Mathematical modeling is the main instrument for assessment of transboundary groundwater flows

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ABSTRACT

The results of studying of transboundary groundwater interaction in Russian-Kazakhstan and Russian-Ukraine boundary area are given. The direction of undisturbed groundwater flows is determined, and changes caused by the exploitation of the aquifers are assessed. The methodological approaches for solving transboundary problems applied to groundwater are determined as a result of mathematical modelling.

Key words: transboundary ground water flows, mathematical modelling

1. INTRODUCTION

Research and forecasting of hydro-geological processes in transboundary aquifers of neighboring countries demands an exact quantitative estimation, especially in case of technogenic load increasing on groundwater. The decision of this problem is provided to the full by creation of the regional mathematical models with borders that are natural borders of a hydrodynamic flow of the groundwater. These borders are probably location on adjacent territories. Monitoring data on groundwater from the territory of neighboring states is necessary for an adequacy of model estimation therefore one of the primary goals is to get agreement on granting of all monitoring data for modelling at interstate level. Information on allocation of existed or planned sources of possible groundwater pollution is of critical importance. Thorough analysis of the hydrogeological situation in the near-boundary zone is necessary, in which experts from both countries can take part. Only such analysis can show which of the bordering countries overpumps the natural transboundary groundwater flow and inflicts damage to the neighbor.

2. METHODOLOGY AND INSTRUMENT

The basic equation describing of a geofiltration process is reduced to a kind having simple physical sense - the sum of flow rates in each point ***i*** of aquifer ***n*** equals to 0 in natural conditions or time difference in capacity in the broken:

$$\sum_i Q_{xi}^n + \sum_i Q_{yi}^n + \sum_i Q_{zi}^{n-1} + \sum_i Q_{zi}^{n+1} + \sum_i Q_{IIi}^n + \sum Q_{IIIi}^n + \sum_i Q_{wi}^n = \sum_i Q_{ci}^n \quad (1)$$

where $Q_{xi}^n = \dfrac{\partial}{\partial x}(T_{xi}^n \dfrac{\partial H_i^n}{\partial x})$ is the plain flow along axis X (m/day), Q_{yi}^n is the same along axis Y, Q_{zi}^{n-1}, Q_{zi}^{n+1} are vertical flows between neighboring aquifers, Q_{wi}^n is an infiltration,

Q^n_{IIi} is an intensity of groundwater extraction, $Q^n_{IIIi} = (H^n_{si} - H^n_i)G^n_{IIIi}$ is groundwater exchange with surface water, H^n_{si} is surface water level, G^n_{IIIi} is conductivity of river-bed deposits, $Q^n_{ci} = S^n_i \frac{\partial H^n_i}{\partial t}$ is change in the capacity for non-stationary filtration regime, H^n_i is required function of water pressure head in point i of aquifer n. First four members of this equation describe a configuration and a condition of water containing thickness other three reflect external sources of disturbance.

This approach shows an important peculiarity of mathematical modeling that new information on regional groundwater flow conditions can be obtained due to the possibility of separate components of the total water balance calculation in accordance with equation (1). These possibilities provide studying and predicting the development pressure influence on underground hydrosphere.

The following problems should be solved by modeling for these purposes:

- to estimate and predict the degree of an admissible exploitation of groundwater,
- to estimate and predict an admissible size of a damage to an underground component of river runoff which is a result of long groundwater extraction in comparison with natural conditions,
- to forecast the contaminated areas extended in groundwater flow from possible pollution sources, and also to track their relative dynamics.

To provide optimal schemes of joint groundwater use in accordance with suggested criteria as a result of modeling the following data are output from the model database:

- *assessment of groundwater depletion*

1. maps of hydroisopiese and maps of water head position relative to the top of aquifer on check time steps that allows to give quantitative assessment of direction, velocity and time of depression cones spreading towards administrative boundaries;
2. graph of groundwater level lowering in inner points of hydrodynamic flow values corresponding to administrative boundaries;
3. graph of the full amount of plane groundwater flow in the case of depression cone spreading on the territory of the neighboring state;

- *assessment of surface water depletion* (Polshkova,2009)

4. graph of value variations in water exchange between surface and groundwaters relative to natural conditions;
5. values of damage to groundwater component of river runoff for all surface water sources;

- *assessment of groundwater contamination*

6. maps of time and areas of contaminated groundwater distribution from the surface sources of pollution which provide determining of sanitary zones of exploited or planned well-fields;
7. discovering of a probable pollution source location if the contaminants in groundwater samples taken from aquifers are detected.

In a number of cases, a major factor defining character and rate of migrant movement in groundwater flow is convectional masstransport which develops according to geofiltration process. Modelling of groundwater pollution in accordance to the piston replacement scheme in comparison with others, demands the least quantity of additional information. In each point of modelled area speeds of migrant movement VX, VY, VZ according to groundwater flow gradient are calculated. Time of pollution front movement to the given node point is the minim of possible time of advancement of the migrant getting out from initial pollution area. This time is calculated by the analysis of all transition times between adjacent node points in 10 directions along each of possible routes of the migrant movement according to a speed vector direction. Calculated flow times in days are input in the model database and are output in the form of an isochrone map. This map depends on the chosen mode and can be a map of front pollution location or a map of sanitary protection zones of water intakes. Such approximation is enough for an extreme estimation of groundwater deterioration rates.

Cartographical database is one of necessary conditions for creation and functioning of mathematical models. Initial information as well as model results should be represented in a form that can be adapted for formats of standard GIS-packages. Thus this possibility should be one of software functions used at modelling. The isochrones map is represented in figure 1 as an example of described scheme.

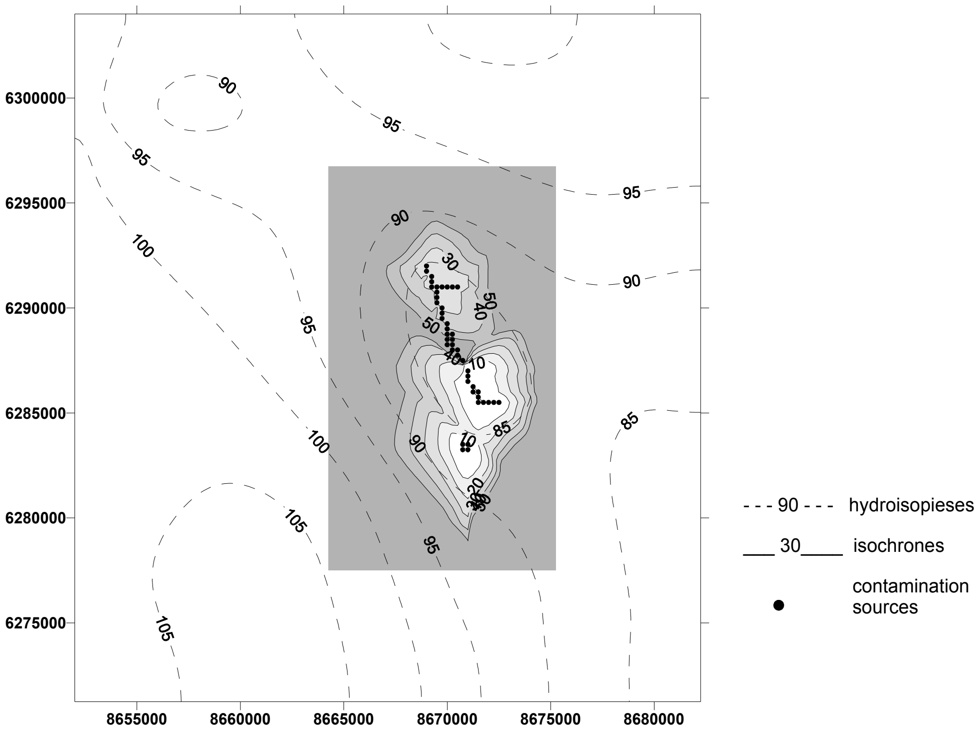

Fig.1 Map of isochrones and areas spreading from contamination sources

3. NUMERICAL MODELS

Now transboundary problems become especially acute for bordering territories of former soviet republics. But all studies were focused mostly at hydrological objects. The first quantitative estimation of the mutual hydrodynamics influence in the process of simultaneous exploitation of aquifers of near-border zones was made for the zone near Russian-Estonian boundary (Mironova *et al*. 2006).

Concerning this article described methodology was approved for calculation of transboundary groundwater flows between Russia and Kazakhstan and Russia and Ukraine.

The modeling area of Russia-Kazakhstan bordering zone is a part of West-Siberian artesian basin and has the size of 800×550 km in plane. The three-layer hydrogeological schematization including first from surface atlym aquifer and two aquifers of chalk deposits was accepted for mathematical model with dimension of 170 × 140 node points. The aquifer's borders are natural borders of aquifer outcrop on an earth surface. At modelling the calculation scheme for not rectangular (quadrangular) blocks was accepted. Node points have an exact geographical coordinates. Natural conditions are reproduced on the beginning of 50-th years. Broken conditions reflect the exploitation of chalk aquifers for 50 years. Coincidence of model results and observed data was satisfactory.

In figure 2 model result for variant of the broken mode is represented.

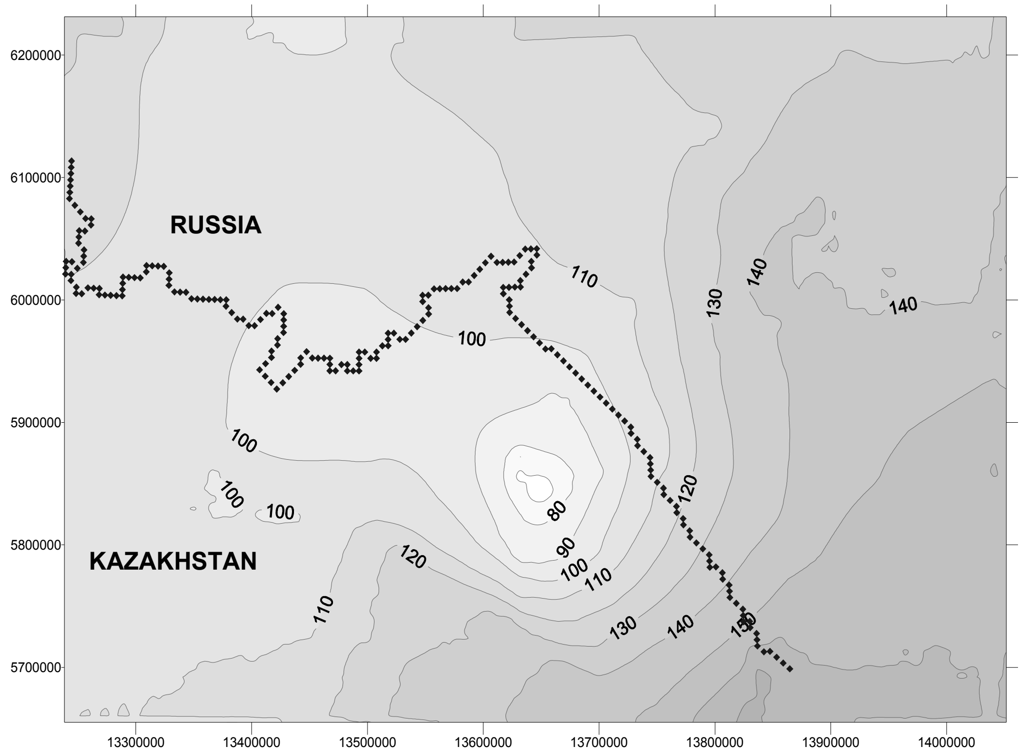

Fig. 2 Map of model water heads for broken groundwater flow conditions in the Russia-Kazakhstan border area

Thus the sum groundwater extraction in Pavlodar city (Kazakhstan republic) from 2 aquifers with value of 530 000m^3/day creates depression cone which extends abroad on Russian territory. Lowering of groundwater level gradually distributes along the administrative boundary on an extent of 300 km and increases up to 40 m for 40-year water intakes exploitation (fig. 3). The plane groundwater, which is grasped by the depression cone along border, increases from 60 up to 135 thousands m^3/day.

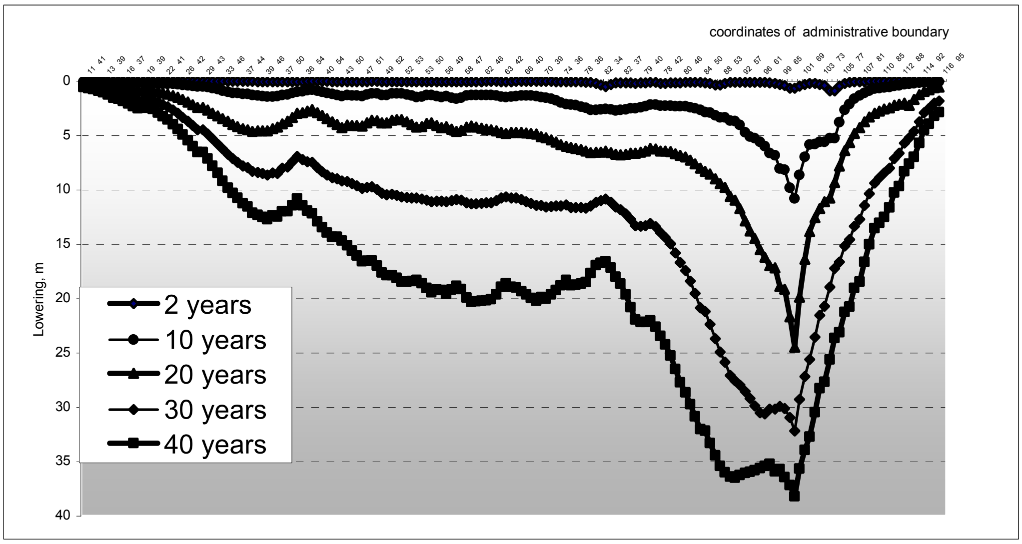

Fig. 3 Lowering in the points along administrative boundary for some time steps

Russian-Ukraine model is extended on territory of 248×276 km of Belgorod and Harkov regions. It reproduces the general groundwater flow for 1 km step as well as four aquifers on depth. Natural conditions were modeled on 1970 year and broken ones from 1970 up to 2009 year. The results for most exploited aquifer are presented on figure 4-5. The maximum lowering of groundwater head in depression cone areas is 55 m for Belgorod city and 80 m for Harkov city in 1980-1982 years.

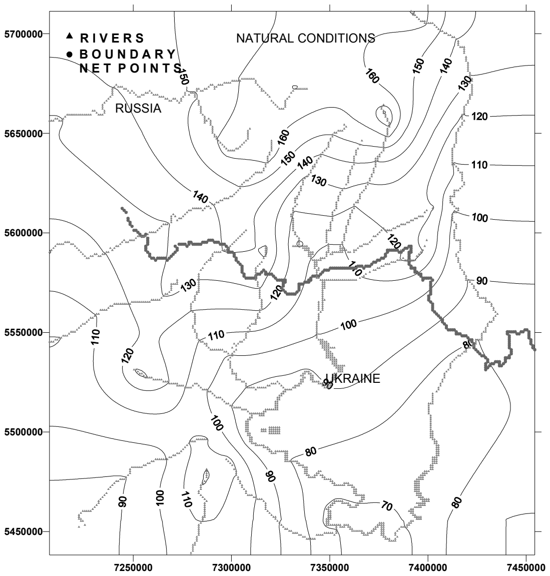

Fig. 4 Maps of model water heads for natural groundwater flow conditions in the Russia-Ukraine border area

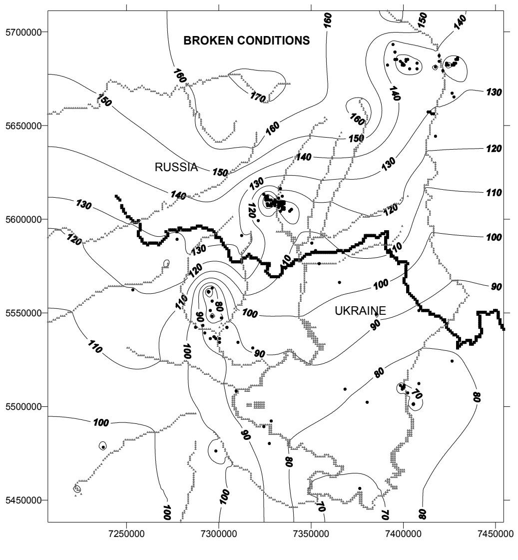

Fig. 5 Maps of model water heads for broken groundwater flow conditions in the Russia-Ukraine border area

Comprising the groundwater head maps it's possible to conclude that the flow character does not change. That is confirmed by quantitative estimation of plane flows across administrative boundary on the model. It increases approximately on 7-8 thousands m/day near Harkov city. Assessment of surface water depletion was made on 2009 in comparison with 1970. Recharge groundwater from surface one increased from 300000 up to 380000 m^3/day and release of groundwater decreased from 3 200 000 up to 2 600 000 m^3/day.

Reduction of water extraction to the middle of 90-th years almost restores the natural condition of groundwater flow near Harkov city.

But excess of water extraction can cause an association of depression cone on Russia-Ukraine transboundary groundwater flow and considerable depletion of aquifer (fig.6).

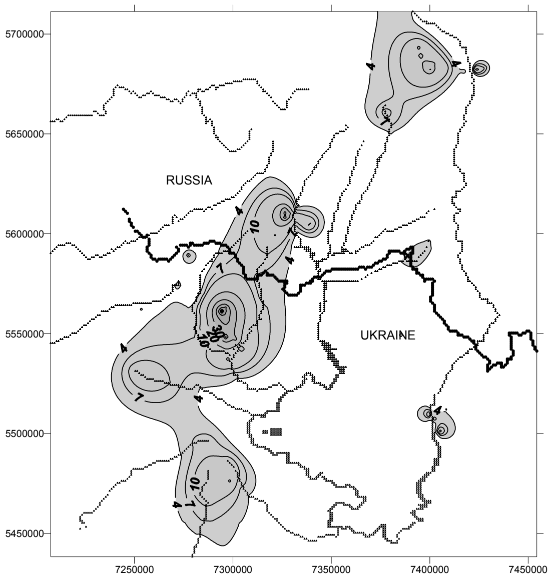

Fig. 6 Contours of generated depression cones in transboundary groundwater flow in the Russian-Ukraine area in 1980-1982

4. CONCLUSIONS

The mathematical models, as an instrument for hydrogeological forecasting, have to be the part of total interior monitoring subsystem. Using such approach, both geological service and government authorities meet the real instrument for assessing present-day and predicted conditions of underground hydrosphere and efficient regulating of the anthropogenic pressure load. All technogenic load on groundwater should be preliminarily estimated with a help of models before possible damages can happen.

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