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CHANGES IN BATHYMETRY AND LAND COVER OF RIPARIAN ZONE OF AN OLD ARTIFICIAL WATER RESERVOIR VEĽKÝ KOLPAŠKÝ

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Abstract: The mining region of Banská Štiavnica (Slovakia) has been inscribed into the UNESCO List of the World and Cultural Heritage in 1993. One of its special features is the system of artificial water reservoirs (locally referred to as “tajchy”) communicating via trenches built in early 18th century. The system was a water source, which drove the mining machines. Accumulation and transfer of sediments mainly depending on changes of land cover in the riparian zone leads to the loss of retention capacity and reduced life of reservoirs. Aim of this study is to analyse changes of the storage capacity/volume of the Veľká Kolpašská water reservoir that took place in the last is 123 years (1889–2012) and changes of land cover (LC) on the riparian zone in the course of the last 63 years (1949–2012). Volume and bottom relief changes were identified by comparison of bathymetric data drawn from the historical map of 1889 with the present data obtained in 2012 by bathymetric surveying. 3D models representing different situations were used for computation of the sediment volume. Results showed 57.801 m^3 of sediments deposited in the course of 123 years that reduced the storage capacity of the reservoir by 7.23%. Changes of land cover in the riparian zone were detected via the analysis of aerial photographs (1949) and orthophotomaps from 2006, up-dated in the field for 2012. Analysis of changes show an increase of land cover categories which contribute to abrasion of banks, and the rate of sediment transfer to the reservoir (by 11.030 m^2) resulting in an increased silting potential.

Keywords: Banská Štiavnica, bathymetry, changes, infilling, mining, riparian, reservoir, technical monument, volume

1. INTRODUCTION

The water reservoir of Veľká Kolpašská is part of the historical water-managing system which along with the town of Banská Štiavnica has been inscribed into the UNESCO List of the World and Cultural Heritage as item No. 400 “Banská Štiavnica and Industrial Heritage in its surroundings”. It is an important technical monument, which proves the advanced level of the past water-managing structures. The next comparable system is to be seen German Harz or in the Saxon Freiburg. The system lost its primary purpose – to supply water to mining machines or to drain out of shafts after end of mining activities. In spite of it, water reservoirs are still fully used for recreation or fishing and they contribute to the flood defense system in the locality. They represent one of the dominant phenomena in the image of the region. Only 23 reservoirs survived of the original 60. They also are the only surface water sources in the region of Banská Štiavnica during the dry seasons.

Deposited sediments represent one of the most serious factors threatening the water reservoirs. They cause loss of the usable volume, damage to manipulation technology, alteration of biological and ecological water quality and lead to the progressive disappearance of reservoirs (Ahmed & Sanchez, 2011; Pradhan et al., 2011; Ristić et al., 2013). Water erosion greatly depends on changes of land cover (LC) not only in the adjacent drainage microbasins but also in the immediate surroundings. Degradation of bank vegetation and disintegration of banks followed by erosion connected with accumulation of sediments are the most serious factors threatening the existence of water reservoirs, dams and ponds in general. Reliable assessment of sedimentation processes based on the research of the rate of silting and study of changes in the bank zone, leading to bank erosion and transport of terrestrial material into the reservoir is the suitable tool for understanding reservoir behaviour. It is important to know and manage the bank zone as an entity where aquatic and terrestrial systems interact (Naiman et al., 2005). The issue of infilling processes of lakes is highly topical all over the world (Boddy & Ganske, 2005; Ceylan et al., 2011; Chang et al., 2003; Childs et al., 2003; Jordan & Fonstad, 2005; Kress et al., 2005; Mcalister et al., 2013;). In Slovakia it is the Water Research Institute (WRI), which is involved with the theme; collection of data by acoustic methods was applied to some other reservoir (Yesuf et al., 2012) or to rivers (Awulachew, 2006; Elçi et al., 2009; Odhiambo & Boss, 2004; Yun & Cho, 2011).

According to the data of the Slovak Water Managment Enterprise (SWME), the topical bathymetric and cross-section data of reservoirs in environs of Banská Štiavnica, managed by the Enterprise, do not exist. Quantification of reservoir infilling and regular updating of data about the volume of the reservoir make it possible to prepare a more realistic prognosis of silting, they offer the necessary basis for efficient protecting measures which minimize the deposition of sediments and other negative phenomena. Bathymetric maps facilitate selection of efficient measures mitigating the negative consequences and saving of continuously increasing maintenance and operation cost.

The principal aim of this study is to collect the topical bathymetric data for the reservoir of Veľká Kolpašská (2012), to identify data from 1889 and establish the volume of sediments in the reservoir by their comparison. Another aim is to analyze the present status and development of land cover structures of the riparian zone as the potential source of accumulated sediments during the 1949–2012 period and to identify the courses of possible sediments inputs. The characteristic of sediment wasn’t investigated in this study.

2. MATERIAL AND METHOD

2.1. Study Area

The water reservoir of Veľká Kolpašská is situated near the village of Banský Studenec, 12 km away from Banská Štiavnica in Slovakia, (Fig. 1). The reservoir was constructed around 1730. The basin of the reservoir stretches on a total area of 1,971 km², and the 5808 m long water divide limits it. The maximum volume of the reservoir in 1889 was 798,900 m³.

2.2. Topographic and Bathymetric Measurements

Field research of the Veľká Kolpašská reservoir took place in on 23 and 24 May 2012. Depth was measured by a double-beam sonar and it was accomplished directly from the vessel using the following instruments: 1. Humminbird 717 (20° or 60° beams, frequency 200 & 83 kHz, quoted precision ± 10cm), and 2. External GPS (Fig. 2.) The measured step was 5 m.

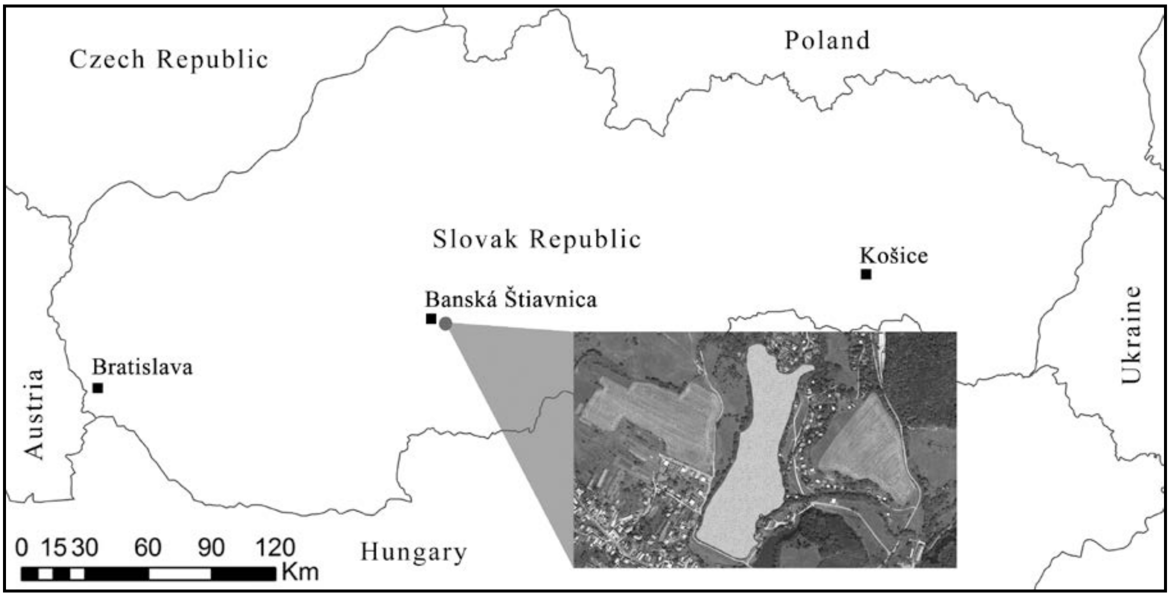

Figure 1. Localization of the Veľká Kolpašská water reservoir

Figure 2. Data obtaining by means of direct measuring from vessel

Reference depth gauging was made in a selected series of points by a calibrated rod in order to avoid any imprecision. Gauging was made twice. Control measurement proved to be in good agreement with the original gauging. Precision of results yielded by the sonar was established at ± 3cm. Individual gauging spots were localised by the GPS. The data about the depth of the bottom were recalculated to absolute sea level altitudes at gauging points. The basis was the known sea level altitude of water table at the time of measurement, i.e. 598.10 m a.s.l. (source SWME). In total, seven profiles A-G (Fig. 4) were constructed, one for every 60 metres in order to determine spatial changes in the bottom of the reservoir under effects of sedimentation. Bathymetric gauging was carried out at 1,639, points, which define the character of the bottom surface in 2012 (Fig. 3). Sea level altitudes and absolute elevations are quoted in the adapted Baltic Altitude System.

The source of historical data about the bottom of the reservoir was the 1889 historical map for calculation of cubage "Kolpašské jazero – Banský Studenec" at scale 1: 10 000 (SWME). Positional accuracy of this map was verified by the SWME. The map was scanned with resolution of 300 dpi in TIFF (Tagged Image File Format). Individual contour lines were vectorised and value Z from the historical plan giving the absolute elevation was added to them. Registration of the vector into S-JTSK (Křovák's mapping) took place in the ArcGIS software. Aerial orthophotomaps (Eurosence, 2006) and maps basic map of the Slovak Republic a (ZM 1:10 000) were chosen for the referential cartographic source material. Registration was processed based on selection of appropriate spot height identifiable in both data sources. Vector of the historic plan as well as the data obtained by field measurement in the space delimited by the flowage line were joined with the same vector layer obtained by digitizing the map of the Slovak Republic 1:10 000, (as of 2006) (Maps of ZM, 2006). Subsequent modelling only took into account changes, which took place within the reservoir. Data from the two sources (time horizons) were processed in Surfer 8, Golden Software. Using the interpolation method of Kriging (Webster & Oliver, 2001) grids with cell size 2x2 m was generated. Prediction quality was verified by Cross-Validation (Deutsch, 2002) procedure. Distribution of residual frequency was normal with the means approximating 0.

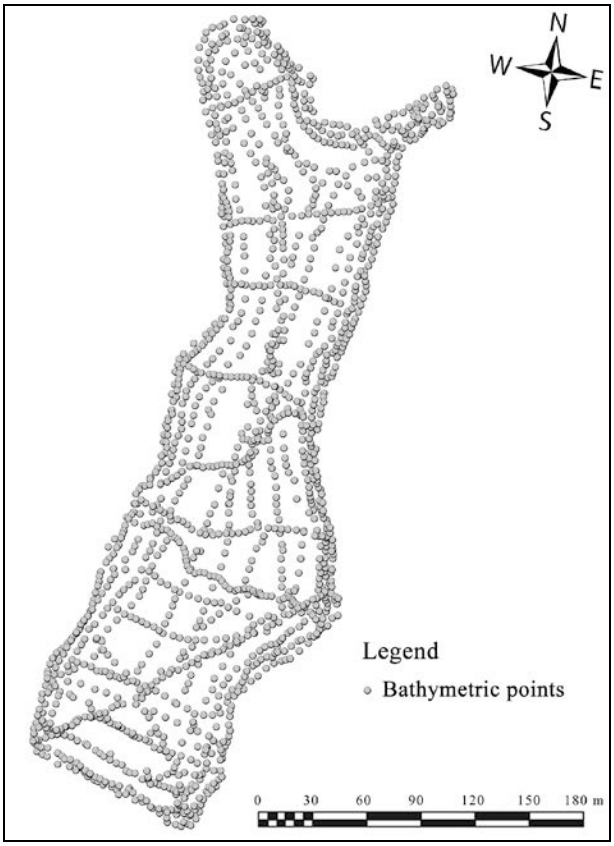

Figure 3. Locations of bathymetric points

2.3. Analysis of the riparian zone

The basic information source for comparison of riverine zone land cover changes were orthophoto images (2006, Eurosence) of the Slovakian S-JTSK system and aerial black-and-white photographs (1949) registered in the GIS into the same coordinate system. Riparian zone was delimited by the borderline 20 m away from the bank line of the reservoir for each time span in GIS using the buffer function. Land cover map of it was compiled by interpretation both sources and by adaptations based on field survey to 2012. The following categories were mapped:

1) Water surface,
2) Disrupted banks with herbaceous growth,
3) Permanent grassland,
4) Dispersed trees with herbaceous undergrowth,
5) Shrubs,
6) Wood stands,
7) Built-up areas.

These categories were classified in terms of sediment production and the potential transport into the reservoir into three groups:

1. Land cover highly prone to sediment detachment and transfer (eroded banks with herbaceous cover, built-up areas),

2. Land cover prone to sediment detachment and transfer (permanent grassland, dispersed trees with herbaceous cover),

3. Land cover not prone to sediment detachment and transfer (shrubs, wood stands). Land cover layers overlaid and contingency tables of changes of land cover for the bank zone delimited around the water reservoirs were compiled.

3. RESULTS

3.1. Changes in volume

Two territorial models representing situation of the reservoir in 1889 and in 2012 (Fig. 4) were obtained by interpolation of entry data via Surfer 8. Calculations of the volume change were accomplished by three computation methods: Trapezoidal Rule – 57.812 m³; Simpson's Rule – 57.794 m³, and Simpson's 3/8 Rule – 57.798 m³. Their arithmetic average of 57,801 m³ (standard deviation 9.451) is considered the resulting value. The relative error of R = 0.03 is below 0.9 hence the computation is acceptable. The result indicates loss of storage capacity of the Veľká Kolpašská reservoir of 7.23% in 123 years.

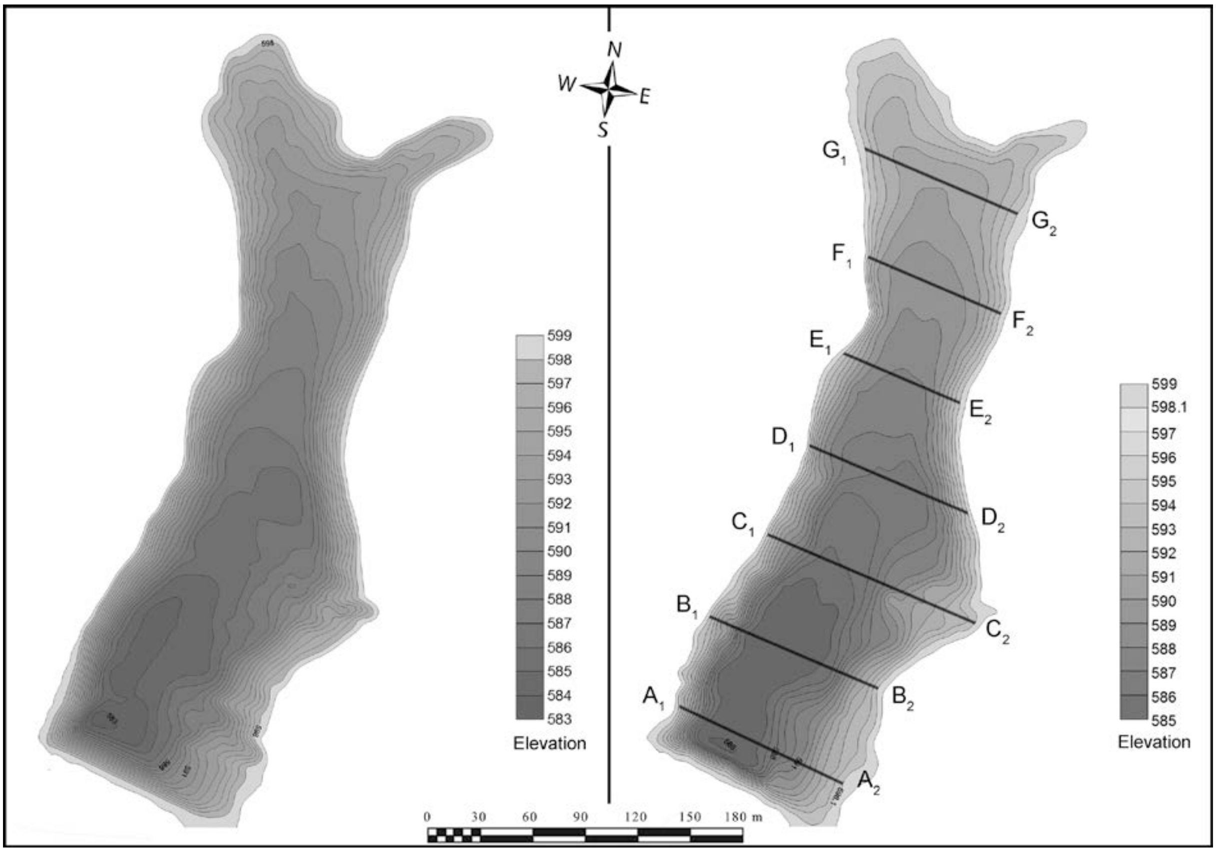

Figure 4. Detail of the bottom relief of the Veľká Kolpašská reservoir in 1889 (left) and in 2012 with cross-section positions (right)

Table 1. Sediment thickness and standard deviation of cross sections

Section	Max. sediment thickness (m)	Average sediment thickness (m)	Standard deviation (m)
A	1.939	1.110	± 0.655
B	2.998	1.112	± 0.822
C	3.517	1.169	± 0.758
D	1.930	0.844	± 0.943
E	1.932	0.830	± 0.598
F	1.764	0.886	± 0.613
G	1.678	1.065	± 0.527

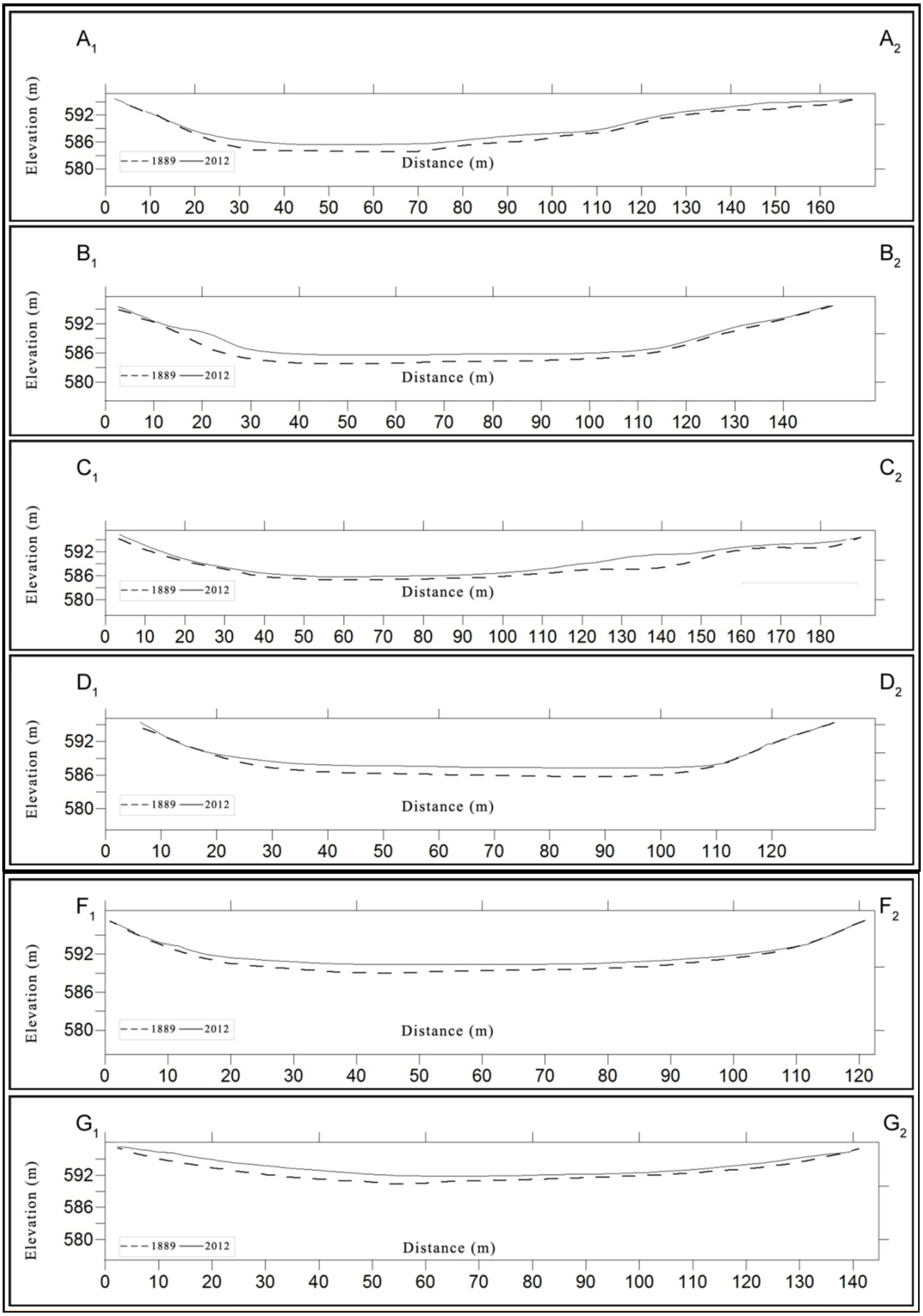

Figure 5. Selected cross sectional profile of Veľký Kolpašský reservoir

In total 7 A-G profiles/cuts were constructed each 60 meters for identification of changes of the bottom under the effect of sedimentation. For the results of the analysis of diagonal profiles see figure

5. The maximal and average thickness of sediments and standard deviation are quoted in table 1.

3.2. Change in land cover of riparian zone

Mapped categories: 1) Water surface, 2) Eroded banks with herbaceous cover, 3) Permanent grassland, 4) Dispersed trees with herbaceous undergrowth, 5) Shrubs, 6) Wood stands, 7) Built-up areas (Table 2).

Table 2. Areas of land cover categories in the riparian zone (1949 and 2012)

Category	**Area (m^2)**	
	1949	**2012**
1	87896	87896
2	0	6783
3	22876	4535
4	9329	16102
5	1763	3581
6	2049	742
7	0	4247
Summary	**123886**	**123886**

4. DISCUSSION

Under the effect of expanding tourism and recreation, new areas covered by herbaceous vegetation emerge. In recent 63 year several buildings prevailingly serving to recreation were constructed here. Many of them are close to the flowage line where they cause erosion and denudation of banks with the prevailing component of fluvial sediments while the building material is scoured to the reservoir. The time span of 63 years of development of land cover the riparian zone suggests that its structure and variability of critical variables (areas of LC classes) distinctly changed. It is the case of increased area of categories contributing to transport of sediments from the immediate vicinity of the reservoir mainly from eroded banks with herbaceous cover and built-up areas (Table 2).

While a relatively steady way of management of the surroundings of the Kolpašská reservoir was pursued in the first half of the 20th century, the overall political transition during the second half of the past century, particularly its last three decades brought some additional dynamic changes into this area. Situation in ownership of realties changed, number of owners of small plots, formerly parts of large arable fields, forest or grassland increased. An extreme example is the elevated number of built-up anthropogenic plots on the banks often close to the bank line. Chaotic constructions in the bank zone leads to severe degradation of the protective function of bank vegetation of all categories.

Comparison of two details of bottom relief (Fig. 4) suggests that infilling affected the extreme depth (area between 585 m a.s.l – 586 m a.s.l contour lines.). Other considerable amount of accumulated sediment which has changed the original relief from 1889 is in the eastern part of the C1-C2 intersection. The greatest part of sediments accumulates precisely in these places. Sedimentation affects several reservoirs in the surroundings of Banská Štiavnica. The result may be transformation of a part of water body into a swamp overgrown by rapidly growing wood species. The Halčiasnsky tajch reservoir is a clear example, where more than a third of water body disappeared. This area is now almost completely forested and changed beyond recognition. The bottom outlet, safety outlet and the dike of Veľká Kolpašská reservoir were reconstructed in 2008–2009. No manipulation with the bottom sedimentation of reservoirs in this area has been carried out. The main reason quoted by the SWME is classification of sediments as dangerous wastes (Law about Wastes of the Slovak Republic, No. 223/2001) cost of excavation and dumping. The problem can be partially solved by emptying the reservoir by water and flushing it by elevated discharges as is was done in other reservoirs of Slovakia, for example Hričov or Orava water works.

The negative anthropogenic impact on banks of the water reservoir cannot be avoided. The Veľká Kolpašská reservoir attracts fishers and holidaymakers. It is rather necessary to search such measures that will stabilize the sediment input. Regular release of bottom water should correspond to the annual regime of maximum rainfalls on the one side while the intensity of such discharge is also important. The energy of the discharge corresponding to the capacity of outlet pipes should be strong enough to clean the bottom of the reservoir and to outwash the fine sediment, which will also prevent the dangerous silting up of the outlet. The proposed procedures and measures are:

1) Water-managing measures: Construction of check-dams and sedimentation reservoirs capturing sediments should be constructed along the main tributaries as well as in the mouths of adjacent drainage basins most susceptible to soil erosion. Regular updating of bathymetric data every five years followed by an assessment of the sedimentation rate; compilation of a databank of transversal profiles for the assessment of morphometric changes in exposed area in terms of silting. Maintenance of a good technological status of the system of drainage ditches across the reservoir

basin, strengthening their of weak sections by a wood wall.

2) Settlement and recreation: Residential and recreational buildings may be important sources of pollution, which affect the reservoir water quality; among them are the wastewater and household waste. Monitoring of waste production and waste management is proposed in order to reduce the risk of these adverse effects. Construction in the bank zone should be restricted and the denuded surfaces prone to erosion should be re-stabilized.

The described measuring process and its result will make it possible to repeat survey of individual profiles, to asses and compare the measurement with that taken in 2012, and to establish future trends of silting. This comparison may serve as the basis for the protection of the reservoir against silting in the most affected places.

Recent geodetic technologies were applied to analysis of another reservoir of this water-managing system in vicinity of Banská Štiavnica, Belianska, but also in other places in the world (Dost & Mannaerts 2008; Choiński & Ptak, 2009, Elçi et al., 2009). It is the quickest, most economic and sufficiently precise way of collecting the bathymetric data in case of deeper reservoirs (over 5 m), where there is no option of exact collection of data by means of a calibrated rod. Similar methodology was also use for the analysis of 129 lakes in New Hampshire (Hollister & Milstead, 2010).

The Veľká Kolpašská reservoir is considered in the context of the UNESCO World Natural and Cultural Heritage. Its area and volume make it one of the biggest reservoirs of the water-managing system of Banská Štiavnica. The rate of infilling (≈469.92 m^3/year) cannot be underestimated and it is at least necessary to start collecting the bathymetric data. Data concerning this locality are only available for 1889 and 2012; hence the trend of infilling has not been observed for 123 years. Based on regular records and their evaluation it is possible to adopt appropriate water managing, environmental and other measures restricting the sediment supply.

5.CONCLUSIONS

The Veľká Kolpašská reservoir is an important source of surface water with great retention capacity. This study focused on identification of existing data for the bottom of the reservoir and changes of the volume, the depth and overall retention in terms of infilling. Calculations were carried out via Surfer 8 based on comparison of two 3D models for the period from 1889 to 2012. Results showed that in the course of 123 years the storage capacity of the reservoir diminished by 57.801 m^3, which is 7.23%. Capacity of the reservoir dropped by average 469.92 m^3/year. Analysis of changes that affected the depth of the bottom of the reservoir indicates the most important change of its relief in points of the greatest depth. Analysis of land cover of the riparian zone showed that the increasing anthropic pressure causes increase of the category "Built-up areas" by 4247.94 m^2. Bank disruption attributable to tourism (swimming, boating) contributes to increased delivery of sediments to the reservoir. The second probable cause is the increase of the heterogeneity of bank zone LC categories accompanied by that of areas severely affected by anthropic activities or permanently attacked riparian zone as well as sediment supply from adjacent drainage basins.

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