Modelling of Mine Water Discharges with Integrated Pump Management

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Abstract

Mine water levels are currently rising to an optimized level in large parts of the Ruhr region in Germany, with the aim of reducing the number of pump stations and shift to submersible pump management from surface. These developments also pose new demands on mine water discharge management into receiving waters and the numerical quality and quantity modelling of the pumped mine water. Therefore, a method has been developed to be able to calculate the pump management typical for submersible pumps using numerical modeling with the established Boxmodell. This method is illustrated using a site example, which demonstrates the effects that the interaction of pump management, the location of the pump site and the hydraulic conditions can have on mine water discharge.

Keywords: Mine flooding, pump management, mine water management, model calculation, mass transport modelling

Introduction

During the active period of hard coal mining in the Ruhr region, the mine workings were kept dry by dewatering the deepest mine areas (Coldewey 1994, Drobniewski 2017). Nevertheless, dams to former mining areas induced higher water levels locally. The water levels in the mines were thus constant over a long period of time. Following the closure of the last mines in the region in 2018, water levels rise almost everywhere or discharge into zones with lower water levels (Vogt 2020).

The DMT mine water modelling software "Boxmodell" calculates the mine water rises based on the known initial conditions (water levels, inflows) and using numerous model input data on the condition of the host rock and the residual mine voids (Eckart 2007). Extensive reference and monitoring data are available for this purpose and are used to calibrate the model.

In some mine water provinces, the target level has now been reached and the water is discharged into the receiving waters. Some older dewatering systems use underground pump stations for this purpose, in which the water levels in the catchment area are kept constant, as was previously the case in active mining. Depending on the exposure of the mines to the surface, only the water inflows or extraction rates vary, which is also considered by the models in the affected regions on the basis of groundwater recharge rates (Bedford 2022). Despite the variable flow rates, the hydraulic and chemical conditions in the catchment area of the pumps are comparatively stable under these conditions.

In new facilities, submersible pumps have been and also continue to be installed, which are lowered from the surface into the rising mine water. As most systems have several pumps installed with a fixed pumping capacity the pumps are switched on and off as required to pump the inflowing water. In most cases this does not correspond to the rate of mine water inflow to the mine (in part influenced by groundwater recharge). As a result, the water levels rise when the pumping capacity is smaller than the inflow and fall when the pumping capacity is higher than the inflow (Fig. 1). While this has no relevant consequences for the chemical composition of the discharged water at some locations, current modelling studies show that this can certainly be the case under sensitive site conditions.

Location

The last mine water pump station in the eastern Ruhr area was discontinued in 2019. Since then, the water levels have been rising depending on the regional distribution of inflows and the volume of residual voids that can be filled as well as the hydraulic connections within the mine water province. The site of the future pump station is centrally located between the two most recently active mines. Fig. 2 shows a clear focus of the inflows in the western area, which resulted in mine water flowing from the west over many years and contributing to the filling of the eastern cavities.

In addition to the quantities, the compositions of the mine waters to the west and east of the future pump station also differ substantially. While the mine water in the western part is characterized by low-salinity and seasonally fluctuating inflows from the overburden, the hydrochemical situation in the east is dominated by highly saline waters from the carbonate layers. Another special feature of the western inflow water is the occurrence of sulfide, which has been detected in the discharge water over a period of more than 10 years. The occurrence of hydrogen sulfide (H2S) is explained by bacterial sulfate reduction and is calculated in this way by the model. The mobilization of pyrite oxidation products (sulfate, iron, manganese, other metals) during the mine water rise is also considered for the entire area.

Modelling of a future pump station

Once a target level for the rising water has been reached, the mine water must be pumped again and discharged into the receiving water (Balzer 2019). Earlier modelling calculations for this scenario used the steady state approach with a constant water level and variable but only slowly changing flow rates due to the inflows (Fig. 1). For a possible use of submersible motor pumps, the resulting hydraulic conditions and the effect on the quality of the discharged mine water should be examined by using numerical modelling. The initial step requires reprogramming of the pump module in the model code, with which the pumps are activated or switched off depending on the inflow and the upper and lower water level limits.

To model this correctly, it is necessary to specify the hydraulic properties of the flow paths. Overall, the naturally flowing water volumes are already very large, averaging more than 20 m^3/min. However, the flow rates induced by the pumps will be much higher at up to 50 m^3/min. The current situation already allows the permeability coefficients between the model boxes to be calibrated in this respect due to gradients within the province (Fig. 3). Even if, according to the current state of knowledge, it is not necessary

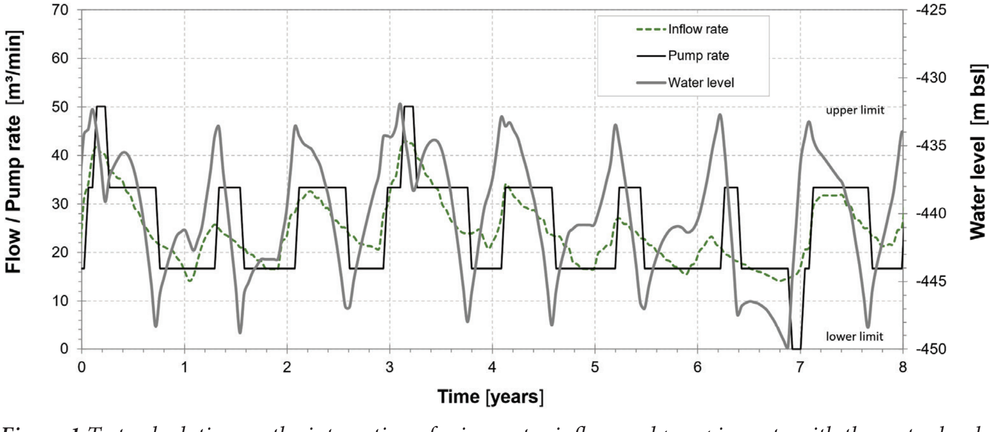

Figure 1 *Test calculation on the interaction of mine water inflow and pumping rate with the water level.*

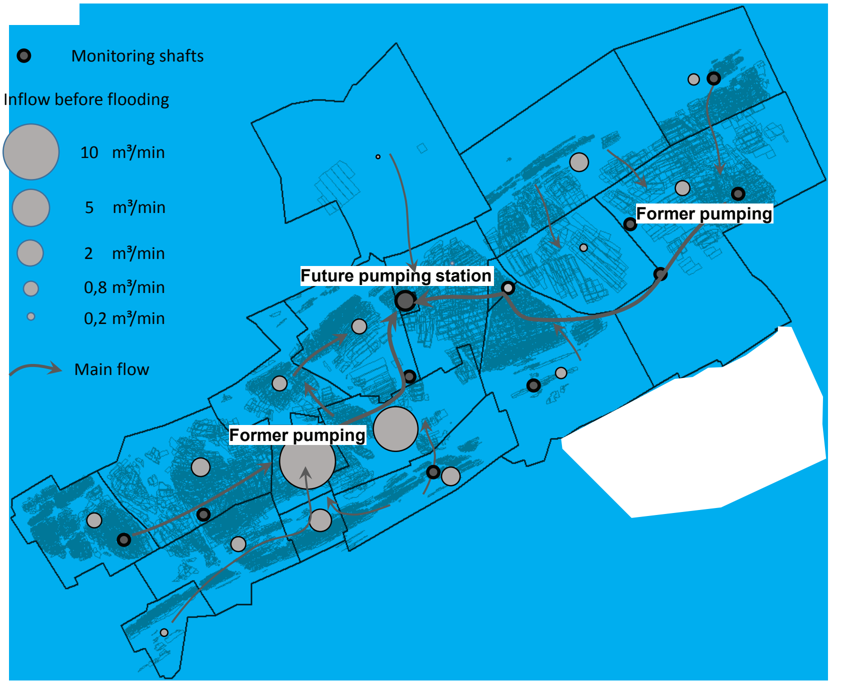

Figure 2 *Water province with distribution of inflows and flow directions to the future pump station.*

to assume that there are any breaks or other plugs in the gallery system, there are still water level differences of approx. 10 m along the flow gradient from west to east. Such effects have not yet been observed and calibrated at other locations due to the usually much lower flow rates.

In a future operation, this will lead to water level differences of up to several tens of meters between the extraction site and the periphery of the water province (Fig. 4). The inertia of the flow system within the water province, which extends over a total of about 33 km, leads to various effects. Particularly in phases of high-water withdrawal and lowering of the mine water level in the pump shaft, the directly neighboring areas will follow the water movements in the shaft. At the peripheral areas with high inflow in the west, however, the changes will only be damped, and the water levels will remain generally higher. This dynamic not only influences the storage volume during pumping operations, but also the quality of the water flowing to the extraction point.

A preliminary evaluation of the substance emissions made it clear that high mine water discharges in summer during low flow rates in the receiving water could lead to exceedance of environmental limits. It would therefore not be possible to lower the mine water level once the upper limit is reached. For this reason, a concept has been developed that utilized higher pumping rates during phases with higher flow rates in receiving waters (mainly in winter and spring). Due to the storage volume of the residual mine voids, it is then possible to slowly raise the water level in summer with low pumping rates and thus minimize the load on the receiving water.

The modelling approach for this concept is based on fixed dilution factors between the water flow in the receiving water and the amount of mine water discharged (Fig. 5). The dilution factor was selected such that the water level can be maintained in a defined level range in the long term with a feasible pumping cycle. In the past, this range was often selected too small during planning, which reduced the degrees of freedom in pump operation. For the site conditions, the pump clearance should therefore be at least 50 m to be able to bridge longer dry phases with low discharges in the receiving water (Fig. 6). This concept of variable, stepless mine water extraction can be realized by

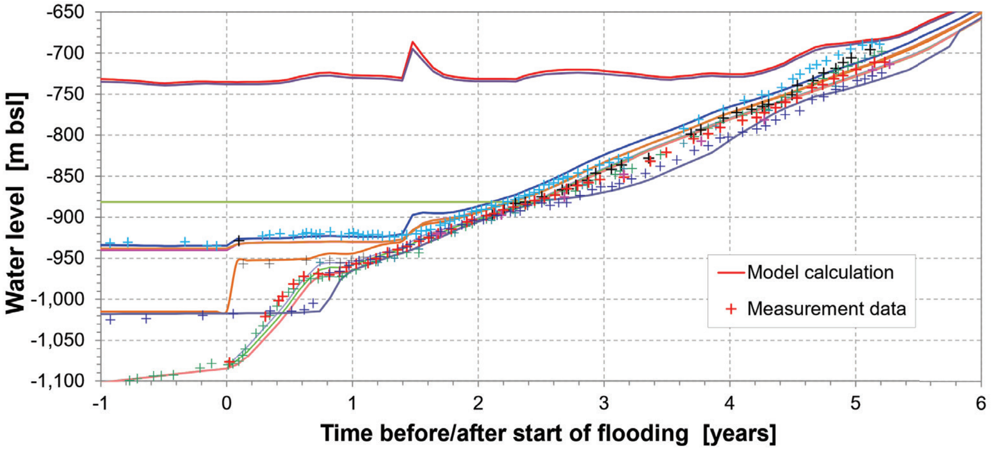

Figure 3 *Water level development in the water province.*

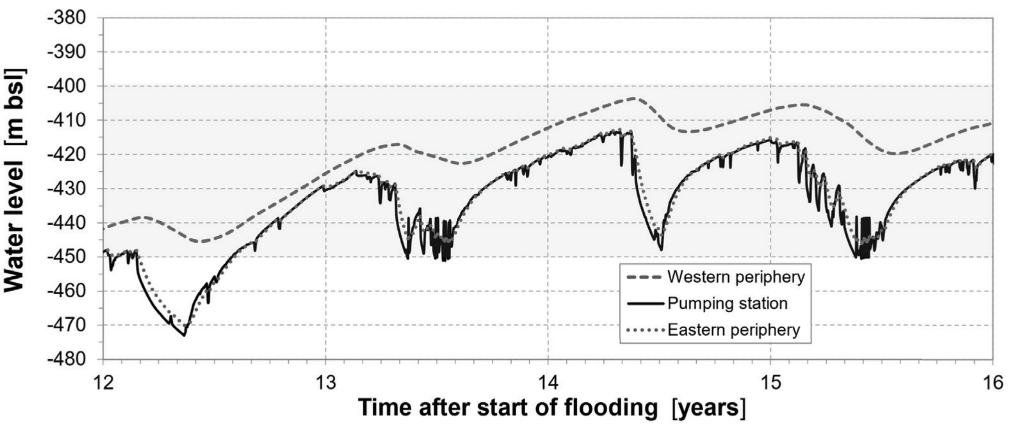

Figure 4 *Spread of water levels in the water province during pumping operation.*

using frequency-controlled pumps with a defined performance interval with variable pumping rates.

However, it is difficult to forecast the climatic conditions in the coming years or decades with sufficient accuracy to provide a suitable basis for such forecasts. Such modelling can therefore only be used to cover the possible range of scenarios and to test sensitivity to extreme situations. In the context of two climatically controlled hydraulic systems, as in this particular case, the temporal parallelism of the underlying reference data for mine water and receiving water is particularly important. The model therefore cyclically repeats an 11-year period 2008–2018, which is fully covered by data on mine water discharge, receiving water flow and regional climate data and for which a sufficiently good calibration could be achieved. This period contains both pronounced dry periods and years with high precipitation and is therefore a suitable basis for estimating future mine water discharges.

The inflow situation into the mine shows an attenuation and temporal shift of the maxima/minima compared to the groundwater recharge and even more so to the surface runoff. However, the described method (Bedford *et al.* 2022) ensures that both data series are based on the same climatic conditions. The main variable is then the rate of mine water pumped, while the chemical composition is calculated by the model.

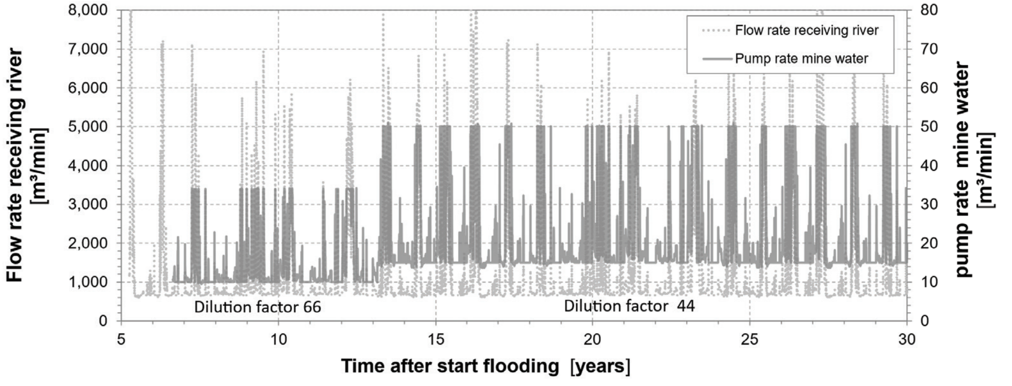

Figure 5 *Flow rates in the receiving river and adjusted pumping rate of the mine water.*

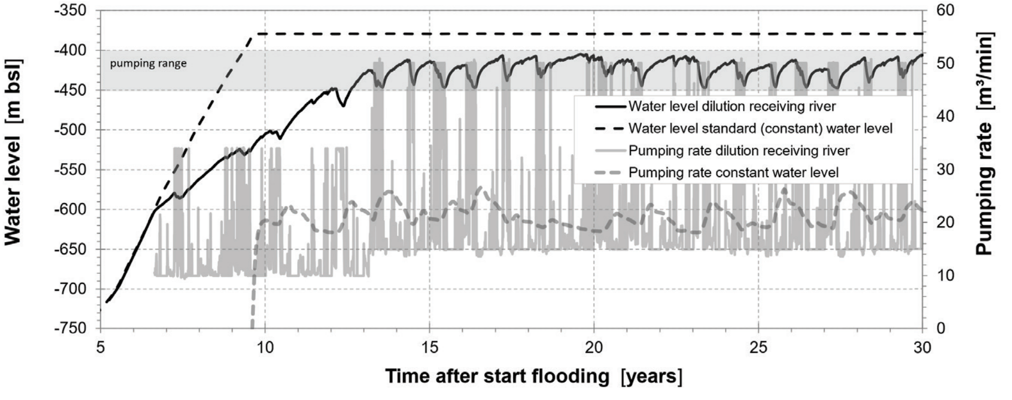

Figure 6 *Pumping rate of the mine water and resulting water levels.*

Quality Calculation

Calculations on reactive mass transport were carried out using this hydraulic concept. These show that, in contrast to constant pumping rates, the model calculates pronounced jumps in concentration in the discharged mine water. This is not limited to individual parameters, but also affects pyrite oxidation products and sulfide in addition to primary dissolved components of the inflows (example chloride in Fig. 7). The relevant higher salt concentrations in the eastern inflow are clearly visible. The substance content of the western catchment area forms the base concentration of the mixed water in the pump.

A higher temporal resolution analysis of the interaction between the extraction rate, which is forced by water levels and the receiving water discharge (Fig. 8), and the resulting concentrations in the mine water (Fig. 9) provides a simple and plausible explanation of this phenomenon. In phases of low extraction rate (with low flow rate in the receiving water), less water is extracted than flows in with the western partial flow. The remaining quantity pushes into the eastern mine areas and thus contributes to the filling of the cavities as the mine water rises. As a result, almost exclusively the low-salinity water is then pumped from the western sub-province.

If the pump rate exceeds the total inflow, the water level is lowered and, in addition to the current inflow, water is also withdrawn from the storage volume. This increases the proportion of water from the eastern sub-province to up to 30% of the total extraction rate. However, the average inflows are distributed west:east at a ratio of 95%:5%. Even if the model considers the fact that

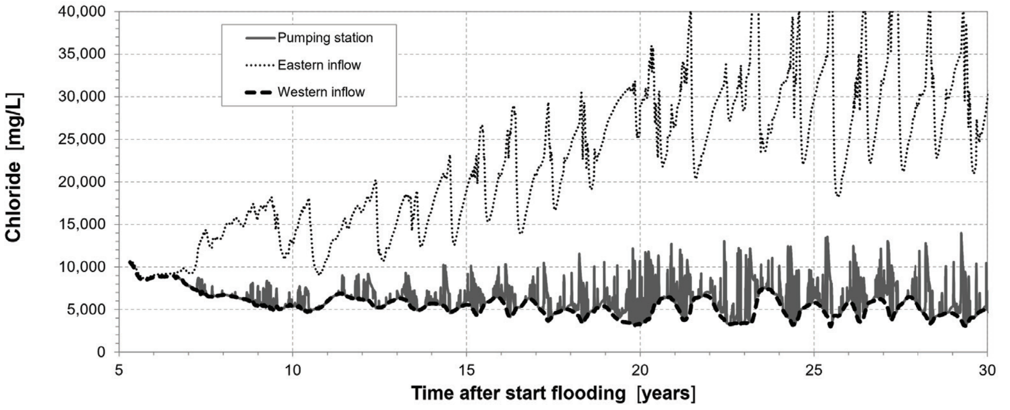

Figure 7 *Calculated development of chloride in the pumped mine water and the partial streams.*

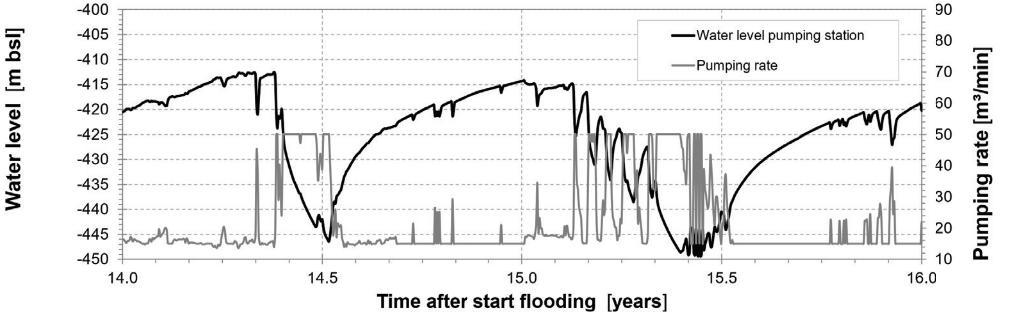

Figure 8 *Detailed analysis of pump rate and water level.*

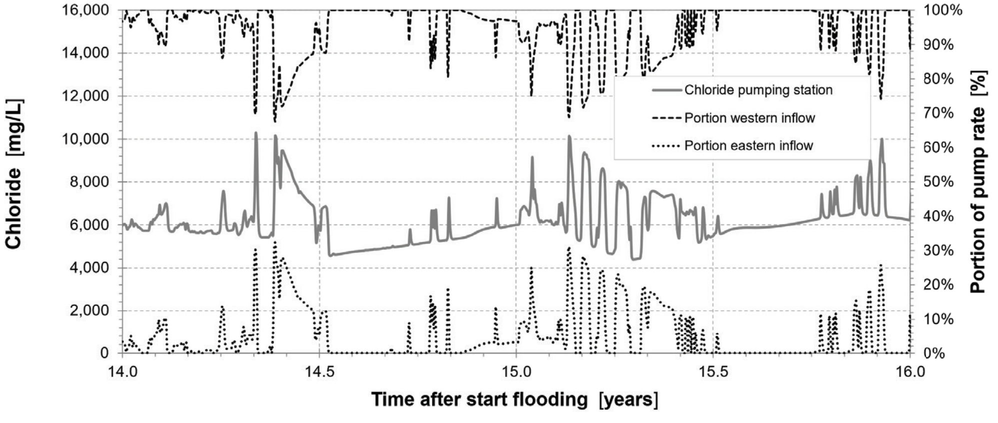

Figure 9 *Detailed analysis of inflow proportions and resulting mine water concentration of chloride.*

western water also flows back again from voids in the east, this leads to peaks in the concentrations but even more such in the discharged loads. As a result, the loads and thus also the mixed water concentrations in the receiving water exceed the equalization actually aimed for via the flow rate ratio.

These fluctuations influence not only dissolved salts, but also secondary releases or formations of iron and sulfide. After washing out the iron mobilized in the rising water, the model again calculates the continuously formed sulfide appearing again in the western inflow. The eastern inflow is likely to have persistently high iron concentrations due to low flow and flush rates. The model does not expect only a mixture associated with FeS precipitation, but a constant change between sulfide and iron surplus in the discharged mine water. If the discharge into the receiving water requires treatment of the mine water regarding these components, this would also mean a constant change between two operation modes in a processing plant.

Conclusions

This site example clearly demonstrates the effects that the interaction of pump management, the location of the pump site and the hydraulic conditions can have on mine water discharge. It is therefore advisable to carefully assess the site conditions and review the plans for the final design of a water province. Various scenarios can be easily checked in advance using numerical models. This requires reactive mass transport models, whose water extraction strategy is developed in coordination with the environmental impact assessments of the water discharge and the technical planning.

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