As part of my first year of PhD, I have first undertaken literature reviews on different aspects of the research : 1) modelling approaches for groundwater flow and heat transfers in coal mines, 2) heat extraction from borehole heat exchangers, 3) solar fluxes, 4) climate disturbances on geothermal gradient, 4) radiogenic heat production in sedimentary areas, together with an extensive review on the geology of Scotland with a focus on the Midlothian Coalfield.

During my placement at the Coal Authority, I had the opportunity to get familiar with the available data to define how they will be used to contribute to my research. Monitoring data (i.e. temperature, flow rate, water level), GIS data and mine plans have been made available through an Academic license. Other data collected online includes geological data (BGS database, Glasgow UKGEOS Observatory) and climate data (Meteorological Offfice website).

The three main research questions of my PhD have been defined:

- What are the main heat sources and heat transfer mechanisms in abandoned flooded coal mines?

- What is the footprint of past mining activities on the heat distribution in coal mines ?

- What are the key mine features influencing the heat exchange rates in mines?

As part of RQ1, I have created a conceptual model of mine workings allowing to simplify the heat transfer problems by isolating the different elements of the mines (i.e. simplification of the geometrical features, identification of the recharge/discharge areas and heat sources). I started to look at the relative contribution of radiogenic heat production, geothermal heat flux and of the solar heat flux on the heat profile and heat production/recharge rate. The amount of solar recharge was determined by evaluating the amount of surface heat flux required to reproduce change in surface temperature in Scotland, using 1D models representing a vertical column of rock. This as been done in order to quantify the amount of recharge available and the footprint area of heat extraction required to provide the required energy to a single-house in the UK, using purely diffusive heat fluxes.

To verify the ability of the finite-element numerical modelling software OGS to deal with heat transfer processes, we started to benchmark the diffusive-advective heat transport within a horizontal porous layer. From there, I have undertaken a sensitivity analysis on the effect of material thermal/hydraulic properties on the rate of heat transfer between a porous coal layer embedded in an undisturbed host rock and on the overall temperature change in the system, depending on the boundary conditions.

As part of the RQ2, I have created 2D models of mines of simple geometries, composed of 3 worked coal seams, for which I have simulated a long-term mining period with water extraction (i.e. 30 years), followed by a recovery period (i.e. 50 years) considering different scenarios (i.e. boundary conditions representing a water originating from different sources). This preliminary analysis showed that perturbations of the geothermal gradient in mines due to mining activities might be permanent.

Based on those 2D models, I also attempted to reproduce temperature profiles in wells, based on data from the Coal Authority.

As part of RQ3, I finally looked at the overall change in energy content within simple 2D models with similar properties and boundary conditions, based on the geometry of the worked coal beds. Results indicated that the spacing between coal beds might influence on the overall heat capacity of a mine. In addition, I have pre-processed available GIS shapefile for future utilization as input to the meshing software GMSH.

Before lockdown, one to one meetings with my main supervisor occurred approximately once a month. The aim is to discuss my progress, what I have been working on, the obtained results and how they can be interpreted, in order to define the next steps (short-term objectives). Those meetings help me focusing on a particular objective for the following weeks, and allow me to get clear answers on the questions I would have. At the start of my PhD, two meetings have been organized with the whole supervisory team in order to discuss larger scale objectives, such has the context of my research, the general research questions, the papers we could aim for. In addition, less formal meetings have been organized as part of 'requests for spontaneous problem solving', with my main and secondary supervisors. Those helps me progressing on my research on a daily basis by avoiding me to be stuck on technical issues (i.e. modeling issues).

Since the lockdown, one-to-one meetings have been organized once with each member of my supervisory team, as well as three group meetings allowing to prepare and give feedback on the confirmation panel, that took place on the 11th June. In addition to preparing the confirmation panel, those meetings have been useful to refine the research questions, the time frame to devote to each task, with a particular focus on the aim of the first paper to be published in the near future. Having more perspective on my project, those meetings have been important to clarify the issues and objectives in terms of what is missing in the literature and what would be fundamental to know, as well as the approaches to solve them.

To summarize, meetings have not been planned at a defined frequency, but are generally organized 3-5 days in advance, when deemed necessary either from my supervisors or myself. Their availability via e-mail allow me to communicate more regularly on the work I am performing in the meantime, which allow them in return to redirect me on the good track if I tend to disperse.

Due to the COVID-19 situation, many conferences have been cancelled (i.e. PGR conference), postponed (i.e. World Geothermal Congress, Mine Water Symposium), or turned into webinar series. Currently, I am attending online events such as the All-Energy webinar series, UK-WING meetings, GeoEnergy group meetings (Edinburgh University) or geothermal-related webinars organized by other institutions (i.e. Subsurface Energy Virtual Conferences organized by Newcastle University, GEORISK International Webinar). During the lockdown, I have also attended a series of online workshop organized by IAD (i.e. Top Tips for Writing a Literature Review, An Introduction to Copyright and Publishing), some of the presentation organized as part of the PhD Horizons Webinar Series, Online DTP Trainings as well as workshop organized by Elsevier on publishing papers. Finally, I have participated earlier in June to an online 3h course on Modelling Geothermal Reservoirs with CMG software and registered to the online courses 'Python for Data Science' and 'Using Python for Research' on edX to improve my understanding of python coding, as well as the 'Research data and management' course from Coursera.

During my first year of PhD, I have performed two presentations of my research project in front of the GeoEnergy group, one presentation at the GradSchool conference as well as one during the confirmation panel. Moreover, I have attended the 7th London Geothermal Symposium in November 2019. In February 2020, a press release has been published by the Coal Authority (CASE partner) on my PhD project (https://www.gov.uk/government/news/mine-water-heat-under-the-phd-spotlight). Finally, I am currently writing an article that aims at being published in the July WING newsletter.

This year, I have been a field demonstrator for the Earth Dynamics course (Siccar point Field Trip) and a tutor for the Hydrology-1 (Semester 1) and Hydrology-2 (Semester 2) courses. I have also been a lab demonstrator (including marking) for the Introduction to Geological Records course, for which I should have been Field demonstrator for the Lake District Field Trip (cancelled because of Covid-19 lockdown). In addition, as a member of the GradSchool Committee, I have been organizing from May monthly online GradTalks sessions (1-hour seminar series where MS and PhD students present their research work).

My goal for the following month is to complete a first paper on subsurface heat extraction. Through this paper, the objective is to get an overall understanding of the energy balance in the subsurface, based on a typical geological profile for Scotland, on the relative contribution from different natural heat sources and on the energy required for a single-house in the UK. Analytical and numerical modeling of purely conductive heat transfers will be used to verify the mathematical and conceptual models. From next September, my objective is to start looking at energy balances in mines, considering both conductive and diffusive heat transfers. The mine will first be modeled as a highly-porous horizontal or dipping layer in a 2D geological profile. Using this model, I aim at getting a better understanding of the effect of 1) the geometry, 2) the boundary conditions and 3) the long-term mining/cooling of galleries, on the temperature distribution in the mine. A key objective will be to characterize the relationship between the temperature of the water in the mine galleries/tunnels, the temperature of the rock surrounding those geometrical features, and the temperature profile measured within the shaft. To conclude, I will start generating 3D models reproducing scenarios similar to those modeled in 2D, to better understand if/how 3D processes can be faithfully represented in 2D.

The lack of historical and current temperature data within the mine galleries represents the greatest challenge, as it limits the possibility to calibrate and verify the numerical models. Before using real case-related data, and hoping than more data will be made public in the meantime, the plan to overcome this issue will be to generate a series of end-member modelling scenarios. Sensitivity analysis will be made on the impact of different properties (i.e. total porosity, permeability, conductivity), of the boundary conditions (i.e. inflow temperature) or the geometry of the mines (i.e. coal beds thickness, flow path length) on the overall temperature change/footprint area of heat extraction in the mine. The choice of the end-member scenarios will be made based on the geological/structural context of the two case study (i.e. Midlothian Coalfield, Dawdon-Horden mining field) and the results will be validated based on the relative trend of temperature profiles and time series.

**Plan of action**

<https://www.star.euclid.ed.ac.uk/urd/sits.urd/run/SIW_YGSL.start_url?27A4A5E2AED411EA8fuEs94wS9K_x763GafKwX4rfVY5kUfsAnOqkTLA0PawbOs1RmyvNG4mVMz6jE4VVrzRlmhdJrYnpLK6nddrAajVX-4IKzvrS2zlvp_uP49lTxcPCunDcsnGTMyTKDdIJTyu-Yy7hqTKKeyZxyyNAXdfvMAtm0lRhevkAk0obFrx_DjD2QpVACyHo3Aey0FAZ4Lkj4yS8pZAFHY5pYLNDaF7tftMhRgSHjvxR6CTy6K6_JJXdiWtJXjN4kxF6yeZG-s22jxiaBXEhGdPI_AVn6o41GpWYC2DdgdWgNr-7nw3rZy9h1tzuXT9oEXlRXcqxpb9ctdMAWBLvZKU8ops5GRxN6b-YZNRIAhYbtWqbcQ>

1. What are your goals for the year ahead in relation to your thesis?

2. Give a rough plan for achieving these goals, identifying any areas that you believe could present challenges. If you are in second year or beyond, please give a rough plan for completing your thesis

Next step is to evaluate the contribution of advective heat transfers on the heat extraction/recharge rate from GSHP, we aim at publishing a first paper on the sustainability of heat extraction from borehole heat exchanger. This paper will focus on heat extraction from shallow depth, aiming at calculating the footprint area and showing the necessity to bring artificial recharge to the ground in order to maintain sustainable production. Calculating the surface heat flux appeared to be closely related to the current state of the geothermal gradient. I have therefore created a python script allowing to simply calculate the surface and bottom heat fluxes along an unsteady-state temperature gradient in heterogeneous ground, based on the output from OGS.

Together with an analysis of the mine-water temperatures available throughout the UK, numerical modeling will allow solving for advective-dispersive heat transfers in coal mines.