ABSTRACT: In numerous lowland areas of the Lower Rhine Embayment private homes were built in the dry 1970s without precautions against high groundwater levels. Portions of the Embayment have both then and now been influenced by groundwater withdrawal connected with opencast lignite mining. Flooding of cellars occurred in many homes in the late 1990s when the water table rose due to heavy precipitation.

The Erftverband - a regional water association in North Rhine-Westphalia - was asked in 2002 to develop a regional groundwater model to simulate hydraulic measures aimed at protecting all affected buildings in flood-prone sectors of the town of Korschenbroich. A study demonstrated that 100 percent protection would require 31 pumping wells for the necessary groundwater drawdown. Re-injection of large amounts of extracted groundwater would be required to maintain the water yield of nearby public waterworks.

In a follow-up study using the model the Erftverband investigated possible cost-saving hydraulic pumping schemes that would operate without reinfiltration. As the region is intensively used for drinking water production, no negative impact on groundwater yield would be acceptable. Accordingly, the challenge was to derive acceptable groundwater drawdown levels. Through unsteady particle tracking analyses it was proven that optimized, selectively timed operation of up to 17 pumping wells would produce no negative impacts on subsurface catchment areas of the waterworks.

Based on transient groundwater simulations over a period of 24 years, a typical range of groundwater recharge conditions was applied to generate a realistic operating scheme for pumping wells. The modeling results showed that a capping of groundwater peaks at the wells could lead to significant reduction of affected buildings in periods with a high water table both under present conditions and in future when mining activity has ceased.

INTRODUCTION

The modeling work presented in this paper was brought about by an unfortunate situation with regard to erection of buildings in a lowland area of the Lower Rhine Embayment which has unfolded over decades. In particular in the vicinity of Korschenbroich and Kaarst in North Rhine-Westphalia many private homes were built in the dry 1970s without any precaution against high groundwater levels. Starting in the late 1990s, when the water table rose significantly due to intensive precipitation, hundreds of homeowners found their dwellings under decimeters of water with little prospect of permanent relief. As a consequence the owners faced serious problems with mold accumulating on walls, damage to building structure and furniture and loss in property values. In hindsight these difficulties could have been anticipated and avoided, given the hydrogeological characteristics of the area and the human interventions taking place locally and regionally.

This case is by no means unique. According to BWK (2003) there are comparable instances of water logging damage in various lowland parts of Germany. However one of the highest concentration of buildings affected by high groundwater levels can be found in Korschenbroich.

HYDROGEOLOGICAL SETTING AND GENESIS OF THE PROBLEM

This section will present the underlying problem in terms of hydrogeology and human activity. The situation will be viewed in its historical development from the 1970s up to the present.

Hydrogeology

Large parts of the towns of Korschenbroich and Kaarst are located in lowland areas that are characterized by a close interaction between groundwater and surface water and low depth to water table. The shallow aquifer consists of quaternary and highly-permeable sand and gravel sediments.
with an average thickness of approximately 30 m. Tertiary sediments are underneath and also belong to the upper aquifer system, which is the primary source of public, industrial and agricultural water supply in the region.

Groundwater flow is affected by various surface water bodies and partially by the influence of groundwater drawdown due to opencast lignite mining 10 kilometers south of Korschenbroich. In the southern sectors of the town the groundwater level is lowered by up to 10 meters, so that maximum anticipated groundwater levels cannot occur under current conditions (Figure 1).

Figure 1: Location of study area with isolines of groundwater drawdown in meters since October 1955

Erection of buildings and subsequent flooding

In the 1970s groundwater recharge rates were far below average, resulting in a sharp drop in the water table. Many houses were built in this period without precaution against high groundwater levels. Architects and builders very often failed to protect foundations against pressing water, ignoring the hydrogeological fact that very high groundwater levels had been recorded in the 1950s and 1960s.

Due to significant increase in precipitation amounts and subsequent rise of groundwater levels in the late 1990s flooding of cellars occurred, affecting hundreds of homeowners. Many of them were confronted with mold accumulating on walls which caused illness and allergies in some individual cases. To a large extent cellar rooms could no longer be used. Resale value of affected homes dropped significantly.

Countermeasures

Upon their own initiative numerous homeowners installed pumps in the sump pits of their basements to keep them dry. This practice has been tolerated by local water authorities until today. Since 2002 local groundwater drawdown initiatives in two sectors of Korschenbroich have received limited approval to pump out a certain amount of water. 80 percent of the pumping costs during winter are financed by the public, 20 percent by the municipality of Korschenbroich.
Determination of buildings at risk

The number of buildings in Korschenbroich subject to flooding under high groundwater conditions was determined by means of a detailed survey of foundation heights (Stadt Korschenbroich 2008). In a next step, for all buildings surveyed, the maximum anticipated groundwater level following extremely wet weather conditions, in absence of any groundwater abstraction influence, was ascertained.

The intersection of foundation heights of unprotected buildings with maximum anticipated groundwater levels resulted in the identification of approximately 3,200 buildings that would be affected by extremely high groundwater (Figure 2). These buildings were grouped according to the extent to which the maximum anticipated groundwater level exceeds the foundation height.

Figure 2: Location of affected settlement areas in case of maximum anticipated groundwater levels

GROUNDWATER MODELING

A regional groundwater model was developed by the Erftverband – a regional water association in North Rhine-Westphalia – in 2002 to simulate hydraulic measures aimed at protection of built-up areas in the affected region (Erftverband 2002).

Initially, modeling efforts supported the policy aim of 100 percent protection of all affected buildings and encompassed reinfiltration of pumped water to maintain the water yield of nearby public waterworks.

For reason of cost, the policy aim is now to provide a significant level of protection through optimized hydraulic pumping schemes that will operate without reinfiltration and will avoid negative impacts on the water yield. Thereby the current task of modeling is first to determine for every well location how much groundwater can be drawn down without negatively impacting water yields and then to ascertain how many buildings will no longer be flood prone.
Description of the groundwater flow model

The regional 3-dimensional groundwater model has been developed with the FEFLOW modeling software (Diersch 2002). This model covers an area of 435 km² north of Garzweiler opencast mine and is bordered to the east by the river Rhine. The horizontal mesh consists of 95,000 elements with mesh refinement in core regions. Vertically the model comprises four relevant aquifers and three aquicludes.

In order to link this model with a large-scale groundwater model used for forecast-modeling in the Rhenish lignite mine area (RWE Power 2007), Dirichlet boundary conditions were applied at the model borders. All relevant groundwater users, infiltration facilities and surface water bodies were considered by means of appropriate boundary conditions. Groundwater recharge was included taking into account spatial variability based on an empirical approach and variation in time. For this purpose, recharge dynamics were considered using monthly factors derived from lysimeter data, differentiated by depth to water table classes (Figure 3).

![Figure 3: Monthly recharge factors as function of depth to water table](image)

The model was calibrated unsteadily based on groundwater flow patterns for selected time-levels and based on time-series of observed groundwater levels at representative observation points. The transient groundwater simulations describe a period of 24 years (1982 - 2006) containing a typical range of recharge conditions. Furthermore, for a timespan of three months groundwater recharge was increased artificially in the study area to reproduce maximum anticipated groundwater levels (“design groundwater levels”).

As waterlogging effects in the area of Korschenbroich will increase significantly in the future, examination of future groundwater conditions is required for a comprehensive hydraulic solution. For this reason, head distributions for future steady state conditions were imported as boundary conditions from the large-scale groundwater model, modified by typical variation of groundwater levels in time.
First modeling studies

In 2002 the Erftverband was asked to simulate hydraulic measures by means of the regional groundwater model, with the aim of protecting all affected buildings in the flood-prone sectors of the town of Korschenbroich (Erftverband 2002). The study showed that 100 percent protection of buildings – in absence of any mining influence in the region – would require 31 pumping wells for the necessary groundwater drawdown. Operation of the wells would result in an average pumping rate of approximately 22 million m³/yr of water and more than 30 million m³/yr in case of maximum anticipated groundwater levels. As the region is intensively used for drinking water production, reinfiltration of large amounts of extracted groundwater would be required to maintain water yield. Consequently, investment and operation costs for realization of this hydraulic scheme would be prohibitively high.

Modeling of innovative pumping schemes

In a follow-up study finished in summer 2008 the Erftverband investigated possible hydraulic pumping schemes that would operate without reinfiltration (Erftverband 2008). Accordingly, the challenge was to determine ideal locations of pumping wells near flood-prone residential areas and to derive acceptable groundwater drawdown levels to avoid negative impacts on the groundwater yield. In addition, the optimization of operation of public waterworks was an aim of the modeling study.

Figure 4 shows the result of derived approvable groundwater capping levels for a typical pumping well in relation to maximum anticipated water level. The modeled well goes into operation when capping level is exceeded. To reach areal drawdown effects capping level is reduced by 0.5 m at the well.

![Figure 4: Approvable groundwater capping level for drawdown at one pumping well](image)

Modeling framework

The following requirements for capping of groundwater peaks at pumping wells were set for the study:

- No negative impact on water yield in catchment areas of public waterworks
- No significant change of subsurface catchment areas of public waterworks
- No negative impact on groundwater balance outside the subject area
• No significant reduction of basic runoff in streams
• Sufficient intake capacity of streams for discharged groundwater.

Simulation scenarios

By means of four model scenarios various strategies for running local hydraulic pumping schemes in combination with optimized operation of public waterworks were investigated (Erftverband 2008). The first two scenarios addressed present groundwater conditions while the third and fourth addressed future conditions which will exist upon reascent of the water table following cessation of mining activity.

Findings – pumping schemes under present groundwater conditions

The two scenarios under present groundwater conditions considered installation of local hydraulic pumping schemes combined with restart of the Lodshof/Waldhütte waterwork north of Korschenbroich, with two different maximum levels of pumping rights (2 or 4.22 million m³/yr).

Based on 11 pumping wells, of which 6 already exist or are planned, spatially differentiated capping levels have been allocated iteratively. Groundwater simulation results under the two different maximum levels of pumping rights show that operation of pumping wells in wet periods leads to lowering of the water table by 30 to 110 cm in the flood-prone parts of Korschenbroich. Under extremely wet conditions a maximum flow rate of 5.9 million m³/yr of pumped water would result when groundwater capping levels are attained. These capping levels range from 50 cm to 150 cm below the maximum anticipated water level. Discharging the water into nearby watercourses would not lead to difficulties, except for the Jüchener Bach under flood conditions.

Based on the optimized operation of pumping wells combined with restarted operation of the Lodshof/Waldhütte waterwork, the number of affected buildings could be reduced by 45 to 47 percent, which corresponds to approximately 900 buildings. Under current conditions, with mining influence in some southern sectors of the municipality of Korschenbroich, more extensive protection measures for homeowners concerned can be implemented than will be feasible under future conditions, when groundwater levels will be significantly higher.

Impact assessment of the optimized pumping scheme shows that there is no persistent drop in the groundwater table and no negative impact on water yield. Based on unsteady backward particle tracking analyses it was proven that the subsurface catchments of nearby waterworks are not affected negatively by selectively timed operation of pumping wells and are maintained within official water protection zones (Figure 5).
Figure 5: Impact of selectively timed and optimized operation of hydraulic pumping wells on transient backward particle tracks starting from wells of waterworks

**Findings – pumping schemes after reascent of water table**

By means of two additional model scenarios, the possibilities for capping of groundwater peaks were investigated under future groundwater conditions in the absence of mining influence. Restart of the Lodshof/Walduhütte waterwork combined with optimized operation of other public waterworks (full use of water rights for groundwater extraction) was considered as an important factor. The second of the two scenarios was set up to investigate the effects of the installation of an additional waterwork to replace a subset of water rights belonging to a waterwork near Garzweiler opencast mine which would cease to exist.

As the southern sectors of Korschenbroich will no longer benefit from mining influence after reascent of the water table, the hydraulic pumping scheme for capping groundwater peaks will have to be extended southwards. The model results of both scenarios show that based on selectively timed operation of 17 pumping wells, the number of affected buildings can be reduced by 33 to 34 percent (approximately minus 900 buildings), but the absolute number of affected buildings rises. Furthermore, the level of protection in the southern sectors will not be the same as that provided today by groundwater withdrawal connected with opencast mining. This is due to the necessary reduction of capping levels. Otherwise negative impacts on the water yield would be the direct consequence of excessive pumping. The maximum volume of extracted groundwater would amount to 7.2 million m³/yr, which is a moderate increase in comparison to the simulated capping scheme under present conditions.

Unsteady backward particle tracking analyses indicate only a slight influence on subsurface catchment areas of the surrounding waterworks, so there would be no negative effect on local groundwater resources and water supply.

The installation of an additional waterwork would not lead to a significant reduction of affected buildings (minus one percent). This is due to the fact that approvable pumping rates should be limited to avoid negative interaction with flanking catchment areas.
CONCLUSION

Based on the transient model simulations applying innovative hydraulic pumping schemes the following conclusions can be drawn:

- Selectively timed and optimized operation of pumping wells without reinfiltration of pumped water should lead to a significant reduction of the number of affected buildings in case of extremely high groundwater levels.
- Due to the fact that reinfiltration and treatment of water is not required and pumping rates are significantly lower than with the concept of 100 percent protection, investment and operation costs will decline considerably.
- Optimized groundwater capping levels will avoid any negative impact on water yield and subsurface catchment, so implementation of a hydraulic pumping scheme would be approvable by water authorities.
- Competent operation of pumping wells must be accompanied by a detailed control and monitoring system to prevent negative impacts of pumping schemes on groundwater balance and watercourses.

REFERENCES

BWK (Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e.V.), Nutzungskonflikte bei hohen Grundwasserständen - Lösungsansätze, Statusbericht, 2003.
Erftverband, Grundwassermodell Neuss, Bergheim, 2002.
Stadt Korschenbroich, Gebäudekataster, Korschenbroich, 2008.

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