Comparative Study of a 1D and 2D Numerical Analysis Modelling a Water Flow at a River Confluence under Accidental High Waters

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Abstract: *There are presented two numerical simulations – 1D and 2D – regarding the water flow on Timiş River in the Town of Caransebeş, Romania, at the confluence with its tributary Sebeş River. There was considered an accidental high waters wave following the synthetical configuration of a given significant hydrograph that happened from 4th to 11th of April 2000. The flow simulation by the two numerical models analysed by the help of HEC-RAS package aim to estimate the flow configuration, the velocities and levels developments, on a confluence river sector with specific bridge and protection structures. The analysis looks to establish some additional technical aspects regarding the flood defence of the urbanised major river plain or the streambed and framing embankments erosion protection.*

Keywords: *River model, 1D / 2D numerical modelling, flow modelling, river levels development, water velocity development.*

1. General considerations

The developed numerical modelling regarding the studied site emerged from a specialized technical expertise [1] upon implications from the accomplishment of a three-storey official building in the immediate flooding plain of Timiș River in the Town of Caransebeş, Romania. There was also considered the procedure engaged for a former 1D numerical simulation [2] generated by the help of HEC-GeoRAS 4.3, an ArcGIS 9.3 implemented version able to generate a 3D type ground surface [3]. The building site is in the crossroads area of Teiuşului and Dâlmei Streets (figure 1), aside of the access ramp to the road bridge over Timiș River (figure 2). As about Dâlmei Street, since it lies on the immediate major river plain, it is high water protected by a concrete parapet of about 0.90m height.

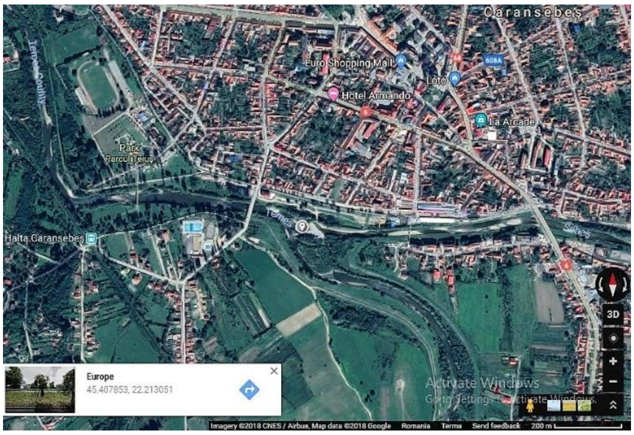

Fig. 1. General plan view of the analysed Timiş - Sebeş confluence river sector in the Town of Caransebeş

Fig. 2. Streambed view towards the crossing road bridge and the left bank of Timiş River downstream the confluence point

About one hundred meters upstream from the road bridge, the Timiș River gets a right-side tributary – the Sebeş River – that besides the natural flow brings the outgoing discharge from Zerveşti tail reservoir of Ruieni Hydropower high head Station. This flow has usual fluctuations between 3 and 54.5 m^3/s and so the present performed analysis follows the accidental situation given by a dysfunctional tail reservoir that would allow the passage of the entire maximum turbinated discharge 2x27.25 = 54.5 m^3/s. As the plan view shows, the confluence comes on the outside of Timiș River bend and its general flow path tends towards the right bank, meaning against the site of the mentioned built area.

The streambed geometry was modelled by considering three connected river sectors: the upstream 1330m sector on Timiş River, the downstream 2270m sector on Timiş River and the upstream 1490m sector on Sebeş River [2]. The spatial streambed configuration (figure 3) was developed by numerical 3D graphic processing [2] of a standard Stereo 70 topographical database consisting from the x,y,z ground points coordinates [1].

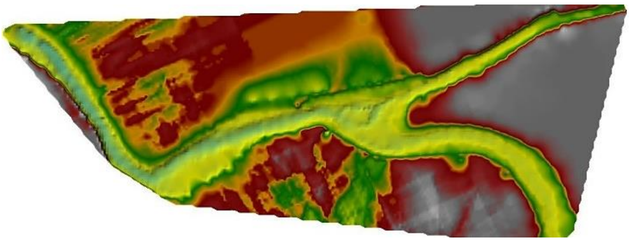

Fig. 3. 3D configuration of Timiş - Sebeş river confluence considering the existing crossing bridge and protection embankment

A 3D ground surface graphical representation can be achieved by the help of a satellite view as supplied by Earth Explorer. Still, as it is limited to a meshing net of 30x30m, the available graphic representation would be quite coarse for a satisfying model. Lazăr et.al. [2] employs a convenient graphical processing method working with supplied topographical measurements. The method engages a 2D graphical interpolation topography software which generates a 3D shape type surface as an .shx file. This surface is further on uploaded by ArcMAP 9.3 where can be divided by discrete triangular elements resulting in a 3D final shape type TIN (Triangulated Irregular Network). In order to be afterwards accepted by RAS Mapper graphic processor module in HEC-RAS 5.05 [4], the spatial shape needs to be converted in an accessible grid file type DTM (Digital Terrain Model). There is to be mentioned that such a satellite type of 3D representation results as usually based on rather poor topographical measurements (relatively reduced number of topographic points) so it can not generate specific configurations – framing flood protection structures or the ground shape in the riverbed – with a proper accuracy. The inconvenient needed to be solved in the HEC-RAS 5.05 model by rectifying the river cross-sections.

2. Development of the 1D river numerical model

The TIN ground representation converted in a DTM raster graphic type file was transformed in a file of .FLT extension (FLoaTing point raster file) that was so uploaded to the RAS Mapper module in HEC-RAS 5.05 (figure 4).

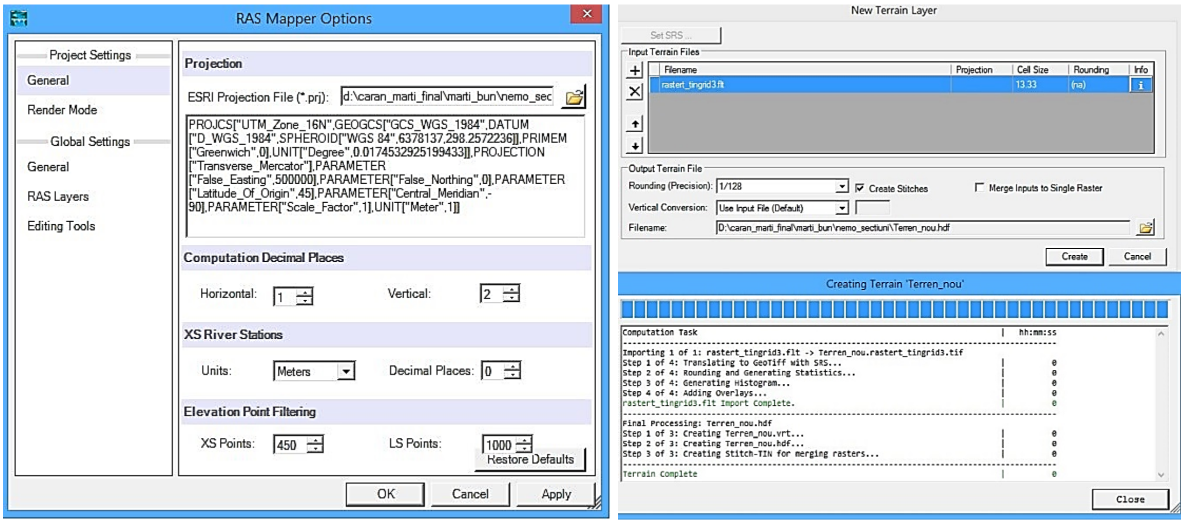

Fig. 4. Uploading the 3D graphic model of the Timiş - Sebeş river confluence sector

The generated ground becomes available only if added in Terrain facility. As already defined in RAS Mapper as a 1D model, the options River and Cross Sections are selected as background map characteristics and shall be available for a 2D model also. By selecting River in the explorer type window and then opting for Edit Geometry, one can perform to draw the river thalweg in the graphic area over the background map (figure 5). The Timiş River path is split at the confluence point and then the three river sectors are merged. The flow paths and the banks lines are to be also defined and saved. After leaving the edit operations, the Compute command must be considered in order to associate all the defined attributes and at the end all the initiated entities are saved (figure 6) [3,5].

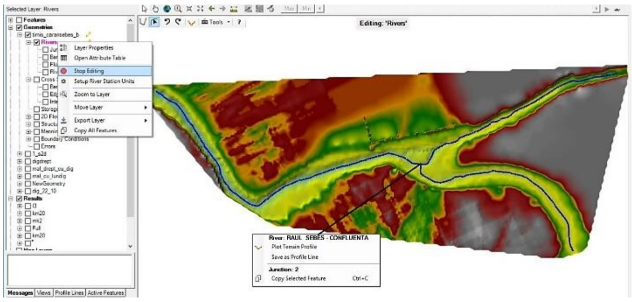

Fig. 5. Graphic digitalization of Timiș and Sebeș Rivers sectors in the confluence area

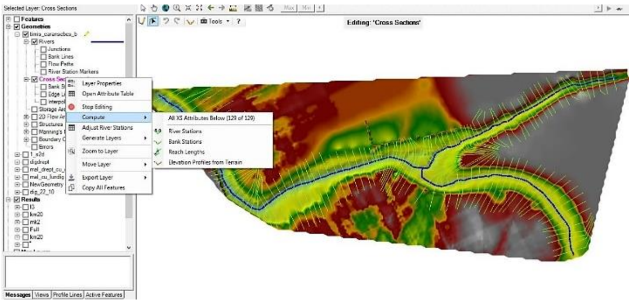

Fig. 6. Graphic digitalization of cross-sections on Timiș and Sebeș Rivers sectors with geometric database development

The two crossing structures – one bridge downstream of the confluence (see figure 1) and the other on the Sebeş River sector – in the RAS Mapper modelled area were considered by adjusting the associated specific cross-sections (figure 7), operation that can be subsequently resumed by addressing to the Geometric Data command in the main menu. Each bridge structure geometry is defined by two predetermined consecutive cross-sections.

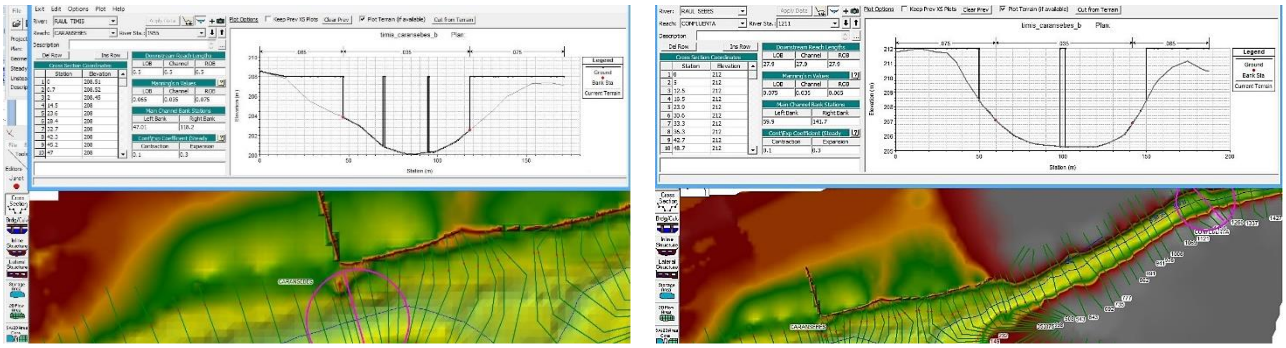

Fig. 7. Adjusting the crossing sections according to the two bridges geometry in the modelled river sector

The surface roughness coefficients in the customary cross-section of the modelled area is considered to vary in the range of 0.075…0.065 for the immediate major plain to 0.035 for the streambed (as recommended by specialized literature and confirmed by previous study [2]).
The relative distances of the upstream and downstream cross-sections edging the modelled Timiș-Sebeș river sector were specified as geometry data with respect to the confluence point and there was also selected the hydraulic facility to be employed by analysis – the impulse method and the energy balance method.

2.1 Initial and boundary conditions

As usual [7], the boundary conditions for a 1D path are assumed as the transited flow (of a given occurrence probability) attached to the upstream cross-sections and the hydrodynamic slope attached to the outgoing downstream cross-section. As for the developed model [1], the water flows were assigned as synthetic high-waters hydrographs to the sections identified by "1487" on

Sebeş River and "3692" on Timiş River, while the given hydrodynamic slope was assigned to the final section on Timiş River identified as "26". The initial flow condition for the 1D model was considered at the value of 15.5 m^3/s for each of the two entering cross-sections, so that their summation on the cross-section "2249" immediately downstream of the joining point to be 31 m^3/s. The maximum level of the enforced hydrograph on Timiş River is 784.82 m^3/s (as proved along a special event that occurred on the spring of 2000), while for the Sebeş River is 54.50 m^3/s (as an accidental coincidence determined by the upstream hydropower arrangement).
The actual river flow numerical simulation is to be developed over a given period of time, as it specifically occurred from the 4th to 11th of April 2000. The running analysis goes for a time step of 20 seconds, while the final results storing is set for each 10 minutes.

2.2 Numerical analysis and results presentation

The common time dependent parameters – water levels, flow and velocity developments – were estimate for all cross-sections by running the numerical analysis for the 1D model. Following the postprocessing operations, the numerical results are stored in distinct files that can be afterwards visualized in the usual RAS Mapper area or by accessing the HEC-RAS main menu, graphical and as spreadsheets.
The following figure 8 brings the graphic representation of the confluence streamlines progress by the RAS-Mapper area and the velocity distribution in the road bridge cross-section as revealed by the help of HEC-RAS menu, both at several moments along the modelled time period: 20:00 on April 5th, 04:00 on April 6th and 08:00 on April 8th, 2000.

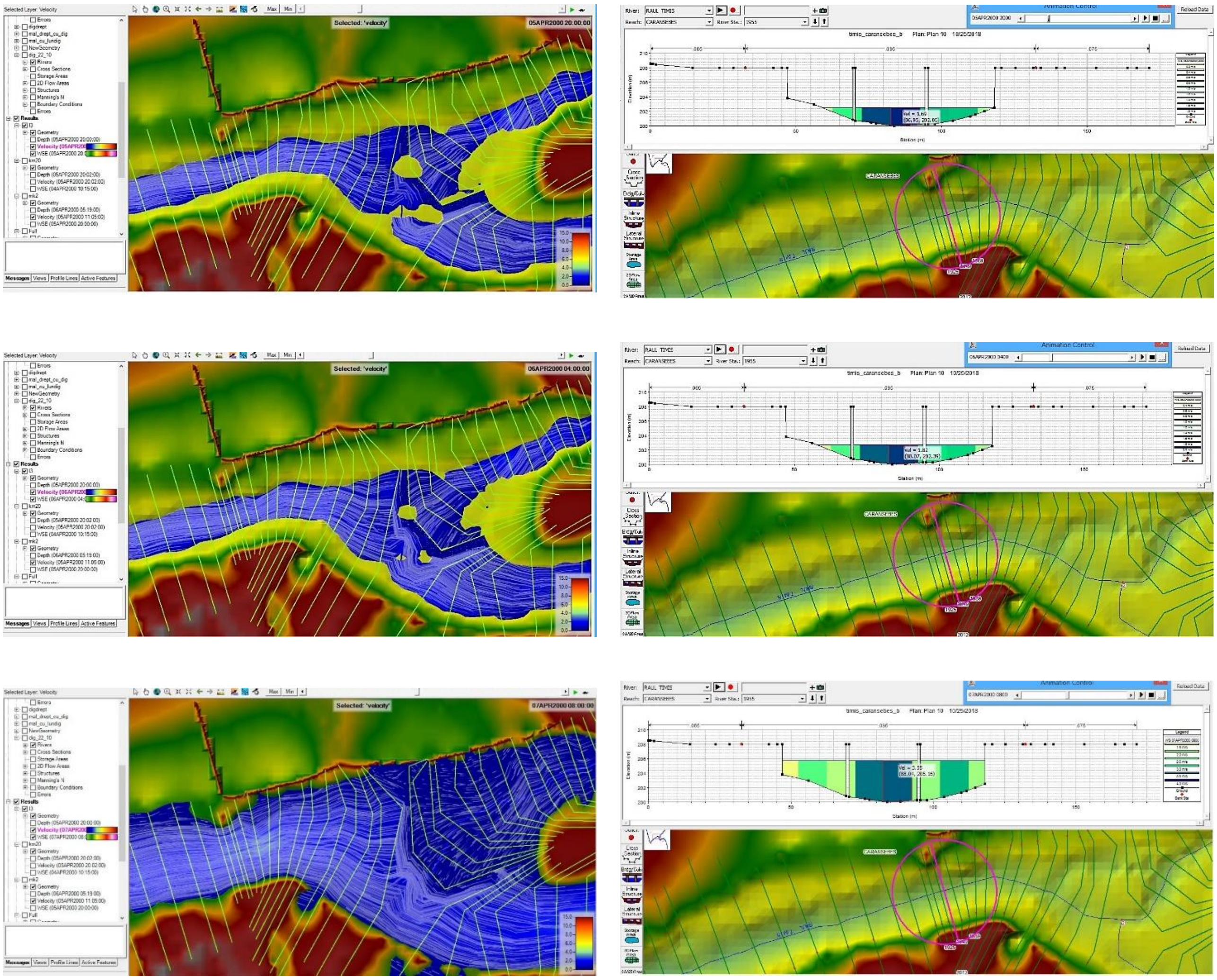

Fig. 8. Streamlines in the confluence area and velocity distribution in the cross-section attached to the downstream road bridge for the 1D river model at several specific moments: 20:00 on April 5th, 04:00 on April 6th and 08:00 on April 7th, 2000

As one can notice from the processed images in figure 8, the streamlines paths bend rather by relatively rough angles and not smoothly as in real natural flow. As about the water flow velocity maximum values in the considered narrowed cross-section at the specific consecutive moments along the hydrograph increasing side, they are 1.69 m/s, 1.82 m/s and 3.55 m/s.

3. Development of the 2D river numerical model

The 3D model built by bi-dimensional interpolation was altered in HEC-RAS 5.05 by the help of the facility that allows placing a fictitious water course, which in this case will model the flood defence embankment on Timiș River right bank in the proximity of the crossing road bridge [8].
The 2D surface domain is generated over the initial ground model. The analysis 2D domain contour is accomplished by the help of 2D Flow Areas facility from the explorer type window. The associated points and their corresponding properties were generated on the area meshed by a 15x15 m grid. Similarly, the embankment axel route was defined and saved. The cross-section of the embankment upper part was then defined by the help of Geometry Data main menu (figure 9), the shape being so attached to each inflection cross-section along the river path. The model's cross-sections are in the end automatically thickened at a maximum in-between distance of 20 m (figure 10).

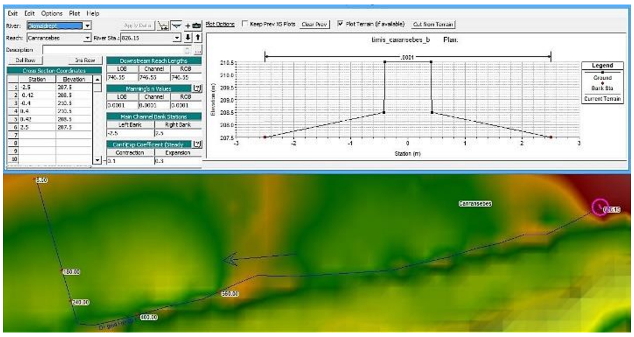

Fig. 9. Geometry data defining the embankment cross-section

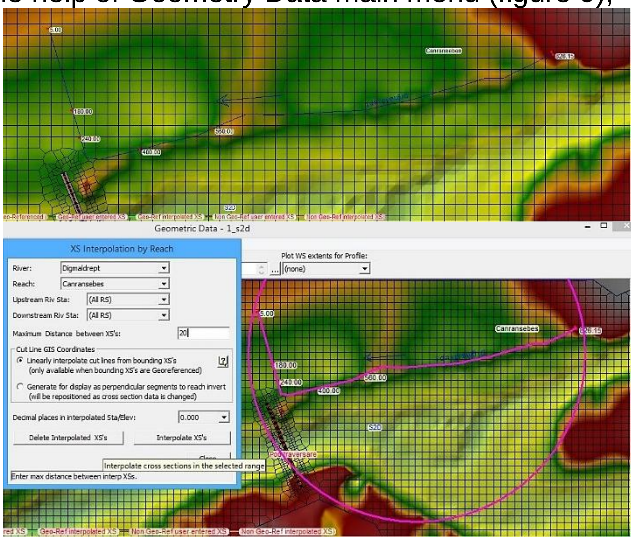

Fig. 10. Cross-sections development along the flood defending embankment route

The Interpolation Surface option is selected in Cross Sections menu in RAS Mapper window. The embankment geometry is exported by the help of Export Layer facility in the explorer type window, by selecting the Create Terrain GeoTiff from XS's option (figure 11).
The modelling of the cross-sections corresponding to the bridges downstream (on Timiș River) and upstream (on the tributary Sebeş River) from the confluence point was performed by breaking the surface lines by associated perimetric domains. The engaged facilities and data corresponding to the confluence downstream bridge are presented in figure 12.

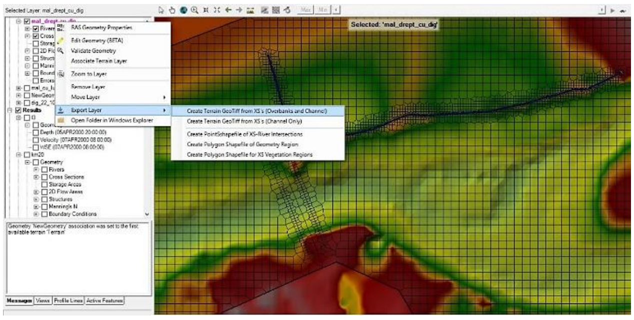

Fig. 11. Options engagement for exporting the protection embankment interpolation area

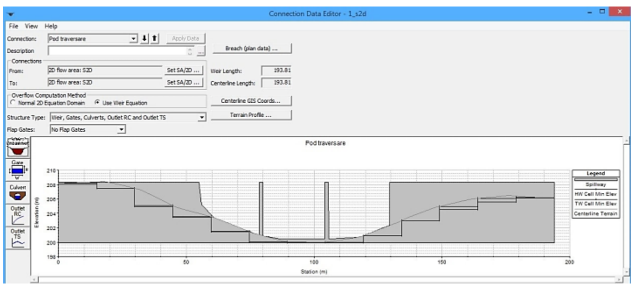

Fig. 12. Facilities and data engaged to define the confluence downstream road bridge

3.1 Initial and boundary conditions

Obviously, the boundary conditions attached to the 2D model, are identical as numerical development (but not as initial levels) to the ones engaged for the 1D model.
The 2D model requires the definition of the three paths as Boundary Conditions Lines by the help of SA/2D Area Conn option. There were defined two upstream paths – BC_S2D_11 on Timiș River and BC_S2D_22 on Sebeș River – and one downstream path as BC_S2D_33 on Timiș River (figure 13).

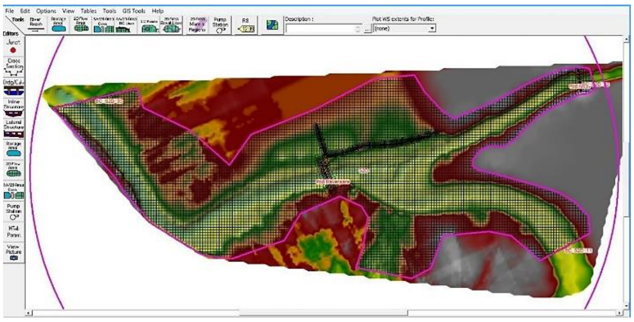

Fig. 13. Locations of upstream and downstream boundary conditions for the 2D analysis model

The high waters flow hydrograph on Timiș River following to reach the 784.82 m^3/s maximum value and the hydrodynamic slope of 0.000475 are attached (upstream / downstream) to path BC_S2D_11. By engaging the energy slope option, the model will deal out the entrance flow distribution upon the boundary line. In the same way, the high waters flow hydrograph on Sebeș River reaching the 54.50 m^3/s maximum value and the hydrodynamic slope of 0.000375 are attached to path BC_S2D_22. The hydrodynamic slope of 0.000375 was attached to the downstream boundary of path BC_S2D_33.
The actual numerical analysis of the water flow transition goes over the known period of time starting from 10:00 on April 4th and ending at 04:00 on April 11th, 2000. The analysis runs at an execution time step of 20 seconds, while the output storage is set for a time step of 10 minutes.

3.2 Numerical analysis and results presentation

The constant or time depending parameters regarding water levels, flows and velocities on each grid cell of the 2D model were reached by running the numerical simulation. Following the postprocessing operations, the numerical results are stored in specific files that can be afterwards accessed to be visualized in any grid cell or along specific routes defined by the user in the 2D domain by engaging the options offered by RAS Mapper area.
There were selected here some significant options that would allow the comparation with the results offered by the previous 1D model, specifically the streamlines progress in the confluence area and the velocity distribution in the downstream road bridge cross-section at the three consecutive moments along the modelled time period: 20:00 on April 5th, 04:00 on April 6th and 08:00 on April 8th, 2000 (figure 14).
One can notice that the streamlines develop by smooth natural like bends. In the same time, by selecting an about middle cell in the cross-section the maximum velocity value is revealed: 1.477 m/s for a water level of 202.46 mSL at the first considered moment, 1.558 m/s for 202.69 mSL and 2.751 m/s for 205.85 mSL respectively.

4. Conclusions

As considering the water velocity development in the narrowed cross-section corresponding to the road bridge downstream the Timiș - Sebeș Rivers confluence, its reached maximum values at three equally consecutive moments along the ascending side of the flow hydrograph for the two 1D and 2D numerical models are relatively presented in table number 1.
By comparing the corresponding velocity values, it rises up that the 1D analysis leads to noticeably increased estimations – with about 12 to 18 % – than the 2D situation, meaning that a one-dimensional modelling overestimates the hydraulic parameters. As about the water levels comparison in the studied cross-section, it results that for relatively low water flow values – as about the initial values of the hydrograph corresponding to the common river flow – one can accept that the proven difference is situated under the error limit of ± 0.06m adopted for the 2D analysis.

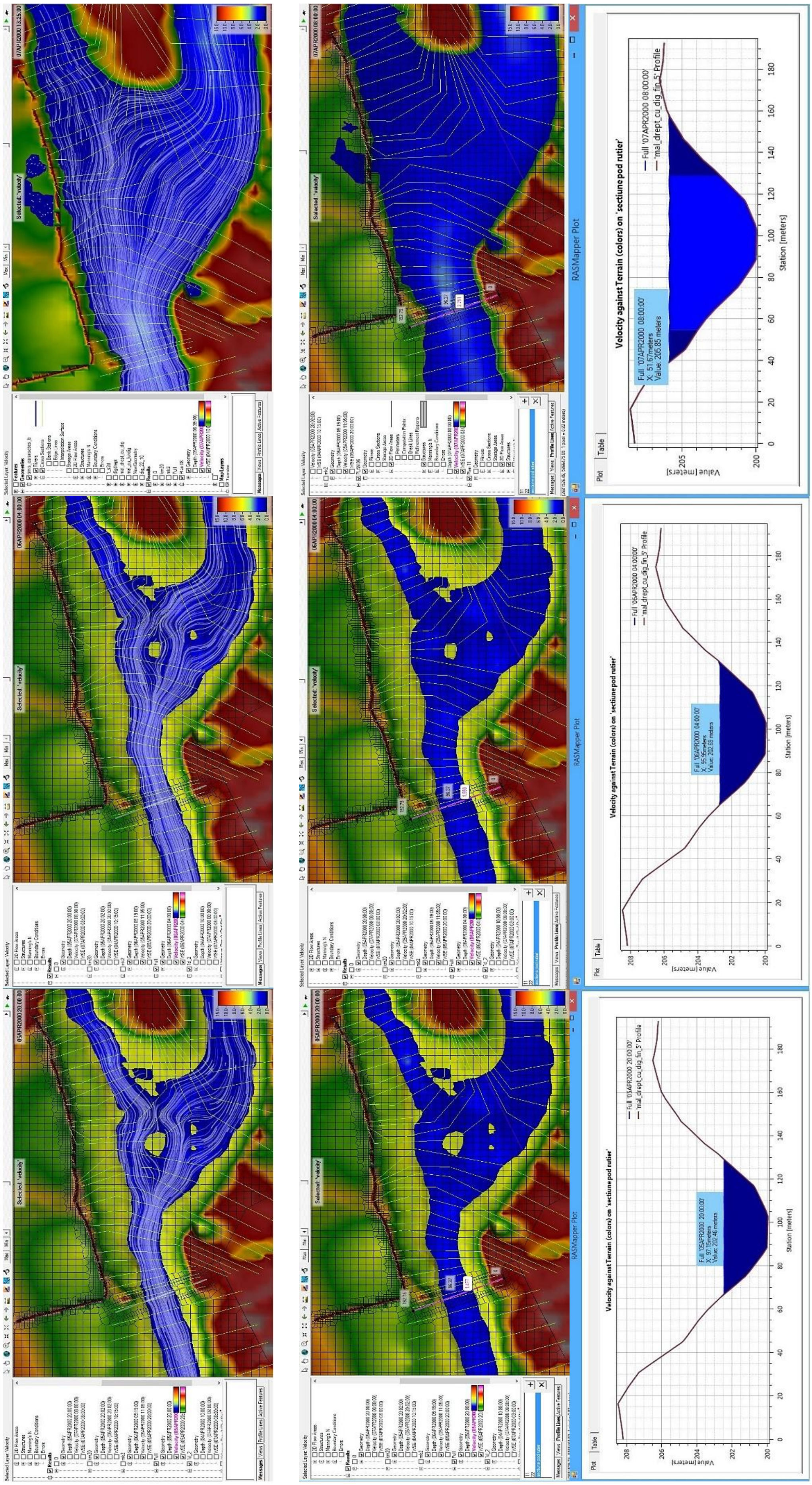

Fig. 14. Streamlines in the confluence area and velocity distribution in the cross-section attached to the downstream road bridge for the 2D river model at the three specific moments: 20:00 on April 5th, 04:00 on April 6th and 08:00 on April 7th, 2000

Table 1: Maximum values on road bridge cross-section

Crt. no.	**parameter**	**1D model** day/hour			**2D model** day/hour			Δ **(1D)-(2D)**
		5/20	6/04	7/08	5/20	6/04	7/08	
1.	Velocity [m/s]	1.690			1.477			0.213 (-12.6%)
	Level [mSL]	202.06			202.46			-0.40
2.	Velocity [m/s]		1.820			1.558		0.262 (-14.4%)
	Level [mSL]		202.39			202.69		-0.30
3.	Velocity [m/s]			3.550			2.751	0.799 (-22.5%)
	Level [mSL]			205.16			205.85	-0.69

Further on, at special situation of lowest occurrence probability (but never the less requested to be considered by the analysis) that would go up to the maximum summated flow value (784.82 + 54.50 = 839.32 m^3/s) the water level difference soon becomes really significant for the crossing structure and the framing embankments as the 1D model underestimates this parameter.
The revealed differences are understandable since the 2D analysis employs the full Saint Venant motion equations, turbulence and Coriolis effects too. In the same time, the 1D analysis as a simplified approach of the flow phenomenon accepts geometry and hydraulic data as estimated by the user, which is not anymore the case for the 2D approach. Besides, the confluence area of the 1D model is developed by a rough geometry. Even by considering a ring area as an improved modelling for the 1D confluence development, the deficiency would not be eliminated since this would assume to introduce two junction points instead of one. A more reliable and still affordable solution for the 1D model would be to intercalate a 2D local confluence model connected to the corresponding cross-sections of the general 1D model.
By considering the fluent / gentle bending streamlines along the modelled river sector and the slightly undulated cross-section water surface revealed by the 2D analysis, one can accept this approach reveals an artificial numerical phenomenon development much closer to the natural one.
Regarding the extreme values reached by the 2D analysis – the maximum velocity of about 2.75 m/s corresponding to the maximum water level of about 205.9 mSL (still in the range of the structures safety levels) for the narrowed road bridge cross-section – there is advisable to closely monitor the streambed erosion process development and so to ensure the crossing and flood protection structures stability by specific proper measures.

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