Method of restoring water level of small rivers

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Abstract. The article presents method for restoring the water level of small rivers that are subjected to degradation on the example of section of the Meklet River. To assess the degradation of rivers, there is proposed method based on maintaining balance between bottom sediments removed from the riverbed and the water volume in the prism of coastal landscape flooding during high water. The methodology for calculating the amount of silt shifting can be used to monitor the state of river beds. When forming coastline on inconvenient coastal landscapes as enclosing structures, the method allows the use of flexible tanker shells filled with excavated bottom sediments.

1 Introduction

Natural factors determine the hydrological conditions for the formation of floods on rivers, on which the regime of water levels depends. The most significant influence of hydrology is expressed on small rivers with reduced capacity [1]. The characteristic elements of geomorphology and relief form zones of waterlogging and flooding along river banks, distorting the natural coastline of streams. Scientists engaged in the classification of rivers and natural zoning of the territory on water regime [2, 3], landscape zoning [4, 5] note that knowledge of the hydrological regime of water bodies is basic information for making decisions related to environmental planning, the use of water resources in the river basin and forecasting emergency situations on small rivers [6, 7, 8]. Hydrogeological conditions determine the natural drainage of territories, the nature of sediments (genesis, properties) of the aeration zone, the structure of the groundwater balance (the ratio of incoming and outgoing items), the level of groundwater and their amplitude [9, 10].

Anthropogenic factors causing flooding of floodplain lands include: regulation of river flow, development of land reclamation, leveling of the soil surface, passages of heavy agricultural machinery, irrational planting of forests' bands, construction of roads and canals in the embankment without taking into account the terrain, crossings on beams,

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terracing of slopes, plowing across the direction of the natural runoff of atmospheric precipitation [11]. Natural and anthropogenic factors, acting on the agrolandscapes of the steppe river basins, accelerate the processes of soil erosion, which leads to an intense wash-off of fine earth into river beds and baulks [12]. As a result, degradation of watercourses occurs, which causes change in the natural coastline, occurrence of emergency situations associated with floods [1, 13]. It is necessary to restore water bodies from degradation.

The object of research was chosen the steppe river Mekleta with clearing areas in the source with the total length of 1.95 km, flowing in the Krasnodar Territory (Fig. 1). The Mekleta river is 9.83 km long and is blocked by three dams. The floodplain of the river is up to 350 m. The width of the river varies from 20 to 130 m. The watershed area is 51.4 km², the average slope of the channel is 3%, the flow rate of 95% availability is 0.03 m³/s; discharge volume is 0.96 million m³. The intra-annual flow distribution is uneven: the maximum discharge is observed in March with the volume of 0.44 million m³; the minimum is from August to December and equals to 0.01 million m³, respectively. The minimum 95% water consumption in the summer-autumn period equals to 0.016 m³/s.

Fig. 1. Geographic location of the Meklet River.

The water regime of the river is characterized by pronounced spring flood and summer-autumn-winter low water. The main source of water for the river is melted snow water and summer precipitation. The river flow is regulated by dams. Sediments block the channel, which leads to flooding of coastal areas during high water. The dams are out of order.

A small runoff during the summer-autumn low-water period and sediment layers have significantly reduced the volume of ponds on the river, creating unfavorable conditions for the accumulation of discharges in ponds for economic purposes. The riverbed has degraded, the historical coastline has been disrupted, reclamation of the riverbed is required to restore its water content.

2 Methods

The main reason for the degradation of small rivers is the deposition of sediments in the channels due to the irrational use of water resources, economic activities on the banks of rivers, which include plowing the soil of the water protection zone, unauthorized discharges

of untreated runoff from adjacent territories, etc. The degree of river degradation depends on the volume of sediment layers in the channel and is manifested by a rise in the water level during the passage of high water [12,13]. When assessing the volume of sediments, normal retaining level NRL in the river is established. The coastal marks of the maximum FRL level for 5% flood of discharge probability are determined. The difference in levels (FRL - NRL = Δh) is used to determine the average depth at which flooding of coastal areas during high water occurs.

To assess the degradation of small rivers, balance method is adopted, where balance is performed between the soil removed from the channel in the form of sediments and the volume of water in the prism of flooding coastal landscapes during high water:

$$W_p = W_n, \quad (1)$$

where W_p - volume of excavated soil from the channel in the form of sediments, m³; W_n - water volume of prism of flooding coastal landscapes, m³.

This method assumes that discharge of 5% availability will be skipped, and the volume of discharge should not leave the channel. In this case, high water discharge will not flood the coastal landscapes. The balance method is illustrated in Figure 2, which reflects the process of flooding of coastal landscapes by high water river discharge.

FRL (%) – maximum level for 5% flood of discharge probability, m; NRL – normal level, m; Δh – depth of prism of flooding coastal landscapes, m; h – depth of the river, m; h_p – sediment layers, m; Δb_1 – flooding strip of the left coastal landscape, m; Δb_2 – flooding strip of the right coastal landscape, m; b_c – width of natural riverbed, m; b_n – river flood width, m.

Fig. 2. Scheme for calculating the parameters of clearing the riverbed.

Coastal landscapes with the width of Δb_1 and Δb_2 will be flooded when the flood passes with the layer of water Δh before the riverbed is cleared. Therefore, the volume of water that will be completely placed in the channel during highwater should be equal to the volume of clearing the river from sediments (1), whence it follows:

$$b_c \cdot h_p = b_e \Delta h + \Delta h (\Delta b_1 + \Delta b_2), \quad (2)$$

where h_p - average depth of channel clearing, m; b_e – width of the restored channel, m; Δh - flooding depth relatively to NRL depending on flow availability, m.

The coastal landscape flooding zone can be determined according to the formula:

$$\Delta b = \bar{i} \Delta h, \quad (3)$$

where $\bar{i}$ – weighted average slope from the coastal landscape to the water's edge.

Flooding bands Δb_1 and Δb_2 are determined by the morphology of the coastal area. In the same area, the size of the flood strip may be different. Consequently, to assess the flooding of the bank, it is necessary to establish weighted average slope of the landscape towards the river.

Solving together equations (2) and (3), dependence for calculating the expected average depth of clearing the riverbed is obtained:

$$h_p = \Delta h \left[\frac{\Delta h(\bar{i}_1 + \bar{i}_2)}{b_e} \right], \quad (4)$$

According to the formula (4), the average depth of clearance is determined, as well as the amount of work on clearing the riverbed. The parameter Δh is taken at 5% river flood of the flow availability. The width of the natural channel b_e is found as weighted average parameter for all calculated river sections.

Consequently, according to formula (4), forecasts for clearing the channels of small rivers are fulfilled.

To clear the river from sediments, hydrometeorological, topographic and engineering geological surveys were carried out. As a result, the transverse and longitudinal profiles of the river were obtained. In total, 8 cross sections were selected at the survey site, where geological wells were drilled to a depth of 5 m and the thickness of sediment layers was determined.

3 Result and discussion

Studies of the amount of sediment in the Mekleta riverbed were carried out on 9 km long section (Fig. 3)

Fig. 3. Plan of research section with sites.

It was found out that sediment layers are represented by clayey silt from dark gray to black with the inclusion of fine sand. Silt occurs at depths from the surface to depths of 1.0-2.0 m everywhere. The surface water level in the Mekleta riverbed during the study period (July 2020) was at absolute marks of 75.55–85.36 m, depending on the relief, which corresponds to the average annual hydrological regime of the river. Groundwater recharge is carried out throughout the entire area of distribution due to infiltration of atmospheric precipitation and is closely related to the hydraulics of the river. Groundwater discharge is carried out by

natural outflow into the Meklet River. The water in the river is sulfate-hydrocarbonate with the salt content of 1.3 mg/dm³.

The research results are presented in typical sites with silt layers' depths. In total, to assess the degradation of the channel, 9 sites were made across for 120 m. Figure 4 (a, b, c) shows sites with the situation.

Fig. 4. Research results on sediment layers.

For 3 sections 1-1 - 3-3, calculation was carried out to assess sediments using the formula (4). The average clearing depth of sediment layers for the 1st section is 1.33 m, for the 2nd section is 1.52 m, for the 3rd section is 1.03 m. The calculation results for the volume of sludge clearing differ from the full-scale volumes by no more than 6-11%. Consequently, the methodology for calculating the amount of clearing from silt can be used for a preliminary assessment of the degradation of small rivers or monitor the state of the riverbed.

When determining the size of sediment layers, sludge samples were taken for suitability for application in the fields as organic fertilizers. The sum of toxic water-soluble salts was determined, which in all samples did not exceed 0.16% with the maximum allowable value of 0.25%. Only in one section was recorded sample with the toxic salt content of 0.42%, with permissible limit of 0.5%. Organic matter was in the range of 6.5-7.07%. In sludge samples, Ph was in the range of 7.7-8.6. Therefore, it can be concluded that bottom sediment layers are suitable for application in fields after reclamation according to the main indicators of Land Protection.

The sediments of small rivers are aleurite, which, under the influence of erosion processes, enters the bottom of rivers and barks every year. Aleurite of steppe rivers consists of fine earth of the fertile layer of chernozem soils, containing large amount of valuable nutrients. Bottom sediment layers are formed from fine earth and are easily washed away by the action of jets. Therefore, sediment layers are classified as weak, easily deformable, easily eroded soils.

Consequently, the siltstone of rivers and barks should be considered as “material” for the formation of natural coastline, which will allow restoring the historical shape of the watercourse. Under condition of absence of pollutants or their presence in quantities that do not exceed the maximum permissible concentrations in bottom sediment layers, they should be used to form coastline within the water protection zone and in places, where it is impossible, due to the narrowness of the channel, to form hydraulic dumps outside the water protection zone.

The solution of the problem is associated with the clearing of fine earth in the channels of watercourses and its transportation to the dump. The most rational way to restore the channels is to clear sediment layers by dredgers, which supply them to the disposal sites to form natural coastline [14, 15].

The methodology for calculating the parameters of clearing and utilizing sediments (4) can be used for various morphological conditions for the formation of natural coastline. One of the options for the formation of natural coastline is presented in Figure 5.

Fig. 5. The scheme of the formation of a natural (historical) coastline.

The advantage of this method is in the construction of flexible tanker shells along the natural coastline on inaccessible landscapes, for example, in built-up areas. Bottom sediments serve as the material for filling the shells.

4 Conclusion

Most of the small rivers in the South of Russian Federation are degraded due to irrational water use, regulated and polluted discharges and accumulation of large volume of bottom sediments in the channels, and as a result, unfavorable conditions are created for the use of river discharge. The way out to restore the water level of small rivers is to clear the channels from sediment layers.

To assess the degradation of small rivers, balance method is adopted, where the ratio between the soil removed from the channel in the form of sediments and the volume of water in the prism of flooding coastal landscapes during high water is carried out. Formula for calculating the average clearing depth of channel has been obtained. The methodology for calculating the amount of clearance from silt can be used for preliminary assessment of the degradation of small rivers and monitoring the state of the riverbed.

It has been established that bottom sediments are suitable for utilization in agricultural landscapes. The amount of toxic water-soluble salts in sediment layers does not exceed the permissible value.

The methodology for calculating the parameters of clearing and utilizing sediments allows the use of flexible tanker shells along the natural coastline on inaccessible landscapes. The material for filling the shells is the bottom sediments of small rivers.

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