# Field Tests and Ecological Assessment of an Opencast Mine-Dewatering using a Horizontal Directional Drilled Well

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## Abstract

Nowadays vertical filter wells are the main element of dewatering in opencast mines in Germany. An alternative – e.g. suitable in cases of limited water levels, reduced thickness of aquifers, or basin structures – are horizontal directional drilled wells (HDD wells). By the use of HDD wells with considerably longer filter screens in combination with free discharge of the drained water out of the pit slope, economies in costs, materials, and land use are anticipated.

With respect to the dewatering effects using HDD wells, some questions remained unanswered so far. Therefore, field tests with a 200 m long HDD well combined with a vertical well interconnecting two hydraulically separated aquifers were realized within the central German lignite district in the south of Leipzig. Based on a structural model, details of the horizontal directional drilling as well as an appropriate position of the HDD well were investigated. For this purpose the information of 250 available exploratory drillings was evaluated. A numerical groundwater flow model was used to simulate the drainage using the software PCGEOFIM.

Besides technical and economic issues an environmental assessment was made. On the basis of the information gathered in the field test, HDD wells and vertical wells were compared theoretically. Therefore a calculation model was set up to investigate the conventional dewatering method using vertical wells in comparison with HDD wells under environmental issues.

Key words: horizontal directional drilled Wells (HDD wells), groundwater modeling, ecological assessment

## Introduction

Dewatering of near-surface unconsolidated rock is an important prerequisite for the technical implementation and safety of mining projects. The removal of water from the overlying rock is also a basic necessity concerning stable pit walls and working planes (Mansel et al. (2015)). Higher residual water levels in overburden operations and out-of-control rising ground water levels could cause pit slope failures.

Nowadays vertical filter wells are commonly used on a large scale in lignite-mine dewatering and depressurization in Germany. Vertical filter wells have a short screened section, particularly in thin aquifers, which is continuously being reduced during the dewatering process (Struzina et al. (2011)). The negative impact of dewatering on resources and the environment must, however, be minimized in time and space.

The research and development project, the results of which are the subject of this paper, focuses on two parts:

- field tests with a 200 m long horizontal directional drilling (HDD) well combined with an infiltration well (fig. 1),
- ecological assessment comparing vertical and horizontal dewatering in open cast mines

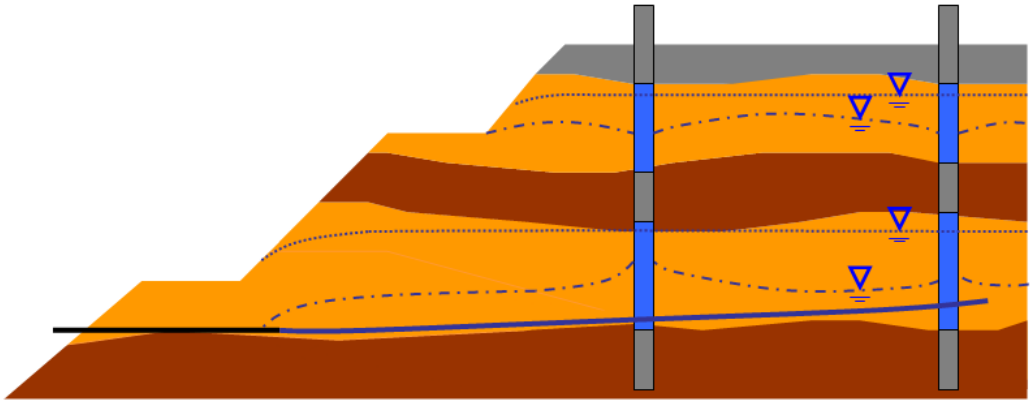

***Figure 1*** *HDD well and two vertical wells draining hydraulically separated aquifers (Struzina 2012).*

The aim of the field test was the combined dewatering of two aquifers using a vertical well for the hydraulic connection and a horizontal well, installed at the bottom of the underlying aquifer, for the dewatering. The application was simulated using numerical groundwater modelling software PCGEOFIM.

The objective of the ecological assessment was to accomplish scientific and practical basic for the application of HDD wells as an environmentally sound method of dewatering in opencast mining.

## Methods

Based on the results of successfully completed project phases (Müller et al. (2009)) the aim of the research project was to develop the scientific and practical basis for the application of an alternative dewatering method. Furthermore, the application of HDD wells has a potential to overcome the environmental drawbacks of the use of vertical filter wells.

### *Study area*

The study area is located in the Central German Lignite District in the south of Leipzig. By gaining a local industrial partner, it was possible to run the field tests in a practical relevant way. Due to the presence of an intermediate 3-10 m thick clayey intercalation within the unconsolidated rock material of aquifer 3, this aquifer is hydraulically divided into an overlying section (aquifer 3.1) and an underlying section (aquifer 3.2). By means of particle size analyses, the sediments of the overlying section are considerably finer and show a better sorting.

*Structural Model and Numeric Groundwater Flow Model*

In order to identify an appropriate position for the horizontal and the vertical well a structural model was developed using Groundwater Modeling System (GMS) by Aquaveo. It is based on information of more than 250 drillings to investigate the geological characteristics like storing conditions, thickness of aquifers and aquicludes and grain size, etc.

Besides, the structural model provides the basis for the hydraulic modelling. The groundwater flow model – modeling software PCGEOFIM (Blankenburg et al. (2013)) was used – is characterized by a dimension of 2.5 x 2.5 km with a basic raster of 50 m cell size. In between this basic raster there are two nested grid refinements of 25 x 25 m and 5 x 5 m, respectively. (fig. 2)

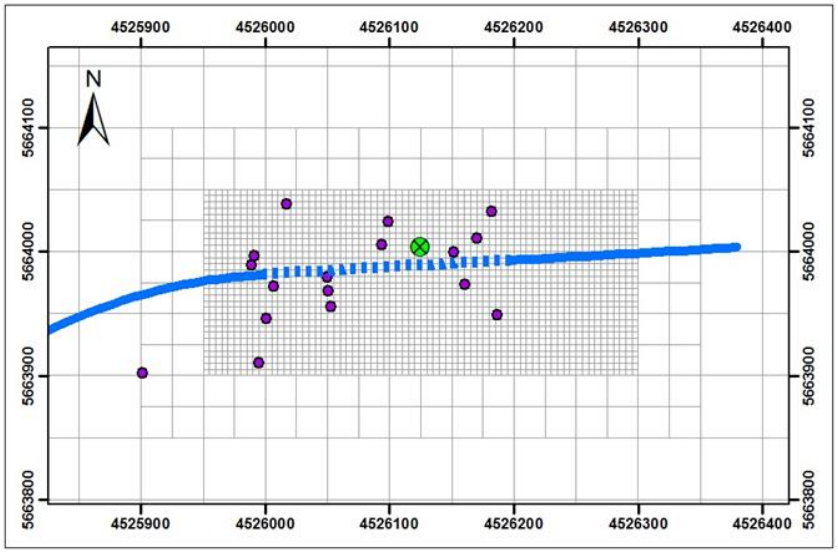


***Figure 2*** *Model resolution, position of HDD well (blue), vertical well (green), monitoring wells (purple).*

The model was calibrates using the measurements from 62 monitoring wells - 36 monitoring wells in direct periphery of the horizontal well, 18 in each aquifer – as well as flow volumes from both wells. Therefore, adjustments of the hydraulic conductivity in between several raster cells were made. In addition, the progress of the extraction process was taken into account. Achieving a standard deviation of 0.35 m of the value pairs (measured - calculated) the calibration was completed successfully.

*Horizontal well*

Differing from the usual design of horizontal directional drillings where the exit point of the drilling is situated on the terrain surface, it was necessary to place it below (fig. 3) to allow dewatering by gravity flow. This lead to adverse circumstances for using drilling mud, which was flowing out of the exit point and had to be pumped to the starting point. Due to the length of the borehole, a protective pipe was used to install the filter well and prevent partial damage (Mücke (2014)). Shortly after the filter screen was positioned in place, the protective tube was pulled out. Finally, a magnetic-inductive flow meter was installed to measure the amounts of drained water.

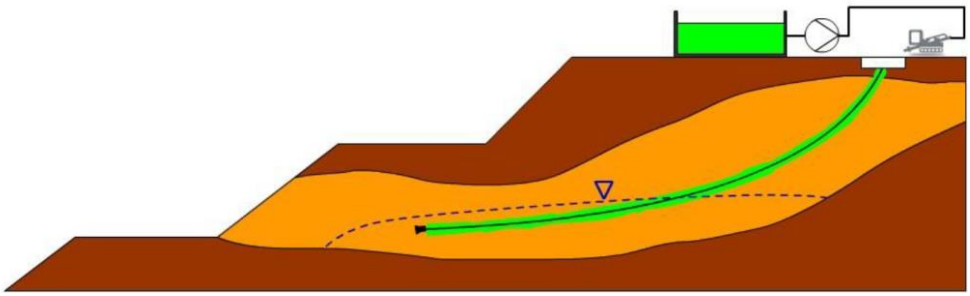

***Figure 3*** *Scheme Horizontal Directional Drilling (Harzer (2012))*

*Vertical well*

Shortly after the installations of the horizontal well, the vertical well was installed to connect the separated aquifers hydraulically. Concerning the interconnection of both dewatering elements an indirect connection was used to avoid damaging of the horizontal well (fig 4). To measure the amount of water that infiltrated from the upper into the lower aquifer a magnetic-inductive flow meter (MID) was installed. The MID was part of a hydraulic shutoff device to measure the entire amount of infiltrated water (fig 5).

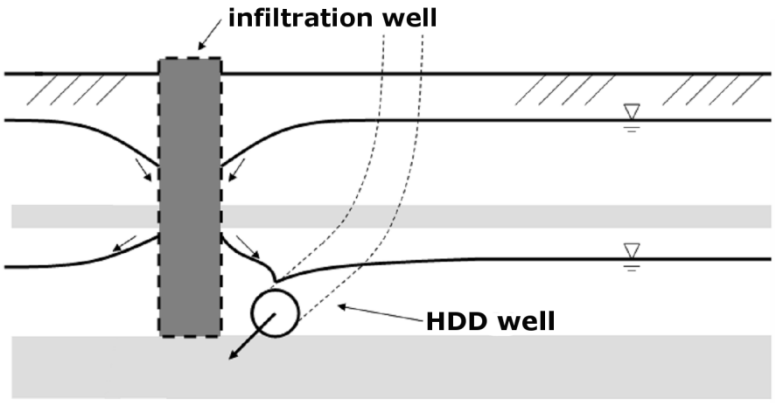


***Figure 4*** *Indirect connection of the vertical and the horizontal well (Struzina, Drebenstedt (2011)).*

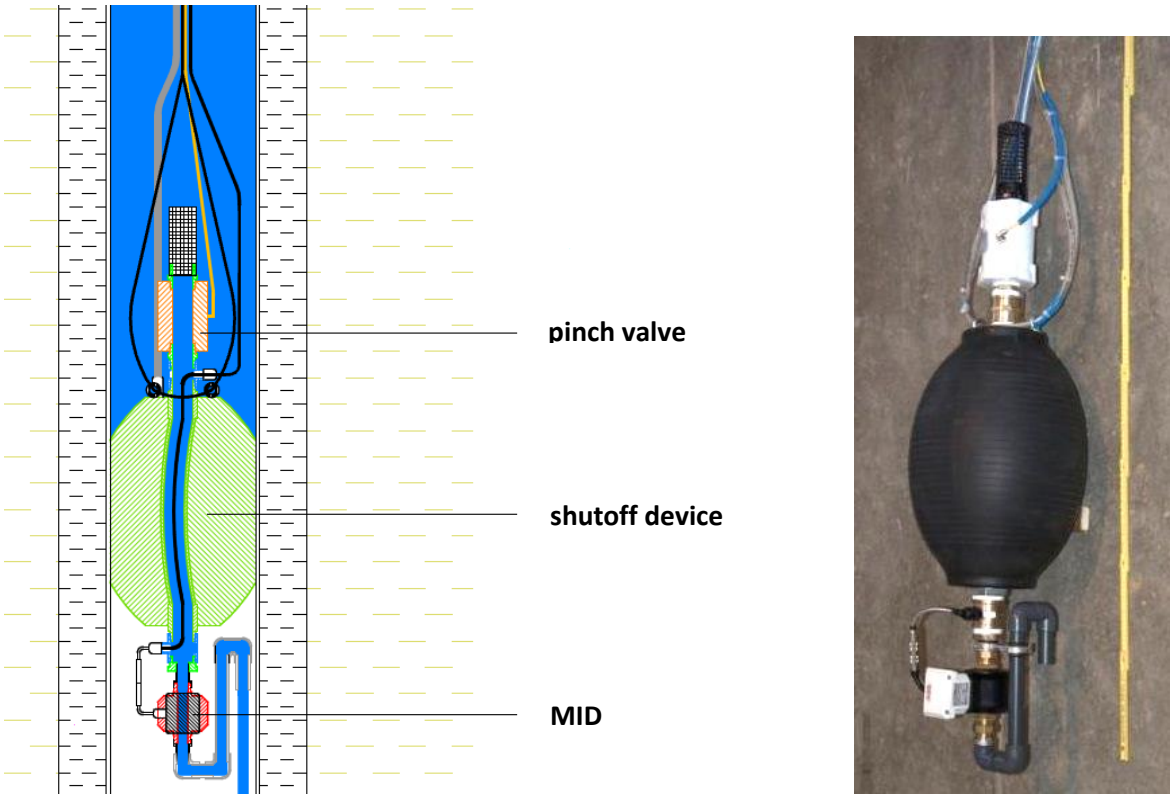


***Figure 5*** *Concept (left) technical implementation (reght) of the measuring device*

*Ecological assessment*

Besides technical and economic issues especially environmentally relevant benefits were motivation for the study. Based on the field test, horizontal and vertical wells were compared theoretically. For this purpose, an ecological assessment was made according to Schmieder, Drebenstedt (2007).

Regarding the dynamic operation mode of an opencast mine different parameters were taken into account.

Input parameters:

- materials (e.g. pipes, cables, pumps, etc.)
- technique (e.g. drill rig, crane, caterpillar, etc.)
- energy consumption for installation and operation

Ecological parameters:

- cumulative expenditure of energy
- cumulative material expenditure
- CO2-equivalent
- SO2-equivalent
- land use

A calculation model was set up as a tool for comparison considering expenses and environmental impacts of opencast mine dewatering (Mansel et al (2015)). Since partially not enough operational data was collected, it was necessary to revert to values of the GEMIS-Database. The result is an assessment of environmental impacts concerning several periods as well as the whole term of the mine operation.

**Results and Discussion**

*Vertical well*

For the installation of the vertical well a flush drill was used which lead to unfavourable conditions regarding well capacity because of decreased hydraulic conductivity. In addition, the dewatering of the lower aquifer was slower than expected which resulted in low infiltration rates. However, during 280 days of operating time 642 m³ of water were drained out of the higher and infiltrated into the lower aquifer.

*HDD well*

Due to the usage of drilling fluid and borehole silting several well developments were necessary to increase the well capacity. The average flow rate of the horizontal well was approximately 80 l/day. During the operating time of 313 days ca. 26.000 m³ of water were drained out of a nearby slope using the horizontal well. The flow volume was measured using a MID (fig 6).

***Figure 6*** *Measuring device of the HDD well.*

*Ecological assessment*

After evaluating retrieved data it became clear that the advantageousness of HDD wells is associated with a close distance to the pit slopes because of shorter pipe sections and the usage of existing pumping stations and their configuration. With long screened sections combined with high lead-time in terms of time and space of the dewatering process, the advantages of horizontal wells are predominant.

Apart from the examined parameters, some influencing factors were not taken into consideration. These are for example:

- amount of residual water
- geometry of the water table drawdown
- geotechnical stability of the excavation slope
- horizontal well with annular backfilling
- horizontal well built with blind hole technique

## Conclusions

Concerning dewatering of opencast mines in Germany, the usage of horizontal dewatering wells is currently limited to a few special cases. Advantages of horizontal wells arise from long screened sections and reduced consumptions of energy, material and land use, whereby environmental relief can be expected.

By means of a field test where the interconnection of two aquifers allowed a combined dewatering with free water runoff using a horizontal well with a 200 m long screened section, information concerning technical, economic and environmental issues was gathered. During the project the modeling software PCGEOFIM was developed further to take channel and pressure pipe flow into account. A numerical flow model was built up to simulate the field tests.

Regarding relevant input parameters, an ecological assessment was made comparing vertical and horizontal wells as main dewatering element. As a result, the length of the screened section as well as the distance to the pit slope and the pumping system turned out to be the main influencing factors for the advantages of horizontal wells.

## Acknowledgements

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