Water distribution on machine canals trace cascade of pumping stations

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Abstract. The article describes the cascades of the main pumping stations in the Commonwealth of the Independent States and Uzbekistan, it is noted that, despite their complexity and many problems, there is almost no information in the literature and very little research has been done. The main goal of the article is to schematically and theoretically show the results of field studies in a system of cascades of pumping stations Amu-Zang-Bobotag in the Surkhandarya region.

1. Introduction

If technically impossible to elevate water with one pumping station, or when elevating head is too high, the water will be elevated through the pumping stations cascade \([1, 2]\). For using the efficiency of all pump stations installed in the cascade of pumping stations, typically front of each pump station is designed with small capacity (small reservoirs) regulating the quantity of water. If not regulatory capacity, synchronous pump stations are not automatically provided. As a result of this arrangement, water consumption on all sections of the machine canal is constant, some sections should not be flooded.

When the canals have regulatory capacities, all pump stations operate automatically. In this case, however, each pumping station must be operated individually because may be variable water consumption along the transferring trace \([3, 4, 5, 6, 7, 9]\).

Currently, there is insufficient water in the countries of the world, transfer of water abundant areas to another region, water is being transferred from one region to another. Water is supplied by pumping stations on the higher position of the source as well as far distance situated areas, Cascade of pump stations is used to elevate water for thousands of kilometers to a certain head. Below we consider some great projects elevated water with huge pump stations cascade.

2. Methods

Analysis of the area of Karshi pumping stations, which is one of the cascades of ground pumping stations in the country, through maps and schemes of irrigation systems, as well as the development of a method of water distribution, is a way to study this work.

3. Materials

**Siberian-Central Asian machine canal.** It was planned in 1980 years. The first project of the “Siberian river” water transfer project to Central Asia is 2550 km, cascade of eight pumping stations 1150 m\(^3\)/h and head of over 110 m, it is planned to install each pump aggregates’ water consumption \(Q = 100 \div 120 \text{ m}^3/\text{h}\). Text with footnotes to references.

**Irtysh-Karaganda pumping stations cascade.** In the 1974 year, for the purpose to supply water Kazakhstan’s Karaganda city and industry from Irtysh River to Karaganda have a distance of 514 km, with a machine canal deliver water 76 m\(^3\)/h, 22 pumping stations with a head of 421 m cascade of pump stations launched\([10, 11]\).
The pumping stations cascade of the Karshi main canal. One of the most unique cascades of Karshi pumping stations in the world, built and launched in 1973. Cascade of these pump stations is 392 thousand hectares in the Kashkadarya region of the Republic of Uzbekistan also supplies water to 10,000 hectares of the Republic of Turkmenistan. Six pump station cascades are located in the Republic of Turkmenistan[12] (Figure 3).

The seven cascade pump stations are located 78.4 km of distance from the Amu Darya River to the Talimarjan reservoir, \(Q=175 \div 195\) m\(^3\)/h elevate water to more than 132 m. In the pump stations, cascades are installed 45 pump units. Their water consumption from \(Q=16.6\) m\(^3\)/s to 39.0 m\(^3\)/s. Because Amudaryo river water is muddy and sandy, parts of pump units very fast happened abrasive deterioration. (Picture 4)

Jizzakh pumping stations cascade. The cascade of Jizzakh pumping stations built and launched in 1972-1975, it was planned to take water through the 938 + 50 pickup facility on the South Mirzachul canal and elevate up to 174.9 m above through the cascade of four pump stations at a distance of 22.8 km. At the present only three upgrades to the cascade pump stations have been launched, to distance 17.1 km and head of 113.68 m with cascades of three pump stations (1st PS - \(Q=137.8\) m\(^3\)/h; 2nd PS - \(Q=90.0\) m\(^3\)/h; 3rd PS - \(Q = 44.47\) m\(^3\)/h) water is elevated (Figure 5).

![Figure 1](image1.png)

Figure 1. Turning Siberian rivers to Central Asia, (a) plan of main channel trace (b) cascade of pumping stations. a- Scheme of the tract from the Belogorevsk water intake facility to the Tuyamuyun reservoir in the Amudarya;

Amu Zang pump stations cascade. The Amu Zang pump station is in the Surkhandarya region, consists of the Amu Zang-1, Amu Zang-2, and Babatog pumping stations, which elevate water to 181.200 hectares of irrigation fields.
The Amu Zang-1 pumping station takes water 25 m$^3$/s from the Amudarya river and elevates the head to 36.40 meters; Amu Zang-2 pumping station supplies 128 m$^3$/sec to head of 43 m and the Babatag pumping station elevates up to 79.0 m and supplies 32.0 m$^3$/sec. (Picture 6)

Based on the information from the Amu Surkhoon Irrigation Systems Basin Administration, there are 76 water intake points along the Amu Zang-1 machine canal. Their total water consumption is $Q=23.85$ m$^3$/s. Through Amu Zang-2 machine canal length there are 59 water intake points with total water consumption of $Q=16.72$ m$^3$/s [13].

Also, there are more than fifty medium and one hundred and twenty small cascade pumping stations in the regions of our country, which elevate water at the head of 100-150m. The pump station cascade exploitation scheme, ensuring that all cascades are interconnected and function correctly, it is made following the water supply schedule taking into account local conditions. During the operation of the pump station cascade, the amount of water in the cascading machine canals of the pumping stations maybe two different[14, 15, 16].

![Figure 2. Turning Siberian rivers to Central Asia. a - plan of main channel trace cascade of pumping stations. b-longitudinal cross-section of pump stations cascade.](image)
Figure 3. Scheme Irtysh-Karaganda Pumping station cascade
a is plan; b is longitudinal section; 1 is pumping stations in motion, 2 is projecting pumping stations; 3 is active canals; 4 is projecting canals; 5 is metal pipelines(tubes); 6 is using like us canal river coasts; 7 is water reservoirs

Figure 4. Karshi pumping stations cascade’s cross-section (a) and plan (b).
In the first case, no water consumers of the machine canals between the pump stations cascade. The change in water consumption is due to the filtration and evaporation along the canal coast[17][18]. The amount of water supplied by the first pumping station is the same as the amount of water supplied by the last pump station in the cascade to elevate water into the machine canal (Scheme 1), that is

$$\sum Q_{\text{cascade}} = Q_{PS-1} = Q_{MC-1} = Q_{PS-2} = Q_{MC-2} = Q_{PS-3} = Q_{MC-3} = Q_{PS-4} = Q_{MC-4} = Q_{PS-5} = Q_{MC-5} = Q_{PS-6} = Q_{\text{machine canal}}$$

Figures 5. Cascading pumping stations schemes:

- **a** – is Jizzakh pumping stations cascade;
- **b** – Amu-Zang pump stations cascade.
Figure 6. Cascading scheme without water intake from machine canals between pump stations cascade. MC is machine canal; PS is pumping station.

In the second case, water is taken by many water consumers from all machine canals in the pump station cascade. Changing water consumption is caused by water filtration, evaporation, and water consumers along the canal (Scheme 2).

\[ \sum Q_{\text{cascade}} = Q_{PS-1} - (WC_{1-\text{left}} + WC_{1-right} + WC_{2-right}) = Q_{PS-2} - (WC_{2-\text{left}} + WC_{3-right} + WC_{3-left}) = \\
Q_{PS-3} - (WC_{3-\text{left}} + WC_{4-right} + WC_{4-left}) = Q_{PS-4} - (WC_{4-\text{left}} + WC_{5-right} + WC_{5-left}) = \\
Q_{PS-5} - (WC_{5-\text{left}} + WC_{6-right} + WC_{6-left}) = Q_{PS-6} = Q_{\text{machine canal}} \]

Figure 7. Cascading scheme is taken water from machine canals between cascade pump stations: WC is water consumers; MC is machine canal; PS is pumping station.

In this case, the water consumption for evaporation is not taken into account, except for the filtration and water consumption of the machine canal.

For identifying water consumption developed by A.G. Petrov along the length of canal trace[19], if water consumption is changeable, the following differential equation is accepted for real one-dimensional turbulent flow.

\[ \frac{\alpha}{g} \frac{\partial u}{\partial t} + \frac{u}{g} \frac{\partial \alpha}{\partial t} + \frac{\partial}{\partial x} \left( \frac{\alpha u^2}{2g} \right) + \frac{\partial h}{\partial x} = i_0 - \frac{u^2}{c_{Hill} R} - \frac{\alpha_1 (u - V) \partial Q_i}{g Q} - \frac{\alpha_2 (u - V) \partial Q_2}{g Q} (1) \]

These are: \( \alpha, \alpha_1, \alpha_2 \) adjustments to the number of motions if the average velocities are not the same; \( \alpha^i \) is a complete correction to the kinetic energy of the flow, assuming continuous kinetic energy fluctuations (pulse) and uneven velocity field[20].

Water consumption from the machine canal is marked – \( Q_{\text{take}} \). No water intake sections’ consumption \((k = 2j + 1, j = 0, 1, 2, \ldots)\) to be equal zero. Thus, equation (1) for the estimated \( k \) section (2) appears as follows.

\[ \frac{\alpha^{(k)}}{g} \frac{\partial u_k}{\partial t} + \frac{u_k}{g} \frac{\partial \alpha^{(k)}}{\partial t} + \frac{\partial}{\partial x_k} \left( \frac{\alpha^{(k)} u_k^2}{2g} \right) + \frac{\partial h_k}{\partial x_k} = \frac{u_k^2}{c_{Hill} R_k} - \frac{\alpha_1^{(k)} (u_k - V_f^{(k)}) \partial Q_f^{(k)}}{g Q_k} - \frac{\alpha_2^{(k)} \delta_k (u_k - V_{c,\text{take}}^{(k)})}{g Q_k} (2) \]

If \( \alpha^{(k)} = \alpha^{(k)}_1 = \alpha^{(k)}_2 \) if it is constant,

\[ \frac{\partial u_k}{\partial t} + u_k \frac{\partial u_k}{\partial x_k} + g \frac{\partial h_k}{\partial x_k} = g (V_0^{(k)} - \frac{u_k^2}{c_{Hill} R_k} + \frac{(u_k - V_f^{(k)}) \partial Q_f^{(k)}}{Q_k} + \frac{\delta_k (u_k - V_f^{(k)}) \partial Q_{c,\text{take}}^{(k)}}{Q_k}) (3) \]

The continuity equation is written as follows.
\[ \frac{\partial \omega_k}{\partial t} + \frac{\partial q_{\text{take}}^k}{\partial x_k} = -q^k_f - \delta_k q_{\text{take}}^k. \]  

(4)

Here: \( q^k_f \) is in the k section of the canal’s losing water consumption by unit length filtration;  
\( q_{\text{take}}^k \) is water consumption from the canal along the length of the unit;  
\( \delta_k \) the coefficient of losing water consumption in the unit length of the canal is calculated as follows.

\[ \delta_k = \frac{\delta_k'}{L_k}; \quad \delta_k' = \frac{1 + (-1)^k}{2} \]

If canal trace at the section under consideration, the amount of transit water left over from water consumption is equal to \( Q_H \) the continuity is based on the following equation:

\[ q_{\text{take}}^k \frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial x} = -q_i \]  

(5)

\[ Q^k = Q_H^k - \sum_{j=1}^{k} x_j q_{f}^j - \sum_{j=1}^{k} \delta_j q_{\text{take}}^k x_j; \]  

(6)

Equals this because of colimitations process if the filtration water is zero \( (q_f^k) = 0 \) then the transit water consumption in the machine canal can be calculated using the following expression:

\[ Q^k = Q_H^k - \sum_{j=1}^{k} \delta_j q_{\text{take}}^k x_j; \]  

(7)

Water is taken from machine canals between the cascades, an example is the cascade of Amu Zang-Babatog pump stations. 134 water consumers take water through machine canals between these cascades.

4. Results

If one pump station in the cascade of pumping stations fails, the other will not work and a major catastrophic situation will occur. For reliable exploitation of the pump station cascade, before each pump station in the cascade, of the capacity or other capacity (from the small reservoir) which will provide it in a real-time interval, the pump station shall be supplied with water equal to the estimated water consumption.

5. Conclusions

When projecting pump stations cascade, should take into account the amount of water consumption that can be taken by water consumers from cascade machine canals. Water consumption of each pump station in the pump station cascade can be calculated according to equation 7 as follows:  
- **in the first case**, the water consumer does not take water from machine canals between pump stations cascade:

\[ Q^k = Q_H^k \]

- **in the second case**, water is taken by water consumers from machine canals between the pump stations cascade:

\[ Q^k = Q_H^k - \sum_{j=1}^{k} \delta_j q_{\text{take}}^k x_j \]

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