VERSITA

STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA

VOL. XLVI, 2012: 41–50 PL. ISSN 0081-6434

DOI 10.2478/v10302-012-0003-1

ŁUKASZ WIEJACZKA (KRAKÓW)[1], RAFAŁ KROCZAK (KRAKÓW)[2],
MAŁGORZATA KIJOWSKA-STRUGAŁA (SZYMBARK)[3]

METHODS FOR THE ASSESSMENT OF CHANGES IN THE BOTTOM MORPHOLOGY OF A MOUNTAIN RESERVOIR

Abstract. The paper presents preliminary results of bathymetric measurements of selected part of bottom of the Klimkówka Reservoir made in 2010. The reservoir is located on the Ropa River in the Polish Carpathians and it has functioned since 1994. In order to capture the changes in the morphology of the Ropa valley caused by the process of siltation of the reservoir measurement results were compared with the state of the morphological relief of the Ropa valley bottom from the period before the creation of the reservoir (presented on the topographic map in scale 1 : 10,000). An assessment of the credibility of the results was done. The results of studies have mainly shown small changes of valley bottom morphology in the part of the lateral tributary of the reservoir due to the intense accumulation of material transported to the reservoir.

Key words: bottom morphology, Klimkówka Reservoir, Ropa valley, Polish Carpathians

INTRODUCTION

Reservoirs built across river valleys decrease the transport of river load. Clastic material carried by a river during floods (both suspended sediment and bed load) is accumulated within reservoir areas, which as a result leads to changes in the morphology of their bottom and decreases in their capacity. The quantity of the material delivered to a reservoir depends on the size of the catchment (in the mountains, larger catchment areas mean larger supplies of material); the gradient and length of a slope; the width of the bottoms of valleys; slope-to-channel subsystem coupling; the degree of catchment deforestation; agricultural use; the density of unmetalled roads in the area; the susceptibility of weathering covers to erosion on slopes; as well as on the intensity of rainfall (its spatial distribution, frequency, and total) and the hydrological regime of a reservoir's tributaries (Łajczak 1986, 1989). There are many publications on the topic of sediment accumulation in the Carpathian reservoirs (e.g. Onoszko 1964, Chomiak et al. 1969, Cyberski 1969, 1970; Łajczak 1986, 1995; Banach 1995, Rzętała 2003, Wiejaczka 2011). A. Jahn (1968) studied changes that occurred on various parts of the bottom of the reservoir located on the Bóbr River in the Sudetes due to the accumulation of sediment layers that varied in thickness. The most commonly discussed issue is the development of deltas, formed in backwater areas, where the greatest accumulations of sediment exists due to decreases in the transport power of a river (e.g. Klimek et al. 1989, Łajczak 2005, Wiejaczka 2011, 2012). Also, many papers address the problem of bank abrasion of water reservoirs resulting from the combined effect of mass movement and hydrodynamic activity of the reservoirs (e.g. Kieraś et al. 1973, Banach 1994, Rzętała 2003, Wiejaczka 2011). Relatively little attention is given to research on the morphological changes in the reservoir basins in their other parts (beyond a bank zone and backwater area), where the accumulation of sediment layers is comparatively smaller. This research was conducted by means of bathymetric measurements of reservoir bottoms, which are performed between long intervals of time. Such measurements allow for the actual increase in sediment layers in a reservoir to be assessed through the analysis of the spatial difference of its volume, and thus make it possible to define the rate of reservoir silting.

This paper presents the results of initial bathymetric measurements of the bottom of the Klimkówka Reservoir conducted in the summer of 2010 by means of a Fishfinder echo sounder. The measurements were taken in the central part of the reservoir, at the mouth of the Przysłup stream, which is the right-bank tributary of the reservoir (Fig. 1, 2). In the selected part of the reservoir, there is an area of intensive accumulation of the material carried by the side tributary, and there are deep parts with a low supply of material (also from bank abrasion). Based on the collected data, a map of the bottom of the reservoir

Fig. 1. Location of the Klimkówka Reservoir in the Polish Carpathians

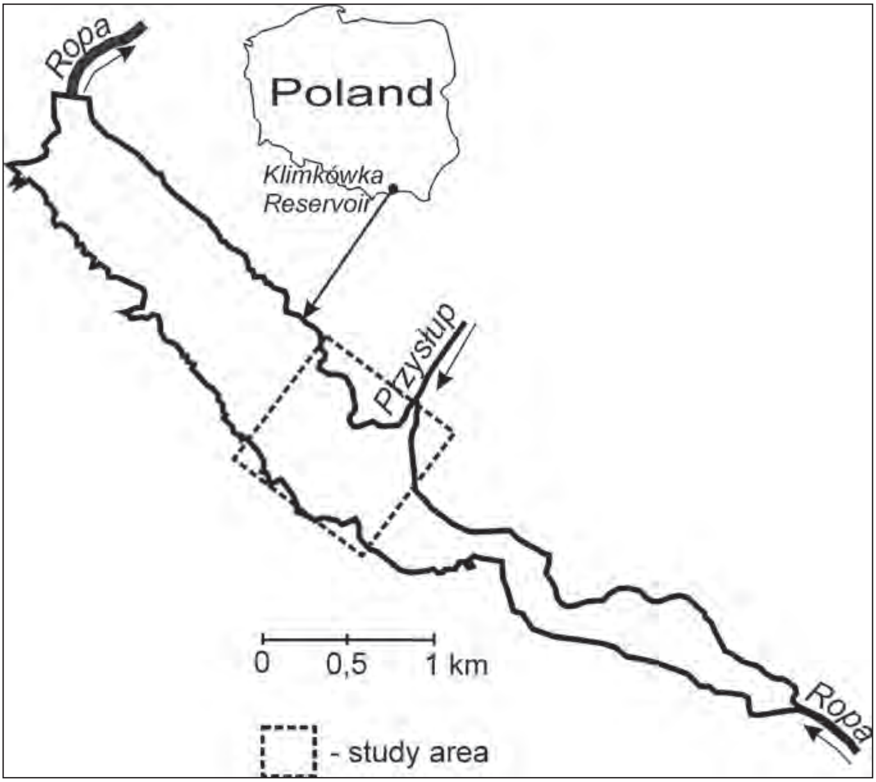


Fig. 2. Study area

was drawn that showed its morphology over the 16 years from the time it began. The obtained results were compared with data that showed the morphology of the Ropa valley from the period before the reservoir was started (initial state), which was read from a topographic map having a scale of 1 : 10,000. The aim of the paper is to assess the results of a comparison of the bathymetric measurements of the bottom of the reservoir with topographic map data that characterize the morphology of the river valley bottom in order to assess the rate of reservoir silting.

The Ropa River, which is a left-bank tributary of the Wisłoka River (a tributary of the Wisła River), is 79 km long, and is one of the rivers that drains the central part of the Polish Flysch Carpathians. The mean annual flow of the river above the reservoir is 1.15 m^3*s^{-1}, and 2.81 m^3*s^{-1} below the dam. The mean river channel gradient in the section above the reservoir is equivalent to 18% (Fig. 3). The Przysłup stream is the biggest side tributary of the Klimkówka Reservoir (13% of the annual water inflow to the reservoir). The catchment area of the stream is equivalent to 24 km^2, its length equals nearly 11 km, and it has a mean drop of 22%. The land cover is dominated by forests, which constitute 62% of the catchment area.

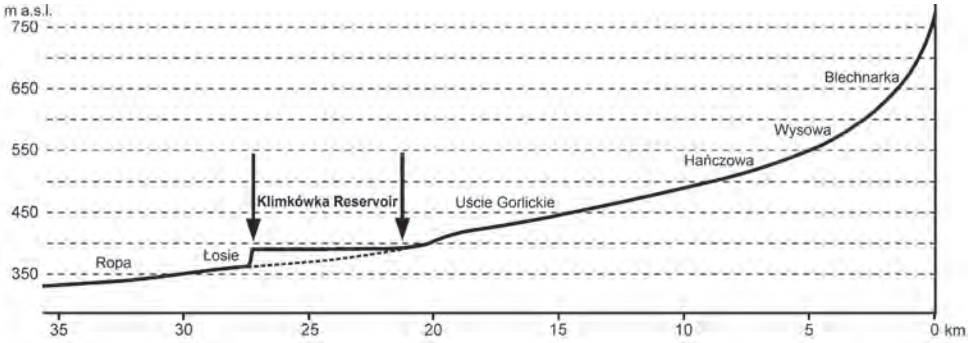


Fig. 3. Longitudinal profile of the Ropa valley, from the springs to the Ropa village

The Klimkówka Reservoir was started on the Ropa River in 1994, and is one of a dozen or so Carpathian reservoirs in Poland (Fig. 1, 2). It is a hydrotechnical facility of average size. Its capacity is equivalent to 43.5 million m^3, with a surface of 3.06 km^2, length of more than 5 km, and a maximum depth of 30 m. The catchment area of the reservoir reaches 210 km^2. The main functions of the reservoir are flood protection as well as increasing of low flows on the Ropa River.

The practical life expectancy of a reservoir terminates when 80% of its initial capacity is filled with clastic material. For the Klimkówka Reservoir, it is equivalent to 12,000 years, assessed based on average suspension retention from 1956 to 1980. However, on the basis of the actual initial increase in the volume of the bottom sediment, it is equivalent to 11,000 years (Łajczak 1986). When the reservoir at Klimkówka was being designed, its total (theoretical) over-growing, estimated on the basis of the silting index (120 m^3*km^2*year), determined for reservoirs on rivers similar to the Ropa River, was estimated to be 100 years (Hennig 2000).

MORPHOLOGY OF THE BOTTOM OF THE KLIMKÓWKA RESERVOIR (BASED ON BATHYMETRIC MEASUREMENTS)

In order to prepare a terrain model of the bottom of the Klimkówka Reservoir at the mouth of the Przysłup stream, the depth of the reservoir was measured by means of an echo sounder. The water level was approximately 395 m a.s.l. The coordinates were taken for each of the 1,000 measuring points (a tourist GPS was used). At each determined point, the terrain's elevation above sea level was defined. Based on this, a digital elevation model (DEM) of the valley that showed the morphological state of the reservoir bottom in 2010 was constructed (Fig. 4). The Moving Surface method was used to interpolate data.

The examined section of the bottom of the Klimkówka Reservoir is located at a height of between 374 m a.s.l. and 395 m a.s.l. The morphology of the bot-

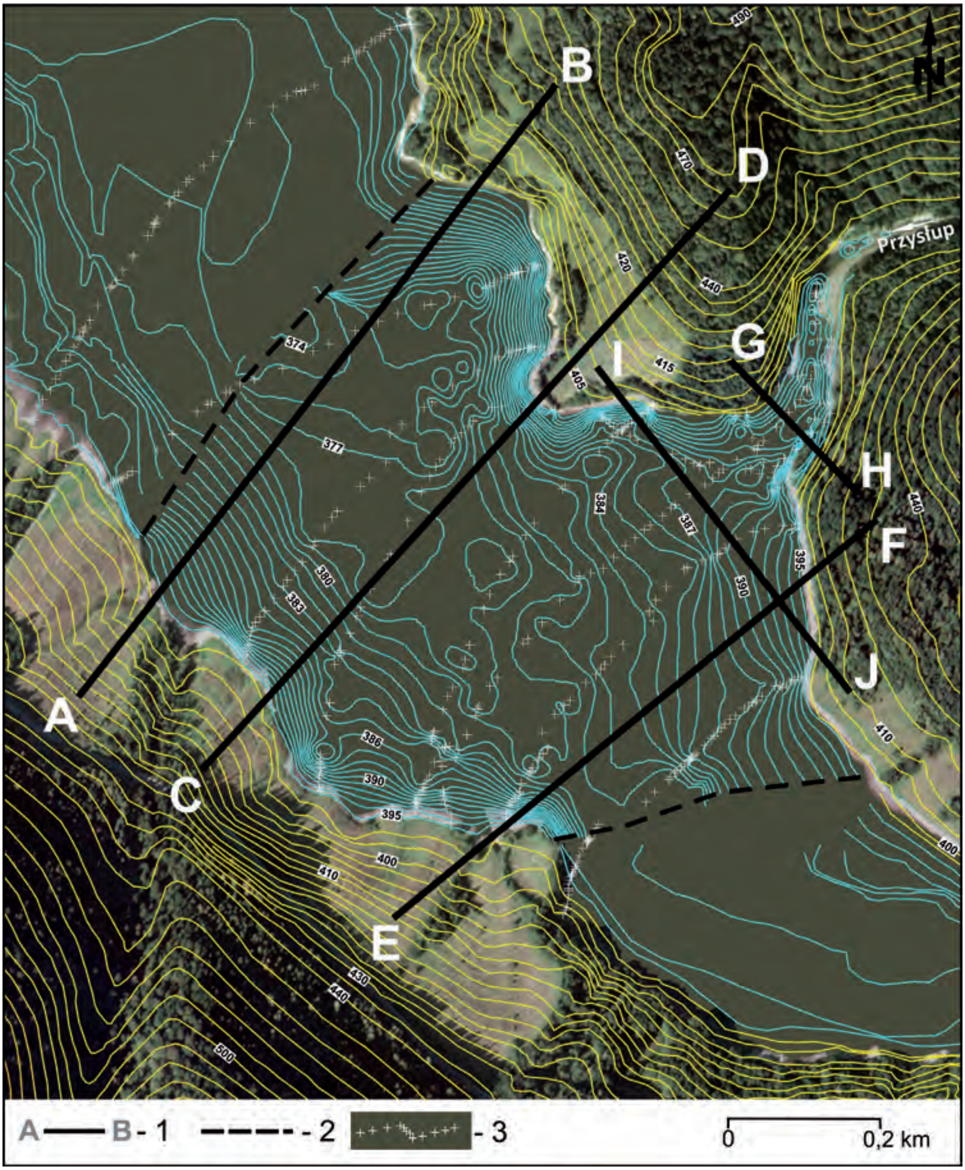


Fig. 4. Topography of the Klimkówka Reservoir in the mouth of the Przysłup stream (state as of 2010, based on the results of bathymetric measurement). 1 — morphological profiles (based on echo sounding); 2 — limit of interpolation; 3 — measurement points

tom, despite the accumulation of sediments supplied by the Ropa River and, in particular, by the Przysłup stream, resembles the topography of the Ropa River from the period before the reservoir was filled with water. The delta of the Przysłup stream builds up on the former alluvial fan of the stream tilted towards the center of the basin. A fundamental change in the morphology of the bottom of the Ropa valley, which can be observed at the completion of the analyzed operating period of the reservoir, is the gradual vanishing of the channel of the Ropa River and the Przysłup stream (they are filling up with sediment). This is also observable when the water level in the reservoir is low. The flattening of the edges of the fluvial terraces, which gradually turn into one slightly tilted surface, is important as well.

CHANGES IN THE MORPHOLOGY OF THE BOTTOM OF THE KLIMKÓWKA RESERVOIR (BATHYMETRIC MEASUREMENTS AND THE TOPOGRAPHIC MAP DATA)

The changes in the morphology of the bottom of the reservoir, which are the result of the build up of the sediment layer accumulated in reservoir bowl, can be detected on the basis of detailed, cyclically performed bathymetric measurements. When measurement series are not performed, it is impossible on the basis of a single measurement to assess changes in the morphology of the bottom of the reservoir (especially below the bank zone). A topographic map can be helpful, but first the reliability of the obtained results should be assessed, especially when the mountain reservoirs located in the valleys of considerable terrain denivelation are being analyzed.

Two terrain models were made in order to compare the morphology of the Klimkówka Reservoir from the period before it was started to its state after it had been in operation for a dozen years or so. The terrain model illustrated in chapter 2, which presents the topography of the bottom of the reservoir in 2010 (Fig. 4), was compared with a terrain model prepared on the basis of a topographic map with a scale of 1 : 10,000 that shows the topography of the Ropa valley from 1964 (Fig. 5). Recording changes in the morphology of the bottom of the Klimkówka Reservoir meant comparing the cross-sections of the Ropa valley that were drawn up on the basis of two terrain models (Fig. 6).

On the basis of terrain observations, as well as comparisons between morphological profiles of the bottom of the Klimkówka Reservoir (Fig. 6), it can be assumed that:

– the channel of the Przysłup stream at the mouth has changed in character from erosive to accumulative,
– at the mouth of the Przysłup stream, the old alluvial fan is building up through intensive accumulation of the material carried by the stream,
– in the relief of the valley bottom, characteristic elements of the terrain's morphology from the time before the flooding, i.e. terraces and the former channel, are disappearing (profile C–D, E–F, I–J),
– a considerable loss in the left-side valley slope, at the mouth of the Przysłup stream (profile G–H, I–J), results from the inaccuracy of the topographic map in relation to the bathymetric measurements, (but it can also ensue from the

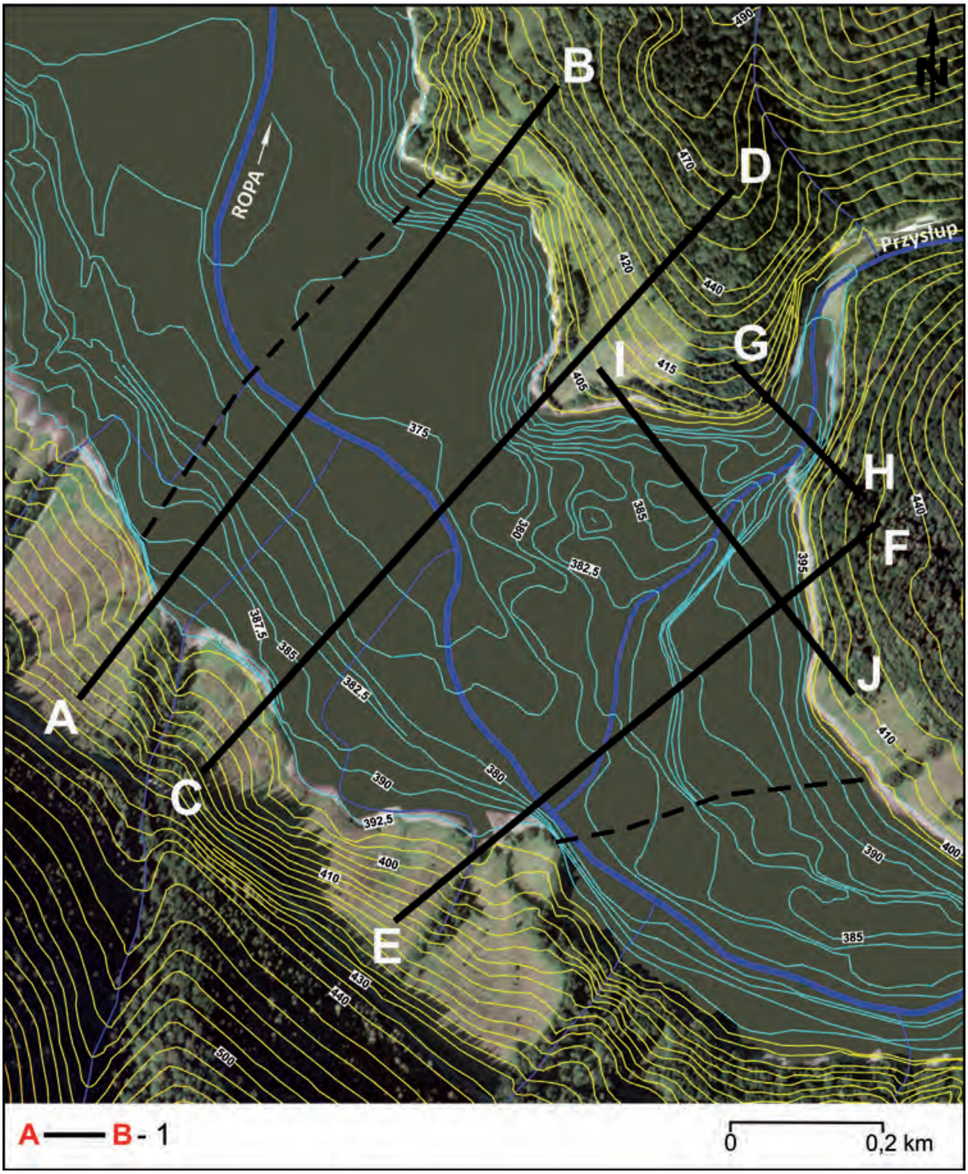
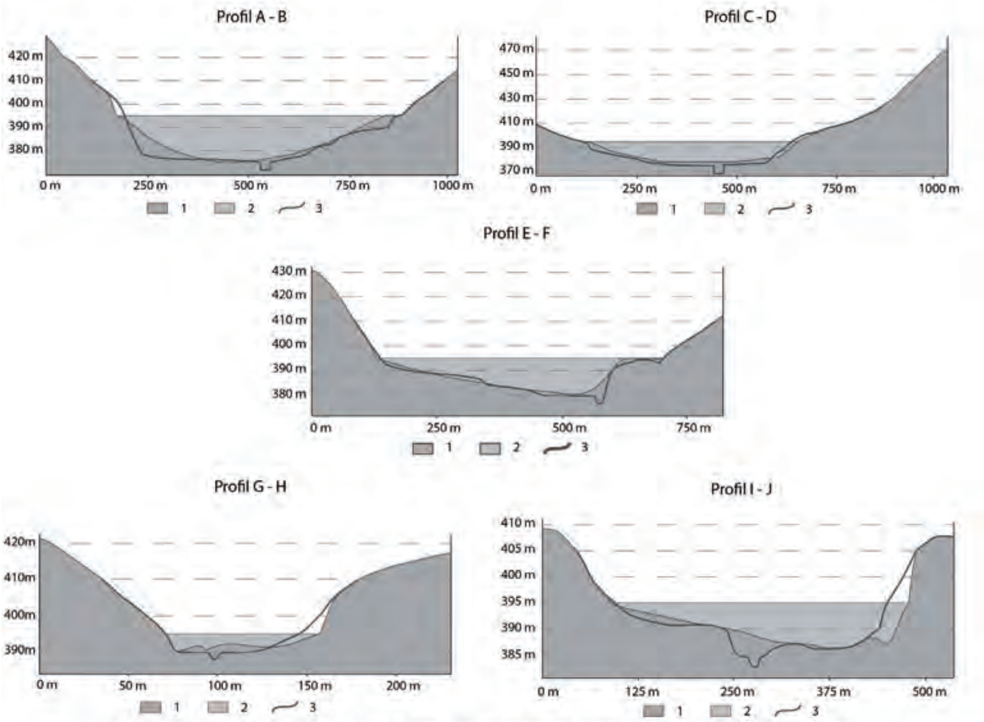


Fig. 5. Topography of the bottom of the Ropa valley in the mouth of the Przysłup stream (state as of 1964, based on the topographic map with a scale of 1 : 10,000). 1 – morphological profiles

exploitation of the stone from the quarry that has been in operation in this place as early as at the beginning of the 20th century),

– the pronounced, considerable accumulation of material (profiles A–B) within the bank zone results from the inaccuracy of the topographic map in relation to the bathymetric measurements,



1 — morphological profile in 2010, 2 — water level in the reservoir on the day of measurements, 3 — morphological profile across the Ropa valley before reservoir construction; y — axis: altitude m a.s.l.

Fig. 6. Morphological profiles of the bottom of the Klimkówka Reservoir

– the increase of the sediment layer in the sections is characterized by a significant diversification, reaching its highest values in section G–H and I–J, and reaching 5 m in the place of the former channel of the Przysłup stream. This value is difficult to verify without conducting sedimentological research when the water level is low.

The final error in the obtained results derived from the comparison of the morphology of the bottom of the reservoir based on bathymetric measurement and the morphology of the Ropa valley based on topographic map data includes fragmentary errors (calibration, measurement, and systematic). Among the most important errors are:

– measurement accuracy of the echo sounder: accurate to 0.1 m in measurements ranging between 1–10 m; accurate to 1 m in depths greater than 10 m; accurate to 4–6 m for a GPS measurement,
– accuracy of the source map (1 : 10,000, i.e. 10 m of terrain),
– calibration errors of the used appliances < 0.1%,
– systematic GPS error connected with taking a measurement in a place partly blocked by the surrounding hills (difficult to define),

– errors derived from asynchronous record of a measurement taken by the echo sounder and GPS (to 1 s)
– a depth measurement error connected with rippling (to 0.2 m),
– distortions and errors made when scanning the topographic map as well as linking it to a system of coordinates; thanks to a double calibration that was based on comparison of road net axes, an accuracy below 6 m was obtained (K r o c z a k 2010).

Only errors defined in statistics as gross errors were unambiguously eliminated. Due to the probability of large summary measurement error, the general balance of the material accumulated in the analyzed area of the Klimkówka Reservoir was not provided.

CONCLUSIONS

The comparison of the obtained results and data concerning the initial state of the bottom (from the period before the reservoir was started) that are derived from topographic map data with a scale of 1 : 10,000 does not give fully reliable results. Performing a series of bathymetric measurements by means of one research method can be reliable. The bathymetric measurements conducted at the mouth of the Przysłup stream are the basis for further studies aimed at defining the dynamics of sediment accumulating in the deeper parts of the reservoir. Defining the rate of the growth of bottom sediment can be possible once new bathymetric measurements are taken after longer intervals of time, and by means of more accurate appliances. It is also possible to assess the overall height of the sediment layer that has been created on the bottom of the Ropa valley from the moment the Klimkówka Reservoir was started if the water level in the reservoir is lowered to levels that allow the outcrops and sediment samples to be taken for sedimentological study. Defining the amount of debris carried by the Przysłup stream during flooding, which should be the aim of separate research, would also be helpful. The presented conclusions, which are the result of a comparison of terrain measurements and topographic map data, are a warning against making deductions based on terrain topography models created on the basis of topographic maps. Such deductions are often encountered in geomorphologic papers. The conclusions should be verified through terrain recognition otherwise they will be unreliable.

[1] *Institute of Geography and Spatial Organization PAS*
Department of Geoenvironmental Research
św. Jana 22, 31-018 Cracow, Poland
e-mail:wieja@zg.pan.krakow.pl

[2] *Pedagogical University of Cracow*
Podchorążych 2, 30-084 Cracow, Poland
e-mail:kroraf@gmail.com

[3] *Institute of Geography and Spatial Organisation PAS*
Department of Geoenvironmental Research
Research Station in Szymbark
38-311 Szymbark 430, Poland
e-mail:ig.szymbark@poczta.onet.pl

REFERENCES

Banach M., 1994. *Morfodynamika strefy brzegowej zbiornika Włocławek*. Prace Geograficzne IGiPZ PAN 161, 181 pp.

Banach M., 1995. *Osady denne — wskaźnik hydrodynamiki zbiornika włocławskiego*. Przegląd Geograficzny 57, 4, 487–497.

Chomiak T., Cyberski J., Mikulski Z, 1969. *Akumulacja rumowiska w zbiornikach retencyjnych (wyniki prac polskiej służby hydrologicznej w latach 1957–1966)*. Prace PIHM 96, 3–30.

Cyberski J., 1969. *Sedymentacja rumowiska w zbiorniku rożnowskim*. Prace PIHM 96, 21–42.

Cyberski J., 1970. *Badania akumulacji rumowiska w zbiornikach retencyjnych w Polsce*. Gospodarka Wodna 2, 43–46.

Hennig J., 2000. *Realizacja inwestycji*. [in:] *Zbiornik wodny Klimkówka — Monografia*. Łagosz T. (ed.), IMGW, Warszawa, 33–44.

Jahn A., 1968. *Geomorfologiczne wnioski z obserwacji dna jeziora zaporowego*. Czasopismo Geograficzne 39 (2), 117–123.

Kieraś W., Majka J., Racinowski R., 1973. *Próba określenia ilościowej charakterystyki abrazji na zbiorniku solińskim*. Gospodarka Wodna 4, 129–131.

Klimek K., Łajczak A., Zawilińska L., 1989. *Cechy sedymentologiczno-geochemiczne osadów delty Soły w zbiorniku Żywieckim*. Problemy Zagospodarowania Ziem Górskich 29, 85–92.

Kroczak R., 2010. *Geomorfologiczne i hydrologiczne skutki funkcjonowania dróg polnych na Pogórzu Ciężkowickim*, Prace Geograficzne IGiPZ PAN, 225, 138 pp.

Łajczak A., 1986. *Retencja rumowiska w zbiornikach zaporowych karpackiego dorzecza Wisły*. Czasopismo Geograficzne 1, 47–77.

Łajczak A., 1989. *Zróżnicowanie transportu zawiesiny w karpackiej części dorzecza Wisły*. Dokumentacja Geograficzna IG PAN 5, 85 pp.

Łajczak A., 1995. *Studium nad zamulaniem wybranych zbiorników zaporowych w dorzeczu Wisły*. Monografie Komitetu Gospodarki Wodnej PAN 8, 108 pp.

Łajczak A., 2005. *Delty w zbiornikach zaporowych — nowy element rzeźby fluwialnej w górach i warunki ich formowania (na przykładzie polskich Karpat)*. [in:] *Antropopresja w górach średnich strefy umiarkowanej i skutki geomorfologiczne na przykładzie wybranych obszarów Europy Środkowej*. Łajczak A. (ed.), Human Impact on Mind Mountain Ecosystem, 2, Uniwersytet Śląski, Sosnowiec, 127–137.

Onoszko J., 1964. *Zamulanie zbiornika rożnowskiego w 19-leciu jego eksploatacji*. Prace IBW–PAN, Gdańsk.

Rzętała M., 2003. *Procesy brzegowe i osady denne wybranych zbiorników wodnych w warunkach zróżnicowanej antropopresji (na przykładzie Wyżyny Śląskiej i jej obrzeży)*. Wydawnictwo UŚ, Katowice, 156 pp.

Wiejaczka Ł., 2011. *Wpływ zbiornika wodnego "Klimkówka" na abiotyczne elementy środowiska przyrodniczego w dolinie rzeki Ropy*. Prace Geograficzne IGiPZ PAN 229, 144 pp.

Wiejaczka Ł., 2012. *Akumulacja materiału zawiesinowego w zbiorniku Klimkówka (polskie Karpaty)*. [in:] *Materiały IV Międzynarodowego seminarium "Problemy geomorfologii i paleogeografii ukraińskich Karpat i terenów przyległych", 6–9 września, Worochta, Ukraina*. Fakultet Geografii Uniwersytetu im. Ivano Franka we Lwowie, Lwów, 181–188.