Linked pools culverts facilities

S Khidirov¹, B Norkulov², Z Ishankulov¹, P Nurmatov¹ and A Gayur¹
¹Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan
²Samarkand State Architecture – Building Institute, Samarkand, Uzbekistan

s.xidirov@tiame.uz

Abstract. A mathematical model is presented, a hydraulic jump that appears during the transition of the flow from a turbulent state \((Fr > 1.0)\) to critical \((Fr < 1.0)\). The main assumptions made to obtain the divergent form of the Saint-Venant hydrodynamic equations are given: - planned (two-dimensional) effects do not affect the flow (but still local energy losses due to sharp turns and changes in the channel shape in the plan can be taken into account; to take into account such losses in local sections of the channel increased local hydraulic resistance is introduced). The results of numerical studies of the downstream of the culvert structure of the medium-pressure reservoir are presented. The developed numerical model using explicit difference schemes is presented. Based on the results of numerical studies of the hydraulic jump, the possibility of establishing the degree of quenching of the excess flow energy having the destructive ability of the construction of the downstream of medium-pressure reservoirs is substantiated. The calculation results showed that an increase in the hydraulic resistance value promotes the displacement of the hydraulic jump against the current and an increase in its associated depths. At the concatenation site of the upstream, there was a sharp decrease in the Froude number from 2.76 to 0.69, with a change in average speed from 8.81 m/s to 3.26 m/s. It is substantiated that from the calculated values of the vertical dimensions of the hydraulic jump with various values of hydraulic resistance and the throughput of the structure, it is possible to determine the horizontal dimensions of the jump, which makes it possible to select the optimal sizes of the downstream attachment zone in and after the hydraulic jump.

1. Introduction
In the practice of operating hydrotechnical and hydropower facilities, to extinguish the excess energy resulting from large changes in the levels of the upper and lower pools, very often their pairing is carried out using a hydraulic jump. The junctions of the object of study of the present work of the Akdarya river-type reservoir, seasonal regulation, located in the Samarkand region of the Republic of Uzbekistan, 50 km below the Akdarya hydroelectric complex, where the Zarafshan river is divided into two constant channels, the northern (Akdarya river) and the southern (Karadarya river) also carried out by a hydraulic jump. The Akdarya reservoir was built to use additional water resources – effluent and channel-cleared waters and is intended to irrigate 5.5 thousand hectares of new land and increase water supply for 12.0 thousand hectares of irrigated land. The dam gate is selected at the narrowest point of the floodplain of the Akdarya River. The width of the alignment at the level of the dam crest is 930 m. The relief of the flooded area is relatively calm; the right bank of the Akdarya river is heavily indented with say and ravines. The reservoir is filled with water in the river. Zarafshan on Akdarya, due to spring nutrition, as well as due to waste water during irrigation of irrigated lands. The first phase was built and commissioned in 1982. The construction of the second stage reservoir
was completed in 1985, the third in 1989. In 2000, the spillway was reconstructed to increase reservoir capacity. In this regard, the nature of the change in the concatenation of biasses occurred, which served as the basis for determining the relevance of this work. As a whole, a large number of domestic and foreign works are devoted to questions of the conjugation of downstream waters, which address the main issues of hydraulics of the downstream, and also formulated the principles of designing the attachments of the downstream, among which fundamental research is occupied by B.A.Bakhmetev, N.Pavlovsky, A.A.Uginchus, M.D.Chertousov, I.I.Levy, D.I.Kumin, A.N.Rakhmanova, H.H.Belyashevsky, F.G.Gunko, K.I.Russian N.P.Rozanova, V.M.Lyatkhera, T.G.Voynich-Syanozhentskogo, T.Rebok X.Rauza, N.Rajaratan, Peterka, and other researchers [1–5].

To achieve high efficiency of the operation of the structure and accurate determination of the size of the structural elements of the downstream in practice, it is necessary to have sufficient information about the vertical and horizontal sizes of the hydraulic jump, their relationship with the hydrodynamic characteristics of the flow, the capacity of the water outlets, and the patterns during combined operation should also be known hydraulic jump with other dampers installed on the sections of the apron and the downstream reservoirs culvert structures [6, 7]. An analysis of the downstream operation of many reservoirs and hydroelectric facilities at the headwater interface section shows a sharp deterioration in their operational conditions, due to improper selection of fastening structural elements, which are accepted based on the conditions for headwater coupling. Despite the abundance of works devoted to the problems of pairing upstream, many of her questions could not be resolved. According to the above, the purpose of the study is determined, the results of which will be presented in this paper.

2. Methods
The authors of this work to determine the necessary parameters of the main tool of the hydraulic jump by calculating the concatenations of the downstream waters taking into account the convenience without additional costs for the construction of energy absorber structures, taking into account the possibility of several series of calculations without any special material costs, the method of numerical research was adopted [8–13].

3. Results and Discussion
For a numerical study of the conjugation of the upstream, we used a one-dimensional model created on the basis of the scalar equation of conservation of mass and the vector equation of conservation of momentum - the system of Saint-Venant hydrodynamic equations. These equations should be applied in the so-called “divergent” form, which automatically provides end-to-end calculation through solution breaks – burs and hydraulic jumps, which for the conditions of this problem have the form:

\[
\begin{align*}
\frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial x} &= 0, \\
\frac{\partial Q}{\partial t} + \frac{\partial Q^2 / \omega + gS}{\partial x} - g \frac{\partial S}{\partial x} \bigg|_{p=const} + \frac{\lambda}{2} V^2 \times \chi &= 0
\end{align*}
\]  

(1)

here: \(t\) is time, \(x\) is the distance, \(g\) is gravity acceleration, \(Z_0\) is water surface mark, \(\omega\) is living cross-sectional area, \(S\) is the static moment of a live section of a relatively free surface (\(pgS\) is pressure force on the live section of the flow), \(\chi\) is the wetted perimeter, \(v\) is cross-section average water velocity, \(\lambda\) is hydraulic friction coefficient. It can be shown that with steady flow (when \(\frac{\partial \omega}{\partial t} = 0, \frac{\partial Q}{\partial t} = 0\) system (1) is reduced to the well-known equation of the curve of the free surface in the channel.
In the above form, the system of equations of Saint-Venant is suitable for channels of complex shape. The function \( g \frac{\partial S}{\partial x} \mid_{h=\text{const}} \) does not contain derivatives of the sought quantities \( Q \) and \( h \) and included, as a term, on the right-hand side. In some simple cases, it can be easily expressed through derivatives of the geometric characteristics of the flow. For example, for a symmetrical trapezoidal prismatic channel \( S = mh^3 / 3 + bh^2 / 2 \) where \( m \) is laying of side slopes, \( b \) is width on the bottom.

Record \( \frac{\partial S}{\partial x} \mid_{h=\text{const}} \) denotes what \( Zf \) in this derivative does not differentiate. Of course \( Zf \) in this case, not an arbitrary quantity, but precisely that this corresponds to the solution of the system (1).

When deriving the Saint-Venant equation, the main hypotheses were adopted on which the successful solution of the one-dimensional Saint-Venant equations is based:

- the depth of the stream should be less than the linear dimensions that are essential for this engineering task, the characteristics of the stream along the length of the channel:
  \[ h \ll L \] (2)
  here: \( h \) is the flow depth; \( L \) is the characteristic horizontal linear size of the problem to be solved;
- planned (two-dimensional) effects do not affect the flow (but still, local energy losses due to sharp turns and changes in the channel shape in the plan can be taken into account; increased local hydraulic resistance is introduced to take into account such losses in local sections of the channel);
- the curvature of the jets in the vertical sections of the flow is small, which allows us to use the hypothesis of hydrostatic pressure distribution over depth;
- the slope of the free surface of the water in the direction perpendicular to the flow is small; between the mark of the free surface of the water and pressure there is a functional relationship;
- density stratification should not occur in the flow; in river flows, density stratification is rare, but in some cases, it does occur (a well-known example is density stratification in a flat river near the bottom intake of a thermal power plant, which dumps partially cooled water into the same river above the intake);
- when studying unsteady processes in rivers, it is permissible to use formulas for the Darcy – Weisbach or Shezi hydraulic friction coefficients derived for steady-state channel conditions, for example, Manning or Forchheimer formulas (situations, where this hypothesis was not true, are known);
- the correction of the amount of motion \( \alpha \) is close to 1, (the velocity plot along the entire alignment is almost uniform) such a hypothesis is not quite correct, even in a wide rectangular channel, when only the shape of the plot affects the correction value in depth [14–17].

The divergent form of the Saint-Venant equations suggests a way to construct finite-difference schemes satisfying the properties of the Saint-Venant equation about the possibility of their high-precision description of a large number of hydraulic phenomena (burs, hydraulic jumps, waves of floods and releases, seiche oscillations in seas, lakes, reservoirs and canals, tidal waves, rolling waves, which in hydraulic engineering are known as difficulties arising at high-speed currents.

When approximating the selected equations, a scheme was used that generalizes for changing channels in the plan, characteristic of the downstream of culverts at the site of the interface of the downstream, a scheme developed by A.N. Militeev, with the participation of M.S. Sladkevich [18]. The scheme has a spaced finite-difference grid, and the depth, cross-sectional area, and pressure are determined at points with integer numbers, and flow and speed are determined at points with half-integer numbers. Finite-difference representations of the laws of conservation of mass and momentum (reduced by a constant density of water \( \rho \)) have the form [19, 20]:
Here, grid functions are denoted in the same way as their continuous counterparts. Their lower indices indicate the numbers of points of the finite-difference grid along the spatial coordinate \( x \). The superscript “1” indicates that the function refers to a new time layer.

For a numerical experiment for calculating the conjugation of the downstream areas, the interface of the lower downstream interface of the culvert and spillway structures of the mid-pressure Akdarya waterworks was selected.

\[
\begin{align*}
\frac{\omega_k - \omega_k^1}{\tau} + \frac{Q_{k+1/2} - Q_{k-1/2}}{\Delta} &= 0, \\
\frac{Q_{k+1/2} - Q_{k-1/2}}{\tau} + K_{k+1} - K_k + g \frac{S_k^1 (Z_{f k+1}) - S_k (Z_{f k})}{\Delta} &= 0, \\
- g \frac{S_{k+1} (Z_{f k+1/2}) - S_k (Z_{f k+1/2})}{\Delta} + T_{k+1/2} &= 0, \\
K_k &= \frac{Q_{k+1/2} v_{k+1/2} + Q_{k-1/2} v_{k-1/2} - \left[ (Q_{k+1/2} v_{k+1/2} + Q_{k-1/2} v_{k-1/2}) \right]}{2}, \\
v_{k+1/2} &= \begin{cases} 
Q_{k+1/2} / \omega_k & \text{если } Q_{k+1/2} > 0, \\
Q_{k+1/2} / \omega_{k+1/2} & \text{если } Q_{k+1/2} < 0.
\end{cases}
\end{align*}
\]

Figure 1. Interface section of the Akdarya Reservoir Biases

Design parameters of the reservoir:
Mark forced retaining level (\( FRL \) – 494.50 m), normal retaining level (\( NRL \) – 493.55 m), dead volume level (\( DVL \) – 480.85 m). Full capacity – 90.0 million m\(^3\). Dead volume – 2.55 million m\(^3\).
Mirror area at \( NRL \) – 11.6 km\(^2\), at \( DVL \) – 1.64 km\(^2\). Length – 8.5 km.

The parameters of the reservoir after the reconstruction of the catastrophic spillway carried out in 2000 and the survey of the bowl in 1997, as well as the clarification of the marks of the spillway wall in 2002, are as follows:
Mark \( FRL \) – 495.33 m, \( NRL \) – 494.60 m, \( DVL \) – 480.85 m. Full capacity taking into account siltation – 92.57 million m\(^3\). Dead volume – 1.3 million m\(^3\).
Design permissible speeds: reservoir filling – 0.5–1.0 m/day; emptying - 0.4 m/day [15].
The numerical model is fully verified by the natural object. Since, in 2000, the overflow dam of the reservoir was reconstructed, the calculated values of the throughput were taken from 86 to 99 m$^3$/s. Numerical experiments were carried out for the case of smooth and with installed dampers, as well as for different values of hydraulic resistance in the expanding section of the fast current.

At the beginning of numerical studies, the hydrodynamic and geometric characteristics of the object of study were adopted, which corresponded to the following design schemes with and without energy absorbers.

After establishing the value of the flow throughput at the headwater interface, the position of the hydraulic jump and its appearance began to change. With an increase in water flow and hydraulic resistance, a change in the position and vertical dimensions of the hydraulic jump was observed.

Dynamics of changes in position and hydraulic parameters.

The jump at the end of the estimated time is shown in the following figure:
4. Conclusions
As a result of numerical studies, a favorable form of a hydraulic jump on a water hole, a fast current, was established. It is established that, with an increase in hydraulic resistance by increasing the artificial roughness at a rapid current and a water hole, the vertical parameters of the hydraulic jump sharply change. The calculation results showed that an increase in the hydraulic resistance value promotes the displacement of the hydraulic jump against the current and an increase in its associated depths. At the concatenation site of the upstream, there was a sharp decrease in the Froude number from 2.76 to 0.69, with a change in average speed from 8.81 m/s to 3.26 m/s. From the calculated values of the vertical dimensions of the hydraulic jump with different values of hydraulic resistance and the carrying capacity of the structure, it is possible to determine the horizontal dimensions of the jump, which makes it possible to select the optimal dimensions of the attachment zone of the lower pool in and after the hydraulic jump.
References

[1]. Bazarov D R and Mavlyanova D A 2019 Numerical studies of long-wave processes in the reaches of hydrosystems and reservoirs *Mag Civ Eng* 87 123 doi: 10.18720/MCE.87.10

[2]. Bazarov D, Shodiev B, Norkulov B, Kurbanova U and Ashirov B 2019 Aspects of the extension of forty exploitation of bulk reservoirs for irrigation and hydropower purposes In: E3S Web Conf. *EDP Sciences*

[3]. Krutov A, Bazarov D, Norkulov B, Obidov B and Nazarov B 2019 Experience of employment of computational models for water quality modelling In: E3S Web Conf. *EDP Sciences*

[4]. Mamajonov M, Bazarov D R, Uralov B R, Djumabaeva G U, and Rahmatov N 2019 The impact of hydro-wear parts of pumps for operational efficiency of the pumping station *J Phys Conf Ser* 1425 012123 doi: 10.1088/1742-6596/1425/1/012123

[5]. Militeev A N and Bazarov D R 1999 A two-dimensional mathematical model of the horizontal deformations of river channels *Water Resour* 26 17

[6]. Bear J and Zaslavsky D 1968 Physical principles of water percolation and seepage

[7]. Bazarov D R 2000 *Scientific justification of new numerical methods for calculating channel deformations of rivers, the channel of which is composed of easily eroded soils* Moscow

[8]. A. M 1987 The forecast of the dynamics of the channels in the head of hydropower facilities by numerical methods.

[9]. A.V. K 1960 Problems of the dynamics of natural water flows. Hydrometeoiizdat.

[10]. Bazarov D R 1997 Three-dimensional mathematical model for streams with a washout bottom *Appl Math Community* 23

[11]. Bazarov D R and Militeev A N 1997 A mathematical model for calculating two-dimensional (in terms of) channel deformations *Appl Math Community* 9

[12]. Bazarov D R Militeev A N 1997 On pulsating solutions of two-dimensional shallow water equations under stationary boundary conditions *Appl Math Community* 12

[13]. Bazarov D R and Shkolnikov S Y 2018 *INTERNATIONAL ACADEMY JOURNAL Web of Scholar Warsaw, Poland*, pp 13–17

[14]. Kartvelishvilli N A 1973 *Flows in undeformable channels* Moscow

[15]. Kuchkarov M 2017 Research of channel processes at ABMCh and development of an event to improve the conditions of damless water intake at ABMCh

[16]. Lyatker V M and Shkolnikov S Y 1981 Tensor structure of hydraulic friction coefficient *Water Resour* 5

[17]. Shkolnikov S Y 1999 Transformation of flood waves propagating in a dry channel *Hydraul Eng*

[18]. Kwon V I 1967 On friction resistance during unsteady motion of an open fluid flow in a channel (Novosibirsk)

[19]. Bazarov D R, Vokhidov O F, Lutsenko L A and Sultanov Sh 2019 Restrictions Applied When Solving One-Dimensional Hydrodynamic Equations In: Proc. EECE 2019, *Lect. Notes Civ. Eng.* 70, pp 299–305

[19]. Zhidkikh V M 1966 Calculation of the coefficient of turbulent exchange in reservoirs during wind waves 7

[20]. Militeev A N 1982 Solving the problems of hydraulics in shallow reservoirs and hydroelectric reservoirs using numerical methods (Moscow)

[21]. Artikbekova F K 2020 Estimating the processes in inlet canal with the consideration of the operational features of pump stations. (Tashkent)