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Hydrogeological conditions of potable water supply the Kuznetsk Coal Basin, Russia

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Abstract. The article deals with hydrogeological conditions of the groundwater resources in the western part of the Kuznetsk depression, a coal and ore mining region. On the basis of a scheme of hydrogeological boundary conditions, a numerical geologic filtration model is developed for calculation of groundwater resources in the study area. The hydrologic budget of the numerical model is evaluated for assessment of infiltration recharge of groundwater resources.

1 Introduction

Ground water in the Kuznetsk Coal Basin is of vital importance, as it is widely used for water supply of industrial and population centers, thus determining the economics of the location in Kemerovo region, being of paramount importance for development of coal, ore and other mineral deposits [1].

Today, water conservation of industrial districts of the Kuznetsk Basin is one of the most topical issues. However, the need for drinking groundwater resources is complicated by the broad-scale development of mining industry followed by drainage of the upper hydrodynamic zone in mining operations.

The research is designed to study hydrogeological conditions of operation of the potable groundwater supply, to develop a numerical model based on the report on groundwater locations, to clarify balance characteristics of the water-intake area and boundary conditions. The water balance estimate is made for wells with the total water rate of 1500 m^2/day as at the end of calculation period (25 years).

2 Materials and methods

As a basis of research, the findings of calculation of groundwater resources in the Nikitinsky 4 site of the Nikitinsky deposit were used as initial data. Geological exploration aimed at calculation of total reserves of potable ground water was performed under the geological assignment of LLC S.D. Tikhov mine by the enterprise LLC Hydrogeological Research Center in 2013-2014.

In the process of field investigation a set of required research was carried out that included sanitary and environmental study of the site around water-supply wells of LLC

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S.D. Tikhov mine, a cluster pumping test of the well No. 4VSN and pumping tests of three other wells.

The basic balance characteristics for the water-intake area assessment method were obtained by a computational simulation using the finite difference method [2] within the framework of the software package Processing Modflow. As preprocessors, Surfer and AutoCAD software packages were used.

3 Hydrogeological conditions

The study area is located on the outskirts of Leninsk-Kuznetsk district, Kemerovo region, about 3.2 km to the west of the settlement Konevo, on the left side of the UR River valley. In terms of geological and hydrogeological classification this area is assigned to the western margin of the Kuznetsk Basin [3,4], and the aquifer extends to the Middle Permian sediments of Ilyinsk subseries. In the overlying aquifer system the Upper Quaternary recent alluvial sediments of the Ur River are confined (Fig. 1) [5].

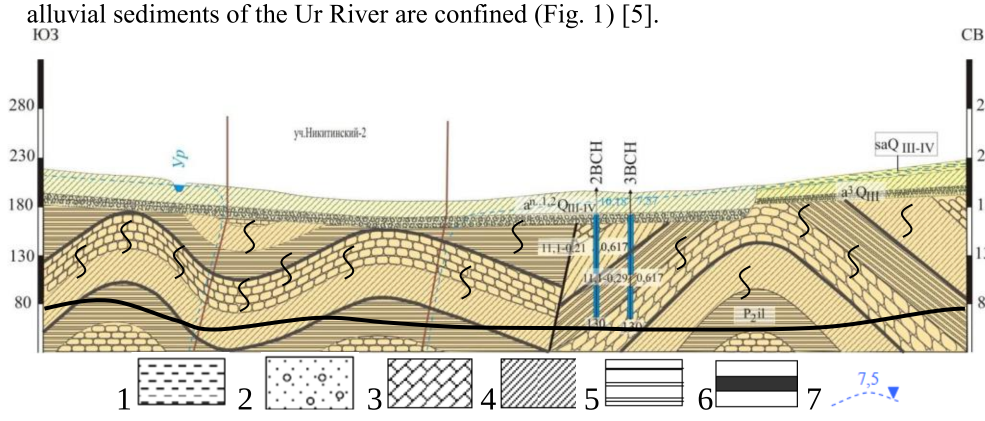

Fig. 1. Hydrogeological section.1– loam, 2 – pebble deposits, 3 – sandstone, 4 – siltstone, 5 – mudstone, 6 – coal, 7 – groundwater table.

3.1 Multi-layered aquifer system of flood plain of the Inya River

Hydrophilic sediments are presented by channel facies deposits of flood-plain, first, second and third upland fringes – fine gravel, pebble roundstone, less often cobble roundstone, sand with sandy-loam and loamy filler (up to 30-40%). A depth of system varies between 3-5 and 15-20 m, increasing from the river bed to the valley side. Water saturation is variable and small. Filtration coefficients vary greatly (0.04-12.1) m/day, transmissivity – 0.1-65.0 m^2/day. In terms of chemical composition, the water is of HCO3-Ca type, fresh with mineralization up to 1.0 mg/L. Aquifer system is fed mainly by infiltration of atmospheric precipitation, infiltration of flood water as well as by water from underlying aquifers. Water is discharged in the local drainage system.

3.2 Multi-layered aquifer system of Middle Permian sediments of Ilyinsk subseries (P2il*)*

Groundwater is assigned to the upper zone of fracture developed to the depth of 100–120 m. Based on findings of geophysical exploration, up to 3-8 water-bearing zones can be noted which are separated by weakly fissured rocks. The depth of the first zone is 10-30 m; a thickness of each zone is 8-10 m on average, in total – interstratified beds of silt,

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sandstone, argillite, coal, are 28-80 m of water-bearing sediments. Groundwater in watersheds and on slopes is found at a depth up to 43-47 m, in river valleys and ravines within 0.5-15.0 m. A level surface in broad terms hugs the terrain. Abundance of water is non-uniform: Sandstones have the biggest water content. Artesian flows, which penetrate aquifer in the area under study, vary from 0.004 to 11.39 l/s with decline of 11.0 and 45.9 m, respectively. The sediments are mostly watered-out in terrain depressions (in the Ur River valley specific yields of wells are as great as 0.2-0.5 l/s) and are significantly smaller in watersheds and on slopes. Rock transmissivity varies from 0.2-30 to 40-68 m^2/day increasing in local areas up to 119-173 m^2/day. Rock permeability varies from 0.007 to 1.87 m/day, with a mean value 0.57 m/day. Aquifer parameters, decrease rapidly with depth. At a depth more than 120-150 m, permeability does not exceed 0.002-0.08 m/day, rarely achieving 0.5 m/day, transmissivity is 0.1-1.8 m^2/day. The natural flow structure changes its shape by artificial drains – mines and pits. In terms of chemical composition, groundwater is HCO3-Ca, Mg-Ca or of mixed cations, fresh or weakly subsaline with mineralization 1 – 1.5 g/dm^3. 500 m to the west of the area and ~2.5 km to the east, coal mining is underway.

4 Model parameters

The calculation model which reflects groundwater reserves is presented by a limited plan view of the layer with the impermeable boundary on the side of the minefield in operation (LLC S.D. Tikhov mine), and also the boundary with constant pressure presented by the Ur River, shifted by 600 m with consideration for channel resistance. In addition, the constant recharge of groundwater reserves due to water discharge from the original slope must be taken into account (Fig. 2).

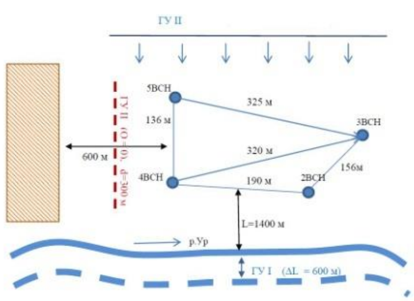


Fig. 2. Boundary conditions.

This method of calculating water level decline envisages both elastic reserves of primary deposits of Middle Permian rocks of Ilyinsk subseries (P_2il), and groundwater spreading due to surface water resources.

In the hydrodynamic filtering area model, the composition of water-bearing material is presented by two layers. The first layer corresponds to the first from the surface artesian-free aquifer of fractured rock 100 m thick with 50 m^2/day transmissivity. The second layer presents an aquifer 50 m thick with transmissibility <10 m^2/day. It characterizes the attenuation zone of open fracture in the fold-mountain ground [6]. (Table1).

Table 1. Filtration and capacity parameters.

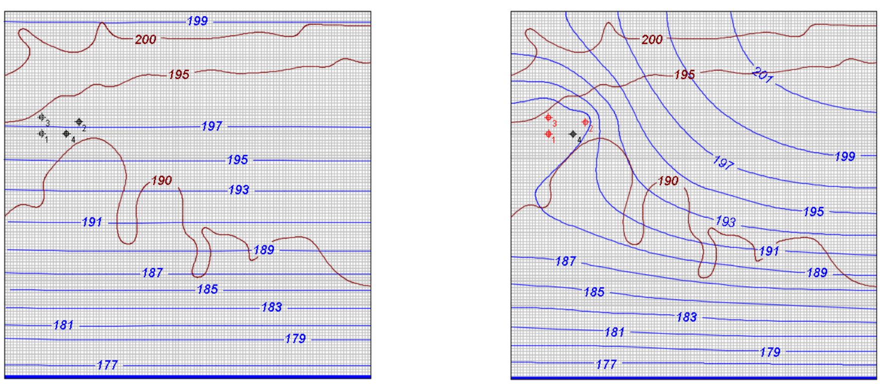
Level	Pressure	Isotropism	k_x m / day	k_y m / day	k_z m / day	Storativity η (m^{-1})	Specific yield μ
1	confined-unconfined	isotropy	0.5	0.5	0.5	10^{-4}	0.25
2	confined	isotropy	0.2	0.2	0.2	10^{-4}	0.25

The area under simulation was covered by the uniformly spaced grid with 25-m pitch in both directions. The southern model boundary, which corresponds to the spatial position of the Ur River is accounted for as a boundary of third kind with consideration for the assessment of hydraulic irregularity of 600-m bed. The western boundary is drawn along the dislocation with a break of continuity. The northern boundary goes along the watershed line corresponding to boundary conditions of second kind (BC II Class) (Fig. 1).

In study of natural groundwater regime, the geologic filtering problem was solved in stationary formulation [7]. As a result, a calculated pressure field was obtained. As a main criterion of computational solution accuracy the value of filtration flow hydraulic gradient 0.008 was taken. At the stage of epignosis modeling, a value of infiltration recharge (0.00033 m^3/day) was estimated by trial and error method.

Analysis of water balance of the numerical model, a value of natural resources is 2945 m^3/day. In this case all resources are formed due to infiltration recharge and discharged in the Ur River. 2460 m^3/day falls to the share of the first aquifer, the remaining 485 m^3/day flows to the second aquifer (Fig. 3a).

Predictive modeling accounts for operation of three running wells. It assumes solution of a non-stationary problem. Initial pressure distribution is taken on the results of solution of stationary problem in each computational layer. The following aquifer storage capacities are set: elastic capacity coefficient, coefficient of storativity and coefficient of elastic water return. All wells are located within the thickness of the first aquifer. The estimated time is 25 years. This interval is split into 300 time steps with a 1.3 multiplier for a more detailed presentation of calculated results in the beginning of water-intake operation and a lesser amount of output data in steady state operation of running wells. The simulation resulted in water table contour maps for natural and disturbed conditions (Fig. 3b).



a b

Fig. 3. Contour maps of water table with: a) calibrated modeling; b) forecast modeling.

Following the results of predictive hydrodynamic modeling it was found that the value of lowering of water in wells did not reach absolute depth marks of the Ur River. Between the river and the wells a local watershed is formed which in long-term operation of water-intake may shift to the river side. Analysis of the model water balance gives the following results. Natural aquifer resources are 1220 m^3/day. The raised resources from the phreatic low do not exceed 278 m^3/day (Table 2).

The Ur River effect on formation of usable groundwater resources in water-supply wells is not noticeable. Therefore, it may be concluded that the main sources of groundwater formation are renewable.

The critical part for forecast of water intake operation is the nature of boundary conditions with due account for mine drainage.

It is essential to investigate the mine field regime and its influence over water-intake at the stage of operation and exploration of ground water.

Table 2. Balance model for the water intake.

Source	in m^3/day	out m^3/day
The water balance of the entire model		
Natural conditions	2950 (Infiltration)	2950 (in river Ur)
Breach of conditions	3140 (capacity)	1640 (in river Ur)
	1640	
The amount of change	**1720** (capacity)	**222** (in river Ur)
	-	
Water balance of the first surface of the aquifer		
Natural conditions		2459 (in the Ur River)
	2945 (Infiltration)	486 (2d aquifer)
Breach of conditions	1407 (capacity)	2645 (in the Ur River)
	230 (bottom)	438 (2d aquifer)
	2946 (Infiltration)	***1500*** (wells)
The amount of change	**1407** (capacity)	**185** (the Ur River)
	230 (1th aquifer)	**47** (2d aquifer)
	-	**-**
Water balance of the second surface of the aquifer		
Natural conditions	485	486
Breach of conditions	315	523
	438	230
The amount of change	**315** (capacity)	**37** (in the Ur River)
	47(2d aquifer)	**230** (1th aquifer)
	1407+315=***1722***	185+37=***222***
	1722-222=**1500 m^3/day**	

5 Conclusion

The epignosis hydrodynamic model of filtration area in the software PMWIN environment was developed and used for prediction of variation in groundwater level in water-intake operation. Analysis of water balance of the numerical model indicated natural groundwater resources are 2940 m^3/day, in which case all resources are formed by infiltration recharge and discharged in the Ur River valley. On the share of the first aquifer fall 2460 m3/day, the remaining 485 m^3/day come to the lower aquifer.

Results of predictive hydrodynamic modeling showed that the value of lowering of water in wells did not reach absolute depth of the Ur River. Between the river and the wells a local watershed is formed which in long-term may shift to the river side. Analysis of the model water balance gives the following results. Natural aquifer resources are 1222 m3/day. The raised resources from the phreatic low do not exceed 278 m^3/day.

The results of numerical modeling show that the Ur River does not act as a boundary of third kind that comes into contradiction with the analytical computational method. The main reason of this discrepancy is infiltration recharge, which in the model plays a role of the additional source of water resources, which is ignored in analytical calculations. Evaluation of water-intake operation in the model with the a total flow rate of 1500 m^3/day demonstrates that the absolute mark of dynamic level in the wells exceeds the level in the Ur River preventing interaction with surface water. In analysis of water-intake operation in the context of interaction with different boundary conditions, the application of numerical modeling is recommended. It allows for obtaining more accurate predictive estimates of changing hydrogeological conditions affected by external factors including water-intake operation in interaction with draining systems of mining enterprises.

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