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COMPARISON OF LAKEBED SURVEYS CARRIED OUT WITH SINGLE-BEAM AND MULTIBEAM SONAR INSTRUMENTS

Zoltán Eke
PhD student, University of Miskolc, Institute of Geophysics and Geoinformatics,
Department of Geodesy and Mine Surveying, University of Miskolc
3515 Miskolc, Miskolc-Egyetemváros
Research Associate, Bay Zoltán Applied Research Public Benefit Nonprofit Ltd., System Design Department
3519 Miskolc, Iglói út 2., e-mail: zoltan.eke@bayzoltan.hu

István Havasi
Associate Professor, PhD, Institute Director, Institute of Geophysics and Geoinformatics, Department of Geodesy and Mine Surveying, University of Miskolc, ,
3515 Miskolc, Miskolc-Egyetemváros, e-mail: gbmhi@uni-miskolc.hu

Abstract
The study first briefly deals with the surveying principle of sonar devices used in practice for underwater depth measurements. After that, it describes both single-beam and multi-beam ultrasonic measurements and the disadvantages and advantages associated with their use. Then, in connection with the bed survey of a mining pond, the authors undertake a comparative study of the two survey methods, giving and illustrating their results and evaluating the experiences obtained from the research task.

Keywords: *ultrasonic depth measurement, single-beam sonar, multibeam sonar, comparative study*

1. The measuring principle of sonar

Nowadays the use of various sonar measuring devices for underwater depth measurement have became more and more common not only abroad, but also in home practice. These devices use sound waves due to their favourable propagating properties in water. The speed of sound is usually 1400-1500 m/s in water. At the same time, the local speed of sound depends on the salinity of the water, its temperature and pressure.

Active sonars measure the depth of the bed bottom with sound waves of a controlled frequency. The principle of depth measurement is based on determining the travel time of the emitted and reflected pulse.

The projectors of bathymetric sonars are characterized by their ability to emit the signals set for the given measurement repeatedly in such a way that their physical characteristics do not change. The sound pulse in water travels almost spherically from its source. The signal reflected from the bottom is received by the sensing hydrophone. Due to their similar operational function, the projectors and hydrophones of an ultrasonic measurement system are often the same hardware components.

2. Single-beam sonar

The history of the development of water depth measurement, the surveying of the lake bed with a single-beam depth sounder, and its results are described in detail in (www3.mbari.org). With these instruments, the depth of the bed points is measured individually at different places. The main instrument elements of a single-beam sonar are the following: a transmitter, a signal converter, a receiver, as well as the control system and display one in certain cases. The measuring device is attached to the side of a water vehicle (e.g. boat) or it is held together with a GPS antenna on a pole by a surveyor. The process of determining the time elapsed between the emission of the measurement signal and its return - from which the depth can be calculated - is called the "ping cycle" (Galli, 2017). Accordingly, one depth data is recorded during such a cycle.

Afterwards let us study the reliability and accuracy of the measurement with the measuring device. In this connection, it is important to mention the following possible problem. It may happen that the signal emitted and propagating on a spherical surface (due to its nature and the topography of the bed) is not reflected from the vertical direction to be measured (true depth), but from a different direction (first signal arrival) (inaccurate depth data) (Galli, 2017). Certain manufacturers remedy this problem with a larger and more expensive instrument, by narrowing/focusing the emitted signal, but this solution does not provide the expected reliable result either due to the following reasons (Galli, 2017). One of the reasons for this is that the sonar is attached to the water vehicle (boat body) or it is hold by a surveyor, thereby the entire system moves together. The other reason is that with increasing depth, the bed area affected by the signal also increases (decreasing resolution and increasing survey uncertainty). Consequently, single-beam sonars are not suitable for high-resolution bed surveys.

3. Multibeam sonar

In the case of multi-beam sonars, however, such a kind of devices are used which are operated with more test signals. The number of signals could be 256, 512 or even 1024. These can be purchased on the market today by anyone having financial resources.

The signal emitting unit of the multibeam sonar is called a projector array, in which the signal emission and the detection of the reflections are performed by a suitable number of hardware fixed in a special arrangement relative to each other. This special, perpendicular arrangement ensures that the resolution of the measurement can be parameterized, together with the arrangement of the emitting hardware elements and the narrowing of the emitted signal within a given angle range. The angular range of the arrangement of the signals can be up to 150°, so the measurement band has a significant width depending on the depth, of course depending on the resolution, and thus the measurement efficiency is high (Eke and Havasi, 2022). The arrangement of the projector and sensor and the resolution of the measurement are shown in Figure 1.

In this case, the path of the extreme signals is significantly longer, so the ping cycle is also longer; however, the number of points measured in a unit of time is still many times higher than the measured ones with a single-beam sonar.

Naturally, the uncertainty resulting from the movement of the ship or boat also occurs in this case, to eliminate which an inertial unit is integrated into the sonar controller, which is able to compensate for the displacement around the three axes, determined to a predefined extent for the given device. The position is determined using two RTK GPS antennas, which are also connected to the controller. It is also important to mention the problem of determining the speed of sound, which stems from the fact that it is not uniform for the entire water column. This is especially critical in the case of still waters, where both the temperature and the speed of sound decrease in proportion to the depth. This deviation can be several tens of m/s, which must be taken into account for accurate measurement. The multibeam systems also include an external sound speed sensor, which prepares the sound speed profile for the entire water column in such a format that the software processing the measurement can take it into account when preparing the final survey result.

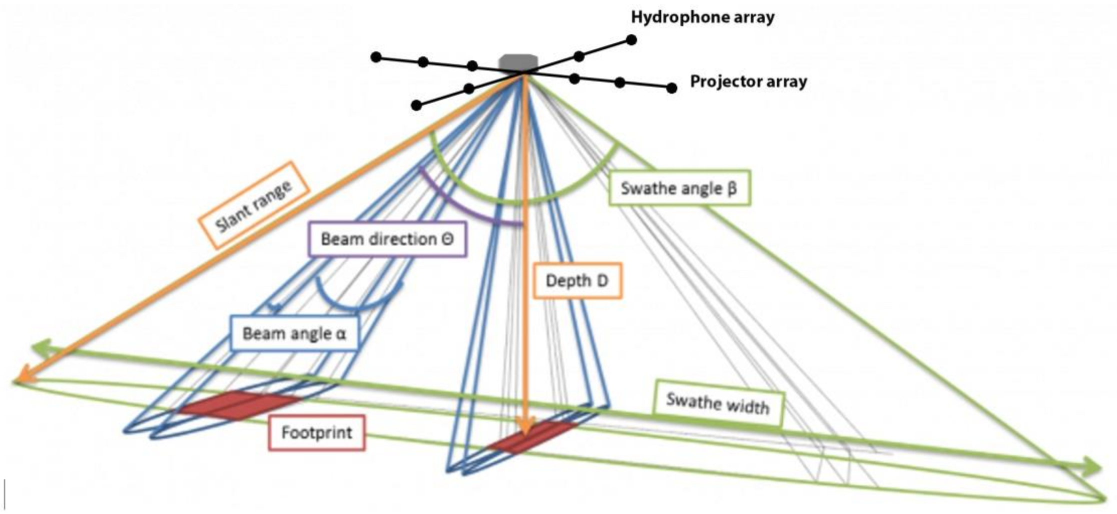

Figure 1. *Survey resolution for a multibeam sonar (https://www.hydro-international.com)*

4. Description of the comparative measurement and the obtained results

In the following, we present a comparative measurement with a single-beam device and a multi-beam device for the same sample area (Khomsin et al., 2021). We carried out the multi-beam sonar measurement in an area where the results of the single-beam measurement were previously obtained. We did not know, however, the exact conditions of the measurement, so during our investigation we try to highlight the characteristics which appear due to the technological differences listed above. The test area is a four-hectare part of the bed of a gravel pit lake.

Based on the survey results of the single-beam device, it was clear that several surveying methods were used, on the one hand, the traditional measurement, which measures the coordinates individually at the push of a button in such a way that the sonar head is attached to the prism rod of an RTK GPS device. The sonar determines the depth from the sonar head, and the RTK GPS measures the position of the sonar head in the EOV coordinate system. From these, the EOV coordinate of the bed point can be calculated. The other method differs from the previous one in that the measurement is automatically performed at a higher frequency with a higher density, the maximum of which can of course be lower than the ping cycle, but it still results in a significant number of measured data on the survey path.

Figure 2 shows the results measured with both single-beam and multi-beam sonar, data of the single-beam survey instrument are red and ones of multi-beam survey device are gray.

Point densities can be characterized as follows:

- single-beam sonar red points,
  - 9 m line distance and 3 m point distance in a manually measured area,
  - automatically measured area 9 m line distance 80 cm point distance.
- multibeam sonar gray points (25 cm resolution, evenly).

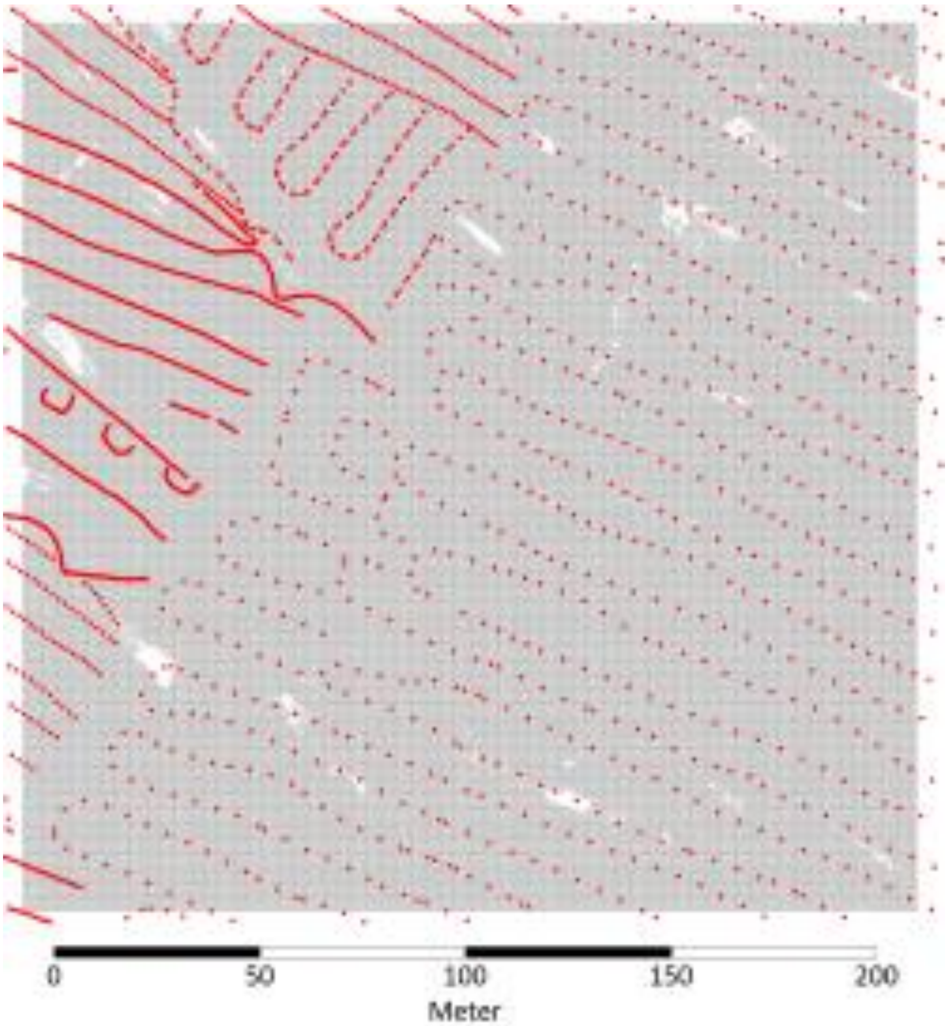

Figure 2. *Surveying results*

Surfaces were later created from the survey data which in the case of the single-beam sonar were interpolated to the entire test area with a resolution of 25 cm and 1 m; and in the case of the multi-beam device, the spots were interpolated with these densities. The following conclusions can be drawn from all of this:

- There is practically no visible difference between the single-beam surfaces, since the original data density is lower than the 1 m resolution, so by increasing the interpolation density, we do not get additional information about the bed.
- On the other hand, a difference can be seen on multi-beam surfaces, because in terms of the micro-topography, the resolution of 1m results in a significant loss of information. The 25 cm resolution, which is medium in terms of the capabilities of the device, also shows minor changes in the surface of the bed in detail. Figures 3 and 4 illustrate the surfaces edited from the data of each device with different resolutions.

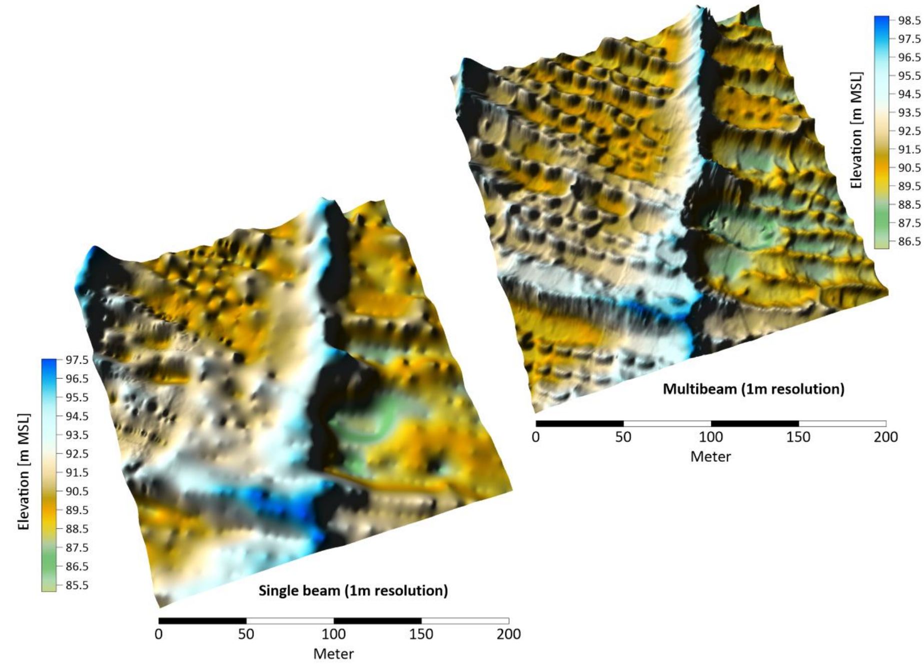

Figure 3. *The surfaces edited from the measurements with a resolution of 1 m*

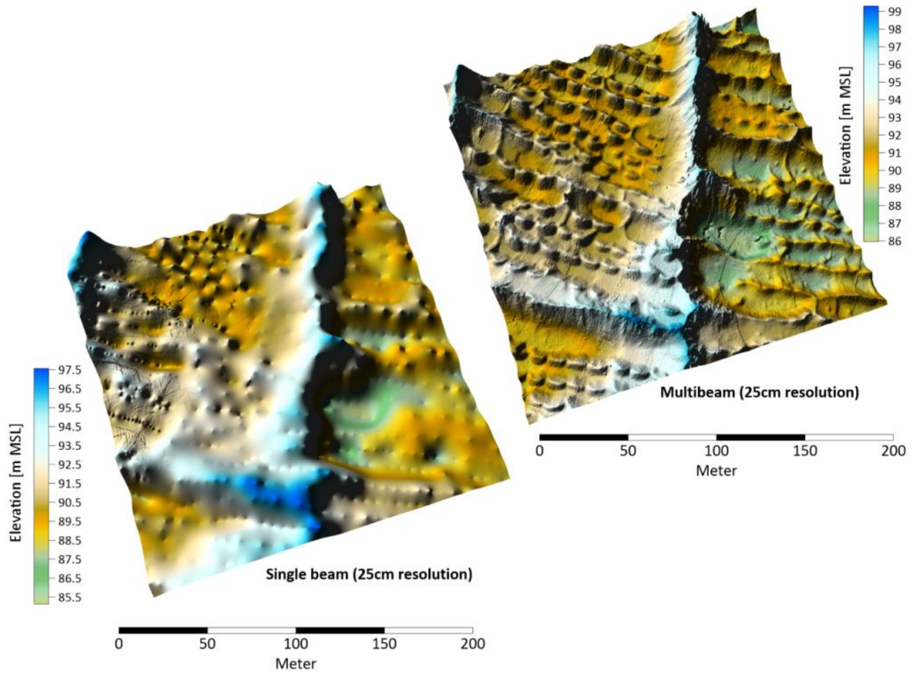

Figure 4. *The surfaces edited from the measurements with a resolution of 25 cm*

We have also prepared the difference of the 25 cm resolution surfaces with contour lines, which is shown in Fig. 5 together with the both surface maps with contour lines. It can be seen that typically the surface edited from the single-beam measurement reproduces the nature of the surface changes, larger shapes appear compared to the multi-beam recording. We can see, however, significant differences in the difference values, which can reach several meters in certain positions, which can be considered a significant difference. During our measurement, the water level of the lake was at the level of 106 m (above the Baltic Sea), which shows that the greatest depth below the water level was around 20 m. It is important to note that the biggest differences are not observed along the measured points but in those places where there is a greater distance between the survey lines of the single-beam measurement. Considering this, of course, in those positions calculated with the interpolation method (kriging) which are far from the measured points.

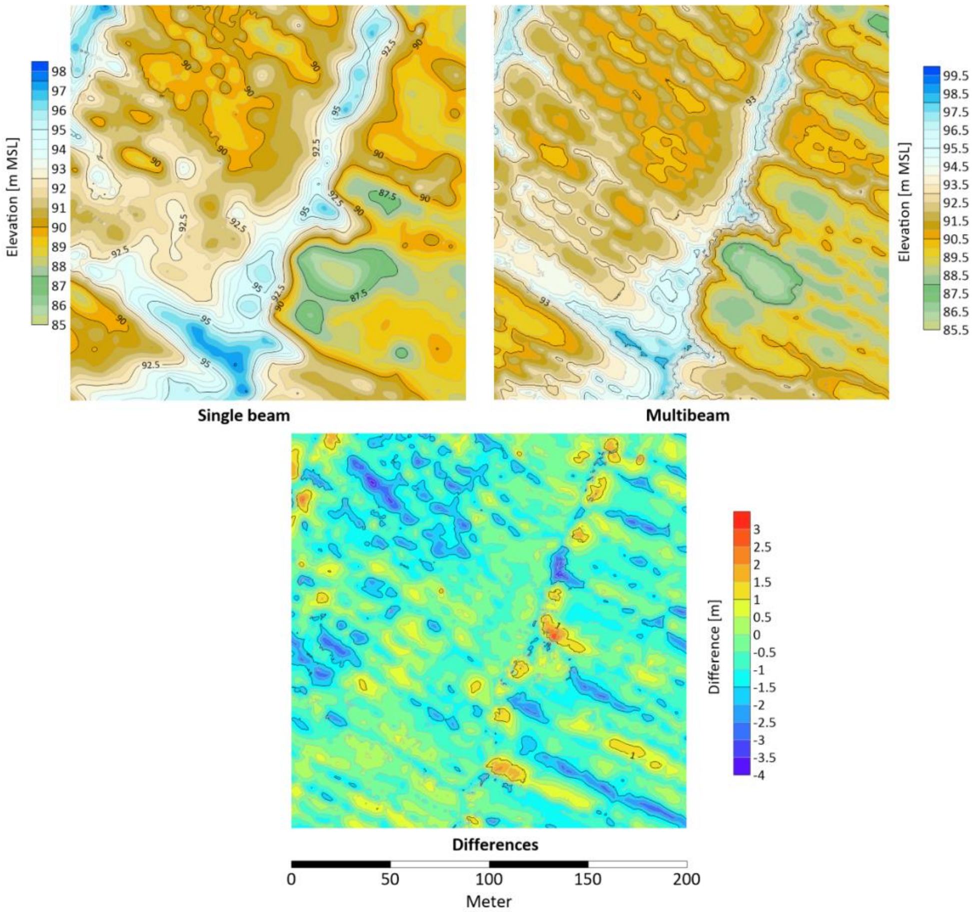

Figure 5. *Contour lines of surfaces with a resolution of 25 cm and the difference formed from them*

Based on the difference map, we can even say that a high density of points is required to survey a highly segmented river bed - such as the mining lake bed affected by extraction.

The difference between the surfaces is 22,864 m^3 in the 40,000 m^2 examined area (the multi-beam surface runs above the single-beam surface on 26,689 m^3 of volume and below it on 3,824 m^3), which means an average level difference of 57 cm in the entire area. One of the reasons for the difference is the above-mentioned point density and interpolation, the other is the component resulting from the technology, which is caused by the uncertainty of the watercraft (swing/pitch forwards and backwards; swings to the side/roll; turning around a vertical axis, floating on waves/heave) and due to the resulted measuring error. The third is an error resulting from a change in sound speed. The sound speed measurement results are shown in Figure 7, which were determined at different times in the studied area. The figure clearly shows the decrease in speed proportional to the depth, as well as the difference in the speed profile at different times. The listed factors are compensated in the case of the multibeam device.

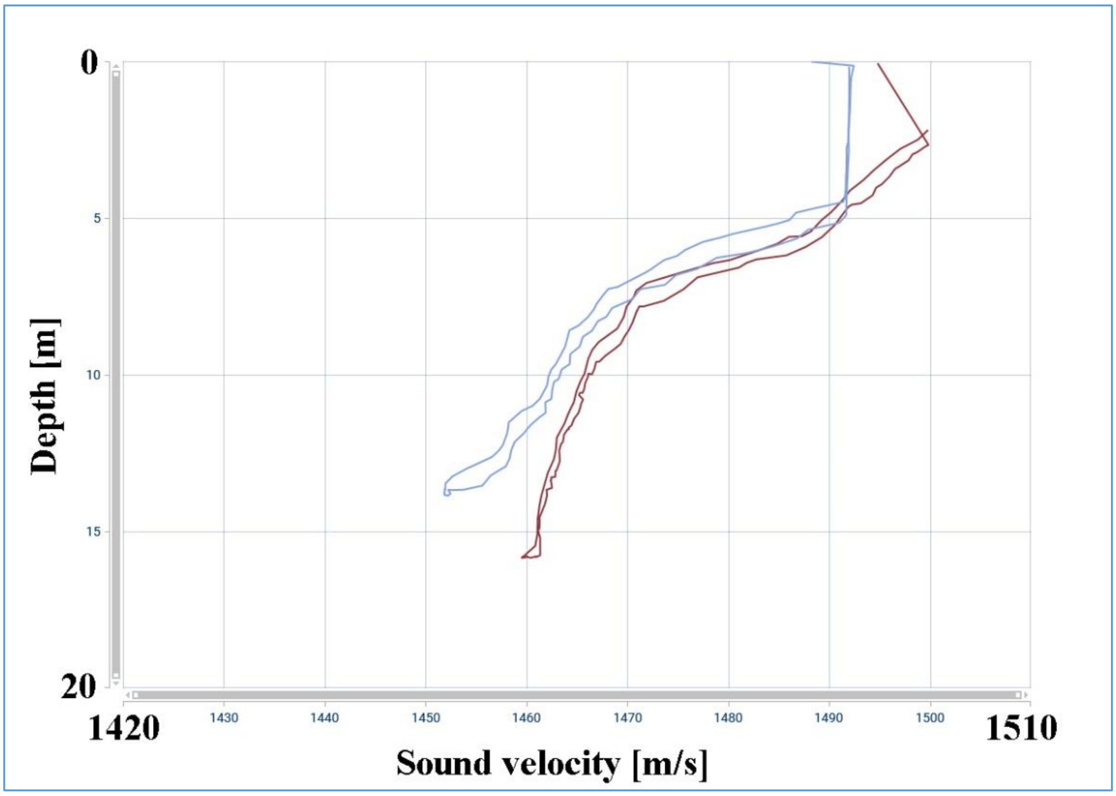

Figure 7. *Sound speed profiles measured at different times*

By indicating the points measured with a single-beam device on the segmented bed surface measured with a multi-beam device, the fundamental problem in the case of underwater bed measurements becomes obvious, if the measurement is carried out point by point (Figure 8). In order to determine the real surface, the shape characteristics must be measured, such as fracture lines (foot line, edges, etc.), and a suitably chosen homogeneous point density must be taken into account on the homogeneous surface part. In the case of the lakebed, however, this is not feasible, as due to its nature we cannot see it. Figure 8 illustrates that the shape characteristics were not really accurately measured in the point by point observed way, not even the ridge line and the valley line. As a result, we got a "smoother surface", where the inaccuracy of the determination of the two shape characteristics appeared with the opposite sign. It follows that, despite the larger deviations (several meters) occurring at points, the average level difference was around 50 cm.

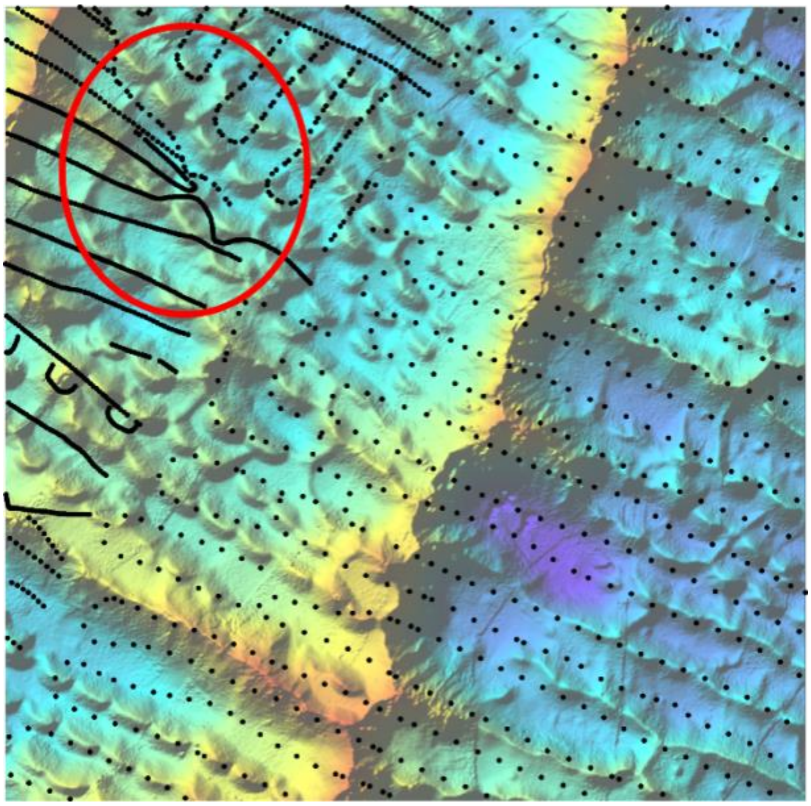

Figure 8. *The point positions measured with the single-beam device on the multi-beam surface*

In Fig. 9 cross-sections were created from the surfaces, and a part of the surface was marked with ellipses in Fig. 8 and Fig. 9. In this part, we can see that the direction of the point by point survey differs from the direction of the change in the shape characteristic of the bed. In this case, only a small amount of the shape characteristics were measured, as a result of which the larger level difference appears. It should also be noted that the data observed with a single-beam sonar were measured in the knowledge of the mining excavation technology, which was also reflected in the surface changes of the bed, so there was information on the segmentation of the bed. This determined the direction of the survey. When presenting the data, we emphasized that the recording of single-beam survey results was done in two ways, manually (fewer measured points on the survey line) and automatically (higher density of points on the survey line). The higher density of points on the measurement line provides significantly more useful information if the density of the measurement lines is also increased, i.e. the distance between the lines is reduced, which significantly increases the time required for the measurement. In the case of point-based bed surveys, the repeatability of the measurement raises further questions, with regard to how precisely the route travelled on the water can be re-travelled and, if applicable, how much the results of the two consecutive measurements differ, since the probability of finding the same measured points (inaccuracies) again is small. In the case of multi-beam surveying, the measured point cloud, which is orders of magnitude more homogeneous, ensures a significantly more accurate bed survey even in the general case when we have no or only very little knowledge of the bed. The result of the repeated measurement is the same as the previous one, even if it was performed on a different survey route.

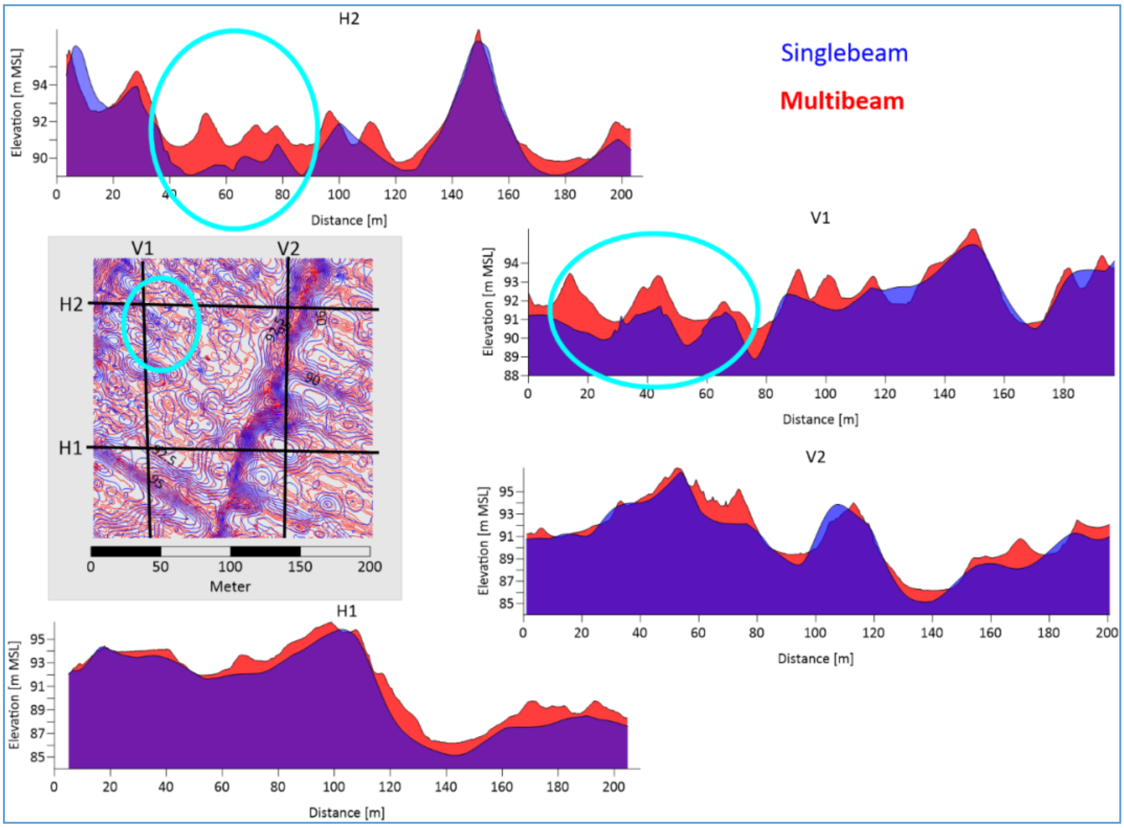

Figure 9. *Cross sections intersecting the two surfaces*

5. Summary

The motivation for writing our study was to present a comparative study of the use of multibeam sonar in connection with a mine surveying task. In fact, it is no longer a new technology, but it has only been available on the market for 1-2 years in a form that can be used for surveys in shallow water (less than 100 m, even 2-3 m) from a simple boat. We have pointed out the shortcomings which occur in the case of the previously only available, now commonly used single-beam devices, highlighting the errors which can affect the survey results.

The purpose of the given lakebed measurement basically determines what kind of tool is required for the reliable execution of the survey. We hope that we were able to provide assistance in choosing the appropriate tool or service for implementation. It should also be noted that the price of multibeam sonars is significantly high. It is several times more than the price of single-beam devices, and at the same time, the surveys performed with them are available in Hungary at the service level as well.

6. Acknowledgments

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References

[1] Multibeam Sonar Theory of Operation, L-3 Communications of SeaBeam Instruments, **https://www3.mbari.org** › data › sonarfunction

[2] Galli, Cs. (2017). *Mapping water depth with modern tools*. Thesis work, ELTE TTK, Budapest.

[3] Eke, Z., Havasi, I. (2022). Development underwater surface measurement – multibeam sonar. *Geosciences and Engineering: A Publication of the University of Miskolc*, 9(14), 81–95. **https://doi.org/10.33030/geosciences.2021.14.081**

[4] Khomsin, Pratomo, D. G., and Saputro, I. (2021). Comparative analysis of singlebeam and multibeam echosounder bathymetric data. *IOP Conf. Series: Materials Science and Engineering*, 1052, 012015. **https://doi.org/10.1088/1757-899X/1052/1/012015**

[5] **https://www.hydro-international.com**