The Jeziorsko Reservoir and its Operation under Flood Conditions in 2010

Tomasz Kałuża
Ireneusz Laks

Flood risk and flooding in the Warta River valley have sparked off an intense debate on the role of the Jeziorsko reservoir in flood protection and shaping of flood water flow conditions downstream of the reservoir. This paper is concerned with the analysis of the Jeziorsko reservoir operation during the advance of a flood wave on the Warta River in May 2010. Analysed are both the factors underlying the reservoir operating scenario being currently in force as well as the impact of possible lowering of the NPP (normal supply level). The chances of finding a more optimal solution are also discussed.

Keywords: Jeziorsko reservoir, flood wave, water management, Warta River

1 Introduction

The flood surge on the Warta River in May 2010 was the third biggest surge since 1947 in terms of water levels and the biggest amongst rainfall surges occurring during this period. River levels have distinctly exceeded both the alarm levels and the long-term high water averages. As regards the surge duration, the phenomenon was a very swift one – only 19 days have elapsed from the peak at the first water-level gauge in Kręciwilk on May 18th till the peak at the Kostrzyn station on the Odra River on June 7th.

Flood risk and flooding in the Warta River valley have sparked off an intense debate on the role of the Jeziorsko reservoir in flood protection and shaping of flood water flow conditions downstream of the reservoir. One of the postulates was that the normal supply level (NPP) should be decreased by 0,5 m and that the reservoir permanent flood reserve should increase. The lowering of the NPP at Jeziorsko would translate to considerable fall in the reservoir useful capacity. If NPP drops down to 120.00 m ASL, the reservoir useful capacity will fall by almost 20 hm3. This paper is concerned with the analysis of the Jeziorsko reservoir operation during the advance of a flood wave on the Warta River in May

2010. Analysed are both the factors underlying the reservoir operating scenario being currently in force as well as the impact of possible lowering of the NPP. The chances of finding a more optimal solution are also discussed.

2 Water management in the Jeziorsko reservoir

2.1 General hydrological data

The Warta River, in western Poland, is the largest tributary of the Oder, which forms part of the boundary between Poland and Germany (Fig. 1). The Warta is Poland's third largest river after the Oder and the Vistula (*Blomquist et al., 2005*). The river flows north from its headwaters in the mountains of southern Poland, then west to the Oder, and is 808.2 km in length. The Warta River basin's 55,193 km^2 area covers approximately one-sixth of Poland.

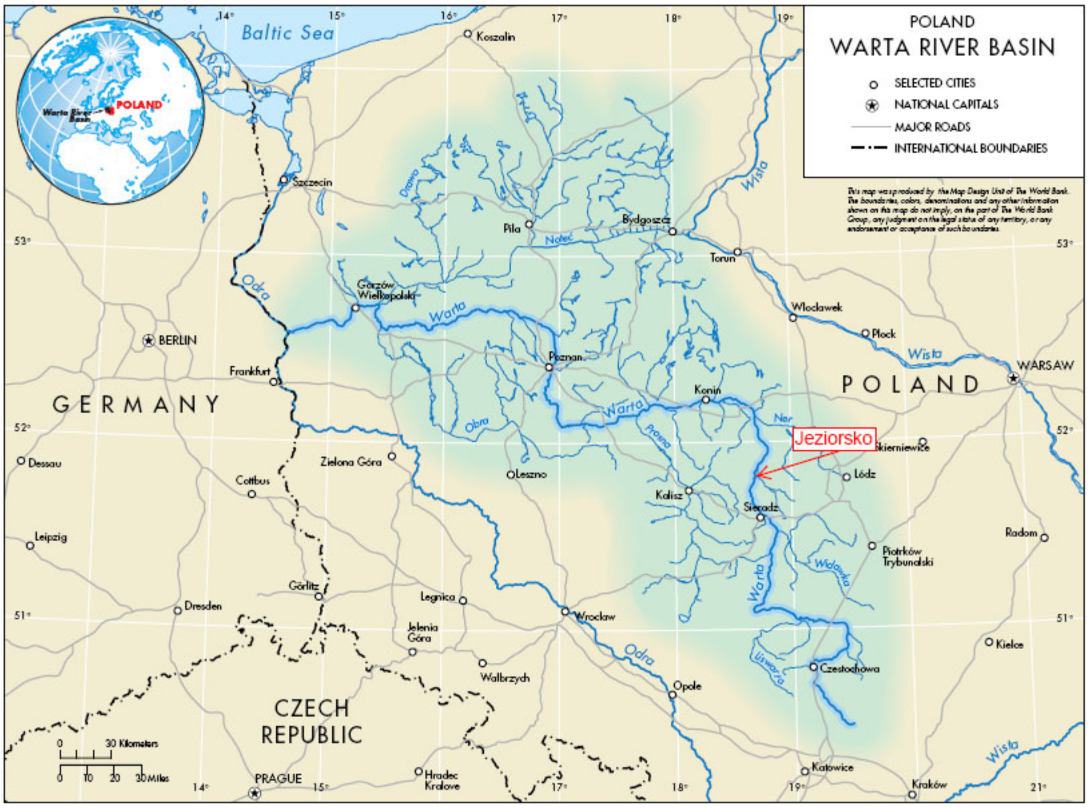

Figure 1: Warta River basin with location of the Jeziorsko reservoir (*Blomquist et al., 2005*)

In the Warta River basin, the most significant reservoir in the basin are Jeziorsko. The Jeziorsko reservoir, completed in 1986, is located closer to the middle of the main stem of the Warta. It was built chiefly for protecting Konin and

Poznan against floods, but also provides electricity, some habitat protection, and supplemental water for drought periods (*Penczak et al., 1998*). The reservoir flooding area encompasses a section of the Warta River reaching from km 484.3 (front dam), to km 503.7. The Warta River catchment area at the front dam section is 9012.6 km^2.

2.2 Role of the Jeziorsko reservoir

The Jeziorsko is a multifunctional reservoir intended for water storage and damming (*Water Management Instructions,* 2008). Its principal tasks include:

- reduction of flood risk in the Warta River valley downstream of the reservoir through attenuation of flood surges,
- shaping of water resources in the river valley by influencing current flow values on the Warta River and controlling the flow within the low and high levels, as a water management measure in the Warta River valley downstream of the reservoir.

Tabelle 1 Summary of basic currently applicable water supply levels, capacities and flooding surfaces (*Water Management Instructions* 2008)

Water levels	Elevation	Full capacity	Reservoir surface
	[m. ASL]	[10^6 m^3]	[km^2]
Normal supply level (NPP)	120.50	162.29	35.54
Maximum supply level (Max PP)	121.50	202.04	36.65
Extraordinary supply level (Nad PP)	122.00	222.55	37.73
Minimum supply level (Min PP)	116.00	28.93	16.45

2.3 Jeziorsko reservoir water management framework

Water management in the Jeziorsko Reservoir is based on its framework management plan, analyses of usage of its water resources and issues concerning its filling up and emptying. In view of conditions required for safe usage of earth dams, the following speed limits of water table rising and lowering have been put in place for the reservoir under normal operating conditions:

- 30 cm / 24 hours – when rising the water table in the reservoir
- 20 cm / 24 hours - when lowering the water table in the reservoir

Departures from these rules are allowed only under flood conditions and following a written consent by the head of the RZGW (Regional Water Management Authority) in Poznań.

3 Model of reservoir retention

In order to analyse the impact of changes in the Jeziorsko Reservoir flood reserve onto the transformation of flood waves, a mathematical model has been developed. The model is based on the reservoir retention equation. The increase (in time) of retention in the reservoir can be written as follows:

$$\frac{dV^k}{dt} = \sum_{j=1}^{m_k} Q_{dop}^j(t) - Q_{odp}^j(t) \qquad (1)$$

Thus, the reservoir retention equation is:

$$V^k(t) = \int_{t_p}^{t_k} \sum_{j=1}^{m_k} (Q_{dop}^j(t) - Q_{odp}^j(t))dt + V^k(t_p) \qquad (2)$$

where Q_{dop} denotes the inflow to the reservoir, Q_{odp} is the outflow and t_p and t_k are the simulation starting and ending time, respectively. During calculations it is often assumed that the integrand is constant over time step and that equation (2) is integrated numerically. In order to compute the water table elevation in the reservoir, parameters must be defined for the reservoir filling up curve $V^k(H_z)$.

Given the reservoir inflow hydrograph, it is possible to obtain the outflow hydrograph by means of an appropriately formulated optimization problem. The problem for the Jeziorsko Reservoir is formulated as follows:

- the objective function is the minimum value of the area between the inflow and outflow hydrographs,
- the reservoir may be filled up (or emptied) to certain elevations which determine the flood reserve volume or the alimentation volume for low water periods,
- the 24-hour rise or fall of water level in the reservoir cannot exceed the limits specified in the operating instruction of the reservoir.

For the so defined objective function and constraints outlined above an optimal outflow hydrograph can be obtained (optimal in terms of the assumed criteria). The optimization problem is strongly non-linear and numerical methods are required to solve it. Calculations presented below were carried out using the steepest descent algorithm (method). Steepest descent is a first-order gradient method. In this method the approximating sequence $Q_{odp}^{(k)}$ is generated using a superposition of two maps i.e. first a search direction is selected and next a point $Q_{odp}^{(k+1)}$ is chosen which minimizes the function along the direction of the selected search vector.

Using the reservoir retention model described above research has been carried out on the operating conditions in the Jeziorsko Reservoir in the course of flood wave passage in 2010 (Fig. 2).

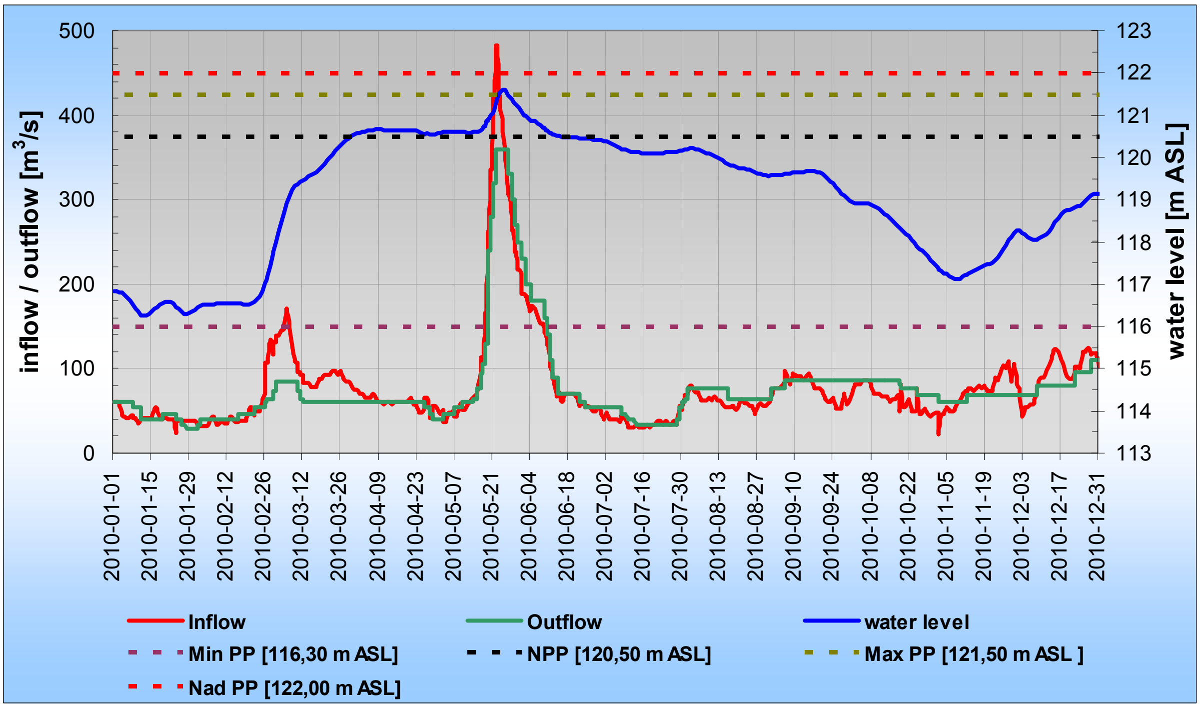

Figure 2: Water inflow and outflow hydrographs and water level in the Jeziorsko reservoir in 2010

The analysis was performed for the period of flood wave passage through the reservoir (from 05.05.2010 to 29.05.2010). Research was done for three NPP values: 120.50 m ASL, 120.30 m ASL and 120.00 m ASL (Fig. 3).

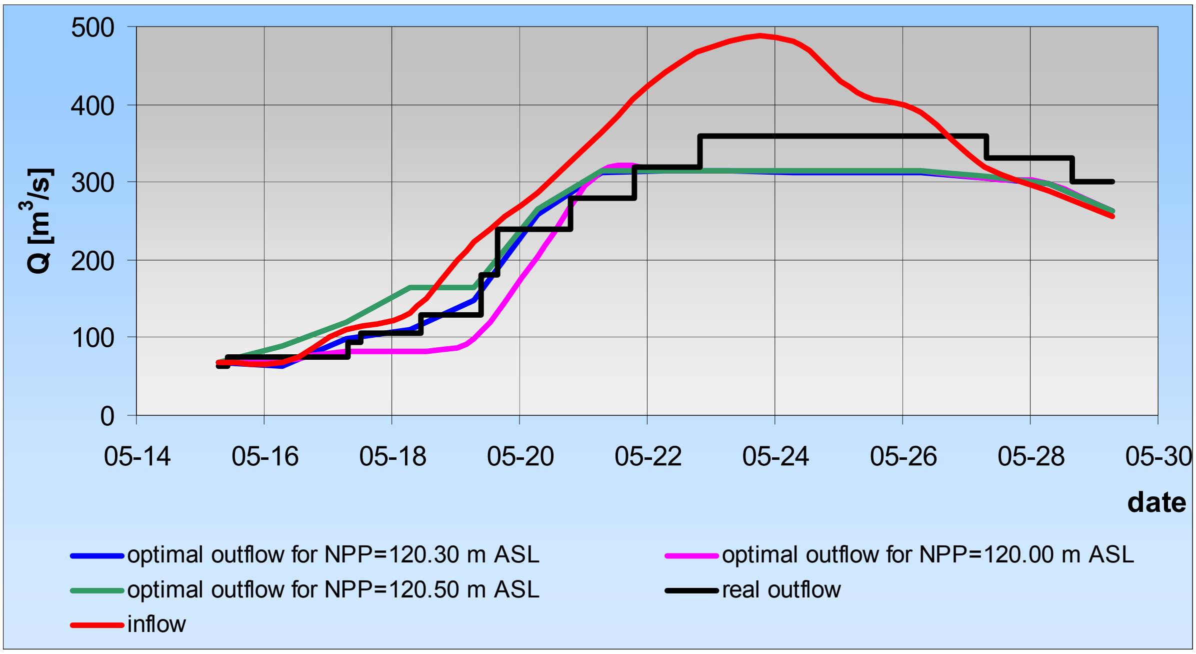

Figure 3: Water inflow and outflow hydrographs for the Jeziorsko Reservoir in the course of flood wave passage in 2010 with optimal discharge hydrographs for assumed values of NPP

Table 2 presents computational results. These results are obtained under the assumption of maximum discharge from the reservoir of 315 m^3/s and the flood wave being consequently reduced to 167 m^3/s. The maximum discharge is determined as a result of a multi-criteria optimization process with imposed operating conditions of the reservoir. Analysis of table 5 yields that lower NPP (storage level of the reservoir) leads to higher flood reserve volume. The prepared reserve for such conditions is zero (for water level of 120.60 m ASL the reserve can be as high as 7.3 hm^3). The prepared reserve results from increased discharge before the arrival of flood wave. This, in turn, is related to the accuracy of inflow forecast for the reservoir. Based on computational results of simulated reservoir operation during the advance of the 2010 flood wave in the Jeziorsko Reservoir for various values of NPP, the number of days with maximum discharge was also determined. For water level of 120.60 m ASL there are 6 such days, whereas for 120.30 m ASL there are only 3 such days.

It should be emphasised that optimal hydrographs of discharge from the reservoir for the 2010 flood wave could be obtained only with the assumption of full knowledge of inflow hydrograph for the whole time interval. These hydrographs should not be directly compared to the real-time ongoing discharge hydrograph which was calculated with considerable uncertainty of inflow forecast. For NPP = 120.50 m ASL the number of days with maximum discharge calculated for the optimal hydrograph clearly indicates the necessity of having a reliable, long-term forecast of inflow (for at least 6 days ahead). If the flood reserve is increased and NPP = 120.30 m ASL, the forecast can be shortened to 3 days, which is more realistic.

Tabelle 2 Computational results of simulated reservoir operation during the advance of the 2010 flood wave in the Jeziorsko Reservoir for various values of NPP

Flood reserve [hm^3]	Water level in the reservoir [m ASL]	Prepared reserve [hm^3]	Number of days of maximum discharge
35.8	120.60	7.3	6
39.7	120.50	2.9	6
43.6	120.40	1.2	5
47.6	120.30	0.0	3
51.4	120.20	0.0	3

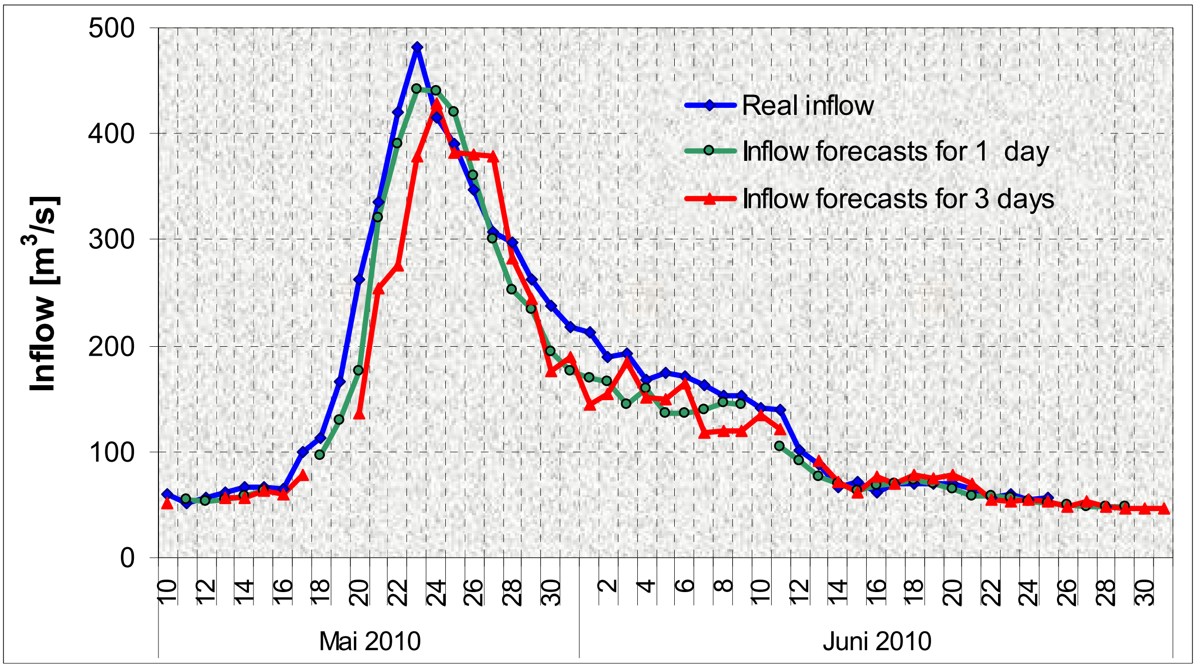

Figure 4: Inflow and outflow values for the Jeziorsko Reservoir in 2010 compared to the inflow forecast

When analysing the situation back in 2010 we can see that the real inflow forecasts inflow forecasts (for 1 and 3 days ahead) for the reservoir have considerably diverged from real inflow values (Fig. 4). This was particularly the case for the 3-day forecast. The maximum difference in flow rate was almost 80 m^3/s and the discrepancy between the real and forecast peak time was one day. Understandably, the 1-day forecast was much more accurate but even here the discrepancy for the peak flow rate values was as much as 50 m^3/s.

4 Investigation of flow conditions on the Warta River section Jeziorsko – Poznań

The analysis of flow conditions on the Warta River section from the Jeziorsko Reservoir to Poznań was carried out using a one-dimensional analysis and forecasting system for unsteady flows, the SPRuNeR (*Wosiewicz et al., 1996*). The programme is based on the Saint-Venant equations. Motion is considered to be one-dimensional. The unknowns are elevation and flow rates. For each time step a nonlinear system of equations, which takes into account both the hydrotechnical structures and the boundary conditions, is solved iteratively.

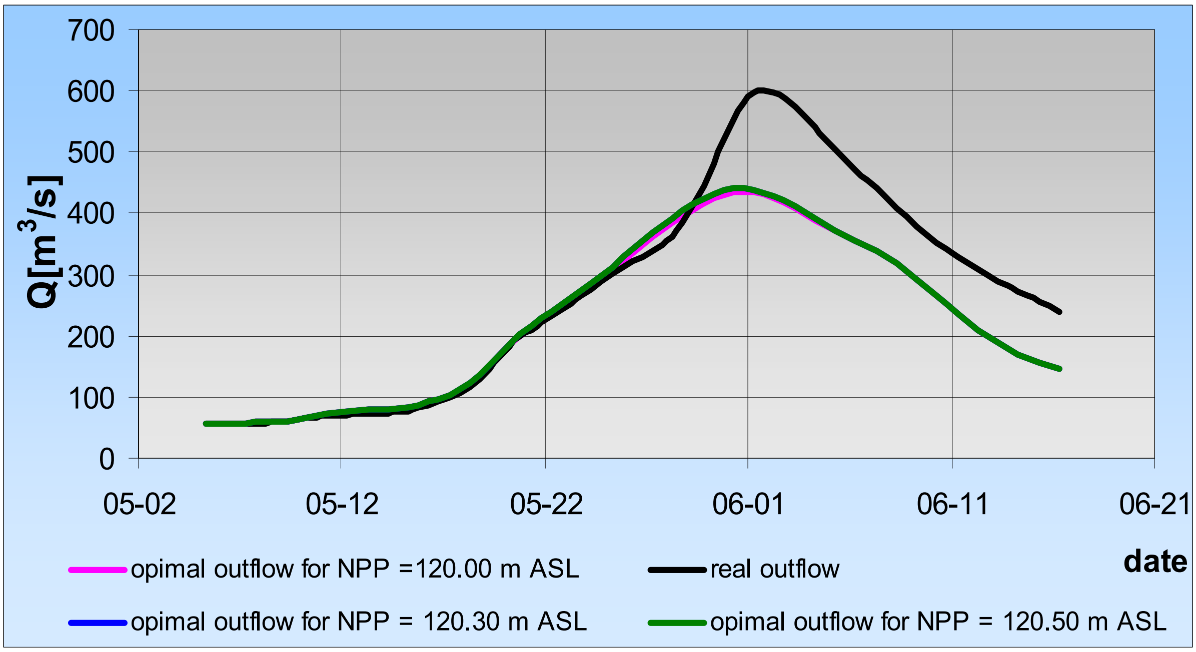

Figure 5: Flow hydrographs for real and optimized discharge calculated for the 2010 flood wave for various NPP variants at the water-level gauge cross-section in Poznań

The computational model for the Warta River section from the Jeziorsko front dam to Oborniki included 201 cross-sections and 204 computational intervals. The model eliminated any influence of boundary conditions onto the Warta section under study. In what concerns the analysis of flood wave passage, the hydrographs of water discharge from the Jeziorsko Reservoir provided by the RZGW Poznań as well as optimized discharges from the reservoir for various NPP values were assumed as the upper boundary conditions (Fig. 3). The principal tributaries of the Jeziorsko – Poznań section were also taken into account. The analysis of computational results in the form of water level and flow hydrographs for individual water gauge cross-sections was limited to the cross-section in Poznań (Fig. 5). Lastly, the roughness coefficients were determined based on aerial photographic analysis and then modified in a calibration process, which involved flood wave data from 1997.

From the analysis of flow hydrograph for real and optimized water discharge calculated for the 2010 flood wave for various NPP variants at the water-level gauge cross-section in Poznań, it appears that the flood wave peak discharge can be reduced by as much as 155 m^3/s. The resulting maximum flow rate in Poznań for real discharge was 601 m^3/s. The differences between individual NPP variants were not significant (Table 3).

Tabelle 3 Summary of calculated maximum flow rates for various NPP variants at the water-level gauge cross-section in Poznań

NPP variants [m ASL]	Maximum flow rate [m^3/s]
120.00	433.38
120.30	440.30
120.50	446.83

5 Summary

The research presented in this paper demonstrates that the principal factors to attenuate flood waves downstream of the investigated reservoir are the speeds of water table rising/lowering in the reservoir. Even if the flood reserve is bigger, the coefficient of maximum flow rate reduction (flood wave transformation) cannot be significantly increased, which is largely decisive for the course of flood downstream of the reservoir.

In contrast to real hydrographs, the obtained optimal discharge hydrographs for flood waves demonstrate that reliable and accurate long-term inflow forecasts are crucial for correct water management of the reservoir. Such forecasts are usually based on a well developed monitoring and hydro-meteorological protection system of the reservoir. With no efficient monitoring and forecasting of inflows to the reservoir under real conditions, discharge hydrographs resembling the optimal hydrographs cannot be achieved. Moreover, based on the performed analyses, the reduction of NPP down to 120.00 m ASL appears pointless. It turns out that under flood flow conditions a more optimal elevation value is 120.30 m ASL.

6 References

Blomquist, W. Tonderski, A. Dinar, A. (2005): Institional and policy analysis of river basin management, The Warta River Basin, Poland. World Bank Policy Research Working Paper 3528, February 2005

Penczak, T. Glowacki, L. Galicka, W. Koszalinski, H. (1998): A Long-Term Study (1985-1995) of Fish Populations in the Impounded Warta River, Poland. Hydrobiologia 368 (1-3):157-173

Water Management Instructions: The “Jeziorsko” Reservoir on the Warta River. (2008): BSiPBW Hydroprojekt Poznań 2008

Wosiewicz, B. Laks, I. Sroka, Z. (1996): Computer system of flow simulation for the Warta river, Prace Naukowe Instytutu Geotechniki i Hydromechaniki Politechniki Wrocławskiej, seria Konferencje 38, Wrocław

Authors:

Assoc. Eng. Tomasz Kałuża

Department of Hydraulic and Sanitary Engineering
Poznań University of Life Sciences
ul. Piątkowska 94A
60-649 Poznań
Poland

Tel.: +48 61 848 77 27
Fax: +48 61 848 77 26
E-Mail: tomasz.kaluza99@gmail.com

Dr. Eng. Ireneusz Laks

Department of mechanics and construction of agricultural buildings
Poznań University of Life Sciences
ul. Piątkowska 94A
60-649 Poznań
Poland

Tel.: +48 61 846 64 10
Fax: +48 61 846 64 02
E-Mail: ilaks@up.poznan.pl