Features of the use of non-destructive testing to combat siltation of the Krasnodar reservoir

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Abstract. The article discusses ways to use non-destructive testing to combat siltation of the Krasnodar reservoir. This article presents the results of solving the problem of silting of the Krasnodar reservoir for the rational use of water resources of floodplain territories. The forecast of changes in sediment for the future is determined considering the increase in overgrowth of the reservoir, further processing of the coastline, as well as a decrease in afforestation and an increase in cultivated areas in the Kuban river basin. The main measures to improve the transport of sediment into the dead volume bowl are considered, and ways to solve the siltation problem through clearing the flooded riverbeds are proposed to be carried out by the method of stirring, since this method is used in reservoirs with flow, because its essence lies in the fact that silt sediments are agitated with the help of a floating dredger with water jets and the pulp is not sucked into the dredger, and suspended sediments are transported by the flow of water into the bowl of the "dead" volume of the reservoir. It should be noted that during georadar studies on soils such as clays and loams, the boundaries are distinguished mainly by the degree of moisture. In our case, water is highly mineralized, and filtration significantly reduced the electrical resistance of soils, therefore, the separation of the lithological composition is possible only on the main lithological differences. With soil moisture more than 20-30% and high mineralization of soils with a relatively low resistance, the depth of the study was no more than 2-3 m.

1. Introduction
In the region of the earthen dam of the Krasnodar reservoir, on the clays of the Upper Pliocene up to a depth of 13-30 m, Holocene and Upper Pleistocene alluvial deposits are deposited, represented mainly by sands of different sizes with a gravel-pebble layer at the base; everywhere, sand is covered by a layer of clay and loam with a thickness of 3 to 7 m [1].

The Krasnodar reservoir is represented by the second flood plain, where the Holocene – Upper Pleistocene aeolian – deluvial sediments, represented by loess-like loamy, macroporous thicknesses from 6 to 12 m, lie down to a depth of 27 to 45 m on lower Pleistocene clays [2] sediments represented in the lower part by sand and gravel-pebble, with a total thickness of 10 to 32 m, and in the upper layer of clay [3] with a thickness of 5 to 15 m.

On the left bank of the Krasnodar reservoir, structures are located within the floodplain and partially the first floodplain terraces of the Kuban River and its left-bank tributaries. The geological structure is relatively homogeneous [4]. Holocene-Upper Pleistocene alluvial deposits occurring on the upper Pliocene clays are ubiquitous. Deposits in the upper part are represented by a layer of clay and
loam with a thickness of 4 to 11 m, and in the lower part - by sands mainly large and gravel and gravel-pebbles with lenticular sandy loam with a total thickness of 4 to 12 m [5].

Hydrogeological conditions in the area of the Krasnodar reservoir are determined by its location in the central part of the Azov-Kuban artesian platform-type basin. The upper part of the basin contains a large number of aquifers confined to the interbeds of sand and gravel-pebbles. To a depth of 300-350 m, the aquifers are hydraulically interconnected (active water exchange zone). The thickness of estuary-clay clays with a thickness of about 100 m serves as an immunity for them. The flooding of the territories adjacent to the Krasnodar Reservoir is influenced by the structure of the first aquifer from the surface, confined to the Quaternary sediments, occurring at depths from 13 to 45 m [6].

The left-bank part of the territories adjacent to the Krasnodar reservoir is located below its normal retaining level and is protected from flooding by protective dams. To protect the adjacent territories along the earthen dam of the Krasnodar Reservoir and low-pressure protective dams, various types of drainage structures (horizontal, vertical and combined) have been built and are in constant operation. The groundwater level regime in these territories is ensured mainly by the operation of drainage facilities. To a lesser extent, it depends on the structure of the gravity-free aquifer, fluctuations in the water level in the Krasnodar reservoir and the infiltration of precipitation [7].

The non-pressure aquifer in the area of the earthen dam, spillway, lock and on the left bank is confined to the thickness of the alluvial deposits of the Holocene and the upper Pleistocene and has a two-layer structure with a poorly permeable layer at the top and well permeable below. The coefficient of the total water conductivity of the aquifer varies from 100 m² / day to 500 m² / day. On the right bank, the non-pressure aquifer is confined to the aeolian-deluvial and alluvial deposits of the upper and middle Pleistocene and has a three-layer structure: a well-permeable layer of macroporous loam at the top [8], a low-permeable layer of clay in the center and a well-permeable layer of sand and gravel-pebble base. The coefficient of the total water conductivity of the aquifer varies from 150 m² / day to 400 m² / day.

At the same time, the results of studying the materials of engineering-geological and hydrogeological studies carried out both at the design stage and after the completion of the construction of the Krasnodar reservoir, show the natural foundations of concrete structures: a navigable lock, a water intake - a water outlet at PK 23 + 50 of an earth dam, a spillway structure with a fish elevator and an earth dam are represented [9], mainly by dissimilar water-saturated sandy soils from loose to dense composition, and partially, the plaz ary clayey soils and earthworks stacked alluvial and bulk, preferably water-saturated sand and clay soils, i.e. category III soils for seismic properties.

Over the years of the Krasnodar reservoir operations, the hydrogeological conditions both of the sites of hydraulic structures and adjacent territories have changed dramatically: groundwater levels have risen due to backwater and additional supply, their current regime depends on the level regime in the reservoir and in the downstream, in the Kuban River [10].

All these unsolved problems are relevant and indicate the need to justify ways to solve the problem of silting of the Krasnodar reservoir for the rational use of water resources of floodplain areas in the modern water management complex of southern Russia [11].

2. Materials and methods

The actual use of the Krasnodar reservoir is currently consistent with the design purpose. The sediment runoff in the Kuban river basin is determined by water erosion. Water erosion is especially pronounced in the mountainous and foothill parts, which is facilitated by the mountain-valley relief and large slopes of river channels. Precipitation falling on the underlying surface, in particular heavy rains, heavy snowmelt, debris from the catchment area into the river, forming sediment runoff. An important role here is played by the composition of the rocks composing the catchment, its afforestation, agrotechnical and water management measures carried out on the catchment area and in the riverbed [12]. The annual sediment runoff of the main rivers flowing into the Krasnodar reservoir, on average, is about 12 million m³ (Figure 1.).
No observations were made of stock sediment runoff in the Kuban River basin. The sediment load runoff modulus is determined analytically by the balance method, assuming a runoff modulus of the bottom sediments of the Kuban River near Krasnodar - 20 t / km² [13]. According to 2017 data, about 1.57 million m³ are formed due to coast processing. Due to the humus of plant debris in areas of the water area overgrown with aquatic vegetation, the sediment volume annually increases by 0.76 million m³.

Total, taking into account all sediment coming from outside the reservoir and forming in the bowl, the annual growth of sediment is 14.37 million m³.

The forecast of changes in sediment for the future is determined with the increase in the overgrowth of the Krasnodar reservoir, further processing of the coastline, as well as a decrease in afforestation and an increase in the cultivated area in the Kuban river basin. Given these factors, the increase in sediment volumes in the reservoir alignment will increase annually by 0.13% and will amount to 18.01 million m³ per year by 2036.

3. Results

The design of the Krasnodar reservoir was carried out with the fixed water levels in the reservoir: normal retaining level with a mark of 33.65 mBs, the main operational horizon; forced retaining level with a mark of 35.23 mBs, the maximum permissible level of water in the reservoir; level of dead volume, with a mark of 25.85 mBs, the minimum permissible water level in the Krasnodar reservoir.

Taking into account these horizons, the transporting ability of the watercourse of suspended and entrained sediments was determined. At the beginning of the Krasnodar reservoir operations, the volume of sediment entering the bowl annually amounted to 6.5 million m³, 2.5 million m³ of which...
was accounted for by sediment and 4.0 million m$^3$ was suspended. The total amount of sediment deposited in the bowl during the operation period amounted to 61.0 million m$^3$ over 10 years; the expected volume of sediment is 0.4 million m$^3$/year, and the ratio of the actual volume of sediment to the expected one is 100.8% of suspended and entrained sediments in the reservoir bowl (up to 95% according to the project) [14].

In 1992, there was an agreement signed between the government of the Krasnodar Territory and the Republic of Adygea to reduce the main working horizon by 90 cm, the normal retaining level was 32.75 mBs. This decision, in addition to technical indicators changes caused by the introduction of new regulatory documents, was primarily political in color. Therefore, the negative consequences of lowering the level were not calculated in detail. This decision led to a decrease in depth and the formation by 2004 of 92.0 km$^2$ of shallow areas, which is about 24% of the total reservoir area, and currently the area of shallow water is 100.0 km$^2$, which is about 26%. This led to the fact that by 2004, 9.1 million m$^3$ of sediment began to accumulate in the bowl of the Krasnodar reservoir annually, i.e. by 2004, sediment volume amounted to 255 million m$^3$, and by 2016 - 347 million m$^3$, (Figure 2).

![Figure 2. Siltation of the bowl of the Krasnodar reservoir: a - along the protective dam of the engineering protection of the Psekups river valley; b - along the Eastern Dam.](image_url)

The constant annual increase in sediment due to further siltation of the Krasnodar reservoir in the event of not taking drastic measures will lead to the fact that in the period from 2019 to 2035 it is predicted that 302 million m$^3$ of suspended particles will settle in the bowl of the reservoir. And the average depth of the reservoir relative to 1975, equal to 6.0 meters, will decrease to 3.5 m by 2035.

The change in the depths of the reservoir is associated with a decrease in the normal retaining level and, as a consequence, an increase in sediment volumes. The current state of the Krasnodar reservoir and its retrospective analysis show that most of the problems of a negative nature are associated with a decrease of 90 cm [15].

This situation can be compared with siltation by this value, which with a reservoir area of 382 km$^2$ is similar to siltation in the amount of 343.8 million m$^3$. During normal operation (until 1992), the annual sediment volume averaged 6.1 million m$^3$. Comparing the results obtained, we can say that siltation by 90 cm at a normal level of 33.65 mBs would occur after 56 years. The main volume of entrained and suspended sediment enters the bowl through the flooded riverbeds that flow into the Krasnodar reservoir.

A surface-sensing radio engineering device was used for work. It is designed to detect point and extended media interfaces with displaying the sensing results on the screen of the recording device in real time and then saving the sensing results to a file for processing and output to the printing device [16]. The measurements were carried out when moving the antennas along the profile of the base of the enclosing dam (Figure 3) with a given step and measuring the reflected signal. During processing and interpretation, GeoScan 32 and RadExplorer 1.4 processing packages were used. According to the
results of processing and interpretation, layers were identified: the upper part of the section with a thickness of up to 20 cm with a dielectric constant of $E = 4$. This is a soil-vegetable layer, slightly moistened; a layer with a thickness of up to 1 m with a dielectric constant $E = 7$, represented by loams of natural moisture; moist clay up to 1.2 m thick with dielectric constant $E = 18$; clay at depths of more than 3 m, moistened by more than 20%, with a dielectric constant of $E > 28$. In GPR studies on soils such as clays and loams, the boundaries are distinguished mainly by the degree of moisture. In our case, water is highly mineralized and filtration significantly reduced the electrical resistance of soils, therefore, the separation of the lithological composition is possible only on the main lithological differences, and, with soil moisture more than 20-30% and high salinity, the depth of study is limited to 2-3 m [17].

![Figure 3](image1.jpg)

**Figure 3.** The subsidence of the base and the loss of stability of the slopes of the earthen dam due to siltation of the Krasnodar reservoir: a - formation of a silt layer; b - subsidence of the base; c - the formation of voids in the base.

In order to transport sediment to a bowl of dead volume, it is proposed to clear the flooded riverbeds in the bowl of the Krasnodar reservoir, the siltation of which is about 1.0 m, including the Pshish River at a length of 33.5 km, a depth of 1.0 m, a width of 50 m; Psekups River at a length of 19.2 km, a depth of 1.0 m, a width of 50 m; Marta River, 13.16 km long, 1.0 m deep, 20 m wide; Kuban river at a length of 33.3 km, a depth of 1.0 m, a width of 80 m.

It is proposed that the flooded riverbeds be cleared by the method of stirring [18]. This method is used in reservoirs with flow, because its essence lies in the fact that silt sediments are agitated with the help of a floating dredger with water jets and the pulp is not sucked into the dredger, and suspended sediments are transported by the flow of water into the bowl of the dead volume of the Krasnodar reservoir. The use of this method is recommended for economic reasons, as it is 2.4 times cheaper than cleaning with pulp removal.

Assessment of siltation of the Krasnodar reservoir is carried out, as a rule, at low water, which does not allow realistically assess safety indicators. In most cases, conclusions are based on visual and instrumental measurements.

4. **Conclusion**

The catalyst for all negative processes is the fraction of depths less than 2 meters, and this leads to a deterioration in the quality of water resources, hence, as a result, an increase in the rate of siltation and overgrowing. It is necessary to eliminate shallow areas on an area of 100 km² of the Krasnodar
reservoir. To develop measures to improve the transport of sediment into the bowl of the dead volume of the Krasnodar reservoir.

The measurements were carried out when moving the antennas at a given step and measuring the reflected signal. The profile measurement speed depends on the detail of the study. According to the results of processing and interpretation, the following layers are distinguished:

- the upper part of the section with a thickness of up to 20 cm with a dielectric constant of $E = 4$. This layer corresponds to a soil-vegetable layer, slightly moistened;
- a layer with a thickness of up to 1 m with a dielectric constant $E = 7$, represented by loams of natural humidity;
- clay with a thickness of up to 1.2 m with a dielectric constant of $E = 18$, moistened;
- clay at depths greater than 3 m, moistened by more than 20%, with a dielectric constant of $E > 28$.

It should be noted that during georadar studies on soils such as clays and loams, the boundaries are distinguished mainly by the degree of moisture. In our case, water is highly mineralized and filtration significantly reduced the electrical resistance of soils, therefore, the separation of the lithological composition is possible only on the main lithological differences. And as practice shows, with soil moisture more than 20-30% and high mineralization of soils with relatively low resistance, the depth of the study is not more than 2-3 m.

References
[1] Yurchenko I F 2017 Automatization of water distribution control for irrigation Int. J. of Advanced and Applied Sciences 4(2) 72–77
[2] Kireicheva L V and Zakharova O A 2002 The effect of cyclic irrigation with wastewater on the properties of gray forest soils Eurasian Soil Science 35(9) 990–995
[3] Abdrazakov F K, Orlova S S, Pankova T A, Mirkina E N and Mikheeva O V 2018 Risk assessment and the prediction of breakthrough wave during a dam accident J. of Interdisciplinary Research 8(1) 154–161
[4] Olgarenko V I, Olgarenko G V and Olgarenko I V 2018 A method of integral efficiency evaluation of water use on irrigation systems Int. Multidisciplinary Sci. GeoConf. SGEM. 18(3.1) 3–9
[5] Yurchenko I F 2018 Information support for decision making on dispatching control of water distribution in irrigation J. of Physics: Conf. Series 1015 042063
[6] Kireicheva L V and Khokhlova O B 2000 Elemental composition of different fractions from the sapropel organic matter Eurasian Soil Science 33(9) 947–949
[7] Ovchinnikov A S, Bocharnikov V S, Skorobogatchenko D A, Borisenko I B, Chernyavsky A N, Abezin V G, Ryadnov A I, Shaprov M N, Kuznetsov N G, Nekhoroshev D A, Sedov A V, Grigorov S M, Fomin S D and Olgarenko V I 2018 The optimum geometrical form modeling of the “striegel” type harrow ARPN J. of Engineering and Applied Sciences 13(23) 9138–9144
[8] Bandurin M A, Vanzha V V, Volosukhin V A, Mikheev A V, Volosukhin Y V and Bandurina I P 2018 Finite-element simulation of permissible load on gate elements of water-conveying structures to assess risks of anthropogenic accidents J. of Physics: Conf. Series 1118(1) 012005
[9] Degtyareva O G, Degtyarev G V, Togo I A, Terleev V V, Nikonorov A O and Volkova Yu V 2016 Analysis of stress-strain state rainfall runoff control system – buttress dam Procedia Engineering 165 1619–1628
[10] Yurchenko I F 2018 Information support system designed for technical operation planning of reclamative facilities J. of Theoretical and Applied Information Technology 96(5) 1253–1265
[11] Bandurin M A, Volosukhin V A, Mikheev A V, Volosukhin Y V and Vanzha V V 2018 Finite-element simulation of possible natural disasters on landfill dams with changes in climate and seismic conditions taken into account J. of Physics: Conf. Series 1015 032011
[12] Yurchenko I F 2017 Methodological foundations for the creation of an information management system for water use in irrigation Bulletin of Russian Agricultural Science 1 13–17
[13] Degtyarev G V, Belokur K A and Sokolova I V 2018 Modeling of the building by numerical methods at assessment of the technical condition of structures Materials Science Forum 931 141–147
[14] Bandurin M A, Volosukhin V A and Vanzha V V 2018 Technology for water economy monitoring of technical state of closed drainage on irrigation systems Int. Conf. on Construction and Architecture: Theory and practice of industry development pp 214–218
[15] Degtyareva O G, Degtyarev G V, Lavrov N L and Aliev D U 2018 Constructive-technological decisions in regulating the flow of atmospheric precipitation Magazine of Civil Engineering 82(6) 32–48
[16] Gaydzhurov P P, Kravchenko G M and Savelieva N A 2014 Finite element modeling of elastic plastic bending of steel beams with use of rod end elements Construction mechanics and design of structures 2 17–22
[17] Chesnokov B P, Abdrazakov F K, Naumova O V, Krivoschhapov D S and Strelnikov V A 2017 The use of ionizing radiation for the tungsten preparation J. of Industrial Pollution Control 1–12
[18] Abdrazakov F K, Pankova T A, Zatinatsky S V, Orlova S S and Trushin Yu E 2017 Increasing efficiency of water resources use in forage crops irrigation Int. J. of Advanced Biotechnology and Research 8 283–293