THE STUDY OF THE DEGREE OF SILT SEDIMENTATION IN THE PUBLIC RESERVOIRS OF THE REPUBLIC OF MOLDOVA

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Abstract: *In the Republic of Moldova, public ponds and reservoirs are at the end of their exploitation period. In the context of climate change, the operation of lakes imposes requirements on the minimum flow to maintain the downstream ecosystem. Extending the exploration period, in compliance with current rules, requires hydrological and hydraulic interventions which is necessary to be done, based on multiple studies such as the study of the behavior of hydrotechnical constructions and of clogging processes. Topography, climate, vegetation, hydrology, and human actions control soil erosion which is a major problem, causing detrimental effects on agriculture and siltation of rivers and reservoirs. Thus, the given article presents the result of the study of the clogging process for one reservoir located in the Northern areas of the Republic of Moldova, in comparative analysis with the designed diagram of the storage capacity, specific to pond/lake, during the exploitation period. The topographic method based on topo-bathymetric profiles was used. The cross-sectionals profiles reveal changes in slopes in the shoreline area, in the tail of the lake and in the vicinity of the, largely, non-functional stavilles. The particular results as well as the general ones, identified by the study, highlight the major causes of the phenomenon, as well as some recommendations for accumulation.*

Keywords: *watershed; reservoirs; clogging; erosion; topo-bathymetric profile; flow*

1. Introduction

The circulation of water in nature operates within a continuous closed circuit known as the global hydrological cycle, which involves a portion of the water from the atmosphere, hydrosphere, and lithosphere [1]. To understand this cycle, its effects, and its consequences, multiple activities are necessary, including terrestrial measurements of water bodies and their behavior over time.

This paper highlights one of the many hydrological phenomena, namely sedimentation. Sedimentation is a complex process that varies according to the sediment production of the drainage basin, the transport rate, and the mode of deposition. The deposition of sediments reduces the storage capacity and lifespan of reservoirs. [2]

The quantitative determination of sedimentation in lakes (calculating the volume of deposited sediment) is based on measurements obtained through traditional topographic and geodetic surveys, bathymetric surveys using echo sounders, photogrammetric methods, and electronic probes, etc. The research on sedimentation in reservoirs aims to find forecasting

methods for the effects, which are necessary for design purposes, as well as to establish measures to mitigate the phenomenon, all with the goal of extending operational duration to the designed parameters. [3]

Sedimentation is a significant issue in the Republic of Moldova, caused both by natural factors (floods, landslides, etc.) and human activities (agricultural land processing, river damming, water body pollution, etc.). Attention to this problem is heightened by the fact that most lakes in the territory of Moldova were constructed in the 1960s to 1980s, reaching the limits of their operational lifespan, which has contributed to a high degree of sedimentation, thereby reducing their water capture capacity. This effect is further pronounced due to the maintenance practices that have been upheld over the last 30 years. Thus, by describing the hydrometeorological factors and the methods of measurement, along with processing the data over different periods, it is possible to construct behavior curves for the water body, serving as a basis for decision-making regarding the design, execution, and operation of hydraulic works. [4]

This article presents a study on the degree of sedimentation in the "Zagarancea" reservoir, located along the course of the Vladnik River, within the administrative territory of the Zagarancea commune in Ungheni County (figure 1).

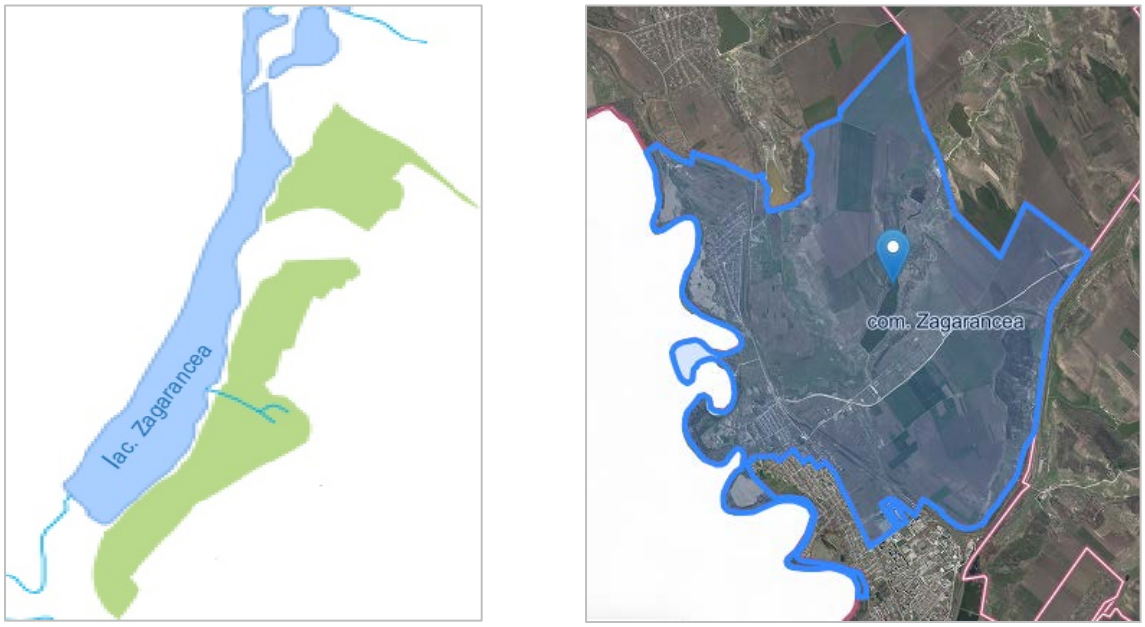

Figure1. The location of the "Zagarancea" reservoir

The Zagarancea Lake was constructed in 1959 (with filling starting that year) and is managed by the State Enterprise "Basin Water Management Authority of Moldova" under the Agency "Apele Moldovei" of the Republic of Moldova, being a public property of the state. In 1985, the dam was reconstructed, and a large flow spillway of the shaft type was added according to the project documentation.

According to the technical passport of the water body, the reservoir has the following parameters: [5]

- Length: 2.9 km and Width: 400 m;
- Maximum Depth: 3.5 m and Average Depth: 1.73 m;
- Surface Area at Normal Water Level: 0.635 km²;
- Water Volume at Normal Water Level: 1.1 million m³;

- Drainage Area at the dam site: 130 km²;
- Type of Reservoir: lake;
- Type of Regulation: seasonal;
- Purpose of the reservoir: irrigation and aquaculture.

The structural components of the Zagarancea reservoir include the following elements:

1) *The dam of the lake* is an earth dam, made from locally extracted clay, with the following parameters:

- Length: 360 m;
- Maximum Height: 6.0 m;
- Crest Width: 6.5 m;
- Upper Slope Angle: 1:8;
- Downstream Slope Angle: 1:2;
- Crest Elevation: 46.0 m.

2) *Large flow spillway of the shaft type*. The shape of the spillway is oval, with dimensions of 5.1 x 17.1 m, and a height of 4 m, constructed from monolithic reinforced concrete. The wall thickness is 0.35 m, with a rectangular cross-section of 2.5 x 2.0 m arranged in four tiers. The discharge head is also made of monolithic reinforced concrete, featuring a vertical-walled dissipater that is extended in plan. The length of the dissipater is 10 m, with an exterior width of 15.5 m and a trapezoidal cross-section. The spillway's discharge capacity, in the event of a flood with a probability of 1%, is 91.8 m³/s.

2. Materials and methods

2.1. Description of the current condition of the lake

Recent examinations have highlighted the unsatisfactory quality of the water in the lake, which is conditioned by the low water level, excessive aquaculture practices, and the lack of water circulation. This has resulted in the process of eutrophication (pollution) of the water, as well as an increase in the degree of sedimentation.

The condition of the structures of the spillway shaft is generally unsatisfactory. The shaft is highly sedimented and filled with debris. The construction structures of the tubular section are in satisfactory condition. The discharge outlet is also generally in satisfactory condition, and it is recommended to construct a monolithic tie beam on the upper side. Currently, topographic and geodetic work is needed to ensure the accurate translation of data from the project documentation into the field.

The dam of the reservoir has been assessed from a technical standpoint. Following the evaluation, rehabilitation activities are currently underway, involving the installation of a reinforced concrete layer on the interior walls (figure 2). Additionally, a concrete tie beam is being constructed on the upper side, in which metal bars are embedded for the future installation of a protective grill. The coordinates and elevations of these dam elements have been marked and verified topographically (figure 2).

The open bypass canal terminates at the reservoir dam and transitions into a metal pipe with a diameter of 600 mm, whose discharge outlet is located in the spillway shaft at a depth of approximately 2.5 m. Additionally, there is a metal pipe with a diameter of 800 mm on the bypass canal, 120 m from the dam, which connects the bypass canal to the lake basin.

The estimated value of sanitary discharge in the irrigation area downstream (considering the future) is 3 l/s. The possible irrigated area is one thousand hectares. According to a chemical analysis of a water sample taken from the reservoir on August 24, 2012, its mineralization is 2076 mg/l.

Figure 2. Geodetic works for the rehabilitation of the large water spillway structure, including the surveying and verification of characteristic points

According to an inventory activity plan, observations and measurements have been conducted on the hydraulic node over the years. During the reservoir inventory carried out in 2012, it was determined that there is a bypass canal running along the entire right bank of the reservoir that was not constructed according to the project. The water level in the reservoir was 1.5 m below the Normal Water Level, specifically at 43.0 m. Due to the created situation (the poor condition of the hydraulic structures and water pollution), a decision was made for the controlled discharge of water. Accordingly, in line with the methodology for managing lakes for aquaculture, natural cleaning of the basin is to be carried out, particularly targeting the sludge that has accumulated over time.

Following the findings by field experts, several conclusions and recommendations were made:

- The hydraulic structures of the Zagarancea reservoir are undergoing rehabilitation, as is the lake basin, meaning that, in case of an emergency, the reservoir does not pose a threat to the safety of the population living downstream.
- A technical examination of the flood spillway structures and the design documentation for major repairs is necessary.
- It is recommended to implement a natural cleaning procedure with controlled discharge of water from the lake, along with monitoring geological processes related to sedimentation.

2.2. Data collection

To assess the degree of sedimentation in a reservoir, topographic and bathymetric measurements will be used. These measurements provide precise data about the shape and depth of the lake basin, as well as the volume of accumulated sediments.

Topographic measurements focused on the land surface around the lake, its banks, and the dry lake basin. The goal is to detail the area's relief to understand water flow and erosion. The measurements were conducted in May 2024 (figure 3) using the CHCNAV I50 GNSS receiver and the MOLDPOS [6] positioning system, to develop the topographic map of the current field situation and to compare the elevations of characteristic points with previous cartographic materials.

Figure 3. GNSS measurements of the Zagarancea reservoir

After processing the data collected from the field, the topographic survey was created (figure 4), determining the coordinates of characteristic points in the national coordinate system MOLDREF99. [7]

By conducting a comparative analysis of the elevations of the points, it was observed that the levels of the structural elements have some deviations. For example, the crest of the dam is supposed to be at an elevation of 46.00 m according to previous project documentation, while measurements revealed a range between 44.45 and 45.00 m.

At the same time, some bathymetric measurements were conducted (figure 5) to determine the depth of the sludge (sediment deposition) along the lake basin. The variation in sediment levels is approximately between 0.80 and 1.00 m relative to the bottom of the lake basin, according to the project documentation.

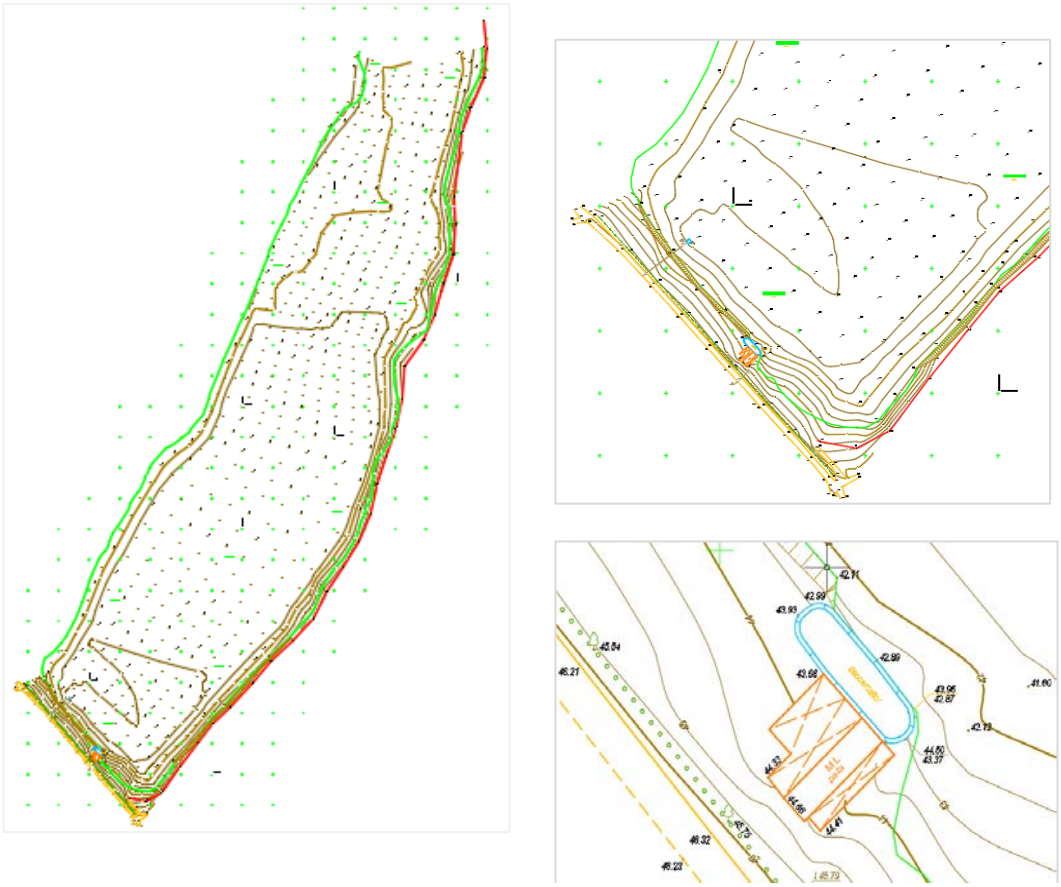

Figure 4. Topographic survey

Figure 5. Bathymetric measurements

Due to the accessibility of the dry lake, topographic and geodetic measurements were conducted on two cross sections to develop the cross profiles (figure 6), where the elevations are recorded vertically in the Baltic Sea height system, while the horizontal axis indicates the points where GNSS observations were made.

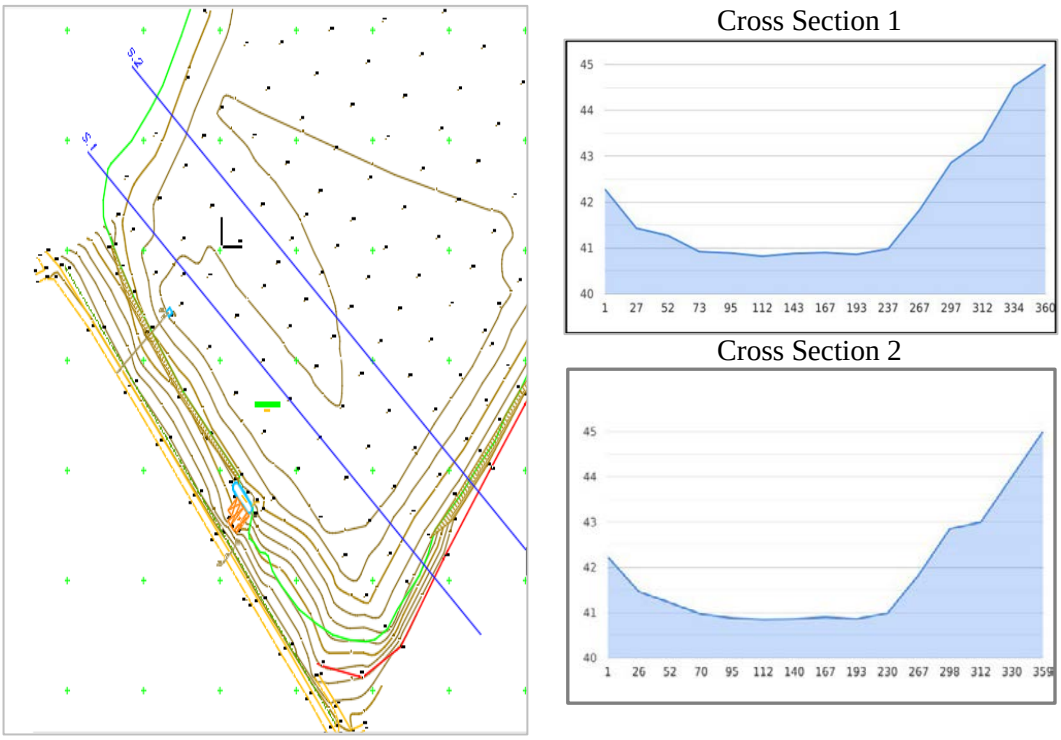

Figure 6. Cross Profiles

Processing the measurements taken, constructing the profiles, and determining the elevations at points in the cross sections allows for the creation of a digital terrain model. Comparative analyses with the anticipated measurements highlight the degree of sedimentation and provide a plan of action for improving the condition of the lake.

2.3. Determination of lake sedimentation

The determination of sediment deposits can be accomplished both in a GIS environment and with the help of CAD software [8]. Based on the measured depths of the sludge relative to the elevations of the lake basin bottom at various points, digital terrain models can be created.

For Zagarancea Lake, a digital model was created using Autodesk Civil 3D software, based on the processing of elevation values from the topographic map of the area. This method allowed for the creation of a TIN (Triangular Irregular Network) model of the lake's surface and the assessment of characteristic sediment volumes over an individual sector covering approximately 181,778.40 m².

To obtain an accurate estimate of the sediment volume, it is essential to adjust this value based on the established bulk density. Sediment depths can be interpolated to provide a more detailed picture of their distribution in the area. Additionally, the use of the TIN model (figure 7) allows for a graphical representation in color gradients of the sediment depth distribution, facilitating spatial analysis.

It is observed that the central part of the lake's surface, located in the depression, tends to have a greater accumulation of sediments than the edges of the lake. This is due to the flow dynamics, which tend to carry more sediments when floodwaters exceed the drainage paths towards the reservoir dam. After generating the digital model, the volume of sedimentation was determined based on the area of the lake basin bottom and the sediment-covered surface relative to their elevations, as presented in the cross profile in figure 7.

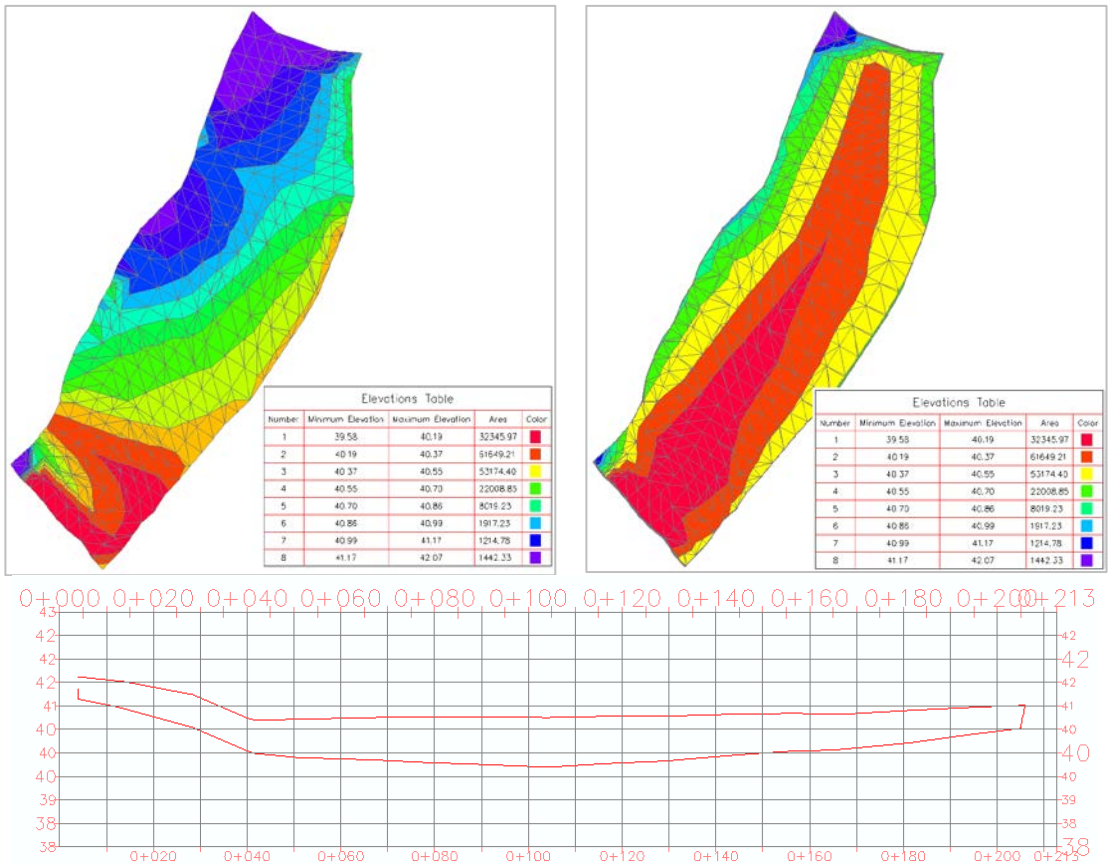

Figure 7. Development of the TIN model for sedimentation volume determination

The morphometric characteristics of the reservoir based on the currently measured field data and the data extracted from the digital model in the pilot area are presented in Table 1.

Table 1. Morphometric characteristics of the individual sector of the lake

Morphometric characteristics		**Zagarancea lake**
Minimum elevation of the basin bottom	$H_{bb.min}$ (m)	39,58
Minimum elevation of the sediment-covered surface	$H_{sc.min}$ (m)	40,60
Maximum elevation	H_{max} (m)	42,07
Average elevation of the basin bottom	$H_{bb.avr}$ (m)	40,37
Average elevation of the sediment-covered surface	$H_{sc.avr}$ (m)	41,18
Maximum width	l_{max} (m)	281,12
Maximum length	L_{max} (m)	766,10
2D Area	A (m^2)	181778,40
3D Area	A (m^2)	182057,70
Sedimentation volume	V (m^3)	145716,65

Using both the TIN method and the square method for determining sediment volume (figure 8), an estimated volume of approximately 145,716.65 m³ of sediment was found in the analyzed sector. Both methods provided consistent results in evaluating sedimentation.

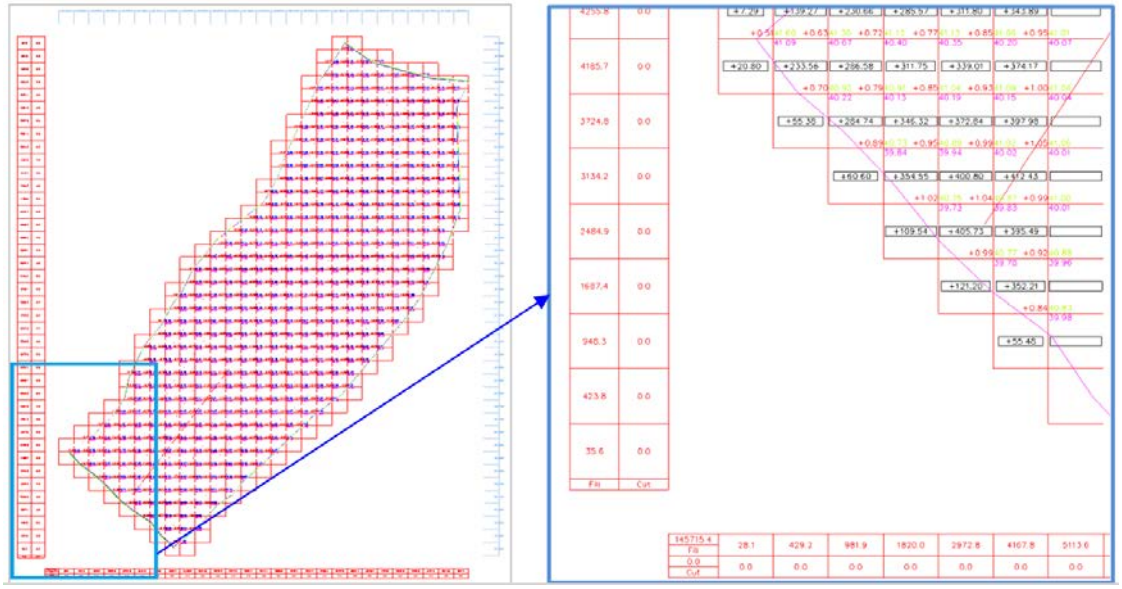

Figure 8. Determination of sedimentation volume using the square method

According to this volume calculation principle in the pilot area, the estimation can be extended to the entire surface of the lake. This will provide a clear picture of the total volume of deposited sediments, thereby facilitating informed decisions regarding their removal.

3. Analysis and Results

The study on the sedimentation degree of the Zagarancea reservoir highlighted significant issues related to water quality and the condition of the hydraulic structures. The analysis of the collected data revealed substantial sedimentation in the lake, with a total estimated volume of approximately 145,716.65 m³ of accumulated sediments over an area of 181,778.40 m², although the actual area is much larger. These results suggest a reduction in the lake's storage capacity, which can impact both its functionality and the surrounding ecosystem.

According to the original project documentation, Zagarancea Lake was supposed to maintain a water volume of 1.1 million m³. The analysis revealed that, considering the sediment volume, the effective storage capacity has now significantly decreased. Comparing the elevations of the characteristic points showed notable deviations, indicating the need for immediate interventions to restore the lake's functionality.

The cross profiles created revealed remarkable variations in sludge depth, ranging from 0.80 to 1.00 m in different areas of the lake. This information is essential for planning cleaning and rehabilitation interventions, providing a visual guide to the distribution of sediments and the most affected areas.

The creation of the digital terrain model allowed for a detailed visualization of the lake's configuration and the sediments. The use of the TIN method facilitated the identification of sediment accumulation areas, highlighting a greater tendency for sedimentation in the central regions of the lake, where water currents converge. The sedimentation of Zagarancea Lake has direct implications for the aquatic ecosystem and fisheries activities. A reduction in water depth can affect temperature, oxygen levels, and, consequently, biodiversity. Additionally, the decrease in water storage capacity can impact irrigation and water resource management in the area.

The recommendations arising from the data analysis suggest implementing intervention measures such as:

- Conducting periodic cleaning operations to maintain the lake's storage capacity.
- Establishing a sedimentation monitoring program to assess long-term effects and adapt management strategies.
- Regulating agricultural and construction activities around the lake to reduce erosion and sediment input.

4. Conclusions

Sedimentation is an inevitable process, but through appropriate management and maintenance measures, its impact can be reduced, thereby extending the lifespan and functionality of the reservoir. Mitigating sedimentation can include desilting activities, such as dredging sediments or more efficient management of the watershed to reduce erosion and sediment transport.

The study of sedimentation in Zagarancea Lake has highlighted the importance of continuous monitoring of water quality and hydraulic structures to prevent their degradation. The results obtained from topographic and bathymetric measurements have shown significant sediment accumulation, affecting the lake's storage capacity and functionality. Implementing rehabilitation and cleaning measures for the lake is essential, as well as developing sustainable management strategies for water resources, to ensure environmental protection and the efficient use of the lake for irrigation and aquaculture purposes. Fostering collaboration among local stakeholders, including agricultural and environmental authorities, is essential for creating effective policies and practices aimed at minimizing sediment inflow and enhancing the lake's ecological health.

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