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Assessment of the Kuybyshev Reservoir bed state: a case study

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Abstract. The generalized results of the Kuybyshev Reservoir bed relief survey using modern methods are presented on the example of two sites. Sakony site area is located on the low left bank of the Kuybyshev Reservoir in the place of sand and gravel mix extraction, Sviyazhsk site – around the cultural heritage object Sviyazhsk island-town. The change in the bottom topography was monitored using the Interferometric Side-Scan Sonar and the HyScan software. Bathymetric maps and transverse profiles for study sites were built. A description of the bottom relief in the studied areas is given. As a result, reservoir bottom survey technique was developed to update its morphometry, possibility of obtained data application is discussed.

1. Introduction

Silting, river channel and current movement, anthropogenic impacts, exogenous processes on the slopes can change reservoir bottom topography, therefore regular repeated studies are required to effectively monitor and evaluate changes and better understand environmental and anthropogenic factors impact [15].

Reservoirs bottom topography study is complicated by several factors – complex and shallow shoreline, intra-annual and interannual water level dynamics. Traditional survey methods make it ineffective to obtain precise geospatial information [15]. Nowadays, modern hydrographic technologies for planning, realization, post-processing and presentation of bathymetric survey results are widely used by researchers on large water bodies (oceans, seas, largest lakes, reservoirs) [1]. This type of equipment is practically not used on rivers and small lakes, due to its specificity (large size, installation of equipment only on large ships, small depths of the investigated water areas, etc.). Hydrographic surveys in reservoirs are usually carried out by small ships at depths of less than 20 m. To construct bathymetric maps of such water bodies, single-beam echo sounders are most often used and even the "proven old-fashioned way" – manual measurements using a lot (measuring tape with a load at the end). Traditional methods have a number of advantages – the mobility of the research team, low weight and size of the equipment. At the same time, they also have disadvantages: a long time for field work (increased labor intensity), the impossibility of a detailed display of the bottom.

Advanced research methods allow precise measurements of the bottom topography and its structure with an accuracy of a decimeter. Modern non-invasive instruments for bottom survey – multibeam echosounder (MBES) to obtain a digital terrain model (DTM); a side-scan sonar (SSS) to obtain a general image of the bottom, sediment echo sounder (SES) to recognize the structure of the bottom etc., are equivalents of a land surface survey using LiDaR, UAV and GPR (Ground Penetration Radar) [13].

The solution to the problem of the bottom relief modelling on large areas with high efficiency and accuracy can be performed using a hydroacoustic interferometer (Interferometric side-scan sonar – ISSS). Side-scan sonar is an instrument that provides a high-resolution image of the bottom on both sides of the boat's way. ISS gives a detailed acoustic picture in digital form. The antennas are towed in water with constant direction, speed and height above the bottom and emit acoustic pulses with constant interval. To construct the bottom topography, the ISSS uses data on boat course, speed, and pitching angles, and navigation receiver data for georeferencing. At final stage of relief construction hydrology is taken into account by entering the sound speed profile.

Side-scan sonars (SSS) perform more effectively in shallow waters than other acoustic systems because of their larger swath widths [2], and the resolution of received data does not change with varying water depth, so they are able to provide near-photographic high-resolution images of underwater areas [11]. Sonar applications are wide, that is the mapping of the main types of sediments [16], sediment distribution patterns study, as a result of natural processes [2] and bank engineering reconstruction [9], differentiation and precise location of various types of natural and or manmade objects by different textural responses [4]. Co-use of side-scan location and ground scanning radar or magnetometer proved to be the most effective for assessment section of loose deposits and distribution of the surface sediments and identification of technogenic objects [14]. For example, complex investigations allow detection and location of underwater pipelines [18], shipwreck identification [7], search for cultural heritage objects [6].

Figure 1. Kuybyshev reservoir bed survey sites location map.

This article presents the results of hydrometric surveys at two sites (figure 1) at the Kuibyshev Reservoir which was formed in 1955-1957 due to the damming of the Volga River by hydraulic structures of the Kuibyshev hydroelectric complex [2,10,12]:

1. Sakony site. The investigated area is located on the low left bank of the Kuibyshev Reservoir near the Sakony village in the place of sand and gravel mix extraction. Fluctuations in the water level is determined by the Kuibyshev Reservoir [17]. The project water levels of the Kuibyshev Reservoir are following: the normal impounded level – 53,0 m, the minimum guaranteed navigation level – 49,0 m, the highest permissible drawdown level before the seasonal flood – 45,5 m. The bottom relief is rugged, with significant variations in elevations. The depth of the reservoir along the fairway varies from 10 to 18 m, and in some depressions – 20-22 m.

2. Sviyazhsk site. Around the cultural heritage site Sviyazhsk island-town. The investigated area is located at the confluence of the Sviyaga and the Volga rivers. Here the width of the Sviyaga River valley reaches 10-12 km. Sviyazhsk is an oval residual island, elongated from southwest to northeast for 1,2 km, 0,6 km wide, with absolute heights up to 75 m. After the Kuibyshev Reservoir creation many residential buildings were flooded, Sviyazhsk became an island connected to the mainland only by a narrow embankment dam. There is a famous cultural and historical complex – an architectural monument of the 16-17 centuries. It was founded by Ivan Grozny in 1552 as a stronghold for the Kazan city capture. Currently, Sviyazhsk is a major tourist center.

2. Materials and methods

At the pre-field stage, the area of the defined water zone, the size of the site was determined, and the tacks were plotted on the electronic map. If necessary (or in case of impossibility of binding), the coordinate locations of the starting and ending points of the tacks with the azimuth direction were marked [3].

The water edge (shoreline) was surveyed along the entire length of the site and the absolute water level was determined by the GeoExplorer 6000 GeoXH GNSS receiver with an accuracy of 10 cm. The bathymetric survey with the help of the ISSS was carried out from a small vessel by one group, consisting of two people – a helmsman and a bathymetrist. The helmsman is responsible for a constant speed, for tacks position and azimuth direction. The bathymetrist is responsible for setting the necessary parameters for a full bed survey, recording the tack on a data medium, timely helmsman warning about rapid changes in the bottom topography that impede further survey, ISSS adjustment when the bottom topography changes from shallow to deep-water.

The change in the bottom topography was monitored using the HyScan program. Its main function is the automation of the ISSS in terms of receiving, visualizing, processing, analysing and archiving the received sonar and parametric information [8]. During survey, the quality of received information is assessed; if necessary, repeated or additional observations are performed.

Bathymetry data were verified, data of shallow depths – up to 1 m, as well as positions with "non-existent" depths, which exceed the average depth according to the data sample by 3 or more times, were screened out. Such errors can occur due to equipment malfunctions. Depth data is combined with shoreline data with water level from a GNSS receiver. Bathymetric maps were built in the Golden Software Surfer program, the data was interpolated by the Kriging method with a 1 m grid step.

3. Results and discussion

3.1. Sakony

On the southern side, the study area is limited by the bank of the Kuibyshev Reservoir, from the northern and north-eastern sides by elongated islands, which are the remnants of ridge elevations of the drowned first floodplain terrace. The study area was 0,327 km^2, on which 63 tacks were made with a total length 19 km. The length of the section – 1.2 km, the average width – 270 m (360 m max). 1044 thousand bathymetric data were collected and processed. The statistics on the depths of the Sakony site are presented in table 1.

Bathymetric survey was carried out in order to identify holes left after the hydromechanized work on the sand and gravel extraction. Based on the obtained data, 3 significant lowering of the bottom relief were revealed (figure 2).

Table 1. Sakony site depths statistics.

Duration	Depth, m	Duration	Depth, m
1%	-15,4	75%	-5.14
5%	-13.79	90%	-3.44
10%	-12.88	95%	-2.78
25%	-10.79	99%	-2.12
50%	-7.85	Average	-8.01
		Maximum	-18.5

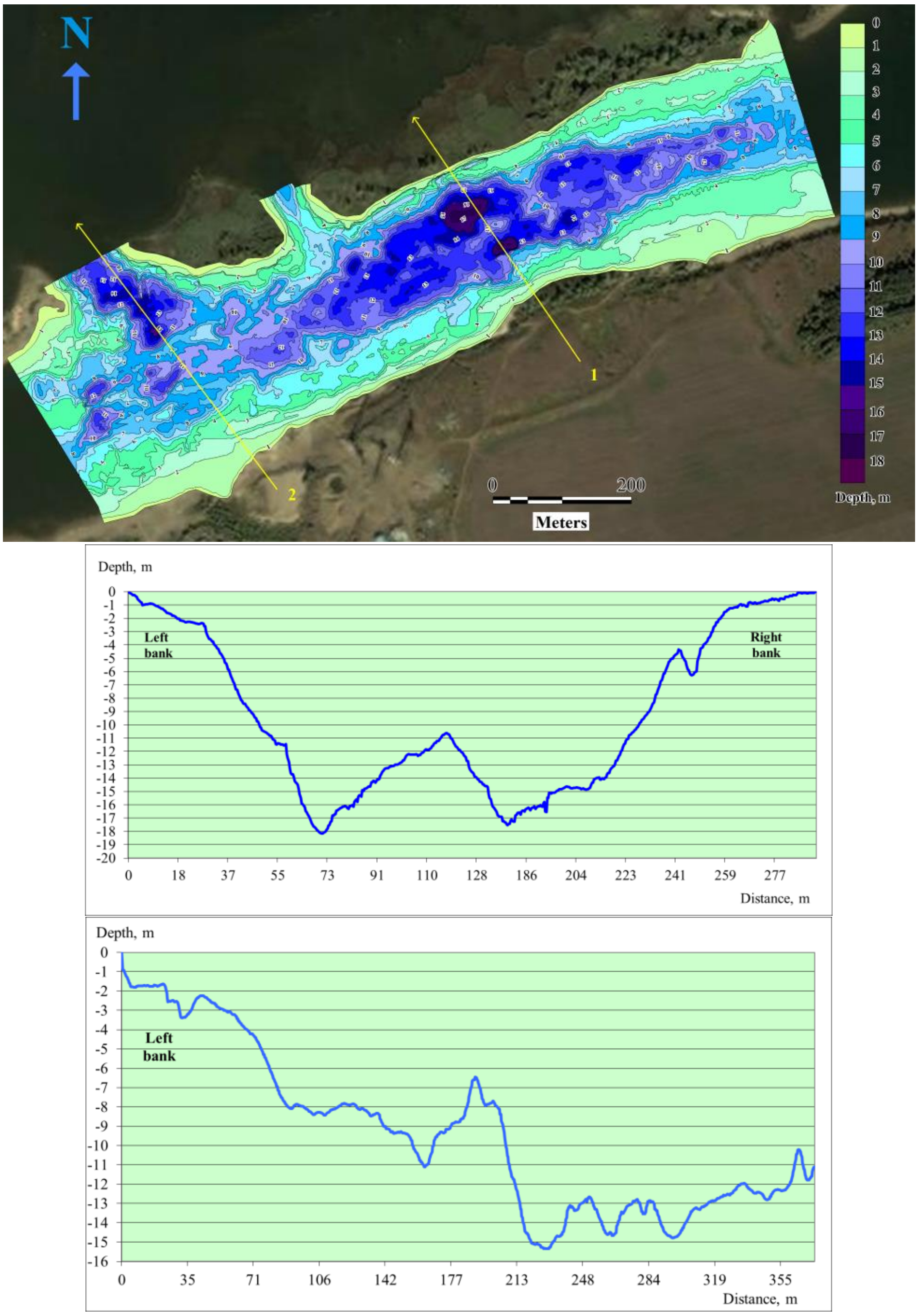

Figure 2. Sakony site. Bathymetric plan and transverse profiles.

The first depression with depths up to 18 m has an elongated shape from southwest to northeast, about 70 m long with a maximum width 50 m. The second depression also has an elongated shape with 40 m length and 20-21 m width. Maximum depths exceeding 18 m were recorded here (18.46 m max). In general, Sakony site is characterized by strong depth heterogeneity: steep local increases and decreases with a variation range of 2-3 m were recorded. Transverse profiles were built through depressions, it is possible to reveal initial relief of the bed (figure 2).

3.2. Sviyazhsk

Information about the bottom relief near the Sviyazhsk Island was interesting to archaeologists that made excavations here. A survey was carried out at a section of the Kuibyshev Reservoir 150-200 m around the Sviyazhsk Island.

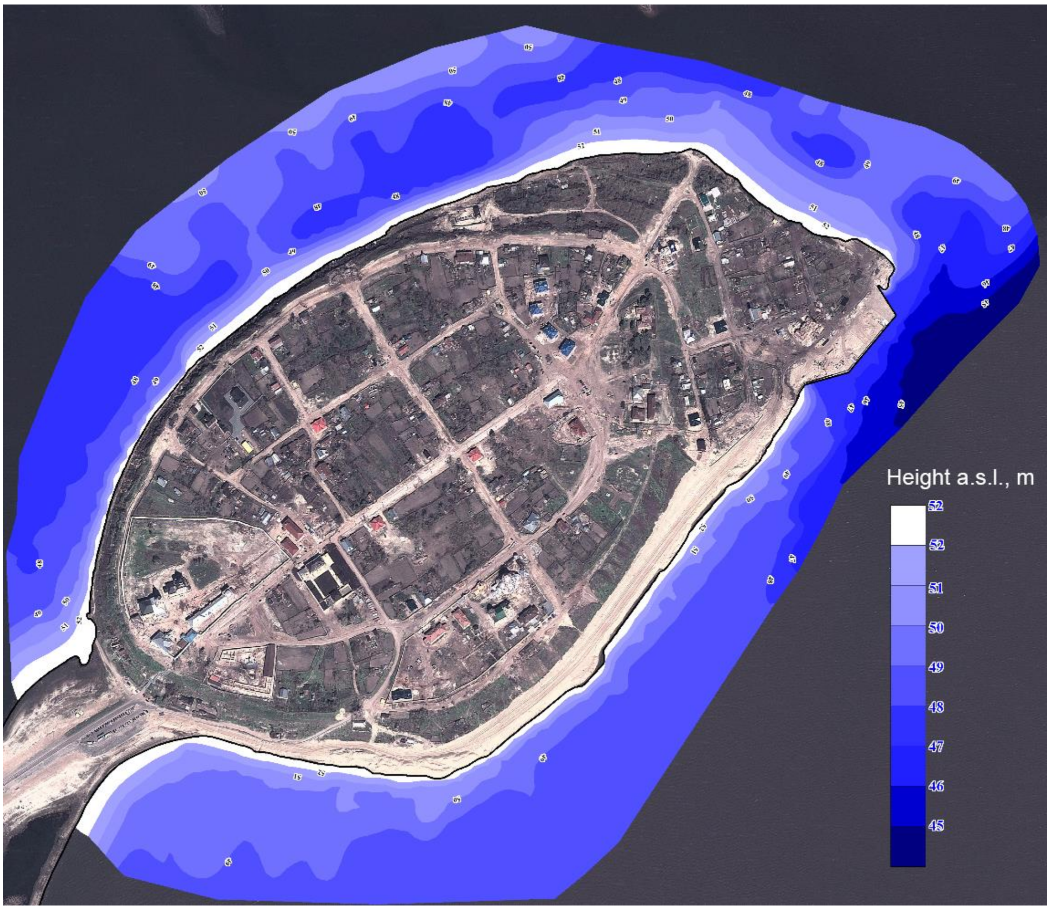

Figure 3. Bathymetric plan for the Kuibyshev Reservoir water area around Sviyazhsk Island.

Within 5 days, about 25 tacks were laid around the island. The nearby water area was characterized by shallow depths (up to 4 m) and large areas occupied by higher aquatic vegetation. The deepest places were fixed in the area of the pier (up to 8-9 m), as a result of dredging works for the unhindered approach of passenger ships. The bottom is sandy-silty, slightly wavy. At the bottom, there are isolated, rare remains of logs and stumps; full-fledged remains of buildings have not been identified. In total, over 182 thousand bathymetry points were collected and processed during the survey. On their basis, the bathymetric plan of the Kuibyshev Reservoir water area around the Sviyazhsk Island was constructed (figure 3).

4. Conclusions

At the Sakony site, 3 significant depressions of the bottom relief were revealed as a result of sand and gravel extraction. Based on the research results, it can be assumed that the initial depths was 11-12 m – in the upper and middle parts, 8-10 m – in lower part of the study area. Thus, it can be concluded that the depth of the excavation during the sand and gravel extraction was 6-7 m for the first two depressions, and 3-4 m for the third one.

At the Sviyazhsk site no flooded structures were identified during the bottom survey, which may be due to bank protection works and sand wash. The bottom of the shorefront within 50 m is flat with a smooth depth increase.

As a result of the research, a reservoir bottom survey technique was developed to update its morphometry. This technique can be used to solve various applied tasks: geoecological assessment of reservoir bed in valuable fish species spawning places, studying the dynamics of the bottom topography under the influence of natural and anthropogenic factors, conducting engineering and hydrological surveys in pipelines state monitoring, as well as detecting under water artefacts, including historical and cultural heritage objects.

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