Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The Reutilization of the Dannenbaum Coal Mine for Heating and Cooling of the Redeveloped Commercial Area Mark 51.7 with Mine Water

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Keywords: abandoned coal mines, mine water, low-ex grids, directional drilling, heating and cooling.

ABSTRACT

It is planned to provide the heating and cooling supply for the redeveloped commercial area Mark 51.7 (former Opel plant 1) by using the thermal source of mine water from the abandoned coal mine Dannenbaum that is located below the area. After the closure of the Dannenbaum colliery in 1958, the shafts were filled and the mine was flooded to above the Level 4, at least up to 190 m below sea level. For the realization of mine water utilization, the subsurface infrastructures of the former Dannenbaum colliery are to be developed via production and injection wells using directional drilling technology. For the heat supply, a well is to be drilled into the water-filled galleries in 8th level at a depth of 816 m below surface with projected undisturbed temperature of up to 36°C. For the cooling a second well is to be drilled into the 4th level at a depth of 334 m below ground, where temperatures of approximate 18°C are expected. The necessary measures for the project are: 1) a low-temperature heating grid (low-ex grid), 2) a cooling network for room cooling and air conditioning, 3) the development of the mine building via two or more directional wells and 4) a heating and cooling center with reversible heat pump system. The heat pump system should provide 80% of the required annual heat requirement and 100% of the annual cooling requirement. The remaining 20% of the peak heat requirement is exceeded by the upstream local heating network provided nearby. The proposed mine water utilization for heating and cooling supply has not been realized in Germany so far. At this stage of the project, it is planned to provide the base load with a maximum of 6,704 MWh of heating and 4,376 MWh of cooling via mine water utilization. In a multi-level modeling concept, the planned mine water utilization is numerically investigated. In this context, the possible influence of the mine water utilization and the regeneration of the heat reservoir in connection with the existing mine water drainage of the RAG is determined.

1. INTRODUCTION

To achieve the ambitious climate action goals of the Paris agreement (COP21), there a very big challenges from the energy transition. While the part of renewables in the electric power sector is rising significantly in the last years, the heating sector is clearly neglected. In Germany, for example, the heat energy accounts 54% of the total energy requirement (Figure 1). Accordingly, we must place more focus on thermal energy transition. Conventional energy sources should be substituted by geothermal energy, bioenergy, wind and solar energy and heat storage.

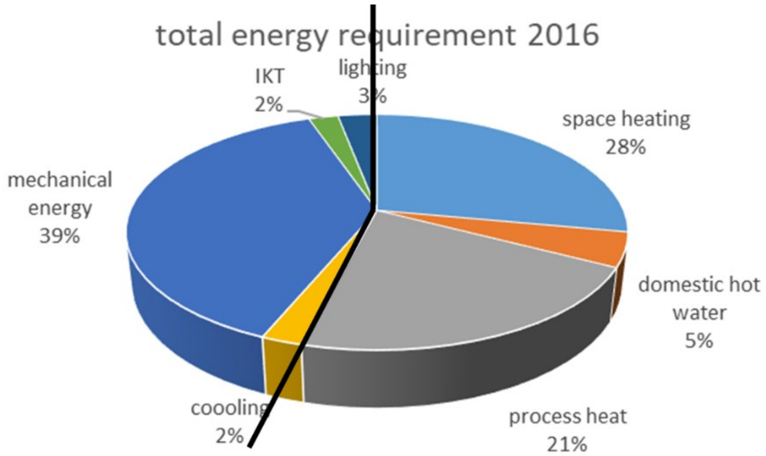


Figure 1: Total energy requirement 2016 in Germany

In the Ruhr area there is one of the largest district heating networks in western Europe with a length of more than 2.000 km and an annual heat supply of 6,500 GWh / a. It is currently almost completely fueled by gas and coal. The International Geothermal Centre have made it to their central task to contribute to the large-scale conversion of district heating in the Ruhr Metropolis and pursue in particular the following three approaches.

(1) Development of deep geothermal potentials for the existing grids
(2) Conversion / expansion to low-ex grids with energetic upgrading of existing geothermal low-temperature reservoirs. In addition to shallow geothermal energy, the Mine Water could be used in the Ruhr area.
(3) Establishment of seasonal heat storage. For this purpose, especially in the Ruhr area, the water-filled mining buildings of the former coal mining could be used.

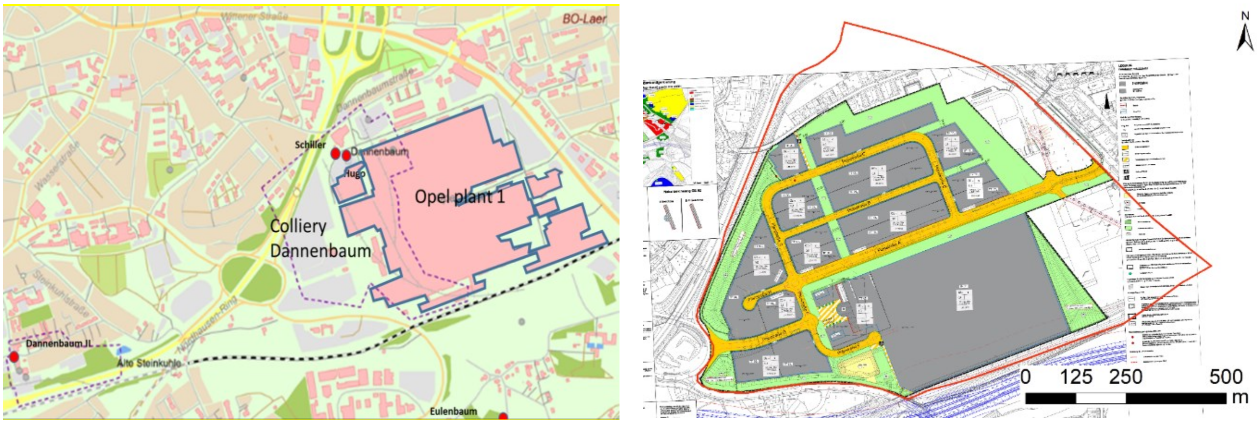
The presented pilot project will take place at the "Mark 51°7" location, which covers the area of the former Opel plant 1 in Bochum (Germany) (Figure 1). By the FUW GmbH (Stadtwerke Bochum group) an energy supply concept has been drafted. Accordingly, heating & cooling of about 40% of the area shall be supplied by using the thermal source of mine water from the former mine Dannenbaum (that lies below the area) with the support of a heat pump system. The overall investment consists of three elements:

(1) The development of the mine building via two or more directional wells
(2) Installation of a low-temperature heating grid (low-ex grid),
(3) Installation of a cooling network for room cooling and air conditioning,
(4) Construction of the heating & cooling centre with reversible heat pump system.

The proposed utilization of mine water via an open doublet system and connection with regeneration of the heat reservoir has not yet been realized in Germany. The heating and cooling grid at Mark 51.7 is to be established as 5th Generation District Heating and Cooling. 5GDHC has a huge potential for scaling-up and rolling out in Germany, and specifically in the Ruhr area, considering the large existing DH networks (mainly 2nd and 3rd generation) which can be upgraded to 5G. The special model character of the project will be emphasized by a comprehensive scientific support program, which includes thermo-hydraulic-density modelling, a comprehensive sensitivity analysis and a monitoring concept. This will allow for a better assessment of economic, technical and environmental risks of future projects.

2. DEVELOPMENT OF THE SITE MARK 51.7

The first coal mining on the site occurred already in the 14th century. The Dannenbaum colliery started operations in 1736. There are various principal adit level and other pits documented. The entire area is characterized by near-surface mining. In 1859 shaft Schiller, 1873 shaft Dannenbaum II, 1888 shaft Hugo and 1899 shaft Eulenbaum were sunk (Figure 2 (a)). The mine layout consists of a total of eight levels with a maximum depth of 820 below ground. In the 20th century, due to operational optimization, the Dannenbaum colliery was merged with the neighboring collieries Prinz Regent and Friedlicher Nachbar via connecting galleries on some levels. The three collieries were aggregated to one water management province, called Friedlicher Nachbar. Figure 3 shows the entire mine layout of the 4th level (blue) and the 8th level (red). In 1958, the final closure of the mine took place. Afterwards the shafts were backfilled and the mine were partly flooded. The current mine water level corresponds to the pumping level of the dewatering location of the formerly colliery Friedlicher Nachbar (Figure 3). The German coal mining company RAG is pumping mine water from a depth of 190 m below seal level with an annual volume of 5.9 million m³ (as of 2017) at this site and discharging it into the Ruhr River.



(a) **(b)**

Figure 2: area Mark 51.7 with (a) former Opel plant 1 and Dannenbaum Colliery with shafts Schiller, Hugo, Eulenbaum and Dannenbaum II in Bochum-Laer, Germany (modified according to www.ruhrkohlenrevier.de) and (b) Development plan (Stadt Bochum, 2019).

Due to the construction of Opel plant I in Bochum, the well-developed site of the abandoned Dannenbaum colliery was reused. Vehicle production took place between the opening in October 1962 until the complete closure of the plant at the end of 2014. The opel site is shown in the Figure 2 (a). The blue framed areas are factory buildings, which were mostly dismantled.

For the preparation and marketing of the area the Bochum Perspektive 2022 GmbH has been founded. A private company formed by the shareholders Adam Opel AG (49% share) and the urban economic development company Bochum (WEG 51% share). The property areas of Adam Opel AG were taken over on 01.07.2015. Figure 2 (b) shows the development plan 947 as of December 2015 of the city of Bochum. MARK 51.7 will be an industrial, technology and knowledge campus that addresses the needs of future work environments and enables companies to provide a highly attractive work climate for their employees all in the spirit of work-life-blending.

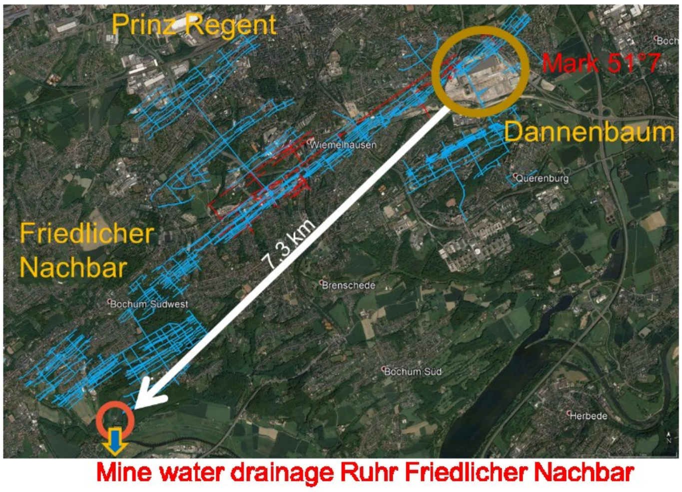


Figure 3: Mine layout of collieries Dannenbaum, Prinz Regent and Friedlicher Nachbar at the 4th level (blue) and at the 8th level (red) (GZB).

3. CONCEPTIONAL DESIGN

3.1 Development of the mine building

The mine water of the abandoned Dannenbaum colliery is to be used innovatively as a geothermal energy reservoir for the planned heating and cooling supply on the Mark 51.7 site. Presently, the mine is flooded above the 4th level, at least up to 190 m below sea level (cf. Chapter 2). It is assumed that within the mine building due to the increased geothermal gradient of the Ruhr carbon an undisturbed temperature level of up to 36°C (Leonhardt, 1983) can be anticipated on the 8th level at a depth of 816 m below surface, which can be used for heating production. For the 4th level at a depth of 334 m below ground, according to the measured water temperatures of Friedlicher Nachbar, a temperature of 18°C is expected, which can be used for cooling. Because the formerly shafts are backfilled, the mine building is to be developed hydraulically via directional drilling into the waterfilled galleries of the 8th level and the 4th level. During the winter months, the up to 36°C "hot" mine water is to be pumped by means of an electric submersible pump (ESP) from the 8th level to the above-ground energetic station. be supplied to the corresponding heat pump system. The mine water cooled down by the heat pumps is to be reinjected into the 4th level with an injection temperature of approx. 18°C (Figure 4). In summer this process is reversible and the "cold" mine water from the 4th level is lifted by means of an ESP, heated by the active cooling mode of the heat pumps (reversible operation) up to 40°C and then reinjected into the 8th level (Figure 4), so that a regeneration of the heat reservoir for the next winter can take place here.

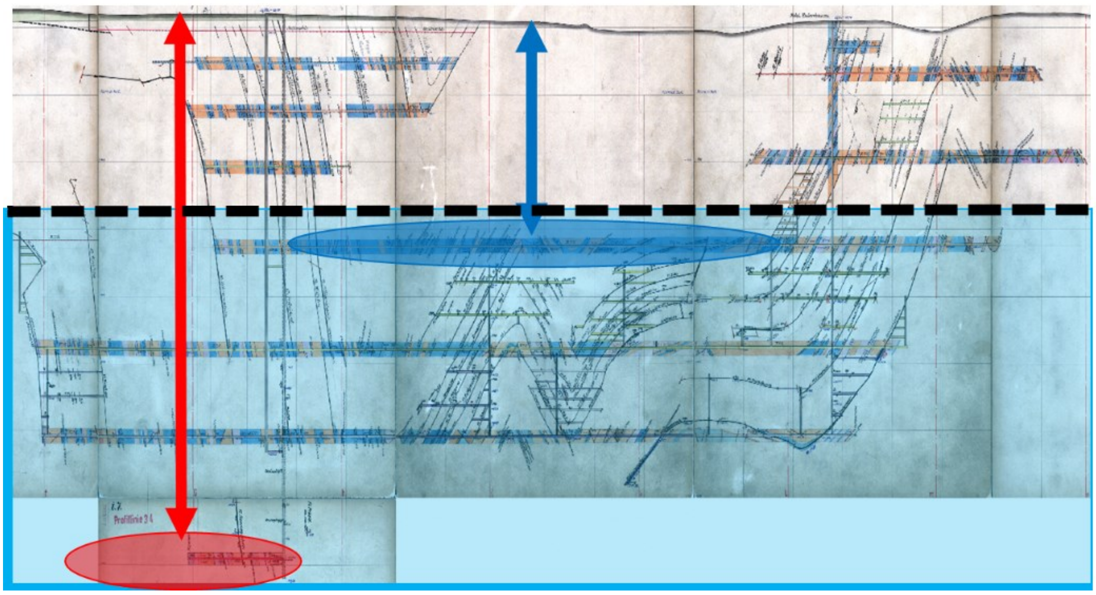


Figure 4: profile section of the colliery Dannenbaum (BR Arnsberg, Abteilung Bergbau und Energie) with the heat (red) and cold (blue) reservoir and the expected water level (dotted line).

The challenge of the directional drilling technique is to drill exactly in the underground galleries (Figure 5) at the desired level. The diameters of the galleries are in the range of approx. 3 - 4 m.

To localize the appropriate target points within the galleries, the following selection criteria were used

- Minimum distance between start and target point.
- Largest possible cross-section (e.g. intersection of galleries).
- Sandstone as surrounding gallery rock (highest residual strength).
- No intersection of geological fault zones and galleries and excavation-damaged zones of the higher level.

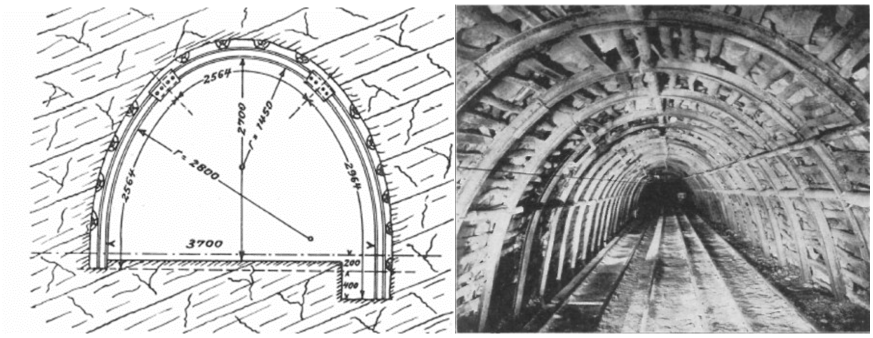


Figure 5: typical gallery of Dannenbaum colliery.

Figure 6 below shows a target range of the 8th level that meets all selection criteria.

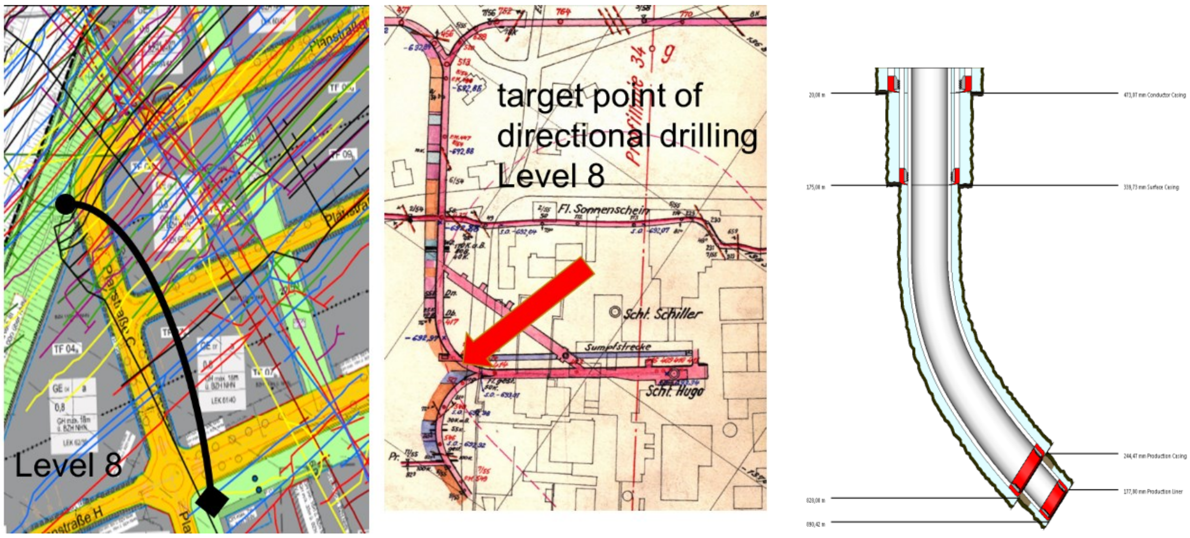


Figure 6 Drilling path, tubing concept and target point of the 8th level well

The drilling path pre-planning was performed using the Landmark Software. Figure 6 shows the drilling path and tubing concept. The lower part of the wells has a drilling Diameter of 311 mm and a production casing diameter 244 mm. Due to the local geology and planned drilling depth, a mobile drilling rig can be used.

3.2 Heating and cooling grid

Due to the new construction with the implementation of the EU Buildings Directive of 2010 it is possible to minimize the energy requirements and grid temperatures accordingly. The establishment of 5th Generation District Heating and Cooling in the area Mark 51.7 could be considered. The area relevant to the low-ex-grid includes the northern (section II east) and eastern part (section III) of Mark 51.7 (Figure 7). For the southern (BA I) and western part, an energy concept has already been implemented or other supply concepts are being pursued.

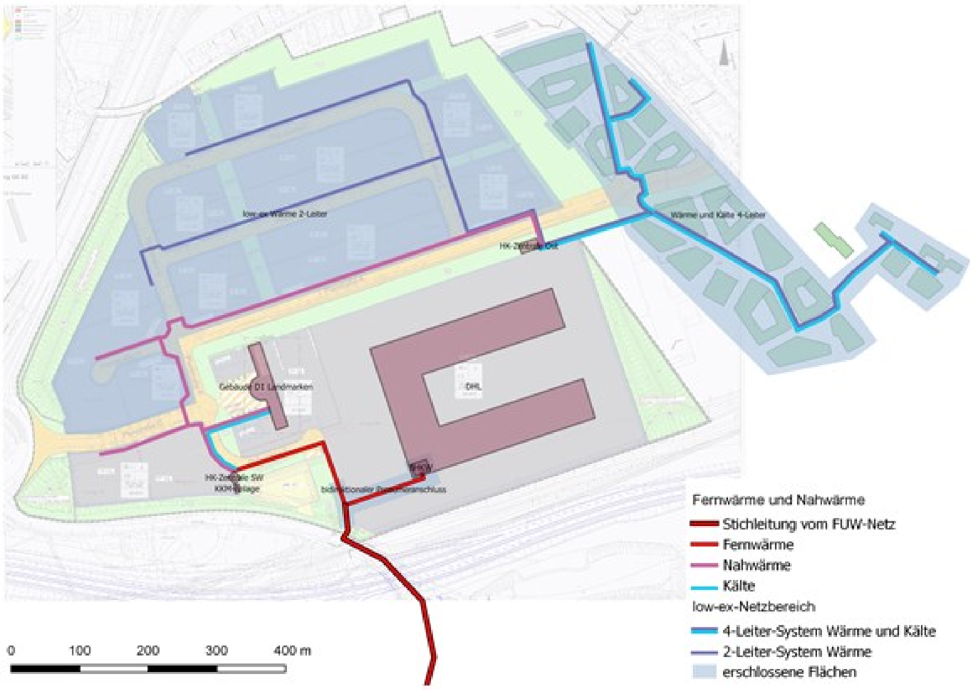
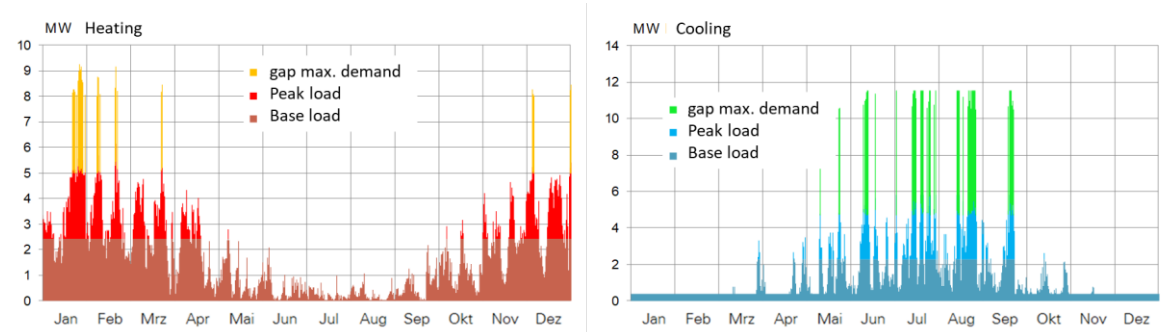


Figure 7: Grid scheme of mark 51.7 changed according Development plan (Stadt Bochum, 2019).

The pumped mine water cannot be used directly, but must be raised or lowered by means of a heat pump / cooling machine to a temperature level that can be used by the customer. Inlet temperatures of the grid are required for the heating case of 48°C and for the cooling case of 10°C, The temperature rise of the heat pump / cooling machine is lower in both cases than in standardized applications. Very high seasonal performance factors can be achieved if the machines used are adapted to these temperatures. The energy demand figures were calculated on the basis of the building area, floor height, density characteristics, energy standard and expected usage. The following Figures 8 (a) and (b) show annual load duration curve for the heating and cooling case (maximum variant).



(a) (b)

Figure 8: Annual load duration curve with base and peak load for (a) the heating case and (b) cooling case (Gertec GmbH, 2018).

At this stage of the project is planned to provide the base load with a maximum of 6,704 MWh of heating and 4,376 MWh of cooling via mine water utilization. This can be achieved by taking into account the electrical power requirement for submerged pump and heat pump / cooling machine seasonal performance factors of 4.79 in the heating case and 4.40 in the cooling case. The pump quantity is 303,000 m³ in the winter half year and 171,000 m³ in the summer half year. The remaining peak heat requirement is exceeded by the upstream local heating network provided nearby.

3.3 Coupling of the systems

The development concept for mine water use with the time characteristic and the magnitude of the energy flows for the feed-in and feed-out into the mine building will be adjusted according to the scenario of heating and cooling supply described in chapter 3.2 on the basis of the determined demand of energy and the temperature drop in the planned supply grid.

An iterative alignment process takes place between the mine water concept and the above-ground spatial and technical specifications. These include the diameter of the wells, the location of the starting points (drilling site), the heating and cooling plant and the heat and cooling grid as well as the dimensioning of the individual plant components such as pumps, pipelines, process measuring and control technology devices etc. Decisive for the dimensioning are, in particular, the volume flows and the temperature differences between flow and return of the grid.

By means of an underground model and numerical thermal-hydraulic simulations (see chapter 4), the developed mine water utilization concept is validated, whereby the extent to which the selected target points of the wells in the mine building under the thermal and hydraulic conditions of the subsurface can sustainably provide the heat and cold volumes over a period of 50 a is considered.

3.4 Permission process

Initial discussions on the approval process have already been held with relevant authorities (mining authority, lower water authority). Requirements and the approval procedure were explained and possible critical points identified. The Authorities requested an evaluation of subsurface conditions by means of density-dependent flow and heat transport calculations. The numerical simulations by delta h Ingenieurgesellschaft mbH, Witten (see chapter 4) shows no significant salination of the upper 4th level and the mine water drainage of Friedlicher Nachbar over reinjected (saline) waters from the lower 8th level. The basic approval capability of project is given.

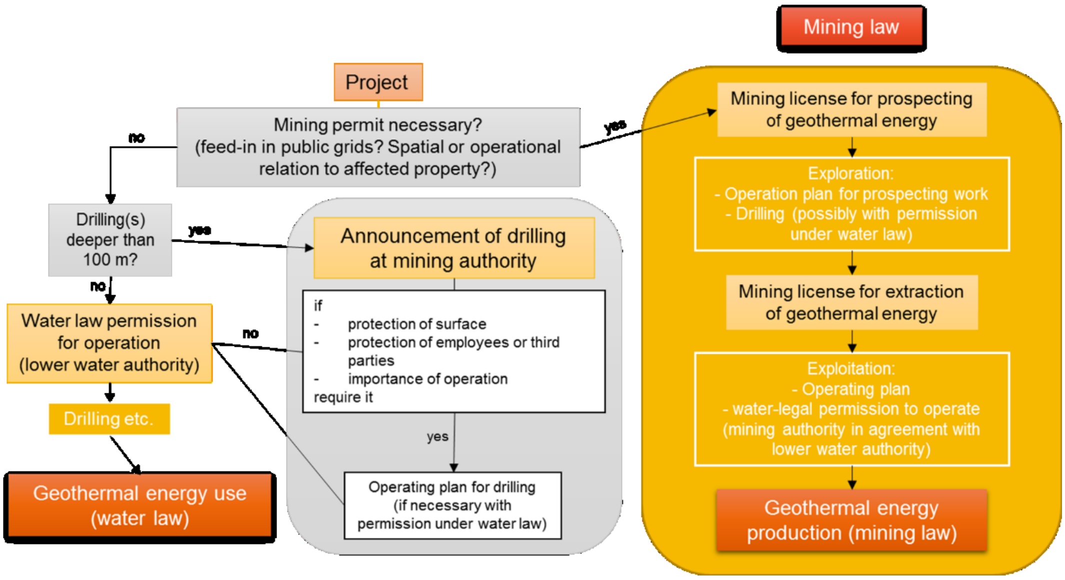


Figure 9: Permission process for geothermal projects in Nordrhein-Westfalia, Germany (GZB, 2019).

Negotiations were also held with the mine owner (E.ON SE). It is required a license agreement to regulate the intervention in mine between E.ON SE and future operator of mine water plant (FUW). It is to prove, that no negative influence by mine water use and no negative impact on filling columns of shafts in the former coal mine Dannenbaum / Prinz Regent is expected. Results of delta h simulations (see chapter 4) show no measurable hydraulic impact from planned mine water use on the shafts. The drainage effect of "Friedlicher Nachbar" with 6 million m³/a massively overshadows the planned mine water use, where only 100.000 to max. 350,000 m³ / a are locally circulated.

4. NUMERICAL MODELLING

4.1 Modelling concept

The existing mine maps of the former collieries Dannenbaum / Prinz Regent were completely digitized and transferred to a 3D subsurface model (Figure 10). In a multi-level modelling concept (Figure 11), the planned mine water utilization is numerically investigated. In this context, the possible influence of the exclusive mine water utilization with regeneration of the heat reservoir in connection with the existing mine water drainage measures of the RAG is also determined.

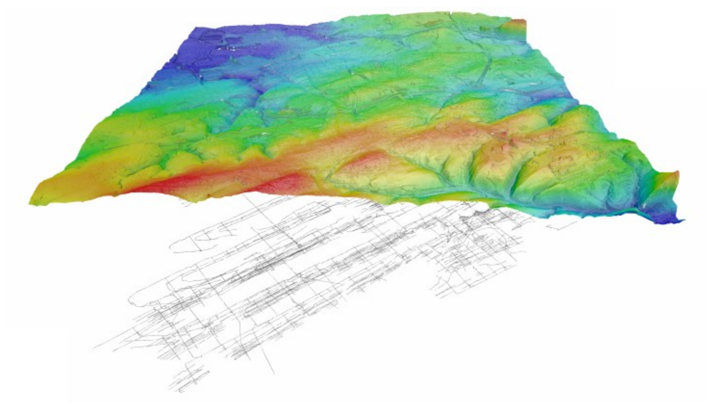


Figure 10: 3D subsurface model with the completely digitized mine layout (delta-h).

Due to the greatly increased groundwater flow in the associated mine buildings and due to the complex, clearly anthropogenically dominated surface drainage system, the hydraulic and hydrogeological interactions are far greater than in the natural environment. A simple reduction of the model area of hydrogeological simulations along drainage systems, water divides and wells is not expedient for the complex problem with very large boundary conditions. The system to be modelled must be integrated into the larger regional context. In addition to the regional model scale, material parameters can be estimated via near-field considerations and failure considerations are initiated. In addition to the problem of the definition of boundary conditions, the permeabilities of the fractured carboniferous rocks and of the fault zones are of major influence for the prognosis of the energy propagation from the mines. By means of small-scale local models, the propagation in the local area of galleries and shafts can be mapped and conclusions can be drawn from fracture distributions to permeability values.

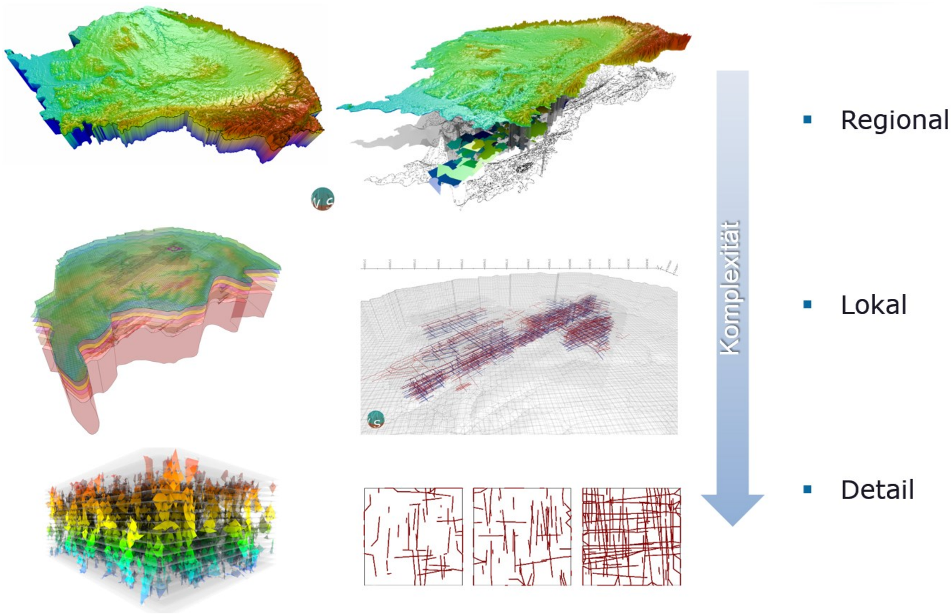


Figure 11: 3-level modelling concept (delta-h).

4.2 First results of numerical modelling

Density-dependent flow and heat transfer calculations were carried out, which simulate the operation of the mine reservoir over a period of more than 600 months. In Figure 12 the flow field is shown as streaks and with water table contour for the winter and summer phase. The color graduation corresponds to the calculated temperature after 50 years. The state in the summer phase differs from the winter phase mainly locally in the periphery of the injection and extraction node points. In particular, the inflow to the 4th level in the extraction zone can be seen in the streaks illustration (Figure 12). A direct bypass or short circuit between the injection and extraction area is not recognizable in both states.

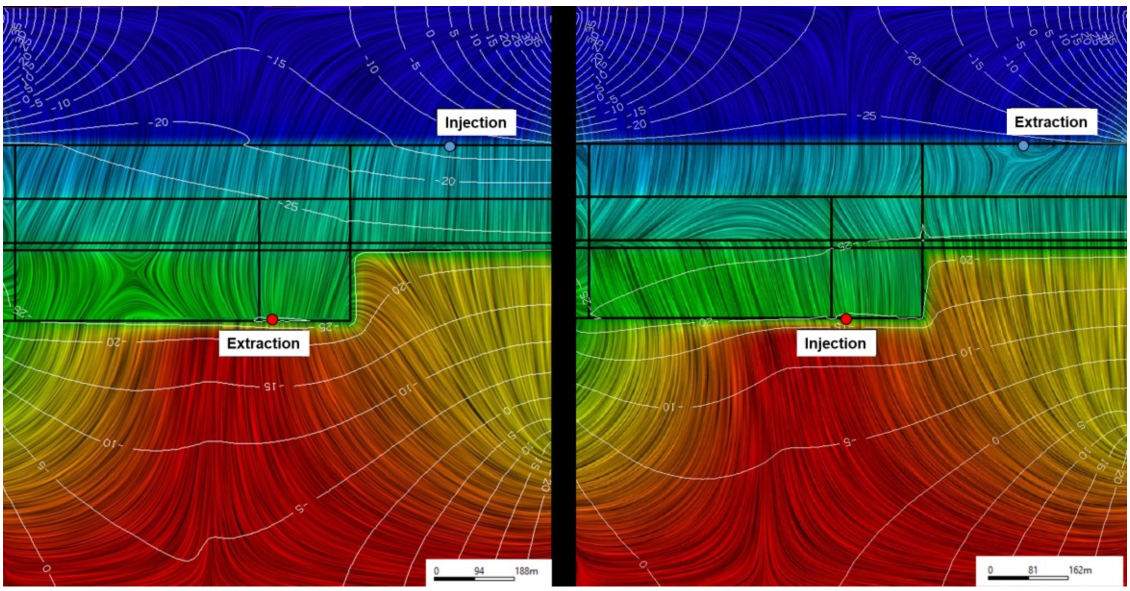


Figure 12: Streaks illustration and water table contour of the flow field, temperature distribution as color graduation for winter phase (left) and summer phase (right) (delta-h).

Also, for the temperature distribution over the entire modelling period, the interventions of the mine water use overlap with the dominant temperature field, which results from the natural geothermal gradient with the depth and the strong drainage effect of the mine. Preliminary results show that due to the drainage effect the temperatures within the galleries of the respective levels are very similar. In the 8th level, the temperatures are cooled significantly by the drainage effect compared to the predicted temperatures due to the natural thermal gradient. However, the mine water utilization and regeneration in summer causes this temperature reduction is compensated to a greater extent again.

5. CONCLUSIONS

The current state of investigation suggests, that under the currently determined boundary conditions a technical realization of the mine water utilization concept for heating and cooling in the abandoned colliery Dannenbaum in Bochum is possible by using directional drilling and implementation of a low-ex grid. The first results of the numerical thermal-hydraulic simulations show that the flooded mine reservoir on the basis of the selected thermal and hydraulic conditions of the subsurface, the determined demand of energy and the temperature distribution in the planned supply grid sustainably provide the heat and cold volumes over a period of 50 years.

In the upcoming project phase (mid to end 2020), it is foreseen to develop the mine galleries successive via directional drilling and to determine the subsurface data on the yield, the temperature and the hydrochemical composition of the mine water via pump tests. Based on this, the numerical model is validated. In the case of a successful technical implementation of the wells and the low-ex grid there is a great potential for a transferability to other mining sites.

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