IMPACT OF LARGE SCALE HYDRO-PROJECTS ON THE CHANGES OF HYDROLOGICAL REGIME – ILLUSTRATED BY THE EXAMPLE OF THE LOWER VISTULA

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Introduction

Rivers are considered the most common and significant factor in the process of earth surface formation. At the same time they constitute a very sensitive 'organism', which quickly reacts to any form of disturbance (Klimaszewski, 1978). Regardless of the size of the river, its course or climate zone in which it functions, construction of a water barrage constitutes the strongest possible interference in the fluvial system. Development of structures regulating the river course appears to play equally significant role and both these elements cause drastic changes in hydrological phenomena and clastic load transport, which, as a result, may lead to formation of a different channel type.

Important research papers referring to the question of water barrages influence on channel processes, including flow regime below the said barrages, involve the following: research by N. I. Makkaveev (1957) below Rybisk Reservoir, on the Volga, as well as bellow Dnieper Reservoir, on the Dnieper; R. S. Chalov et al. (2001) on the Ob river, below Novosybirsk Reservoir; Z. Babiński (1992, 2002) on the Vistula river, below the Włocławek dam (2000); B. V. Belyj et al. (2000) on the Yenisei river, bellow Sayano–Shushenskaya Reservoir; E. D. Andrews (1986) bellow Flaming Gorge reservoir, on the Green river; M. Kondolf (1997) on Keshweek Reservoir, on the Sacramento river; N. Zdankus and G. Sabas (2006) below the hydro power plant in Kaunas, on the Neman river; X. X. Lu and R. Y. Siew (2006) below Manwan Reservoir, on the Mekong river.

Scope of research

The object under study constitutes a fragment of the lower and estuary reach of the Vistula river, i.e. from Włocławek (675th km) to Tczew (908th km). The lower Vistula concentrates approximately 65% of Vistula's water resources and approximately 30% of Poland's hydro-energetic resources. It displays features of a transit river with complex hydrologic system. Its water regime is predominantly shaped in the upper and, albeit to a smaller extent, the middle part of the basin. The lowland tributaries provide relatively stable flows (Rusak, 1982). High water stages of the lower Vistula occur mostly in March and April, less often in late spring and summer. The former are caused by early-spring meltwater run-off, often intensified by movement of slush and floating ice. The latter, on the other hand, usually short, result from heavy rainfalls. In both cases flood waves occur, having the relative height of 3-5 m (Babiński, 1992), up to maximum 8 m. Lower water stages are observed mainly at the turn of autumn and winter (September – November). The maximum discharge on the lower Vistula took place in March 1924, when it amounted to 8620 $m^{3}\cdot s^{-1}$ in Płock and 8305 $m^{3}\cdot s^{-1}$ in Włocławek. Such discharges have not occurred ever since. The average discharge on the lower Vistula channel, in Toruń, amounts to 1000 $m^{3}\cdot s^{-1}$.

The natural hydrologic regime of the lower Vistula is perturbed by the dam in Włocławek, which has been operating since October 1968. Its influence tends to be most evident in the direct vicinity of the barrage, however, it actually extends over the entire lower and estuary reach of the river.

Materials used

Hydrologic data used for the purpose of this study was provided by, among others, the administrator of the Hydro Power Plant in Włocławek. The data includes prior unpublished statements on the inflow of water to Włocławek Reservoir in the years 1970-2006. Another important source material involves the records on 46 flood waves which were allowed to go through the water barrage in Włocławek in the years 1970-2010. The data on hourly water stages was obtained from Regional Water Management Authority in Warsaw. The records were acquired from a digital limnigraph located at the water barrage lower floodgate in Włocławek. The material covers the period from November 1996 to December 2009. Thanks to the web portal ran by the Institute of 1Meteorology and Water Management - National Research Institute (www.imgw.pl/pogodynka) separate data was gathered from November 2008 to December 2010 concerning discharges and water stages at Włocławek and Toruń gauging stations. Moreover, own gauging stations were installed and separate observations were conducted regarding the hourly changes of water stages.

Results of research

Work regime of the water barrage in Włocławek in the last 40 years can be divided into three characteristic systems of operation:

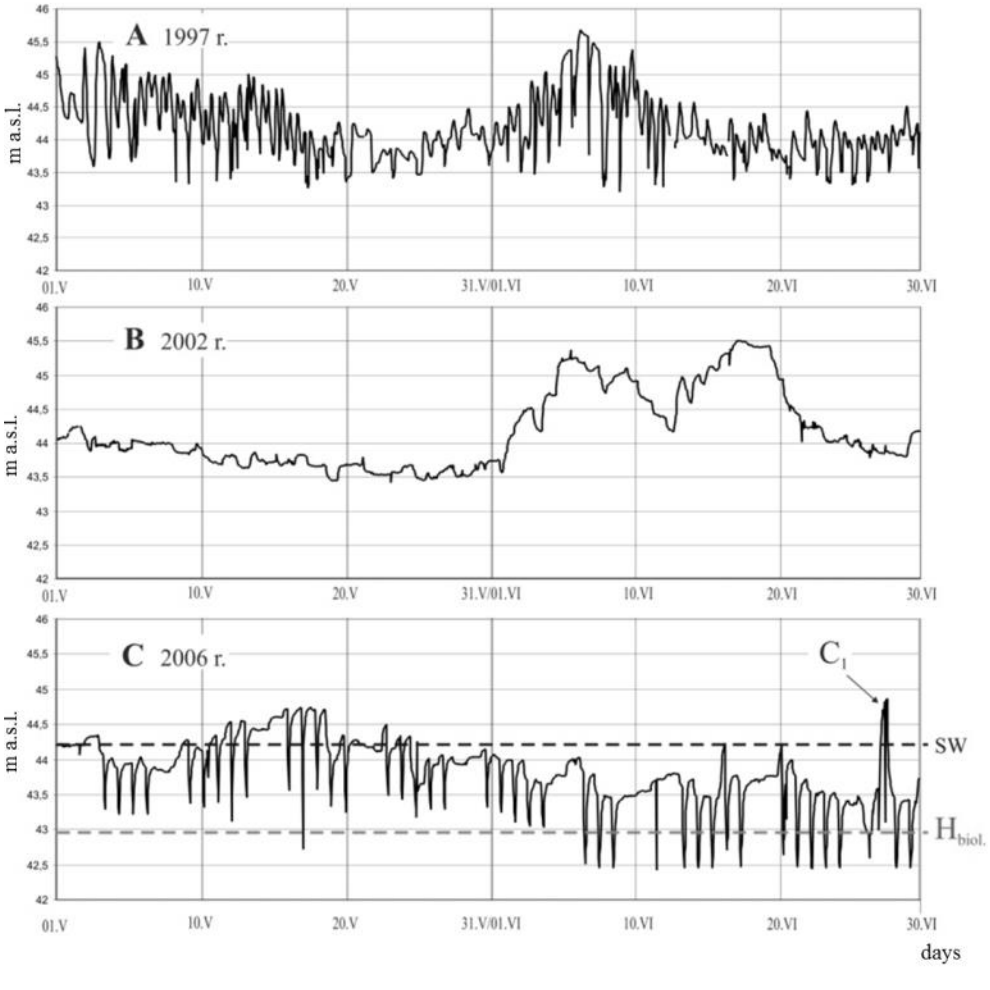
Regime I - from January 1970 to February 2002 the power plant operated at peak-capacity - intervention mode. Such organization of work had great impact on hourly changes of discharge rate (daily fluctuation of water stages) below the dam (pic. 1 - A), daily amplitude of which ranged from 2.0 to 3.0 m (Babiński, 1982). At that time daily fluctuations of water stages were noticeable on the entire reach down to Chełmno. In the Fordon profile (100 km away from the barrage) the changes reached up to 50 cm (Machalewski et al., 1974). The highest rate of amplitude in the range from 0.5 to 2.0 m occurred in the river channel up to 30 km away from the barrage. Farther away the fluctuation gradually minimized. Moreover, due to short breaks between water discharges, waves tended to overlap and made the impact of the dam appear more perceptible at shorter distance.

Regime II - it was assumed that from February 2002 the power plant would work exclusively in constant-flow mode, i.e. the supply of water to Włocławek Reservoir was meant to be equal to the discharge released by the dam (pic. 1 - B) and the minimum acceptable flow was to be maintained at 350 $m^3 \cdot s^{-1}$ (Decyzja..., 2001). However, the provisions stipulated in the new decision were in effect only for half a year. As a result of equalized flow occurrence, the daily amplitudes of water stages fluctuation amounted to average 0.2 m and did not exceed 0.5 m (pic. 1 - B). Such work regime of the power plant was close to the natural hydrologic regime.

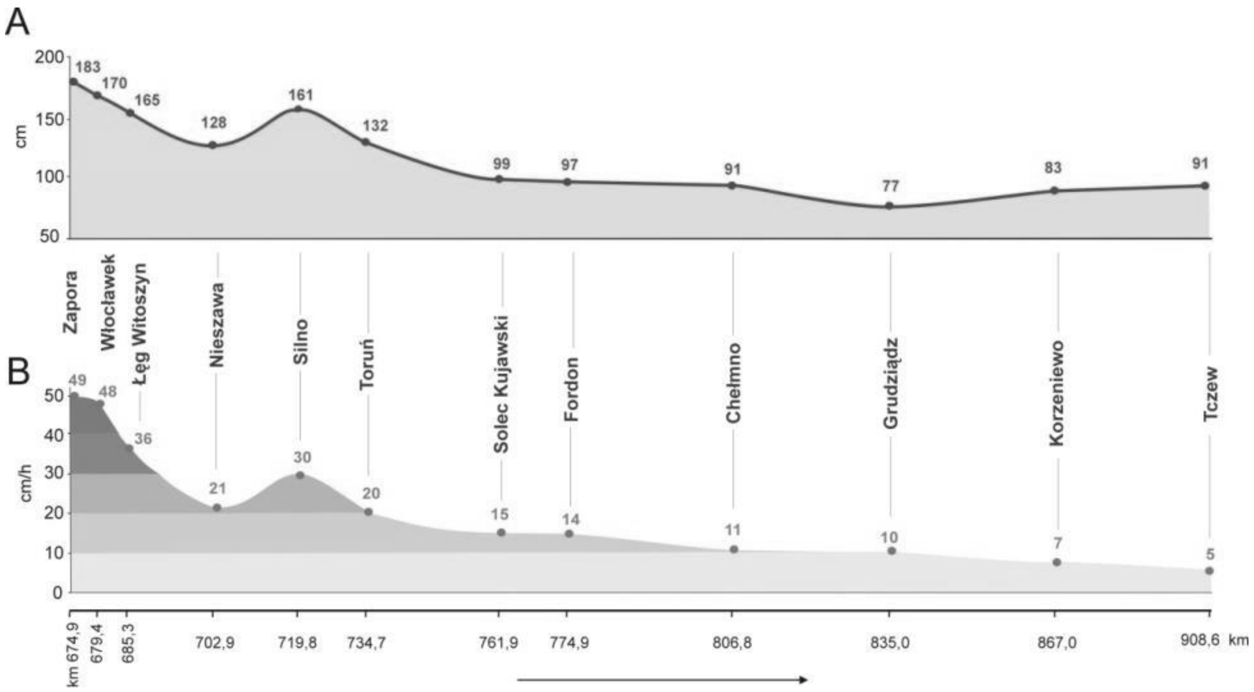
Regime III - from September 2002 a repair system had to be implemented. For approximately 8 hours a day water discharges from the reservoir ceased entirely, i.e. the maintenance of biologic flow stipulated in the permit required by Water Law Act from 2001 was breached. 1 - C). The procedures were carried out on workdays, usually from 8 am to 1 pm, excluding periods of high water supply to the Włocławek Reservoir (Komunikat..., 2007; Komunikat..., 2010). The said mode of operation was implemented in order to carry out maintenance, which included repairs of spillway, sheathing of the check dam that stabilizes the surface of water below the weirs and the power plant, as well as filling the 12 - 17 m deep pools (spot incisions) directly below the stabilizing check dam, which tend to occur after a flood wave flows through. Due to the implementation of the repair-intervention system of work, the daily amplitudes of fluctuation amounted up to 3.0 m (pic. 1 - C). Over 80% of days in a year displayed amplitudes ranging from 0 m to 1.0 m, and approximately 3% - over 2.0 m. Observations indicated that operation of the water barrage during the repairs conducted at the lower station of the dam, which involved limiting the discharge of water from Włocławek Reservoir for approximately 6 hours, resulted in occurrence of water surface fluctuation at the station in Toruń (60 km below) at the amplitude of up to 1.5 m, and in Fordon (100 km below) with an amplitude reaching approximately 7.0

m. Intervention mode of operation at low discharges proved to be particularly adverse for the water environment of the Vistula, since water flow was lower than the biologic one within a long reach of the river. At that time considerable fragments of river bed started to emerge within the bank zone and at the entire width of the channel behind mounds.

From September to the beginning of 2010 over 30 intervention discharges of water were performed from the reservoir to increase the depth of the navigation route for the large-size load transport on the Vistula (pic. 1 – C -C_1). At the reach between Włocławek and Silno (distance of approximately 45 km) navigation with large vessels at the discharges lower than 800 $m^{3}\cdot s^{-1}$ is rendered impossible (due to bed thresholds uncovered by erosion). "Instruction for water management at the water barrage in Włocławek" from 2006 stipulates that such large spills may be performed only when the discharge from the hydro power plant maintains intensity of 1170 $m^{3}\cdot s^{-1}$, and the spill may last no longer than 12 hours. The capacity of water discharged in such situations (as an artificial small flood wave) was to be approximately 30 mln m^3 (7.4% of total capacity or 56.6% of reservoir's useful capacity). Before the scheduled discharge, water in the reservoir was meant to be retained for the period of 2 to 7 days.



Pic. 1. Example hydrograms of the course of hourly water stages below the dam in Włocławk, illustrating three different operation regimes of the barrage: A – peak-capacity–intervention mode; B - constant flow mode; C – repair-intervention mode; C_1 – water supply to the lower reach of the Vistula channel by the alimentation wave for the purpose of navigation (compilation based on the data obtained from a digital limnigraph RZGW Warsaw - Inspectorate in Włocławek); SW - mean water level from the period of many years; H_{biol}. - water level corresponding to the minimum acceptable flow of 350 $m^{3}\cdot s^{-1}$ - Decyzja..., 2001).



Pic. 2. Course of the selected parameters of the wave supplying the channel in the longitudinal profile of the lower Vistula (June 25th - 28th, 2007). A - elevation height of the wave in cm, B - maximum value of water level fluctuation in cm·h^{-1}.

So far a claim has been maintained that when the dam begun to operate the daily fluctuation of water stages caused by the operation of Włocławek power plant occurred on a 200 km-long reach down the river (Machalewski i in., 1974). The experiment conducted in June, July, September and October 2007 revealed that the actual impact range of dam operation greatly exceeded 200 km. Hourly changes in the level of water surface were observed at 12 gauging stations located at the reach between Włocławek and Tczew during the intervention discharge of water performed to allow for the transport of a tanker from the river shipyard in Płock to Gdańsk.

Data analysis showed that the elevation of the supply wave (the height of the wave) did not exceed bank water level at any of the stations and ranged from the maximum of 183 cm in Włocławek to the minimum of 77 cm in Grudziądz (160.1 km below the dam). In Tczew, 234 km below the barrage, the culmination amounted to 91 cm (pic. 2 - A). Local modifying factors clearly influenced the course and shape of the wave. The said factors include (among others): possible channel and valley retention, hydrotechnical structures, accumulation of channel sand formations. For that reason the elevation of the wave, instead of decreasing along the course of the lower Vistula, increased in the measurement profile of Silno, Korzeniewo and Tczew in comparison to the higher located reaches (pic. 2 - A).

The maximum recorded hourly fluctuation of water level at the stage of increase amounted to 49 cm·h^{-1} in the dam profile and 48 cm·h^{-1} in Włocławek. It decreased to 21 cm·h^{-1} in Niszawa. Then again increased to 30 cm·h^{-1} in Silno and decreased back to 20 cm·h^{-1}in Toruń. Further down the river the value did not exceed 20 cm·h^{-1} and it amounted to only 5 cm·h^{-1} in Tczew (pic. 2 - B). Observation of the consecutive three supply waves, which occurred in 2007 on July 22nd, September 23rd and October 14th, showed that propagation of the waves, and the value of hourly water stages fluctuation in particular, was considerably influenced by the initial filling ratio of the Vistula channel (immediately before the water discharge from Włocławek Reservoir). Observation of four different waves allowed to formulate a conclusion that the impact range of power plant operation on the hydrologic conditions depends on the extent to which the channel is filled with water. The higher are the water stages, the shorter is the distance at which fluctuation occurs.

Summary and conclusions

While assessing the influence of the dam in Włocławke on the water stages regime of the Vistula river one may assume that during low discharges the largest hourly fluctuations of water stages occur on the reach between the dam and Toruń (distance of 60 km) and range from 49 to 20 $cm \cdot h^{-1}$. Taking into consideration that for the natural course of a large river fluctuation of water stages does not exceed 10 $cm \cdot h^{-1}$ (Zdankus, Sabas, 2006), it can be assumed that fluctuations lower than the said value are observable only below that reach, in Korzeniewo and Tczew (i.e. over 160 km below the dam). The maximum hourly fluctuation at these stations amounted to 7 and 5 $cm \cdot h^{-1}$ respectively. However, at the farthest located station (Tczew) daily fluctuation of water stages reached over 80 cm, while elevation of the alimentation wave amounted to 91 cm. On this basis one may assume that the impact of dam operation in Włocławek on the course of hydrologic conditions, such as hourly fluctuation of water stages, extends to over 160 km long reach down the river, while its range of influence on daily changes covers over 230 km.

In May 2007 the new repair-intervention regime of Włocławek dam operation caused ecological catastrophe on the lower Vistula. After supplying the channel for the purpose of navigation it took an hour to replenish the deficiency of useful capacity in Włocławek Reservoir. In order to achieve it, the level of water below the dam was lowered to the level of biological flow. Additionally, discharge was ceased for approximately six hours (due to planned maintenance works on the check dam stabilizing the lower weirs and the power plant). Overlapping of these two factors caused considerable lowering of the water stages on the reach between Włocławek and Grudziądz, which lasted approximately 10 hours. All aspects combined resulted in great fish and molluscs mortality (photo 1).

Photo 1. Employee of a company extracting gravel from the river in Fordon - Bydgoszcz (100 km below the dam) helping molluscs to return to water - May 2007. Molluscs were aground due to the lowering of water flow at the dam in Włocławek to the value below biological flow (photo from Nowości Toruńskie journal).

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