Modelling boundary pillar filtration in systems of pumped abandoned mines

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Keywords: Coal mines, mine water modelling, groundwater modelling, MODFLOW

ABSTRACT

Three coal mines: Paryż, Porąbka-Klimontów and Sosnowiec (Upper Silesian Industrial Region, Southern Poland) are abandoned for about 10 years. Like most of abandoned mines in the Region, they are continuously pumped in order to keep the mine water level low enough to protect neighbouring active coal mines.

The model described in this paper has been developed to support an analysis of water level changes in mines: Paryż and Sosnowiec on the inflow to mine Porąbka-Klimontów. Within each mine the water flow is determined by the network of former roadways. However, the filtration through boundary pillars seems to be laminar. Therefore, the interconnected system of three mines has been modelled using 2D MODFLOW approach. This paper describes the approach, technical details and results of modelling. The approach is particularly unconventional in using standard MODFLOW packages like River or Well to model the filtration through boundary pillars.

INTRODUCTION

Study area is located in Southern Poland, in Upper Silesian Coal Basin. In this coal basin over 60 coal mines were active in 1990, most of them interconnected. Until now 29 mines are closed, but most of them still pumped to keep water level low enough to ensure protection for active mines. Three mines: Paryż, Porąbka-Klimontów and Sosnowiec are the example of such system of abandoned coal mines. They are continuously pumped in order to protect neighbouring active coal mines, mainly coal mine Kazimierz-Juliusz.

Currently, there is a plan to rise up the water level in two mines: Paryż and Sosnowiec in order to reduce the pumping costs. However, all three mines form a joint system, where groundwater flows from one mine to another through narrow boundary pillars. Therefore, after rising up the mine water level in mines Paryż and Sosnowiec, higher inflow to deepest mine Porąbka-Klimontów is expected (Frolik *et al.*, 2004; Frolik & Gzyl, 2005). In the last mine, the water level cannot be raised up due to threat for neighbouring active coal mine Kazimierz-Juliusz. Consequently, the plan of rising up the water levels in two mines may give no cost reduction of pumping the whole interconnected mined system. The model described in this paper has been developed to support an analysis of water level changes in mines: Paryż and Sosnowiec on the inflow to mine Proąbka-Klimontów. Since boundary pillar filtration was recognised as main mechanism of water flow between interconnected mines, this was also the main focus of constructed model.

Conceptual Model

Base assumption for conceptual model of the area was maximum simplification of hydrogeological conditions. Less complicated models usually are not only easier to understand by non-modellers, but also easier to identify and calibrate. Since good calibration of the model is essential before making any predictions, simplistic approach may often be the best one in terms of model prediction accuracy. Taking these facts into consideration, the several assumptions have been made in order to construct the conceptual model of the site.

Modelling area

The modelling area is generally the same as former area of mines: Porąbka-Klimontów and Sosnowiec (fig. 1). In fact flows only within the areas of these 2 mines are modelled – inflows from former mine Paryż is only given as Northern boundary conditions of the model. The bottom of modelling area is a coal seam 510 – the richest historical seam of Upper Silesian Coal Basin. This seam is easily recognizable all around the Basin, since its thickness reached even 30 m in some areas. The approach of the model is that although the coal exploitation in some places have gone deeper than seam 510, the most important is the flow in the sandstone series above seam 510. Consequently, the zone south from outcrops of seam 510 is excluded from modelling area. Due to major faults present in this area seam 510 has different elevation in each mine.

Recharge and discharge

Recharge of the system takes place through infiltration of atmospheric precipitation at upper boundary of the model as well as the inflow from former mine Paryż at the northern boundary. Drainage is solely through pumping systems installed in the shafts of mines Porąbka-Klimontów and Sosnowiec. Flow between Mine Sosnowiec and Porąbka-Klimontów also takes place.

Flows within the mines

In principle, within each mine the water flow is determined by the network of former roadways and mine workings. However, the most important factor for the whole model is filtration through boundary pillars, that seems to be laminar. Therefore, the flows within the mines have been also modelled as laminar through homogeneous field. This is very rough simplification, with which it is impossible to predict precisely the actual shape of water table within the mines. However, with that approach it is possible to predict the inflows to the mines and that was in fact the aim of the model.

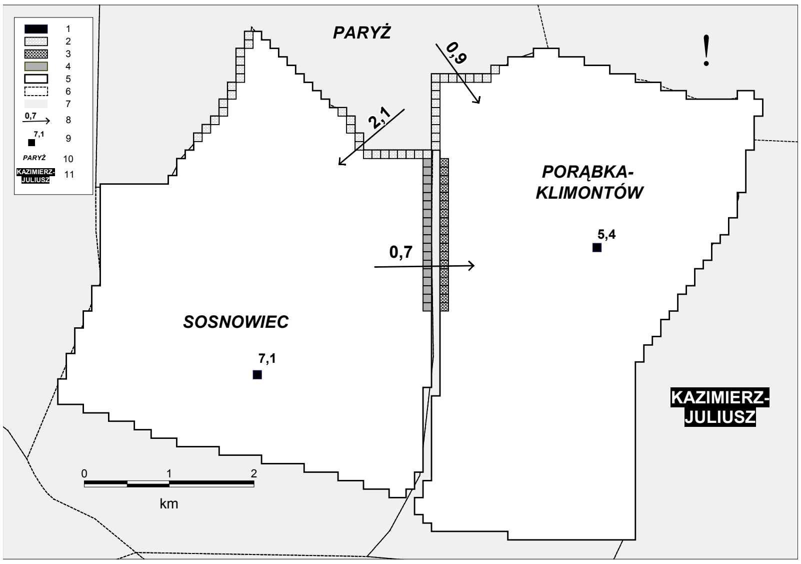


Figure 1: Boundary conditions and calibrated flows in variant for 2004. 1-constant head boundary; 2- fake "river" boundary; 3-fake "injection wells"; 4-general head boundary; 5-modelling area; 6-boundaries of former mining areas; 7-areas outside model domain; 8-flows among the mines; 9-inflows to dewatering pumping systems; 10-names of former mining areas; 11-names of still active coal mining areas.

Flows among the mines

It was assumed that the water exchange among 3 mines: Paryż, Porąbka-Klimontów and Sosnowiec takes places only by filtration through boundary pillars. Since mines boundaries run along the large fault causing huge differences in the elevation of seam 510 (and the base of the model) in each mine, current water level within the mines Porąbka-Klimontów and Sosnowiec is below the base of seam 510 in mine Paryż. Also water level in mine Porąbka-Klimontów is deeper than the base of seam 510 in mine Sosnowiec. Consequently, the flows from mine Paryż to mines Sosnowiec and Porąbka-Klimontów as well as the flow from mine Sosnowiec to mine Porąbka-Klimontów can be simplified as free "dripping". The rate of this "dripping" then depends only on water level and the elevation of seam 510 in the mine that is losing the water. The water level in mine receiving the water makes no difference to the conditions of flow between the mines, as long as the water level there is low enough to sustain "dripping" conditions.

GROUNDWATER FLOW MODEL

Structure and boundary conditions

Groundwater flow model has been created using standard MODFLOW software (McDonald & Harbaugh, 1984, 1988; Harbaugh & McDonald, 1996a, b) with the assumption of unconfined conditions. 2D model consists of 1 layer with homogeneous conductivity field. The model domain has been divided into blocks of dimensions 100 × 100 m. Lower horizontal boundary is set arbitrally at the depth of the bottom of deepest shaft for each mine and this boundary is characterized by no-flow conditions (*Q=0*). Upper boundary reflects the topography of the site and its type is constant flow (*Q=const*) in order to model the recharge through infiltration. Lateral boundaries are generally in line with former mining areas of mines Porąbka-Klimontów and Sosnowiec, except the southern boundary that runs along the outcrops of seam 510. Eastern, southern western and partially northern boundary had no-flow character. In remaining parts of northern boundary, where geological data and mining maps have shown the possibility of pillar filtration flow from mine Paryż into mines Sosnowiec and Porąbka-Klimontów, head dependent flow boundary $Q = f(\Delta H)$ has been set. In this case Q meant flow from mine Paryż and ΔH was the difference between the water level at former mine Paryż and the base of seam 510 at the same mine near the boundary. Since standard General Head Boundary (GHB) package would make the flow dependent also on the water level in the mine at the lower side of the pillar (and that would be against the conceptual model). Therefore, GHB could not be used in this specific case. So, in order to technically implement desired boundary into MODFLOW model an unconventional approach have been selected. Standard RIVER package has been used, although no real river has been modeled in fact. In this case the head at Paryż mine was the fake "head in river" and the elevation of the base of seam 510 was the fake "elevation of riverbed bottom". Consequently, the conductivity of pillar was fake "riverbed conductivity". As a result, former coal mine Paryż have been modeled as fake "river", from which the water can flow into 2 other mines, and the rate of flow is dependant only on the actual water level at Paryż mine and the conductivity of pillar. This is totally in line with previously recognized conceptual model, assuming free "dripping" from mine Paryż into mines Porąbka-Klimontów and Sosnowiec. It was even more complicated to implement this type boundary into pillar connection between mines Sosnowiec and Porąbka-Klimontów, since this time the boundary had to be placed inside the model. This time, to avoid the unwanted influence of lower mine (Porąbka-Klimontów) on the inflow from upper mine (Sosnowiec) the model domains of these 2 mines have been separated. As a result the model consists in fact of 2 separate models for each of the mines. The flow between the mines is modeled as GHB taking the water away from domain of mine Sosnowiec. Then, the same amount of water is “injected” into the domain of mine Porąbka-Klimontów through a set of virtual injection wells modeled using WELL package (*Q=const*). This artificial boundary system allows for building the groundwater model in line with the previously recognized conceptual model. Last, but not the least the pumping systems keeping the water level at the main shafts at mines Porąbka-Klimontów and Sosnowiec has been modeled using standard MODFLOW constant head boundary (*H=const*) in one block per each mine. In this case meant the established dewatering level of the given mine.

Model calibration

Model calibration has been conducted for *quasi*-steady flow conditions in year 2004. Calibration aim was the flows (pumping rates) measured at dewatering systems of mines Porąbka-Klimontów and Sosnowiec in 2004 (table 1; fig. 1). In order to reach desired levels of flow rate, the conductivity of pillars and the recharge rate has been calibrated. The level of dewatering in 2004 was treated as known exact value of constant head boundary at mines Porąbka-Klimontów and Sosnowiec as well as the “head” in a fake river that modelled inflow from mine Paryż. Because *quasi*-steady flow conditions were reached at the interconnected system of mines only in 2004, there was unfortunately no technical possibility to verify calibrated model on another set of flow rate data.

Former mine	Dewatering level [m above sea level]	Inflow [m^3/min]	
		Total	Only from neighbouring mines
Paryż	+30	12,0	-
Porąbka - Klimontów	-190	5,4	1,6
Sosnowiec	-121	7,1	1,4

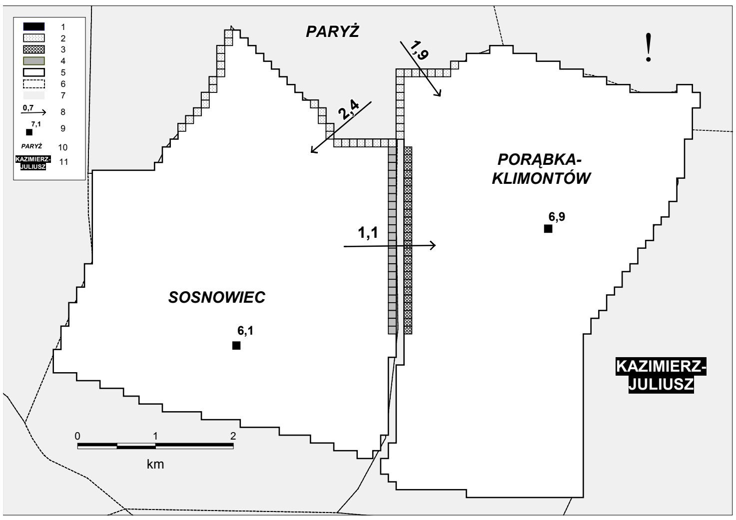
Table 1. Calibrated flows for *quasi*-steady flow conditions in 2004.

Prediction

Calibrated model has been used for prediction of inflows to pumping stations at mines Porąbka-Klimontów and Sosnowiec after increasing the dewatering level at mine Paryż from +30 to +50 m a.s.l. and at mine Sosnowiec from -121 to -70 m a.s.l. The predicted inflows after reaching quasi-steady flow conditions are shown in table 2 and fig. 2. It is predicted, that due to abovementioned increase in dewatering level an increase in inflow to deepest mine Porąbka-Klimontów (from 5,4 to 6,9 m^3/min) will occur. This will be accompanied by drop of inflow to mine Paryż (of about 0,51 m^3/min) as well to mine Sosnowiec (of about 1 m^3/min).

Former mine	Dewatering level [m above sea level]	Inflow [m^3/min]	
		Total	Only from neighbouring mines
Paryż	+50	10,7	-
Porąbka - Klimontów	-190	6,9	3,0
Sosnowiec	-70	6,1	1,3

Table 2. Prognosis of flows after increasing dewatering levels at mines Paryż and Sosnowiec.



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In spite of preliminary character of this perdition (due to no possibility to verify the calibrated model), it seems to be clear that rising up the water level at mines Paryż and Sosnowiec will lead to significant increase of inflow to deepest mine Porąbka-Klimontów. Since there are no possibility to rise up the water level at this mine (due to protection of active neighboring mine Kazimierz-Juliusz), more water would have to be pumped from huge depth. Consequently, the idea to lower the cost of pumping through rising the water level at 2 mines would result in probably higher financial loss at 3rd , deepest mine. Therefore, changing the dewatering pattern in that way is not recommended.

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