Mine Water Recovery in the Coal Mining District of Aachen - Impacts and Measures to Control Potential Risks

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Abstract. After 800 years of mining activities, coal mining came to an end in the district of Aachen in 1992. Dewatering measures were terminated at the end of 1993/ beginning of 1994. Since then, mine water in the coal mining districts of Aachen and South-Limburg has been allowed to recover in a controlled, step-by-step-manner in order to ultimately achieve natural groundwater conditions. During mine water recovery potential impacts to the ground surface are anticipated and acted upon; it is assumed that within several years following completion of mine water recovery all major impacts of mining activities in the area will have ceased.

Introduction

The coal mining district of Aachen forms a transition zone between the carboniferous deposits of the Ruhr area to the east and the coal deposits in the Netherlands and Belgium to the west. For several hundred years transnational mining of coal deposits was conducted along the German/Dutch border. Coal mines located in the Dutch South-Limburg district were abandoned in 1975.

When the EBV Aktiengesellschaft shut down the coal mine Emil Mayrisch in Alsdorf (Rheinland) in 1992, coal mining activities in the district of Aachen ended after 800 years. This shut down also terminated the transnational mining tradition in the mining districts of Aachen and South-Limburg.

The coal district of Aachen and South-Limburg is located north of the city of Aachen and includes an area of approximately 400 km^2 (Fig. 1).

The small river Wurm runs from south to north through the central part of the coal mining district of Aachen and South-Limburg. In this area the coal deposits are covered only by a thin layer consisting of unconsolidated sediments of quaternary and tertiary age; coal deposits are exposed at ground surface in the Wurm valley.

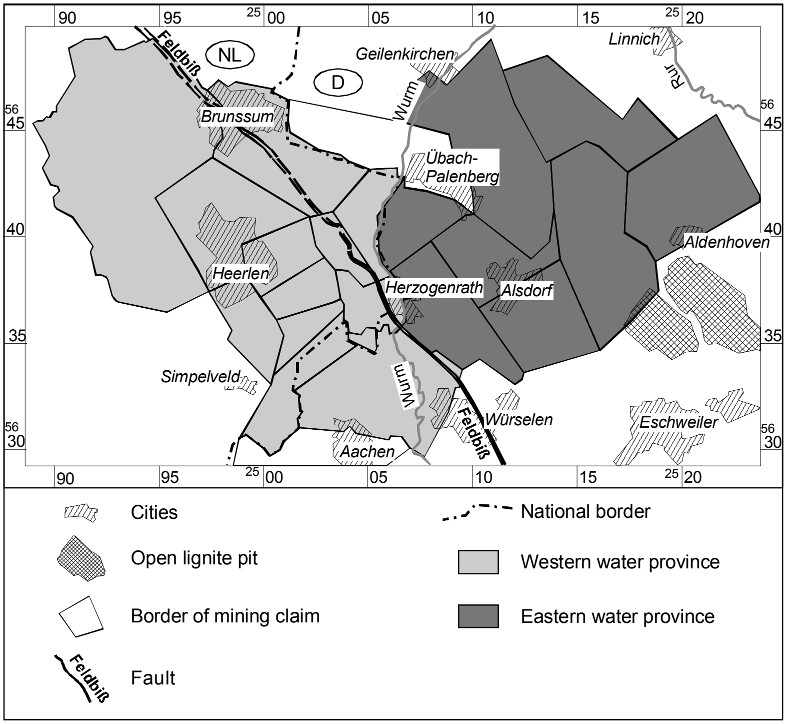

Fig. 1. Location plan of the mining fields of the coal mining district of Aachen and South-Limburg

In the Wurm area coal mining was abandoned in 1969. Following closure of the Dutch mines located to the northwest in 1975, coal mining activities continued only in the eastern part of the district of Aachen, east of the Feldbiß fault.

When the withdrawal of the technical equipment in the mine fields east of the Feldbiß fault was terminated at the beginning of 1994, the remaining mine dewatering works were shut down. The final draw-down cone resulting from dewatering activities covered an area of approximately 400 km^2.

Regional Geological Setting

The coal mining district of Aachen and South-Limburg is located in the transition zone between the Eifel and the Lower Rhine Basin. The carboniferous deposits are exposed along the Wurm valley north of Aachen; in most other areas these deposits are overlain by up to several hundred meters of unconsolidated deposits.

The coal bearing formations of the Aachen district generally consist of sandy, silty and clayey deposits of Namur C to Westfal B age. The carboniferous deposits run from SW to NE and dip generally at a shallow angle of less than 20 degrees to the south and southeast. At distances of several hundred meters to several kilometres anticlines, faults and up-throw faults occur. In addition to fold tectonics there are also NW-SE running cross-faults which subdivide deposits into large blocks. The main cross-faults - Feldbiß, Sandgewand and Diagonal-Sprung - form a step-fault system. The fault displacement is between 100 and 500 meters. In the Aachen area variscian folded bedrock is overlain by tertiary sediments. Towards the end of the Oligocene the sedimentation of lignite deposits started; the deposits are up to 250 m thick. The most recent deposits of tertiary age consist of 200 to 300 m of gravel/sand and clay. During the quaternary age the district of Aachen and South-Limburg was covered by terrace deposits of the Maas and Rhine rivers.

Hydrogeological Conditions

Groundwater Conditions in the Carboniferous Bedrock

During operation of the dewatering system east and west of the Feldbiß fault two distinct and hydraulically separate water provinces were established (Fig. 2).

In the eastern water province the 865 m-niveau (-735 m below sea level) was the lowest point of the central dewatering system. Mine water isolated in the Maria mine field discharged towards the central dewatering system of the eastern groundwater province via a connecting tunnel at the -440 m level.

The western water province consisted of the German Gouley-Laurweg mine field and the Dutch mine fields in the northwest and west. After shut-down of the central dewatering system, groundwater in the Dutch mine fields was pumped only from shaft Beerenbosch II, located in the southeast of the South-Limburg district. The groundwater level in the field Gouley-Laurweg was maintained at -167 m (below sea level) by pumping groundwater from the Von-Goerschen-shaft.

During operation of the coal mines a hydraulic connection existed between the mine fields Domaniale and Gouley-Laurweg; this allowed groundwater seepage from the German mine field into the Dutch mine field Domaniale.

Groundwater Conditions in the Overlying Sediments

In the mining district of Aachen and South-Limburg groundwater is extracted from the tertiary sediments in connection with dewatering measures for open pit lignite mining. The open pit Inden is located Southeast of the coal mining district of Aachen (Fig. 2); in the year 2000 a total of 92 million m^3 groundwater were extracted in order to keep the open pit dry. Since 1975, shallow groundwater conditions have also been impacted by dewatering measures in the open pit Hambach, located approximately 10 km further to the northeast. Groundwater extraction from the Hambach open pit amounted to approximately 330 million m^3 in 2000. In addition, several drinking water production facilities extract groundwater from various aquifers in the overlying sediments.

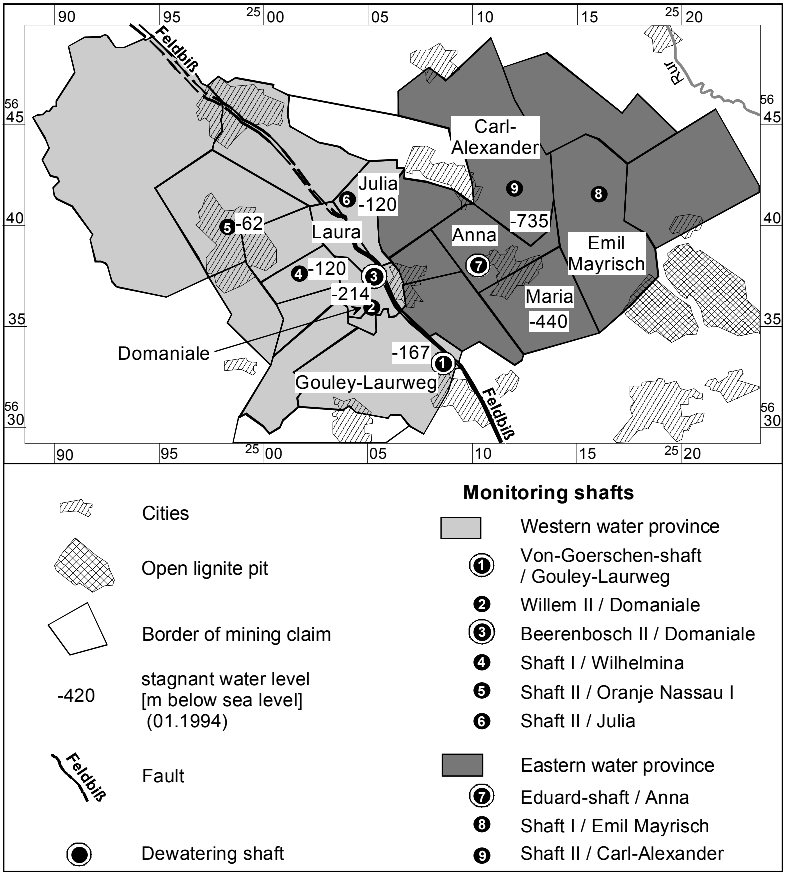

Fig. 2. Stagnant water levels in the coal mining district of Aachen and South-Limburg

Risk Assessment of Mine Water Recovery and Conceptual Design of a Controlled Step-by-Step Recovery

In 1990, EBV Aktiengesellschaft submitted a final operations plan to the mining authority in Aachen; the plan included the recovery of mine water in the coal district of Aachen and South-Limburg to the natural groundwater level.

Problems associated with the recovery scheme consisted mainly of the water level difference of approximately 550 m in the coal mines east and west of the Feldbiß fault. If water levels at adjacent mining structures (distances of only 18 m in some places) significantly differ, the remaining rock might suddenly collapse and inflowing water might gush into the eastern mine field. In particular, the sudden decrease of the water level west of the Feldbiß fault might cause the destruction of shaft fillings in this area. Detailed rock-mechanical and hydraulic investigations showed that a controlled recovery of mine water levels would inhibit extensive groundwater inflow as well as preventing any risk to the ground surface.

In addition, the impact of the groundwater recovery process on potential risks caused by former mining shafts had to be assessed; former methods used to secure abandoned mine shafts do not meet present-day safety standards. As approved by the mining authority, the dewatering system was shut down in the shafts west of the Feldbiß fault in January of 1994. The dewatering shaft located in the Wurm valley was kept operational in order to be able to actively control and regulate the mine water recovery process. At the same time the dewatering system for the eastern mine field was shut down at the end of 1993; any existing deep shafts in this area were secured according to the guidelines to ensure long-term stability.

The EBV Aktiengesellschaft conducted an intensive measuring program in order to monitor the mine water recovery process, including measurements of mine water levels and groundwater levels in monitoring wells installed in the overlying sediments, hydrochemical investigations and geodetic measurements. Pump tests of several months duration are conducted regularly in the former dewatering shafts in order to further assess hydraulic connections between different mine fields and to balance water inflow. Test results are particularly important as a basis for hydraulic calculations with respect to predicting future mine water recovery (further flooding of adjacent mine structures) and hydrochemical conditions of mine water at the time of reaching water levels present in the receiving water bodies.

Results of the Mine Water Recovery to Date

Water Provinces West of the Feldbiß Fault

Results of mine water recovery in the shafts west of the Feldbiß fault are summarized in fig. 3. During the initial phase since 1994 those mine fields in the south where the dewatering levels had been lowest (Gouley-Laurweg and Domaniale) were flooded first. During this period, water levels initially recovered at a rate of a maximum of 1.3 m/d and subsequently reduced to a rate of 0.3 m/d. After app. 16 months the stagnant mine water level in the northern Dutch district was reached, resulting in an overall uniform water level in all of the western province of -62 m (below sea level). Above -62 m, mine water in the Dutch mine fields rose considerably slower at a rate of 0.01 to 0.03 m/d due to the larger area which had to be flooded. During this phase of the mine water recovery a relatively high mine water level was established in the German mine field Gouley-Laurweg.

Mine water recovery in the western water province was regulated in such a way that the hydraulic gradient is directed from south to north. As a result, highly mineralised mine water from the north was pushed back.

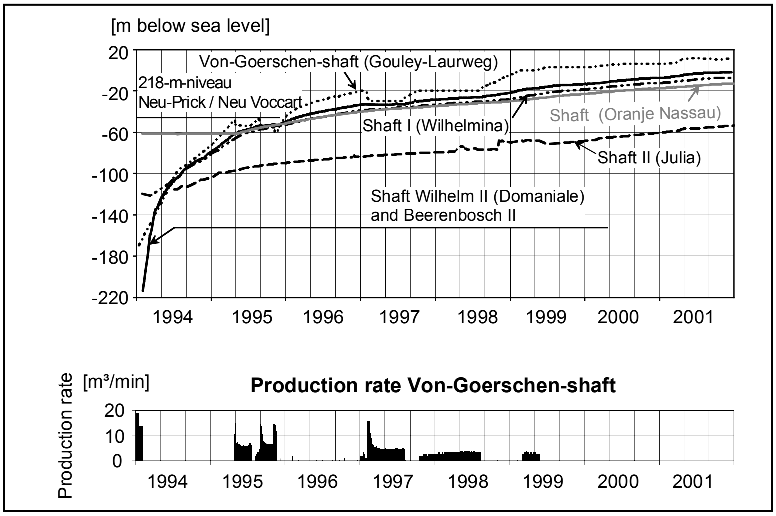

Fig. 3. Mine water recovery in the coal district of Aachen and South-Limburg west of the Feldbiß fault (monitoring period 1994 to 2001)

Mine water recovery is also monitored by regular hydrochemical investigations. Results of hydrochemical investigations conducted in the shafts west of the Feldbiß fault are summarized in fig. 4.

Mine water present in the mine fields Gouley-Laurweg and Domaniale are of the sodium-hydrogencarbonate-sulfate-type. The relatively high sodium content (> 500 mg/l) indicates the strong impact of highly mineralised deep water. The high hydrogen-carbonate-content (> 1,000 mg/l) also indicates the impact of infiltration groundwater originating in the overlying sediments.

During operation of the dewatering system the mineral content of the mine water in the Von-Goeschen-shaft was relatively low, with electric conductivity values of app. 1,500 to 2,000 µS/cm. In contrast, the electric conductivity of mine water in the northern Dutch mine field Domaniale (as determined in the shaft Beerenbosch II) was app. 9,000 µS/cm with iron concentrations of 10 to 24 mg/l.

During the initial mine water recovery phase in the mine field Gouley-Laurweg the total mineral contents slowly increased continuously to app. 2,800 µS/cm (12.1996).

Generally, groundwater chemistry in the mine fields Gouley-Laurweg and Domaniale gradually adjust. This is basically a consequence of highly mineralised deep groundwater and mine water from the Dutch mine fields being pushed back due to an overall increase of mine water levels. Further recovery of mine water levels will lead to further reduction of total mineral contents.

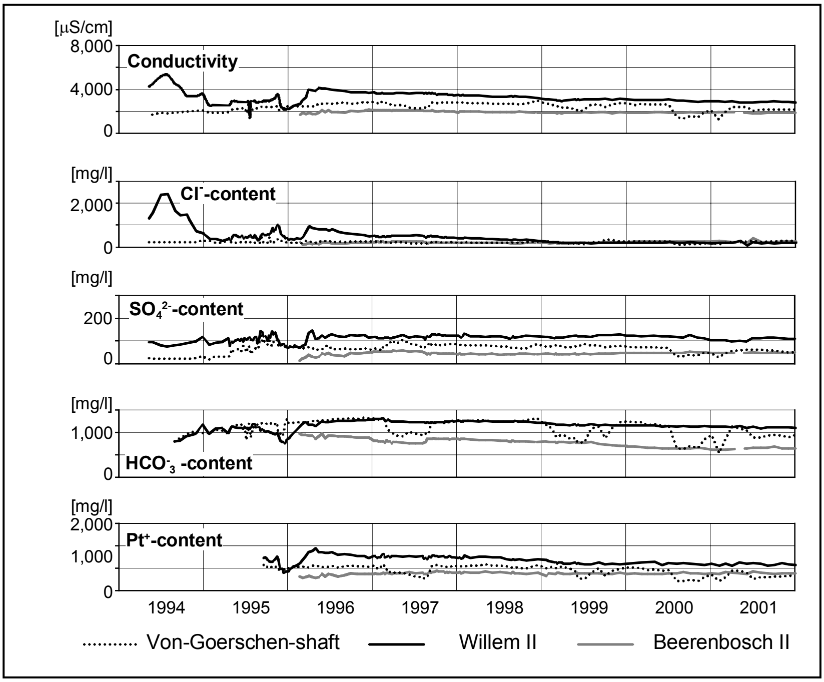

Fig. 4. Mine water chemistry in the coal district of Aachen and South-Limburg west of the Feldbiß fault (monitoring period 1994 to 2001)

Water Provinces East of the Feldbiß Fault

After the lower parts of the mines east of the Feldbiß fault were flooded the rate of mine water recovery was very uniform (Fig. 5). The groundwater level recovered at a rate of 0.20 m/d up to the level of accumulated mine water in mine field Maria of approximately -440 m (below sea level). Only when flooding the major mining floors the rate of mine water recovery decreased significantly. When exceeding the level of accumulated mine water in mine field Maria the mine water recovery rate in all of the eastern water province decreased significantly due to the larger volumes of mine cavities to be flooded. The average mine water recovery rate was 0.1 m/d.

Mine water in shaft 1, Emil Mayrisch is of the sodium-chloride-type, and is supplemented primarily by inflow of deep groundwater. Low concentrations of hydrogen-carbonate, sulphate and alkaline earths indicate that there is little impact of infiltrating surface water.

Electric conductivity values in shaft 1, Emil Mayrisch remained relatively constant at between 6,060 and 6,815 µS/cm until March, 1996, when mine water recovery levels reached -710 m (below sea level).

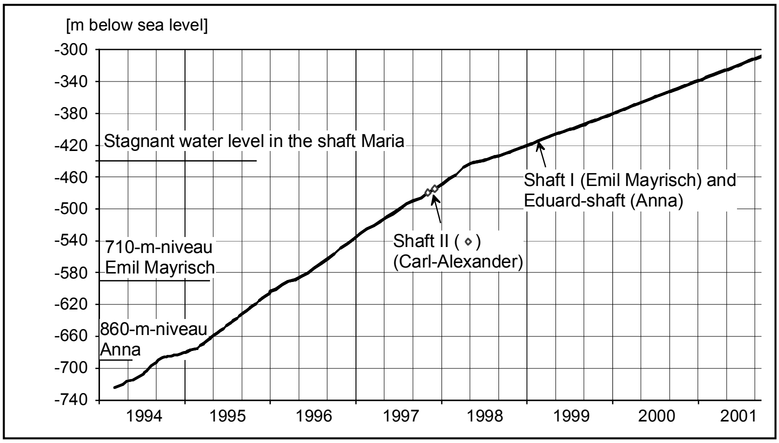

Fig. 5. Mine water recovery in the coal district of Aachen east of the Feldbiß fault (period 1994 to 2001)

Above the -710 m (below sea level), electric conductivity levels increased slightly to between 7,500 and 8,000 µS/cm (see Fig. 6). This indicated a considerable decrease in electric conductivity values compared to those measured during the operation of the mine dewatering system, which is due to the fact that highly mineralised groundwater present along deep fault zones is forced back.

Contrary to mine water present in shaft I, Emil-Mayrisch, groundwater accumulated in the Eduard-shaft, Anna, is of the sodium-chloride-hydrogen-carbonate-type. Significant hydrogen-carbonate concentrations (approximately 700 to 800 mg/l) indicate a considerable impact by infiltrating surface water. The electric conductivity of 2,800 µS/cm in the mine water present of the Eduard-shaft is considerably lower than that of the mine water at Emil Mayrisch.

Impacts on Groundwater in the Overlying Sediments

Monitoring of groundwater conditions in the overlying sediments started rather early in connection with the mine water recovery process. This data is available for the assessment of potential impacts of mine water recovery on overlying sediments groundwater quality. Based on a comparison between 1998 groundwater monitoring results and those obtained during long term monitoring it can be concluded that the mine water level recovery east of the Feldbiß fault does not impact groundwater conditions in the overlying sediments.

Impacts of Mine Water Recovery on Ground Surface Conditions

Flooding of Unconsolidated Fills in Old Mine Shafts

There are app. 850 former shafts in the coal mining district of Aachen; 90 % of these are old mine shafts resulting from ground owner operated mining activities which were sunk prior to the beginning of the 19th century. As part of the controlled mine water recovery available data on former mine shafts was reviewed and assessed in terms of the potential risk posed by each individual shaft. Criteria for risk assessment include location and size of shaft, kind of fills, preciseness of location, depth of shaft, surrounding land use, and thickness and type of overlying sediments. The flooding of unconsolidated fills of old mine shafts during mine water recovery poses another potential risk. During flooding the fill column is subject to buoyancy and cohesion is reduced. Buoyant material might collapse into open cavities and result in collapsing of the mine shaft. Predictions of projected mine water recovery levels and associated potential impacts on the overlying sediments are essential for an overall assessment. These documentations and evaluations have been compiled for the coal mining district of Aachen; they will have to be adjusted accordingly to incorporate future monitoring results.

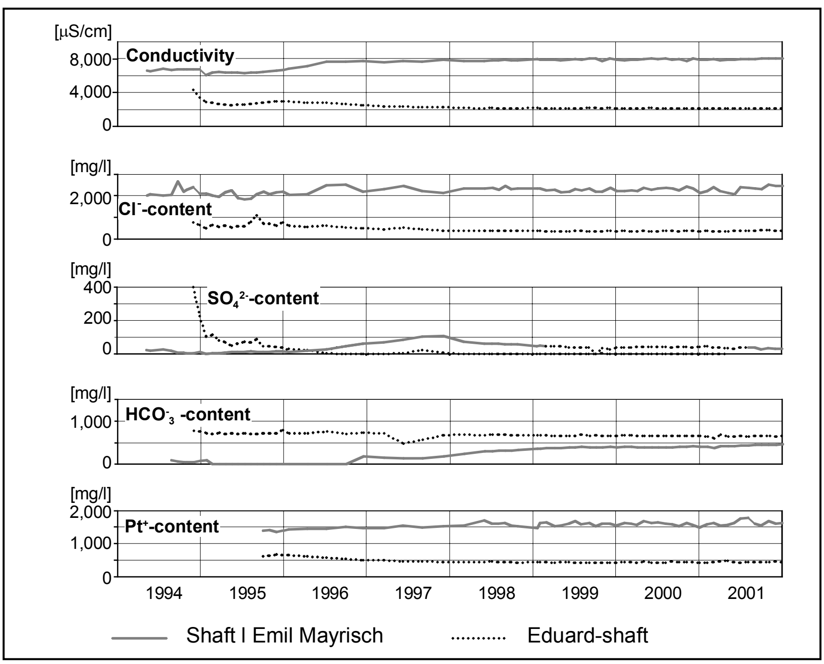

Fig. 6. Mine water chemistry in the coal district of Aachen east of the Feldbiß fault (monitoring period 1994 to 2001)

Terrain Heaving

To date there is only little information available on the impacts of mine water recovery in mining areas on ground surface conditions.

PÖTTGENS (1990) evaluates conditions in the coal mining district of South-Limburg. Geodetic monitoring results obtained between 1975 and 1985 in connection with mine water level recovery were evaluated. According to PÖTTGENS, the amount of terrain heaving is estimated to amount to approximately 2 to 3 % of the ground subsidence caused by mining activities.

In agreement with the responsible mining authority a geodetic monitoring program was developed to accompany the mine water level recovery. The objective of this monitoring program was to document the spatial distribution of terrain heaving as basis for the assessment of potential future damage at the ground surface level. Monitoring data to date has been compiled in iso-maps showing lines of corresponding amounts of terrain movement. Data evaluation indicates that movements of app. 10 mm/a have occurred in the area west of the Feldbiß fault since shut-down of the dewatering system. Terrain heaving generally occurred in large, extended areas; differences in heaving rates are anticipated only along tectonic fault lines or the edges of mine fields.

In the area east of the Feldbiß fault the groundwater level was lowered by a total of about 800 m as part of the overall dewatering scheme. It is anticipated that during the mine water level recovery terrain heaving of a total of 0.25 m will occur.

Outlook

Experience gained in the coal mining district of Aachen to date following shut-down of the mine dewatering systems indicate that potential risks associated with the recovery of mine water levels to the original ground water levels can be controlled even in very old former mining areas. The controlled mine water recovery process has to be managed based on a detailed analysis of mining related and hydrogeological conditions.

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