Numerical Modelling of a Refurbished Triple Stepped River Sector with Side Fish Passage

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Abstract: *The paper presents a 2D numerical modelling by HEC-RAS 5.07 of a restored and refurbished hydraulic arrangement on Târnava Mică River in Mureș County, Romania. The arrangement consists of a concrete triple step accompanied by a side fish passage and is considered to be transited by a high waters flow (given as a levels synthetic hydrograph of the specific discharge phenomenon from 15^{th} -16^{th} of April, 2000). The numerical simulation of the hydraulic phenomenon, performed on the 2D generated structure, looks to illustrate the high water flow discharge modality by establishing the unsteady hydraulic parameters. Further on, specific hydraulic aspects regarding the sanitary (ecological) flow discharge by the fish passage need to be specified.*

Keywords: *Fish passage, ecological discharge, highwaters, unsteady flow, water velocity, stream lines, computer hydraulics*

1. General information

The subjected Târnava Mică River sector (fig.1) is situated in the area of the Bălăuşeri Village, south-east of Mureş County, in the center of Transylvania Plateau, Romania. The numerical model starts as based on an existing deteriorated river triple bottom step for which a rehabilitation technical project needs to be developed [1]. Under these circumstances, the present analysis also considers the accomplishment of a fish passage as required in order to ensure the ecosystem restoration, and banks stone protection works respectively in order to longer maintain the river sector arrangement.

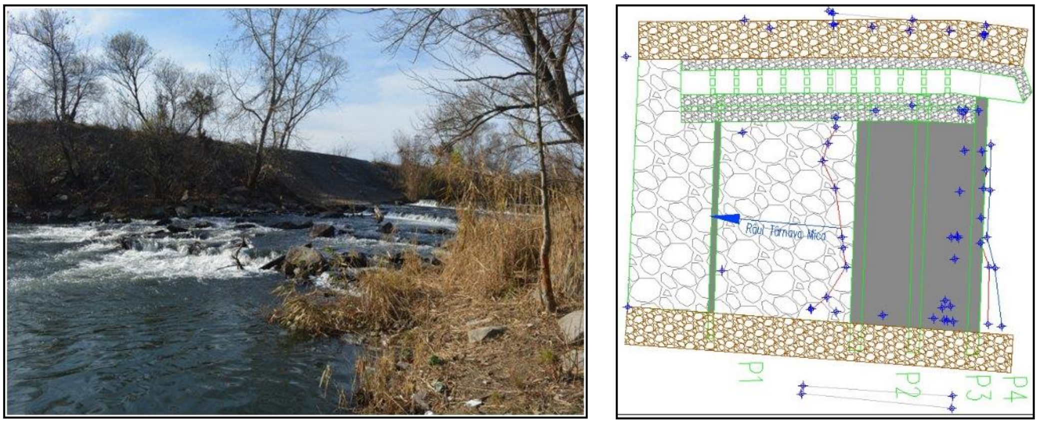

Fig. 1. Site view of the triple stepped sector on Târnava Mică River and the designed plan-view for the refurbished hydraulic arrangement with fish passage on the right bank

The site in the Bălăuşeri Village area is situated at an average level of about 328.50 mSL. The 2D geometrical modelling of Târnava Mică River valley was accomplished for a sector of about 50m. There was employed a geometry data base produced from topographical measurements ("Stereo 70", supplied by an AutoCAD file of .dxf extension) as a leveled plan-view, five river crossing profiles and one riverbed longitudinal profile. A detailed cross-view of the designed fish passage (fig.2) was also developed.

Considering all the geometrical features given by the technical design views (the fish passage channel with the 10 rows of shaped stones including) and required for defining the model mesh, the analyzed flowing paths (the three stepped river sector and the fish passage) were divided by 89 cross-sections in 88 straight segments.
By considering the AutoCAD configured plan of the existing site as background, a 1D numerical model was first developed in HEC-RASv.4.1 [2] as covering the 89 cross-sections. Further on, a 3D shape type surface (as a .shx extension file) was obtained from the attached site configuration by employing a topographic two directions (x,y) linear interpolation software.

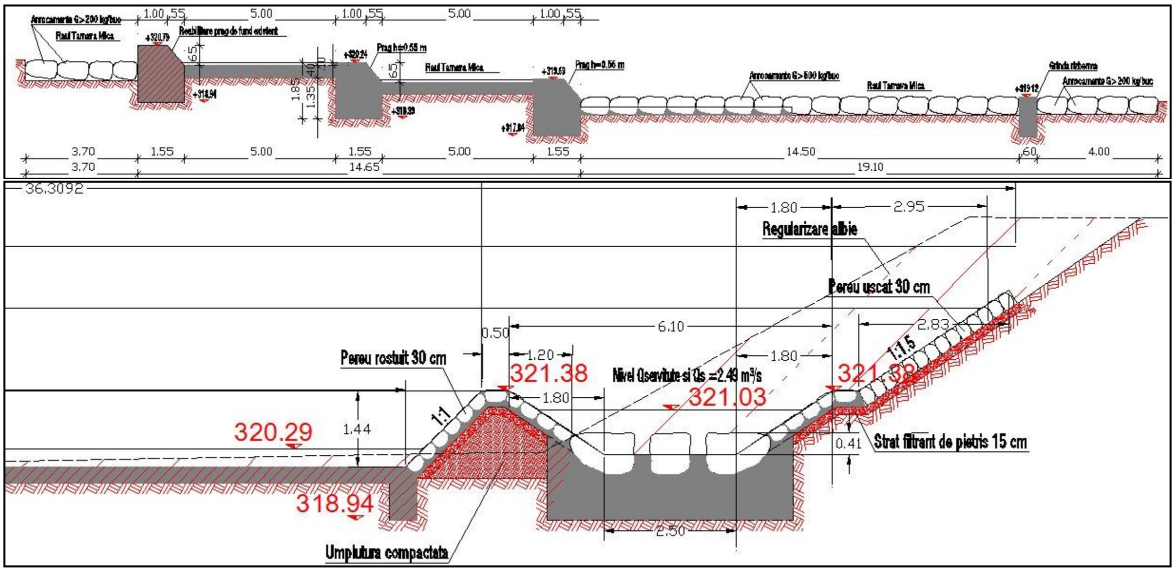

Fig. 2. Longitudinal profile by the triple step arrangement and detail cross-section by the first concrete casted three-stone row on the fish passage

The 3D surface contour was defined by the topographic supplied coordinates (x, y and z - ground level) of four corner points, i.e. P_{left_down}(477214.92,544796.27,320.434), P_{left_up}(477214.92,544832.96,320.437), P_{right_down}(477257.64,544796.27,321.436) and P_{right_up}(477257.64,544832.96,321.436). This space sloped surface was then uploaded by ArcMAP9.3 [3] and meshed by triangular discrete elemental surfaces, obtaining the final 3D discrete surface of **T**riangulated **I**rregular **N**etwork type. In order to be compatible to RAS Mapper graphical processing module in HEC-RASv.5.07 [4], the TIN surface needed to be converted into a **D**igital **T**errain **M**odel grid type file.

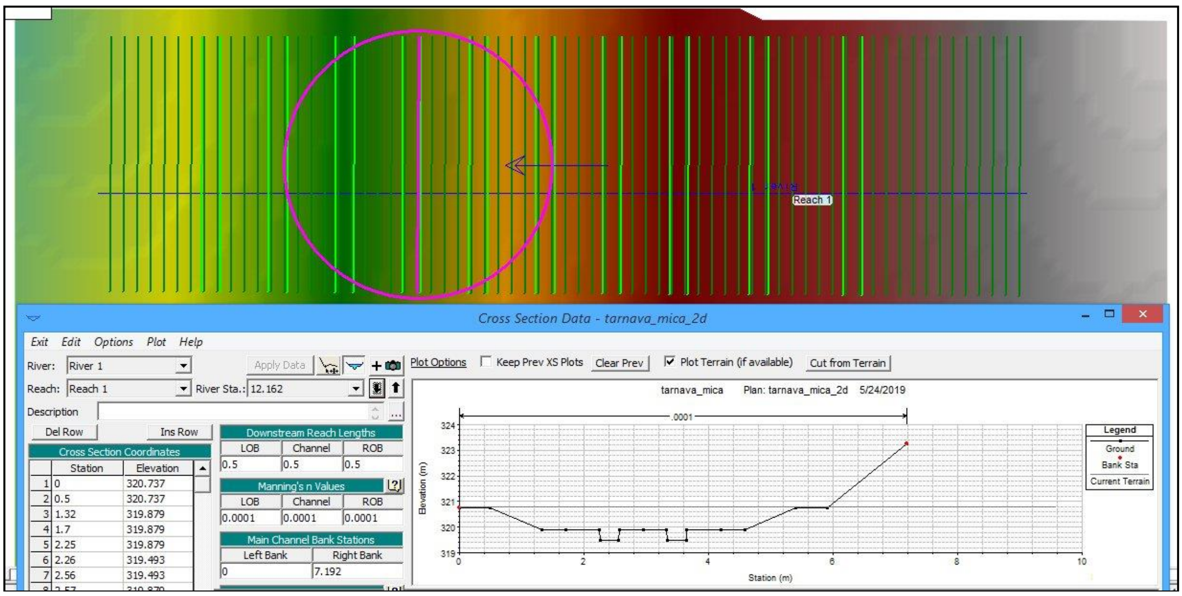

Fig. 3. Accomplishment of the prior 1D fish passage path with the cross-sections editing

Several other specific numerical modelling operations were then followed within HEC-RASv5.07 software package [5,6,7] in order to properly consider the right side designed fish passage (fig.3 and 4) and the restored concrete steps river sector with the corresponding left bank. The final modelled domain of the hydraulic arrangement is illustrated by figure 5.

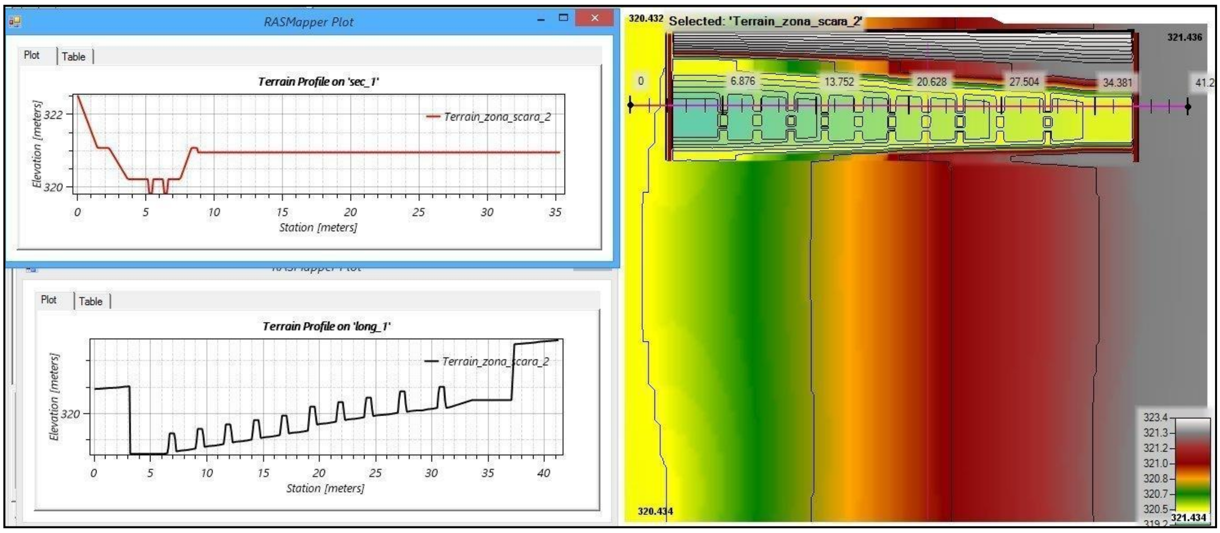

Fig. 4. Level lines of the fish passage updated area, together with a cross-section and a longitudinal profile by the designed structure

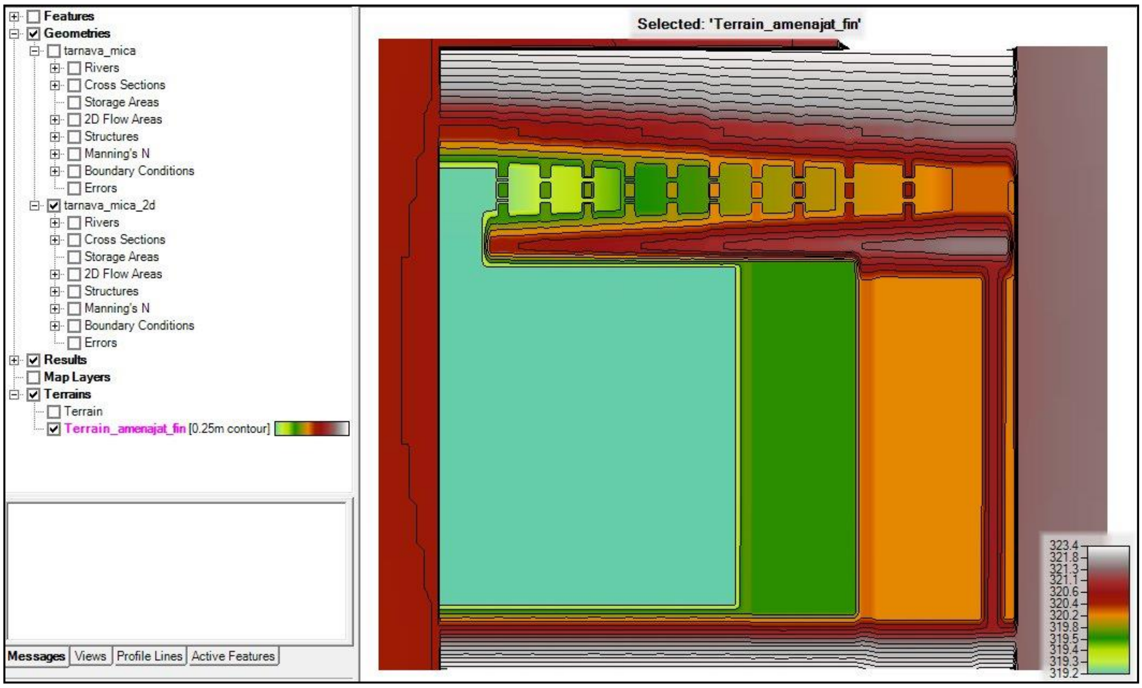

Fig. 5. Updated ground view with level lines (of 0.25m step in elevation) of the modelled hydraulic arrangement

The concerned river sector maximum values of water flows with the two overcoming probabilities of 5% and 1%, as corresponding to the hydraulic arrangement importance class, were supplied by the water authority: $Q_{5\%}$ = 245 m^3/s and $Q_{1\%}$ = 430 m^3/s. At the same time, one has to consider the enforced sanitary flow to be discharged by the triple stepped sector with side fish passage at a value of about 2.49 m^3/s. The employed river-bed roughness coefficient of 0.065 was estimated by considering the foreseen natural constitution.

2. Numerical modelling of the hydraulic phenomenon

The discrete numerical model developed by HEC-RAS 5.0.7 [4] considers the originally existing 3D site surface as obtained by bi-dimensional interpolation of the arranged sector on Târnava Mică River. As built on this surface, the analysis model of the designed hydraulic arrangement was generated (fig.5). By considering the 2D Flow Areas facility in the explorer type window, the contour S2D of the analysis domain was drawn (fig.6). The 2D mesh spacing was set at 0.50m on both horizontal directions. After defining the structural points connected to the mesh (*Generate Computations Points*), their property data tables can be generated (*Compute Property Points*).
In order to employ a condense mesh in the area of the 10 rows of shaped stones in the fish passage, break lines were defined by engaging *Geometric Data* from main menu. The editing size of cells in the area of all breaking lines was set in-between 0.05m minimum and 0.25m maximum.

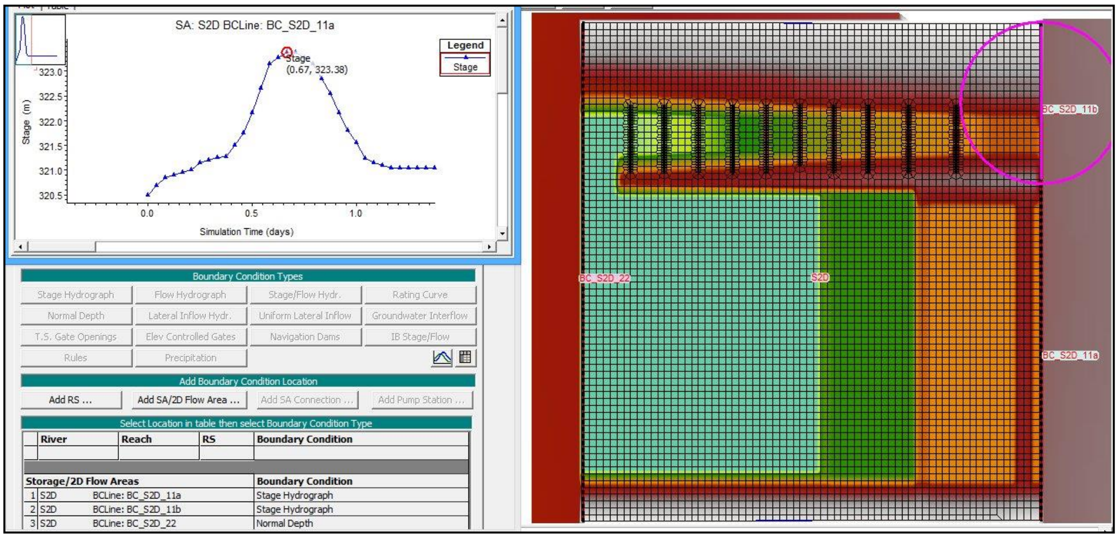

Fig. 6. 2D discrete numerical model of the hydraulic arrangement on Târnava Mică River, with two discharging paths (three stepped river sector and fish passage), and the boundary condition represented by the accidental flow hydrograph

As about the boundary conditions of the model, they are defined by *Geometric Data* in main menu as BC Line type, so by considering the *SA/2D Area BC Lines* option. Three boundaries were defined for the present S2D domain: two at the upstream entering edge, *BC_S2D_11b* as corresponding to the fish passage flow path and *BC_S2D_11a* as corresponding to the three stepped river sector, and one at the downstream outgoing edge, *BC_S2D_22*. An accidental flow hydrograph of 408.50 m^3/s maximum discharge (given from a measured phenomenon) as corresponding to the maximum level of about 323.38 mSL was attached to each of the two upstream boundary lines and the river hydrodynamic gradient of 0.0085 was assigned to the downstream boundary line.
The actual flow discharging numerical simulation was set to develop over the specific period of time from 01:00 on April 15th to 05:00 on April 16th, 2000, as corresponding to the most significant measured high waters phenomenon on the concerned sector of Târnava Mică River.
The analysis was set to run with a time step of 0.1s and a mapping interval of 10s, while the time interval of results storage was fixed to 5 minutes.

3. Flow numerical simulation and results presentation

Following the run of the actual numerical simulation of the discharging phenomenon, the specific developing parameters – water levels, discharges and velocities – were obtained over the entire S2D modelled domain of Târnava Mică River sector.
The main analysis output, after performing the results post-processing graphic operations on the 2D model, is further on presented. So, the following 7 and 8 highlight the flow development – particles trajectories, water depths (m) and longitudinal / transverse water surface profiles – by the two paths at the significant moment 01:04.18 when the sanitary discharge of about 2.48m^3/s

passes the hydraulic arrangement. Further on, figure 9 shows the particles trajectories as overlaid to water velocity spectrum (m/s), accompanied by a longitudinal and a transverse velocity profiles, for the same specific moment.
The next four figures, 10, 11, 12 and 13, present also the main characteristics of the flow phenomenon by the modelled hydraulic arrangement – particles trajectories, water depths (m), water velocities (m/s), longitudinal / transverse water surface and velocity profiles, but for the moment 17:05 when the maximum discharge of 408.50m^3/s passes the structure.

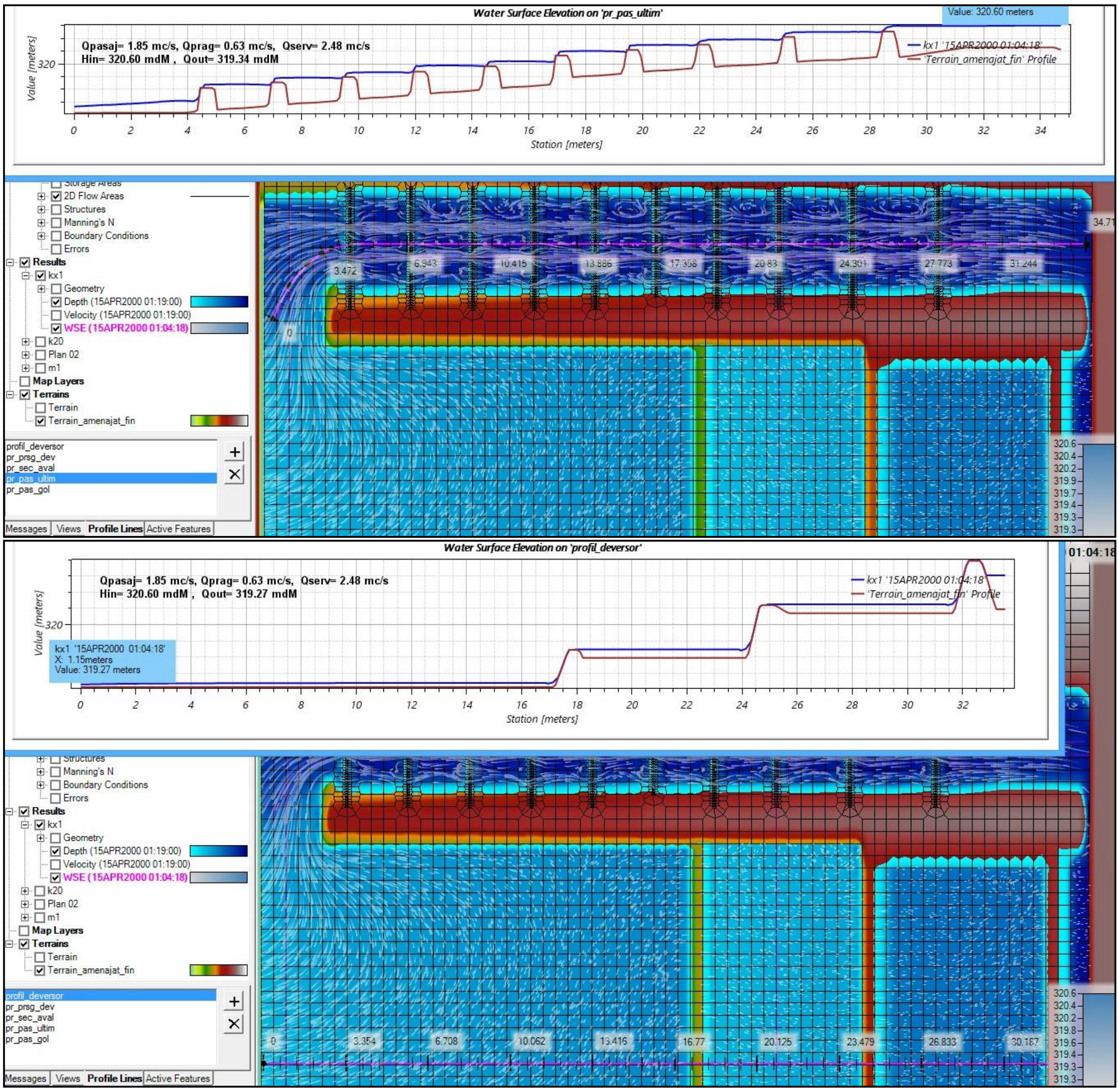

Fig. 7. Particles trajectories overlaid to water depth together with water surface longitudinal profiles by the middle lines of fish passage (over the 10 rows central stones) and of stepped river sector, at the specific moment when the sanitary flow (2.48m^3/s) is discharged

The last figure, 14, brings out the water flow and piezometric line time development correlation for the fish passage upstream entrance border (BC_s2s_11b) and the arrangement downstream outgoing border (BC_s2s_22).

4. Conclusions

The discrete numerical model represents a river hydraulic structure composed from a triple stepped sector with a side fish passage, arrangement transited by an accidental high water flow defined by a representative recorded water levels hydrograph, allowing the possibility of considering a fragmented assignment of entering boundary conditions.

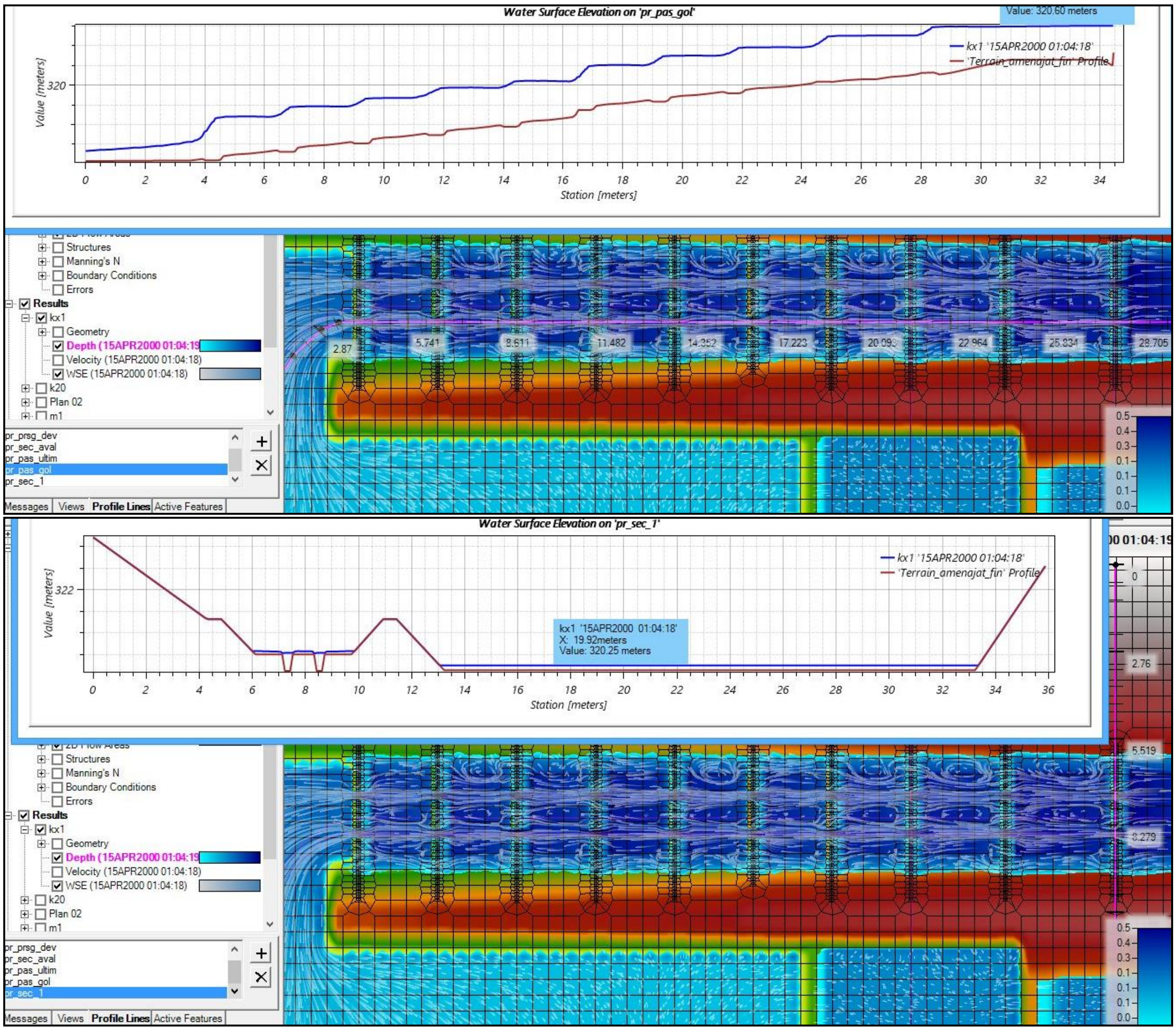

Fig. 8. Particles trajectories overlaid to water depth together with water surface longitudinal unfolding by the fish passage rows gaps and transverse profile by the first upstream three stones row of the side passage, at the specific moment when the sanitary flow (2.48m^3/s) is discharged

The specific hydraulic parameters reached by the actual numerical simulation of the flow passing phenomenon lead to a distinct appraisal of discharged values by the triple stepped sector and fish passage paths, at the considered output storing time interval.

By analyzing the graphically presented output (fig.7 and 8), one can witness the total sanitary flow of about 2.48m^3/s discharging mainly by the fish passage (at about 1.85m^3/s) and also by the triple stepped sector (at about 0.63m^3/s). The corresponding water levels for this specific moment came out about 320.60mSL upstream and about 319.34mSL downstream.

One can also notice that the water velocity values spectrum (fig.9) goes about from 0.05 to 0.93m/s by the fish passage flowing path, and from 0.05 to 0.50m/s by the three stepped river sector.

So, one may assume that the analyzed restored and enhanced hydraulic arrangement could be in general conformable for the ichthyofaunal requirement under sanitary flow discharging conditions also, complying so with ecological and environmental protection general necessities.

As from graphical output concerning the fulfilment of maximum flow value of about 408.50m^3/s (fig.10 and 11), by observing the stream lines one can also visualize the discharging modality under extreme conditions. The maximum velocity values for this special situation (fig.12 and 13) reach at about 7.19m/s, at the first stones row in the fish passage entering area, while in the downstream area of this flowing path drops to about 3.94m/s.

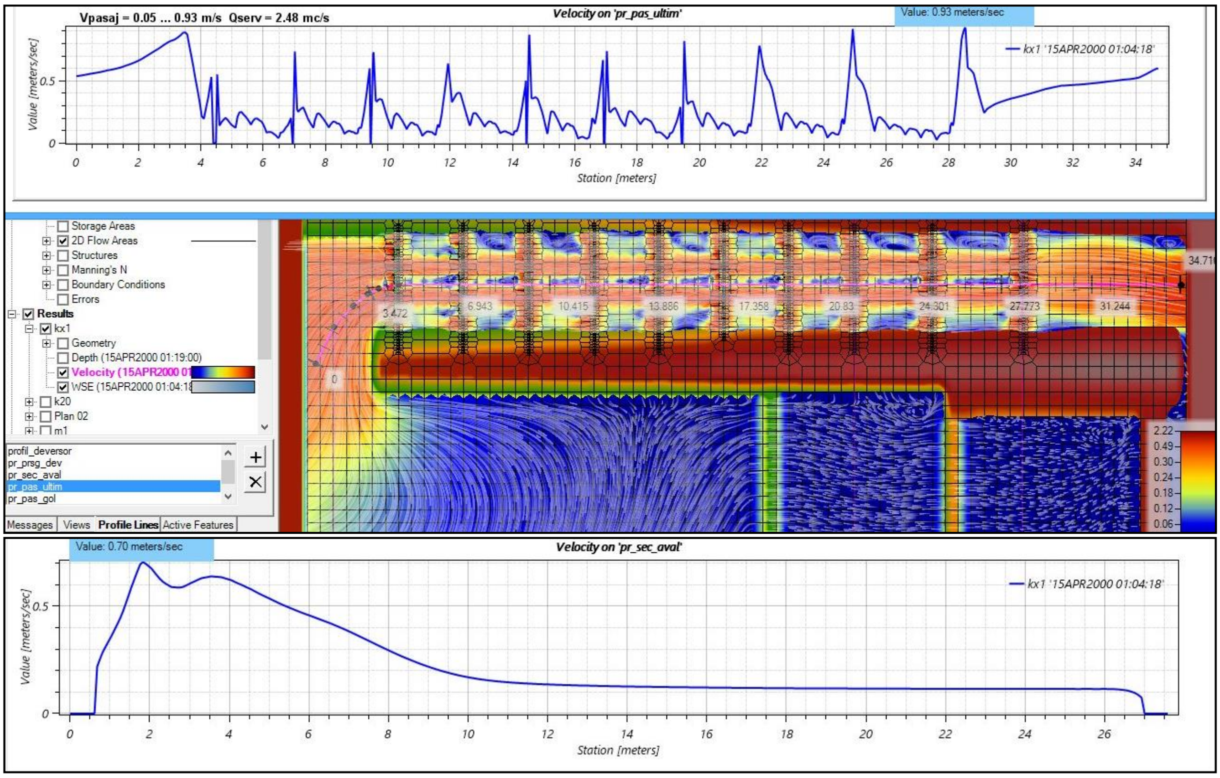

Fig. 9. Particles trajectories overlaid to water velocity spectrum together with longitudinal (by the fish passage middle line) and transverse (downstream area) velocity profiles, at the specific moment when the sanitary flow (2.48m^3/s) is discharged

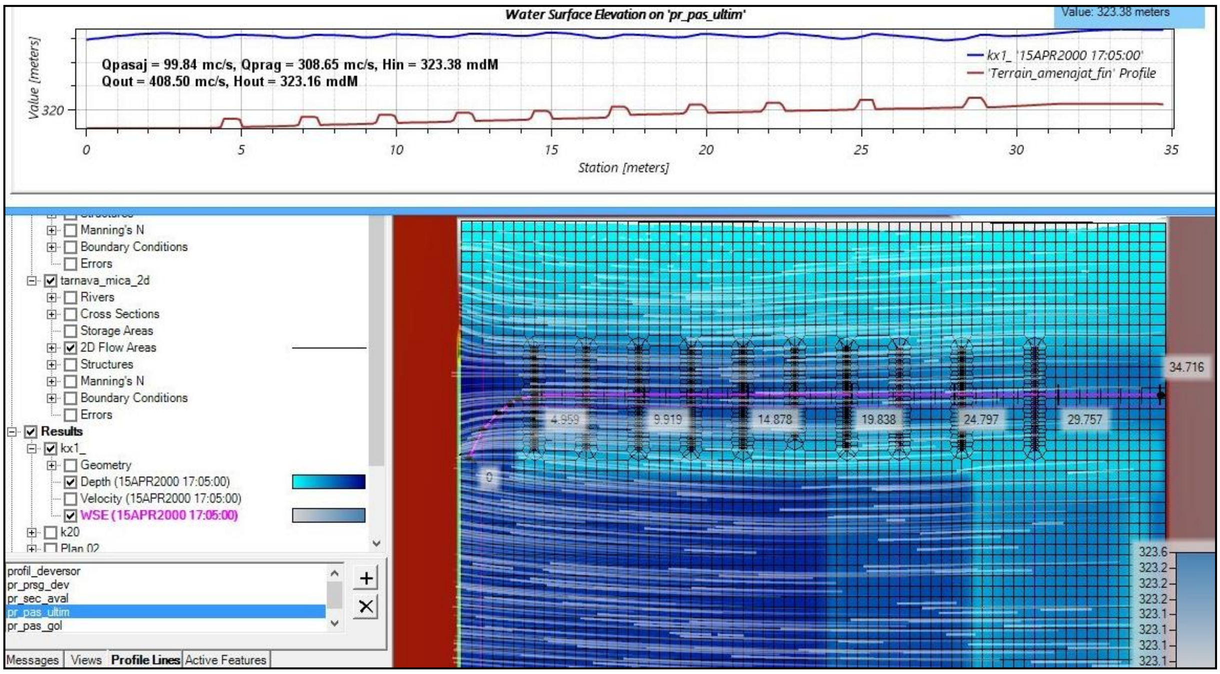

Fig. 10. Particles trajectories overlaid to water depth spectrum together with water surface longitudinal unfolding by the fish passage middle line, at the specific moment when the maximum flow (408.50m^3/s) is discharged

The maximum water levels along the high waters flow phenomenon rise to about 323.38mSL in the model upstream entering edge and to about 323.16mSL in the downstream outgoing edge (fig.14). These extreme levels are to be considered with respect to the two Târnava Mică River sector side banks, which according to the supplied ground plan run at an average level of about 323.80mSL.

Thus, according to the reached results under the given circumstances of the foreseen hydraulic structure, the water levels development lies below the existing side edges of the river valley.

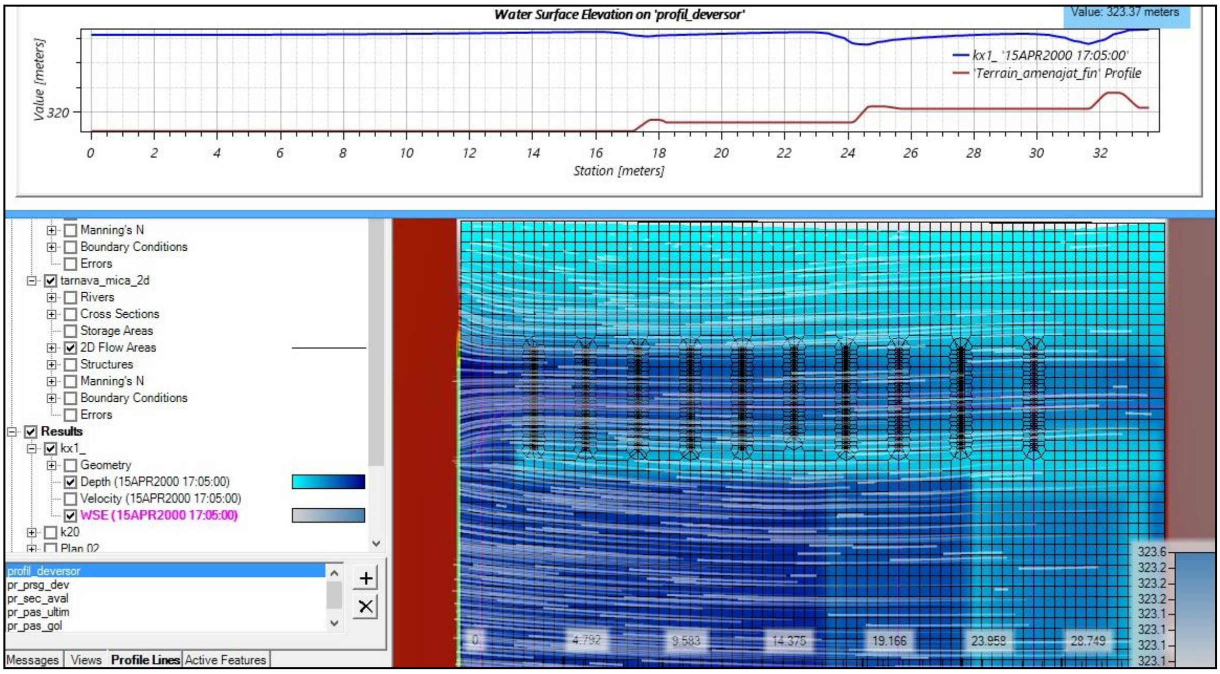

Fig. 11. Particles trajectories overlaid to water depth spectrum together with water surface longitudinal unfolding by the stepped river sector middle line, at the specific moment when the maximum flow (408.50m^3/s) is discharged

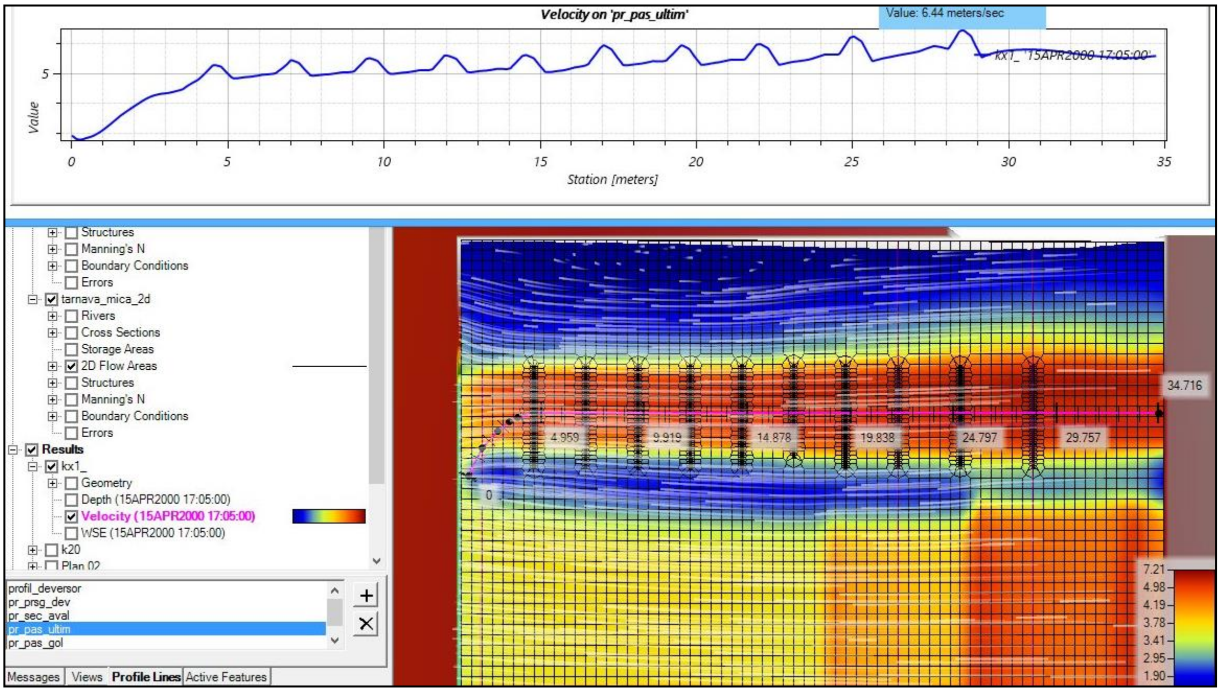

Fig. 12. Particles trajectories overlaid to water velocity spectrum together with velocity longitudinal unfolding by the fish passage middle line, at the specific moment when the maximum flow (408.50m^3/s) is discharged

At the same time, by considering the upstream entering and downstream outgoing water energy levels,

$h_{E1} = h_1 + \frac{\alpha \cdot {v_1}^2}{2g} = 323.38 + \frac{1.05 \cdot 7.19^2}{2 \cdot 9.807} = 326.15 mSL$, $h_{E2} = h_2 + \frac{\alpha \cdot {v_2}^2}{2g} = 323.16 + \frac{1.05 \cdot 3.70^2}{2 \cdot 9.807} = 323.89 mSL$, one can estimate that the total energy drop by the modelled hydraulic arrangement [8] is about 2.16m.

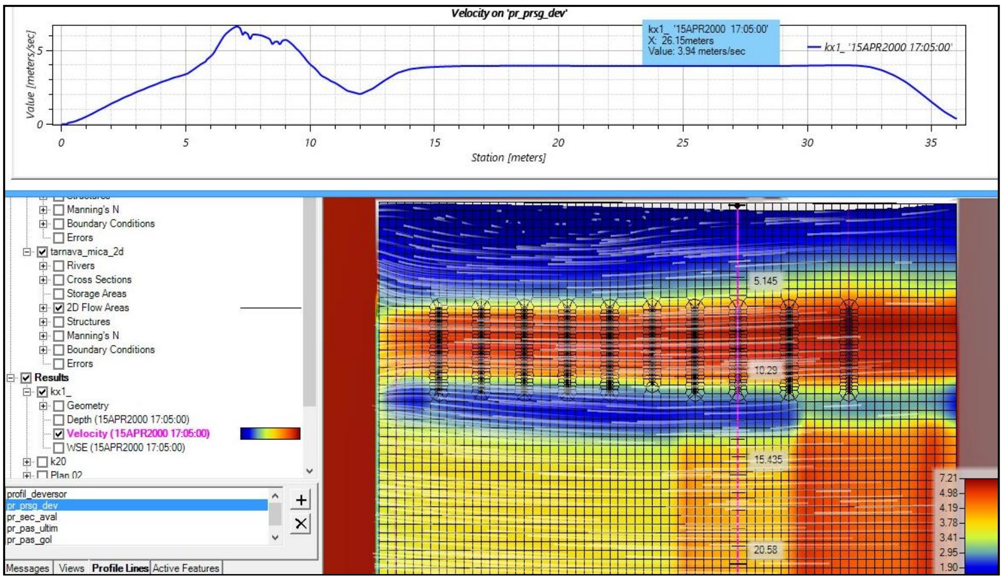

Fig. 13. Particles trajectories overlaid to water velocity spectrum together with velocity entire transverse profile by the second step, at the specific moment when the maximum flow ($408.50 m^3/s$) is discharged

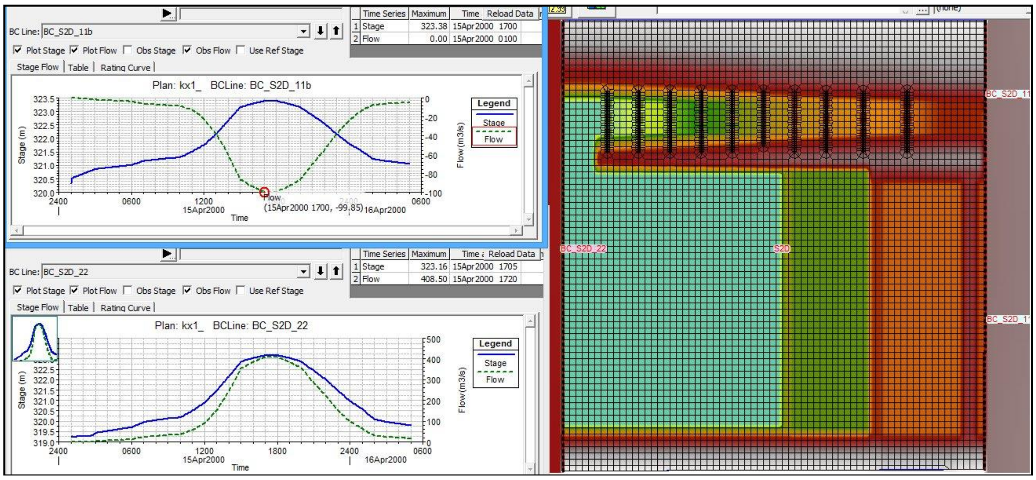

Fig. 14. Correlated water flow and level time development by the fish passage entrance (above) and entire arrangement outgoing borders of the Târnava Mică River modeled sector

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