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## Geoinformational Modeling And Estimations Of Formation Groundwater Factors In Changed Ecological And Hydrogeological Conditions (On Example Of The Aydar-Arnasay Lake System, Uzbekistan)

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### ABSTRACT

In the researches has considered the principles of constructing a geo-information system based on modern GIS technologies, justified the boundary and initial conditions, developed a regional mathematical model of the Aydar-Arnasay Lake System (AALS) territory and implemented it on the basis of modern modeling programs Vizual Modflow for analyzing and assessing the dynamics of AALS development and its relationship with the components of the geological environment. The factors of groundwater formation are given and evaluated taking into account changes in water management conditions, their current state is highlighted and recommendations are given on substantiating the tasks of groundwater monitoring in these territories.

### KEY WORDS

Mathematical modeling, geofiltration process, boundary conditions, geographic information system, influence of the lake system, data bank, groundwater label, groundwater monitoring, water resources management.

### INTRODUCTION

Water, as one of the main components of the natural environment, is critical for the maintenance of life on Earth. The problems of resources and water quality, their decisive role for the economy and functioning of ecosystems in the 21st century have acquired particular relevance, both in Central Asian countries and the World as a whole. One of the two main rivers

of the Aral Sea basin, both rivers is transboundary, the Syrdarya and Amudarya rivers of irrigation and drinking water resources and a resource of hydropower [2, 7, 13]. The Republics of Kyrgyzstan and Tajikistan are located in the upper reaches, Uzbekistan in the middle and Kazakhstan in the lower reaches of the river. The flow of the Syrdarya river was

regulated mainly for the needs of irrigation. For this, several reservoirs were built in the upper and middle reaches of the river, as well as the Toktogul, Kairakkum and Chordarya and other reservoirs [5].

As a result of water releases from the Toktogul reservoir in the winter 1993-2019. In the amount of 37.61 km<sup>3</sup>, the water level in the Aidar-Arnasay lake system (AALS) increased by 10.9 m. from 236 m (1991) to 245.9 (2006), to 246.8 (2018). ), the length of the AALS increased by 250 km, the width up to 15 km. in the winter, the drawdown of the reservoir led to the flooding of part of the land in the middle reaches and the discharge of water into the Arnasai depression, to date, more than 40 km<sup>3</sup> of water has accumulated in the Arnasai depression. This reservoir has become a source of destabilization of the natural environment over a large area. At the same time, the amount of water available for irrigation of agricultural crops has sharply decreased. there was a shortage of irrigation water in 2000 - 2018 in the Syrdarya and Jizzakh regions, in central Fergana of Uzbekistan and Southern Kazakhstan [2, 5, 7]. AALS is one of the most important wintering grounds for waterfowl in Uzbekistan and Central Asia. In winter, from 60 to 120 thousand birds are concentrated here. In recent years, due to insufficient water release, the volume of water and the area of the water area are significantly reduced, the salt content on the lands of the drained territory has increased.

The government of Uzbekistan has developed an action plan to ensure the stability of the environmental situation and the effective use of the AALS for the period 2008 - 2020. however, the further fate of the lake system, the possibility of stabilizing the situation, entirely depends on the operation of the Toktogul reservoir. In 2008, the AALS, as an important natural site, was included in the Ramsar list of wetlands of international importance.

#### THE AIM AND GOALS OF THE OBJECT OF RESEARCH

Due to its geographic and climatic characteristics, the water resources and soils of Uzbekistan are strongly influenced by negative environmental factors. Land degradation is the

most important factor leading to declining land productivity, crop yields and declining livestock productivity. Land degradation is also due to their flooding, which prompted the need to study the impact of AALS on the hydrogeological conditions of the northern part of the Mirzachul area. AALS was formed in the northern part of the deserts in the high-water year 1969 as a result of the discharge of 21 km<sup>3</sup> of water from the Chardara reservoir into Lake Aydar [2, 9]. The data presented indicate the influence of AALS on the hydrogeological conditions of the northern part of the Mirzachul deserts and require their study on the basis of 3D visualizations with modern geoinformation systems (GIS) and the method of mathematical modeling, and further development of environmental protection measures.

The purpose of this research is to develop environmental protection measures based on the assessment and forecast of the impact of the AALS on the environment under various scenarios of changes in the water-economic situation in the northern part of the Mirzachul area using 3D modeling and based on GIS.

To study the process of changing the hydrodynamic (and hydrochemical) regime of groundwater in the AALS and the hungry steppe, it is necessary to envisage the following set of works. Research objectives of the proposed work:

Collecting geodata, analyzing and assessing the dynamics of the AALS development and changes in the components of the geological environment;

Creation of a geographic information system AALS based on ArcGIS;

Development of a mathematical geofiltration model for AALS under various scenarios of changes in the water management environment;

Development of 3D modeling and the performance of numerous computational experiments to calculate the geometric characteristics of the AALS;

Development of recommendations for the creation of automated monitoring of the relationship between surface and ground waters of the AALS;

Development of a general concept of environmental protection measures for the AALS. In the collection of geodata (Fig. 1.), in the geological structure of the AALS, Paleozoic rocks take part, forming a large asymmetric anticline with a row broken by multiphase granodiorite intrusion in the south and southwest [9]. In the rest of the territory, on the surface, continental Neogene-Quaternary deposits of significant thickness are widely developed, which are of the greatest interest and determine the conditions for the formation of modern hydrogeological and engineering-geological processes.

At present, the total area of the reservoir is about 3400 km<sup>2</sup>, the volume is 40 km<sup>3</sup>. The research of the State Enterprise “Institute HYDROINGEO” [2, 14] established the influence of the AALS groundwater on the adjacent territories. After the discharge of water from the Chardara reservoir in 1969 into the lake. Aydar the area of the lake system reached 200 km<sup>2</sup>, and the water salinity varied from 2 to 4 g/l. Since 1993, in connection with the exploitation of the Chardara reservoir, water releases have resumed, and the highest absolute level marks were traced from March to June and a subsequent decline until the end of the year (the energy regime of the reservoir operation). Water releases in March amounted to 1390 million m<sup>3</sup>, in April 242 million m<sup>3</sup> in June 1019 million m<sup>3</sup>, after which they were absent until the end of the year. In subsequent years, there was a constant rise in the water level in the system of lakes with the discharge of surface runoff in the winter months and the first months of spring.

The Arnasai basin is generally a regional drain for the Pliocene-Quaternary aquifer of the deserts [2, 14], but the AALS modified the hydrodynamic structure due to the backwater of the upper zone of the water supply by: a) for groundwater -6-8 km, (hydro chemical measuring point -N<sup>o</sup>77); b) for sub-pressure -10-15 km (hydro chemical measuring point -N<sup>o</sup>.86); c) for pressure water-

35 km. (Hydro-seismic well N<sup>o</sup>.3814, Syrdarya). Here the pressure water level rose by 1.7 m (+6.4 m -1993; +8.1 m -2016). Located in the northern part of the deserts research object within the Republic of Uzbekistan, where the degradation of water and land resources is significant due to a change in the water situation in the region.

On the other hand, it is often possible to obtain a characteristic of the process on the basis of a computational experiment, while checking the accuracy of the results obtained. Moreover, now modeling is increasingly used to study hydrological and hydrogeological processes, the very physical essence of which becomes clear only as a result of geoinformation modeling [1, 3, 6].

### MATHEMATICAL MODELS BASED ON MODERN GEOINFORMATION SYSTEMS (GIS)

In the first case, we mean the relationship between surface and groundwater, and in the second, about geofiltration modeling, which can be considered a kind of mathematical modeling, i.e., numerical modeling is the study of differential equations of the process on a computer (in this last version, modeling is reduced to, ultimately, to the solution of systems of algebraic quasilinear equations of parabolic type with the process under study), the latter includes the geoinformation:

$$\left\{ \begin{array}{l} \mu \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left( kh \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( kh \frac{\partial h}{\partial y} \right) - k_0 \frac{H-h}{H} \pm f \\ \mu^* \frac{\partial H}{\partial n} = \frac{\partial}{\partial x} \left( T \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left( T \frac{\partial H}{\partial y} \right) + k_0 \frac{H-h}{H} - Q_{\text{крб}} \end{array} \right. \quad (1)$$

with initial and boundary conditions,

$$\left. \begin{array}{l} h(x,y,t) = \varphi(x,y); \quad (x,y) \in G, \quad t = t_0 \\ H(x,y,t) = \varphi_1(x,y); \quad (x,y) \in G, \quad t = t_0 \end{array} \right\}, \quad (2)$$

$$\left. \begin{array}{l} h(x,y,t) = \psi(x,y); \quad (x,y) \in \Gamma, \quad t > t_0 \\ H(x,y,t) = \psi_1(x,y); \quad (x,y) \in \Gamma_1, \quad t > t_0 \end{array} \right\}, \quad (3)$$

$$-kh \frac{\partial h}{\partial n} = q_{\Gamma}(t), \quad (x,y) \in \Gamma_2, \quad t > t_0 \quad (4)$$

$$-kh \frac{\partial h}{\partial n} = \gamma(h_a - H), \quad (x,y) \in \tilde{A}_3, \quad t > t_0 \quad (5)$$

where  $\mu$  and  $\mu^*$  - coefficient of free and elastic water loss of the aquifer and confined horizon (dimensionless value);  $h=h(x, y, t)$  and  $H=H(x, y, t)$  - groundwater level from the confining

surface to the free surface and the confined horizon,  $m$ ;  $k$  and  $T$  – geofiltration coefficient and water permeability,  $m/day$ ;  $f(x, y, t) = Q_{\epsilon} - Q_{\delta} - Q_{ucn}$  – infiltration recharge of groundwater, consists of a part of atmospheric precipitation and irrigation water (filtration from a river, canals) seeping into the aquifer. Here:  $Q_{ucn}$  – evaporation from the groundwater level has an aerial character and is a function of spatial and temporal coordinates;  $Q_{\epsilon}$  – in the case of a canal, a river that feeds groundwater;  $Q_{\delta}$  – in case of drainage, drains groundwater;  $Q_{ckb}$  – wells consumption;  $Q_{ckb} = Q(t) \delta(x-x_0, y-y_0) t > t_0$ ;  $\delta$  – the Dirac function;

$$\delta = \begin{cases} 1/\Delta x^2 & x = x_0, \quad y = y_0 \\ 0, & x \neq x_0, \quad y \neq y_0 \end{cases},$$

$\varphi(x, y), \varphi_1(x, y)$  – Specified and sufficiently smooth function in  $G$ ;  $\psi(x, y), \psi_1(x, y)$  – given functions on the boundary  $\Gamma - \Gamma_3$ ;  $q_r(t)$  – known functions if the boundary section is impenetrable or passes through streamlines;  $x, y$  – spatial and  $t$  – time coordinates,  $t_0$  – initial calculation time.

Let us investigate the change in the ground water level (GWL), that is, we solve the equation (1) - (5) in the region  $G$ ; this area will be called the filtration area and we will assume that it is bounded by a sufficiently smooth curve  $\Gamma_i$ , in the cut it is a continuous line. The water exchange of watercourses in the aquifer can be represented as follows [16]): when feeding from a river or

canal:  $Q_p = k(h_p - h/\Phi)$ ; when draining ground water:  $Q_{\delta} = k(h_{\delta} - h/\Phi)$ ;  $Q_p$  – filtration losses from the river;  $Q_{\delta}$  – drainage value of groundwater;  $\Phi$  – filtration resistance of streams;  $h_p$  – water level in a river or water level in a canal;  $h_{\delta}$  – water level in the drain; pressurized groundwater is fed mainly from underground inflow, is discharged by ascending filtration into the upper layer and underground outflow into the proluvial plain or sediments of river valleys.

Equations (1) - (5) form the basis of the mathematical model of groundwater filtration in intermountain river valleys. Currently, the geographic information system has received wide development with the introduction of modeling and automation into it - with the help of which many tasks are solved at the present stage. From the beginning, GIS has been used for collecting, checking, integrating and analyzing information, with a large number of groups of operations required for systematization and schematization of geodata [3, 6]. Some operations were characterized by the interconnection of manual and computer-based methods of analyzing maps, diagrams and others. The most important function of GIS as a tool for analyzing information, solving the problem of collecting and preparing, developing a structure (Fig. 2-3), building base and thematic maps, as well as tasks related to spatial analysis of geodata and modeling. In the process of preparing the initial data for the mathematical model, produced.



Figure: 1. A fragment of the collection of factual material on a GIS basis. (in the legend: 1- geological well; 2- hydroisogyps; 3- hydrographic network; 4- relief; 5- hydrogeological section)

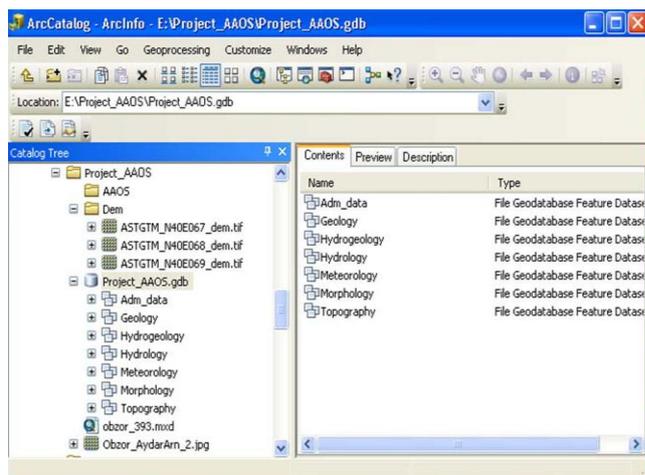


Figure: 2. Geobase structures.

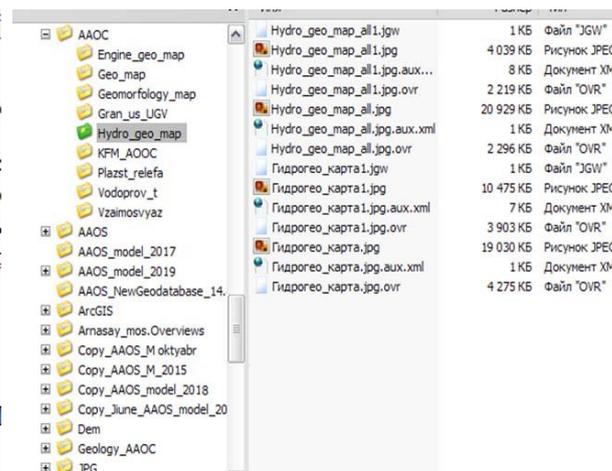


Figure: 3. A fragment of hydrogeological data

research on transforming various types of spatial hydrogeological data (for example, from isolines of a topographic map to a GIS relief model, wells location, hydrological network, etc.); storage and sampling of factual material, operational reserves of groundwater and their use, water balance of AALS, organization of spatial data for their analysis, editing of data manipulation and their assessment (Fig. 4-5). Analysis and mapping of the relief on a large scale showed that in the area under consideration, according to the genetic and geometrical features, there are sloping, drainless channel-

like depression - Arnasai and the Tuzkan lacustrine plain. Mountain heights reach 220-1100 m above sea level, the relative elevations of watersheds over valley channels usually do not exceed 100-200 m and rarely reach 400 m. Steep and rocky watersheds and slopes are developed here in the same way as in the middle mountains, in the area of distribution of limestone metamorphic schists of the Upper Silurian, Middle Devonian and Carboniferous. The following relief forms are distinguished here [2, 14]:

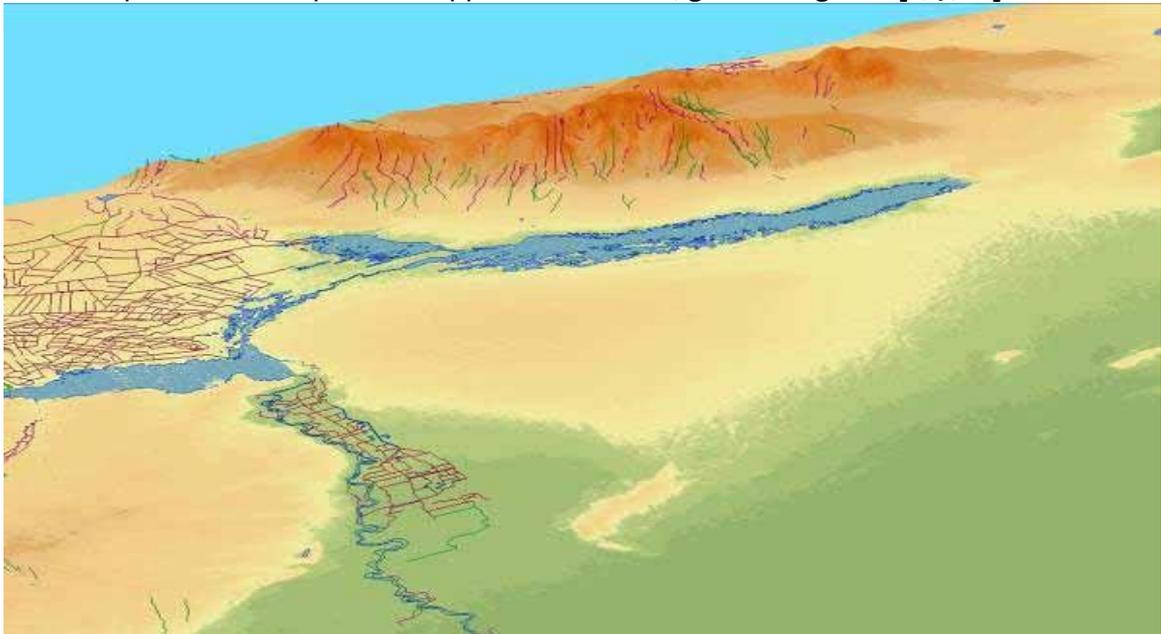
- a) Low mountains, sharply braced with rocky steep slopes;

- b) Low mountains with smooth steep slopes;
- c) Weakly dissected with steep slopes;
- d) With smooth gentle slopes.

The low-mountain, sharply dissected relief is developed in the southern and southwestern parts of the Nurata ridge. The maximum absolute marks are 1000-1100 m.

Hydrogeological conditions of the area. The described area includes the Northern Nurata foothill groundwater field, which is located at the junction of the Syrdarya artesian basin and the Nurata-Turkestan group of fractured water basins, as well as partly the Dustlik and East Kyzylkum groundwater fields. [9]. The aquiferous complex of alluvial-proluvial Upper

Quaternary deposits ( $apQ_{III}$ ) is distributed in the north of the described territory, occupying a significant area of the foothill plain. He is the first from the surface. Water-bearing rocks are represented by an alternating stratum of pebbles, sands, crushed stone, covered from the surface by loams and sandy loams. The thickness of loams and sandy loams increases from south to north and amounts to 0.5-20 m. The deposits of the described complex are underlain in the central part of the area by mid-Quaternary, and in the west by Miocene in the east by Pliocene deposits. With increasing distance from the mountains in the section, loams, sandy loams begin to predominate, and pebbles and gravel are gradually replaced by sands, gross and gravel [2, 9, 14].



**Figure 4. Three-dimensional elevation model AALS based on GIS.**

The thickness of the aquifer varies from 30 to 80 m. The general direction of movement of groundwater flows from south to north, towards the Aydar spill. The slopes of the groundwater table decrease from the foothills to the plain from 0.008 to 0.002. The

depth of the groundwater level from the foothills towards the Aydar spill is from 83 m to 1.0 m. The depth of the groundwater level varies from 116 m near the mountains to 1-2 m at the Aidar spill [2,14].

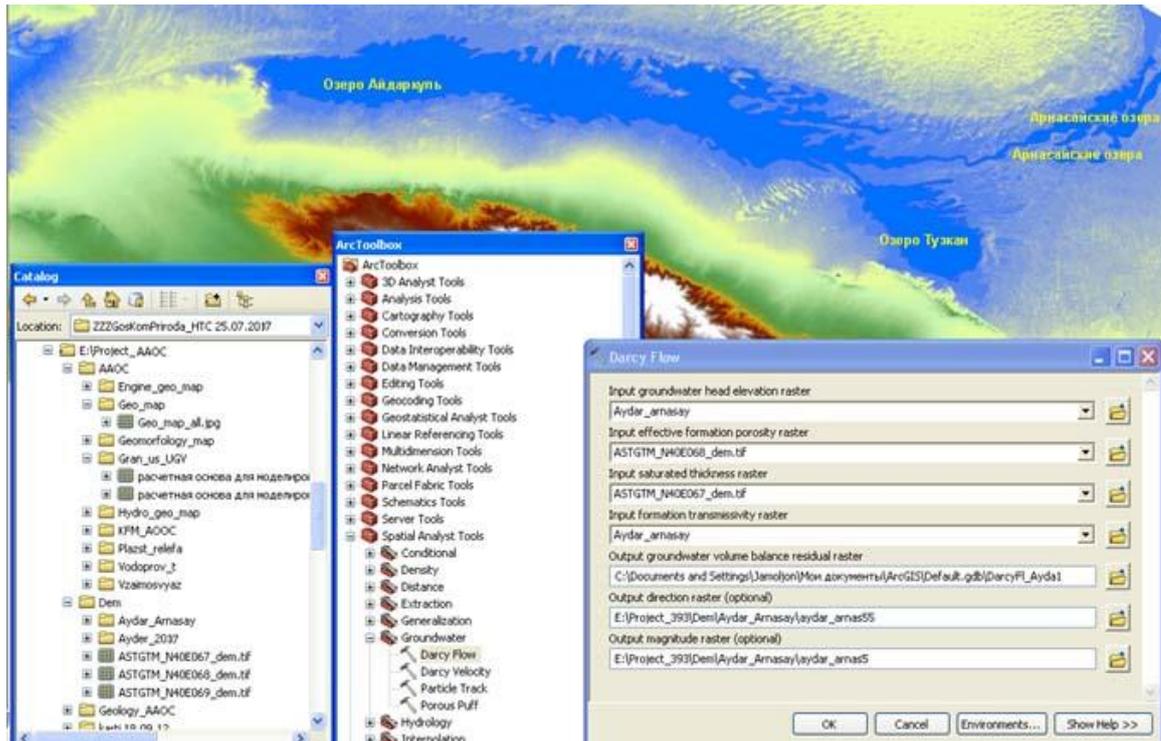


Figure: 5. Spatial analysis of geodata based on GIS

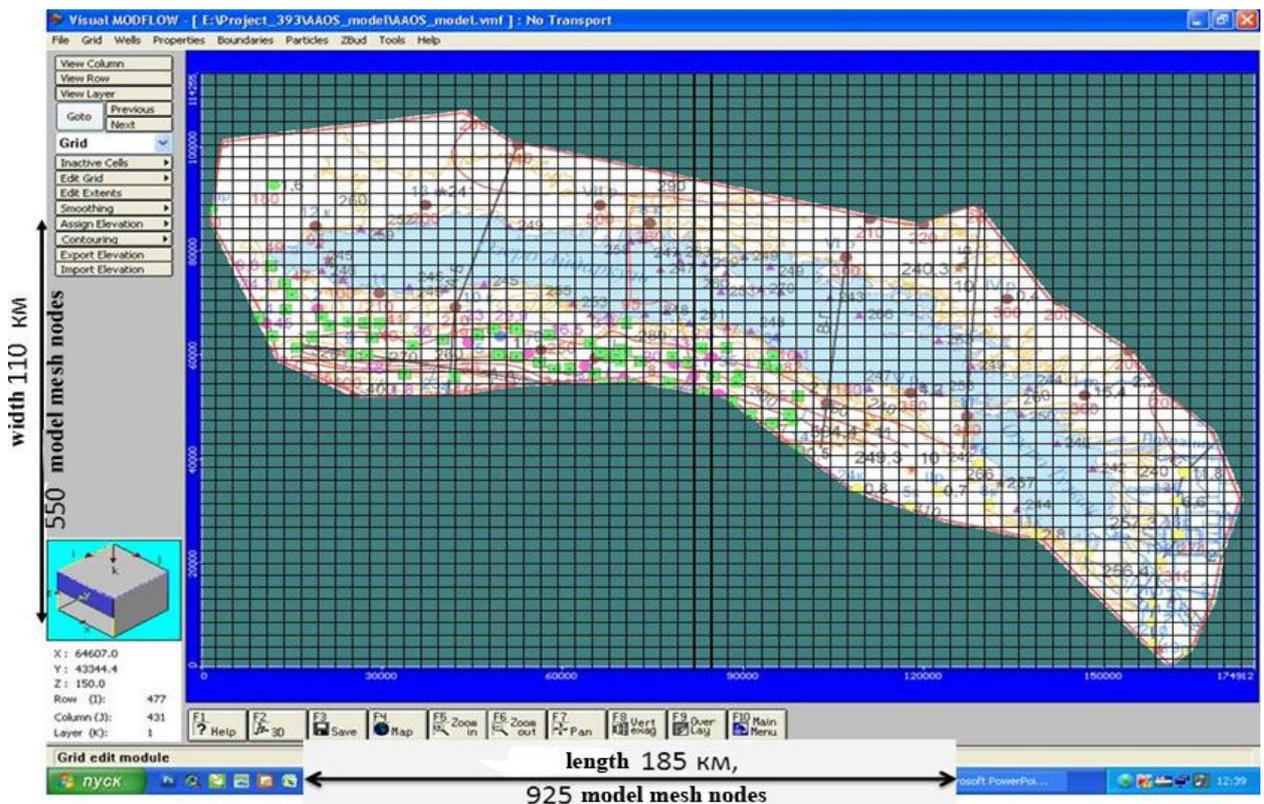


Figure: 6. Grid model of AALS based on Visual Modflow

Water balance for 2009, m<sup>3</sup>/day, negative expenditure items exceed the incoming - 1360226 m<sup>3</sup>/day. Based on the assessment of

the AALS water surface areas based on satellite images and other factual materials,

a long-term morphometric characteristic of AALS was compiled for the period from 1994 to 2016 inclusive (see Fig. 7).

**VISUALIZATION OF SIMULATION RESULTS**

On the basis of GIS from satellite images, the area of reservoirs and wetland areas for September 2011 are determined in Fig. 7. The areas of the water surface of the AALS reservoirs have been estimated (Table №.1). In the AALS, in addition to the discharge of surface water from the Chardara reservoir, there is a drainage runoff from the collector-drainage network of the territories of the Syrdarya and Jizzakh regions, and the discharge through the hydro mode stations, Pogranichny, Akbulak collectors and the Kly river collector accounts for 97% of the drainage flow [2, 14].

These values constitute one of the income items of the balance sheet for which the

parameters of the model are calculated. Average years flow rates of collectors  $m^3 / s$  for the period from 2000 to 2016 and intra-annual distribution of runoff among collectors feeding the AALS. In assessing the natural resources of groundwater, the materials considered indicate (Fig. 8-9) that flooding occurs along the southern coast of the AALS, i.e. in the northeastern regions of Lake Tuzkan and Aidar, which correlates well with the results of the simulation model (Fig. 8-10) of the balance of releases from the Chardara reservoir and observations by automated devices developed by the authors for well No. 3H set in the northeastern part of Lake Tuzkan

From the chronological graph for this well it can be seen that during the second half of 2014 and the first half of 2015 there was a plain, mainly a zone of medium flooding, and from 07.09.2014 to 07.09.2015 the flooding confirms the modeling results

**Assessment of the water surface areas of the AALS reservoirs**

Table №1

Reservoirs	Water surface area, ha	Wetland area, ha
Chardara reservoir	26186,31	4630,32
Arnasay lake system	19724,04	10739,34
System of lakes Aydarkul and Tuzkan	314817,48	28196,37
<b>Total</b>	<b>360727,83</b>	<b>43566,03</b>

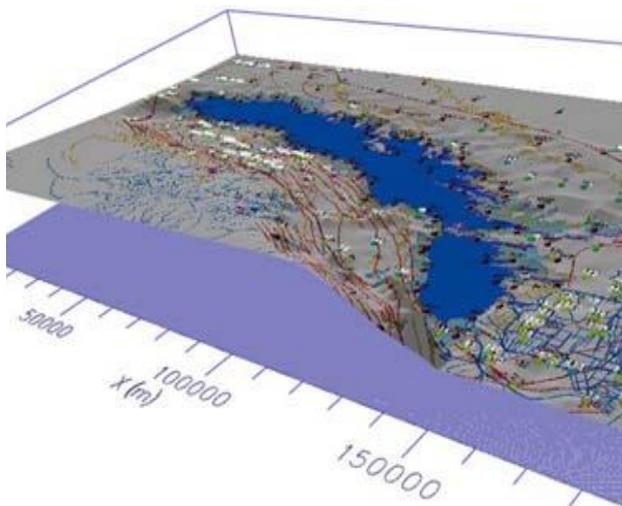


Figure 7. General 3D view of the AAO on the model.

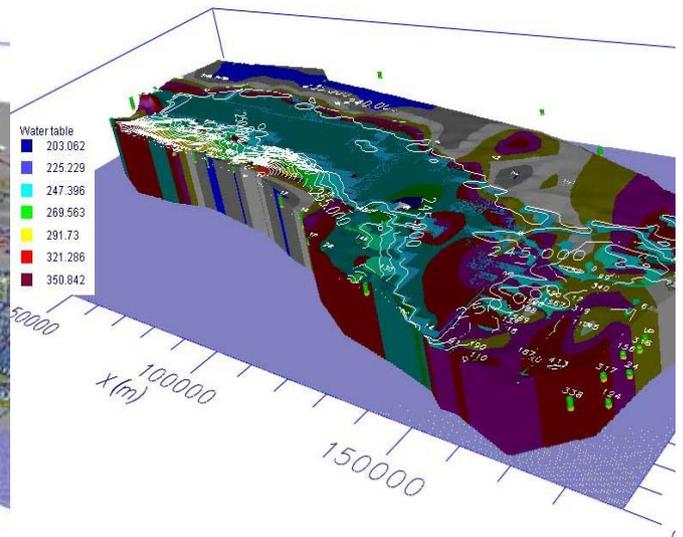
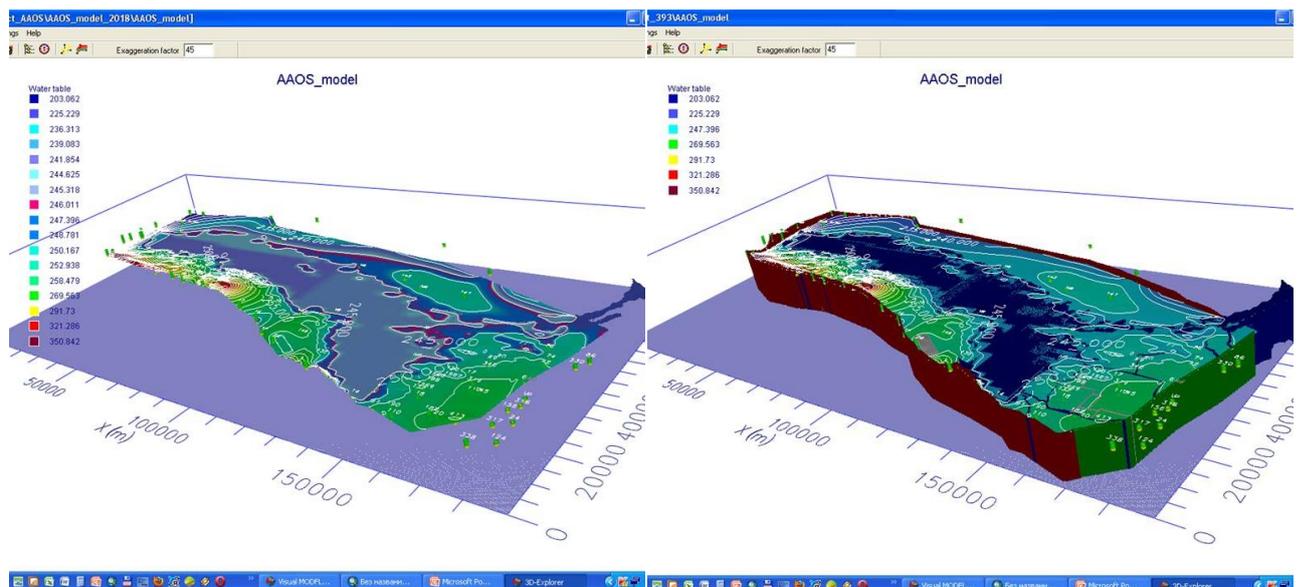


Figure 8. 3D view with filtration parameters



**Figure 9. Carrying out computational experiments for 3D modeling.**

**Figure 10. 3D modeling with hydroisogypsum mark.**

From the material considered, it follows that in the territory where the AALS is located, a stable flooding zone had already formed by 1992, the size and depth of groundwater in which varies depending on the size of the flooded areas (Fig. 9-10). Flooded zones are represented by groundwater and confined waters with a slight difference in elevation due to specific reasons.

### CONCLUSION

A GIS-based information and reference system AALS was created and a local local database (LDB) was developed based on the results of previously performed studies. A mathematical geofiltration model of groundwater flow based on ModFlow, adjacent to the territory of influence of AALS, has been developed. Formed digital cartographic spatio-temporal qualitative and quantitative indicators of groundwater, processing of space images, mapping work, numerical and analytical calculations.

GIS is also used to sample and generate measurement data distributed over the watershed, which is then used as input to digital hydrological models. In the future, the integration of hydrological models into GIS programs, together with the processing of observations at stations and posts in real time, can solve many problems of hydrological forecasting.

In some territories, there is a redistribution of pressures and groundwater levels in time. For example, in bush 61ap in 1992, the groundwater levels exceeded the level of confined waters, and in 2003, after renewed discharges from the Chardara reservoir into the lake system, the confined waters rose above the ground waters. The water levels in the area are slightly lower than in the reservoir;

- Therefore, there should be no losses or replenishment with mineralized water.
- According to the operation service, the change in the water level in the reservoir in October-January, when there is no inflow and withdrawal of water from the bowl, is about 1 cm / month (at a level of  $\Delta 246.5-247$  m). If we assume that with a filled reservoir the losses will even double, the amount of losses for filtration, taking into account the additional capacity, will be 38-40 million  $m^3$ /year
- The surface area of the Arnasay reservoir with a capacity of 950 million  $m^3$  at the mark  $\Delta 249.5$  m will be 231, 8  $km^2$ , at the mark  $\Delta 245$  m (dead volume): it is 168.32  $km^2$ .
- The actual losses for evaporation will depend on the regime of emptying the reservoir, which in turn depends on the actual water supply of irrigated lands and water shortages for irrigation.

- After deducting all losses, an average of 437-440 million m<sup>3</sup>/year can be used for irrigation purposes.

The research results will be used to improve the ecological, in particular, the hydrogeological situation in the northern part of the Hungry Steppe of Uzbekistan. It is widely used by organizations of the State Committee on Nature protection RUz,

Hydromet RUz, Lend Kadastr and The Ministry of Agriculture and Water Resources of Uzbekistan, private farmers of the Association of water users, research institutes and Syrdarya, Jizzakh and Navain hydrogeological regime stations, research and design institutes of Uzbekistan, as well as the South Kazakhstan Hydrogeological and Meliorative Expedition.

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