Groundwater Flow Model in the Area of the Extensive Open Pits Lignite Mining Activities

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Abstract

Due to completion of lignite production in the Konin Lignite Area, the opportunity for a new open pit construction is considered. In the vicinity of the new potential mining area, there are two open pits still in operation and a post-mining reservoir, which is under the process of flooding. The dewatering of these pits results in change of hydrodynamic conditions in the area, which will influence the mine water inflow into the new open pit and its environmental impact. All these phenomena were simulated in a transient groundwater flow model, in which the new open pit as well as neighboring open pits are simulated.

Keywords: open pit, lignite, groundwater modeling

Introduction

Due to completion of lignite production in the Konin Lignite Area located in the central part of Poland, the opportunity for a new open pit construction is considered. The „Mąkoszyn - Grochowiska" deposit with geological reserves of 80 MT and lignite production capacity of 3.5 MT/year is an option. Outside of the potential mining area, there are still two open pits in operation - „Tomisławice" open pit (5 km away) and „Drzewce" open pit (21 km away) - as well as "Lubstów" post mining void (11 km away), which is under the process of flooding (Fig. 1). As a result, the modeling study for the new open pit has been performed which take into consideration the changeable hydrodynamic conditions in the area influenced by dewatering of the neighboring pits as well as process of flooding the post-mining reservoirs.

Site description and hydrology

The lignite deposit „Mąkoszyn-Grochowiska" is located in the area of Greater Lake District (Kondracki 2000). It occurs in the Notec river valley with many lakes and wetlands. The ordinates of the land are from 90 to 110 m a.s.l. Outside of the river valley an upland areas grow up to 160 m a.s.l. and they are cut by erosive glacial gutters. A very significant element of hydrology of this region are lakes (Brdowskie, Głuszyńskie, Lubotyńskie, Modzerowskie), mainly groove and post-glacial ones. The average annual precipitation amounts to approximately 550 mm/y and the land evaporation is 500 – 520 mm/y (Ziętkowiak 2003). Through the northern part of the deposit the first-order watershed runs, separating the Odra and Vistula basins (Fig. 1). The average groundwater flow from this area accounts from 0.9 l/s/km^2 (Graf 2003) for Vistula basin in the north, to 2.19 l/s/km^2 for Odra basin in the south (Orsztynowicz, Wierzbicka 1970).

Geological and hydrogeological conditions

The region of the deposit lies in the northern part of the basin called niecka mogileńsko-łódzka, which roof is formed by upper Cretaceous sediments. Taking into account the dewatering conditions, two hydrogeology complexes have been determined within this area: Quaternary complex and Neogen – Paleogen- Cretaceous complex. The hydrogeological conditions in these areas are characterized by four aquifers – two over and two below the lignite seam (Fig. 2). The first aquifer (Quaternary) of free water table consists of the sands and gravels just below the terrain surface. Its thickness is from 1 to 20 m and average permeability of 0.000174 m/s, but sometimes in old buried valleys it reaches thickness of 40 m and permeability

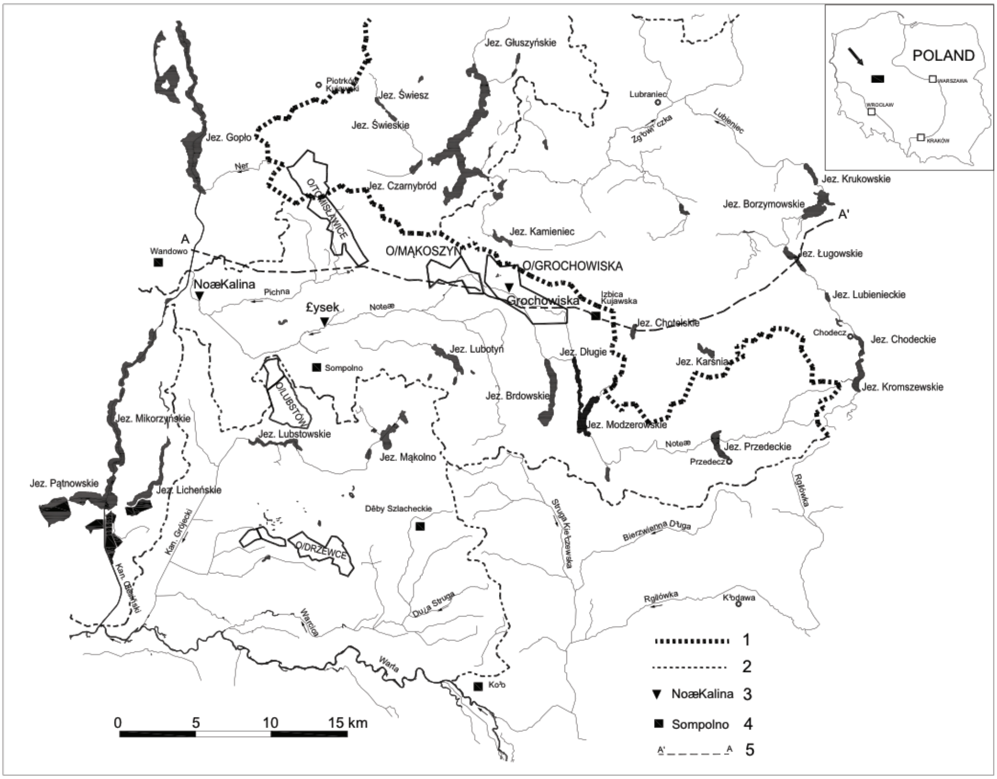

Figure 1 *Hydrographic map of the „Mąkoszyn – Grochowiska" lignite deposit area (modified from Stachy ed., 1987). Explanations: 1- first order watershed, 2-other watersheds, 3-hydrometric station, 4-precipitation station, 5-hydrogeological*

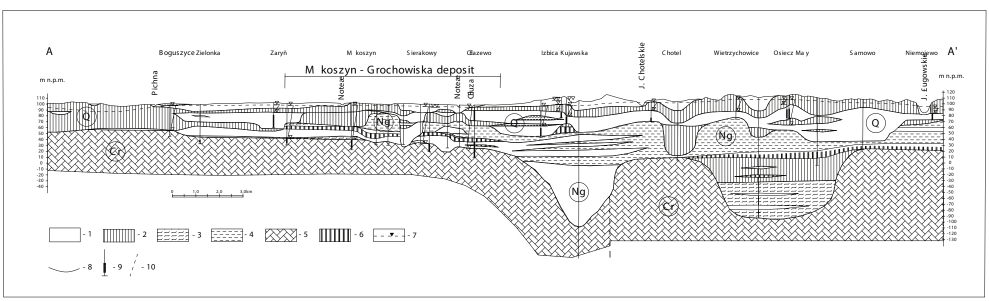

Figure 2 *Hydrogeological cross-section (Szczepinski Straburzyńska-Janiszewska, 2011). Explanations: 1-fine sands, 2-glacial tills, 3-silts, 4-clays, 5-marls and dolomites, 6-lignite, 7-Neogene-Paleogene-Mesosoic aquifer piezometric surface, 8-stratigraphic boundary, 9-screeded intervals, 10-faults.*

of 0.000578 m/s. The second aquifer (Quaternary) is located in sandy layers and lenses within clays with thickness 10 - 20 m and permeability varies from 0.000058 to 0.00029 m/s. The third aquifer (Neogene-Paleogene) is located in the fine widespread Neogene and reduced Paleogene sands underlying the lignite seam. Its thickness varies from 10 to 60 m and permeability from 0.000012 to 0.00017 m/s. The fourth aquifer occurs in the fissured Cretaceous marls and limestones underlying Neogene - Paleogene sands, with permeability coefficient from 0.000034 to 0.00035 m/s. The specific yield of aquifers varies from 0.06

to 0.203 and storativity varies from 0.00015 to 0.002.

Groundwater in the Quaternary aquifers are under unconfined and semi-confined conditions and Neogene-Paleogene and Cretaceous aquifers occurs under confined conditions. Slight isolation and sometimes its lack between the Cretaceous and Neogene-Paleogene lignite underlying aquifer, enable hydraulic contacts between these aquifers, which is provided by the similar water table level and the low variability of chemical composition.

The recharge areas are the moraine uplands occurring to the south and east of the deposit. The Quaternary water-table aquifer is recharged by infiltration of precipitation and the lower aquifers are recharged by leakage of water from the Quaternary aquifers or directly through the hydrogeological windows. The Quaternary water table is from 120-140 m a.s.l. in the recharge areas up to about 90 -100 m a.s.l. in the area of the deposit. The groundwater level in the Neogene - Paleogene - Cretaceous complex is few meters lower than in the overburden aquifer and stabilize from 120 m a.s.l. to 100 m a.s.l. in the deposit area. In natural conditions groundwater was discharged by rivers and many lakes. Currently, as a result of the "Drzewce", „Tomisławice" and "Lubstów" opencasts dewatering, they become the center of groundwater discharge for all aquifers in the western part of the area.

Mine dewatering

Lignite production in the "Mąkoszyn-Grochowiska" deposit is planned to be carried out in the years 2026-2044. The opening of the deposit is foreseen in the western part of the "Mąkoszyn Field" and the lignite production will progress to the south-east direction towards the "Grochowiska Field". It is assumed to start construction of the drainage system from 2022. It is expected that groundwater will be lowered by pumping wells to the depth of 30 – 60 m and the cone of depression will be developed in the Quaternary and Neogene-Paleogene sands as well as in the Cretaceous marls and dolomites. Currently, the groundwater level in the neighboring "Drzewce", "Tomisławice" and "Lubstów" open pits is lowered to 30 - 80 m. Water from the drainage system will be discharged through a network of pipelines, ditches and canals to Notec river. After the ending of lignite production, the post-mining reservoir located in the south-eastern part of the "Grochowiska Field" will be flooded.

Groundwater flow model

A 3-dimensional finite difference model has been used based on MODFLOW code (McDonald and Harbaugh 1988) in conjunction with the MODFLOW-Surfact (Version 3) code. The modeling has been undertaken using the Groundwater Vistas (Version 5.36) software package (ESI 2006). The conceptual model for the area was based on investigations undertaken by the Geological Institute and mining company. A three-dimensional numerical model has been developed, which covers an area of 1293 km^2. The model is discretized with a uniform 250 m by 250 m grid, which gives a grid mesh of 181 rows and 155 columns. The model was divided into five vertical layers - three aquifers and two aquitards. The aquifers represent: 1. the upper Quaternary water table porous aquifer, 2. the lower Quaternary porous aquifer, 3. the Neogene-Paleogene-Cretaceous porous - interstice aquifer which includes interconnected the sands and marls and mudstones. Between the aquifers, there are two layers represented by aquitards comprised of clays and silts.

The south and east external boundaries were determined by the rivers and lakes and the north boundary of the model was located far outside of the potential range of the cone of depression. Depends on types of hydrogeological interactions these boundaries are represented by 1. H = const. 2. Q = 0 and 3. Q = f(H) boundary conditions. The west boundary of the model was located on to the east side of the "Tomisławice", "Drzewce" and "Lubstów" open pits. The dewatering operations as well as the process of flooding the post mining open pits were modeled by progressive assignment of Modflow the Time-Variant Specified Head cells H = f (t) to active mining areas in accordance with the respective project mine plans and/or modelling studies performed for these open pits before.

Municipal wells located in the model were represented by boundary condition Q=const. and rivers and lakes inside of the model area were simulated using Modflow's River cells Q=f(H) with streambed conductance from 0.001 to 5 m/d. The dewatering operation of the "Mąkoszyn-Grochowiska" was modeled by progressive assignment of Modflow the Time-Variant Specified Head cells H = f (t) in accordance with the mine plan. The effective infiltration Q = const., varies over the area and depends on the lithology of the land. It differs from 4.6 to 15.3% of average annual precipitation. To ensure appropriate representation of the change of effective infiltration during the groundwater table fluctuation, the recharge and evaporation packages were used for modelling studies.

At the first stage of model calculation, the groundwater flow model for quasi-natural conditions was performed at the end of 2008, i.e. before the starts the "Tomisławice" and "Mąkoszyn-Grochowiska" pits dewatering and just before the flooding of the "Lubstów" post-mining water reservoir. The model was calibrated for steady-state condition (Fig. 3). The heads from steady-state runs were used as initial conditions for the transient simulation for the period from 2008 to 2009, in which the model was verified, taking into account dewatering of the "Tomisławice" and "Drzewce" pits, as well as flooding the "Lubstow" post mining reservoir. The model calibration and verification has been based on the available water level data recorded in wells and piezometers located in all aquifers.

In the next stage the predictive simulation was carried out for the period from 2010 to 2021, to determine the hydrodynamic conditions in the area of the "Mąkoszyn-Grochowiska" deposit just before the dewatering of this pit. In each 5 year stress periods covering the time span from 2010 to 2021, the boundary conditions simulating the "Tomisławice" and "Drzewce" deposits dewatering and the "Lubstów" post-mining reservoir flooding were assigned. The heads from 2021 were used as initial conditions for transient simulation of "Mąkoszyn-Grochowiska" dewatering process in years 2021 – 2044. It was assumed that the dewatering of this open pit be simulated in four stress periods: 2022-2029, 2030-2034, 2035-2039 and 2040-2044 by progressive assignment of Modflow the Time-Variant Specified Head cells H = f (t) in accordance with the mine plan. Its range has been limited by the area of dewatering wells. Due to the hydraulic contacts between all the aquifers, the Neogene-Paleogene-Cretaceous aquifer was assumed as the basic one from the dewatering point of view.

Results and discussion

The results of calibration and verification were evaluated taking into account the adjustment of the measured and simulated heads and groundwater flow as well as the simulated mine water inflow into the neighboring pits to the field measured inflow.

The results for steady state conditions indicate effective infiltration of 1.83 l/s/km^2. The recharge from precipitation amounts to 11.0 % for layer I, 6.2 % for layer II and 1.0 % for layer III of the average precipitation for this area (0.55 m/y) (table 1). Layer I, which is almost totally recharge from precipitation is discharged to rivers, lakes and open pits dewatering system of "Drzewce" and Lubstów" (43.5 %), while 56.5% of the groundwater percolate to lower layers. Discharge out of the model area represent mainly the drainage by open pits located in the western part of the area (Fig 4).

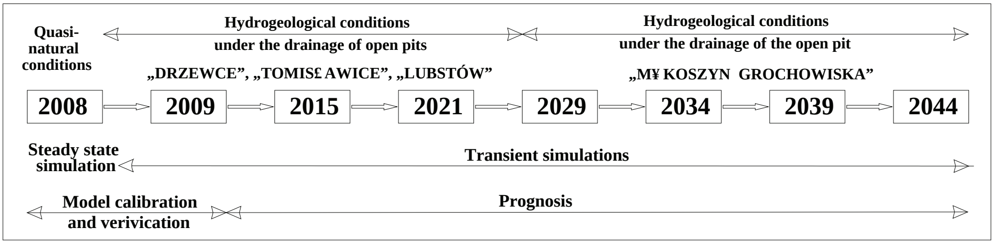

Figure 3. Stages of the model solution for "Mąkoszyn-Grochowiska" open pit.

Table 1. *Groundwater balance at the „Mąkoszyn-Grochowiska" region in quasi-steady state conditions at 2008 , [m³/min].*

Layer	Recharge from precipitation	Discharge out of the model area	Leakage from overlying layer	Discharge to rivers and lakes (external boundary conditions)	Intake wells
I	142.0	15.1	–	46.7	–
II	–	24.4	80.2	37.8	3.5
III	–	3.7	14.5	–	10.8

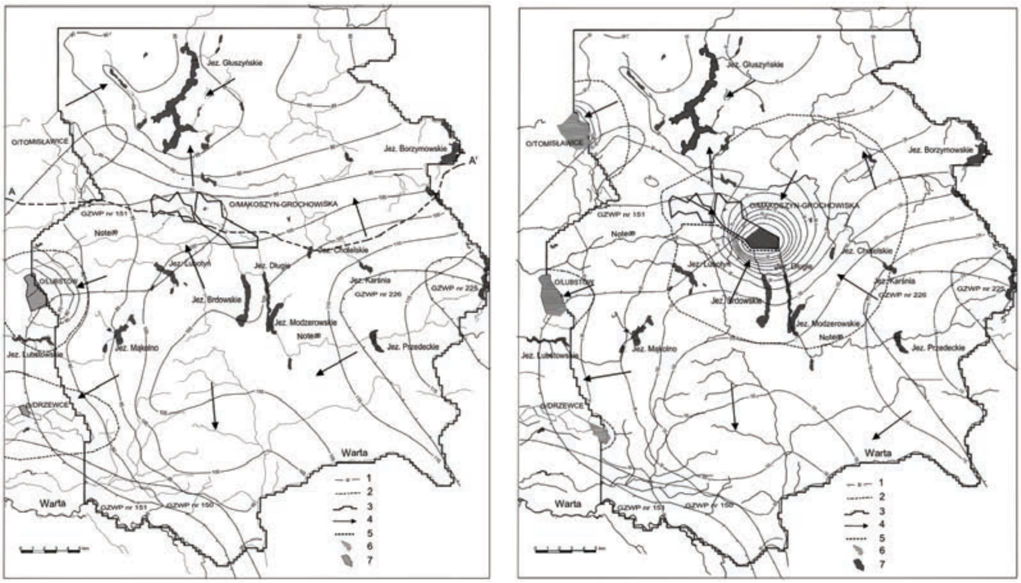

Figure 4 Map of of hydroizohipses of the Neogene-Paleogene-Mesozoic aquifer a) in quasi-natural conditions, 2008 y, b) in hydrodynamic conditions for 2044 y., computer model prediction. Explanation: 1-piezometric surface of Neogene-Paleogene-Mesosoic aquifer, 2-range of the cone of depression, 3-model boundary, 4-groundwater flow direction, 5-hydrogeological cross-section, 6-mine drainage area, 6-pit lakes

Table 2. *Groundwater balance at the „Mąkoszyn-Grochowiska" region, before dewatering operations at 2021, [m³/min].*

Layer	Recharge from precipitation	Discharge out of the model area	Leakage from overlying layer	Discharge to rivers and lakes (external boundary conditions)	Intake wells	Recharge from static resources
I	157.6	14.8	–	43.9	–	3.4
II	–	23.7	102.3	31.6	3.5	0.1
III	–	33.4	43.6	–	10.7	0.6

The groundwater balance at the "Mąkoszyn-Grochowiska" region, just before starting of dewatering operations at 2021 indicates that discharge to rivers and lakes will decrease, while the leakage from layer I increases due to moving the dewatering system in the "Drzewce" pit toward western boundary and starting dewatering operation in the "Tomisławice" open pit. As a consequence, the mine water inflow from layer III increases (Table 2).

The groundwater balance at the end of lignite production in the "Mąkoszyn-Grochowiska" pits at 2044 shows further decrease of discharge to rivers and lakes

Table 2. Groundwater balance at the „Mąkoszyn-Grochowiska" region, before dewatering operations at 2021, [m³/min].

Layer	Recharge from precipitation	Discharge out of the model area	Leakage from overlying layer	Discharge to rivers and lakes (external boundary conditions)	Intake wells	Recharge from static resources
I	157.6	14.8	–	43.9	–	3.4
II	–	23.7	102.3	31.6	3.5	0.1
III	–	33.4	43.6	–	10.7	0.6

Table 3. Groundwater balance at the „Mąkoszyn-Grochowiska" region at the end of dewatering operations at 2044, [m³/min].

Layer	Recharge from precipitation	Discharge out of the model area	Leakage from overlying layer	Discharge to rivers and lakes (external boundary conditions)	Intake wells	Recharge from static resources
I	166.8	22.4	–	40.6	–	4.4
II	–	21.2	108.2	25.9	3.5	0.1
III	–	48.9	57.8	–	10.7	1.8

* including groundwater inflow to dewatering system of „Mąkoszyn-Grochowiska" open pit

and greater leakage from layer I to lower layers (Table 3). It is due to dewatering of "Mąkoszyn-Grochowiska" pit and the process of flooding "Drzewce", "Lubstów" and "Tomisławice" post mining voids (Fig. 4).

The results of the modelling study for mining conditions (2022 – 2044) indicate that during the "Makoszyn – Grochowiska" dewatering system operation groundwater mine water inflow into the proposed open pit mine will reach from 40 to 60 m³/min. Due to the lowering of groundwater table the average effective infiltration in the area of cone of depression will account for 3.18 l/s/km² and reach 18.6% of the average precipitation ratio. The cone of depression will develop in all directions, covering Notec river and its tributaries as well as nearby lakes. The total area covered by the upper Quaternary aquifer will reach 130 km², and by the Paleogene-Neogene-Mesozoic aquifer 390 km² (Szczepiński 2011).

The modelling studies performed in the area with many open pits require taking into consideration not only the pit being under the study but also other pits, which dewatering or flooding may influence on the study area. Because dewatering is a process variable in time and space, the models must be solved in transient simulation and in each stress period it is necessary to update boundary conditions representing the dewatering systems of all pits in the modeled area.

References

Anderson M.P., Woessner W.W., 1992, Applied Groundwater Modeling, Groundwater Flow and Advective Transport. Academic Press Inc., San Diego–New York–Boston.

Czyż J., Jagodziński Z., 2008 – "Mąkoszyn – Grochowiska" deposit exploitation project. KWB Konin S.A., Kleczew, (not published). (in polish)

Fiszer J., Derkowska-Sitarz M., 2010 Forecast of development of depression cone and water inflows to brown coal mine Konin including designed open pits Tomisławice and Ościsłowo. Biul. Państw. Inst. Geol., 442: 37-41. (in polish)

Graf R., 2003 – Comment on the hydrographic map of Poland. 1: 50 000, Sompolno sheet, UAM w Poznaniu(in polish)

Kondracki J., 2000 – The Regional Geography of Poland. PWN, Warszawa. (in polish)

McDonald M.G., Harbaugh A.W., 1988, A Modular Three-Dimensional Finite Difference Ground-Water Flow Model. Techn. of Water-Resources Investigations of the U.S. Geol. Surv. Book 6, Chapt. A1, Washington.

Orsztynowicz J., Wierzbicka B., 1970 – The share of groundwater in the Odra river basin and the rivers of West Pomerania. Zakład Badania Odpływu IMGW, Warszawa. (in polish)

Stachy J. ed., 1987 – The Hydrological Atlas of Poland, IMGW. Wyd. Geol. Warszawa. (in polish)

Szczepiński J., 2013 Numerical modeling in hydrogeological studies to assess the impact of open pit mines on the environment. Wydz. Geoinż., Górn.i Geol. PWr p.200 (in polish)

Szczepiński J. Straburzewska-Janiszewska B., Prediction of the depression cone range for lignite open pit Mąkoszyn-Grochowiska KWB "Konin" S.A., 2011 Biul. Państw. Inst. Geol., 445: 671-684. (in polish)

Ziętkowiak Z., 2003 – Comment on the hydrographic map of Poland.1 : 50 000, Izbica Kujawska sheet, UAM w Poznaniu (in polish)