Minewater utilization as a secondary heat source and heat storage in a smart local heating and cooling distribution system

ESHAGH GOUDARZI MSc, **HELEN TURNELL** PhD, **CATARINA MARQUES** PhD FInstR, **GRAEME MAIDMENT** PhD CEng MIMechE FInstR
School of Engineering, London South Bank University
goudarze@lsbu.ac.uk

1. Introduction

Mine water has been gaining increasing attention in recent years as a potential source for heat recovery and storage. This is due to its unique properties that make it an ideal medium for capturing and storing large amounts of thermal energy. Mine water is naturally heated by the earth's geothermal energy and typically has a constant temperature throughout the year, making it an excellent source of renewable energy. Additionally, the water's high thermal conductivity and large volumes provide an effective means for storing and transferring heat. With the increasing demand for sustainable energy sources and the need to reduce greenhouse gas emissions, the utilization of mine water for heat recovery and storage has become an attractive option for many industries and communities. In this project, we will explore the benefits of using mine water for heat recovery and storage, as well as some of the risks and challenges that need to be overcome to fully realize its potential as a renewable energy source.

One promising strategy is the integration of other sources of energy for heat recovery and storage with mine water systems. Previous studies indicate that nearly 54% of the primary energy used in the supply of electricity is wasted annually in the UK (Association for Decentralised Energy, 2017), with heat energy being the most easily dissipated form of energy. This research explores the feasibility of recovering and storing waste heat in mine water for inter-seasonal variation demands in Barnsley, South Yorkshire. Historical data has been investigated to aid interpretation in both 2D and 3D software packages. Furthermore, local mine techniques and coal mining maps were also examined to estimate the capacity in the upcoming stages of the project.

2. Purpose

The work builds on a feasibility study in Barnsley, South Yorkshire which showed that recovering up to 7MW of heat from the glass manufacturing and using the old mine workings as a means of storing and recovering heat is feasible and can be economic. In the original concept, the mine water allows for seasonal storage of heat and provides back-up and top-up to the main energy source, industrial waste heat. Recovering 7MW of waste heat requires a significant amount of water. Flooded abandoned mines are relatively permeable compared to untouched subsurface formations, and the mines in Barnsley present a high pumping rate opportunity. To minimize costs, it is desirable to use a minimum number of wells.

In this study, data from sources across a range of disciplines, including maps, historic records, logs, and relevant research, have been analysed in detail to construct a model of the subsurface and simulate the behaviour of groundwater flow. The objective is to predict the impact of different management strategies on the system over the long term. The approach demonstrates the value of combining the data into a single model, using all the available information, for example, taking account of the historic variation in workings between Room-and-Pillar and Longwall mining. Key parameters of the proposed scheme can be tested from this data-based model. The work shown explored the likelihood of different worked seams in the area to meet the proposed scale of local demand, i.e., to recover 7MW of heat energy. This model has been built through a novel approach using software such as BGS Groundhog and Schlumberger Petrel/Eclipse 300. In the next steps, these tools will be utilized to investigate the thermal response and the relevant flow behaviour of the model, building upon reservoir engineering techniques. This requires simplification of the grid and consideration of relevant rock properties. The results will be analysed to quantify the uncertainty ranges for such a project and reduce the risk of planning expensive test boreholes. Model results correlated with temperature measurements and flow tests will be extremely valuable for evaluating the commerciality of this and future similar projects in Barnsley and elsewhere.

2.1. Project Aim

The main aim of this research is to evaluate the feasibility to use minewater as a source of heat and for subsurface heat storage in Barnsley, for example from industrial waste heat.

The feasibility study will answer the following questions:

- What is the size of the local energy resource available from minewater? Is it extendable to multiple schemes in the future?
- What is the overall efficiency of the energy system?
- What is the impact of flow direction, rate/ abstraction/injection on sustainability over time?
- At what scale is the scheme economically efficient? (from abstraction point to surface excluding distribution and license costs).

2.2. Modelling Aim

The purpose of numerical modelling is to examine subsurface flow and temperature variation for a range of parameters in different energy recovery scenarios in Barnsley. The model can:

- predict the flow and thermal impacts of heat recovery on the long-term sustainability of the system.
- improve understanding of how to balance the system for example -
    - Quantify range (maximum and minimum) of water flow from different mine seams.
    - Examine the possible interconnectivity geometries.
    - Quantify the refresh (refill) rate for the system.
- test the impact of formations between seams on temperature and flow distribution.
- help to define the best locations for drilling abstraction and injection boreholes.

3. Functional Description of the Structural Model

3.1. Borehole Records and Groundhog

The initial model in Groundhog 3D enabled visualization of borehole data and a simplified 3D subsurface model, in order to gain a better understanding of the geological structure and stratigraphy of the subsurface. This information was then used to construct a more detailed model in Petrel. In this study, scans of 45 historical boreholes within the area were reviewed. Lithological information, depth and thickness variations were obtained from BGS records and digitised in Groundhog. Figure 1 provides an example of a borehole record showing a typical stratigraphic description and summary log from 1869. Additionally, regional geology maps and valuable regional correlations from 18th-century reports were used to understand the fluviatile depositional environment for the interpolation in Petrel.

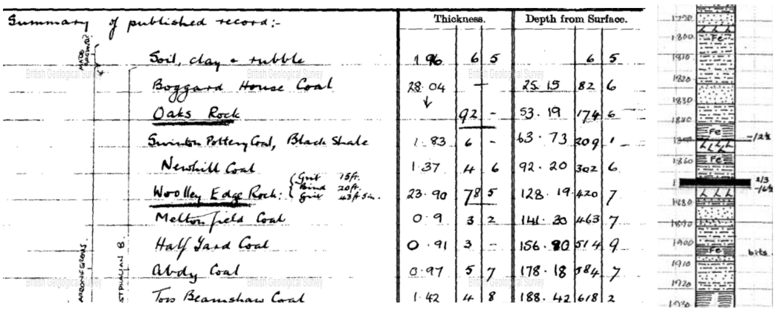


Figure 1: Example of borehole data recorded from 1896 (BGS)

Figure 3 shows the locations of some of the boreholes in the area centred around the glass factory. The colours represent the different geological layers at depth.

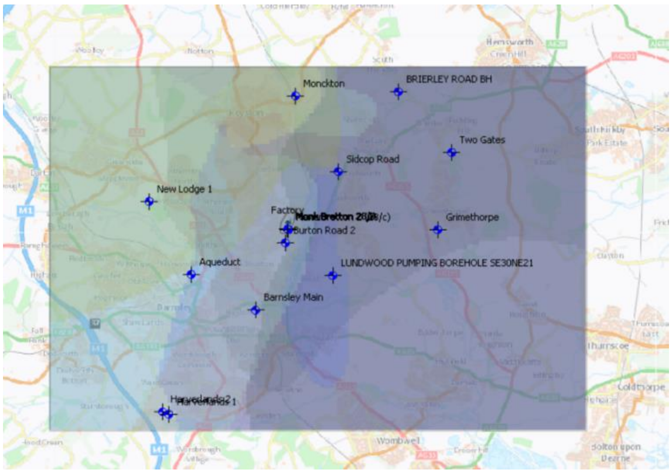


Figure 2: Well distribution around glass factory - the source of waste heat.

Figure 3 shows the digitised strata and thicknesses of layers in different boreholes. On the right-hand side shows transmissivity derived from the given lithologies (typical properties) for a small section of one well. Transmissivity describes the ability for fluid flow within the plane of the material and is defined as the in-plane permeability multiplied by the material thickness. Sands and abandoned mines have the highest transmissivity while clay has the least (Smith, Jones, and Johnson 2019).

A 3D model framework was created for the subsurface geometry of the coal seam stratigraphy in the area (Figure 4).

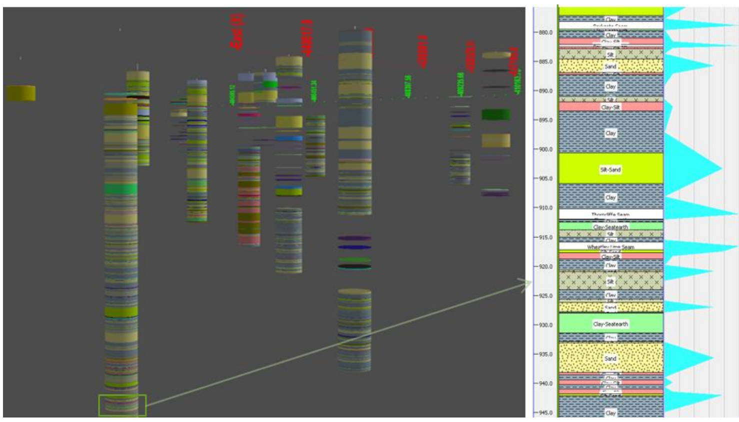


Figure 3: Digitised boreholes using Groundhog. Colours show different lithologies for a small section, lithology vs depth and a curve for transmissivity in light blue.

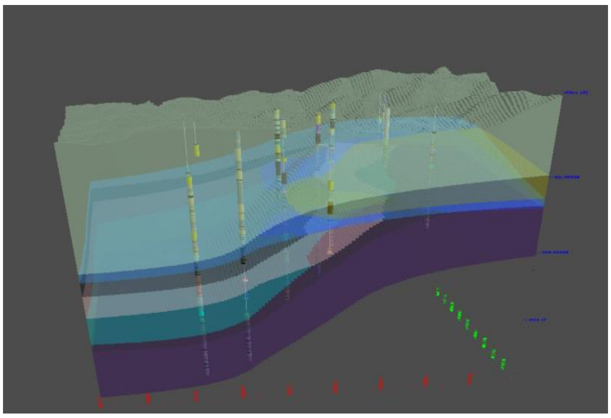


Figure 4: A simplified 3D model from correlating the borehole data. Colours represent subsurface formations.

3.2. Numerical Modelling in Petrel

Petrel is a numerical software that uses mathematical and computational algorithms to interpret geological and geophysical data both to build a static model and for a dynamic model to simulate reservoir behaviour as fluids are extracted through pumping. To begin with, information on the stratigraphy, sedimentology, and structural geology of the area were integrated into Petrel from the geological interpretations described above. Mine working maps for each specific coal seam provided more detailed depth data for better correlation between wells, see Figure 5. In a separate exercise, the 2D maps were assessed also were imported to calculate total mine volume in each seam, refer section 4. Figure 5 displays the map and the location of mineworking in Barnsley seam, source of heat and heat storage, in 2D and 3D within the area.

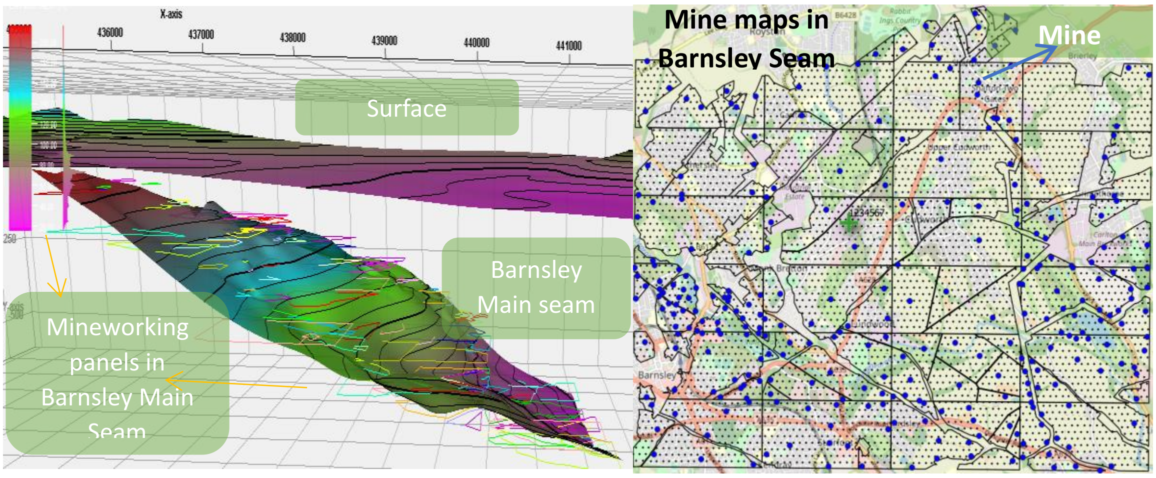


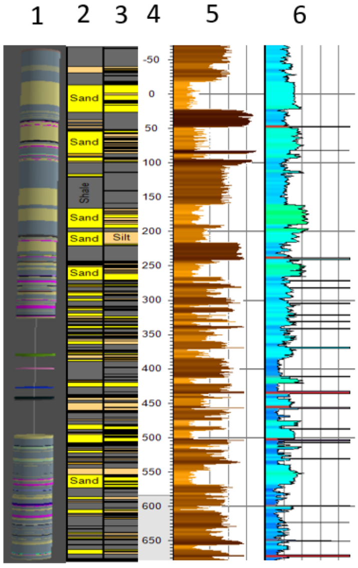
Figure 5: Mineworking panels in Barnsley main seam, right 2D, left, imported to 3D grid model and interpolated.

3.2.1. Gamma and Porosity Log

Well logs including data from drilling and well logging operations, such as gamma ray, and porosity logs are expected for a reliable 3D model. Different physical measurements provide lithological interpretation presented as continuous curves over the depth of measurement. The gamma log (GR), measures the natural radioactivity of rocks. Gamma ray logs are commonly used to identify and correlate different rock formations within a well. The Petrel software necessitates the availability of gamma log data, and in the absence of such data, it becomes imperative to generate a gamma log through lithological data obtained from coring. In this method, the lithology, or rock type, of the core samples was identified. Then the gamma ray emission properties of the lithologies were identified by using established values for typical lithologies. Due to the absence of direct logs, synthesised logs were prepared. Detail descriptions of lithologies at 0.5m intervals for 6 wells correlated these lithologies with gamma variation from a set of fluviatile gamma logs. Thus, provided typical log patterns from wells from similar depositional environments were used to create “synthesised log” for either gamma or porosity log.

In this research, porosity values were assigned to each 0.5m lithology unit and compared b with the log data associated with the gamma variation. A lithology-porosity table was produced for the interpreted facies linking BH data with the log values. This table was used to convert the lithological data to porosity values. Figure 6 illustrates an example of the assimilation of lithological data to synthesised well logs for 700m for the Brierly Road borehole.

Column 1 displays lithological variation from Groundhog. Column 2 shows interpreted lithology; filled in the gaps using data from adjacent wells and simplified the detail integrating thin layers into thicker units. Column 3 displays facies logs using synthesised gamma logs. This shows variation consistent with log patterns associated with fluviatile depositional environment/facies. Column 4 represents depth (m), while column 5 displays gamma logs obtained from lithological data at intervals of 0.5m. Finally, column 6 displays the similarly derived porosity logs.



Code	Name	Parent	Background
0	Sand		
1	Silt		
2	Coal		
3	Shale		
4	Sand-Silt-Clay		

Figure 6: Brierley Road borehole, well cross section data. Continuous and discrete curves; Wireline data vs depth.

3.2.2. 3D Modelling in Petrel

In Petrel, the next step after importing the prepared well log data is to correlate the logs using appropriate relationships between different layers of rock. This involves analysing the logs for common patterns and using stratigraphic facies. Facies are rock units that have similar properties as determined by the depositional environment (DE) that characterizes the formation, such as lithology, porosity, and permeability. Petrel interpolates the facies data across the grid between the well control points. This involves assigning each cell (in the 3D structural grid) a facies value based on the well data (Smith, Brown & Johnson, 2018). For quality assurance, the resulting 3D model was compared to regional interpretation based on other stratigraphic borehole data beyond the area of interest. Figure 7 shows the “Winter Seam – Low Beamshaw” zone, the cold source, inside the 3D facies model and the location of correlated well logs, while Figure 8 displays the porosity model for the same zone.

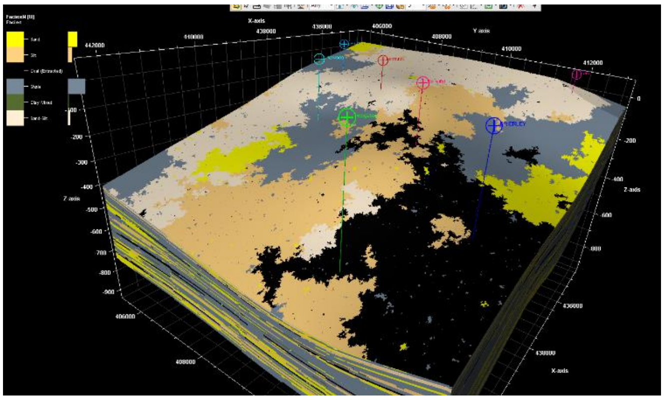


Figure 7: Model from top Winter Seam showing lithology variation (facies) model - cold source.

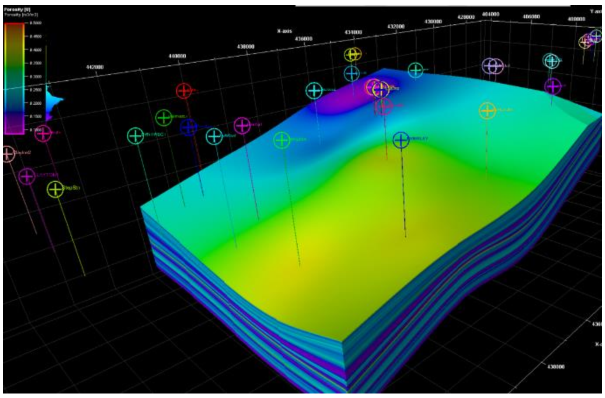


Figure 8: Model from Porosity model, Winter Seam - cold source

3.2.3. Permeability

Permeability is a measure of how easily fluid can flow through a porous medium, such as a rock formation, while porosity is a measure of the volume of pore space within a rock formation (Cheng and Agterberg ,1995). While there is a relationship between porosity and permeability, they are not directly proportional to each other. However, when the porosity and lithology data for a given formation are available, it is possible to estimate the permeability of the formation without requiring laboratory measurements by utilizing published empirical relationships (Mavko, Mukerji & Dvorkin ,2009). These relationships are typically based on core data and laboratory measurements, calibrated for a specific geological formation, and they can provide an estimate of the permeability for similar formations (Hajimoradloo and Moslemifar, 2019). Figure 9 depicts the permeability model that was derived from the analysis of porosity and facies logs.

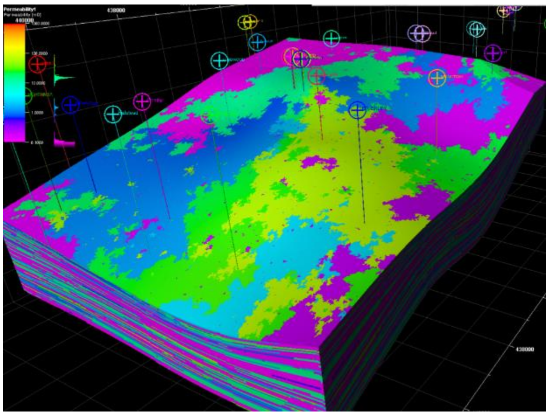


Figure 9: Permeability model, from top of the Winter Seam - cold source

4. Initial investigation of capacity and feasibility in Barnsley

This section analyses and discusses the demand, feasibility, opportunities, and future steps related to the subject at hand.

4.1. Heat demand in Barnsley and UK

For the proposed scheme of 7616 dwellings in the Barnsley area, an annual heat demand of 63,647 MWh of heat is required, and an additional 8 MW of heat is needed to support peak heat demand (Marques et al., 2023). This additional heat could be provided by utilizing stored waste heat in abandoned mines. Figure 10 illustrates the seasonal variation in heat demand for UK buildings, which is averaged in Figure 11 and compared to a constant mean. This shows that excess heat, if can be stored for 6 months could be used during the other 6 months.

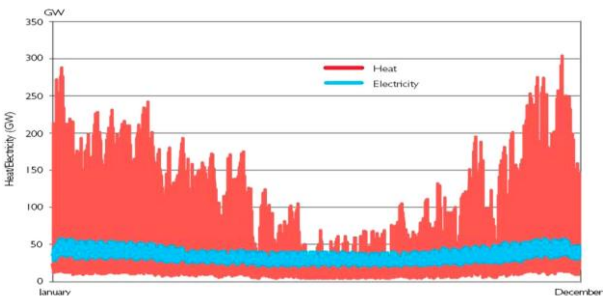


Figure 10: Seasonal variation in half-hourly heat demand for UK buildings (DECC, 2012)

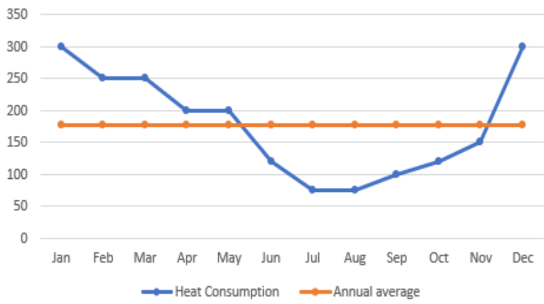


Figure11: Annual heat consumption vs average annual het demand

4.2. Void space analysis comparing supply and demand.

Storing 7 MW of heat requires a large volume of water and void space. The required flowrate to support 7MW heat based on temperature difference is displayed in Figure 12. This high-rate requires sources in high-transmissivity layers like sandstones, faults, and abandoned mines.

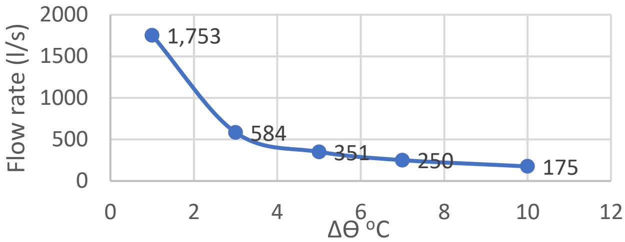


Figure 12: Required flow rate for storing 7MW of heat.

For the proposed operation's heat storage source (Barnsley Main seam), the seam thickness averages 2.5 meters, and the temperature can reach over18°C. The recorded water level confirms that the shallowest flooded seam below the area is Winter, at a depth of 138 metre below ground level (mbgl). Within the area, the Winter seam has an average thickness of 0.8 to 1.5 meters. Figure 13 shows the mineworking panels in the Winter seam from the top, where the red points indicate the use of longwall mining technique, and blue points represent the room and pillar mining technique. The longwall technique is extensively used in this coal seam. The thickness of mineworking panels in longwall mining technology can vary depending on several factors, such as specific geological conditions, the size and capacity of the equipment used, and safety considerations. In the UK, the thickness of these panels is typically around 2 to 5 meters (Smith, J. 2022). In contrast, the thickness of mineworking panels in the room and pillar technique is typically around 1.5 to 3 meters. However, given the variety of mining companies and technologies used since the 18th century, it is impossible to estimate the exact thickness of mineworking panels irrespective of coal seam thickness. Therefore, the thickness of the Barnsley seam is considered 2.5 meters, the same as the coal seam thickness. Unlike the Winter seam, the mines in the Barnsley seam are old, and the main mining technique used is room and pillar. The volume of the Winter seam is calculated based on average coal thickness, which has an average thickness of 1.1 m. However, due to the thin layer of coal, it is expected that the mine thickness and consequently the void volume will be at least double the coal volume. The volume of mineworking panels in each seam has been determined by integrating the available data in the model.

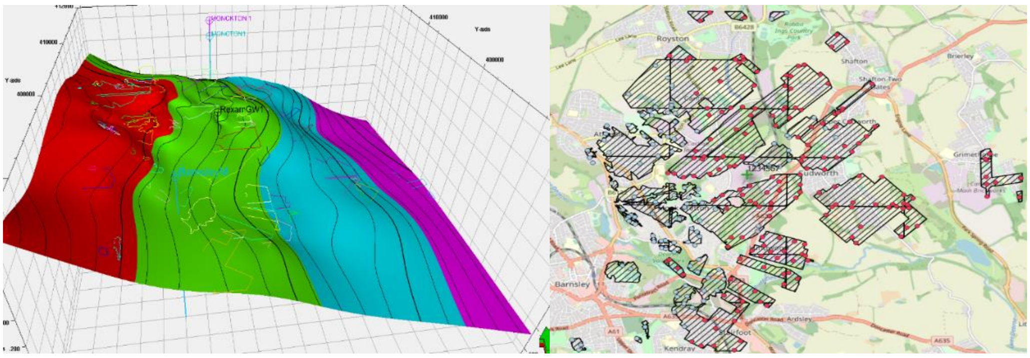


Figure 13: Mineworking map in Winter seam from the top (right-hand-side) and in 3D (left-hand-side)

The volume of the coal in mineworking panels in the Winter seam, the cold source, was estimated to be 13.1M.m^3, while the volume of mineworking panels is expected to be at least 26 M.m^3 conservatively. Barnsley seam is considerably larger with a volume of 92.5M.m^3. Assuming that the system is operational 70% of the time during the 6 storing months due to maintenance issues and demand limitations, a minimum void volume of 3.87 M.m^3 of water is required for storage in abandoned mines if 5°C of heat is extracted during circulation. There is some uncertainty in the void volume estimate. Mines worked after 1949 are expected to be collapsed due to the high-rate excavation in the Longwall technique, while older mines are partially collapsed. The roadways and connections could also be blocked at some points. Figure 14 shows estimates of the required mine volume in Barnsley's seams for a range of parameters. Winter and Barnsley volumes are compared with the required mine volume from the worst-case scenario (only 10% void volume) to the most probable situation (20% available void volume).

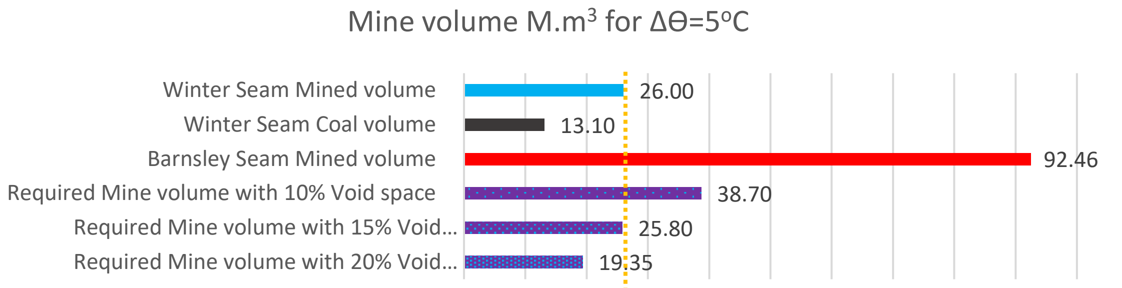


Figure14: Available mine volume vs required mine volume to accommodate required amount of water for ΔΘ=5ºC.

According to the graph, the Barnsley seam is capable of holding the required amount of water, while the Winter seam presents some challenges. If a section of the Winter seam is blocked due to panel collapse or a percentage of void volume lower than expected, it may not be able to accommodate the necessary water volume. Figure 15 compares the potential continuous pumping rate from the Winter seam over a six-month period under various void space and heat transfer conditions. The orange colour on the graph represents the available flowrate from the Winter seam, while the blue colour indicates the additional flowrate required to support a 7MW energy output in each scenario.

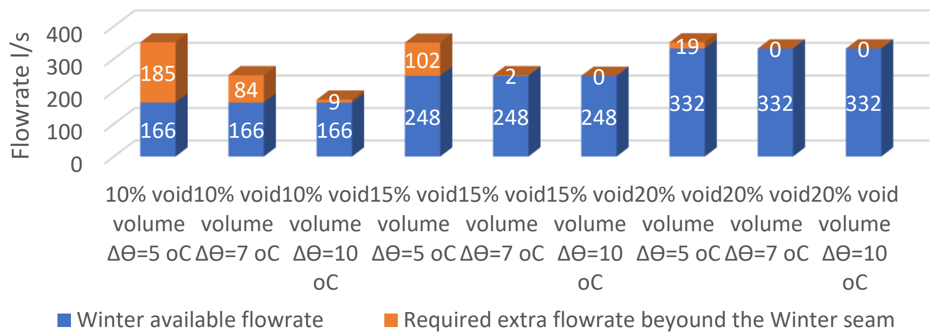


Figure 15: Winter seam: Additional abstraction flowrate to support 7mw HP.

Under the most probable scenarios, the Winter seam alone is sufficient to support a 7 MW heat scale project. However, additional flowrate may be required during periods of high demand. The Beamshaw seam, which is located at a shallower depth of 171 mbgl, may be able to provide the necessary extra flowrate. The Winter and Beamshaw seams are connected at Wharncliffe Woodmoor 4&5, the local colliery in the area. We analysed the volume of mineworking panels in the Beamshaw seam and found that the total volume of both the Beamshaw and Winter seams is considerable and allows for later extensions of the project at a larger scale.

The volume capacity of a heat recovery and storage project must be studied carefully over the long term to ensure the efficient and effective utilisation of heat flow. In addition to analysing the structure and volume capacity of the system, it is essential to evaluate the flow circulation and heat transfer within the structure. By gaining insights into these factors, we can better manage the project and optimize its performance.

5. Conclusion

After This work has developed a new approach to quantify key variables in different low-carbon SLES scenarios for Barnsley. Energy storage in mine water can help to balance seasonal demand variation in addition to offering a long-term heat source. In the primary study mine water in local coal seams analysed and showed it can provide sufficient volume to heat homes at scale in Barnsley.

The subsurface model shows the overall rock properties distribution consistent with relevant published interpretations and model results can be tested against site temperature measurements and pump tests for validation.

flow modelling, the next step to create a thermal subsurface model in Eclipse 300 would integrate the required data, which may include geological and petrophysical data, as well as data on reservoir fluids and their properties. This data can then be used to create a three-dimensional geological model of the subsurface, which will serve as the basis for the thermal model. The thermal model will incorporate information on the thermal properties of the reservoir rock and fluids, as well as the temperature distribution throughout the reservoir. This model will then be used to simulate the behaviour of the reservoir over time, taking into account changes in temperature, pressure, and fluid flow.

Ultimately, the goal of creating a thermal subsurface model in Eclipse 300 is to better understand the behaviour of the source and optimize production, by providing insights into factors such as well placement, production rates, and the timing of production.

6. References

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