Recommendations for the assessment and forecast of shore deformations in the average flow of the Amudarya river

Bekhzod Norkulov[1*], *Dilshod* Nazaraliev[1], *Bobur* Shodiev, *Iqboloy* Raimova[1, 2], and *Ozoda* Vafoeva[1]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, Uzbekistan
[2]Research Institute of Irrigation and Water Problems, Tashkent, Uzbekistan

Abstract. The paper presents the results of the field and numerical studies of the bank destruction in the middle section of the Amudarya River. The article presents the main factors of destruction of the banks during floods and low water flow. In addition, recommendations for protecting the coast from erosion are also developed. As a result of research into the process of intensive local reshaping of an easily eroded channel, hydraulic schemes have been developed for the occurrence of local bank erosion both in steady and unsteady motion in an open stream.
The recommendations are based on some patterns of interaction between the river channel and the flow during the period of low water and high-water flow. The external manifestation of this interaction is the coastal deformations, leading to the planned displacement of the channel.

1 Introduction

Natural deformations of river channels are mainly due to sediment imbalance, both along the length and in the transverse profile of the river channel [1-3]. The instability of river channels is due to the significant saturation of the river flow with channel-forming sediments, which cause intensive development of the channel process. Such development is often carried out in directions that create great inconvenience for human economic activity. In some situations, channel deformations cause great damage to the national economy. As an example, the following can be cited: as a result of the accumulation of sediments on the bottom, the water horizon can rise above the floodplain, which creates a threat of flooding of the cultivated lands and settlements located around the floodplain. Intense bank erosion, typical for the rivers of Central Asia, also leads to undesirable consequences, such as the washout of nearby cultivated lands and settlements and disruption of normal water supply to irrigation fields through the damless intake structure. The channel process on the Amudarya is characterized by special cases of intense bank erosion caused by a short-term flow dump on the shore. This phenomenon was called deigish, which in translation into English means "bad water". Later, this term was extended to all cases of coastal erosion

*Corresponding author: behzod1983@mail.ru

[4-7].

While studying the bank deformations of lowland rivers, one should understand the retreat of the bank edge under the influence of channel erosion and changes occurring in the thickness of coastal rocks during floods. The main factors are the degree of restriction of the flow by large channel forms and the angle of the flow to the bank [8, 9].

On the site in the area of the damless water intake of Karshi Mian Canal, deigish is observed on the left bank of the Amudarya near the village of Kyzylayak. The phenomenon of deigish occurs in those cases when there is a significant discrepancy between the structure of the bottom topography and the velocity field of the flow. This occurs in conditions of sharp changes in the flow of water and sediment. On the Amudarya River, the following regularity in the runoff of bottom sediments has been observed. The river flows through alternating narrowing and widening of the river channel. In accordance with this, regular changes in the sign of channel deformations constantly occur. In those cases when the erosion of channel formations predominates in the upper sections of the valley expansion, in the lower section of this expansion, the channel process acquires an accumulative direction. Sediment delay leads to the fact that the narrowing of the channel, following the expansion downstream, passes them less and a zone of erosion appears in the upper part of the next expansion. As the accumulated sediments in the lower part of the expansion are diminished, their flow along the narrow parts increases due to erosion, and signs of accumulation appear in the upper part of the expansion. They disappear as soon as the accumulation of sediments begins again in the lower part of the next expansion. It has been traced that the change in the sign of deformations in Amudarya occurs 1 time in 2 years [10].

In addition, it should be noted that the wandering of the main channel of the Amudarya River occurs due to an increase in water intake, river overload is laid down below the water intake site, due to frequent discharges of sediment during cleaning into the floodplain of the river. This led to the deposition and rise of the channel bottom and intensive wandering of the flow and , thus, causing partial displacement of the main flow to the left bank. As a result of a change in the profile of the channel and the formation of so called “dump concept”, the main channel wanders along a wide floodplain. A meandering channel is formed in the water intake area and in the coastal zones of intense erosion, especially on the right bank of the river below the water intake site in the KMC headworks, a deigish is observed [11, 12].

2 Research methods

The study of the results of field and numerical studies in the middle section of the Amudarya River, the assessment of the state of the Amudarya riverbed, the occurrence of local bank erosion both in steady and unsteady motion in an open stream is the research method of this work.

3 Results and discussions

Calculations of bank deformations according to the formulas recommended below can be made with any lead time. In this regard, the approach to defining the concepts “short-term forecast” and “long-term forecast” in these recommendations is conditional and their selection as independent settlement operations is dictated by practical considerations. All recommended formulas, being built on a single fundamental basis, differ from each other, as a rule, according to the values of the entered numerical coefficients.

According to calculations of coastal deformations, the amount of displacement of the edge of the coast X, m, for one flood in the design range is determined by the formula

$$\mathrm{X} = k_1 \cdot k_2 \cdot k_3 \frac{\rho_w(\bar{H}+h_1)}{(H+h)}(B-2B_1) \quad (1)$$

where k_1 is the channel asymmetry coefficient; k_2 is the shore erosion factor; k_3 coefficient of moistening of soils of the coast; ρ_w is respectively, the density of water (usually $\rho_w = 1.0\ t/m$ and soil, t/m^3; $\bar{H}$ - the average depth of the channel, m; h_1 is the height of the peak of the flood, m; H is the greatest depth, m; h is the height of the coast, m; B is the full width of the channel, m; B_1 is the width of the part of the channel from the line of the greatest depths of the flow to the eroded bank, m,
The channel asymmetry coefficient is determined by the formula

$$k_1 = \left[\frac{B_1}{(B-B_1)}\right]^2 \quad (2)$$

The coast erosion coefficient is calculated by the formula

$$k_2 = -\frac{1}{2h}[(h_1-h_0)+(t_1/t)(h_0-h_2)] \quad (3)$$

where h_0, h_2 is the height of the water level, respectively, at the opening of the ice cover and at the end of the flood, m; t_1 is the duration of the rise of the flood from the time of the opening of the ice cover to the onset of the peak of the flood, days; t is the duration of the period from the opening of the river to the end of the flood, days,

On rivers, the h_0 parameter is defined as the level corresponding to the beginning of the flood. In this case, the duration of the level rise t_1 and the duration of the entire flood period t should be measured from the actual start of the flood [13-15].

$$k_3 = h_1/h \quad (4)$$

When determining the magnitude of the retreat of the edge of the coast according to the formula (1), the level of reference of various parameters was taken to be the water level of 50% probability in the design section (Fig. 1).

In this work, a series of calculations of the current flows in the Amudarya River during high floods with a water flow rate of 6800 m^3/s is carried out. It should be noted that in the Client's data on the relationship between flow Q and water level Z in the Amudarya River at the KMC water intake (Fig. 1), the maximum water flow was 5250 m^3/s. To carry out hydraulic numerical experiments, the Q-Z connection diagram fig. 1 was extrapolated.

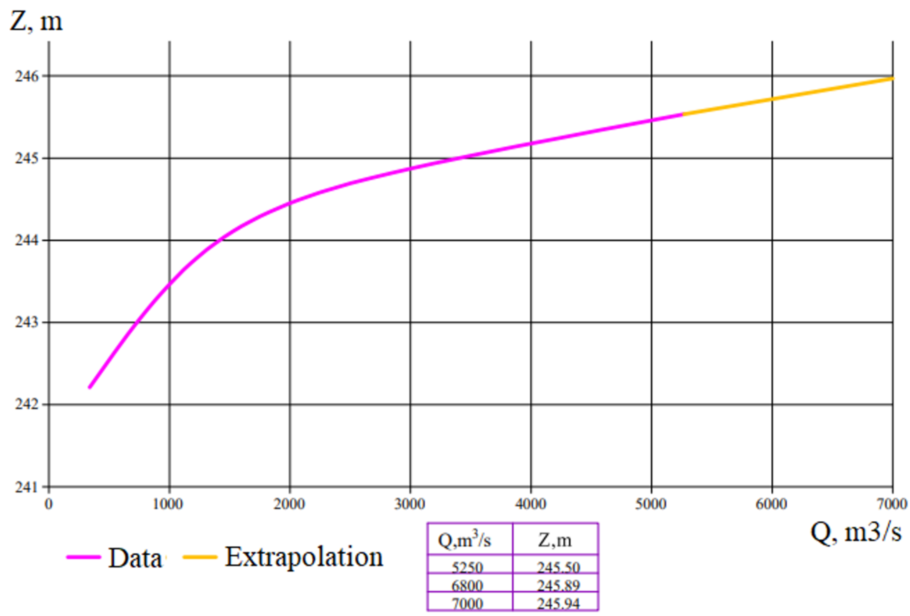

Fig. 1. Extrapolated graph of the relationship between the flow and water level in the Amudarya River at the water intake of the Karshi Main Canal

In formulas (1) and (3), the parameters that take into account the development of the flood h_0, h_1, h_2, t_1 *and* t refer to year 2021. As a result, formula (1) is an estimate.

Calculations of coastal deformations according to formula (1) are limited by the conditions when $2B_1 < B$.

To estimate the average long-term crest of the coast retreat value $\bar{X}$ m/year, it is recommended to use the formula

$$\bar{X} = mBq\frac{\rho_w}{\rho}\frac{(\bar{H}+h_1)}{(H+h)} \tag{5}$$

The parameter m is a product of the form

$$m = k_1\left(1-\frac{2B_1}{B}\right) \tag{6}$$

The values of m are given in Table 1

The parameter q is the product of the coefficients k_2 and k_3, in which all values of the characteristic flood levels and the dates corresponding to them refer to long-term averages, and can be expressed as follows:

$$q = \frac{\overline{h_1}[(\overline{h_1}-\overline{h_0})+\overline{t_1}/t(\overline{h_0}-\overline{h_2})]}{2h^2} \tag{7}$$

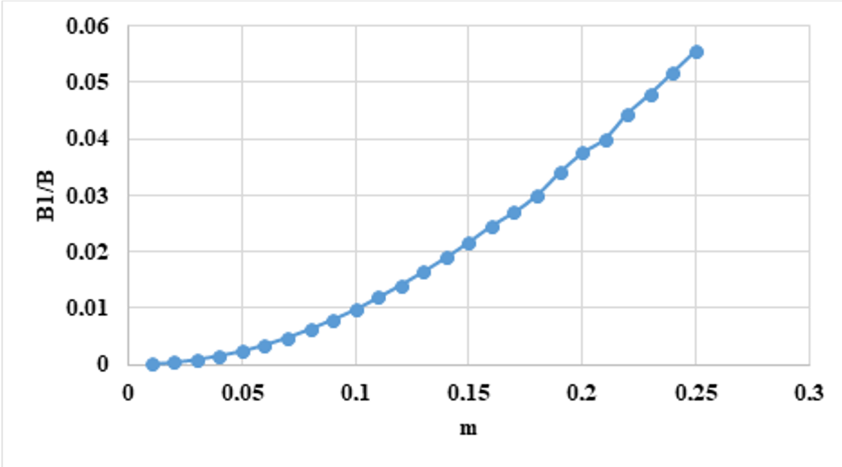

Fig.2. Determination of the condition for predicting coastal deformations

The predicted average value of the retreat of the edge of the coast for a given period $X_{\mathrm{p}} > M$ is found by the formula

$$X_{\mathrm{p}} = mBTq\frac{\rho_w}{\rho}\frac{(\bar{H}+\bar{h}_1)}{(H+h)} \quad (8)$$

where T is the period, years.

Formula (8) is recommended to be used to predict the retreat of the bank edge for a period of three years and for the entire estimated period of operation of structures being built in the near-river zone.

During the forecast period, the line of maximum depths may shift, which, in turn, will affect the B_1 value. These changes can be taken into account by introducing into formula (8) an additional expression 2.6 B_1 / B. Then we will obtain a formula for determining the magnitude of the retreat of the edge of the shore with a long-term forecast X_{dr}, m.

$$X_{\mathrm{dr}} = 2.6mB_1Tq\frac{\rho_w}{\rho}\frac{(\bar{H}+\bar{h}_1)}{(H+h)} \quad (9)$$

When solving engineering problems, there is often a need to obtain the maximum predicted value of the bank edge retreat in 1-2 years. In these cases, calculations must be made taking into account high floods on the rivers. Such accounting is achieved by replacing in formula (8) the average long-term value of the flood peak $\overline{h_1}$ by the maximum observed level h_{max} [15-19]. Then we obtain a formula for determining the magnitude of the retreat of the bank edge with a short-term forecast $X_{k.r}$, m.

$$X_{k.\mathrm{r}} = mBTq_1\frac{\rho_w}{\rho}\frac{(\bar{H}+h_{max})}{(H+h)} \quad (10)$$

The parameter can be found by the formula:

$$q_1 = \frac{h_{max}[(h_{max} - \overline{h_0}\,) + (\bar{t_1}/t\_(\overline{h_0} - \overline{h_2})}{2h^2}$$

At the early stages of the design, when the initial data for calculating possible bank deformations using formula (8) is still insufficient, the approximate value of the retreat of the bank edge for a given period Xp p, m, can be obtained using the following formula:

$$X_{\text{pp}} = 0.2mBT\frac{\overline{h_1^2}}{h^2}\frac{(\bar{H}+\overline{h_1})}{(H+h)} \quad (12)$$

where $\overline{h_1}$ is the height of the peak of the flood, numerically equal to the height of the floodplain.

Calculations were made for the section of the Amudarya river in the damless water intake of the KMC, which develops according to the type of free meandering. The coast has a height of up to 2-3 m and abruptly breaks into the water. The surface of the floodplain near the shore is relatively flat; during floods of low frequency, it is inundated.

Based on the analysis of field studies, the initial parameters were obtained (Table 2), which were used to solve several problems,

The first task was to calculate the retreat rates of the crest for each of the previous five years. For this, formula (1) was used. The calculation results are given in Table. 3,

The second task was to predict the average long-term rate of coastal erosion. To solve it, formula (5) was applied. As a result, the average rate of coastal deformations over 5 years was obtained (see Table 3). In this case, given the lack of information about the level regime for a longer period, this value can be considered as a long-term predictive average.

The third task was to establish the maximum value of possible coastal erosion per year. For this purpose, formula (10) was used. The calculations took into account the maximum water level in the flood for the previous observation period. It was noted in the third year (see Table 2). The result is also given in Table. 3,

Table 2. Coastal erosion in Amudarya during 2021

Year	*B*	*B₁*	*B-B₁*	*H*	$\bar{H}$	*h*
2021	600	100	500	10	6.6	6.0
Months	h_1	h_0	h_2	t_1	t	ρ
March	5	0	-1	43	100	1.75
April	4	-1	0	37	80	1.75
May	7	1	-2	40	110	1.75
June	5	2	-1	38	105	1.75
July	6	2	1	42	95	1.75
Average parameter value	5.4	0.8	-0.6	40	98	1.75

Table 3. Erosion intensity during Spring and Summer months

Design parameters	Months					Average monthly parameters
	March	April	May	July	August	
k_1	0.04	0.04	0.04	0.04	0.04	0.04
k_2	0.45	0.38	0.59	0.34	0.37	0.42
k_3	0.83	0.66	1.16	0.83	1.00	0.90
$k_1 \cdot k_2 \cdot k_3$	0.015	0.01	0.027	0.011	0.015	0.015
q	0.37	0.25	0.68	0.28	0.37	0.39
q_1						0.66
ρ_w/ρ	0.57	0.57	0.57	0.57	0.57	0.57
$\bar{H}+h_1$, m	11.6	10.6	13.6	11.6	12.6	12.0
$H+h$, m	16	16	16	16	16	16
$H+h_{max}$, m	-	-	13.6	-	-	-
m	0.027	0.027	0.027	0.027	0.027	0.027
mB, m	16	16	16	16	16	16
X, m/year	2.48	1.51	5.23	1.81	2.69	2.74
$\bar{X}$, m/year	-	-	-	-	-	2.67
$X_{\text{k.p.}}$, m	-	-	5.11	-	-	

Intensive erosion of the banks of the Amudarya river occurs as a result of the filling of the main channel with alluvial deposits during a sharp drop in the water level. The filling of the main channel with alluvial sediments is explained by the oversaturation of the flow with bottom and near-bottom sediments due to changes in the speeds of movement of surface and bottom jets.

Since one of the main reasons for the occurrence of intense erosion of the banks of the Amudarya River in the meanders is the stall of the flow, i.e. the formation of a stall current, based on long-term data of field studies of the river, in [20], the cause of the occurrence of a stall current is explained as follows. The analysis of the resulting stall current begins with a consideration of the specific features of the meandering course of the channel flow.

During the rise of flood waters, the upper part of the bend is subjected to increased erosion, and sedimentation and formation of sand ridges occur in the rift section. The sources of sediments are: suspended sediments coming from the upper reaches of the river - sediments formed from the erosion of the upper part of the bend, as well as partial sediments from the erosion of the floodplain in the upper part of the bend. Some of these sediments are deposited on the rift, and some goes downstream. During the period of flood waters that fill the entire channel, the main direction of sediment movement almost coincides with the movement of the main flow on the surface, i.e. dynamic axis of flow. During this period, the location and direction of the sand ridges should most likely coincide with the direction of the main flow on the surface. During the recession of the flood, the flow changes its direction in accordance with the direction of the sand ridges.

On winding - meandering channels, as is known, there is a downward displacement of the flow when the flood rises or an upward displacement of the flow when the water level drops.

Based on observations in nature of the flow regime and bank erosion, this phenomenon can be explained as follows:

a) the downward displacement of the flow during the rise of the flood usually occurs with a continuous flow of the flow with an average or low water flow. The channel shape becomes relatively stable and steady, the flow from point B in the deep channel of the upper part of the bend, through the rift B goes to point B in the deep channel of the lower part of the bend. At point B, due to prolonged erosion, the channel also becomes quite deep. In addition, the channel on the rift due to erosion is significantly deepened, and the current becomes less intense. However, when the flood begins to rise, the hydraulic slope of the water surface increases sharply, and the flow velocity increases rapidly. Since the horizon in the lower part of the bend has not yet had time to rise, the flow core is displaced to point B downstream;

b) after the rise of flood waters, a sandy ridge might be formed in the upper reaches of the erratic section. The direction of these sandy ridges basically coincides with the direction of the core of the stream during the floods. Since these sandbanks will be quite high when the water level drops, the direction of the flow changes in accordance with the direction of the sandbanks during the recession of the flood, and the direction of the flow and the direction of the sandbanks form an angle between them. When the current speed increases, the direction of the current deviates somewhat downstream, forming an angle.

Since sand ridges are mostly formed during the rise of the flood, then during the period of water recession, the direction of the flow must change and be at some angle to the sand ridges or deviate downstream. This is the displacement of the flow upstream during the recession of the flood.

Thus, sandy ridges on the rift are formed during the rise of the flood (at its peak) and are washed away during the recession of the flood. A flow stall occurs on a rift during the erosion of sand ridges and mounds. Under the conditions of the Amudarya River, the intensity of the decline in the level of flood waters is always much greater than the intensity of lowering the elevation of the top of the sand ridges. During the period of complete filling of the channel with flood waters, the slope of the water surface is quite uniform. Under these conditions, it is difficult to determine by the type of water surface where the channel passes and where the floodplain begins, although local workers on the Amudarya quite successfully determine areas of large and small depths of the stream. In conditions where the degree (speed) of lowering the water level is much higher than the rate of lowering the top of sandy ridges and mounds, depressions form on the surface of the water.

With a further decrease in the water level, waves are formed on the water surface near the sandy mounds. The hydraulic slope of the water surface on the rift towards the bend increases sharply. At this time, the flow velocity over the sandy ridges and hillocks approaches the critical one, and a critical depth is established above the hillocks. Consequently, when the intensity of the fall of the flood water level is much greater than the intensity of the lowering of the tops of the sand ridges and hillocks, the sand hillocks and ridges, due to the significant steepness of the slope of the water surface, are subject to increased erosion. The erosion products in the form of a spit move from the rift to the bend and press the coastal current against the bend. At the same time, we note that the height of sandy ridges and mounds on the rift should not be the same throughout the entire section of the channel, and the fractional composition of sediments at different points of the bed is also not the same. The depth of the flow during the flood is significant, and it is almost the same in different sections, and therefore the intensity of erosion at different points in the channel section is the same. However, when the water depth is insignificant, a completely different picture can be observed: in this case, the depths at two points are already not the same, i.e. the intensity of erosion at different points is different; near the bend, the erosion occurs more intensively than at other points of the section. After some time, the cross section of the channel will change its shape, as shown in the cross section. In this case, at the bottom points on the bend, as the erosion proceeds, the depth of the flow will increase. As a result, this will lead to the fact that the main flow will mostly flow in the zone of greatest erosion. This will be the flow stall. Thus, the width of the main stream is much less than the width of the erratic section; at the same time, its depth greatly increases. In addition, the slope will intensify during the flood recession due to the intensive deposition of coarse sediment fractions and the subsidence of part of the suspended sediments in the bottom layers of the flow in the direction of the main section, i.e. due to excessive turbidity of the flow, the main direction of the channel is clogged. Such a dump is formed instantly by a sharp turn of the flow towards the shore. Usually, during the deigish, the width of the active channel in front of the eroded shore is much greater than in the area of the eroded shore.

The probability of a flow stall towards the coast can most often occur when, with a sharp rise in flood waters, it will be followed by a sharp drop in the water level (flood), than in cases where there is a sharp rise in flood waters and then a slow decline in their level.

The above-mentioned coastal channel deformations, as a rule, occur in combination with deep ones (bottom erosion or its rise as a result of sediment deposition). To obtain sufficiently reliable data on deep deformations, we carried out surveys of the bottom with an echo sounder (Fig. 3) in a section of the river channel with a length of about 800-1000 m and obtained data on the change in the average bottom over time (intensity of deep deformation) in the studied section of the river

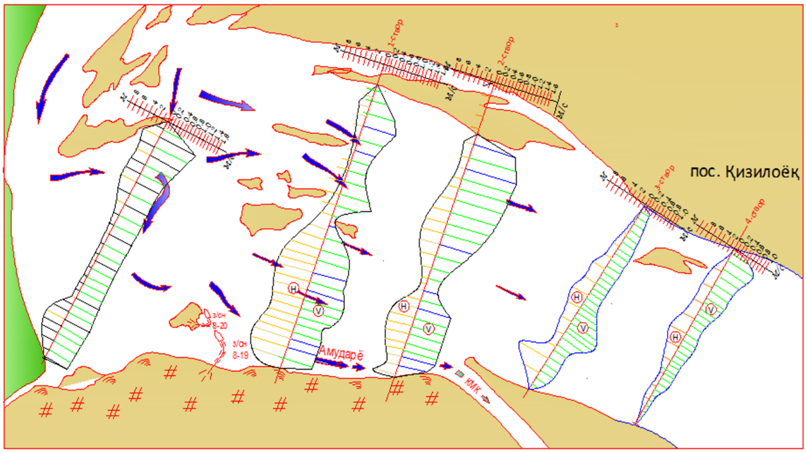

Fig. 3. Intensity of deep deformation in the studied section of the river

In this study, it was found that the average flow rate was several times higher than the washout rate determined for soils crossing the Amudarya River. The sharp variability of the flow rate and level, high speed, the saturation of the flow with nanoparticles moving and suspended along the bottom of the stream, and their abrupt change in the nature of transportation constantly change the channel, increasing the intensity of deformation processes in the plan. As a result of the removal of pulp from the cleaning of sediments entering the Karshi Main Canal, a narrowing of the channel in the lower section is observed, and the left bank is washed out [8, 9].

As can be seen from the figures, at an average flow velocity in the range of 0.5-2.0 m/s, the maximum value of water withdrawal from the river without a dam is observed at Pulysindon rock. The dynamics of the change in depth showed that when the water level rises, the height of the river bed increases, and decreases in low water.

It should be noted that due to sharp fluctuations in the level in this area, a change in the left bank is also observed. In this hydraulic process, the length of the deigish was up to 1.5 km. The Amudarya has a complex hydrograph in this area, so there can be several types of macro and mesoforms in one section of the river. In particular, the change in the water regime of the river has little effect on the shape of the channel, and these cases can be observed while maintaining the channel forms of the previous regime.

4 Conclusions

1. In the study area, as a result of the displacement of the main flow of the river in the area of the main water intake at a length of 1200 m, the flow concentrated in one channel, the width of which, depending on the water flow, varied from 250 to 500 m. Island located between the right and middle channels at a length of 2000 m, shifted to the left, towards the middle channel by 200-280 m forming a large shallow sandbank in the head part of the left channel.

2. The width of the bed of this channel along the water's edge was 320-350 m. Below the water intake point, an erosion of the island located between the left and right channels was observed from the side of the right stream at a width of 80 ... 150 m and a washout strip with a length of up to 1500 m. Comparison of the constructed transverse profiles each showed that deep bottom deformations in the area above and below the water intake manifest themselves in different ways: both in the form of erosion and in the form of drifting.

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