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Methods for Analyzing the Hydrogeological Characteristics of the Aquifers in the Vicinity of Nuclear Power Plants Using Indicators

Keywords:
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bromide ion,
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Shelter object.

The mathematical modeling of migration of the unsorbed indicator on the way of filtration flow of the first from the surface alluvial-quaternary aquifer underground waters was completed. The imitation modeling was performed to justify the using of isotope or indicator methods to obtain reliable data on aquifer parameters, in particular, the permeability coefficient. Three-dimensional geofiltration model was used and the verification of received predictive results with the results of the field observations was completed. Program complex Visual MODFLOW 2011.1 was used as a tool to manage and edit model and the model's data, which gave a chance to improve the accuracy and performance of the model while increasing the efficiency of mathematical modeling.

Introduction

The permeability coefficient of aquifers is one of the main parameters of soils, which significantly affects the accuracy of forecasts of changes in radio-hydrogeological conditions of the territory and the radiation situation in the environment. High accuracy of forecasts is the key to the effectiveness of management decisions on the non-proliferation or minimization of groundwater radionuclides spreading in the environment and protection of groundwater against pollution. A filtration coefficient which is equal to 30 m/day for the entire thickness of the alluvial aquifer, at the territory of Chornobyl NPP, was determined in 2014, according to two pumping water from water's intake wells, drilled to maintain the water level in the inlet and outlet channels [1]. However, the first unconfined aquifer consists of sandy layers, ranging from dusty to medium sized, to medium-sized to large ones with gravel and pebble inclusions and thus possibly having varying infiltration properties. Therefore, the determination of the permeability coefficients of individual sandy layers was proposed to be carried out using artificial tracer (bromide ion as NaBr) or isotope (tritium) methods with the involvement of mathematical modeling of migration processes.

The purpose of the work was to develop a method of obtaining aquifer parameters at specific depth intervals by verifying the results of simulation mathematical modeling of the propagation of indicators with field observations.

Materials and methods

The essence of the method includes:

1. Carrying out imitation mathematical modeling of the launch and propagation of an indicator (e. g. sodium bromide) or an isotope (e. g. tritium), which includes the determination of inlet points, horizontal and vertical trajectories and propagation velocities, and possible locations (observation wells) of fixation in an aquifer.
2. Simulation takes place for either variants of the permeability coefficient: 30, 5, 2.1 m/day.
3. Using mathematical modeling, two clusters of observation wells 16-1A, 16-2A, and 9-2A, 9-3A were selected, which are located approximately in one strip of groundwater flow. Launch of sodium bromide took place in well 16-1A, and observations of the propagation of the indicator, according to mathematical modeling, occurred in well 9-3A. Observations were also made in wells 16-2A and 9-2A.

4. Bromide ion was used as an indicator in the form of NaBr.

5. Verification of the predicted results of the indicator distribution with the data of field observations on the wells allowed to determine the filtration parameters at separate intervals of the aquifer in which the migration of the indicator occured [2, 3].

For the simulation, a three-dimensional geofiltration model created using Visual Modflow 2011.1 was used.

Visual MODFLOW is the most complete, and user-friendly, modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulation. This fully integrated package combines powerful analytical tools with a logical menu structure. Easy-to-use graphical tools allow to:

quickly dimension the model domain and select units;

conveniently assign model properties and boundary conditions;

run model simulations for flow and contaminant transport;

calibrate the model using manual or automated techniques;

optimize pumping and remediation well rates and locations, and visualize the results using 2D or 3D graphics.

The model input parameters and results can be visualized in 2D (cross-section and plan view) or 3D at any time during the development of the model or the displaying results [4].

Results

Simulation of mathematical modeling in Visual MODFLOW 2011.1 is aimed at obtaining the prognosed trajectory of bromide ion movement in groundwater on slice between wells 16-1A and 9-3A. These wells are located near the walls of the Shelter object on the first ledge of the cascade wall. Now they are located under the Arch.

We used created earlier and supplemented with new data three-dimensional finite-difference model of the Chornobyl NPP and the 30 km around it.

To obtain such a model, the investigated area is divided by the system of planes into elementary, interconnected blocks, and all filtration hydrodynamic parameters belong to the center of such a block, which is called the computational node.

This model covers a rectangular territory approximately 8 km long and 13 km wide (fig. 1). In total, the model consists of three layers, which are divided into 412 columns and 301 rows. It includes data on aquifers, aquitards, permeability coefficients, etc.The model reproduces a three-layer filtration region, which consists of two aquifers — the upper unconfined and the lower confined, separated by a weakly permeable layer in the filtration plan.

Visual MODFLOW 2011.1 makes it possible to simulate to simulate, among other things, the movement of indicators in groundwater, which has been used.

Sodium bromide was chosen as an indicator for the experiment. 16-1A and 9-3A wells, located in a single line

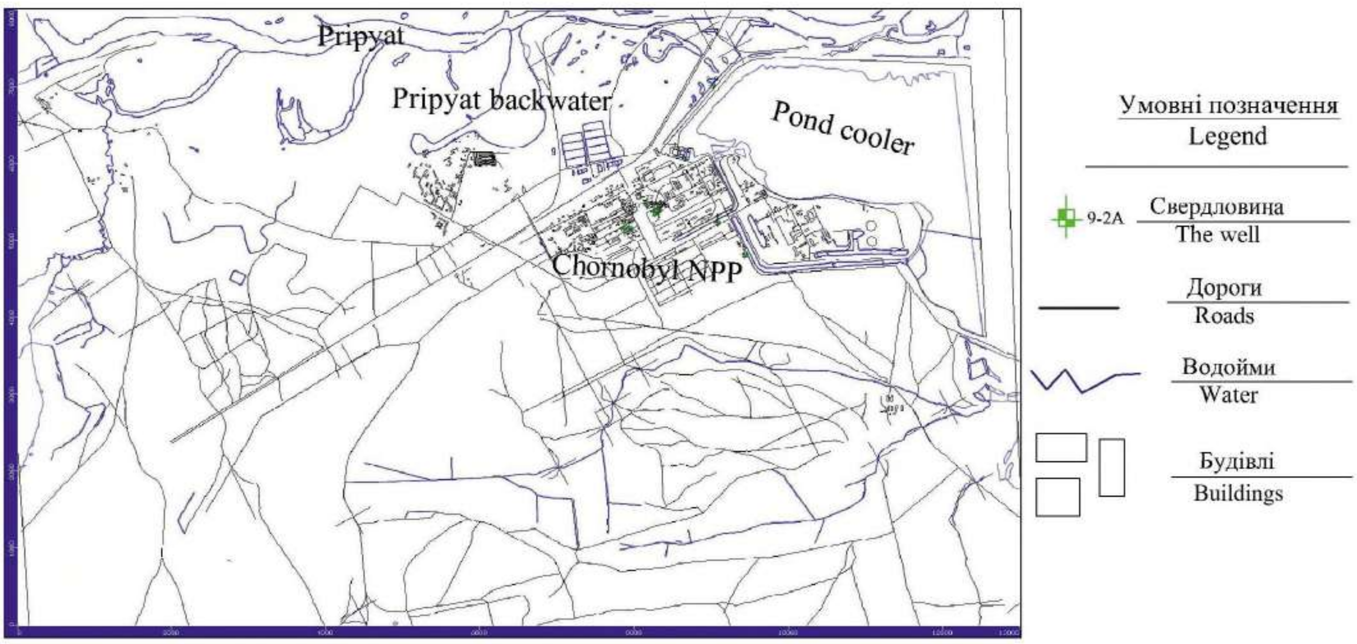

Fig. 1. General view of the mathematical model of the 30 km territory adjacent to the Chornobyl NPP

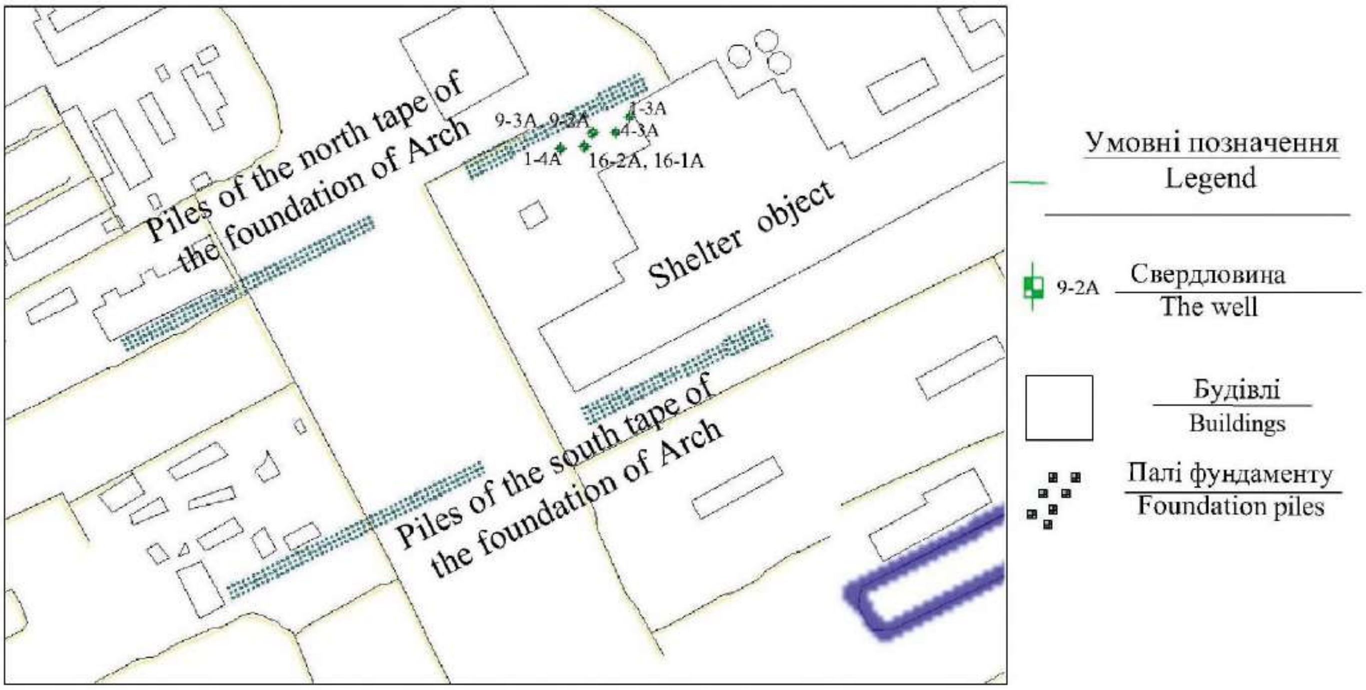

Fig. 2. Fragment of a mathematical model, used on experiment with tracking of bromide ion moving. Location — Shelter object

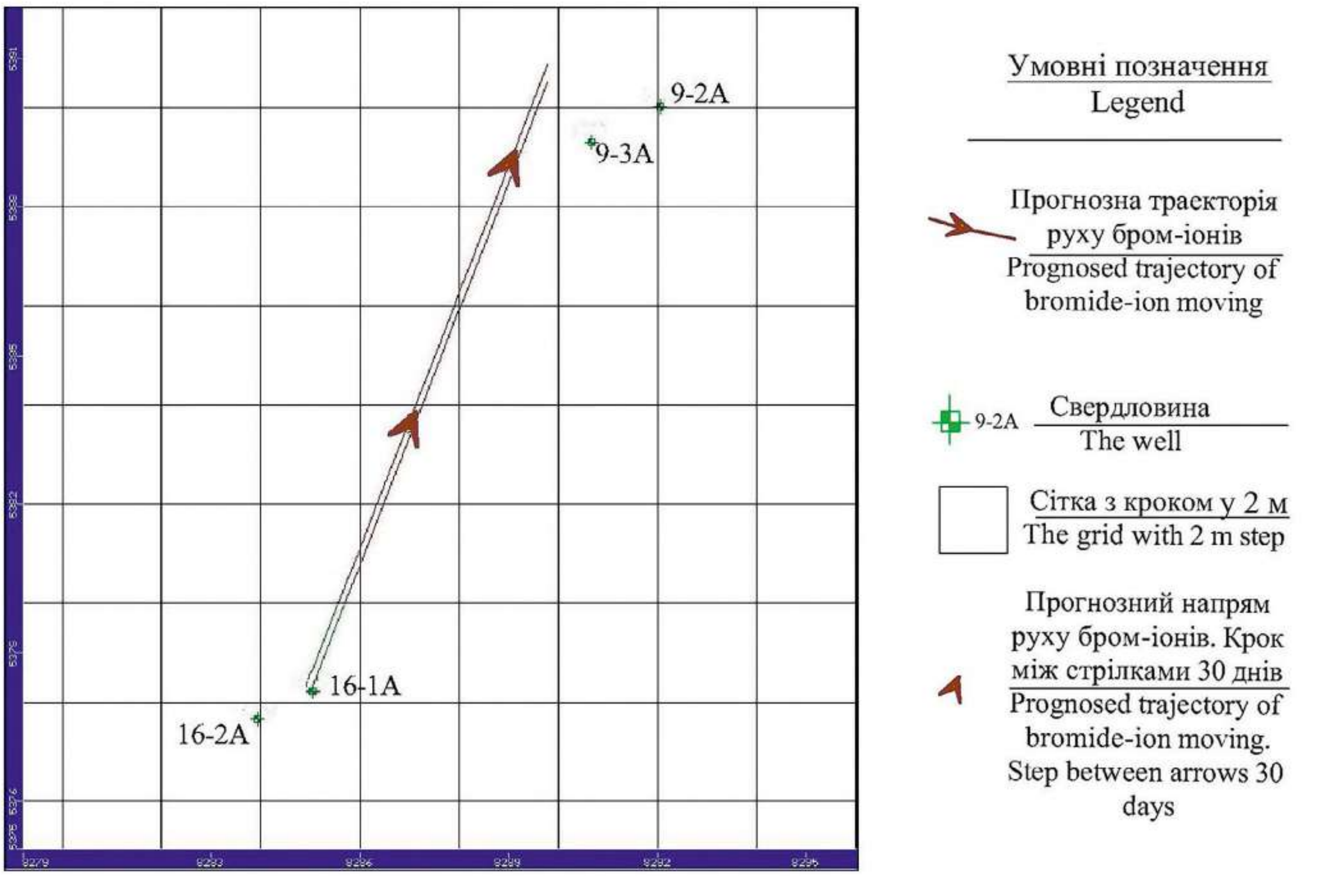

Fig. 3. The prognosed trajectory of motion of sodium bromide (NaBr), which is injected in the model into the well 16-1A at K_f = 30 m/day

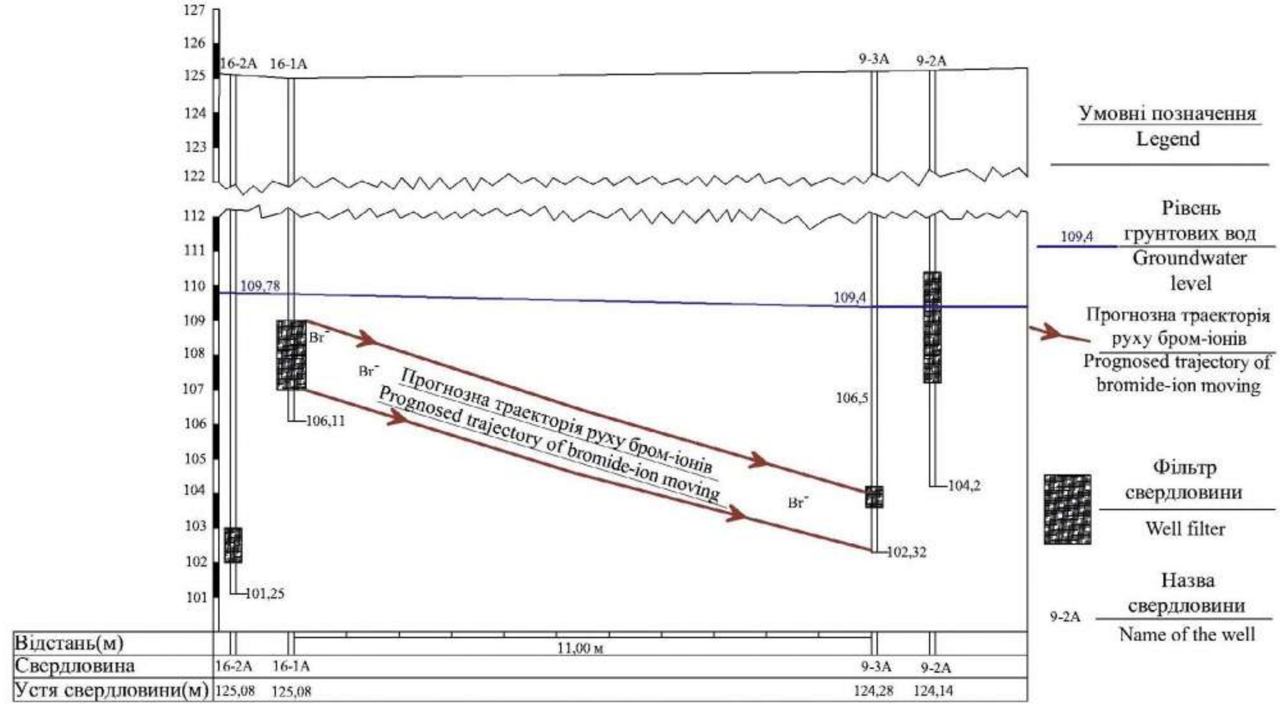

Fig. 4. Profile of the prognosed trajectory of motion of sodium bromide (NaBr), which is injected into the well 16-1A at K_f = 30 m/day

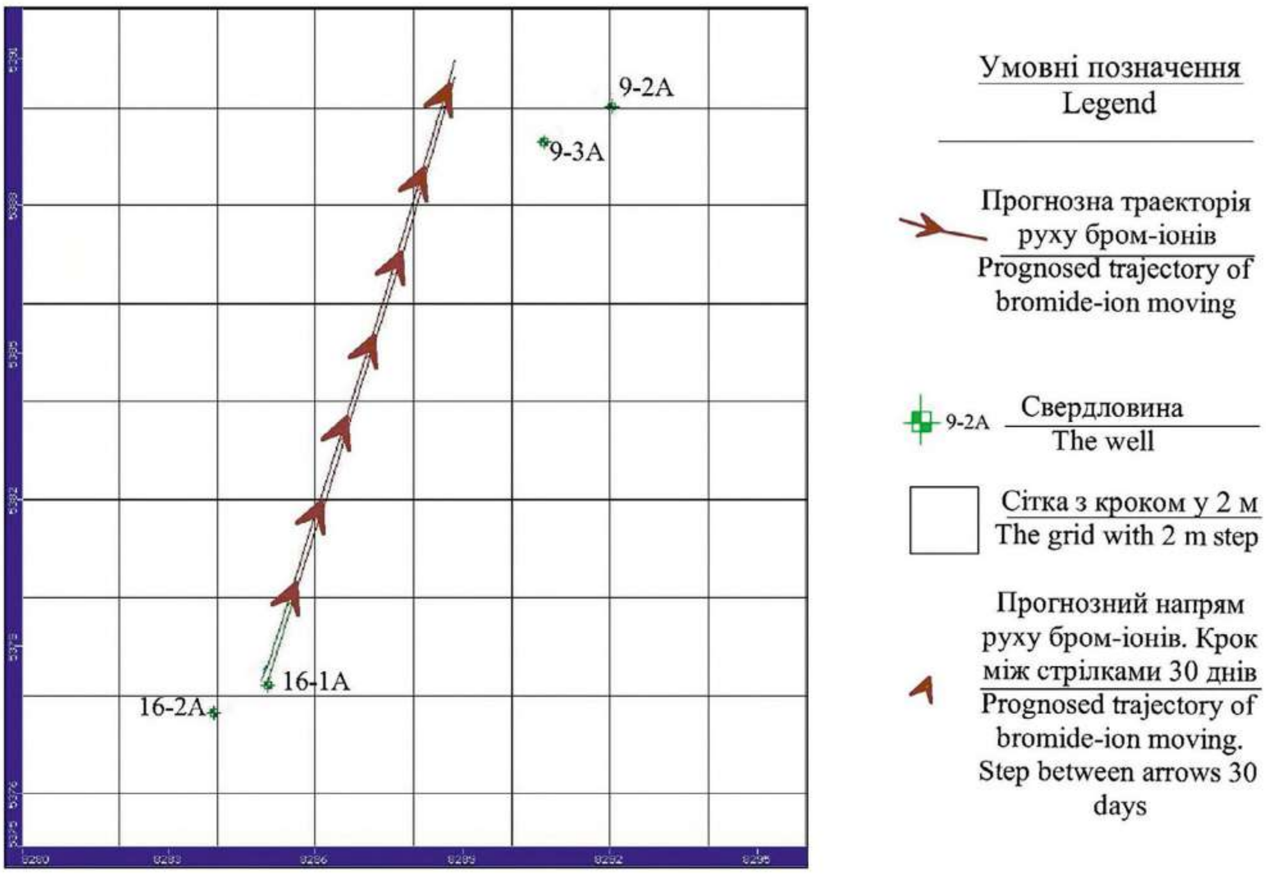

Fig. 5. The prognosed trajectory of the movement of sodium bromide (NaBr) injected into the well 16-1A at K_f = 5 m/day

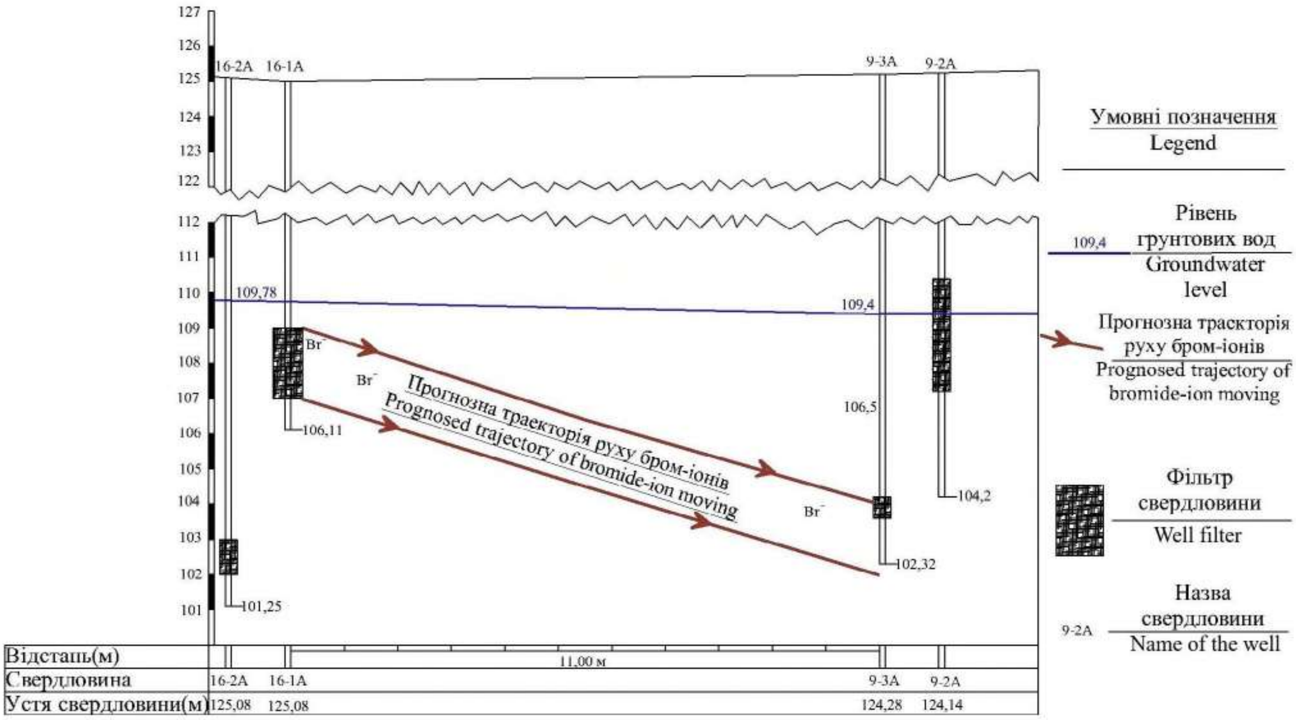

Fig. 6. The profile of the prognosed trajectory of motion of sodium bromide (NaBr), which is injected in the model into the well 16-1A at K_f = 5 m/day

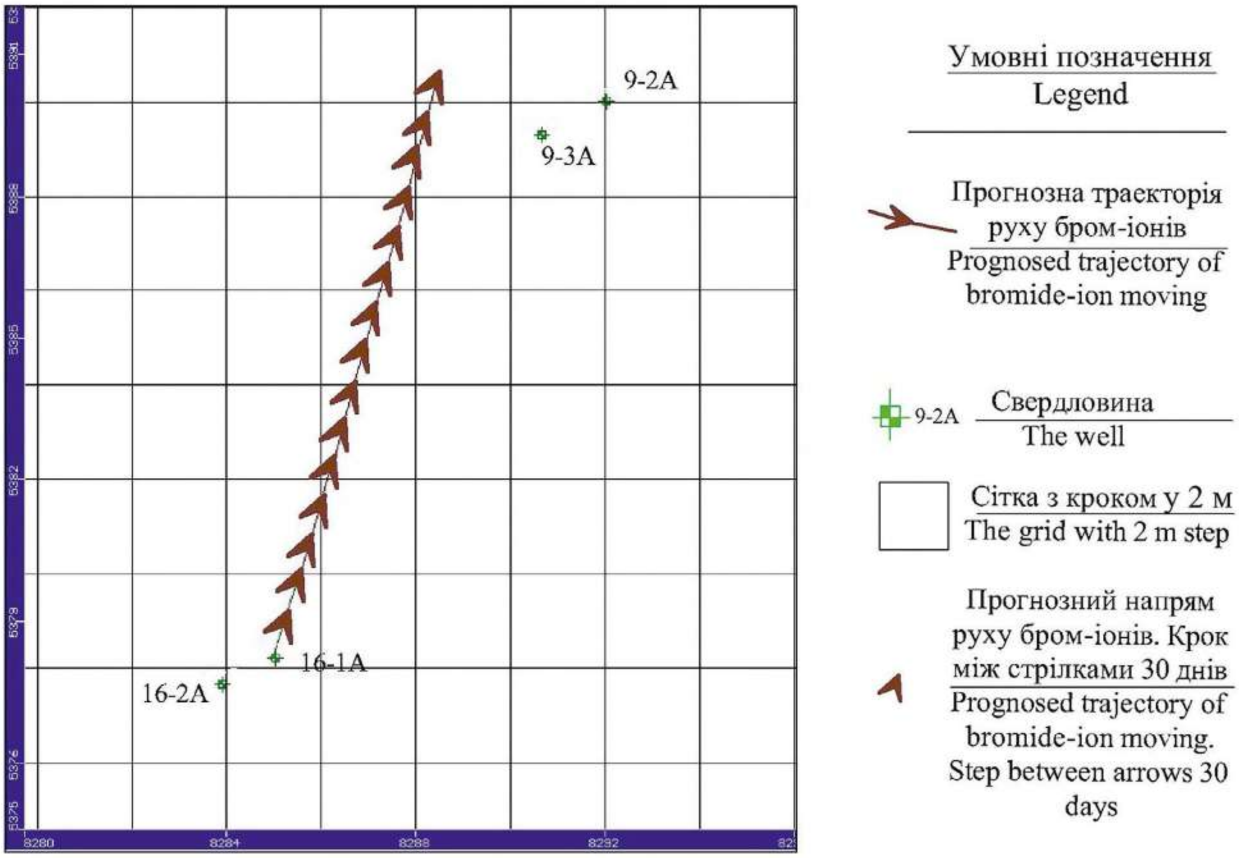

Fig. 7. The prognosed trajectory of the movement of sodium bromide (NaBr) injected into the well 16-1A at K_f = 2.1 m/day

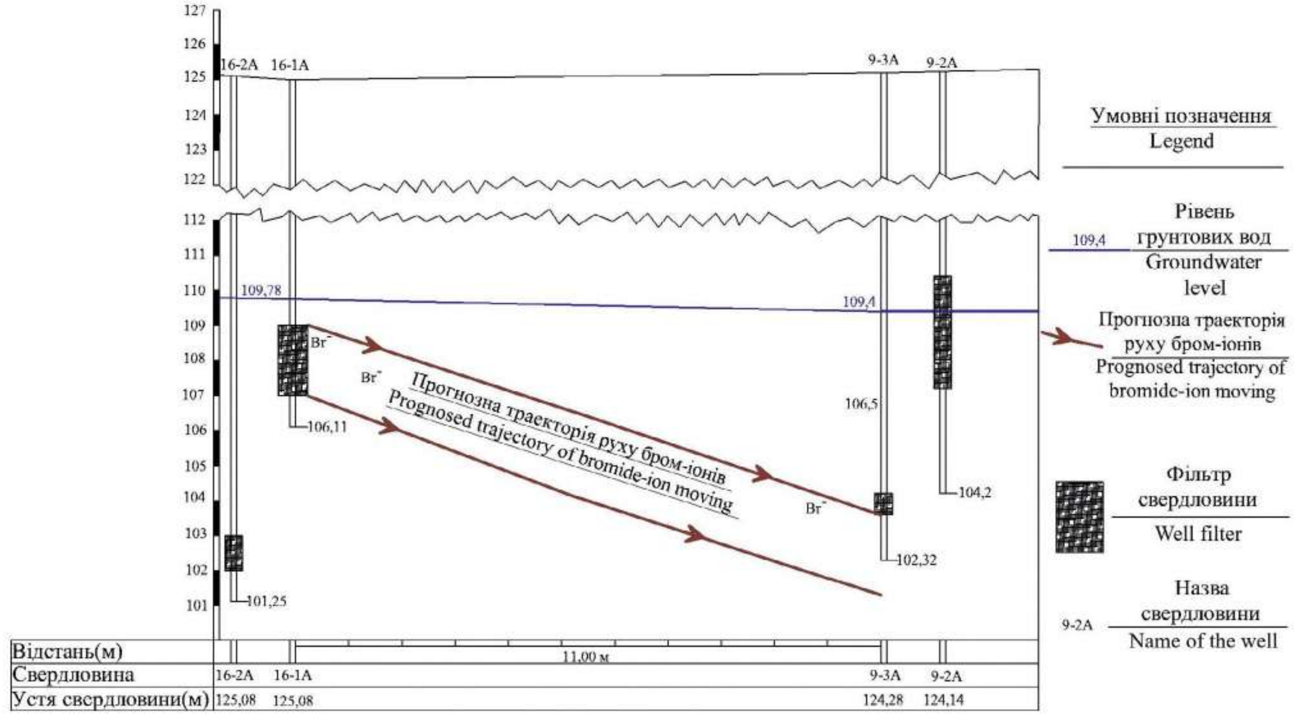

Fig. 8. Profile of the prognosed trajectory of motion of sodium bromide (NaBr) injected into the well 16-1A at K_f = 2.1 m/day

of groundwater flow, were selected for modeling distribution of the bromide-ion. The simulation was performed for three values of the permeability coefficient: 30, 5 and 2.1 m/day.

Option A. The model contains a permeability coefficient of the entire thickness of the alluvial aquifer — 30 m/day. In figs. 3 and 4 the simulated trajectory of the movement of the indicator from well 16-1A in the direction of well 9-3A is showed. The arrows indicate the direction of movement, and the step between the arrows is 30 days. Taking into account the possible error in the simulation, it can be said that the indicator will reach the well 9-3A in 2–2.5 months. However, the migration of the indicator occurs at the top of the aquifer, which is represented by dusty or fine sands, permeability coefficient of which can be much lower.

Option B. The simulation was performed at a filtration coefficient of 5 m/day. In figs. 5 and 6 it is shown that at a filtration coefficient of 5 m/day there is an increase in the time required for the indicator to reach the location of well No. 9-3A. In total, this time is 7 months. There is also a slight (0.3-0.2 m) increase in the depth of passage of the indicator near the well 9-3A.

Option C. Since after the introduction of the indicator on May 24, 2018 in well 16-1A, it was not detected in well 9-3A for 15 months, a simulation of this situation was carried out (figs. 7 and 8).

The simulation of results shows that the indicator will reach the observation well in 15 months at a permeability coefficient of 2.1 m/day. At this, increase of the depth of the indicator passage by another 0.5–0.7 m in relation to the conditions of option A occurs.

In our experiment, monitoring of the propagation of the indicator will continue in the future, but it is clear that the filter coefficient in the depth range of the aquifer 101–110 m may not be more than 2.1 m/day. This correlates well with the permeability coefficients that are characteristic of fine and dusty sands. Further experimentation will clarify the parameters of the aquifer.

Conclusions

The prognosed results of application of a method for determining aquifer parameters by verification of mathematical modeling and actual observations data on indicators or isotopes are demonstrated. The final results will be obtained after reliable fixation of the bromide ion in the samples from the observation well 9-3A.

Acknowledgements

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Методи аналізу гідрогеологічних характеристик водоносних горизонтів в околицях атомних електростанцій з використанням індикаторів

Виконано математичне моделювання міграції з підземними водами індикатора, що не сорбується, по шляху фільтрації ґрунтових вод першого від поверхні алювіально-четвертинного водоносного горизонту. Імітаційне моделювання виконувалось з метою обґрунтування використання ізотопних чи індикаторних методів для отримання достовірних даних про параметри водоносного горизонту, зокрема, коефіцієнта фільтрації. Було використано тривимірну геофільтраційну модель та виконано верифікацію отриманих прогнозних результатів з даними натурних спостережень. Було використано програму Visual Modflow 2011.1 як засіб управління моделлю та редагування даних, які містяться в ній, що дало змогу покращити точність та характеристики моделі, відповідно, збільшивши ефективність математичного моделювання.

Ключові слова: математичне моделювання, підземні води, масоперенос індикатора, бром-іон, коефіцієнт фільтрації, об'єкт «Укриття».

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Методы анализа гидрогеологических характеристик водоносных горизонтов в окрестностях атомных электростанций с использованием индикаторов

Выполнено математическое моделирование миграции с подземными водами несорбируемого индикатора по пути фильтрации грунтовых вод первого от поверхности аллювиально-четвертичного водоносного горизонта. Имитационное моделирование выполнялось с целью обоснования использования изотопных или индикаторных методов для получения достоверных данных о параметрах водоносного горизонта, в частности, коэффициента фильтрации. Была использована трехмерная геофильтрационная модель и выполнена верификация полученных прогнозных результатов с данными натурных наблюдений. Использована программа Visual Modflow 2011.1 как средство управления моделью и редактирования содержащихся в ней данных, что позволило улучшить точность и характеристики модели, соответственно увеличив эффективность математического моделирования.

Ключевые слова: математическое моделирование, подземные воды, массоперенос индикатора, бром-ион, коэффициент фильтрации, объект «Укрытие».

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