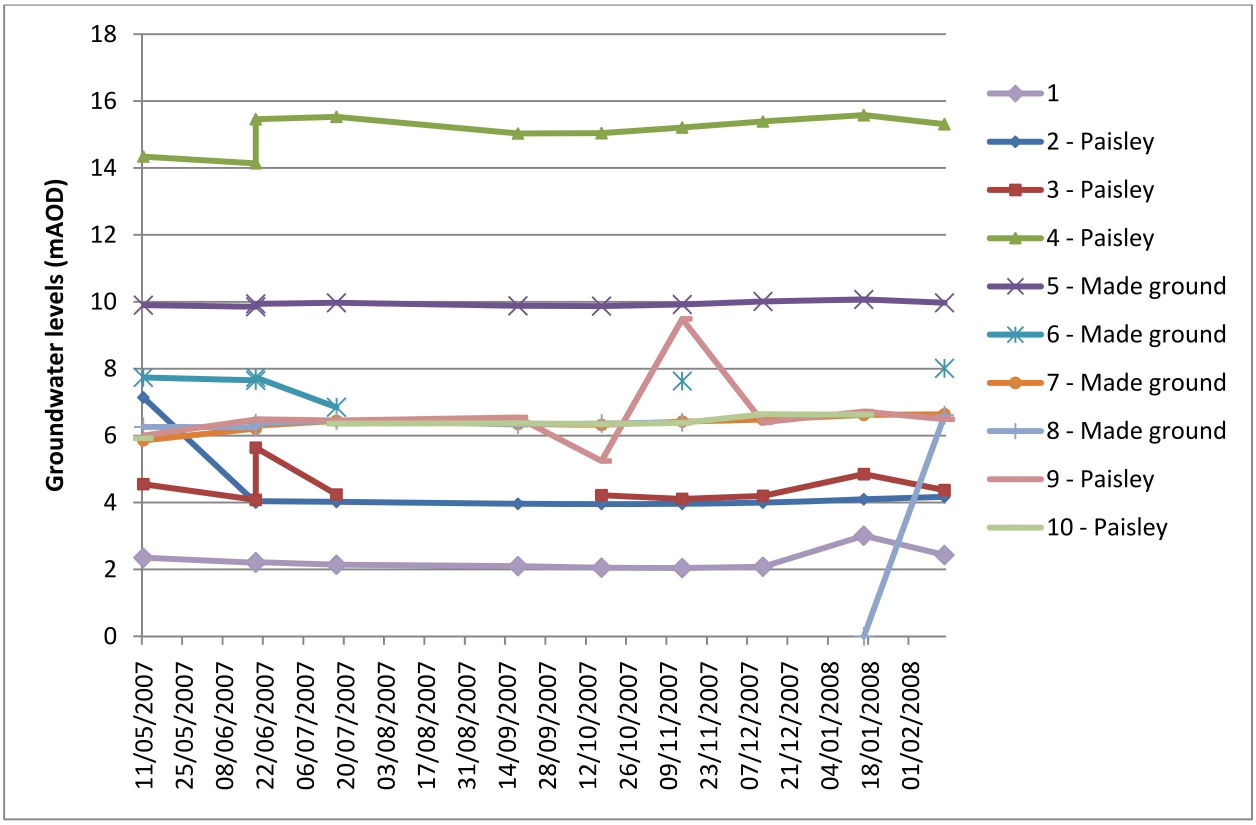

Figure 12 Groundwater level data series collected as part of the M74 extension site investigation works (M74 Boreholes 1-10)

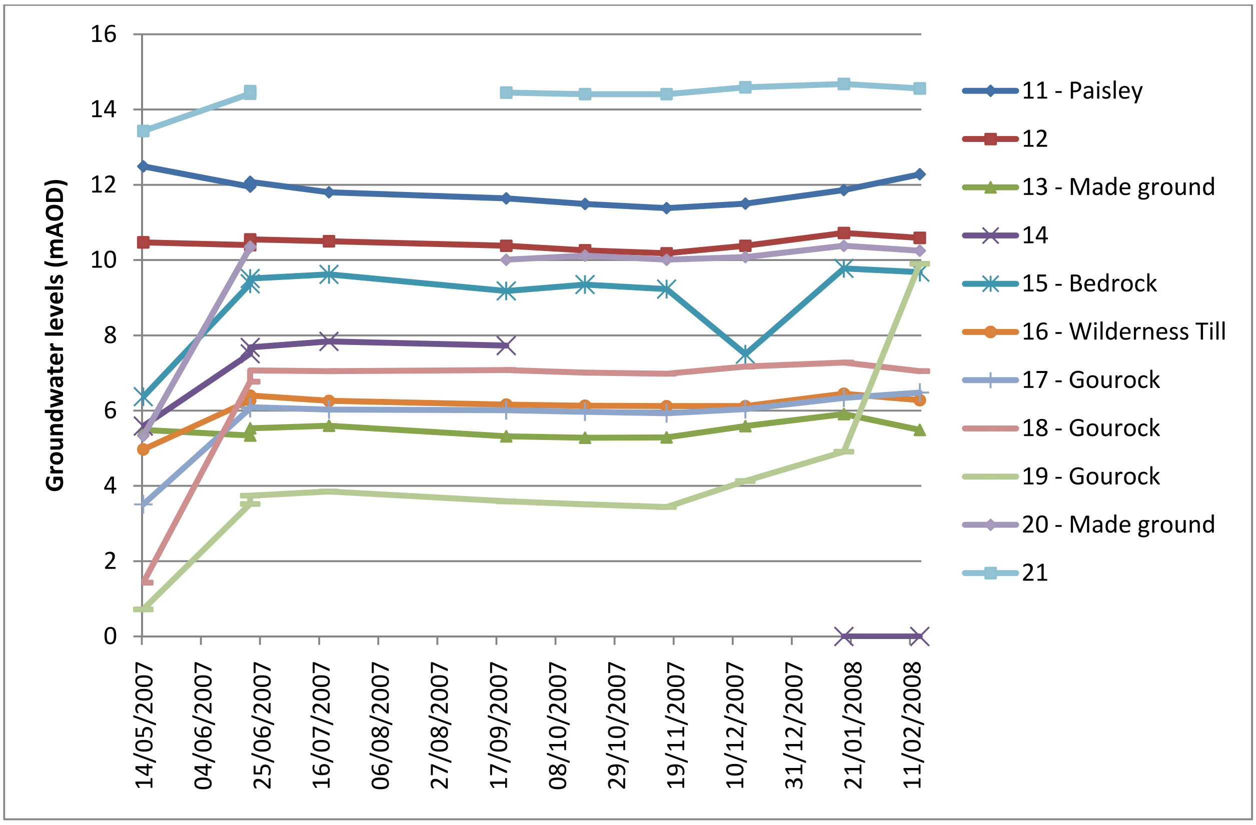

Figure 13 Groundwater level data series collected as part of the M74 extension site investigation works (M74 boreholes 11-21)

5.4.3 Commonwealth Games Village

Groundwater level data was collected from boreholes within the Commonwealth Games Village (CV) site on a weekly or monthly basis for a nine month period, from July 2008 to Feb 2009. The boreholes at the CV site are tightly clustered, with 62 boreholes within an area of 0.35 km^2. While the data can be used to improve understanding about where groundwater is and how it behaves within the CV site itself, they are of limited use in informing inform our understanding about the wider hydrogeological setting, unless they are used in combination with data from other sites. The observed fluctuation in groundwater levels over the nine month monitored period tends to be less than 1 m, and in some cases is less than 0.5 m, which is also typical of data from most other sites. However, the CV data only span a short time period, which may not be representative of the full range of recharge events. The groundwater level depth is variable across the site, ranging from less than 2 metres below ground level (mbgl) to more than 17 mbgl, which may reflect the fact that the boreholes are measuring groundwater levels in different geological units. At present borehole depth information is not available for these boreholes, so the monitored geological unit is unknown. This is key data that need to be included in the database before further data analysis.

5.4.4 Shawfield

Groundwater level data were collected quarterly from the Shawfield site for just less than one year between December 2007 and October 2008. Because only four groundwater level measurements are available for each borehole, very little can be said about seasonal trends and response to recharge. Groundwater level fluctuation over the monitored time period was typically less than 0.5 m, which is less than that observed at other sites, and is likely to be a reflection of the sampling interval (quarterly measured groundwater levels have been observed to underestimate maximum and minimum groundwater levels – Section 5.4.1). The groundwater levels provided for Shawfield were referenced to Ordnance Datum (i.e. sea level) rather than local ground level; the borehole datum is not currently available. The DTM was used to obtain a value for borehole ground surface elevation and so calculate a depth to groundwater level. This varies across the site from 0.5 to 10 mbgl, but is typically between 2 and 4 mbgl. However, these values may be affected by any inaccuracies in the DTM.

5.5 GROUNDWATER LEVELS ACROSS THE STUDY AREA

Having established, using the GSI3D geological model, the most likely geological unit of each of the monitoring boreholes in the Clyde Gateway, M74 extension and Shawfield sites, it is possible to start analysing the groundwater levels for the geological units independently, and to create groundwater level contour maps for each geological unit across the area for which data are available. In this way the different spatial and temporal trends, groundwater flow directions and the extent of hydraulic continuity between the units can be assessed. The degree of interpretation that we can do is largely dependent on the number and spatial distribution of monitoring boreholes within each geological unit. Only three geological units were considered to have sufficient data coverage to permit the construction of groundwater contour maps: Made Ground, the Gourock Sand Member and the Paisley Clay Member. Even for these units, the spatial distribution of monitoring boreholes for the Paisley Clay and the Gourock Sand members is so restricted that groundwater contours can only be drawn across part of the study area, and with reduced confidence.

Because the groundwater level data was collected from the different sites at different times, it is not possible to use groundwater levels from a single point in time for the contouring exercise. This being so, a representative average groundwater level for each of the boreholes was used to derive the contours. The minimal seasonal variation observed in the borehole records for the Clyde Gateway site – typically less than 2 m – where groundwater level data for more than two years at a 15 minute interval is available, offers some justification for this decision.

5.5.1 Made ground

There are 38 boreholes which are thought to be measuring groundwater levels within Made Ground. Most of these are located along the M74 extension and within the Shawfield regeneration site. It may be debatable whether Made Ground can be effectively treated as a distinct aquifer or groundwater unit, particularly on a regional scale, because of its typically highly heterogeneous nature, with little or no lateral or vertical continuity. However, Made Ground is a significant deposit locally in urban areas: groundwater is likely to be present within the unit as well as in natural superficial deposits, and the effects of groundwater in Made Ground are likely to be similar to those seen in natural deposits in terms of issues like drainage, structural foundations, and contaminated land. For these reasons, and because so many of the monitoring boreholes for which data are available appear to be monitoring the Made Ground, it has been treated here as a distinct geological unit. However, the characteristics of Made Ground, in particular its heterogeneity, must be borne in mind when interpreting groundwater level data for this unit.

Contours of groundwater levels (in metres above Ordnance Datum – mAOD) were drawn initially by hand and subsequently produced automatically using the ArcGIS interpolation Inverse Distance Weighting (IDW) package. In general there is fairly good agreement between the hand drawn and ArcGIS derived contours. However, because the IDW interpolation treats all data points indiscriminately, the contours include bull-eyes that a hydrogeologist using expert judgement might disregard as hydrogeologically unrealistic.

Because there was overall good agreement between the hand-drawn contours and the ArcGIS derived contours, the IDW interpolated groundwater level contours (in the form of a raster file) were imported into the GSI3D model. The imported groundwater level surface appears as a line within the geological sections and is expressed in metres above Ordnance Datum.

Since the groundwater level contours are a 2D raster surface, and are not confined to the modelled extent of the Made Ground in the 3D model, there are areas within the geological sections where the groundwater level surface lies below the base of the Made Ground unit, or extends through two or more sections of Made Ground that appear from the 3D model to be hydraulically isolated. In such instances, expert judgement must be applied: e.g., if the groundwater level lies below the base of the Made Ground then it is likely that the unit is dry at that point. To overcome this issue, the raster groundwater level contour surface has been clipped to the 3D envelope of the geological unit using GOCAD. Figure 12 shows a cross-section from the GSI3D model with the contoured groundwater level surface for Made Ground, and illustrates some of the issues mentioned here. Note that even where the Made Ground has a continuous lateral extent, where it has an undulating base some sections may be hydraulic isolated from others.

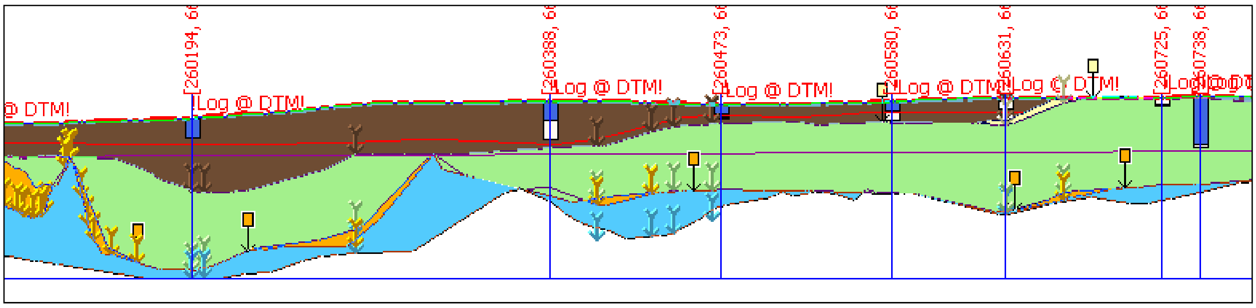

Figure 14 Geological cross-section from the central Glasgow GSI3D model with groundwater levels for the Made Ground shown as a red line.

5.5.2 Gourock Sand Member

Twenty boreholes are thought to be monitoring groundwater levels within the Gourock Sand Member. These boreholes are fairly well distributed along the valley of the River Clyde, but all lie in close proximity to the river itself. While there was insufficient data to draw detailed groundwater contours, it was possible to hand draw simple groundwater level contours that delineate approximately the groundwater head gradient through the Clyde valley. Groundwater levels appear to fall from 6 mAOD in the southeast of the study area (the Eastfield area) to -1 mAOD near the city centre (Figure 15). These simple groundwater level contours were interpolated in ArcGIS in the same way as those for the Made Ground (Section 5.5.1) to form a raster surface, which was clipped to the 3D volume of the Gourock Sand Member and imported to the GSI3D model (Figure 14). These contours can now be viewed within the geological cross-sections in the GSI3D model (Figure 14). In general there is good agreement between the groundwater level contours and the level of the River Clyde, suggesting that groundwater in the Gourock Sand Member is in hydraulic continuity with the river. The geometry and thickness of the Gourock Sand Member is such that there is likely to be a fairly continuous thickness along much of its length, permitting groundwater flow down through the Clyde valley. However, in the Carmyle area of Glasgow the Gourock Sand Member thins to a metre or less wide, and in this area it is not clear how the flow of groundwater through the unit from further up the valley will behave.

Clipping the derived groundwater levels to the 3D volume of the Gourock Sand Member offers the opportunity to view its likely saturated extent. In the Carlton and Bridgeton areas the unit is likely to be unsaturated, based on the groundwater level contours and the unit geometry (Figure 15). Even if the derived groundwater levels are wrong by 1 to 2 m, the predicted saturated extent of the Gourock Sand Member shown in Figure 15 is unlikely to be significantly changed.

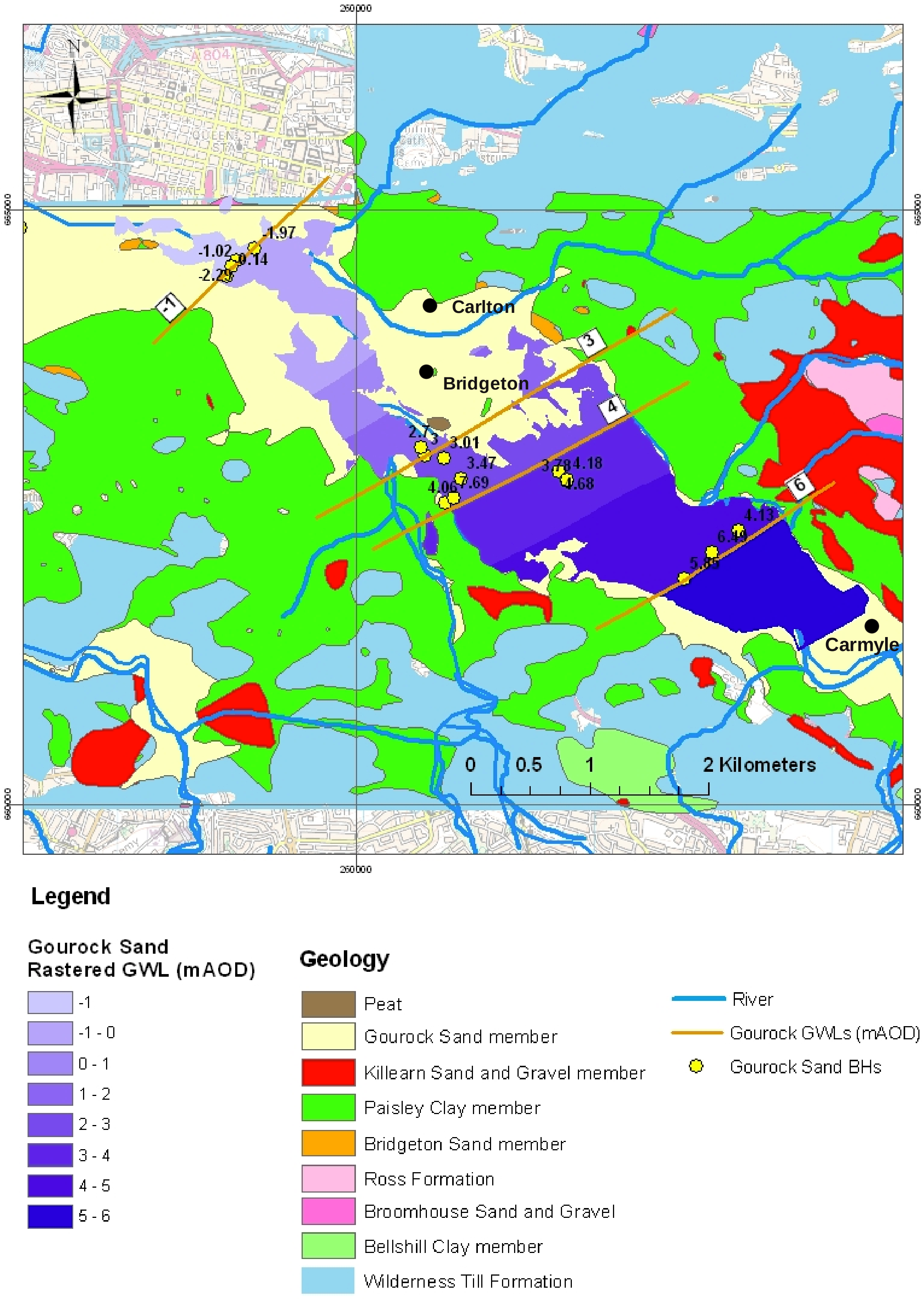

Figure 15 Groundwater level contours (as an interpolated raster surface and as contour lines) for the Gourock Sand Member, clipped to the 3D volume of the unit.

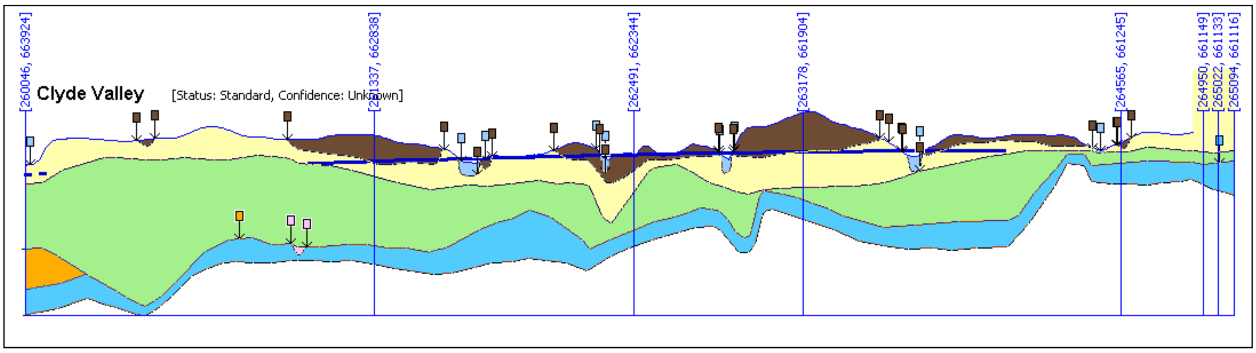

Figure 16 - GSI3D cross-section along the valley of the River Clyde. The contoured water level for the Gourock Sand Member is shown in Blue. Thinning of the sand unit at the eastern end of the Clyde valley can also be seen.

5.6 VALIDATION OF THE DEFINED MONITORED GEOLOGICAL UNITS

One of the largest uncertainties related to the interpretation of the groundwater level data is which geological unit the data relate to. The data that have been supplied by consultants for the regeneration sites was often collected as part of contaminated land site investigation, where the main priority was bulk groundwater chemistry assessment rather than detailed analysis of groundwater behaviour within different units. As has been discussed above, key borehole attribute data, including information on borehole construction, depth and screened interval, are not readily available. Collection of future groundwater data in accordance with the newly developed protocol and templates developed through the LARCI initiative (Section 3) should resolve this problem. Without this information, the monitored geological unit was determined primarily using borehole depth information in combination with the GSI3D model for central Glasgow (Section 5.3).

The problem with this approach is that the borehole screened interval is not known and that the GSI3D model may be inaccurate in places. To try and improve data interpretation this year, before the LARCI protocol is in place, further efforts were made to obtain attribute borehole information for key boreholes from GCC. For a small sample of boreholes (15) the original borehole logs were checked against information within the database and against the monitored geological unit determined from the GSI3D model. For eight of these boreholes there was a match between the true monitored geological unit and that derived from the GSI3D model. In four cases the geological sequence within the GSI3D model does not match that from the borehole lithological description. For half of the sites there were discrepancies over the borehole depth, which is likely to contribute to the observed mismatch.

As part of a separate review of the central Glasgow GSI3D model, improvements have been made to the delineation of the geological boundaries, which has increased the accuracy of the model but is likely to affect the original delineation of geological units for the groundwater monitoring boreholes. The newly calculated GSI3D model in combination with the original borehole logs should be used to reassign the monitored geological unit for each boreholes, with an improved level of certainty. This would also improve the level of confidence in the derived groundwater level contours and help assist in the selection of boreholes for the pilot network.

5.7 PERMEABILITY OF SUPERFICIAL DEPOSITS IN THE CLYDE VALLEY

A limited amount of permeability data is available for the superficial deposits present in the Clyde valley. The data was derived primarily from falling head tests, packer tests and constant head tests done as part of site investigations (Table 8, Figure 17).

The available data indicate that the Gourock Sand Member is the most permeable geological unit overall, with an average permeability (geometric mean) of 0.75 m/d, although the variability in permeability in the unit is very large, ranging across five orders of magnitude (Table 8).

Permeability values for the Bridgeton Sand Member are comparable to those for the Gourock Sand Member, though fewer high permeability results are seen. The average permeability of the Paisley Clay Member is lower than the overlying Gourock Sand Member (geometric mean of 0.11 m/d), but there appear to be more permeable horizons (with permeability values more than 50 m/d) recorded within the Paisley Clay Member. Permeability values for the Wilderness Till Formation are consistently lower than 0.2 m/d (Table 8).

Table 8 Summary permeability values (all in m/d) for superficial deposits in Glasgow

	Count	One-off value	Mean	Geometric Mean	Median	Q25	Q75	Max	Min
Made Ground	1	0.330							
Gourock Sand Member	14		12.28	0.75	0.840	0.090	8.23	112.32	0.0044
Paisley Clay Member	17		16.34	0.11	0.068	0.013	0.259	164.16	1E-05
Bridgeton Sand Member	6		2.05	0.20	0.124	0.030	2.55	8.69	0.0094
Broomhouse Sand and Gravel Member	1	0.168							
Wilderness Till Formation	5		0.074	0.054	0.082	0.045	0.103	0.131	0.009

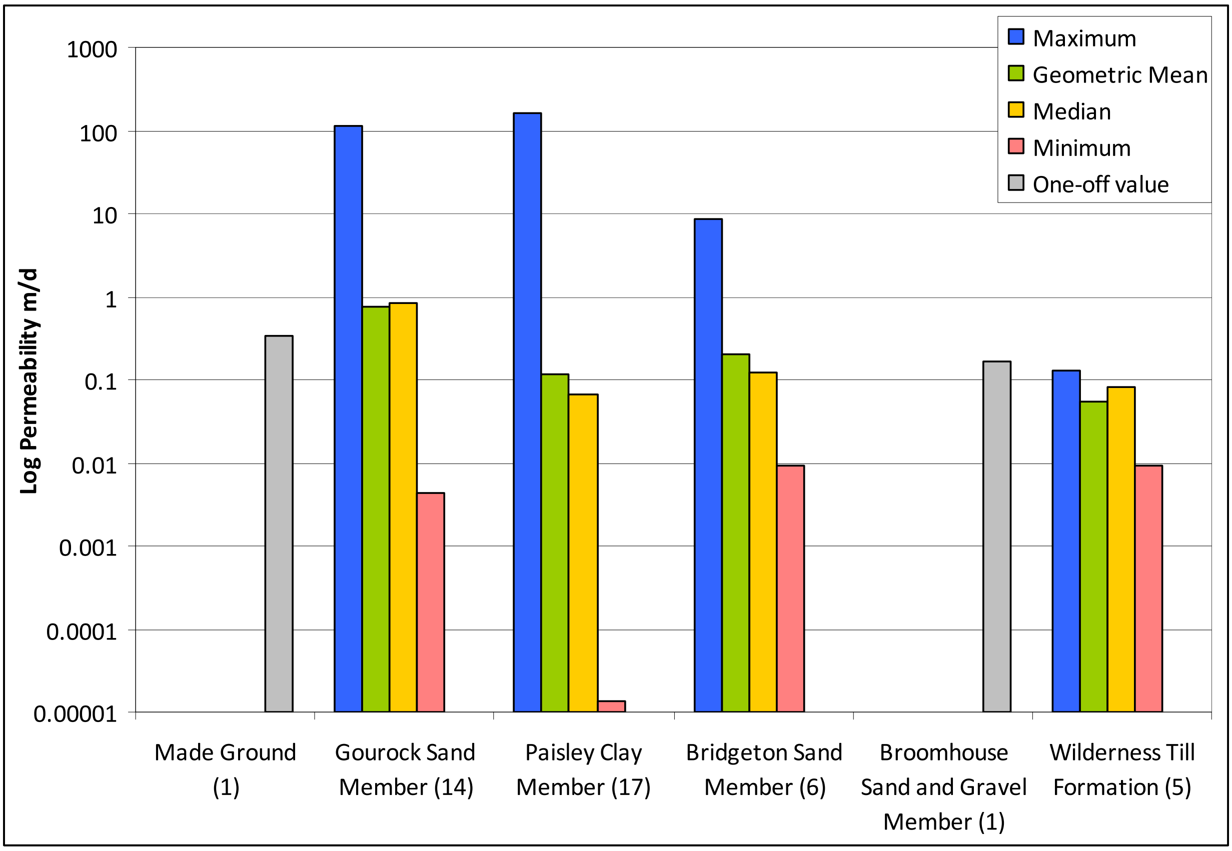

Figure 17 Graphical summary of permeability data (log m/d) for superficial deposits in Glasgow. The number of samples for each geological unit is given in brackets.

6 Designing a pilot monitoring network

6.1 DEFINING OBJECTIVES

With continued urban population growth and regeneration, and increased climatic variability, there is a growing need to develop a permanent urban groundwater monitoring network in Glasgow to meet future information and policy needs. This needs to be done in conjunction with major groundwater stakeholders within Glasgow, including the Scottish Environment Protection Agency (SEPA), GCC and other relevant Local Authorities, Scottish Water, and organisations such as the Clyde Gateway Partnership. In the long term, it may be most suitable that SEPA takes over the operational responsibility for any groundwater monitoring network, as part of their responsibility for monitoring and managing groundwater resources under the Water Framework Directive. The work done to date by this project indicates there is good potential for developing a permanent, representative groundwater monitoring network in Glasgow using existing monitoring boreholes. The Glasgow groundwater monitoring database developed this year (Section 2) and the preliminary analysis of the initial data already collated (Section 5) have been been instrumental in steering the development of a permanent monitoring network in the future, and in ensuring the network is representative of the urban hydrogeology, and that it meets stakeholder needs. The principle drivers for a groundwater monitoring network which were identified through engagement with key stakeholders (Section 4) are:

- the need to better understand the hydrogeological regime to meet regulatory requirements; and
- the need to understand the effects of regeneration on the groundwater system, in particular the impacts of SuDs

Work in this project to date has brought up a number of issues that will impact on the effective operation and usefulness of a groundwater monitoring network in Glasgow, including the availability and distribution of existing or possible new monitoring boreholes, the quality of existing monitoring data, the efficiency of data collection, transfer and entry to a monitoring database, the use to which the monitoring data could and will be put, and the probable complexity of Glasgow's hydrogeological regime. Because of the potential problems inherent in setting up and operating a new monitoring network, the plan within this project has always been to design, set up and trial the operation of a pilot network in one part of Glasgow, before moving to the stage of designing and setting up a whole-city network. The most appropriate area for this pilot network is the overall Clyde Gateway regeneration area.

Based on the defined principle drivers and this staged approach, the objective of this pilot network is therefore both to produce data to allow the development of a good, representative understanding of the whole urban hydrogeological regime related to regulatory requirements (i.e., groundwater quantity, flow and quality; and particularly related to sustainable drainage (SuDS) and flooding) **and** to act as a trial for a potential larger, whole-city network in the future.

Implicit in the objective to develop a better understanding of the hydrogeological regime is the need to focus attention on more permeable geological (aquifer) units, and to focus on the shallowest hydrogeological zone: i.e., the superficial deposits, in which most existing monitoring boreholes are completed.

Because of the much greater costs of collecting and analysing groundwater chemistry data compared to groundwater level data, the primary objective of the pilot network will be to monitor groundwater levels, although it will be possible to collect groundwater chemistry samples from the boreholes in the network.

6.2 TARGETED DESIGN

The design of the pilot network is a compromise between the availability of suitable existing boreholes, the current monitoring schedule of the consultancies which currently operates the boreholes, and the available funds at BGS for installing dedicated automatic groundwater level loggers in selected boreholes. The network must include sufficient boreholes with a suitable spatial and depth distribution to allow for the development of a representative understanding of the groundwater system.

It is envisaged that the core of the pilot network will consist of up to 12 boreholes, each installed with a dedicated automatic groundwater level and temperature logger as part of this project (and at least two will be capable of measuring groundwater conductivity). Each logger will be capable of measuring and recording data at frequent intervals (e.g. every 15 minutes) for many months before the data must be downloaded. The full index data (e.g. on borehole geology and construction) for each of these boreholes must be known.

The high frequency data from these 12 boreholes will be be supplemented by additional data collated from selected existing monitoring boreholes from the four main regeneration sites (including some of those for which initial data have already been collated and analysed in this report) and, where relevant, other sites not yet identified. Monitoring data from these boreholes is being collected at different frequencies depending on the demands of the regeneration sites, and in most cases will not be available at the same frequency as for the 12 dedicated network boreholes. However, combining the collection of detailed data from a small subset of dedicated loggers with the collation of existing data (at various levels of detail) from a wider set of boreholes will provide the best compromise, given limited resources, in terms of generating high quality, representative, useful groundwater monitoring data.

The within the pilot network, both the 12 core boreholes and the additional supporting boreholes, will be selected to provide a representative distribution both across different geological units (spatially and with depth), and across the study area. The spatial distribution and depth of the existing monitoring boreholes for which preliminary analysis has been done (Section 4) have provided the basis for designing the network and selecting boreholes to be installed with data loggers. The analysis has also highlighted gaps in key hydrogeological areas (i.e. areas where the highest permeability geological units are found) where there is currently no available groundwater monitoring information. More work is planned to try and identify potential monitoring boreholes in these areas.

The following criteria were defined to select potential boreholes for adoption onto the pilot network:

- The borehole construction details must be known, including borehole depth, ground surface and measurement datum, and accurate grid reference.
- There must be a high level of confidence in the monitored geological unit (i.e. the screened interval and seal details must be known).
- Long-term (at least 2 years) access to the borehole must be agreed.
- The borehole should be more than 3 m deep and there should be no evidence in the monitoring record that the borehole goes dry for extended periods of time.
- Boreholes that show very variable groundwater level fluctuations over time should not be selected.
- The geology around the borehole should be reviewed to ensure that the borehole is representative of the surrounding geological unit.

A review of the existing boreholes and the interpreted hydrogeology of the study area, and an initial selection of boreholes for the pilot network has been done. Based on this, it is likely that a major focus of the network will be the Gourock Sand Member. This is a comparatively thick and extensive shallow geological unit within the Quaternary (superficial deposits) sequence that is present along the length of the Clyde valley through Glasgow, which appears to have relatively high storage and transmissivity and therefore form a significant aquifer unit; it is also likely to be in continuity with the River Clyde. A secondary focus is likely to be the Paisley Clay Member, which underlies the Gourock Sand Member over much of the study area. Despite its name, this unit appears to consist of similar sands as the Gourock Sand Member, with similar permeability, and the available data indicate that groundwater levels in the Paisley Clay Member show similar seasonal fluctuations to those in the Gourock Sand Member. A third Quaternary geological unit, the Bridgeton Sand Member, may also be significant in groundwater terms: this underlies the Paisley Clay Member across much of the study area, and appears to be in direct connection with the Gourock Sand Member where the Paisley Clay is absent. There may also be merit in monitoring groundwater levels within Made Ground to assess the degree of hydraulic continuity between Made Ground and underlying natural geological units. This would be of particular interest to the implementation of SuDs and in the migration of contaminants associated with near surface activities.

6.3 SELECTING BOREHOLES FOR THE PILOT NETWORK

An initial shortlist of 15 existing monitoring boreholes currently maintained by consultancies on the major regeneration sites has been identified for potential adoption onto the pilot network.

However, since the initial interpretation of groundwater monitoring data and review of boreholes for the pilot network, two new or improved information sources have meant that this initial shortlist will need significant revising.

Firstly, additional borehole geological logs were obtained from GCC for many of the monitoring boreholes for which they had previously been missing. These showed that many of the previously recorded borehole depths, as reported by consultancies with the monitoring data, were incorrect. The database therefore has to be checked and updated with the correct depths, and these used, along with the borehole lithological descriptions and construction details to revise the defined monitored geological units.

Secondly, the central Glasgow GSI3D geological model has recently been refined and updated, with significant changes to the modelled geological sequence, and in particular to the thickness of many of the modelled units. Because the GSI3D model was the main source used to define the monitored geological units for the monitoring boreholes (because of the lack of geological log data for most of the boreholes), the defined geological units now appear wrong in many cases.

A further iteration of data updates, validation and interpretation and then pilot network design is therefore needed before a final shortlist of boreholes can be drawn up. Once this is done, the shortlist will be discussed with GCC and, through them, with the relevant consultancies, to ensure that the selected boreholes are logistically suitable and acceptable for adoption onto the pilot network: e.g., related to site security and access. Already, as a result of consultation between consultancies and GCC this year, groundwater monitoring at the Commonwealth Games Village site has been extended for a further two years, so that the monitoring is now scheduled to finish in early 2013.

Once a final set of boreholes is selected, they will be installed with automatic data loggers to monitor groundwater level and temperature at regular, frequent (e.g. 15 minute) intervals. These loggers have been purchased with funds from an associated BGS project.

7 Future work

7.1 DATA CAPTURE, TRANSFER AND ENTRY TO THE DATABASE

The data capture templates developed through this project and the associated LARCI initiative are currently being considered for adoption by GCC senior management, and have been circulated to all major groundwater investigation/regeneration consultancies in Glasgow for comment. Preliminary responses have been positive. If the templates are approved by GCC management, feedback from GCC and consultancies will be used to update them if necessary, before they are finalised. It is envisaged they will quickly be adopted as the primary means of reporting groundwater monitoring data by consultancies.

Once the new template-based protocol is in place, the first reporting of data from consultancies in the new format will be used as a trial to test the entry of reported data to the groundwater monitoring database. Any required changes identified as necessary will then be made to either the templates, the data transfer procedure, and/or the database.

Once this new protocol is fully working, it is envisaged that very little staff effort will be needed by either GCC or BGS to ensure that the groundwater monitoring database is regularly updated with new monitoring data, so that its value is maintained.

In the future it is hoped there will be an extension to the LARCI work, most likely under NERC knowledge exchange funding, so that a much more complete sub-set of templates can be developed for GCC – for example engineering, geotechnical, or geophysics data templates.

Work is also required to integrate the groundwater monitoring database with BGS corporate databases, such as SOBI and Wellmaster. This could increase the amount of index data held for the groundwater monitoring boreholes, and reduce duplication of data between different BGS datasets.

Additional monitoring data are also needed to fill in the gaps where no groundwater monitoring data have so far been identified, even in the relatively small Clyde Gateway area. To try and fill in these gaps we will be carrying out a one-off targeted data search for all potential sources of groundwater monitoring (e.g. short-term Part 2A investigation boreholes, or new regeneration sites). This will be done first for the Clyde Gateway area, and later for the whole of the Glasgow urban area. Any current or still existing monitoring boreholes in these gaps will be assessed for their suitability for providing high quality monitoring data for the database, and/or for becoming part of the pilot monitoring network. Particular effort will be put into locating the original borehole construction details and geological logs for any monitoring boreholes identified.

7.2 DATA INTERPRETATION

A further iteration of data interpretation is needed now that additional borehole index and geological log data are available, and the GSI3D model has been revised. This will be done using the same general methodology as described in Section 5 of this report.

Detailed geostatistical analysis will be carried out to assess the spatial distribution of the monitoring boreholes and the distribution of monitored geological units, in order to increase confidence in identifying a representative selection of monitoring boreholes for the pilot network.

Up to date rainfall data for the study area will be obtained, so that the relationship between ongoing groundwater level fluctuations and rainfall can be examined.

Once suitable time-series datasets (at least 2 years of data) are available in the database, e.g. from the pilot network, it is envisaged that these could be exported as whole datasets into the GSI3D model to allow four dimensional (3D plus time) analysis of groundwater level variations within the pilot network area.

7.3 DESIGN AND IMPLEMENTATION OF PILOT MONITORING NETWORK

A further iteration of pilot network design will be done following the revised data interpretation and re-definition of monitored geological unit, following which a final shortlist of boreholes will be drawn up.

The shortlist will be discussed with GCC and, through them, with the relevant consultancies, to ensure that the selected boreholes are logistically suitable and acceptable for adoption onto the pilot network: e.g., related to site security and access.

Once a final set of boreholes is selected, they will be installed with automatic data loggers to monitor groundwater level and temperature at regular, frequent (e.g. 15 minute) intervals. These loggers have been purchased with funds from an associated BGS project.

7.4 TOWARDS A CITY-WIDE, LONG-TERM MONITORING NETWORK

Once the pilot network is up and running and analysis of data from the network has started, work will begin on investigating the feasibility of developing a larger, long-term monitoring network across the Glasgow urban area.

Project Bibliograpy and References

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

BALL D F. 1999. An overview of groundwater in Scotland. *British Geological Survey Technical Report* WD/99/44.

BALL D F, MACDONALD A M, Ó DOCHARTAIGH B É, DEL RIO M, FITZSIMONS V, AUTON C A, LILLY A. 2004. Development of a groundwater vulnerability screening methodology for the Water Framework Directive. Final Report of SNIFFER Project WFD28, September 2004.

BERLIN DIGITAL ENVIRONMENTAL ATLAS (BDEA). 1993. Chapter 2.4: Quality of near-surface groundwater, Senate Department for Urban Development, http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/edinh_02.htm

BONSOR H C AND Ó DOCHARTAIGH B É. 2010. Groundwater monitoring in urban areas – a pilot investigation in Glasgow, UK. *British Geological Survey Internal Report* IR/10/020

CARDIFF BAY ADVISORY COMMITTEE. 2009. Cardiff Bay Advisory Committee, Minutes January 2009, Vale of Glamorgan Council, Agenda Item No. 09-02-25, accessed online at: http://www.valeofglamorgan.gov.uk/our_council/council/minutes,_agendas__reports/reports/cabinet/2009/09-02-25/references__meetings/cardiff_bay_advisory_committee.aspx

CARDIFF HARBOUR AUTHORITY. 2007. Groundwater Monitoring, accessed online at: http://www.cardiffharbour.com/harbour/groundwater/groundwater%20monitoring.htm

DAS GUPTA A, JAYAKRISHNAN R,ONTA P R. AND RAMNARONG V. 1995. Assessment of groundwater quality for the Bangkok aquifer system, *Models for Assessing and Monitoring Groundwater Quality, Proceedings of a Boulder Symposium*, IAHS Publication, **227**; 3

DOHR F AND GRUBEN W. 1999. Groundwater Monitoring System of the City of Munich, *City of Munich Report*, pp167.

HALL I H S, BROWNE M A E AND FORSYTH I H. 1998. Geology of the Glasgow district: Memoir for 1: 50 000 Geological Sheet 30E (Scotland). British Geological Survey.ISBN 0-11-884534-9.

EC. 2007. Common implementation strategy for the water framework directive: Guidance on Groundwater Monitoring, (2000/60/EC) *European Commission Technical Report 002-2007, No. 15*, ISBN 92-79-04558-X ISSN 1725-1087.

EC. 2009. COMMISSION DIRECTIVE 2009/90/EC of 31 July 2009 laying down, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, technical specifications for chemical analysis and monitoring of water status, *Official Journal of the European Union*, pp 2.

FOSTER S, MORRIS B, LAWRENCE A. AND CHILTON J. 1999. Groundwater impacts and issues in developing cities – An Introductory review, in: Chilton, J. (ed) Groundwater in the Urban Environment: selected city profiles, *International Association of Hydrogeologists Publication*, Vol. 21, pp3-18.

FRY V AND KELLY T. 2008. Management of the London Basin Chalk Aquifer, *Environment Agency Status Report 2008*, pp 55.

GRAHAM M T, Ó DOCHARTAIGH B É, FORDYCE F M AND ANDER E L. 2008. A Preliminary Tool to Assess Threats to Shallow Groundwater from Soil Pollutants in Glasgow (GRASP). *British Geological Survey Internal Report* IR/08/057.

GRATH J, WARD R AND SCHEIDLEDER A. 2005. Drafting Group GW 1 – Groundwater Monitoring European Groundwater Conference 2006 – Presentation Abstracts – Chapter 1.1.4, pp 7.

GRISCHEK T, NESTLER W, PIECHNICZEK D AND FISCHER T. 1996. Groundwater modelling for the Cardiff Bay Barrage, UK – Prediction, Implementation of Engineering works and validation of modelling, *Hydrogeology Journal*, **4;** 1; 48-63.

HEATHCOTE J A, LEWIS R T AND SUTTON J S. 2003. Groundwater modelling for the Cardiff Bay Barrage, UK – Prediction, Implementation of Engineering works and validation of modelling, *Quarterly Journal of Engineering Geology and Hydrogeology*, **36;** 2; 159-172.

HOWARD K W F. 2002. Urban Groundwater Issues – an introduction, in: HOWARD, K. W. F. and ISRAFILOV, R. G. (eds) (2002) Current Problems of Hydrogeology in Urban areas, Urban Agglomerates and Industrial Centres, NATO Science Series, IV Earth and Environmental Series, - Vol. 8, pp 1-16.

JOUSMA G AND ROELOFSEN F J. 2004. Worldwide inventory on groundwater monitoring, *International Groundwater Resources Assessment Centre Report pp 69.*

KIM Y-Y, Lee K-K AND SUNG I H. 2001. Urbanisation and the groundwater budget, metropolitan Seoul area, Korea, *Hydrogeology Journal,* **9**;401–412.

KITTU N, VARADORAJ N AND CHAKKARAPANI R. 1999. Impact of urbanisation on groundwater in the Madras coastal area, Tamil Nadu, India, in: Chilton, J. (ed) Groundwater in the Urban Environment: selected city profiles, *International Association of Hydrogeologists Publication*, Vol. 21, pp3-18.

KOREIMANN C, GRATH J, WINKLER G, NAGY W AND VOGEL W R. 1996. Groundwater monitoring in Europe, *European Environment Agency Topic Report 14/96,* Copenhagen, pp 143.

LEE J-Y, YI M-J, YOO Y-K, AHN K-H, KIM G-B AND WON J-H. 2001. A Review of the National Groundwater Monitoring Network in Korea, *Hydrological Processes,* **21;** 907-919.

LOVATT M J. 2008. Assessing the Importance of Depth to Groundwater in a Methodology for Prioritising Threats to Groundwater Quality from Surface Contaminants in the Clyde Gateway, Glasgow. Unpublished MSc thesis, University of Strathclyde.

LERNER D N, CHISALA B N AND TAIT N G. 2008. Estimating the Pollution Risks to Urban Groundwater from Industry and Sewers, *iEMSs 2008: International Congress on Environmental Modelling and Software,*

MERRIT J E, MONAGHAN A A, LOUGHLIN S C, MANSOUR M., Ó DOCHARTAIGH B É and HUGHES A G. 2009. Clyde Gateway Pilot 3D Geological and Groundwater Model. *British Geological Survey Commissioned Report* CR/09/005.

MUNICH CITY COUNCIL. 2010. Department of Environment and Health, Groundwater monitoring in Munich http://www.muenchen.de/Rathaus/rgu/vorsorge_schutz/wasser/grundwasser/39001/index.html, accessed 19/02/2010

NIETO P, CUSTODIO E AND MANZANO M. 2005. Baseline groundwater quality: a European approach, *Environmental Science and Policy***, 8;** 399-409.

Ó DOCHARTAIGH B É. 2005. Review of hydrogeological knowledge of the Clyde Basin. *British Geological Survey Internal Report*, IR/05/079.

Ó DOCHARTAIGH B É. 2009. Groundwater research needs in Glasgow and the Clyde Basin, 2009. *British Geological Survey Internal Report* IR/09/036.

Ó DOCHARTAIGH B É, GRAHAM,M T AND MACDONALD A M. 2007. A summary of groundwater work within the Clyde Basin project, 2005-06*. British Geological Survey Internal Report,* IR/07/042.

Ó DOCHARTAIGH B É, FORDYCE F M AND BONSOR H C. 2009. Developments to GRASP 2008/09. GRASP: a GIS tool to assess pollutant threats to shallow groundwater in Glasgow. British Geological Survey Internal Report, in prep.

Ó DOCHARTAIGH B É AND MACDONALD A M. 2009. Baseline Scotland: groundwater chemistry of the Carboniferous aquifers of the Midland Valley. British Geological Survey Open Report, OR/11/021.

ONORATI G, Di MEO T, BUSSETTINI M, FABIANI C, FARRACE F G, FAVA A, FERRONATIO A, MION F, MARCHETTI G, MARTINELLI A AND MAZZONI M. 2006. Groundwater quality monitoring in Italy for the implementation of the EU water framework directive, *Physics and Chemistry of the Earth*, **31;** 1004-1014.

RAMNARONG V. 1999. Evaluation of groundwater management in Bangkok: Positive and negative, in: Chilton, J. (ed) Groundwater in the Urban Environment: selected city profiles, *International Association of Hydrogeologists Publication*, Vol. 21, pp3-18.

ROBINS N S. 1986. Groundwater chemistry of the main aquifers in Scotland. *British Geological Survey Report* **18**, No. 2. ISBN 0-11-884380-X.

RUTTER H, CUNNINGHAM J, JACKSON C, AND LEWIS M. 2004. Hydrogeological parameterisation of the Thames Gateway GSI3D model. *British Geological Survey Internal Report*, IR/06/042.

UK TAG. 2010. http://www.wfduk.org/. Accessed 1 November 2010.

WOLF L. 2007. Managing urban groundwater as a resource – hidden problems and hidden opportunities, *Water*, **21;** 19-20.

WOLTER R, ROSENBAUM S AND HANNAPPEL S. 2001. The German Groundwater Monitoring Network, *Proceedings MTM-III, The German Groundwater Monitoring Network*, pp 6.

Appendix 1 Draft templates for data capture

Glasgow City Council | British Geological Survey, Natural Environment Research Council

User Guide to GCC/BGS groundwater data templates

GENERAL NOTES

These templates have been designed by the British Geological Survey (BGS) and Glasgow City Council (GCC) to systemise groundwater data reported from Glasgow City area. The templates aim to significantly reduce the number of unique reporting formats handled by GCC and BGS, and to ensure a minimum level of borehole index information is known for all groundwater monitoring data. The templates will therefore enable datasets as reported by consultants and contractors to be used to much greater effect by GCC and BGS.

All headers shaded dark grey, denote ***required information*** – without this information the associated groundwater data cannot be used.
All headers shaded pale grey header denote ***optional information***, depending on what data have been collected from a borehole, or site.

Units of all data must be consistent with the units provided in the headers. Where units are left undefined (e.g. "<units>") in the template column headers, they must be defined by the data inputter.

INDEX OF TERMS

Site Name:	Name of monitored site
Site Borehole ID:	Name of borehole, as recorded by consultant/contractor on site.
GCC Borehole ID:	Unique borehole ID code according to Glasgow City Council borehole records (this should be left blank for GCC to complete)
BGS Borehole ID:	Unique borehole ID code according to the British Geological Survey record system (this should be left blank for BGS/GCC to complete).
Purpose of drilling:	Purpose of construction of the borehole – e.g. Geotechnical investigation / groundwater monitoring.
mbgl:	Metres below ground level
mftc:	Metres from top of casing
maod:	Metres above Ordnance Datum
Top of Casing (moad):	Elevation of top of casing in borehole (metres above Ordnance Datum)
Casing Diameter (mm):	Casing diameter (millimetres). [Note, casing and screening are internal liners put inside a borehole.]
Top of screen (moad)	Elevation of top of screen in borehole(measured as metres above Ordnance Datum)
Screened Interval (mbgl/mftc):	Screened interval of borehole (measured either in terms of metres below ground level or metres from top of casing). Units to be deleted accordingly.
Screen diameter (mm):	Screen diameter (millimetres).
Screened interval (2) (mbgl/mftc):	If more than one interval of borehole is screened, details of all screening need to be recorded on the datasheet in separate rows.
Monitored unit:	Inferred geological unit, or formation, monitored by the borehole.
Metadata available:	Indicate types of other borehole metadata available, besides lithological data – e.g. Engineering data types
Measurement type:	Method by which groundwater-level was measured (e.g. by diver device or manual dip)
Measurement datum:	Datum of groundwater-level measurement (i.e. mbgl/mftc/moad)
Measurement/Sampling date:	Date at which groundwater-level or groundwater chemistry sample taken in field. Multiple measurement dates for a single borehole should be entered as unique rows.
Temp (°C):	Temperature of groundwater in degrees celsius
pH:	pH of groundwater
Eh (mV):	Redox potential of the groundwater (milli volts)
DO (mg/l):	Dissolved oxygen content in groundwater – measured as milligrams per litre
SEC (µS/cm):	Conductivity of the groundwater, in microSiemens per centimetre
TOC (mg/l):	Total organic carbon, measured in milligrams per litre
DOC (mg/l):	Dissolved organic carbon, measured in milligrams per litre
Bicarbonate (as HCO3 mg/l):	Bicarbonate, measured as HCO3 in milligrams per litre
Additional data:	Any additional groundwater data, along with units of measurements.

<insert Consultancy Company LOGO and Details>	<Area for Consultancy Index level data (Report Number, etc.)>
SITE NAME	<enter site name>

SITE BOREHOLE ID	<ID>	GCC BOREHOLE ID	<ID>	BGS BOREHOLE ID	<ID>
Date of Drilling:	<date>	**Purpose of Drilling:**	<purpose>	**Driller:**	<driller>

BOREHOLE INSTALLATION INFORMATION

Easting:	<easting>	**Northing:**	<northing>	**Total borehole depth:**	<depth>	**Units** <mbgl/mftc>	
Ground elevation (maod):	<elevation>	**Top of casing (maod):**	<elevation>	**Casing diameter (mm):**	<diameter>		

Top of screen (maod):	<elevation>	**Screened interval:**	<interval>	<units mftc/mbgl>	**Screen diameter (mm):**	<diameter>	**Monitored unit:**	<geological unit>
Top of screen 2 (maod):	<elevation>	**Screened interval 2:**	<interval>	<units mftc/mbgl>	**Screen diameter (mm):**	<diameter>	**Monitored unit:**	<geological unit>

LITHOLOGICAL INFORMATION

Material descriptions					**Metadata available**
Lithology	Lithological material description (Text)	Top of Interval (mbgl/mftc/ maod)	Base of interval (mbgl/mftc/ maod)	AGS fill pattern	<yes/no. If yes, to list type data available>
Lithology	Lithological material description (Text)	Top of Interval (mbgl/mftc/ maod)	Base of interval (mbgl/mftc/ maod)	AGS fill pattern	<yes/no. If yes, to list type data available>
Lithology	Lithological material description (Text)	Top of Interval (mbgl/mftc/ maod)	Base of interval (mbgl/mftc/ maod)	AGS fill pattern	<yes/no. If yes, to list type data available>
Lithology	Lithological material description (Text)	Top of Interval (mbgl/mftc/ maod)	Base of interval (mbgl/mftc/ maod)	AGS fill pattern	<yes/no. If yes, to list type data available>

Page x of y

Glasgow City Council British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL Borehole data Template 2011

<insert Consultancy Company LOGO and Details>	*<insert Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>*

SITE NAME

Borehole ID	Date	LAB CHEMISTRY DATA						INORGANIC CHEMISTRY – MAJOR IONS								
		pH	SEC (µS/cm)	Total dissolved solids (mg/l)	TOC (mg/l)	DOC (mg/l)	Hardness (as $CaCO_3$)	Ca (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	Si (mg/l)
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value

Page Xa of y

Inorganic Groundwater Chemistry Template 2011

<insert Consultancy Company LOGO and Details>	<insert Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Borehole ID	Date	INORGANIC CHEMISTRY – MINOR/TRACE IONS																					
		Ag (µg/l)	Al (µg/l)	As (µg/l)	B (µg/l)	Ba (µg/l)	Be (µg/l)	Br (µg/l)	Cd (µg/l)	Ce (µg/l)	Co (µg/l)	Cu (µg/l)	F (µg/l)	Fe (µg/l)	Hg (µg/l)	I (µg/l)	La (µg/l)	Li (µg/l)	Mn (µg/l)	Mo (µg/l)	Nd (µg/l)	Ni (µg/l)	NO_2 (µg/l)
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value

Page Xb of y

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Inorganic Groundwater Chemistry Template 2011

<insert Consultancy Company LOGO and Details>	<insert Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Borehole ID	Date	INORGANIC CHEMISTRY – MINOR/TRACE IONS																	
		NH_4 (µg/l)	P (µg/l)	Pb (µg/l)	Rb (µg/l)	S (µg/l)	Sc (µg/l)	Se (µg/l)	Si (µg/l)	Sn (µg/l)	Sr (µg/l)	Th (µg/l)	Ti (µg/l)	Tl (µg/l)	U (µg/l)	V (µg/l)	W (µg/l)	Y (µg/l)	Zn (µg/l)
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value

Page Xc of y

Glasgow City Council British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL Inorganic Groundwater Chemistry Template 2011

<insert Consultancy Company LOGO and Details>	<insert Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Borehole ID	Date	ORGANIC CHEMISTRY – PAHs														
		Ace (µg/l)	Anth (µg/l)	Chrys (µg/l)	Fanth (µg/l)	Fluor (µg/l)	Naph (µg/l)	Phen (µg/l)	Pyr (µg/l)	B(a)A (µg/l)	B(a)P (µg/l)	B(b)F (µg/l)	B(k)F (µg/l)	B(ghi)P (µg/l)	DB(ah)A (µg/l)	I(123cd) (µg/l)
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value

Page Xa of y

British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL Organic Groundwater Chemistry Template 2011

<insert Consultancy Company LOGO and Details>	<insert Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Borehole ID	Date	ORGANIC CHEMISTRY – PCBs															
		PCB-19 (µg/l)	PCB-26 (µg/l)	PCB-29 (µg/l)	PCB-31 (µg/l)	PCB-52 (µg/l)	PCB-62 (µg/l)	PCB-101 (µg/l)	PCB-118 (µg/l)	PCB-119 (µg/l)	PCB-131 (µg/l)	PCB-138 (µg/l)	PCB-147 (µg/l)	PCB-153 (µg/l)	PCB-157 (µg/l)	PCB-173 (µg/l)	PCB-180 (µg/l)
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value

Page Xb of y

Organic Groundwater Chemistry Template 2011

< insert Consultancy Company LOGO and Details >

<Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Borehole ID	Date	FIELD WELL HEAD CHEMISTRY DATA						
		Temp (°C)	pH	Eh (mV)	DO (mg/l)	SEC (µS/cm)	Bicarb (as HCO_3 mg/l)	*Blank for additional data (UNITS)*
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value
ID	Date	Value	Value	Value	Value	Value	Value	Value

Page x of y

British Geological Survey

Groundwater Field Chemistry Template 2011

<insert Consultancy Company LOGO and Details>

<Area for Consultancy Index level data (Report Number, Author, Driller's name etc. etc.)>

SITE NAME

Measurement type	<diver/manual>
Measurement datum	<mbgl/mftc/moad>

Borehole ID	Date	Time	Groundwater level
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value
ID	Date	Time	Value

Page x of y

British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL

Groundwater Level Template 2011

Appendix 2 Summary groundwater level data for the main regeneration sites in Glasgow

Clyde Gateway boreholes

ID	10% GW level (mbgl)	90% GW level (mbgl)	Seasonal variation (m)	Median (mbgl)	Average of 10-90% (mbgl)	Derived Monitored Unit
226	3.03	4.02	1.62	3.42	3.44	Wilderness Till
227	5.00	5.69	1.39	5.42	5.40	Bedrock
228	5.85	6.24	1.08	6.08	6.08	Bridgton Sand
229	4.39	5.53	1.55	5.19	5.16	Paisley Clay
230	4.41	5.38	1.72	4.83	4.88	Broomhouse Sand and Gravel
231	4.30	5.02	1.42	4.68	4.67	Gourock Sand
232	3.98	4.37	1.08	4.21	4.20	
233	4.53	5.09	1.84	4.71	4.73	Gourock Sand
234	4.63	5.69	3.34	5.05	5.05	Gourock Sand
235	5.84	6.34	0.59	6.20	6.18	Gourock Sand
236	3.55	6.22	3.26	4.28	4.63	Bridgton Sand
237	3.51	4.38	1.69	4.15	4.09	Gourock Sand
238	5.67	6.07	1.07	5.93	5.92	Gourock Sand
239	6.15	6.55	1.21	6.31	6.33	Gourock Sand
240	5.25	6.24	1.21	5.98	5.87	Gourock Sand

M74 extension boreholes

ID	10% GW level (mbgl)	90% GW level (mbgl)	Seasonal variation (m)	Median (mbgl)	Average GW level (mbgl)	Derived Monitored Unit
1	6.422	6.861	0.97	6.74	6.65	
2	8.773	9.28	3.18	9.23	8.91	Paisley Clay
3	10.892	11.796	1.56	11.66	11.43	Paisley Clay
4	1.655	2.87	1.44	1.93	2.09	Paisley Clay
5	2.714	2.862	0.22	2.8	2.79	Made Ground
6	4.845	5.48	1.16	5.025	5.12	Made Ground
7	6.798	7.245	0.78	7.035	7.06	Made Ground
8	4.612	4.853	0.36	4.745	4.73	Made Ground
9	8.063	9.136	4.25	8.575	8.43	Paisley Clay
10	9.406	9.868	0.72	9.67	9.66	Paisley Clay
11	3.189	4.011	1.11	3.66	3.64	Paisley Clay
12	0.977	1.328	0.54	1.145	1.14	
13	5.859	6.201	0.63	6	6.01	Made Ground
14	5.034	6.472	2.25	5.15	5.56	
15	5.74	8.043	3.41	6.07	6.47	Bedrock
16	3.055	3.455	1.48	3.25	3.34	Wilderness Till
17	3.486	4.152	2.97	3.805	3.99	Gourock Sand
18	5.489	6.434	5.85	5.62	6.18	Gourock Sand
19	7.421	9.662	9.18	9.165	8.70	Gourock Sand
20	2.536	3.826	5.05	2.78	3.25	Made Ground
21	2.622	3.016	1.25	2.78	2.85	

Commonwealth Games Village boreholes

ID	10% GW level (mbgl)	90% GW level (mbgl)	Seasonal variation (m)	Median (mbgl)	Average GW level (mbgl)
309	-	-	-	-	7.08
265	6.234	6.306	0.1	6.300	6.28
241	2.487	2.991	0.63	2.670	2.72
242	2.654	3.356	0.99	3.000	2.98
243	2.159	2.590	0.55	2.500	2.43
244	2.571	3.040	0.56	2.750	2.76
245			-		2.32
253	7.184	7.564	1.01	7.250	7.35
254	7.185	7.260	0.1	7.205	7.22
255	7.315	7.465	0.2	7.385	7.39
256	7.335	7.535	0.25	7.405	7.43
273	5.790	6.126	0.42	5.990	5.96
274	7.230	7.238	0.01	7.230	7.23
275	4.502	4.894	0.49	4.630	4.69
276	6.042	6.178	0.17	6.170	6.12
277	5.806	5.830	0.03	5.830	5.82
278	7.682	7.698	0.02	7.690	7.69
279	9.038	9.350	0.39	9.070	9.17
280	8.744	8.776	0.04	8.760	8.76
281	8.876	8.916	0.05	8.900	8.90
283	4.996	5.028	0.04	5.020	5.01
257	7.240	7.370	0.19	7.320	7.31
284	7.604	7.724	0.15	7.660	7.66
285	6.726	6.846	0.15	6.750	6.78
292	3.942	4.158	0.27	4.030	4.05
293	3.836	3.980	0.18	3.900	3.91
294	3.598	3.782	0.23	3.710	3.69
295	6.754	6.786	0.04	6.770	6.77
296	5.452	5.516	0.08	5.500	5.49
297	1.920	2.344	0.53	1.960	2.10
298	2.132	2.332	0.25	2.140	2.22
299	2.544	2.776	0.29	2.640	2.66
258	7.440	7.645	0.3	7.520	7.54
300	1.938	2.234	0.37	1.970	2.07
301	3.686	3.774	0.11	3.750	3.73
304	4.452	5.604	1.44	4.620	4.96
305	7.346	7.426	0.1	7.410	7.39
306	5.102	5.166	0.08	5.110	5.13
307	6.236	6.852	0.77	6.820	6.59
308	6.932	7.012	0.1	6.980	6.97
259	7.277	7.333	0.07	7.305	7.31
260			-		5.68
261	3.894	4.240	0.43	3.990	4.06
266	17.240	17.316	0.14	17.260	17.27

267	16.860	17.513	0.94	17.125	17.16
268	17.712	17.876	0.22	17.795	17.79
286	3.174	3.861	0.75	3.485	3.51
302	5.138	7.141	2.15	6.800	6.43
270	7.116	7.762	1.83	7.310	7.46
271	1.956	3.882	3.03	2.490	2.72
272	5.570	6.465	1.7	5.765	5.96
282	4.212	5.149	1	4.655	4.66
303	4.446	4.698	0.42	4.590	4.56
287	0.860	2.270	1.68	2.100	1.80
288	1.820	2.364	0.68	1.970	2.05
289	1.840	2.144	0.38	2.120	2.01
290	1.788	2.242	0.63	1.910	1.98
291	1.922	2.363	0.56	2.230	2.19
262	7.118	7.582	0.58	7.350	7.35
263	7.467	7.523	0.07	7.495	7.50
264	6.292	6.308	0.02	6.300	6.30
310		-		-	5.75

Shawfield boreholes

ID	10% GW level (mbgl)	90% GW level (mbgl)	Seasonal variation (m)	Median (mbgl)	Average GW level (mbgl)	Derived Monitored Unit
370	2.889	3.178	0.4	2.905	5.10	Gourock Sand
371	2.965	3.285	0.422	3.111	3.18	Gourock Sand
372	7.088	7.210	0.152	7.088	1.06	Made Ground
373	5.818	5.910	0.125	5.833	3.54	Made Ground
374	6.589	6.668	0.1	6.635	1.87	Made Ground
375	5.962	6.259	0.406	5.988	5.52	Paisley Clay
376	4.053	4.062	0.012	4.061	6.74	Gourock Sand
377	6.821	7.153	0.419	7.005	5.01	Made Ground
378	5.837	6.267	0.46	6.070	9.44	Made Ground
379	14.100	14.828	0.91	14.140	1.19	Made Ground
380	12.383	12.623	0.3	12.510	2.40	Made Ground
381	4.118	4.421	0.359	4.335	3.21	Paisley Clay
382	12.855	13.519	0.83	13.187	3.31	Made Ground
383	5.076	5.701	0.85	5.629	3.34	Made Ground
384	2.665	2.735	0.085	2.683	5.91	Made Ground
385	2.888	3.028	0.2	2.954	2.94	Made Ground
386	2.859	3.161	0.311	3.000	3.69	Gourock Sand
387	6.970	7.380	0.5	7.140	3.14	Made Ground
388	5.840	6.138	0.4	5.910	1.53	Made Ground
389	3.046	3.232	0.246	3.083	3.98	Made Ground
390	3.242	3.746	0.72	3.410	0.93	Gourock Sand
391	5.191	5.558	0.463	5.312	1.74	
392	3.865	4.236	0.53	3.945	1.48	Gourock Sand
393	7.605	7.773	0.24	7.686	0.61	Gourock Sand
394	6.196	7.092	0.914	6.623	3.86	Paisley Clay
395	3.128	3.536	0.554	3.227	5.80	Paisley Clay
396	13.132	13.228	0.12	13.180	2.32	Made Ground
397	5.342	6.416	1.342	5.510	2.98	Wilderness Till
398	15.704	16.004	0.33	15.845	0.55	Paisley Clay
399	3.635	4.971	1.405	4.223	6.02	
400	7.395	7.458	0.09	7.410	2.98	
401	7.886	8.587	0.944	7.953	-2.06	
402	7.241	7.324	0.103	7.262	2.22	
403	6.894	7.107	0.216	6.997	3.40	
404	7.480	7.558	0.09	7.505	3.38	
405	7.381	7.455	0.095	7.443	3.38	
406	7.417	7.473	0.08	7.434	3.36	
407	7.428	7.512	0.12	7.448	3.34	
408	6.377	6.497	0.15	6.455	2.96	Made Ground
409	6.468	6.612	0.18	6.560	5.35	Made Ground
410	6.442	6.705	0.29	6.570	4.43	Made Ground
412	5.715	6.139	0.53	6.010	10.66	Paisley Clay
413	3.436	3.508	0.084	3.458	6.53	