Morphometric elements of the channel and hydraulic flow parameters in the zone of the river backwater

N Maalem1*, Kh Khasanov1 and Kh Nishanbaev1

1Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

kh.khasanov@mail.ru

Abstract. The article is devoted to the analysis of the dynamics of the morphometry of the river bed and the hydraulic parameters of the flow under conditions of flow regulation. For the analysis of the dynamics of the bed morphometry and hydraulic elements of the flow, the Nietbaitas hydro-array located in the zone of the sub-flow of the lower reaches of the Amudarya river in Uzbekistan was selected. As a result of the analysis of data from long-term field studies and hydrometric measurements at the Nietbaitas hydrometstomy of the Amudarya river, functional relationships were established between the morphometric elements of the channel and the hydraulic parameters of the flow. The dynamics of the Chezy coefficient, hydraulic resistance, and the roughness coefficient of the channel in conjunction with the hydrodynamic characteristic of the flow are established. Adapted formulas are recommended for determining the calculated values of the Chezi coefficients, roughness, and average flow velocity, taking into account the decelerating effect of the banks of the Amudarya river bed.

1. Introduction

To increase the water supply to the irrigated lands of the Republic of Uzbekistan in the lower reaches, the Takhiatash waterworks facility which is 215 km long was built in 1974 and the Tuyamuyun water reservoir which is 450 km from the former mouth of the Amudarya river was commissioned in 1982. As a result of the construction of the above facilities, significant changes occurred in the course and direction of the channel processes with the reformation in the riverbed. The river bed in the considered section is divided into numerous channels and branches with temporary and permanent islands, i.e. floodplain multi-arm also takes place [1, 2, 3].

In this section, the river bed is subject to extremely severe deformations: the river wanders within its floodplain, the river section in question is located between two hydropower plants, the river bed is heavily influenced by the operating mode of the Tuyamuyun and Takhiatash hydropower plants.

As a result of channel processes, agricultural areas, settlements are eroded and huge damage is caused to the national economy Figure –1. Besides, as a result of backwater, the average flow rate decreases, this contributes to the siltation of the channel and a decrease in river capacity in place with a decrease in the useful volume of the reservoir.
Figure 1. Deformation processes during the spring-summer period on the section of the Amudarya river between the Tuyamuyun-Takhiatash hydropower plants: a) A section of the river near spur No. 30. The volume of the eroded left bank is 5560 m³; the length of the washed-out area is 30 m; b) A section of the river near Sh. Rashidov bank. The volume of the eroded left bank is 8560 m³; the length of the washed-out area is 20 m; (Spurs of the Rashidov bank) c) A section of the river near the settlements of Banquet-Mahsim. The volume of the eroded left bank is 540560 m³; the length of the washed-out area is 7930 m; d) The washed-out banks of the river near the village of Ellikala.

These processes occur as a result of the influence of the structure on flow dynamics. Therefore, the study of the flow dynamics in the vicinity of structures in conjunction with the dynamics of the channel morphometry is important in the practice of hydrotechnical 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 bed, taking into account the influence of hydrotechnical and hydropower structures on flow dynamics. Based on the foregoing study, the dynamics of channel morphometry and hydraulic flow parameters affecting the course and direction of channel processes in the conditions of regulated river flow are defined as the main goal of this scientific work [4, 5, 6, 7, 8, 9, 10].

2. Methods
When studying the dynamics of the morphometric elements of the channel and the hydraulic parameters of the Amudarya river flow, the river can be divided into the following conditional zones: the plot of general reproduction, characterized by intense reflections of the channel and the riverbank:
- a section of the cramped mode, where the riverbed is constrained by various structures (bridges, gas and water pipelines of the system or other engineering and communications facilities (Kipchak hydraulic yard);
- a section of the retaining mode flow, on which the river bed is blocked by dams, blocking structures:
- a free-flow section of a stream on which there is no influence of the constructed structures of hydraulic engineering and hydropower designation on the flow dynamics.

According to the main purpose of this work, the dynamics of channel morphometry and hydraulic flow parameters in the area of flow restriction by a pontoon bridge are considered. To establish the relationship between the morphometric parameters of the riverbed and the hydraulic parameters of the flow, the VI observation periods have been accepted for the last 25 years, characterized by the highest water levels of the Amudarya River. Changes in the morphometry of the riverbed and hydraulic parameters of the flow are analyzed. Empirical formulas were tested for calculating the flow capacity, taking into account the influence of the sidewalls of the channel, the hydraulic elements of the flow with a comparison with their measured values. To identify functional patterns between channel morphometry and hydrodynamic flow characteristics, the data of hydrometric measurements were processed using standard programs of an electronic computer.

3. Results and discussion

To study the dynamics of the morphometric elements of the channel and the hydraulic flow parameters in the backwater area, the Nietbytas hydraulic yard was selected. The Nietbytas hydraulic station has been operating since 1983. The hydraulic station is located 8 km above the Takhiatash hydroelectric complex and the flow mode here is affected by the backwater created by the hydroelectric complex (figure 1). When passing the flood, the flow mode is free. The average diameter of bottom sediments is $d_s = 0.11\text{ mm}$ and the slope of the water surface on this hydraulic seal is $i = 0.00011$. The width of the channel varies from 200 to 700 m.

To analyze the relationship between the morphological parameters of the riverbed and the hydraulic characteristics of the flow in the Nietbytas hydraulic ram, the data of the high water periods of the observed stages were selected. Such stages over the past 25 years have refused the VI stages of observation. As the results of many researchers of channel processes show, high-water stages most fully reflect the interconnections and dynamics between the morphological elements of the flow and the hydraulic parameters of the flow [11, 12, 13, 14, 15].

Based on the data of the selected observation stages, graphs were constructed between the channel width - $(B)$ and the water flow rate as a function - $(Q) - B = f(Q)$ as well as between the depth of flow - $(H)$ and the water flow rate $(Q)$ in the form of the function is $H = f(Q)$ “figures 3-14”.

![Figure 2](image_url.png)  
Figure 2. Schedule $H_{cp} = f(Q)$ target Nietbytas according to the I stage of observation

![Figure 3](image_url.png)  
Figure 3. Schedule $H_{cp} = f(Q)$ target Nietbytas according to the II stage of observation
Figure 4. Schedule $H_{av} = f(Q)$ target Nietbytas according to the III stage of observation

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

Figure 6. Schedule $B = f(Q)$ target Nietbytas according to the I stage of observation

Figure 7. Schedule $B = f(Q)$ target Nietbytas according to the II stage of observation

Figure 8. Schedule $B = f(Q)$ target Nietbytas according to the III stage of observation

Figure 9. Schedule $B = f(Q)$ target Nietbytas according to the IV stage of observation

Figure 10. Schedule $n = f(Q)$ target Nietbytas according to the I stage of observation

Figure 11. Schedule $n = f(Q)$ target Nietbytas according to the II stage of observation
The relations between $H = f(Q)$ and $B = f(Q)$ were established by the static method of correlation analysis for each year of observations separately.

Figures 2-5 show graphs of the relationship between the average depth of the stream and the flow rate of the river for high water years.

According to the presented graphs, it is possible to characterize the dynamics of the depth of the water flow in this hydraulic seal.

As the analysis shows, the relationship between the average depth of the flow and the water flow for the III and IV stages of observation is linear, the remaining high-water stages I, II, V, and VI of the observation stage have indicative relationships.

These data characterize the conditions of regulated run off of the water Amudarya river.

The relationships between the average depth of the flow and the flow rate in stages I, II, III are satisfactory, the correlation coefficient is from 0.65 to 0.86 but they have different types of communication functions. In stage IV, the relationship between the average flow depth and water flow is too weak.

There is no connection between the width and the water flow for I and II stages, the IV stage is good, has an indicative connection and the correlation coefficient is 0.85.

In stage IV, the relationship between the width and flow rate of water decreased, for all stages there are different types of communication functions.

The weak relationship of the hydraulic flow parameters, except for the depth and width with the water flow rate, is due to the influence of water backwater by the Takhiatash hydroelectric complex. With a minimum flow of water in the river, the flow mode in the Nietbojtas section is retaining, while the maximum flow mode is free. Such an unstable flow regime can contribute to the development of channel processes in different directions. Such an unstable flow mode can contribute to the development of channel processes in different directions. The formation of backwater contributes to a decrease in the average speed, a decrease in speed to a value less than the non-declaring speed, corresponding to the soil of the channel will lead to the beginning of the process of siltation of the channel.

In the case of a free flow mode, an increase in the velocity of the non-erosive one will erode the river bed.

As the compiled graphs show the relationship between the depth of the stream and the flow rate of water in this hydraulic ram, the regular relationship between the average depth of the flow and the flow rate is disrupted due to the sharp variability from the operation mode of the reservoirs. In the high-water, I, III stages of observation, the relationship between the average depth and water flow was satisfactory with the values of the correlation coefficient 0.65 and 0.72, respectively. In the II high-
water observation stage, the relationship between the average depth and water flow rate sharply increased the value of the correlation coefficient was 0.87.

Due to the strong influence of the operating modes of the two reservoirs in the backwater zone, an increase in the intensity of deformation processes in the gauge was observed, the depth of the flow was variable and the hydrograph of the river changed sharply, and various functional relationships between these flow parameters were established. Such a sharp change in the depth of the stream and, accordingly, the water level between the reservoirs contributed to an increase in the intensity of coastal deformation in the form of dages.

To establish the relationship between the morphological element — the width of the channel — \( B \) and the flow rate of water \( Q \), the graphs were plotted as shown in figures 6–9.

The relationship between the channel width and water flow rate for the second stage of observation was the lowest with a correlation coefficient of 0.05 I stage had a logarithmic relationship with a correlation coefficient of 0.24 for II stage of observation there was the best functional relationship between the width and flow rate.

The value of the correlation coefficient at this stage was 0.87. This is explained by the fact that, in this high-water stage, there was a large period of the free flow of water, closer to the quasi-stationary flow movement. IV stage of observation of communication was indicative. The correlation coefficients were 0.50, It should be noted that for all stages of observation the channel width varied over very wide ranges, which indicates the continuation of intense coastal deformations.

As is known from classical channel hydraulics, the energy reserves of the water flow are mainly spent on friction along the length of the channel and local hydraulic resistance [16].

Friction losses due to developed turbulent flow motion, characteristic of open flows, mainly depend on channel roughness and hydraulic radius. The strength of the riverbed counteracting the flow movement is the hydraulic resistance of the channel and the hydraulic radius, in many hydraulic calculations, engineering practice of hydraulic engineering and hydropower design is taken into account with the Chezy-S coefficient in the Chezy formula for the average flow speed. Since the depth of the stream and the width of the channel along the stream are very variable, very often in engineering calculations the motion is assumed to be uniform or quasi-stationary, which will allow engineers to calculate the average flow velocity to determine the value of the Chezy coefficient from the classical empirical formulas of Manning, N.N. Pavlovsky and I. Agroskin and others [17, 18, 19]

In fact, the movement in the riverbeds is unsteady and the value of the Shesi coefficient depends on the type of liquid, the roughness coefficient of the channel, and the dynamics of the channel shape along the stream. In addition, the shape of the channel in the plan, the presence of the floodplains of the riverbed, the cover of the riverbed and its floodplain by various vegetations strongly influence the value of this parameter, and from many natural and artificial factors were given.

The graphs of the relation between the roughness coefficient and the water flow rate \( n = f (Q) \) for the I, II, III, IV stages of observation along the Nietbytas section are shown in figures 12–13. In all graphs, there is a tendency for a decrease in the roughness coefficient with an increase in the flow rate of water in the river.

But in the graph of stage I of the observation, the largest value of the roughness coefficient is \( n = 0.075 \), and as the flow rate increases, the roughness coefficient decreases, reaching the lowest value \( n = 0.01 \) with a maximum water flow rate of 2800 m\(^3\)/s. The value of the correlation coefficient is 0.50. But in the graph of stage II, the observed values of the roughness coefficient at a minimum flow rate are 0.045, here the roughness coefficient also decreases with increasing water flow rate and its smallest values (\( n = 0.017 \)) are achieved at a flow rate of 2500 m\(^3\)/s. Here a satisfactory relationship is obtained between the roughness coefficient and the water flow, with a correlation coefficient of 0.75.

In the communication graph III stage of the observation \( n = f (Q) \), the fluctuations in the change in the roughness coefficient are still growing. The maximum value of 0.08 is observed at a minimum flow rate of water in the river, and with an increase in flow rate, the roughness coefficient decreases, reaching its minimum of 0.014 at a flow rate of 2800 m\(^3\)/s. A good correlation was established
between the roughness coefficient and water flow. The value of the correlation coefficient was equal to $R^2 = 0.91$.

On the communication graph in the IV stage of observation $n = f(Q)$, the largest coefficient values at the minimum flow rate are $n = 0.015$. Here, the roughness coefficient also decreases with increasing water flow in the river. The lowest value of the roughness coefficient is 0.017 at a flow rate of 2200 m$^3$/s.

As the analysis of the $n = f(Q)$ communication graphs showed for the Amudarya river hydraulic yards, a decrease in the roughness coefficient with an increase in water flow is observed.

The initial stages of these connections were weaker; in the last stages, an improvement in communication is observed, which shows the gradual stabilization of the channel process in the Nietbytas range.

To establish the reliable calculated dependencies for the Shesi coefficient, this gives a result corresponding to the real values of the average flow rate, the results of calculations of several formulas of Manning, I. I. Agroskin, D. Altshul, V. N. Forchheimer, I. F. Karasev and other researchers were matched [20, 21].

The results of multivariate calculations showed that the Manning formula gives good convergence with the data of field studies in the zone of general erosion, taking into account the inhibitory effect of the river bed. The braking effect of the riverbank is taken into account by a correction factor which, in the absence of floodplains, is determined by the modified formula of I. F. Karasev. To obtain the above formula, the conservation of momentum for the following dynamic scheme was used:

![Dynamic diagram of the mechanism of inhibition of flow by the river bank.](Figure 14)

Select the flow compartment between the calculated sections I-I and II-II. The equations of equilibrium of the following forces acting on the calculated compartment are drawn up:

1. Mutually balanced hydrodynamic pressure forces:

   $$ p_1; p_2; \sum p = 0; \quad (1) $$

2. Gravity projections:

   $$ \chi \delta \cdot RI \quad (2) $$

3. Bottom friction:

   $$ \chi \cdot \delta \cdot \gamma \cdot \frac{v^2}{C_0^2} \quad (3) $$

Where, $g$ is gravity referred to unit mass, m/s$^2$, $\chi$ is Wetted channel perimeter, m; $R$ is Hydraulic radius; $C_0$ is Chezy coefficient, determined for uniform flow motion according to the Manning formula in the form:

$$ C_0 = \frac{1}{n} \cdot \frac{1}{R^\frac{5}{n}} \quad (m/s^3) \quad (4) $$

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

$$ t = \frac{\delta}{v} \quad (c) \quad (5) $$
\( \delta_b \) - Height of the protrusion of the roughness of the river bank (m);

\( v \) - Average flow rate (m/s);

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

Where, is the coefficient taking into account the ratio between the flows in the transit zone and 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 \( \varphi = 0.002 \).

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

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

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

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

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:

\[
n = n_0 \cdot \sqrt{\frac{2 \cdot \varphi \cdot R^2}{g \cdot \chi \cdot n_0^2} + 1} \quad (9)
\]

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

The calculation results showed that in all years of observation, the calculated values according to the proposed formula and the measured values of the average flow rate, hydraulic resistance, and roughness coefficient give good convergence.

The average deviation between the measured and calculated values of the average flow velocities and the Chezy coefficient in the area of the total erosion of the Amudarya river bed was 0.25 % and 0.81, respectively. In this case, a change in the value of the coefficient of hydraulic resistance was observed from 0.054 to 0.001.

It should be noted that the dynamics of all these parameters of the channel at various costs corresponded to the values of the roughness coefficient of the channel in the zone of the cramped area, which had some dynamics from 0.056 to 0.001. In the second and third high-water years of observation, the calculated and measured values of the average flow speed also gave good convergence, the calculated and measured values of velocities varied from 0.16 m/s to 1.89 m/s, with a change in the value of the Chezy coefficient from 16.62 up to 70.05 m 0.5 / s.

The average deviation between the measured and calculated values of the average flow velocities and the Chezy coefficient in the area of the total erosion of the Amudarya river bed for the second high-water year was 0.12 and 2.7 %, respectively. In this case, a decrease in the coefficient of hydraulic resistance was observed from 0.025 to 0.003.
It should be noted that the dynamics of all these parameters of the channel at various costs corresponded to the values of the roughness coefficient of the channel in the zone, which had some dynamics from 0.066 to 0.011.

In III, IV, high-water stages of observation, the calculated values of the hydraulic flow parameters that determine the nature of the channel process and the Chezy coefficient, hydraulic resistance changed in correlation with the flow dynamics and channel roughness. At these stages of observation, the influence of the operation mode of the Tuyamuyun and Takhiatash reservoirs on the dynamics of channel morphometry and hydraulic flow parameters is noticeable. The formation of significant deviations between the calculated and measured values of the hydraulic flow parameters can be explained by the noticeable influence of the structures on the flow dynamics. Based on the foregoing, we can conclude that for conducting practical calculations it is possible to adopt calculation formulas based on the theoretical foundations of classical hydraulics and taking into account the inhibitory effect of the river bank [22, 23, 24].

4. Conclusions

Based on the discussion of the results of monitoring the dynamics of the morphometry of the riverbed and the hydraulic parameters of the water flow located on the site of the pontoon bridge, characterized by constraint to draw the following conclusions:

1. On the Amudarya River section, located in the zone of influence of the Tuyumun and Takhiatash reservoirs, intense deformations occur, both deep and planned;

2. As the graphs of the relationship between depth and water flow rate show, the sharp variability of the depth of the stream and the water level cause the formation of deigish in different sections of the considered section of the Amudarya river;

3. When calculating the channel capacity for determining the calculated value of the average flow rate and the value of the Chezy coefficient, the Chezy and Manning formulas with a correction coefficient are recommended taking into account the inhibitory effect of the river bed;

4. For a section of the Amudarya river where general erosion continues. The numerical value of the coefficient is established taking into account the ratio of the preserved longitudinal exchanging masses between flows in the transit zone and 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;

5. In the Nietbytas range, on all all $n = f (Q)$ communication graphs, the third type of change in the roughness coefficient is observed, i.e. with an increase in water consumption, the roughness coefficient decreases. In the initial stages, these connections were weaker, in the last stages there is an improvement in communication, which shows the gradual stabilization of the channel process;

6. In general, the analysis of the channel roughness coefficient under the conditions of regulated water flow in the flow backwater section showed that the channel process has not yet stabilized and, due to the influence of the operating modes of two irrigation reservoirs, it is not possible to identify the functional relationship between the integral characteristic of the river channel forces that counteract the flow movement - hydraulic resistance riverbed and flow rate of water moving in it $- n = f (Q)$. 

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