Groundwater Discharge from a Near Surface Aquifer into Deep Coal Production Horizons as Post Mining Hot Spots of Water Logging Probability

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Abstract Coal mining in the German Ruhr area is accompanied by intensive water management efforts concerning ground and surface waters. Land subsidence has created the need to rebuild, regulate and maintain surface waters in order to prevent water logging. Dewatering of the coal production horizons does not dewater the surface near aquifer, as it is separated from the coal production horizons by thick aquitards. In the future leakage from these aquifers may be subject to change. Coal mining in this area will have ceased until the year of 2018, when government aid is phased-out. Dewatering of the deep horizons is planned to be maintained in the post mining system to prevent negative effects on the surface. To optimize the post mining water management system important information can be obtained from today's groundwater dynamics.

Key Words Post mining water management, areal groundwater dynamics, dewatering of deep aquifers

Introduction

Industrial mining and water hoisting from underground mines have been important parts of the industrial heritage of the Ruhr Area for at least the past 150 years. Coal production started in the south of the area where carboniferous strata is visible on the surface near the River Ruhr. Today mining is taking place in a depth of about 700 to 1000 m below the surface. A large number of closed mines is located in the area. Today three mines are still operated. From the interconnected underground water extraction system in 2007 about 98 10^6 m^3/yr (MUNLV 2008) of mine water was pumped to the surface and discharged mainly into the rivers Emscher and Lippe, tributaries of the River Rhine.

To understand regional groundwater dynamics the hydrogeology of the Münster-Basin must be considered. The diameter of this basin is approximately 150 km from east to west and 80 km from north to south (Struckmaier 1990), see fig. 1. The carboniferous rock of the basin is covered with

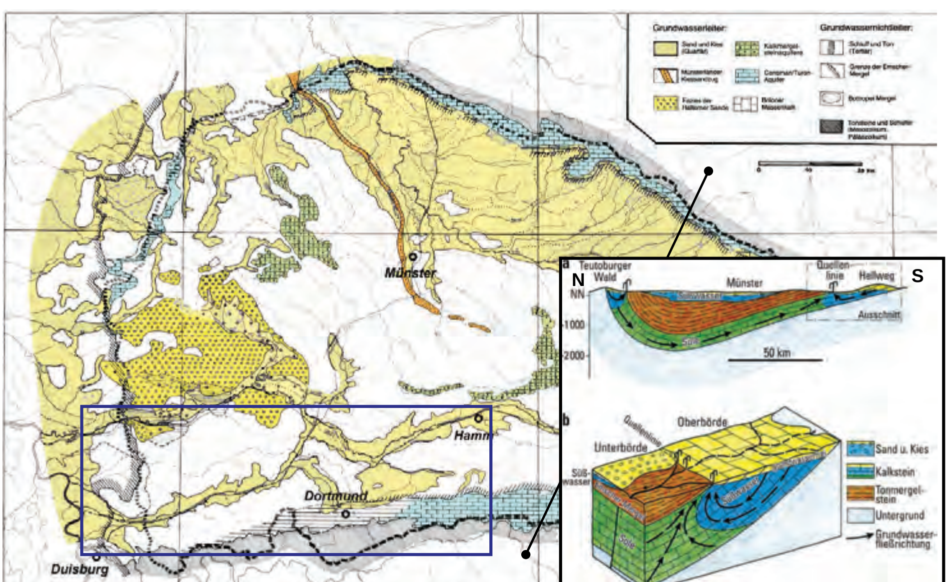

Figure 1 *Münster Basin and Ruhr Area (blue frame).Cretacious aquifers (blue colours) and Aquitards (hatched border) from DMT 2008 and black frame showing cross section from Michel 1963.*

cretaceous sediments. They are divided into lower fairly water permeable parts (limestone) and a rather impermeable marl stone layer (the so called Emscher-Mergel) at the top that can be as thick as 600 m (Struckmaier 1990).

Below Emscher-Mergel confined groundwater is found throughout the basin. Cretaceous limestones are locally used to extract mineral water. Information on the pre-mining hydrodynamics are quite sparse as mining has such a long unbroken history and started in a rural area. Artesian wells were known to exist along a historic trade route (Hellweg). Waters from these wells can be saline as well as fresh water. Mining activity affects this system in such a way that the amount of mine water that is annually extracted decreases the natural discharge from the basin.

Recharge of groundwater (downward movement) at the rim of the basin and discharge of groundwater (upward movement) in the center of the basin is the general picture that can be painted of the regional groundwater movement. Within this large scale flow system, smaller disconnected flow systems are, of course, possible and established. In general high groundwater recharge rates occur in the Ruhr Area. A mean of approx. 190 mm/yr was calculated for the Emscher and Lippe Region on the whole (Meßer 2010).

Results of Local Groundwater Discharge Quantification

Monitoring of groundwater levels in the unconfined uppermost aquifer allows to construct surface maps of the groundwater level. For an area close to the city of Dortmund a groundwater surface map of the surface near aquifer was constructed to be used as initial condition in a groundwater model (see fig. 2). The aim of the model was to evaluate the effects of a planned reconstruction of the local rivers. These rivers nowadays still contain sewage that is transported to treatment plants by this way, which characterizes

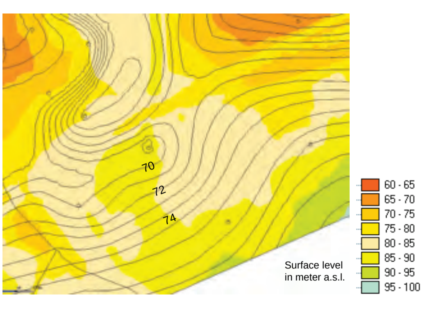

Figure 2 *Piezometers (circles) and constructed isolines of groundwater levels. The colour shade is showing the surface elevation.*

a system that was created to manage waste water transportation and treatment during the boom times of mining in the beginning of the 20th century. The local association Emschergenossenschaft is currently rebuilding this system to re-construct the rivers and to establish an underground sewage transport to the treatment plants. Groundwater models are used extensivly in this area to predict the effects of changed water levels in the rivers and drainage systems.

To simulate the observed groundwater surface with a model it is important to know all significant sinks and sources for groundwater in the area. Groundwater recharge was calculated using a GIS-based method that was developed for urban areas (Meßer 1997). It takes small-scale variations of landuse and sealed surfaces into account that are typical of that area. Local groundwater withdrawal occurs by wells, by drainage systems that are constructed to drain building foundations and river dams and by the sewage system that in parts may lie below the groundwater table and can exhibit damaged and leaky parts. These are believed to drain groundwater (Reichel 2008) which is subject to manyfold efforts to measure groundwater-borne fluxes and to rebuild these systems.

For the shown area (fig. 2) all legal wells were taken into account. Furthermore all sewers were known with their bottom levels and their condition concerning groundwater tightness. This has become standard practice for groundwater modelling in the area. Unknown groundwater withdrawal is believed to occur in areas with high groundwater levels and private buildings, caused by the leaky sewage system and connected private drainage systems. For the shown example area this does not seem to be of major importance, as groundwater levels are no less than four to five meters below the land surface.

When using all known points of groundwater withdrawal in the model, it is obvious that the observed groundwater surface can not be simulated without supplementary sinks for groundwater. In fig. 2 a cone of depression is visible that does not correspond with artificial withdrawal. Groundwater discharge into the underlying aquitard was hypothesized before, but no published evidence was found. The possibility of natural downward groundwater discharge does appear to be possible from the location of the area within the regional flow system of the Münster-Basin. As it has been explained above, the center of the basin is characterized by discharge within the regional groundwater flow system, whereas recharge is taking place at the rim predominantly in the area where carboniferous strata outcrop on the surface.

The thick aquitard (Emscher-Mergel) is believed to yield a hydraulic conductance in the order of 1—5 10^{-8} m/s for its matrix. The dense marl rock is crossed by a number of fracture zones. In these fracture zones the hydraulic conductivity is believed to be increased by at least one or two orders of magnitude. Unpublished geologic maps show the position of a fault zone in the example area of fig. 2. A groundwater model was used to estimate the groundwater withdrawal that is needed to create a groundwater surface observerd. For the area of about 90.000 m² shown in fig. 3 a flux of about 90.000 m³/yr is needed to achieve a modelled groundwater surface close to that observed.

Discussion

Downward groundwater movement is believed to be possible in this area, because groundwater is taken from the deep horizons (carboniferous strata) and the pressure is consequently lowered by mining activity. In general the surface near aquifer and the coal production horizons can be viewed as decoupled systems. In some parts they are not. To our estimate this connection occurs at a number of places within the Ruhr Area. These places are viewed as hot spots for post mining groundwater uprise when the leakage from these aquifers decreases.

After mining will have been stopped, water management (withdrawal of water from the deep horizons) will not cease for a number of reasons to avoid negative effects on the land surface. Nevertheless controlled uprise of the pressure within the carboniferous horizons will help to minimize costs and optimize the post mining system. To optimize this system the mining company (RAG) is running an elaborated model that is based on the geometry and interconnectivity of the underground voids and its (lateral) recharge by the regional flow system (Eckart 2004). As long as the water pressures in the deep horizons do not affect the quantity of discharge from the surface aquifer (which was investigated in this paper) no effect with respect to groundwater levels at the surface is expected. As the flow of groundwater through the aquitard of the Emscher-Mergel uses conduits provided by fracture zones, spatial predictions of the interaction between the flow systems within the Münster-Basin are complicated with respect to discrete water pressures. A more exact knowledge of the system could be derived by water balance calculations of the Münster-Basin on the whole.

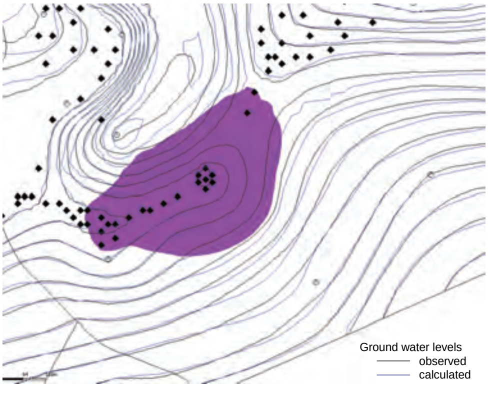

Figure 3 *Results of a calculation using a groundwater sink of 1 m³/(m² yr). The shaded area represents the area with more than 10m difference between observed and calculated levels without considering discharge. Black diamonds indicate assumed groundwater discharge to the deeper aquifer.*

Conclusions

It can be expected that downward leakage from the surface near aquifer will decrease when pressures in the deep aquifers rise, as soon as saturated conditions are established downstream. Therefore, after the end of coal production in the German Ruhr Area water management of deep aquifers will continue to be an important issue. Pumping of mine water is currently not intended to be ceased within the time frame of human planning. Nevertheless it may be possible to optimize the system. The problem owner (RAG and RAG foundation in the future) runs and optimizes the system based on the datapool that was gathered during the period of mining. Water extraction was primarily aimed at mine safety during coal production in that era. Water extraction in the future (in the post mining system) will be primarily aimed at the security of the land surface and to avoid water logging at the surface. This is a turnaround in management goals and may need a new paradigm concerning the tools that are used.

At land surface the main water management assignment is to organize surface water drainage as land subsidence has created the need to install polder pumping schemes. This is organized by Emschergenossenschaft and Lippeverband (EGLV). To account for effects the regulation of surface water poses on groundwater EGLV owns and maintains groundwater models for large parts of the Ruhr Area. For today's hydrologic setting (active mining) groundwater discharge into deep horizons is used for some places as boundary condition within these models. For the future hydrologic setting (post mining condition) this discharge could decrease to an unknown degree. It is not necessary to let deep water pressures rise to surface levels (which will be avoided) to picture a decreasing downward discharge. Exact predictions of piezometric pressures are hampered by the fact that the aquifers are connected by fracture zones. This is why water budget calculations seem to be of great value. Existing models of the surface aquifers can be used to identify the water fluxes that are believed to move downward into deeper aquifers. Regional models based on water budget conservation can not explain groundwater pressures with high spatial accuracy. They could, however, be used to give general answers to the movement of the recharge/discharge border within the Münster- Basin due to a change of water management.

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