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PROPOSAL OF POTENTIAL FLOOD CONTROL

Aneta KRAKOVSKÁ[1], Jana NOVÁKOVÁ[1], Jan UNUCKA[1,2], Iva MELČÁKOVÁ[1], Vladimír LAPČÍK[1], Peter ANDRÁŠ[1,3], Lukáš KLIMŠA[1]

[1]*VŠB-TU Ostrava, Faculty of Mining and Geology, 17. listopadu 15/2172, 708 33 Ostrava-Poruba, {jmeno.prijmeni}@vsb.cz; aneta.krakovska@vsb.cz*

[2]*Czech Hydrometorological Institute Ostrava, K Myslivně 3/2182, 708 00 Ostrava-Poruba, jan.unucka@chmi.cz*

[3]*Faculty of Natural Sciences, Matej Bel University, Tajovského 40, 974 01 Banská Bystrica; Slovakia, andras@umb.sk*

Abstract: Since the properties of water in river beds began to be influenced by anthropogenic factor, is the flood impact much stronger and less predictable. This paper is focused on floods, which are caused by the injudicious alteration of the River Odra bed near the municipality of Albrechtičky. Changes in the river bed caused overflow to the populated area instead of alluvial meadows. Suggested solution is the recovery of the parallel river bed. As the flow regime has never been controlled in this area, it was necessary to carry out new measurement. In this case it was methodology of flow measurement what has been used for the flow calculation. Flow measurement has been carried in five profiles. In some parts, where the channel has the smallest capacity, the measurment has been taken by the laser rangefinder. From these measured values was the maximal capacity determined by Chezy equation. Subsequently the proposal of flood control has been simulated by the hydrodynamic model HEC-RAS. According to the results of the Chezy equation and consumption curves has been found capacity of parallel channel about 3 – 7 $m^3.s^{-1}$ in the smallest parts. It means, that it is able to take about thirty days of the Odra's flow. By using hydrological modelling were compared inundation areas during the current and newly proposed route, and it has been found that the inundation area at the confluence of parallel troughs would decrease almost by the half. It would be appropriate to propose the connection of the River Odra bed and parallel river bed in the flood area, it would cause decrease of the flow. The advantage of the proposal of flood control is certainly its near-natural character. It will improve reserves of surface water in the floodplain and ecological status of river.

Keywords: flood, flood measures, flow measurement, parallel channel, river basin capacity

1. INTRODUCTION

Water – strategic resource, have been the most important criterion for the choice of suitable location since the beginning of the colonization. Between 1980 and 2006, 77% of economic losses in Europe were caused namely by the floods (Bubeck et al., 2012). The main difficulty associated with this process is the multi-variable and non-linear relationship between indices and risk levels (Wang, 2015). Therefore, it was necessary to pay attention to protection of the property and fertile soil. Flood control must contain encouraging measures for greater accumulation and retention water in the catchment area, erosion protection of land resources and finally protection of afflicted location.

It is important to ensure design flow peak of riverbed capacity in the urban area as well as stability of banks and longitudinal profile. On the other hand, there is essential slowing progress in countryside comprising a high-flood-water, support of overflowing in floodplain, retention of flood flow in terrain depressions and use of natural channels.

For the selection of suitable flood control is necessary to evaluate its impacts to aquatic ecosystems. It is significant to take into consideration a morphology of the riverbed and preserve "good ecological status" and "good ecological potential" according to The Water Framework Directive (WFD, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy). Many water authorities have problem to comply to WFD, because there are difficult exacting criteria assessment (Weiß et al., 2008).

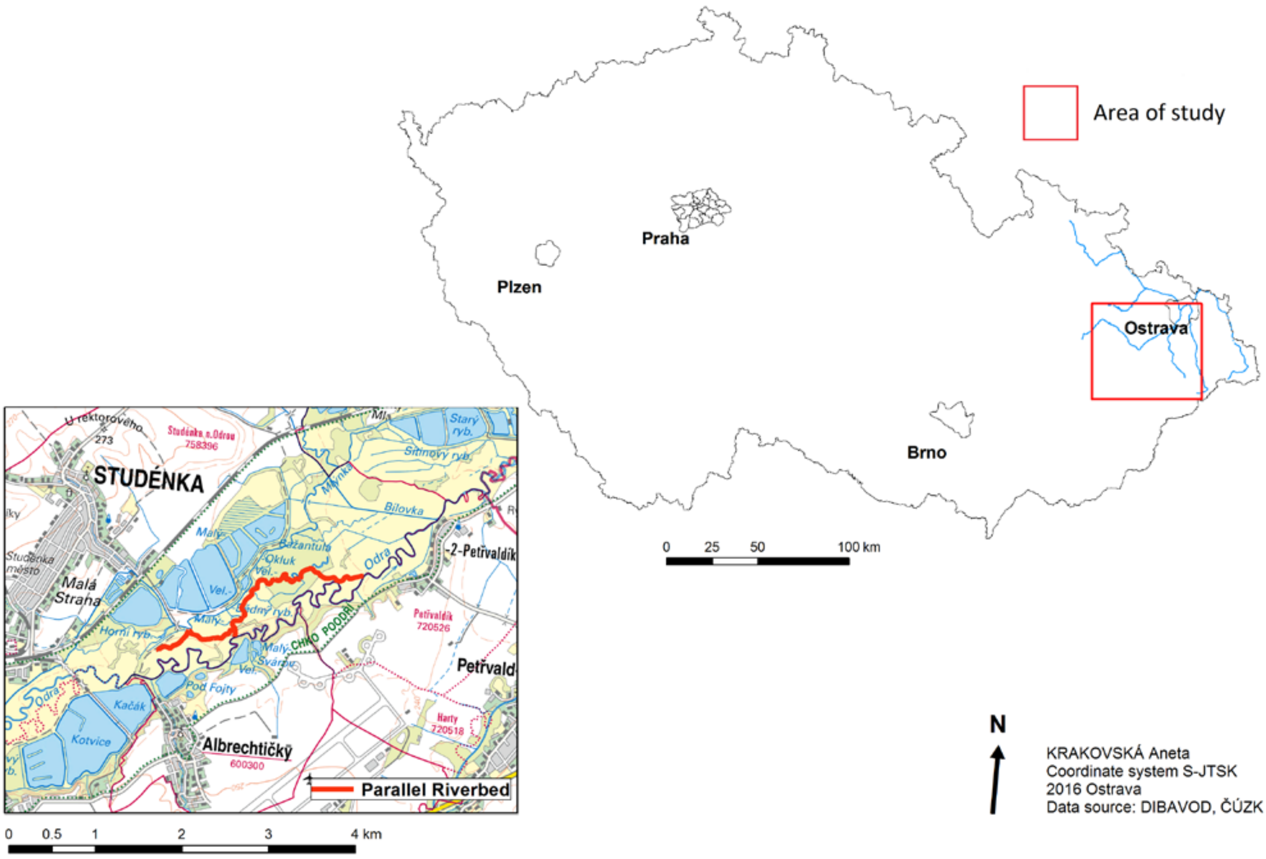

Figure 1 Map of riverbed in the Czech Republic and the overall riverbed.

Basic classification of the flood control is divided into near-nature and technical protection. Administrative procurations are used in the preventive sphere, which includes definition of the flood zones, legislative aspect, forecasting and warning systems and public education (Čamrová & Jílková 2006; Máchová & Hovorka, 2013).

There is little conflict between the protection of people and property and the improvement of environmental conditions. In addition, various non-structural measures such as the development of flood hazard maps, local flood fighting corps, and flood warning systems support risk management and reduce excessive river engineering (Nakamura et al., 2006).

Technical measures include following principles. For water retention, it is appropriate to perform regulation of the extent and structure of forests and agriculture, for example to expand permanent grassland. Very effective device for interception of flood flow are retention tanks, what decrease peak discharge and transform volume of high-flood-water wave into long time interval by temporary accumulation (Novák & Novák Jr., 2011).

Another type of flood control is flow or lateral polder according to TNV 75 2415. Partial flood control measure in the urban areas may be increasing the capacity of the channel and adjusting the transverse or longitudinal profile. It is carried by deepening and broadening the flow, but also by the increasing river gradient (Máchová & Hovorka, 2013). However, these changes can lead to disadvantages of the catchment areas on the lower course of the river. It is needed to take into consideration the proposal of peak flow for capacity of the riverbed according to TNV 75 2103.

Although the mechanisms acting at large spatial and temporal scales are relatively well-identified, small scale habitat heterogeneity and dynamics, as well remain poorly understood (Garcia et al., 2012).

From the point of view of the flood protection it is also important to stabilize the longitudinal profile by weirs, boulder chutes, gravel damming and stabilize banks and enlargement of longitudinal slope (Zuna, 2008). Control of silting on the riverbeds is also very important.

Location of interest is situated on the cadastral territory of Studenka nad Odrou on the east of the Czech Republic (Fig. 1). Floods in this area are problem since the 80s of the last century. In the years 1960-1966 there was repeatedly amplified and stabilized bank in the point of connection with parallel channel. The reason has been probably use of the meadow for the agriculture purposes. Consequence is the enhancement of the left bank of the River Odra in excess of right bank and thereby inundation of urban area. Proposed flood control in this paper is use of parallel river bed. Elaborated ideological study of the hydrological regime has been proceed and its flow capacity has been evaluated.

2. MATERIAL AND METHODS

Selection of profiles for flow measurements has been based on the morphological changes in the riverbed (Fig. 5). First profile (PF1) has been chosen at the beginning of the parallel riverbed after the confluence of the Mlýnka flume and the influx from Slaňáky. Second profile (PF2) is situated on the reflux from the Lakes Koňské, Důlské, Karasovo. Another two profiles are situated at the very parallel riverbed. Third profile (PF3) is located at the nearest measurable place from the “rip current”, where water flow from the River Odra at higher flow rate. Fourth profile is situated near to the reflux from Mlýnka. The last of the profiles is located near to confluence with the Odra riverbed. The measurement has been carried out according to the methodology of Kříž et al., (1979) for over two years. Measurements were performed in minimal, average and maximal water flow, during the year.

The methodology of calculations

Evaluation of the flow has been carried out by numerical method (Řehánek & Kříž, 2002). Measurement using the laser rangefinder in the capacity smallest sections has been carried out for the evaluating of maximal flow capacity. It was selected nine profiles near to the rip current and three profiles near to the confluence parallel channel with the River Odra. By the calculating of the flow capacity has been found out what amount is the river bed able to hold and when it leads to pouring from the bank. Capacity depends on the shape and size of cross section and roughness of the bottom and banks (Just, 2005). For the calculation has been used the Chezy equation for a steady flow of the natural channel.

$$Q = C \cdot S \cdot \sqrt{R \cdot I}$$

where
Q [$m^3.s^{-1}$] is flow
C speed factor [$m^{1/2}.s^{-1}$]
S swept area [m^2],
R hydraulic radius [m]
I slope of the bottom

Calculation of the Chezy coefficient *c* has been carried out according to the Manning

$$c = \frac{1}{n} R^{\frac{1}{6}}$$

where
n [-] *is* roughness of the bottom and banks
R [m] is hydraulic radius.

In this work has been used value of Manning coefficient $n_{min-max}$ = 0,050-0,080 for “small stream with weeds and pools”.
Resultant value indicates the amount of the water in the completely full channel without overflowing.

The methodology of the modelling

Simulation of the proposed flood control has been carried out using the HEC-RAS 4.1.0. HEC-RAS is hydrodynamic model allows to perform steady and unsteady flow conditions in river channels and floodplains (Papaioannou, et al., 2016), sediment transport (Gibson et al., 2006) and water quality modelling (Fan et al., 2009). Criterion of selection this program was the use of industry standards FEMA / NFIP or software, which is flexibly used by Flood Forecasting Service of the Czech Republic (hereinafter FFS CR). Usually, 1D modelling is preferred due to the small computational cost in combination with the efficient results that can be provided (Tsakiris, 2014). HEC-RAS have been used in many studies of river and floodplain analysis (e.g. Gain et al., 2015; Kunzler et al., 2012; Pappenberger et al., 2005) it is suitable as well for regional scale flood modelling (Knebl et al., 2002).

Among the methods of simulation there belong a simulation according to the level and Q in the main stream or using some time series manipulations.

Computations is based on the Bernoulli Equation and Manning formula. HEC-RAS uses basic equation $Q = C.W.H^{3/2}$ (Dyhouse, et al., 2003).

W … is the width of the crest [m]
C … weir coefficient
H… water level [m]

Input data is digital terrain models as GRID layers of river’s lines, bank’s lines and 100-year floodplain in the shape file (.shp) spatial data format (Unucka, 2014). All of these layers are available in the digital-based water management data (DIBAVOD VÚV TGM).

3. RESULTS AND DISCUSSION

For a description of individual profiles are recorded GPS coordinates and the width between the riverside edges, maximum depth and average water level, calculated from the measured data. Further, according to maps of the National Geoportal INSPIRE is listed land use and land cover.

Table 1 PF1- profile 1 parameters

PF1 Bridge near the Slaňáky	
GPS coordinates	18.093946 49.712877
width [m]	3.8
depth [m]	1.5
Ø water level [m]	0.35
Land use	Agricultural area with natural vegetation
Land cover	Pond landscape

Figure 2 PF1 – profile 1, Bridge near the Slaňáky

Lakes have backwater character and profile have gently flowing character thanks to the influx from the flume Mlýnka. Measurement has been performed from the bridge Pasečný (Fig. 2, Table 1). Banks are reinforced by the concrete wall, which is part of the bridge pillar. Behind the pillar there are loamy and unstable banks. Bottom is ragged and formed by the boulders.

In the surrounding area are occurring *Salix alba*, *Salix fragilis*, *Alnus glutinosa*, *Sambucus nigra*, *Betula pendula*, *Quercus petraea*. This is tapered part of the channel, therefore measured velocity is higher. Profile is overshadowed in the growing season by the trees, such as *Acer campestre*, *Alnus glutinosa*, *Tilia platyphyllos*, *Carpinus betulus*.

The second profile (Fig. 4, Table 2) is situated on the reflux flows from Lake Karasovo into the parallel channel bed. This profile is the smallest from all of them. The banks are loamy and the bottom is gravel. Influx flows through the "Havránkové kolca".

Figure 3 profile 2, Reflux from lakes

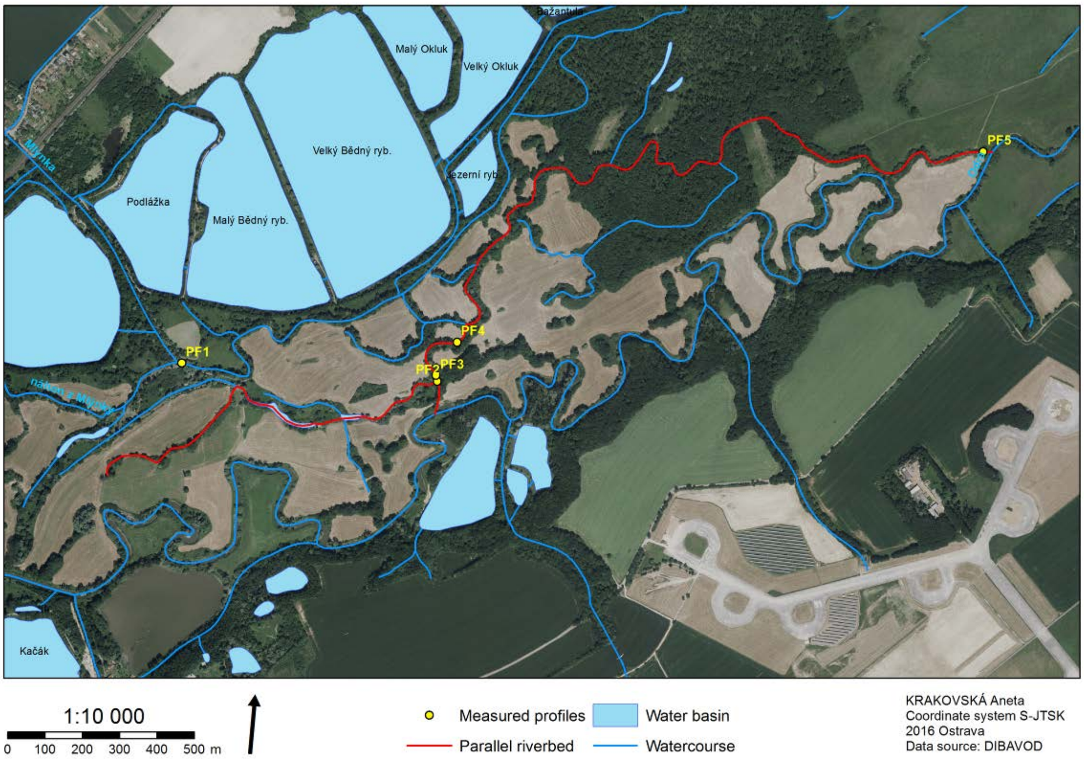

Figure 4. Profiles on the parallel riverbed

This inflow profile is coming from the system of lakes, particularly from Karasovo. During increased flows is also subsidized by the water from the Odra River bed. The bottom is rocky and banks are loamy. Feature of the water is flowing, but is loaded with vegetation in summer, especially with duckweed *(Lemna minor).*

The third profile (Fig. 6, Table 3), as well as the previous one, is overshadowed with the full-grown trees. Both profiles are surrounded abundant vegetation consisting mainly from the *Urtica sp.* and unoriginal *Impatiens glandulifera.*

Table 2. PF2 – profil 2, Reflux from lakes

PF2 Reflux from lakes	
GPS coordinates	18.103429 49.712942
width [m]	0.8
depth [m]	0.45
Ø water level [m]	0.075
Land use	Agricultural area with natural vegetation
Land cover	Pond landscape

Table 3. PF3 – profile 3, Rip current

PF3 Rip current	
GPS coordinates	18.103545 49.713046
width [m]	11.5
depth [m]	1.2
Ø water level[m]	0.024
Land use	Agricultural area with natural vegetation
Land cover	Pond landscape

Figure 5 PF3 – profile 3, Rip current

The bottom of this profile is formed from the finer materials then previous profile. Sediments are gravel and banks are partly made up from the sand. Profile is situated in the slight bend of the flow. In the riverbed, especially at the accumulative bank, there is occurring a large amount of shells *Unio pictorum.* Near to this profile there is beaver burrow. Next profile (Fig. 7, Table 4) is situated close to the confluence with the influx from the flume Mlýnka.

Table 4. PF 4 - profile 4,Tapered part of parallel channel

PF4 Tapered part of parallel channel	
GPS coordinates	18.104136 49.713878
width [m]	12.9
depth [m]	1.75
Ø water level [m]	0.039
Land use	Agricultural area with natural vegetation
Land cover	Pond landscape

Figure 6 PF4 – profile 4, Tapered part of parallel channel

Figure 7. PF5 – profile5, Confluence parallel channel and the Odra riverbed

Channel is lined by tall trees with the largest representation of *Acer campestre, Alnus glutinosa, Carpinus betulus.*

The last profile (Fig. 8, Table 5) is located about 50 meters ahead of confluence parallel channel with the Odra riverbed. In the distance of 200 river meters there is a crossing across the channel. It is created from the concrete ring and structural waste. The bottom of the profile is stony, ragged contains also structural rubble from the crossing. Banks are loamy and unstable with the undermining process. There is a high flow and partly shadow. The dominant is a full-grown *Fraxinus excelsior*, *Salix fragilis* and shrubs of *Crataegus L*, *Sambucus nigra*, and there are *Rubus fruticosus* on the banks.

Table 5. PF5 – profile 5, Confluence parallel channel and the Odra riverbed

PF5 Confluence parallel channel and the Odra riverbed	
GPS coordinates	18.12275 49.719662
width [m]	8.29
depth [m]	1.75
Ø water level [m]	0.119
Land use	Agricultural area with natural vegetation
Land cover	Pond landscape

Particular quantities were calculated for each profile according to Mattas (2001). Resultant values were compared with actual flow in the water gauging profile in Bartošovice (Table 7)

Values measured on September 13th 2013 seems to be low beside Odra flow rate, however it is caused by drying of the channel in the summer months. In the 7th and 8th months of this year average temperature was 20 (respectively 19) °C, which is 3°C above long-term average monthly temperature (average 1961-1990). In the summertime there is usually a still water and periodical pools. All profiles, except second one (PF2), are influenced by the actual water level of Odra River. The greatest correlations (Table 6) have been observed at the first profile (PF1), which is directly connected to the flume Mlýnka, which is fed by water from the Odra River and the confluence of the Odra (PF5), where the correlation probably causes backwater.

Table 6. Correlations stream flow between profiles and the Odra River

	PF1	PF2	PF3	PF4	PF5	Odra
PF 1	1	0.52	0.75	0.73	0.76	0.91
PF 2	0.52	1	0.17	0.19	0.02	0.2
PF 3	0.75	0.17	1	1	0.94	0.89
PF 4	0.73	0.19	1	1	0.94	0.89
PF 5	0.76	0.02	0.94	0.94	1	0.96
Odra	0.91	0.2	0.89	0.89	0.96	1

From the measured values of the water level and calculation of the flow there was possible to create consumption curve. They were used to determine maximal flow in the riverbed. Resulting values can be seen in one of the tables. Capacity of the channel (Table 8) in the smallest measured sections, are in between the range from $3m^3.s^{-1}$ to $7m^3.s^{-1}$. Let's say, that parallel channel has currently capacity 30 days flow.

During terrain exploration it has been found out, that parallel channel, near to the confluence, is completely filled up during 30 $m^3.s^{-1}$ recorded in the Bartošovice station. Unfortunately it was not possible to measure in these conditions but according to the calculation it can be assumed flow around 6.5 $m^3.s^{-1}$.

Table 7 Calculation stream flow for all profiles PF1-PF5

Q [$l.s^{-1}$]	**PF1**	**PF2**	**PF3**	**PF4**	**PF5**	**Odra - Bartošovice**
13. 09. 2013	238	0.42	0.76	1.08	38	989
01. 03. 2014	596	14.51	16	11	27	3 510
19. 07. 2014	394	3	2	3.4	45	1 180
04. 08. 2014	374	7	8			1 450
20. 11. 2014	543	1.8	1.55	1.78	193	5 400
11. 04. 2015	769	7	375.00	342.00	500	10 600

Table 8 Calculation stream flow capacity of the parallel channel

	BN1	**BN2**	**BN3**	**BN4**	**BN5**	**BN6**	**BN7**	**BN8**	**BN9**	**S1**	**S2**	**S3**
S [m^2]	9.100	6.224	9.410	6.798	8.726	9.983	10.106	11.910	8.950	10.302	11.320	9.365
O [m]	12.356	10.190	12.196	9.787	9.162	10.155	10.270	13.756	10.290	8.239	9.793	9.268
R [m]	0.736	0.611	0.772	0.695	0.952	0.983	0.984	0.866	0.870	1.250	1.156	1.011
i [-]	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
n	0.070	0.055	0.055	0.055	0.060	0.060	0.065	0.056	0.065	0.070	0.070	0.065
v [$m^2.s^{-1}$]	0.451	0.507	0.592	0.552	0.625	0.638	0.589	0.628	0.543	0.642	0.609	0.600
Q [$m^3.s^{-1}$]	**4.106**	**3.155**	**5.574**	**3.754**	**5.452**	**6.371**	**5.957**	**7.483**	**4.859**	**6.615**	**6.898**	**5.619**

Table 9. Flow area of parallel channel, profile 1 and profile 9

Nr. profile	Q level		Q [m^3.s^{-1}]	Flow area [m^2]		Q [m^3.s^{-1}]	Flow area [m^2]
1	Q10	**Current status**	3.2	1.64	**Proposal**	3.7	1.81
	Q20		3.7	1.81		4.5	2.08
	Q50		4.5	2.08		5.6	2.42
	Q100		5.8	2.49		6.3	2.63
9	Q10		3.2	11.38		3.7	5.5
	Q20		3.7	12.41		4.5	6.31
	Q50		4.5	13.93		5.6	7.44
	Q100		5.8	16.16		6.3	8.16

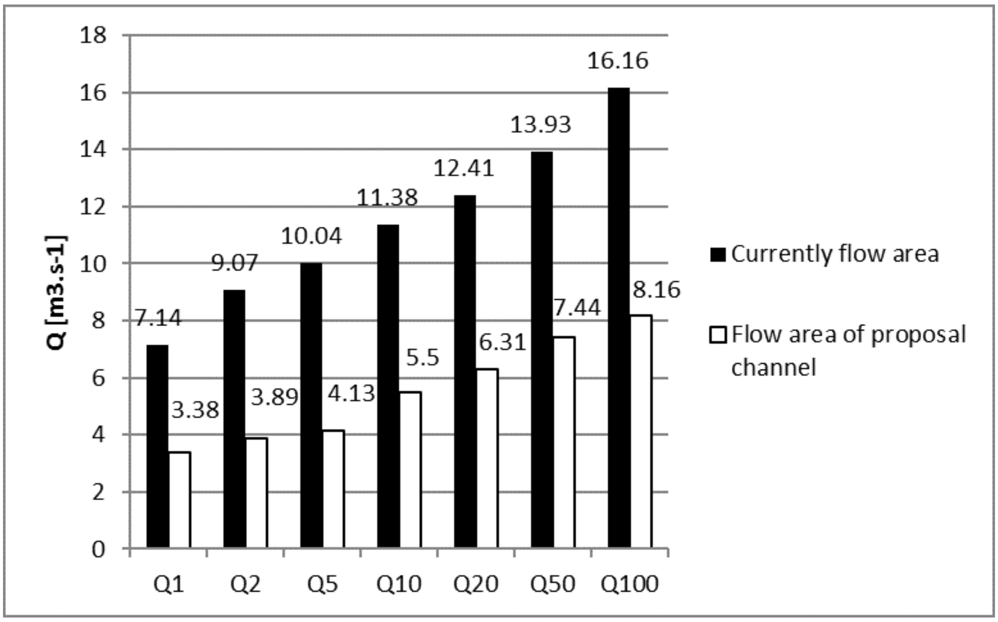

Figure 8. Comparison of capacity flow area currently and proposal channel

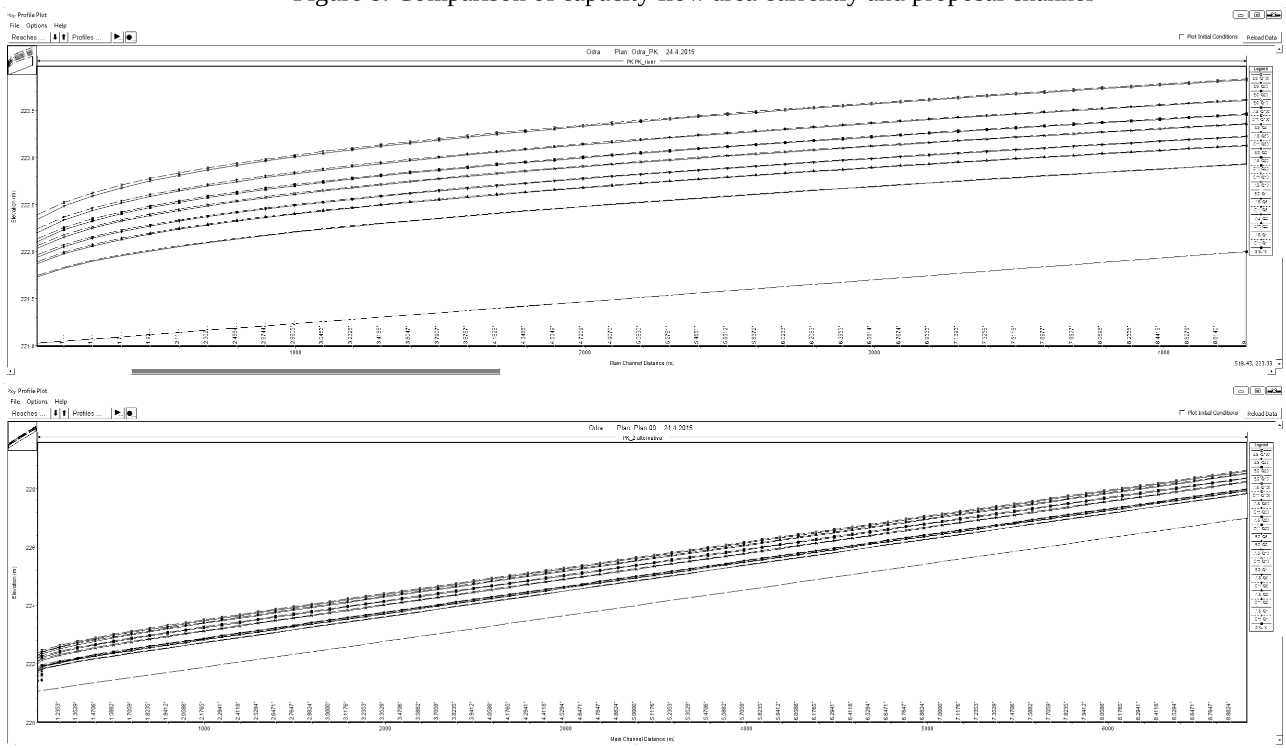

Figure 9. Vizualization of river profile, x-axis: length of the flow, y-axis: elevation

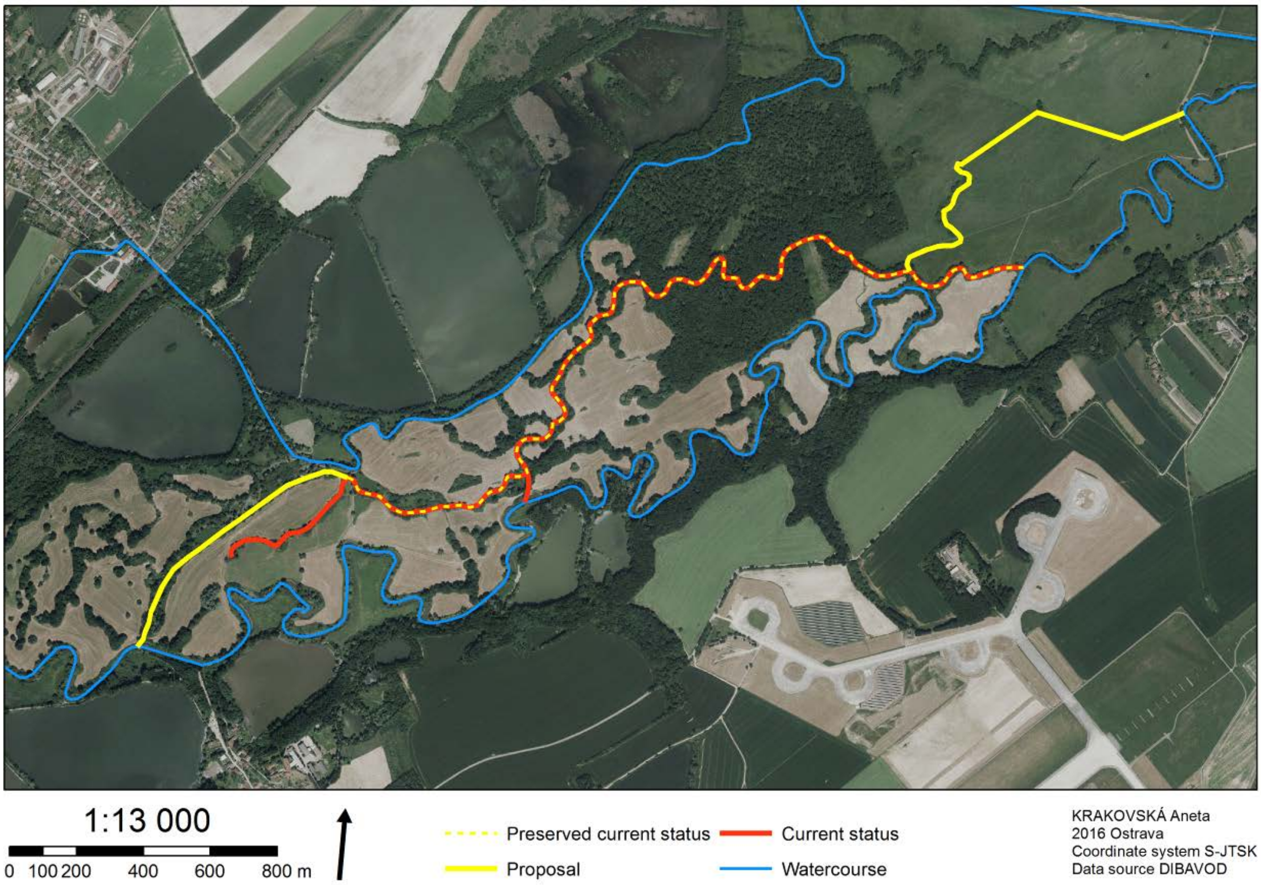

Figure 10. Proposal for the new riverbed

Simulation of the proposal use in the hydrodynamic model

Analysis using the HEC-RAS hydrodynamic model has been focused on the use of parallel channel as a relief channel. Two scenarios were calculated for the current situation. For the current status, where water from the Odra stream flows over the bank ripping, and the second option in case of connecting the parallel channel at the Odra footbridge.

Schematization of the longitudinal profile has been made for both variants in form of a graph, where the x-axis is the length of the flow and the y-axis elevation (Fig. 10). It shows a comparison of the longitudinal profile parallel channel in the current state and design variant.

Table 9 shows the values of the flow area at the beginning and at the end of the parallel channel, in the case of both variants. Comparison of currently flow area and flow area of proposal channel is also expressed by the graph (Fig. 9). The comparison has been made at the last profile near to the confluence with the Odra. The chart shows that the connection of the parallel channel ahead of the Odra footbridge would reduce the flow area by half.

4. CONCLUSION

Now, parallel channel reduces the flow from the Odra River at the rip current. To solve the problem of Albrechtičky it should have been resolved the proposal of the connection of riverbed at this place. In this area, there are clear remains of a water channel, which is now earthed and formed by the periodical pools, wetlands and bushy shrub vegetation and full-grown trees.

Proposing of the new riverbed should be based mainly on the technical standards TNV 75 2101 **-** The greening of river flows and TNV 75 2103 Adjustments of rivers.

Advantage of the submitted flood control is its near-natural character. For the reduce of the flow would be helpful to not only divide it into the parallel channel, but also the fact, that the new channel leads through the riparian forests and alluvial meadows where the possible flooding is desirable. For this reason, it should not be suitable to suggest the expansion of capacity, except mentioned silting parts. Diversity of the channel should stay preserved. There would be enough to remove sledges on the silting parts. Last part of the channel should be divided into two branches (Fig. 11), where one of them should copy the current channel and second one should be connected to Lake Gelnarovo and from there to the old riverbed Bílovka. This would prevent backflow after connecting the parallel channel with the main channel of the Odra.

After the implementation of the flood control, it would be necessary to maintain the parallel channel into permanent flow, to avoid excessive silting ponds.

Positive impacts include the creation of the new aquatic and the wetland habitats, increase of the inventory of surface water in the floodplain, improvement of the ecological state of course which would consist in creating new havens and breeding ground for fish and other aquatic animals. There is requested recovery of protected species *Misgurnus fossilis* and *Carassius carassius,* which have been occurred there in the past. In the comparison with the other flood control this one would have lower maintenance costs, low traffic and free service. In terms of preparation, implementation and speed of onset of effect it is a short term matter. In order to achieve as effectively and efficiently as possible the 'active involvement' described in the Floods Directive, it is essential to know what the main goals of participation and collaboration in the flood risk management plan are (Hartmann & Spit, 2016).

REFERENCES

Bubeck, P., Botzen, W. J. W. & Aerts, J. C. J. H. 2012, *A Review of Risk Perceptions and Other Factors that Influence Flood Mitigation Behaviour.* Risk Analysis. 32, 1481–1495.

Čamrová, L. & Jílková, J. 2006. *Flood damage and tools for their reduction.* Prague: JDS print Prague, 420 p. (in Czech)

The Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy)

Dyhouse, G. R., Hatchett, J. & Benn, J. 2003. *Floodplain Modelling Using HEC-RAS.* Watertown, Bentley Institute Press. 696 p. ISBN 978-1-934493-02-1.

Fan C., Ko C-H. & Wang W-S. 2009**.** An innovative modelling approach using Qual2K and HEC-RAS integration to assess the impact of tidal effect on River Water quality simulation. Journal Environment Manage, 90(5),1824–1832.

Gain, A. K., Mojtahed, V., Biscaro C., Baldi S. & Giupponi C. 2015. *An integrated approach of flood risk assessment in the eastern part of Dhaka City.* Nat Hazards, 79(3), 1499–1530.

Garcia, X.-F., Schnauder, M. & Pusch, T. 2012. *Complex hydromorphology of meanders can support benthic.* Hydrobiology. 685, 49–68 p.

Gibson, S., Brunner, G., Piper, S. & Jensen M. 2006. *Sediment Transport Computations in HEC-RAS.* Eighth Federal Interagency Sedimentation Conference, Reno, NV, 57-64.

Hartmann, T. & Spit, T. 2016, *Legitimizing differentiated flood protection levels – Consequences of the European flood risk management plan*. (55), Part 2, 361–367.

Just, T., 2005. Water management revitalization and their use flood protection. Prague: Agency for Nature Conservation and Landscape Protection of the Czech Republic AOPK. 359 p. (in Czech)

Knebl, M., Yang, Z-L., Hutchison, K. & Maidment, D. 2002. *Regional scale flood modelling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin*. Journal Environment Manage. 75(4), 325–336.

Kříž, V., Kupčo, M. & Sochorec, R., 1979. *Flow stream measurement.* Made on purpose text of the Czech Hydrometerological Institute HMÚ. Prague: HMÚ, 120 p. (in Czech)

Kunzler, M. Huggel, C. & Ramirez, M. J. 2012, *A risk analysis for floods and lahars: case study in the Cordillera Central of Colombia.* Nat Hazards 64. 767–796.

Máchová, J. & Hovorka, P., 2013. Flood control measures. 1st edition. Vodňany: Moderate Fishing School and College of Water Resources and Ecology. ISBN 978-80-87096-17-8, 169 p. (in Czech)

Mattas, D., 2001. *Practical hydrometric exercises. Instructions.* Prague. Czech Technical University CVUT. Faculty of civil engineering. Department of hydraulics and hydrology. 24 p. (in Czech)

Nakamura, K. Tockner, K. & Amano K., 2006, *River and Wetland Restoration: Lessons from Japan.* Bioscience.. 56, 419-429.

Novák, L. & Novák L. Jr., 2011. Flood control measures in the Czech Republic. Prague: Czech Association of Scientific and Technical Societies. (in Czech)

Papaioannou, G., Loukas, A. & Vasiliades, L. 2016. *Flood inundation mapping sensitivity to riverine spatial resolution and modelling approach.* Natural Hazards. 1-16.

Pappenberger, F., Beven, K., Horritt, M. & Blazkova, S. 2005, *Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations*. Journal of Hydrology. 302, 46–69.

Řehánek T. & Kříž V. *Tutorial of hydrology*. Vyd. 1. Ostrava: University of Ostrava, Faculty of science, 2002. ISBN 80-704-2823-6.

Technical Norm TNV 75 2415, *Polders.* January 2013. Prague: Sweco Hydroprojekt s.c. 18 p.

Technical Norm TNV 75 2103, *River training.* 2014. Prague: Sweco Hydroprojekt a.s.. 47 p.

Technical Norm 75 2101, *The greening of river flows.* 2009. Prague: Sweco Hydroprojekt s.c.17 p.

Tsakiris, G. 2014. *Flood risk assessment: concepts, modelling, applications.* Nat Hazards Earth System

Sci, 14, 1361–1369.
Unucka, J. 2014. *Environmental modelling 1*. Ostrava: Ostrava University, 209 p. (in Czech)
Wang, Z., Lai, Ch., Chen, X., Yang, B., Zhao, S. & Bai, X. 2015, *Flood hazard risk assessment model based on random forest.* Journal of Hydrology, 527, 1130–1141.
Weiß, A., Matouskova, M. & Matschullat, J. 2008, *Hydromorphological assessment within the EU-Water Framework Directive-trans-boundary cooperation and application to different water basins.* Hydrobiologia. 603, 54-72 p.
Zuna, J., 2008, Torrent control. Prague: Czech Technical University CVUT. 638 p. (in Czech)

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