1CE037P3 INTERREG IVB Project Central Europe

LABEL

Project activity 3.3.4

LUŽNICE – NOVÁ ŘEKA – NEŽÁRKA WATER MANAGEMENT JUNCTION

ASSESSMENT OF THE EFFECTS OF DESIGNED AND POSSIBLE RETENTION MEASURES ON HYDRAULIC CHARACTERISTICS OF THE LUŽNICE AND NEŽÁRKA RIVERS

PP18 – Povodí Vltavy, státní podnik

Authors – VRV, a.s. **ČVUT Praha**

Introduction

Historical events show that natural disasters are parts of the earth's processes. In the region of the Czech Republic, floods play the most important role. It is desirable to increase the flood protection of endangered urban areas.

One possible way for mitigating flood damage accentuates is effective reservoirs and water management systems flood control (if there is adequate flood control storage present). In conjunction with other measures such as flood control measures within urban areas (preferably nature friendly) or various landscape measures (increase or recovery of retention capacity, soil conservation measures, proper agricultural management) it is often possible to reduce economic damage significantly or even save lives.

This study was contracted by Povodí Vltavy, state enterprise. The study is one of the works supported by the LABEL international project (LABE-ELBE Adaptation to flood risk).

Area of interest

The area of interest is located in the upper part of the Lužnice River basin (Fig. 1). More specifically, the water management junction is delimited by the section of the Lužnice River watercourse from the Novořecké splavy hydraulic structure to the junction with the Nežárka River, the section of the Nežárka River watercourse from the mouth of the Nová řeka watercourse to the junction with the Lužnice River, and finally the entire Nová řeka artificial watercourse. The length of this imaginary triangle is approx. 73 kilometers. The town of Veselí nad Lužnicí, which is located just on the junction of the Lužnice and the Nežárka River courses, is subject to detailed assessment of flow characteristics. Other urban areas (i.e. Dráchov, Soběslav, Planá nad Lužnicí, Sezimovo Ústí, Tábor, Bechyně) are subject to the expertise of investigated measures. The area of the water management junction is located within the Třeboňsko protected landscape area, the region was declared a UNESCO biosphere reserve, it is part of the Natura 2000 system. In terms of water management, the area is unique by the highest density of ponds in the Czech Republic.

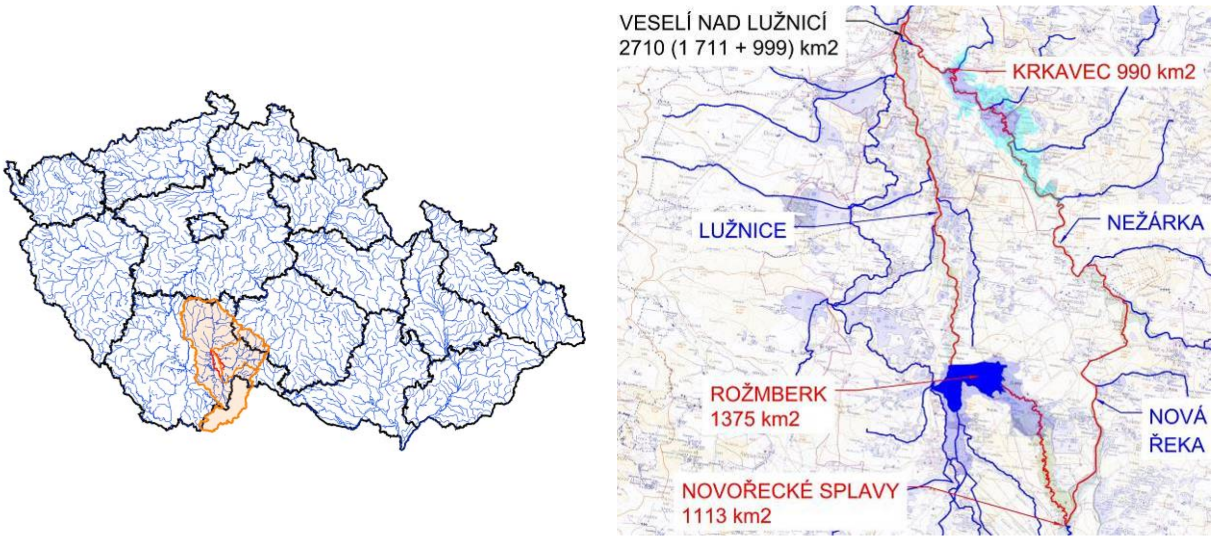

Fig. 1: The Area of interest

It is not surprising that Rožmberk Pond, the greatest Czech pond, is located there. This important reservoir (sometimes called "the Southern Bohemian Sea" or "The king of Czech ponds") was built up on the Lužnice River in the 16th century. Among other interesting facts, respectable 750 000 m^3 of material were used for the construction of the earth dam body. The present flood control storage (hereinafter referred to as "V_r") of Rožmberk Pond equals 13,6 mil. m^3. With respect to recent floods

experience (especially the disastrous August 2002 flood) it was decided to investigate the possibility of increasing V_r to 29,5 mil. m^3 without the need for decreasing the conservation storage of Rožmberk Pond.

The Novořecké splavy hydraulic structure and the 13,5 km. long Nová řeka artificial watercourse is the second important structure in terms of flood control. It was built up together with Rožmberk Pond. The main purpose of the structure is the possibility of diversion of the flow to the Nová řeka River and thus partial flood protection of Rožmberk Pond. The structure was recently reconstructed (new gated weir); the main reason for the reconstruction was a better possibility of regulating the flow in the Nová řeka diversion. In addition, a 6,9 km long levee was constructed on the left bank of the Nová řeka River. During the August 2002 flood, the levee collapsed and Rožmberk was endangered. In the next years, the levee was reconstructed. The water transfer capacity is up to 96 m^3/s according to newly proposed handling regulations (for comparison, the flow with a 100-year return period equals 310 m^3/s in the Novořecké splavy profile).

The town of Veselí nad Lužnicí was significantly affected by recent floods in the last years (2002, 2006, 2009, 2010). That was the reason for beginning the preparation of flood control measures within the built-up area of the town. Designated areas will be protected up to flows with a 0.02 occurrence probability (50-year flood) in the case of the implementation of these measures [3].

Beside the proposed flood control measures, it is desirable to investigate other ways of the mitigation of flood discharges with respect to the endangered town of Veselí nad Lužnicí and other urban areas below the junction of Nežárka and Lužnice Rivers. On the contrary to the Lužnice River, where there are possibilities for affecting the course of floods to some extent (Rožmberk and the Novořecké splavy hydraulic structure), the management of flood events in the Nežárka River basin is currently not possible. There does not exist any control element such as a reservoir with flood control storage. That was the reason to study and assess the Krkavec flood release basin (hereinafter referred to as “Krkavec”) and its capability for additional flood protection. The concept of setting up a water reservoir for water supply purposes at the Krkavec dam site (approx. 2 km. away from Veselí nad Lužnicí) firstly appeared about forty years ago. The idea of the Krkavec flood release basin then emerged within the solution of the international FLAMIS project [1]. The results of this project were an important source of information for this work. Krkavec was solved in two basic variants: Variant A (V_r=7 mil. m^3) and Variant B (V_r=34,4 mil. m^3).

Aims of the study

The objectives of the study could be divided into three phases. Firstly, basic data and related works were gathered and processed (ihe list of the most important works is attached). Secondly, the definition of scenarios with respect to the combinations of Rožmberk and Krkavec (the existing and the proposed Rožmberk, two variants of Krkavec), together with hydrological considerations, followed. Note that the peak flow of the given return period under the junction could be caused by various combinations of flows on the Nežárka and the Lužnice Rivers (up to the given period, with the conservation law obeyed). Thirdly and finally, flood control of the defined scenarios was solved. The results of these simulations are inflows (reduced) to the town of Veselí nad Lužnicí. The selected scenarios of inflows are the subject for a detailed hydraulic evaluation of flow characteristics with respect to designed flood control measures within Veselí nad Lužnicí.

Solution

The methodology of the solution of the third phase is based on flood control of two reservoirs situated on adjacent watercourses and on the use of detailed numerical 2D modeling.

The analysis of the relation of the storage V_r, harmless discharge (i.e. the flow when the first more significant flood damage occurs, hereinafter referred to as “D_h”) and the estimated return period of exceeding the harmless discharge (i.e. if the outflow from the reservoir must be higher than D_h, hereinafter referred to as “N_{Dh}“) is essential within the solution of flood control. Hydrological data represent boundary conditions; these are the most common theoretical design floods of a selected return period and/or major historical floods (if available). The solution of flood routing (flood wave transformation in a reservoir) is affected by the reservoir operations, the characteristics of both the pool and the outlets. Simulating models are typically repeatedly used here. In this study, the HEC

ResSim (Hydrologic Engineering Center – Reservoir Simulation) model was used. The flood routing is based on the storage (continuity) equation.

If a new reservoir is designed, it is useful to analyze the relation of hydrological data, the harmless discharge D_h and the volume of the storage V_r (or generally the volume available for flood routing). When there is a sufficient number of flood hydrographs available for a given catchment, a set of volumes of floods above the harmless discharge D_h (i.e. parts of volumes of floods when flows exceed D_h) can be derived. It is worth mentioning that two floods with similar peak flows can differ in volume remarkably. The set of volumes can be statistically processed then (i.e. fitted with a suitable probability distribution). Since the volume above D_h (V_{Dh}) approximately equals the necessary volume of V_r, the dependence of the necessary magnitude of V_r with respect to the estimated return period of exceeding the harmless discharge N_{Dh} can be determined. Thus, for the given volume of V_r , it is possible to assess the expected return period N_{Dh}. The availability of a sufficient number of flood hydrographs is very rare for applying the described technique. The above mentioned dependence can be at least estimated with a straightforward utilization of theoretical flood waves with different return periods, for example (see Fig. 2).

A detailed hydraulic evaluation of flow characteristics for the selected scenarios with a reduced inflow to Veselí nad Lužnicí was performed with the aid of a detailed two-dimensional model because of the complexity of the flooded area and complicated flood flow conditions. The FAST 2D two-dimensional numerical model was used as the simulation tool. The model enables the simulation of a free surface steady water flow in domains with a complex geometry.

The FAST2D model is based on the set of depth-averaged Reynolds equations often called 'shallow water equations', which can be derived by the integration of the Reynolds equations for a three-dimensional flow over the depth of the water layer. The partial differential equations are solved numerically with a finite volume procedure. The method employs non-orthogonal curvilinear grids.

During the practical application of the model the domain of interest first has to be covered with the computational grid, which is described by the Cartesian coordinates of the grid cell corners. FAST2D uses non-orthogonal curvilinear computational grids, which enable the model boundaries to be fitted to the shape of the modeled territory, or occasionally also the internal grid lines to be fitted to the shapes of the main obstacles (dams, roads, etc.).

In the second step of the model building procedure, it is necessary to specify the terrain elevation for all the grid points in the model and to create the final numerical representation of the modeled domain. The primary data can be cross sections and/or digital terrain model (DTM) data defined as data sets containing the coordinates of 3D points and 3D lines. For every control volume, a roughness value must be further defined. The distribution and the adjustment of the roughness coefficients is the main task of the calibration phase of the model design.

The method used for modeling the flow obstacles depends on the height of the obstacles relative to the water depth. Overflowed shapes are modeled using local terrain elevation modifications, higher obstacles are taken into account by blocking off the corresponding control volumes in the computational grid (vertical wall). A third possible method of an obstacle modeling simply uses very high values of roughness coefficients in the affected regions and simulates the influence of clusters of small overflowed obstacles that cannot be resolved with the coarser computational grid.

On the model boundaries (external, sometimes also internal), the corresponding boundary conditions have to be specified.

Together with other outputs of the flood control solution, the relationship of the volume V_r and the expected return period N_{Dh} was derived for the Krkavec flood release basin (theoretical flood waves were utilized here, see Fig. 2). The boundary values of harmless discharges D_h for Krkavec were considered as D_h in the town of Veselí nad Lužnicí on the Nežárka River: in the present state (74 $m^3/s \approx Q_2$) and after the designed flood control measures (198 $m^3/s \approx Q_{50}$). It was found out that Krkavec in Variant A (V_r = 7 mil. m^3) is able to maintain D_h = 165 m^3/s when flood routing a theoretical design flood with a 100-year return period (the peak flow of the flood equals 234 m^3/s, the volume of the flood above the mean discharge 12,3 m^3/s equals 95.7 mil. m^3). It is necessary here that the flow up to D_h is released downstream without or with insignificant filling of V_r as well as maintaining D_h while V_r is filling (rising water level and energy head before the entrance of outlets). This leads to the necessity of sizable gated bottom outlets.

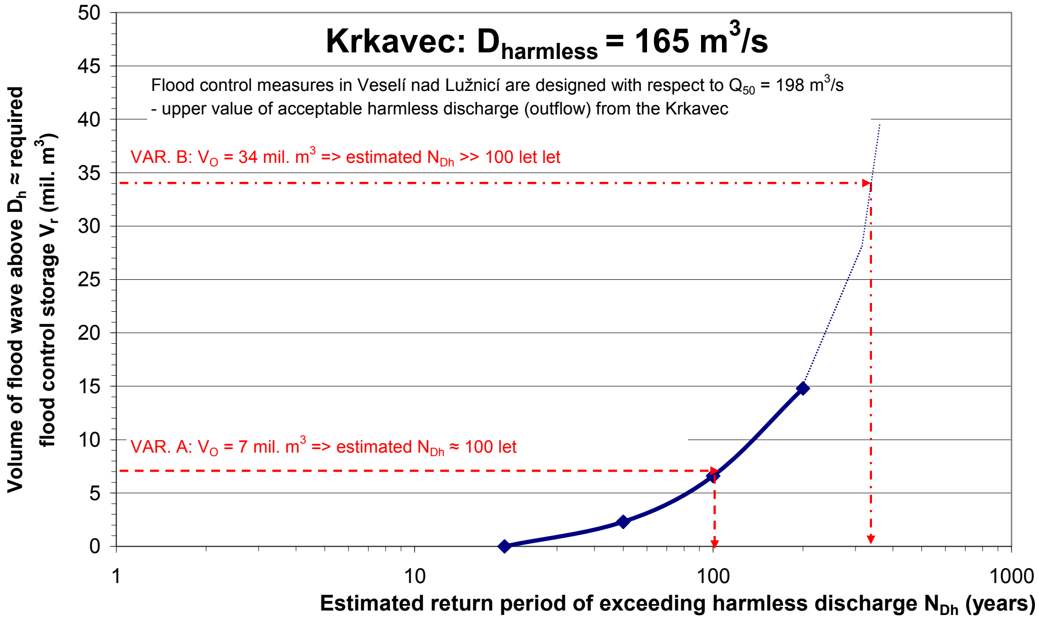

Fig. 2: Estimated return period of exceeding harmless discharge N_{Dh}

Rožmberk Pond had been subject to a flood control analysis in the work [2] already, the results of this work were used in this study. Rožmberk Pond will be able to maintain D_h ≈ 40 m^3/s when flood routing a theoretical design flood with a 100-year return period (the peak flow of the flood equals 210 m^3/s, the volume of flood above the mean discharge 3,6 m^3/s equals 53,9 mil. m^3) assuming the proposed increase of Rožmberk's V_r becomes operative. The inflow from the Rožmberk – Veselí nad Lužnicí interbasin must be taken into account when evaluating the inflow to the town of Veselí nad Lužnicí (on the contrary the Krkavec – Veselí nad Lužnicí interbasin is small – Fig. 1).

When evaluating the feasibility of Krkavec flood retention pond, although Variant B offers much wider possibilities in regulating outflows, there are important territorial collisions. Probably the most momentous collision is flooding of the village of Val – its local part Hamr. The area is flooded even in Variant A, in this case, however, a possibility of designing flood control measures is real.

The effect of flood protection of the evaluated reservoirs for other urban areas downstream of the town of Veselí nad Lužnicí decreases with the increasing catchment area and the magnitude of the released outflow (harmless discharge).

The HEC ResSim program (used within the study for flood routing) appears as a promising tool for studying reservoir and/or water management systems. Some numerical problems which occurred during simulations will probably be fixed up in future versions.

The performed flood control analysis and flood routing simulations led to the assessment of inflows to the town of Veselí nad Lužnicí for the whole range of defined scenarios. Several scenarios (see below) were selected as the most informative ones for the detailed assessment of hydraulic characteristics in the town of Veselí nad Lužnicí.

The results of numerical hydraulic modeling constitute an extremely large amount of digital data, which can be analyzed using visualization and analyzing tools. A possible graphical evaluation of simulation results includes streamlines, water elevation maps, water depth maps and flow velocities maps. An example of such an evaluation is given in Fig. 3.

In this study, we have continued with the model of Veselí nad Lužnicí that was developed in the framework of the international FLAMIS project. The existing model was slightly modified by the inclusion of supplementary geodetic data improving the information about terrain elevations in the flooded area and the primary model calibration based on the flood situation in 2002 was successfully

verified using new calibration simulations and the comparison of the results with known high water marks from the flood in 2006. The designed geometry of the proposed flood control measures in Veselí nad Lužnicí was further implemented into the modified model and several variants of theoretical flood events were analyzed based on the model simulation results.

Tab.1 Selected scenarios for detailed assessment by numerical 2D modeling (RP...return period)

Scenario		Unaffected flow [m^3/s]	Flood routed flow	Remark
1	Below junction	251 (RP=50)	251	
	Nežárka	198 (RP=50)	198	
	Lužnice	53 (RP=5-10)	53	
2	Below junction	251 (RP=50)	251	
	Nežárka	127 (RP≈10)	127	
	Lužnice	124 (RP=50)	124	
3	Below junction	394 (RP>100)	246 (RP<50)	165 m^3/s + 81 m^3/s
	Nežárka	234 (RP=100)	165 (RP>20)	Flood routing by Krkavec var. A, D_h = 165 m^3/s
	Lužnice	160 (RP=100)	41+40=81 (RP <20)	Flood routing by Rožmberk V_r=29.5 mil. m^3 plus inflow from interbasin
4	Below junction	315 (RP=100)	280 (RP=50-100)	155 m^3/s + 125 m^3/s
	Nežárka	155 (RP=20)	155	Flood routing by Krkavec var. A, D_h = 165 m^3/s → assumption that flood is unaffected
	Lužnice	160 (RP=100)	85+40=125 (RP≈50)	Flood routing by Rožmberk V_r=13.5 mil. m^3 plus inflow from interbasin

The simulated cases included two different states (with and without the influence of the flood mitigation effects resulting from the improvement of flood control storage) and selected combinations of discharges at the inflow to Veselí nad Lužnicí and at the junction of the Lužnice and Nežárka Rivers:

- Scenario 1 – uninfluenced state, discharges with a 50-year return period on the Nežárka and the Lužnice Rivers under the junction
- Scenario 2 – uninfluenced state, discharges with a 50-year return period on the Lužnice River and the Lužnice River under the junction
- Scenario 3 – influenced state (Rožmberk with the increased volume V_r, Krkavec in Variant A: D_h = 165 m^3/s), transformed discharges with a 100-year return period on both the rivers
- Scenario 4 – influenced state (Rožmberk with the present volume V_r, Krkavec in Variant A: D_h = 165 m^3/s => flood is not routed, see Tab. 1), transformed discharge with a 100-year return period on the Lužnice River, untransformed complementary discharge with an approx. 20-year return period on the Nežárka River(155 m^3/s).

Scenarios 1 and 2 correspond to the design flood scenarios that have been used as the basis for the project of flood control measures in Veselí nad Lužnicí. The simulation results for these scenarios have therefore been used as reference values for the evaluation of flood mitigation effects expected in scenarios 3 and 4.

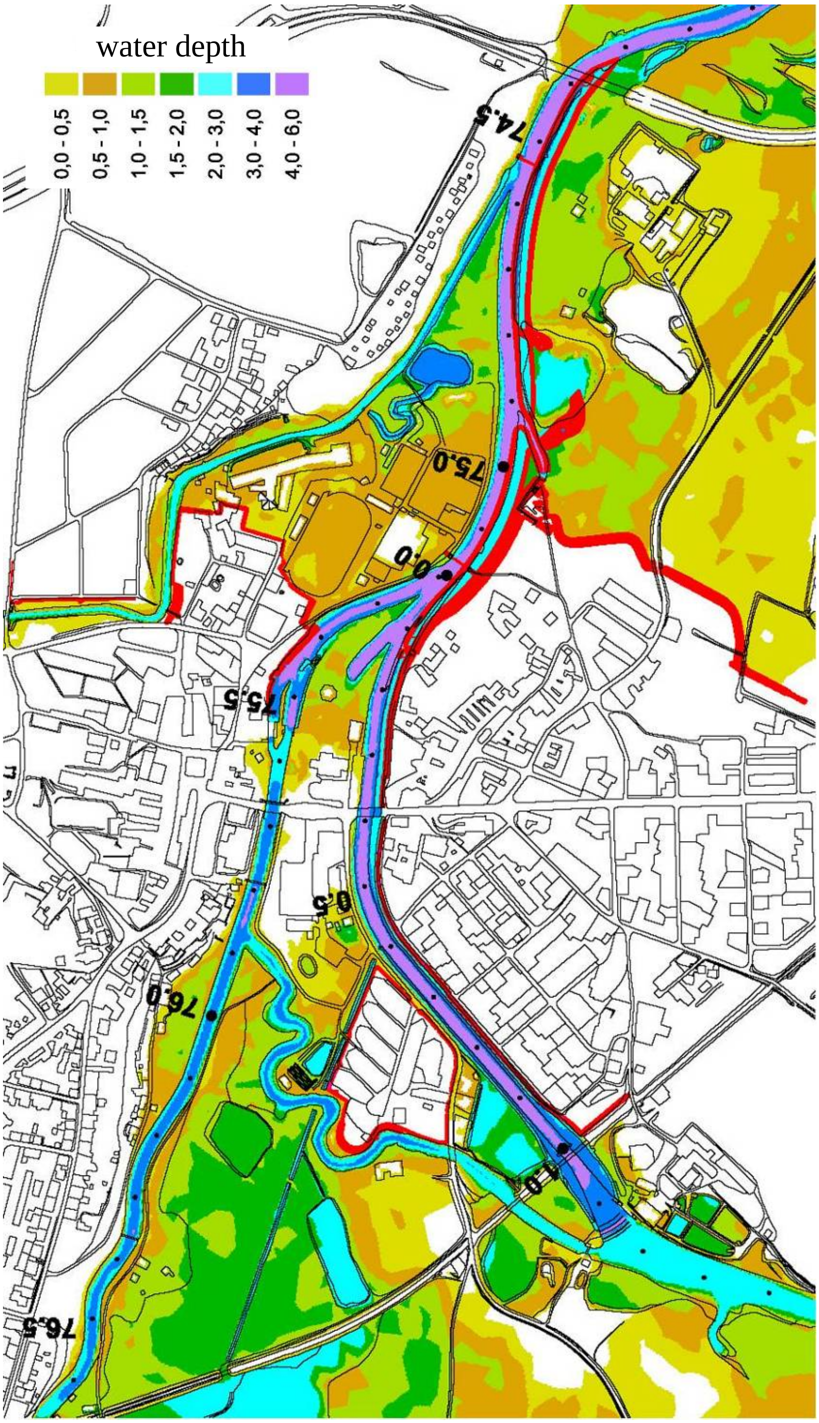

Fig. 3: Water depth map for Veselí nad Lužnicí – scenario 1

The comparison of the results for scenario 3 with the reference results has shown that this scenario leads to similar water elevations in the flooded area. It can be considered that the implementation of the flood discharge mitigation measures can theoretically lead to a reasonable increase in the flood protection rate up to floods with a 100-year return period (coming simultaneously on both the rivers). On the contrary, the reservoir flood routing in scenario 4 appeared as insufficient because the simulated water elevations exceeded the reference water level values.

The study has confirmed considerable sensitivity of numerical modeling to the quality and accuracy of geometry data. The modification and improvement of the digital terrain model based on complementary geodetic information has led by itself to a slight increase in simulated water elevations in the reference variants. Numerical modeling of flood flow events has generally unavoidable uncertainties resulting from the limitations of input data and other sources such as model schematization and the approximation of real processes. The uncertainty factor rises with the increasing complexity of the flood flow conditions, which is surely the case of the problem studied here. In this context, every flood discharge mitigation measure resulting in the reduction of the inflow to Veselí nad Lužnicí (even for design flood states) is highly advisable and definitely increases the safety of the planned flood control measures.

Results

- If Krkavec is designed properly (Variant A requires a high value of harmless discharge) and if the increase of Vr on Rožmberk occurs, the flood protection rate in Veselí nad Lužnicí will have theoretically increased up to floods with a 100-year return period (coming simultaneously on both the rivers).
- Variant B of Krkavec offers much wider possibilities in flood control but at the cost of probably unacceptable territorial collisions.
- Although Krkavec in Variant A has relatively small flood control storage with respect to the design flood, it constitutes the counterpart to Rožmberk Pond. Additional optimization of both the waterworks together with the Novořecké splavy hydraulic structure (with respect to continuously improving hydrological forecast for example) is possible.
- The designed increase of Rožmberk’s flood control storage is an important and recommended measure in flood protection.
- With regard to the complexity of flood conditions and all other uncertainties (hydrologic, geodetic, numerical, approximation of real processes etc.), every measure which leads to the reduction of inflows to Veselí nad Lužnicí is advisable.
- A flood mitigating effect of both the reservoirs can be expected downstream of the junction. Generally, the effect increases with higher flood control storages and decreases with increasing both the catchment area and the harmless discharges. With regard to hydrological complexity, an additional evaluation is suitable for proper enumeration.

Suggested next steps

- Discussions of the willingness for the implementation of the Krkavec flood release basin with municipalities (the town of Veselí nad Lužnicí, the village of Val) and other important organizations (CHKO Třeboňsko, Povodí Vltavy, state enterprise, South Bohemian regional office etc.).
- Investigation of the feasibility of flood control measures in the village of Val, local part of Hamr
- Evaluation of property rights and possibilities in the mitigation of other territorial collisions.
- More detailed investigation of the Krkavec flood release basin (dam site, design and layout of outlets, assessment of dam safety, preliminary surveys etc.).

The most important references

[1] FLAMIS Project – Final Report. ČVUT Praha, ČHMÚ, PVL, Ecole Polytechnique Fédérale, Lausanne, Praha and Lausanne, 2006.

[2] Rožmberk Pond – the study of increasing its flood control capacity. VODNÍ DÍLA – TBD, a.s., Praha, 2008.

[3] Flood control measures of the town of Veselí nad Lužnicí. VH - TRES, s.r.o., České Budějovice, 2011.