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Dynamics of hydraulic resistance in the zone of constraint of the riverbed

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Abstract. The article is devoted to the analysis of the dynamics of the morphometric parameters of the river channel and the hydraulic parameters of the flow under constrained conditions. The Kipchak hydraulic track located in the lower reaches of the Amu Darya River, constrained by the pontoon bridge, is characterized by intensive channel processes. The dynamics of the hydraulic resistance of the channel depending on the flow during the periods of observation in a confined section of the river has a wide range of 0.045 to 0.068, with a change in the roughness of the channel within 0.0195 to 0.065. The calculated values of the flow rates, taking into account the inhibitory effect of the river banks, gave a satisfactory agreement with the measured ones, the hydraulic resistance of the channel, depending on the value of this parameter, varied within 0.045 to 0.068 with the dynamics of the Chezy coefficient from 27 to 67 m0.5 / s

1. Introduction and purpose of research

In order to increase the water supply of the irrigated lands of the Republic of Uzbekistan in the lower reaches of the Amu Darya, in 1974 the Takhiatash hydroelectric facility was built at 215 km and in 1982, the Tuyamuyun reservoir was commissioned at 450 km from the mouth of the Amu Darya. The constructed pontoon bridge serves to ensure transit through the Amu Darya River.

Because of the construction of the above facilities, significant changes occurred in the course and direction of the channel processes with the reformation of the riverbed, in the lower pool of these structures there is erosion and lowering of the bottom, in the upper pool siltation and rise of the channel bottom. All these processes occur because of the influence of the structure on the flow dynamics. The study of flow dynamics near structures in conjunction with the dynamics of the channel morphometry is important in the practice of hydraulic engineering and hydropower construction. To ensure the safety of the constructed structures, it is necessary to carry out forecast calculations of channel processes in the river channel, taking into account the influence of hydrotechnical and hydropower structures on flow dynamics. Based on the foregoing study of the dynamics of the channel morphometry and hydraulic flow parameters that affect the course and direction of the channel processes, in conditions of regulated river flow, it is determined as the main goal of the scientific work. [1, 2, 3, 4, 5]

IOP Conf. Series: Materials Science and Engineering **869** (2020) 042012 doi:10.1088/1757-899X/869/4/042012

2. Solution methods

Studying the dynamics of the morphometric elements of the channel and the hydraulic parameters of the Amu Darya river flow, we can divide the river channel into the following conditional zones:
-an area of general erosion characterized by intense erosion of the riverbed and riverbank;
-a section of the restricted flow regime where the riverbed is constrained by various structures (bridges, gas and water systems or other engineering and communications facilities, Kipchak hydraulic ramp;
-a section of the retaining flow regime, on which the riverbed is blocked by dams, blocking structures;
-a section of the free flow regime in which there is no influence of structures on flow dynamics.

The aim of this work is to consider the dynamics of channel morphometry and hydraulic flow parameters in the oppression zone by a pontoon bridge. To establish the relationship between the morphometric parameters of the riverbed and hydraulic flow parameters, VI observation periods over the past 25 years characterized by a high water rate of the Amu Darya River. Changes in the morphometric parameters of the riverbed, hydraulic parameters of the stream was analyzed; empirical formulas for calculating the flow capacity are tested taking into account the influence of the side walls of the channel, the hydraulic elements of the stream are compared with the measured values. To identify functional patterns between channel morphometry and hydrodynamic flow characteristics, the data of hydrometric measurements were processed using standard programs on a computer. [7, 8, 9, 10, 11, 12, 14]

The Kipchak hydraulic gauge, which is located 185 km below the Tyuyamuyun reservoir, in the section of the pontoon bridge and belongs to the section of the cramped stream flow, was selected for research 'Figure 1'. The width of the pontoon bridge is 300 m. The bridge narrows the riverbed by 2 times and the current passes here in a retaining mode. Here, the average diameter of bottom sediments is 0.12 mm and the slope of the water surface is $i = 0.00012$

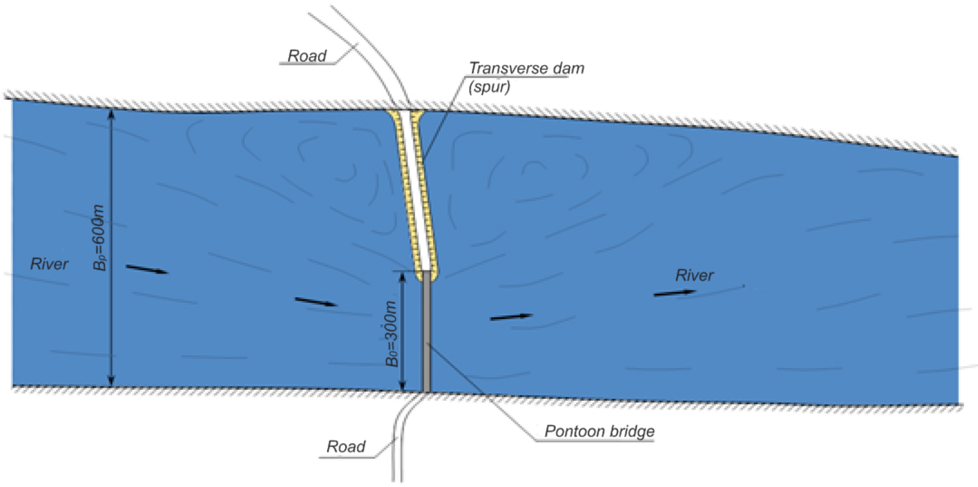

Figure 1. The layout of the pontoon bridge on Amu Darya River in the area of the Kipchak hydraulic ram.

3. Results

To analyze the relationship between the morphological parameters of the riverbed and the hydraulic characteristics of the flow in the Kipchak hydraulic ram, the data of high-water periods for the last 25 years of the observation stages were selected. As the results of many researchers of channel processes show, high-water years most fully reflect the relationships and dynamics between the morphological elements of the flow and their hydraulic parameters.

According to the data of the selected observation years, graphs were constructed between the channel width B and the water flow rate in the form of a function QB = f(Q) between the depth of the flow H

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and the water flow rate Q in the form of a function H =f(Q) ‘Figures 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13’.

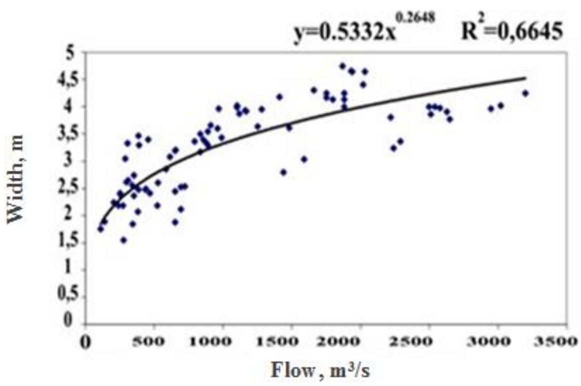

Figure 2. Schedule H_{cp} = f (Q) target Kipchak according to the I stage of observation

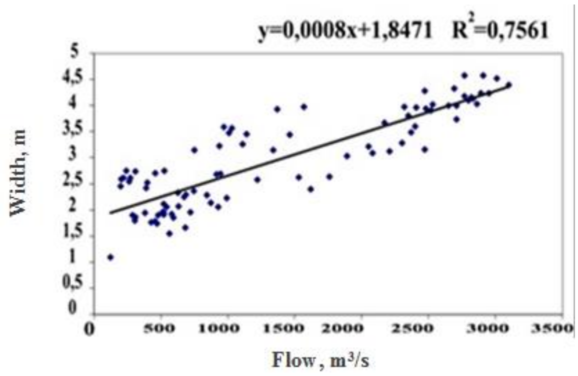

Figure 3. Schedule H_{cp} = f (Q) target Kipchak according to the II stage of observation

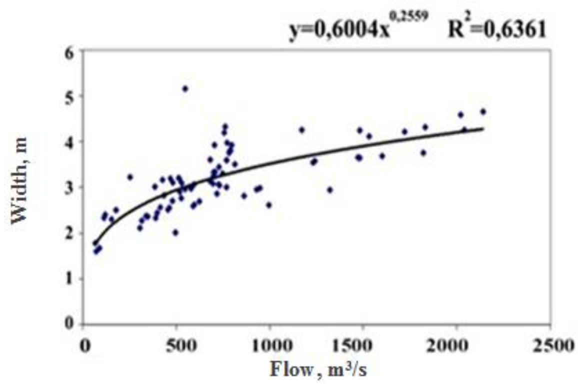

Figure 4. Schedule H_{cp} = f (Q) target Kipchak according to the III stage of observation

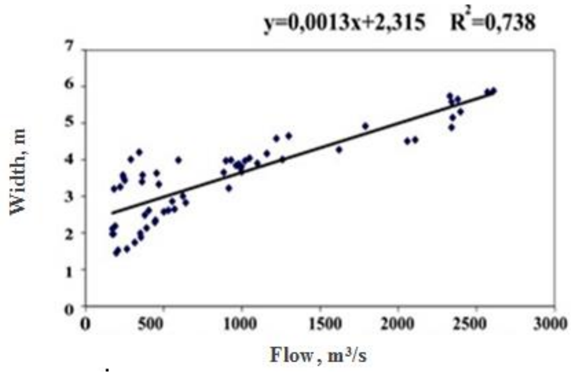

Figure 5. Schedule H_{cp} = f (Q) target Kipchak according to the IV stage of observation

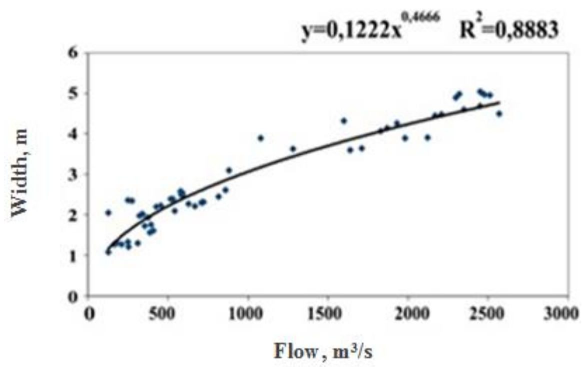

Figure 6. Schedule H_{cp} = f (Q) target Kipchak according to the V stage of observation

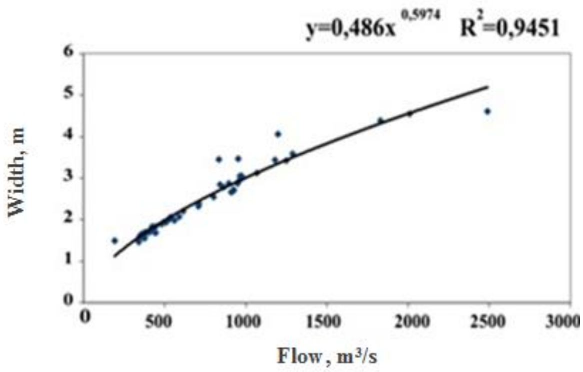

Figure 7. Schedule H_{cp} = f (Q) target Kipchak according to the VI stage of observation

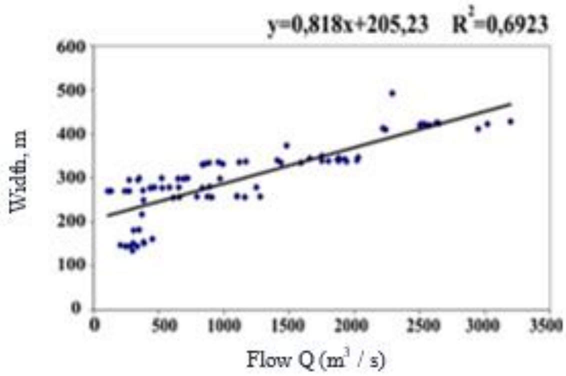

Figure 8. Schedule B = f (Q) target Kipchak according to the I stage of observation

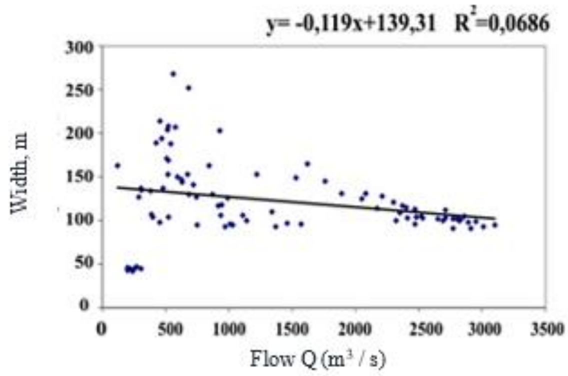

Figure 9. Schedule B = f (Q) target Kipchak according to the II stage of observation

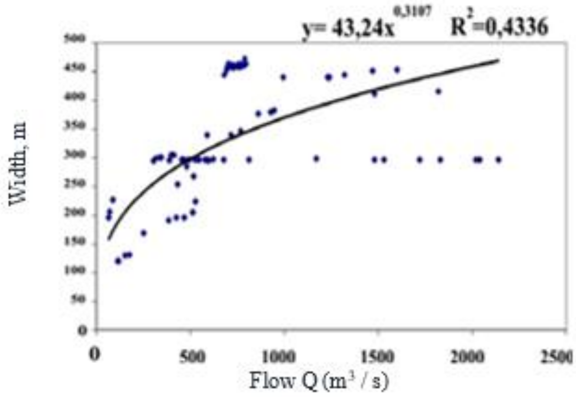

Figure 10. Schedule B = f (Q) target Kipchak according to the III stage of observation

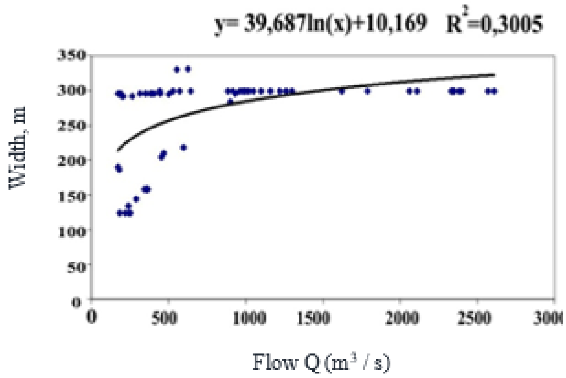

Figure 11. Schedule B = f (Q) target Kipchak according to the IV stage of observation

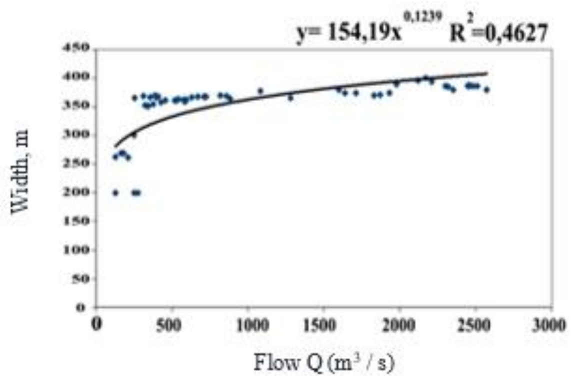

Figure 12. Schedule B = f (Q) target Kipchak according to the V stage of observation

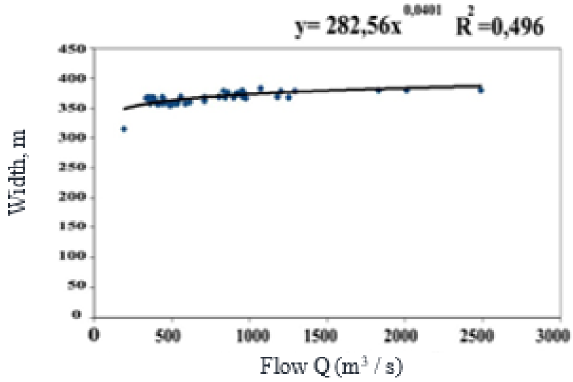

Figure 13. Schedule B = f (Q) target Kipchak according to the VI stage of observation

The relations between H = f (Q) and B = f (Q) were carried out by the statistical method of correlation analysis for each year of observations separately.
In the 'Figures 2, 3, 4, 5, 6, 7' show graphs of the relationship between the average flow depth and water flow for high-water years, which characterize the dynamics of the depth of the water flow in this hydraulic seal.

An analysis of the relationships between the average flow depth and water flow rates for stages III and IV showed a linear dependence, the remaining stages I, II, V, and VI of the observations have indicative relationships, and their correlation coefficients range from 0.64 to 0.94 have satisfactory relationships of average depth of flow from water flow.

The average depth of the flow at the maximum flow rate of the first stage of observations changes from 1.5 to 4.5 m. At maximum flow rate, the average flow depth decreases to 3.75 m. The relationship between the average depth and water flow rate at the first stage of observations is significant, but weak in correlation coefficient 0.66. In the next second multi-water observation stage, the relationship between the average depth and water discharge increased and the correlation coefficient reached 0.76.

The compiled graphs of the relationship between the depth of flow and the flow rate of water in this hydraulic seal showed a regular relationship between the average depth of flow and the flow rate of water in stages IV and V1 of the observations. The weakest relationship between the average depth of flow and water flow was at the III stage of observations with a correlation coefficient of 0.63. The intensity of deformation processes in the range, the variable nature of the depth of the stream, and the sharp variability of the river hydrograph led to the establishment of various functional relationships between these parameters. In the last high-water stage VI of observations, the relationship between the average depth and water flow rate increased sharply and the value of the correlation coefficient was 0.94. The connections between the channel width and the water flow for linear stages I and II are linear, the connection at the first stage is logarithmic, for the third, fourth and sixth stages of observation, the links are indicative, and the correlation coefficients are low.

To establish the relationship between the width of the channel B and the water discharge Q, the graphs was plotted as shown in 'figures 8, 9, 10, 11, 12, 13'. From the constructed graphs, there are can be seen that the smallest channel width is observed with a decrease in discharge in the first - I stage of observation and with the increase in water flow in the river, the channel width increases. The greatest width of the channel was being observed at the highest flow rate. The relationship between the channel width and the flow rate of the first year of observations is weak and the correlation coefficient reached 0.69.

At the second stage of observations, an increase in the channel width was be observed depending on the flow rate, the maximum value of which was at a flow rate of 3000 m^3/s and amounted to 100 m, with a further increase in flow rate, the width remained constant. At this stage of observations, as well as in the first, the relationship between the channel width and flow rate to 3000 m^3/s was be weakly traced, which corresponded to a sharply changing flow regime according to the classification of open channel hydraulics. The largest channel width at the first stage of research was 275 m; at the second stage, the channel width began to decrease to 100m.

In the third stage of observations at a maximum flow rate of 4,500 m^3/s, the channel width was 950m, at the fourth stage of observation the width was 750 m. At the V stage of observations at a maximum flow rate of 2500 m^3/s, the channel width was 350 m, and the VI stage is 385m. The 25-year observation period with six high-water years, the channel width in this section increased by 150 m. Observations showed that in the Kipchak section the riverbed narrows twice as compared to other sections, and the flow here is restricted.

As is known from classical channel hydraulics, the energy reserves of a water stream were be mainly spent on friction along the length of the channel and local hydraulic resistances. The friction losses during turbulent flow movement, which is characteristic of open flows, mainly depend on the roughness of the channel and the hydraulic radius. The forces that counteract the flow movement: the hydraulic resistance and the hydraulic radius was be taken into account in many hydraulic calculations by the Chezy coefficient C for the average flow rate. Since the depth of the stream and the width of the channel along the stream is very variable, very often in engineering calculations the motion was be assumed to be uniform or quasi-stationary, which allows the calculation of the average flow velocity to determine the values of the Chezy coefficient using the classical empirical formulas of Manning, NN Pavlovsky, II Agroskin and m other legs [15, 16, 17, 18].

Actually, the movement in the river channels is unsteady and the values of the Chezy coefficient depend on the type of liquid, the roughness coefficient of the channel, the dynamics of the channel shape along the flow. In addition, the shape of the channel in the plan, the presence of floodplains, and coverage the channel and its floodplains by various vegetation and from many natural and artificial factors.

The graphs of the relationship between the roughness coefficients and the water flow rate n = f (Q) for the I, II, III, IV, V, and VI stages of observations along the Kipchak alignment are presented in 'Figures 14, 15, 16, 17, 18, 19'

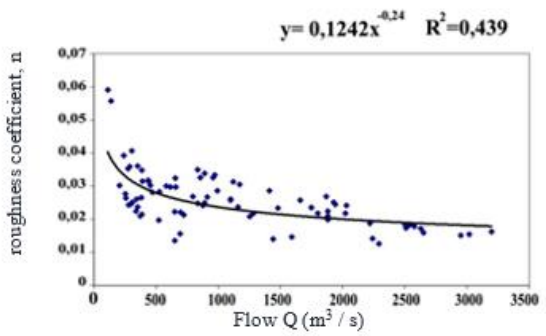

Figure 14. Schedule n = f (Q) target Kipchak according to the I stage of observation

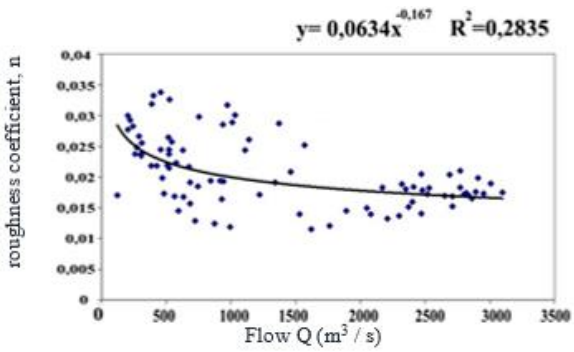

Figure 15. Schedule n = f (Q) target Kipchak according to the II stage of observation

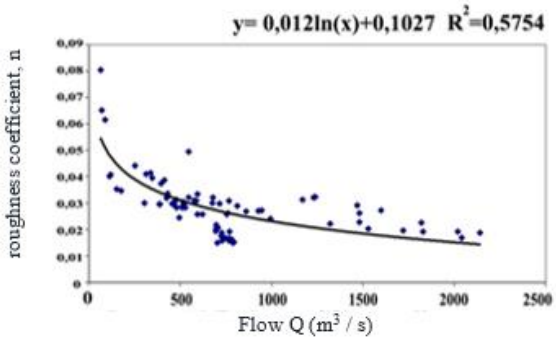

Figure 16. Schedule n = f (Q) target Kipchak according to the III stage of observation

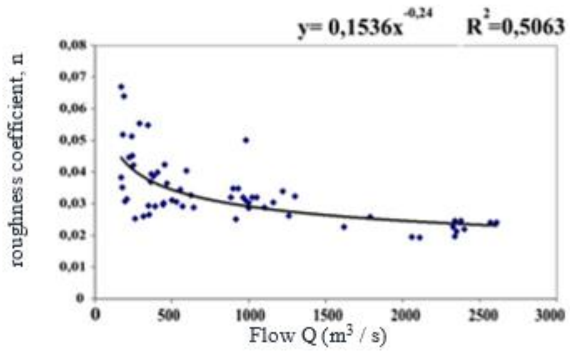

Figure 17. Schedule n = f (Q) target Kipchak according to the IV stage of observation

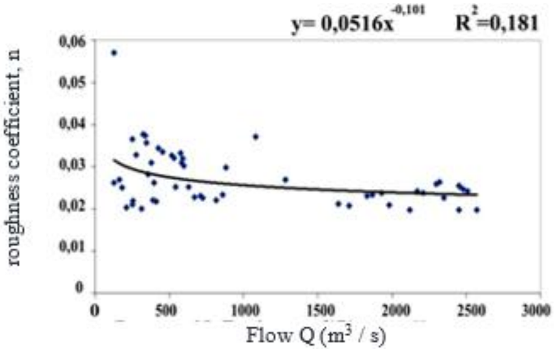

Figure 18. Schedule n = f (Q) target Kipchak according to the V stage of observation

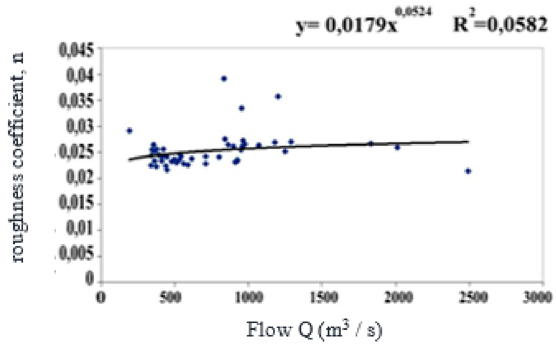

Figure 19. Schedule n = f (Q) target Kipchak according to the VI stage of observation

On all graphs, there is a tendency to decrease the roughness coefficient with increasing water flow in the river. On the graph of stage I of the observations, the largest value of the roughness coefficient is n = 0.06, and as the flow rate increases, the roughness coefficient decreases, reaching the lowest value (n = 0.015) with a maximum water flow rate of 3300 m^3/s.
In the graph of the second stage of observations, the roughness coefficient values at a minimum flow rate are 0.035, here there is a decrease in the roughness coefficient with increasing water flow rate and its smallest values (n = 0.017) have a flow rate of 2500 m^3/s.
On the communication graph of the III stage of observations n = f (Q), changes in the roughness coefficient are observed. The maximum value equal to 0.08 was observed at the minimum water flow rate and with its growth, the roughness coefficient decreases, reaching 0.012 at the flow rate
2200 m3 / s, here the relationship between the roughness coefficient and water flow is satisfactory, the correlation coefficient is R2 = 0.57.
On the communication graph, stage IV of observations, n = f (Q), the largest values of the coefficient are n = 0.07. Here, the roughness coefficient also decreases with increasing water flow in the river. The highest value of the roughness coefficient is 0.017 at a flow rate of 2700 m^3/s. On the graph of stage V of the observations, the values of the roughness coefficient range from 0.02 to 0.058, with a larger flow rate from 0.02 to 0.028.
On the communication graph of the VI stage of observations, the values of the roughness coefficient at lower costs are 0.04, with a higher flow rate of 0.02.
At stage V and VI of the observations, a satisfactory relationship between the roughness coefficient and water flow rate was not observed.
An analysis of the n = f (Q) communication plots on the Amudarya river hydraulic rams showed that there are all three types of types of changes in the roughness coefficient with increasing water flow.
The dynamics of the hydraulic resistance of the channel, depending on the flow rate over the years of observation in a confined section of the river, had a wide range from 0.045 to 0.068, depending on the roughness of the channel 0.0195 to 0.065. 'figures 20, 21, 22, 23'.

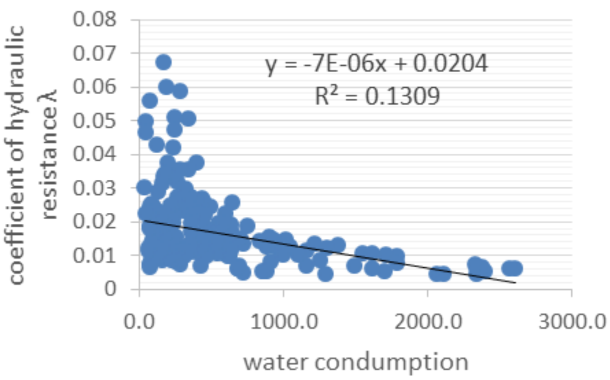

Figure 20. A graph of the hydraulic resistance of the channel λ = f (Q) in the Kipchak alignment according to the data of the observation stages.

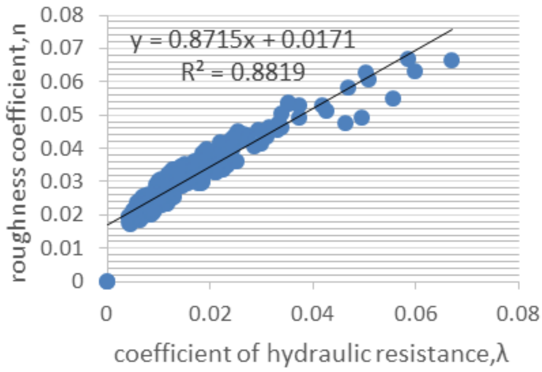

Figure 21. Graph λ = f (n) in the Kipchak alignment according to the data of the Vth observation stage.

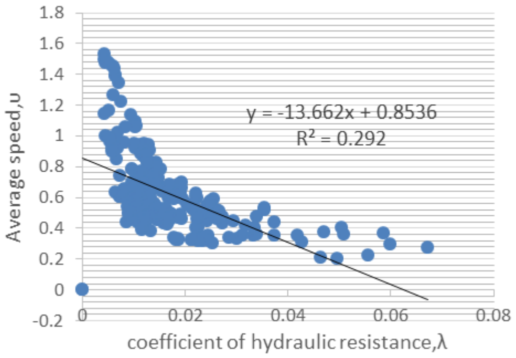

Figure 22. Graph λ = f (υ) in the Kipchak alignment according to the data of the V th stage of observations**.**

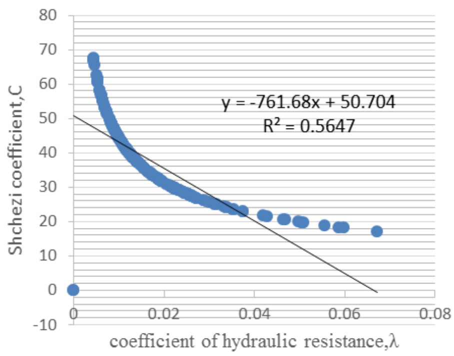

Figure 23. Graph *λ=f(C)* in the Kipchak alignment according to the data of the V th stage of observations.

The calculated values of the flow rate, taking into account the inhibitory effect of the riverbanks, gave a satisfactory agreement with the measured values and the hydraulic resistance of the channel, depending on the value of this parameter, varied within 0.045 to 0.068 with a Chezy coefficient from 27 to 67 m 0.5/s. The calculated values of the Chezy coefficient taking into account the inhibitory effect of the channel when compared with the measured values of the average speed showed good convergence. Analysis of studies showed that:

Stage II of observations refers to the first type, i.e. with increasing water consumption, an increase in the roughness coefficient was be observed; the first and third stages of observations belong to the second type, i.e. roughness coefficients remain unchanged with increasing flow of water in the river.

IV, V, VI stages of observations belongs to the third type, i.e. with an increase in water consumption, the roughness coefficient decreases.

In the Kipchak alignment, on all communication graphs n = f (Q), a third type of change in the roughness coefficient is observed, i.e. with an increase in water consumption, the roughness coefficient decreases. The initial stages of observations showed a weak connection; in recent years, observations have improved, which shows a gradual stabilization of the channel process in the Kipchak alignment.

To establish reliable calculated dependences for the Chezy coefficient, yielding a result corresponding to real values of the average flow rate, the calculation results were be compared using several formulas: Manning, I.I. Agroskin, D. Altshul V.N. Goncharova, N.N. Pavlovsky, F. Forchheimer, I.F.Karasev and other researchers.

The calculation results showed good convergence with the data of field studies of the Manning formula, taking into account the inhibitory effects of the riverbanks. The braking effect of the coasts was be taken into account by a correction factor, which, in the absence of floodplains, is determined by the modified formula of I. F. Karasev. [19, 20]

When deriving the above formula, the equation of conservation of momentum was used for the following dynamic scheme 'Figure 24'.

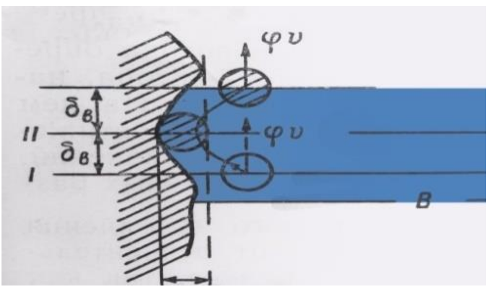

Figure 24. Dynamic diagram of the mechanism of inhibition of flow by the riverbank

Selecting the flow compartment between the calculated sections I-I and II-II, we draw up the equation of equilibrium of the following acting forces on the calculated compartment: mutually balanced hydrodynamic pressure forces:

$$p_1; p_2; \sum p = 0; \quad [1]$$

-gravity projections:

$$\chi \delta_в \gamma RI \quad [2]$$

-bottom friction force:

$$\chi \cdot \delta \cdot \gamma \cdot \frac{v^2}{c_0^2} \quad [3]$$

Where, g - gravity referred to unit mass, m / s^2;

χ - Wetted channel perimeter, m;

R - Hydraulic radius;

C_0 - Chezy coefficient, determined for uniform flow motion according to the Manning formula in the form:

$$C_0 = \frac{1}{n} R^{\frac{1}{6}} \text{ (м/с}^3\text{)} \quad [4]$$

The dynamics of the momentum of the flow in the considered section for the time moment is

$$t = \frac{\delta_в}{\upsilon} \text{ (c)} \quad [5]$$

$\delta_в$ - Height of the protrusion of the roughness of the river bank (m);

v - Average flow rate (m/s);

$$2 \cdot \frac{\gamma}{g} \cdot \varphi \cdot R \cdot \delta_b^2 \cdot v = \left(\gamma \cdot R \cdot I - \frac{\gamma \cdot v^2}{C_0^2} \right) \cdot \delta_b \cdot \chi \cdot \frac{\delta_b}{v} \quad [6]$$

Where, $\varphi -$ is the coefficient taking into account the ratio between the flows in the transit zone and in the laminar layer to the average flow velocity, the size and shape of the perturbations relative to the height of the roughness protrusions, the continuity of the perturbations on the banks of the river bed, and other mass transfer factors not explicitly taken into account. Processing data from long-term hydrometric observations made it possible to determine the numerical value of this coefficient in the area of the total erosion of the Amudarya River channel, which is equal to φ=0,002

The formula for the average flow rate, taking into account the inhibitory effect of the banks of the channel, has the following form:

$$v = C_0 \cdot \sqrt{\frac{g \cdot \chi \cdot R \cdot I}{R \cdot (2 \cdot \varphi \cdot C_0^2 + g \cdot \frac{\chi}{R}}} \quad [7]$$

Using formula (7), the determination of the Chezy coefficient taking into account the inhibitory effect of the coasts were carried out according to the following formula:

$$C = C_0 \cdot \sqrt{\frac{g \cdot \chi}{R \cdot \left(2 \cdot \varphi \cdot C_0^2 + g \cdot \frac{\chi}{R} \right)}} = k_C \cdot C_0 \quad [8]$$

According to abovementioned, to determine the calculated value of the roughness coefficient taking into account the inhibitory effect of the banks of the river channel, we obtain the formula in the following form:

$$n = n_0 \cdot \sqrt{\frac{2 \cdot \varphi \cdot R^{2/3}}{g \cdot \chi \cdot n_0^2} + 1} \qquad [9]$$

where: n_0 - coefficient of roughness for flat flow conditions; n - coefficient of roughness taking into account the inhibitory effect of the riverbank.

The calculations showed that at all stages of observation, the calculated values according to the formula and the measured values of the average flow rate, hydraulic resistance and roughness coefficient showed good convergence.

The dynamics of the calculated and measured values of average velocities ranged from 1.18 to 1.84 m / s, with a change in the value of the Chezy coefficient from 77.06 to 71.45 m/s. The average error of the measured and calculated values of the average flow velocities and the Chezy coefficient in the general erosion section of the Amudarya River was 0.25 and 0.81, respectively, while a change in the coefficient of hydraulic resistance was observed vary from 0.006 to 0.001. It should be noted that the dynamics of all these channel parameters at various flow rates corresponded to the dynamics of the channel roughness coefficient in the cramped zone from 0.016 to 0.011.

At the second and third stages of observations, the calculated and measured values of the average flow velocity showed good convergence. The calculated and measured values of velocities varied from 1.26 to 179 m / s, with a change in the value of the Chezy coefficient from 39.06 to 46.05 m/s, their average error in the area of the total erosion of the Amu Darya River for the second stage of observations was 0.05 and 1.7%, respectively. At the same time, the values of the hydraulic resistance coefficient decreased from 0.005 to 0.001.

The dynamics of changes in these parameters of the channel at various costs corresponded to changes in the values of the roughness coefficient of the channel in the cramped area from 0.014 to 0.011.

At stages IV, V, and VI of the observations, the calculated values of the hydraulic parameters of the flow, the Chezy coefficient, and the hydraulic resistance changed in relation to the dynamics of flow and roughness of the channel.

At the IV, V, VI stages of observations, the calculated and measured values of the average flow velocity showed good convergence and varied within the limits of the IV stage of observations from 0.54 to 1.14 m / s, with a change in the value of the Chezy coefficient from 39.30 to 45, 20 m/s, roughness coefficient values in the range from 0.036 to 0.023 hydraulic resistance in the range of 0.027 to 0.005. At the fifth stage of observations, from 0.52 to 0.58 m/s, with a change in the value of the Chezy coefficient from 20.08 to 11.20 m0.5 / s, and the hydraulic resistance of the channel within 0.048 to 0.012. At the VI stage of observations, from 0.67 to 1.37 m/s, with a change in the value of the Chezy coefficient from 38.18 to 36.65 m/s., An increase in the strength of the riverbed was observed, which counteracts the movement of the flow - the hydraulic resistance of the channel in the limits 0.02 - 0.06.

The average error between the measured and calculated values of the mean flow velocities and the Chezy coefficient in the area of the total erosion of the Amu Darya river for the long-term observation years was 1.25 and 1.7%, respectively.

4. Conclusions

Based on the analysis of studies on the dynamics of the morphometry of the riverbed and the hydraulic parameters of the water flow located on the site of the pontoon bridge, the following conclusions are drawn:

- In the Kipchak section, the riverbed narrows twice in comparison with other sections, and the flow moves in a cramped mode;
- when calculating the channel capacity to determine the calculated value of the average flow velocity and the values of the Chezy coefficient, the Chezy and Manning formulas with a correction coefficient taking into account the braking effect of the shores are recommended;
- for the Amudarya river section, where the total erosion continues, the numerical value of the coefficient taking into account the ratio of the preserved longitudinal exchanging masses between the

flows in the transit zone and in the laminar layer to the average flow velocity, the size and shape of the disturbances relative to the height of the roughness protrusions, the continuity of disturbances on the banks of the river channel and other factors mass exchange, not explicitly taken into account, is equal to 0.002-0.001.

- in the Kipchak alignment, on all communication graphs $n = f(Q)$, a third type of change in the roughness coefficient was observed, i.e. with an increase in water flow, the roughness coefficient decreased, at the beginning of the first stages of observations, communications were weaker, in the last stages of observations they increased, which indicates a gradual stabilization of the channel process;
- on the whole, the analysis of roughness coefficients in a regulated channel in the area of restricted flow movement showed that the channel process has not yet stabilized and, due to the influence of pressure on the river channel by the pontoon bridge, it was not possible to identify a functional relationship between the integral characteristic of the river channel forces counteracting the flow movement: hydraulic resistance channel and flow rate of water in it $n = f(Q)$.

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