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MODELLING AND EFFECT ASSESSMENT OF FLOOD WAVE CAUSED BY SMUKAŁA RESERVOIR DAM BREAK, RIVER BRDA, KM 21+500÷14+800

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Abstract: Modelling the effects of hydraulic catastrophe of a dam consists in determining the initial conditions of the flood wave in the section of the dam and controlling the flow on the hydraulic structures in the river valley. In the solution of the problem, the following factors are of a special importance: the shape and gradient of the river valley, technical housing, the cover of plants and the assumed scenario of the catastrophe. The results of the model research on the River Brda, obtained on the basis of hydraulic calculation with HEC-RAS program, have been presented.

Streszczenie: Modelowanie skutków hydraulicznych katastrofy zapory sprowadza się do określenia warunków początkowych propagacji fali wezbraniowej w przekroju zapory oraz sterowania przepływem na budowlach hydrotechnicznych w dolinie rzeki. Wpływ na rozwiązanie problemu mają takie czynniki jak: ukształtowanie i spadek doliny rzeki, zabudowa techniczna, porost roślinny oraz przyjęty scenariusz katastrofy. Przedstawiono wyniki badań modelowych na rzece Brdzie, otrzymane na podstawie obliczeń hydraulicznych za pomocą programu HEC-RAS.

Резюме: Моделирование гидравлических последствий катастрофы плотины заключается в определении исходных условий распространения набухающей волны в сечении плотины, а также в управлении течением на гидротехнических постройках в долине реки. На решение вопроса влияют такие факторы, как: конфигурация и уклон долины реки, техническая застройка, флора, а также принятый сценарий катастрофы. Представлены результаты модельных исследований на реке Брда, полученные на основе гидравлических расчетов с использованием программы HEC-RAS.

1. INTRODUCTION

New hydraulic structures constructed on Brda river have changed flow conditions of potential flood caused by water releases from Smukała reservoir (Brda river, 21+500 km). That makes it necessary to estimate a new emergency reaction time for the housing estate on the left site of the river above the newly projected Czyżkówko weir. Information on the flood wave velocity and its reach is essential to the choice of an effective method of the protection of the endangered sites.

Threat forecasting is not a simple task because it is difficult to imagine a disaster scenario, and acknowledge that this is a likely event. That means we should be prepared for something we subconsciously do not allow to happen and do not accept. But dam disasters do occur and one of their main reason is the erosion of embankment

[11]. A flood wave leaving dam breach travels at high velocity bringing damage to the river terraces.

The purpose of the analysis is justification for a given scenario based on model tests. Both the disaster scenario and the choice of parameters describing a dam embankment are subjective. Given the experience in this field [1]–[4], [6], [10] the Smukała dam break mechanisms and the duration were estimated on the basis of statistical description parameters that have been identified as a result of the analysis of historical dam disasters.

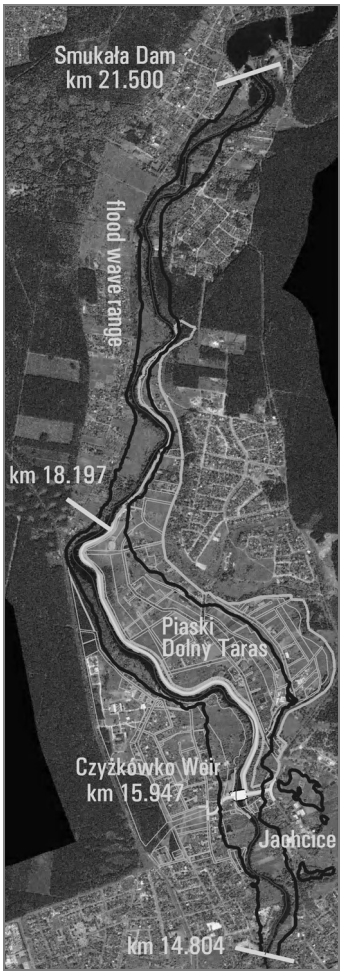


Fig. 1. The Brda River valley below the Smukała dam. Localization the Piaski – Dolny Taras housing and catastrophic flow areas

The scope includes the development of hydraulic calculation of flood wave propagation in the Brda river valley – in present conditions and after Czyżkówko weir construction in 15+947 km. The construction will cover a section of the river reach of a length of 5.6 kilometers. In order to prevent the flow on a low left terrace of the valley construction of a lateral dam is planed (km 15+950 ÷ 18+290) (Fig. 1). Terrain model was built based on a digital map [7], and a DTM data [8] of Piaski – Dolny Taras housing in Bydgoszcz. River model was constructed based on cross-sections taken for the sake of Czyżkówko weir design. The Smukała dam technical parameters have been provided by the ZEW Koronowo.

Hydraulic calculations have been made using a computer program HEC-RAS [5], provided for general use by the USACE (U.S. Army Corps of Engineers). Documentation and executables can be downloaded from the web server at www.hec.usace.army.mil. The program allows to analyze unsteady flows by solving the Saint Venant equations. The derivation of these equations is based on "Unsteady Flow in Open Channels" [9] by James A. Liggett.

Version 4.0 of HEC-RAS, released in March 2008, includes new modeling capabilities for gates at hydraulic structures, which proved to be useful in this case. A gate opening height can be related to any of the flow parameters at any point of the model. That flow parameter could be an upstream water level at the hydraulic

structure or at the flow gauge situated several miles away or a flow discharge in one of the tributaries. There are special editors for entering the rules for gate opening height. Initial state of the opening, conditions under which the gate starts to move and the rate of opening changes can be defined. An example of the gate opening data is presented on Figure 2.

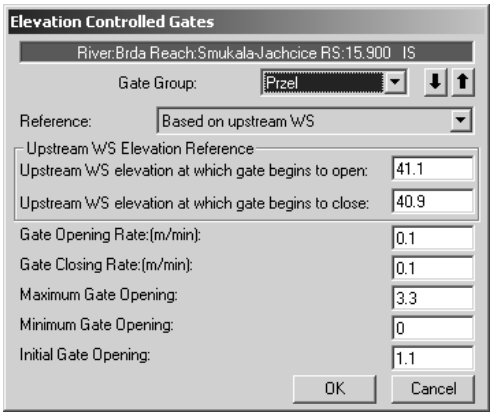


Fig. 2. Example of the gates opening height data editor in the HEC-RAS

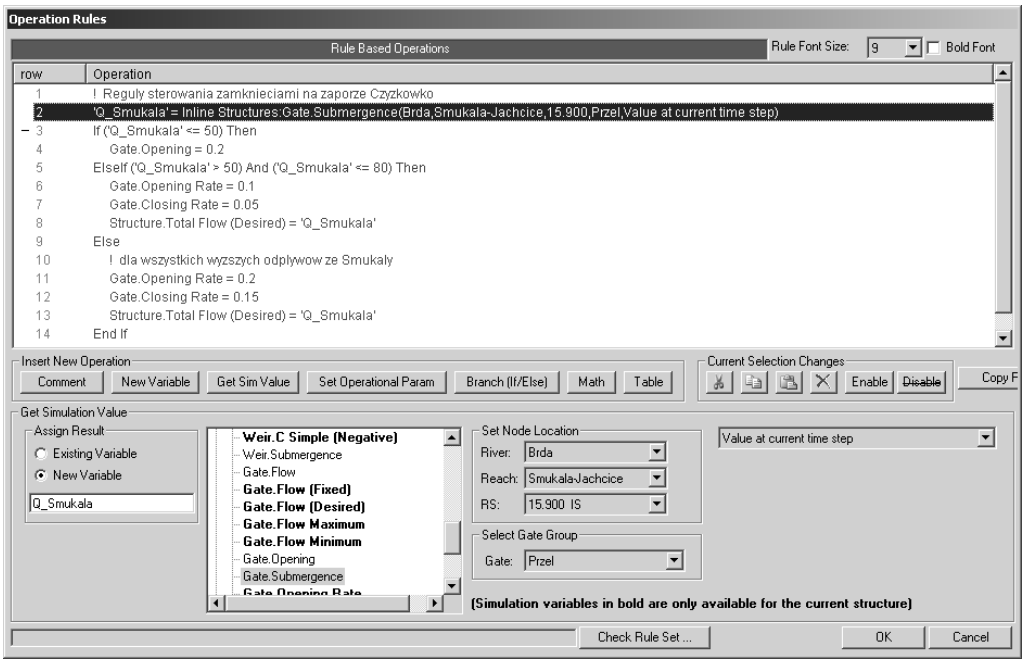


Fig. 3. Gates opening rules editor in the HEC-RAS

In more complex operations one can use an advanced editor where any of the flow parameters can be accessed at any point of the model (Fig. 3). Using the "if-then" procedure gate opening rules of high degree of complexity can be defined.

2. PROPAGATION OF A FLOOD WAVE

Two dam embankment failure mechanisms are taken into account: breach developing due to flow over the dam crest and piping caused by the filtration through the dam core. The piping is considered to occur during normal reservoir operation, when the water level does not rise above the allowed maximum. In case of overflow the condition required for the creation of the breach is the upstream water level exceeding the dam crest level. The breach developing time can last from several minutes to several hours, depending on the height, type of the construction, the soil used and the technical condition of the embankment.

Breach outflow hydrograph is based on a linear progression kinematic model. Breach width and time of its developing were calculated with various formulae and presented in Table 1. Additionally, the development of the breach was simulated using commercial BOSS-BREACH computer program, in which geotechnical parameters of the embankment soil are taken into account.

Table 1

Comparison of width and breach time creation calculated with various methods

Method	Average width of breach – B [m]	Time of breach creation – t [h]
Bureau of Reclamation [1]	29	0.31
MacDonald and Langridge-Monopolis [6]	48	0.49
Von Thun and Gillette [10]	42	0.14
Froehlich [4]	48	0.97
FERC [2] MIN	19	0.10
FERC [2] MAX	38	1.00
BREACH [3]	28	0.50
Summary		
Minimal value	19	0.10
Average value	36	0.50
Maximal value	48	1.00

Finally, following kinematic model parameters were assumed:

- $B = 36$ m, $t = 0.5$ h for overtopping,
- $B = 34$ m, $t = 0.5$ h [4] for piping.

The breach discharge is influenced by the downstream conditions which in turn depend on flow conditions on the hole river reach from Smukała reservoir to

Czyżkówko weir. The following assumptions are made for simulations of the wave leaving the breach. Breach starts to develop at time $t = 0$ h. On the hole river reach, from Smukała dam to Czyżkówko weir, an uniform flow $Q = 52.5$ m^3/s exists (a 50% event for the Smukała dam). The top of a wooden watertight bulkhead (42.0 m above sea level) is the maximum breach erosion level.

During the overtopping all other weir gates are completely open; reservoir water level reaches the dam crest and the inflow to the reservoir is 149 m^3/s (a 0.02% event).

In case of piping, reservoir water level is at its normal, weir gates are all closed (only small sluice gate or the power plant turbines operate) and the inflow to the reservoir is 52.5 m^3/s (a 50% event).

Simulation results for both disaster mechanisms are presented below in the form of hydrographs and tables for four characteristic cross sections: Smukała dam (km 21+500), Piaski – Dolny Taras housing estate at the end of lateral Czyżówko dam (km 18+197), Czyżówko weir (15+947) and Jachcice housing estate (14+804).

First of all, simulation of Smukała dam break for the present conditions was performed (without Czyżkówko weir). The purpose of these calculations was to obtain material for comparative analysis of the impact of the proposed Czyżkówko weir on flood wave transformation conditions. Next, operating conditions of Czyżkówko weir were determined. In addition to the general assumptions, in the following simulations it is assumed that the Czyżkówko weir has three flap gates of total span of 21 m. The initial upstream water level at Czyżkówko weir is assumed as a normal operational level – 41.00 m above sea level. Simulations were made for the following scenarios of Czyżkówko weir gates operation:

1) flap gates kept up in fully raised position (results marked with symbol ZZ),

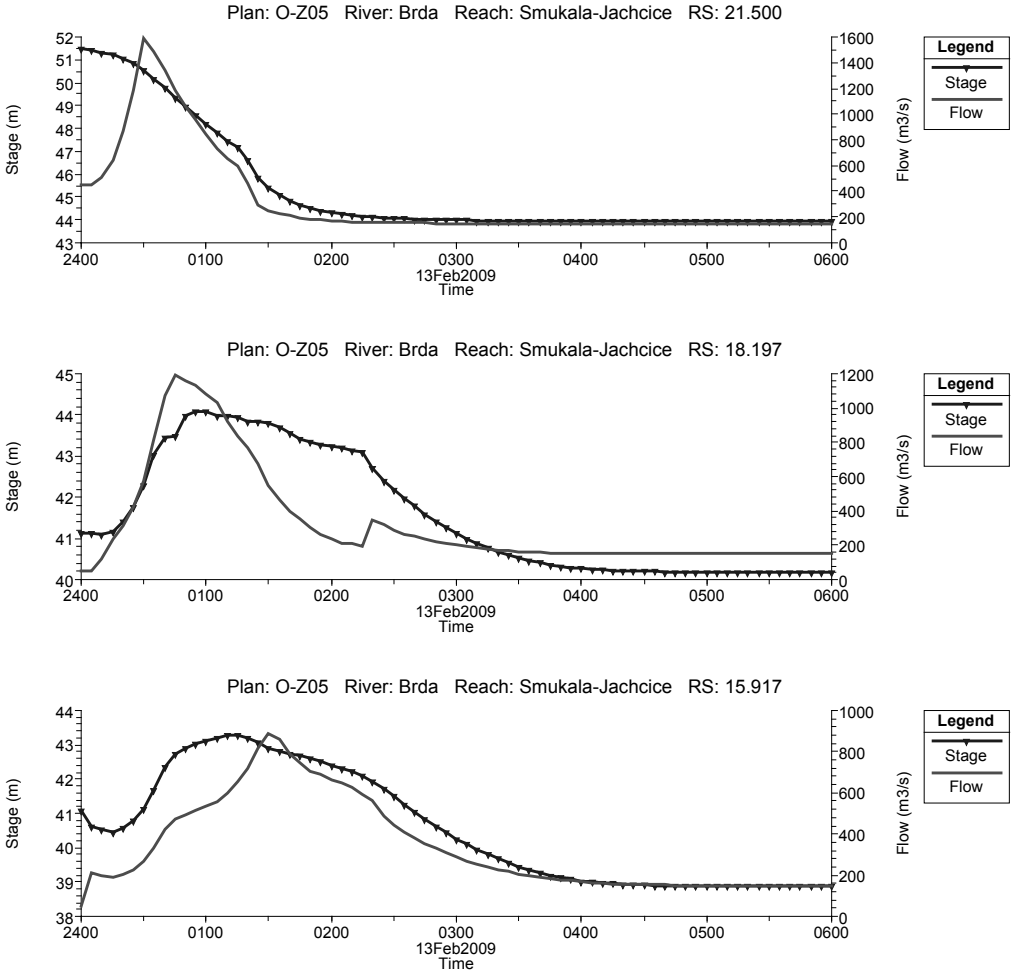
2) flap gates gradually lowered to reach the lowest position after 30 minutes from the beginning of the simulation (Z30),

3) flap gates gradually lowered to reach the lowest position after 5 minutes from the beginning of the simulation (Z05),

4) flap gates kept fully lowered (ZO),

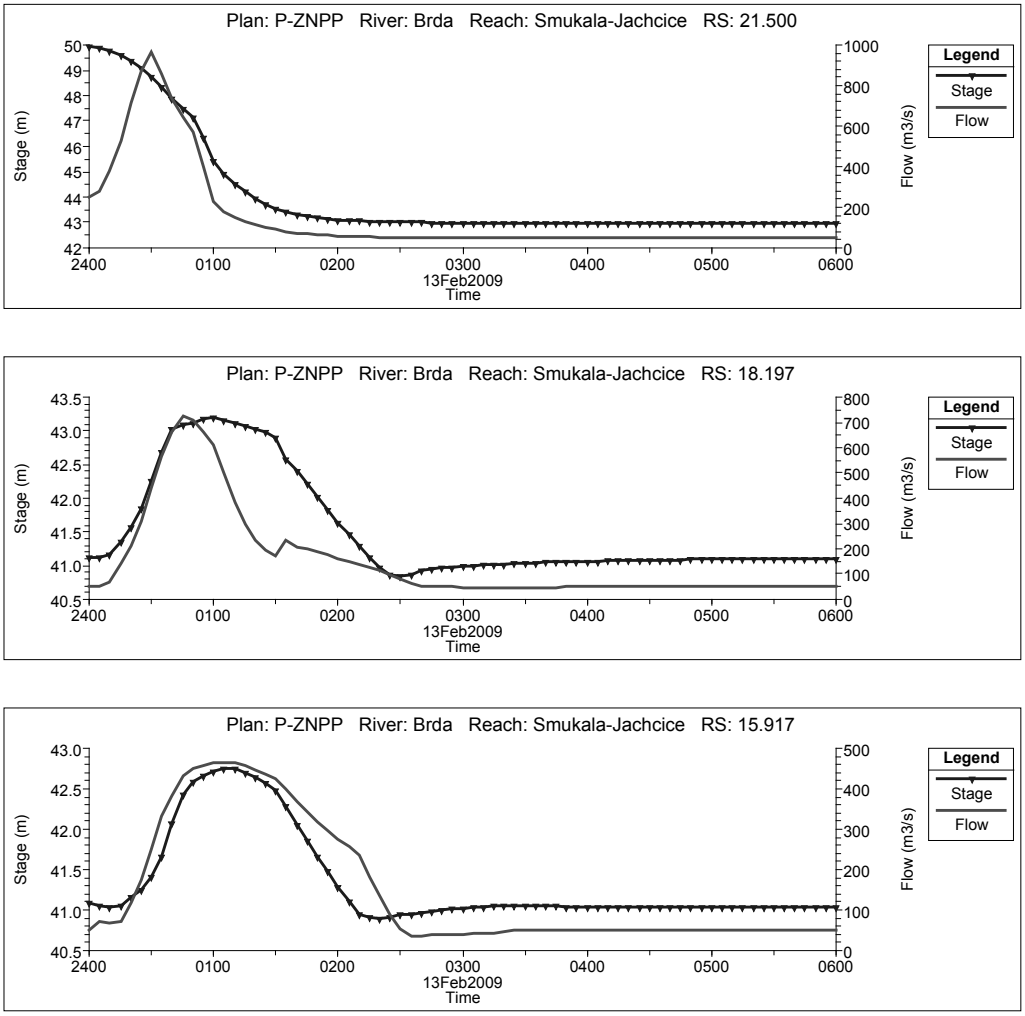
5) flap gates are lowered to keep normal water level 41.0 as long as possible (ZNPP).

Simulation results for two selected cases are presented graphically and in tables (Figs. 4, 5). Czyżkówko left lateral dam significantly narrows the flow area on a distance of 2.5 km upstream the main dam. This in turn reduces the capability of transformation of the wave arising as a result of the breach in the Smukała dam. Smukała dam overtopping inevitably results in the overtopping and distraction of the lateral Czyżkówko dam. Therefore, simultaneous occurrence of overtopping above both dams is expected. Using the methods described for the Smukała dam, the width of the breach in the lateral Czyżkówko weir was estimated as $B = 26$ m and breach developing time $t = 0.5$ h.



Cross-section	km	Max. flow	Re-duction	Time	Time difference	Max. state	Time	Remarks
		[m3/s]		[h]	[h]	[NN]	[h]	
Smukała dam	21+500	1594	–	0:30	–	51.46	0:00	
Piaski h.e.	18+197	1188	25%	0:45	0:15	44.08	0:55	
Czyżkówko weir	15+947	885	44%	1:30	1:00	**43.27**	1:10	Catastrophy of Czyżkówko res.
Jachcice h.e.	14+804	782	51%	1:40	1:10	41.83	1:40	

Fig. 4. Flow and stage hydrographs for simulation Z05 – Smukała dam overtopping and Czyżkówko flap gates lowered within 5 minutes



Cross-section	km	Max. flow	Re-duction	Time	Time difference	Max. state	Time	Remarks
		[m3/s]		[h]	[h]	[NN]	[h]	
Smukała dam	21+500	962	–	0:30	–	49.92	0:00	
Piaski h.e.	18+197	724	25%	0:45	0:15	43.18	1:00	Maximal water level
Czyżkówko weir	15+947	466	52%	1:05	0:35	42.75	1:05	transgressed. Max. P.P.
Jachcice h.e.	14+804	450	53%	1:20	0:50	40.22	1:20	

Fig. 5. Flow and stage hydrographs for simulation ZNPP – Smukała dam overtopping and Czyżkówko flap gates lowered to keep the normal water level

3. CONCLUSIONS

Because of the specific nature of dam break simulations, boundary and initial conditions are essential to the creation of disaster scenarios. Since it is impossible to verify these scenarios in the natural conditions, we attempt to reflect these conditions in

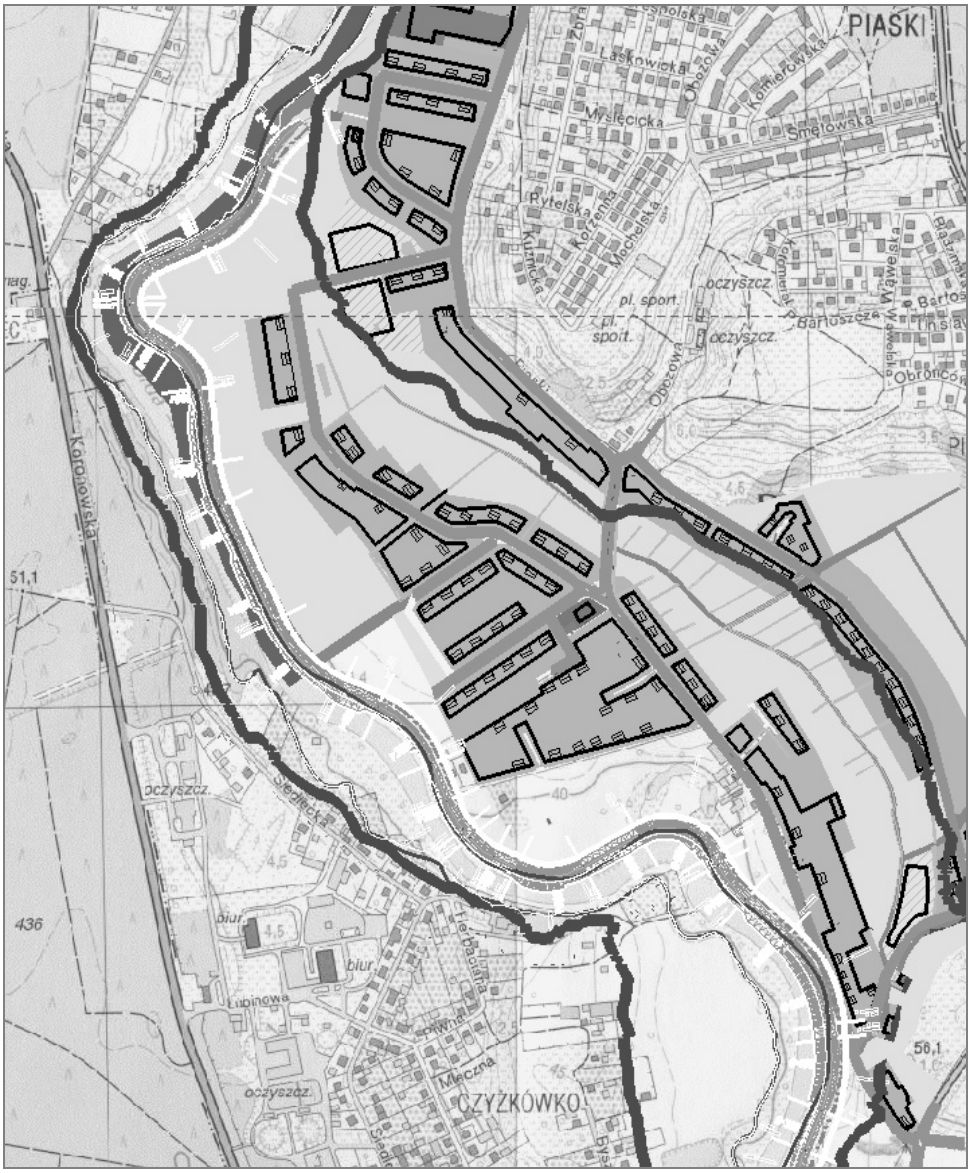


Fig. 6. Flooding area for the Smukała dam break

models. Limitations resulting from the availability of the software and the computational methods abilities have caused the most of the dam break flood wave propagation research were made on physical models. New HEC-RAS modelling possibilities, i.e. all weir gates types and operation rules for the gates, easily enable for unsteady flow simulations in channels.

Based on hydraulic modelling the description of the flood wave resulting from unexpected extreme operational conditions at Smukała dam has been presented. Overtopping of the Smukła dam results in the overtopping of the Czyżkówko lateral dam no matter the operational conditions at the Czyżkówko weir and the way of the flap gates manoeuvring. Calculated water levels indicate that it is likely for the lateral Czyżkówko dam to be overflowed at its full length. It is impossible to determine a place where the breach could develop based on the current simulations results. The closer to the main Czyżkówko dam the breach develop, the more severe its consequences would be, as more water will be discharged from the breach. It was assumed that the breach will develop in the vicinity of the Czyżkówko main dam gates and the water from the breach will be discharged directly into the downstream pool of the dam. It is the most disastrous scenario for the terrain below the dam.

For the assumed general conditions in case of piping of the Smukała dam it is possible to avoid Czyżkówko weir overtopping and its catastrophe. If the flap gates of Czyżkówko weir could be completely lowered in less that 30 minutes then maximal water level in Czyżkówko reservoir should not exceed the lateral embankment crest level. Despite the fact that the maximum water level will be exceeded, it won't come closer to the embankment crest than 0.20 m.

Regardless the cause and mechanism of the breach formation it is advised to lower the flap gates of the Czyżkówko weir as soon as possible. It will lower the maximum water level and lessen the risk of another catastrophe. Time the flood wave needs to get the Czyżkówko weir is 35 minutes for piping and 60 minutes for overtopping. Maximum flood wave range caused by the overtopping of lateral Czyżkówko dam is shown in Figure 6.

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