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The height of the pumping unit suction pipe inlet relative to the riverbed bottom

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Abstract. Currently, 78% of all irrigated land in Uzbekistan is provided with water by pumping stations and installations. The water sources of most pumping stations are rivers and irrigation channels that transport a large amount of bottom and suspended sediments. Due to the lack of consideration of bottom sediments moving in the form of ridges, when installing the pumping units suction pipeline, during their operation, these bottom pumps flow from the water intake source in the interior of the units. As a result, intensive waterjet wear of the flow part and the impeller of the pumps occurs. This leads to an intensive reduction in the main parameters of the pumps, as well as reduces their repair period. Currently, this is one of the major problems of pumping stations that take water from the Zarafshan river, as well as those operating on the Karshi, Amu-Bukhara, Amu-Zang and Jizzakh main channels. Laboratory studies were carried out on the experimental installation to determine the height of ridges with different granulometric composition of bottom sediments. As a result, a formula was obtained for determining the height of the ridge, taking into account the heterogeneity of ridge forms. Based on the obtained formula, a method for setting the height of the pumping unit suction pipe inlet relative to the riverbed bottom is recommended. The application of the proposed method does not allow bottom sediments to enter the inner part of the pumps, as a result of which their intensive abrasive wear decreases, the inter-repair period increases, while maintaining its main parameters for a long time.

1. Introduction

Large transboundary rivers of Central Asia, such as the Amu Darya, Syr Darya, Zarafshan, as well as medium and small rivers always transport a huge amount of bottom and suspended sediments. Numerous laboratory and field studies have proved that the flow rate of bottom sediments moving in the form of bottom ridges in watercourses is on average 20% of the flow rate of suspended sediments [1]–[4].

Currently in Uzbekistan from 4.3 million hectares of irrigated land is 2.3 million hectares are supplied with water by pumping stations owned by the Ministry of water economy of the Republic of Uzbekistan. A total of 1,693 pumping stations with 5,301 units of pumping units are in operation, with a total capacity of about 7,000 m^3/s. About 1 million more hectares of land is irrigated by small pumping stations and installations of water user associations and farms. In total, about 78% of all irrigated land is irrigated by pumping stations and installations [5]. In addition to natural watercourses,

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Uzbekistan's irrigation systems operate large main channels that also transport bottom and suspended sediments. Passing through the pumps of pumping stations, these deposits lead to abrasive wear of the internal parts [6]–[8]. Due to the omission of bottom sediments moving in the form of ridges during the installation of the suction pipeline of pumping units, during their operation, these bottom pumps flow from the water intake source in the interior of the units [9]–[11]. As a result, intensive waterjet wear of the flow part and the impeller of the pumps occurs. This leads to an intensive reduction in the main parameters of the pumps, as well as shortens their inter-repair period [12]–[16]. Currently, this is one of the big problems of pumping stations that take water from the Zarafshan river. These problems are also encountered at pumping stations operating on the Karshi, Amu-Bukhara, Amu-Zang and Jizzakh main channels [17], [18].

2. Materials and methods

The purpose of experimental studies was to assess the influence of various granulometric compositions of bottom sediments on the height of the riverbed ridges. Based on the obtained dependence, the height of the installation of the pumping unit suction pipe inlet relative to the riverbed bottom is determined.

The following research objectives were identified:

1. Checking the applicability of the inhomogeneity coefficient of mixtures in the form - $\varepsilon = d_{av.}/d_i$ with the involvement of the available data on the granulometric composition of heterogeneous bottom sediments.

2. Identification of the relationship between the ridge height and the heterogeneity coefficient of mixtures:

$$h_r = f\,(\varepsilon = d_{av}/d_i)$$

3. Determining the effect of the average size, sediment composition, and hydraulic flow characteristics on the height of the ridge:

$$h_r = f(H, \vartheta, Q, I, \vartheta/\vartheta_0, d_{av.}, d_{max}, d_{av}/d_i)$$

here: d_{av} – the average diameter of the sediment;
d_{max} – the maximum diameter of the sediment;
d_i – particle sizes with the corresponding percentage of security (i=5, 10, 15, 25, 35, 50, 60, 65, 70, 75, 85, 90, 95);
ϑ and ϑ_0 – average and non-washing flow rate;
H – the average flow depth;
I – slope of the free water surface;
q_s – bottom sediments expense;
ε – coefficient of sediments heterogeneity;
h_r – the ridge height.

Due to the difficulty of assessing the effect of heterogeneity of different types of natural sediments on the formation and movement of bottom ridges in full-scale conditions, the main experiments were performed in the laboratory. Experimental studies were conducted in the laboratory of the Tashkent Institute of irrigation and agricultural mechanization engineers on a hydraulic tray (Figure 1).

Artificial mixtures of various types were used as experimental material. Bottom sediments of the Chirchik river in the foothill section of the Gazalkent dam were used as the main experimental material. Types and varieties of manufactured sediments correspond to V.N.Goncharov's classification. Of these varieties of each type, experimental mixtures are taken, which are shown in Table 1, and in Figure 2 in the form of graphs of the granulometric composition of experimental mixtures.

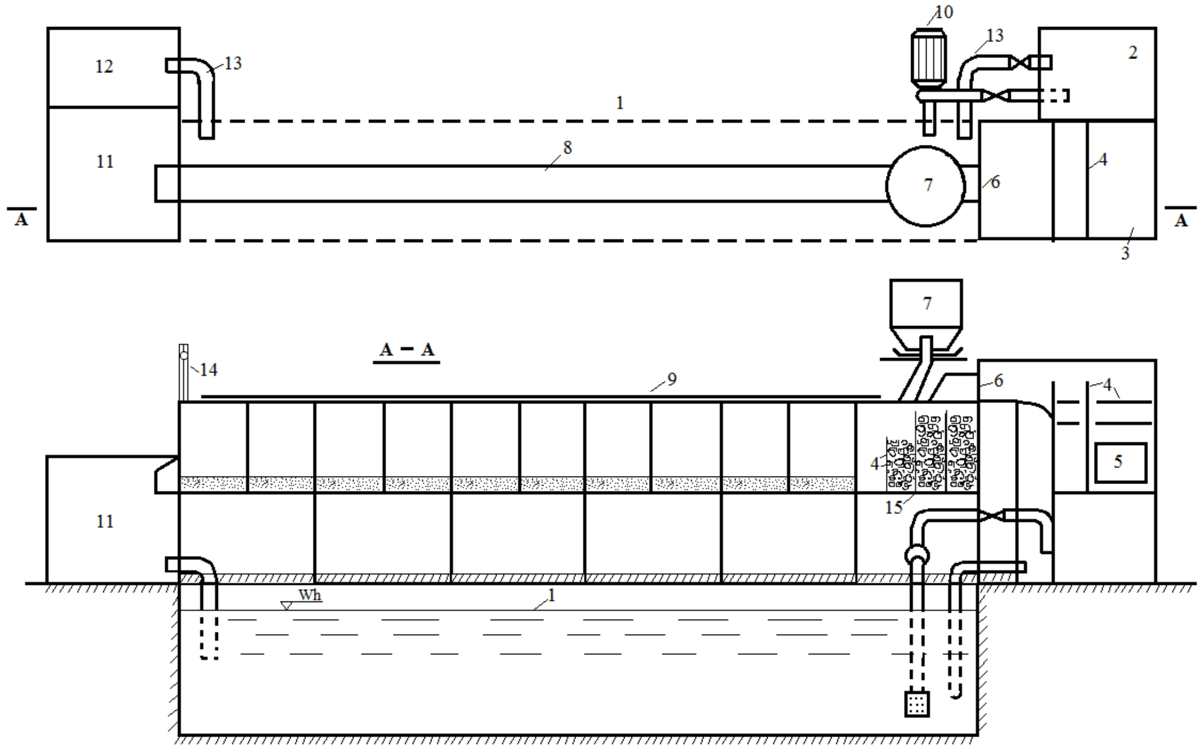

Figure 1. Scheme of a flat glazed experimental unit: 1-main pool; 2-main tank; 3-water intake tank; 4-dampener grids; 5-connecting pipe; 6-spillway; 7-dispenser; 8-tray; 9-rail; 10-centrifugal pump; 11,12-sump pool; 13-return pipes; 14-control panel; 15-chips-dampers.

Table 1. Grain-size distribution of artificially made sediment

No.	Type of sediment	Grain-size distribution in % mass, for particle size in mm									d_{av} (mm)	$\varepsilon = \frac{d_{av}}{d_{50}}$
		10÷7	7÷5	5÷3	3÷2	2÷1	1÷0,5	0,5÷0,25	0,25÷0,1	<0,1		
1	Edge fractioned	-	-	56,75	2,25	2,75	4,5	14,9	14,25	4,6	2,49	0,83
2	Small fractioned	9,5	8,5	8,75	13,75	22,25	14,75	8,75	9,25	4,5	2,51	2,24
3	Large fractioned	-	-	36,5	27	18	11,5	5,07	1,31	0,62	2,53	1,24
4	Evenly fractioned	11,1	10,1	10,1	11,1	11,1	11,1	11,1	12,1	12,2	2,51	2,8
5	Mean fractioned	-	14,4	14,8	15,3	32,7	18,6	2,2	1,25	0,75	2,48	1,88
6	Homogeneous	-	-	-	100	-	-	-	-	-	2,50	1,0

The experimental studies included six series of main experiments. Each series included from ten to fifteen experiments, with water consumption - Q=5, 10, 15, 20 l/s. With constant water consumption, only the amount of solid flow rate was changed (from 1 to 6 experiments were conducted). A total of 81 experiments were performed.

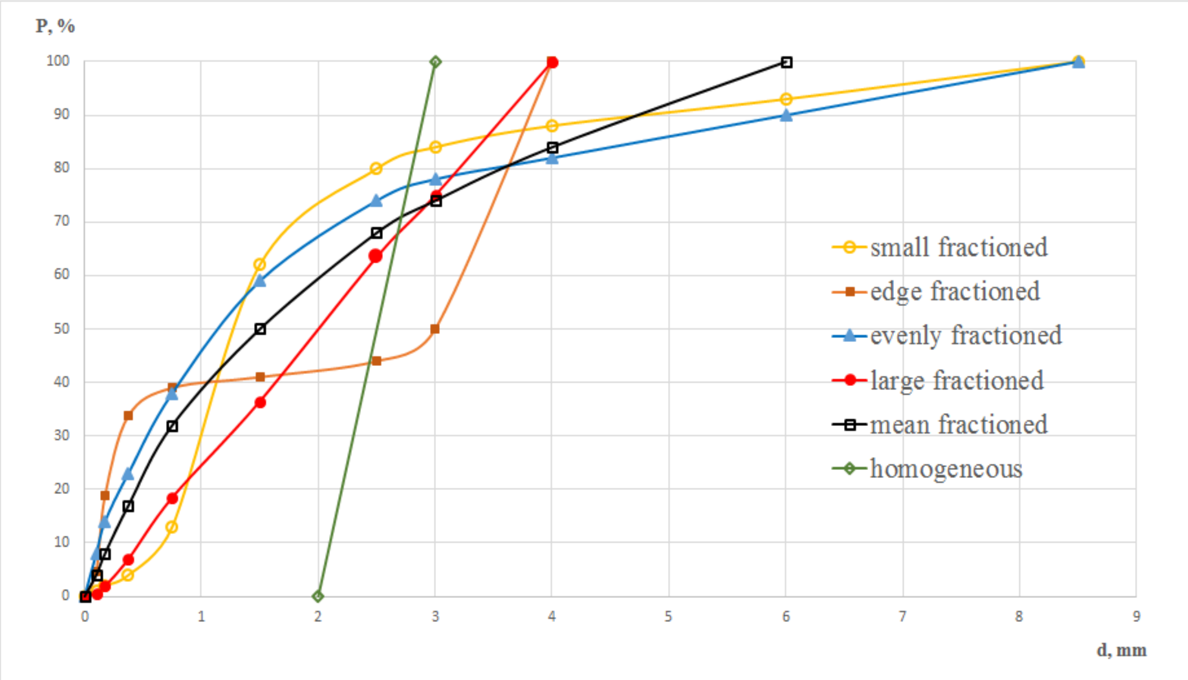

Figure 2. Grain-size distribution of experimented mixtures.

3. Results and Discussion

Determination of the bottom sediment height is necessary to set the height of the inlet suction pipes of pumping units relative to the bottom of the channel, determine the height of the threshold of intakes, estimation of roughness of the channel when determining the hydraulic resistance of the channel, the calculations of the movement of bed load and deformation of riverbed, etc. [19].

In order to set the connection of ridge height of various sediment composition with constant mean particle size and relative flow velocity, from the obtained experimental data we created graphical relationships of - $h_r / d = f(\vartheta / \vartheta_0)$ (Figure 3).

Data analysis of the influence of particle size of sediment on the height of the ridges, depending on ϑ/ϑ_0- h_r = $f(d, \vartheta/\vartheta_0)$ show fine fraction material (d_i=0,1÷10,0 mm; $d_{av.}$=2,51 mm) to experimental data with large fractional material (d_i=0,1÷5,0 mm, $d_{av.}$=2,53 mm), height of ridges with equal values - ϑ/ϑ_0, tends to decrease. With increasing flow rate, the influence of particle size on the height of the ridges increases. If ϑ/ϑ_0=2,2 ÷ 2,4 ridges have a maximum height. With a further increase in the ratio of speeds (ϑ/ϑ_0> 2,4) ridge height decreases [18]. At the same time, the influence of sediment size also decreases. At values - ϑ/ϑ_0= 2,3÷2,5 the influence of sediment size on the height of the ridges is insignificant.

The following design formula was obtained on the basis of the analysis of the graphical relationship with accuracy of 0,7÷0,9 [18]:

$$\frac{h_r}{d} = -K_g \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^2 + K_{\text{н}} \cdot \left(\frac{\vartheta}{\vartheta_0} - 1{,}1\right) \quad (1)$$

here: K_g- the proportionality factor for the i-th composition, which, on the basis of the graphical dependence obtained (Figure 4), is determined by the following formula:

$$K_{\text{г}} = 4{,}38 \cdot e^{0{,}23 \cdot \varepsilon} \quad (2)$$

$K_{\text{н}}$ – the coefficient depending on the heterogeneity of the ridge, based on the resulting graphical dependence (Figure 5), is determined by the formula:

$$K_{\text{н}} = -9{,}2\varepsilon^2 + 35{,}8\varepsilon + 12{,}7 \quad (3)$$

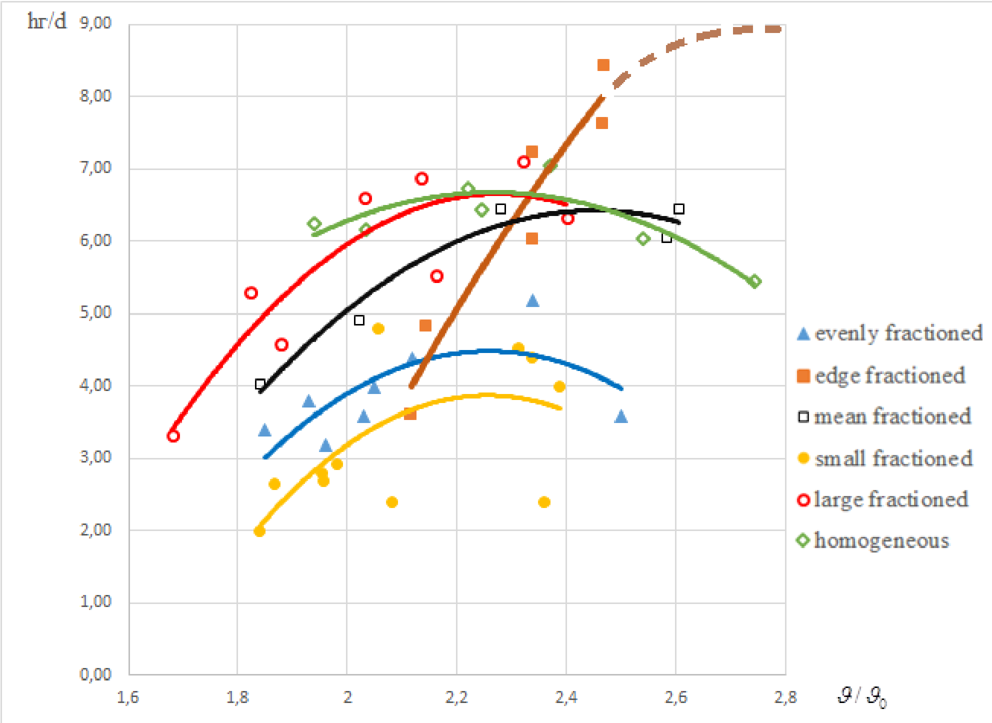

Figure 3. Plot of ridge height and sediment composition to the relative flow velocity.

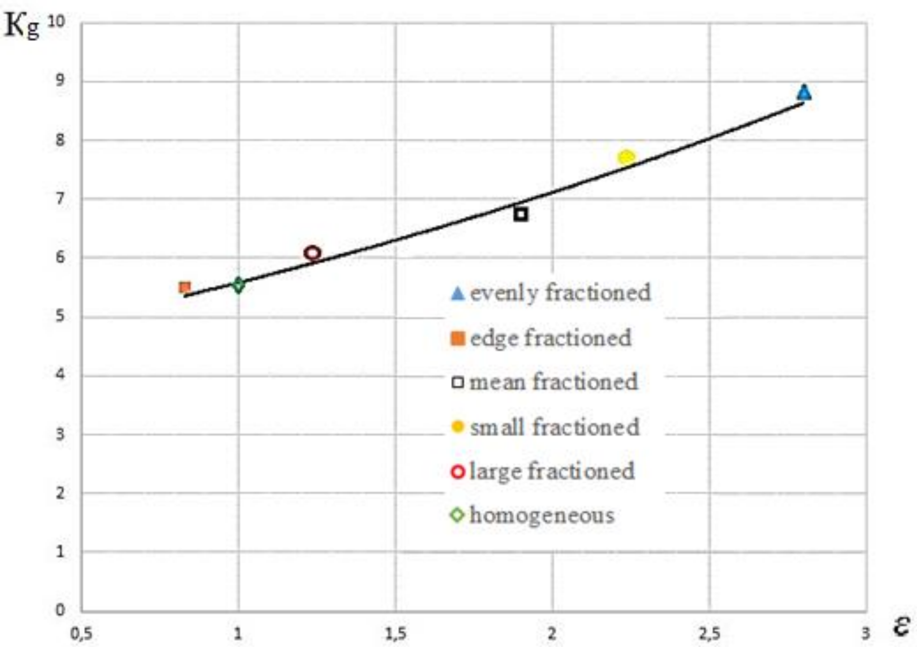

Figure 4. Dependence graph of the coefficient K_g on the heterogeneity of sediment.

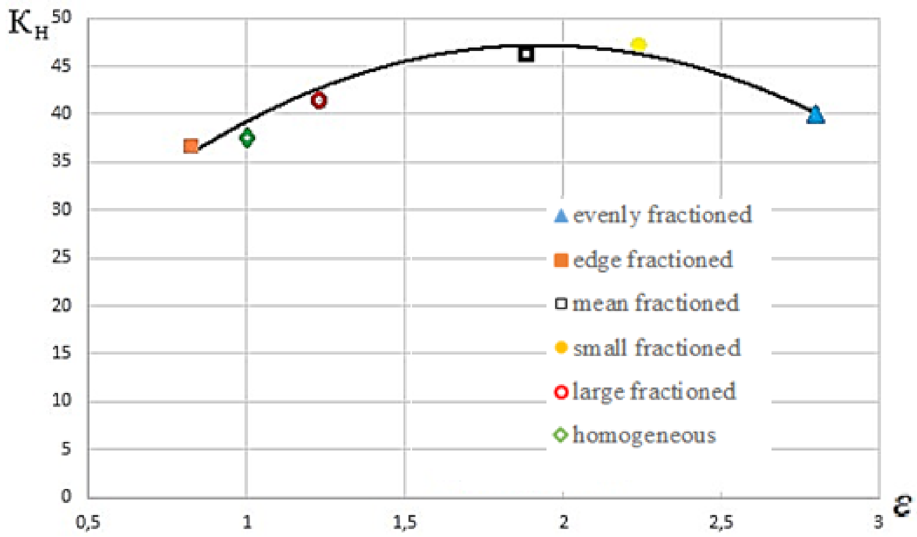

Figure 5. Dependence graph of the coefficient K_H on sediment heterogeneity.

Substituting (2), (3) in (1) we get the following formula:

$$\frac{h_r}{d} = -4{,}38 \cdot e^{0{,}23\cdot\varepsilon} \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^2 - (9{,}2\varepsilon^2 - 35{,}8\varepsilon - 12{,}7) \cdot \left(\frac{\vartheta}{\vartheta_0} - 1{,}1\right) \quad (4)$$

here:

$$h_r = d\left(-4{,}38 \cdot e^{0{,}23\cdot\varepsilon} \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^2 - (9{,}2\varepsilon^2 - 35{,}8\varepsilon - 12{,}7) \cdot \left(\frac{\vartheta}{\vartheta_0} - 1{,}1\right)\right) \quad (5)$$

When conducting experiments on an experimental tray, a change in the size of its height was observed in the form of a ridge pulsation (Figure 6). When the dynamic balance is reached, the ridge height begins to grow and when a certain height is reached, at the maximum average speed, it is quickly washed away (within 45-60 seconds) and takes on an average size. After a certain time, the process is repeated again. This phenomenon has also been observed in field studies on natural watercourses. Therefore, the final ridge height should be taken equal to:

$$h_r = h'_r + \Delta h_r \quad (6)$$

here: h_r – calculated ridge height, m;

h'_r – the average height of the ridge, determined by the formula (5);

Δh_r – pulsation value of the ridge height, m.

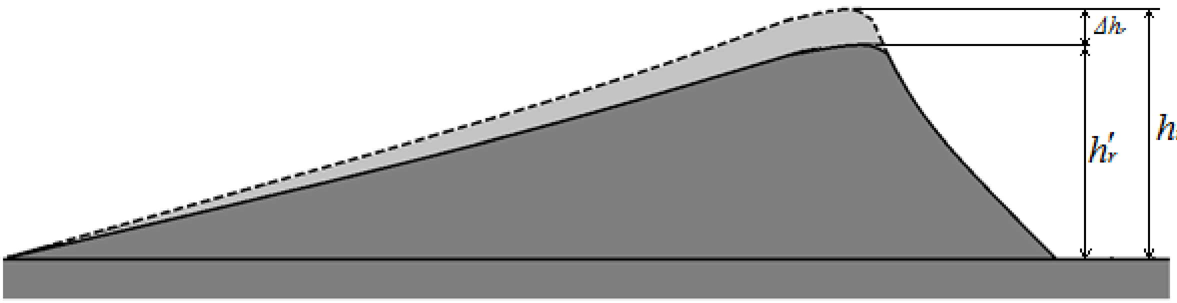

Figure 6. Calculation scheme for determining the estimated ridge height.

The pulsation value of the ridge height depends on the types and sizes of sediments, the ridge form and varies within - $\Delta h_r = (1{,}03 \div 1{,}15) h_r$.

Measurements and calculations made it possible to determine the values of the ridge height pulsation Δh_r depending on their form within $(1{,}03 \div 1{,}15)h_r$.

In known sources, the height of the pumping unit suction pipe inlet h_1 relative to the riverbed bottom (Figure 7) is assumed to be different [20]–[23]. But none of them specify the calculation formula for its definition. All dependencies for determining the height of the installation h_1 are determined based on the diameter of the suction pipe inlet part D_{in}. For example, based on [24] the minimum value of the inlet height is $h_1=0{,}4D_{in}$, and according to the recommendations of most authors [9], [10], [20]–[23], [25] it is accepted $h_1=(0{,}5 \div 0{,}8)D_{in}$. All operating pumping stations were designed and built on the basis of this data, which is still ongoing. Also, no work on this topic takes into account the movement of bottom sediments in water sources with a washed-out channel, i.e. when water is taken directly from the river or big channels.

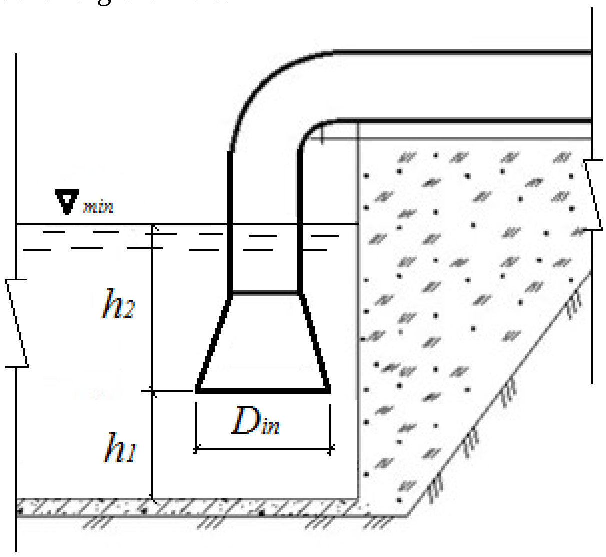

Figure 7. Existing scheme for determining the height of the inlet of a vertically installed suction pipe of the pumping unit.

Only in [26] it is indicated that the turbidity of water should be taken into account when determining h_1. On the basis of laboratory and field tests, the author of the work indicates that it is more expedient to take water intake of clean water $h_1=0{,}5D_{in}$, and in the turbidity water, he recommends taking $h_1=(0{,}9 \div 1)D_{in}$. Assuming that he experimented for the water intake chamber pumping station, where he took into account the need not to siltation of the pumping chamber, when the case of the water intake pumps water directly from the river or big canal where with pronounced ridges, the movement of sediment, accounting for the ridge height of the pump when determining the height of the entrance of the suction pipe is an important need to protect pumping equipment and pipelines from abrasive wear.

After analyzing all the work performed to solve this problem, we recommend taking the height of the pumping unit suction pipe inlet relative to the riverbed bottom (Figure 8) equal to:

$$h = h_{\mathrm{r}} + 0{,}5D_{in} \qquad (7)$$

here: $h_1 = h_{\mathrm{r}}$- the ridge height, determined by the formula (6);

h_2 – value equal to $0{,}5D_{in}$;

D_{in} – diameter of the suction pipe inlet part.

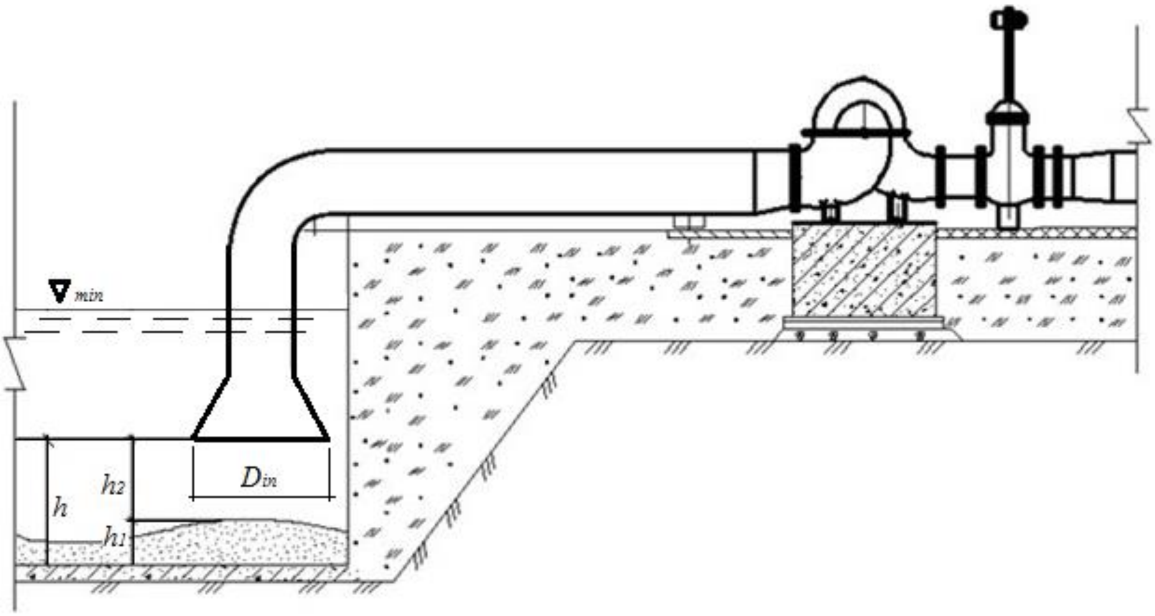

Figure 8. The proposed scheme for determining the height of the pumping unit suction pipe inlet relative to the riverbed bottom.

4. Conclusions

1. Based on taking into account the bottom ridges height, a method has been developed for determining the height of the installation of the pumping unit suction pipe inlet relative to the bottom when water is taken directly from the river or large channels.
2. The use of the recommended method will make it possible to optimize the height of the suction pipe inlet installation, which will prevent bottom sediment from entering the flow part of pumps and pipelines.
3. The exclusion of bottom sediment suction will significantly reduce the abrasive wear of the pump flow and impeller, which will increase the repair period, and therefore their overall service life.

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