

THE USE OF HEC-RAS MODELLING IN FLOOD RISK ANALYSIS

IOSUB MARINA¹, MINEA I.¹, HAPCIUC OANA¹, ROMANESCU GH.¹

ABSTRACT. – **The use of HEC-RAS modelling in flood risk analysis.** The fact that, in the Ozana drainage basin, most of the people have built their homes in the river valley, determines that a study focused on identifying the areas exposed to hydrological risk is vital, mostly in the development decisions for villages and in the creation of management plans for emergency situations. This study analyses the mapping methodology of the flood prone areas in the middle and lower sector of the Pluton river, which is a tributary of Ozana river, in its upper sector. In order to correctly draw the flood risk maps, the HEC-RAS method has been used, together with the HEC-GeoRAS extension, in ArcGIS. The results that have been obtained, correlate with the field situation in a very high proportion: for a 1% occurrence flood, almost 123 households have been damaged, and according to the simulation, a number of 147 buildings have been damaged, therefore other probabilities (that overcome the 1% situation) can be used for similar simulations.

Keywords: HEC-RAS, risk, flood, flood band, Ozana

1. INTRODUCTION

At present, GIS modelling for floods or delimiting some flood prone areas is very advanced, and numerous mathematical methods for calculating the extent of a river (according to its flow rate, the water infiltration rate into the soil, land use etc) have been developed. These mathematical models have been integrated into GIS software, whose purpose is to create a model that would replicate the shape of the landscape as precise, as possible (Edsel et al. 2011). The flood risk maps have a clear purpose of identifying vulnerable areas and the population that is exposed in a certain region; they represent a useful tool during General Urban Plan creation, and intend to be used in the interdiction of constructing houses in the affected areas and creating management plans for emergency situations, as close as possible to the probabilities of certain events of this type (Iosub et al, 2014).

The existing hydrological models are numerous. In 1991, there were 65 known hydrological models, and during the years, this number has risen, but attention has been directed only to the most important. (Edsel et al. 2011). Therefore, in 1995, Singh counted and considered 26 to be the most used, on the planet (Singh et al. 2006). In 1998, The Subcommittee on Hydrology of the Interagency Advisory Committee on Water Data has indexed models created and used by state institutions in the USA, which were synthesised by Wurbs, in 7 categories (Wurbs, 1998). In 2002, Singh and Fevert published two books, inside

¹ "Alexandru Ioan Cuza" University, Faculty of Geography, Carol I, no. 20, 700505 Iași, Romania
E-mail: iosub.marina@gmail.com

which they have discussed about 38 models, and in 2006, 24 more models have been added to the list.

HEC-RAS is a software for one-dimension or two-dimensions simulations of the evolution of a flood, which could have a stable or an unstable flow rate, sediment transport, change of the river bed etc. The name "HEC-RAS" is derived from the creators of the software: Hydrologic Engineering Center, which stands as a subdivision of the Institute of Water Resources, U.S Army Corps Of Engineers (HEC), and "RAS" is an acronym from "River Analysis System". The software itself, has four main river analysis possibilities: the constant flow rate at the surface of a considered river profile; simulation of an unsteady flow of water; calculations of the sediment transport and modifications of the river bed; and analysis of the water quality (U.S. Corps of Engineers, 2003, Tate et al. 1999). When using the HEC-GeoRAS extension, the data can be easily inserted into the equation, and the results can be exposed through maps of hydrological risk (Merwade, 2012).

This paper is focused solely on the first possibility, of simulating a constant water flow rate and the total surface occupied by flood water, could be calculated, for different flow rate probabilities. The focus area is the valley of the Ozana river and its most important tributary from the mountaneous region, Pluton, where all the villages of the Pipirig commune are located.

2. AREA OF STUDY

The Ozana drainage basin is located in the northern part of the Neamt county, North-Eastern region, Romania. The valley of the Ozana river passes through 3 communes (12 villages) and the city of Targu Neamt. The area of the Ozana drainage basin occupies a total of 419 km², and its perimeter is 136 km long. The basin is elongated for 54 km on a west-east direction, and the average length is approximately 8,5 km. The hypsometric range value in the basin is around 1225 m, between the maximum altitude of Muntii Stanisoarei, Bivolul Peak (In the west), and the confluence region with Moldova river (in the east). The maximum altitude reaches 1530 m in height, and the minimum is 275 m at the river output. The average height is 687 m, and the average basin slope is 27,6°. Therefore, the basin is shaped as a large amphitheater, descending from the west, to the east. More than half of the basin is represented by the mountaneous region and high hills, from where the most important tributaries spring: Pluton, Dolhești, Domesnic, Secu, Nemțișor, out of which the first 4 are right side tributeries, and only one is located on the left river side, making Ozana basin an asymmetrical one.

The average annual flow rates have large variations, depending on the pluviometric characteristics of each year; for example, the recorded flow rate at Pluton, varies from 0.08 m³/s (1986) and 0.77 m³/s (1970), at Leghin it varies between 0.49 m³/s (1986) and 3.67 m³/s (1996) (Iosub et al., 2011).

The area we will focus our attention on, is represented by Ozana's main tributary from the mountain area, downhill from the confluence with the main river in the Pipirig depression. The area is exposed to flood risk, and significant

hydrological events, leading to floods have been more frequent, in the period following the year 2000 (Romanescu et al., 2013).

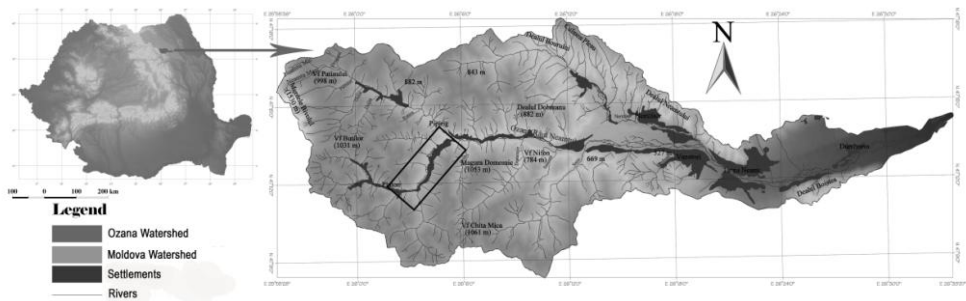


Fig. 1. Geographical location of the study area

3. MATERIALS AND METHODS

3.1 Survey Data

For running of flood simulation, a numerical terrain model that replicates the field reality very well, had to be generated. For this purpose, the most suitable instrument and data that could be obtained, was in the form of topographical maps, at a scale of 1:5000, off of which the contour lines and altitude points have been extracted through on-screen digitization. Then, by using the layers obtained after the digitization of the hydrological network, the TIN model was generated (Triangulated Irregular Network).

3.2 Preprocessing

This stage consists of the creation of attributes for layers that will be exported from ArcGIS, into the Hec-Ras software, and they will build the *geometry file*.

The first layer that was digitized was the river, *Stream Centerline* (Fig. 2); this was drawn on the line that runs through its center. Then, the *Flowpath Centerline* that defines the central flow direction of the river, is automatically created, and, in the same layer, the limits of the floodland are digitized. The attribute table of the layer contains very little data, reason for which the HEC-RAS module semi-automatically transfers the data from the numerical terrain model, into the attribute table. For this to be done, the *Stream*

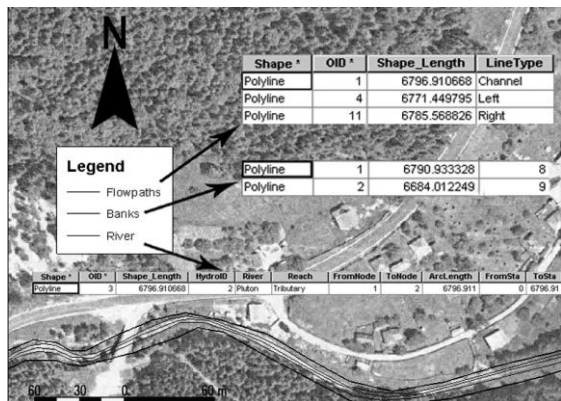


Fig. 2. Stream Lines, Flow Paths, Bank Lines

Centerline Attributes is selected, and each point of the vector file is given an altitude value from the terrain model. In order to morphographically characterise the flood zone, several lines are drawn, to determine the banks of the river bed and the floodplain.

Cross sections are the lines drawn to mark the transversal sections of the river, which have the purpose of extracting altitude values from the terrain model, and create a terrain profile, along the river's drainage channel (Fig. 3). The intersection of the cross sections and other layers, offers HEC-RAS attribute values, such as the limit of banks which marks the transit from the drainage channel to the floodplain; the distance between sections and Manning's values. There has to be an adequate number of sections, and the distance between them has to be short, for the data that is extracted to be more precise. The drawing method is strictly specified, the lines have to be drawn perpendicularly to the river's flow direction (from upstream, to downstream), they always have to be digitised from the left, to the right, they have to cover the entire region between slopes, in order to completely include the floodplain, and correctly model a flood. For Pluton, the distance between them varies in a straight line, between 20 - 50 m and have a width that varies between 200 – 500 m. There are a total of 181 cross sections.

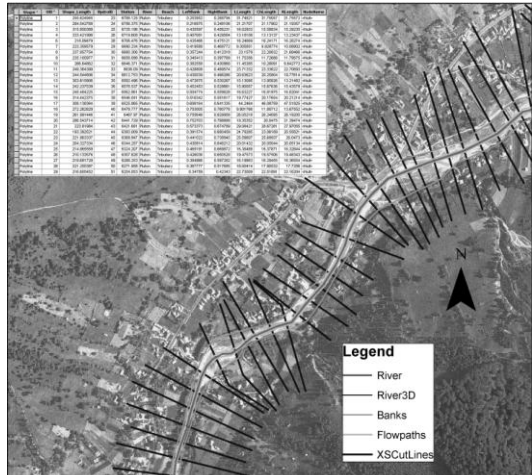


Fig. 3. Cross sections

For Pluton, the distance between them varies in a straight line, between 20 - 50 m and have a width that varies between 200 – 500 m. There are a total of 181 cross sections.

The creation of the bridges and footbridges layer is based on the cross sections; initially for drawing the Cut Lines, the bridges have been directly identified and they were drawn before or after a bridge, so that they could be given attribute values. The bridges have to include the banks and fall perpendicularly on the river's flow direction. The needed attributes are: name of the river, the number of the nearest section, and supplementary information about the bridge, such as it's usage type, distance to the nearest section, and width. Two bridges were analysed, one situated on DN15B near Pluton village, and one situated in Pipirig.

3.3 Processing

After the project has been made, it is exported from ArcGis into the HEC-RAS software, and in the *Geometry Data* menu, a verification has to be made, regarding the quality of the data. Because the land use has not been taken into consideration, as a layer in ArcGis in HEC-RAS, the Manning values will be associated to the file, to asses the width of the channel or the physical characteristics of the drainage channel, and the drainage determined by gravity.

The attribute data for Pluton and Ozana rivers was inserted, according to the table created by Manning, and the most suitable values for mountain rivers, poorly modified by man were inserted, which also contain gravel, stones and natural vegetation (with the following values: min 0.025, normal 0.030, max. 0.035).

Also, in HEC-RAS, the bridges and footbridges are verified, to correctly insert the data about the bridge structure. The data consists in the number of pillars and the span of the bridge opening, compared to the water course and it's banks. The bridge will be redrawn, if it is not correctly drawn, when viewed in a transversal (cross) section.

Another step in the creation of a simulation consists of the data insertion process, regarding the river flow characteristics, during different flow rates and water levels. A separate profile has been made for each occurrence probability (of 0,01%, 0,1%, 1%, 2%, 5%, 10% etc) and the existing (or previously calculated) flow rates were given to each station or intersection point. (Fig. 4).

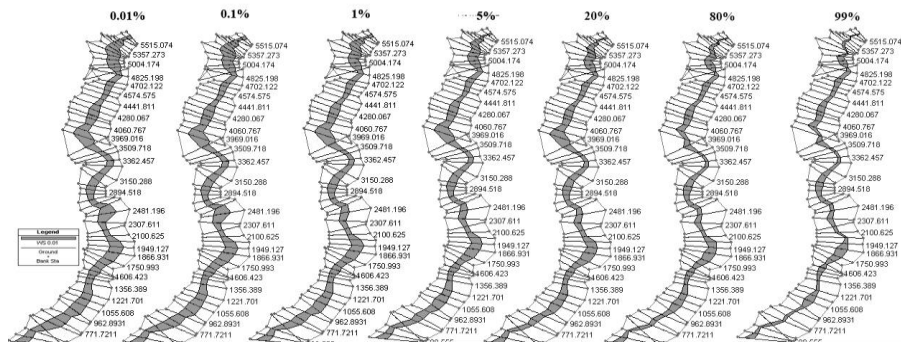


Fig. 4. Cross sections revealing the flood extents and evolution, for different occurrence probabilities for Pluton river

In order to run the flood simulation in HEC-RAS, the subcritical drainage regime has to be chosen, under the *Steady Flow Analysis* menu, after which the "Compute" option will be clicked. The result is verified, and it will be displayed as an array of cross sections of the corresponding river, which extends its active surface, depending on the flow rates values. The verification can be made according to each cross section, individually, and the oscillation of the water level can be observed on each section. This model will be exported as *Gis Data*, in this software, the extension will be changed once more, and then the project will be imported in ArcGis, where the post-processing phase will follow.

3.4 Postprocessing

From this point, the postprocessing of the data begins, in the *Ras Mapping* menu, where a new layer is created, based on the exported file, from HEC-RAS, and also, a TIN terrain model. In order to create a map of the flood zones, ArcGis needs a new file, named *Steady Flow*, which will be accompanied by the data extracted from the terrain model. In order for the TIN terrain model to fit accordingly with the exported file, it will automatically be converted into a DEM.

After the new layer is created, the next step is to import the data from HEC-RAS into ArcGis; when they appear in the workspace, they will consist of a polygon, that joins the ends of the cross sections (Fig 5a). By using the *Water Surface Generation* command, all the sections created in HEC-RAS will be selected and the result will be the limit of the flood zones (Fig. 5c).

In order to generate a layer depicting the areas with the highest depth, depending on the occurrence probability, the *Floodplain Delineation using Rasters* command is used. The surface occupied by water will be converted into a numerical model, then, from the result, the terrain model is automatically subtracted. The result is positive, where the water level is higher than the topographic level; and negative, where the terrain would remain dry (Fig. 5d). The final result is shown as polygons which reveal the level, up to which the water rises, for a certain occurrence probability.

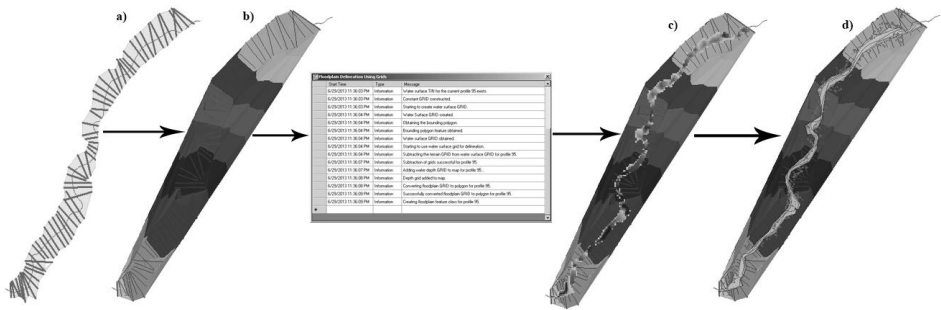


Fig. 5. Example of postprocessing the data exported from HEC-RAS, for the Pluton river section, from the hydrometrical station, until its confluence. a) The import of raw data, b) Creation of the numerical model for each section, c) Processing the data, with the *Water Surface Generation* tool function d) Creation of polygons which show the limit of flood zones, using the *Floodplain Delineation using Rasters* command

4. RESULTS AND DISCUSSIONS

The final product of the methodological workflow, is the overlay of the houses located at a distance of under 1 km, from the river's bed, with the flood zones. Three situations have been chosen to be detailed, with occurrence probabilities of 1% ($75 \text{ m}^3/\text{s}$), 0,1% ($112 \text{ m}^3/\text{s}$) and 0,01% ($149 \text{ m}^3/\text{s}$).

The final maps are Hazard and Water depth maps. The Hazard map consists of a floodband line for a very specific climatic and hydrological event, in this case, taking into consideration a certain flow rate and water level, at a given temporal repeatability. As it can be observed in figures 6 and 7, the flood areas extend into the land, but the damaged area isn't that great. One of the practical applications of this map is given by the fact that it can be taken into consideration for General Urban Plan design, and it can be an important decisional element, when the built up area is being redrawn, so that a new house or construction can be properly built. This is also a basic decision material, when building local or



Fig. 7. 1% vs 0.1% vs 0.01% flood probabilities, Dolhești village



Fig. 7. 1% vs 0.1% vs 0.01% flood probabilities, Pluton village

national roads, in order to avoid their rupture or their clogging with silt transported by the river, during floods, which would lead to the occurrence of local or zonal imbalance in the well being of economic or social activities. Overlaying these maps on top of aerial images, could have a large impact on peoples's awarness that the specified area, where there are several buildings, is not safe, and authorities should take action and create protection plans and also inform the population living in these areas, through large information campaigns.

At the scale of the drainage basin, a significant surface could be affected, and the number of houses that would be flooded is relatively great. At a

0,01% flood on the Pluton river, 108 buildings would be damaged, in a small river sector, only downstream of the the hydrometrical station; while for a flood occuring at 0,1%, the number drops to 98; and for a 1% probability, the total damaged building number is 86. These values are valid for the situation that doesn't take into consideration embankments and other hydrotechnical constructions meant to protect the village (however, the existing ones are insignificant). According to the county emergency situations plan (2010), in the case of a flood with an occurance probability of 1%, 82 households would be damaged, this official number beeing very similar to the one obtained from the HEC-RAS simulation model.

5. CONCLUSIONS

The one-dimensional modeling was created using the HEC-RAS software, which relied on Manning's roughness coefficients. The results have been validated with the help of the report regarding flood situations, emitted by Neamt County Council.

The difference in results, compared to the real life situation, associated to a 1% flood probability, could be justified by the fact that the study analysed houses, while the report presents actual households. Other probable causes would be the terrain model at a scale of 1:5000, which could have a better resolution, and the lack of data regarding land use and embankments.

The novelty information derived from the study is associated to the analysis of flood occurrences of 0,1% and 0,01%, which help evaluate the flood risk for extreme hydrological events.

It can be stated that this model, while using relatively little input data, can predict the water level and flood affected areas, for extreme hydrological events, with a high degree of precision.

This model is a useful tool in the creation of safety and management during extreme flooding events.

Acknowledgements

This work was supported by the strategic prant POSDRU/159/1.5/S/133391, Project "Doctoral and Post-doctoral programs of excellence for highly qualified human resources training for research in the field of Life sciences, Environment and Earth Science" cofinanced by the European Social Fund within the Sectoral Operational Programme for Human Resources Development 2007-2013.

REFERENCES

1. Edsel, B., Janey, V., Camp, E., LeBoeuf, J., Penrod, J., P., Dobbins, M., Abkowitz, D. (2011), *Watershed Modeling and its Applications: A State-of-the-Art Review*, The Open Hydrology Journal, vol. 5, p. 26-50.
2. Iosub, M., Lesenciuc, D. (2012), *Hydrological risk characteristics of the Ozana river valley*, Present Environment and Sustainable Development, vol. 6, no. 2, Edit. Universităţii, Iaşi, p. 210.
3. Iosub, M., Enea, A., Hapciuc, O. E., Romanescu, G., Minea I. (2014), *Flood risk assessment for the Ozana river sector corresponding to Leghin village, Romania*, 14th SGEM GeoConference on Water Resources. Forest, Marine And Ocean Ecosystems, SGEM2014 Conference Proceedings, ISBN 978-619-7105-13-1/ISSN 1314-2704, June 19-25, Vol. 1, p. 315-322.
4. Merwade V. (2012), *Tutorial on using HEC-GeoRAS with ArcGIS 10 and HEC-RAS Modeling*
5. Romanescu, G., Stoleriu C. (2013), *Causes and effects of the catastrophic flooding on the Siret River (Romania) in July – August 2008*. Nat Hazards, 63: 1351 – 1367.
6. Singh, V.P., Frevert, D.K (2006), *Watershed models*, Ed. Taylor&Francis, New York, ISBN 0-8493-3609-0, p. 629.
7. Tate, E., Maidment, D. (1999), *Floodplain Mapping Using HEC-RAS and ArcView GIS*, Center For Research in Water Resources, Austin – Texas, p. 223.
8. U.S. Army Corps of Engineers (2003), *HEC-RAS User Manual*. Davis, C
9. Wurbs, R.A. (1998), *Dissemination of Generalized Water Resources Models in the United States*, Water International, 23(3): p.190–198.
10. ***, (2010) *Planul judeţean de apărare împotriva inundaţiilor, fenomenelor meteorologice periculoase, accidentele la construcţii hidrotehnice şi poluări accidentale*, Consiliul judeţean pentru situaţii de urgenţă, Neamţ