DARIUSZ POPIELARCZYK, TOMASZ TEMPLIN, MARCIN GRYSZKO
University of Warmia and Mazury in Olsztyn

ELABORATION OF DIGITAL BOTTOM MODELS ON THE BASIS OF SINGLE BEAM ACOUSTIC MEASUREMENTS WITH DIFFERENT RESOLUTION

ABSTRACT

The paper presents results of the experiments carried out on the 40 ha part of the Lake Śniardwy using satellite and hydrographic integrated technology. Bathymetric survey at the Lake Śniardwy has been conducted with the measurement profiles designed every 50 meters and 5 meters one after another. The collected data have been elaborated with spatial interpolation method called kriging in order to create Digital Bottom Model. The results of conducted experiments show comparison of two bottom models created on the basis of 50 m and 5 m profiles.

Keywords:
bottom models, single beam, lake.

INTRODUCTION

The inland water reservoirs in Poland consist of lakes, rivers and channels. In most cases there are shallow estuaries — usually lakes. The maximum depth — 112 m can be found in Lake Hańcza in the north — east Poland but many lakes have an average depth of 5–20 m and almost do not have up-to-date digital charts. Most of them have been measured almost 50 years ago. Existing analogue maps do not present the real and accurate bottom surface. Therefore it is very important to explore their bottom shape to ensure the general safety by creating digital, bathymetric charts and digital bottom visualizations, marking the inland waterways and especially dangerous shallow stone reefs on inland waterways.

The accuracy of the generated digital terrain model depends on the amount of raw hydrographic data. Shallow inland water reservoirs are usually measured with the use of single beam hydrographic systems. The process of collecting raw data is run along pre-defined profiles.

The paper describes results of two parts of the experiment based on the measurements of the same area of the Lake Sniardwy but with different resolution of pre-defined profiles. The raw sounding data were elaborated and finally two independent digital bottom models were created.

INTEGRATED BATHYMETRIC MEASUREMENTS

Integrated Bathymetric System

The experiment was carried out on the biggest lake in Poland — Lake Śniardwy with the use of Integrated Bathymetric System developed by the research team of Chair of Satellite Geodesy and Navigation (University of Warmia and Mazury in Olsztyn). The technology of bathymetry surveying used to examine under water environment is based on DGPS technology and single frequency digital echosounder [1]. The developed Integrated Bathymetric System basically consists of:

- The DGPS positioning system;
- The bottom detection system;
- The special GPS and GIS software.

The Differential GPS positioning system uses two professional GPS receivers. The first of them, placed at a known mark is a stationary receiver called base or master reference station. There can be used the permanent reference station or a local station set up only for the dedicated project. The base station receiver determines the errors of measurement data between fixed and observed station position (corrections). The DGPS corrections in RTCM v. 2.2 format are sent via GPRS (General Radio Packet Services) to the rover GPS receiver in unknown location and can be applied to measurement data.

The hydrographic equipment includes EA 501 P Simrad single frequency digital hydrographic echo sounder and YSI 600R sonde for water quality sampling. The EA 501 P system basically consists of transducer, transceiver and personal computer. The DGPS receiver can be connected to the Laptop serial port (NMEA-GLL format), and position data can be provisionally combined with the measured echo data. The EA 501 P Simrad general specification is as follows: the transceiver 200 kHz frequency, max freshwater detection depth — 600 m, accuracy about 0.25% of measured range, calculation interval for 0 to 10 per second. The YSI 600R provides water quality sampling for both surface water and groundwater. This sonde measures temperature, conductivity, dissolved oxygen, and pH. The speed of sound in water is estimated by a simple empirical formula [2]. The YSI 600R sonde is also used for pollution monitoring [3].

The special GPS and GIS software of the system allows the measurement profiles to be designed, enables navigation along the profiles, recording and combining the positioning/bathymetric data, and finally creating bathymetric maps. For elaboration of raw-data the originally developed software Echo Converter is used.

Bathymetric measurements

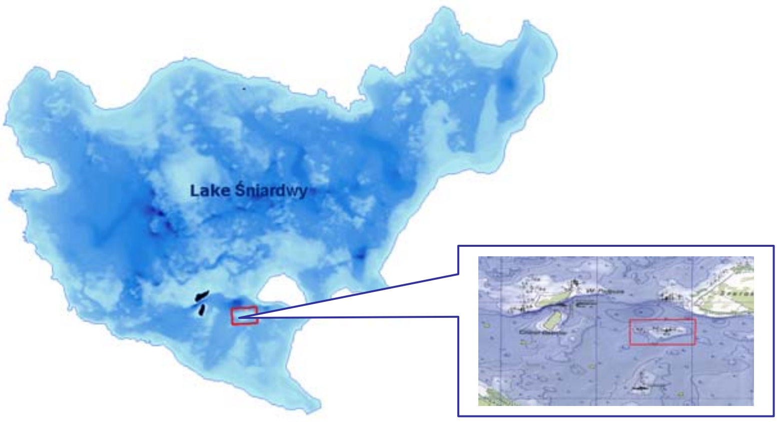

Fig. 1. Lake Śniardwy — test area location

Bathymetric survey at the Lake Sniardwy has been conducted with the measurement profiles designed every 50 meters and 5 meters one after another. In the first part of the experiment based on 50 m profiles 1,936 raw sounding data were collected. The mean depth is 4.34 m, minimum depth is 0.57 m and maximum 12.65 m. These raw data was collected during Lake Sniardwy bathymetric campaign held from 5th July 2005 to 8th September 2005.

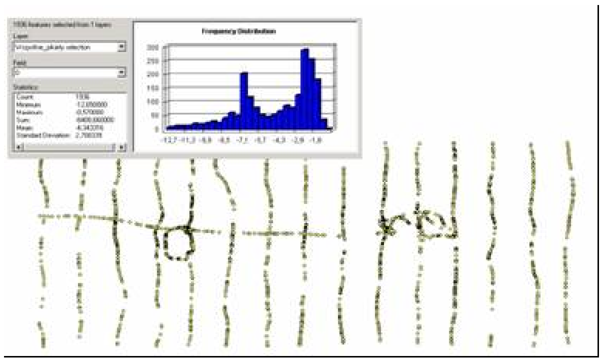

Fig. 2. Bathymetric survey draft — the measurement profiles designed every 50 meters one after another

In the second part of the experiment based on 5 m profiles 27,826 raw data were recorded.

The mean depth is 4.90 m, minimum is 0.40 m and maximum 12.60 m. The data was collected during measurements held in September 2006.

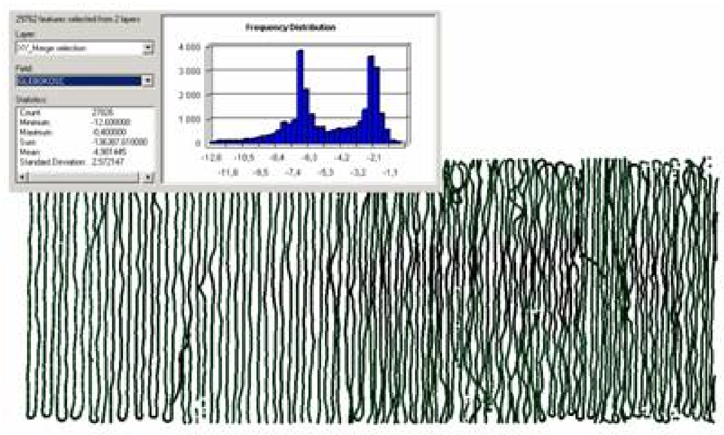

Fig. 3. Bathymetric survey draft — the measurement profiles designed every 5 meters one after another

SPATIAL INTERPOLATION METHOD

Elaboration of the digital bottom model was carried out with the spatial interpolation method named kriging. Kriging is a geostatistical estimation procedure of the value of the parameter in random location of the interpolation area. This method is based on the assumption that interpolated parameter is treated as regionalized variable. The spatial dependence of points is expressed throughout the semivariogram.

The chart of the experimental semivariogram was plot with the use of the following formula:

$$\gamma^*(h) = \frac{1}{2N(h)} \cdot \sum_{x_i - x_j = h} (Z(x_i) - Z(x_j))^2 , \tag{1}$$

where: γ^* — value of the experimental semivariance of the distance h;
$N(h)$ — number of pairs of points localized in distance h;
$Z(x_i)$ — value of the parameter in point x_i.

The value of the experimental semivariance was calculated for the distance interval of 1m.

The next step of the assignment was to fit the theoretical and experimental semivariogram. This task was performed with the spherical semivariogram model expressed by the following formula [4]:

$$\gamma = C_0 + C_1[1.5 \cdot \tfrac{h}{a} - 0.5 \cdot (\tfrac{h}{a})^3] \text{ for } h \le a; \tag{2}$$

$$\gamma = C_0 + C_1 \text{ for } h < a. \tag{3}$$

The algorithm of the estimation of the parameter in point x_0 consists of the following steps [5]:

1. The calculation of the terms in matrix V where $Cov(x_i, x_j)$ is the assumed semivariance model

$$V = \begin{pmatrix} Cov(x_1, x_1) & \cdots & Cov(x_k, x_1) & 1 \\ \vdots & \ddots & \vdots & \vdots \\ Cov(x_1, x_k) & \ldots & Cov(x_k, x_k) & 1 \\ 1 & \ldots & 1 & 0 \end{pmatrix}, \tag{4}$$

where: x_i — sample points;
k — number of points taken into account in calculations.

2. The determination of the terms in matrix v, where $Cov(x_0, x_j)$ is the assumed semivariance model for point x_0 and sample points taken into calculations

$$v = \begin{bmatrix} Cov(x_0, x_1) \\ \ldots \\ Cov(x_0, x_k) \end{bmatrix}, \tag{5}$$

where: x_i — sample points;
k — number of points taken into account in calculations.

3. The solution of the set of the equations and determination weight vector L:

$$VL = v, \tag{6}$$

where:

$$L = \begin{pmatrix} \lambda_1 \\ \vdots \\ \lambda_k \\ \mu \end{pmatrix}.$$

4. The calculation of the estimated parameter $\hat{Z}(x_0)$ using following set of equations:

$$\begin{cases} \hat{Z}(x_0) = \sum_{i=0}^{k} \lambda_i Z(x_i) \\ \sum_{i=0}^{k} \lambda_i = 1 \end{cases} ; \tag{7}$$

$$\Downarrow$$

$$\hat{Z}(x_0) = Z' L = Z' V^{-1} v , \tag{8}$$

where
$$Z = \begin{bmatrix} Z(x_1) \\ \vdots \\ Z(x_k) \end{bmatrix} .$$

5. The calculation of the estimation ariance $\sigma^2(x_0)$:

$$\sigma^2(x_0) = Cov(0) - v' L = Cov(0) - v' V^{-1} v . \tag{9}$$

Size of the matrices used in calculations depends on the number of sample points. In case of large set of points taken into calculations the computational complexity of the algorithm increases significantly. Therefore, the algorithm had to be extended of the sample selection methods. According to Olea [5], the number of sample points greater than 10 had insignificant influence on the value of the estimated parameter.

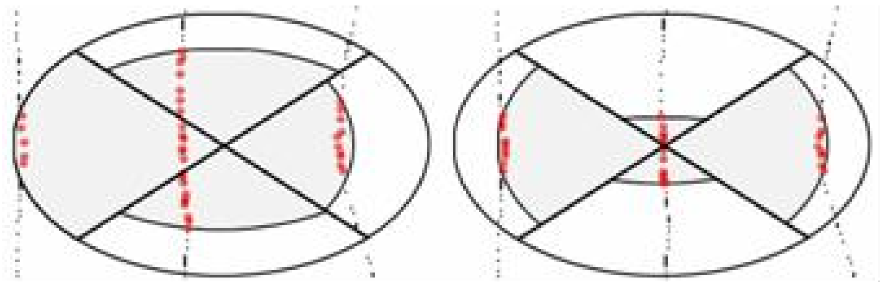

Fig. 4. Sampling methods scheme

In the computer program, developed on the purposes of the assignment, the search area is an ellipse split into four sections (fig. 4). Because of the direction of the measurement profiles the major axis of the ellipse is directed perpendicular to the profiles. In each section points localized nearest estimated point are selected.

The final result of the assignment is a regular grid with estimated value in each point of the grid. On the purposes of this article two calculations of the digital bottom model were made.

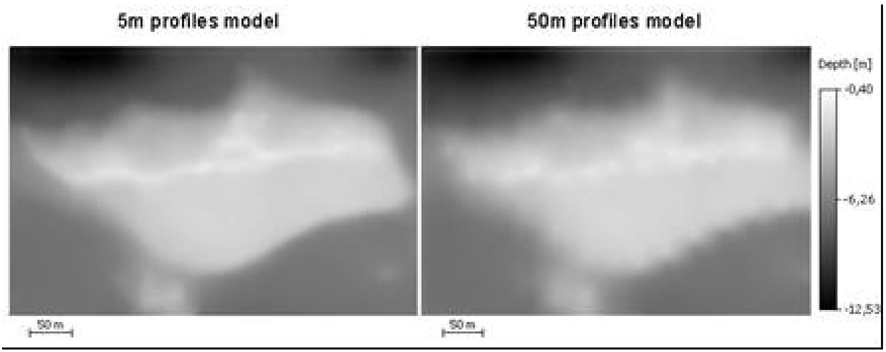

Fig. 5. Digital bottom models calculated on the basis of 5 m and 50 m profiles

DIGITAL BOTTOM MODEL

Regular grid was interpreted using GIS software, which provides an ideal environment for datum conversion, geo-referencing, profile extraction, interpretation and visualization. Digital Bottom Model was generated with the use of ESRI ArcGIS Software and ArcGIS 3D Analyst extension. The regular grid resultant in interpolation process was used to construct Digital Bottom Model. Collected 3D points and DBMs from both parts of experiment are presented in Figure 6 and 7.

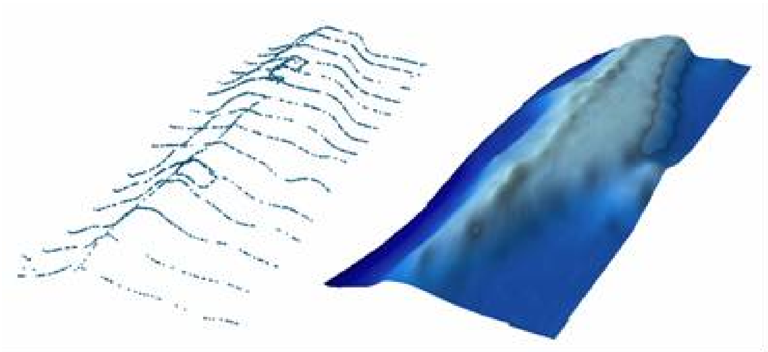

Fig. 6. Digital Bottom Model (DBM): 3D points, digital bottom models (the measurement profiles designed every 50 meters one after another)

Additional analyze was a substraction of depth values of both models which gives a 3D representation of the models differences. These analyzes were performed with the use of ArcView and the ArcGIS 3D Analyst extension. Results in the form of differences model and histogram of depth differences are presented in figure 8 and 9.

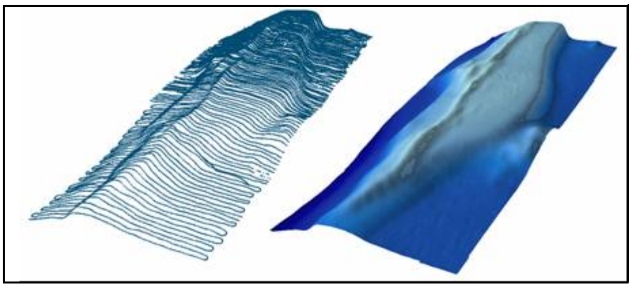

Fig. 7. Digital Bottom Model (DBM): 3D points, digital bottom models
(the measurement profiles designed every 5 meters one after another)

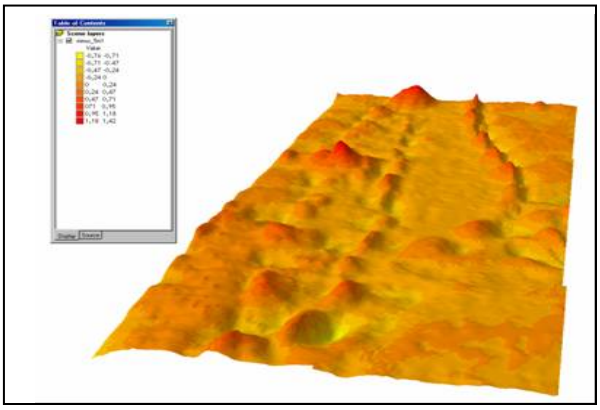

Fig. 8. Depth differences

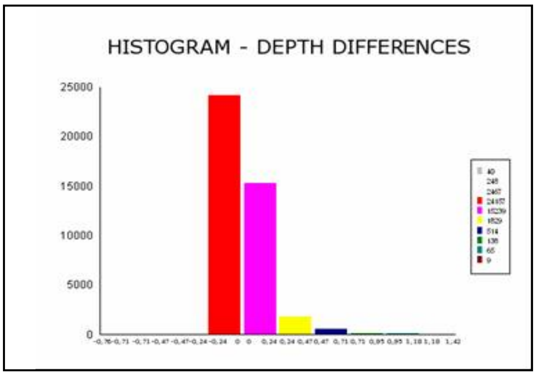

Fig. 9. Frequency distribution of the depth differences values

CONCLUSIONS

The low cost and high efficient Integrated Bathymetric System has been used for bathymetric measurements on the 40 ha part of Lake Sniardwy, the largest inland reservoir in Poland. The chosen test area occurs to be very sophisticated with unexpected, underwater slopes and faults. Moreover the shallow part of the tested area includes long dangerous stone reef. Therefore it is very important to sound such places, elaborate digital navigation charts and create digital bottom model and visualizations.

Collected bathymetric data were elaborated with the use of spatial interpolation procedure called kriging. This method turned out as a very useful tool in a elaboration process of hydrographic data. Despite inconvenient structure of input data the surfaces resultant in the interpolation process are solid, smooth and they represent bottom surface very well. The results of interpolation show that kriging can be applicable in elaboration and analyzing of hydrographic data.

Comparison of both bottom models shows that maximum differences between models occur in areas with various relief. The highest and the lowest value of the difference were encountered respectively on the underwater slope and on flat area. This information is very useful in process of defining measurement profiles.

Generally, the shapes of both elaborated bottom models are very similar but the model based on 50 m pre-defined measurement profiles can turn out as insufficient in case of localizing unexpected, underwater obstacles. Therefore potential dangerous areas should be covered with higher density of measurement profiles.

Having actual charts based on high resolution sounding the inland waterways can be physically localized by buoys or by navigation signs in the case of underwater stones and reefs. The digital up-to-date maps and the DGPS system provide reliable and precise satellite navigation service for users, as well as the precise monitoring service for sailing boats in the case of emergency, mainly due to the unexpected strong winds and storms.

The 50 m separated profiles sounding data were collected during the Lake Śniardwy hydrographic campaign, which was run within the confines of realization scientific project Project on Civil Protection and Safety System for Development of Eco-Tourism in Warmia and Mazury Region with GNSS Applications, granted by the Ministry of Science and Higher Education in Poland.

The 5 m separated profiles sounding data measurement, digital bottom models elaboration and analyses were conducted within the confines of realization scientific project Application of dynamic positioning techniques DGPS/EGNOS/RTK/GPRS and bathymetric measurements for creation of an Interactive Underwater Surface Object Base, granted by the Ministry of Science and Higher Education in Poland.

REFERENCES

[1] Popielarczyk D., Oszczak S., Technology of Bathymetric Survey with Satellite Positioning GPS System and Digital Echo-Sounder, CD-ROM Proceedings of International Association of Geodesy 2001 Scientific Assembly, Budapest 2001.

[2] Clay C. S., Medwin H., Acoustic Oceanography, Wiley Interscience, New York 1977.

[3] Popielarczyk D. Oszczak S., GPS Positioning in Monitoring of Inland Water Contamination, The 5th International Conference on New Trends of Development in Aviation, Section III Combat Use of Air Force, Air Force Academy in Kosice, Slovak Republic 2002.

[4] Bardossy A., Introdution to Geostatistics, Institute of Hydraulic Engineering, University of Stuttgart, Stuttgart 2003.

[5] Olea R. A., Geostatistics for engineers and earth scientists, Kluwer Academic Publishers, Massachusetts 1999.

[6] Stateczny A., Methods of the Comparative Navigation (in Polish), Gdynia 2004.

[7] Magnuszewski A., GIS in physical geography (in Polish), Warszawa 1999.

Received March 2008
Reviewed June 2008