Project: Sustainable Hydro Assessments and Groundwater Recharge Projects
Project acronym: SHARP

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APPENDIX: Long version of good practices

GP 10	Urban groundwater monitoring using 3D geological information to inform hydrogeological understanding

Project Partner:
International Resources and Recycling Institute (IRRI)

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Urban groundwater monitoring - new approaches using 3D geological information to inform hydrogeological understanding

For the first time in Earth's history, more than half of the human population now live in cities. With continually increasing urban population size and density, coupled with the as yet unknown impacts of predicted climate change, urban groundwater is becoming an increasingly important water resource. In any city, groundwater is a potential resource for abstraction for potable or industrial supply; and a potential energy resource via ground source heating and/or cooling schemes as part of efforts to reduce urban carbon footprints. Groundwater also critically provides baseflow to rivers to maintain flow rates sufficient for the good health of aquatic ecosystems. In cities with industrial heritage, groundwater is also likely to face risk from contaminated land, and to provide a mechanism for the transport of these contaminants to final surface water receptors. In many cities, groundwater is the receptor for storm water runoff via Sustainable Drainage Schemes (SuDS) which are increasingly being introduced in an attempt to mitigate urban flooding and reduce the pressure on piped drainage networks.

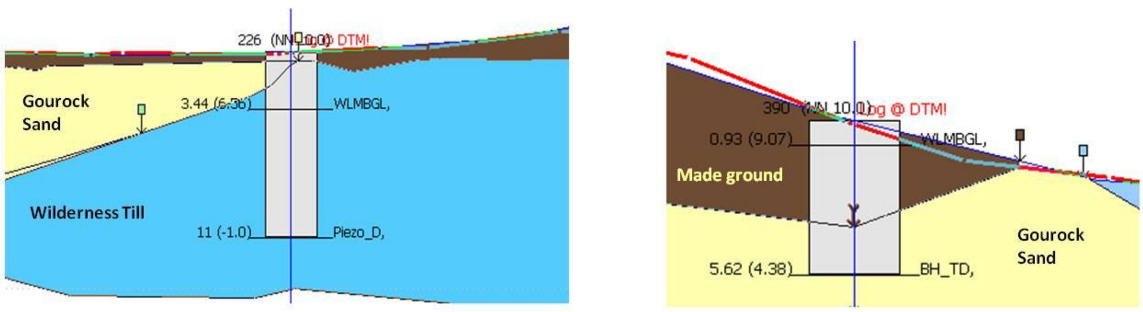
However, the effects of each of these processes upon the groundwater system need to be understood in detail if we hope to properly manage the quality and quantity of this resource to keep it fit for its myriad uses in a 21st century city. The basis to understanding groundwater systems is the availability of sufficient suitable information on key hydrogeological parameters, including the temporal and spatial distribution of groundwater levels and groundwater chemistry. This information can only be collected through effective groundwater monitoring.

This report describes work being carried out by the British Geological Survey to investigate and trial groundwater monitoring strategies in a case study city: Glasgow, UK. Glasgow has a complex geology with a repetitive sequence of faulted Carboniferous sedimentary bedrock overlain by an intricate pattern of Quaternary deposits associated with periods of glaciation. As such, 3D geological models have proved very helpful in attempting to visualise and understand the relationship between the various deposits and the likely behaviour of groundwater within them. In addition, groundwater data in Glasgow is relatively sparse and good quality historical records of groundwater levels and quality are largely not available. Much of the groundwater level data lacks important metadata such as datum elevation and the depth the screen was installed, which makes valid interpretation of the data difficult. By using the 3D geological model to validate the groundwater level data we were able to develop confidence in the quality of our data points and select only the most reliable for use in a pilot monitoring network.

Nature of the practice: - Methodology

The objective was to use 3D geological models as a means to validate and assign confidence to the available groundwater data and to aid in its subsequent interpretation to begin to understand the behaviour of the system.

The 3D geological framework model was used to provide a hydrogeological context to the groundwater data. By using the geological model in conjunction with borehole log records and groundwater level data, it is possible to determine which hydrogeological unit each borehole is most likely to be sampling. For each borehole, the total depth, depth and length of screen, and a representative average groundwater level, were imported into the 3D geological framework model (Figure 1). In some instances, borehole logs were absent, in which case the 3D model was also used as a proxy to determine the hydrogeological unit being sampled.



a) The borehole lies primarily within one unit. There is a high confidence that borehole 226 is sampling the Wilderness Till.

b) The borehole intersects more than one unit. There is a low confidence that borehole 390 is sampling the Gourock Sand.

Figure 1: Incorporation of borehole log data into GSI3D for validation of monitored geological unit.

At some borehole locations there were contradictions between the geology recorded in the logs and the geology expected by the model. To reflect this uncertainty, confidence criteria were applied to the defined hydrogeological unit for each monitoring borehole. Low confidence was applied if the borehole intersected more than one geological unit in the geological model, and the borehole could not be validated against any lithological record from a borehole log, or if the borehole record and the GSI3D model contradicted each other. Medium confidence was attributed to boreholes where there was reasonable certainty in the hydrogeological unit being sampled, but which could not be verified by a lithological description. Finally high confidence was assigned to boreholes that showed good agreement between the GSI3D model and the borehole log and for those that intersected just one geological unit. In this way the 3D geological model was used to validate the data acquired from the borehole logs and to develop a picture of which horizons each borehole was monitoring.

By using the 3D model to confirm with acceptable certainty which unit each borehole was sampling, it was possible to create subsets of the data comprised of boreholes monitoring the same geological unit. Boreholes were identified as monitoring seven different geological units, including artificial (or made) ground; five distinct Quaternary (superficial deposit) units; and bedrock, although the largest subsets of boreholes are monitoring made ground and the Gourock Sand Formation, a natural deposit of Quaternary age.

Using these subsets, groundwater level contours based on an average groundwater level for each borehole were created to investigate the prevailing groundwater flow direction and to help infer the degree of connection between adjacent hydrogeological units (Figure 2).

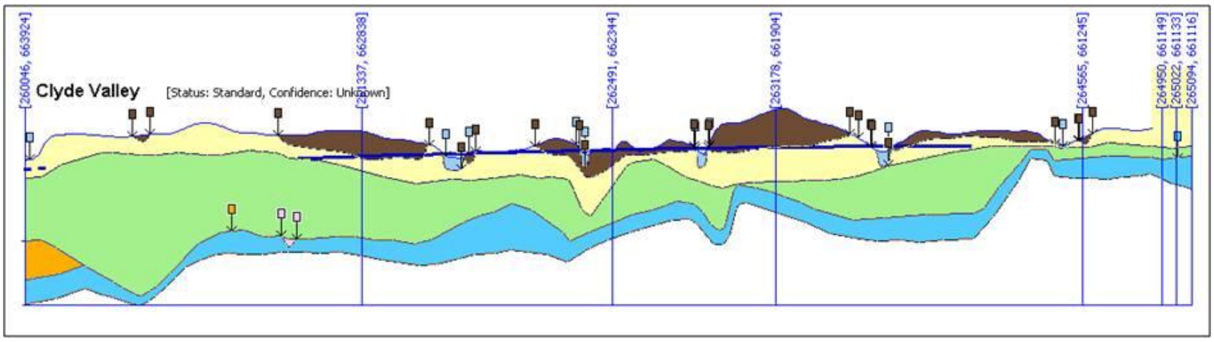


Figure 2: Cross section along the valley of the Clyde with the contoured water table within the Gourock Sand Formation shown in blue.

However, even for the Gourock Sand Formation, for which there are most monitoring points, the available groundwater level data (from 20 boreholes) proved insufficient to produce detailed groundwater contours. Instead, the groundwater level data were employed to create simple hand drawn groundwater contours that delineate the approximate groundwater head gradient through the study area. These contours were converted into a 2D raster surface and imported into the 3D geological model (Figure 3). In the model the groundwater level contours can be viewed in cross-section (figure 2) and indicate good agreement between the groundwater level contours and the level of the River Clyde, which implies that there is hydraulic connection between groundwater in the Gourock Sand Formation and the river in this area. The 3D geological model shows that the geometry and thickness of the Gourock Sand Member is such that there is likely to be a relatively constant thickness along much of its length, permitting groundwater flow throughout the study area. However, in some locations, the geological model indicates that the Gourock Sand Member thins to about 1 metre thickness, indicating that groundwater flow in this area is likely to be different, and potentially highlighting the need for monitoring in this area.

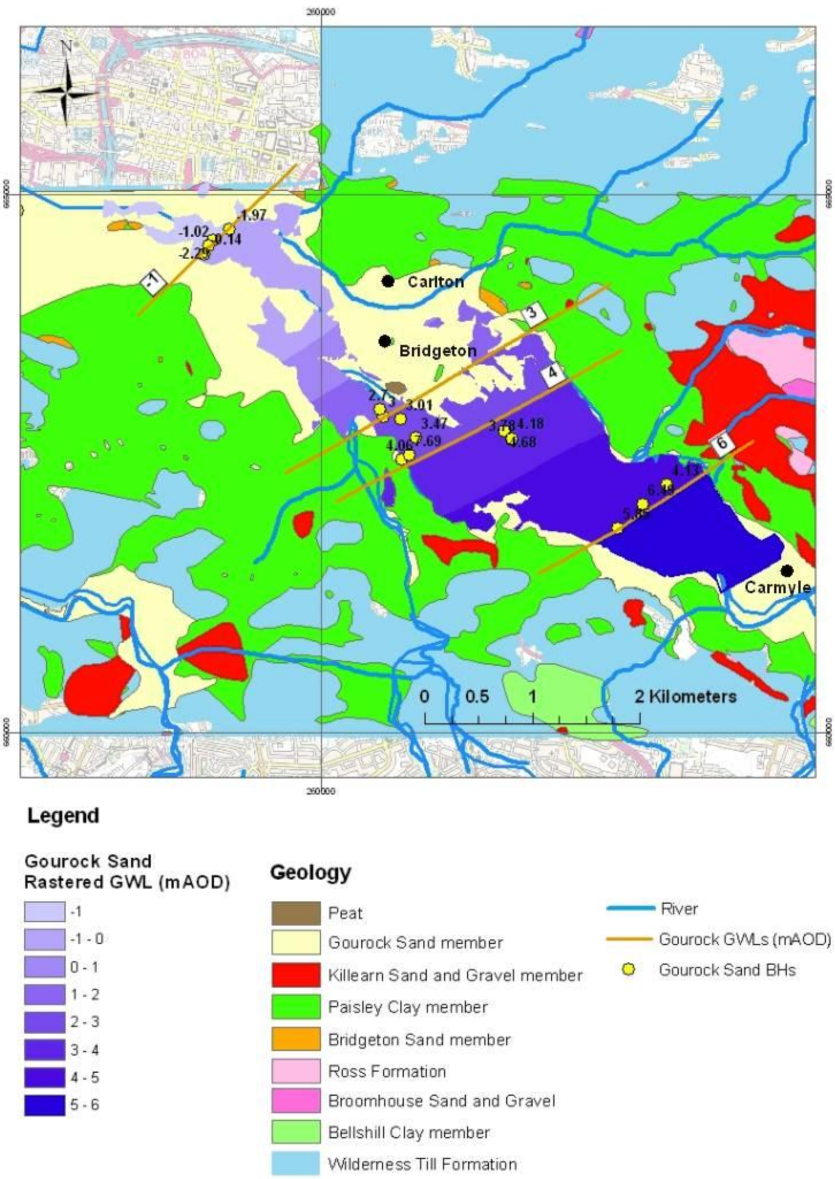


Figure 3: Groundwater contours for the Gourock Sand Member as an interpolated raster surface and as contour lines.

Future

Use of the 3D geological framework model has facilitated the development of hydrogeological knowledge within a study area in Glasgow. Understanding gleaned from the interpretation of the available groundwater level data within the 3D context provided by the geological model has resulted in the identification of one particular geological unit (the Gourock Sand Member) as being a potentially locally significant hydrogeological unit, and its selection as a major focus of the future development of the groundwater monitoring network. In the same way, other geological units have been identified as a secondary focus for monitoring.

The 3D geological framework model has proved a powerful tool to aid hydrogeological understanding in this complex urban area. Its value in informing the refinement of conceptual groundwater understanding and future monitoring network design is in the ease of use of the model for providing context to groundwater monitoring data; and in the enhanced interpretation that is possible by visualising detailed geological understanding in three dimensions.

Such 3D geological models are a relatively new tool and as yet are only available for limited areas, and at present are time-intensive and therefore costly to develop. This is likely to curtail the widespread application of this methodology in the near future. However, the development of 3D geological tools is fast becoming the norm in many parts of Europe, including other areas of the UK and the Netherlands, and where such models do exist, the cost savings of using them to inform hydrogeological understanding could be considerable.

The content of this document is based upon the work detailed in the following BGS internal reports:

Bonsor HC, Ó Dochartaigh BÉ. Groundwater monitoring in urban areas – a pilot investigation in Glasgow, UK.

Bonsor HC, Bricker SH, Ó Dochartaigh BÉ, Lawrie KIG. Groundwater monitoring in urban areas: pilot investigation in Glasgow, UK, 2010-11.