# Surveying of Small Water Reservoirs for Water Management Purposes

**Jakub Fuska and Viliam Bárek**

**Abstract** Small water reservoirs are important part of the landscape that is changing under various anthropogenic and natural processes. Knowledge of the actual parameters, such as actual water reservoir storage capacity or the amount of sediment accumulated in the water reservoir is crucial for the further operation and for the fulfilling of the water reservoir purposes. Data collection and processing for obtaining of the actual information is executable as non-contact mapping with the use of sonar and GNSS receiver. This paper describes the experience of the Department of Landscape Engineering with the use of this method for the data collection and data processing to the format of raster and vector digital elevation models of water reservoir bottom. Achieved average accuracy in the creation of these models is in the interval of 13–29 mm. These parameters make the use of non-contact mapping the available, accurate and quick option for the surveying in the water management.

**Keywords** Echosounding · Water reservoir · Siltation · Digital elevation model

## 1 Introduction

Water reservoir bottom and its shape are changing in time due to the various processes within the body of the water reservoir, but mostly under the influence of processes in its watershed. The most important factor that affects the reservoir is the process of sedimentation, transport and accumulation of eroded material in the body of water reservoir. This process leads to siltation, which results in decrement of

J. Fuska (✉) · V. Bárek
Faculty of Horticulture and Landscape Engineering, Department of Landscape Enginering, Slovak University of Agriculture, Hospodárska 7, 949 76 Nitra, Slovakia
e-mail: jakub.fuska@uniag.sk



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water storage capacity. Knowledge of the actual status of siltation is necessary for the decision-making in the reservoir maintenance and operation, but it can also offer the view to the processes of erosion and sediment transport in the watershed. Smaller input of the finer soil particles occurs when they travel for a longer distance due to the wind erosion effect (Urban et al. 2013).

Mapping of the water reservoir bottom can be executed with various approaches, methods and equipment. Common applications are based on the geodetic surveying of the identical cross-sections in different time stage (Holubová 1998; US GS 97-4138 1997) or as the creation of the cross-sections of the digital elevation model (DEM) of the water reservoir bottom (Ceylan et al. 2011). Another method is using the DEM of reservoir in various time stages and its comparison on overall scale—as the creation of the map of sediment thickness (US GS 03-383 2003; US GS 2005-5040 2005; Weis and Kubinský 2014; Fuska et al. 2014). These tasks are easily executable in GIS environment, which is advanced and effective tool for the creation and usage of the models with the goal of the research, predict and know the spatial chronological and functional aspects of geographical sphere (Varga et al. 2013).

For the creation of water reservoir bottom DEM can be used various input data, such as historical contour maps or technical documentation or more accurate and actual data of the direct surveying (GNSS, total station, photogrammetry, LIDAR). Surveying with the methods of geodesy are usually precise and accurate, but the necessity of the emptied reservoir may complicate the surveying. On the other hand, the application of the non-contact surveying (sonar, radar) offers the availability of the data collection during the proper operation of the reservoirs or ponds, when the water level is at its common water level.

## 2 Materials and Methods

Application of the DEM's varies in accordance to the research purposes, therefore the used model creation and interpolation, but also the input data requires different approach. In general it is available to use both raster and vector models, if it is necessary, there are created more models of the reservoir bottom in different time stages.

### *2.1 Surveyed Reservoirs*

The use of non-contact surveying and its applications for the purposes of this paper are demonstrated at three water reservoirs in Nitra district: Golianovo, Lukáčovce and Kolíňany (Fig. 1; Table 1).

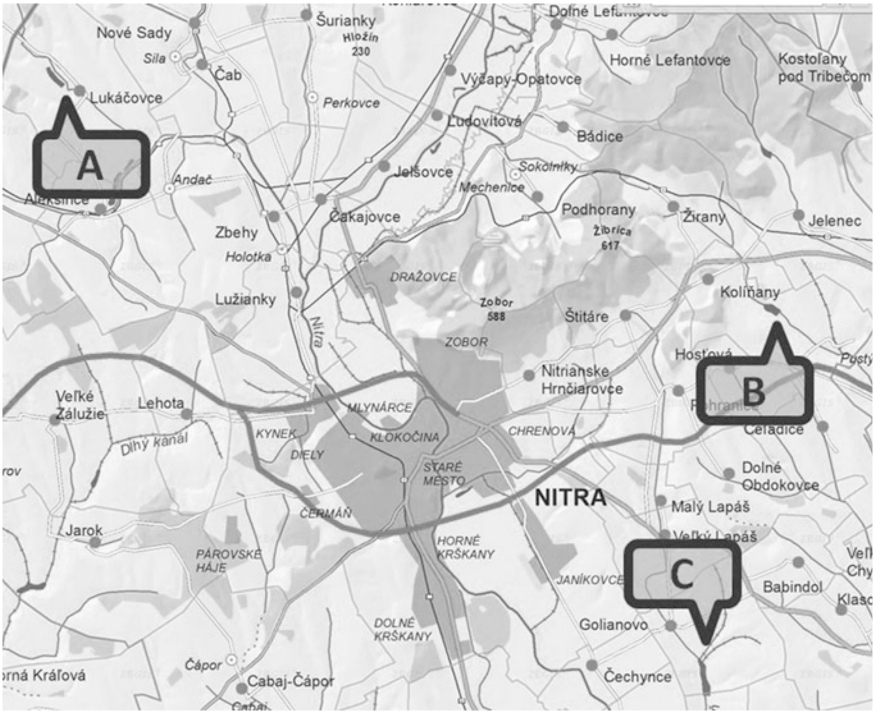


Fig. 1 Surveyed water reservoirs: *A* Lukáčovce; *B* Kolíňany; *C* Golianovo

**Table 1** Parameters of surveyed water reservoirs

| Name | Operation elevation of water level (m ASL) | Water volume at operation water level ($m^3$) | Water surface area at operation water level (ha) |
|---|---|---|---|
| Golianovo | 179.5 | 336,000 | 27.2 |
| Lukáčovce | 163.3 | 81,200 | 5.8 |
| Kolíňany | 149 | 106,000 | 13.0 |

## 2.2 Surveying Equipment

Data collection is executed with the setup of GNSS receiver and fisher echosounder. Position is obtained with Leica GNSS 1200+ receiver that allows the RTK measurement in high accuracy (usually less than 50 mm in 2D). Depth measurement is done with the fisher echosounder Garmin GPSmap 421 s with 200 kHz dual beam (14°/45°) probe. Depth measurement data as the NMEA string is sent by NMEA cable to the GNSS receiver, where it is stored as the annotation for each surveyed point. Echosounder probe is fixed in given distance from the GNSS pole tip. Whole equipment is mounted to the boat and fixed with the set of ropes to obtain the normal direction of echosounder and GNSS pole to the water level.

### 2.3 Surveying Method

Data collection of the input point data is carried during the sailing with raft boat propelled with electric engine. This vessel allows the mapping in various conditions (also in reservoirs in protected areas). Sail routes are parallel to the reservoir dam with distance 20 m between each route. Sailing is done in two routes, where the distance between the route profiles is 10 m, this mapping result in the surveying of reservoir cross-sections with distance 10 m between the profiles (Fig. 2). Data collection is done as the automatic surveying with the criterion of 2 m distance between the points. Sailing route directions are prepared as the lines, which are created in AutoCAD and imported to the GNSS controller, where these lines are displayed and used as the aid to navigate the sailing.

### 2.4 Data Processing

Surveying job is imported from CF memory card of GNSS controller to Leica Geo Office to gather the data for export to MS Excel to process the data to XYZ-coordinate of points at the reservoir bottom. Only the points with available depth measurement and with XYZ Accuracy of GNSS surveying better than 50 mm are used. Calculation of Z-coordinate is done from the Z-coordinate of GNSS surveying and depth measurement of echosounder (Fig. 3).

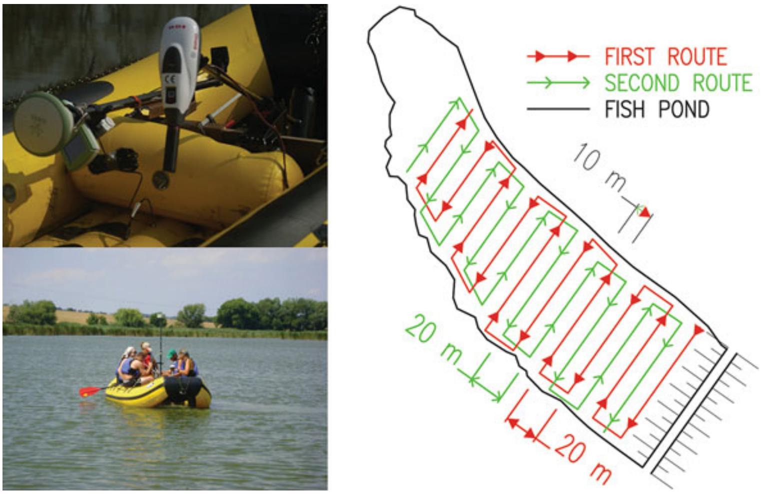


**Fig. 2** Survey equipment (*top left* and *bottom left*) and example of sailing routes orientation (*right*) Surveying of fish pond Lukáčovce

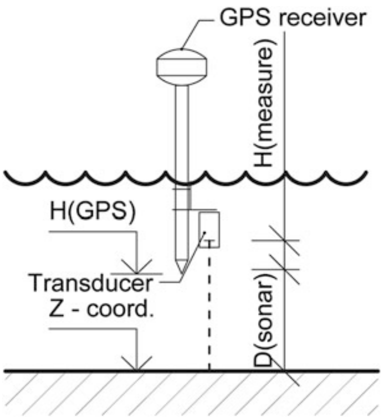


**Fig. 3** Calculation of the elevation of the point at the reservoir bottom

All point data are loaded in ArcMAP and exported to shapefile. Afterwards the amount of points is reduced, only the points distributed in approximately 10 × 10 m grid are kept.

To describe the shape of the reservoir shoreline it is usually difficult to obtain the data by direct surveying as the shoreline and reservoir banks are inaccessible in most parts due to strong vegetation growth (reed, cattail, brushes and trees). In accordance to this situation the shoreline is gathered as the boundary from ortophotomap, additional surveying is done to obtain the elevation—usually near the dam or at the open parts of shoreline (if available).

$$Z_{coordinate} = H_{GPS} + H_{mount} - H_{measure} - D_{sonar} \quad (1)$$

## 2.5 Digital Elevation Model of Reservoir Bottom

Data of the non-contact surveying (points at the reservoir bottom), direct surveying (elevation of water level at the shoreline) and from ortophotomap (shoreline shape) are used to create the DEM's in ArcMAP, for the purposes of small water reservoirs are used following model creation methods:

- Topo to raster—cell size 2 × 2 m, suppression of sink filling
- Spline with tension—cell size 2 × 2 m, weight of tension 0.1
- TIN model—using the rules of Delaunay triangulation

## 2.6 Historical Data of the Water Reservoirs

For the purposes of the reservoir bottom development assessment it is necessary to know the elevation and topography in different time stages. For the creation of the reservoir bottom DEM from the past can be usually used the available project documentation data, such as contour plans or geodetic surveying data. These data are in fact unavailable for most of the small water reservoirs, because the technical drawings, design plans and geodetic surveying data are often missing. This situation is result of the transfer of the competences and responsibilities between the state authorities and companies (Slovak water management enterprise, Hydro—ameliorations state enterprise, etc.), where also the archives were moved and large part of the documents is missing. Usually there are available documents of the Operation manuals or Programs of the technical and safety maintenance of the reservoirs, where is usually only numerical data about stored volumes at certain water levels.

If there is available contour plan or geodetic field survey in the point-class representation, there can be DEM in raster or vector format created with same settings as DEM of actual reservoir bottom.

### *2.7 Analysis and Calculations with the Use of Water Reservoir Bottom DEM*

Created elevation models of the water reservoir bottom can be used for various purposes, which can be divided into following groups:

- Volume characteristics: actual and original water storage capacity (water volume), actual volume of sediments
- Reservoir bottom profiles creation

## 3 Results and Discussion

### *3.1 Analysis of Water Storage Capacity*

This analysis is shown at the example of fish pond in Lukáčovce. This fish pond is second in the system of the three fish ponds. First fish pond does not exist anymore as it was buried with the excavated sediment from second and third pond and there is no existing data or design drawing of this fish pond. Actual function of the surveyed second fish pond is fish production. Data collection was done in two steps:

- Direct GNSS surveying in the January 2013, when the fish pond was emptied; there was 48 points surveyed at the reservoir bottom
- Non-contact mapping in August 2013 duriing the common operation of fish pond, there was 2337 points surveyed

For the creation of the actual fish pond bottom DEM was used “Topo to raster” and “Spline with tension” raster models and vector TIN model.

Water storage capacity describes the amount (volume) of water that is stored in the water reservoir usually in the conditions of water level at the operation level. This data is crucial for the management of the water reservoir to fulfil its purposes —for example the amount of water that is available for the irrigation or water supply purpose. This capacity is developing in accordance to the siltation of water reservoir (reduction of capacity) or excavation of sediments (increment of capacity). Volume of stored water can be calculated from both raster and TIN model of reservoir bottom. In case of raster models the actual water reservoir bottom DEM and elevation of the water level (usually the common operation water level) are used for the creation of the water depth as the subtraction of bottom elevation from the water level (Fig. 4).

Afterwards the sum of the water depths at each cell is multiplied by the area of one cell to obtain the total volume of water reservoir storage capacity.

$$V_{water} = \sum_{n=1}^{i} Depth_{water,i} \times Area_{cell} \tag{2}$$

Calculation of storage capacity with the use of TIN model is done as the calculation of volume between the surface of reservoir bottom (TIN model) and surface of water level (polygon of water reservoir shoreline with the elevation of water level) (Table 2).

Results of the mapping and storage capacity have shown that the current storage capacity of fish pond in Lukáčovce has been decreased to the approximately 58 % of the presumed water storage capacity mentioned in operation manual of this fish pond.

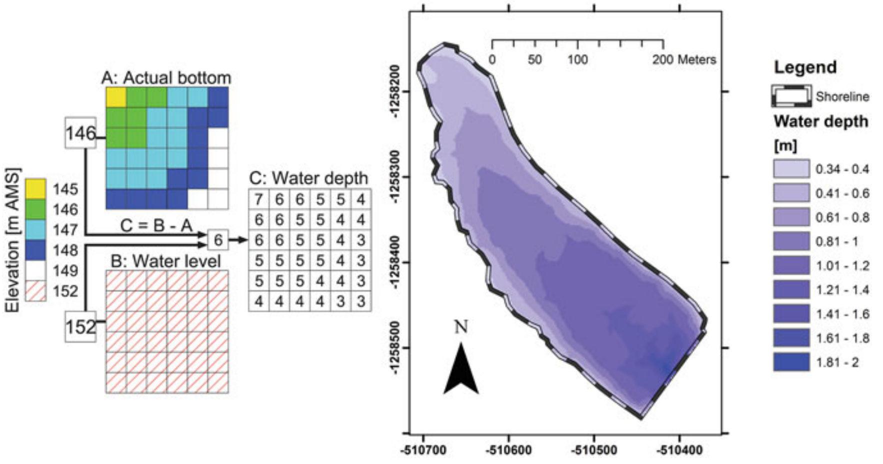


**Fig. 4** Map of water depth creation scheme (*left*), Map of water depth in Lukáčovce fish pond (*right*)

**Table 2** Actual storage capacity of fish pond in Lukáčovce fish pond

| Model interpolation method | Topo to raster | Spline with tension | TIN | Presumed volume |
|---|---|---|---|---|
| Water volume ($m^3$) | 47,479 | 46,803 | 46,376 | 81,200 |
| % of presumed volume | 58.5 | 57.6 | 57.1 | 100 |

## 3.2 Analysis of Actual Volume of Sediments in Water Reservoirs

This analysis is shown at the example of water reservoir in Golianovo, which is partially silted in the water inflow part. The strong growth of reed occurs in this part that made it inaccessible—only the visual checking was available that shows the inflow part is fully silted and growth with reed and cattail plants.

Surveying of this water reservoir was done in three days:

- March 2011, there was 717 points surveyed
- April 2011, there was 318 points surveyed during the first day and 1214 points during the second day

For the original and actual bottom DEM creation was used the "Topo to raster" interpolation method. For the creation of original bottom DEM was used the original design ground plan with display of contours. Dem of actual water reservoir bottom was created from the set of points from non-contact surveying.

Volume of the sediment with the use of raster models is calculated similarly to the calculation of the water storage capacity. First step is the creation of the map of the sediment layer thickness created as the subtraction of the raster DEM of original bottom from the raster DEM of actual bottom. This calculation requires the DEM of original and actual bottom have the same cell size and boundary.

Volume of the sediment in the reservoir is calculated as the sum of sediment thickness at each cell multiplied by the cell size of the sediment thickness map (Table 3).

$$V_{sediment} = \sum_{n=1}^{i} Thickness_{sediment,i} \times Area_{cell} \tag{3}$$

Calculation has shown that there is approximately 82,000 $m^3$ accumulated in this reservoir, but the accuracy of this calculation is scattered by the missing and precise

**Table 3** Amount of sediment accumulated in water reservoir in Golianovo

| Part of reservoir | Sediment amount ($m^3$) |
|---|---|
| Silted part | 43,414 |
| Functional part | 38,578 |

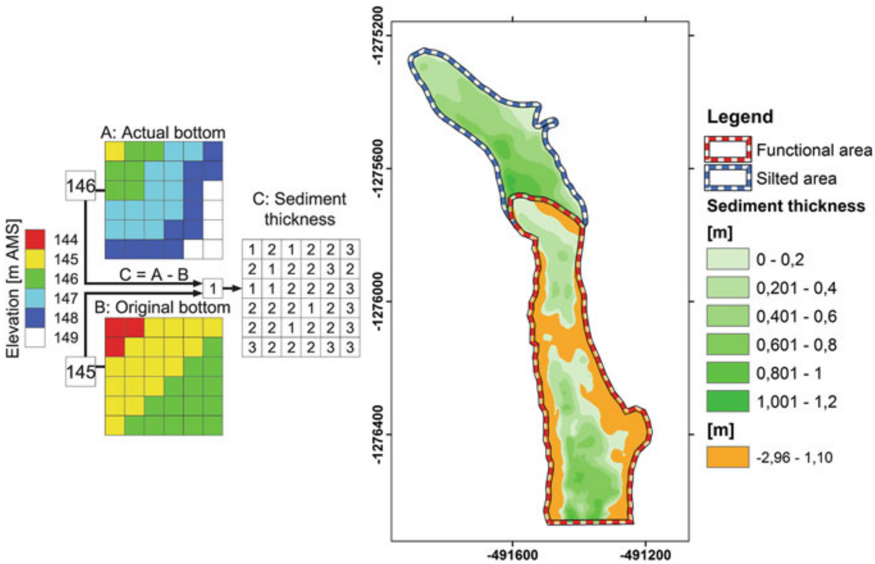


**Fig. 5** Map of sediment thickness creation scheme (*left*), Map of sediment thickness in Golianovo water reservoir (*right*)

mapping of the silted part. There is also missing large part of the reservoir documentation, maps and plans from the period of life span of this reservoir that documents the reconstruction and maintenance processes in this reservoir. We presume that the large part of reservoir near the shoreline was deepened during the operation of the reservoir that results in displaying of the negative sediment amount (Fig. 5). This is the result of the process of subtraction of the original elevations from the actual elevations.

## *3.3 Reservoir Bottom Profiles Creation*

This method was shown at the water reservoir in Kolíňany. This reservoir was built for the purposes of the irrigation water supply; nowadays it functions as the fish production pond and as the recipient of treated wastewater from the local water treatment facility.

Non-contact surveying was executed during two days in July 2013:

- During the first surveying was collected 4411 points
- During the second surveying was collected 4404 points

Design and proposal of the various tasks and works, such as excavations, reconstruction of the entrance to the reservoirs and fish ponds for the trucks,

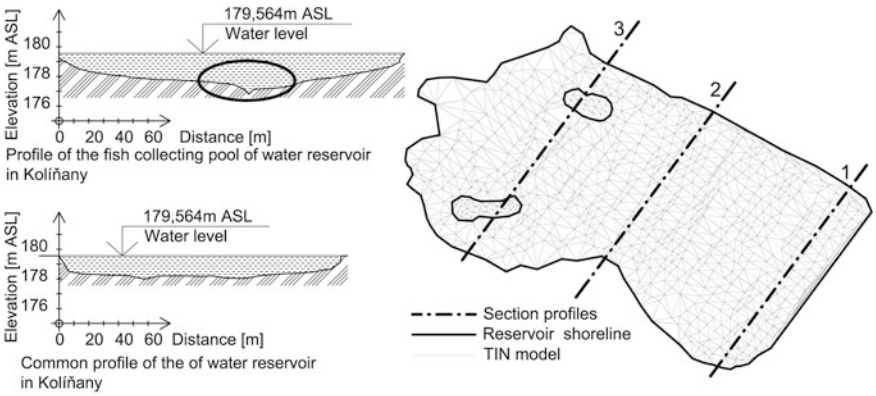


**Fig. 6** TIN model of Kolíňany water reservoir bottom (*left*), results of the bottom profiles construction in AutoCAD (*right*)

requires the input data in the format of bottom cross-sections and profiles. These tasks are easily available with the use of TIN model, which is exported from the ArcMAP to AutoCAD for further processing consisting of creation of the section planes, rotation of the cross-sections and modification of scale to non-uniform value to emphasize the elevation proportions. This process is easily executable with the extraction of the cross-section vertices, modification of elevation values and automatized redrawing with the use of AutoCAD scripts (Fig. 6).

## *3.4 Accuracy of the Created Water Reservoir Bottom Models*

Overall performance of data collection, processing and DEM creation was tested at the fish pond in Lukáčovce as the comparison of elevation of the points surveyed directly with the GNSS receiver Leica with the elevation of these points derived from both raster models and from TIN model.

General accuracy of the mapping is given by the partial accuracy of the used equipment. GNSS mapping with the use of Leica 1200+ with the corrections from SmartNet network offers the accuracy better than 50 mm in XYZ coordinates under the common conditions of RTK mapping. Sonar depth measurements with the use Garmin GPSmap 421 s usually offers the accuracy about 20 mm.

Results have shown that the best accuracy is achieved with the use of TIN model, where the average accuracy is 13 mm. Average accuracy of the raster models is slightly worse (29 mm accuracy for Topo to raster and 22 mm for Spline with tension model) (Fig. 7; Table 4).

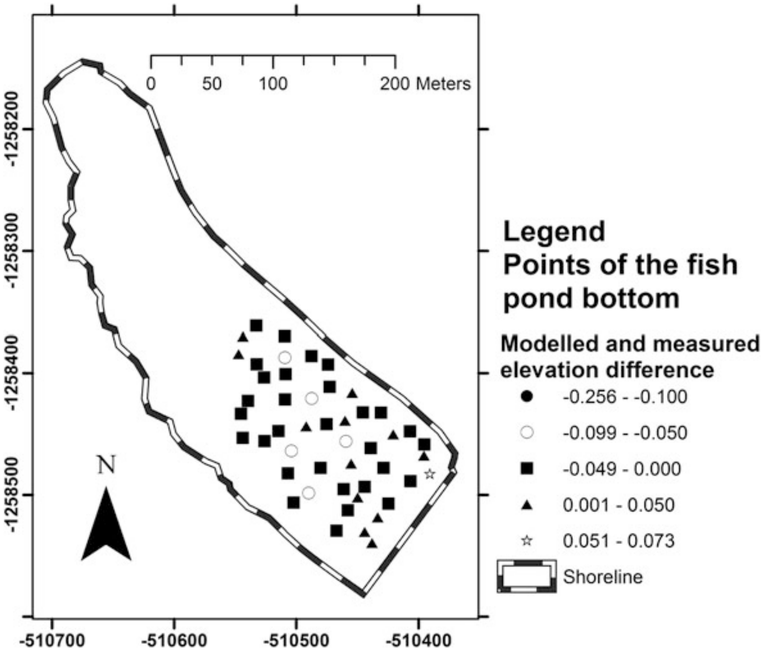


**Fig. 7** Difference of the elevations of the surveyed points and models created with various methods at the Lukáčovce fish pond bottom: Topo to raster (*left*), Spline with tension (*middle*); TIN (*right*)

**Table 4** Accuracy of reservoir bottom models

| Statistical measure | ΔZ: TIN | ΔZ: Topo to raster | ΔZ: Spline |
|---|---|---|---|
| Average | −0.013 | −0.029 | −0.022 |
| Standard deviation | 0.028 | 0.048 | 0.031 |
| Minimum | −0.068 | −0.256 | −0.114 |
| Maximum | 0.057 | 0.072 | 0.044 |
| Range | 0.125 | 0.328 | 0.158 |
| Median | −0.016 | −0.028 | −0.016 |
| Absolute minimum | 0 | 0.001 | 0.001 |
| Variance | 0 | 0.002 | 0.001 |
| Root mean square | 0.031 | 0.057 | 0.038 |

## 4 Conclusion

Water reservoir bottom is the entity that is changing over time due to the activities and processes in the watershed and in the own body of the water reservoir. Mapping of the reservoir bottom topography and its changes is in the focus of various studies with the use of various tools, from simple mapping with the leading lines or sounding poles to more sophisticated non-contact methods of data collection. GNSS and sonar mapping offers the possibility of the mapping during the common operation without the necessity of the emptying the water reservoir. Overall accuracy of the created DEM is comparable to the accuracy that is generally achievable by the GNSS surveying (TIN model: 13 mm; Topo to raster: 29 mm; Spline with tension model: 22 mm). Application of the mapping and model creation is useful in the assessment of the water reservoir for the evaluation of the actual water storage capacity for the purposes of the usage of the water reservoir or for the proposal of the maintenance processes and works. Usage of the TIN model for the creation of the cross-sections can also offer a strong support and input data for the design and reconstruction of water reservoirs. Use of the equipment for the non-contact surveying requires the preparation of the vessel direction navigation lines to obtain the input data in the proper distribution, which is processed to the pattern of square network of points for the creation of the digital elevation models in raster and vector models.

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