INVENTORY TAKING OF THE UPPER WATER RESERVOIR IN PUMPED-STORAGE POWER STATION IN ŻYDOWO USING CLASSICAL LAND SURVEY METHODS AND INTEGRATED HYDROACOUSTIC AND GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

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ABSTRACT

The article presents the results of land survey and hydrographical works completed on Lake Kamienne – the upper water reservoir of the Pumped-Storage Power Station in Żydowo. The power plant with the capacity of 150 MW built in 1960 uses the difference in water level between Lake Kamienne and Lake Kwiecko of ca. 80 m. The detailed inventory of a part of the coastline was taken using the classical land survey techniques (Total Station), while for the remaining part it was taken using the GPS/EGNOS Thales Mobile Mapper satellite navigation receiver. The bathymetric measurements of the lake were carried out on the bases of GPS/RTK satellite positioning using the Ashtech X-Treme receiver while hydroacoustic sounding was conducted using the Simrad EA501P hydroacoustic system. The article describes the individual stages of the work and methods for raw land survey and hydrographical data processing. Development of the digital bathymetric chart, digital elevation model of the bottom and the visualization of Lake Kamienne were the final effects of the work.

1. INTRODUCTION

Lake Kamienne is a tunnel valley lake ca. 2800 m in length (north-south) and maximum ca. 600 m in width. The estimated maximum area of that lake in case of the maximum water level (162.20 m) is 99 ha, and at minimum water level (158.50 m) 78.5ha. The oblong tunnel valley lake has a moderately developed coastline in vast majority overgrown with trees. The banks are steep and rocky. On the northern end of the lake there is a very shallow bay overgrown with water plants. This bay has a small tributary. The eastern bank, overgrown with trees, is very steep and in many places inaccessible from the landside. In some places the soil slides together with the trees to the water, which hinders measurement works during coastline inventory taking significantly.

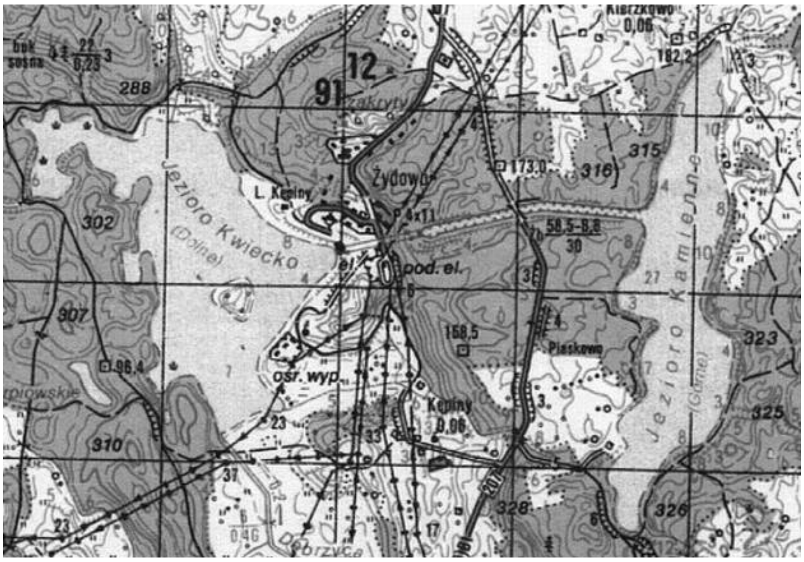

Fig. 1. Lake Kamienne and Lake Kwiecko.

2. METHODOLOGY OF STUDIES

Development of the digital coastline and bathymetric charts of Lake Kamienne including the inlet channel on the basis of current land survey and satellite measurements as well as current hydroacoustic sounding was the objective of the work undertaken. The period of plants vegetation, mainly deciduous trees, made conduct of classical and GPS measurement during the summer season impossible. For that reason the test measurements were planned for late autumn. The coastline inventory taking was conducted using the classical Total Station system as well as GPS receivers. The bathymetric measurements were conducted using hydroacoustic sounding and GPS/RTK satellite positioning technique.
Before commencement of measurement works on Lake Kamienne the following preparatory works were conducted:

the direct object area inventory was taken,
the methodology of study was defined,
the major measurement profiles were designed.

After familiarizing with the object, immediately prior to the field measurements, the following works were carried out:

The local reference station was established. Using the GPS technique the coordinates of measurement control network were determined,
The Integrated Bathymetric System was started up and calibrated.

3. COASTLINE INVENTORY TAKING

It was assumed that the measurement of the coastline would be conducted by means of the classical method (Total Station) from the shore. During the first day of measurements the measuring instrument Leica TC 605 was positioned on consecutive points of the measurement network and the measurement of the northern part of the lake was conducted moving along the shore.
During the first day of measurements it was found out that a significant part of the coastline is inaccessible from land as a consequence of abrupt, steep slopes.
The experience determined conducting further measurements of the coastline using a rowboat. As a consequence of highly diversified coastline, trees and difficult

atmospheric conditions (fog) classic measurements by Total Station method from the rowboat were supplemented with satellite measurements using a Thales Mobile Mapper receiver with the post-processing option. For that purpose, especially for the needs of the project, a GIS library with appropriate attributes was established.

Fig. 2. Lake coastline measurement using a rowboat.

For the purpose of obtaining bathymetric measurements and to present the extremely diversified land relief of the land part the topographic survey of the 20 m wide belt along the coastline was conducted. The survey of the land part was conducted using a Thales Mobile Mapper receiver with the post-processing option.
Measurement for each of the raw data took ca. 10-20 seconds, which assured horizontal accuracy of measurement within 1 m in post-processing. This accuracy is sufficient for collecting information on the adjacent area in that type of survey. As a consequence of very difficult and diversified field situation, high density of trees and lack of access to the coastline the choice of the GPS method proved a highly effective method of survey securing the required accuracy. Nevertheless, this type of survey is only possible at the time when trees have no foliage and in the summer such a survey would be impossible.
In total, during the field survey, the data for ca. 1600 points was collected that allowed development of the 3D model of the land belt surrounding the lake. The following figure presents a fragment from the survey of raw data points.

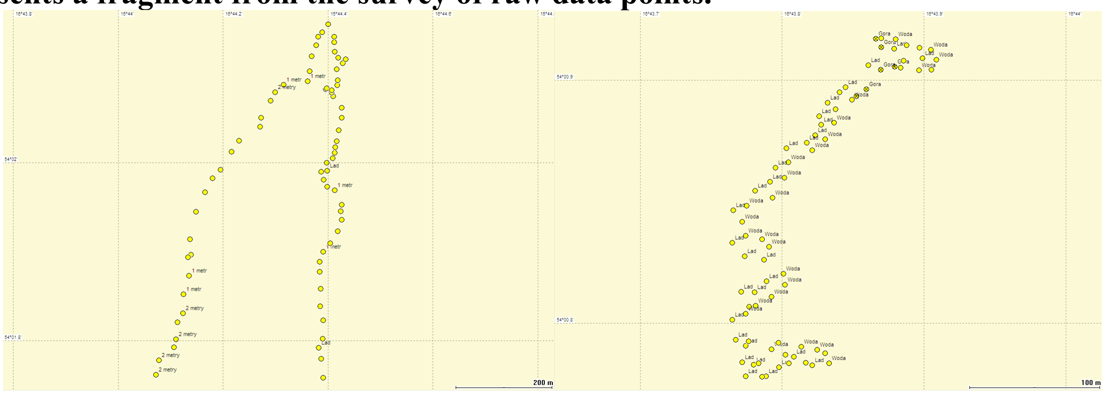

Fig. 3. Fragment from the survey of staff stations of the coastline and land section conducted within the frameworks the study.

4. HYDROACOUSTIC SOUNDING

To achieve high accuracy of depth measurement conducted using single frequency echo sounder it is necessary to conduct the measurement system calibration. Hydroacoustic measurements are carried in different water reservoirs during different weather conditions. The vertical distribution of water temperature can be different in different parts of the water body and it can vary in time. That is why, before commencement of the bathymetric measurements and during them the distribution of sound wave propagation speed depending on the depth should be tested. In relatively shallow waters with constant temperature the sound speed measured for different depths can be averaged and sounding works can commence after inputting the value into the measurement system. When we deal with a deep reservoir with highly diversified water temperatures at different depths the vertical distribution of acoustic waves speed should be measured and adjustments for individual depths should be computed. The vertical distribution of ultrasound waves speed in water can be measured using the calibration probe or the so-called calibration plate (calibration board).

On the first day of measurements, before commencement of sounding, the tests of water parameters were conducted to determine the sound propagation speed in water. The sound speed in water has fundamental influence on the accuracy of depth measurements using hydroacoustic methods.

The values of temperature, salinity and water pressure in a given place depend mainly on the depth. The sound speed distribution depends mainly on the thermal structure of water and less on the salinity. Temperature decreasing with depth causes a decrease in sound speed but at the same time with depth increase the hydrostatic pressure increases causing an increase in sound speed.

Before hydroacoustic sounding of Lake Kamienne the YSI 600R device was used for testing the conductivity and temperature and the YSI2SS software was used for computation of sound speed in water on the basis of the formula developed by Medwien in 1977 [1].

On the basis of the results form sound speed in water tests and bar check calibration the Simrad EA 501P system was calibrated for depth measurement in Lake Kamienne. The sound speed in water was 1445m/s in average.

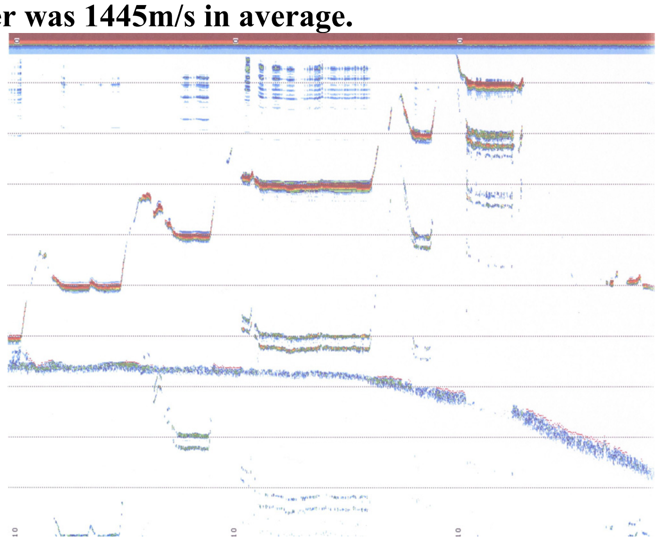

Fig. 4. Calibration of Simrad EA 501P echosounder.

After testing correctness of reference station and precise GPS/RTK positioning operation on Lake Kamienne, and following calibration of depth measurement system the field survey work was started.
Ashtech Z-Xtreme receiver operating in the RTK (Real Time Kinematic) mode was used for determining the boat position during sounding. During the measurements the file with the position and raw data for post-processing mode were also recorded. ArcMap v. 8.3 by ESRI Inc. was used for navigation through the measurement profiles. The basic measurement profiles were designed in the East-West directions at the interval of 20 m. The boat position, determined in real time, allowed precise navigation of the boat along the earlier designed measurement profiles. During measurements satellite navigation was conducted depending on the variability of the reservoir bottom along the profiles at the distances of from 5 to 20 m.

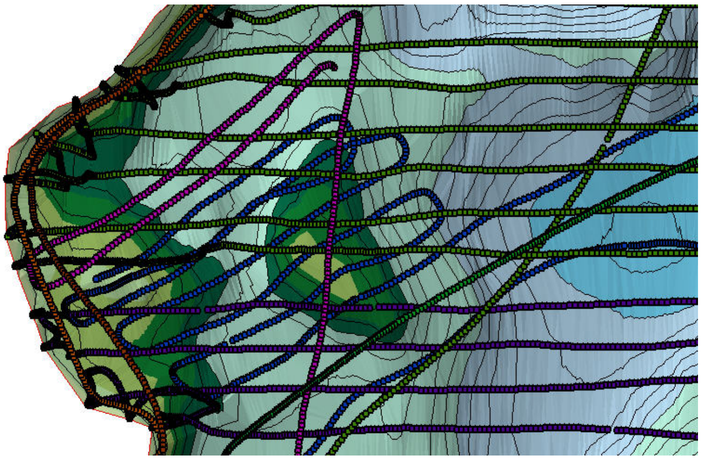

Fig. 5. Increasing the measurements level of detail after locating the shallow banks.

5. PROCESSING OF RAW DATA FROM HYDROACOUSTIC SOUNDING

After conducting the field measurement campaign on Lake Kamienne the bathymetric data recorded was processed. Data from hydroacoustic sounding along individual measurement profiles was recorded as echograms in the form of binary files containing the following data: echogram image recorded for printing under office conditions, depths, position and basic setup data of the echosounder.

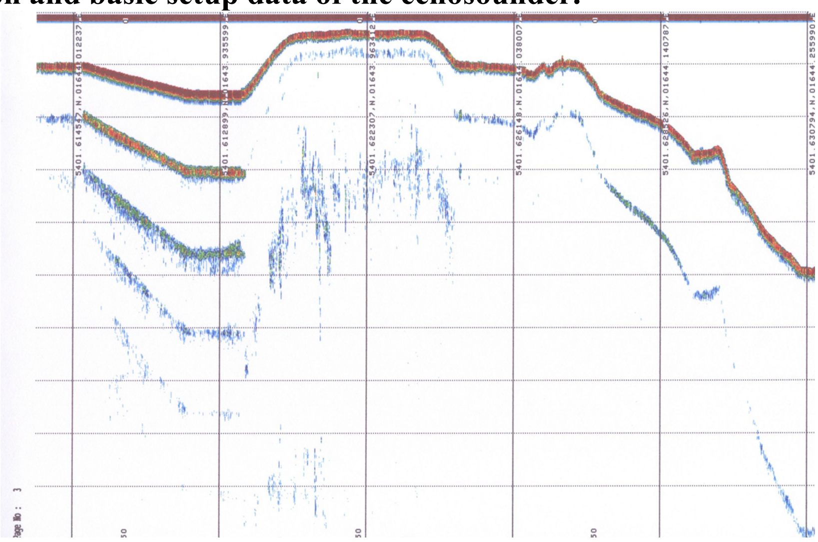

Fig. 6. Echogram from the area of inlet channel to the upper reservoir (Lake Kamienne).

All echograms were printed and next used for verification of the numeric data recorded from the measurement: position with the depth.
The raw data from hydroacoustic sounding was processed using the software by the authors called Echo Converter and Echo View.

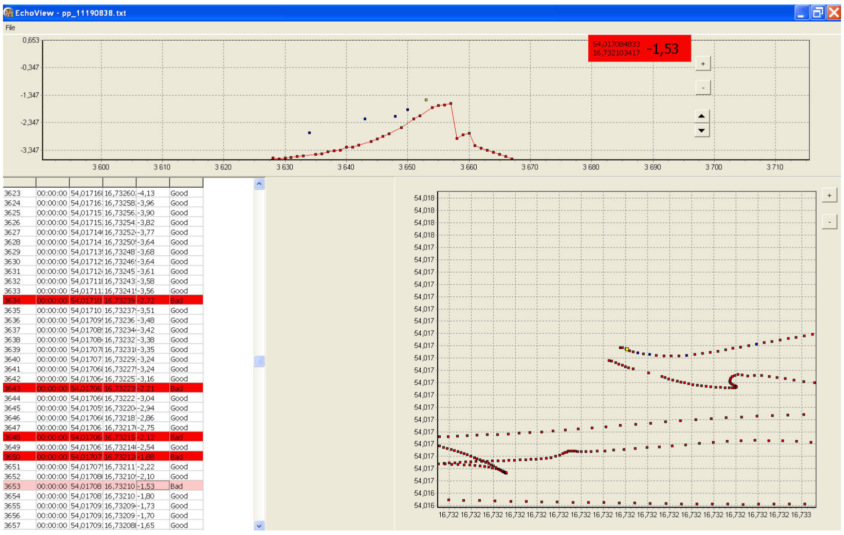

Fig. 7. Filtration of raw depth data in Echo View application.

Verified and filtered measurement data had to be brought to the common water level. The specific characteristics of the upper reservoir of the pumping-storage power plant caused that during the measurement campaign the water level changed depending on the operational schedule of the power plant in Żydowo.
To determine the final water level on a given measurement day the digital readings from the power plant water level indicator, data on the height of the GPS antenna positioned on the boat during hydroacoustic sounding computed in post-processing mode and data from own readings of water level on concrete steps at the outlet of the channel to Lake Kamienne were considered.

Table 1. Computation of depth adjustments for each day of measurements

Zero level: 162,20 m	Day 1 16.11.07	Day 2 17.11.07	Day 3 18.11.07	Day 4 19.11.07
Direct readings	161,32	162,21	162,18	162,14
RTK/OTF	161,35	162,23	162,19	162,14
Digital water level indicator	161,32	162,21	162,18	162,13
Adjustments made [m]	0,87	-0,01	0,02	0,07

For conversion of ellipsoid heights to the system of ordinary heights the values of computed distances of the geoid from the ellipsoid within the range of from 32.46 m (northern part of Lake Kamienne) to 32.50 m (southern part of Lake Kamienne) were applied.
As a result of processing the raw measurement data the set of staff points of the reservoir bottom converted to one water level that formed the database for development of the Digital Elevation Model of Lake Kamienne Bottom.

6. DEVELOPMENT OF THE DIGITAL ELEVATION MODEL OF THE BOTTOM

There are a number of methods for modelling 3D data such as terrain models. The most popular among them are regular grid surface (grid) and triangulated irregular network (TIN). Both of them are commonly used for creating and representing surfaces in GIS.
TIN structures are most often used for visualization of non-homogenous surfaces that are more diversified in selected parts of the area surveyed. They allow diversification of the number of points describing the surface depending on the diversity of the given surface. In that model the space is represented in the form of the network of non-overlapping triangular elements created as a result of connecting irregularly distributed points with coordinates x, y, z. That design assures the possibility of adjusting the spatial distribution of triangles to best reflect the relief of the surface.
Performance of the tasks related to inventory taking and design of the digital model of the area of the upper water reservoir at the storage-pumping power station in Żydowo required obtaining the detailed data concerning the coastline and shape of the bottom of Lake Kamienne. The measurement procedure applied linked to performance of acoustic sounding assuming higher density of measurements in locations of particular importance for computations allowed collecting an extensive and consistent set of data allowing development of a precise Lake Kamienne bottom model.
On the basis of collected and processes bathymetric data on Lake Kamienne the digital model of the lake bottom and inlet channel was developed. The regular coverage with the data and performance of additional measurements related to determination of the course of the coastline and obtaining detailed information on bottom shape allowed generating the digital elevation model of the reservoir bottom as a TIN structure.

7. DEVELOPMENT OF THE INLET CHANNEL SPATIAL MODEL

Performance of works involved in the design of a bottom model of the water reservoir with the inlet channel required conducting a number of operations. The subject scope involved encompasses performance of the:

- **analysis of archival maps and technical documentation of the inlet channel,**
- **determining the course of the upper edge and bottom of the channel,**
- **design of the inlet channel spatial model,**
- **interpolation of the coastline course at the selected water level.**

As the result of the conducted analyses of cartographic material and technical documentation of the channel the characteristic points were determined (horizontal coordinates x, y and normal heights) that allowed representation of the shape and course of the lower and upper edge of the channel walls. During the work the following materials that were made available by the orderer were used:

1. **Topographic maps in scale 1:500 (4 sheets – 16a, 17a, 17c, 17d),**
2. **Topographic maps in scale 1:1000,**
3. **Longitudinal profile of the channel in scale 1:100/1000,**
4. **Cross sections of the canal 1 -1, 2 -2 in scale 1:200,**
5. **Longitudinal profile – cross section 11 -11 (balance reservoir) scale 1:200.**

On the basis of the determined elevation data points the layers presenting the course of the bottom and the upper edge of the channel wall were generated.
Regular design of concrete plates allowed decreasing the number of points necessary for precise representation of channel shape and construction of the true model necessary for further analyses and computations.

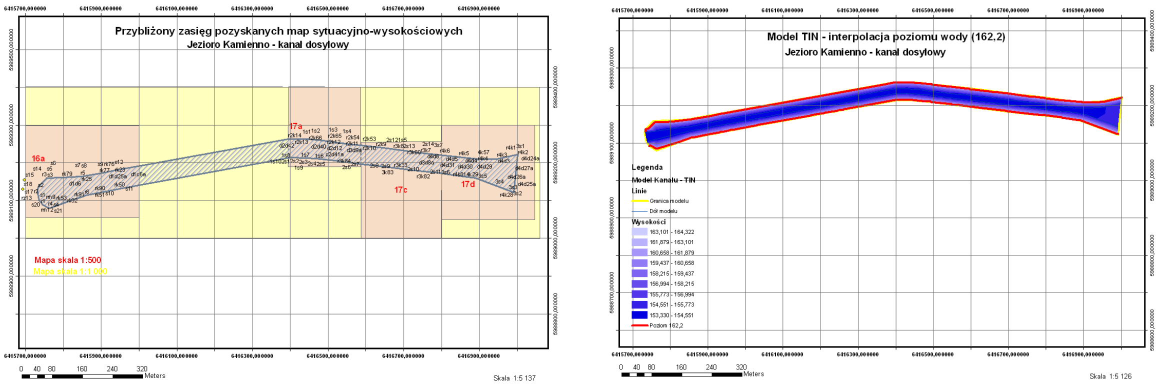

Fig. 8. Map of the inlet channel (topographic maps, measurement points obtained from the topographic maps, contour line defining the water level on the spatial model of the channel.

Design of the inlet channel spatial model was done using the ArcView software by ESRI with the extension 3D Analyst and Spatial Analyst.

Fig. 9. Spatial model of the channel – TIN, interpolated on the basis of the archival materials and technical documentation made available.

The next stage of work involved determination of the coastline course at the assumed level of water for Lake Kamienne and the contour line representing that water level in the inlet channel. Determining the homogenous course of the coastline allowed performance of further works involved in computing the volume of water in the lake and inlet channel.

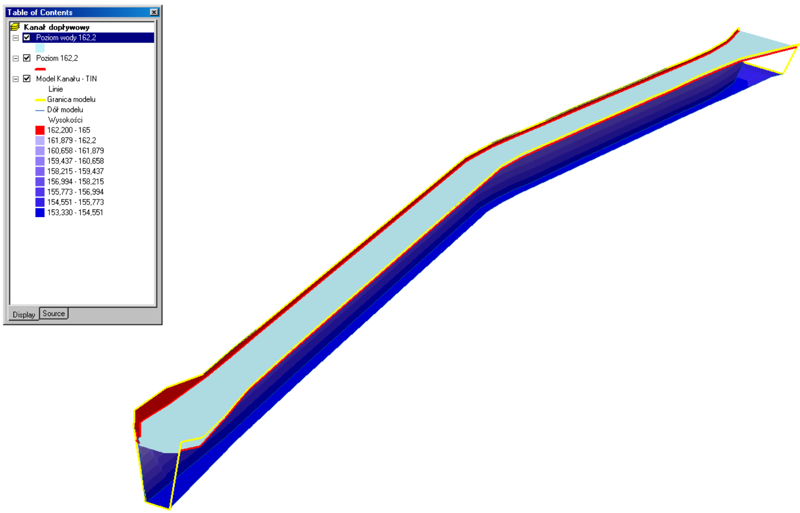

Fig. 10. Course of the contour line defining the water level on the spatial model of the channel –3D view.

8. CREATION OF THE DIGITAL ELEVATION MODEL OF LAKE KAMIENNE

As a result of bathymetric survey conducted for basic profiles designed at 20 m interval 59,973 spot heights were obtained. The minimum depth measured was -0,4m, while the maximum depth was -35,8m. The average depth was determined at the level of -7,5m, and the standard deviation at - 7,2m.

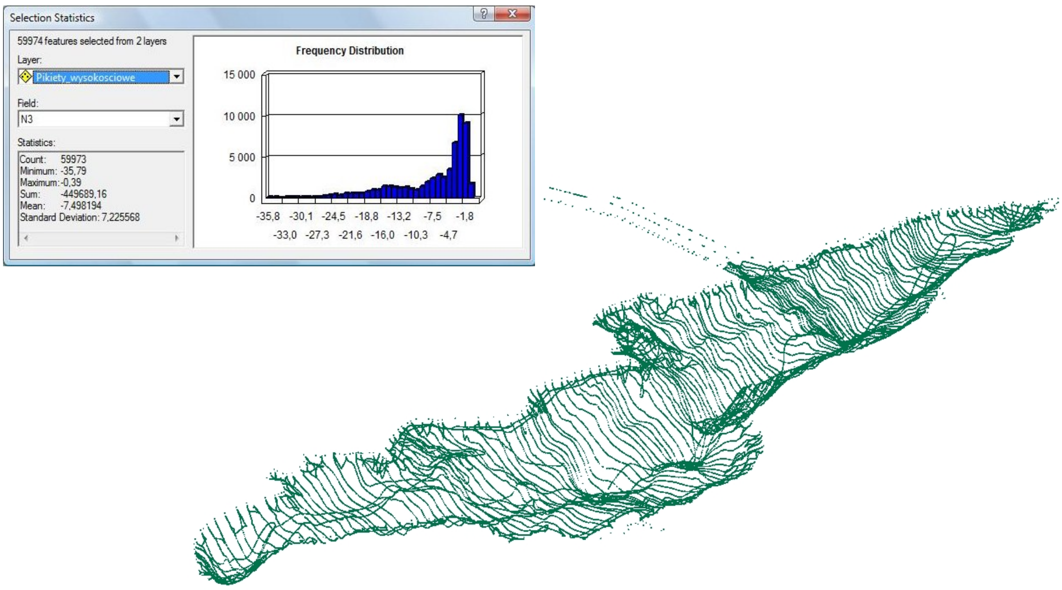

Fig. 11. Statistical distribution of elevation points obtained as the result of bathymetric measurements, distribution of TIN model nodes.

For the purpose of eliminating the measurement errors the data obtained was subjected to time correlation and filtration using the applications developed by the authors called Echo Converter and Echo View. The resulting set of elevation data points was used for construction of the digital TIN model containing the triangulated irregular network characterizing the water reservoir bottom surface.

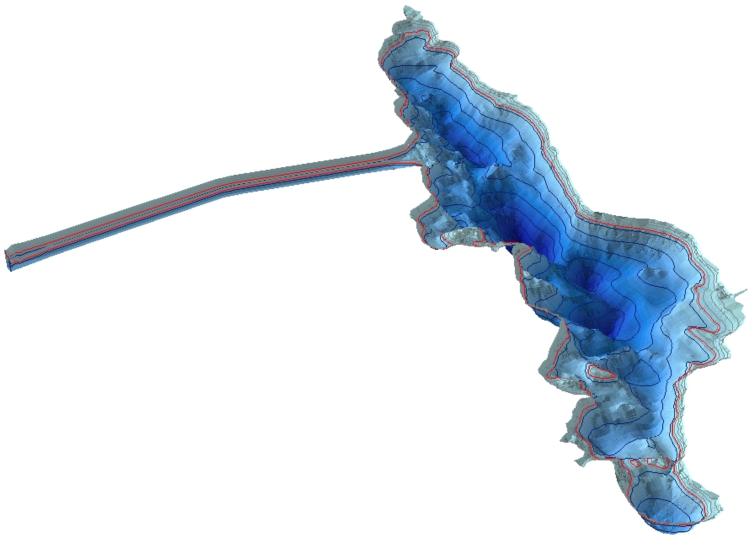

Fig. 12. TIN model of Lake Kamienne with coastline and contour line -3.70m marked in red.

ArcView 9.2 software by ESRI with the extension 3D Analyst and Spatial Analyst was used to generate the model.

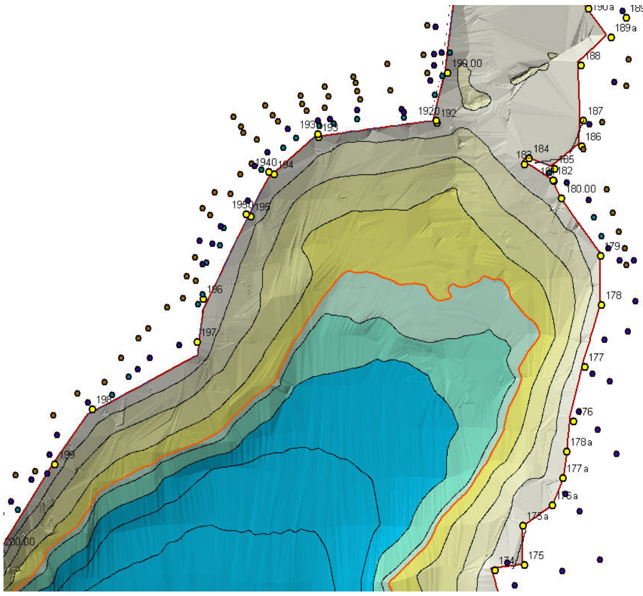

Fig. 13. Digital elevation model of the bottom with coastline data points.

On the basis of the developed Digital Elevation Model of the Bottom spatial visualizations were prepared and the bathymetric chart of Lake Kamienne, the upper reservoir of the Pumping-Storage Power Plant Żydowo in the scale of 1 : 2 500 was developed. In the chart the cut of bathymetric contour lines at the interval of 1 m was made to the depth of 4 m (brown). The contour line -3.7 m is charted in red. The contour lines from 5m to 35m are presented in black. The bottom shape was presented in the form of the raster in shades of blue.

9. CONCLUSION

As a result of survey and hydrographical works conducted on Lake Kamienne – the upper reservoir of the Pumping-Storage Power Plant Żydowo, the Digital Elevation Model of the Bottom and the bathymetric chart of the reservoir in the scale of 1: 2500 were produced.

During the work, classical survey methods (Total Station) were applied. Because of the difficult weather conditions (fog) classical survey measurements had to be complemented by taking the inventory using the GIS Thales Mobile Mapper GPS receiver with post-processing option. Application of classical and satellite methods allowed completing the full scope of works planned for taking the inventory.

Hydroacoustic sounding was carried out on the basis of single beam ultrasound probe. Processing of the data from bathymetric survey required adjustments to the depth measurements as a consequence of changing water level at different stages of the work. The adjustments were computed on the bases of the readings from the digital water level indicator of the power plant and verified by the height computations by means of GPS OTF technique.

The Digital Elevation Model of the Bottom of the reservoir and of the inlet channel was used for computation of the capacity of the upper reservoir of the Pumping-Storage Power Plant Żydowo. The results obtained allowed optimisation of power plant operation.

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