Modeling of hydrogeological processes in irrigation areas based on modern programs

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Abstract. This article uses modern modeling systems to assess the impact of intensive irrigation on the state of groundwater and the rocks of the aeration zone. In doing so, existing ideas about aquifer recharge, flow, consumption, and changes in groundwater quality were considered, studying these areas' hydrogeological and reclamation hydrogeological conditions. Groundwater balance analysis was performed based on the results of solving the inverse non-stationary problem for total groundwater deposits. The correspondence of underground water at control points during this period (results of regular observations of Kashkadarya GGS) and underground water seeping into the collector-drainage network in natural and model conditions was observed. According to the research results, renewable (flowing) underground water reserves in the general balance are 15671-2476 = 13195 m³/day, while the indicators of consumption and saturation of underground water reserves are equal to 2476 and 8915 m³/day. It was proved based on the results obtained with sample solutions to the problem, taking into account the rise or fall of the level of underground water in different parts. The article determined that the accumulation of underground water reserves in the region is mainly due to the increase of infiltration in newly developed lands. At the beginning and end of the modeling period, the depth of the groundwater table was shown using maps and marked with numbers.

1 Introduction

To find the parameters of the model, that is, its initial and boundary conditions, in the process of planning natural conditions, the configuration of the water layer, the distribution of its properties - water permeability, migration properties, pressures, concentrations of components, as well as places where there are artificial or natural sources of influence on the water system - groundwater saturation or consumption is determined [1,2].

Following the purpose of the work, when planning the hydrogeological conditions of the area, the possibility of combining several aquifer soils into calculation complexes was taken into account. The natural hydrogeological environment is schematized as a system of

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hydraulically connected horizons separated by low permeability layers, considering existing ideas about aquifer recharge, flow, consumption, and changes in groundwater quality [3].

In doing so, we followed the accepted hydrogeological stratification, the existence of the determined collector-drainage flow and changes in water quality in it, the degree of exploration of the horizon, the availability of sufficient data to determine the parameters of the filtration coefficient, and the level mode [4,5].

At the same time, in addition to the traditional information on the results of filtration experiments and the calculated values of filtration coefficients, the results of petrographic analysis during spatial planning, the results of determining the salinity of rocks on samples taken during exploration, their aqueous and salty-sour properties, chemical analyzes of water, comparative and volume weight determination results, natural moisture, maximum molecular moisture capacity of soil samples were taken into account as much as possible [5–7].

The introduction of GIS in some arid regions and improved water resource management by this system can be an innovation for some regions. But, GIS is just software, and for processing and obtaining solutions, one needs to collect data and enter the analysis results. This program becomes a useful data source for us [8]. Data collection and entry into GIS are also highly diversified and based on many selections. There are many ways and methods to collect data. Consequently, the types of data are numerous [19-20]. Filling GIS with unnecessary information causes the user to be lost in a huge information mess. Therefore, it is essential in research to get only the necessary data and choose the proper analysis software for it [9–11]. Vegetation studies using satellite images to classify the area into classes provide the best results to date. It is possible to monitor the changes in the field by observing the development of the plant and its germination [12].

2 Materials and Methods

MODFLOW's modular three-dimensional finite model of fluid flow in a porous medium MTZDMS was used to perform the specified geological tasks: modular three-dimensional multicomponent mass transfer model RNTZD was used to model the advection, diffusion, and chemical reactions of mixtures in the groundwater system. MODFLOW is provided with a professional graphical user interface, supporting models (programs), and modeling tools, and the graphical interface allows presenting source data in Excel format, ArsGis shapefiles, text sets, Surfer Grid files, and Excel tables.

All modeling results were presented in real geographic coordinates for coordinate binding operations. The used graphic tools made it easy to perform the following possibilities:

- quick change of modeling area and measurement units;
- convenient adjustment of modeling space and boundary conditions (cases);
- when calibrating the model using manual and automated methods;
- when visualizing results when using two- or three-dimensional graphics.

The model represents the aquifer system by a discretized region consisting of a series of nodes and various connected parts. Such a central grid forms the structure of the digital model. In the plan, the model covers the area of the first stage of development of the Karshi desert with its natural boundaries.

The modeled area is 9023 km2; the number of 500 x 500 nodes of one plane equals 250000 nodes. The grid line spacing during modeling is 150x220 meters: in this area, the model is represented by twelve layers for modeling mass transfer processes.

Separated layers are arranged according to the following lithological differences:

1 – layer: loam and sand; rarely sandy soils;

2 - layer: sand, gravel, loamy, rarely loamy soils;

3 – layer: sandstone, gravel, gravelly sand, rarely clay;
4 - layer: siltstone and cemented sandstone in equal parts, sandy soils, clay, loam;
5 – layer: more cemented sandstone, siltstone, less siltstone, sand, gravelly sand.
6 – layer: sandstone, siltstone;
7 – layer: clay, siltstone, siltstone with sandstone;
8 – layer: sandstone and siltstone;
9 – layer: siltstone and sandstone;
10 – layer: sandstone;
11 – layer: siltstone clay, clay;
12 – layer: sandstone.

The expansion of irrigated areas during the development of the Karshi desert is shown in Figure 1. The conformity of natural processes to model processes was determined by comparing the degree between model and natural features.

The correspondence of underground water at control points during this period (results of regular observations of Kashkadarya GGS) and underground water seeping into the collector-drainage network in natural and model conditions was observed.

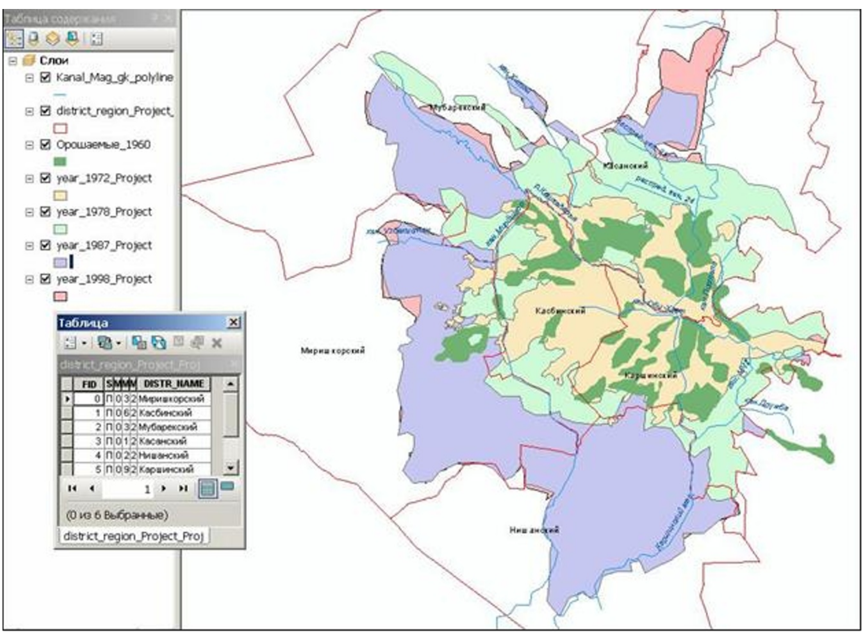

Fig. 1. Expansion of irrigated areas during development of Karshi desert.

The basis of the solution of this option is calibrated to evaluate the balance items in the first approximation and to change the type of boundary conditions.

Calibration of the infiltration model was carried out in 2 variants.

In the first option, the given values of the incoming balance substances are distributed according to the plan according to the given filtering properties of the deposits by the number of sample layers. In this variant, because the shear is represented by a multi-layered layer of varying thickness with large water table gradients, the same volume is added downstream to the underlying model layer, resulting in the model layers being pressurized but not filling the overlying layer.

To remove these limitations, groundwater infiltration was modeled using the BCF-2 package in model version 2, which allows modeling the rise of the groundwater level (water table) to unsaturated model layers from the beginning of irrigation operations. For this, threshold values of wetting (wetting) THRECH are included in the model. The computer code uses this value to determine whether a drained or inactive part can be wetted (active). To maintain the stability of the numerical solution, the following conditions are fulfilled: in the same repetition, the neighboring parts are not wetted as a result of the action of the wetted part; only a variable head section below or horizontally adjacent to a drained section may cause another section to become wet. When using this approach, the correspondence of the model values of the obtained levels with the actual values at the control points was higher. At the same time, this basis has more possibilities for implementing the mass transfer model. Filtration losses from canals were introduced as a "River" boundary condition, i.e., the relationship between the aquifer and the water level in the canal was modeled. In this case, the model parts were given the following values: hydraulic conductivity of the river bed, pressure in the channel, and height of the channel bed base.

Modeling of such relationships for non-stationary conditions includes 5 periods of change (first - January-February; second - March-May; third - June-August; fourth - September-October; fifth - November-December); these values vary from period to period.

In the model, the depth of the channel bed is assumed to be 3.0 meters; the height of the water column is 1.5 meters; the width of the channel is taken according to the topographical basis; the thickness of sediment deposits under the bedrock – 1.0 meters; the filtration coefficient in this area is equal to 0.05 m/day. Finding a solution to a non-stationary problem takes 9000 days (25 years) period, for which 300 attempts (stress periods) were made, the duration of each of which was 30 days.

In solving the problem, infiltration losses from irrigation canals and irrigated fields were corrected. Sometimes, after the filtering parameters were adopted, the correction was not applied to the model. In addition to balance items, inflows, and outflows to neighboring zones by region were determined.

3 Results and Discussion

The amplitudes obtained in the modeling did not exceed the real values. This situation is also confirmed by comparing the model values of groundwater pressures with the actual values at certain points of the regime network recorded during this period.

The above shows that the filtering parameters we adopted and the balance items calculated during the inverse problem-solving process are the correct work done. In particular, the inputs and outputs of the groundwater balance calculated in the model for the entire area can be considered to be close to their actual values (Table 1).

Table 1. Groundwater balance (average annual values) according to results of solving inverse non-stationary problem for total groundwater deposits (for period of 25 years, 1971-1995)

Time		Incoming substances of balance, m^3/k				
Years	Days	Infiltration	Infiltration from channels	Cross-border flows	Build up to capacity	Total
1	360	-1.802	2.796	0.276	0.657	6.532
2	720	-1.802	3.281	0.317	1.034	6.435
3	1080	-4.287	3.038	0.348	1.172	8.843
4	1440	-4.732	2.861	0.373	1.336	9.302
5	1800	-7.289	2.845	0.4	1.485	12.019
6	2160	-8.024	2.818	0.426	1.726	12.995
7	2520	-10.559	2.767	0.454	1.925	15.705
8	2880	-12.698	2.676	0.484	2.256	18.113
9	3240	-12.068	2.977	0.514	2.439	17.999
10	3600	-11.241	2.678	0.545	2.794	17.258

Continuation table of № 1.

Time		Incoming substances of balance, m^3/k				
Years	Days	Infiltration	Infiltration from channels	Cross-border flows	Build up to capacity	Total
11	3960	-10.915	2.54	0.573	2.996	17.025
12	4320	-10.396	2.383	0.603	3.093	16.476
13	4680	-11.008	2.297	0.632	3.206	17.143
14	5040	11.478	1.976	0.661	3.498	17.614
15	5400	-12.589	2.153	0.689	3.756	19.187
16	5760	-10.522	2.669	0.721	3.215	17.127
17	6120	-11.457	2.274	0.733	3.444	17.908
18	6480	-11.442	2.18	0.751	3.592	17.966
19	3840	-10.435	2.317	0.777	3.553	17.082
20	7200	-11.861	2.232	0.804	3.76	18.657
21	7560	-10.638	2.988	0.828	2.009	16.459
22	7920	-12.919	2.858	0.833	1.862	18.473
23	8280	-13.772	2.781	0.861	2.316	19.731
24	8640	-12.467	2.804	0.93	2.515	18.716
25	9000	-11.001	2.837	0.928	2.251	17.018
Average for 25 years		9.896	2.681	0.618	2.476	15.671

Continuation table of № 1.

Consumable (output) substances of balance, m^3/k					
Flow in collector drainage system	Drainage into river	Evaporation	Outflows across borders	Decrease along border line	Total
0.617	0.558	0.087	0.338	4.932	6.532
0.744	0.578	0.097	0.286	4.73	6.435
1.008	0.597	0.102	0.253	6.881	8.846
1.428	0.616	0.109	0.375	6.775	9.302
1.756	0.619	0.114	0.356	9.173	12.019
2.247	0.648	0.122	0.342	9.636	12.995
2.685	0.677	0.131	0.33	11.882	15.704
3.534	0.743	0.158	0.324	13.353	18.112
4.2	0.803	0.185	0.382	12.429	17.998
4.54	0.798	0.2	0.315	11.405	17.257
4.975	0.833	0.223	0.309	10.686	17.025
5.094	0.858	0.226	0.3	9.996	16.475
5.421	0.899	0.271	0.293	10.258	17.142
5.788	0.905	0.367	0.221	10.332	17.613
6.406	0.958	0.551	0.28	10.991	19.186
6.087	0.965	0.64	0.336	9.097	17.126
6.484	0.985	0.746	0.313	9.379	17.902
6.757	1.031	0.832	0.324	9.022	17.965
6.663	1.025	0.854	0.355	8.185	17.081
7.143	1.031	0.944	0.377	9.161	18.687
7.379	1.157	0.99	0.853	6.078	16.458
7.861	1.193	1.012	0.856	7.55	18.472
8.469	1.254	1.074	0.854	8.079	19.73
8.319	1.232	1.26	0.845	7.058	18.715
7.929	1.207	0.232	0.84	5.809	17.018
4.941	0.887	0.501	0.426	8.915	15.671

Balance sheet items: infiltration (filling) from irrigated fields – 9.896 m^3/day, filtering through channels (river flow) – 2.681 m3/day, infiltration (filling) from irrigated fields – 0.618 m^3/day, storage capacity – 2.476 m^3/day. The average for the total 25-year modeling period is 15.671 m^3/day.

Outgoing (consumable) items of the balance sheet: Flowing into the collector drainage system (drainage) – 4.941 m^3/day, Drainage of the Kashkadarya River (flow of the river) – 0.871 m^3/day, evaporation – 0.501 m^3/day, flows across the boundary – 0.426 m^3/day, consumption of underground water – 8.915 m^3/day. The average for the total 25-year period was 15.670 m^3/day.

In our opinion, renewable (flowing) underground water reserves in the total balance are 15.671-2.476 = 13.195 m^3/day, where the indicators of consumption and saturation of underground water reserves are equal to 2.476 and 8.915 m^3/day. These numbers are obtained by model solutions of the problem, considering the rise or fall of the groundwater level in different parts of the area during the modeling time itself.

3 years after the beginning of land development, the groundwater became saturated, and as a result, the flow in the collector drainage system began to increase. During the next 12 years (5,400 days of modeling), it increased from 1,157 to 6.944 m3/day, then for the next 5 years, it remained at 7.0 m3/day, and for the last 5 years at 8.102 m3/day. The amount of evaporation began to change 6 years after the beginning of land development.

In the next 7 years, it increased from 0.116 to 0.289 m3/day, and then, in 4 years, it reached 0.752 m3/day, gradually increasing to 1.273 m3/day and remaining unchanged in the last 2 years. As a result of this distribution of the components of the groundwater balance, the groundwater level in the irrigated areas has increased intensively. According to the modeling results, the conditions of hydroisogypsum for layers 2 and 3 are given at the beginning and end of the modeling period.

Except for the banks of the Kashkadarya River, the model layer 2, defined before the beginning of the modeling period, is mostly drained. The underground flow is formed as a result of the absorption of surface water and is directed parallel to the river (Fig. 2). At the end of the modeling period, the flow area expanded significantly, covering the entire second flat terrace of the Kashkadarya River, except for the developed areas of the accumulative-delta and denudation-accumulation plain and structural-denudation highlands (Fig. 2). Before the start of modeling, the area saturated with groundwater in layer 3 was significantly larger than in the second layer (Fig. 3a). At the end of the modeling, it slightly expanded due to the saturation of the areas within the accumulative-delta plane and the eolian-deflation plane (Fig. 3b).

The depth of the groundwater table at the beginning and end of the modeling period is shown in the figures.

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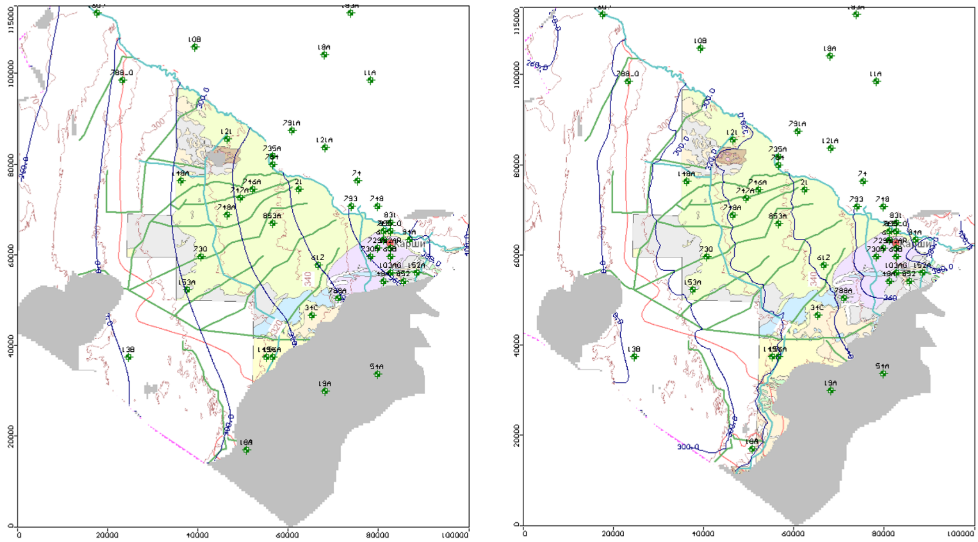
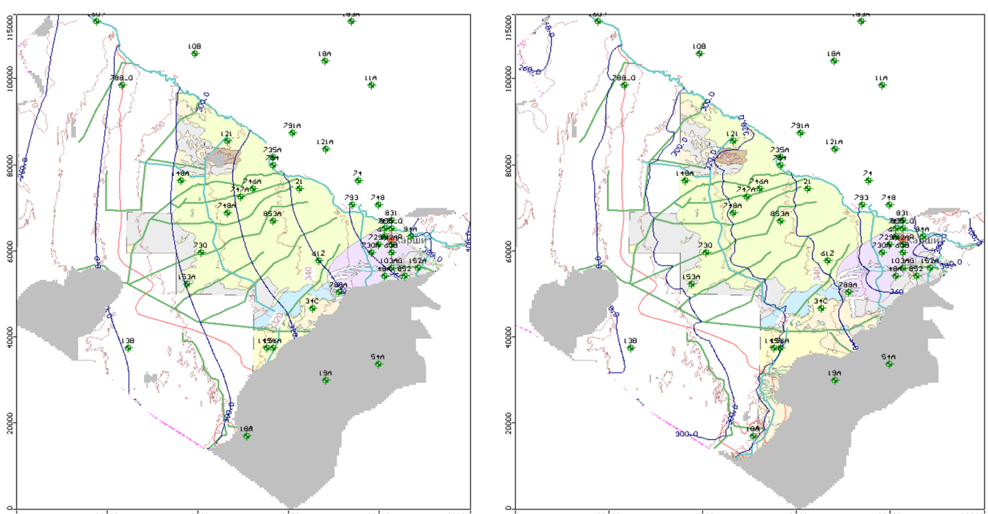


a) *b)*

- drained part of model layer

Fig. 2. Location of hydroisogypsums (model layer 2) at beginning (a) and at end (b) of modeling period.

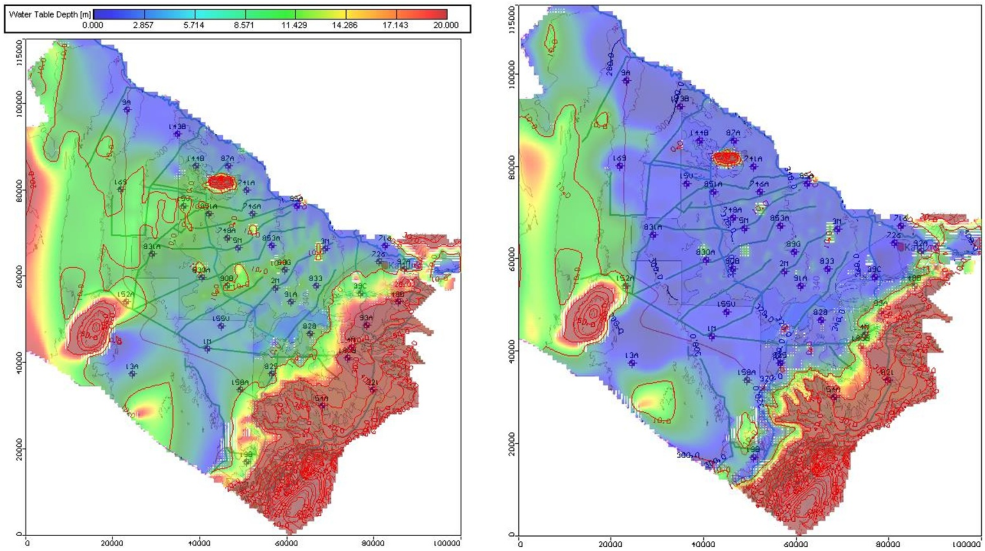


a) *b)*

- drained part of model layer

Fig. 3. Location of hydroisogypsums (model layer 3) at beginning (a) and end (b) of modeling period.

At the beginning of the modeling period, a very negative situation was observed in the accumulative-deltaic and eolian-deflationary-accumulative plains (Fig. 4a). Areas with a depth of 8 to 12 meters were separated from the areas with a groundwater level of 2 to 5 meters.



a) *b)*

Fig. 4. Water table depth at beginning (a) and end (b) of modeling period

In the modeling process, the areas where the groundwater level is at a great depth have completely disappeared. In the western part, in the area of the eolian-deflationary-accumulative plain, the underground water level was determined to be 8-15 meters, and the areas with a depth of more than 20 meters were lost.

At the boundary of the denudation-accumulation plane, there are places where the depth of the groundwater level is more than 20 meters, and the depth changes sharply from 3 meters to 20 meters.

4 Conclusions and Recommendations

The model created based on modern methods divides the Karshi desert region is terrain into structural denudation, denudation accumulative, accumulative delta, eolian deflationary-accumulative genetic categories. As a result of the development carried out in the desert area, the water management conditions of the area have changed significantly, the amount of water allocated to irrigated areas is from 400 It has grown to 2100 million m³. Irrigated areas also expanded steadily from 1970 to 1995, and this process continues today. It has been determined that the development of gray lands in the Nishon, Mirishkor, Kasbi, and Mubarak districts caused the expansion of such areas. In the modeling process, indicators of the rise or fall of the groundwater level in different parts of the territory were considered. During the entire period, it was determined that the accumulation of the capacity reserves of groundwater in the area was mainly due to increased infiltration in the newly developed lands. The accumulation process continued more intensively in certain periods. In the first 10 years, the storage capacity increased from 3,696 to 11,097 m³/day. Over the next 25 years, accumulation ranged from 9.99 to 7,235 m³/day, decreasing to 3,558 m³/day at the end of the modeling period.

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