

**EVALUATION OF THE NON-CONTACT MEASURING
OF WATER RESERVOIR BOTTOM TOPOGRAPHY**

Jakub Fuska, Viliam Bárek, Peter Halaj, Jozefína Pokrývková, Anna Báreková
Slovak University of Agriculture in Nitra, Trieda Andreja Hlinku 2, Nitra, Slovakia

Abstract

During the operation of the water reservoirs in common conditions there occur the processes of the siltation as the result of the erosion in the watershed and also the processes of sediment displacement within the reservoir or sediment escape out of the reservoir as the result of the inflowing water during the floods or higher water discharges during the spring snowmelt. These processes are forming the shape of the water reservoir and this process affects the depths of water and total amount of stored water. The changes of the topography of smaller water reservoirs are not monitored periodically or occasionally and the methodology for the measuring is not made. For the larger reservoirs there is used the method of periodical measuring of the reservoir profiles as the cross-sections of the reservoir bottom. The comparison of the identical profiles is then used for evaluation of the siltation processes and calculation of the water capacity and sediment quantity difference during the revised time period. The method works with the depth measuring (echo sounding, level staves, calibrated lead line) and measuring of the distance of depth measuring in profiles. The goal of this paper is to assess the new method of monitoring of the reservoir topography with non-contact system of sonar and GPS receiver, which measures and generates the field of points with known coordinates at the bottom. These points can be used in GIS software for the creation of the TIN model that represents the reservoir bottom shape. The assessment of this method is done as the assessment of the accuracy of the created TIN model. This is done as the comparison of the geodetically measured elevation of points and elevation of points extracted from TIN model. The method was tested at the swimming pool, where steady and mostly plain bottom can be measured with geodesy tool – GPS measuring and compared with the TIN model created from data collected with non-contact measurement with GPS and sonar during the sail with small vessel. The comparison of the modeled elevation and the real bottom elevation offers the evaluation of the accuracy of the method. The results lead to conclusion that modeled elevations (calculated from data of TIN model created from the non-contact measured input data) differs from the direct GPS measurement in approx. 20mm in plain parts and 70mm in sloped parts of the swimming pool bottom.

Key words: water reservoir bottom topography, TIN model creation, TIN model accuracy

INTRODUCTION

Small water reservoirs are reservoirs with water volume max. 2 mil. m³, maximum water depth is 9m and volumetric flow rate for hundred years (Q_{100}) is not larger than 60 m³. s⁻¹. (STN 73 6824). In accordance to Ministry of Environment of SR (2002) document “General document of water protection and usage of water” there are 198 small water reservoirs in Slovak Republic. Reservoir siltation is causing the problems related to the reduction of the flow capacity, deterioration of the sailing conditions related to the reduction of the volume. Bottom sediments create important part of the river ecosystems, which has the potential to accumulate various pollution (toxic/ heavy metals, radionuclides and organic matter) from the water (Hucko, 2007). Erosion and the transporting effect of the flowing water are the most important natural processes are. These processes lead to the production

of the eroded material that is carried by rivers and then it is accumulated in the water reservoirs, where the eroded material can settle at the reservoir bed. In the longer time period this effect can lead to the partial or full siltation of the reservoir. Flowing water allows eroded material to move and settle, but it also affects the particles, that are actually presented in the reservoir, by lifting them from the reservoir bed (result of the larger discharge during the snow melting or during the floods) and then relocates them in the reservoir bed (reshape of the reservoir bed) or allow the existing sediment to escape from the reservoir (reshape of the reservoir bed and also change of the volume of the captured sediment and volume of the accumulated water). The shape of the reservoir bed is also formed by anthropogenic processes, mostly by the maintenance work, when the bottom sediments are extracted and removed from the water reservoir. Various tasks of the water reservoir management can be done with the use of the topography of the reservoir bed, such as creation of the cross-sections, assessment of the actual water capacity, periodical measuring of the sediment quantity development or relocation. Reservoir bed topography can be represented in various forms, such as contours, set of points with known coordinates, set of cross-sections or as the digital terrain model in raster or vector format. This paper deals with the possibility of the creation of the water reservoir bed TIN model and assessment of its accuracy.

MATERIAL AND METHODS

Surveyed site

Measuring was done in the swimming pool in Topolčany. The dimensions of pool are 50m x 21m, minimum depth 1,6m, maximum depth 2,3m. The bottom of the swimming pool is horizontal in two levels (1,6m and 2,3m depth), with the slope that connects the horizontal parts. Deeper part is about 30m long, sloped part length is about 10m long and the shallower part is about 10m long. This swimming pool was selected as the testing locality because of its configuration of the parts (two plain parts and sloped part), that will offer the assessment of the methodology in different conditions: deeper plain bottom, shallower plain bottom and sloped part.

Equipment

For the GPS data collection of the point position we used the GPS rover Leica 1200+, that allows the RTK surveying. Global positioning system (GPS) is the positioning system consisting of the cosmic navigation satellites, which emits the radio signal, that is received and processed by the receiver. Receiver calculates the time difference of the signal emitting of and signal receiving and from this difference the distance to particular satellite is calculated. The position of the satellites is known, and with the distances "satellite – receiver" is calculated the position of the receiver (Rapant, 2002).

RTK surveying is the differential GPS surveying method which uses the carrier phase observations corrected in real time. The accuracy of RTK surveying is about 2cm. This method requires the radio connection with the base station for the obtaining of the real-time corrections (Gopi, 2005). For the depth measurement we used the Garmin GPS Map 421s sonar system. Sonar transducer was mounted on the pole of the GPS rover. The principle of sonar measuring is in the emitting and receiving of acoustic pulse, that are propagated from the transducer to the target (or the bottom of sea or water reservoir and lake) and back. Signal is received and processed and in accordance to known velocity of sound in water with known temperature and time of sending and receiving of the pulse is calculated the distance to target (Lurton, 2002). Connection and communication of the GPS system and sonar system was made with the NMEA connection, when the depth measurement from sonar was sent via NMEA interface to the GPS controller. NMEA specification (National Marine Electronics Association) categorizes ASCII data stream in the comma-separated sentence based on the information contained in each sentence. It is necessary to know the structure of the NMEA sentence, because it

will be divided for obtaining of the desired part of data (Thota, 2006). GPS rover with sonar transducer was mounted to the raft boat transom with the set of clamps. Raft boat was propelled with the trolling electric motor.

Data collection

The goal of the work is assessment of the methodology for creation of the TIN model of the water reservoir bed and assessment of its accuracy. TIN model is created from the points collected with the geodetic GPS receiver and low-cost sonar system. This method was tested in the swimming pool in Topolčany. The depth of water is varying from 1,6m to 2,3m, where the elevation of the bottom and slope is uniform at both longer sides of the swimming pool. That allowed us to create the TIN model of the bottom and to compare the model with the bottom elevation measured with the GPS receiver. The evaluation of the swimming pool bottom model accuracy offers the estimation of the accuracy of the method that can be obtained in the further field work in the proper water reservoirs (fish ponds, irrigation reservoirs, etc.). TIN model is 3D representation of the terrain surface, that is built of the non-overlapping irregular triangles (TIN=Triangulated irregular network). The points of these triangles have known x, y, z-coordinates and these points are laying at the surface of modelled terrain (Longley et al., 2005). For the creation of TIN model, there were used two groups of points. First group of points was collected with the non-contact measuring (points in the inner part of pool), the second group was collected with the direct measuring. The idea of non-contact data collection is the measuring of the point coordinates as the measuring of the GPS position (x, y, z-coordinate) of the sonar transducer and depth measuring with the sonar during the sail from raft boat. The combination of these measuring results in the coordinates of the point at the bottom of the water reservoir, where x and y-coordinate are measured with GPS receiver and z-coordinate is calculated in accordance to Equation 1 and its graphical expression at Figure 1.

$$Z - coord. = H_{GPS} + 0,1m - D_{SONAR} \quad [1]$$

where

Z-coord. = z- coordinate of the point at the bottom

0,1m = distance from GPS pole tip to the sonar transducer

H_{GPS} = z – coordinate of the tip of the GPS pole

D_{sonar} = depth measured with sonar

Direct data collection was done as the measuring of the point at the swimming pool margin with the GPS receiver and the measuring of the distance from the margin to the bottom with the geodetic level staff. The combination of these measuring results in the coordinates of the boundary point of the TIN model of the bottom of the water reservoir, where x and y-coordinate are measured with GPS receiver and z-coordinate is calculated in accordance to Equation 2 and its graphical expression at Figure 1. This point does not represent the true boundary of the swimming pool, but it is suitable for the creation of TIN model of swimming pool bottom.

$$Z - coord. = H_{MARGIN} - D_{STAFF} \quad [2]$$

where

$Z\text{-coord.}$ = z - coordinate of the boundary point

H_{MARGIN} = z – coordinate of the tip of GPS pole = elevation of swimming pool margin

D_{staff} = depth measured with level staff (distance from margin to bottom)

Accuracy of the created TIN model was done as the comparison of the elevation of the control points at the swimming pool bottom directly collected with the GPS receiver with the elevation extracted from TIN model. These points were collected only for the purposes of the accuracy assessment and they were not used for the TIN model creation. Data collection of the control points at the swimming pool bottom was done in the emptied pool in 16. april 2013. The points were collected in the area of the swimming pool and the line of the start and end of the slope was estimated by visual checking of the swimming pool bottom.

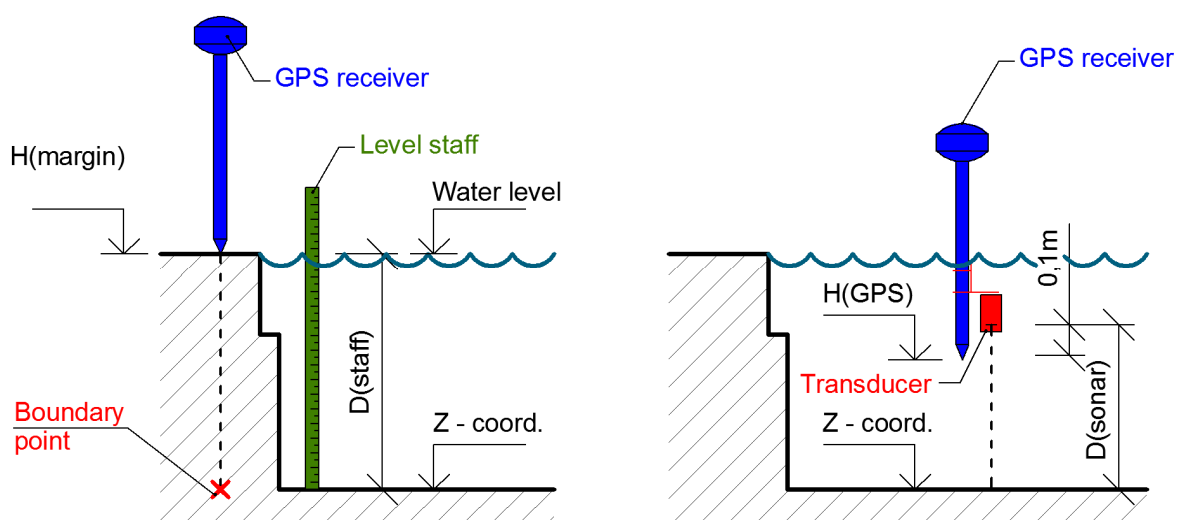


Figure 1. Scheme of the non-contact measuring of the z -coordinate of the point at the bottom (right) and direct measuring of the z -coordinate of the boundary point (left)

RESULTS AND DISCUSSION

During the data collection procedure in the 9th September 2012 there was collected 213 points with the non-contact method during the sail and 22 points with direct measuring method. These points were used for the creation of the swimming pool bottom TIN model. The characteristics of the collected data are shown in the Table 1.

Table 1. Characteristics of collected data

Category of data collection	Amount of points	GPS accuracy of collected points [mm]		
		Min.	Max.	Average
Non-contact method (GPS+sonar)	213	49	23	33
Direct measuring method (GPS)	22	300	12	42

The accuracy of the sonar measuring is quite sufficient, but the accuracy of the direct GPS measuring method is lower. The revision of the collected data has shown, that the accuracy of two points (Point nr. 12 and 13) is worse than 200mm. That indicates the failure of the RTK measuring, which occurred during the data collection. This problem was solved by adding of the same elevation – average elevation of the properly measured points from direct measuring, to all GPS points.

The 3D point data were loaded in ArcGIS 9.3 and the TIN model of the bottom was created. The TIN model and collected 3D points are shown at Figure 2.

Control points were loaded in ArcGIS 9.3 as the 2D points (elevation of the points were not added as z-coordinates of the point). For the evaluation of the TIN model accuracy the input points were divided into three groups (as shown at Figure 3):

- Points of the shallow part
- Points of the sloped part
- Points of the deeper part

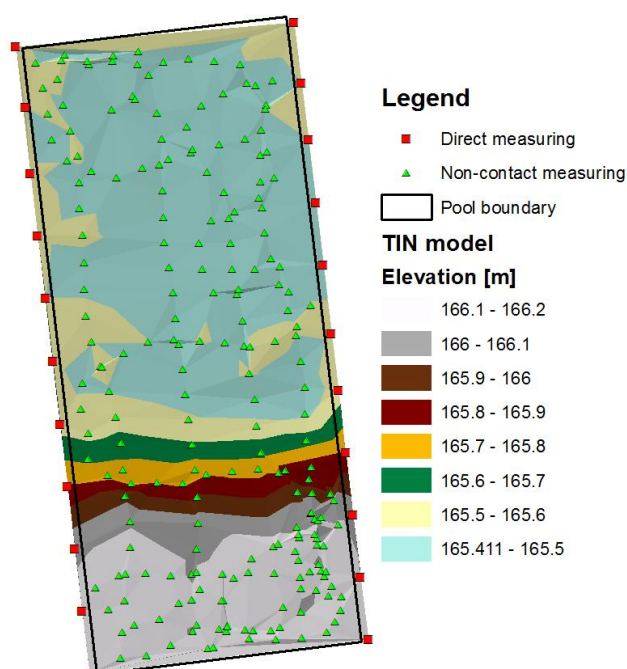


Figure 2. TIN model of the swimming pool bottom and input data – 3D points

Each group of points was evaluated separately, as the evaluation criterion was selected the difference of the true elevation of the control point (collected with GPS at the bottom of the emptied pool) and the elevation of the control point extracted from TIN model. The elevation of the points from TIN model was extracted and added to attribute table of the control points (Add Surface Information tool) and the difference of elevations was calculated in accordance to Equation 3.

$$dZ = Z_{TIN} - Z_{TRUE} \quad [3.]$$

Where

dZ = difference of the elevations

Z_{TIN} = elevation of the control point extracted from TIN model

Z_{TRUE} = true elevation of the control point

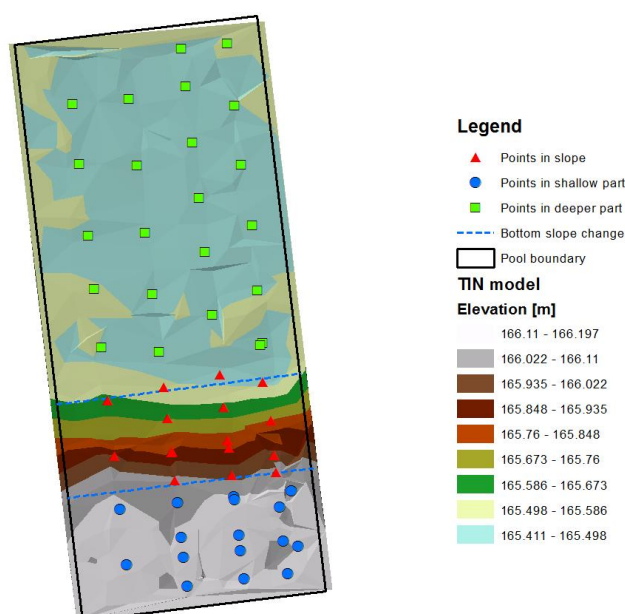


Figure 3. Control points for the evaluation of the TIN model accuracy

The values of the elevation difference calculated in accordance to equation 3 can be positive or negative. Positive value indicates that the model in the revised point is above the true bottom and negative value indicates that the model in the revised point is under the true bottom. The assessment of the accuracy – assessment of the elevation differences is shown in Table 2, where the results of statistical functions calculated in MS Excel 2010 are shown. The statistics are done in accordance to work of Halva (2012) for the comparison of the modelled and measured values of the characteristics of bottom elevation.

Table 2. Comparison of the differences of elevation

Statistical function	Part of swimming pool		
	Sloped part	Deep part	Shallow part
Count of revised points	16	16	23
Average vertical accuracy of direct measured points [m]	0.021	0.022	0.020
Minimum dZ	-0.136	-0.050	-0.051
Maximum dZ	0.014	0.014	0.013
Average dZ	-0.076	-0.017	-0.025
Standard deviation of dZ	0.041	0.018	0.018
Variance of dZ	0.002	0.000	0.000
Root mean square of dZ	0.087	0.025	0.031
Range of dZ	0.150	0.064	0.064

From the results shown in Table 2 it is significant, that the average elevation difference as the main characteristic shows quite sufficient accuracy of the created TIN model in the plain parts (both deeper and shallower part), but the accuracy of the sloped part is worse than 50mm and varies from -136mm to +14mm. For the analysis of the sloped part accuracy there was created the map of the control points of sloped part, where the categorization of points was done in accordance to the elevation difference dZ, as shown at Figure 3.

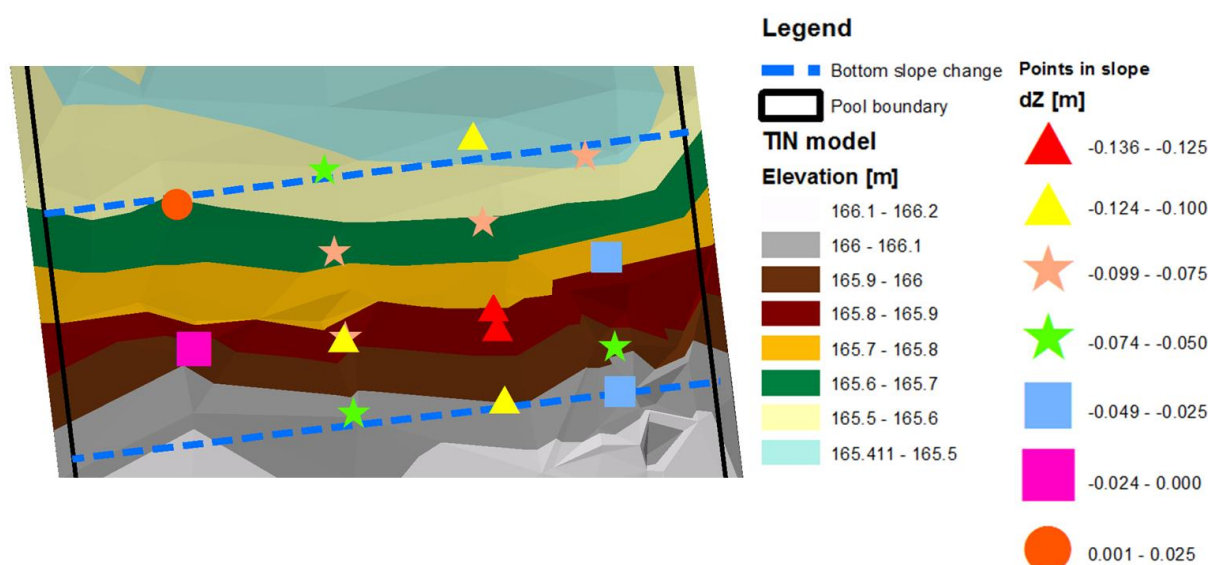


Figure 3. TIN model of the swimming pool bottom and input data – 3D points

The greatest differences of the elevation are in the middle part of the swimming pool bottom slope. These findings show the need of the verification of the data collection and TIN model creation in the field experiments at the water reservoir with rough bottom with the presence of the slopes or convex or concave shapes of the bottom. The verification should be done as the depth measuring from the vessel with sounding line or sounding pole for the depth measuring and multiple GPS measurements of the vessel position and elevation. From the results of this work we can presume the accuracy of the non-contact measuring and TIN model creation in values 75mm in sloped parts and 20mm in plain shapes of the reservoir bottom. It is also an interesting paradox that the larger depths of swimming pool had shown better average accuracy than the shallower parts of the swimming pool.

CONCLUSIONS

Topography of the small water reservoirs is changing in time as the result of the natural processes and artificial effects in the watershed or directly in the water reservoirs. These changes may lead to negative effects to the reservoir functions and purposes, but these changes are not monitored periodically and also the methodology of this kind of monitoring is not made.

The purpose of this paper is to propose the basic principle of the monitoring of the topography of the water reservoir and to evaluate the ability and accuracy of this methodology. Principle of the work is in the collection of the coordinates of the points at the bottom with the non-contact measuring with sonar and GPS receiver during the sail with small vessel propelled with electric engine.

This method is available for use at the most of the small water reservoirs of Slovakia, where it can be proficient in many tasks, such as monitoring of the actual elevation/depth of the reservoirs, calculation of the water mass content and so on.

The accuracy of the method is about 20mm in plain surfaces of the reservoirs, but the accuracy of the method in sloped parts is about 70mm. Further testing of the methodology shall be done to evaluate the accuracy in the common field conditions.

ACKNOWLEDGEMENTS

The work was supported by the Research Support Scheme of the Slovak Research and Development Agency - APVV, No. 0274-10 and VEGA project no. 1/0744/13.

REFERENCES

- Fazekašová, D 2012, ' Evaluation of Soil Quality Parametres Development in Terms of Sustainable Land Use , *Sustainable Development – Autoritative and Leading Edge Content for Environmental Management*, 2012. pp. 435-458.
- Gopi, S 2005, *Global Positioning System: Principles and Applications*. New Delhi: Tata McGraw-Hill Education, 2005.
- Halva, J 2012, ' Porovnanie výsledkov interpolácií pri tvorbe máp v presnom poľnohospodárstve. In Symposium GIS Ostrava 2012, Proceedings. Současné výzvy geoinformatiky. Ostrava: VŠB - Technická univ. Ostrava. 2012. ISBN 978-80-248-2792-6
- Holubová, K 1998, *Problems systematic monitoring of erosion-sedimentation processes in water works*. Institute of Water Management. Bratislava.

Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 7, Part 1
ISSN 1313-2539, Published at: <http://www.scientific-publications.net>

Hucko, P. 2007. *Sediments of river and reservoirs*: Proceedings from the international conference. Bratislava: The Association of Slovak Scientific and Technological Societies at Water research institute in Bratislava. 2007. 229 p.

Igaz, D, Horák, J, Kondrlová, E & Čimo, J. 2011, Digestate influence after biogas production on soil parameters. *Journal of International Scientific Publications: Ecology & Safety*, vol. 5, part. 1 (2011), pp. 213-220.

Kondrlová, E, Igaz, D & Horák, J 2012, Determination of sample preparation method for laser diffraction: from suspension towards soil paste. *Növénytermelés*. Proceedings of the 11th Alps-Adria Scientific Workshop. vol. 61, suppl., pp.275-278.

Longley, P, Goodchild, M, Maguire, D & Rhind, D.W. 2005, *Geographic Information Systems and Science*. Second edition. Wiley and Sons.

Lurton, X 2002. *An introduction to underwater acoustics: principles and applications*. Springer, Chichester: 2002.

Ministry of Environment of SR. 2002. *Generel ochrany a racionálneho využívania vôd*, 2nd edition. Bratislava: Ministry of Environment of SR. 2002

Rapant, P 2002, *Global positioning Systems*. VŠB – TU, Ostrava, 202 s.

STN 73 6824: Small water reservoirs

Thota, Ch 2006. *Programming MapPoint in NET*. O'Reilly Media, Sebastopol, 376 p.