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THE RESEARCH OF DEFORMATION PROCESSES IN REGULATED STREAMS

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Abstract. Different kinds of deformation occur in the most regulated rivers and stream channels. That courses the changes of stream channels in cross-sectional and longitudinal profiles. Regulated streams banks overgrow with dense grass and woody vegetation. That creates favorable conditions for the accumulation of sediments, what rises channel silting and channel's slopes reduction. In that cases naturalization processes evidence in the regulated stream channels. The objective of research is to estimate the self-naturalization of regulated streams. The main tasks to achieve the objective of the study are to evaluate the deformations occurring in regulated stream channels of the Jiesia catchment and to determine the reasons of their occurrence. The technical state of regulated streams in randomly selected 58 places was analyzed. Sections of regulated streams of the Jiesia catchment were selected for the studies in respect of their designed bed slope and type of soil prevailing. Having summarized the study results it was determined that the deformations of slopes and channel bed are the most frequent deformations occurring in regulated streams. The most significant deformations occur in the zone of channel flow. In 63.4% of all studied cases large amounts of sediment and soil particles accumulate here forming a 0.2-0.40 m thick layer. Also during the formation of deformations on channel slopes, meandering of channel bed was occurred in 67% of all the studied cases. Changes in the profile of regulated streams and non-maintenance of the streams induce the development of naturalization processes in regulated streams.

Keywords: channels, regulated streams, sediment, vegetation, deformations, meanders.

1. Introduction

During the long and intensive period of land reclamation works, the greatest part (82.6%) of rivers and streams of Lithuania has been regulated. During the regulation process of channels of rivers and streams their natural bends were eliminated, and the cross-sectional profile of channels was formed artificially. Rivers regulated in such way became comparatively straight channels arranged in the valley of a former meandering stream. It was calculated that currently the amount of regulated channels of rivers and streams reaches 82.6%, while natural channels cover only 17.4% of total river network (Jablonskis *at al.* 2001).

Recently there has been a lack of funds for the reconstruction, repair and maintenance works of land reclamation systems in Lithuania; therefore even regulated streams have become derelict. As there is no possibility for proper maintenance of regulated streams, their technical state is constantly becoming worse. Slopes of non-maintained regulated streams tend to overgrow with thick grass, bushes or even trees. The stability of such stream slopes is disordered, different kinds of deformations occur in channels of the streams. Ground slipping from the stream slopes accumulates on the foot of slopes making the streambed narrower. Certain amount of ground accumulated in the stream channel creates obstacles for water flow and thus distorts the flow of the stream. During the deformation processes of stream channel and slopes, the bed of regulated streams becomes meandered (i.e. natural stream bends appear). Stream slopes overgrown with grass and woody vegetation, stream channel formed by deformation processes and stream bends formed by the stream flow create favorable conditions for the formation of naturalization processes of regulated stream channels.

Currently, the objective is to achieve the self-naturalization of regulated streams with as little expenses as possible. However, the streams are also to carry out their main function, i.e. they must be able to let the excess water from drainage systems. As the study results have shown, a certain part of regulated streams may be at least partially naturalized, and in such way their natural balance would be restored. Some of researchers have noticed that the maintenance of naturalized streams is much easier, and under favorable conditions no maintenance works are needed at all. Naturalization is particularly needed for the improvement of ecological conditions and landscape (Rimkus and Vaikasas 1997).

The objective of the studies was to evaluate the deformations occurring in regulated stream channels of the Jiesia catchment, and to determine the reasons of their occurrence.

2. Study object and methodology

Regulated streams contained in the river Jiesia catchment were chosen as study objects. The river Jiesia is one of the smallest tributaries of the river Nemunas. Catchment area of the river Jiesia covers 473.7 km^2. 63 % of total catchment area is covered with heavy-textured soils containing bad filtration qualities; in the upper reaches (and particularly in middle reaches) of the river non-sloping flat loam plains are prevailing. Wood density of the catchment is 20%. The catchment of the river Jiesia is narrow and rather symmetrical. Only 4 tributaries of the river Jiesia (the Šventupė, the Girmuonis, the Šlapakšna and the Vyčius) are longer than 10 km. The hydrographic network of the river catchment contains 358.7 km of river channels from which 259.5 km (72.4%) are regulated (Jablonskis at al. 2001). In Lithuania regulated river channels make up 82.6% of total length of river network. It means that in the Jiesia catchment the channels of rivers and streams were less affected by the land reclamation works and other kind of human activity.

Certain sections of regulated streams of the Jiesia catchment were selected for the studies in respect of their designed bed slope and type of soil prevailing. On the basis of those criteria, the technical state of regulated streams in randomly selected 58 places was analyzed. During the studies the following points were determined:

1. Cross-sectional and longitudinal deformations of regulated streams;
2. Overgrowth of slopes and bed with grass and woody vegetation;
3. Peculiarities of deformations and naturalization of channels.

The information about present technical state of the study objects was summarized into special logbooks preliminary made for the evaluation of the condition of streams. The following observation criteria were presented in the logbooks:

1. purpose of land around the study objects, agricultural land use (arable land, grassland – pasture, derelict land plots);
2. flora growing on channel slopes (thickness of grass, species prevailing, density of shrubs);
3. cross-sectional and longitudinal deformations of channels;
4. present configuration of the channel (width, depth, meandering parameters);
5. state of channel bed (sediment layer, level of vegetation cover on the bed).

In the selected segments of regulated streams the cross-section of channel beds (for the evaluation of cross-sectional deformations) and longitudinal channel profiles (for the determination of channel bed slope) were measured. The data collected was compared with the design material of stream regulation, as well as with the data of repair and reconstruction works of streams. The latter repair and reconstruction projects were fulfilled in 1997-1998. Deformations on the studied streams occurred within the period of the last 9-10 years. Thus the extent of the deformations of regulated stream channels calculated in such way has developed during a certain period of time.

On the basis of calculated study results, a graph of the distribution of average standard deformations within a cross-sectional profile of stream channels is created.

The information contained in logbooks is systemized, the data is processed with mathematical statistics methods. The paper presents the mathematical – statistical analysis of different data collected and results calculated during the study period.

3. Study results and discussion

Cross-sectional deformations of channels of the studied objects were evaluated having compared the measurement results with the material of design, repair and reconstruction works (Kauno... 1997; Prienu...; 1995). Summarized study data of deformations are presented in the graphical chart (Fig 1).

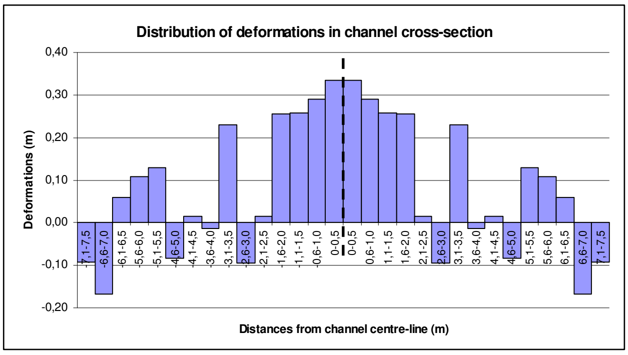

Fig 1. Distribution of cross section deformation in regulated streams

Figure 1 presents the chart of the distribution of average standardized deformations within a channel profile. The chart shows average digital values within a 0-5-m interval across the stream channel.

Profiles of the regulated streams channels are distributed into 3 deformation areas where deformations typical to those areas occur: 1 – area of water flow effect, 2 – middle part of slope, 3 – upper part of slope.

As it is seen from the summarized data presented the chart, landslides most often occur on the upper part of the slopes (0.09-0.17 m deformations on the average). Landslides of the upper part of slopes occur in 72.8% of all studied cases. In the middle part of slopes (2.0-6.5 m from channel axis) deformations are insignificant (0.02-0.12 m, sometimes 0.23 m). The most significant deformations were observed in the area affected by water flow, i.e. where water flow effect is most intensive. In this area (2.0 m from channel axis) in 63.4% of all studied cases a large amount of sediment and slid soil accumulates (0.25-0.30 m). In all the rest cases (36.6%) under the conditions of higher gradients of streambed the stream flow tends to form a channel with the bed below the designed level. Such conditions enhance the cessation of sediment accumulation; however the channel experiences constant scour and deformation. Soil washed from slopes and channel bed is transported downstream and deposits within a stretch of lower gradient where water flow velocity decreases. This results in the accumulation of sediment, which enhance the changes in design parameters of the channel. Cross-sectional profile of the channel rarely remains stable: a smaller channel with narrower bed is formed on the designed stream channel. Such cases made up 6.8% of all studied variants.

Considering the available data and information, it can be stated that the deformations presented in the chart occurred within a period of the last 9-10 years, i.e. since the repair or reconstruction works performed in the studied streams. Thus average deformations occurring every year may also be calculated in the following way. However, it must be considered that deformations may have occurred during a comparatively short period of time and may have stabilized later. In such case it is rather difficult to say if particular deformations have been forming regularly, or if they are random and momentary.

Results of research show the most frequent deformations include 0.1-0.33-m high accumulations of sediment and soil deposits. In the negative part of deformations also 0.1-0.17-m high deformations including scours of channel bed and slides of slopes. This implies that the distribution is not symmetric with the declination to the side of positive frequency values. This is explained by the fact that in the studied objects the tendencies of sediment formation and accumulation of soil slid from channel slopes into channel beds are dominant.

Having made the mathematical-statistical analysis of deformations measuring results it was determined that the weighted average value of deformations is 0.2 m. This implies that the formation of sediment and soil layer is the most frequent type of deformations. Negative deformations are less frequent. The latter deformations most often occur as the leaching and deposition on middle and upper parts of slopes. The variation scope of values is 2.1 m (from 1.2 to –0.9 m). Standard deviation of data set σ = 0.42 m. The dependence of deformations extent on their position in the channel profile is expressed by a correlation coefficient R=0.639 (determination coefficient R^2=0.409). This shows a strong relation between the b is determined according to Student criterion t_{actual} = 6.49. The calculated value exceeds the theoretical value several times (t_{theor}=1.304) (Kruopis 1993). This shows a reliable estimation of cohesion of the relation between the distributions of deformations within the channel profile.

As the study results show, landslides of the upper part of slope often depend on soil depressions and different types of human activity (often farming activity) resulting in the landslide of soil from the upper part of slope towards the foot of slope. In the middle part of slope deformations are rare, however here the tendency of increased accumulation of soil slid from the upper part of slope is observed. The most significant deformations are observed in the area of water flow where the water flow is constantly affecting the channel and changing its configuration. Flowing water scours the foot of slopes and thus creates conditions for the sediment accumulation on the channel bed. After the accumulation of sediment in water flow area the vegetation starts developing. Higher roughness of channel bed results in lower water flow velocities, which on its turn creates favorable conditions for the additional sediment accumulation. At the onset of sediment accumulation process the gradient of channel bed decreases, which enhances the accumulation of sediment not only in the initial place of deformation formation, but in the whole affluent zone as well. Influence of surface water, hydro-dynamic pressure of soil and grain-size composition of soil also contribute to the formation of slopes deformations (landslides of slopes). All the facts mentioned enhance the erosion processes of slopes and accumulation of soil slid from the slopes on the foot of the slope.

Accumulated sediment and distorted slopes form in such way a new profile of the channel bed. As a result, the gradient of the stream and its flow velocity change, which ensures favorable conditions for further formation of cross-sectional and longitudinal deformations of channels of regulated streams.

Cross-sectional channel deformations highly influence the position of regulated streams channels in the plan. When cross-sectional deformations occur, the signs of meandering of channel beds instead of straight channels are observed. Soil slid from slopes on the foot of slopes creates obstacles for water flow, which results in the occurrence of cross-sectional circulation in the channel. Strong water flow starts scouring channel slopes. Due to the flow circulation scoured particles of slope soil are transported into the opposite side of the flow where they form shallows in the course of time. This enhances the processes of side accumulation and side erosion (Basalykas 1956). Having deviated from the designed position, the channel bed creates meanders similar to those of natural streams.

Meandering streambed was observed in 67% of all studied stream channels. This is most often found in the stretches of channels where sandy-loam soils are prevailing (69.7%), where sediment is accumulating (42.6%) or where slopes deformations are observed (72.8%). Usually in such stretches of channels no maintenance or repair works are carried out.

More intensive meandering of channel induces lower water flow velocities. Leaching and transport of sediment discontinues, sediment accumulation begins, and the conditions become favorable for the development of aquatic vegetation on the channel slope. Increased water roughness in the channel results in even more intensive reduction of flow velocity.

The photos provided depict the state of streams, showing the meandering of streambed and their overgrowth with grass vegetation (Fig 2).

a)
b)


Fig 2. The intensity of grass vegetation cover and meanders formation in the channels of the regulated Girmuonis (a) and Vycius (b) streams

Figure 2(a) shows the intensity of grass vegetation cover in the channel of the regulated stream Girmuonis. After the accumulation of sediment on the streambed, high moisture-tolerant plants started growing (calamus, cats-tails). When there are plant in the channel, water flow velocity and hydraulic conductivity of the channel decrease, which creates perfect conditions for channel silting. In this particular case the channel bed is overgrown with thick aquatic vegetation and thus stable water is retained in the channel. This stretch of the channel does not perform its initial role as a water discharge pipe of drainage system. Figure 2(b) shows the peculiarities of meander formation in the channel bed of the regulated stream Vycius. Considering the data collected from Agricultural Department of the Municipality of Kaunas district, during the last 5-8 years no maintenance and repair works were performed in the catchment are of the stream Jiesia. In non-maintained slopes perfect conditions occur for the rapid development of high grass vegetation (nettles, thistles) that spread over the entire stream slopes and choke other plants (Berankienė 1997). The examples discussed clearly show that deformations developed in non-maintained streams enhance the designed changes of channels of regulated streams.

Width and depth of channels of studied regulated streams were also measured during the study period. The chart of distribution of the results between present width and depth of stream channels was made (Fig 3). Linear interrelation of those parameters was determined. Resilience level of the relation is expressed by the coefficient of determination R^2=0.61.

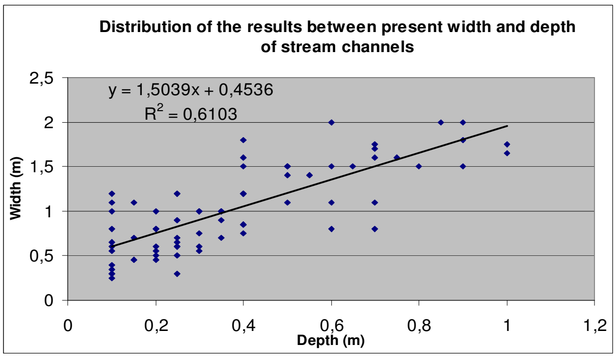

Fig 3. Distribution of the results between present width and depth of stream channels

It was observed B/h ratio for investigated streams. Operated natural data it was estimated that B/h ration from 3.0 to 3.6 for analyzing streams. V. Altunin has been analyzing data channels parameters B, h, and its B/h ration for steady rivers. According to his calculation B/h ratio for small streams with meanders is 4-5 (Altunin 1972; Vaikasas 2000). These differences show that investigated streams are not natural and steady, but after some time its can reach that ratio. After that regulated streams channels profiles become steady and their configuration will become near parabola. According to V. Altunin all steady rivers channels are parabola form (Altunin 1972; Vaikasas 2000).

Thickness of sediment layers accumulated in regulated streams was also measured during the studies. A connection between the depth of sediment layer and type of soil prevailing in the territory was determined.

There were summarized study data of sediment accumulation and deformation occurrence under the conditions of different types of soils. The results show that sandy-loam soils are prevailing the thickness of the layer of slid soil and accumulated sediment is changing within a wide range (0 – 1.05 m), and most often (50%) the layer mentioned varies from 0.1 to 0.73 m. When heavy loam soils are prevailing, the range of accumulated sediment layer formation is 0.-0.8m, however most often (50%) the formed layer is 0.3-0.55-m thick. Thus it can be stated that sandy loam soils are less stable therefore here the most significant deformations occur.

Relation between thickness of sediment layer and designed gradient of channel bed was also analyzed during the studies. It was determined that the largest amount of sediment accumulates under the conditions of low gradients (0.4 – 0.6 ‰) forming a 0.1-0.65 m thick sediment layer. When gradients are higher (1 – 2.5 ‰), sediment layer is only 0.2-0.3 m thick. Formation of sediment layer most often depends on different obstacles occurring in channels.

In 17.2% of all studied cases the slopes of streams were overgrown with bushes and trees. This most often occurred in streams located in outer woods or forests. Obviously, those streams were not properly maintained for several years. During the last years slopes and channel of those streams overgrew with thick high grass, thin bushes and separate trees.

4. Generalization of study results

Having summarized the study results it was determined that the deformations of slopes and channel bed are the most frequent deformations occurring in regulated streams. The main deformations observed in the study objects include:

1. Landslide of slopes, soil slid from slopes, soil scour (in middle and upper parts of slopes);
2. Channel bed silting and leaching, scour of foot of slope, accumulation of slid soil on foot of slopes, overgrowth of channel bed with grass vegetation (in area of water flow).

One of the most frequent channel deformations – landslide of slopes – usually depends on soil grain-size composition, stratification of soil layers, improper human activity and other factors. Bank erosion is a complex phenomenon in which many factors play a role, but in general it is flow, sediment transport, and bank properties that determine rates of bank retreat (Richards 1982).

The main factors causing channel deformations of regulated streams include:

1. Surface water, human activity, vegetation grown on channel slopes (in the zone of slopes);
2. Water flow in the channel, stability of slopes (in the zone of water flow).

Bank properties include: material weight and texture; shear and tensile strengths; groundwater level; permeability; stratigraphy; geometry; and vegetation (Mosselman 1992). With such a wide range of contributing factors, it is useful to consider bank erosion in terms of broad process categories. Lawler identified three bank-erosion process domains: subaerial preparation; fluvial entrainment of bank sediment; and mass failure mechanisms (Lawler 1992; Lawler 1995).

However it should be noted that in respect of certain conditions the same factor may enhance different channel deformations and the same deformation may be a result of several factors.

All the mentioned and other related factors inducing channel deformations occur due to the non-maintenance of regulated streams. Currently, due to the lack of funds allocated for the maintenance of land reclamation systems, it is impossible to maintain properly all regulated streams and ensure their designed operation properties. As a result, proper functioning not only of regulated streams as water recipients but of all drainage systems may be disturbed. Affluent of outlet may result in flooding and loss of nearby land areas.

To maintain the initial state of regulated streams is a complicated and expensive task. This is not an economically optimal exploitation way of water recipients even if the allocation of funds was sufficient. The dynamic balance between the effect of flow and state of the channel is unstable, which means that deformation processes are inevitable in channels. As the studies of naturalization processes have shown, there is a possibility to create nature-based dynamic balance in regulated streams as well, i.e. the exploitation ways are to be changed and improved (Vaikasas and Rimkus 1997).

Only separate stretches of streams should be renaturalized; nearby them there should be no land plots valuable from the agricultural point of view. Therefore when renaturalizing regulated streams it is necessary to consider natural condition in each separate case. Considering the practice of foreign countries, within the area of renaturalization thin vegetation and bushes are to be eliminated in short stretches on one of another bank of stream in succession.

In Lithuania the main means of naturalization is natural overgrowth of channels with bushes, trees and grass vegetation. Natural meandering of channels and formation of shallows is a significantly slower process. Therefore natural naturalization is acceptable from technological as well as ecological points of view (Rimkus and Vaikasas 1997).

In western European countries those processes are enhanced artificially. In such case the meanders of stream channels are re-established faster, adapting them to local landscape conditions. Unfortunately, this requires large expenses and work input. Channel meanders may be created having excavated them in certain places or having arranged small dikes. Then the channel flow would be distorted and conditions for intensive bed processes would be created. Artificial meandering of channels stabilizes water levels increased during the flood. More favorable conditions for the self-purification of flow from certain pollutants and nutrients are created in the meandering flow (Vaikasas and Rimkus 1997). During the artificial naturalization of streams the re-establishment and maintenance of channel meanders are particularly important, highest channel flow velocities are to be reduced, stable channel is to be formed, flow transport capacity is to be induced (Vaikasas and Poškus 2003). Applying “mild” maintenance means of canalized streams used in western European countries, it is possible to coordinate sufficient hydraulic conductivity of streams and gradually improve their hydro-dynamic balance and natural diversity. To achieve this, meandering of straightened stream bed is recommended (Vaikasas 2000).

As the results of studies carried out by researchers of Water Management Institute show, the naturalization processes of regulated streams and channels as well as the activity of their water recipients may be successfully coordinated. In such way their environment protection effects to nature will be improved. Moreover, the maintenance of water recipients will become less complicated and much cheaper. During the naturalization process of regulated streams the balance between flow impact and channel stability is gradually restored, and the need for maintenance works decreases (Rimkus 2000)

5. Conclusions

The most frequent deformations occurring in regulated streams include the deformations of their slopes;

The most significant deformations occur in the zone of channel flow. In 63.4% of all studied cases large amounts of sediment and soil particles accumulate here forming a 0.2-0.40-m thick layer;

Sediment accumulation and distorted slopes result in the changes of designed stream channel, which creates favorable conditions for further development of cross-sectional and longitudinal deformations;

During the formation of deformations on channel slopes, meandering of channel bed is observed. Meandering streambed occurred in 67% of all the studied cases;

In the channel with accumulated sediment favorable conditions for the development of aquatic vegetation are observed. The vegetation impedes water flow in channels and thus enhances further formation of deformations;

Changes in the profile of regulated streams and non-maintenance of the streams induce the development of naturalization processes in regulated streams.

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