Geographia Polonica 2012, 85, 4, pp. 33–43

Geographia Polonica
Volume 85, Issue 4, pp. 33–43
http://dx.doi.org./10.7163/GPol.2012.4.23

INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES
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DIFFERENTIATION OF TEMPORAL WATER LEVEL DYNAMICS IN THE BESKO AND KLIMKÓWKA RESERVOIRS (THE LOW BESKIDS, POLAND)

Łukasz Wiejaczka[1] • Katarzyna Wesoły[2]

[1] Institute of Geography and Spatial Organization
Polish Academy of Sciences
Św. Jana 22, 31-018 Kraków: Poland
e-mail address: wieja@zg.pan.krakow.pl

[2] The Regional Water Management Board in Kraków
Marszałka J. Piłsudskiego 22, 31-109 Kraków: Poland
e-mail address: katarzyna.wesoly@wp.pl

Abstract

This article compares the observed water level changes during a hydrological year, in the two Carpathian reservoirs: the Besko and the Klimkówka. The analyzed reservoirs are located within the same physico-geographical unit – the Low Beskids, but the reservoirs operate on rivers with different hydrological regimes (the Wisłok River and the Ropa River). The performed analysis shows that during the year, the analyzed reservoirs are characterized by different water level dynamics. The water level changes of the reservoirs are determined by the management of the reservoirs, and more importantly, by the inflow volume as well as the supply distribution throughout the year. The analysis uses archive material provided by the Regional Water Management Board in Kraków, Poland. The material pertains to the change of water levels in the Besko and Klimkówka Reservoirs between 1996 and 2011.

Key words

Besko Reservoir • Klimkówka Reservoir • hydrological regime • the Low Beskids • the Polish Carpathians • the Ropa River • the Wisłok River • water level

Introduction

Two reservoirs operate within the Low Beskids: the Besko and the Klimkówka. The Besko Reservoir is located on the Wisłok River in the eastern part of the region, whereas the Klimkówka Reservoir is located on the Ropa River in the western part of the region (Fig. 1). The Besko Reservoir has been in operation since 1978. The reservoir dam is located at the 172.8 km point, on the Wisłoka River course. The reservoir has a 15.38 million m^3 capacity, a surface area of 1.31 km^2 at full supply level (337 m a.s.l.), and a depth of 30 m. The water basin has two main branches: in the Wisłok Valley (approximately 5 km long) and in the Czernisławka Valley (approximately 2.5 km long). The main goal of building this facility was to level the minimal flows on the Wisłok River below its location in order to protect biological life and to provide for water withdrawal from the water intake at Iskrzynia (mainly for the town of Krosno). Under normal operating conditions, the compensating outflow of water equals 0.9 m^3 s^{-1}. Flood control is of secondary importance.

Figure 1. Location of the Besko Reservoir and Klimkówka Reservoir within the Polish Carpathians and the Low Beskids.

The Klimkówka Reservoir was started in 1994, and is the youngest reservoir in the Polish Carpathians, with the exception of the Czorsztyn--Sromowce Wyżne Reservoir complex. The aim of the facility was flood control and to level the Ropa River low flows. The firm yield of water from the reservoir equals 2 $m^3 s^{-1}$. The Klimkówka Reservoir has a maximum capacity of 43.5 million m^3, a surface area of 3.06 km^2, and a depth of 30 m. The length of the basin amounts to 6 km. The water dam is located at the 54.4 km point on the course of the river, which is approximately 20 km south of Gorlice.

Compared to other Carpathian reservoirs, the analyzed reservoirs are not large hydro-technical facilities. The catchment areas of the Besko and Klimkówka Reservoirs have a similar surface: 207 km^2 and 210 km^2. In the case of the Besko Reservoir, the absolute heights in the catchment areas fluctuate between 360-770 m a.s.l.; for the Klimkówka Reservoir between 370-750 m a.s.l. The Wisłok River is approximately 21 km above the Besko Reservoir, whereas the Ropa River is 18 km above the Klimkówka Reservoir. Although the rivers on which the reservoirs have been built drain the same area of one physico-geographical unit (Fig. 1), the rivers are characterized by different hydrological regimes. This difference is due to the fact that the rivers are located at the ends of the Low Beskids (a transitory area between the Western and Eastern Carpathians). Dynowska (1973) assumed that there is one type of hydrological regime of rivers for the area of the Low Beskids, i.e., unbalanced with freshets: spring, summer and winter, as well as with rain-ground-snow supply. However, she emphasized that the regime of the Wisłok River is a transitory regime between the rivers of the Western Beskids, which apart from spring freshets have very distinct summer freshets, and the rivers of the Eastern Beskids, which are not characterized by more considerable summer freshets, and where the main freshet occurs in spring, whereas the secondary one occurs in the winter. The hydrological regime reflects the temporal river flow changeability, which determines the amount of water that flows into the reservoirs during a year. The fluctuations of a reservoir's water level are determined by the volume of water inflow and water outflow. The water outflow of a reservoir depends on its water management. For most of the year (apart from seasonal freshets), the outflow volume for reservoirs is normally constant. During the year, the changes in the full supply level in reservoirs, mark the area where the transformation of the morphology of river valleys takes place. These changes also condition the intensity and the nature of the geomorphological, hydro-chemical, and hydro-biological processes in the reservoirs.

The aim of the paper it to show the differences in the temporal water level dynamics of the Besko and Klimkówka Reservoirs. Both of these reservoirs are located within the same physico-geographical unit, yet operate on rivers with different hydrological regimes.

The study uses archive material which pertains to the daily water levels of the Besko and Klimkówka Reservoirs (readings at 06:00 UTC). The archive material also pertains to mean daily inflow volumes for the reservoirs during the hydrological years 1996-2011. The data was made available by the management of the Besko and Klimkówka dams, with the consent of the Regional Water Management Board in Kraków (all figures, except Fig. 1).

The problem concerning the changes in water levels in mountain reservoirs is rarely mentioned in literature. A detailed analysis is presented only in Soja's study (2002), with reference to the Dobczyce Reservoir, and in Wiejaczka's analysis (2011) of the Klimkówka Reservoir. Soja (2002) conducted an analysis of mean, maximum, and minimum annual water levels in the Dobczyce Reservoir for the 1988-1998 period. The author drew attention to the connection between the volume of the water supply and the height of the water impoundage in the reservoir in the individual years throughout the multiannual period. The course of the mean, minimum, and maximum annual water levels in the Dobczyce Reservoir during the multiannual period is similar. An increase in the maximum levels can only be noticed in years characterized by high freshets, whereas in years when low-water periods occurred on the Raba River, a decrease in the minimal levels can be observed. During freshets, water levels can rise by 2.5 m within a period of 2-3 days. Freshets play a significant role in the shaping of the full supply level in the Dobczyce Reservoir. In the analyzed multiannual period, the maximum increase in the water level during the day was 1.5 m (8-9 July 1997).

Analysis of the annual dynamics of the water levels in the Klimkówka Reservoir conducted in Wiejaczka's study (2011), pertains to the multiannual period of 1995-2006. The study results indicated that annual water level amplitudes in the Klimkówka Reservoir are considerably bigger than the analogical amplitudes presented in Soja's study (2002) and observed in the Dobczyce Reservoir (with a capacity three times greater than the Klimkówka Reservoir). The annual water level amplitudes in the Klimkówka Reservoir were in the range of 5.54-17.14 m, and the average annual amplitude calculated for the whole multiannual period amounted 10.36 m. The differences between annual maximal and minimal water levels in the Dobczyce Reservoir were in the range of 1.34 m to 15.52 m; the average value of the amplitude for the whole multiannual period was 5.09 m.

The problem of the changes in the water impoundage in the dammed reservoirs was presented in a synthetic way in a study by Łajczak (1995). The author stated that water level fluctuations in shallow reservoirs (functioning as stilling basins) that operate on Carpathian rivers, are subject to distortions resulting from the influence of the upper cascade basin as well as from the internal water management of the two reservoirs complex. These reservoirs are characterized by rapid changes in filling, though seasonal water level fluctuations do not exceed 2 m.

The information concerning the water level fluctuations of the Carpathian reservoirs, as well as the influence of the fluctuations on the selected elements of the environment, are also covered in studies by Baran and Gwiazda (2006), and Wojtuszewska (2007).

Annual cycle of the water inflow and outflow in the Besko and Klimkówka Reservoirs in the years 1996-2011

The analysis of the average monthly inflow volume into the reservoirs in the multiannual period of 1996-2011, is presented in Figures 2 and 3. The analysis suggests there are three intensified periods of water supply for the Besko Reservoir, and two with high inflow volumes for the Klimkówka Reservoir. In the case of the Besko Reservoir, the first period with the highest inflows is in March (6.70 $m^3 s^{-1}$) and April (6.57 $m^3 s^{-1}$), and it commences as early as in February (3.51 $m^3 s^{-1}$). The second period, which has significantly smaller freshet inflows, occurs in July (4.96 $m^3 s^{-1}$) and the third period is in September (3.32 $m^3 s^{-1}$). The period of low inflow values for the Besko Reservoir occurs in the autumn-winter months, between October (2.14 $m^3 s^{-1}$) and January (2.85 $m^3 s^{-1}$). May (3.08 $m^3 s^{-1}$) and August (2.06 $m^3 s^{-1}$) divide the freshet periods. In the case of the Klimkówka Reservoir, only two clear periods of high inflow values can be observed. Similar to the Besko Reservoir, the first one can be observed in March (5.12 $m^3 s^{-1}$) and April (4.73 $m^3 s^{-1}$). There is an intensified supply in the summer period during June (4.80 $m^3 s^{-1}$) and July (4.25 $m^3 s^{-1}$) for the Klimkówka Reservoir. For the Besko Reservoir there is an intensified supply only in July.

May is the month dividing the spring and summer freshets with high inflow values for the Klimkówka Reservoir. The low inflow values for the Klimkówka Reservoir start in the late summer in August (1.93 $m^3 s^{-1}$) and finish in January (2.26 $m^3 s^{-1}$), similar as in the Besko Reservoir.

In an annual cycle, the average monthly water outflows from the Besko and Klimkówka Reservoirs show a high degree of similarity to the average inflows (Fig. 2 and 3). This similarity proves that the regime of the water outflow from the reservoirs is conditioned, to a great extent, by the hydrological situation in the catchment area of the reservoir. It is particularly visible in the case of the Besko Reservoir, where the differences between the values of average monthly water inflows and outflows are minimal (Fig. 2). In an annual course of the water outflow from the Klimkówka Reservoir, a temporal delay with reference to outflow dynamics can be observed (Fig. 3). This results from the greater potential of the Klimkówka Reservoir (in reference to the Besko Reservoir, which

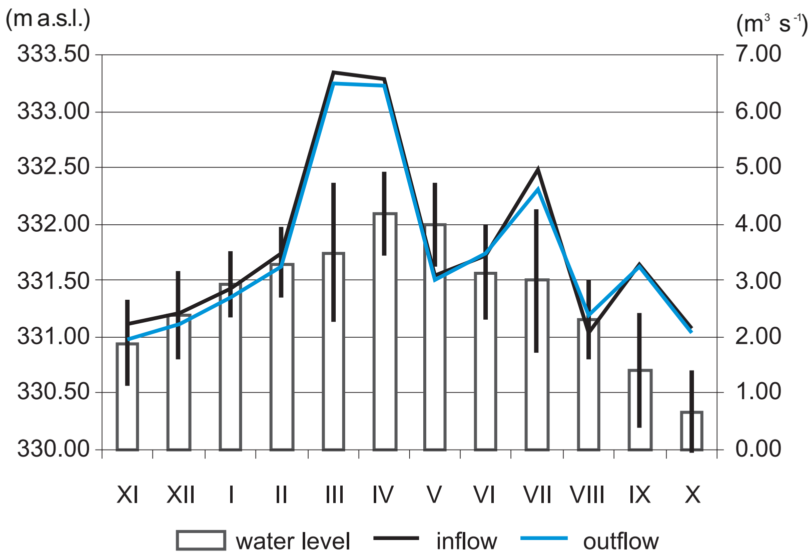

Figure 2. Average monthly inflows, outflows, and average monthly water levels (with standard deviation) in the Besko Reservoir for the years 1996-2011.

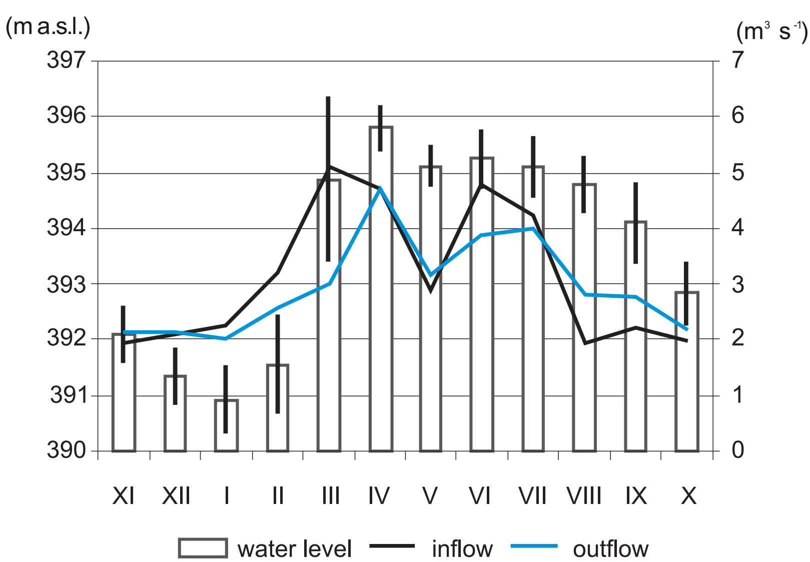

Figure 3. Average monthly inflows, outflows, and average monthly water levels (with standard deviation) in the Klimkówka Reservoir for the years 1996-2011.

is 3 times smaller in terms of capacity) to capture freshet waves and store water as well as from the Klimkówka Reservoir's ability to gradually empty after the freshet period. When analyzing the volume of a daily outflow in the selected years of the studied multiannual period, it can be said that for most of the year, the outflow from the Besko and Klimkówka reservoirs is maintained at the guaranteed level.

Annual dynamics of water levels in the Besko and Klimkówka Reservoirs in the multiannual period of 1996-2011

Under normal operating conditions, the Besko Reservoir's level is between 319.8 m and 332.0 m a.s.l. in the winter half year, and 330.5 m a.s.l. in the summer half year (within the so-called compensatory capacity). When the aforementioned figures are exceeded, the storage capacity of the flood control zone is filled. Once the level has been reached (336.0 m a.s.l.), water levels can reach in particular cases 337.0 m a.s.l. (flood control capacity). The minimum normal water level is 319.8 m a.s.l. A reservoir volume less than the figure of 319.8 m a.s.l., is defined as dead volume. The annual course of water levels in the Besko Reservoir has not yet been the subject of a detailed study.

Under normal operating conditions, the Klimkówka Reservoir's normal water level is between 395.8 m and 375.1 m a.s.l., i.e., within the usable volume. During freshet periods, water accumulates in the reservoir within the flood control capacity. This capacity is between 395.8 m and 398.6 m a.s.l. Below the figure of 375.1 m a.s.l., water levels are within the limits of the dead volume. Wiejaczka, in his study (2011), conducted an analysis of the changes in the upper water levels in the Klimkówka Reservoir in the multiannual period 1995-2006. The presented materials indicate that in the periods being analyzed, the highest water levels in the Klimkówka Reservoir during the year occurred between April and August. In the remaining months, the level was considerably lower. In an annual cycle, the lowest water level in the reservoir occurred in January and February. In the 1996-2011 multiannual period, the annual dynamics of the level in the Klimkówka Reservoir were very similar to the changeability seen in 1995-2006, which was stated in Wiejaczka's study (2011).

A comparison was done between the average monthly water levels in the Besko and Klimkówka Reservoirs and the average monthly water inflows and outflows (Fig. 2 and 3). The results proved that the water level dynamics in the analyzed reservoirs throughout the year were similar to the annual changeability of the water inflow in these facilities.

The comparison between the annual dynamics of the average monthly water levels in the Besko and Klimkówka Reservoirs (Fig. 2 and 3) show that the highest values, in the case of the Besko Reservoir, are in April (332.09 m a.s.l.) and May (332.0 m a.s.l.). In the Klimkówka Reservoir, the period of the high mean levels is much longer. The period commences as early as March (394.89 m a.s.l.), and terminates in August (394.81 m a.s.l.). It is also worth mentioning that the highest mean level, noticeably diverging from the remaining ones, can be observed in April (395.81 m a.s.l.), whereas in the months of May to July, the reservoir's water level is relatively stable. A visible decline in the average monthly levels in the Besko Reservoir occurs as early as in June (331.57 m a.s.l.) and July (331.5 m a.s.l.). A decline in the level continues only until October, when the lowest mean value in an annual cycle is observed (330.33 m a.s.l.). A decline in the average monthly levels in the Klimkówka Reservoir is not noticeable until August, although a more visible decline in the height of the level is observed from September (394.11 m a.s.l.); and lasts until January (390.92 m a.s.l.). A constant rise of the average water levels in the Besko Reservoir, heading towards the April maximum, occurs as early as in November (330.94 m a.s.l.). In the Klimkówka Reservoir, an increase in the average monthly levels is short (February and March), but rapid.

The average maximum monthly water levels in the Besko Reservoir ranges from 331.04 m a.s.l. (October) to 333.35 m a.s.l. (July) and to 333.43 m a.s.l. (March). In the Klimkówka Reservoir, the average maximum monthly water levels fluctuates from 391.02 m a.s.l. (January) to 395.93 m a.s.l. (April) (Fig. 4). The period with the highest values of the maximum monthly levels in the Besko Reservoir (above 333.0 m a.s.l.) occurs twice throughout the year (spring and summer). In the Klimkówka Reservoir, this period (over 395.0 m a.s.l.) lasts from March until July, with the maximum in April (395.93 m a.s.l.). From August until October, a noticeable decline in the height of the average

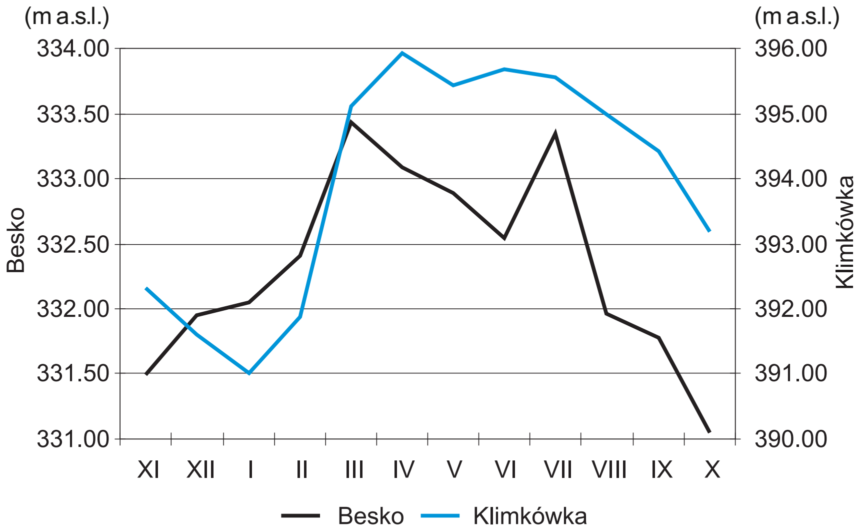

Figure 4. The average maximum monthly water levels in the Besko Reservoir and Klimkówka Reservoir for the years 1996-2011.

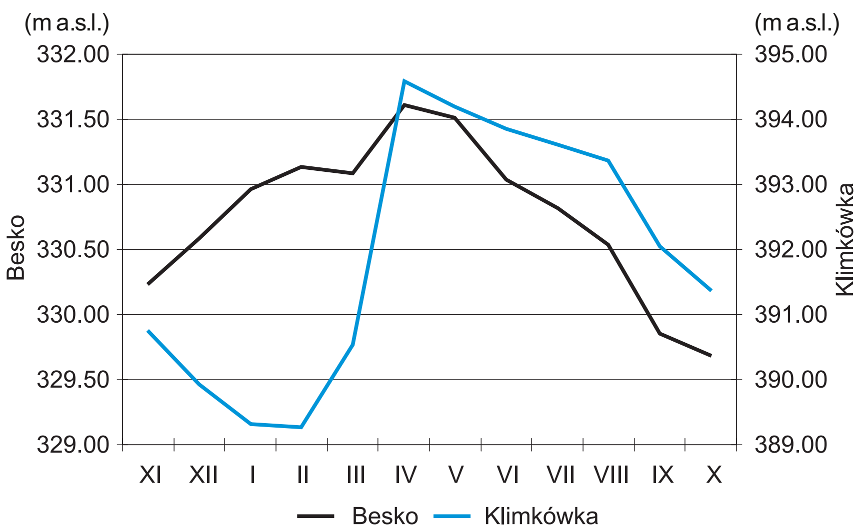

Figure 5. The average minimum monthly water levels in the Besko Reservoir and Klimkówka Reservoir for the years 1996-2011.

maximum monthly water levels can be observed in the Besko Reservoir. Similarly, in the Klimkówka Reservoir, a decline period starts in August, but it lasts until January. In the Besko Reservoir, the increase in the value of the average maximum monthly water levels starts in November, with only a slight slowing of the dynamics seen from December until January. In the Klimkówka Reservoir, increase in the value of the average maximum monthly water levels starts only in February, and it is very rapid.

The average minimum monthly levels in both reservoirs (Fig. 5) show one clear maximum: in April (331.63 m a.s.l. – Besko; 394.58 m a.s.l. – Klimkówka). There is also one minimum, which in the case of the Besko Reservoir, occurs in October (329.68 m a.s.l.), and in the case of the Klimkówka Reservoir, in February (389.26 m a.s.l.). The increase in the average minimum monthly water levels in the Besko Reservoir is smaller and less spread over time (from November until April, with a significant decline in March). In the Klimkówka Reservoir, this increase is rapid at the end of winter and the beginning of spring (from February until April). A decline in the values of the average

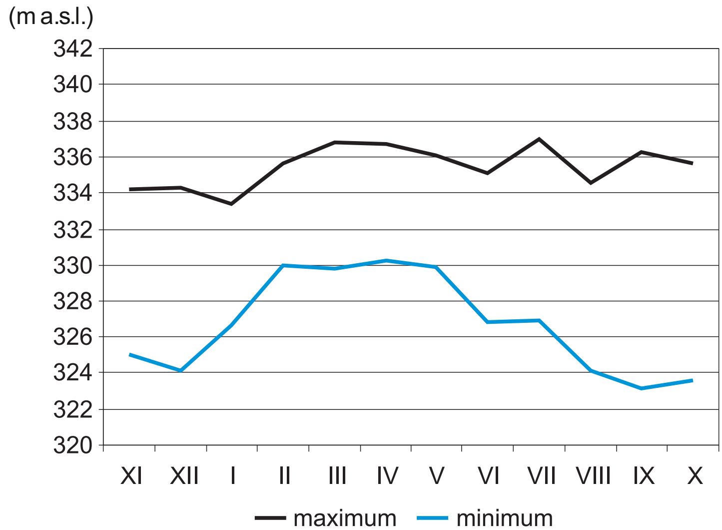

Figure 6. Extreme water levels in the Besko Reservoir in the annual cycle, for the years 1996-2011.

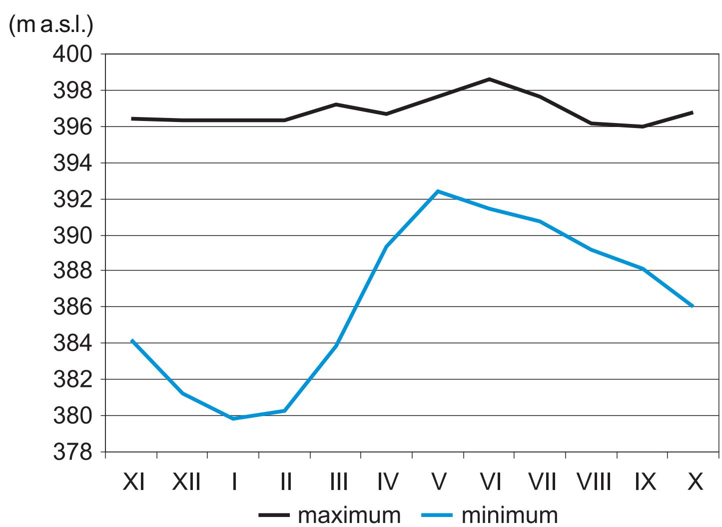

Figure 7. Extreme water levels in the Klimkówka Reservoir in the annual cycle, for the years 1996-2011.

minimum monthly water levels in both reservoirs, shows similar dynamics.

During the year, the maximum water levels in the Besko Reservoir in the periods being analyzed, fluctuated between 333.39 m a.s.l. in January (1996) and 336.99 m a.s.l. in July (2008). The minimum water levels in the Besko Reservoir in the analyzed periods, were from 323.16 m a.s.l. in September (1998) to 330.25 m a.s.l. in April (2011) (Fig. 6). The maximum water levels observed in an annual cycle in the Klimkówka Reservoir (Fig. 7), were between 395.96 m a.s.l. in September (2010) and 398.6 m a.s.l. in June (2010). The lowest levels were between 379.87 m a.s.l. in January (2001) and 392.37 m a.s.l. in May (2007).

Changes in the daily water levels are proof of clear differences in the shaping of the water levels in an annual cycle in the reservoirs being analyzed. Figure 8 presents an example of daily water levels in the Besko and Klimkówka Reservoirs in 2011. The Besko Reservoir definitely shows smaller dynamics of the daily levels in comparison with the Klimkówka Reservoir. For most of the year, there is a similar level of water impoundage in the Besko Reservoir. The periods of high water levels, a result of the increased supply, are short-term.

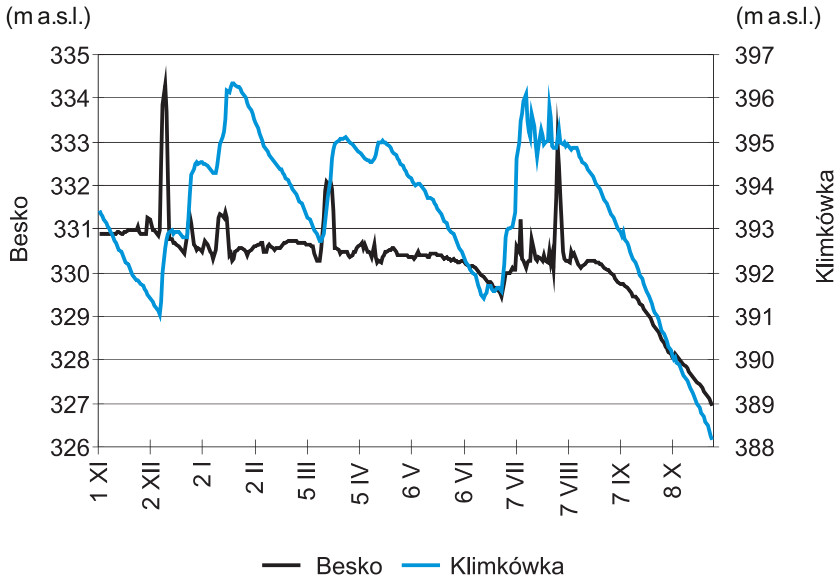

Figure 8. Daily fluctuations of water levels in the Besko Reservoir and Klimkówka Reservoir in 2011.

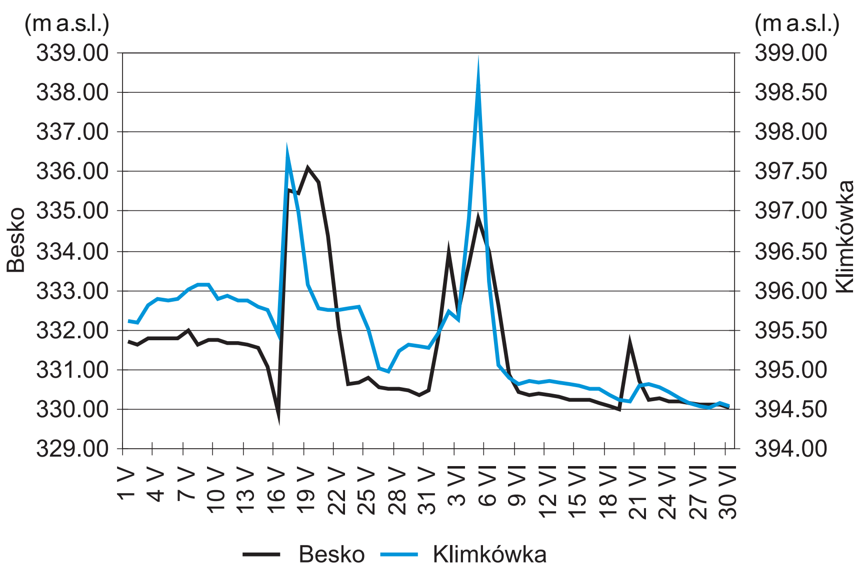

Figure 9. Daily fluctuations of water levels in the Besko Reservoir and Klimkówka Reservoir in May and June 2010.

In the Klimkówka Reservoir, the opposite is true, because periods with high water levels last much longer. Periods with low water levels dividing the high water level periods, are shorter. The low water levels typical for the Carphatian rivers (especially the Low Beskids), are extremely important for the annual dynamics of daily water levels in the Carpathian reservoirs. During the low water level periods in rivers, the amount of inflow to the reservoir is several times less than the outflow. Consequently, the level is rapidly and considerably decreased. The last such low-water level occurred at the turn of 2010-2011 (Fig. 8). When there is a noticeable and prolonged lack of supply, a very quick reaction of both reservoirs occurs that is seen in the dynamic decline of the level.

In the multiannual period being analyzed, the daily changes in the level in the Besko and Klimkówka Reservoirs under normal operating conditions (apart from the freshet periods) reached

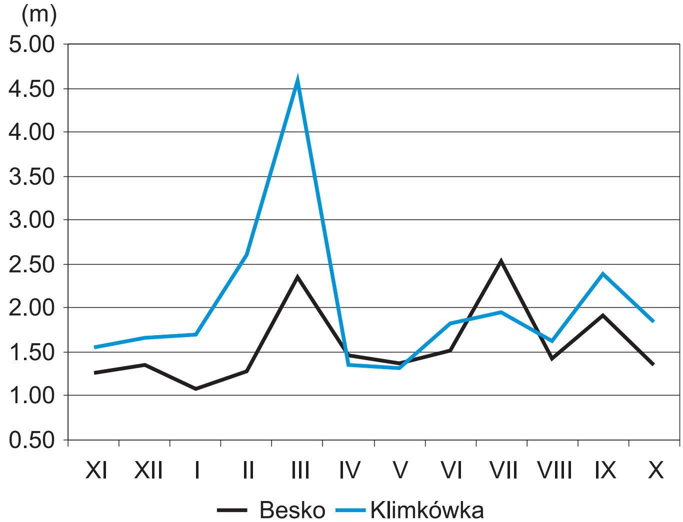

Figure 10. Average monthly amplitude of water levels in the Klimkówka Reservoir and Besko Reservoir for the years 1996-2011.

from 10 cm to 99 cm. These changes took place when the water level was decreasing. Similar fluctuations were observed during the periods of small freshets, when the water level was rising. In the case of large freshets, an increase of the Besko Reservoir's level reached 5.96 m in one day; in the Klimkówka, 3.82 m. When the reservoirs were being emptied after a freshet wave had been captured to increase flood control capacity, a decrease in the water levels amounted to a maximum of 2.86 m in the Besko Reservoir, and 3.08 m in the Klimkówka Reservoir. Figure 9 presents an exemplary scale of daily water level fluctuations in the Besko and Klimkówka Reservoirs in the aforementioned hydrological situations.

The amplitude of water level fluctuations, i.e., the difference between a maximum and minimum water level in a given period, is a significant parameter that describes the dynamics of water levels in reservoirs. In the multiannual period 1996-2011, there were two months during in every year (Fig. 10) characterized by higher values of monthly amplitudes of water level fluctuations in the Besko Reservoir. In March, an average monthly amplitude of the water level fluctuations reached 2.35 m; in July, 2.53 m. In the Klimkówka Reservoir, the highest difference between the minimum and maximum water level occurred in March (4.58 m on average). A higher amplitude of water level fluctuations; 2.38 m, was also observed in September. This value is similar to the highest average monthly amplitudes recorded in the Besko Reservoir. The higher values of the water level amplitudes in the Klimkówka Reservoir in the winter-spring months, in comparison with the amplitudes in the Besko Reservoir, result from the greater water inflow dynamics into this reservoir in the mentioned period. Most of the year (in autumn-winter and spring-summer months), significantly smaller and more stable water level fluctuations can be observed in both reservoirs. In the Besko Reservoir, in the 1996-2011 period, water levels in the months between October and February fluctuated between 1.07 m and 1.36 m; from April through June, they fluctuated between 1.37 m and 1.52 m. In the case of the Klimkówka Reservoir, the average monthly amplitude of the water level fluctuations between October and January was between 1.54 m and 1.95 m. The extreme values of the monthly amplitudes of water impoundage in the Besko Reservoir, which were recorded in the multiannual period being analyzed, ranged between 0.16 m (January 2002) to 10.16 m (August 2007). In the Klimkówka Reservoir, the extreme recorded fluctuations of the level were from 0.16 m (March 2006) to 11.23 m (May 1996).

Summary

Despite the fact that the Besko and Klimkówka Reservoirs operate within the same physico-geographical unit, they are characterized by different water level dynamics throughout the year. This mainly results from the different hydrological regime of the Ropa River and Wisłok River in their courses above the water dams. In the reservoirs, the water level courses during the year are conditioned by the water management, and most of all, by the supply volume. The Besko Reservoir shows definitely smaller dynamics of daily levels in comparison with the Klimkówka Reservoir. During the year, periods with high daily water levels, as take place in the Klimkówka Reservoir, are far longer compared to those in the Besko Reservoir, where daily water levels are characterized by greater stability. An increased water supply for the Besko Reservoir can be observed 3 times during the year – between early spring and autumn. These periods are characterized by smaller and smaller flows which are evenly spread over that time period. Consequently, the annual water level dynamics (an increase and a decrease) are quite constant. As for the Klimkówka Reservoir, there are only 2 periods of increased water inflow: in spring and summer (with a similar inflow volume). In an annual cycle, the changeability of water levels in the Klimkówka Reservoir is stable in the period of increased supply, as well as very rapid at the turn of winter and spring. Then, after a period when the reservoir has been poorly supplied with water, there is a rapid increase in the inflow volume caused by thaw and underground feeding.

In the winter and spring periods, the Klimkówka Reservoir shows higher values of monthly amplitudes of water level fluctuations in comparison to the Besko Reservoir. This is caused by a more even distribution of the water inflow volume into the reservoir over this period. The distribution of the Besko Reservoir inflows is somewhat even, especially in winter and the end of spring – beginning of summer period. The results are smaller water level fluctuations.

The Besko and Klimkówka Reservoirs are both located within one physico-geographical unit of the Polish Carpathians, and both reservoirs have different water level fluctuations. A comparison between the water level dynamics with reference to other Carpathian reservoirs, which operate on rivers with considerably different hydrological regimes, would constitute an interesting analysis. A synthetic analysis is also required for the problem of the changes of water impoundage in the dammed reservoirs that are in operation in one complex. A comparison between the dynamics of the water level fluctuations in reservoir units located on rivers with different hydrological regimes (for example, the Czorsztyn-Sromowce Wyżne or the Rożnów-Czchów Reservoirs on the Dunajec River, and the Solina-Myczkowce complex on the San River) is also needed. There are no studies documenting the influence of reservoir water level fluctuations on different elements of the environment, so this is another area requiring further research. A suggested analysis of the dynamics of the level in the Carpathian dam reservoirs, as a factor conditioning the course of many environmental processes, would provide information about how the potential role of water level fluctuations in individual reservoirs shape the surrounding environment.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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Article first received • January 2012
Article accepted • June 2012