ENVIRONMENTAL ENGINEERING
The 8th International Conference
May 19–20, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-7106 print / ISSN 2029-7092 online
ISBN 978-9955-28-828-2 (2 Volume)
ISBN 978-9955-28-827-5 (3 Volume)
http://enviro.vgtu.lt

I MODELING OF HYDRAULIC CONDUCTIVITY IN THE REGULATED STREAMS OF SOUTHEAST LITHUANIA

Oksana Barvidiene[1], **Valentinas Saulys**[2]

Vilnius Gediminas technical university, Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania.
E-mails: [1]Oksana.barvidiene@vgtu.lt; [2]valentinas@vgtu.ltaaa@vgtu.lt

Abstract. The presented work aims to evaluate the changes in hydraulic conductivity and the planning possibilities for the naturalization of regulated streams in the Southeast Lithuania. The investigations have been carried out in sections of the regulated streams Neměža, Ž–2, Žalesa and Girija. The hydraulic roughness coefficient, varying within 0,030 and 0,094, has been determined on the basis of morphometric parameters of the regulated streams, and on distribution and density of woody vegetation in the cross profile of the channel. Sections of the flood hydraulic conductivity reserve decreased to the water overflow to the valley limit already exist in the regulated streams of southeast Lithuania. Having calculated the hydraulic roughness coefficients, HEC–RAS (River Analysis System) is used to estimate the influence of woody vegetation on the hydraulic conductivity of the stream. According to simulation results in the investigated sections of the regulated streams the hydraulic conductivity reserve is lost when the hydraulic roughness coefficient reaches the limit of 0.060–0.080. Thus, if the channel slopes were overgrown with woody and grass vegetation and the roughness coefficient exceeded 0.060–0.080, the hydraulic conductivity of the channels could be used to reduce the channel roughness to the admissible limit (0.060).

Keywords: regulated streams, overgrowth of slopes, woody vegetation, hydraulic conductivity

1. General instructions

Grass and woody vegetation is one of the natural factors influencing the condition of the streams, regulated by drainage systems. Investigations have established that grasses increase the surface roughness of the regulated stream channels and also reduce water flow velocities, stimulate sedimentation and increase the flood risk. The grass vegetation growing in the watercourse is rather flexible and can easily change space position. Therefore, hydraulic roughness is highly changeable in the channels overgrown with grass vegetation. The laboratory investigations, performed by Corollo *et al.* (2008), focused on the influence of the ratio between water depth and height of grass vegetation on water velocities. In the naturally overgrown channels grass vegetation is either available only on the bottom and slightly increases the roughness, or fills the whole water flow and reduces hydraulic conductivity significantly. Analysis of all measured flow velocities has established that the ratio between the water inundation depth and height of grass vegetation but not the density of grass vegetation in the channel has the strongest influence on water velocities. However, at the decreasing vegetation density the water velocities increase in the vegetated areas and decrease in the free flow layers above the grass, i.e. the velocity diagram changes.

Eventually, woody vegetation appears in the unmown channels of regulated streams. However, hydraulic conductivity of trenches is naturally reduced by trees and shrubs growing on the slopes as they increase the hydraulic roughness coefficient up to 0,147 and more.

Foreign scientists have widely analyzed the resistance of woody vegetation. The hydraulic roughness coefficient n, which is related to Shezi formula, is used to establish the hydraulic conductivity (Conn 1998;). The studies on the distribution of water velocities in the regulated streams and trenches overgrown with woody vegetation have been started recently (Lớpez, Garćia 2001). For example, Järvelä (2004) simulates hydraulic resistance in the channel when the growing woody vegetation (trees and shrubs) are covered with leaves and when leaves have fallen.

Woody vegetation, like any other obstacle in the flow, has negative influence on the hydraulic conductivity of streams, however, it is stated, that in Lithuania a number of stream sections have a hydraulic conductivity reserve. Here, the channels with limited vegetation usually contain the flood water and the risk of hydraulic conductivity deficit is low (Barvidienė *et al.* 2007, 2008). Flowing through the grass stems cleans the water from silt and organic materials, which is environmentally useful.

2. Research Object and Methods

Analysis of the regulated channel roughness coefficient is based on the cases of the Nemėža, Ž–2, Žalesa and Girija streams. These streams have been chosen as standard samples of woody and grass vegetation cover.

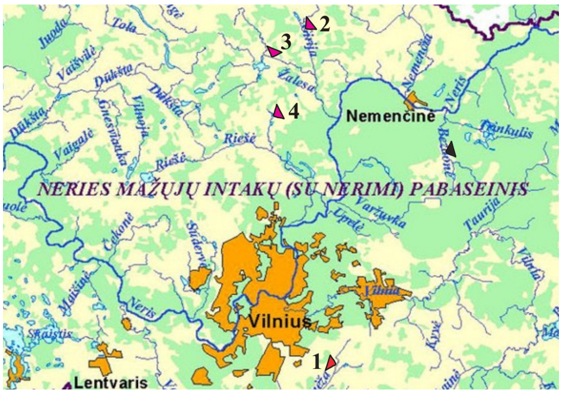

Fig 1. Investigation site

The methodology of hydraulic calculations for the trenches overgrown with trees and shrubs and misshapen trenches, developed at the Lithuanian Water Research Institute, is used to establish hydraulic roughness coefficients in the regulated streams (Rimkus *et al.* 1998).

The Nemėža (1) is affluent of the Rudamina. Total length of the stream – 10.3 km, regulated basin area – 42.8 km^2. It is relatively straight. The investigation focuses on the middle section of the stream – pickets 22 to 29. In the upper part of the investigated section (pickets 27 – 29) gradient is 4.5 ‰, in the lower part (pickets 22–27) – 0.6 ‰. According to the data of Water Planning Institute, in summer the lowest 90 % probability discharge at the beginning of the investigated section – 0.333, at the end – 0.365 m^3/s, in spring the highest 10 % probability discharge at the beginning of the investigated section – 5.11, at the end – 5.50 m^3/s (NE1–NE23). The Girija (2) is affluent of the Žalesa. The 4 km length section starting at the influx is regulated. Length of the stream – 5.5 km, basin area – 35.2 km^2. The investigation focuses on the middle section of the stream – pickets 3 to 11. In different profiles of the investigated section of the stream the gradient varies from 2.5 to 3 (sections Gi1–Gi8). The Žalesa (3) is affluent of the Neris. The regulated part starts at the sources and goes 7.6 km. Length of the river – 18.8 km, basin area – 97.1 km^2. The investigation focuses on the middle section of the stream – pickets 8 to 13. In different profiles of the investigated section of the stream the gradient varies from 0.3 to 2.5 ‰ (sections Za0–Za5). The whole stream Ž-2 (4) is regulated. Its length – 4.5 km, basin area – 10.5 km^2 (Gailiušis 2001). The investigation focuses on the middle section of the stream – pickets 2 to 17. In different profiles of the investigated section of the stream the gradient varies from 0.5 to 8 ‰ (sections Z1-Z17).

Establishment of the roughness coefficient n requires measuring of the following parameters of the stream: width of the trench channel bed b, slope coefficient m, diameter of tree stems d, widths of the shrubby belt on the left and right slopes, widths of not overgrown lower and upper belts on the left and right slopes, density of woody vegetation *T*, number of stems per linear meter of tree belt on the left and right slopes. Estimation of the roughness coefficient also requires measuring widths of the belts on the slope overgrown with large-stemed grasses, heights of grass and density of grass on the bed. Gradient of the calculated section is based on the data the Water Planning Institute. The roughness coefficient n is calculated according to the following formula:

$$n = \sqrt{\frac{R^{1/3}\lambda}{2g}} \qquad (1)$$

where λ – the coefficient of hydraulic slope friction ; R – hydraulic radius.

Having established the hydraulic roughness coefficients of the regulated streams, water levels are measured to estimate the influence of woody vegetation on hydraulic conductivity of the stream. The HEC-RAS programme is used for simulation of water levels in the regulated streams. The software (HEC-RAS-River Analysis System), created by the Hydrology Engineering Centre, is designeded for one-dimensional calculations of permanent flow, unstable flow and sediment movement (HEC–RAS 2008). Water levels are calculated from cross profile of one section to the other according to the flow energy conservation equation:

$$Y_2 + Z_2 + \frac{\alpha_2 v_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 v_1}{2g} + h_e \qquad (2)$$

where Z_1 and Z_2 – distances from the reference plane to the channel bed; Y_1, Y_2 – water depths in the first and second sections; v_1, v_2 – mean water flow velocities in the sections; α_1, α_1 – Koriol coefficients in the sections; g – gravitational acceleration; h_e – energy losses.

The flow energy losses between the two sections consist of the run losses and local losses *i*:

$$h_w = L\lambda + \zeta\left(\frac{\alpha_2 v_2^2}{2g} - \frac{\alpha_1 v_1^2}{2g}\right) \qquad (3)$$

where L – comparative distance of the river flow; λ – hydraulic friction coefficient; ζ – coefficient of the local losses.

HEC-RAS uses the channel geometry and flow data parameters in the analysis of hydraulic phenomena. These parameters are designed for making cross-sections along the flow. The so-called bank stations are used in every cross-section to segment it into the left inundated territory, the right inundated territory and the main channel. For every cross-section HEC-RAS uses several introduced parameters, which describe form, height and relative flow-wise coordinate (x, y) of the cross-section: number of the flow station, coordinates and heights for every point of the cross-section, location of the stations on the left and right banks, lengths of arms between the left inundated territory, the channel central line and the right inundated territories of the adjacent cross-sections, the channel roughness coefficients. HEC-RAS is accepted when energy height in the cross-section is constant and the velocity vector is perpendicular to the cross-section. Then the flow geometry and the discharge values for each branch in the whole system of rivers are established. The geometric parameters of the channel and discharge values are the primary variables used in the hydraulic calculations. HEC-RAS programmed and the direct approach methods are used for calculation of water surface profiles between the cross-sections in the permanent and slightly changing flow. The main calculation procedure is based on the iterational solution of the energy equation. The water surface height in the adjacent cross-section is calculated by the direct approach method and using the data of the flow discharge and water surface height in one cross-section. The water overflow index has been established in the investigated stream sections. It is considered positive ($h_V \leq h_G$), when water height in the investigated regulated stream channel (h_V) is lower or equal to the depth of the regulated stream (h_G) (no overflow), and negative ($h_V > h_G$), when in the channel the water level (h_V) is higher than the depth of the regulated stream (h_G) (water overflows).

3. Results and Discussion

The field research in the regulated streams of south-east Lithuania shows varying density of woody vegetation in the investigated streams. In the Nemėža stream density of woody vegetation varies within 0.01 and 0.68 unit/m^2, in the Ž-2 stream - within 0.17 and 5.42 unit/m^2, in the Žalesa - within 0 and 2.14 unit/m^2, in the Girija - within 0 and 3.33 unit/m^2. Dependency between the density of woody vegetation and hydraulic roughness coefficient is observed. Table 1 presents sections of the Nemėža (NE6), Ž-2 (Z6 and Z14), Girija (Gi1 and Gi7) Žalesa (Za2) regulated streams, and the measurement data, necessary for calculation of hydraulic roughness coefficient, and the established hydraulic roughness coefficient n.

The field measurements and hydraulic calculations of the Nemėža stream have established that the hydraulic roughness coefficient *n* here changes from 0.030 to 0.045. Table 1 show that in the NE6 section the hydraulic roughness coefficient is 0.033, and density of woody vegetation – 0.16 unit/m^2.

Table 1. Data for calculation of roughness coefficient and calculated values *n*

Sections	NE6	Z6	Z14	Gi1	Gi7	Za2
Width of the bed, m	0.60	4.6	2.41	4.71	3.5	2.11
Slope coefficient, m	3.9	1.7	0.4	0.5	0.5	0.6
Gradient, ‰	0.6	8.0	0.5	2.4	3.0	0.8
Mean tree stem diameter on the left bank, m		0.09	0.01		0.05	0.08
Mean tree stem diameter on the right bank, m	0.016	0.031	0.01		0.04	0.08
Width of lower shrub free belt on the left slope, m	6.56			4.65	0.65	
Width of shrubby belt on the left slope, m		0.11	1.89		3.65	2.02
Width of lower shrub free belt on the right slope, m	3.96			4.50	0.02	0.01
Width of shrubby belt on the right slope, m	3.48	2.54	2.4		4.18	7.30
Number of stems per linear meter of tree belt on the left slope, units		1.3	7.3		8.6	2.1
Number of stems per linear meter of tree belt on the right slope, units	9.6	3.1	16.6		10.9	4.6
The hydraulic roughness coefficient on the section *n*	0.033	0.044	0.053	0.039	0.067	0.042

Table 2. Values of hydraulic roughness coefficient *n* for the regulated streams Nemeža, Z-2, Girija and Žalesa at maximal spring season flows 10 % Q_{Max} (h_V – water level; h_G – bed depth)

Roughness coefficient *n*	The investigated sections of the stream	Number of sections	Water level in the stream
0.025–0.034	The Ž-2 (Z16, Z17), the Nemėža (NE17–NE23, NE1, NE8), the Žalesa (Za4)	12	$h_V < h_G$
0.035–0.044	The Ž-2 (Z5, Z6, Z8, Z10, Z12, Z15), the Nemėža (NE3–NE7, NE9–NE16), the Girija (Gi1–Gi6, G18), the Žalesa (Za1–Za3, Za5, Za6)	25	$h_V < h_G$
0.045–0.054	The Ž-2 (Z1, Z3, Z4, Z7, Z9, Z11, Z13, Z14,), the Nemėža (NE2)	8	$h_V < h_G$
0.055–0.067	The Girija (Gi7)	1	$h_V < h_G$

According to the field measurement data of the Girija stream, the hydraulic roughness coefficient *n* varies within 0.036 and 0.067. In the section Gi1 the hydraulic roughness coefficient is 0.039, and the density of woody vegetation is 0.0 unit/m^2, in the section Gi7 the hydraulic roughness coefficient is 0.067, and the density of woody vegetation is 4.52 unit/m^2. Field measurements in the Žalesa stream show that the hydraulic roughness coefficient *n* varies from 0.033 to 0.042.

In the section Za2 the hydraulic roughness coefficient is 0.042, and the density of woody vegetation is 0.97 unit/m^2. In the stream Ž-2 the field investigations show the hydraulic roughness coefficient *n* to be varying within 0.030 and 0.053. In the section Z14 the hydraulic roughness coefficient is 0.053, and the density of woody vegetation is 1.25 unit/m^2. In all these cases water level h_V is lower than the stream channel depth h_G (Table 2).

At the present hydraulic roughness coefficient (0.025–0.094), estimated by field investigations, all the investigated stream sections have positive water overflow index. In all cases water level in the channel (h_v) is lower than the depth of the regulated stream (h_G). Thus, at the maximum spring discharges the water does not overflow the regulated stream channel.

When the channel roughness changes from 0.025 to 0.166, water levels also change (*H*, m). At the increasing hydraulic roughness coefficient in the regulated channels water level rises and, having reached certain limit, overflows. Having increased the stream roughness coefficient to 0.060, in two sections of the regulated stream Ž-2 the water overflow index becomes negative. When the roughness coefficient reaches 0.080, the water overflow index becomes negative in 6 of 14 sections. In the channel the water level rises higher than the depth of the regulated stream channel.

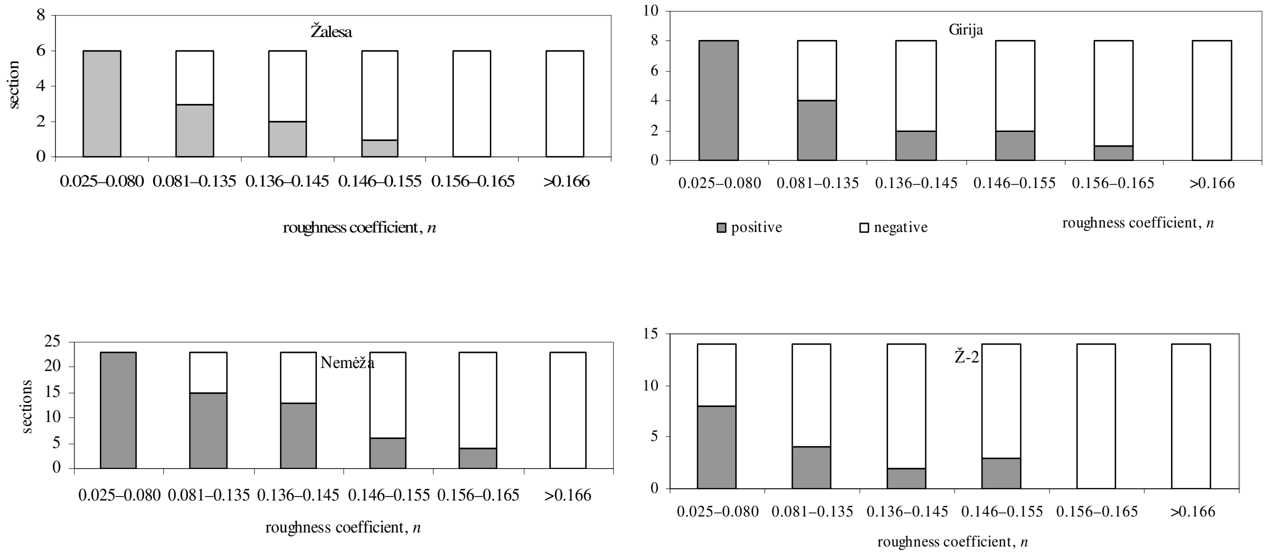

Fig 2. Water overflow parameters at maximal spring season flood flow of 10 % probability with increase of roughness coefficient *n* values

Simulation of the stream overgrowth with woody vegetation, i.e. change of the hydraulic roughness coefficient *n*, water overflow indices, when water levels are simulated in the Neměža, Girija, Žalesa and Ž-2 streams by changing the hydraulic roughness coefficient, are presented in Fig.2. Having increased the stream hydraulic roughness coefficient from 0.081 to 0.135, at the spring highest 10 % probability discharge the water level exceeds the channel depth (the overflow index in the channel is negative) and the channel cannot contain this discharge in 8 of 23 sections in the Neměža stream, in 10 of 14 sections in the Ž-2 stream, in 3 of 6 sections in the Žalesa stream and in 4 of 8 sections in the Girija stream. When the hydraulic roughness coefficient increases to 0.136–0.145, water overflows in 10 sections of the Neměža, in 12 sections of the Ž-2, in 4 sections of the Žalesa and in 6 sections of the Girija.

When the roughness coefficient value is 0.170, negative water overflow index is observed in all the investigated stream sections. At the given values of hydraulic roughness coefficient, the maximal spring discharge of 10 % probability overflows the channel. To avoid that Rimkus (1998) suggests thinning of woody vegetation or other methods to reduce the channel roughness. For example, when slopes of the stream channel are overgrown with woody and grass vegetation and the hydraulic roughness coefficient exceeds the value of 0.060–0.080, the channel hydraulic conductivity requirements provide formation of the belt not overgrown with trees at the slope bottom, or thinning trees on the whole slope, or removal of all vegetation from one of the slopes and, in this way, the channel roughness coefficient is reduced to the admissible limit (0.060).

In the case of cutting trees and shrubs (Lamsodis 2002; Lamsodis *et al.* 2006) it is recommended to leave the southern slope overgrown as here woody vegetation shadows the channel better, smothers grass and water vegetation on the left slope and on the channel bed and, at the same time, reduces silting of the channel. If the stream is overgrown with large-stemed grass vegetation (roughness value 0.290 and more), the slopes can be mown to avoid the overflow of the maximal spring 10 % probability discharges. The frequency of mowing should hinder the large-stemed grasses from dominance on the slopes (roughness coefficient under 0.080).

The Nemėža takes the north-east to south-west direction, thus, the woody vegetation should be left on the south-eastern slope of the regulated stream. The Ž-2 stream flows from west to east, thus, here the woody vegetation should be left on the southern slope of the stream. At present, the stream roughness coefficients have not reached the critical value (0.060–0.080) yet. The water overflow index is positive in all the investigated stream sections, so the removal of trees and shrubs is not required. The regulated streams Girija and Žalesa are at the outskirts with no cultivated fields around, thus, there is no point in removing woody or grass vegetation here. In these sections significant increase in density of woody vegetation along with rising hydraulic roughness value is even acceptable. The cycle of the regulated stream becomes analogous to that of natural streams.

Due to varying geographical characteristics of South-East Lithuania, in hilly uplands the gradients are on average by 20 % higher than those in sandy plain, even when the roughness of the lower stream part and other parameters are similar. In south-east Lithuania hydraulic conductivity of regulated streams more than twice exceeds that of regulated streams in the Middle Lithuania region. Thus, in south-east Lithuania there are many possibilities to stimulate naturalization processes by allowing woody vegetation on the slopes of regulated streams even in the territories surrounded by cultivated fields, where overflow to the floodplain is undesirable.

As spring overflow to the floodplain in natural not-regulated channels is of periodical character and this is useful for the self-cleaning of the water, in the naturalization process of the regulated streams, reestablishment of natural overflow to the valley can be of great value. The problems of channel hydraulic conductivity, maintenance and reconstruction require complex solution, involving estimation of economical as well as environmental needs.

4. Conclusions

When the roughness of the lower part of stream cross-section and other morphometric parameters are similar, in south-east Lithuania hydraulic conductivity of the streams overgrown with woody vegetation more than twice exceeds that of overgrown trenches in the Middle Lithuania lowland. In this respect south-east Lithuania has many possibilities for planning ecological measures in drainage network by allowing trees and shrubs on the slopes.

The stream hydraulic roughness coefficient, established on the basis of morphometric parameters of the regulated stream channels, density and distribution of woody vegetation in the cross profile of the channel, varies within 0.030 and 0.094. This brings to the statement that regulated streams in south-east Lithuania already have sections with the flood hydraulic conductivity reserve reduced to the overflow limit.

The simulation has established that in the investigated sections of regulated streams the hydraulic conductivity reserve is lost when the hydraulic roughness coefficient reaches the limit of 0.060–0.080. This brings to the statement, when slopes of the stream channel are overgrown with woody and grass vegetation and the roughness coefficient exceeds the value of 0.060–0.080, the channel roughness should be reduced to the admissible limit (0.060), which ensures hydraulic conductivity of the channels.

References

Barvidienė, O.; Šaulys, V. 2008. Influence of woody vegetation or regulated stresams in southeast Lithuania for hydraulic conductivity. In *Proc. of the 7th International Conference "Environmental Engineering"*: Selected papers, vol. 1. Ed. By D. Čygas, K. D. Froehner. May 22–23, 2008, Vilnius, Lithuania, Vilnius: Technika, 495–501. ISBN 978-9955-28-264-8.

Barvidienė, O.; Šaulys, V. 2007. Reguliuotų upelių hidraulinio laidumo modeliavimas [Streams by controlling the hydraulic conductivity model]. *Vandens ūkio inžinerija* [Water Management Engineering], 32(52): 59–64.

Coon, W. F. 1998. Estimation of roughness coeffients for natural stresam channels with vegetated banks. *US Geological Survey Water-Supply Paper*, 2441: 1–133.

Corollo, F.; Ferro, V. 2008. Flow velocity profile and turbulence characteristics in a vegetated straight flume. *River Flow*, 351–358.

Gailiušis, B.; Jablonskis, J.; Kovalenkovienė, M. 2001. *Lietuvos upės. Hidrografija ir nuotėkis* [Lithuanian rivers. Hydrograph and runoff]. Kaunas, 794 p.

Hydrologic Engineering Centers River Analysis System (HEC-RAS) web site [online]. Available from Internet: http://www.hec.usace.army.mil/software/hec-ras/.

Jävelä, J. 2004. Determination of flow resistance caused by non-submerged woody vegetation. *Intl. J. River Basin Management*, 2(1): 61–70.

Lamsodis R. 2002. Sumedėjusios augalijos melioracijos grioviuose rūšinė sudėtis ir paplitimas [Botanical structure and spread of woody vegetation in drainage channels]. *Vandens ūkio inžinerija inžinerija* [Water Management Engineering], 20(42): 31–40.

Lamsodis, R.; Morkūnas, V.; Poškus,V.; Povilaitis, A. 2006. Ecological approach to management of open drains. *Irrigation and Drainage*. 55(5), 479–490.

Lopez, F.; Garcia, M. H. 2001. Mean flow and turbulence structure of open channel flow through nonemergent vegetation, *Hydraulic Engineering,* 127: 392–402.

Rimkus, A.; Vaikasas, S. 1998. Natūralizuojamų kanalų hidraulinio-matematinio modelio papildymas ir jo taikymas. [Supplementing of hydraulic-mathematical model of canals and its application for planning of naturalization], *Vandens ūkio inžinerija* [Water Management Engineering], 5(27): 80–88.