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'Old versus new': Comparing mine water geothermal systems in Glasgow

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ABSTRACT

With the increasing improvements being made to energy sources across the renewables sector, and their application to the UK wide energy mix, interest into the development of geothermal energy in the UK is becoming more prominent. With only a small number of active or discontinued UK based mine water geothermal systems, the development of a research-based pilot scheme could prove to be highly informative when assessing the nature of the resources available. The established site at Shettleston, Glasgow has been operating with varying degrees of success for the past 20 years but associated scientific data collection was performed post installation. Conversely, during the installation of the Glasgow UKGEOS (UK Geo-Observatory) mine water geothermal project, scientists were invited to conduct research alongside the British Geological Survey (BGS), beginning with a 199 m deep observation borehole. Daily sampling and analysis of waters will generate an extensive subsurface hydrochemical dataset, in line with extensive research and development aims laid out by the Natural and Environmental Research Council (NERC) for the 15-year lifespan of the research facility. Initial hydrochemical analysis of sampled drilling fluids and groundwaters has been completed for both sites. Physicochemical properties of the waters, including pH, electrical conductivity (μS/cm), oxidation-reduction potential (ORP), temperature, and total dissolved solids were measured alongside major and minor ions and the total alkalinity. Stable isotopes of ^{18}O and ^{2}H were analysed in waters collected from UKGEOS. Shettleston data also includes temperature and conductivity depth profiles.

1. INTRODUCTION

De-risking new low carbon technologies is imperative if their uptake is to be successful. The British Geological Survey's (BGS) UK Geoenergy observatory projects (UKGEOS) are pilot programmes in Chester, Cardiff and Glasgow with the intention to provide access for understanding and familiarisation of the subsurface characteristics. The pilot study constructing a Mine Water Geothermal System (MWGS) at Cuningar in the East End of Glasgow, represents a state-of-the-art research facility to help progress the uptake of this low carbon energy resource. With one such MWGS already installed in nearby Shettleston (Banks et al., 2009) in 1999 (SUST, 2006), this paper looks to draw data from and compare the new site with the old. The Shettleston site has largely run successfully throughout its 20-year life span (Banks et al., 2019), but has experienced only sporadic performance during recent years. The Natural and Environmental Research Council (NERC) UKGEOS site is intended to become a functioning observatory which will run for at least 15 years. Proof of feasibility here could encourage the installation of private systems and together these would trigger a shift towards decarbonisation of the UK heating sector. Successful installation and operation of such systems require robust characterisation of physical, chemical and hydrogeological conditions. This paper will review and compare available data from the two Glasgow MWGS locations. Further study of the mine water system at the UKGEOS site will build on this initial information and aid the delivery of a MWGS template that can be applied to locations throughout the UK and across the world.

2. CONTEXT

The Shettleston MWGS was designed by John Gilbert Architects (JGA) in 1997 as part of a 16-unit social housing development for the Shettleston Housing Association (SHA). The feasibility of such a scheme was demonstrated through a pilot project in Mossend, Lanarkshire in around 1992 which provided heating for a portable cabin. The small team of engineers and a geologist who behind the Mossend system collaborated with JGA to produce a plan for the Shettleston scheme (Banks et al., 2009). The primary aims of JGA were to use sustainable and local materials, conserve instead of supply energy, and anticipate maintenance issues (SUST, 2006). The resulting heating system included solar water panels for preheating water in the communal heating system and water abstracted at c. 12°C from a flooded coal mine, quoted at 100m depth below ground level (bgl) (SUST, 2006). Water from the mine was heated up to 55°C through the use of two heat pumps with a combined output of 65 kW, before used for heating. Originally the used mine water was circulated through the houses as grey water for feeding toilet cisterns, however this quickly became an issue as the oxygenated waters precipitated out iron oxides which discoloured basins and blocked valves (SUST, 2006). Beyond this observation, little historic information exists regarding water quality details of the Shettleston mine water resource. No documented sampling or data collection was recorded prior to installation and sporadic data has been collected since. The in-line filter between the borehole pump and the heat pump array is replaced every three months and collects ochre and other particulates, with quantities being greatest after heavy rainfall (Banks et al., 2009). Characterising the deposits on the filter was performed through X-Ray Diffraction (XRD) (Fraga Pumar, 2007) in order to decipher the origins of the clogging particles. Analysis deduced a large quartz content and these particulates were speculated to be from sandstone units within the mined Carboniferous Middle Coal Measures.

The construction and installation of the UKGEOS facility is part of a larger BGS project to improve the understanding of geothermal potential of the UK. The planned network of 12 boreholes is being constructed to monitor how the warm waters found in the mines move and change over time. The site aims to collect data on various aspects of such a system, including temperature, connectivity, the current state of coal mines, water chemistry, response to pumping and microbial influences, in order to understand how geothermal systems can contribute to heat supply in towns and cities. The site location was informed by detailed BGS investigations into underlying geology and local mining history, which pinpointed optimal access points for flooded workings. Part of the baseline monitoring involved drilling, logging and hard rock coring of a 199m borehole (borehole designation: GGC01; British national grid: 260915.13, 663109.36) to obtain a complete, unmined sedimentary succession and determine the local geological profile. The completed borehole will act as seismic monitoring point for future activities at the geo-observatory.

3. METHODS

3.1 Shettleston Housing Association

Data on temperature and depth from the mine system at SHA were collected through the installation of two 22 mm diameter and stainless-steel cased Schlumberger Diver data loggers. A Baro-Diver performed uninterrupted, real-time atmospheric pressure monitoring for a duration of 9 months. A Micro-Diver was attached to the submersible pump hose and inserted into the abstraction borehole to monitor water levels and temperature of mine waters. The Micro-Diver was attached the hose-beltloop closest to the pump interface and recorded temperature and pressure measurements every 15 minutes between August 2016 and April 2017. Data were collected for temperature and conductivity with depth in August 2016. An In-Situ Rugged CTD dipmeter was lowered into the borehole from the top of the well head and measured temperature and conductivity values at regular increasing intervals. In February 2016 the abstracted water at Shettleston was sampled from the borehole's submersible pump, and analysed for physicochemical parameters (Banks et al., 2019). Samples were also analysed for major ion concentrations using ion chromatography (IC) at the labs of the School of Engineering at the University of Glasgow.

3.2 UK Geo-Observatories

The following methods correspond to the water sampling and analysis methodology detailed in Burnside et al. (2016). The drilling commenced on the 27th of November 2018 and was completed on the 12th of December 2018. The drill fluid was 13,000 litres of recirculating mains tap water, stored in settlement tanks and replaced by fresh tap water once on the 6th of December 2018. Samples collected after the termination of drilling were taken following the borehole flushing, and control samples. The samples were collected at 8am each day from the surface opening of the drilled borehole and the settlement tank containing the returned drilling fluids. Samples for laboratory analysis were decanted in duplicate using clean polypropylene screw cap vials and filtered to 0.45µm to remove any particulate matter. Samples for $\delta^{18}O$ and $\delta^{2}H$ isotopic analysis were taken using clean polypropylene screw cap vials and sealed with Parafilm to prevent any sample evaporation. Control samples were supplied by the British Geological Survey in the form of the mains water and analysed in parallel with the other samples. Analyses of the physicochemical properties of the waters were performed as close to the time of sampling as possible. The waters were tested for pH, temperature, electrical conductivity, total dissolved solids and oxidation-reduction potential using a handheld Myron P Ultrameter II. Alkalinity was determined as $CaCO_3$ at with a Hach Model 16900 digital titrator, using sulphuric acid and bromcresol green – methyl red pH indicator. Where required, the equipment was calibrated before each sampling episode and the water samples were refrigerated as soon as possible after collection.

Anion and cation concentrations were determined using the same method as the Shettleston samples. Stable isotope analyses were undertaken at the SUERC laboratories, East Kilbride. For $\delta^{18}O$ analysis, each sample was over-gassed with a 1% CO_2-in-He mixture for 5 min and left to equilibrate for a further 24 h. A sample volume of 2 ml was then analysed using standard techniques on a Thermo Scientific Delta V mass spectrometer set at 25 °C. Final $\delta^{18}O$ values were produced using the method established by Nelson (2000). For $\delta^{2}H$ analysis, sample and standard waters were injected directly into a chromium furnace at 800 °C (Donnelly et al., 2001), with the evolved H_2 gas analysed on-line via a VG Optima mass spectrometer. Final values for $\delta^{18}O$ and $\delta^{2}H$ are reported as per mil (‰) variations from the V-SMOW standard in standard delta notation. In-run repeat analyses of water standards (international standards V-SMOW and GISP, and internal standard Lt Std) gave a reproducibility better than ±0.3‰ for $\delta^{18}O$, ±3‰ for $\delta^{2}H$.

4. RESULTS AND DISCUSSION

4.1 Shettleston Results

Once corrected for atmospheric pressure, the water level was derived and found to fluctuate between 12.3 and 13.2 m bgl (Figure 1.). The water level is at its lowest around October 2016 and rises to its highest point at April 2017. The water level is consistent and does not vary more that 1m depth across the 9-month sampling period. Short term perturbations of water level show daily repeating timescales and may be a result of submersible pump operation. Further research is required to understand the relationship between pump operation and borehole water level. Figure 2 shows the conductivity and temperature with depth of the borehole. The conductivity displays a step increase at 20-22 m below ground level from around 480 to 880 µS cm^{-1}. This may be indicative of chemical stratification within the borehole and the extent of influence of meteoric surface water. The temperature of the water shows a slight decrease to 20m depth before becoming more stable between 20-30m, from there it gradually decreases down to the maximum depth. Between the water at the surface (12.6 m) to the maximum depth (47.3 m) there is a 0.5 ºC fluctuation from 11.81 to 11.31 ºC. The decrease in temperature and lower conductivity values from 12.6 to 20 m indicate that the top portion of the water column is derived from a different source than waters below 20 m. It is most likely that these are fed by meteoric waters. The warmer waters are perhaps only reflective of the summer (August 1st) temperatures, and these would perhaps vary with the seasons, becoming cooler than the deep waters in winter. The deeper waters are more stable and show a steady temperature plot, characteristic of ground water unaffected by surface seasonal change. The results from the ion chromatography determinations for the sample taken in February 2016 are shown in Table 1, with all values in milligrams per litre. The physicochemical properties of the water have been published in Banks et al. (2019). The water pumped from the borehole-pump interface was clear with no visible indication of ochre presence.

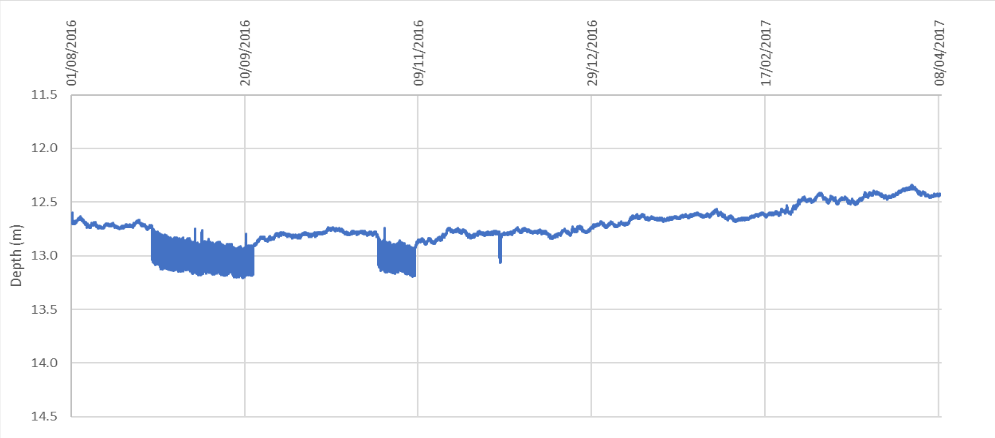

Figure 1: Water level fluctuations in metres below ground level in the SHA borehole in metres. Corrected for variations in atmospheric pressure using surface Baro-log data.

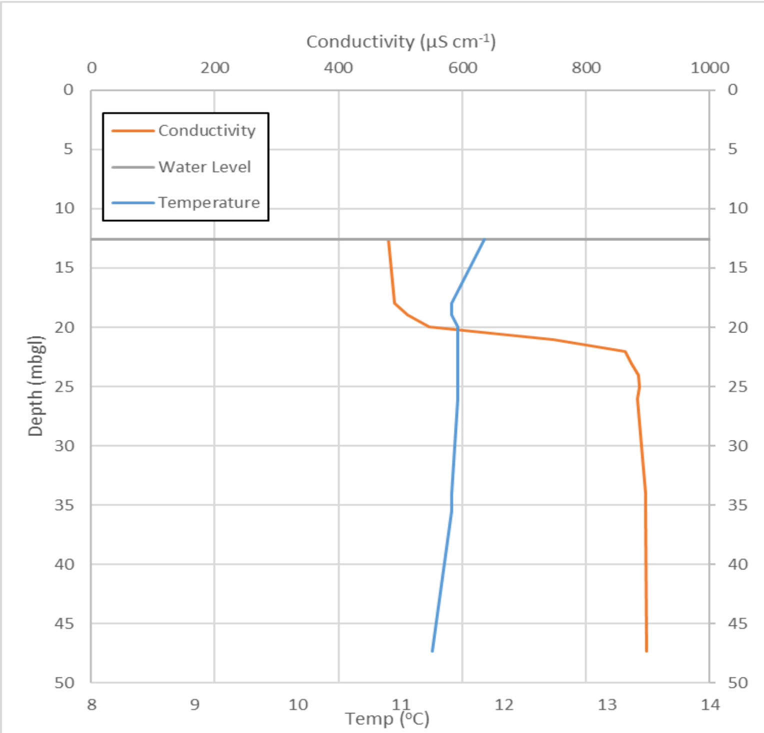

Figure 2: Changes in conductivity and temperature of SHA borehole waters with depth (recorded on 1st August 2016).

Chloride	Bromide	Nitrate	Sulphate	Bicarbonate	Sodium	Potassium	Magnesium	Calcium	Ammonium
52	<dl	<dl	59	416	39	5.8	42	105	<dl

Table 1: Water chemistry values for Shettleston, all values in milligrams per litre (mg/l), '<dl' = below detection limit.

4.2 UK Geo-Observatory Results

The results of the Ultrameter analysis of physicochemical properties for the UKGEOS borehole and the drill fluid settling tank are shown in Figure 3. The conductivity and TDS values fluctuate greatly, but trend sub parallel to each other, highlighting their connected relationship. The lowest values for conductivity and TDS in the settling tank are below 100 µScm^{-1} and ppm respectively on the 6th of December 2018 this correlates with the day on which the drill fluids were replaced by clean mains water. The ORP of the borehole samples remain steady around +200mV, however it varies between +100 and +300 mV for the settling tank waters. The pH values were all circum-neutral to slightly alkaline: with a range from 7.15 to 9.16.

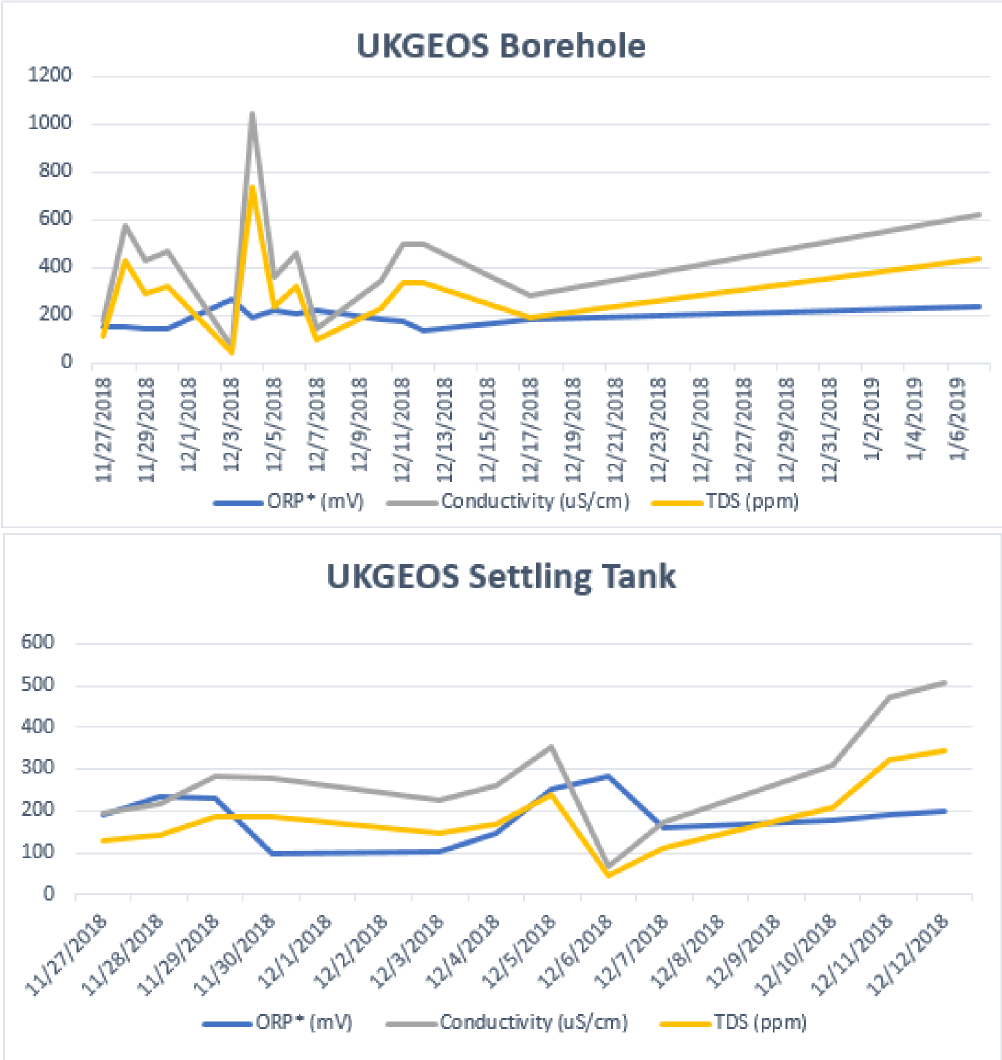

Figure 3: Changes in oxidation-reduction potential (ORP), conductivity and total dissolved solids (TDS) for the UKGEOS Borehole (top) and Settling Tank (bottom) waters across the sampling dates in winter 2018/19.

The baseline mains water used for drilling had a pH value of 6.53, conductivity of 88 µS cm^{-1}, TDS of 58.5 mg/l and ORP of +648 mV. These are the highest values for ORP, the lowest for pH and the second lowest for conductivity and TDS, after the fresh mains water return fluid from the 6th of December.

Cation and anion characterization of the sampled waters from the UKGEOS borehole and the drill fluid settling tank can be seen in Figures 4 and 5. The concentrations show a more continuous trend for the settlement tank water samples, but again show minimum values around 6th December, when the drill fluid was replaced by mains water. The borehole waters, sampled at 8am, were left overnight and therefore were likely influenced to a greater extent by the lithologies and rock water chemistry than the settlement tank waters. This is perhaps the reason the borehole waters display more fluctuations in ion concentration, since there were new lithologies each day which the borehole water was exposed to.

The results of the oxygen and hydrogen stable isotope analysis are shown in Figure 6. The global meteoric water line (GMWL) is depicted by the red dotted line. The apparent spread of δ^2H is a result of the large mass difference between the two stable isotopes relative to the mass of the hydrogen element. However, the sample average plots directly on the GMWL, reflecting that the sampled borehole and settlement tank waters were derived from the mains water drill fluid.

4.3 Comparing Mine Water Geothermal Systems

The datasets pertaining to the 20-year-old installed system at SHA and the newly developed UKGEOS site describe environmental chemistry data which allow insights into the nature and history of the waters used for geothermal heating in Glasgow. The data for the UKGEOS site was part of a wider appeal to academics, with the aim to provide world class research around the geo-observatory. The included data is solely from the associated seismic borehole, installed to measure any tectonic events and to produce an intact core sample from the 199 m deep well. This well does not comprise part of the mine water system per se, but it is a crucial part of the knowledge acquisition process established by the BGS. Understanding the subsurface and hydrochemistry of Glasgow in a location unaffected by mine workings allows the comparison for sites which penetrate deliberately into open worked mines. The database which the BGS and academics will ultimately construct from the UKGEOS project will generate in-depth understanding of the interconnectivity between mine workings, whilst improving understanding around how mines respond to pumping and the mine water's thermal response to heat abstraction. This will be generated through pump tests, chemical or thermal tracers and continued sampling in the methods described above. These insights will prove useful for government or industry installations of the low-carbon heating schemes, as challenges and any necessary remediation steps will be better understood, and the UKGEOS site will act as a pilot study to perhaps prove feasibility when applying for economic support and grants.

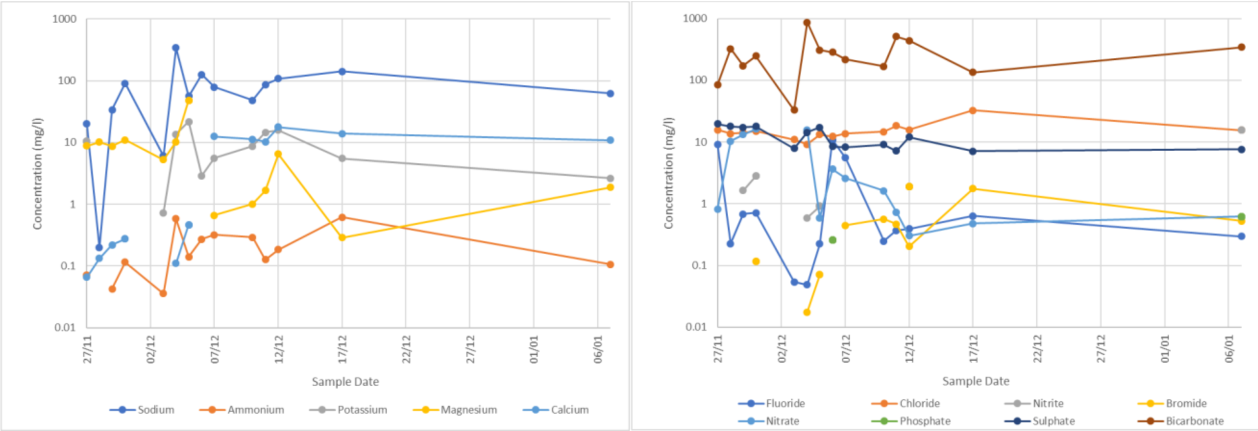

Figure 4: Changes in cation (left) and anion (right) concentrations in mg/l in the UKGEOS borehole across the 14 sampling days in winter 2018. Note: Y axis is logarithmic scale.

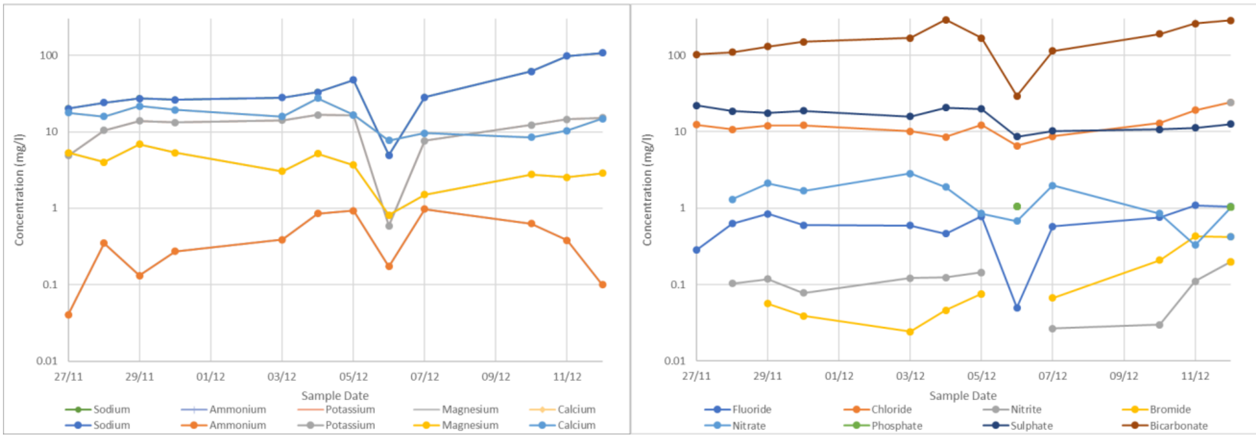

Figure 5: Changes in cation (left) and anion (right) concentrations in mg/l in the UKGEOS return drill fluid settling tank across the 12 sampling days in winter 2018. Note: Y axis is logarithmic scale.

The SHA geothermal system, although being installed in 1999 has data of the same nature, i.e. physicochemical properties and ion concentrations of the borehole water. However, planning and installation of the system was not conducted with the same degree of research and preparedness. The system is quoted to penetrate workings at around 100m depth (SUST, 2006); however, during routine maintenance, the pump interface has been physically measured to be 42 m bgl and dipmeter measurement met impenetrable physical resistance at a depth of 47.3 m bgl, which may indicate the true depth of the floor of the mine void. The same can be noted for the reinjection well which makes up half of the doublet system; it is unclear to which horizon the spent waters are rejected to. Speculation suggests a higher level of coal workings or a permeable horizon in the coal measures sequence (Banks et al., 2019). Research on Shettleston mine waters was conducted, and data was published after the commissioning of the heating system (Banks et al., 2019; Banks et al., 2009). The system worked well in the early stages, but more recently has stopped functioning with minimal understanding of the cause. Clogging of the reinjection borehole, miscommunication between electrical control units, buildup of ochre and loss of pressure could all have had an influence (D. Henderson, pers. comm.).

The research extents of the two different projects will likely result in a markedly improved understanding of subsurface processes in the mine waters of Glasgow after the UKGEOS project commences, providing greater insight into the geomicrobiological, hydrochemical, geophysical and hydrogeological processes involved. The Shettleston installation can be viewed as a success, it is a low carbon heating construction which served as a pilot study for many of the GMWS installed worldwide and has provided heating for SHA for much of the last 20 years. It was funded by Scottish Homes (now part of the Housing and Regeneration directorate of the Scottish Government), during a competition for the creation of a sustainable housing development. The project fund was £700,000, far less than the £31 million allocated across the three UKGEOS sites (Cardiff, Cheshire and Glasgow). The UKGEOS installation, although generating state of the art research about the subsurface, has a location which is not proximal to any significant heat demand. The project is planned to exist for 15 years as a subsurface observatory, which will provide valuable data to assist the uptake of MWGS across the nation in the coming years. However, once the lifespan has been completed, there is no obvious manner for the system to become fitted to any heat consumer for low carbon heating. The large capital expenditure by NERC does not accurately represent the likely funds available for a similar private sector installation, rendering the economics of the system unrepresentative for industry uptake.

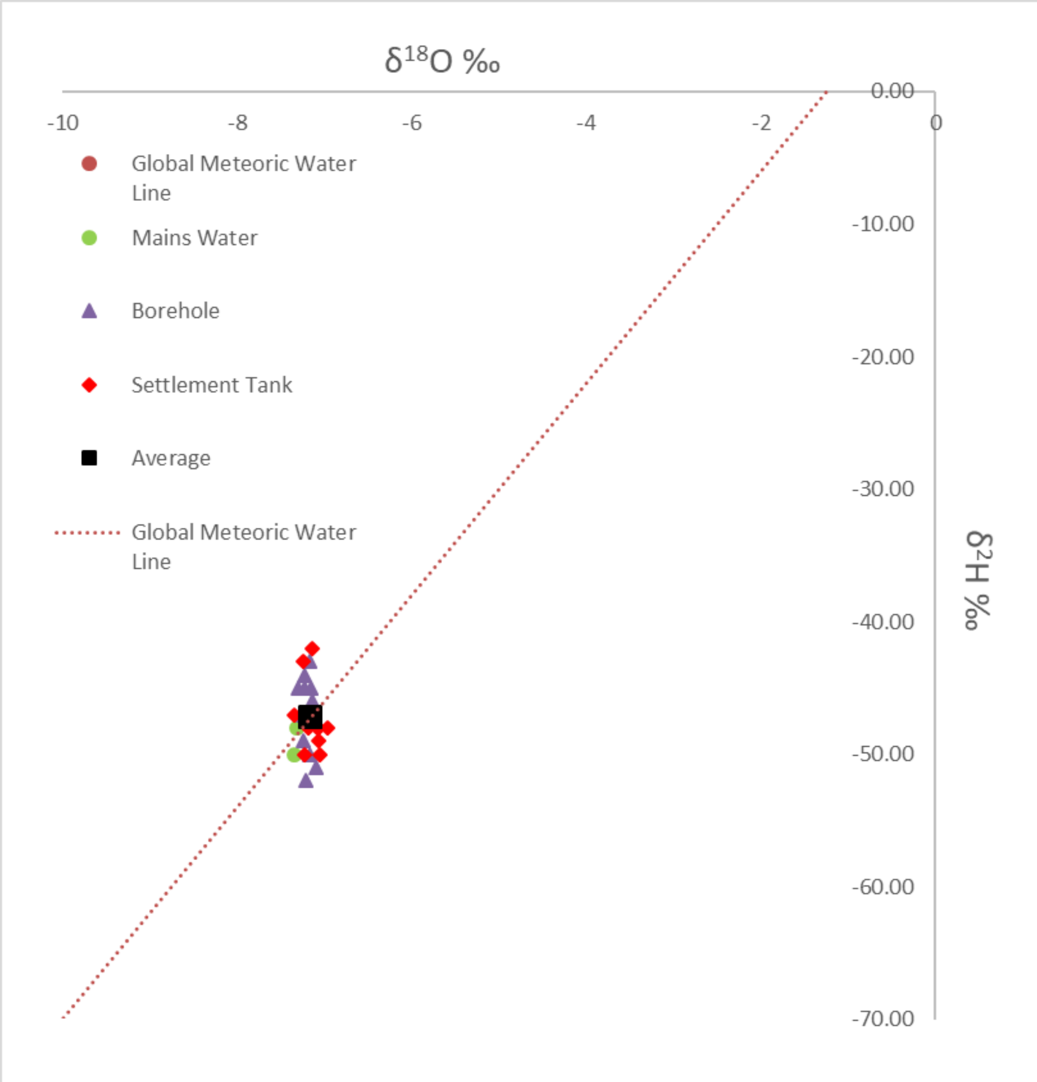

Figure 6: Stable isotope plot for oxygen and hydrogen of the borehole and settlement tank water samples, plotted against the mains water and the global meteoric water line (GMWL)

5. CONCLUSIONS

In the past 20 years there have been only two permanent MWGS established in Glasgow, the 65kW heating system in Shettleston and the larger ongoing developments of the UKGEOS site in Cuningar. The two installations took different approaches to research and planning. Shettleston consisted of a small team of engineers, architects and a geologist, and sought funding from the Scottish Homes initiative. The system was designed and installed without reported research into mine water chemistry or accurate depth measurements, but it did prove to run successfully for a good portion of its 20-year history before, more recently running into issues. The later data collection has provided an insight into the true depth and the chemical nature of the mine workings in question. The UKGEOS project presents a larger scale installation with many different academic bodies conducting research on the site bringing their own funding, on top of a large government research and development fund. This paper has presented some of the many datasets which are hoped to be generated by the project's 15-year lifespan.

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