# Hydrodynamic modeling and GIS tools applied in urban areas

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*In connection with resolving the flood issue all of the interested parties endeavour to mitigate the flood negative impacts to the lowest acceptable level. At a time, efforts are exercised to effectively prevent their reoccurrence. The main objective of this paper is to present possibilities of hydrological models and GIS tools in delineating with the flood event threatened urbanised areas. These very areas present the most jeopardised ones. The paper presents conceptual and empirical side of the GIS supported hydrodynamic models in quite a detail. Presented in the paper are results of multiple studies realised within the selected (part of the) basin of river Olšava. Proper selection of the way the results will be processed would facilitate to use the attained outputs also in the future process of creating flood - hazard and flood - risk maps.*

***Keywords****: hydrodynamic models, GIS tools, urban areas*

## Introduction

The issue is devoted to the nature of natural hazards of flooding, with an emphasis on urban areas. With the still an increasing number of repeated scenarios of natural disasters are increased emphasis on solutions of flood issues [1]. Floods, as a currently phenomenon are just for Central Europe still a hot topic. The situation is confirmed by the events of the past months have brought immense destruction, caused severe flash floods. This trend is enhanced by defining the territory of the country that is threatened by floods in such areas restrict human activities or excluded altogether from their use. The issue of flood events is all the more necessary to monitor and be in control of the built-up areas of towns and villages. The company has a lot of potential options for reducing the effects of floods. One of the solutions offered flood modeling activities just in urban areas, with the support tools of geographical information systems (next GIS) and hydrological models. It is through flood modeling activities in such areas paves the way for increased readiness state authorities on a timely response, but also increases the level surface before re-occurrence of flood events. Part of the contribution is an empirical application of GIS tools and selected hydrodynamic models to specific river water Olšava localized in the eastern part of Slovakia. The risk of flooding just in urban areas of Slovakia increases also unsuitable management of the related construction of new settlements in the built-up areas, so-called floodplains areas [2]. From this it is significant that the modeling of flood events for the purposes of flood protection is important. A key underlying the processing issue represents the fulfillment of the obligations arising from the Directive of the European Parliament [3]. In Slovakia, the Directive has been transformed into a form of the Act No.7/2011 Coll. on flood protection. The issues of hydrodynamic modeling related to the modeling of flood events urbanized area is devoted to such [4, 5]. Different levels of simulation flood situations conducive to estimate the economic and social impacts in the process of modeling the intensity of flood events for urban areas. The advantage of modeling is the ability to simulate not only the real state (simulation in real time) in the monitoring area, as well as proposals for measures to prevent the negative impacts floods and evaluate their effect [6, 7]. Flood hazard maps can be in the final stage of processing modeling of floods illustrate the scope of potential risk areas during extreme floods, threats to houses and apartments and other important objects of infrastructure in urban areas. In resolving the recommendations will be taken into consideration Directive and national legislation in the field of flood risk assessment. Applied methodology can be used to deal with this type of studies in other basins of watercourses SR. Modeling results, which will be presented in the form of digital map outputs, which can serve to determine the of flood threats and flood risk assessment. Presented compiled hydrodynamic model will serve as a basis for the proposed measures to mitigate the scale, respectively, eliminate flooding in the selected territory.

## Case study location

River basin Olšava (Fig. 1) is located in the southwestern part of eastern Slovakia, in Košice surrounding the upper part of the river basin district Prešov. From the point of view of the hydrological basin is part of the sub-basin Hornád (4-32), a specific part of the basin Hornád under Torysa (4-32-05). Olšava is a left tributary of the Hornád with a total length of 49,60 km and catchment area of 339,54 km$^2$. It rises in Slanské vrchy under

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the hill Chabzdová at an altitude of 680 m above sea level and opens into Hornád near the village Ždaňa. Basin Olšava has elongated shape with a substantially left tributary developed and poorly developed right tributary because of close parallel flowing water stream Torysa. Density of river basin network is 0,412 km per km$^2$, which is very low compared to the value of the average density of river network in the branch plant Kosice, which is 1,01 km per km$^2$. Lower regions of the flow from the mouth to the Hornád village Bidovce flows Košice lowlands with an average natural longitudinal gradient from 2,0 to 4,5 ‰. In the middle section of the village after village Bidovce Opiná the valley narrows and longitudinal gradient ranging from 5 to 11 ‰. The upper section of the village Opiná the source has the character of a brook with a longitudinal gradient reaching a value of up to 30 ‰. Lower and middle section is characterized by unbalanced path with sharp meanders and multiple arms. In the upper section of the trough directionally balanced with relatively smooth path. Highest average flow rates are achieved in the spring (March - April), as a result of the melting of the snow, the lowest in the late summer and autumn months (August - September). In terms spilling large water spill-over occurs only in certain sections, for example, stretch between Bohdanovce and Blažice [8].

*Fig. 1. Study area.*

## Methodology of preparing the feasibility study

For hydrodynamic modeling is a broad choice of the level achieved accuracy or detail of the individual from the sub-model. The choice is influenced by the purpose, basin topography, rocks, soils, land use and other available information. Despite the complexity of the models for the origin and quantity parameters are often required very simple information [9]. The actual manufacturing process modeling in urban areas should be presented in a simplified form based on two levels:

- geodetic measurements (spatial localization of all monitored objects and events),
- graphics processing (process modeling and visualization of the results obtained).

*Geodetic measurements* are mainly focused on the positional location and altitudinal measurements for appropriate documentation floodplain boundaries and the basic characteristics of the watercourse. Geodetic measuring is carried out in a coordinate system *Unified Trigonometric Cadastral Network* and *Baltic vertical system*. In most cases it is possible to use the surveying instruments type „ *Universal Total Station* ”. Geodetic measurements of all objects that are directly related to the processing of flood plans are mostly conducted via Real time kinematic [10, 11]. More details about solution to this problem we can find in [12].

*Graphical processing*

Part of the graphic processing is the preparation of documents in digital form for the process modeling during floods in built-up areas.

The basis for modeling (simulation) expression of floods not only in urban areas is 1D and 2D of hydrodynamic modeling [13]. Their basis is built on physical relationships resulting from law of conservation of mass and momentum [14]. The most used 1D of hydrodynamic models (the HD) belongs to HEC-RAS.

*HEC - RAS*

Is a 1D HD model for calculating the values for steady and unsteady flow. It is free software under the freeware license, including the rich documentation and case studies [15].

HEC-RAS model is able to simulate subcritical and above critical flow in natural and artificial channels simple or composite profile. The basic method of calculation is based on Bernoulli's equation and Manning's relation. Calculation of floodplains is also fully supported. The basic equation has the form:

$$Y_2 + Z_2 + \frac{\alpha_2 v_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 + v_1^2}{2g} + h_e \, , \qquad (1)$$

where: $Y_1, Y_2$ ....water depth in the considered cross-sections 1, 2
$Z_1$, $Z_2$ .... mean height of the bottom of the considered transverse sections (hydraulic gradient)
$v_1$, $v_2$ .... mean velocity profile
$\alpha_1$, $\alpha_2$ .... weightings speed
$g$ ......... acceleration due to gravity
$h_e$ ........ loss of energy

For the flow in the river channel HEC-RAS uses three calculation methods:
1. dynamic wave approximation,
2. kinematic wave approximation,
3. diffusion wave approximation [16].

Presented 1D HD model will be the subject of an application use in modeling flood in selected urban areas. Essential part of the processing is also supporting the use of GIS tools. Current trends in GIS provide spatial location with the implementation of the spatial coordinates of subjects with their visualization in different views (2D, 3D). GIS is in recent years at the forefront in the creation process information systems. Through GIS tools can be examined spatially localized objects, events different character and also describe them by appropriate selection of attributes. By these GIS features are categorized into the categories of geographically oriented information systems. Addressing this issue should be based on knowledge of the authors listed in the following section. The group of foreign authors is important as a starting material to mention just work from *Maidment*, which is considered trafficker of hydrodynamic modeling at a general level. The proof is his most famous work as *Handbook of Hydrology*, *Hydrologic and Hydraulic Modeling Support with Geographical Information Systems* [17, 18]. Another well-known author is *Shamsi* with work *GIS Applications for Water, Wastewater and Storm water Systems* [19]. [18, 20 - 22] and many others in theirs writings offer lessons for dealing with the issue. Since the issue of modeling of flood events is so large that it is impossible to list all authors who have addressed the topic. Introduction of the above authors was limited to the level of world's most famous works.

## Results

Based on the presented methodology was processing divided into the following sub – tasks (Fig. 2):

1. *Pre-processing involves:*
   - Geodetic survey.
   - Preparation *shp.* (shapefile) layers needed to hydrological - mathematical calculation.

2. *Hydraulic analysis and calculation* – section devoted to the description of hydraulic calculations, evaluation of the accuracy of input data such as. flow Q and the values surface roughness coefficients (by Manning´s roughness coefficients).

3. *Post-processing – visualization and interpretation of the results with the support of GIS.*

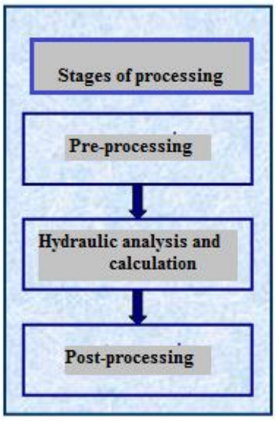



*Fig. 2. Overview of the processing procedure.*

In the process to fulfilling the pre - processing has been subject to geodetic measurement (Fig. 3):
- cross sections,
- geometry of objects on the flow and its close environs.

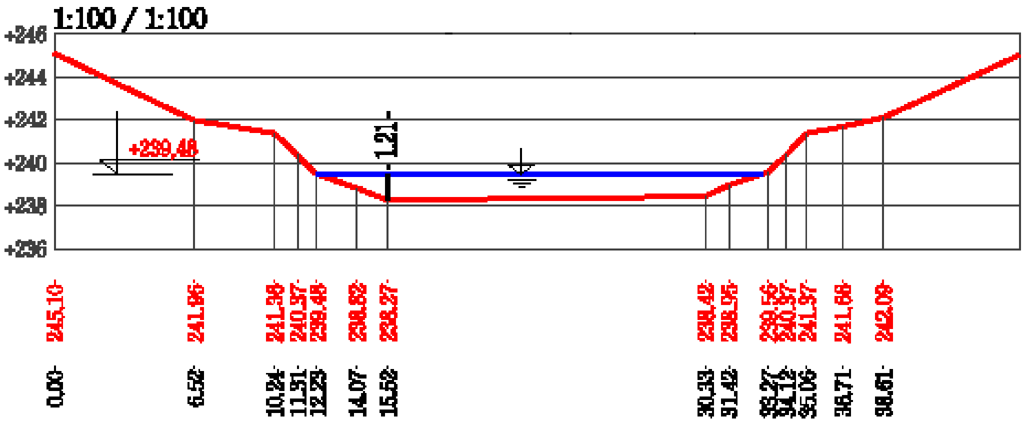



*Fig. 3. Results of geodetic measurement and processing of cross section.*

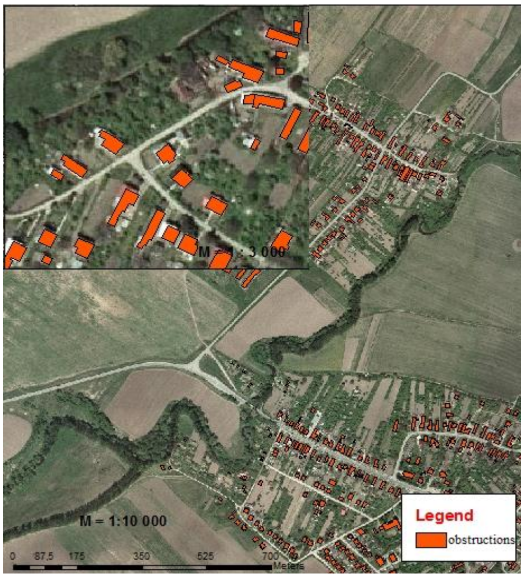
The result of processing provides Fig. 4. divided into many parts.


*a) Cross sections*


*b) Stream line(centerline)*


*c) Boundary of banks*


*d) Boundary of flowpath*




*e) View of obstructions*


*f) Land use*


*g) Boundary of ineffective areas*

*h) Overview of all processed layers*

*Fig. 4. Input data for hydrodynamic modeling in HEC-RAC (channel geometry and objects).*

Hydraulic calculation required values of *n* - average annual flow *Q (average flow rate)* [23] (Tab. 1). These data were provided by the Slovak hydrometeorological institute. It was these hydrological values of river basin Olšava:

*Tab. 1. Overview of flow values Q on river basin Olšava.*

| | |
|---|---|
| The average annual flow | $Q_y = 2{,}11\ m^3/s$ |
| Individual n - annual discharges | $Q_1 = 25\ m^3/s$ |
| | $Q_2 = 34\ m^3/s$ |
| | $Q_5 = 49\ m^3/s$ |
| | $Q_{10} = 60\ m^3/s$ |
| | $Q_{20} = 72\ m^3/s$ |
| | $Q_{50} = 87\ m^3/s$ |
| | $Q_{100} = 100\ m^3/s$ |

Boundary conditions, such as the altitude levels in individual profiles, the value of the energy gradient levels, flow values $Q_{20}$,$Q_{50}$,$Q_{100}$ obtained from Slovak hydrometeorological institute, or by measuring in the surface (on the river basin). Values called channel surface roughness coefficients for individual profiles were determined by the character of the watercourse (Tab. 2):

*Tab. 2. Manning´s roughness coefficients by [24].*

| | |
|---|---|
| Roads | 0,025 |
| Rivers | 0,03 |
| Commercial zone | 0,032 |
| Residential areas | 0,035 |
| Agricultural zones | 0,040 |
| Buildings | 1,00 |

The examination of the surface regimes selected during flood flows (Tab. 2) was used software HEC-RAS. This software is used for solution hydraulic steady and unsteady flow in open channels and artificial objects and natural streams [25]. The calculation can request the three main categories of data:

- channel geometry and objects (Fig. 4)
- roughness coefficients,
- boundary conditions (for the calculation of normal depth was set value S = 0,001), (Fig. 5).

To assess the hydraulic capacity of the open basin and objects in terms of maximum runoff was used schematisation at steady non-uniform flow, the solution of which we had established longitudinally profiles levels, corresponding to the different n-annual flow. Result of schematisation geometric parameters of cross sections presented following Fig. 6.

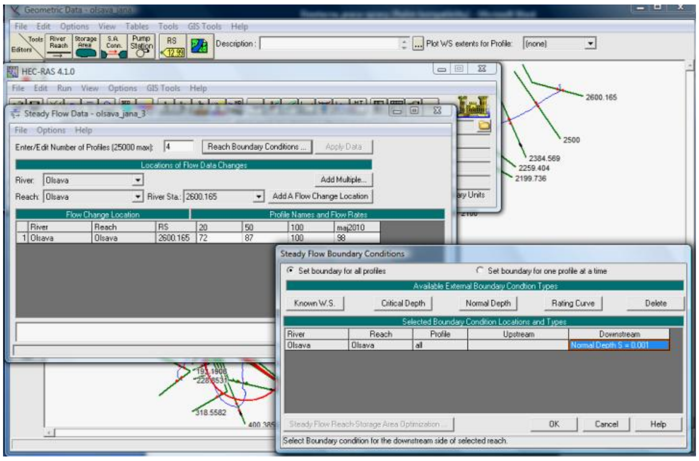


*Fig. 5. Input screen of boundary data in HEC-RAS.*

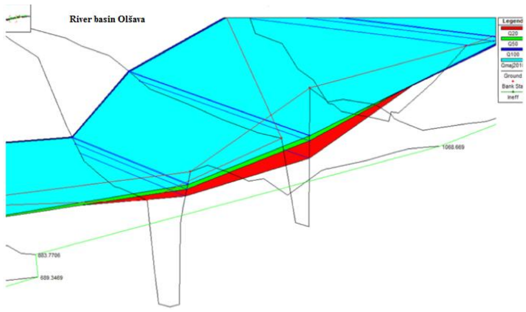
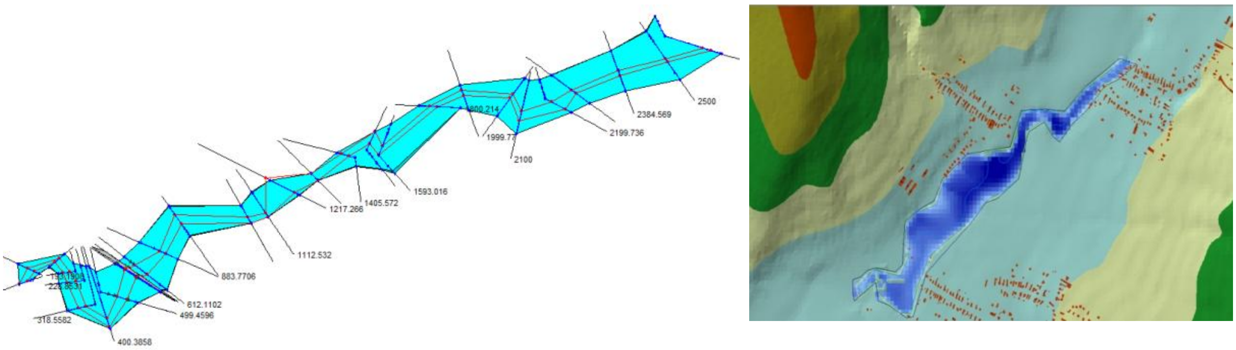



*Fig. 6. Schematisation of geometric parameter of cross sections in HEC-RAS.*

The part of analysis and hydraulic calculation was getting following results (see Fig 7):



*a) Processing of vector data with the known value of the water level*

*b) Presentation od DTM with inundation polygon in study area*

*Fig. 7. Flood depth map.*

The output of flood modeling activities for selected values flows in urbanized areas was polygon presenting the extent of flooding throughout the modeled area. Graphical presentation described also Fig 8.

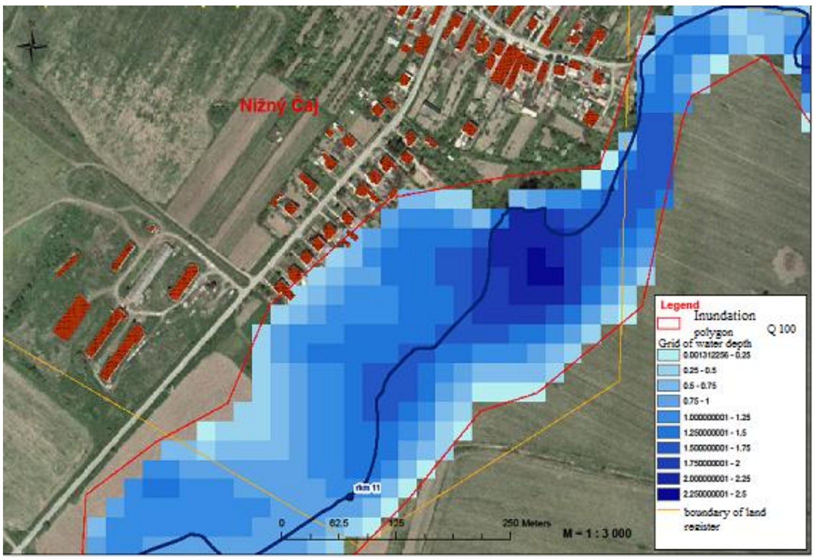



*Fig. 8. Inundation polygon in study area.*

The achieved results of flood modeling in urban areas are an effective basis for mapping flood hazard and flood risk.

## Conclusion

Landscape is a complex system, where there is a large process. Monitoring and understanding of hydrological processes is becoming more important to protect human life and property. To understand the interdependence and constantly ongoing hydrological processes we can help their models simulated in a computer environment. Currently GIS is a tool for processing large amounts of spatial data and information obtained measurements and observations whose information value is dependent on their correct interpretation. Integration of GIS tools in terms of hydrodynamic simulation modeling is solved for the subject area of interest real benefit information. Therefore, the process of modeling of floods in urban areas is a priority axis hydrodynamic modeling with use GIS tools. The present study is a comprehensive application of currently available tools that are consistent with the adoption of Directive of the European Parliament (2007/60 EC). The presented results can serve as a basis for the acquisition of general knowledge in the field of flood modeling activities in urban areas and to present other options at processing spatial information, which form an integral part of the final presentation of the results obtained.

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## References

[1] Kratochvil, J.: Methodology and tools for Risk Analysis. In: Říha, J. et al.: Risk analysis of flood area. (1st edition ). *WORKSHOP 2002. Conference proceedings. Book 2. Brno, ECON publishing, s.r.o, 2002, 174 p. ISBN 80-86433-15-3*.

[2] Zeleňáková, M.: Assessment of flood risk. (1st edition ), Technical *university of Košice, Faculty of Civil Engineering, Department of Environmental Engineering, Košice, 2009, 101 p., ISBN 978-553-0315-4*.

[3] Directive of the European parliament and of the council 2007/60/EC on the assessment and management of flood risks, *(online), (Cited 2013.12.12):* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:288:0027:0034:en:pdf

[4] Mišík, M., Kučera, M., Ando, M.: Flood modelling and mapping of urban areas: *Proceedings of the Conference „River basin and flood risk management", (2011) p.1-6, (online), (Cited 2013.12.12):* http://www.vuvh.sk/download/ManazmentPovodi_rizik/zbornikPrispevkov/Konferencia/Prispevky/SekciaA/Misik_Kucera_Ando.pdf

[5] Cipovová, K.: Implementation of directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks. *Flood Risk map of Levice town, (online), (Cited 2013.12.12)*: http://www.zzvh.sk/data/files/71.pdf

[6] Sabolová, J.: The use of hydrodynamic modeling in terms of water policy of the Slovak Republic. *PhD. thesis. Technical university of Košice, 2012, 109 p.*

[7] Gergeľová, M., Kuzevičová, Ž., Kuzevič, Š., Zeleňáková, M.: GIS as a support tool in the process of hydrodynamic modeling of the existing watercourse. In*: Acta Hydrologica Slovaca, Vol.13, Issue 2 (2012). P. 394-403, ISSN 1335-6291*.

[8] Giba, M., Sabolová, J., Cikrayová, Z., Petrová , Z., Harmanová, M.: The determination of flood lines and flood risk at Olšava after the flood in May 2010: *Report of Slovak Water Management Company*.

[9] Singh, V. P., Woolisher, D. A.: Mathematical modeling of Watershed Hydrology. In: Journal of hydrologic Engineering, *Vol. 7, Issue 4 (2002). P. 270-292, ISSN 084-0699*.

[10] Černota, P., Labant, S., Weiss, G., Harman, P.: Determine of the inert waste volume and landscaping proposal landfill. In: The coal ores - Geological Exploration. *International Conference on extractive industries. Příbram, 2012. P. 6-11, ISSN 1210-7697.*

[11] Labant, S., Weiss, G., Weiss, R., Kovanič, L., Harman, P.: Selected sections of surveying: *Editional center of Faculty BERG, Košice, 2013. 118 p. ISBN 978-80-553-1407-5*.

[12] Weiss, G., Gašinec, J.: The compatibility investigation of 2D geodetic points by using the GPS technology. *In: Acta Montanistica Slovaca. Vol. 10, Issue 2 (2005). P. 256 – 262, ISSN 1335-1788, (online), (Cited 2013.12.12)*: http://actamont.tuke.sk/pdf/2005/n2/28weiss.pdf

[13] Mišík, M., Kučera, M., Ando, M., Stoklasa, M.: Flood mapping of large areas. 2011, (online), (Cited 2013.12.12):http://www.vuvh.sk/download/ManazmentPovodi_rizik/zbornikPrispevkov/Konferencia/Prispevky/SekciaA/Misik_Kucera_Ando_Stoklasa.pdf

[14] Fencík, R., Danek, L., Daneková, J.: Use of GIS applications and hydrodynamic modeling in the development of flood maps. *International Conference, Ostrava, 2011, (online), (Cited 2013.12.12):*

http://gis.vsb.cz/GIS_Ostrava/GIS_Ova_2011/sbornik/papers/Danekova.pdf

[15] Hydrologic Engineering Center, *(online), (Cited 2013.12.12):* http://www. hec.usace.army.mil

[16] Unucka, J.: Modeling of hydrological processes with the support of remote sensing and GIS. In: Information technology for modeling crisis situations. *Ostrava, 2007, P. 30-36, ISBN 978-80-248-1537-4*.

[17] Maidment, D.R. ED.: Handbook of Hydrology. *1st edition. London, 1983, McGraw-Hill Professional. 1424 p., ISBN: 978-0070397323*.

[18] Maidment, D., Djokic, D. ED.: Hydrologic and Hydraulic Modeling Support with Geographic Information Systems. *Redlands, 2000, ESRI Press. 232 s. ISBN: 978-1879102804*.

[19] Shamsi, U. M.: GIS Applications for Water, Wastewater and Stormwater Systems. *Boca Raton, 2005, CRC Press. 413 p. ISBN: 0-8493-2097-6*.

[20] Vieux, B. E.: Distributed Hydrologic Modeling Using GIS. *Dordrecht, 2004, Kluwer Academic Publishers. 289 p., ISBN: 978-1402024597*.

[21] Lyon, John G. ED.: GIS for Water Resources and Watershed Management. *Boca Raton, 2003, CRC Press. 266 p., ISBN: 0-415-28607-7*.

[22] Bedient, P.B., Huber, W.C. et Vieux, B.C.: Hydrology and floodplain analysis. *4th edition. Prentice Hall, London, 2004, 795 p., ISBN: 978-0131745896, 2007*.

[23] Adamec, M., Trizna, M., Říhová, V., Unucka, J., Gergeľová, M.: On 2D or 3D parameter derivation for rainfall-runoff models. *In: Acta Montanistica Slovaca. Vol. 17, Issue. 3 (2012), P. 204-208, ISSN 1335-1788*.

[24] Brachtl, I., Taus, K.: Roughness coefficients of open channels. *VÚVH, 1962, Slovakia*.

[25] Halaj, P., Jurík, Ľ., Matyo, J., Bárek, V.: HEC-RAS model use for study of technical and biotechnical measures effect on increasing of water retention in stream channel and floodplain, *2006, (online), (Cited 2013.12.12)*: http://www.cbks.cz/sbornikstrecno06/prispevky/posterii_clanky/p2-6.pdf