THE RESEARCH OF HYDRODYNAMIC PROCESSES IN REHABILITATING RIVERS OF LITHUANIA

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Abstract
From the 1920s through the 90s, most streams in Lithuania were channelized. Channelization is the deepening, clearing and straightening of meandering streambeds resulting increase of water flow velocity and the rate at which water drained away from agricultural land. Channelized and straightened streams have better hydrodynamic parameters and different morphological properties, but at the same time that caused more unfavourable conditions for natural biodiversity along stream beds and banks reducing the amount of vegetation which means less food and cover for wildlife. Most of West European countries have a good practice for restoring of channelized rivers. This experience is quite new in Lithuania and starting with pilot projects. The most important purpose of these projects is to choose the appropriate restoration measures and evaluate their effectiveness under conditions of dense channel network and tile drainage systems in Lithuania. Two channelized streams, selected for a pilot project are discussed in this paper. The main purpose is to restore stream meandering with minimal efforts allocating artificial obstructions at a right place and reach the necessary stream velocities to initiate the stream bed deformation. For this purpose detailed channel geometry data were collected and 1D hydrodynamic model applied. The results of different scenarios revealed that installed obstructions can accelerate deformations processes initiate the meandering process and at the same time it will not have any significant effect on the agricultural land along restored stream.
Key words: regulated streams, current velocity, discharge and streams restoration means.

Introduction

Land reclamation was the most frequent reason for channelizing of streams in Lithuania. Over 46 000 km stretches of streams were straightened and over 17 000 km the new ditches excavated during the intensive reclamation period in Lithuania (Gailiusis e*t al*., 2001). That caused alterations in streams morphometry including changes of furrow line, forms of the shoreline, the bottom substrate and changes of flow hydrodynamic. The riverbed straightening increased flow velocity, sediment transport and longitudinal gradients. More intensive erosion processes in appeared the upper reaches caused by increased stream power what lead to broadening and shallowing of straightened streams beds. Meanwhile, the sediment accumulation processes dominate in downstream reaches of straightened streams. Therefore, straightened streams with monotonous, fast currents and silty bed caused water ecosystems with poor conditions for fishes and invertebrates. Due to these modifications, the regulation of the rivers was named as one of the greatest threats to wildlife biodiversity and ecosystems (Rosenberg *et al*., 2000; Nakamura & Yamada, 2005; Horsák *et al*., 2009).

In order to restore morphometric, hydraulic and especially ecological conditions close to the natural ones the straightened reaches should be restored. This can return conditions close to previous (natural) which is much more favourable for the natural flora and fauna. Therefore, restoration of channelized streams is a prerequisite for more favourable water ecosystems. A good practice of stream restoration already exists in many countries and restoration projects are very popular over some decades in Europe and other continents (The river..., 1998; Coops & Geest, 2007; Morten e*t al*., 2007; Aulaskari, 2008; Pavils, 2003, 2006, 2007; Living..., 2006; Jormola e*t al*., 2007). In many cases restoration or self-restoration of channelized streams covers the measures which can be defined as full or partial recovery of morphological parameters and ecological functions in rivers almost completely destroyed by channelization. The main purpose of river restoration projects is to restore the disturbed natural balance, increase natural biodiversity and improve water quality in the channelized streams.

The aim of river and stream restoration is achieved using different methods and tools. Restoration tools directly modify hydraulic and morphometric parameters of flow. To evaluate the direct and indirect effects on the bed processes the hydrodynamic modelling can be used (Guidelines..., 2005; Paškauskas e*t al*., 2000; Vaikasas, 2007). It enables to predict the impact of the implemented measures on river morphometric and hydrodynamic characteristics, and the living conditions for ichtiofauna (Ward, 1998; Ward e*t al*., 2002; Dave, 2003).

The aim of the article is to assess the effect of river restoration tools on flow hydrodynamics and stream bed changes consequently.

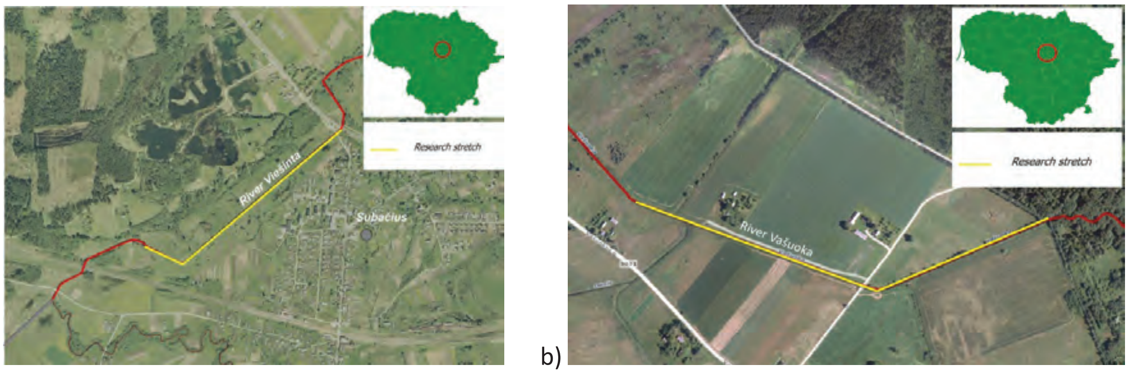
Materials and Methods

Identification of channelized and natural stream parts was carried out on the basis of GIS database – 'GDB10LT' employing data layer 'Hidro_L' and database of orthorectified images 'ORT10LT' for controlled process. The recognition was done using

Table 1

The main characteristics of streams Viešinta and Vašuoka (Gailiušis *et al*., 2001)

Stream name	Main river name	Length of stream L, km	Stream catch-ment area A, km^2	Average dischar-ge Q, $m^3 s^{-1}$	Total natural length of stream L_n, km	Total regulated length of stream L_r, km	Average flow velocity v, $m s^{-1}$	The gradient of section i, $m km^{-1}$
Viešinta	Lėvuo	24	235.5	1.16	8.5	15.5	0.6	0.87
Vašuoka	Viešinta	34	128	0.66	0	30	0.46	2.25



a) b)

Figure 1. The fragments of Viešinta and Vašuoka streams.
(In yellow – parts of streams selected for restoration).

automated data processing by standard tools of ArcGIS and visual image analysis. Finally, all streams were separated into natural and channelized/straightened reaches and straightened stream sections divided into 7 groups, which were identified by stream catchment area, bed slope and river surrounding areas (forest, urban area or arable land).

For this study two streams - Viešinta and Vašuoka were selected. These streams belong to the fifth group of identified streams. The main characteristics of selected streams are presented in Table 1.

The location of Viešinta and Vašuoka rivers straightened stretches are presented in Figure 1.

In both selected stream parts by restoration project are foreseen to install artificial obstacles and is expected to achieve the start of stream meandering. The purpose was to verify that the threshold velocity will be reached. For that purpose 1D numeric model was developed using HEC-RAS software. The simulation of obstructions was performed modelling steady state flow for selected stream section. Geometrical characteristics for the model were obtained by field surveying. Using ArcGIS tools digital terrain model was created. Latter the by user interface Hec-GeoRas all data transferred to HEC-RAS. Model was calibrated under natural channel conditions for boundary conditions using measured flow rate, water level etc. An acoustic device ‘Stream-Pro ADCP’ was used for discharge, bed depth and velocity measurements. Topography was surveyed with the Trimble GPS/RTK. The shear stress coefficients were estimated visually in the field and latter corrected by calibration procedure. After calibration procedure, the channel geometry was corrected allocating artificial barriers along the stream. Model with modified channel geometry is continuously used simulating different stream flow and analysing distribution of velocities along the stream.

The differences of velocities with natural channel geometry and modified one enable to estimate the effect of obstructions for initiating stream bed erosion of the opposite side and the starting of meandering process. Threshold velocities depend on type of soil that is in a particular place. Composition of soil particles was found in each of the relevant section using data of 4 geological wells.

Results and Discussion

Water bodies differ in their natural characteristics, so there are differences between the aquatic communities that live there. According to the fact that Lithuanian water bodies are divided into separate types, each type is described by such natural factors that have the greatest impact on the aquatic communities structure (Nemuno..., 2010). Three main factors that describe the types of rivers and lead to the major differences in aquatic communities are: the absolute height, the catchment area and the river bed slope. According

Table 2

Groups of straightened streams' sections in Lithuania

Group	The type of river	The environment of biodiversity	Gradient m km^{-1}	Area of catchment A, km^2	The absolute height, m
1	1	-	-	<100	<200
2	2	forest	<0.7	100-1000	<200
3	2	field	<0.7	100-1000	<200
4	2	outskirts	<0.7	100-1000	<200
5	3	field	<0.7	100-1000	<200
6	3	forest	<0.7	100-1000	<200
7	3	outskirts	<0.7	100-1000	<200

to Lithuania's accepted river typology, the selected objects - Viešinta and Vašuoka belong to the third type of streams.

Regulated streams are divided into 7 groups according to the natural environment. The allocation of straightened sections into groups takes into account the fact that restoration of streams (basin area < 100 km^2) with regulated segments are associated with the emission-cleaning function along the way to larger bodies of water. It was decided that regulated streams with catchments area less than 100 km^2 can be restored without engineering tools to achieve good ecological status (Nemuno..., 2010). Natural instability, periodic drying, light vulnerability and a very high percentage of straightening are the main factors to leave regulated streams and their ecosystems for self-naturalisation with the proper protective bands. So all streams' sections of the first type are assigned to the first group.

For better ecological conditions, restoration engineering tools are suggested to be used only in water bodies with catchments area bigger than 100 km^2. Table 2 presents the groups of regulated streams considering different microclimatic and natural biodiversity conditions.

These groups include all straightened streams and rivers in Lithuania. The first group of streams (basin area < 100 km^2) consists of the majority of regulated streams. Due to this large group amount of regulated streams (24 371.6 km), ecological instability and other reasons, this group was not analysed. Groups of river stretch from No. 2 to No. 7 cover river basins area – 100-1000 km^2. River group No. 2 flows through a forest area, No. 3 flows through the fields, No. 4 flows through the outskirts. The slope of these three groups does not exceed 0.7 m km^{-1}. Meanwhile, rivers of groups No. 5 – 7 flow through the appropriate fields, forest and outskirts, and the slope is greater than 0.7 m km^{-1}. The summary table of straightened streams sections in Lithuania is presented in Table 3.

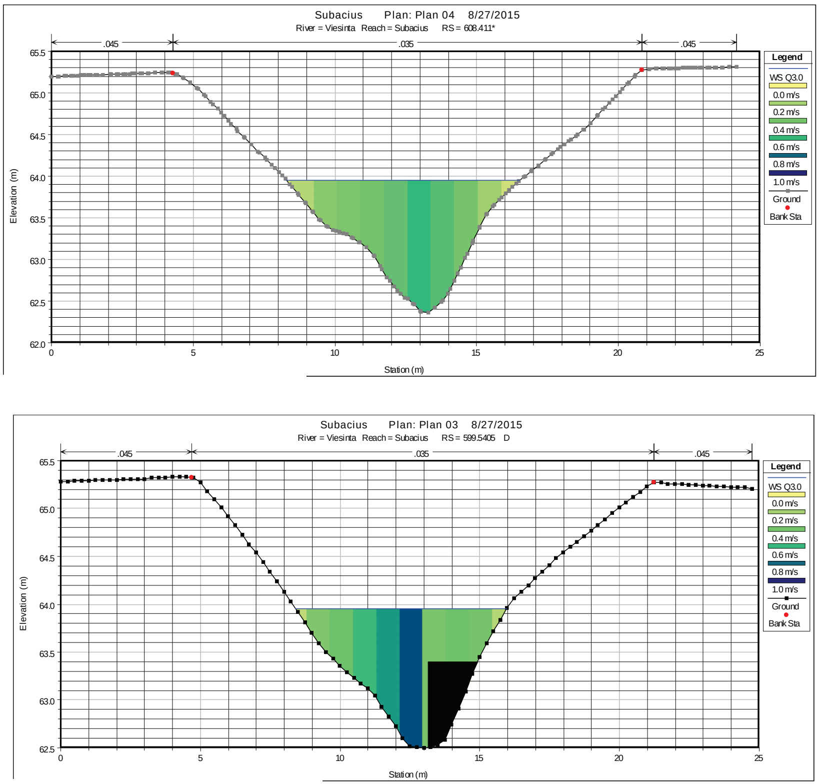
Channelized stream segments were explored and grouped. Two straightened streams – Viešinta and Vašuoka – have been selected as the fifth stream group for the pilot project. The investigated segments of streams are located in agricultural lands. Channel bed slope of along selected segments are greater than 0.7 m km^{-1}. That makes it possible to expect more rapid and effective impact of applicable restoration tools.

The numerical simulation using 1D model was performed for two scenarios: with obstacles and without obstacles. The purpose was to find out the difference of flow velocities in the absence of obstacles and install them. The differences of velocities enabled

Table 3

Summary table of straightened streams' sections in Lithuania

River basin	Group					
	Length L, km					
	2	3	4	5	6	7
Venta	1.163	16.153	2.997	6.325	0.821	0.143
Lielupė	10.236	82.276	23.481	24.723	2.776	2.620
Dauguva	-	15.785	-	-	-	-
Nemunas	14.355	228.892	15.273	-	-	-
Total:	25.754	343.106	41.751	31.048	3.597	2.907



a)

b)

Figure 2. The distribution of velocity in profiles No. 608 (no barrier) (a) and No. 599 (installed barrier) (b), when the flow rate 0.65 $m^3 s^{-1}$.

to estimate the effect of obstructions for channel bed erosion and the beginning of meanders formation. Threshold velocities depend on a type of ground in a particular place. The distribution of velocity in cross sections is presented in Figure 2.

After installation of obstructions the highest differences of velocities in these cross-sections are at the flow rate, when water level reaches the height of obstructions. The average flow rate when water level becomes equal to top of obstruction was 0.65 $m^3 s^{-1}$. The changes of velocity vary in the range from 15 to 50%. Increasing flow rate over 0.65 $m^3 s^{-1}$ water level is overtopping the barriers. The average flow velocity in cross-section increases, but the difference between velocities with obstructions and without them decreases. It means that overall effect of obstructions on channel erodibility gradually decreases. To avoid large distribution of velocities along the channel bed, the parameters of barriers should be similar and any cross-sectional configuration should be taken into account.

Each implemented barrier must be designed in such a way as to reduce one-third of the flow cross-section. However, if it is not reached, barriers should have the same dimensions. At this case the efficiency can be insignificant in the deeper and wider areas of stream bed. The changes of velocity occur not only in places where obstacles were installed. This takes place in intermediate cross sections, because hydrodynamic changes take place throughout the flow after installation of barriers. The changes of water level due to installed obstructions are insignificant and fluctuate in the range of 3-7 cm. This means that implemented measures will not have significant impact on flood risk. The highlights of the flow velocity distribution in the river bed with barriers and without it at 1.5 $m^3 s^{-1}$ flow are presented in Figure 3.

Figure 3 shows that the effect of barriers is significant. High-speed curve peaks indicate changes of the flow velocity around them. Velocities between the barriers slightly reduce after the installation of barriers and this enables to accumulate washed silt.

The impact of the installed barriers to the channel bed formation can be assessed by the flow rates and prevailing soils. According to the soils of Viešinta river (gravel sand, fine sand with gravel impurities, and dust) and the table of threshold velocities, it was found that gravel sand is washed when stream velocity is 0.70-0.75 m s^{-1} and fine sand is washed when stream velocity is 0.35- 0.45 m s^{-1} (flow velocities are taken at 1-2 m water depth of the bed). Figure 3 shows that some barriers are ineffective and do not reach the threshold velocities. If the velocities are ineffective, the settings of barrier parameters are changed until the desired velocity is obtained. In order to determine the long-term impact of the barriers, it is necessary

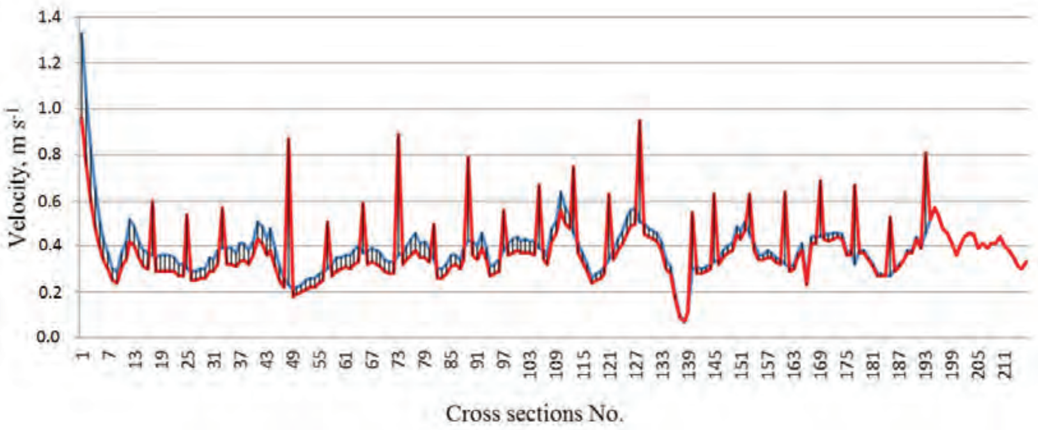


Figure 3. Comparison of velocities with barriers and without at flow rate 1.5 $m^3 s^{-1}$
(In red – with barriers, in blue – without barriers).

to carry out the hydrological calculations and to determine the selected flow pattern within a year. This remains an actual topic of future research.

The obtained geological data from straightened part of Vašuoka stream showed that the loam dominates with threshold velocities from 1.30 to 1.40 m s^{-1}. Flow velocities may exceed 1 m s^{-1} in the selected stream after removing the existed thresholds and implementing restoration tools. The results show that only a theoretical possibility of the bed erosion processes remains. However, only minimal washouts are expected due to the loam soil with grass and bushes along the riversides.

In conclusion, it can be noted that it is possible to achieve such a flow velocity variation that causes the primary deformations of channel and initiates the stream meandering if the proposed methodology of artificial barriers is properly implemented along the riverbed. One dimensional model of steady flow cannot evaluate the future development of the process, but the results show that this methodology proposes fast and low cost for streams' restorations.

Conclusions

1. The analysis of straightened streams' databases shows that straightened streams cover 1-3 type of rivers in Lithuania.
2. The stretches of straightened streams were divided into 7 groups depending on river type, bed gradient and type of environment (forest, outskirts and field).
3. The first type of river sections assigned to the first group of straightened streams (A <100 km^2). Self-naturalization is proposed to the first group of streams.
4. Good ecological status (biological, chemical) could be achieved by artificial tools. Depending on the different microclimatic conditions and biodiversity, large straightened streams (> 100 km^2) were divided into 2-7 groups. The partial and full restoration by using bioengineered means can be used for mentioned groups.
5. The largest distribution of velocities appears during the minimum flow discharge (0.65 $m^3 s^{-1}$). In this case water level stays beside of obstruction top level and cross sections of flow change in the biggest level. In these cases the distribution of velocities varies from 15 to 50%.
6. The changes of water level due to installed obstructions are insignificant and fluctuate in the range of 3-7 cm. This means that implemented measures will not have significant impact on flood risk.
7. The fluctuation of flow velocities will increase the initial bed deformations depending on the dominated types of soil, which initiate the formation of meanders. According to the calculations and visual assessment of the current situation, it is very likely that the riverbed meanders will form in the area of river floodplain.

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