Application of numerical modelling for evaluation of operating conditions of water intakes for domestic and drinking purposes in the area of oil fields operation

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Abstract: The research is focused on preserving the resources of domestic and drinking water supply in the areas of operation of numerous oil fields. The basis of the study is the well-known principle of protection of groundwater from contamination during its operation, which is implemented at existing water intakes for domestic and drinking water supply through the organization of sanitary protection zones (SPZs). In the conditions of mass application, in order to calculate their boundaries for the most common analytical methods of calculation, in practice, a simplified schematization of hydrogeological conditions is often allowed, not fully considering the complex spatial structure of the filtration flows. The solution of the predicted hydrodynamic problem in the form of a spatial distribution of heads under the influence of water intake is obtained with the calculation of all balance characteristics on a numerical model. The model distribution of heads is used to solve the hydrodynamic problem in the nonstationary formulation. Recommendations for schematization of hydrogeological conditions for the purpose of justification of local hydrogeodynamic models and the study of filtration parameters in the course of experimental filtration work for the calculation of operational reserves were developed. The results of numerical modelling allow evaluating the influence of any potential source of contamination by its geographical coordinates.

1. Introduction
Hydrodynamic modelling was carried out in co-authorship with the staff of the National Tomsk Polytechnic University, within the framework of the scientific project No. 16-35-50181 with the financial support of the Russian Foundation for Basic Research. Modelling of hydrogeological conditions was carried out with the goal to estimate features of formation of groundwater reserves with reference to the substantiation of research of protection of operating groundwater intakes of domestic-drinking purposes from potential surface contamination in the areas of producing oil fields. The work is based on the results of the generalization of the sampling data of 30 reference hydrogeological wells, stock cartographic and report materials for the Middle Ob basin of the groundwater flow (the Vartovsky oil and gas bearing region). Data processing was aimed at assessing the conditions for the development of potential contamination with the aim of developing recommendations for clarifying the size of sanitary protection zones using the capabilities of numerical modelling. The main advantage of modelling lies in the possibility of taking into account such elements of the hydrogeological section as the layered occurrence of water-bearing rocks and segregated strata, the complex shape of the outer boundaries of the filtration area, the spatial
heterogeneity of filtration parameters, the complex nature of exciting wells, etc., which cannot be taken into account in the framework of schematization of hydrogeological conditions for the purposes of analytical hydrodynamic calculations. The numerical model of the filtration area was created on the basis of the available cartographic material represented by heterogeneous maps in uncoordinated coordinate systems. The processing of the initial data was carried out in stages using geoinformation systems and eventually merged in the GMS (Groundwater Modelling System) as a set of electronic layers allowing for their joint processing, including the ability to digitize key objects.

2. Research
The tasks of hydrodynamic modelling are primarily related to the need to quantify the degree of protection of groundwater from contamination, which is formed under the influence of the geological structure and hydrogeological conditions of the water-bearing strata and can be most reliably estimated with the most complete consideration of the influence of many interrelated factors on the basis of water balance equations. From practical points of view, it is of interest to identify the spatial structure of the filtration flows, which can be used as a basis for assessing the shape and size of sanitary protection zones for both active water intakes and those being designed.

3. Results and discussion
The solution of the predicted geofiltration problem in a stationary setting is represented by the calculated field of heads, which is formed under the influence of the total impact of natural (infiltration recharge, constant head in the river channel) and artificial (operation of individual water intakes) boundary conditions.

Based on the predicted field of pressure on the regional model of the operational water-bearing complex of Paleogene deposits, the maximum dimensions of the capture zone of the filtration flow of water intake wells have been obtained in a stationary setting (for an unlimited lifetime). Shown on the map (Figure 1), they provide an opportunity to assess the potential conditions of contamination of producing aquifers, taking into account the spatial location of potential contamination sources. The flow path diagram allows localizing those areas where surface or deep contamination can get into the catchment zone of the water intake well and indicate the areas within which foci of contamination cannot impair the operation of production wells (Figure 1) under any circumstances.
Figure 1. Scheme of the flow paths development for an unlimited lifetime (limiting dimensions of the filtration flow zones covered by production wells are shown).

The above scheme allows assessing the danger of any potential source of contamination, according to its geographical coordinates. If the location of the pollution source is outside the areas occupied by flow paths, it cannot impair the operating conditions of any water intake under any conditions. Conversely, if a potential source of contamination falls within the boundaries of the field of flow paths, contamination of water intake is inevitable, but the question of the period of time during which this can occur remains open. The results of numerical modelling provide a reasonable answer to this question. To do this, it is sufficient to analyse the time during which filtration takes place in the direction of the flow paths of the filtration flow. An example of such an analysis is shown in Figure 2. From the point of view of practical evaluation of the structure of the filtration flow, the limiting dimensions of the filtration flow zones covered by production wells should be limited. For the sake of demonstration, in Figure 3 the time for the filtration flow to reach the wells is reduced to 2000 years. In this case, the size of the water-capture area in the projection to the surface is on average 6 km.

Figure 2. Parameters of the selected flow path (indicated by an arrow): location, length (~ 31 km) and the time of motion of a fluid particle along the indicated trajectory (3.85 × 10^7 days or 105 thousand years).
Keys:
- flow paths;  - heads and their marks;

**Figure 3.** Dimensions of the filtration flow zones covered by production wells being formed for 2000 years (average size of the water intake zone is 6000 m).

Restriction of the estimated time by the duration of operation of water intakes of 10,000 days, which is taken as the standard for calculating the operational reserves of groundwater, sharply reduces the dimensions of the filtration flow zone covered by production wells.

An analysis of the structure of filtration flows in the vicinity of water intake wells shows that during their operation during the service life the dimensions of the filtration flow coverage zone practically do not exceed the boundaries of the calculated cell of the regional numerical model. Consequently, in the formation of artificial filtration flows under the influence of water intake, the priority remains for vertical overflows, which does not contradict the schematization of the hydrogeological conditions adopted for analytical calculations of operational reserves. The dimensions of the filtration flow zones covered by production wells correspond to the boundaries of the third belt of the sanitary protection zone. An analysis of their spatial location allows us to conclude that the mass exploitation of the groundwater of Paleogene deposits does not lead to the unification of pressure sinks. The water intakes according to the nature of their impact on groundwater can be considered as single dispersed sources of disturbance of the filtration flow.

The influence of potential foci of contamination on the operation of the water intake well has been modelled. Based on the prediction field of head, the structure of probable movement of groundwater near a single water intake well 7-857 is analysed. The location of probable potential contamination sources is shown in Figure 4.

Figures 5 and 6 show the planned structure of the filtration flows in the zone of production well No. 7-857. For the northern focus of potential contamination, a quantitative characteristic of the filtration flow along four distinct flow paths is given. The length of the flow paths: minimum - 2753 m, maximum - 3856 m; average - 3278 m. The time of groundwater movement: minimum - 16622300
days or 45540 years; maximum - 24953800 days or 68367 years; average - 20840700 days or 57098 years.

Figure 4. Location of probable surface potential contamination sites in the vicinity of production well No. 7-857: 1, 2 - conditional numbers of potential contamination foci, background shading corresponds to the prediction field of heads.

Key:
- northern focus of potential contamination (4 grid cells) and its number;
- southern focus of potential contamination (4 grid cells) and its number;
Key:
- focus of potential contamination;
- production well and its number;
- flow paths, direction is indicated by arrows;

**Figure 5.** The filtration flow in the zone of production well No. 7-857 ((directed along the flow paths from the centres of the cells of the northern focus of contamination to the well), the background shading corresponds to the prediction field of heads.
Figure 6. The filtration flow in the zone of production well No. 7-857 (directed along the flow paths from the centres of the cells of the southern focus of contamination to the river), the background shading corresponds to the prediction field of heads (for other notations, see Figure 5).

4. Conclusion
The influence of potential sources of contamination depends to a large extent on the structure of filtration flows, which helps to identify numerical modelling. The regional model shows that with the intensive exploitation of groundwater in Paleogene deposits, existing water intakes by the nature of their impact on groundwater can be considered as single dispersed sources of disturbance of the filtration flow. When using modelling, the calculated zones of sanitary protection reduce the dimensions in the plan by taking into account the vertical component of flow paths.

The influence of the location of a potential source of contamination on the quality of groundwater in an operational aquifer under the influence of the direction of the filtration flow for a local water intake site is shown. For a single water intake, represented by well 7-857, the southern focus of potential contamination cannot threaten the quality of groundwater.

In this case, the source of substandard solutions is located below the well along the flow of groundwater, but it can influence the composition and quality of the surface water of a river. On the contrary, the halo of potential contamination of the northern outbreak, located at a distance of about 2.5 km to the north, can be almost completely intercepted by well 7-857. However, the filtration time in these directions is multiples of the criteria for the calculated parameters of the third belt of the sanitary protection zone of water intakes from persistent chemical contamination. Therefore, the location of potential sources of contamination shown in Figures 5 and 6 cannot have a significant effect on the change in the composition of groundwater operated by well 7-857.

Thus, the application of numerical modelling can significantly increase the reliability of predictive estimates of hydrodynamic predictions associated with practical calculations of the size of sanitary protection zones for both existing and planned water intakes, especially in areas of active economic activity.

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