# Utilisation of Mine Water from Abandoned Mines – Example "Anthracite Mine Ibbenbüren", Germany

Marion Stemke, Georg Wieber

*Johannes Gutenberg-Universität Mainz, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany, mstemke@uni-mainz.de*
*wieber@uni-mainz.de*

## Abstract
Sustainable and environmentally friendly energetic and non-energetic raw material extraction plays an increasingly important role in security of supply. The European Union compiles a list of critical raw materials at regular intervals. On this basis, mine water from the Ibbenbüren coal mine were examined. The results show that critical elements occur in the mine water. The concentration increases with depth. For the flooded Westfeld, the elements Al, B, Co, Li, Mg, Sr and Zn could be determined in the outflow and the loads determined. The calculation of the geothermal potential shows that about 900 single-family homes could be supplied with heat from the freely discharge mine water.

**Keywords:** Mine Water, Critical Raw Materials, Anthracite Coal Mine, Rare Earth Elements (Ree), Geothermal Use

## Introduction
Every 3 years, the EU compiles a list of economically most important raw materials with a high supply risk called critical raw materials. Access to resources is of strategic importance to Europe's goal of achieving climate neutrality, which could lead to a shift from the current dependence on fossil fuels to raw materials that are largely sourced abroad and for which global competition is increasingly fierce (EU 2020). Because of this, other sources of raw materials are also increasingly coming into focus. These include in particular mine water from both closed and operating mines. Many of the substances listed as critical raw materials also occur in traces in the mine water of mining operations. Many of the substances listed (Table 1) as critical raw materials occur in traces in mine water and could be recovered before discharge into surface water.

Based on this list, the mine water of the Ibbenbüren anthracite mine were analysed for critical raw materials.

The Ibbenbüren hard coal mine, which was closed in 2018 as part of the energy transition, is located in north-western Germany. Mining took place in the East (closed in 2018) and West (closed in 1978) fields. The Ibbenbüren coalfield consists of Carboniferous strata that clearly protrude from the surrounding area as a ridge, north of the town of Ibbenbüren. The entire structure has a length of around 15 km and a width of 5 km and towers over the surrounding terrain by up to 100 metres. In relation to the Mesozoic hinterland, the Carboniferous horst structure is bounded by two NW – SE trending fault systems – the

***Table 1*** *2020 Critical Raw Materials (from EU 2020).*

| | | | | | |
|---|---|---|---|---|---|
| Antimony | Cobalt | Hafnium | Natural Graphite | Phosphorus | Vanadium |
| Baryte | Coking Coal | Heavy REE | Natural Rubber | Scandium | Bauxite |
| Beryllium | Fluorspar | Light REE | Niobium | Silicon metal | Lithium |
| Bismuth | Gallium | Indium | Platinum Group Metals | Tantalum | Titanium |
| Borate | Germanium | Magnesium | Phosphate rock | Tungsten | Strontium |

northern and southern Carboniferous margin faults (Melchers *et al.* 2019). In addition, the Carboniferous horst structure is divided into several smaller blocks by numerous transverse faults. Due to the fault zones, the area can be morphologically divided into three areas, the western part (Dickenberg), the eastern part (Schafberg) and the rift structure (Bockradener Graben) in between (Fig. 1). The terrain drops steeply south of the ridge into the valley of the Ibbenbürener Aa (Münsterland basin) (Goerke-Mallet 2000). The north-eastern slope of the Ibbenbürener Hochplateau is less steep than the south-western one and merges into the North German Lowlands (Lower Saxony Basin) (Busch 2016).

In the west field, mining ended at the level of -500 mNHN, while in the east field it took place to a depth of 1430 mNHN.

In its undisturbed condition, the coal bedrock represented a fissure aquifer with moderate yield. With the advance of mining into the depths, the rock was loosened and cavities created. With the advance of mining into the depths, the rock was loosened, cavities were created and thus the fissuring was increased. These loosenings cause increased infiltration rates of precipitation water. In the East Field and Bockradener Graben, infiltration is restricted by the Quaternary deposits, which are up to 30 m thick. In contrast, the western field has only a slight weathering cover, which leads to a higher proportion of precipitation in the mine water. While the mine water from the West field flows out of the Dickenberger adit without pressure, the East field is currently being flooded. Previously, the mine water was lifted here and piped to the Püsselbüren wastewater treatment plant (Domalski, 1988).

## Methodology

A total of 305 water analyses from various sources from a period of 1957 to 2018 were collected. These come from data from Lotze *et al.*1962, Bässler 1970, Domalski 1988, DMT 2019, Rinder 2020 as well as from the mine operator (RAG AG), the Arnsberg district government (https://www.elwasweb.nrw.de) and own analyses. Of these, 128 are from the West Field, and 177 from the East Field. All analytical values below the detection limit were considered in the evaluation with half of the concentration level.

## Results

Some critical raw materials were detected in the mine water. For most critical elements, there is either no sufficient data basis or the measurement data are below or in the range of the detection limit. Figure 2 shows the elements Al, B, Li, Mg, Sr and Zn as a function of depth for the East Field. Except for the elements B, Mg and Sr the concentration level of the individual substances increases with depth. The deeper mine water in the East field are no longer accessible due to mine closure. As a result, the extraction of raw materials from these depths would not be economically viable, as the recoverable quantities would be offset by the additional costs of drilling and pumping.

At present, only the mine water from the Dickenberger adit (West field), which flows out without pressure, is available for raw

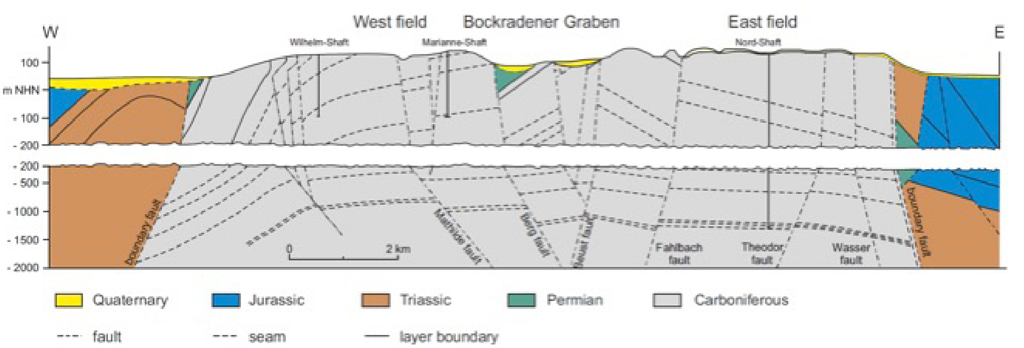


*Figure 1 Geological section through the Ibbenbüren coalfield (modified after Domalski 1988).*

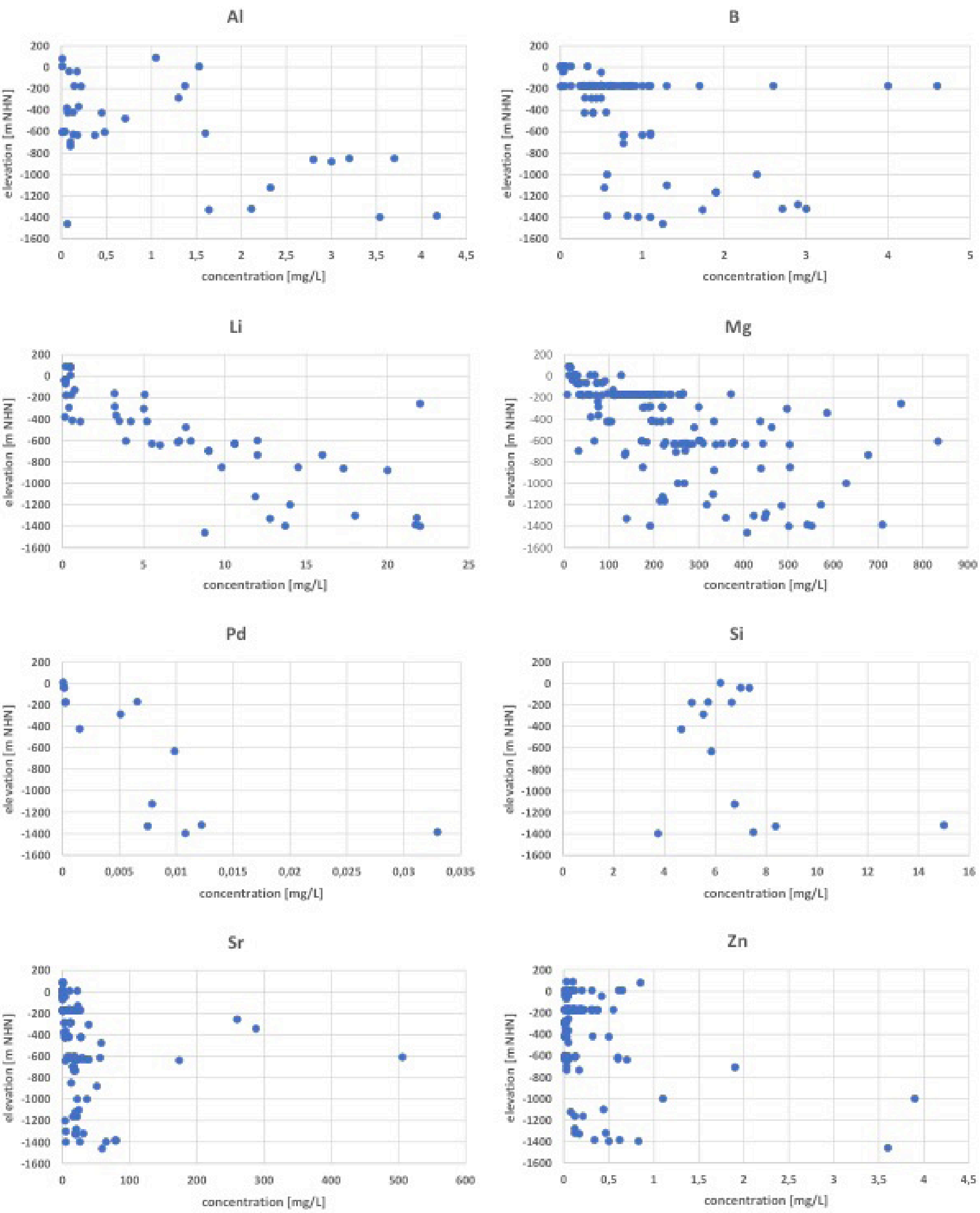


*Figure 2 Concentrations as a function of depth in the east field.*

material extraction. In the long-term average, 8.1 m³/min flow out here (DMT 2019). 39 water analyses could be assigned to the Dickenberger adit and the concentration level of the critical elements calculated. According to DMT forecasts (2019), the mine water after flooding of the East Field will correspond to those of the West Field. The discharge rate in the east field is expected to be 4.46 m³/min. Table 2 shows the resulting annual loads based on these data and forecasts.

In addition, it would also be possible to extract energy from the Dickenberg adit. Heat can be conducted both over solid rock as the conductive part (heat conduction) of the heat flow and as mass-supported transport

***Table 2** Mine water loads Dickenberger adit (West field) and loads predict East field.*

| Element | Quantity | West field Dickenberger adit | Mine water loads | East field loads (predict) | Total loads |
|---|---|---|---|---|---|
| | | mg/L | kg/a | kg/a | kg/a |
| Al | 5 | 0.47 | 2,001 | 1,102 | 3,103 |
| B | 39 | 0.12 | 511 | 281 | 792 |
| Co | 5 | 0.12 | 511 | 281 | 792 |
| Li | 5 | 0.65 | 2,767 | 1,524 | 4,291 |
| Mg | 39 | 136 | 579,000 | 318,808 | 897,808 |
| Sr | 39 | 0.95 | 4,044 | 2,227 | 6,271 |
| Zn | 39 | 0.62 | 2,640 | 1,453 | 4,093 |

in and over liquids as the convective part (convection) of the heat flow (Kaltschmitt *et al.* 1999). According to Baehr & Stephan (2006), heat conduction represents a transport of energy between neighbouring molecules due to a temperature difference present in the material. In solids, heat conduction is the only energy transport, while convection and heat radiation can still occur in gases and liquids (Baehr & Stephan 2006).

The terrestrial heat flux density is composed of a conductive and a convective part of the heat flux as well as the heat production summed up along the depth. In the continental crust, the conductive part of the heat flux density dominates (Kaltschmitt *et al.* 1999, Clauser 2009, Wieber 2014) and results from the following equation:

$$q_{kond} = -\lambda \cdot \frac{\Delta T}{\Delta z}$$

With: $q_{kond}$ = conductive part of the heat flow [W/m²], $\lambda$ = thermal conductivity [W/mK], $\Delta T$ = temperature gradient [K], $\Delta z$ = layer thickness [m].

Energy can be transported through the macroscopic movement of fluids. Due to a temperature gradient, heat and energy flow as enthalpy and kinetic energy of the fluid and flow through an (imaginary) surface. This process is called convection and can be described according to Fourier's law for the boundary transition between wall and fluid.

As already mentioned, the Dickenberg gallery drains the groundwater of the flooded west field in free fall with an average discharge of 8.1 L/min corresponding to approximately 135 L/s and a temperature of approximately 12 °C. After flooding, the east field should have a discharge of approximately 4.46 m³/min (corresponding to 74.3 L/sec) with comparable physico-chemical conditions. In total, this corresponds to an average discharge of approx. 200 L/sec, whereby there are strong fluctuations in the discharge, especially in the West Field.

The existing temperatures are not sufficient for direct use for heating purposes. However, they can be raised to a higher temperature level with the help of heat pump technology. Compression heat pumps are predominantly used here, whereby a working fluid is compressed and thus heated. The heat medium changes its aggregate state (liquid/gaseous) when absorbing or releasing heat energy. The energy obtained with this technology (evaporator power) consists of the geoenergy "mine water" as well as the drive energy of the heat pump. The mine water of the anthracite mines in Ibbenbüren offer ideal conditions for geothermal utilisation, as the temperature of continuously 12 °C enables an effective yield, as the mine water are captured and permanently discharged through the galleries.

Two basic options can be distinguished for the geothermal use of mine water for heat pump systems:

- Utilisation of the freely leaking mine water in the deep gallery and/or
- Use of the thermal energy in the flooded mine workings (e.g. shafts).

Heat pump systems require a water quantity of 0.25 to 0.3 m³/h for 1 kW evaporator capacity at a temperature difference of 3K. This corresponds to a water volume of 0.228 L/s at a temperature difference of 1K. The extractable heat/evaporator capacity ($W_{thermal}$) can be calculated for the heat capacity of water

(4200 J/L/K) for a freely discharging water quantity (Q) of 200 L/s and a temperature drop from 12 °C to 2 °C (ΔT: 2 °C):

Extractable heat = heat capacity * ΔT * Q

The geothermal potential of the freely leaking water amounts to around 8,800 kW under the above-mentioned boundary conditions. This geothermal energy corresponds to the heat demand of about 900 modern single-family homes, with the geothermal energy being supplied from the mine at a free gradient. Electrical energy (about one fifth of the energy yield) is only needed to operate the heat pump. There are no changes in the "mine" system due to the use of the leaking water.

Multiple geothermal energy is stored in the rocks of the mine than in the leaking groundwater. In the case of a more extensive use, however, the energy would have to be technically extracted by pumping out or cooling the impounded mine water/rock body. This in turn requires greater technical effort and energy consumption.

## Conclusions

The measured data show that critical raw materials are present in the mine water of the Ibbenbüren mine. For most critical elements, however, there is either insufficient data for a reliable assessment of the concentration level or the analyses are only in the range of the detection limit. In the outlet of the Dickenberg adit, the elements Al, B, Co, Li, Mg, Sr and Zn occur in higher concentrations. However, economic extraction is not possible at present. However, boundary conditions may change as the state of the art advances. After the flooding of the East Field and the completion of the newly planned "mine water channel", long-term measurements for critical elements in the mine water would be useful. Especially with the development of technical innovations, the extraction of critical elements from the Ibbenbüren mine water could be ecologically and economically profitable.

Calculations of the geothermal potential from the mine water also show that up to 900 single-family homes could be supplied with heat. Further investigations using the mine rocks to increase the energy yield should be considered.

## Acknowledgements

The authors thank all co-organisers for hosting the IMWA2021 Conference. Amy Kokoska, Hetta Pieterse as well as Glenn MacLeod provided critical comments on earlier versions of this text. This work was made possible within the framework of the "Forum Bergbau Wasser" Foundation, which is hereby thanked for the support provided. We owe special thanks to Dr. Rinder for providing his reserve samples.

## Reference

Baehr HD, Stephan K (2006) Wärme- und Stoffübertragung. – 757 S.; Berlin – Heidelberg – New York (Springer)

Bässler R (1970) Hydrogeologische, chemische und Isotopen-Untersuchungen der Grubenwässer des Ibbenbürener Steinkohlenreviers. – Z.deutsch. geol. Ges., Sonderh. Hydrogeol. Hydrogeochem. 209-286

Busch W, Walter D, Xi F, Yin X, Coldewey WG, Wesche D, Hejmanowski R, Malinowska A, Kwinta A, Witkowski WT (2016) Bergwerk Ibbenbüren der RAG AG. Analyse von Senkungserscheinungen außerhalb des prognostizierten Einwirkungsbereiches, Gutachten TU Clausthal im Auftrag der Bezirksregierung Arnsberg Abteilung Bergbau und Energie in NRW

Clauser C (2009) Heat Transport Processes in the Earth's Crust. – Surveys in Geophysics, 30: S. 163-191; Berlin – Heidelberg – New York (Springer)

Domalski RF (1988) Bergmännische Wasserwirtschaft der Steinkohlenbergwerke Preussag AG Kohle/Ibbenbüren und Gewerkschaft Sophia-Jacoba/Hückelhoven Ein Vergleich. Mitt. Westfälische Berggewerkschaftskasse, H. 60, 174 S.; Bochum

DMT GmbH (2019) Abschlussbetriebsplan des Steinkohlenbergwerks Ibbenbüren Anlage 17 Prognose zur optimierten Wasserannahme nach Stilllegung des Steinkohlenbergwerkes Ibbenbüren (Ostfeld). https://www.rag-anthrazit-ibbenbueren.de/grubenwasserhaltung/wie-laeuft-das-genehmigungsverfahren-ab/abschlussbetriebsplan/

European Union (2020) Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. https://eur-lex.europa.eu/legal-content/DE/TXT/

?uri=CELEX%3A52014DC0297

Kaltschmitt M, Huenges E, Wolff H (Hrsg.) (1999) Energie aus Erdwärme – Geologie, Technik und Energiewirtschaft. - 265 S.; Stuttgart (Deutscher Verlag für Grundstoffindustrie)

Lotze F, Semmler W, Kötter K, Mausolf F (1962) Hydrogeologie des Westteils der Ibbenbürener Karbonscholle. – Forschungsberichte des Landes Nordrhein-Westfalen, Nr. 999: 113 S., 45 Abb., 8 Tab.; Köln und Opladen (Westdeutscher Verlag)

Melchers C, Westermann S, Reker B (2019) Evaluierung von Grubenwasseranstiegs-prozessen. – Techn. Hochschule Agricola [Hrsg.]: Berichte zum Nachbergbau, H. 1:130 S., Bochum.

Rinder T, Dietzel M, Stammeier J A, Leis A, Bedoya-González D, Hilberg S (2020). Geochemistry of coal mine drainage, groundwater, and brines from the Ibbenbüren mine, Germany: A coupled elemental-isotopic approach. Applied Geochemistry, 104693

Wieber G (2014) Hydrogeologie und Wärmefluss de gefluteten Grube Mercur in Bad Ems, Rheinisches Schiefergebirge. – In: Jber. Mitt. Oberrhein. Geol. Ver., N. F. 96: 361-377, 8 Abb., 3 Tab., Stuttgart