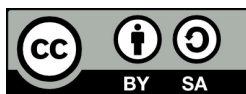# HIGH WATER LEVEL OBSERVATIONS ALONG THE UPPER COURSE OF THE OLT RIVER (ROMANIA) FROM A HYDROLOGICAL MODELLING ASPECT

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Abstract
Along its upper course, the Olt River (Romania) flows through several settlements, which are endangered by flooding. The multiannual water flow at Tomești station, the first hydrometric station along the Olt River, is 1.51 m³/s, but in case of extreme events the river flow reached even 41.8 m³/s. The aim of this study is to analyze the flood events along the upper course of the Olt River (section between Tomești and Cârța settlements) by using the HEC-RAS and the HEC-GeoRAS hydrological modeling software programs. The river cross section model showed how the main channel narrowed (characteristic to some locations) which can be considered as one of the causes of a possible overflow.

Keywords: flood-flash flood, Olt River, Tomești – Cârța, hydrological modelling, inundation

1. Introduction

In recent years numerous studies have been carried out on the topic of the flood and flash flood events. The European Environmental Agency declared that flooding is considered among the most important and destructive natural hazards in Europe in terms of economic loss (EEA 2010). Studying the flooding events became more and more important, since their frequency and the damages they cause have increased. Barredo 2007 demonstrated that the yearly occurrence of flood events was higher in the period after the 1990's compared to earlier decades. The author (Barredo 2007) gathered the number of flood events from the period 1950-2005 that hit the European Union, including Romania. For each decade and finally in the period between 2001-2005 the number of flood events was as fallows: 11, 7, 21, 33, 64, 104.

Floods are the result of hydro-meteorological factors that take effect under specific catchment conditions. If societal systems are also involved in the process (as an influencing factor and/or endurer), the term flood disaster is used (EEA 2010). The term flash flood is used to a flood event caused by an excessive rainfall in a short period of time - generally less than 6 hours (EEA 2010; Lóczy et al. 2012), but in some works (Marchi et al. 2010; Lóczy et al. 2012) flooding events caused by storm durations of 16-31 hours are considered flash floods as well.

Factors involved in the formation of a flood can be grouped into two classes: (1) causing or generating factors - meteorological events, high intensity rainfalls producing high amounts of precipitation, (2) influencing factors - soil and lithology hydraulic properties, initial soil moisture, land use/ land cover, slope angle, catchment shape/ drainage path length (Pirkhoffer et al. 2009;

Marchi et al. 2010; Borga et al. 2011; Czigány et al. 2011). The relationship between climate change and hydrologic floods was widely researched, but no concordant answer had been given since now. In some cases the same reference – Kundzewicz et al., 2007 – is used for reasoning both the negative and the positive relation between these two (de Moel et al. 2009; EEA, 2010). However, it is generally accepted that the frequency of high intensity rainfalls, as a generating factor of flash floods, is increasing (de Moel et al. 2009; EEA 2010; Marchi et al. 2010; Túri et al. 2013). The runoff coefficient can be considered and quantified as an overall effect of the influencing factors. Researches on several European flood and flash flood events revealed that the phenomenon can occur at low runoff coefficient conditions as well (Borga et al. 2011).

By analyzing 25 flash flood events from all over Europe, (Marchi et al. 2010) grouped the causing rainfall events into three groups: (1) storm events lasting up to 7 hours producing less than 100 mm precipitation, characteristic to continental climate (2) storm duration of 7-22 hours producing 100-300 mm precipitation, characteristic to Mediterranean and Alpine Mediterranean region, (3) rainfall events lasting for 22-34 hours with precipitation amount of up to 700 mm, characteristic mostly to Mediterranean region, but they appear in continental regions as well. The latter category is a transition between flash flood and flood. Regarding the peak discharges, European flood/flash flood events were grouped based on almost the same climatic conditions. The continental Central Europe flash floods can be characterized by lower peak discharges than those from other parts of the continent, e.g. the Mediterranean region. Central European flash floods mostly occur in the summer season (Gaume et al. 2009).

Since flooding events can cause serious economic losses that can reach billions of EUR in a year (EEA 2010) forecasting and researching efforts, like the European Flood Alert System, Hepex initiative (Thielen et

al. 2009), the Hydtare project (Borga et al. 2011), Vulmin project (Chendeş et al. 2015) are very important. The necessity of flood maps was put on official ground in the European Union by introducing the EU Flood Directive (2007/60/EC) that resulted in a flood mapping wave in Europe (de Moel et al. 2009).

Flooding events got a great attention in Romania as well. Based on the number of flood disasters that occurred in Europe in the period 2003-2009, Romania was considered the most affected country (EEA 2010). Flood analyses conducted on continental scale generally include examples from Romania as well (Barredo 2007; Gaume et al 2009; Marchi et al. 2010; Borga et al. 2011).

According to the WHO Flood Hazard Distribution Map for Romania, the highest flood hazard indexes are characteristic to rivers in the Southern and Westernmost part of the country and to the Siret River in the Eastern part of the country. In central Romania, the Carpathian area and the Transylvanian Basin, rivers generally have medium flood hazard indexes with high values on some river segments (WHO 2010). Romania has flood maps that cover almost the entire territory of the country and are mostly of flood extent and flood exposure type (de Moel et al. 2009).

Flood analyses and maps on national, catchment and sub-catchment level are performed by the "Romanian Waters" National Administration and are integrated in the National Flood Risk Management Plan (Ministerul Mediului 2016). Event related approaches are mostly characteristic to research articles and analyze mostly small river catchments from the Siret, Prut, Mureş, Someş, Prahova river basins (Haliuc and Frantiuc 2012; Minea 2013; Miftode 2015; Hapciuc et al. 2016; Românescu and Stoleriu 2017; Roşca et al. 2014; Ráduly 2014, Hognogi et al. 2011; Sanislai Nicuşor 2012; Zaharia et al. 2017). The Olt river basin is not well documented from this point of view, even if a total length of about 1342 km river
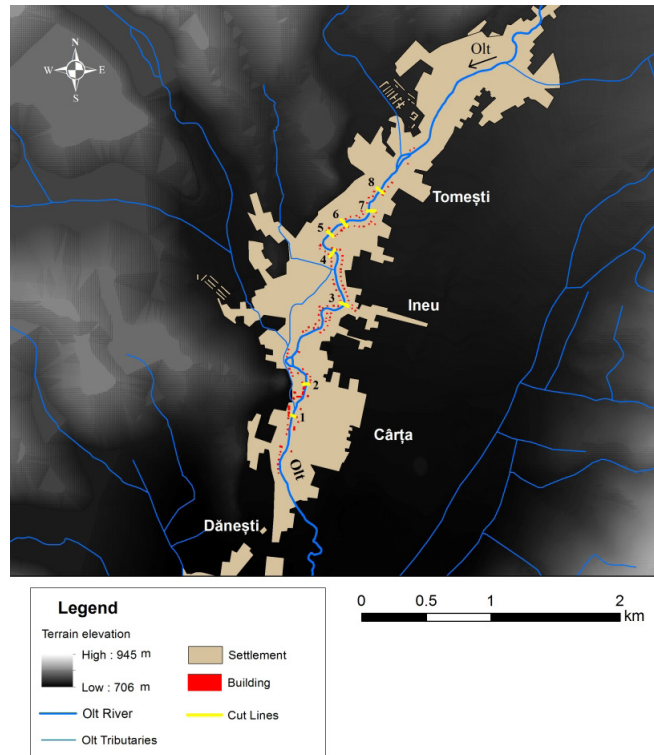
Fig. 1. Digital Elevation Model of the upper course of Olt River between Tomeşti and Dăneşti (downstream to Cârţa) settlemets (based on 1:25000 and 1:5000 topographic maps)

reaches are under potential significant flood risk (Ministerul Mediului 2016).

The aim of this study is to better understand the response of the river channel and its close environment to different runoff values based on historical peak discharges. Owerflow conditions at each analyzed cross section along the upper course of the Olt River are also investigated.

2. Study area and Olt River characteristics

The Olt River is an important left tributary of the Danube River and has its source in the Eastern Carpathians, Giurgeu Mountains, Romania (Ministerul Mediului 1992). After several kilometres of its source, the Olt River flows through seven settlements in the Ciucul de Sus Basin (Upper Ciuc Basin), thus the annual water flow or its seasonal variability relevantly influences the everyday life of the

local people.

Our study area is represented by the river reach located between Tomeşti and Cârţa settlements (Csíkszenttamás és Csíkkarcfalva) in the Upper Ciuc Basin, since the area affected by the first overflows along the river is located at Cârţa settlement (Fig. 1).

Along the Olt River, the first hydrometric station is placed at Tomeşti village (Csíkszenttamás) where water level and the flow of the river (discharge) are measured. The hydrometric station is located approximately 25 km downstream to the source of the Olt River. Along this section it collects about twenty one major first stream order tributaries, while between Tomeşti and Cârţa settlements there are two major tributaries flowing into the Olt River (Ministerul Mediului 1992). The difference in altitude between its source and its reach at Cârţa settlement is about 545 meters (1260

m elevation at the source of the Olt River, 715 m elevation at Cârța settlement) with a catchment area of about 250 km^2 (Circab 2014).

The annual water flow can be characterized by spring high waters and winter low waters. The seasonal water flow regimes show a percentage of 44-45% in springtime, 21-26% in summertime and 10-24% in autumn – winter season (SGA Harghita 2012). The general multiannual water flow at Tomești station is 1.51 m^3/s (Circab 2014).

Flood events have been recorded on the Olt River since the 1800s (Vitos 2002; edited by Dános-Kacsó 1970). In the last five decades the water level reached or exceeded the 200 cm height seven times and larger overflows occurred in four cases (SGA Harghita Tomești station measurements). The river regime shows high water levels in March and April, which is due to the combined effect of the snow melting and spring rainfalls. However, the major flood events occurred mostly in July that can be very probably explained by the high intensity of the summer rainfalls during thunderstorms. Thus flood risk is a crucial issue of the upper course of the Olt River endangering the built environment.

3. Methodology

The aim of this study is to analyze the overflow conditions between Tomești and Cârța settlements in order to understand the causes of flooding downstream to Tomești station.

The main steps of the research process involve the digital representation of the study area, river channel field measurements, digital representation of the river channel and flow characteristics. Topographical, hydrographical and hydrological data were used and processed in ArcGIS, HEC-RAS and HEC-GeoRAS softwares.

Data sets and data processing

Contour lines and river network were vectorised using the ArcGIS 10.2.1 software based on the topographic maps of 1:5000 and 1:25000 scales (Gauss-Krüger projection) provided by by the Harghita County Cadastral Office.

Topographic maps of 1:5000 scale have contour intervals of 0.5 m inside the built-up area and along the main water courses and 2.5 m outside the settlements. These elements were used to extract accurate data about the topographic relief of the flood plain site (Olt River environment) of the study area. The available 1:5000 scale maps cover only the close environment of the settlements. The topographic maps of 1:25000 scale have contour intervals of 5 m and were used for digitizing the major contour lines representing the elevation of the relief towards the mountainous area (Harghita Mountains on the western side and Ciucului Mountains on the eastern side). There were not digitized all the contour lines of the catchment area. The contour lines were used to build a TIN (Triangulated Irregular Network) and a DEM (Digital Elevation Model) model, as digital representations of the study area. These models are important elements of the further analysis.

Hydrological data processing and modelling

The hydrographical elements and hydrological data are represented by the main course of the Olt River, its major tributaries, the riverbed/channel cross sections of the Olt River, free water level and water flow of the Olt River. The watercourses were digitized based on the topographic maps. Data regarding eight riverbed cross sections on the Olt River between Tomești and Cârța villages was obtained by direct field measurements in April, 2018. Water level and flow data were provided by the Harghita County Water Management Administration Office.

The hydrographical and hydrological data regarding the main course of the Olt River were processed in HEC-RAS (Hydrology Engineering Center's - River Analysis System) software that has been designed by

Table 1. Selection of the most representative high water events at Tomeşti station between 1970-2016

Date of flooding	Free surface water level (cm)	Max. Water flow/ peak discharge (m³/s)	Precipitation amount (mm) 0-1 day before flooding	Precipitation amount (mm) 10 days before flooding
1970. V. 13-24	400	No data	No data	No data
1997. VIII. 29. 7:00	201	22.3	No data	No data
1993. VII. 23. 4:00	240	28.6	No data	No data
2005. VII. 13. 6:00	230	26	78	No data
2010. VII.1. 7:00	300	41.8	28.5	120.2
2016. VI. 2. 20:00	210	23.5	48.5	133.3

the US Army Corps of Engineers (USACE) -Hydrological Engineering Center (CEIWR-HEC) and provides a multi-dimensional representation of rivers and water flow, alluvium flow and deposition, risk analyzes (US Army Corps of Engineers 2010). We used the HEC-RAS 4.0.1 version, which can be downloaded for free.

The HEC-GeoRAS is a module that can be attached to the ArcGIS software in order to gain spatial data needed for hydrological model building and transfer it afterwards to the HEC-RAS platform (US Army Corps of Engineers 2005). Application of the HEC-GeoRAS module proved to be successful in model building of small river basin watercourses (Nagy 2017).

4. Results and discussion

Table 1. presents a selection of the most important peak discharges occurred on the Olt River at Tomeşti station. The highest free water level of the past five decades that occurred on the upper course of the Olt River was registered in May, 1970. We had not got peak discharge data for this event. The most extreme flooding event in terms of peak discharge in the last ten years had been observed in July 2010 when 300 cm free surface water level was registered. Considering the precipitation data, the 2016 flood event can be recognized as a flash flood, even if the peak discharge was much lower than the one registered in 2010. In 2016 a one hour long rainfall event produced 43.2 mm precipitation.
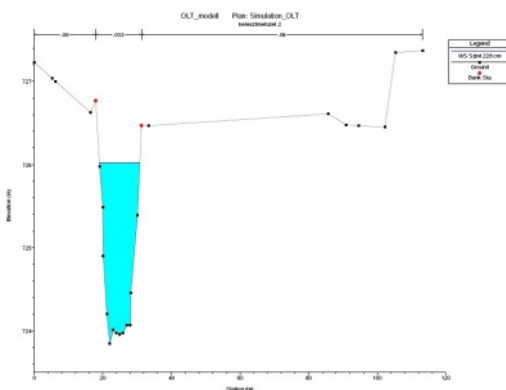

Fig. 2. 228 cm free water level on the Olt River at Tomeşti village in 2016 - digital representation in riverbed cross section (left) and real image of the same location (right)
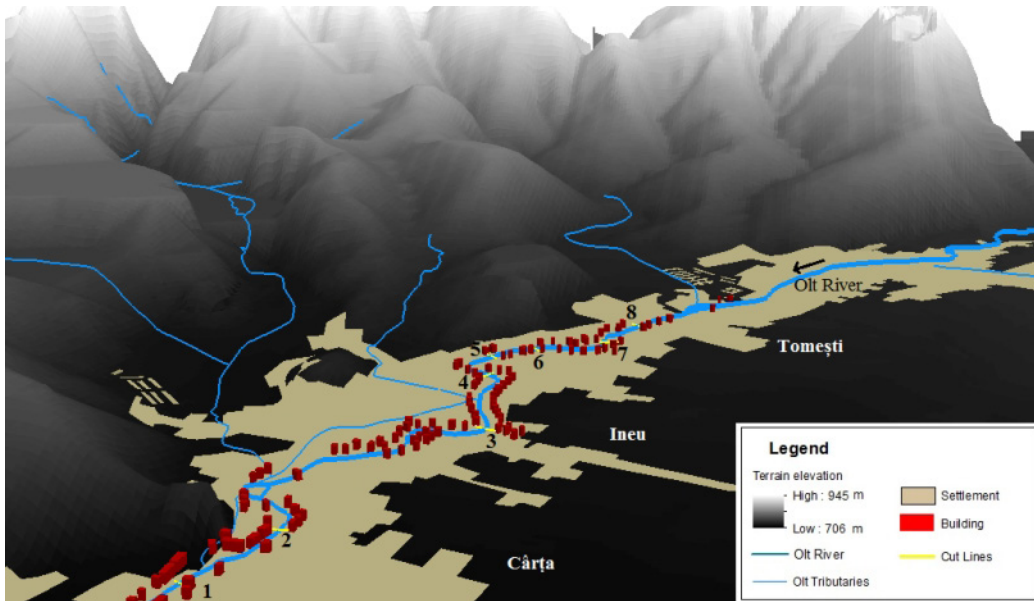
Fig. 3. Representation of the built up area between Tomeşti and Cârţa villages on a 3D model

During the high water events that occurred in 2005 and 2016 along the upper course of the Olt River the hydrometric station registered maximum free water levels of 230 cm and 210 cm respectively at Tomeşti settlement. In both cases the water was inside the channel. In the same time each Tomeşti water level caused an overflow at Cârţa settlement. Fig. 2. shows a digital representation and a real state condition of the Olt River channel cross section at Tomeşti station during the 2010 flood event with 228 cm water level, prior to reach the maximum value. At 228 cm level the water is still in the riverbed at Tomeşti station. In 2010, the 300 cm max. water level meant already the slight overflow at the uppermost station as well.

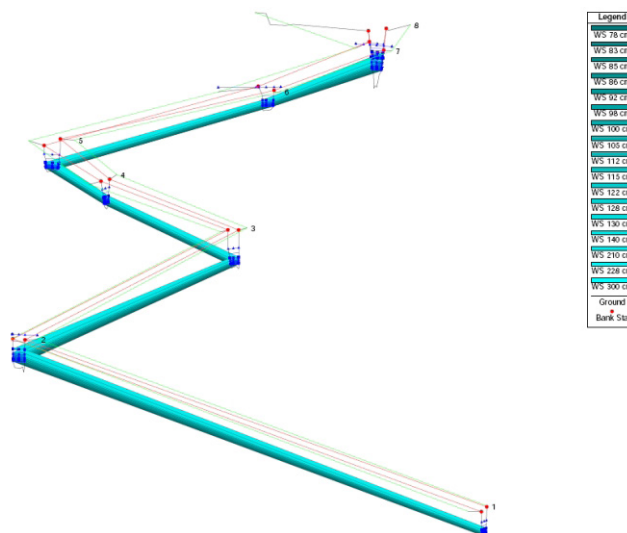Since the reach of the Olt River between Tomeşti and Cârţa villages is undiked,

Fig 4. Different free water levels represented on a multiple channel cross section plot between Tomeşti and Cârţa villages
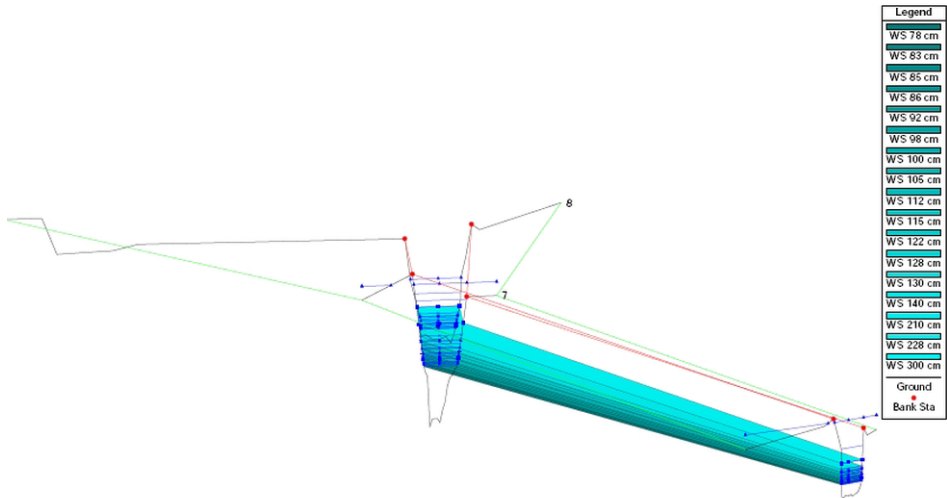
Fig. 5. Different free water levels represented on a multiple channel cross section plot
(8-6 cross sections) at Tomești village

the high-water events endanger the built environment. Fig. 3. presents the location of the closest buildings relative to the Olt River. It can be observed that the area adjacent to the river is almost completely built up that result a high vulnerability to flooding hazard.

River channel cross sections are represented on a HEC-RAS digital model (Fig. 4.). The model shows overflows at 300
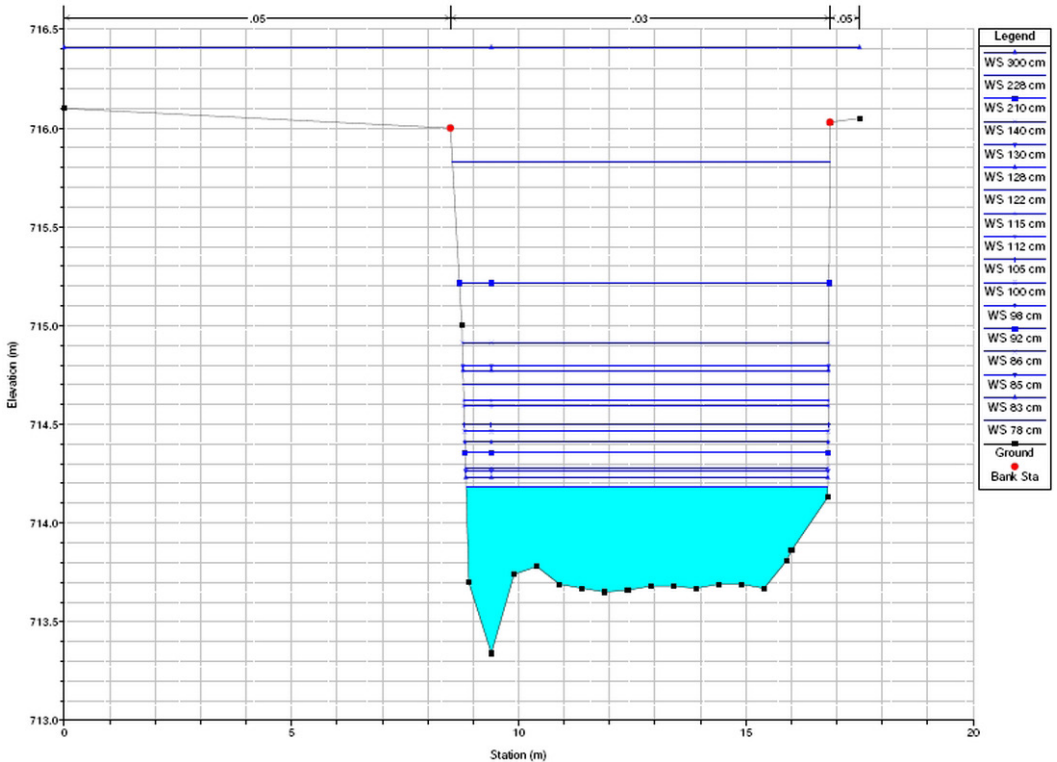

Fig. 6. . Different free water levels represented on the 7th channel cross section plot at Cârța
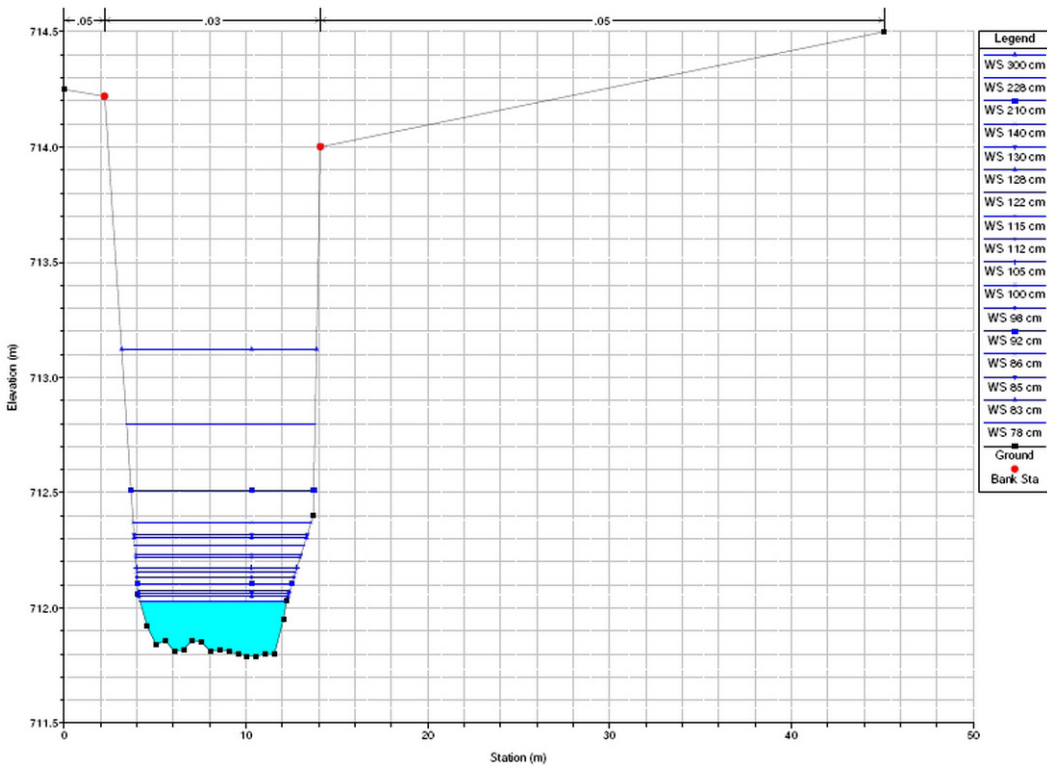
Fig. 7. Different free water levels represented on the 8th channel cross section plot at Cârța village

cm water level, but not in case of all sections. On the upstream area, at 300 cm water level, the overflow appears at the 7th section. On the downstream area the overflow at 300 cm does not occur at the last section, but it is present at the penultimate section.

Fig. 5. presents the first three sections in the upstream area. The model makes it easy to visualize the narrowing of the river channel. Among the possible water levels which were simulated in this model we interpret the 300 cm water level situation. Because of the narrowing of the river channel the water-filled section is getting gradually closer to the river banks. At a water level of 300 cm measured at the hydrometric station (cross section 8), the river does not produce an overflow yet. In case of the following cross-sections which show a narrower channel shape (data recorded at sections 6-7), the 300 cm water level already indicates water overflow.

Fig. 6-7. present the downstream conditions at 300 cm water level (measured at Tomești station). Because of the changes in the river channel cross section shape, at the lowermost section (at Cârța), an overflow doesn't take place. However, the area can be affected by the overflow that occures at the 2nd cross section. We need to consider the discharge of that tributary that enters into the Olt River between the first and second cross sections for the interpretation of the flooding at Cârța village. That means, that high amount of precipitation is needed on the tributary's drainage basin as well in order to produce an overflow at the last cross section.

Each cross section width is lasting until the first building's placement in the close environment of the river. Thus, it can be concluded that at 228 cm free water level condition there is no overflow in either case. At a slight increase of the level over the 228 cm, the first overflow appears at the 2nd and 7th cross sections.

5. Conclusions

In this study high water conditions were analyzed along the upper course of the Olt River. Representation of a multiple channel cross section of the upper course of the Olt River was made for the first time. Between Tomeşti and Cârța settlements, in the absence of flood protection dykes, the terrain features allow the high water levels to easily reach the built up area. This situation can happen over the 228 cm free water level condition.

In order to better understand the flooding conditions at Cârța area, more measurements are needed on the Olt River tributaries.

Acknowledgements

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