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The design of environmentally friendly flood protection measures on the catchment of Klišský creek

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Děkan

V Praze dne 11. 3. 2011

I declare that this thesis is my own work. I used literature and background material presented in the attached list of references.

In Prague on 30 April 2011

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Abstract

The floods and protection against them are nowadays more and more frequent topics for discussion. This thesis is focused on a small watercourse, the Klišský creek. It brings information about the catchment of the creek; description of the natural condition, rates of N year discharges and history of flood events. Three possible variants of environmentally friendly flood protection measures were designed on the given plot on the creek and evaluated. I considered their efficiency and suitability according to certain criteria. The main purpose was to alleviate devastating flood effects during the increased water rate and at the same time not to harm ecological condition of the place, or if possible, improve it. The outcomes of the multi criteria analysis are described in the final part and the overall effectiveness and viability of the best variant is considered.

Key words: flood, torrential rain, flood protection measure, detention basin, wetland

Contents

Introduction

The topic of my thesis is „Environmentally friendly flood protection measures“. I find this topic of great importance, interest and urgency. In recent times floods have become more frequent and more devastating both in the Czech Republic and in the rest of the world. Floods and other natural disasters seem to have become almost a common occurrence. What is the cause of this increase in such extreme situations? Some blame human activities, others point to natural climate changes. Wherever the truth lies, the nature is too powerful and humans have to respect it.

Humans cannot command wind or stop water. However, they can respect nature´s laws and patterns, live in harmony with it. They can let water flow naturally and give it space to overflow. In the past, humans attempted to manage water flows however they pleased. Rivers were straightened, shortened, houses built wherever humans liked. The damage that was and will be caused by floods is the revenge for such reckless behaviour.

A slight increase in rainfall has been observed in the last decade; however it cannot be considered the main cause of floods. More blame is to be put on human interventions in the flow of rivers, disrespect for the needs of rivers during an increased rate of water flow (building up active flood zones) or lowered infiltration capacity of land in the catchment areas as a result of massive development of houses or new road and motorway construction.

In my thesis, I will describe the actual situation of a small stream, the Klíšský creek, which flows near and through the city of Ústí nad Labem. In summer 2010 the area was hit by a flash flood, causing damage to property and paralysing temporarily the life in the neighbourhood of the stream.

My aim is to suggest possible versions of environmentally friendly flood protection measures and evaluate their efficiency and suitability according to certain criteria. I do not intend to provide exact technical specifications of these versions but to assess their overall effectiveness and viability.

Methodology

While working on this thesis I proceed as follows. First, I collected all the necessary materials and data about the creek. I obtained important material from the municipality of Ústí nad Labem and from the manager of the Catchment of Klíšský creek, from the Management of the Catchment of Ohře River, state company, plant Teplice. I also conducted some observational research in the area. Valuable data were gained from the Czech Hydrometeorological Institute, mainly daily rainfall amounts and discharges of the creek. Further, I studied literature focused on the topic of flood protection measures, in particular environmentally friendly flood protection measures. I made my own design of solutions of flood protection measures on chosen plot and finally I evaluated them. In regard to the process, my thesis is divided into three main parts; background research, research application and results with discussion.

The first part, The Background research, starts with brief explanations of several scientific and technical terms, which I find useful for better understanding of the thesis. I provide some definition or description of terms. Further in this part, I describe the whole area of interest; the catchment of Klíšský creek. There is a description of the natural condition of the territory and a brief history. After that, I describe the watercourse itself in more detail; where it flows, the profiles of the stream, discharges and flood plain zone of the creek. Also, I give an overview of the recorded flood events on the creek and focus on the last and biggest one of the August 2010. Here I tried to bring as much information regarding the event and use it for design of the solution of flood protection measures. Lastly I bring some specific information that may concern any flood situation now or in the future.

In The Research application part I suggest possibilities of flood protection. On the given parcel I designed three variants of environmentally-friendly flood protection measures. The design of the variants is based on the knowledge gained from the literature, the observations of realized projects and from the discussion with specialists.

From the three variants proposed I tried to choose the optimal one. The selection of the optimal variant follows the Methodology for design and construction of optimal variant of flood protection measure and anti-erosion measure to alleviate extreme hydrological events-flood and drought in the landscape.

The aim of this activity is to collect material for the assessment process, which will lead to the recommendation and selection of the optimal variant from the various proposed methods and options, therefore, from the options, or systems of flood protection measures and erosion control measures in a certain type of landscape.

It is assumed that a variant of the proposed methodology will be created according to the optimal (best of the best) and not only in the hydrological sense, from the perspective of hydrological safety, but it will meet the claims of the other aspects such as ecological, social, economic, water management and health. (*Kovář, 2008*)

The important step in the assessment process is to set the criteria for adjudication of variants. In my case I chose five criteria. The first one is hydrological criterion; how much water is the facility able to catch? The second one is economic criterion; how much does it cost? The third one is ecological; does the construction bring a positive change to the biodiversity of the area? The fourth criterion is technical; how difficult is it to make it? The fifth-aesthetical one: How does it fit in the landscape?

For the hydrological criterion, I calculated the water retention capacity of each facility and also I consider its possible control of water velocity. Therefore I used verbal-numerical scale for assessment of the criterion. The evaluating scale:

[5] The best variant; maximal retention capacity more than 20 000 cubic meters, high mitigating effect on water velocity

[4] Very good variant; retention capacity more than 10 000 cubic meters, significant velocity control

[3] Medial variant; retention capacity less than 10 000 cubic meters, moderate velocity control

[2] Sufficient variant; minimal or no retention capacity, partial water velocity control

[1] Insufficient variant; no retention capacity and no water control potential

I calculated capacity for water retention of each facility. I needed the surface of the basin, distances and height of the dam. The values were obtained from the map of the city of

Ústí nad Labem website. The application is made in GIS programme and distances can be measured precisely. The equation I used (*Vrána, 2008*):

$$V_i=0,5.(S_i+S_{i+1}).\Delta h$$

V_i ***volume in between two contour line [m³]***

S_i ***area limited of contour line i [m²]***

S_{i+1} ***area limited of contour line i+1 [m²]***

Δh ***difference of the high of adjacent contour line***[1]

To set the volume of detention basin is possible from the equation:

$$V=S.C.P$$

V ***volume of the basin [m³]***

S ***surface of the catchment [m²]***

C ***runoff coefficient***

P ***precipitation[m]***

For runoff coefficient I used the value of 0,05 for the area covered with vegetation. I calculated the filling time for a given discharge. The values of discharges were taken from the Study of the area (*Krise, 2008*).

For the permanent partial flooding of wetlands I calculated the minimum of water necessary to take from the creek. The equation for this is:

$$W_{\text{income}} = P\text{-}E\text{-}I$$

W_{income} ***Water income [mm]***

P ***precipitation [mm] annual average***

E ***evaporation [mm] annual average***

I ***infiltration [mm]***

We have to multiply it by surface of the wetland and add volume of the wetland itself.

The average annual precipitation of the area is 610 mm (*CHMI, 2011*), annual average evaporation 365mm[2] and infiltration capacity for this site is $K=10^{-6}m.s^{-1}$ for year it is 31 536mm

[1] Commonly this equation is used with map of scale 1:2000 and bigger with contour line 1m apart. I use it for map of scale 1:10000 with contour lines 2m apart.

The value for economical criterion of each variant I estimated according to primary investment; the cost of the material which I need for constructing the dam or slide. I consult the price of material with a construction engineer and with the prices publicly accessible on the internet. I calculate approximate cubature of dams and slide and multiply it by average price of material. The values of the criterion are stated in Czech Crowns.

Ecological criterion was evaluated from the point of view of biodiversity; if the variant brings positive effect on natural condition of the locality, if the biodiversity increase?

[5] The best variant; high improvement of natural condition and increase of biodiversity

[4] Good variant; positive change in natural condition and some increase of biodiversity

[3] Medial variant; slight positive effect on the natural condition and biodiversity

[2] Neutral variant; neither positive nor negative effect

[1] Totally unsatisfactory variant; deteriorate effect on the locality

For technological criterion I consider technical demands of realization of each variant, demands of project documentation and also risk of default of realization.

[5] The most demanding variant; detailed and professional project documentation, complicated construction, special security requirement, risk of default or failure

[4] Demanding variant; construction is not so complicated, the documentation is needed, security requirements, risk of default

[3] Medial variant; no special requirements for construction, no reason for default

[2] Modest variant; simple construction, no risk of default

[1] The simplest variant; very easy or any construction

Aesthetical criterion I assess according to overall impression of each variant. How it fits in the landscape, if it is attractive and interesting solution of landscape design.

[5] The best variant: create very good impression from the locality, high increase of attractiveness of the place.

[4] Good variant: create positive impression from the locality, interesting solution

[3] Medial variant; neither positive nor negative effect

[2] Not so suitable variant; disruptive effects are partially limited

[2] The data obtained from observation in Bedřichov (Jizera mountains) 1.3.-30.9.2010 made by Masaryk University in Brno

[1] Totally unsuitable variant; disruptive effect

Each variant was assigned the value of every criterion.

	Var. A	Var. B	Var. C	unit	Var. A	Var. B	Var. C
Hydrological criteria	Pa1	Pb1	Pc1	[Relative unites]	Ua1	Ub1	Uc1
Economical criteria	Pa2	Pb2	Pc2	[Czech Crowns]	Ua2	Ub2	Uc2
Ecological criteria	Pa3	Pb3	Pc3	[Relative unites]	Ua3	Ub3	Uc3
Technological criteria	Pa4	Pb4	Pc4	[Relative unites]	Ua4	Ub4	Uc4
Aesthetical criteria	Pa5	Pb5	Pc5	[Relative unites]	Ua5	Ub5	Uc5
				Total ∑	∑Ua	∑Ub	∑Uc

Table of P and U values

We need to transfer value P to value U which lies in the interval <0;1>

$U = \left[\frac{P - Pp}{Pk - Pp} \right]^k$, (resp. $U = 1 - \left[\frac{P - Pp}{Pk - Pp} \right]^k$ e.g. for the technical criteria)

Pp is P initial Pp = Pmin – d ; d = (Pmax – Pmin) / 10

Pk is P final Pk = Pmax + d.

P is arithmetic average of P for one criterion. Because value U is in interval <0;1> the average of U is value 0,5.

From this we calculate parameter k for each criterion. Then for every parameter P we substitute values from the table and we get U values.

Vertically, we sum values for each variant and we get complex indicator for each variant. The variant which has the biggest value of the indicator is the best one. In comparison with the others, It has the best characteristics, it is the most suitable; it is the optimal one.

Final formula for estimation of each variant can be formed as:

$$U_v = \sum_{i=1}^{k} U_i$$

U_v ***final value of each variant***

k ***symbol of the criterion***

i **number of criterion**

U_i ***corresponding indicator to each variant***

In the part results and conclusion you find the outcomes from the analysis, their evaluation and discussion.

Background research

Terminology

Flood

We can find loads of definitions of flood. I chose two; first one is from the Czech Water Act.

“Flood shall be a temporary marked increase in the water level in a watercourse or other surface water body, causing water to flood the surrounding land outside the watercourse channel, and being possible causing factor of a damage; flood shall also be a condition under which water can cause damage by the fact that it cannot temporarily flow away in a natural manner or the outflow of water is insufficient or the area is flooded by a concentrated outflow of precipitation. Flood can be caused by natural factors, particularly by snow melting, rain or movement of ice (natural flood) or other factors, in particular by failure of a water management structure which may lead to its collapse or by taking emergency measures in critical situations (special flood).” *(The Water act, 2001*)

“Flooding is related to increased discharge in stream channel. Stream discharge leaves the stream channel and covers all or parts of the adjacent floodplain.” (*Potter, 2003*)

Torrential rain

Torrential rain is a strong abundant rain, which has fast on-set and takes short or long period. Usually it is connected with the thunderstorm. Frequently this event occurs in summertime. In most cases, it takes about 30 minutes, which is characterized for dynamics of storm rain.

Torrential rain sometimes brings extreme amount of precipitation in a very short time so that water cannot normally run off from the area where attacked. Alternatively, the rain comes in various storm units and the precipitation repeatedly falls out on the same territory that causes very dangerous accommodation of rainfalls.

In both cases, the torrential rains can cause flash flood.

We consider precipitation with intensity of 30mm/h as an intensive rain. In extreme cases the intensity of rain reaches up 100mm/h.

Flash flood

Flash flood is rapid flooding of a territory, often caused by torrential rain. Rain falls quickly on saturated or dry soil that has poor absorption ability. In addition, causation of flash flood can be failure of barrier holding back water (dam break etc.). Flash floods usually take short time (up to 6 hours), affect the areas of small size and occur on the small watercourses. The typical time of occurrence is from April until September.[3]

Flash floods are typical for dry areas or mountainous/foothills areas. It could occur also in areas where the infiltration to the soil is limited e.g. paved urban areas or areas with congested sewage.

The danger of the flash flood is its rapidity, intensity and unpredictability. It converts small innocent creeks or dry watercourse into the violent and big rivers with great strength. Landslides, especially in mountainous areas where the steep slopes accelerate the speed of the water, accompany the floods.

Flood control

Miller, J. B. simply expressed the idea of protection against flood in his book *Floods - People at Risk, Strategies for Prevention* (1997). He said:"Keep the flood away from the people! Keep the people away from the flood!"

In the spirit of the idea mentioned above, we can divide the flood control on two main groups. First one, which keeps the water away from the people, is technical (structural) flood protection measures. Especially, it is retention dams, dikes, increase of channel capacity, its stabilization (fortification), building of protection walls and civil engineering-biological measures to reduce erosion and increase retention in the watershed. For keeping the people away from the flood serves the nontechnical (non-structural) flood control such as a definition

[3] Web: National weather service

of floodplain zones and their legal provision, forecasting and warning systems, public education and responsible behaviour in flood risk situations.[4]

From the point of view of health and life protection of the people, there are more important technical flood protection measures on the watercourses with the reaction time less than 3 hours. [5]

Environmentally-friendly flood protection measures and river restoration

Environmentally-friendly flood protection is closely connected with river restoration. Aim of river restoration is to return a watercourse in its pre-disturbed state. It wants to repair the wrong actions, which were done on it in the past (e.g. shortening, rectifying, deepening their channels or bank and bottom reinforcement). River restoration wants to bring the rivers and creeks back in their natural channels, renovate their retention capacity and increase biodiversity and aesthetic value of the area.[6]

Environmentally-friendly flood protection measures aims to achieve both nature conservation and flood risk management objectives. It uses the natural characteristics and processes of the watercourses to prevent or mitigate devastating effects of floods. The main objectives include:

1. Support of natural alluvial flooding (Flood banks removed or set them back from watercourse)
2. Construction of close natural channels (Restoration of meanders and natural channel depth or width)
3. Support of retention of flood water in the depressions in floodplain (Making pools, bogs, swamps)
4. Construction of multifunction semi-dry detention basin
5. Slowing down the stream (Creation of berms, backwaters and different channel profiles, addition of gravel and stones in the channel)
6. Remove obstacles from the channel(weirs, grades)

[4] Web: CECWI
[5]Web: CECWI
[6]Web: Agricultural and rural development

(*Just, 2005*), [7]

Detention basin/ Polder

Detention basin is water management facility, which is designed to protect against flooding. It is consider as a small water reservoir. They are made by damming of watercourse. Detention basin are also called “dry ponds”, in case there is no water permanently, or “wet ponds”, where is some water all the time.

Single purpose dry polder as only hydro technical object we do not consider as environmentally-friendly flood protection measure and with restoration has nothing in common. It is quite difficult to utilize inner area of the basin; because even it is “dry” the soil is really moisture which is not optimal condition for cultivation. Another problem is security of the structure. The dam is dry for long time and when flood comes suddenly has to catch big amount of water; there is a danger of dam failure. Also the dam is vulnerable to vandalism or the damages of animals. So it has to be checked regularly. That is why the costs of maintenance are high. (*Just, 2005*)

Semi-dry multifunction polders are interesting for restoration. They bring more functions that are positive to the area. Complete flooding zone and adjust surrounding has natural character. There is permanent partial flooding in the basin (it has also a positive effect for the stability of the dam) with wetlands, pools, meadows and riparian forest (willows are recommended for their moisture toleration). The inner area and adjust surrounding don serve for intensive agricultural purposes. (*Just, 2005*)

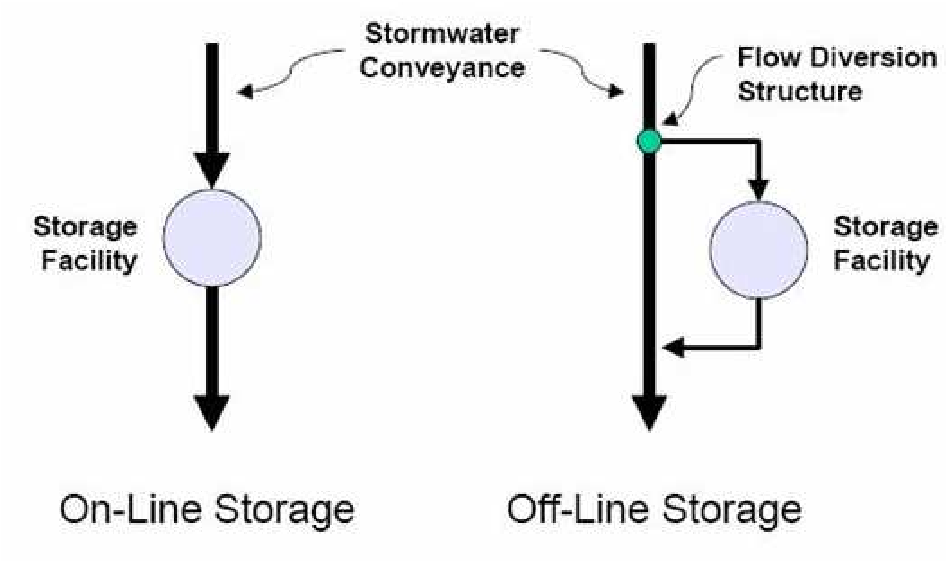
There are two options for the construction: On-line storage and off-line storage.
“Online storage uses a structural control facility that intercepts flows directly within a conveyance system or stream.

Off-line storage is a separate storage facility to which flow is diverted from the conveyance system.”[8] Off-line storage has certain advantages over the online one. It allow closed retention which cloud be used just during the culmination. The online storage fills continuously in dependence on rising of water level. On the other hand the off-line system has

[7] Web: Agricultural and rural development
[8] Web: Storm water quantity and quality management

also its disadvantages; it functions only to a certain extend of flood, the solution of water income is complicated and when it is flooded completely it does not help anyhow, neither slow down the water flow. (*Just, 2005*)

There are high demands on security of dams, because in case of failure the breakthrough wave would have had much worse consequences that the natural flood wave.



1 Scheme of two possible ways of detention basin[9]

Wetlands

Wetland is an area of land whose soil is saturated with moisture. It is flooded by water either temporarily or permanently. Wetlands are natural or manmade, with running or stagnant water, with fresh, brackish or salt water.

As wetlands we consider marshes, bogs, swamps, sloughs, tules, bayous fens with herb and woody vegetation, estuaries of rivers, lagoons, ponds, pools, lakes, and dams. (Just, 2004), (*Hammer, 1991*)

In Czech condition, we often consider the wetland as an ecosystem in which the carbon fixation predominates directly from the atmosphere. These ecosystems are reeds (littoral zones of pond and lakes), river floodplains, flooded meadows, riparian forests, and peat bog. (*Just, 2004*)

[9] Web: Web: Storm water quantity and quality management

“Wetlands are considered the most biologically diverse of all ecosystems.” There are many species of plants and animals (amphibians, reptiles, birds etc.).

They can serve as a natural wastewater purification system, retain water in the landscape and help to mitigate flood discharges of watercourses. (*Just, 2004*)

From the water management point of view wetlands represent active form of water retention in the landscape. They are attractive for restoration because of their low initial and managing costs. Additionally, the wetland flooding itself leads to the fast development of naturally authentic communities. (*Just, 2004*)

Close to the wetlands are other objects (e.g. pools), which do not have character of small water reservoirs. Pools are depressions, made by digging, without bottom outlets. Above all, they are constructed as a valuable site to the fauna and flora. However, various wet depression could significantly help to increase retention capacity or flood discharge of the area.

Legislation

The main legislative acts which deal with the construction of flood protection measures:

The Water act No.254/2001, on Water and Amendments to Some Acts (The Water act), especially chapter 9 Protection against floods.

Building act No.50/1976 coll., on town and country planning and building code (Building Act)

Act No. 114/1992 Coll., on the protection of nature and landscape

Act No. 185/2001 Coll., on wastes

Recommendation from Ministry o Environment, Czech technical standards (ČSN 75 2410, TNV 75 2910, TNV 75 29200

The locality

Natural conditions of the catchment area

Geography

The Klišský creek lies in the north of the Czech Republic near the town of Ústí nad Labem in the catchment of the Elbe River, river-drainage area of the North Sea. It is situated

below the Ore Mountains. The total length of Klišský creek is 13.96 kilometres and area of the catchment is 39.45 square kilometres. The creek starts in the village of Libouchec from the Jílovský stream with water divider in the altitude of 446 m. s. l. It flows in a southerly direction and it empties into the Bílina River in Ústí nad Labem in the altitude of 136 m. s .l. (*Krise, 2008*)
Ústí nad Labem is surrounded by three large protected landscape areas (PLA) and various smaller natural sites. The Elbe sandstones PLA are situated in the north, The Eastern Ore Mountains PLA in the west and North West and Bohemia Uplands PLA in the east. The major part of the Klišský creek goes though the last one.

Climate

The catchment of the Klišský creek lies in the mild temperate climate zone with warm summers and cold winters. The average annual temperature ranges from 8 to 10 °C. The coldest month is January with the temperature around - 1°C and the warmest month is July with the temperature around 19°C. (*CHMI, 2011*)

The average annual precipitation is 610mm (long-term average from the years 1978-2010). The highest annual average is 978mm in 2010. We can observe a slight increase in the precipitation in the last five years. Till the year 2000, there was no daily amount of precipitation higher than 50mm, but in the last five years the precipitation frequently exceeded 50 mm, the highest figures being in the years 2002, 2009 and 2010. (*CHMI, 2011*)

Geology

Like a most of the territory of the north of the Czech Republic, the area around Ústí nad Labem belongs to the Bohemian massif. The geological structure is very complicated, displaying rocks of diverse age, origin and chracteristics. It is reflected in a rich variety of forms of relief. The area displays the Ore Mountains' crystalline rocks (gneiss, Telnice granite massif); chalk sediments (particularly sandstone rocks) rise in the Tisá Sandstone Rocks as well as in erosion remains on the crystalline plateau in the basins of the River Elbe and the River Bílina. Sedimentary and volcanic rocks represent tertiary activity, the most visible in this area. [10]

[10] Web: Statutory city of Ústí nad Labem official site

Around the creek we can find mostly diluvial, loamy and stone sediments. There are loess (late Pleistocene); fluvial sandy clay and loamy sands, quaternary sedimentary; rock-clay, loess, gravel, sand, tertiary volcanic rocks; basalt, phonolite, Mesozoic sedimentary rocks; sandstone, marl, clay stone. [11]

The most frequent soils which we can find around the creek are luvi soils.

Hydrology

The observed creek belongs to the basin of the Bílina River. Bílina is the biggest tributary of the Elbe River, it deepened a valley in the Teplice Uplands in the Ústí nad Labem region and it joins the Elbe River below Větruše in Ústí nad Labem. [12]

The Elbe River is the main watercourse in the region. At Porta Bohemica, it breaks through the Bohemian Uplands, where it has formed a valley going as deep as 300-500 m below the original terrain surface. Sluices beneath the Střekov Castle dam the stream and along its flow, the banks have been technically adapted. In some parts, the banks are similar to the original natural environment these days (the right riverbank from Olešnice downstream as far as the left bank in Povrly). [13]

History

The references to the Klišský creek we can find already in 13th century. The springs of the creek collect on the meadow near the village of Knínec. In 1487, wise councillors purchased a half of the stream of Jílovský creek from the Vartenberks from Děčín to strengthen steam of Klišský creek. Up to the present day water flows in the channel from Jílský creek in direction to the village of Knínec. The channel starts in the village of Libouchec on a garden of one cottage. There we can find original plate mark of water divide from the year 1487. [14]

Klíšský creek on its way passes villages of Žďár, Strážky and Boštěšice were the life pulsed already in 12th century. People used the water from the creek for mills and fountains. Then on Bukov the watercourse enters the town of Ústí nad Labem. Initially the creek was a

[11] Web: Czech geological survey
[12] Web: Statutory city of Ústí nad Labem official site
[13] Web: Statutory city of Ústí nad Labem official site
[14] Web: Chvojensko.cz

romantic part of the town. Later how the town grew up people started to use the creek as a black dumping side. Perhaps that is the reason the creek disappeared under the ground at the beginning of 20 century. It flows in Earth’s crust break. By the stadium continues into the underground tunnel that goes in parallel with Masarykova Street or under it. It flows through Spolchemie and under the railway station west vents into the Bílina River.

2 Photos from the same place but in different times, near the nowadays street of U Stadionu [15] , (Kirs, 2008)

Description of the creek

In the year 2008 was elaborated study of floodplain zones of Klišský creek. The reason for this study was the increasing danger of floods, the need to evaluate new investment intentions in the floodplain zone and from the perspective of flood protection. Mayor data about the watercourse I extract from this study (*Kirs, 2008*).

Water course

Klišský creek originates in the village of Libouchec and it flows through the fields to the village of Malé Chvojno. First it crosses the road I/13 and then it goes under the old train way at the industrial part of the village of Malé Chvojno. It continues to the village of Ždár where takes along the Ždárský creek from the left side and enters the tide forest valley. There is diversion structure for the Habronický pond (Bílý creek) in the village of Strážky. Then the creek crosses meadow with small young forest of willows, below which the Ptačí creek vents into it

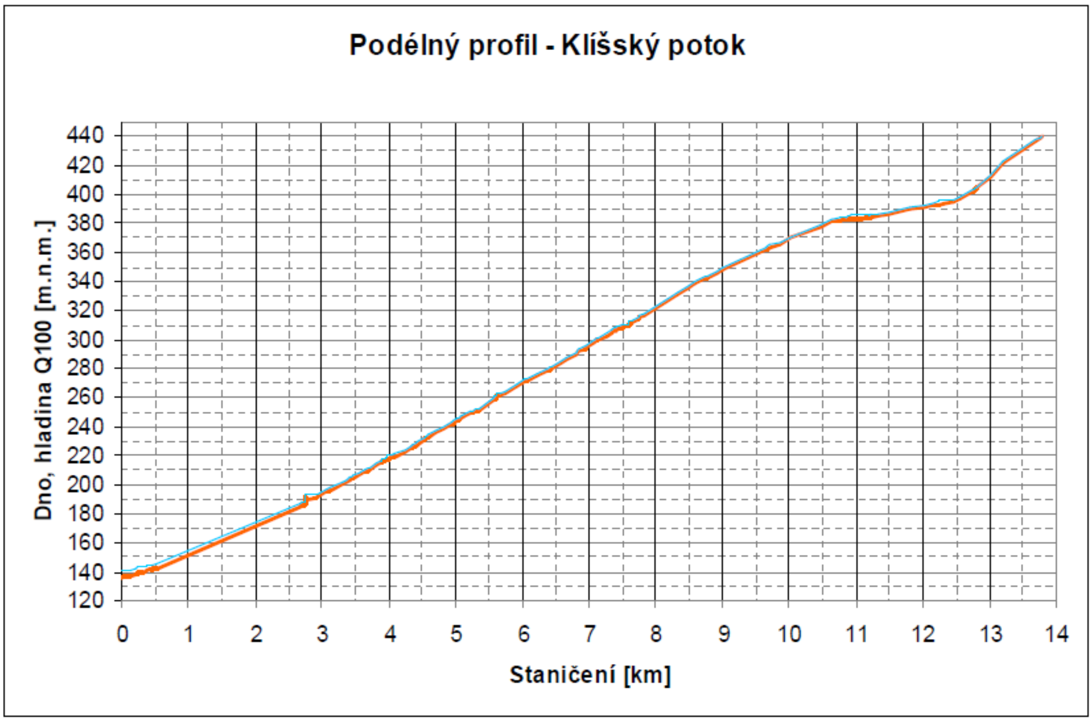
[15] Web: Chvojensko.cz

from the left side. It passes through the village of Božtěšice where in lower part Chuderovský creek comes into it from the left. Then it already enters the town of Ústí nad Labem. The Bílý creek from the Habronický pond comes again in it from the right side and then it continues to the stadium. There is the retaining watercourse baffle (štěrková přehrážka) just before the creek enters into the closed profile under the town. Once it goes up on the surface by the spa under the Panská Street and then again goes back in the underground in the area of Spolchemie. Under the train station of Ústí nad Labem west empties to the Bílina River.

The profiles

Longitudinal profile

We can see the longitudinal profile of the creek on the graph. It starts from the altitude of 446 m. s. l. and finish in the altitude of 136 m. s. l. On the length of 13,96 km crosses height of 310 meters. The slope of the creek is 2,22 %.



3 Longitudinal profile of Klišský creek (*Kirs, 2008*)

Cross section profile

The width of the channel oscillates from 3 to 10 metres. Through the landscape the channel is wider, about 7meters, but when it passes urban area it reaches a length of only 4 meters. Also the depth is changing in regard to where the stream is passing. Usually in urban site the channel is deeper and the banks are much steeper.

The Channel

When it passes through the urban areas the stream is in the channel with the bottom and sides made from the stones or it is concrete. In the field and forest the stream is natural. In the town of Ústí nad Labem it is in the deep concrete or stony channel and in the underground part goes into the closed tunnel with concrete ceiling beam, arcs and frames.

Vegetation and fauna

The creek is lined with trees along mayor part of its way. Behind them is arable land or meadows. The main tree species are black alder, ash and willows. The creek belongs to the trout zone in regard to the classification of fish zones, we find there trout. However, their abundance was grater in the past.

Hydrological dates

Basic hydrological data was set by Czech hydrometeorological institute on 4th of July 2008, the branch office in Ústí nad Labem, Ing. Jirásková (code: PO8541001042/OH). All information I took from Study of floodplain zone of Klíšský creek.

Watercourse: Klíšský creek

Hydrological numbers of the catchment:

1. 1-14-01-105
2. 1-14-01-105
3. 1-14-01-105
4. 1-14-01-105
5. 1-14-01-103

Profile:

1. estuary into the Bíliny River km 0.000
2. above the right side bank tributary Bílý creek km 3.312
3. above the left side bank tributary Chuderovský creek km 4.548
4. road bridge above the left side bank tributary Ptačí creek km 6.222
5. above the right side bank tributary in the village Žďár km 11.150

N-years discharges

N-leté průtoky (ČHMÚ) v $m^3.s^{-1}$:

Tok	Profil	[km^2]	Q_1	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}
1. Klíšský	ústí do Bíliny	39.45	7.8	9.8	**11.7**	14.7	**18.5**	28.3	**39.0**
Klíšský*	limnigraf Bukov	35.90	7.3	9.1	**11.0**	13.7	**17.4**	26.5	**36.6**
2. Klíšský	nad Bílým potokem	25.40	5.7	7.0	**8.5**	10.7	**13.5**	20.6	**28.4**
3. Klíšský	nad Chuderovským p.	19.30	4.4	5.5	**6.6**	8.3	**10.5**	16.0	**22.5**
4. Klíšský	nad Ptačím potokem	16.30	3.8	4.8	**5.7**	7.2	**9.0**	13.8	**19.1**
*Klíšský***	*nad Žďárským p.*	*5.86*	*2.7*	*3.3*	***4.0***	*5.1*	***6.4***	*9.7*	***13.5***
5. Klíšský	nad obcí Žďár	3.48	2.4	3.0	**3.6**	4.6	**5.8**	8.8	**12.2**
*Klíšský***	*nad žel. (M. Chvojno)*	*1.56*	*2.2*	*2.7*	***3.3***	*4.2*	***5.3***	*8.1*	***11.2***

Třída přesnosti: IV., tzn. Q_{100}, Q_{50} (±60%), Q_{10} (±40%)

* hydrologické údaje byly doplněny N-letými průtoky limnigrafu Bukov

** *podle plochy povodí byly návrhové průtoku dále rozděleny*

4 Table of discharges (*Kirs,2008*)

Details of high water values are changeable according to new findings. The manner and extent of their potential influence is not known to CHMI.

Study of floodplain zone of Klišský creek

The study was made in 2008 and gives us the detail description of watercourse behaviour at the N-years discharges Q_5, Q_{20} and Q_{100}. The authors of the study evaluate the damages, which these discharges can cause and also the state of the flood protection of adjust lands (floodplain zone for the discharges Q_5, Q_{20}, Q_{100} and active Q_{100})

They point out critical sections on the creek for the future extreme discharges and recommend increase in flood protection.

During the Q_5 discharge there is harmless local flooding of lower inundation (reed, bank vegetation, meadows and gardens)

In case of Q_{20} discharge, there is a partial flooding of meadows and part of the land No. 53 of the village of Žďár. Between the villages of Žďár and Strážky water flows over the lower inundations (bank vegetation and forest). Between village of Strážky and Božtěšice are also flooded the lower inundation (bank vegetation, meadows, gardens, small football ground). In the town of Ústí nad Labem above the street of Božtěšická is partly flooded build-up area on the right bank. Before the creek empties to Bílina River right above the railway station of Ústí nad Labem west, it overflows Revoluční Street. The closed profile is congested and water outflow from relieve valve.

When the water reaches the discharge of hundred years Q_{100}, water overflows the road I/13 (Chlumec – Libouchec). Over the village of Žďár water flows across meadows and in the village floods build-up area before the lower bridge. There are gardens flooded with water in the village of Strážky. In lower part of village of Božtěšice and in the town of ÚL over the Božtěšická Street adjust gardens and build-up areas are flooded. Water floods both banks under the outflow from the closed profile in the town of ÚL. In case of discharge limitations in the closed channel, there will be higher flooding then it is calculated.

The construction of floodplain zone was made as a combination of water-levels calculated and levels of energy in cross section profiles in CAD program. The extension of floodplain zones was constructed with regard to the velocity in the inundations and differences in water levels of independent currents in the cross section profiles. The authors also used video records of the area. Final correction was made during the terrain survey in the field.

Active floodplain zone

Active floodplain zone was estimated according the Methodology of estimation of active floodplain zone (Ministry of environment, version from April 2005): We consider as an active floodplain an area with 80% of total discharge of hundred flood discharge and area where the velocity of the flow lap over 0,5 m.s-1. Design of active floodplain zone is made as a combination of a calculation and a terrain observation.

Important restrictions of activity in the floodplain zone are anchored in the Water Act, section 67 (see following). Unfortunately, people do not respect this law. Consequently, floods cause much higher damages and losses that is necessary.

"1) Locating, permitting and building structures inside the active zone of the flood plain area is prohibited except for water management structures aimed at regulating the watercourse, flood flow routing, performing flood protection measures or measures which are otherwise related to the watercourse or improve the flow regime, structures for water retention, waste water and rain water disposal and also necessary transport and technical infrastructure structures, organizing the setting up of hop fields, if they are set up in the flood plain areas demarcated pursuant to Act 97/1996 Coll., on Protection of Hops, as amended, on condition that measures to minimize the effect on flood flows will be simultaneously put into effect.

2) The following is also forbidden in the active zone

a) extracting raw materials and soil in a manner deteriorating the surface water flow and carrying out terrain modifications deteriorating the surface water flow,

b) storing materials, substances and objects that could be washed away,

c) erecting fences, hedges and similar obstacles,

d) establishing campgrounds and other temporary accommodation facilities.

3) The water authority may stipulate restrictive conditions for the flood plain areas outside the active zone. This applies also if an active zone has not been determined." (*The Water act, 2001*)

Recommendations for improvement of flood protection

The authors of the study of Klišský creek suggest some innovation and recommendation on the watercourse to increase flood protection, they are:

Downstream direction

Km 13,330

Sanation of gash between the original channel and new drainage channel in supply ditch from Jílský creek; usage of the old supply ditch for transposition of water and reduction of the flow across the meadow on the left side

Km 12,798 Protection of the inhabitants

Reduce traffic on the road I/13 (Chlumec-Libouchec); water overflow the road

Km 11,500 Protection of the pond

Reduce inflow to the pond in right inundation above the village of Žďár before water overflow the site dam of the pond.

Km 10,930-10,908 Not to deteriorate the outflow condition in the right build-up area

Do not enlarge embankment on the left bank

Km 7,000

Do not renovate the football ground in the left inundation under the village of Strážky, during the floods will be damage again.

Km 6,660 To stop ruptures of the left bank above the mill

Seal up the entrance to the closed supply ditch on the left side by the old weir.

Km 2,669 Securing the smooth flow in the underground tunnel

To put the metal bars on the entrance to catch big objects. Do not put the engineer networks in the tunnel. Do not reduce the capacity of the tunnel and to reduce damages on the networks.

Km 0,360-0,240 Protection of the area of Spolchemie

Facilitate outflow from the area of Spolchemie to the Revoluční Street

Km 0,227 Protection of the area of Spolchemie against the increased water level

Remove the bars under the relieve valve. (*Kirs, 2008*)

Floods on the creek

Oldest records about floods on Klišský creek are from July 1927 (8-9.7.1927). In the village of Krásný Les, not far from the village of Libouchec, fell 209 mm of precipitation. There was thunderstorm with hails of egg size. Two people were killed. The water took everything which what was in its direct way. However, the houses, which were built on good place or with socl, resisted. [16]

The next flood came after the long time in July 1987 (1.7.1987)

The last and biggest one came in August of last year (12.-15. 8.2010).

Flood 2010

The torrential rains during the days of 7th and 8th of August brought an extreme amount of precipitation. The second batch of fruitful rain came on the 12th of August. Already saturated soil could not infiltrate more water and as a result was flood. The culmination was on 12th of August and took two hours.

The damages on the creek were evaluated to 35 millions of Czech Crowns. Most affected was the lower part of the channel, concretely, the section from the reunion with the Chuderovský creek until the entrance into the underground. Water damaged the concrete and stone fortification of the bottom and sides of the channel. The reason was the great velocity of

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[16] Web: iDnes.cz/zpravy

water. Further damages were inflicted in the underground tunnel and later on the tunnel for the pedestrians under the railway station.

The damages were in the villages of Žďár (more than 1 million Czech Crowns), Boštěšice, Ústí nad Labem.

5 The underground tunnel for pedestrians under the railway station and an area near of Spolchemia from the day 12.8.2010.[17] [18]

Rightly the flood of the last year demonstrated the unpredictability of the extreme situation on the small streams.

From the Czech Hydrometeorological Institute in Ústí nad Labem I got the information about daily precipitation and discharges on Klišský creek. From the data we can see the discharge dependence on rainfalls.

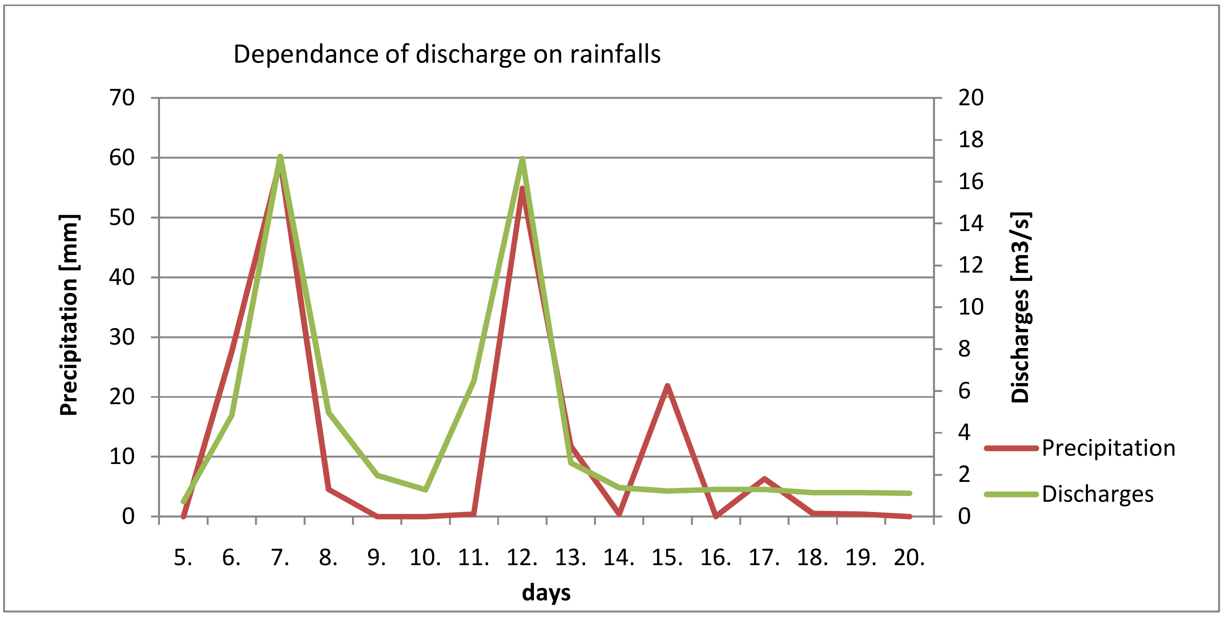
Daily precipitation in mm, station Ústí nad Labem Kočkov 375 m.s.l., for the period of 5.-20.8 2010

Day	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Precipitation [mm]	0	27,6	59,5	4,5	0	0	0,4	54,9	11,8	0,4	21,9	0	6,3	0.5	0.4	0

Average daily discharges in $m^3 \cdot s^{-1}$ for the period of 5.-20.8 2010, Klíšský potok LG station Ústí nad Labem

Day	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Discharge [m^3/s]	0,715	4,83	17,2	4,97	1,96	1,28	6,48	17,1	2,57	1,38	1,22	1,29	1,29	1,14	1,15	1,11

[17] Web: Sportovní noviny
[18] Web: Novinky.cz



6 Graph of dependence of discharge on rainfalls

From the graph we can see reaction of discharge on the precipitation. There is direct correlation between discharge and precipitation from 5th day to 14th day, sharp increase of rainfalls and sharp increase of discharge. Then there is, not so big, but significant increase in precipitation and no change in discharge at all.

Specific characteristics, problems

Floods have always been a natural and integral part of the hydrologic cycle in our country. In last decades has changed a lot of things in the act, behaviour and costumes of the people. Some of them are directly or indirectly connected with flood on our stream, here I will point them out.

First I mention an increase of build-up area around the creek. New family houses grown on the slopes of the stream like mushrooms after the rain. The trend to settle outside but close the town led to spread out the urban areas mainly in Božtěšice Village. Fields and meadows converted to a concrete area which has a way smaller infiltration capacity. "Urbanization of a drainage basin increases the amount of runoff reaching a channel and decreases the lag time between a precipitation event and peak flow."(*Potter, 2003*) The problem is also the need of drainage system of the houses which is obligatory according to the law. For some people is complicated or too expensive connect their house to a central municipal drainage system. They do their own (or with few other houses) outflow from their drainage system and let it empty to the creek. This is problem for the manager of the catchment, because it is unexpected and unknown increase of discharge of the stream. (*Stejskal, 2011*)

Another question is why the losses are greater on the new houses then on the old ones. The great problem of today is too short human memory. Too long period of time between the floods let the people forget where the water went trough. Before people lived few generations on the same place and knew where and how high water came. They had a lot of observation from nature; for example, when the stone called Frog in the stream was flooded they knew that big flood will come. There were plenty of these observations and people follow it and respect it when they constructed their houses.[19]

Also water from a nearby highway flows to the creek. It is another considerable source of increased discharge. (*Stejskal, 2011*)

Further there is the matter of floodplain active zone. They set the active floodplain zone of Klišský creek in the year of 2008, but it came into force in 2009. Until this time people had built whatever and wherever they pleased and still they can if they have enough money. (*Stejskal, 2011*)

[19] Web: iDnes.cz/zpravy

Research Application

The objective of this research is to find the optimal solution how to mitigate the destructive effects of flood on the Klišský creek. The aim is to slow down the velocity of water and catch as much water from the increased discharge as possible to the designed flood protection measure. We have limited possibilities of area. I try to find the optimal way to satisfy the flood protection objects with minimal negative effect on nature.

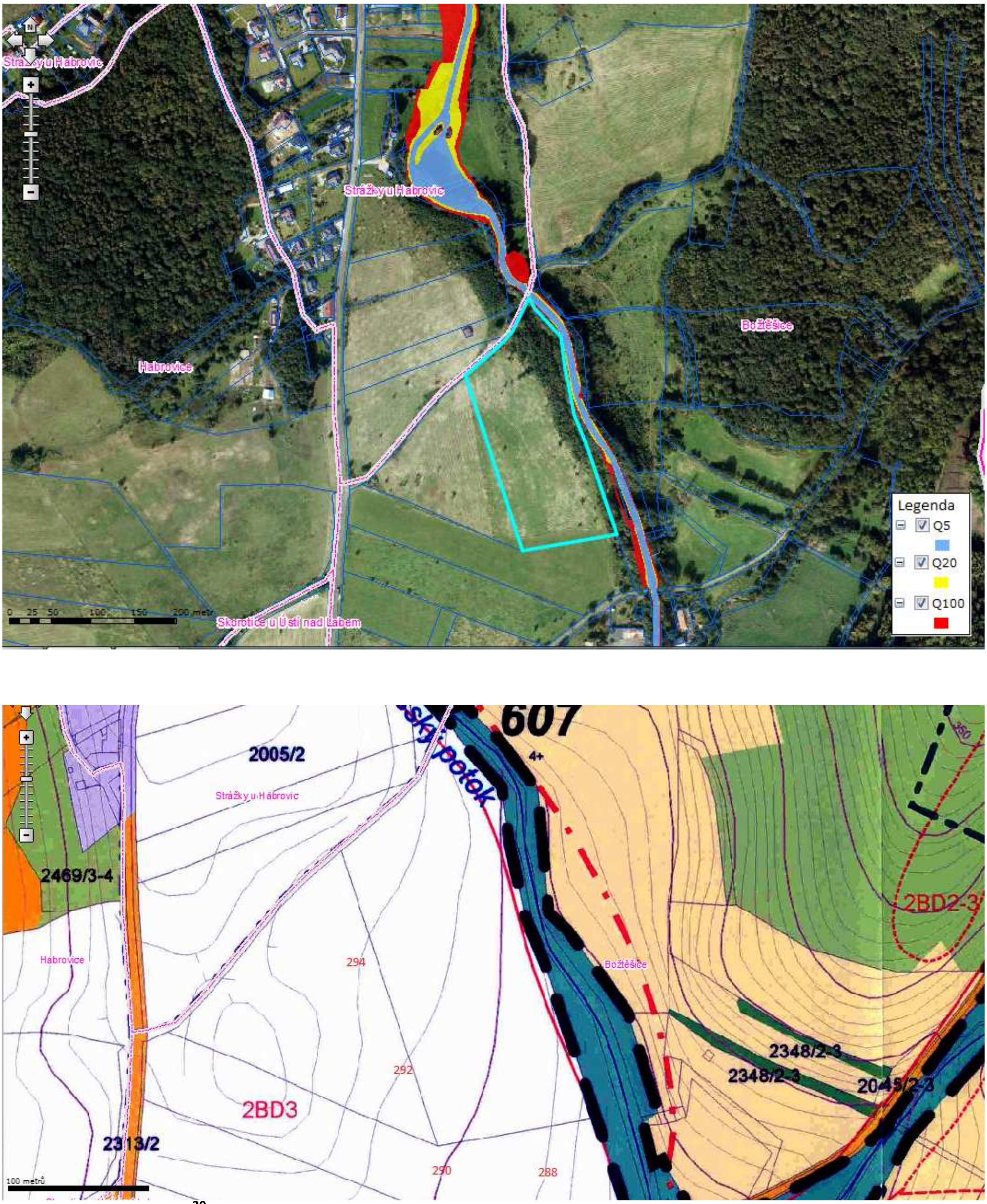
The observed plot

The possible area for realization of any flood protection facility is located between 6,4 km and 7,0 km of the creek. This locality has been chosen in regard to the morphologic condition, technical possibilities and ownership possibility, the last one was fundamental constraint. This plot is without build-up areas along the creek. There is a space for water to inundate and easy access to the place. Specifically, it is parcel number 227/1 from cadastral area of the village Božtěšice own by Land Fund of Czech Republic. The plot is 29 633 m^2 big with arable land. It is under protection of large Protected Landscape Area, agricultural fund land. The altitude of the terrain runs between 296m.s.l. and 286m.s.l. The slope of the plot is relatively big.

For my measurements I used N year discharges from the 4. measured place-road bridge above the left side bank tributary Ptačí creek km 6.222 . The values are:

The creek	Measured place	Catchment area [km^2]	Q_1 [m^3/s]	Q_2 [m^3/s]	Q_5 [m^3/s]	Q_{10} [m^3/s]	Q_{20} [m^3/s]	Q_{50} [m^3/s]	Q_{100} [m^3/s]
Klišský	Road bridge above the tributary Ptačí creek 6,222km	16,3	3,8	4,8	5,7	7,2	9,0	13,8	19,1

7 Table of discharges (*Kirs, 2008*)



8 Maps of the locality [20]

[20] Web: Regional plans of municipalities in the district of Ústí nad Labem, current 10th of June 2010

Description of the variants of flood protection measure

Variant A

Semi-dry detention basin

Effective option to retain large amount of water is detention basin. I create the off-line semi-dry detention basin on the left bank of the creek. Along the contour line of 288m.s.l I constructed the dam of high of 4 meters, which create the detention space along with natural slope of the terrain. The maximal surface of basin is 15 800 square meters. The length of the dam is 430 m, the width of the dam in its crown is 3 meters, and slope of it is 1:3 from the waterside and 1:2 from the airside. There should be some steel concrete construction inside the dam for stabilization.

In the stream, there has to be water diversion structure and from there a supply channel to bring water to the basin. At the entrance there is a structure for regulation of water inflow. Small creek flows through the basin. There is an outlet from the basin in lower part. It is possible to regulate both inflow and outflow from the basin. Another channel will bring the water back to the stream. There should be security spillways over the dam.

Maximal capacity of the basin is 29 800 cubic meters.

I decided to make a wetland in the basin. There will be permanent partial flooding of the basin. I calculated with average high of water level 0,2 m in the basin. Of course, due to the slope the water will not be spread evenly. I recommend making diverse structures in the inner part of the basin; create some depressions and elevations. The wetland needs constant income of water. The equation for water income: $W_{income} = P\text{-}E\text{-}I$

I need to take 0,017 cubic meters per second from the watercourse. This value is small enough that it cannot harm the stream regime.

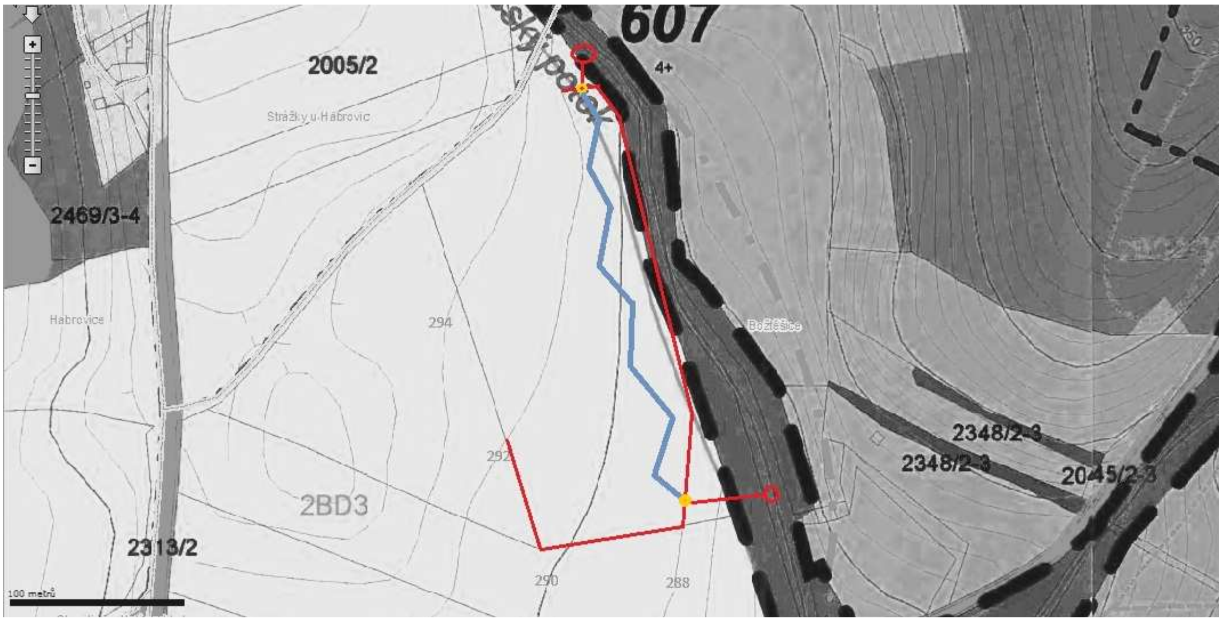
Wetland capacity is approximately 1 620 cubic meters.

Retention capacity of the basin is 28 220 cubic meters. When I calculated dimension of basin in regard to precipitation, I used equation $V=S.C.P$

The retention capacity is sufficient for the rain of 35 mm.

Four meter high dam is a huge intervention in the landscape. I suggest plant vegetation all over the dam. Inside I would plant wetland vegetation; grass, shrubs and trees which are moisture tolerant. Further from the flooded area can grow other type of vegetation; local collection of shrubs and trees.

The cubature of the dam is approximately 19 000 cubic meters. The costs of primary investment are 66,5 millions CZC , in regard to average cost of material of the dam wall 3 500 CZC per cubic meter.



9 Scheme of dam of the basin

Variant B

Sysytem of wetlands

Another possibility to retain water in the landscape is to create wetland. In our condition when the slope of the terrain is relatively big is better to create system of wetlands. I suggest constructing two dams along the two contour lines. One along the contour line of 288 m.s.l. and the second one on the contour line of 290 m.s.l. So I create two separate basins. Both of them have dam of 2 meters high with both slopes 1:3. They are 270 meters and 370 meters long. Their width in crown is 3 meters. The maximum surface of both wetlands is 15 100 square meters (8600m^2 upper one, 6500 m^2 lower one). The dams is made from the stones/gravel and soil.

As well as in the first variant we need diversion structure in the stream and from there a supply channel for water impound into the basin. At the entrance there is a structure for regulation of water inflow. Small creek flows through the first basin. There is another regulation structure in the first dam and the creek continues to the second basin. There is an outlet from the basin in lower part. It is possible to regulate water income and outcome of all regulation structures. Last is a channel which brings water back to the watercourse. There should be security spillways over the both dams as well.

Maximum volume of both basins is 15 100 cubic meters.

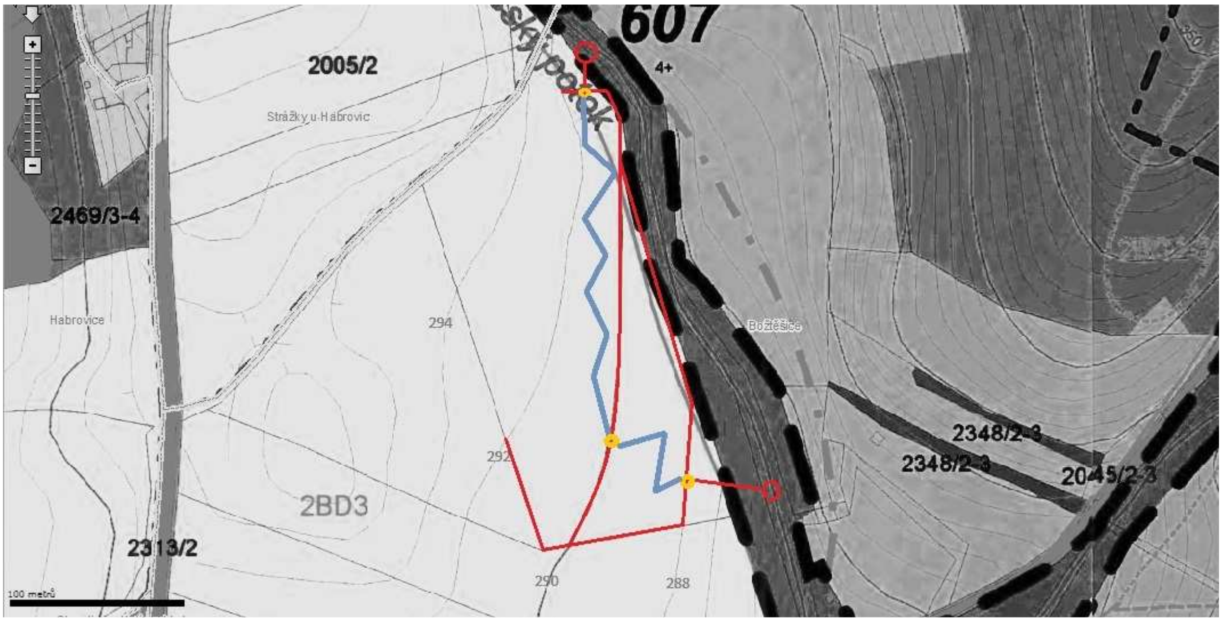
As in the previous variant, I leave the basins with permanent partial flooding. I calculated with average high of water level 0,2 m in the basins. Of course, due to the slope the water will not be spread evenly. I recommend making diverse structures in the inner part of the basin; create some depressions and elevations. The wetland needs constant income of water. From the same equation for water income I calculated that I need to take 0,015 cubic meters per second from the watercourse. This value is small enough that it cannot harm the stream regime.

Wetland capacity is approximately 1510 cubic meters.

Retention capacity is 13 590 cubic meters. It is able to catch water of the rain of 17mm.

For both dams I suggest vegetation cover.

Cubature of both dams is approximately 10 000 cubic meters. The costs of primary investment are 25 millions CZC , in regard to average cost of material of the wetland wall 2500 CZC per cubic meter.



10 Scheme of dams of the wetland

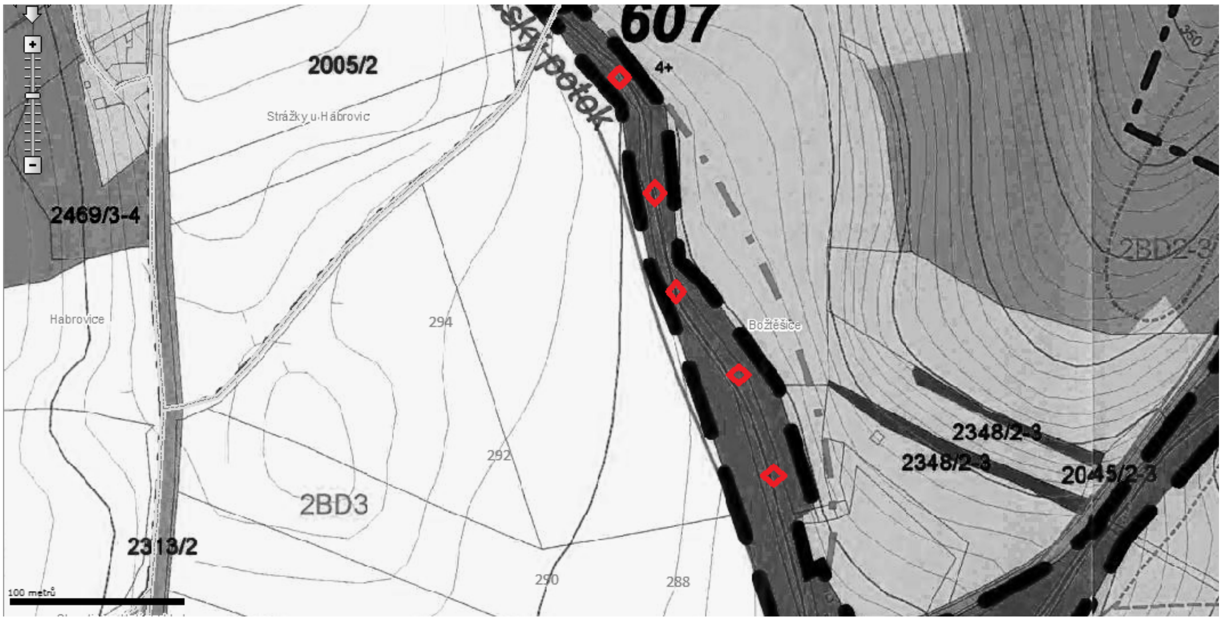
Variant C

Stone slides

We can call this variant also minimal variant. In this case we make minimum arrangements with minimal costs. The easiest way how to slow down the velocity of water is to increase wetted perimeter of the profile, respectively to increase roughness of the bottom of the channel. We can make some riffles, slides or weirs in the stream from stone or wood.

I make five stone slides/boulder chutes from stones of larger sizes to increase the roughness of channel profile. It causes considerable friction which leads to effective control of kinetic energy.

The slides are 5 meters long, 3,5 meters wide and 0,5 meter deep. I need approximately 27 cubic meters of stones for constructing five slides. The costs of primary investment are 0.07 millions CZC, in regard to the average cost of material of the slides 1 500 CZC per cubic meter.
There is no retention capacity in this case, but important decrease of water velocity.
This measure is only from natural material; stones. It creates harmony with the surroundings and does not disturb the landscape.



11 Scheme of the slides

Analysis

Variant A

From hydrological point of view, variant A is the best one. The retention capacity of the basin is more than 20 000 cubic meters, exactly 28 220 cubic meters. Also the water velocity decreases significantly. P=5

Variant A is very expensive. We need quality material for construction of the dam wall, water construction concrete with reinforcement. Cost of this material is very expensive. The rest of the wall is made from combination of gravel and soil which decreases the average price of material. The primary investment cost are 65,5 mil. CZC

To consider ecological aspect, the created wetland will have a positive impact on all surroundings. The transformation of arable land surely increases biodiversity of the locality, new organisms and plants will occur there. P=4

From the technological point of view, I consider variant A as a very difficult. To build the dam of detention basin is the most complicated. It has to comply all security requirements (hard inside construction, outlets and emergency spillways). Detailed project documentation is essentially. The more complicated is the construction the greater is risk of default. P=5

To put 4 meter high dam into the landscape can never have good aesthetical effect. But we mitigate negative impression with vegetation cover and interesting solution of inner part of the basin; creating of pool and islands. P=2

Variant B

Variant B is very good option from the hydrological point of view. The retention capacity of the measure is more than 10 000 cubic meters, 13 590 cubic meters, and it has significant velocity control P=4

The cost of two dam is depended on the price of gravel and soil. The dams are long and bulky so we need a lot of material. The total costs of primary investment are 25 mil. CZC.

The created wetland will have a positive impact on all surroundings. The transformation of arable land surely increases biodiversity of the locality, new organisms and plants will occur there. P=4

Technically, variant B is little bit less difficult than variant A. The dams of wetland could be done from soil and stones without any inside construction. But it also has to have all security requirements; there should be emergency spillways and outlets from the basin. Project documentation is also essential. P=4

From the aesthetical point of view, this variant can be an attractive element of the landscape. The two dams with little slope and a lot of vegetation may not give negative impression for the human eye. P=4

Variant C

I classify variant C as a sufficient variant from the hydrological point of view. Although there is no retention capacity, the slides decrease velocity of water importantly. P=2

For this variant I calculate the primary cost of the stones. Total costs for all slides are 0,07 mil. CZC.

From the ecological point of view, I evaluate it as medial variant. Slides do not affect negatively the biodiversity of the stream, when they are well made and do not stop migration of fish and other organisms. Small water organisms could find refuge under the new stones. P=3

From technological point of view is modest variant. It has simple construction. It is not demanding on project documentation, there is no risk of default. P=2

Arrangement of this variant is too small to affect human impression from the place and if so, it would be positively. It is made from natural material; stones. It creates harmony with the surroundings and does not disturb the landscape. P=3

Results and discussion

Results

	Var. A	Var. B	Var. C	unit	Var. A	Var. B	Var. C
Hydrological criteria	5	4	2	[Relative units]	0.90	0.58	0.06
Economical criteria	65,5	25	0,06	[mil. Czech Crown]	0.00	0.42	1.00
Ecological criteria	4	4	3	[Relative unites]	0.87	0.87	0.02
Technological criteria	5	4	2	[Relative unites]	0.10	0.42	0.94
Aesthetical criteria	2	4	3	[Relative unites]	0.23	0.65	0.50
				Total ∑	2.1	2.94	2.52

12 Table of result values

The winner of the analysis is variant B, system of the wetlands. Variant C takes the second rank and variant A is the last one. Complex indicator of variant B is the highest, which means it has the best characteristics of all variants, variant B is the optimal one. Although its retention capacity is not the best, it gains other variants on the ecological and aesthetical aspect. The looser is surprisingly variant A which has the biggest retention capacity. On the other hand it has very low values of U indicator for technical, economical and aesthetical criteria. Variant C is well evaluated for its economical and technological modesty.

This evaluation was made supposing that all criteria have the same weight. In reality, some criteria are more and other less important to us. We can assign specific weight to each variant with help of Fuller method of pair comparison. We compare every criterion with others and match the winners, than I sum up number of winnings. With final values I recalculate U indicators and I get new result.

<table>
<tr><td rowspan="2">1Hydrological criteria</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="2">3</td><td rowspan="2">0.3</td></tr>
<tr><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">2Economical criteria</td><td></td><td>2</td><td>2</td><td>2</td><td rowspan="2">1</td><td rowspan="2">0.1</td></tr>
<tr><td></td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">3 Ecological criteria</td><td></td><td></td><td>3</td><td>3</td><td rowspan="2">4</td><td rowspan="2">0.4</td></tr>
<tr><td></td><td></td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">4 Technological criteria</td><td></td><td></td><td>4</td><td>4</td><td rowspan="2">1</td><td rowspan="2">0.1</td></tr>
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5 Aesthetical criteria				5	1	**0,1**

13 Table of Fuller method evaluations

For my research the fundamental criteria are ecological and hydrological. If I take this into account I get different results from the analysis.

	Var. A	Var. B	Var. C	unit	Var. A	Var. B	Var. C
Hydrological criteria	5	4	2	[Relative units]	0.27	0.17	0.02
Economical criteria	65,5	25	0,06	[mil. Czech Crown]	0.00	0.04	0.10
Ecological criteria	4	4	3	[Relative unites]	0.35	0.35	0.01
Technological criteria	5	4	2	[Relative unites]	0.01	0.04	0.09
Aesthetical criteria	2	4	3	[Relative unites]	0.02	0.07	0.05
				Total $\sum$	0.65	0.67	0.27

14 Results with weighed criteria

We can see that the winner of these results is also variant B, but only by 0,02 in front of variant A. Variant C is the is the last one with big difference. The results changed due to considering of weigh of criteria.

Discussion

Variant B won in both analyses. The measure with two terraced wetlands brings the greatest benefits to the place. It increases flood protection, biodiversity and aesthetical value of the place. In the first analysis, the resulting values of all three variants are very close to each other. In terms of overall benefits, there is not a big difference in the cardinal utility between the very costly arrangement (variant A) and the intervention with minimal costs (variant C).

I think it is possible to find another better solution if we do not consider the ownership constraint. The given plot limited my solutions a lot. It is situated on one side of the stream, which brings many disadvantages. The area of the plot is not utilized effectively. It is necessary to build a very long dam to retain a relatively small amount of water. From the calculation, I realized that the cubature of the dam would be almost 2/3 of retention volume. If we could build the dam across the valley, we would a get greater retention effect with a shorter dam and therefore with lower cost.

Another problem of the plot is its relatively steep slope; water cannot inundate large area, if the dam is not high enough. The dam of detention basin is the best and not problematic up to five meters. However, every high dam is a great intervention in the landscape, so it is not a popular measure. The more so as the plot is situated in the Protected Landscape Area of Bohemia Highlands and my aim is to design an environmentally friendly flood protection measure.

There is still another possible solution, which we did not consider; to excavate the basin area and thus increase the retention volume without raising the dam. In this case, we could also use the soil dug out for the construction of the dam and reduce the costs.

Undoubtedly, the good thing about the variants proposed is the wetland; permanent flooding in the basin would have a very positive effect on the area. In the case of variant B, two terraced dams could be an interesting and attractive element of the landscape.

The regulation structures of all dams let us control inflow and outflow from the basins. We can decide how much water we can let flow in during the flood event. I have figures about the 5 year, 20 year and 100 year discharges for the place. If the discharge is on a hundred year level of 19,1 m^3/s and we let flow in the basin A discharge of the 10 m^3/s, the basin will be full in 47 minutes. It alleviates the damage on the downstream part of the channel to the level of twenty year flood, but only for this short period of time. After filling, it becomes death space without any additional help in water control, such as slowing down the water velocity thanks to a wider profile. We can decide to impound a smaller amount of water, so it will last longer.

The problem is to estimate how long we will need to keep the water in the basin, when to start taking it and how much water we should take. Precipitation and its depending discharge are unpredictable. As we can see from the graph of dependence of discharge on the rainfall (figure no. 6), the reaction of discharge is unstable. There is a direct correlation between the discharge and precipitation in the first days (5.-14.8. 2010), a sharp increase in rainfalls and sharp increase in discharge. But then, there is a significant increase in precipitation (15. and 17.8. 2010) and no change in discharge at all. This is the problem of the torrential rain. It is local; affects a very small area and is especially heavy. It is difficult to forecast where exactly the rain will occur. The Variant A is able to catch the water from the rain of 35mm and variant B of 17mm. Undoubtedly, these capacities are not big enough for hundred year precipitation.

The flood protection measures are useful help to mitigate effects of floods. However, they have their limitations. The effective flood defence functions as a complex of structural and non structural measures. From the non structural ones, the responsible behaviour of people is important. People themselves can influence the increase in the retention capacity of their land by not using so much concrete and other impermeable materials and using more natural materials. Green roof could be an example of an interesting solution for water retention of every one's land. Also respect for floodplain zones plays a fundamental role. People should not build houses wherever they please. Simply, respect the needs of watercourses and give them their space. Sometimes, the non structural measures bring greater benefits with minimal costs incurred. Before making any big and costly structural flood protection measure is good to consider its real effectiveness.

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Appendices

1. **Hydrological map of the catchment of Ohře River and lower part of Elbe River[21]**
2. **Detailed map of the catchment of Klišský creek[22]**
3. **Scheme of the cross section profile of detention basin**
4. **Scheme of the cross section profile of system of wetlands**

[21] Web: Plán oblasti povodí Ohře a dolního Labe

[22] (Krise, 2008)