RESULTS OF A NUMERICAL STUDY OF CURRENTS IN THE VICINITY OF A DAMLESS WATER INTAKE

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Abstract

The problem of sustainable water intake in the conditions of significant fluctuations of flow rates and water level is significantly exacerbated by erosion of river beds. A typical example of such conditions is the damless water intake into the Karshi Main Canal (KMC) where the main flow of the Amudarya river continuously moves along a wide floodplain, changing the direction of currents. As a result, it is very difficult to withdraw the required volume of water from the river to the canal especially during dry years due to the high instability of currents at the entrance to the canal. Within the framework of the performed numerical studies, the conditions of flow spreading (vectors of depth-average velocities) were studied in the specific time intervals and crossings in the water intake area. The results of the study confirmed that without special engineering measures it is practically impossible to assure stable water diversion into the canal. As a preliminary solution of the problem, it was proposed to make a trench along the right bank in the area of water intake into the canal.

Key words: damless water intake, Karshi main canal, downstream, Froude number, flow rate

TЎҒОНСИЗ СУВНИ ОЛИШ МИНТАҚАСИДА ОҚИМЛАРНИ СОН ЕЧИМЛИ ТАДЌИҚОТЛАР НАТИЖАЛАРИ

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Аннотация

Оким ва су ҳужмасида натикасида дарё ўзани ювилиши туфайли улардан сув олиш сезиларли даража да куйинчаради. Бунга оддий мисол сифатида – Қарши магистрал каналга тўғонсиз суви олиш бўлиб, бунда Амударё оқимдаги доимий равиша қишлоқ қўярдаги ҳаракатланиб, оқим ўйнанганлигин ўзгартиради. Натикада, зарур бўлган сув ҳажмини дарёдан каналга ўкчалириш куйинчаради, айниқса, сув кам бўлган ўйлаарда каналга оқимни кириси бекар бўлади. Уткилган рақамли тадқиқотлар натикасида оқимнинг тарқалиш шароитлари (тезлик векторлари ўртача чуқурлик) бўлаб мажлум вақт оралда ва сув олиш сув олиш жойларида ўрганилди. Тадқиқот натикалари махсус муҳандислик чораларнинг каналга барқарор суви олишни таъминлашнинг иложи йўқлигини тасдиқлади. Муаммонинг дастлабки ечими чораларисиз каналга суви олиш жойида қишлоқ қўярдаги ўйни натикасида куриш ва қўярдаги бўлаб, бунда Амударё каналга оқимни кириси таъминлашдан қўятганлиги тасдиқлади. Муаммонинг дастлабки ечими чораларисиз каналга суви олиш жойида қишлоқ қўярдаги ўйнанганлигин ўзгартиради.

Таъч сўзлар: тўғонсиз суви олиш, Қарши магистрал канал, пастки бьеф, оқим тезлиги

РЕЗУЛЬТАТЫ ЧИСЛЕННОГО ИССЛЕДОВАНИЯ ТЕЧЕНИЙ В РАЙОНЕ БЕСПЛОТИННОГО ВОДОЗАБОРА

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Аннотация

Проблема устойчивого водозабора в условиях значительных колебаний расхода и уровня воды значительно усугубляется разъездами уровней реки. Типичный пример таких условий - Бесплотинный водозабор в Каршинском магистральном канале (КМК), где основной поток реки Амударья непрерывно движется по широкой пойме, изменяя направление текущих. В результате очень сложно отвести необходимый объем воды из реки в канал, особенно в засушливые годы из-за высокой нестабильности течений на входе в канал. В рамках проведенных численных исследований изучены условия растекания потока (векторы средних глубинных скоростей) на конкретных временных интервалах и переходах в районе водозабора. Результаты исследования подтвердили, что без специальных инженерных мероприятий обеспечить стабильный водозабор в канал практически невозможно. В качестве предварительного решения проблемы предлагалось сделать траншею по правому берегу в районе водозабора в канал.

Ключевые слова: бесплотинный водозабор, Каршинский магистральный канал, число Фруда, скорость потока.
Methods. Topographic maps [15], satellite acquisitions [2,17], as well as materials of topographic survey and data of measurements of the cross sections of the Amudarya river [1] were used to build up a mathematical model of the relief of the river bed which will be used for hydrodynamical modelling of the currents in the area of the damless water intake in the canal. Maps were transformed into a uniform metric Gauss-Kruger coordinate system [12] in the ARC Map program and were used to determine the modelling area, tie materials to the terrain, determine some of the morphological characteristics of the river. Measurements of the river cross-sections near the water intake, carried out in 1986 and 2018 [1], were digitized and, thus, received coordinate references. While building a mathematical model of the terrain for hydrodynamic modelling, all materials were collected in a single coordinate metric system and linked into a single model. As a result, a rectangular computational grid was determined and built, covering the modelling area.

In many cases, the flow of water in canals and river beds of a complex shape could be described by the two-dimensional Saint-Venant’s equations which are the laws of conservation of mass and momentum of water flow [4, 5, 6, 7, 8, 10, 16, 18]. The conditions for application of the equations, including the issues related to the setting up of the boundary conditions are well grounded, for example, in [3, 12, 8, 10, 13, 16, 18].

The scope of these studies was limited to calm water currents with Froude numbers less than one (Fr < 1). In this case, the following boundary conditions to close the Saint-Venant’s equations recommended in [3, 10, 12, 16, 13, 19, 20, 21, 22, 23, 24] were used:

1. On the impenetrable boundary: on the river bank, the dam-one boundary condition is required. The condition: normal component of the velocity vector is equal to zero (thus, the normal component of the specific flow rate vector is equal to zero).

2. At the entrance boundary, at which the flow enters the modelling area, two boundary conditions are required. The first of them, as a rule, is the setting up a normal boundary of the velocity value or the specific water consumption. However, it is possible (hypothetically) to set up a water level. In the second case, there is the need to set up the value of water velocity tangential to the boundary. This speed is often set to zero.

3. At the outlet boundary, at which the flow leaves the region, one boundary condition is required. Usually this is the water level or specific water discharge.

In many cases, situations in which the boundary conditions are known reliably enough are rare.

In many cases, it is necessary to select a fragment of the modelling area and set up boundary conditions based on general considerations [3] if modelling the entire stream is not possible. This approach was used in this paper.

Results and Discussion. This paper presents the results of a series of calculations of the current field in the river bed during floods and low-water conditions.

Two-dimensional Saint-Venant’s equations were solved numerically using an explicit finite-difference scheme described in [10]. In order to study the flow regime in the river channel the following conditions were set: an initial water level in the area, a water flow rate at the entrance to the area, a water flow rate of water withdrawn from the river to the canal and the curve of the relationship between the flow rate and the water level at the exit from the area. After that, calculations were carried out until the time when the flow regime is stabilized and the sum of the flow rate withdrawn from the river to the canal and the flow rate at the exit from the area will become equal to the flow rate of water at the entrance to the area.

The results of the initial calculations of the current field were carried out based on the available topographic data (Fig.1).

Based on the analysis of the results of the initial calculations a finite-difference grid was prepared. The steps along the length of the grid in the water intake zone were two times shorter than at a long distance from it. The calculation results using this grid are shown in Fig. 2.

In numerical experiments, the parameters of the curve of the relationship between the flow rate and the water level at the exit from the area considered and the roughness coefficient (n) varied widely. The results obtained showed that even if n = 0 in the zone downstream of the water intake, the water level at the water intake did not change. It is most likely that the stream was getting turbulent (Fr ≈ 1) in the zone before the expansion of the river channel. Therefore, the hydraulic characteristics of the flow above this section are practically independent of the flow regime in the downstream part of the river bed. The turbulence of the flow is the consequence of the narrowing of the channel due to the dumping of slurry (sediment) by dredgers at the right bank and natural sediment deposition at the left bank. Taking these facts into account, it was decided to restrict the modelling of a section of the river bed in the immediate vicinity of the water intake. Analysis of the calculation results showed that at n = 0.021 the level regime in the water intake zone is the most similar to the one actually observed.

The performed numerical experiments allowed to make the conclusion that it is impossible to ensure the required water flow rate into the canal without carrying out engineering measures. Therefore, in all the numerical experiments carried out, it was assumed that dredging works were carried out along the right bank in the form of a trench. The trench has a width of 10 to 20 m and its bottom is 5.5 m lower than the natural river bottom.

In order to obtain a detailed picture of the currents in the water intake zone, two different computational grids were used, namely: (a) uniform grid with steps ΔX = 1.5 m and ΔY = 20 m, as well as (b) an uneven grid with smaller steps ΔX = 7.5 m ΔY = 10 m near the water intake. Fig. 3. shows vectors of velocities in the water intake zone at the flow rate in the river Q = 300 m³/s and at the withdrawal into the channel Q = 50 m³/s.

It can be seen from the figure that the flow rates above the trench are significantly lower than without it. Apparently, with a sufficient length of the trench, even small deposits can be almost completely intercepted in it.

![Fig.1. Flood velocity field (Q = 6800 m³/s, n = 0.021)](image1)

![Fig.2. Flood velocity field (Q = 6800 m³/s, n = 0.021). Option with a large distance from the exit boundary of the computational domain from the water intake)](image2)
It was shown in [1] that the volumetric sediment concentration $S$ in Amudarya river is well reflected by the Begnold's formula:

$$
S = \frac{\rho_p}{\rho_w} \left( \frac{\lambda^V}{2gh} \right)^{0.13} \frac{V^2}{W^{1/2}}
$$

(1)

where: $\rho_p$ and $\rho_w$ - density of sediment mineral and water, respectively, $V$ - water velocity, $W$ - settling velocity, $h$ - depth, $\phi$ - sediments' internal friction angle, $n$ - river bed'roughness coefficient, $I$ - bottom's slope. River bed hydraulic friction coefficient:

$$
\lambda = \frac{2gh^2}{h^3}
$$

(2)

Estimates of sediment concentration made using (1), at $I=0, \phi=15^\circ, W=1.32 \times 10^{-2} m/s$, which corresponds to fine sand with diameter $d=0.15 mm$ ([14], Table 1) are given in the table below.

Thus, a trench about 5.5 m deep can potentially reduce sediment concentration by three orders of magnitude. Of course, such a decrease in sediment concentration occurs over a sufficiently long deposition path Additional research will be carried out to determine it.

![Fig.3. Low water velocity field ($Q = 300 m^3/s$, $Q_0 = 50 m^2/s$, $n = 0.021$). Uniform grid.](image)

### Table 1

| Option | $h$, m | $V_1$, m/s | $Q_0$, $m^3/s$ | $S$ |
|--------|--------|-------------|----------------|-----|
| Without engineering measures | 1 | 1.6 | 1.21 | 1.22 | $2.77 \times 10^4$ |
| With trench | 6.7 | 0.45 | 0.34 | 0.35 | $5.01 \times 10^6$ |

**Conclusions.** A system of initial data adapted to the conditions of the water intake zone of the Karshi Main Canal was prepared. Mathematical model to study water flows in the vicinity of the intake into the Karshi Main Canal was built. It is based on the two-dimensional equations of Saint-Venant and available limited initial data. The adapted software allowed to carry out numerical hydraulic experiments and analyse the results obtained in the form of a flow pattern. Fragments of the area adjacent to the water intake into the Karshi Main Canal were digitized as part of studies of phenomena of various scales. Digitized fragments of the area were used to simulate currents during low-water periods and during high floods. Analysis of the initial data and the results of numerical studies allowed to conclude that in the narrowing section of flow downstream of the water intake into the Karshi Main Canal the flow reaches critical velocities during high floods with $F_r = 1$. Analysis of the results of numerical experiments allowed to conclude that carrying out engineering measures required to insure the withdraw the required water volume to the Karshi Main Canal in the low-water period. However, insufficient initial data does not allow to definitely state that that implementation of certain measures with a high degree of probability will ensure the stable flow of the required volumes of water into the canal. Nevertheless, carrying out dredging works along the right bank of the river will ensure a certain stability of the water flow into the canal. Dredging options considered in the paper with the establishment of trenches 20 m wide and 5.5 m deep and long enough can be effective sediment interception measures.

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