RESEARCH OF DEFORMATION PROCESSES IN REGULATED STREAM CHANNELS OF LITHUANIA

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Abstract
Deformations occurred in natural and regulated stream change beds lateral and longitudinal profiles. This is particularly evident in regulation furrows, where their initial state is known. Research showed that landslips of the upper slopes in regulated watercourses is the most common deformation (72.8% of studied cases), and the largest deformation occurs in the lower part of the slope (63.4%), where the accumulation of the moved silt and soil is. It was found that the deformation changes the bed plan as well. 59.1% of regulated streams distort furrows and make meanders due to deformation effects. The analysis of river beds widths and depths ratio relationship with discharge of channel running flow observed that ratio B/H increases with increasing flow evenly in regulated beds, while the above-mentioned ratio varies unevenly in the natural watercourse. Cross-sectional shape also varies in regulated and natural beds: heterogeneous form beds dominated in natural beds, while parabolic cross section shape is approaching during the deformation in regulated beds, what is more favourable for the living environment.
Key words: deformation of channels, rate of width and depth, processes of naturalization.

Introduction

Recently, the majority of regulated streams have become abandoned and neglected. Banks of abandoned regulated rivers are overgrown with lush grass and dense shrubs or even trees. There are many factors (run-off of surface water, water flow in the bed, growing vegetation in the bed and on the slopes, etc.) that cause various kinds of deformations in regulated river beds. The analysis of regulated stream beds deformation processes showed that erosion of slopes, leaching beds and silt accumulation are the most common deformations of regulated stream bed. That creates favourable conditions for the overgrowth of riverbeds with grasses, shrubs and forest vegetation. Deformation, which occurred on the impact of various natural factors, determines changes in river beds of cross sectional and longitudinal profiles. Landslide soil of slopes accumulates in the foothills of the bed slopes thus narrowing the stream bed. Parts of the soil create resistance for flow of water and distort stream flow. Bed is silting in the low slope areas, while washed out processes are observable in beds with rather great slope areas. Erosion products are brought together with surface runoff from the surrounding areas and complement accumulating silt layers in beds. Bottom of the regulated stream begins to curve during the deformational processes in bottom and the slopes, - that form natural meanders of streams. Stream slopes with overgrown grassy and woody vegetation, the stream bed formed of deformation processes and stream meanders created by water flow create favourable conditions of naturalization processes for regulated streams. This changes the distribution flow energy of rivers and water aeration conditions.

The objective of the research was to evaluate the deformation processes in Jiesia and Merkys rivers basins.

Materials and Methods

The research was carried out in natural and regulated tributaries of Jiesia and Merkys rivers basins. The Jiesia river basin is located in the central part and the Merkys river basin - in the southern part of Lithuania. Amarnia, Čirvija, Grūda, Spengla are tributaries of the river Merkys. Vyčius and Kumė are tributaries of the river Jiesia. Both natural and regulated streches of all these tributaries were investigated. During the research it was attempted to measure lateral and longitudinal deformations of regulated streams, the current configuration of the bed and the bottom, the overgrowth of the slopes with grassy vegetation, beds deformation and naturalization patterns, accumulated silt layers dependence on the prevailing soil.

The longitudinal profiles of streams were measured to adjust deformation in selected sections and to determine the cross-section chances - transverse sections were evaluated. In order to assess the tendency of the transverse deformations, the research objects cross sections were divided into 3 zones: a bed, slope and upper slope parts. The format and amount of deformation in the longitudinal and transverse profile were taken into account. 100-200 m length natural and regulated rivers in the Jiesia and Merkys river basins were selected. Selected sections were subdivided into every 10 m sections. Flow width, slope coefficients and the thickness of accumulated silt layers were measured. The location of profiles was estimated by the GPS device. Straight cuts, geological surveys were made to determine the dominant soils. Leveling was used to evaluate the slope of the bottom of the selected sections. Grass and woody vegetation growing on slopes were visually assessed. The condition of studied streams was evaluated and information was entered into forms. Information was structured, data was processed by methods of mathematical statistics, the relationship between the formated of silt layer and the prevalence of soil properties was determined.

Results and Discussion

The prevailing deformation was determined in different cross-sectional parts of streams (bed, slope and upper slope part), regardless the researched object parameters. With reference to aggregated data, it can be stated that soil loss was asserted at the upper slope area (an average from 0.09 to 0.17 m), which set 72.8% of the cases studied. The latter area was affected not only by surface run-off, but also by heavy equipment moving in this area and existing human activities. The slight deformation was determined in the middle zone of slope (from 0.02 to 0.12 m, in some cases up to 0.23 m). The fact that erosion of the stream usually starts at the slope and upper part of slope was determined by Ragauskas (2004) as well. This is explained by the fact that poorer vegetation grows in these places and the turf is more vulnerable, and surface runoff also affects the stability of slopes. The largest deformation occurs in the zone of water flow, where the channel is usually affected by water flow. In this area, in the majority (63.4%) of the studied cases, large alluvial soil and landslip from slopes (from 0.25 to 0.33 m) are accumulated. Soil is eroded from the bottom and the slopes are transported downstream. When eroded soil reaches the strech with lower slope or low water flow rate, then the deposited silt settles. That is a result of concentration of alluvial deposits, which determine the design parameters of the riverbed changes. Only in rare cases the transverse profile of the bed remains constant - these were 6.8% of such cases.

Deformation of regulated streams and their distribution in different zones of the cross-section are presented in Figure 1. Along with the supplied cross-section the areas, in which their inherent deformation occurs, are revealed.

Deformation is not evenly distributed in beds, but the positive deformations are pointed up. This is explained by the fact that there is a tendency of siltation dominated in the studied sites and accumulation of soil slopes in the footslopes. Assuming that the determined deformation had formed during the period of 7-9 years and the beds of streams alluvial layers on average range from 0.25 to 0.33 m, it is estimated that over one year from 0.03 to 0.04 m thick layer of silt are formed. These results were confirmed by Varnelis (2004), because he found that in sandy loam soils accumulate 4 cm of deposits and in loam soils - about 3 cm of deposits during the period of one year.

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 -0.9 to 1.2 m). Standard deviation of data set is s = 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 medium relation between the distributions of deformations within the channel profile. Correlation coefficient reliability is determined according to Student criterion t_{actual} = 6.49. The calculated value exceeds the theoretical value several times (t_{theor} = 1.304 when α = 0.1) (Kruopis, 1993). This shows a reliable estimation of cohesion of the relation between the distributions of deformations within the channel profile.

Cross-sectional channel deformations highly influence the position of regulated stream channels in the plan. When cross-sectional deformations occur,

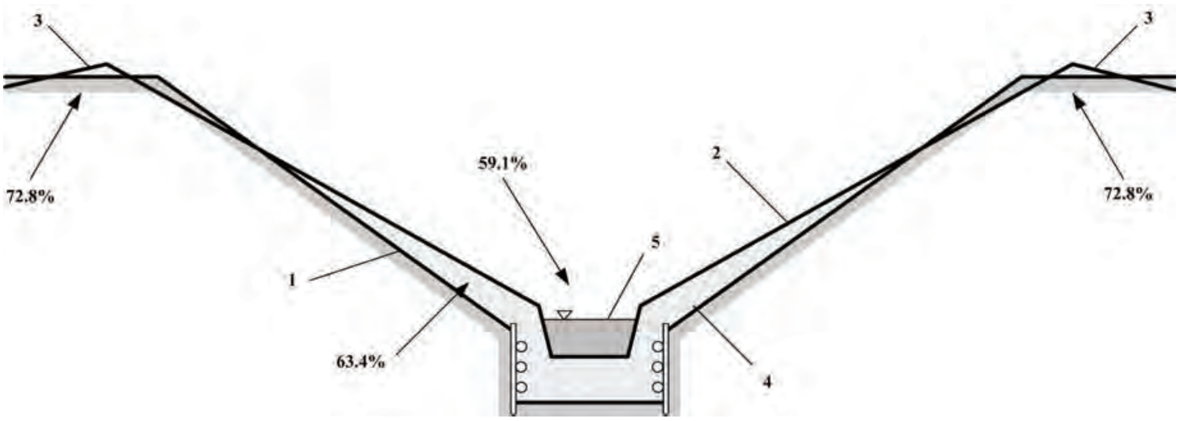

Figure 1. The distribution of deformation in different zones of regulated stream.
1 – designed stream cross section, 2 – present state of regulated stream, 3 – deformation of upper slope part, 4 – soil of landslip slope and accumulated layer of silt, 5 – new stream bed with meanders.

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. Having deviated from the designed position, the channel bed creates meanders similar to those of natural streams.

Meandering streambed was observed in 59.1% 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 slope deformations are observed (72.8%). Usually in such stretches of channels no maintenance or repair works are carried out.

The balance of water flow velocity and granulometry composition of soil occured in natural streams. In this case, the flow prevents accumulation of silt, but also scour does not exist in stream beds furrow and leaching. However, this process can be influenced by side factors, such as human activities, vegetation and other.

It was found that plants began to grow in the bottom with sediments: sweet calamus (*Acorus calamus L.*), cat's-tails (*Typha L.*). They slow down the flow rate, reduce water permeability and thus capacitate the accumulation of sediments in strem beds. There are suitable conditions for tall grassy vegetation (great nettle (*Urtica dioica L.*), mugwort (*Artemisia*), thistles (*Cirsium*) and etc.) to spread rapidly, which cover all slopes of the stream and displace other plants in neglected streams. Berankienė (1997) confirms the same composition of grassy vegetation species in her studies. Millar (2000) concluded that bank vegetation does exert significant and quantifiable control on alluvial channel patterns. Hession and other researches (2003) also indicated that stream-bank vegetation significantly influences the morphology. Their data indicate that rates of deposition and lateral migration are both higher in nonforested reaches than in forested reaches (Allmendinger et al., 2005). Provided examples show that vegetation growing in river banks and beds make considerable influence on changes of longitudinal and transverse profiles in neglected regulated streams.

Examining the spread of woody vegetation in researched sections showed that the slopes of the streams in 17.2% of the studied cases are overgrown with shrubs and several trees. The density of woody vegetation on the stream slopes is $t = 0.141 \pm 0.011$ pcs./m^2. The genus of willow (*Salix*) plants dominated in target sections: purple willow (*Salix purpurea*), gray willow (*Salix cinerea*), osier (*Salix viminalis*). It was found that the distribution of woody vegetation is unequal in researched objects. The middle zone of slopes is the most densely wooded, where the proper moisture regime formed the most favorable conditions for the development of vegetation. In the source of literature (Survilaite et al., 2006) the data are presented confirming that the middle zone of slope is wooded the most densely. This is because of the lack of moisture in the upper part of slope and because of too much moisture in the lower part of the slope.

The increase of woody vegetation on slopes of the streams is the most often seen in streams discharging near forest or wooded areas. This is confirmed by the literature (Lamsodis, 2002), where results claim that woody vegetation is denser and more common on the slopes of streams located in forests and near them. Moreover, it generates the diversification of plants as well. Lamsodis (2006a) found that herbaceous and woody vegetation growth intensity increases sediment accumulation on the bottom of regulated rivers while the growth of woody vegetation on the slopes reduces it (Lamsodis et al., 2004, 2006a).

The layer of silt accumulation thickness was measured in regulated streams. Correlation was estimated between the thickness of silt and prevailing soil in the area. The summarised research information showed silt layer thickness when light clay loam, medium loam, light loam and sandy loam soils are prevailing. It can be maintained that sandy soils are the most affected, that is why the largest alluvial deposits are evident on beds of streams. Poškus (2008) also indicates that sediment particle size has a realtion with the soil, which dominates in regulated streams. Ragauskas (2004) argues that soil particles washed by surface runoff from surrounding areas also augment the acumulated silt in regulated streams. Studies have shown that the biggest amount of soil is leached in sandy loam ditches, less – in loam (Ragauskas, 2004).

Width of streams. The research showed that the width of stream varied from 5.36 to 12.38 meters in natural and regulated stream sections. The main results of research are presented in Figure 2.

It was found that changes of streams width are related with natural processes there. Another reason for the change of the width of beds is grassy vegetation. It was researched that the changes of width varied to 21% due to the influence of vegetation on slopes. It was found that a greater impact for width of the beds had both grassy vegetation and individual trees. Flow width is reduced, the water flow is tightened and leaching is formed in these places. Self-naturalization processes were started in rivers that are why the width of beds become heterogeneous.

Having measured results of stream widths, it can be said that the flow rate is not the main factor influencing

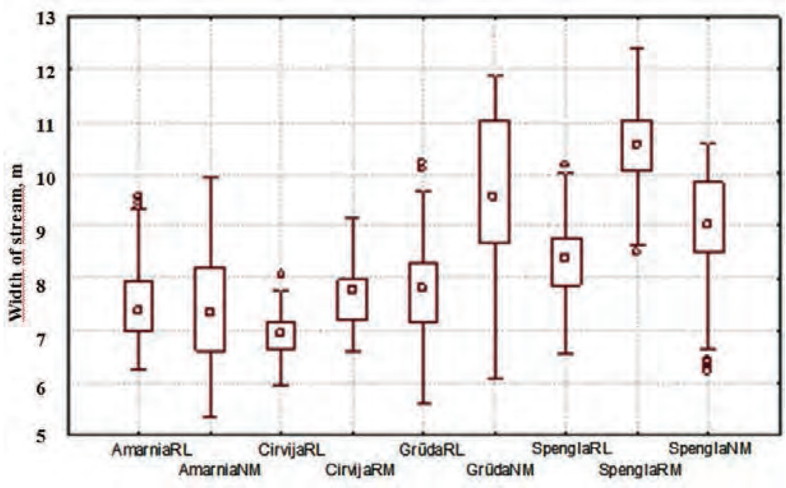

Figure 2. The variation of stream width in researched rivers (RL – regulated stretch located in field, RM – regulated stretch located in forest, NM - natural stretch located in the forest).

the increase of flow widths. Estimating them by the state in terms of naturality, it is clear that the variety of width of natural streams is compared wider to those sections where self-naturalization processes are insignificant. The widths in natural stretch of Amarnia were found 1.4 time higher compared with widths of Amarnia regulate section. Cirvija natural beds widths are 1.2 times higher compared with the regulated bed of Cirvija. The bed width of Grūda natural stretch is 1.3 times higher compared with the bed widths of regulated sections. Spengla natural stretch widths are 1.2 times wider compared with the Spengla regulated river stretch. That shows that the variety is consistent for natural and self-naturalizated rivers. This is a necessary condition ensuring the natural and self-naturalizated processes in stream beds.

The ratio of stream width and depth (B/H). The relation between stream width and depth ratio (B/H) and river flow (Q) was analyzed in natural and regulated rivers. The evaluation of the collected research data is presented in Figure 3.

It is observed that the width and depth ratio are bigger at the flow rate of 50-60 $m^3 s^{-1}$ in natural streams than in regulated ones, where the same B/H ratio value is reached with the flow rate more than 200 $m^3 s^{-1}$. This can be explained by the fact that the natural

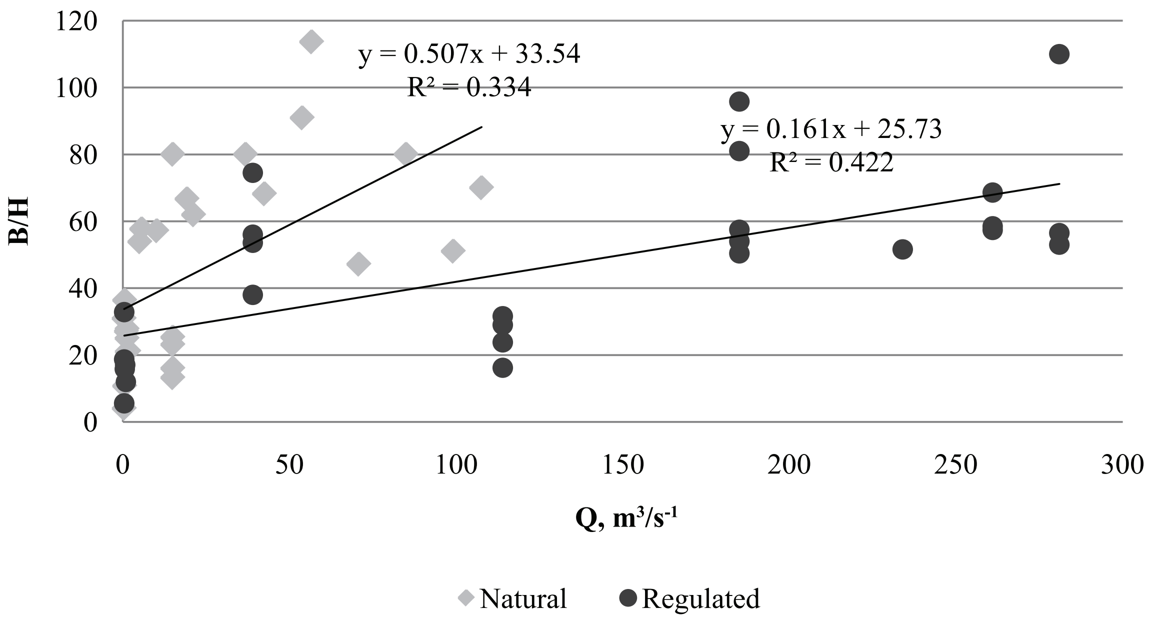

Figure 3. The relation between flow rates (Q), bed width and depth ratio (B/H) in natural and regulated rivers.

a) b)

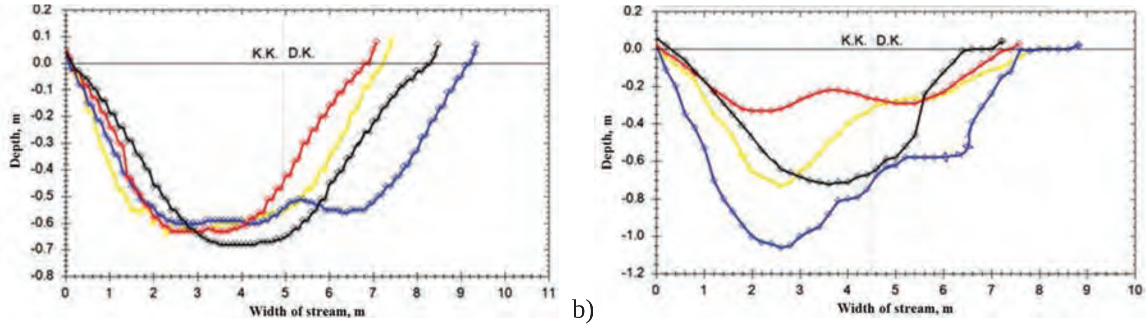

Figure 4. Cross section profiles of regulated and natural river Amarnia.

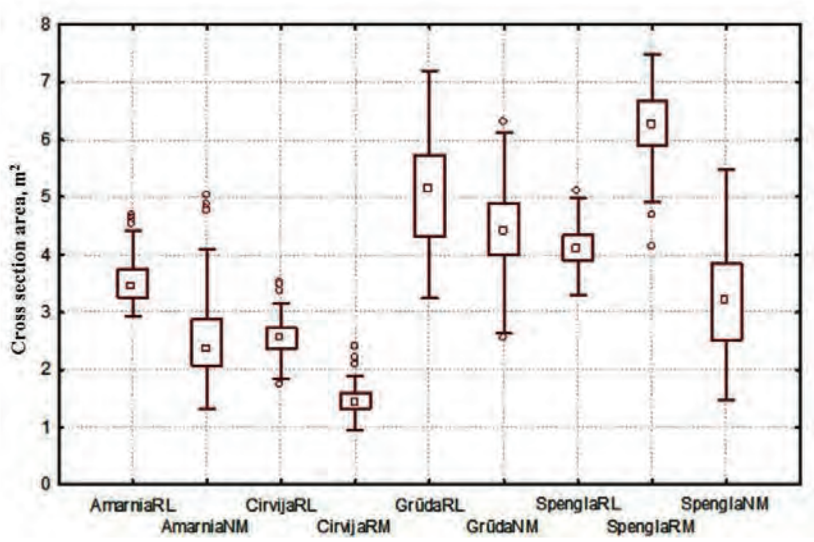

Figure 5. Variations of cross sections in selected streams (RL – regulated stream in field, RM – regulated stream in forest, NM – natural stream in forest).

rivers with higher flow rate have more conveying power than regulated ones. This can be described as a self-regulatory of the bed, which forms contours of the bed. Kleinhans (2010) determined that increasing potential-specific stream power implies more energy to erode banks and indeed correlates to channels with high width–depth ratio. Meanwhile, the width and depth ratio with rivers flow discharge increases gradually in regulated rivers. This shows that the cross section form of the regulated river is artificially formed as trapezoidal, where the increasing flow rate and furrow width and depth ratio increase gradually.

Rivers form and cross section. It was found that the most common form of regulated watercourses is parabolic, regardless the cross section area of the bed. The symmetric parabolas are specific for regulated streams (Figure 4a.). This is mostly due to the fact that natural rivers were regulated by changing them to trapezoidal cross-section profiles. During the deformation, corners of artificial steep profile become rounded and the profile becomes parabolic, i.e. close to natural. Meanwhile, forms of natural beds are more heterogeneous and changing along the stream (Figure 4b.). In Figure 4b, profiles that illustrate the patterns of natural meandering, as well as formation of rifles and pools are presented. In respect of physical sense, big (in this case up to 3.8 times) changes of cross section area and shape of stream determine pulsation of flow rate in furrow. That force aeration and formation of favorable conditions for the aquatic animals and invertebrates.

The research reveled that area of cross sections varied in the range from 1.04 to 7.50 m^2. The most commonly it is founded that broad area range varies in natural streams, while more narrow – in regulated ones. The distribution of cross section area is presented in Figure 5.

Obviously, that variety of shapes and cross section forms dominate in natural streams. That forms different conditions of flow and at the same time creates favourable conditions for aquatic animals. Regulated cross sections remain with similar shape along the river bed, so they do not create favorable conditions for living nature, because bed remains homogeneous. And only during the long recovery process, it is observed that regulated streams also assume heterogeneous cross-sections, which are more favorable for the living environment.

The analysis shows that the most common deformations of regulated streams are landslip of slopes and accumulation of soil in the footslopes, as well as wash out of the bed or deposition of sediment. One of the most observed types of deformations (63.4%), a landslip from slopes and accumulation at footslopes, mainly depends on soil type, surface and ground water exposure, lamination, inadequate human economic activity and other factors. Maximum deformation affects in water flow area where the water flow keeps an effect of the bed and changes its configuration. Flowing water erodes slopes, thereby enabling the accumulation of silts at the bottom of the stream. Accumulation of silts in flow area helps to develop vegetation. Herbaceous vegetation growing on bed of streams caused the affluent and reduced the flow rate. The deposited silt from upstream is brought with the surface runoff of soil particles (wash products) and form silt deposition. It was found that sediment particles washed from the surface are usually small particles of sludge, which mainly contain organic materials appropriated from the cultivated fields. These particles mostly pollute rivers and streams into which they fall. But it should be mentioned that, depending on conditions, the same factor can cause different deformations of the bed, and the same riverbed deformation can be a consequence of several confounding factors.

Literature (Ragauskas, 2004) also indicates that part of deposites is formed from soil particles with surface runoff from adjacent areas, which riparian strips are not able to protect from. Therefore, sediment retention buffer strips are very important from environmental point of view, because the number of nutrients in fine particles, which were washed out from the fields, is much more higher than in water running from upstream (Račinskas, 1990). Therefore, the erosion products of solid particles not only complement the silt at the bottom of the river, but also they contain chemical elements, which increase the eutrophication of water bodies. These materials also promote the overgrowth of the river bottom and increase resistance to water flow.

One of the means of the protection from surface run-off - streams protection strips, which are very important in those sections, which are near the area of the cultivated land (Ragauskas, 2004). Račinskas (1983) found that 1 meter wide strip covered by grass holds up to 82.4% of deposits of surface runoff. Ragauskas (2004) indicates that inappropriate human activities along the regulated streams cause deformations in upper part of slopes (Ragauskas, 2004). Therefore, the main source of deposition is the basin of regulated streams, because the measured amount of deposits depends not only on the stream flow parameters (bottom widths and slopes) (Poškus et al., 2008; Lamsodis et al., 2006). The results revealed that the eroded material from banks was deposited on the lower bank areas and at the bottom of the ditch where it is potentially transported further during peak discharge events (Stenberg et al., 2013).

In this way, the accumulation of silt and deformed slopes form a new stream bed, so the slope of the stream, flow rate are changing and generate favorable conditions for the development of lateral and longitudinal deformation of regulated stream beds and formation of the stream which is more similar to the natural channel.

Conclusions

1. It was found that the most common deformations of regulated streams are landslips of slopes and siltation in bottom of streams. It was investigated that sufficiently large amounts of deposits and landslips of slopes (approximately 0.25 to 0.33 m) were acumulated in watercourses (63.4% of the cases studied).
2. There are favourable conditions for development of aquatic vegetation in deposited regulated streams which slow down the flow rate, reduce water flow and at the same time increase bed deformations.
3. The research showed that the largest amount of deposits concentrate in regulated streams located in sandy loams. The range of accumulation of deposits on the layer thickness varies from 0 to 1.05 m, while the majority (50%) of the primer layer is formed from 0.1 to 0.73 m thick.
4. In studied streams it was found that their slopes in 17.2% of the cases studied are overgrown with shrubs and isolated trees. The middle zone of slopes is wooded the most densely, where due to the proper moisture regime the most favorable conditions for the development of vegetation are formed.
5. The regulated river beds meandering features occur due to slope deformations. The formation of meanders was identified at 59.1% of the studied streambeds.
6. It was found that the cross section of regulated rivers get parabolic shape due to the ongoing deformation processes. Asymmetry of cross section profiles is characteristic for self-naturalization streams. Meanwhile, forms of natural beds remain heterogeneous with a variety of characteristic forms.

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