# Concept for Monitoring Impacts of Rising Mine Water Levels in the Ruhr Region, Germany

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# CONCEPT FOR MONITORING IMPACTS OF RISING MINE WATER LEVELS IN THE RUHR REGION, GERMANY

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*ABSTRACT: For safe operations of the active hard coal mines in the Ruhr region, a complex system of mine water drainage facilities at active and already abandoned coal mines is in use. According to the political agreement of the "Kohlerunde" from 2007, the subsidised hard coal mining will end until the year 2018, if this decision will not be revised in 2012. Beyond this point of time, further operations of these water drainage measures would not be necessary any more from the mere point of view of mine safety. A cessation of pumping would cause a rising mine water level in a large area. Along with the mine water recovery, in the urban area of the Ruhr-area various impacts on the ground-water balance in the caprock and at the ground surface are to be expected amongst others. The potential effects have to be predicted at an early stage and the mine water recovery has to be monitored with regard to the potentially harmed objects in order to finally be able to decide on the levels up to which the mine water is allowed to rise. On behalf of the mining authorities of the state North Rhine-Westphalia, a sample catalogue for a differenciated monitoring of the effects of the mine water recovery in different stages and different mining-geological-hydrogeological parts of the Ruhr region has been worked out as a first work step in this context.*

*KEYWORDS: post mining, rising mine water level, effects of mine water recovery, monitoring, Ruhr region (Germany)*

*RESUME: D'obtenir une opération secure des mines de l'houille dans la région de Ruhr, un système complexe de drainage des eaux minières était établi pour les mines en opération ainsi que pour les mines encore abandonnées. Selon l'accord d'état sur le charbon à 2007 la production de l'houille, subventionnée par une aide financière étatique, sera terminée jusqu'à l'année 2018, supposée que cette décision ne sera pas révisée dans l'année 2012. Après l'année 2018 les mesures de drainage ne seront pas nécessaires concernant seulement la sécurité des mines. Par une fin de pompage la nappe des eaux minières monteraie dans une région très large. Parallèlement à cette re-montée, des effets divers au régime des eaux souterraines sont attendue à l'égard des formations géologiques superposantes le Carbonifère ainsi que des effets hydrogéologiques superficielles, des mouvements du terrain ou des risques des effondrements. En ordre des autorités une recommendation pour un système d'observation (monitoring) des conditions hydrogéologiques était élaboré.*

*MOTS-CLEFS: des mines de l'houille abandonnées, re-montée des eaux minières, effets de la re-montée région de Ruhr (Allemagne)*

## 1. Introduction

For safe operations of the active hard coal mines in the Ruhr region (Germany), a complex system of mine water drainage facilities is in use at active and already abandoned mines. In 2007, representatives of politics and the Ruhrkohle AG as the last remaining German hard coal mining company agreed on a coal-political understanding, the main idea of which is to terminate subsidised

hard coal mining in Germany by the year 2018. At that time, further operation of water drainage facilities would no longer be required from a mine safety point of view.

The coal-political agreement 2007 and the report on long-term costs commissioned by the federal government assume that mine water drainage facilities existing at the time of termination of hard coal mining in the Ruhr region will continue to operate until further notice. However, it can be assumed that while operating mines are successively being shut down, thought will be given to how to reduce costs of water drainage measures by partially or completely flooding still open mine workings. As a result of such actions, mine water levels would rise in large areas which might lead to various impacts on the caprock groundwater regime and at the ground surface. Resulting potential risks in the Ruhr region have to be assessed at an early stage and the mine water level recovery process has to be designed accordingly in order to minimize these risks. This design should be based on the development of scientific prediction models and on the inventory and monitoring of potential impacts prior to and during mine water recovery.

On behalf of the mining authorities of the state of North-Rhine Westphalia (district government of Arnsberg, division 8 mining and energy in NRW), a report was prepared on the compilation of potential impact areas and risks associated with a large scale mine water level recovery in the Ruhr region. The report identifies investigation and research requirements to fill information gaps and compiles a catalogue of measures for the identification and monitoring of potential impacts.

## 2. Initial Situation

Based on experiences gained regarding impacts of mine water level recovery in abandoned mines in North-Rhine Westphalia and Europe, the following potential impacts were identified in the report:

With respect to flooding of mine workings:

- Impact on water quality in carboniferous rocks;
- Ground heave, particularly discontinuous ground heave;
- Diffuse or concentrated inflow of mine gas at the ground surface through loosened ground zones or mine shafts;
- Increased risk of collapse features due to flooding of unsecured shafts;
- Increased risk of settlement, subsidence or collapse features due to flooding of near-surface mining areas.

With respect to groundwater recovery in caprock sediments:

- Impact on groundwater quality in caprock sediments;
- Recovery of groundwater levels in caprock sediments;
- Development of wetlands at the ground surface;
- Inundation of contaminated ground;
- Increased ground heave.

During groundwater recovery up to surface water levels:

- Increased discharge into rivers;
- Impact on water quality in rivers;
- Sudden wave like groundwater burst from former dewatering galleries.

Based on specific geological, hydrogeological and mining conditions of the Ruhr region, the various impact potentials were thoroughly investigated and assessed with respect to their respective

relevance. Should mine water drainage facilities continue to operate, qualitative and quantitative impacts on receiving water courses have to be assessed.

## 3. Setting

The Ruhr region covers 4 435 $km^2$ and thus represents the largest economic area in Europe. 40 % of this area is used for urban development and traffic/transportation, 15 % is covered by forests, 5 % is covered by surface water courses and 40 % are used as agricultural land. 45 % of the total area are directly affected by mining activities. There are approximately 5.3 million people living in the Ruhr region.

In the southern Ruhr region, the hard coal bedrock crops out directly at the surface or underneath thin overlaying sediments of quaternary age over a maximum width of approximately 18 km (fig. 1). Towards the northwest, carboniferous rocks are overlain by massive deposits of permian to quaternary age. At the northern boundary of the active mining area, the surface of carboniferous rocks is encountered between -1 000 and -1 200 mNHN. The hard coal rock mass was folded variscanly and reshaped by intensive syn- to postvariscan break tectonics.

With respect to its caprock composition, the Ruhr region can be subdivided generally into a central and eastern "Westphalian district" (Münsterland), which is essentially made up of upper cretaceous sediments, and into a western "Lower Rhine district" (Niederrheinische Bucht), which consists of thick sediments of permian, triassic and tertiary age (fig. 1).

The "Westphalian area" is subdivided into three units (fig. 2).

- A deep ground-water storey developed in joints and fissures at the caprock base (essentially limestones of cenoman/turon age)
- The overlaying Emscher-marlstone acting as hydraulic barrier
- An upper groundwater storey overlaying the Emscher marlstone (Haltern sands, among others)

The Emscher marlstone as hydraulic barrier is of central importance for the assessment of potential impacts of the mine water recovery process on the groundwater situation in the caprock. The Emscher marlstone is considered to be free of groundwater below depths of > 50 m. In areas where the thickness of the Emscher marlstone exceeds 100 m, it is considered to act as a hydraulic barrier even when impacted by mining activities (JÄGER ET AL., 1990). In the southern areas of the Ruhr region, where the Emscher marlstone is less than 50 m thick, the lower groundwater storey (cenoman/turon layers) and the near-surface groundwater storey are hydraulically connected.

The composition of the upper groundwater storey overlaying the lowly permeable Emscher marlstone is very heterogeneous. The geographical distribution of the Haltern and Osterfeld sands is of particular importance for water supply in the northern part of the Ruhr region. The sands consist of productive pore aquifers containing groundwater with a low mineral content.

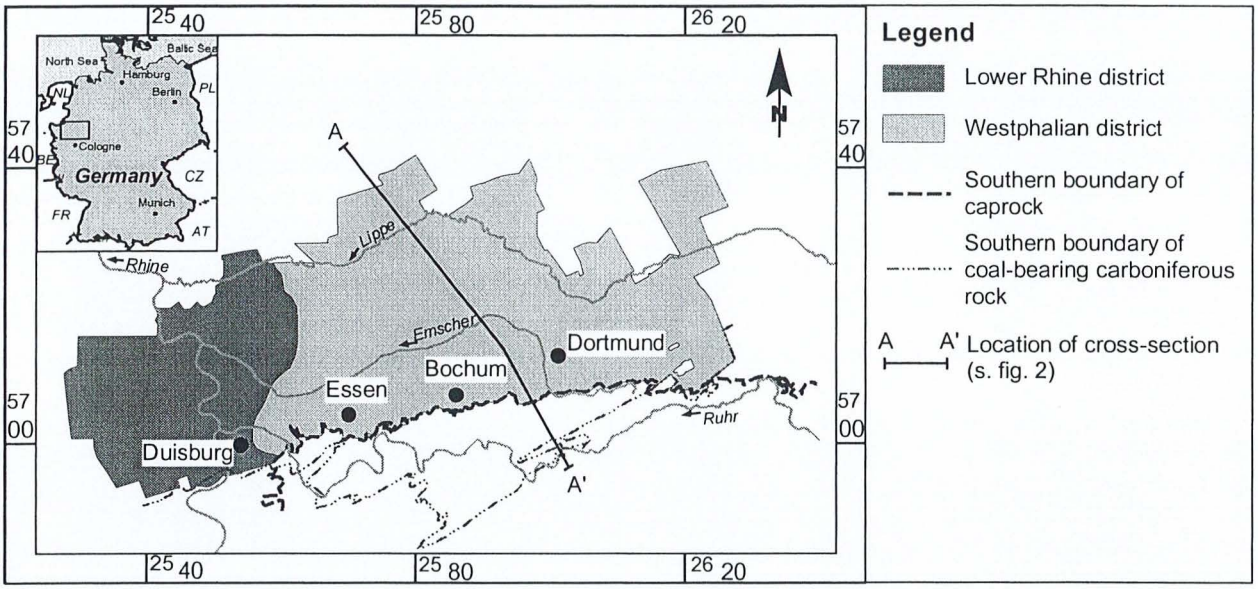


Figure 1: Rough geological classification of the Ruhr region

The Lower Rhine area is characterized by a considerably more complex caprock composition. Sedimentation already started during zechstein (Permian). The thickness of cretaceous sediments decreases towards west; they are overlain by tertiary sediments of considerable thickness and quaternary deposits (Rhine terraces) which are relevant to the regional water supply. From a hydrogeological point of view and with respect to potential impacts of the mine water level recovery process, four main units can be distinguished:

- An aquitard at the caprock base (Permian);
- A deep, heterogeneous ground-water storey underlaying the Ratingen clay and the silty Lintfort layers (Tertiary);
- An upper groundwater storey (sands and gravels of tertiary and quaternary age) overlaying the silty Lintfort layers.

This profile is only developed completely at the north-western boundary of the Ruhr region. Sediments underlaying the tertiary deposits successively thin out towards the west and south. Towards the east, there is a continuous transition zone towards the "Westphalian district".

Especially in the western part of the Ruhr region, the lower ground-water storey is characterized by highly mineralized $NaCl^-$ groundwater which extends down to the tertiary Walsum sands. Similar to the Emscher marlstone in the "Westphalian district", the silty Lintfort layers and the Ratingen clay of the "Lower Rhine" district represent a laterally extensive, near-surface aquitard which separates highly mineralized deep groundwater from the near-surface fresh-water aquifer. Rhine-terraces of quaternary age and tertiary sands form a near-surface aquifer overlaying the Lintfort sediments; this aquifer is recharged by rainwater.

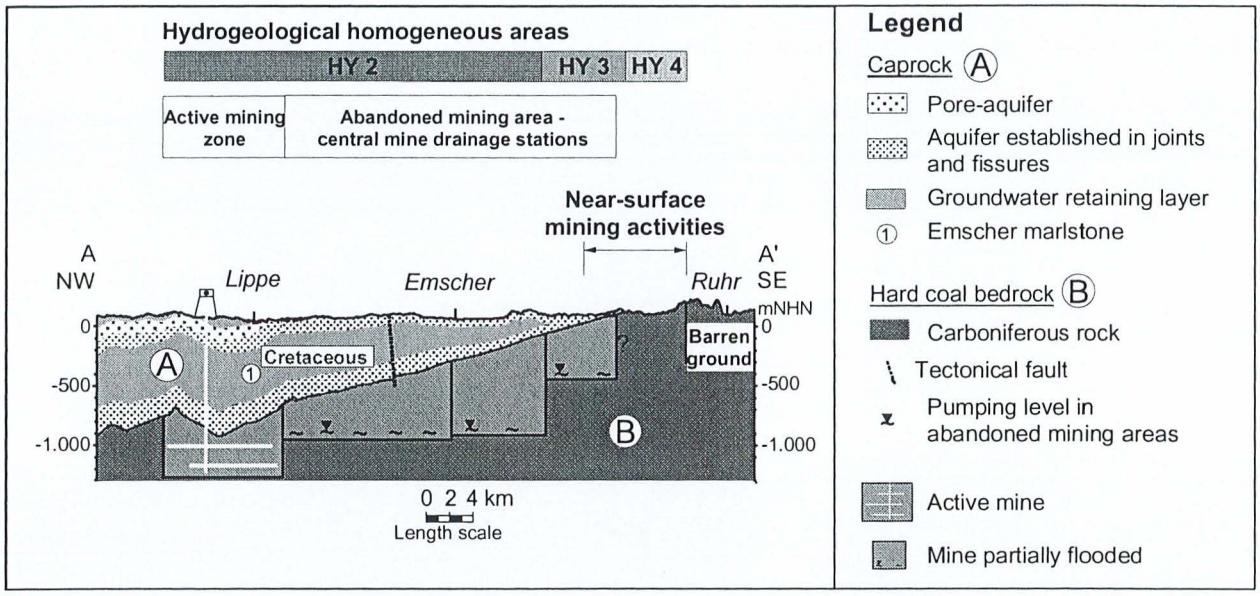


Figure 2: Schematic hydrogeological cross-section (A-A') of the "Westphalian district" (according to JÄGER ET AL., 1990)

## 4. Mining Impacts

### *4.1. Mining Zones*

Mining activities in the Ruhr region commenced in the southern part around the 14$^{th}$ century. While hard coal mining activities moved northward, hard coal mines in the southern and central Ruhr regions were decommissioned successively until the year 2000. Due to the numerous underground connections between abandoned areas and active mines, dewatering activities in the Emscher basin have to be continued in order to protect active mines. The DSK presently operates eight central dewatering facilities in the central and southern parts of the Ruhr region for this reason.

With respect to the groundwater situation in and around mines, the Ruhr-area can be subdivided into three main zones (fig. 3):

1. Active mining area in the northern, western and eastern parts of the Ruhr region
2. Abandoned mining areas affected by central dewatering facilities in the central and southern parts of the Ruhr region
3. Abandoned mining areas (areas with former open pit and near-surface mining activities) outside the impact area of central dewatering facilities in the south-eastern and eastern part of the Ruhr region.

The actively mined area comprises approximately 1 540 km$^2$. The area impacted by central dewatering facilities extends towards the south to the Ruhr river and comprises approximately 1 060 km$^2$. Mine water levels at the central dewatering stations are kept between -445 mNHN and -950 mNHN.

In the southeastern part of the Ruhr region, where hard coal mining originated, large former mining areas (appr. 290 km$^2$) are located outside the immediate area of influence of the central dewatering stations. Here, groundwater levels in the abandoned mines have already recovered to the natural surface water level.

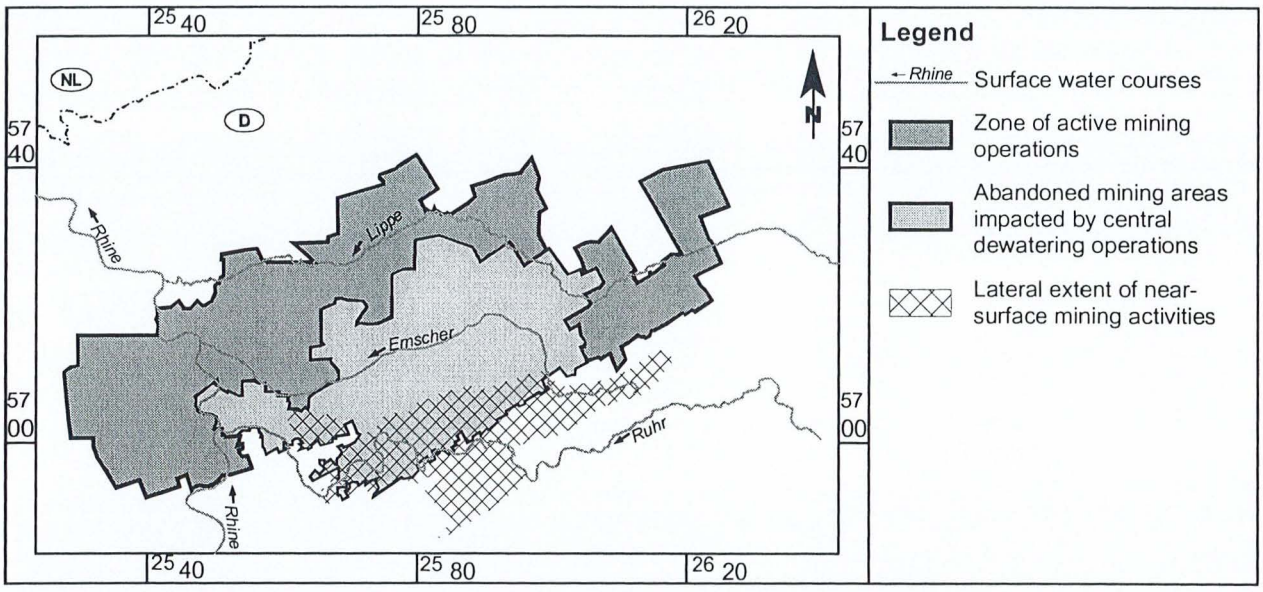


Figure 3: Water management situation in the Ruhr region including near-surface and open pit mining areas (state 12.2006)

### *4.2. Mining Legacies*

Mined areas resulting from hard coal mining activities extend across the entire Ruhr region. According to the approach defined by the mining authority of the State of North-Rhine-Westphalia the following mining cavities have to be distinguished with respect to type and extent of potential impacts at the ground surface (BEZIRKSREGIERUNG ARNSBERG, 28.09.2006):

- mine workings resulting from deep mining activities (depth > 100 m)
- mine workings resulting from near-surface mining activities (depth < 100 m, thickness of overlaying bedrock > 30 m)
- mine workings resulting from near-surface mining activities (depth < 100m, thickness of overlaying bedrock < 30 m)
- surface openings from mining activities (shafts, adits)

According to the prevailing teaching opinion, impacts of deep mining activities at the ground surface cease within 5 years following termination of mining as a result of converging mine workings. Recent soil movements therefore mainly occur in zones of ongoing mining activities.

In areas with former near-surface mining activities, impacts at the ground surface can not be ruled out for a long time after cessation of mining. Generally, these surface impacts are restricted to shallow depressions in the size of decimetres; however, collapse features at the ground surface may also develop. In addition, near-surface mining activities are characterized by the fact that a collapse of the ground surface may occur at any point in time. The zone with near-surface mining activities comprises approximately 550 $km^2$ (fig. 3) across the southeastern part of the Ruhr region.

According to an inventory compiled by the district government of Arnsberg (BEZIRKSREGIERUNG ARNSBERG, 28.09.2006) a total of 11 500 abandoned surface openings (shafts and adits) have been identified to date. The majority of these surface openings are located within the zone of near-surface mining activities across the southeastern boundary of the Ruhr region. Only a fraction of these shafts are secured according to present technical standards.

The mine water recovery process may impact both, the ground surface stability within the zone of near-surface mining activities as well as the stability along inadequately secured shafts of deep mining activities outside this zone. In addition, ground collapse features may also occur regardless of any mine water recovery impacts. Mining authorities have documented 1 500 collapse features since the 1960's (appr. 30 collapse features per year) for the Ruhr region.

### *4.3. Mine Drainage Measures*

Besides the quantity of mine water discharge, its water quality is of essential importance with respect to potential impacts of mine water recovery on the water-bearing underground and the contaminant situation in surface water bodies. From southeast towards northwest, the mineral content of mine water increases with increasing depth and decreasing percentage of groundwater generated from precipitation.

The different characteristics of groundwater inflow are reflected by the amount and quantity of water pumped at the mine drainage stations. In 2005, the DSK produced a total of 89.5 million $m^3$ of mine water (DSK, 04.2006). The majority of mine water (64.7 million $m^3$) was produced by central dewatering stations operating in abandoned mining areas. The highest groundwater inflow with the lowest degree of mineralization of 2 000 and 6 000 µS/cm occurs in abandoned mining areas located near the Ruhr valley. The electrical conductivity of mine water discharges pumped from active hard coal mines is in the order of > 30 000 µS/cm up to more than 100 000 µS/cm.

Depending on the groundwater flow regime during the mine water recovery process, various types of groundwater inflow are likely to be established as separate layers. In some parts of the Ruhr region, highly mineralized mine water is expected to rise into the overlying caprock. Also, highly mineralized groundwater often occurs naturally in the base layers of the caprock. However, it can be assumed that, particularly in the southern part of the Ruhr region, a freshwater cap may develop.

The development of the mine water chemistry fundamentally depends on mine water drainage control measures during the successive closure of mines.

### *4.4. Methane Emissions at Ground Surface*

Degassing processes at the ground surface generally occur laterally diffuse or line-like along loosened zones. In addition, degassing processes should be expected along mine shafts. Generally diffuse methane gas represents a considerable risk of explosion in those areas where the gas is concentrated in buildings or underground cavities such as basement rooms or drainage pipes.

During the mine water level recovery, process mine gas which may previously have accumulated in open mine cavities is gradually displaced. As a result, gas pressure rises and the impact potential at the ground surface increases for a limited period of time.

As soon as the water pressure exceeds the residual rock gas pressure, degassing processes are interrupted. Mine water level recovery therefore may reduce residual degassing processes in the long term. In addition, active gas extraction measures, e.g. when utilizing mine gas, may considerably mitigate problems associated with methane-gas emissions at ground surface.

The highest amount of degassing occurs in the southeastern part of the Ruhr region, where caprock sediments are thin or missing completely.

### *4.5. Mining Induced Soil Movements*

Hard coal mining legacies in the Ruhr region include underground cavities and surface openings as well as subsidence areas which require long-term dewatering measures in order to prevent wetlands or flooding of populated areas (polder areas). In the Ruhr region, artificially drained polder areas resulting from mine subsidence include a total area of 970 $km^2$. In this area, measures for controlling the distance between groundwater levels and the ground surface have to be operated on a long-term basis. Locally, groundwater flow towards the pumping stations may increase during the mine water level recovery process as groundwater which had previously drained into the open mine workings now is no longer removed from the near-surface groundwater storey.

Based on past experiences from other abandoned mines (HEITFELD ET AL., 2005), ground heave will occur during the mine water level recovery process. Rising groundwater levels within the caprock sediments might have an impact the hydraulic pressure, resulting in more frequent and severe soil heave.

Potentially relevant uplift differences may occur locally in areas, where during the mine water recovery process groundwater levels vary considerably in the caprock, e.g. along tectonic faults (HEITFELD ET AL., 2004). Considering this assessment and monitoring of groundwater conditions in caprock sediments are particularly important.

## 5. Protected Natural Objects

The inventory of affected natural objects provides an important basis for the assessment of potential impacts of the mine water level recovery process. This applies to aquifers relevant to groundwater management, areas for drinking water and mineral water production, discharge areas and ecologically important natural habitats as well as to areas where a water level increase in bedrock or caprock sediments may directly affect the ground surface (collapse features at the ground surface, wetlands, inundation of contaminated ground).

The chloride content of surface water will decrease once the discharge of highly mineralized mine water is terminated. However, mine water may discharge directly into former dewatering galleries and into surface water courses along the southern boundary of the Ruhr region. Here, the mineralization affect might continue.

Potential impacts of the mine water recovery process are especially relevant with respect to the regional groundwater supply. In the northern part of the Ruhr region and in the Lower Rhine area there are several groundwater reservoirs supplying drinking water (fig. 4). In these areas, near-surface aquifers are generally protected from qualitative changes resulting from the mine water recovery process (rising saline water). Based on the present state of knowledge, negative impacts can not completely be ruled out, as the protective effect particularly along fault zones has not been investigated in detail yet.

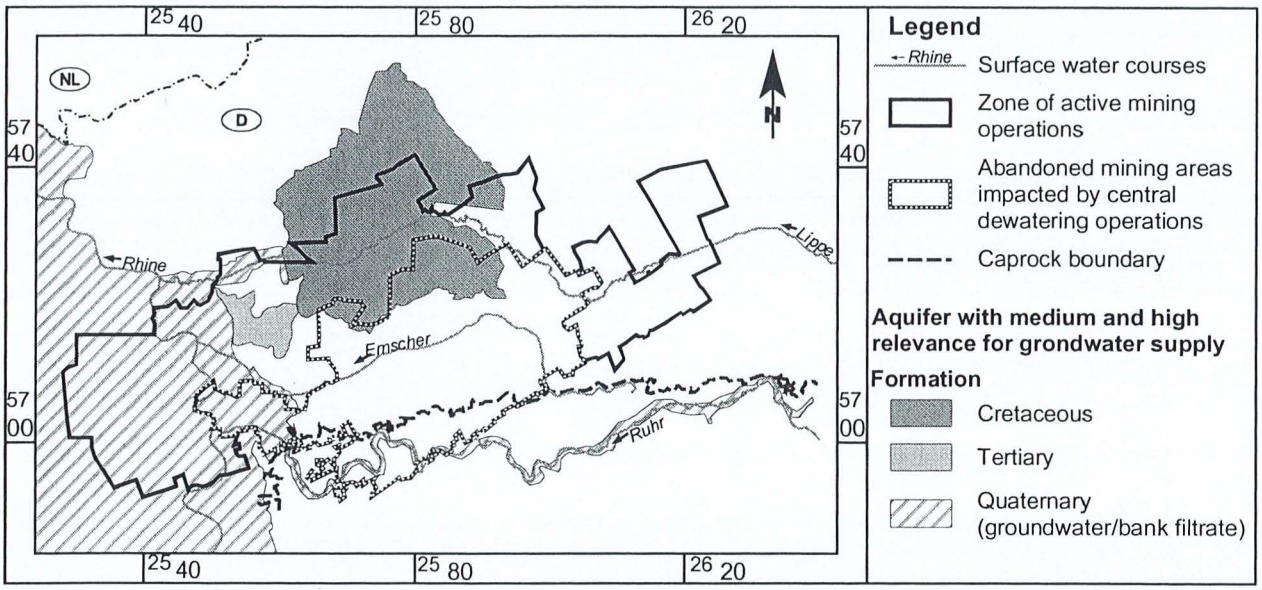


Figure 4: Aquifers relevant for groundwater supply in the Ruhr region

## 6. Hydrogeological Homogeneous Areas

A geological-hydrogeological model of the Ruhr region was developed as basis for the identification and assessment of potential impacts caused by the mine water recovery process. The composition of the caprock sediments is of particular importance. Based on the main caprock classification units and associated mining impact factors, four hydrogeological homogeneous areas were defined for the Ruhr region with respect to potential impacts of the mine water recovery process (fig. 5).

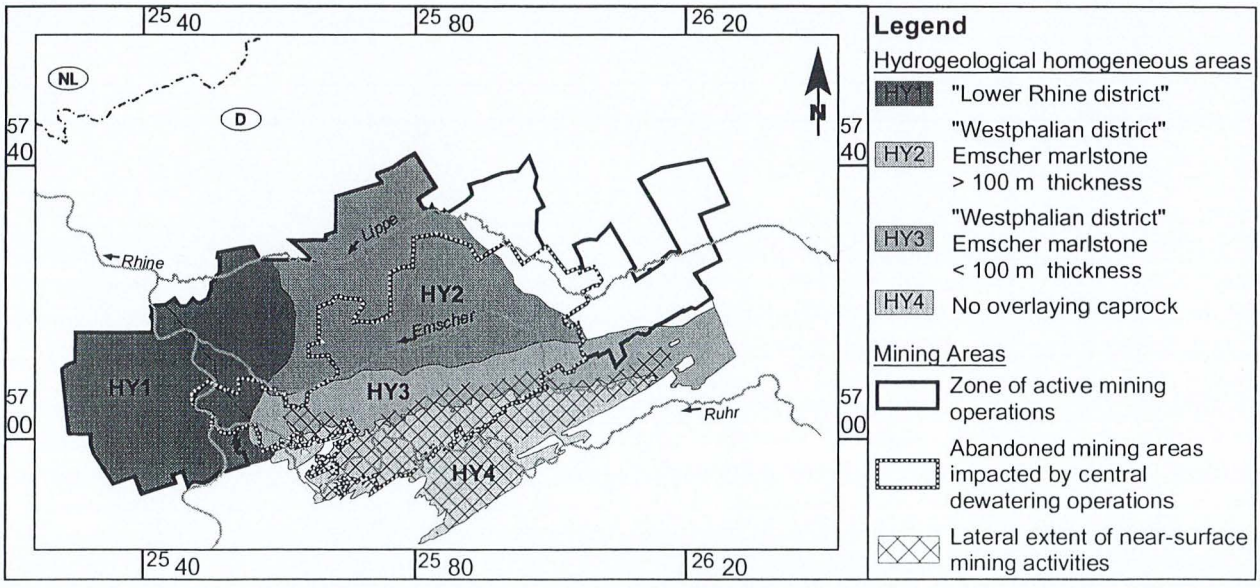


Fig. 5: Hydrogeological Homogeneous areas in the Ruhr region

The hydrogeological homogeneous areas deliniate zones with comparable impact potential due to the mine water level recovery process. In the northern and western part of the Ruhr region, the impact potential is generally lower due to hydraulic barriers established by some of the caprock sediments. Towards the south-east, the caprock thickness decreases and the impact potential rises in turn. These distinguishing criteria are considered preliminary and have to be verified by further detailed analyses.

## 7. Components of a Monitoring System

Extent and type of protected objects and areas will be defined according to the impact potential of different phases of the mine recovery process. Two aspects have to be taken into account: the regional classification of the Ruhr region by zones of different impact potentials and the fact that the impact potential depends on the actual mine water level. The regional structure of the monitoring system is based on hydrogeological homogeneous areas; in addition, the amount of groundwater inflow during operation of respective mines will be considered an indicator of expected mine water recovery impacts. As a result, the Ruhr region is subdivided into a total of six monitoring zones A to F (fig. 6). The time scale for the monitoring system includes three recovery phases, which are defined by water levels rising in the deeper carboniferiuos rock (recovery phase 1), water levels flooding the near-surface abandoned mine workings within the carboniferious rock (recovery phase 2) and water levels reaching the caprock base (recovery phase 3).

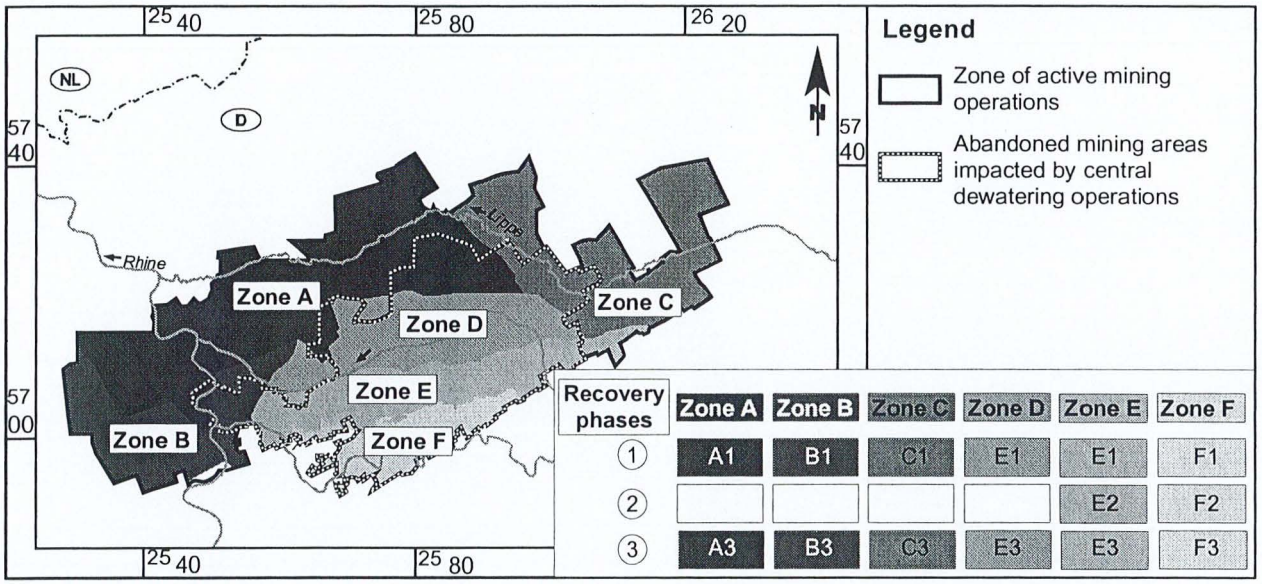


Figure 6: Modular monitoring system in the Ruhr region including monitoring zones

By combining these time and regional classification elements during the mine water recovery process, monitoring measures can be assigned accordingly, resulting in a modular monitoring system (fig. 6). Each monitoring modul includes a package of measures specifically designed for special impact potentials in each respective recovery area and respective recovery phase. In addition to monitoring the ongoing mine recovery processes, sufficient time has to be allowed for defining the actual status prior to concrete impacts to happen. Uncertainties concerning the prediction and the evaluation of mine recovery impacts have to be verified by appropriate monitoring measures.

The present sample catalogue of monitoring measures is an initial rough framework for comprehensive monitoring in the Ruhr region. Monitoring measures, intervals and parameters have to be adjusted continuously according to the ongoing increase of knowledge concerning the developing mine water recovery process.

Based on the present state of knowledge, the monitoring areas E and F in the area of near-surface mining activities are considered problematic zones for the mine water recovery process with respect to water management conditions and the mine gas situation. Monitoring and protective measures have to be focussed on these areas.

## 8. Monitoring Measures

The sample catalogue describes monitoring measures required for each individual stage and zone of the mine water recovery process, including recommendations for monitoring intervals and parameters. Among others these include:

- Monitoring of the actual water level: appropriate monitoring stations are required to obtain mine water samples and a hydrochemical depth profile. The number of sampling stations have to be determined according to the hydraulic conditions within the abandoned mine area and its respective size (a minimum of one sampling location for each mine).
- Monitoring of gas pressure: the gas pressure of flooded areas and/or the gas inflow volume at neighbouring active mine areas has to be determined; sampling locations also have to be monitored for degassing processes.
- Monitoring of groundwater conditions at the caprock base: monitoring of deep piezometers at appropriate hydrogeologically relevant locations with an increased impact potential due to the mine water recovery process (e.g. fault zones, mining fracture zones). Inventory and supplementation of the monitoring system in hydrogeologically problematic areas.
- Monitoring of soil movements: establishment of a levelling point system for the measurement of soil heave and for the detection of potential discontinuities due to the mine recovery process. In areas of abandoned near-surface mines, additional monitoring of risk areas by site inspections, intensive monitoring of sewage pipe systems etc.
- Shaft securing measures: in areas of deep mining activities, all of those shafts have to be secured whose base extends to the final mine water recovery level.

An inventory of the present status and its evaluation with respect to the impact potential identified in the sample catalogue will be an important first step for the implementation of the monitoring concept. A collection and compilation of the existing data and monitoring stations from various institutions will be required.

## 9. Final Remarks

With the newly developed sample catalogue for monitoring the mine water recovery process in the Ruhr region, the mining authority of the state of Northrhine-Westphalia is now prepared for the challenge imposed by the political agreements of the "Kohlerunde" of 2007.

As a matter of fact, it is not quite certain to date, whether the mine water in the Ruhr region will actually rise to levels of surface water or whether a permanent mine water drainage system has to be installed at a still unknown level for security reasons.

Such a decision will be based on a sound technical assessment of the impacts of various groundwater recovery scenarios with the participation of concerned authorities, associations and mining companies. A basis for decision-making will be established by target-oriented monitoring measures.

In this context, the long-term utilization of mining sites (e.g. mine gas, geothermal energy) has to be taken into account at an early stage.

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