

EXPERIMENTAL ANALYSES OF ROCK WEIRS

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Abstract

The article presents results of the experimental research of river restoration structures, rock U-weirs, W-weirs, A-weirs. Authors have focused on analyses of influence of these structures on hydraulic and geo-morphological process at micro and mezzo habitat scale. They also analyze potential of 1D and 2D hydrodynamic numeric models HEC-RAS and CCHE2D in design of the structures. The simulation results were supported by series of experimental measurements on physical models. Rock weirs have proved to be relatively cheap, highly multifunctional structures contributing to quality habitat and eliminating creation of migration barriers. They provide improving of recreational and aesthetic value, making banks and channel slope steady, maintaining the function even in case of a high ambivalence of streams, etc. Their main advantage is based on the fact that it is a construction related to nature with used materials and construction system. A two-dimension hydrodynamic model of CCHE2D has proved a potential to design and verify the functioning of structures of these types. The 1D hydrodynamic model HEC-RAS has proved the ability, at a specific schematic degree, to provide exact and reliable results.

Key words: rock weirs design, HEC-RAS, CCHE2D, river habitat restoration

INTRODUCTION

Human impact on rivers represents complex process that leads to various negative consequences (Fazekašová et al., 2014; Horák et al., 2013; Jurík and Kaletová, 2010). These symptoms include changes in the diversity of river and floodplain landscapes (Čimo et al., 2009, Čimo et al 2011). A climate change impact also manifested in degradation of river water quality and cause increase of invasive plants and animal species and the disappearance of many native plants and animal species (Semancová et al, 2014; Horák et al., 2011; Igaz et al., 2010; Igaz et al., 2011). River restoration projects play important role in processes of environmental management. Instream restoration techniques should create instream features compatible with the natural conditions of the site. Focusing on the restoration of natural processes we prefer the restoration techniques which supporting creation of natural array of habitat types in a stream network (Roni et al, 2002). This approach also provides suitable spawning and nursery habitats for autochthone aquatic species habitat variability and also greater chance of habitat availability for all life stages. In these context, the last few decades has also become more important to minimize negative effect of hydraulic man-made structures with goal to restore natural functions respecting requirements for minimizing of flood threats (Baird, 2001). The hydraulic structures affect global processes of sediment transport and accumulation, changes of the river bed morphology and also flow conditions. The rock-weirs as grade-control structures are commonly built to control channel erosion processes, increase pool frequency and improve fish habitat (Salant et al, 2012). Therefore, an optimal design of a river restoration structures has to take into account several aspects. These rock weirs are usually called by alphabet (U-, A-, V-, W-weirs) and have some common characteristics (Mooney et al., 2007):

- Loose rock construction materials (individually placed or dumped rocks with little or no concrete);
- Extents spanning the width of the river channel;
- An abrupt change in the water surface elevation at low flows.

The purpose of this article is study rock weirs functioning and clarify characteristics of river restoration structures and to verify an application potential of 1D hydrodynamic model Hec-Ras and

2D hydrodynamic model CCHE2D for process of these river restoration structures. The principles of rock weir design are presented in fig.1, 2 and 3. The material of the rock weir must resist active forces of drag, lift, and buoyancy while subjected to flowing water in a channel. The complex manual for rock weir design may be found in literature i.e. Mooney et al., (2007).

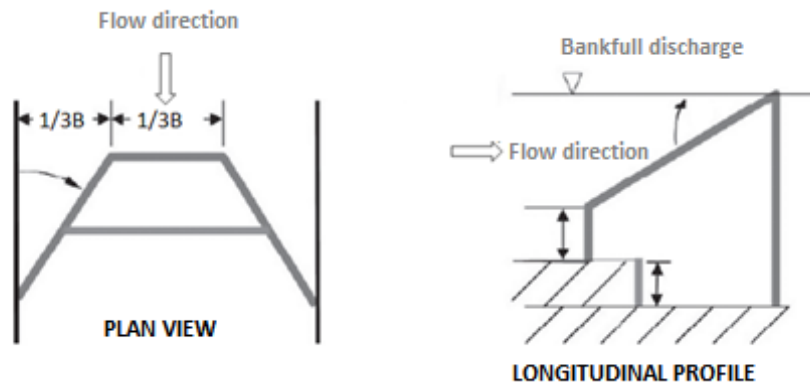


Fig. 1. The A – rock weir design principles (adopted after Thornton et al., 2011)

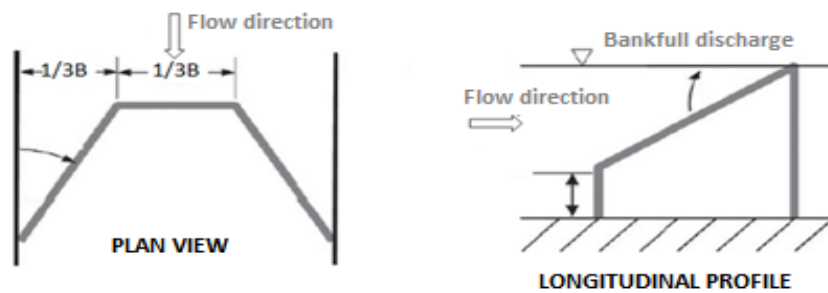


Fig. 2. The U – rock weir design principles (adopted after Thornton et al., 2011)

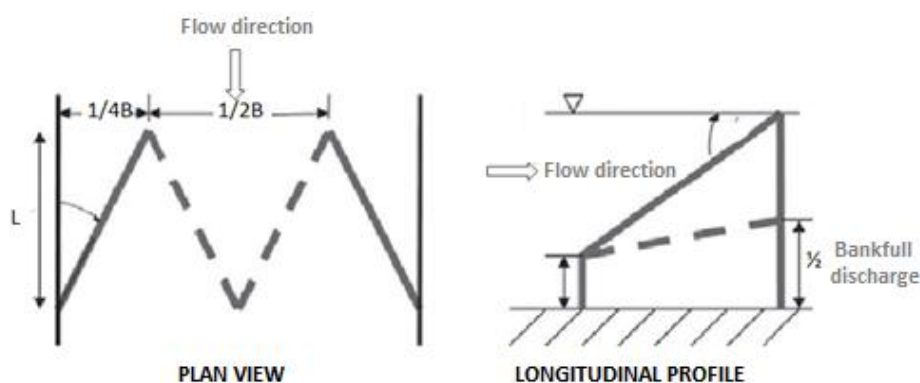


Fig. 3. The W – rock weir design principles (adopted after Thornton et al., 2011)

MATERIAL AND METHODS

Experimental research has been carried out on physical model at reduced scale in the Hydraulic laboratory of the Department of Water Resources and Environmental Engineering SUA in Nitra. The hydraulic flume has dimensions of 12 m x 0.4 meters x 0.4 meters with an adjustable bed inclination. The basic configuration of the physical model in the flume is presented in fig. 4. The bed morphology

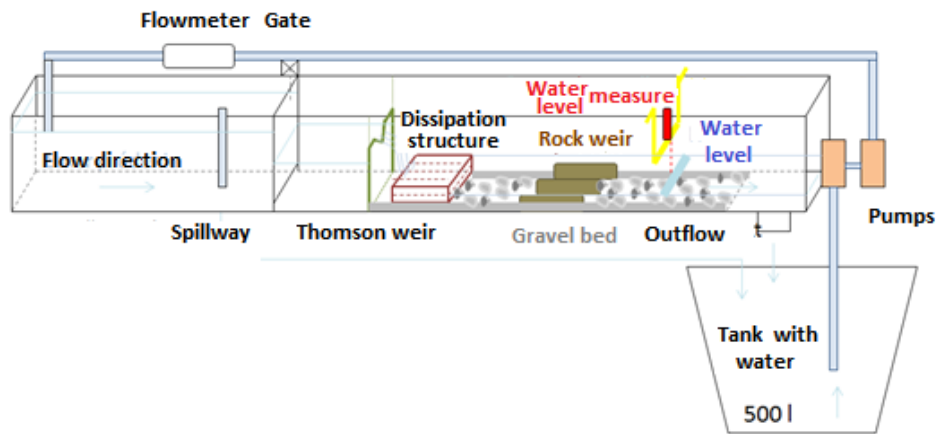


Fig. 4. The basic configuration of the physical model at reduced scale

Bed load material granulometry is described by granulometric curve with median grain size $d_{50} = 7.7$ mm below structure and $d_{50} = 8.8$ mm above structure what represents $d_{50} = 0.077$ m a $d_{50} = 0.088$ m in reality. The material of rock weir consists of cobbles and very coarse gravel (50 - 80 mm). Bed morphology was mapped by laser distance measurer and digital level. Then bed morphology was schematized by in square grid from 1 x 1 cm to 10x10 cm according to rate of bed morphology changes (fig. 8). Experiments have been done for discharges $Q = 0.50 \text{ l.s}^{-1}$; 0.79 l.s^{-1} ; 1.00 l.s^{-1} ; 1.50 l.s^{-1} ; 2.00 l.s^{-1} ; 2.50 l.s^{-1} . We measured water level course in the central part of the flume in flow direction for rock weirs A (fig. 9) and U (fig. 7) and in three longitudinal profiles for rock weir-W (fig. 6). After every experiment we measured flume bed morphology changes.

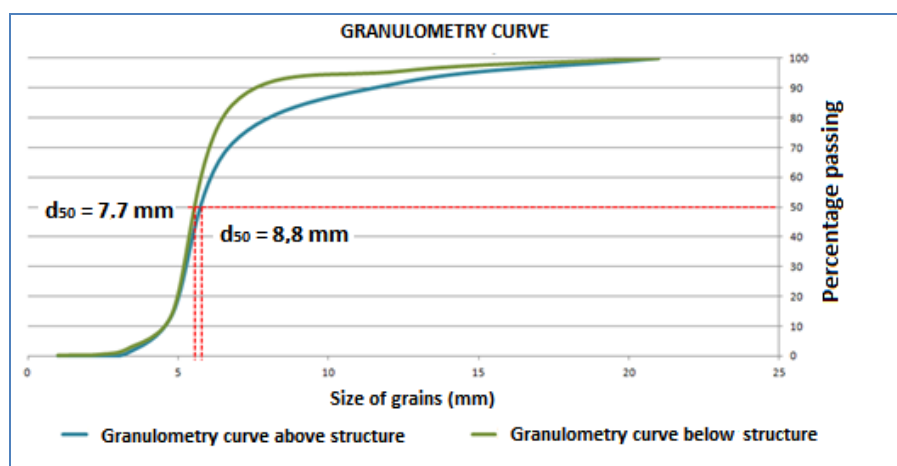


Fig. 5. Granulometry curve of bed load material

We have used 1D models used in Hec-Ras model was developed by the United States Army Corps of Engineers (USACE 2006) For numerical experiments. Model is designed to model complex phenomena and processes in the river systems. This software allows calculations of one-dimensional

steady non-uniform and unsteady flows, solving of hydraulic engineering tasks, design of modifications stream channels, design of water works, pollution transport modelling, modelling of temperature of surface water, bed load transport, modelling of accumulation-erosion processes in stream channels (Halaj et al., 2014). CCHE2D is a complex package for two-dimensional simulation and analysis of river flows, pollutant transport, non-uniform sediment transport, prognosis of both morphologic and coastal processes. The continuity equation and the momentum equations are governing equations used for simulating the flow field in x and y directions (Jia and Wang, 2001).



Fig. 6. W – rock weir / discharge ($Q_{scale} = 10,27 \text{ l.s}^{-1}$, $Q_{real} = 3,247 \text{ m}^3.\text{s}^{-1}$)



Fig. 7. U – rock weir/ discharge ($Q_{scale} = 10,27 \text{ l.s}^{-1}$, $Q_{real} = 3,247 \text{ m}^3.\text{s}^{-1}$)

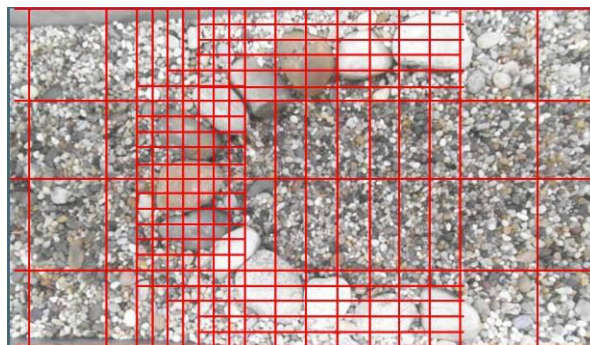


Fig. 8. The measurement grid of U – rock weir for preparation of geometry input file

RESULTS AND DISCUSSION

Numerical modeling has a good potential to verify design parameters over large ranges of input parameters and boundary conditions. A numerical hydrodynamic model should describe significant flow patterns and the important dominant physical processes. The 1D numerical hydrodynamic model HEC-RAS simulates changes in hydraulics while neglecting vertical and lateral variability of the flow characteristics. Two-dimensional model CCHE2D contents lateral differences in velocity and water surface elevation, but does not into account flow patterns that are not parallel to the stream bed. On base of carried out experiments we compare the results obtained by both models and measured characteristics. The examples of outputs are shown in fig. 10, 11 and 12.



Fig. 9. A – rock weir (Discharge $Q = 2,5 \text{ l} \cdot \text{s}^{-1}$ ($0,791 \text{ m}^3 \cdot \text{s}^{-1}$))

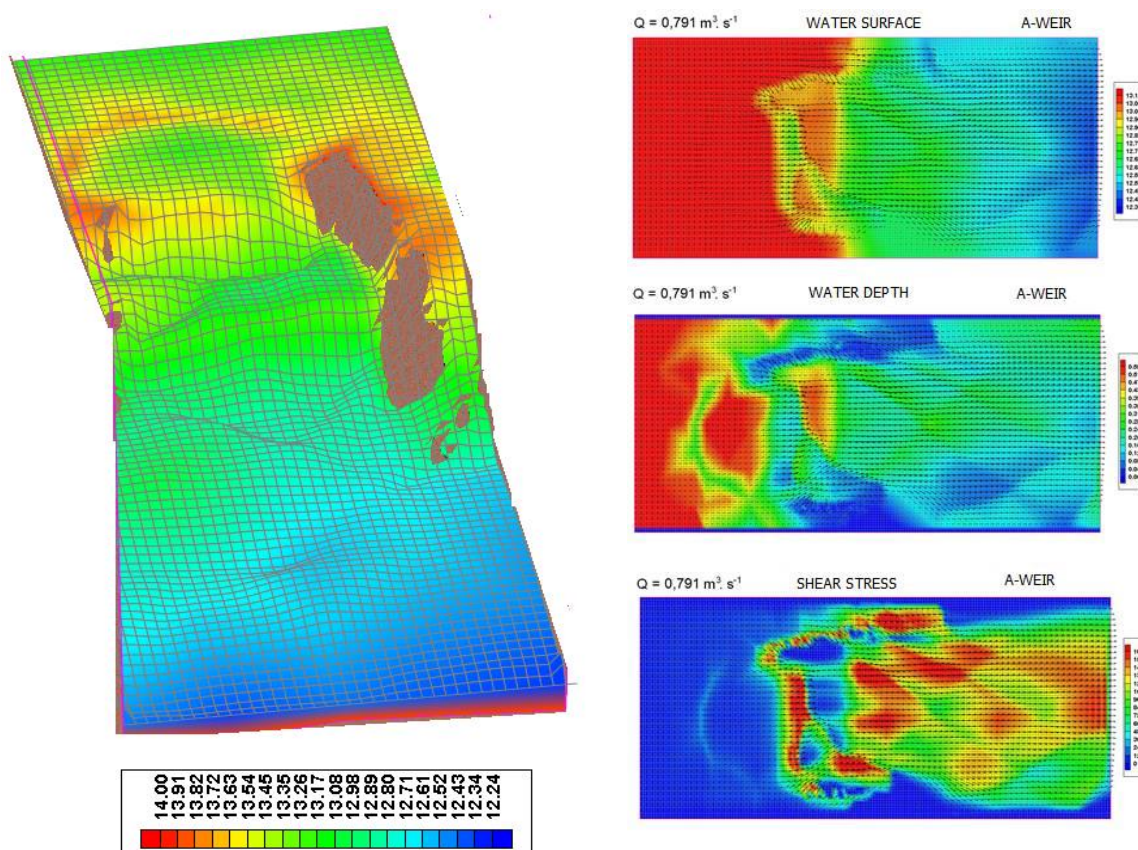


Fig. 10. The 3D view on A-weir water level course simulation results obtained by CCHE2D model (left) and some flow characteristics calculated for A-weir for $Q = 2,5 \text{ l} \cdot \text{s}^{-1}$ ($0,791 \text{ m}^3 \cdot \text{s}^{-1}$) right

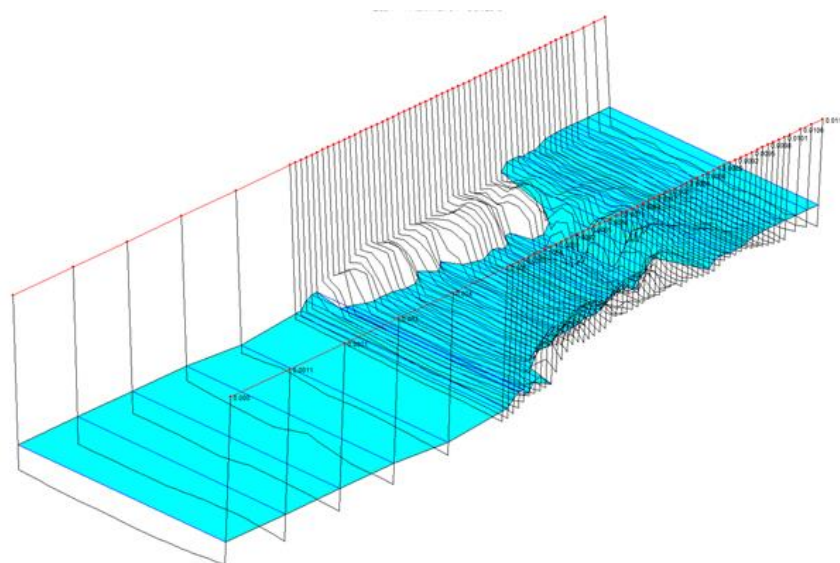


Fig. 11. The 3D view on U-weir water level course simulation results obtained by HEC-RAS model

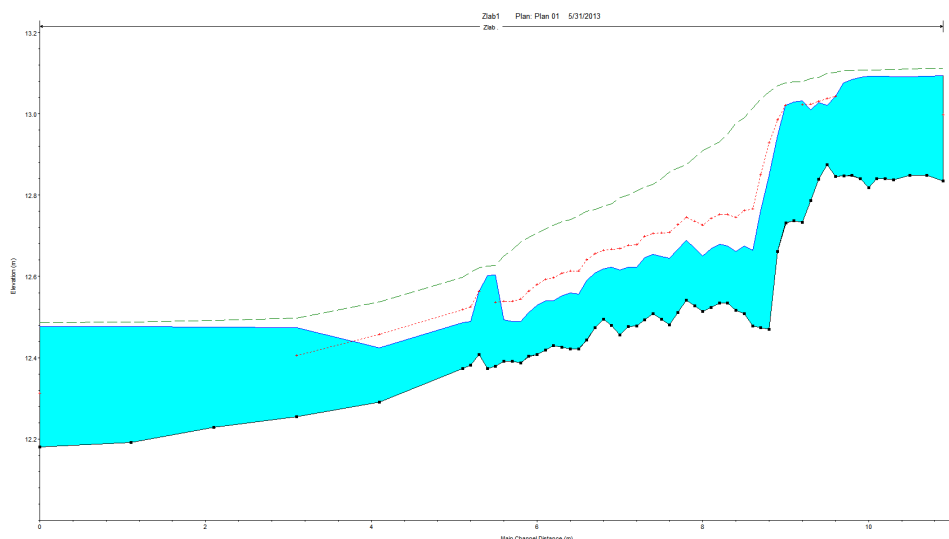


Fig. 12. Longitudinal profile of water level course in centerline of U-weir/ simulation results obtained by HEC-RAS model

The carried out computations and correlation analysis between values measured on physical model and calculated by models have values of Pearson's correlation coefficients and mean absolute errors which are presented in table 1.

Tab. 1. Comparison of statistical parameters between measured and calculated results

Model	Pearson's correlation coefficients	Mean absolute errors
HEC-RAS	0.987	0.0399 m
CCHE2D	0.990	0.0288 m

Our results correspondent with findings of who describes advantages and limits of 1D and 2D hydrodynamic models (Mooney et al., 2007). In case of the 2D model it's necessary to create the sufficiently dense measurement grid to keep required accuracy of results. For 1D model we have setup small distances between cross sections to achieve accurate results in places with the higher dynamic of flow (EA, 2009; Mu anad Zhang, 2007).

CONCLUSIONS

Rock weirs have proved to be highly multifunctional structures contributing to a quality habitat, eliminating a migration barrier, improving a recreational and aesthetic value, making banks and channel slope steady, maintaining the function even in case of a high ambivalence of streams, etc. Their main advantage is based on the fact that it is a construction related to nature with used materials and construction system. The experimental study represented by physical as well as numerical modeling focuses on questions how variations of structure geometry affect local flow conditions and subsequent changes in channel morphology. Results of the numerical modeling allow designers to determine the appropriate geometry for generating desirable flow parameters. The results may also be coupled with the results of the physical model to develop a method to predict critical variables. The analysis and results of the numerical modeling, laboratory experiments on model as well as field data provide a process-based method for understanding how structure geometry affects flow characteristics, scour development, fish passage, water delivery, and overall structure stability. A one-dimension model of HEC-RAS has proved an ability, at a specific schematization degree, to provide exact and reliable results such as hydraulic characteristics including mean bed shear stress and scour depths. A two-dimensional model of CCHE2D has proved a huge potential to design and verify the functioning of structures of these types. With a processed morphological structure in details, the model enables an exact development of design and verification of its function for various endurance conditions in form of both graphical and text outputs.

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REFERENCES

- Baird, D.C. 2001. Santa Ana River rehabilitation project along the middle Rio Grande. New Mexican Decision-Makers Field Guide No. 1 Water, Watersheds, and Land Use in New Mexico: Impacts of Population Growth on Natural Resources, Santa Fe Region (ed. P.S. Johnson), Bureau of Mines and Mineral Resources, Socorro, NM, pp. 108–109.
- Čimo, J., Igaz, D., Špánik, F. and Maderková, L. (2009). *Changes in temperature assurance of the most grown sorts of vegetables in conditions of climate change*. In Journal of International Scientific Publications: Ecology & Safety. vol. 3, no. 1, pp. 201-209. ISSN 1313-2563
- Čimo, J., Horák, J., Maderková, L., Igaz, D. 2011. Trends of soil freezing on Danubian lowland. In: Journal of International Scientific Publications: Ecology & Safety, vol. 5, part. 1, pp 221-228. ISSN 1313-2563.
- Environment Agency, 2009. Desktop review of 2D hydraulic modelling packages. Environment Agency Science Report-SC080035/SR. 53 p.
- Fazekašová, D., Huttmanová, E., Fazekaš, J. 2014. Time and Spatial Variability of Physical and Chemical soil Parameters in Conditions of the Sustainable Soil Use in Carpatian region Management 2014. In: International conference Management 2014. pp 421-424. ISBN 978-80-8165-052-9.

Halaj, P., Velísková, Y., Sokáč, M., Bárek, V., Fúška, J. 2014. Modelling of contaminant dispersion in streams - 1D versus 2D model use comparison: case study on the Ondava .In: Ecology & Safety. -- ISSN 1313-2563. Vol. 8, no. 1 (2014), pp. 393-399.

Horák, J., Igaz, D., Šinka, K., Kondrlová, E., Štekauerová, V. Čimo, J. 2011. Estimates of nitrous oxide (N₂O) emission from arable soils in the selected region of Slovakia using a process-based agro-ecosystem model. In: Journal of International Scientific Publications: Ecology & Safety, Vol. 5, part. 1, pp 229-240, 2011. ISSN 1313-2563.

Igaz, D., Čimo, J., Horák, J. 2010. Hodnotenie výskytu sucha v podmienkach Podunajskej pahorkatiny. In Acta hydrologica slovac, 2010, roč. 11, č. 2, pp 375-381. ISSN 1335-6291

Igaz, D., Horák, J., Kondrlova, E., Čimo, J. 2011. Digestate influence after biogas production on soil parameters. In: Journal of International Scientific Publications: Ecology & Safety., vol. 5, part. 1, pp. 213-220. ISSN 1313-2563

Jia, Y, Wang, S. 2001. CCHE2D - Two-dimensional hydrodynamic and sediment transport model for unsteady open channel flows over loose bed. Technical Report No. NCCHE-TR-2001-1. 89 p.

Jurík, E., Kaletová, T. 2010. Base flow and drought in landscape In , Minsk, Water, climate change and human health. Minsk : Baraksin A. H., 2010. Pp. 110-119. ISBN 978-985-6929-74-1.

Mooney, D.M., Holmquist-Johnson, C.L., & Holburn, E 2007. Qualitative Evaluation of Rock Weir Field Performance and Failure Mechanisms. USBR-Technical Service Center, Denver, CO. 2007.

Mu Jin-bin, Zhang Xiao-feng, Real-time flood forecasting method with 1-D unsteady flow model, Journal of Hydrodynamics, Ser. B, Volume 19, Issue 2, 2007, pp. 150-154

Roni, P., Beechie, T.J., Bilby, R.E. Leonetti, F.E ., Pollock, M.M, 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds GR Press North American Journal of Fisheries Management 22 (1), pp. 1-20.

Salant NL, Schmidt JC, Wilcock PR, Budy P. Unintended consequences of restoration: Loss of riffles and gravel substrates following weir installation. J Environ Manage 2012;109: pp. 154-163.

Semancová, P., Fazekášová, D., Kotorová, D., Michaeli, E., Solár, V. 2014. The biological activity of soil ecosystems in the locality of dry polder Besa. In: 14th international multidisciplinary scientific geoconference SGEM 2014. Volume II, Forest ecosystems, marine and ecosystems, pp. 259-266.

Thornton, Ch.I., Menengetti A.M., Collins, K., Abt, S.R., Scurlock, M.S. 2011. Stage-Discharge Relationships for U-, A-, and W-weirs in Un-submerged Flow Conditions. In JAWRA Journal for the American Water Resources Association 2011. No. 47, pp. 169-178.