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THE STUDIES ON FLOODPLAIN RESTORATION: A CASE STUDY OF THE UPPER DUNAJEC RIVER

Summary

Long-term observations of Upper Vistula tributaries, made by the author, showed that the narrowing and straightening of rivers and their floodplains resulted in accelerated riverbed erosion and the increase of flood risks. River floodplains are widely acknowledged as being very important for biodiversity, therefore by their narrowing they lose their natural patterns and, as a consequence, decline in habitat and species diversity.

In the last years a new approach in river management and engineering appeared: the EU Water Framework Directive constitutes an important step for more ecological river training. In consequence an increasing number of restoration projects have been initiated in the last years.

In the present paper the author tried to study and check the possibilities of flood plain widening upstream of the town of Nowy Sącz situated along the Dunajec River (km: 111.900 – 107.500), where devastated lands occurred. In the urban area of Nowy Sącz the levees distance was left unchanged. For the new conditions the numerical simulation by 1D mathematical model Rubarbe was carried out. The obtained results showed a significant decrease in the flood peaks upstream of Nowy Sącz and lesser decrease in the town.

Key words: mountain river, floodplain restoration, 1D model

INTRODUCTION

River floodplains are widely acknowledged as being very important for biodiversity. However, in Europe only small areas are left in a relatively undisturbed condition. Most rivers channels have been changed as a result of hydraulic works, as canalization and flood levees setting. As a result, the floodplains lost their natural patterns with a consequent decline in habitat and species diversity. The narrowing and straightening of the rivers and their floodplains resulted also in the increase of flood risks [Andrews, 1996, Naiman et al., 1993]. In the last years a new approach in river management and engineering appeared: the EU Water Frame Directive [EC/60/2000] which constitutes an important step for more ecological river training. In consequence, an increasing number of restoration projects have been initiated in the last years [Hunzinger, 1999, Jaeggi, 1984, Poulard et al., 2004]. One measure is to broaden floodplains and to create river widening that permit braiding within a limited area. These measures lead to floodplain restoration and to limit the flood risks. In the present paper we try to check the possibilities of flood plain widening upstream of the town of Nowy Sącz situated on Dunajec River in Poland (Fig. 1).

CONTEXT

Natural riverine environments are dynamic and form biologically diverse ecosystems. Channel migration and frequent flooding are important factors of this dynamics. However, the human activities minimized the floodplain areas by exploring them for agriculture and industrial development. Throughout the years there has been observed a tendency towards cutting rivers channels off their floodplains.

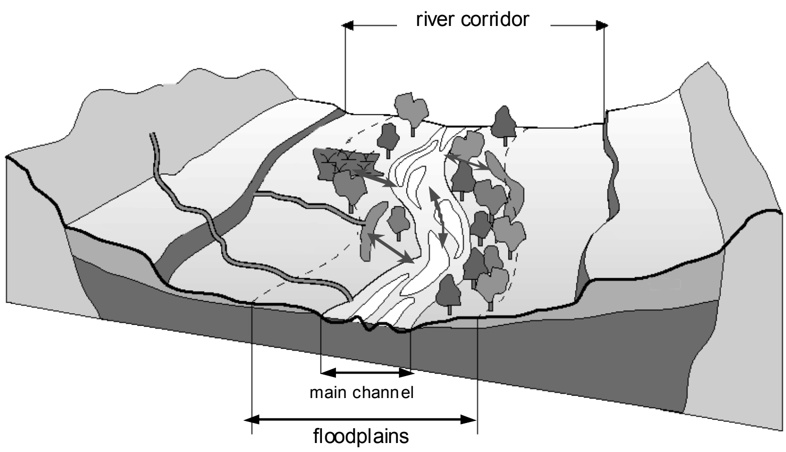

Figure 1. Longitudinal and vertical corridor continuity.
[adapted from „Determination de l'espace de liberte …1998].

The construction of levees protects the land behind them, but also confines the floodplains. This decreases the water storage capacity of floodplains and, consequently, increases the flood wave peak. The constructed levees give the opportunity for urban development behind them. However, this could lead to increase flood damages if the levees were broken. Moreover, the levees provide protection only up to a specific design capacity.

The main reason to restore the floodplains is to help to reduce downstream flood peaks. Many important and rare habitats could occur on extended floodplains. In the European Union Countries the projects of setting-back of levees have been carried out on the rivers [Natural Flood Defences … 2004]. This solution enlarges the storage capacity of a floodplain and leads to enlargement and initiates the process of floodplain restoration.

METHODS OF ANALYSIS

The floodplain restoration project should be implemented as a set of actions having the river channel and its valley restoration as a principal objective. Therefore, the project calls for integrated studies based on the comprehensive understanding of the river system, the morphological and hydrological processes found in the riverbed and its valley. The scheme in Fig. 2 presents the studies on levees restoration as the sequence of actions. The multidisciplinary work with the engineers and biologists is recommended.

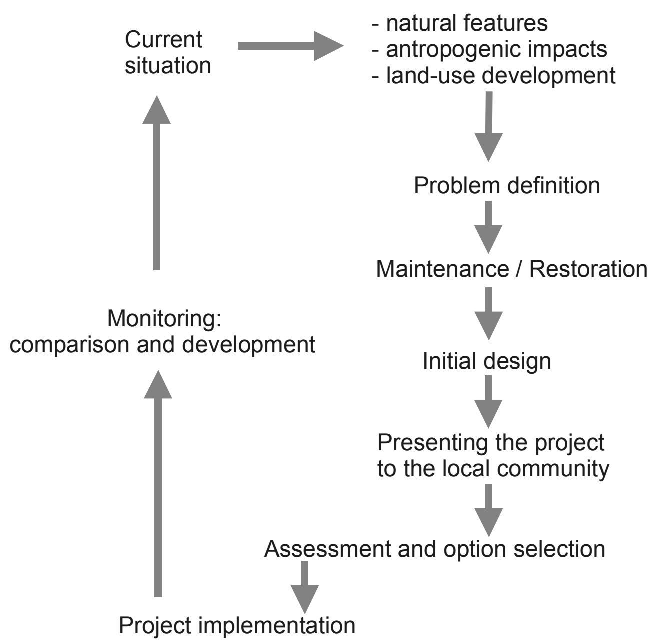

Figure 2. A sequence of actions of the studies on a floodplain restoration project

In the paper, only few of presented actions are developed. The current state of the riverbed and its valley is examined according to the EU Water Framework Directive [EC/60/2000]. The studies on riverbed evolution during the years were done on the base on the statistical model of riverbed erosion [Lapuszek, 2003]. The model is based on the assumption that minimal annual water stages correspond to the changes of riverbed level in the gauging station [Lapuszek, 2003]. In a particular gauging station this data series for each determined time interval is approximated by the linear regression. The investigated equation (1) gives the relation between annual minimum water stage (*H*) and time (*T*) and it also illustrates the main trends of changes in the gauging station in a long time period:

$$H_i(T) = aT + b \tag{1}$$

where:

T – year of observation,

a, *b* – estimated parameters of equation (1).

The intensity of changes in time is expressed by the slope coefficient *a*.

The studies on the riverbed evolution during the long period of time are important because of the assessment of anthropogenic and natural impacts on the river geomorphology.

Organising a levees distance-widening project is a complex task and requires the land-use development analysis. It concerns the issue of the local authority and the stakeholders (for example: inhabitants, farmers, anglers, tourists). In the literature there are many algorithms for helping with the identification of long-term sustainable solution for the local society and the environment [Cuff, 2001]. Technical experts (hydrologists, ecologists, engineers, special designers) define possible solutions for the problem definition. The preliminary computation concerning the simulation of the flood wave propagation for the case of the floodplain broadening is also a very important action. In the current paper the computations are carried out by a 1D RubarBE model [Paquier, 2003]. The model is relied on:

– de Saint Venant equations for water:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{2}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\beta \frac{Q^2}{A}\right) + gA\frac{\partial z}{\partial x} = -g\frac{Q^2}{K^2 AR^{4/3}} + kq\frac{Q}{A} \tag{3}$$

– equation for conservation of sediment mass [Paquier, 2003]:

$$(1-p)\frac{\partial A_S}{\partial t}+\frac{\partial Q_S}{\partial x}=q_S \tag{4}$$

– and sediment transport capacity relation [Meyer-Peter and Müller, 1948]:

$$C_s=\frac{8L_a\sqrt{g}}{(\rho_s-\rho)\sqrt{\rho}}\cdot\left(\rho JR-0.047D_{50}(\rho_s-\rho)\right)^{3/2} \tag{5}$$

where :

- A – cross-sectional flow area (m^2),
- C_s – sediment transport capacity (m^3/s),
- D_{50} – median diameter of sediment (m),
- g – acceleration due to gravity (m/s^2),
- J – friction slope,
- K – Manning-Strickler coefficient ($m^{1/3}/s$),
- L_a – active width (m),
- Q – water discharge (m^3/s),
- q – lateral water flow per unit of length (m^2/s),
- Q_s – sediment discharge (m^3/s),
- q_s – lateral sediment flow per unit of length (m^2/s),
- R – hydraulic radius (m),
- t – time (s),
- x – streamwise coordinate (m),
- z – water surface elevation (m),
- β – the coefficient of quantity of movement,
- ρ – density of water (kg/m^3),
- ρ_s – density of sediment (kg/m^3).

The computations were carried out without taking account of the sediment movement.

For the preliminary studies the 1D model is appropriate enough. It allows to make basic assessment of the wave propagation in the main channel and in the floodplains. If it is found that simulation results are satisfactory, the more detailed computation should be conducted using more comprehensive model. When the project is completed, it should be performed to the local community and discussed. Then, the final solution is implemented.

CASE STUDY DESCRIPTION

The Dunajec River, in southern Poland, is a one of the most important mountain tributary of the Wisła River. The total area of the Dunajec River catchment is 6798 km^2. In km 67.5 of the river course, the Rożnów-Czchów dam is located. The Dunajec River is characterized by very high differences in water discharges during the year. Its channel is characterized by erosion and deposition process which occurs with varied intensity along the whole river course. During the floods the significant riverbed and river banks erosion occurs (Fig. 5). In the current paper the reach located between 111.300 – 104.800 km of Dunajec River is studied. In kms 107.500 – 104.800 the river runs through the town of Nowy Sącz. The characteristic parameters of the experimental reach are presented in Table 1.

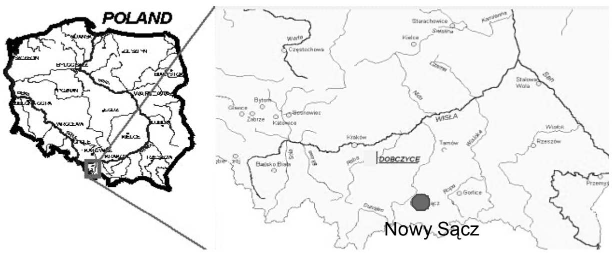

Figure 3. Dunajec River location in Southern Poland

Table 1. Parameters of the experimental reach

Parameter	Value
The area of the catchment [km^2]	4360
Mean width of the riverbed [m]	80 - 180
Mean slope [-]	0.0022
Variation of slope after works [-]	0.003
Nominal diameter [mm]	40
Mean annual flow [m^3/s]	60.7
Highest observed flow [m^3/s] in 1934	3300
Lowest flow [m^3/s]	11.0
Mean low flow [m^3/s]	14.2
Mean annual flow [m^3/s]	60.7
$Q_{1\%}$ - 100-year flood [m^3/s]	3530
$Q_{5\%}$ - 20-year flood [m^3/s]	2440

RESULTS AND DISCUSSION

Dikes were constructed along the experimental reach of the Dunajec River between the years 1978 and 1990. The height of the dikes is 4.0 – 5.0 meters and they close the floodplains with the width of 340 – 450 meters. The constructed dikes protect the town of Nowy Sącz and adjacent areas against the 100-year flood. During the field observations and studies, it was observed that the whole flood plain area is covered dense with bush and small trees beyond the town reach. Moreover, between kms 111.300 and 107.500 (upstream Nowy Sącz), just behind dikes the adjacent areas form mostly wasteland. Therefore, the current studies concern the possibility of widening the flood plains throughout the mentioned length of the experimental reach (Fig. 4). There are a few technical possibilities of floodplains restoration. In the paper it is not discussed the engineering works but only the influence of the widening on flood wave and river bed erosion [Kreiss et al., 2005].

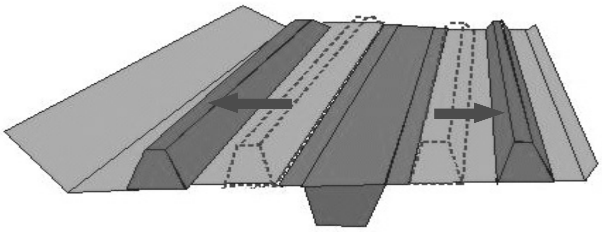

Figure 4. Scheme of proposed levees replacing

The river bed is slightly meandering and the width varies from 88 to 186, the bank line is in the bigger part of the reach regular and the banks are protected by rip-rap and gabions. A part of the banks where the remains of destroyed groyens occur are characterized by development of fish. The stream power value indicates high sediment transport what was verified by the field observations and calculations (Table 2) [Rhoades, 1987].

Table 2. Main channel cross-section characteristics [Mikulska, 2005]

Cross section	Kilometer	Bankfull discharge Q_{bf} [m^3/s]	Width for Q_{bf} [m]	Depth for Q_{bf} [m]	Mean slope [‰]	Stream power [W/m^2]
P1	111.300	199.1	112	2.4	0.0031	38.4
P2	109.900	219.7	88	2.9	0.0026	53.8
P3	108.700	221.5	144	3.0	0.0016	35.2
P4	107.500	218.0	130	3.1	0.0022	36.2
P5	106.000	217.6	150	2.1	0.0022	31.3
P6	104.800	228.5	186	2.2	0.0016	26.5

According to the EU Water Framework Directive [EC/60/2000], the current state of the main channel, banks and banks zone and floodplain areas is examined on the base on the field observations and measurements (Table 3).

Table 3. River state evaluation on the studied reach

Evaluation category	General parameters	Evaluation
Main channel		
Channel geometry	meandering, concentrated flow with width differences, regular cross- sections	moderate to good
River bed material	natural gravel bed	good
Vegetation in the main channel	very limited - typical for mountain river	moderate
Erosion and sedimentation	important	moderate
Flow	relatively varied velocities	moderate to good
Hydraulic structures	one low weir	good
Banks and bank zone		
Vegetation	dense willow bushes	good
Flood Plain		
Flood plain constrains	dikes from 120 to 200m from the river no contact with the valley, limited possibility of main channel development	bad
Flood plain vegetation	exists in some areas dense without out keeping	moderate

The studies on riverbed evolution during the almost 100 years at the Nowy Sącz gauging station give the information concerning the anthropogenic (river training, levees construction) and natural (floods) impacts on the river channel. Planning the levees distance widening, it is necessary to recognize and define the geomorphologic processes that occur in the long period of time throughout the studied river course. However, the most important thing is to analyze the impact of anthropogenic factors and the flood waves on the riverbed changes. It is known that the riverbed will respond for many years after the time of changes in the river channel and in its valley. But their direction is difficult to predict. Therefore, the carried out analysis can be helpful in assessing the consequences of a project on the riverbed evolution in the future.

The observations show that up to 1 meter of bed degradation occurred during the period of 1925-2009 (Fig. 5). The observations show that the process of high riverbed erosion occurred as a consequence of river training (narrowing and straightening of riverbed, levees construction – narrowing the floodplain areas) and flood events (Fig. 5). High bed load transport is observed, especially during the floods in the reaches located close to the Nowy Sącz gauging station. The riverbed is composed of gravels with many gravel deposits observed along the reach, and the river often changes its course.

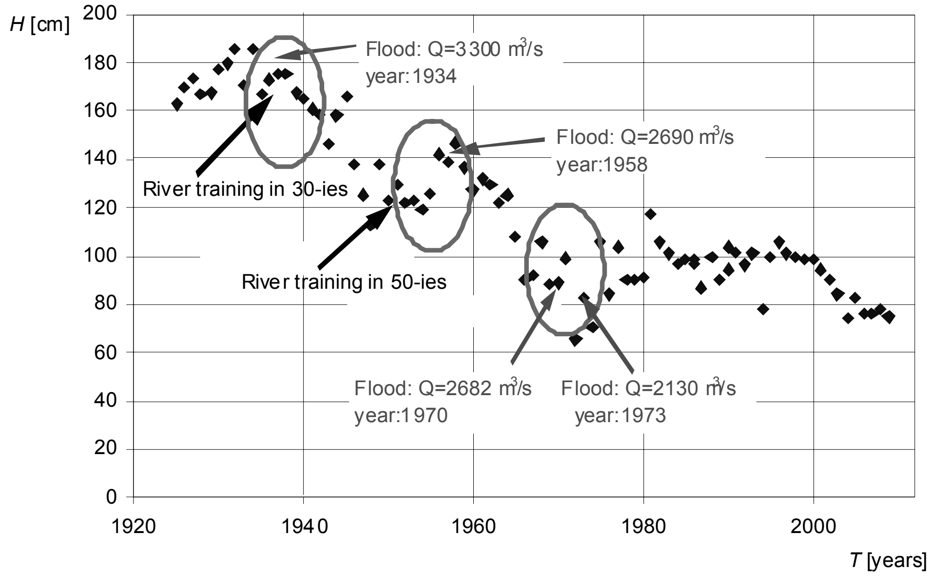

Figure 5. The riverbed erosion observed at the Nowy Sącz gauging station

Preliminary computation concerning the new project is the next step of current study. In order to simulate the flood wave for the case of the flood plain partial broadening along the experimental reach the computations were carried out for the following data:

– 6 natural river cross-sections including flood plains,

– flood wave measured at the Nowy Sącz gauging station in 1970 (Q_{max} = 2682 m^3/s, about the 20-year flood),

– nominal bed load diameter: d = 0.04 m.

The simulation was done for two cases:

– natural cross-sections with existing dikes,

– natural cross-sections with partially broadened dikes distance (about 500m) from kms 111.300 to 107.500.

Computations were done by the RubarBE [Paquier, 2003] 1D model. Throughout the whole experimental reach the reduction of flood peak discharge is observed up to the value of Q = 2154 m^3/s. The decrease is sustained in the area of Nowy Sącz (Fig. 6), in spite of the dikes location very closely to the river bed: it is caused by the very short distance (about 1 km) and short time of flood peak course (about 15 minutes for the whole reach). It has to be mentioned that downstream of Nowy Sącz levees distance is widened.

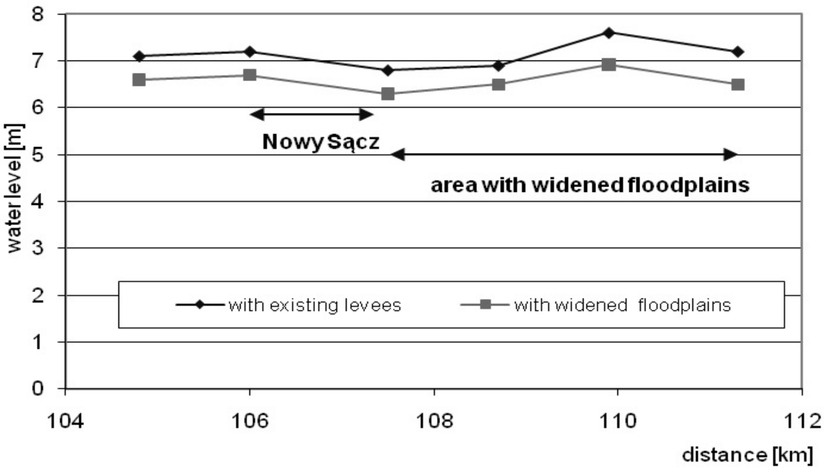

Figure 6. The water level computed for $Q = 2682\ m^3/s$

The computations show that in the case of floodplains extension the water level decreases up to 0.5 m throughout the kms 104.800 – 108.700. The water level decreases up to 0.6 m throughout the area of widened floodplain areas (Fig. 6). The computation results show that proposed solution reduces peak flows and decreases the probability of downstream flooding. Even reduction of peak discharge height of a few centimeters only, can be beneficial for the downstream area.

In the paper the current studies are treated as theoretical considerations. From economic point of view, the presented idea of project in itself does not seem very well founded. However, when it would appear that the condition of the existing levees is so bad and the costs of repairing them are very high, we should consider the construction of new levees away from the main river channel. In longer period of time, such solution will bring many environmental and economic benefits.

The Water Framework Directive [EC/60/2000] does not explicitly require the floodplains restoration action. However, the issue of flood management is included. Moreover, the Directive requires all the water bodies within the European Union Countries to be in 'good ecological status' by 2015. For regulated river systems it is required to identify and quantify the past effects on the biological quality parameters. These effects should be mitigated in order to reach 'good ecological potential' by the studied river. The floodplains restoration activity seems to be a good tool to mitigate both: flood damages and past effects on the low quality of the biological parameters of the river.

Flood peak reduction and a delayed rise to flood peak will cause that the flooding is less likely and more time is available to implement flood damage downstream. Restored and wide enough floodplains could be most biologically productive and species-rich ecosystems. The main objective of the floodplains extension should be improving the quality of the natural environment. Restoration efforts should target at improvements of the dynamics of the floodplains and the creation of diverse habitats. Now, as the studies show (Table 3), the existing floodplain vegetation evaluates on the moderate level. And it forms very poor environment for diverse habitat development. The fluctuation of water levees which can be varied by as much as 7.0 m during the flood wave, will subject the floodplain and riparian vegetation. Moreover, the new river dynamics will result in the creation of diverse habitats, as gravel and sand banks, shallow and deeper waters, establishing spawning grounds for fish. Now, because of very narrow floodplains, the process of riverbed erosion occurs with the high intensity especially during the flood events (Fig. 5). It causes the frequent riverbed lowering, and the refuges and spawning areas are destroyed. Moreover, the riverbed lowering causes the rapid ground water lowering as well. This process is also destructive for the proper vegetation developing in the floodplain area. The levees distance widening should be studied as a project that will provide many benefits that often are of high economic value. The only few aspects of it are presented in the paper.

CONCLUSIONS AND PERSPECTIVES

Conclusions:

1. Restoration of flood plains is important for the biodiversity and flood mitigation
2. The previous river training resulted in important bed erosion
3. The widen dike distance allows river to regain its more natural course.
4. The first computations indicate the positive effect of dike widening, even along the rather short distance.

Perspectives :

1. Computation different types of dikes widening.
2. Taking into account another approach to compound channel [Bousmar et al., 2005].
3. Application of different method for floodplain roughness coefficients calculation.

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